RM0468
Reference manual

STM32H723/733, STM32H725/735 and STM32H730 Value line advanced Arm®-based 32-bit MCUs

Introduction

This reference manual targets application developers. It provides complete information on how to use the STM32H723/733, STM32H725/735 and STM32H730 memory and peripherals.

The STM32H723/733, STM32H725/735 and STM32H730 are lines of microcontrollers with different memory sizes, packages and peripherals.They are referred to as STM32H72x and STM32H73x hereafter.

The devices include ST state-of-the-art patented technology.

For ordering information, mechanical, and electrical device characteristics refer to the corresponding datasheets.

For information on the Arm® Cortex®-M7 with FPU core, refer to the corresponding Arm *Technical Reference Manuals*.

Related documents

- Arm® Cortex®-M7 technical reference manual, available from www.arm.com
- Cortex®-M7 programming manual (PM0253)
- STM32H723xx, STM32H733xx, STM32H725xx, STM32H730xx, and STM32H735xx datasheets
- STM32H72xx/73xx errata sheet.

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1 Documentation conventions

1.1 General information

The STM32H72x and STM32H73x devices embed an Arm® Cortex®-A7 with FPU core.

1.2 List of abbreviations for registers

The following abbreviations[a] are used in register descriptions:

read/write (rw)	Software can read and write to this bit.
read-only (r)	Software can only read this bit.
write-only (w)	Software can only write to this bit. Reading this bit returns the reset value.
read/clear write0 (rc_w0)	Software can read as well as clear this bit by writing 0. Writing 1 has no effect on the bit value.
read/clear write1 (rc_w1)	Software can read as well as clear this bit by writing 1. Writing 0 has no effect on the bit value.
read/clear write (rc_w)	Software can read as well as clear this bit by writing to the register. The value written to this bit is not important.
read/clear by read (rc_r)	Software can read this bit. Reading this bit automatically clears it to 0. Writing this bit has no effect on the bit value.
read/set by read (rs_r)	Software can read this bit. Reading this bit automatically sets it to 1. Writing this bit has no effect on the bit value.
read/set (rs)	Software can read as well as set this bit. Writing 0 has no effect on the bit value.
read/write once (rwo)	Software can only write once to this bit and can also read it at any time. Only a reset can return the bit to its reset value.
toggle (t)	The software can toggle this bit by writing 1. Writing 0 has no effect.
read-only write trigger (rt_w1)	Software can read this bit. Writing 1 triggers an event but has no effect on the bit value.
Reserved (Res.)	Reserved bit, must be kept at reset value.

a. This is an exhaustive list of all abbreviations applicable to STMicroelectronics microcontrollers, some of them may not be used in the current document.

1.3 Glossary

This section gives a brief definition of acronyms and abbreviations used in this document:

- **Word**: data of 32-bit length.
- **Half-word**: data of 16-bit length.
- **Byte**: data of 8-bit length.
- **AHB**: advanced high-performance bus.

1.4 Availability of peripherals

For availability of peripherals and their number across all sales types, refer to the particular device datasheet.

1.5 Availability of security features

For security feature availability please refer to the table below:

Table 1. Availability of security features

Security feature	STM32H730xB, STM32H733xG and STM32H735xG	STM32H723xE/G and STM32H725xE/G
Embedded Flash memory (FLASH): – Flash Secure-only area	Available	Not available
Security memory management: – Secure access mode – Root secure services (RSS)		
On-the-fly decryption engine (OTFDEC)		
Cryptographic processor (CRYP)		
Hash processor (HASH)		

2 Memory and bus architecture

2.1 System architecture

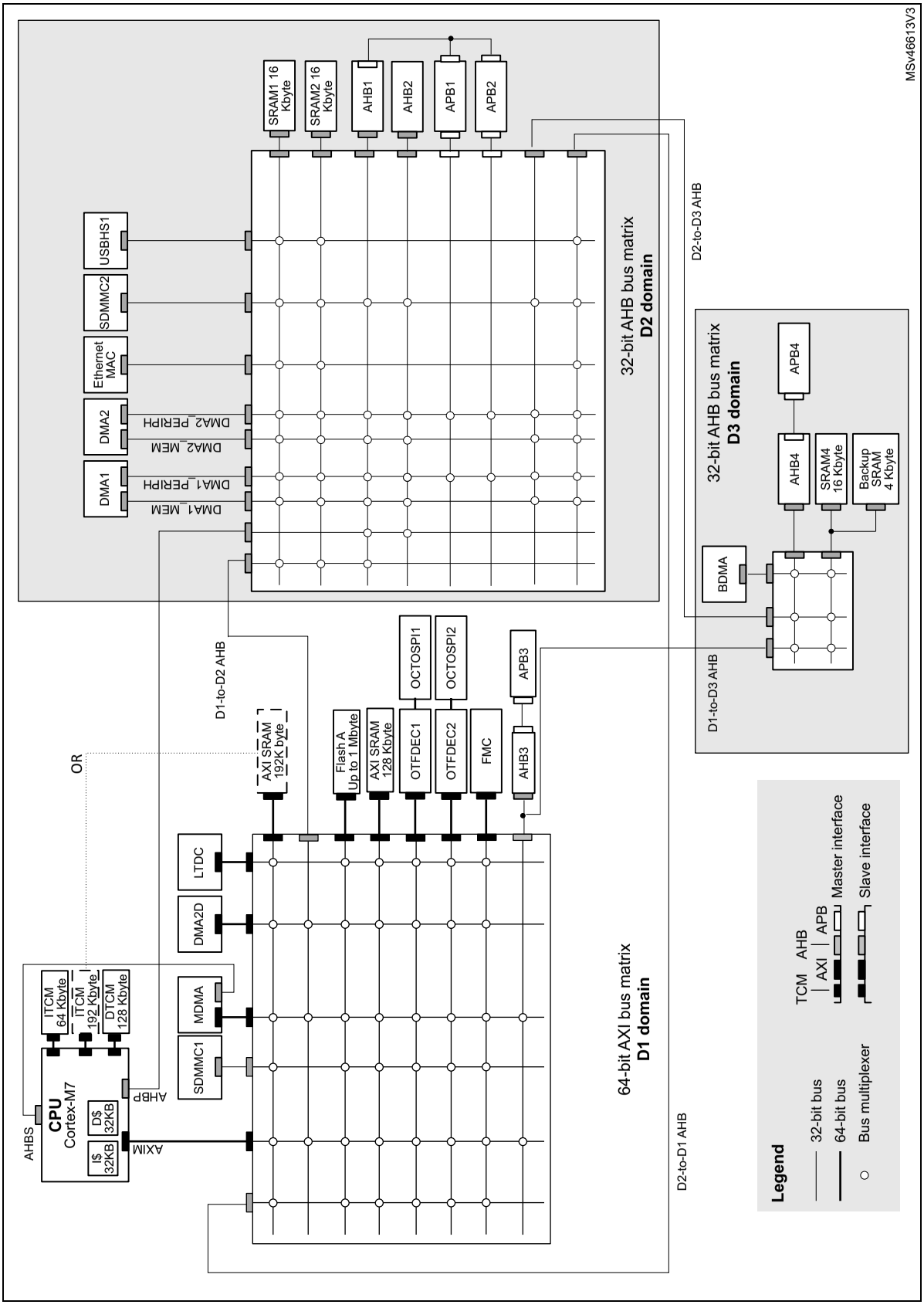
An AXI bus matrix, two AHB bus matrices and bus bridges allow interconnecting bus masters with bus slaves, as illustrated in *Table 2* and *Figure 1*.

Table 2. Bus-master-to-bus-slave interconnect

	Bus master / type(1)																
	Cortex-M7 - AXIM	Cortex-M7 - AHBP	**Cortex-M7 - ITCM**	**Cortex-M7 -DTCM**	SDMMC1	**MDMA - AXI**	MDMA - AHBS	**DMA2D**	**LTDC**	DMA1 - MEM	DMA1 - PERIPH	DMA2 - MEM	DMA2 - PERIPH	Eth. MAC - AHB	SDMMC2 - AHB	USBHS1 - AHB	BDMA - AHB
Bus slave / type(1)	**Interconnect path and type(2)**																
ITCM	-	-	**X**	-	-	-	X	-	-	-	-	-	-	-	-	-	-
DTCM	-	-	-	**X**	-	-	X	-	-	-	-	-	-	-	-	-	-
AHB3 peripherals	X	-	-	-	-	X	-	-	-	X	X	X	X	X	X	X	-
APB3 peripherals	X	-	-	-	-	X	-	-	-	X	X	X	X	X	X	X	-
Flash bank 1	**X**	-	-	-	X	**X**	-	**X**	**X**	X	X	X	X	X	X	X	-
AXI SRAM	**X**	-	-	-	X	**X**	-	**X**	**X**	X	X	X	X	X	X	X	-
RAM shared between ITCM and AXI	**X**	-	-	-	X	**X**	-	**X**	**X**	X	X	X	X	X	X	X	-
OCTOSPI	**X**	-	-	-	X	**X**	-	**X**	**X**	X	X	X	X	X	X	X	-
FMC	**X**	-	-	-	X	**X**	-	**X**	**X**	X	X	X	X	X	X	X	-
SRAM1	X	-	-	-	-	X	-	X	-	X	X	X	X	X	X	X	-
SRAM2	X	-	-	-	-	X	-	X	-	X	X	X	X	X	X	X	-
AHB1 peripherals	-	X	-	-	-	X	-	X	-	X	X	X	X	-	X	-	-
APB1 peripherals	-	X	-	-	-	X	-	X	-	X	X	X	X	-	X	-	-
AHB2 peripherals	-	X	-	-	-	-	-	-	-	X	X	X	X	-	X	-	-
APB2 peripherals	-	X	-	-	-	X	-	X	-	X	X	X	X	-	X	-	-
AHB4 peripherals	X	-	-	-	-	X	-	-	-	X	X	X	X	-	X	-	X
APB4 peripherals	X	-	-	-	-	X	-	-	-	X	X	X	X	-	X	-	X
SRAM4	X	-	-	-	-	X	-	-	-	X	X	X	X	-	X	-	X
Backup RAM	X	-	-	-	-	X	-	-	-	X	X	X	X	-	X	-	X

1. **Bold** font type denotes 64-bit bus, plain type denotes 32-bit bus.
2. “X” = access possible, “-” = access not possible, shading = access useful/usable.

Figure 1. System architecture



2.1.1 Bus matrices

AXI bus matrix in D1 domain

The D1 domain multi AXI bus matrix ensures and arbitrates concurrent accesses from multiple masters to multiple slaves. This allows efficient simultaneous operation of high-speed peripherals.

The arbitration uses a round-robin algorithm with QoS capability.

Refer to *Section 2.2: AXI interconnect matrix (AXIM)* for more information on AXI interconnect.

AHB bus matrices in D2 and D3 domains

The AHB bus matrices in D2 and D3 domains ensure and arbitrate concurrent accesses from multiple masters to multiple slaves. This allows efficient simultaneous operation of high-speed peripherals.

The arbitration uses a round-robin algorithm.

2.1.2 TCM buses

The DTCM and ITCM (data and instruction tightly coupled RAMs) are connected through dedicated TCM buses directly to the Cortex-M7 core. The MDMA controller can access the DTCM and ITCM through AHBS, a specific CPU slave AHB. The DTCM and ITCM are accessed by Cortex-M7 at CPU clock speed, with zero wait states.

2.1.3 Bus-to-bus bridges

To allow peripherals with different types of buses to communicate together, there is a number of bus-to-bus bridges in the system.

The AHB/APB bridges in D1 and D3 domains allow connecting peripherals on APB3 and APB4 to AHB3 and AHB4, respectively. The AHB/APB bridges in D2 domain allow peripherals on APB1 and APB2 to connect to AHB1. These AHB/APB bridges provide full synchronous interfacing, which allows the APB peripherals to operate with clocks independent of AHB that they connect to.

The AHB/APB bridges also allow APB1 and APB2 peripherals to connect to DMA1 and DMA2 peripheral buses, respectively, without transiting through AHB1.

The AHB/APB bridges convert 8-bit / 16-bit APB data to 32-bit AHB data, by replicating it to the three upper bytes / the upper half-word of the 32-bit word.

The AXI bus matrix incorporates AHB/AXI bus bridge functionality on its slave bus interfaces. The AXI/AHB bus bridges on its master interfaces marked as 32-bit in *Figure 1* are outside the matrix.

The Cortex-M7 CPU provides AHB/TCM-bus (ITCM and DTCM buses) translation from its AHBS slave AHB, allowing the MDMA controller to access the ITCM and DTCM.

2.1.4 Inter-domain buses

D2-to-D1 AHB

This 32-bit bus connects the D2 domain to the AXI bus matrix in the D1 domain. It allows bus masters in the D2 domain to access resources (bus slaves) in the D1 domain.

D1-to-D2 AHB

This 32-bit bus connects the D1 domain to the D2 domain AHB bus matrix. It allows bus masters in the D1 domain to access resources (bus slaves) in the D2 domain.

D1-to-D3 AHB

This 32-bit bus connects the D1 domain to the D3 domain AHB bus matrix. It allows bus masters in the D1 domain to access resources (bus slaves) in the D3 domain.

D2-to-D3 AHB

This 32-bit bus connects the D2 domain to the D3 domain AHB bus matrix. It allows bus masters in the D2 domain to access resources (bus slaves) in the D3 domain.

2.1.5 CPU buses

Cortex®-M7 AXIM bus

The Cortex®-M7 CPU uses the 64-bit AXIM bus to access all memories (excluding ITCM, and DTCM) and AHB3, AHB4, APB3 and APB4 peripherals (excluding AHB1, APB1 and APB2 peripherals).

The AXIM bus connects the CPU to the AXI bus matrix in the D1 domain.

Cortex®-M7 ITCM bus

The Cortex®-M7 CPU uses the 64-bit ITCM bus for fetching instructions from and accessing data in the ITCM.

Cortex®-M7 DTCM bus

The Cortex®-M7 CPU uses the 2x32-bit DTCM bus for accessing data in the DTCM. The 2x32-bit DTCM bus allows load/load and load/store instruction pairs to be dual-issued on the DTCM memory. It can also fetch instructions.

Cortex®-M7 AHBS bus

The Cortex®-M7 CPU uses the 32-bit AHBS slave bus to allow the MDMA controller to access the ITCM and the DTCM.

Cortex®-M7 AHBP bus

The Cortex®-M7 CPU uses the 32-bit AHBP bus for accessing AHB1, AHB2, APB1 and APB2 peripherals via the AHB bus matrix in the D2 domain.

2.1.6 Bus master peripherals

SDMMC1

The SDMMC1 uses a 32-bit bus, connected to the AXI bus matrix, through which it can access internal AXI SRAM and Flash memories, and external memories through the Octo-SPI controller and the FMC.

SDMMC2

The SDMMC2 uses a 32-bit bus, connected to the AHB bus matrix in D2 domain. Through the system bus matrices, it can access the internal AXI SRAM, SRAM1, SRAM2, SRAM4, backup RAM, Flash memory, and external memories through the Octo-SPI controller and the FMC.

MDMA controller

The MDMA controller has two bus masters: an AXI 64-bit bus, connected to the AXI bus matrix and an AHB 32-bit bus connected to the Cortex-M7 AHBS slave bus.

The MDMA is optimized for DMA data transfers between memories since it supports linked list transfers that allow performing a chained list of transfers without the need for CPU intervention. Through the system bus matrices and the Cortex-M7 AHBS slave bus, the MDMA can access all internal and external memories through the Octo-SPI controller and the FMC.

DMA1 and DMA2 controllers

The DMA1 and DMA2 controllers have two 32-bit buses - memory bus and peripheral bus, connected to the AHB bus matrix in D2 domain.

The memory bus allows DMA data transfers between memories. Through the system bus matrices, the memory bus can access all internal memories except ITCM and DTCM, and external memories through the Octo-SPI controller and the FMC.

The peripheral bus allows DMA data transfers between two peripherals, between two memories or between a peripheral and a memory. Through the system bus matrices, the peripheral bus can access all internal memories except ITCM and DTCM, external memories through the Octo-SPI controller and the FMC, and all AHB and APB peripherals. A direct access to APB1 and APB2 is available, without passing through AHB1. Direct path to APB1 and APB2 bridges allows reducing the bandwidth usage on AHB1 bus by improving data treatment efficiency for APB and AHB peripherals.

BDMA controller

The BDMA controller uses a 32-bit bus, connected to the AHB bus matrix in D3 domain, for DMA data transfers between two peripherals, between two memories or between a peripheral and a memory. BDMA transfers are limited to the D3 domain resources. It can access the internal SRAM4, backup RAM, and AHB4 and APB4 peripherals through the AHB bus matrix in the D3 domain.

Chrom-Art Accelerator (DMA2D)

The DMA2D graphics accelerator uses a 64-bit bus, connected to the AXI bus matrix. Through the system bus matrices, internal AXI SRAM, SRAM1, SRAM2 and Flash memories, and external memories through the Octo-SPI controller and the FMC.

LCD-TFT controller (LTDC)

The LCD-TFT display controller, LTDC, uses a 64-bit bus, connected to the AXI bus matrix, through which it can access internal AXI SRAM and Flash memories, and external memories through the Octo-SPI controller and the FMC.

Ethernet MAC

The Ethernet MAC uses a 32-bit bus, connected to the AHB bus matrix in the D2 domain. Through the system bus matrices, it can access all internal memories except SRAM4, backup RAM, ITCM, DTCM and external memories, through the Octo-SPI controller and the FMC.

USBHS1 peripheral

The USBHS1 peripheral uses 32-bit buses, connected to th

e AHB bus matrix in the D2 domain. Through the system bus matrices, it can access all internal memories except SRAM4, backup RAM, ITCM, DTCM and external memories, through the Octo-SPI controller and the FMC.

2.1.7 Clocks to functional blocks

Upon reset, clocks to blocks such as peripherals and some memories are disabled (except for the SRAM, DTCM, ITCM and Flash memory). To operate a block with no clock upon reset, the software must first enable its clock through RCC_AHBxENR or RCC_APBxENR register, respectively.

2.2 AXI interconnect matrix (AXIM)

2.2.1 AXI introduction

The AXI (advanced extensible interface) interconnect is based on the Arm® CoreLink™ NIC-400 Network Interconnect. The interconnect has six initiator ports, or ASIBs (AMBA slave interface blocks), and eight target ports, or AMIBs (AMBA master interface blocks). The ASIBs are connected to the AMIBs via an AXI switch matrix.

Each ASIB is a slave on an AXI bus or AHB (advanced high-performance bus). Similarly, each AMIB is a master on an AXI or AHB bus. Where an ASIB or AMIB is connected to an AHB, it converts between the AHB and the AXI protocol.

The AXI interconnect includes a GPV (global programmer view) which contains registers for configuring certain parameters, such as the QoS (quality of service) level at each ASIB.

Any accesses to unallocated address space are handled by the default slave, which generates the return signals. This ensures that such transactions complete and do not block the issuing master and ASIB.

2.2.2 AXI interconnect main features

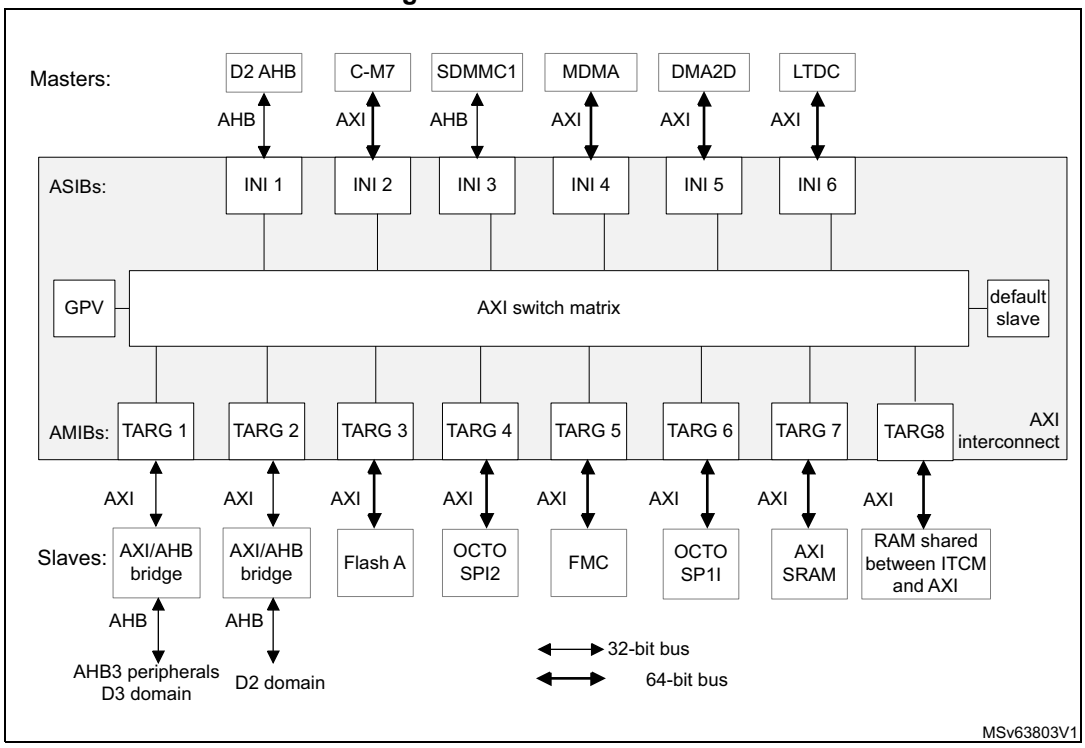
- 64-bit AXI bus switch matrix with six ASIBs and eight AMIBs, in D1 domain
- AHB/AXI bridge function built into the ASIBs
- concurrent connectivity of multiple ASIBs to multiple AMIBs
- programmable traffic priority management (QoS - quality of service)
- software-configurable via GPV

2.2.3 AXI interconnect functional description

Block diagram

The AXI interconnect is shown in *Figure 2*.

Figure 2. AXI interconnect



ASIB configuration

Table 3 summarizes the characteristics of the ASIBs.

Table 3. ASIB configuration

ASIB	Connected master	Protocol	Bus width	R/W issuing
INI 1	AHB from D2 domain	AHB-lite	32	1/1
INI 2	Cortex-M7	AXI4	64	7/32
INI 3	SDMMC1	AHB-lite	32	1/1
INI 4	MDMA	AXI4	64	4/1

Table 3. ASIB configuration (continued)

ASIB	Connected master	Protocol	Bus width	R/W issuing
INI 5	DMA2D	AXI4	64	2/1
INI 6	LTDC	AXI4	64	1/1

AMIB configuration

Table 4 summarizes the characteristics of the AMIBs.

Table 4. AMIB configuration

AMIB	Connected slave	Protocol	Bus width	R/W/Total acceptance
TARG 1	Peripheral 3 and D3 AHB	AXI4(1)	32	1/1/1
TARG 2	D2 AHB	AXI4(1)	32	1/1/1
TARG 3	Flash A	AXI4	64	3/2/5
TARG 4	OCTOSPI2	AXI4	64	2/1/3
TARG 5	FMC	AXI4	64	3/3/6
TARG 6	OCTOSPI1	AXI4	64	2/1/3
TARG 7	AXI SRAM	AXI4	64	2/2/2
TARG 8	RAM shared between ITCM and AXI	AXI4	64	2/2/2

1. Conversion to AHB protocol is done via an AXI/AHB bridge sitting between AXI interconnect and the connected slave.

Quality of service (QoS)

The AXI switch matrix uses a priority-based arbitration when two ASIB simultaneously attempt to access the same AMIB. Each ASIB has programmable read channel and write channel priorities, known as QoS, from 0 to 15, such that the higher the value, the higher the priority. The read channel QoS value is programmed in the *AXI interconnect - INI x read QoS register (AXI_INIx_READ_QOS)*, and the write channel in the *AXI interconnect - INI x write QoS register (AXI_INIx_WRITE_QOS)*. The default QoS value for all channels is 0 (lowest priority).

If two coincident transactions arrive at the same AMIB, the higher priority transaction passes before the lower priority. If the two transactions have the same QoS value, then a least-recently-used (LRU) priority scheme is adopted.

The QoS values should be programmed according to the latency requirements for the application. Setting a higher priority for an ASIB ensures a lower latency for transactions initiated by the associated bus master. This can be useful for real-time-constrained tasks, such as graphics processing (LTDC, DMA2D). Assigning a high priority to masters that can make many and frequent accesses to the same slave (such as the Cortex-M7 CPU) can block access to that slave by other lower-priority masters.

Global programmer view (GPV)

The GPV contains configuration registers for the AXI interconnect (see *Section 2.2.4*). These registers are only accessible by the Cortex-M7 CPU.

2.2.4 AXI interconnect registers

AXI interconnect - peripheral ID4 register (AXI_PERIPH_ID_4)

Address offset: 0x1FD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r				r			

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size
0x0: N/A

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm®

AXI interconnect - peripheral ID0 register (AXI_PERIPH_ID_0)

Address offset: 0x1FE0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r							

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Peripheral part number bits 0 to 7
0x00: Part number = 0x400

AXI interconnect - peripheral ID1 register (AXI_PERIPH_ID_1)

Address offset: 0x1FE4

Reset value: 0x0000 00B4

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r				r			

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity bits 0 to 3
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: Peripheral part number bits 8 to 11
0x4: Part number = 0x400

AXI interconnect - peripheral ID2 register (AXI_PERIPH_ID_2)

Address offset: 0x1FE8

Reset value: 0x0000 002B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r				r	r		

Bits 7:4 **REVISION[3:0]**: Peripheral revision number
0x2: r0p2

Bit 3 **JEDEC:** JEP106 code flag
0x1: JEDEC allocated code

Bits 2:0 **JEP106ID[6:4]**: JEP106 Identity bits 4 to 6
0x3: Arm® JEDEC code

AXI interconnect - peripheral ID3 register (AXI_PERIPH_ID_3)

Address offset: 0x1FEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REV_AND[3:0]				CUST_MOD_NUM[3:0]			
								r				r			

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REV_AND[3:0]**: Customer version
0: None

Bits 3:0 **CUST_MOD_NUM[3:0]**: Customer modification
0: None

AXI interconnect - component ID0 register (AXI_COMP_ID_0)

Address offset: 0x1FF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r							

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Preamble bits 0 to 7
0xD: Common ID value

AXI interconnect - component ID1 register (AXI_COMP_ID_1)

Address offset: 0x1FF4

Reset value: 0x0000 00F0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r				r			

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component class
0xF: Generic IP component class

Bits 3:0 **PREAMBLE[11:8]**: Preamble bits 8 to 11
0x0: Common ID value

AXI interconnect - component ID2 register (AXI_COMP_ID_2)

Address offset: 0x1FF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r							

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Preamble bits 12 to 19
0x05: Common ID value

AXI interconnect - component ID3 register (AXI_COMP_ID_3)

Address offset: 0x1FFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r							

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Preamble bits 20 to 27
0xB1: Common ID value

AXI interconnect - TARG x bus matrix issuing functionality register (AXI_TARGx_FN_MOD_ISS_BM)

Address offset: 0x1008 + 0x1000 * x, where x = 1 to 8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **WRITE_ISS_OVERRIDE**: Switch matrix write issuing override for target
0: Normal issuing capability
1: Set switch matrix write issuing capability to 1

Bit 0 **READ_ISS_OVERRIDE**: Switch matrix read issuing override for target
0: Normal issuing capability
1: Set switch matrix read issuing capability to 1

AXI interconnect - TARG x bus matrix functionality 2 register (AXI_TARGx_FN_MOD2)

Address offset: 0x1024 + 0x1000 * x, where x = 1, 2, 7 and 8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BYPASS_MERGE
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **BYPASS_MERGE**: Disable packing of beats to match the output data width. Unaligned transactions are not realigned to the input data word boundary.

0: Normal operation

1: Disable packing

AXI interconnect - TARG x long burst functionality modification register (AXI_TARGx_FN_MOD_LB)

Address offset: 0x102C + 0x1000 * x, where x = 1 and 2

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FN_MOD_LB
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **FN_MOD_LB**: Controls burst breaking of long bursts

0: Long bursts can not be generated at the output of the ASIB

1: Long bursts can be generated at the output of the ASIB

AXI interconnect - TARG x issuing functionality modification register (AXI_TARGx_FN_MOD)

Address offset: 0x1108 + 0x1000 * x, where x = 1, 2, 7 and 8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **WRITE_ISS_OVERRIDE**: Override AMIB write issuing capability
- 0: Normal issuing capability
- 1: Force issuing capability to 1

Bit 0 **READ_ISS_OVERRIDE**: Override AMIB read issuing capability
- 0: Normal issuing capability
- 1: Force issuing capability to 1

AXI interconnect - INI x functionality modification 2 register (AXI_INIx_FN_MOD2)

Address offset: 0x41024 + 0x1000 * x, where x = 1 and 3

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BYPASS_MERGE
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **BYPASS_MERGE**: Disables alteration of transactions by the up-sizer unless required by the protocol
- 0: Normal operation
- 1: Transactions pass through unaltered where allowed

AXI interconnect - INI x AHB functionality modification register (AXI_INIx_FN_MOD_AHB)

Address offset: 0x41028 + 0x1000 * x, where x = 1 and 3

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WR_INC_OVERRIDE	RD_INC_OVERRIDE
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **WR_INC_OVERRIDE**: Converts all AHB-Lite read transactions to a series of single beat AXI transactions.

0: Override disabled

1: Override enabled

Bit 0 **RD_INC_OVERRIDE**: Converts all AHB-Lite write transactions to a series of single beat AXI transactions, and each AHB-Lite write beat is acknowledged with the AXI buffered write response.

0: Override disabled

1: Override enabled

AXI interconnect - INI x read QoS register (AXI_INIx_READ_QOS)

Address offset: 0x41100 + 0x1000 * x, where x = 1 to 76

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AR_QOS[3:0]			
												rw			

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **AR_QOS[3:0]**: Read channel QoS setting

0x0: Lowest priority

0xF: Highest priority

AXI interconnect - INI x write QoS register (AXI_INIx_WRITE_QOS)

Address offset: 0x41104 + 0x1000 * x, where x = 1 to 76

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AW_QOS[3:0]			
												rw			

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **AW_QOS[3:0]**: Write channel QoS setting
0x0: Lowest priority
0xF: Highest priority

AXI interconnect - INI x issuing functionality modification register (AXI_INIx_FN_MOD)

Address offset: 0x41108 + 0x1000 * x, where x = 1 to 76

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **WRITE_ISS_OVERRIDE**: Override ASIB write issuing capability
0: Normal issuing capability
1: Force issuing capability to 1

Bit 0 **READ_ISS_OVERRIDE**: Override ASIB read issuing capability
0: Normal issuing capability
1: Force issuing capability to 1

2.2.5 AXI interconnect register map

Table 5. AXI interconnect register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x1FD0	AXI_PERIPH_ID_4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT [3:0]				JEP106CON [3:0]			
	Reset value																									0	0	0	0	0	1	0	0
0x1FD4	AXI_PERIPH_ID_5	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Reserved							
	Reset value																									0	0	0	0	0	0	0	0
0x1FD8	AXI_PERIPH_ID_6	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Reserved							
	Reset value																									0	0	0	0	0	0	0	0
0x1FDC	AXI_PERIPH_ID_7	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Reserved							
	Reset value																									0	0	0	0	0	0	0	0
0x1FE0	AXI_PERIPH_ID_0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x1FE4	AXI_PERIPH_ID_1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID [3:0]				PARTNUM [11:8]			
	Reset value																									1	0	1	1	0	1	0	0
0x1FE8	AXI_PERIPH_ID_2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION [3:0]				JEDEC	JEP106ID [6:4]		
	Reset value																									0	0	1	0	1	0	1	1
0x1FEC	AXI_PERIPH_ID_3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REV_AND[3:0]				CUST_MOD_NUM [3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0x1FF0	AXI_COMP_ID_0																									PREAMBLE[7:0]							
	Reset value																									0	0	0	0	1	1	0	1
0x1FF4	AXI_COMP_ID_1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE [11:8]			
	Reset value																									1	1	1	1	0	0	0	0

Table 5. AXI interconnect register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x1FF8	AXI_COMP_ ID_2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value																									0	0	0	0	0	1	0	1
0x1FFC	AXI_COMP_ ID_3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value																									1	0	1	1	0	0	0	1
0x2000 - 0x2004	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x2008	AXI_TARG1_ FN_MOD_ ISS_BM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x200C - 0x2020	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x2024	AXI_TARG1_ FN_MOD2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BYPASS_MERGE
	Reset value																																0
0x2028	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x202C	AXI_TARG1_ FN_MOD_LB	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FN_MOD_LB
	Reset value																																0
0x2030 - 0x2104	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x2108	AXI_TARG1_ FN_MOD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x210C - 0x3004	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Table 5. AXI interconnect register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x3008	AXI_TARG2_ FN_MOD_ ISS_BM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x300C - 0x3020	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x3024	AXI_TARG2_ FN_MOD2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BYPASS_MERGE
	Reset value																																0
0x3028	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x302C	AXI_TARG2_ FN_MOD_LB	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FN_MOD_LB
	Reset value																																0
0x3030 - 0x3104	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x3108	AXI_TARG2_ FN_MOD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x310C - 0x4004	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x4008	AXI_TARG3_ FN_MOD_ ISS_BM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x400C - 0x5004	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Table 5. AXI interconnect register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x5008	AXI_TARG4_ FN_MOD_ ISS_BM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x500C - 0x6004	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x6008	AXI_TARG5_ FN_MOD_ ISS_BM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x600C - 0x7004	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x7008	AXI_TARG6_ FN_MOD_ ISS_BM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x700C - 0x8004	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x8008	AXI_TARG7_ FN_MOD_ ISS_BM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x800C - 0x8020	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x8024	AXI_TARG7_ FN_MOD2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BYPASS_MERGE
	Reset value																																0

Table 5. AXI interconnect register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x8028 - 0x8104	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x8108	AXI_TARG7_ FN_MOD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x810C- 0x9004	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x9008	AXI_TARG8_ FN_MOD_ ISS_BM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x900C - 0x9020	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x9024	AXI_TARG8_ FN_MOD2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BYPASS_MERGE
	Reset value																																0
0x9028 - 0x9104	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x9108	AXI_TARG8_ FN_MOD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x910C- 0x42020	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Table 5. AXI interconnect register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x42024	AXI_INI1_ FN_MOD2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BYPASS_MERGE
	Reset value																																0
0x42028	AXI_INI1_FN_ MOD_AHB	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WR_INC_OVERRIDE	RD_INC_OVERRIDE
	Reset value																															0	0
0x4202C-0x420FC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x42100	AXI_INI1_ READ_QOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AR_QOS [3:0]			
	Reset value																													0	0	0	0
0x42104	AXI_INI1_ WRITE_QOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AW_QOS [3:0]			
	Reset value																													0	0	0	0
0x42108	AXI_INI1_ FN_MOD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x4210C-0x430FC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x43100	AXI_INI2_ READ_QOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AR_QOS [3:0]			
	Reset value																													0	0	0	0
0x43104	AXI_INI2_ WRITE_QOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AW_QOS [3:0]			
	Reset value																													0	0	0	0

Table 5. AXI interconnect register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x43108	AXI_INI2_ FN_MOD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x4310C - 0x44020	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x44024	AXI_INI3_ FN_MOD2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.		BYPASS_MERGE
	Reset value																																0
0x44028	AXI_INI3_ FN_MOD_AHB	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WR_INC_OVERRIDE	RD_INC_OVERRIDE
	Reset value																															0	0
0x4402C-0x440FC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x44100	AXI_INI3_ READ_QOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AR_QOS [3:0]			
	Reset value																													0	0	0	0
0x44104	AXI_INI3_ WRITE_QOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AW_QOS [3:0]			
	Reset value																													0	0	0	0
0x44108	AXI_INI3_ FN_MOD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x4410C-0x450FC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x45100	AXI_INI4_ READ_QOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AR_QOS [3:0]			
	Reset value																													0	0	0	0

Table 5. AXI interconnect register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x45104	AXI_INI4_ WRITE_QOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AW_QOS [3:0]			
	Reset value																													0	0	0	0
0x45108	AXI_INI4_ FN_MOD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x4510C- 0x460FC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x46100	AXI_INI5_ READ_QOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AR_QOS [3:0]			
	Reset value																													0	0	0	0
0x46104	AXI_INI5_ WRITE_QOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AW_QOS [3:0]			
	Reset value																													0	0	0	0
0x46108	AXI_INI5_ FN_MOD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0
0x4610C- 0x470FC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x47100	AXI_INI6_ READ_QOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AR_QOS [3:0]			
	Reset value																													0	0	0	0
0x47104	AXI_INI6_ WRITE_QOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AW_QOS [3:0]			
	Reset value																													0	0	0	0
0x47108	AXI_INI6_ FN_MOD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRITE_ISS_OVERRIDE	READ_ISS_OVERRIDE
	Reset value																															0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

2.3 Memory organization

2.3.1 Introduction

Program memory, data memory, registers and I/O ports are organized within the same linear 4-Gbyte address space.

The bytes are coded in memory in Little Endian format. The lowest numbered byte in a word is considered the word's least significant byte and the highest numbered byte the most significant.

The addressable memory space is divided into eight main blocks, of 512 Mbytes each.

2.3.2 Memory map and register boundary addresses

Table 6. Memory map and default device memory area attributes

Region	Boundary address	Arm® Cortex®-M7	Type	Attributes	Execute never
External Devices	0xD0000000 - 0xDFFFFFFF	FMC SDRAM Bank2	Device	-	Yes
	0xCC000000 - 0xCFFFFFFF	FMC SDRAM Bank1 (or remap of FMC NOR/PSRAM/SRAM 4 Bank1)			
	0xC8000000 - 0xCBFFFFFF	FMC SDRAM Bank1 (or remap of FMC NOR/PSRAM/SRAM 3 Bank1)			
	0xC4000000 - 0xC7FFFFFF	FMC SDRAM Bank1 (or remap of FMC NOR/PSRAM/SRAM 2 Bank1)			
	0xC0000000 - 0xC3FFFFFF	FMC SDRAM Bank1 (or remap of FMC NOR/PSRAM/SRAM 1 Bank1)			
	0xA0000000 - 0xBFFFFFFF	Reserved			
External Memories	0x90000000 - 0x9FFFFFFF	OCTOSPI1	Normal	Write-through cache attribute	No
	0x80000000 - 0x8FFFFFFF	FMC NAND Flash memory			
	0x70000000 - 0x7FFFFFFF	OCTOSPI2			
	0x6C000000 - 0x6FFFFFFF	FMC NOR/PSRAM/SRAM 4 Bank1 (or remap of FMC SDRAM Bank1)		Write-back, write allocate cache attribute	
	0x68000000 - 0x6BFFFFFF	FMC NOR/PSRAM/SRAM 3 Bank1 (or remap of FMC SDRAM Bank1)			
	0x64000000 - 0x67FFFFFF	FMC NOR/PSRAM/SRAM 2 Bank1 (or remap of FMC SDRAM Bank1)			
	0x60000000 - 0x63FFFFFF	FMC NOR/PSRAM/SRAM 1 Bank1 (or remap of FMC SDRAM Bank1)			
Peripherals	0x40000000 - 0x5FFFFFFF	Peripherals (refer to *Table 7: Register boundary addresses*)	Device	-	Yes

Table 6. Memory map and default device memory area attributes (continued)

Region	Boundary address	Arm® Cortex®-M7	Type	Attributes	Execute never
RAM	0x38801000 - 0x3FFFFFFF	Reserved	Normal	Write-back, write allocate cache attribute	No
	0x38800000 - 0x38800FFF	Backup SRAM			
	0x38004000 - 0x387FFFFF	Reserved			
	0x38000000 - 0x38003FFF	SRAM4			
	0x30008000 - 0x37FFFFFF	Reserved			
	0x30004000 - 0x30007FFF	SRAM2			
	0x30000000 - 0x30003FFF	SRAM1			
	0x24050000 - 0x2FFFFFFF	Reserved			
	0x24020000 - 0x2404FFFF	RAM shared between ITCM and AXI			
	0x24000000 - 0x2401FFFF	AXI SRAM			
	0x20020000 - 0x23FFFFFF	Reserved			
	0x20000000 - 0x2001FFFF	DTCM			
Code	0x1FF20000 - 0x1FFFFFFF	Reserved	Normal	Write-through cache attribute	No
	0x1FF00000 - 0x1FEFFFFF	System Memory			
	0x08100000 - 0x1FEFFFFF	Reserved			
	0x08000000 - 0x080FFFFF	Flash memory bank 1			
	0x00040000 - 0x07FFFFFF	Reserved			
	0x00010000 - 0x0003FFFF	RAM shared between ITCM and AXI			
	0x00000000 - 0x0000FFFF	ITCM RAM			

All the memory map areas that are not allocated to on-chip memories and peripherals are considered “Reserved”. For the detailed mapping of available memory and register areas, refer to the following table.

The following table gives the boundary addresses of the peripherals available in the devices.

Table 7. Register boundary addresses(1)

Boundary address	Peripheral	Bus	Register map
0x58026400 - 0x580267FF	HSEM	AHB4 (D3)	*Section 10.4: HSEM registers*
0x58026000 - 0x580263FF	ADC3		*Section 28.7: ADC common registers*
0x58025800 - 0x58025BFF	DMAMUX2		*Section 17.6: DMAMUX registers*
0x58025400 - 0x580257FF	BDMA		*Section 16.6: BDMA registers*
0x58024C00 - 0x58024FFF	CRC		*Section 21.4: CRC registers*
0x58024800 - 0x58024BFF	PWR		*Section 6.8: PWR registers*
0x58024400 - 0x580247FF	RCC		*Section 8.7: RCC registers*
0x58022800 - 0x58022BFF	GPIOK		*Section 11.4: GPIO registers*
0x58022400 - 0x580227FF	GPIOJ		*Section 11.4: GPIO registers*
0x58021C00 - 0x58021FFF	GPIOH		*Section 11.4: GPIO registers*
0x58021800 - 0x58021BFF	GPIOG		*Section 11.4: GPIO registers*
0x58021400 - 0x580217FF	GPIOF		*Section 11.4: GPIO registers*
0x58021000 - 0x580213FF	GPIOE		*Section 11.4: GPIO registers*
0x58020C00 - 0x58020FFF	GPIOD		*Section 11.4: GPIO registers*
0x58020800 - 0x58020BFF	GPIOC		*Section 11.4: GPIO registers*
0x58020400 - 0x580207FF	GPIOB		*Section 11.4: GPIO registers*
0x58020000 - 0x580203FF	GPIOA		*Section 11.4: GPIO registers*

Table 7. Register boundary addresses(1) (continued)

Boundary address	Peripheral	Bus	Register map
0x58005800 - 0x580067FF	Reserved	APB4 (D3)	Reserved
0x58006800 - 0x58006BFF	DTS		*Section 30.6: DTS registers*
0x58005400 - 0x580057FF	SAI4		*Section 56.6: SAI registers*
0x58004C00 - 0x58004FFF	Reserved		Reserved
0x58004800 - 0x58004BFF	IWDG		*Section 50.4: IWDG registers*
0x58004000 - 0x580043FF	RTC & BKP registers		*Section 51.7: RTC registers*
0x58003C00 - 0x58003FFF	VREF		*Section 32.3: VREFBUF registers*
0x58003800 - 0x58003BFF	COMP1 - COMP2		*Section 33.7: COMP registers*
0x58003000 - 0x580033FF	LPTIM5		*Section 48.7: LPTIM registers*
0x58002C00 - 0x58002FFF	LPTIM4		*Section 48.7: LPTIM registers*
0x58002800 - 0x58002BFF	LPTIM3		*Section 48.7: LPTIM registers*
0x58002400 - 0x580027FF	LPTIM2		*Section 48.7: LPTIM registers*
0x58001C00 - 0x58001FFF	I2C4		*Section 52.7: I2C registers*
0x58001400 - 0x580017FF	SPI/I2S6		*Section 55.11: SPI/I2S registers*
0x58000C00 - 0x58000FFF	LPUART1		*Section 54.7: LPUART registers*
0x58000400 - 0x580007FF	SYSCFG		*Section 13.3: SYSCFG registers*
0x58000000 - 0x580003FF	EXTI		*Section 20.6: EXTI registers*

Table 7. Register boundary addresses[1] (continued)

Boundary address	Peripheral	Bus	Register map
0x5200BC00 - 0x5200BFFF	OTFDEC2	AHB3 (D1)	*Section 42.6: OTFDEC registers*
0x5200B800 - 0x5200BBFF	OTFDEC1		*Section 42.6: OTFDEC registers*
0x5200B400 - 0x5200B7FF	OCTOSPI I/O		*Section 26.5: OCTOSPIM registers*
0x5200B000 - 0x5200B3FF	Delay Block OCTOSPI2		*Section 27.4: DLYB registers*
0x5200A000 - 0x5200AFFF	OCTOSPI2		*Section 25.7: OCTOSPI registers*
0x52009000 - 0x520093FF	RAMECC D1 domain		*Section 3.4: RAMECC registers*
0x52008000 - 0x52008FFF	Delay Block SDMMC1		*Section 27.4: DLYB registers*
0x52007000 - 0x52007FFF	SDMMC1		*Section 60.10: SDMMC registers*
0x52006000 - 0x52006FFF	Delay Block OCTOSPI1		*Section 27.4: DLYB registers*
0x52005000 - 0x52005FFF	OCTOSPI1 control registers		*Section 25.7: OCTOSPI registers*
0x52004000 - 0x52004FFF	FMC control registers		*Section 24.7.6: NOR/PSRAM controller registers*, *Section 24.8.7: NAND Flash controller registers*, *Section 24.9.5: SDRAM controller registers*
0x52002000 - 0x52002FFF	Flash interface registers		*Section 4.9: FLASH registers*
0x52001000 - 0x52001FFF	Chrom-Art (DMA2D)		*Section 18.5: DMA2D registers*
0x52000000 - 0x52000FFF	MDMA		*Section 14.5: MDMA registers*
0x51000000 - 0x510FFFFF	GPV		*Section 2.2: AXI interconnect matrix (AXIM)*
0x50003000 - 0x50003FFF	WWDG	APB3 (D1)	*Section 49.5: WWDG interrupts*
0x50001000 - 0x50001FFF	LTDC		*Section 38.7: LTDC registers*
0x50000000 - 0x50000FFF	Reserved		-
0x48024400 - 0x48024 7FFF	CORDIC	AHB2 (D2)	*Section 22.4: CORDIC registers*
0x48024000 - 0x480243FF	FMAC		*Section 23.4: FMAC registers*
0x48023000 - 0x48023FFF	RAMECC D2 domain		*Section 3.4: RAMECC registers*
0x48022800 - 0x48022BFF	Delay Block SDMMC2		*Section 27.4: DLYB registers*
0x48022400 - 0x480227FF	SDMMC2		*Section 60.10: SDMMC registers*
0x48021800 - 0x48021BFF	RNG		*Section 39.7: RNG registers*
0x48021400 - 0x480217FF	HASH		*Section 41.7: HASH registers*
0x48021000 - 0x480213FF	CRYPTO		*Section 40.7: CRYP registers*
0x48020400 - 0x480207FF	PSSI		*Section 37.5: PSSI registers*
0x48020000 - 0x480203FF	DCMI		*Section 36.5: DCMI registers*

Table 7. Register boundary addresses(1) (continued)

Boundary address	Peripheral	Bus	Register map
0x40040000 - 0x4007FFFF	USB1 OTG_HS	AHB1 (D2)	*Section 62.14: OTG_HS registers*
0x40028000 - 0x400293FF	ETHERNET MAC		*Section 63.11: Ethernet registers*
0x40024400 - 0x400247FF	Reserved		Reserved
0x40022000 - 0x400223FF	ADC1 - ADC2		*Section 28.7: ADC common registers*
0x40020800 - 0x40020BFF	DMAMUX1		*Section 17.6: DMAMUX registers*
0x40020400 - 0x400207FF	DMA2		*Section 15.5: DMA registers*
0x40020000 - 0x400203FF	DMA1		*Section 15.5: DMA registers*
0x40017800 - 0x40017FFF	DFSDM1	APB2 (D2)	*Section 35.7: DFSDM channel y registers (y=0..7)*, *Section 35.8: DFSDM filter x module registers (x=0..3)*
0x40015800 - 0x40015BFF	SAI1		*Section 56.6: SAI registers*
0x40015000 - 0x400153FF	SPI5		*Section 55.11: SPI/I2S registers*
0x40014800 - 0x40014BFF	TIM17		*Section 46.6: TIM16/TIM17 registers*
0x40014400 - 0x400147FF	TIM16		*Section 46.6: TIM16/TIM17 registers*
0x40014000 - 0x400143FF	TIM15		*Section 46.5: TIM15 registers*
0x40013400 - 0x400137FF	SPI4		*Section 55.11: SPI/I2S registers*
0x40013000 - 0x400133FF	SPI1 / I2S1		*Section 55.11: SPI/I2S registers*
0x40011C00 - 0x40011FFF	USART10		*Section 53.8: USART registers*
0x40011800 - 0x40011BFF	UART9		*Section 53.8: USART registers*
0x40011400 - 0x400117FF	USART6		*Section 53.8: USART registers*
0x40011000 - 0x400113FF	USART1		*Section 53.8: USART registers*
0x40010400 - 0x400107FF	TIM8		*Section 43.4: TIM1/TIM8 registers*
0x40010000 - 0x400103FF	TIM1		*Section 43.4: TIM1/TIM8 registers*

Table 7. Register boundary addresses(1) (continued)

Boundary address	Peripheral	Bus	Register map
0x4000E400 - 0x4000E7FF	TIM24	APB1 (D2)	*Section 44.4: TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 registers*
0x4000E000 - 0x4000E3FF	TIM23		*Section 44.4: TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 registers*
0x4000D400 - 0x4000D7FF	FDCAN3		*Section 61.5: FDCAN registers*
0x4000AC00 - 0x4000D3FF	CAN Message RAM		*Section 61.5: FDCAN registers*
0x4000A800 - 0x4000ABFF	CAN CCU		*Section 61.5: FDCAN registers*
0x4000A400 - 0x4000A7FF	FDCAN2		*Section 61.5: FDCAN registers*
0x4000A000 - 0x4000A3FF	FDCAN1		*Section 61.5: FDCAN registers*
0x40009400 - 0x400097FF	MDIOS		*Section 59.4: MDIOS registers*
0x40009000 - 0x400093FF	OPAMP		*Section 34.6: OPAMP registers*
0x40008800 - 0x40008BFF	SWPMI		*Section 58.6: SWPMI registers*
0x40008400 - 0x400087FF	CRS		*Section 9.8: CRS registers*
0x40007C00 - 0x40007FFF	UART8		*Section 53.8: USART registers*
0x40007800 - 0x40007BFF	UART7		*Section 53.8: USART registers*
0x40007400 - 0x400077FF	DAC1/2		*Section 31.7: DAC registers*
0x40006C00 - 0x40006FFF	HDMI-CEC		*Section 64.7: HDMI-CEC registers*
0x40006400 - 0x400067FF	I2C5		*Section 52.7: I2C registers*
0x40005C00 - 0x40005FFF	I2C3		*Section 52.7: I2C registers*
0x40005800 - 0x40005BFF	I2C2		*Section 52.7: I2C registers*
0x40005400 - 0x400057FF	I2C1		*Section 52.7: I2C registers*
0x40005000 - 0x400053FF	UART5		*Section 53.8: USART registers*
0x40004C00 - 0x40004FFF	UART4		*Section 53.8: USART registers*
0x40004800 - 0x40004BFF	USART3		*Section 53.8: USART registers*
0x40004400 - 0x400047FF	USART2		*Section 53.8: USART registers*
0x40004000 - 0x400043FF	SPDIFRX1		*Section 57.5: SPDIFRX interface registers*
0x40003C00 - 0x40003FFF	SPI3 / I2S3		*Section 55.11: SPI/I2S registers*
0x40003800 - 0x40003BFF	SPI2 / I2S2		*Section 55.11: SPI/I2S registers*
0x40002C00 - 0x40002FFF	Reserved		Reserved
0x40002400 - 0x400027FF	LPTIM1		*Section 48.7: LPTIM registers*
0x40002000 - 0x400023FF	TIM14		*Section 44.4: TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 registers*
0x40001C00 - 0x40001FFF	TIM13		*Section 44.4: TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 registers*
0x40001800 - 0x40001BFF	TIM12		*Section 44.4: TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 registers*

Table 7. Register boundary addresses(1) (continued)

Boundary address	Peripheral	Bus	Register map
0x40001400 - 0x400017FF	TIM7	APB1 (D2)	*Section 47.4: TIM6/TIM7 registers*
0x40001000 - 0x400013FF	TIM6		*Section 47.4: TIM6/TIM7 registers*
0x40000C00 - 0x40000FFF	TIM5		*Section 44.4: TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 registers*
0x40000800 - 0x40000BFF	TIM4		*Section 44.4: TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 registers*
0x40000400 - 0x400007FF	TIM3		*Section 44.4: TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 registers*
0x40000000 - 0x400003FF	TIM2		*Section 44.4: TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 registers*

1. Accessing a reserved area results in a bus error. Accessing undefined memory space in a peripheral returns zeros.

2.4 Embedded SRAM

The STM32H72x and STM32H73x devices include:

- 128 Kbytes of AXI-SRAM mapped onto the AXI bus on D1 domain
- 64 Kbytes of instruction TCM RAM
- 128 Kbytes of data TCM RAM
- 192 Kbyte SRAM on D1 domain that can be shared between to Instruction TCM or AXI-SRAM with 64 Kbyte granularity (see *Section : RAM shared between ITCM and AXI RAM*)
- 16 Kbyte SRAM1 mapped on D2 domain
- 16 Kbyte SRAM2 mapped on D2 domain
- 16 Kbyte SRAM4 mapped on D3 domain

The embedded system SRAM is divided into up to five blocks over the three power domains:

- D1 domain, AXI SRAM:
  - AXI SRAM is mapped at address 0x2400 0000 and accessible by all system masters except BDMA through D1 domain AXI bus matrix. AXI SRAM can be used for application data which are not allocated in DTCM RAM or reserved for graphic objects (such as frame buffers)
- D2 domain, AHB SRAM:
  - AHB SRAM1 is mapped at address 0x3000 0000 and accessible by all system masters except BDMA, SDMMC1 and LTDC, through D2 domain AHB matrix. AHB SRAM1 can be used as DMA buffers to store peripheral input/output data in D2 domain.
  - AHB SRAM2 is mapped at address 0x3000 4000 and accessible by all system masters except BDMA, SDMMC1 and LTDC, through D2 domain AHB matrix.

AHB SRAM2 can be used as DMA buffers to store peripheral input/output data in D2 domain.

- D3 domain, AHB SRAM:
  - AHB SRAM4 is mapped at address 0x3800 0000 and accessible by most of system masters through D3 domain AHB matrix. AHB SRAM4 can be used as BDMA buffers to store peripheral input/output data in D3 domain. It can also be used to retain some application code/data when D1 and D2 domain enter DStandby mode.

The system AHB SRAM can be accessed as bytes, half-words (16-bit units) or words (32-bit units), while the system AXI SRAM can be accessed as bytes, half-words, words or double-words (64-bit units). These memories can be addressed at maximum system clock frequency without wait state.

The AHB masters can read/write-access an SRAM section concurrently with the Ethernet MAC or the USB OTG HS peripheral accessing another SRAM section. For example, the Ethernet MAC accesses the SRAM2 while the CPU accesses the SRAM1, concurrently.

The TCM SRAMs are dedicated to the Cortex®-M7:

- DTCM-RAM on TCM interface is mapped at the address 0x2000 0000 and accessible by Cortex®-M7, and by MDMA through AHBS slave bus of the Cortex®-M7 CPU. The DTCM-RAM can be used as read-write segment to host critical real-time data (such as stack and heap) for application running on Cortex®-M7 CPU.
- ITCM-RAM on TCM interface mapped at the address 0x0000 0000 and accessible by Cortex®-M7 and by MDMA through AHBS slave bus of the Cortex®-M7 CPU. The ITCM-RAM can be used to host code for time-critical routines (such as interrupt handlers) that requires deterministic execution.

The backup RAM is mapped at the address 0x3880 0000 and is accessible by most of the system masters through D3 domain's AHB matrix. With a battery connected to the V_{BAT} pin, the backup SRAM can be used to retain data during low-power mode (Standby and V_{BAT} mode).

Error code correction (ECC)

SRAM data are protected by ECC:

- 7 ECC bits are added per 32-bit word.
- 8 ECC bits are added per 64-bit word for AXI-SRAM and ITCM-RAM.

The ECC mechanism is based on the SECDED algorithm. It supports single-error correction and double-error detection.

When a half word is written to an internal SRAM (except DTCM and ITCM) and a reset occurs, this half word is not really written to the SRAM after reset. This due to the ECC behavior.

To ensures the data are effectively written to DTCM and ITCM internal memories, read back the programmed data.

The ECC is always active except when the CPU frequency boost feature is used. In that case the ECC is no more active on TCM RAMs. The CPU frequency boost can be enabled through the CPUFREQ_BOOST option byte in FLASH_OPTSR2_PRG register.

Refer to *Section 4: Embedded Flash memory (FLASH)* for a description of the CPUFREQ_BOOST option byte and to *Section 3: RAM ECC monitoring (RAMECC)* for details on RAM ECC monitoring.

RAM shared between ITCM and AXI RAM

192 Kbyte of RAM can be used either as ITCM or as AXI SRAM. This feature can be configured through the TCM_AXI_SHARED[1:0] option byte in FLASH_OPTSR2_PRG register as described in *Table 8*.

Table 8. ITCM/DTCM/AXI configuration

TCM_AXI_ SHARED[1,0]	ITCM size (Kbyte)	ITCM memory mapping	AXI size (Kbyte)	AXI memory mapping
00	64	0x00000 0000 - 0x0000 FFFF	320	0x2400 0000 - 0x2404 FFFF
01	128	0x0000 0000 - 0x0001 FFFF	256	0x2400 0000 - 0x2403 FFFF
10	192	0x0000 0000 - 0x0002 FFFF	192	0x2400 0000 - 0x2402 FFFF
11	256	0x0000 0000 - 0x0003 FFFF	128	0x2400 0000 - 0x2401 FFFF

Refer to *Section 4: Embedded Flash memory (FLASH)* for a description of the TCM_AXI_SHARED option byte.

2.5 Flash memory overview

The Flash memory interface manages accesses to the Flash memory. It implements the erase and program Flash memory operations and the read and write protection mechanisms.

The Flash memory is organized as follows:

- A main memory block divided into sectors.
- An information block:
  - System memory from which the device boots in System memory boot mode
  - Option bytes to configure read and write protection, BOR level, watchdog software/hardware and reset when the device is in Standby or Stop mode.

Refer to *Section 4: Embedded Flash memory (FLASH)* for more details.

2.6 Boot configuration

In the STM32H72x and STM32H73x, two different boot areas can be selected through the BOOT pin and the boot base address programmed in the BOOT_ADD0 and BOOT_ADD1 option bytes as shown in the *Table 9*.

Table 9. Boot modes

Boot mode selection		Boot area
BOOT	**Boot address option bytes**	
0	BOOT_ADD0[15:0]	Boot address defined by user option byte BOOT_ADD0[15:0] ST programmed value: Flash memory at 0x0800 0000
1	BOOT_ADD1[15:0]	Boot address defined by user option byte BOOT_ADD1[15:0] ST programmed value: System bootloader at 0x1FF0 0000

The values on the BOOT pin are latched on the 4th rising edge of SYSCLK after reset release. It is up to the user to set the BOOT pin after reset.

The BOOT pin is also re-sampled when the device exits the Standby mode. Consequently, they must be kept in the required Boot mode configuration when the device is in the Standby mode.

After startup delay, the selection of the boot area is done before releasing the processor reset.

The BOOT_ADD0 and BOOT_ADD1 address option bytes allows to program any boot memory address from 0x0000 0000 to 0x3FFF 0000 which includes:

- All Flash address space
- All RAM address space: ITCM, DTCM RAMs and SRAMs
- The TCM-RAM

The BOOT_ADD0 / BOOT_ADD1 option bytes can be modified after reset in order to boot from any other boot address after next reset.

If the programmed boot memory address is out of the memory mapped area or a reserved area, the default boot fetch address is programmed as follows:

- Boot address 0: FLASH at 0x0800 0000
- Boot address 1: ITCM-RAM at 0x0000 0000

When the Flash level 2 protection is enabled, only boot from Flash memory is available. If the boot address already programmed in the BOOT_ADD0 / BOOT_ADD1 option bytes is out of the memory range or belongs to the RAM address range, the default fetch will be forced from Flash memory at address 0x0800 0000.

Embedded bootloader

The embedded bootloader code is located in system memory. It is programmed by ST during production. It is used to reprogram the Flash memory using one of the following serial interfaces:

- USART1 on PA9/PA10 pins, USART2 on PA3/2 pins, and USART3 on PB10/PB11 or PD8/PD9 pins.
- I2C1 on PB6/9 pins, I2C2 on PF0/PF1 pins, and I2C3 on PA8/PC9 pins.
- USB OTG FS in Device mode (DFU) on PA11/PA12 pins
- SPI1 on PA7/6/5/4 pins, SPI3 on PC12/11/10/PA15 pins, and SPI4 on PE14/13/12/11 pins.
- FDCAN1 on PH13/PH14 and PD1/PD0 pins.

For additional information, refer to the application note AN2606.

3 RAM ECC monitoring (RAMECC)

3.1 Introduction

The STM32H72x and STM32H73x devices feature a RAM ECC monitoring unit (RAMECC). It provides a mean for application software to verify ECC status and execute service routines when an error occurs.

3.2 RAMECC main features

SRAM data are protected by ECC. The ECC mechanism is based on the SECDED algorithm. It supports single- and double-error detection, as well as single-error correction:

- 7 ECC bits are added per 32-bit word.
- 8 ECC bits are added per 64-bit word for AXI-SRAM and ITCM-RAM.

RAM data word integrity is checked at each memory read access, or partial RAM word write operation. Two cycles are required to perform a partial RAM word write (read-modify-write).

The RAMECC monitoring unit includes the following features:

- RAM ECC monitoring per domain
- RAM failing address/data identification

3.3 RAMECC functional description

3.3.1 RAMECC block diagram

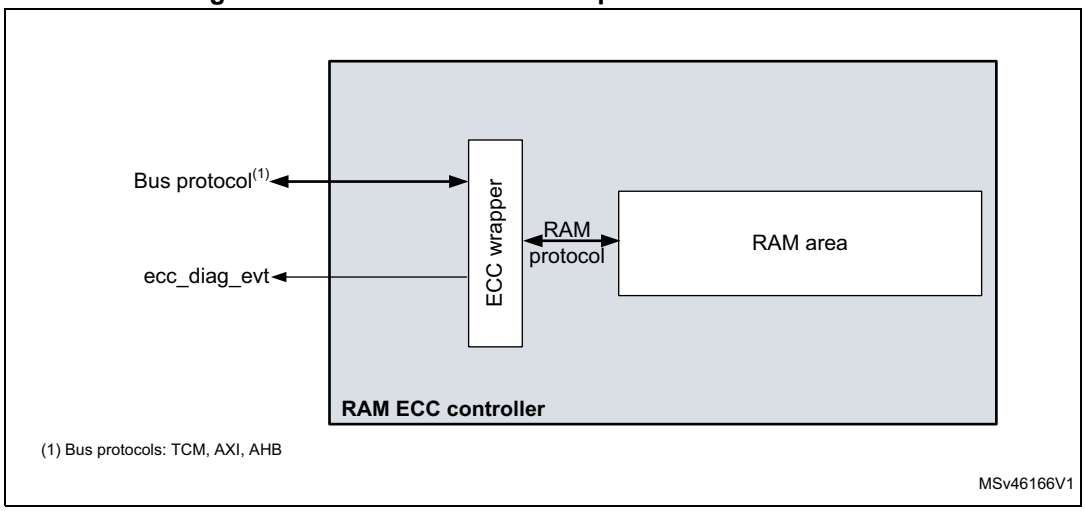
An ECC controller is associated to each RAM area. It performs the following functions:

- ECC encoding: ECC code computation and storage.
- ECC decoding: RAM data word loading and ECC code decoding to detect errors
- Error detection: single- and double-error detection
- Error correction: single-error correction.

Note: All the RAM ECC controllers are always enabled except when the boost_cpu_freq feature is enabled (refer to the description of the CPUFREQ_BOOST option byte).

Figure 3 describes the implementation of RAM ECC controllers.

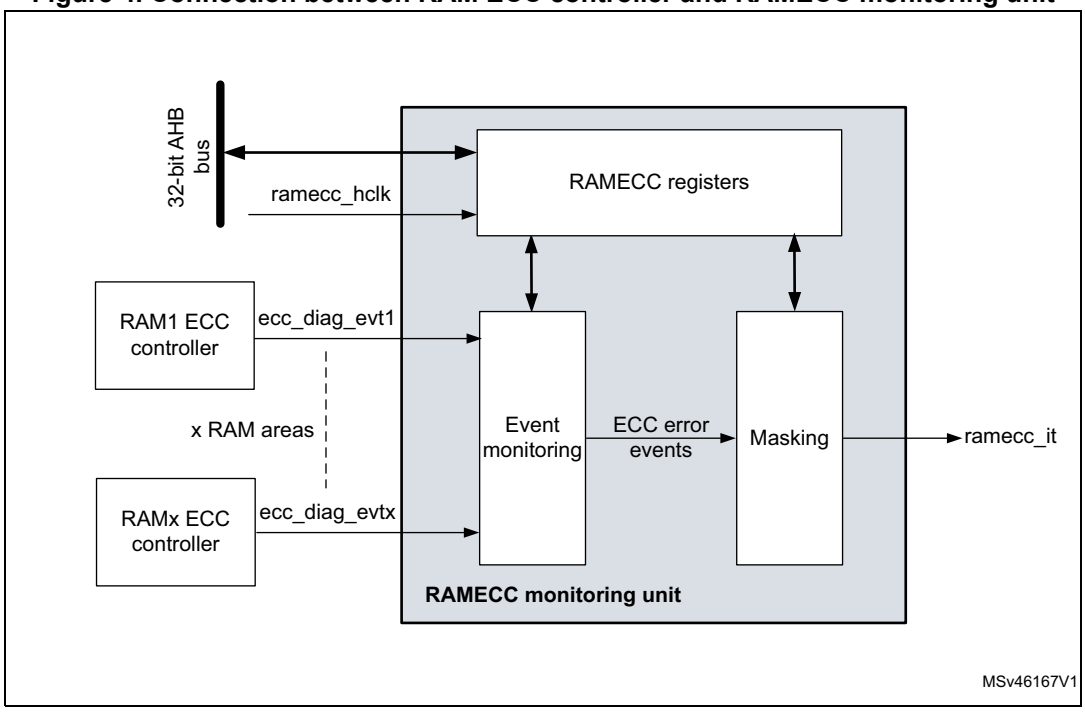
Figure 3. RAM ECC controller implementation schematic



A dedicated RAM ECC monitoring area is defined for each domain (see *Section 3.3.3: RAMECC monitor mapping*. The RAMECC allows the collection of ECC diagnostic events from each RAM ECC controller and provides a mean for the CPU to verify the ECC status.

Figure 4 shows the connection schematic between the RAM ECC controller and the RAMECC monitoring unit.

Figure 4. Connection between RAM ECC controller and RAMECC monitoring unit



3.3.2 RAMECC internal signals

Table 10 gives the list of the internal signals that control the RAMECC unit.

Table 10. RAMECC internal input/output signals

Internal signal name	Signal type	Description
ramecc_hclk	Input	AHB clock
ecc_diag_evtx	Input	ECC diagnostic event generated by RAMx ECC controller x
ramecc_it	Output	Interrupt generated by the RAMECC monitoring unit when an ECC error is detected.

3.3.3 RAMECC monitor mapping

STM32H72x and STM32H73x devices features three RAMECC monitoring units (one per domain). The inputs from the ECC controllers are mapped as described in *Table 11*. The RAM ECC event monitoring status and configuration registers are described in *Section 3.4: RAMECC registers*.

Table 11. ECC controller mapping

RAMECC units	Monitor number	SRAM ECC event monitoring status and configuration registers		Address Offset
D1 domain RAMECC unit	1	AXI SRAM ECC monitoring unit		0x20
	2	ITCM-RAM ECC monitoring unit		0x40
	3	DTCM-RAM ECC monitoring unit	D0TCM	0x60
	4		D1TCM	0x80
	5	ETM RAM ECC monitoring unit		0xA0
	6	SRAM ECC: AXI SRAM sharable with ITCM-RAM ECC monitoring unit		0xC0
D2 domain RAMECC unit	1	SRAM1 ECC monitoring unit	SRAM1_0	0x20
	2	SRAM2 ECC monitoring unit	SRAM2_0	0x40
	3	FDCAN RAM ECC monitoring unit		0x60
D3 domain RAMECC unit	1	SRAM4 ECC monitoring unit		0x20
	2	Backup RAM ECC monitoring unit		0x40

3.4 RAMECC registers

RAMECC registers can be accessed only in 32-bit (word) mode. Byte and half-word formats are not allowed.

3.4.1 RAMECC interrupt enable register (RAMECC_IER)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GECCDEBWIE	GECCDEIE	GECCSEIE	GIE
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **GECCDEBWIE**: Global ECC double error on byte write (BW) interrupt enable

When GECCDEBWIE bit is set to 1, an interrupt is generated when an ECC double detection error occurs during a byte write operation to RAM (incomplete word write).

0: no interrupt generated when an ECC double detection error occurs on byte write

1: interrupt generated if an ECC double detection error occurs on byte write

Bit 2 **GECCDEIE**: Global ECC double error interrupt enable

When GECCDEIE bit is set to 1, an interrupt is generated when an ECC double detection error occurs during a read operation from RAM.

0: no interrupt generated when an ECC double detection error occurs

1: interrupt generated if an ECC double detection error occurs

Bit 1 **GECCSEIE**: Global ECC single error interrupt enable

When GECCSEIE bit is set to 1, an interrupt is generated when an ECC single error occurs during a read operation from RAM.

0: no interrupt generated when an ECC single error occurs

1: interrupt generated when an ECC single error occurs

Bit 0 **GIE**: Global interrupt enable

When GIE bit is set to 1, an interrupt is generated when an enabled global ECC error (GECCDEBWIE, GECCDEIE or GECCSEIE) occurs.

0: no interrupt generated when an ECC error occurs

1: interrupt generated when an ECC error occurs

3.4.2 RAMECC monitor x configuration register (RAMECC_MxCR)

Address offset: 0x20 * x

Reset value: 0x0000 0000

x is the ECC monitoring unit number

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCELEN	ECCDEBWIE	ECCDEIE	ECCSEIE	Res.	Res.
										rw	rw	rw	rw		

Bits 31:6 Reserved, must be kept at reset value.

Bit 5 **ECCELEN**: ECC error latching enable

When ECCELEN bit is set to 1, if an ECC error occurs (both for single error correction or double detection) during a read operation, the context (address, data and ECC code) that generated the error are latched to their respective registers.

0: no error context preserved when an ECC error occurs

1: error context preserved when an ECC error occurs

Bit 4 **ECCDEBWIE:** ECC double error on byte write (BW) interrupt enable

When ECCDEBWIE bit is set to 1, monitor x generates an interrupt when an ECC double detection error occurs during a byte write operation to RAM.

0: no interrupt generated when an ECC double detection error occurs on byte write

1: interrupt generated if an ECC double detection error occurs on byte write

Bit 3 **ECCDEIE:** ECC double error interrupt enable

When ECCDEIE bit is set to 1, monitor x generates an interrupt when an ECC double detection error occurs during a read operation from RAM.

0: no interrupt generated when an ECC double detection error occurs

1: interrupt generated if an ECC double detection error occurs

Bit 2 **ECCSEIE**: ECC single error interrupt enable

When ECCSEIE bit is set to 1, monitor x generates an interrupt when an ECC single error occurs during a read operation from RAM.

0: no interrupt generated when an ECC single error occurs

1: interrupt generated when an ECC single error occurs

Bits 1:0 Reserved, must be kept at reset value.

3.4.3 RAMECC monitor x status register (RAMECC_MxSR)

Address offset: 0x24 + 0x20 * (x - 1), (x= ECC monitoring unit number)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEBWDF	DEDF	SEDCF
													rc_w0	rc_w0	rc_w0

Bits 31: 3 Reserved, must be kept at reset value.

Bit 2 **DEBWDF:** ECC double error on byte write (BW) detected flag
This bit is set by hardware. It is cleared by software by writing a 0
0: no error detected
1: error detected

Bit 1 **DEDF:** ECC double error detected flag
This bit is set by hardware. It is cleared by software by writing a 0
0: no error detected
1: error detected

Bit 0 **SEDCF:** ECC single error detected and corrected flag
This bit is set by hardware. It is cleared by software by writing a 0
0: no error detected and corrected
1: error detected and corrected

3.4.4 RAMECC monitor x failing address register (RAMECC_MxFAR)

Address offset: 0x28 + 0x20 * (x-1), (x= ECC monitoring unit number)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FADD[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FADD[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **FADD[31:0]:** ECC error failing address
When an ECC error occurs the FADD bitfield contains the address that generated the ECC error.

3.4.5 RAMECC monitor x failing data low register (RAMECC_MxFDRL)

Address offset: 0x2C + 0x20 * (x-1), (x= ECC monitoring unit number)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FDATAL[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FDATAL[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **FDATAL[31:0]:** Failing data low

When an ECC error occurs the FDATAL bitfield contains the LSB part of the data that generated the error. For 32-bit word SRAM, this bitfield contains the full memory word that generated the error.

3.4.6 RAMECC monitor x failing data high register (RAMECC_MxFDRH)

Address offset: 0x30 + 0x20 * (x-1), (x= ECC monitoring unit number)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FDATAH[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FDATAH[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **FDATAH[31:0]:** Failing data high (64-bit memory)

When an ECC error occurs the FDATAH bitfield contains the MSB part of the data that generated the error.

Note: This register is reserved in case of 32-bit word SRAM.

3.4.7 RAMECC monitor x failing ECC error code register RAMECC_MxFECR)

Address offset: 0x34 + 0x20 * (x-1), (x= ECC monitoring unit number)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FEC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FEC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **FEC [31:0]:** Failing error code

When an ECC error occurs the FEC bitfield contains the ECC failing code that generated the error.

3.4.8 RAMECC register map

Table 12. RAMECC register map and reset values

Offset	Register name reset value	Register size																														
		31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**RAMECC_IER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GECCDEBWIE	GECCDEIE	GECCSEIE	GIE
	Reset value																													0	0	0	0
0x20 * x (x = monitoring unit number)	RAMECC_MxCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCELEN	ECCDEBWIE	ECCDEIE	ECCSEIE	Res.	Res.
	Reset value																											0	0	0	0		
0x24+0x20 *(x -1) (x = monitoring unit number)	RAMECC_MxSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEBWDF	DEDF	SEDCF
	Reset value																														0	0	0
0x28+0x20 * (x -1) (x = monitoring unit number)	RAMECC_MxFAR	FADD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C+0x20 * (x -1) (x = monitoring unit number)	RAMECC_MxFDRL	FDATAL[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x30+0x20 * (x -1) (x = monitoring unit number)	RAMECC_MxFDRH	FDATAH[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x34+0x20 * (x -1) (x = monitoring unit number)	RAMECC_MxFECR	FEC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

4 Embedded Flash memory (FLASH)

4.1 Introduction

The embedded Flash memory (FLASH) manages the accesses of any master to the 1 Mbyte of embedded non-volatile memory. It implements the read, program and erase operations, error corrections as well as various integrity and confidentiality protection mechanisms.

The embedded Flash memory manages the automatic loading of non-volatile user option bytes at power-on reset, and implements the dynamic update of these options.

4.2 FLASH main features

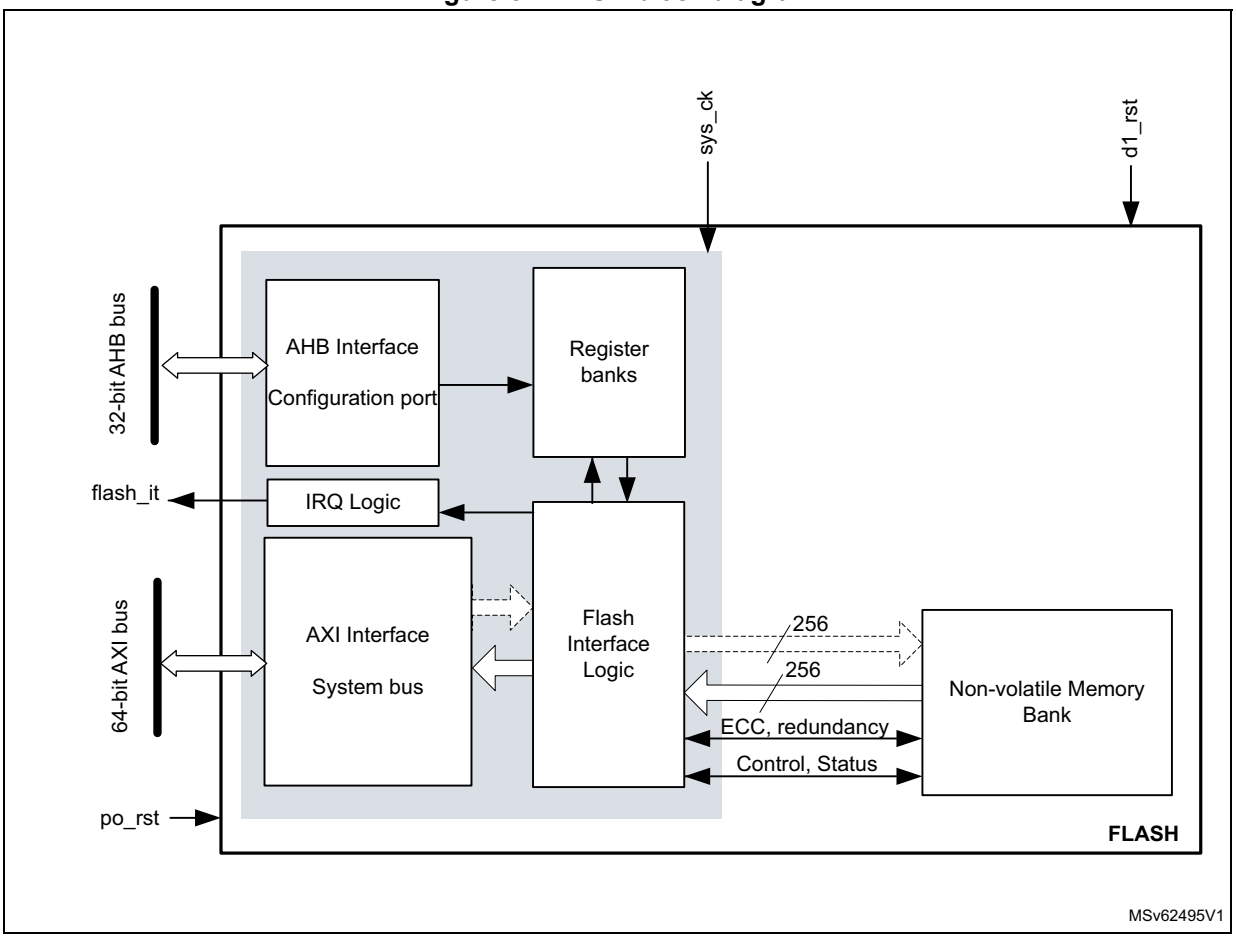
- Up to 1 Mbyte of non-volatile memory (one bank)
- Flash memory read operations supporting multiple length (64 bits, 32bits, 16bits or one byte)
- Flash memory programming by 256 bits
- Sector erase, bank erase
- Error Code Correction (ECC): one error detection/correction or two error detections per 256-bit Flash word using 10 ECC bits
- Cyclic redundancy check (CRC) hardware module
- User configurable non-volatile option bytes
- Flash memory enhanced protections, activated by option bytes
  - Read protection (RDP), preventing unauthorized Flash memory dump to safeguard sensitive application code
  - Sector write-protection (128-Kbytes)
  - One proprietary code readout protection (PCROP) area. When enabled, this area is execute-only.
  - One secure-only area. When enabled this area is accessible only if the STM32 microcontroller operates in Secure access mode.
- Read and write command queues to streamline Flash operations

4.3 FLASH functional description

4.3.1 FLASH block diagram

Figure 5 shows the embedded Flash memory block diagram.

Figure 5. FLASH block diagram



4.3.2 FLASH internal signals

Table 13 describes a list of the useful to know internal signals available at embedded Flash memory level. These signals are not available on the microcontroller pads.

Table 13. FLASH internal input/output signals

Internal signal name	Signal type	Description
sys_ck	Input	D1 domain bus clock (embedded Flash memory AXI interface clock)
po_rst	Input	Power on reset
d1_rst	Input	D1 domain system reset
flash_it	Output	Embedded flash interface interrupt request

4.3.3 FLASH architecture and integration in the system

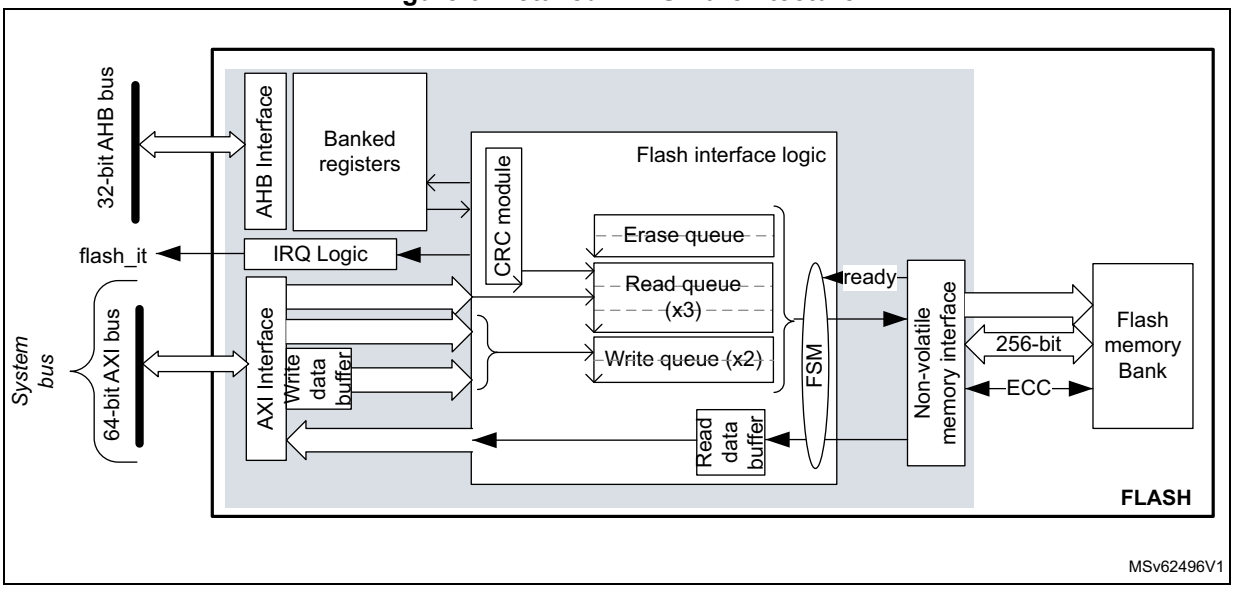
The embedded Flash memory is a central resource for the whole microcontroller. It serves as an interface to one non-volatile memory bank, and organizes the memory in a very specific way. The embedded Flash memory also proposes a set of security features to protect the assets stored in the non-volatile memory at boot time, at run-time and during firmware and configuration upgrades.

The embedded Flash memory offers one 64-bit AXI slave ports for code and data accesses, plus a 32-bit AHB configuration slave port used for register bank accesses.

Note: The application can simultaneously request a read and a write operation through the AXI interface.

The embedded Flash microarchitecture is shown in *Figure 6*.

Figure 6. Detailed FLASH architecture



Behind the system interfaces, the embedded Flash memory implements various command queues and buffers to perform Flash read, write and erase operations with maximum efficiency.

Thanks to the addition of a read and write data buffer, the AXI slave port handles the following access types:

- Multiple length: 64 bits, 32 bits, 16 bits and 8 bits
- Single or burst accesses
- Write wrap burst must not cross 32-byte aligned address boundaries to target exactly one Flash word

The AHB configuration slave port supports 8-bit, 16-bit and 32-bit word accesses.

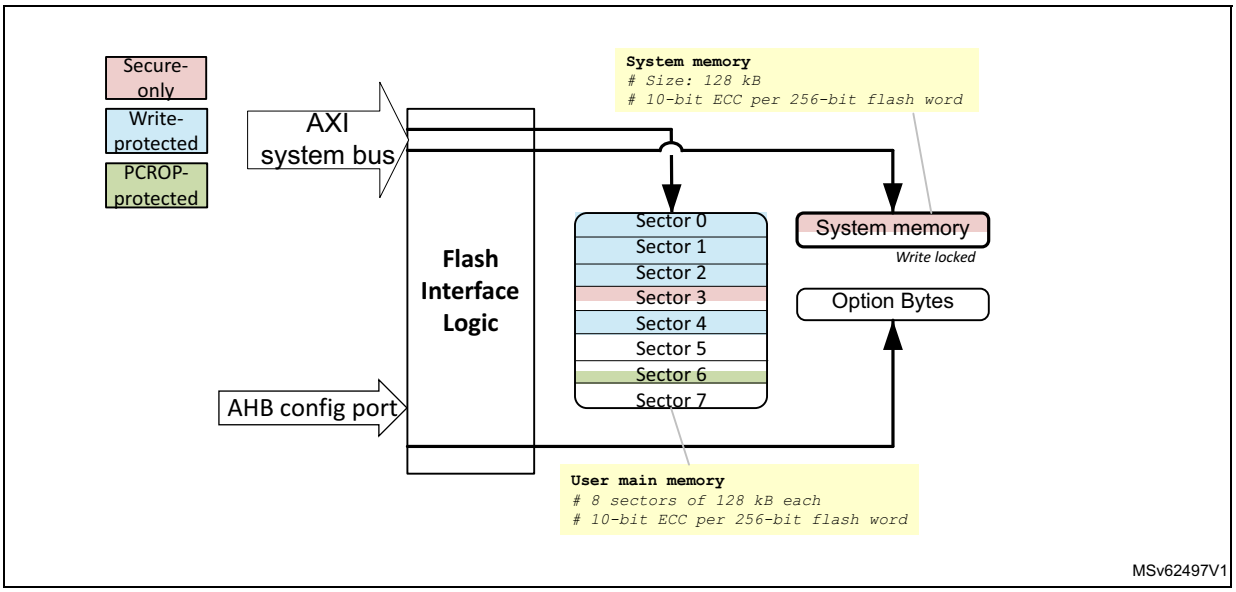
The embedded Flash memory is built in such a way that only one read or write operation can be executed at a time.

4.3.4 Flash memory architecture and usage

Flash memory architecture

Figure 7 shows the non-volatile memory organization supported by the embedded Flash memory.

Figure 7. Embedded Flash memory organization



The embedded Flash non-volatile memory is composed of:

- A memory block of up to 1 Mbyte, with Flash-word rows of 256 bits + 10 bits of ECC per word
- A system memory block of 128 Kbytes
- A special region dedicated to option bytes storage

The embedded Flash memory interface logic supports the following architecture partitioning:

- A user Flash memory mapped to the 1-Mbyte memory block. It is divided into eight sectors of 128 Kbytes. The user Flash memory is ECC protected.
- A system Flash memory mapped to the 128-Kbyte system memory block. The system Flash memory is ECC protected
- A set of non-volatile option bytes loaded at reset by the embedded Flash memory and accessible by the application software only through the AHB configuration register interface.

The overall Flash memory architecture is summarized in *Table 15*.

Table 14. Flash memory organization (STM32H730 devices)

Flash memory area	Address range	Size (bytes)	Region name	Access interface	SNB(1)
User main memory	0x0800 0000- 0x0801 FFFF	128 K	Sector 0	AXI ports	0x0
System memory	0x1FF0 0000- 0x1FF1 FFFF	128 K	System Flash memory (read-only)		N/A(2)
Option bytes	N/A	-	User option bytes	Registers only	N/A

1. SNB contains the target sector number for an erase operation. See *Section 4.3.10* for details.
2. Cannot be erased by software.

Table 15. Flash memory organization (STM32H723/733 and STM32H725/735 devices)

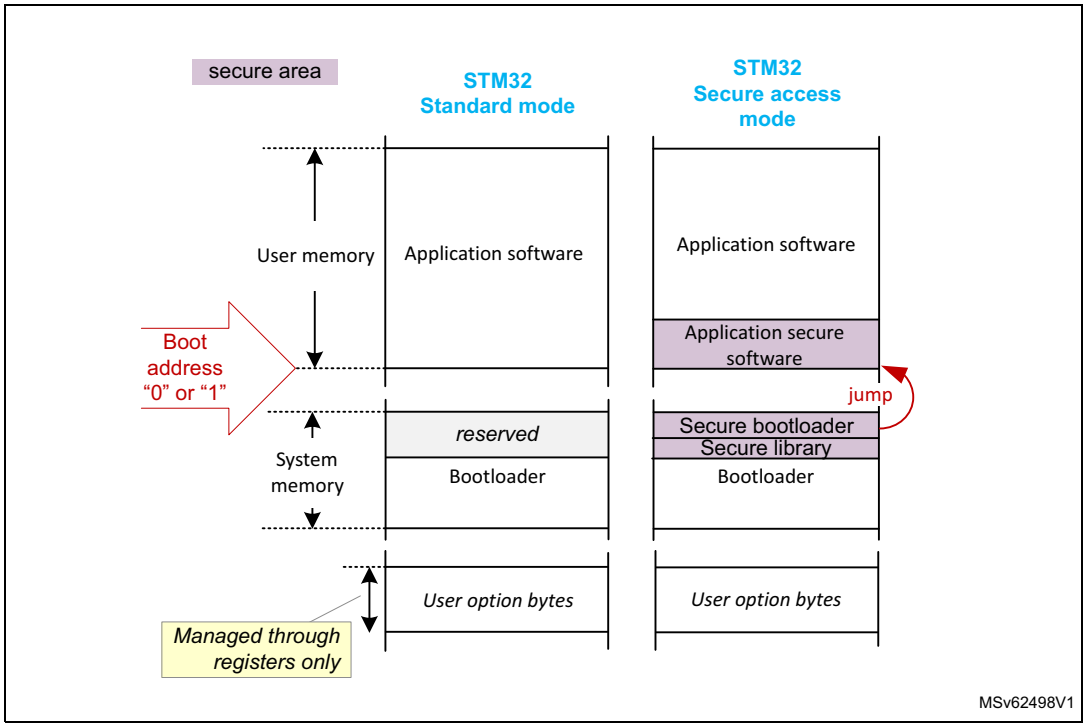
Flash memory area	Address range	Size (bytes)	Region name(1)	Access interface	SNB(2)
User main memory	0x0800 0000- 0x0801 FFFF	128 K	Sector 0	AXI ports	0x0
	0x0802 0000- 0x0803 FFFF	128 K	Sector 1		0x1
	...	...	...		...
	0x080E 0000- 0x080F FFFF	128 K	Sector 7		0x7
System memory	0x1FF0 0000- 0x1FF1 FFFF	128 K	System Flash memory (read-only)		N/A(3)
Option bytes	N/A	-	User option bytes	Registers only	N/A

1. For devices with 512 Kbytes of Flash memory, only sectors 0 to 3 are available.
2. SNB contains the target sector number for an erase operation. See *Section 4.3.10* for details.
3. Cannot be erased by software.

Partition usage

Figure 8 shows how the embedded Flash memory is used both by STMicroelectronics and the application software.

Figure 8. Embedded Flash memory usage



User and system memories are used differently according to whether the microcontroller is configured by the application software in Standard mode or in Secure access mode. This selection is done through the SECURITY option bit (see *Section 4.4.6*):

- In Standard mode, the user memory contains the application code and data, while the system memory is loaded with the STM32 bootloader. When a reset occurs, the core jumps to the boot address configured through the BOOT pin and the BOOT_CM_ADD0/1 option bytes.
- In Secure access mode, dedicated libraries can be used for secure boot. They are located in user Flash and system Flash memory:
  - ST libraries in system Flash memory assist the application software boot with special features such as secure boot and secure firmware install (SFI).
  - Application secure libraries in user Flash memory are used for secure firmware update (SFU).

  In Secure access mode, the microcontroller always boots into the secure bootloader code (unique entry point). Then, if no secure services are required, this code securely jumps to the requested boot address configured through the BOOT pin and the option bytes, as shown in *Figure 8* (see *Section 5: Secure memory management (SMM)* for details).

Note: For more information on option byte setup for boot, refer to Section 4.4.7.

Additional partition usage is the following:

- The option bytes are used by STMicroelectronics and by the application software as non-volatile product options (e.g. boot address, protection configuration and reset behaviors).

Note: For further information on STM32 bootloader flashing by STMicroelectronics, refer to application note AN2606 “STM32 microcontroller system memory boot mode” available from http://www.st.com.

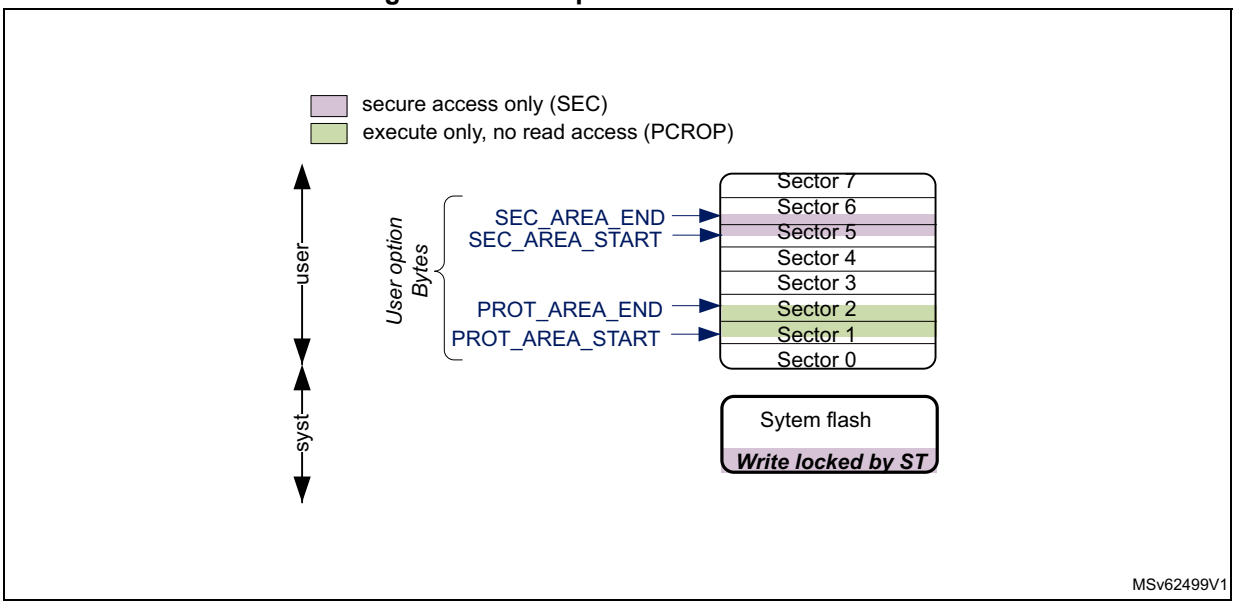
4.3.5 FLASH system performance enhancements

The embedded Flash memory uses read and write command queues in order to enhance Flash operations.

4.3.6 FLASH data protection schemes

Figure 9 gives an overview of the protection mechanisms supported by the embedded Flash memory. A PCROP and a secure-only area can be defined in the Flash memory bank. The properties of these protected areas are detailed in *Section 4.5*.

Figure 9. FLASH protection mechanisms



4.3.7 Overview of FLASH operations

Read operations

The embedded Flash memory can perform read operations on the whole non-volatile memory using various granularities: 64 bits, 32 bits, 16 bits or one byte. User and system Flash memories are read through the AXI interface, while the option bytes are read through the register interface.

To increase efficiency, the embedded Flash memory implements the buffering of consecutive read requests.

For more details on read operations, refer to *Section 4.3.8: FLASH read operations*.

Program/erase operations

The embedded Flash memory supports the following program and erase operations:

- Single Flash word write (256-bit granularity), with the possibility for the application to force-write a user Flash word with less than 256 bits
- Single sector erase
- Bank erase
- Option byte update

Note: Program and erase operations are subject to the various protection that could be set on the embedded Flash memory, such as write protection and global readout protection (see next sections for details).

To increase efficiency, the embedded Flash memory implements the buffering of consecutive write accesses.

For more details refer to *Section 4.3.9: FLASH program operations* and *Section 4.3.10: FLASH erase operations*.

Protection mechanisms

The embedded Flash memory supports different protection mechanisms:

- Global readout protection (RDP)
- Proprietary code readout protection (PCROP)
- Write protection
- Secure access only protection

For more details refer to *Section 4.5: FLASH protection mechanisms*.

Option byte loading

Under specific conditions, the embedded Flash memory reliably loads the non-volatile option bytes stored in non-volatile memory, thus enforcing boot and security options to the whole system when the embedded Flash memory becomes functional again. For more details refer to *Section 4.4: FLASH option bytes*.

4.3.8 FLASH read operations

Read operation overview

The embedded Flash memory supports the execution of one read command while two are waiting in the read command queue. Multiple read access types are also supported as defined in *Section 4.3.3: FLASH architecture and integration in the system*.

The read commands are associated with a 256-bit read data buffer.

Note: The embedded Flash memory can perform single error correction and double error detection while read operations are being executed (see Section 4.3.11: Flash memory error protections).

The AXI interface read channel operates as follows:

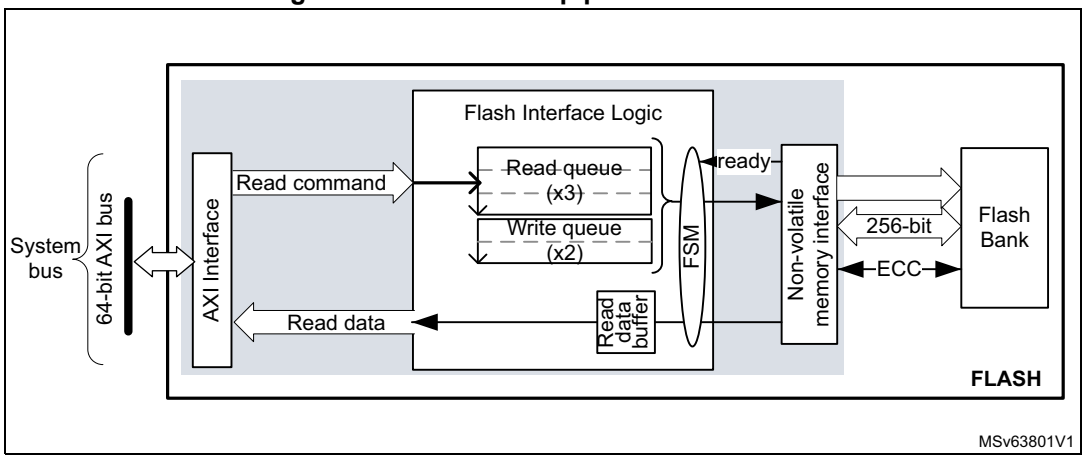
- When the read command queue is full, any new AXI read request stalls the bus read channel interface and consequently the master that issued that request.
- If several consecutive read accesses request data that belong to the same Flash data word (256 bits), the data are read directly from the current data read buffer, without

triggering additional Flash read operations. This mechanism occurs each time a read access is granted. When a read access is rejected for security reasons (e.g. PCROP protected word), the corresponding read error response is issued by the embedded Flash memory and no read operation to Flash memory is triggered.

The Read pipeline architecture is summarized in *Figure 10*.

For more information on bus interfaces, refer to *Section 4.3.3: FLASH architecture and integration in the system*.

Figure 10. FLASH read pipeline architecture



Single read sequence

The recommended simple read sequence is the following:

1. Freely perform read accesses to any AXI-mapped area.
2. The embedded Flash memory effectively executes the read operation from the read command queue buffer as soon as the non-volatile memory is ready and the previously requested operations have been served.

Adjusting read timing constraints

The embedded Flash memory clock must be enabled and running before reading data from non-volatile memory.

To correctly read data from Flash memory, the number of wait states (LATENCY) must be correctly programmed in the Flash access control register (FLASH_ACR) according to the embedded Flash memory AXI interface clock frequency (sys_ck) and the internal voltage range of the device (V_{core}).

Table 16 shows the correspondence between the number of wait states (LATENCY), the programming delay parameter (WRHIGHFREQ), the embedded Flash memory clock frequency and its supply voltage ranges.

Table 16. FLASH recommended number of wait states and programming delay

Number of wait states (LATENCY)	Programming delay (WRHIGHFREQ)	AXI Interface clock frequency vs V_{CORE} range			
		VOS3 range 0.95 V - 1.05 V	VOS2 range 1.05 V - 1.15 V	VOS1 range 1.15 V - 1.26 V	VOS0 range 1.26 V - 1.40 V
0 WS (1 FLASH clock cycle)	00	[0;35 MHz]	[0 MHz;50 MHz]	[0 MHz;67 MHz]	[0 MHz;70 MHz]
1 WS (2 FLASH clock cycles)	01	]35 MHz;70 MHz]	]50 MHz;100 MHz]	]67 MHz;133 MHz]	]70 MHz;140 MHz]
2 WS (3 FLASH clock cycles)	10	]70 MHz;85 MHz]	]100 MHz;150 MHz]	]133 MHz;200 MHz]	]140 MHz;210 MHz]
3 WS (4 FLASH clock cycles)	11	-	-	-	]210 MHz;275MHz]

Adjusting system frequency

After power-on, a default 7 wait-state latency is specified in FLASH_ACR register, in order to accommodate AXI interface clock frequencies with a safety margin (see *Table 16*).

When changing the AXI bus frequency, the application software must follow the below sequence in order to tune the number of wait states required to access the non-volatile memory.

To increase the embedded Flash memory clock source frequency:

1. If necessary, program the LATENCY and WRHIGHFREQ bits to the right value in the FLASH_ACR register, as described in *Table 16*.
2. Check that the new number of wait states is taken into account by reading back the FLASH_ACR register.
3. Modify the embedded Flash memory clock source and/or the AXI bus clock prescaler in the RCC_CFGR register of the reset and clock controller (RCC).
4. Check that the new embedded Flash memory clock source and/or the new AXI bus clock prescaler value are taken in account by reading back the embedded Flash memory clock source status and/or the AXI bus prescaler value in the RCC_CFGR register of the reset and clock controller (RCC).

To decrease the embedded Flash memory clock source frequency:

1. Modify the embedded Flash memory clock source and/or the AXI bus clock prescaler in the RCC_CFGR register of reset and clock controller (RCC).
2. Check that the embedded Flash memory new clock source and/or the new AXI bus clock prescaler value are taken into account by reading back the embedded Flash

memory clock source status and/or the AXI interface prescaler value in the RCC_CFGR register of reset and clock controller (RCC).

3. If necessary, program the LATENCY and WRHIGHFREQ bits to the right value in FLASH_ACR register, as described in *Table 16*.
4. Check that the new number of wait states has been taken into account by reading back the FLASH_ACR register.

Error code correction (ECC)

The embedded Flash memory embeds an error correction mechanism. Single error correction and double error detection are performed for each read operation. For more details, refer to *Section 4.3.11: Flash memory error protections*.

Read errors

When the ECC mechanism is not able to correct the read operation, the embedded Flash memory reports read errors as described in *Section 4.7.7: Error correction code error (SNECCERR/DBECCERR)*.

Read interrupts

See *Section 4.8: FLASH interrupts* for details.

4.3.9 FLASH program operations

Program operation overview

The virgin state of each non-volatile memory bitcell is 1. The embedded Flash memory supports programming operations that can change (reset) any memory bitcell to 0. However these operations do not support the return of a bit to its virgin state. In this case an erase operation of the entire sector is required.

A program operation consists in issuing write commands. The embedded Flash memory supports the execution of one write command while one command is waiting in the write command queue. Since a 10-bit ECC code is associated to each 256-bit data Flash word, only write operations by 256 bits are executed in the non-volatile memory.

Note: The application can decide to write as little as 8 bits to a Flash word. In this case, a force-write mechanism to the 256 bits + ECC is used (see FW bit of FLASH_CR register).

System Flash memory cannot be written by the application software.

It is not recommended to overwrite a Flash word that is not virgin. The result may lead to an inconsistent ECC code that will be systematically reported by the embedded Flash memory, as described in *Section 4.7.7: Error correction code error (SNECCERR/DBECCERR)*.

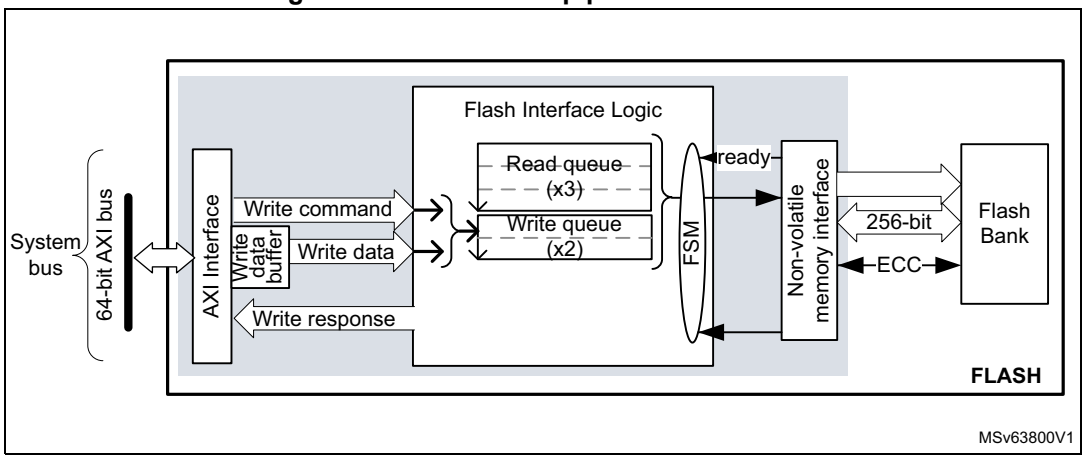
The AXI interface write channel operates as follows:

- A 256-bit write data buffer is associated with the AXI interface. It supports multiple write access types (64 bits, 32 bits, 16 bits and 8 bits).
- When the write queue is full, any new AXI write request stalls the bus write channel interface and consequently the master that issued that request.

The write pipeline architecture is described in *Figure 11*.

For more information on bus interfaces, refer to *Section 4.3.3: FLASH architecture and integration in the system*.

Figure 11. FLASH write pipeline architecture



Managing write protections

Before programming a user sector, the application software must check the protection of the targeted Flash memory area.

The embedded Flash memory checks the protection properties of the write transaction target at the output of the write queue buffer, just before the effective write operation to the non-volatile memory:

- If a write protection violation is detected, the write operation is canceled and write protection error (WRPERR) is raised in FLASH_SR register.
- If the write operation is valid, the 10-bit ECC code is concatenated to the 256 bits of data and the write to non-volatile memory is effectively executed.

Note: No write protection check is performed when the embedded Flash memory accepts AXI write requests.

The write protection flag does not need to be cleared before performing a new programming operation.

Monitoring ongoing write operations

The application software can use three status flags located in FLASH_SR in order to monitor ongoing write operations.

- **BSY**: this bit indicates that an effective write, erase or option byte change operation is ongoing to the non-volatile memory.
- **QW**: this bit indicates that a write, erase or option byte change operation is pending in the write queue or command queue buffer. It remains high until the write operation is complete. It supersedes the BSY status bit.
- **WBNE**: this bit indicates that the embedded Flash memory is waiting for new data to complete the 256-bit write buffer. In this state the write buffer is not empty. It is reset as soon as the application software fills the write buffer, force-writes the operation using FW bit in FLASH_CR, or disables all write operations.

Enabling write operations

Before programming the user flash, the application software must make sure that PG bit is set to 1 in FLASH_CR. If it is not the case, an unlock sequence must be used (see *Section 4.5.1: FLASH configuration protection*) and the PG bit must be set.

When the option bytes need to be modified or a mass erase needs to be started, the application software must make sure that FLASH_OPTCR is unlocked. If it is not the case, an unlock sequence must be used (see *Section 4.5.1: FLASH configuration protection*).

Note: The application software must not unlock a register that is already unlocked, otherwise this register will remain locked until next system reset.

If needed, the application software can update the programming delay and programming parallelism as described at the end of this section.

Single write sequence

The recommended single write sequence is the following:

1. Unlock the FLASH_CR register, as described in *Section 4.5.1: FLASH configuration protection* (only if register is not already unlocked).
2. Enable write operations by setting the PG bit in the FLASH_CR register.
3. Check the protection of the targeted memory area.
4. Write one Flash-word corresponding to 32-byte data starting at a 32-byte aligned address.
5. Check that QW has been raised and wait until it is reset to 0.

If step 4 is executed incrementally (e.g. byte per byte), the write buffer can become partially filled. In this case the application software can decide to force-write what is stored in the write buffer by using FW bit in FLASH_CR register. In this particular case, the unwritten bits are automatically set to 1. If no bit in the write buffer is set to 0, the FW bit has no effect.

Note: Using a force-write operation prevents the application from updating later the missing bits with a value different from 1, which is likely to lead to a permanent ECC error.

Any write access requested while the PG bit is set to 0 is rejected. In this case, no error is generated on the bus, but the PGSERR flag is raised.

Clearing the programming sequence error (PGSERR) and inconsistency error (INCERR) is mandatory before attempting a write operation (see Section 4.7: FLASH error management for details).

Adjusting programming timing constraints

Program operation timing constraints depend of the embedded Flash memory clock frequency, which directly impacts the performance. If timing constraints are too tight, the non-volatile memory will not operate correctly, if they are too lax, the programming speed will not be optimal.

The user must therefore trim the optimal programming delay through the WRHIGHFREQ parameter in the FLASH_ACR register. Refer to *Table 16* in *Section 4.3.8: FLASH read operations* for the recommended programming delay depending on the embedded Flash memory clock frequency.

The application software must check that no program/erase operation is ongoing before modifying WRHIGHFREQ parameter.

Adjusting programming parallelism

The parallelism is the maximum number of bits that can be written to 0 in one shot during a write operation. The programming parallelism is also used during sector and bank erase.

There is no hardware limitation on programming parallelism. The user can select different parallelisms depending on the application requirements: the lower the parallelism, the lower the peak consumption during a programming operation, but the longer the execution time.

The parallelism is configured through the PSIZE1/2 bits in FLASH_CR1/2 register.

Table 17. FLASH parallelism parameter

PSIZE	Parallelism
00	8 bits (one byte)
01	16 bits
10	32 bits
11	64 bits

Programming errors

When a program operation fails, an error can be reported as described in *Section 4.7: FLASH error management*.

Programming interrupts

See *Section 4.8: FLASH interrupts* for details.

4.3.10 FLASH erase operations

Erase operation overview

The embedded Flash memory can perform erase operations on 128-Kbyte user sectors.

Note: System Flash cannot be erased by the application software.

The erase operation forces all non-volatile bit cells to high state, which corresponds to the virgin state. It clears existing data and corresponding ECC, allowing a new write operation to be performed. If the application software reads back a word that has been erased, all the bits will be read at 1, without ECC error.

Erase operations are similar to read or program operations except that the commands are queued in a special buffer (a two-command deep erase queue).

Erase commands are issued through the AHB configuration interface. If the embedded Flash memory receives simultaneously a write and an erase request, both operations are accepted but the write operation is executed first.

Erase and security

A user sector can be erased only if it does not contain PCROP, secure-only or write-protected data (see *Section 4.5: FLASH protection mechanisms* for details). In other words, if the application software attempts to erase a user sector with at least one Flash word that is protected, the sector erase operation is aborted and the WRPERR flag is raised in the FLASH_SR register, as described in *Section 4.7.2: Write protection error (WRPERR)*.

The embedded Flash memory allows the application software to perform an erase followed by an automatic protection removal (PCROP, secure-only area and write protection), as described hereafter.

Enabling erase operations

Before erasing a sector, the application software must make sure that FLASH_CR is unlocked. If it is not the case, an unlock sequence must be used (see *Section 4.5.1: FLASH configuration protection*).

Note: The application software must not unlock a register that is already unlocked, otherwise this register will remain locked until next system reset.

Similar constraints apply to bank erase requests.

Flash sector erase sequence

To erase a 128-Kbyte user sector, proceed as follows:

1. Check and clear (optional) all the error flags due to previous programming/erase operation. Refer to *Section 4.7: FLASH error management* for details.
2. Unlock the FLASH_CR register, as described in *Section 4.5.1: FLASH configuration protection* (only if register is not already unlocked).
3. Set the SER bit and SNB bitfield in the corresponding FLASH_CR register. SER indicates a sector erase operation, while SNB contains the target sector number.
4. Set the START bit in the FLASH_CR register.
5. Wait for the QW bit to be cleared in the corresponding FLASH_SR register.

Note: If a bank erase is requested simultaneously to the sector erase (BER bit set), the bank erase operation supersedes the sector erase operation.

Standard Flash bank erase sequence

To erase all bank sectors except for those containing secure-only and protected data, proceed as follows:

1. Check and clear (optional) all the error flags due to previous program/erase operation. Refer to *Section 4.7: FLASH error management* for details.
2. Unlock the FLASH_CR register, as described in *Section 4.5.1: FLASH configuration protection* (only if the register is not already unlocked).
3. Set the BER bit in the FLASH_CR register.
4. Set the START bit in the FLASH_CR register to start the bank erase operation. Then wait until the QW bit is cleared in the corresponding FLASH_SR register.

Note: BER and START bits can be set together, so above steps 3 and 4 can be merged.

If a sector erase is requested simultaneously to the bank erase (SER bit set), the bank erase operation supersedes the sector erase operation.

Flash bank erase with automatic protection-removal sequence

To erase all bank sectors including those containing secure-only and protected data without performing an RDP regression (see *Section 4.5.3*), proceed as follows:

1. Check and clear (optional) all the error flags due to previous programming/erase operation. Refer to *Section 4.7: FLASH error management* for details.
2. Unlock FLASH_OPTCR register, as described in *Section 4.5.1: FLASH configuration protection* (only if register is not already unlocked).
3. If a PCROP-protected area exists set DMEP bit in FLASH_PRAR_PRG register. In addition, program the PCROP area end and start addresses so that the difference is negative, i.e. PROT_AREA_END < PROT_AREA_START.
4. If a secure-only area exists set DMES bit in FLASH_SCAR_PRG register. In addition, program the secure-only area end and start addresses so that the difference is negative, i.e. SEC_AREA_END < SEC_AREA_START.
5. Set all WRPSn1/2 bits in FLASH_WPSN_PRG to 1 to disable all sector write protection.
6. Unlock FLASH_CR register, only if register is not already unlocked.
7. Set the BER bit in the FLASH_CR register.
8. Set the START bit in the FLASH_CR register to start the bank erase with protection removal operation. Then wait until the QW bit is cleared in the corresponding FLASH_SR register. At that point a bank erase operation has erased the whole bank including the sectors containing PCROP-protected and/or secure-only data, and an option byte change has been automatically performed so that all the protections are disabled.

Note: BER and START bits can be set together, so above steps 8 and 9 can be merged.

Be aware of the following warnings regarding to above sequence:

- No other option bytes than the one indicated above must be changed.
- When the event above occurs, a simple bank erase is done, no option byte change is performed and no option change error is set.

4.3.11 Flash memory error protections

Error correction codes (ECC)

The embedded Flash memory supports an error correction code (ECC) mechanism. It is based on the SECDED algorithm in order to correct single errors and detects double errors.

This mechanism uses 10 ECC bits per 256-bit Flash word, and applies to user and system Flash memory.

More specifically, during each read operation from a 256-bit Flash word, the embedded Flash memory also retrieves the 10-bit ECC information, computes the ECC of the Flash word, and compares the result with the reference value. If they do not match, the corresponding ECC error is raised as described in *Section 4.7.7: Error correction code error (SNECCERR/DBECCERR)*.

During each program operation, a 10- bit ECC code is associated to each 256-bit data Flash word, and the resulting 266-bit Flash word information is written in non-volatile memory.

Cyclic redundancy codes (CRC)

The embedded Flash memory implements a cyclic redundancy check (CRC) hardware module. This module checks the integrity of a given user Flash memory area content (see *Figure 6: Detailed FLASH architecture*).

The area processed by the CRC module can be defined either by sectors or by start/end addresses. It can also be defined as the whole bank (user Flash memory area only).

When enabled, the CRC hardware module performs multiple reads by chunks of 4, 16, 64 or 256 consecutive Flash-word (i.e. chunks of 128, 512, 2048 or 8192 bytes). These consecutive read operations are pushed by the CRC module into the required read command queue together with other AXI read requests, thus avoiding to deny AXI read commands.

CRC computation uses CRC-32 (Ethernet) polynomial 0x4C11DB7:

$$X^{32}+ X^{26}+ X^{23}+ X^{22}+ X^{16}+ X^{12}+ X^{11}+ X^{10}+ X^{8}+ X^{7}+ X^{5}+ X^{4}+ X^{2}+ X + 1$$

The CRC operation is concurrent with option byte change as the same hardware is used for both operations. To avoid the CRC computation from being corrupted, the application shall complete the option byte change (by reading the result of the change) before running a CRC operation, and vice-versa.

The sequence recommended to configure a CRC operation is the following:

1. Unlock FLASH_CR register, if not already unlocked.
2. Enable the CRC feature by setting the CRC_EN bit in FLASH_CR.
3. Program the desired data size in the CRC_BURST field of FLASH_CRCCR.
4. Define the user Flash area on which the CRC has to be computed.Two solutions are possible:
   - Define the area start and end addresses by programing FLASH_CRCSADDR and FLASH_CRCEADDR, respectively,
   - or select the targeted sectors by setting the CRC_BY_SECT bit in FLASH_CRCCR and by programming consecutively the target sector numbers in the CRC_SECT field of the FLASH_CRCCR register. Set ADD_SECT bit after each CRC_SECT programming.
5. Start the CRC operation by setting the START_CRC bit.
6. Wait until the CRC_BUSY flag is reset in FLASH_SR register.
7. Retrieve the CRC result in the FLASH_CRCDATAR register.

The CRC can be computed for the whole bank by setting the ALL_BANK bit in the FLASH_CRCCR register.

Note: The application should avoid running a CRC on PCROP- or secure-only user Flash area since it may alter the expected CRC value. A special error flag defined in Section 4.7.10: CRC read error (CRCRDERR) can be used to detect such a case.

CRC computation does not raise standard read error flags such as RDSERR, RDPERR and DBECCERR. Only CRCRDERR is raised.

4.3.12 FLASH reset and clocks

Reset management

The embedded Flash memory can be reset by a D1 domain reset (d1_rst), driven by the reset and clock control (RCC). The main effects of this reset are the following:

- All registers, except for option byte registers, are cleared, including read and write latencies.
- Most control registers are automatically protected against write operations. To unprotect them, new unlock sequences must be used as described in *Section 4.5.1: FLASH configuration protection*.

The embedded Flash memory can be reset by a power-on reset (po_rst), driven by the reset and clock control (RCC). When the reset falls, all option byte registers are reset. When the reset rises up, the option bytes are loaded, potentially applying new features. During this loading sequence, the device remains under reset and the embedded Flash memory is not accessible.

The Reset signal can have a critical impact on the embedded Flash memory:

- The contents of the Flash memory are not guaranteed if a device reset occurs during a Flash memory write or erase operation.
- If a reset occurs while the option byte modification is ongoing, the old option byte values are kept. When it occurs, a new option byte modification sequence is required to program the new values.

Clock management

The embedded Flash memory uses the microcontroller system clock (sys_ck), here the AXI interface clock.

Depending on the device clock and internal supply voltage, specific read and write latency settings usually need to be set in the Flash access control register (FLASH_ACR), as explained in *Section 4.3.8: FLASH read operations* and *Section 4.3.9: FLASH program operations*.

4.4 FLASH option bytes

4.4.1 About option bytes

The embedded Flash memory includes a set of non-volatile option bytes. They are loaded at power-on reset and can be read and modified only through configuration registers.

These option bytes are configured by the end-user depending on the application requirements. Some option bytes might have been initialized by STMicroelectronics during manufacturing stage.

This section documents:

- When option bytes are loaded
- How application software can modify them
- What is the detailed list of option bytes, together with their default factory values (i.e. before the first option byte change).

4.4.2 Option byte loading

There are multiple ways of loading the option bytes into embedded Flash memory:

1. **Power-on wakeup**

   When the device is first powered, the embedded Flash memory automatically loads all the option bytes. During the option byte loading sequence, the device remains under reset and the embedded Flash memory cannot be accessed.

2. **Wakeup from system Standby**

   When the D1 power domain, which contains the embedded Flash memory, is switched from DStandby mode to DRun mode, the embedded Flash memory behaves as during a power-on sequence.

3. **Ad-hoc option byte reloading by the application**

   When the user application successfully modifies the option byte content through the embedded Flash memory registers, the non-volatile option bytes are programmed and the embedded Flash memory automatically reloads all option bytes to update the option registers.

Note: The option bytes read sequence is enhanced thanks to a specific error correction code.

In case of security issue, the option bytes may be loaded with default values (see Section 4.4.3: Option byte modification).

4.4.3 Option byte modification

Changing user option bytes

A user option byte change operation can be used to modify the configuration and the protection settings saved in the non-volatile option byte area.

The embedded Flash memory features two sets of option byte registers:

- The first register set contains the current values of the option bytes. Their names have the _CUR extension. All “_CUR” registers are read-only. Their values are automatically loaded from the non-volatile memory after power-on reset, wakeup from system standby or after an option byte change operation.
- The second register set allows the modification of the option bytes. Their names contain the _PRG extension. All “_PRG” registers can be accessed in read/write mode.

When the OPTLOCK bit in FLASH_OPTCR register is set, modifying the _PRG registers is not possible.

When OPTSTART bit is set to 1, the embedded Flash memory checks if at least one option byte needs to be programmed by comparing the current values (_CUR) with the new ones (_PRG). If this is the case and all the other conditions are met (see *Changing security option bytes*), the embedded Flash memory launches the option byte modification in its non-volatile memory and updates the option byte registers with _CUR extension.

If one of the condition described in *Changing security option bytes* is not respected, the embedded Flash memory sets the OPTCHANGEERR flag to 1 in the FLASH_OPTSR_CUR register and aborts the option byte change operation. In this case, the _PRG registers are not overwritten by current option value. The user application can check what was wrong in their configuration.

Unlocking the option byte modification

After reset, the OPTLOCK bit is set to 1 and the FLASH_OPTCR is locked. As a result, the application software must unlock the option configuration register before attempting to change the option bytes. The FLASH_OPTCR unlock sequence is described in *Section 4.5.1: FLASH configuration protection*.

Option byte modification sequence

To modify user option bytes, follow the sequence below:

1. Unlock FLASH_OPTCR register as described in *Section 4.5.1: FLASH configuration protection*, unless the register is already unlocked.
2. Write the desired new option byte values in the corresponding option registers (FLASH_XXX_PRG).
3. Set the option byte start change OPTSTART bit to 1 in the FLASH_OPTCR register.
4. Wait until OPT_BUSY bit is cleared.

Note: If a reset or a power-down occurs while the option byte modification is ongoing, the original option byte value is kept. A new option byte modification sequence is required to program the new value.

Changing security option bytes

On top of OPTLOCK bit, there is a second level of protection for security-sensitive option byte fields. Specific rules must be followed to update them:

- **Readout protection (RDP)**

  A detailed description of RDP option bits is given in *Section 4.5.3*. The following rules must be respected to modify these option bits:

  – When RDP is set to level 2, no changes are allowed. As a result, if the user application attempts to reduce the RDP level, an option byte change error is raised (OPTCHANGEERR bit in FLASH_OPTSR_CUR register), and all the programmed changes are ignored.

  – When the RDP is set to level 1, requiring a change to level 2 is always allowed. When requiring a regression to level 0, an option byte change error can occur if some of the recommendations provided in this chapter have not been followed.

  – When the RDP is set to level 0, switching to level 1 or level 2 is possible without any restriction.

- **Sector write protection (WRPSn)**

  These option bytes manage sector write protection in FLASH_WPSN_CUR1/2R registers. They can be changed without any restriction when the RDP protection level is different from level 2.

- **PCROP area size (PROT_AREA_START and PROT_AREA_END)**

  These option bytes configure the size of the PCROP areas in FLASH_PRAR_CUR registers. They can be increased without any restriction by the Arm® Cortex®-M7 core. To remove or reduce a PCROP area, an RDP level 1 to 0 regression (see *Section 4.5.3*) or a bank erase with protection removal (see *Section 4.3.10*) must be

requested at the same time. DMEP must be set to 1 in either FLASH_PRAR_CUR or FLASH_PRAR_PRG, otherwise an option byte change error is raised.

- **DMEP**

  When this option bit is set, the content of the corresponding PCROP area is erased during a RDP level 1 to 0 regression (see *Section 4.5.3*) or a bank erase with protection removal (see *Section 4.3.10*). It is preserved otherwise.

  There are no restrictions in setting DMEP bit. Resetting DMEP bit from 1 to 0 can only be done when an RDP level 1 to 0 regression or a bank erase with protection removal is requested at the same time.

- **Secure access mode (SECURITY)**

  The SECURITY option bit activates the secure access mode described in *Section 4.5.5*. This option bit can be freely set by the application software if such mode is activated on the device. If at least one PCROP or secure-only area is defined as not null, the only way to deactivate the security option bit (from 1 to 0) is to perform an RDP level 1 to 0 regression, when DMEP is set to 1 in either FLASH_PRAR_CUR or FLASH_PRAR_PRG registers, and DMES is set to 1 in either FLASH_SCAR_CUR or FLASH_SCAR_PRG.

  If no valid secure-only area and no valid PCROP area are currently defined, the SECURITY option bit can be freely reset.

Note: It is recommended to have both SEC_AREA_START> SEC_AREA_END and PROT_AREA_START> PROT_AREA_END programmed when deactivating the SECURITY option bit during an RDP level 1 to 0 regression.

- **Secure-only area size (SEC_AREA_START and SEC_AREA_END)**

  These option bytes configure the size of the secure-only areas in FLASH_SCAR_CUR registers. They can be changed without any restriction by the user secure application or by the ST secure library running on the device. For user non-secure application, the secure-only area size can be removed by performing a bank erase with protection removal (see *Section 4.3.10*), or an RDP level 1 to 0 regression when DMES set to 1 in either FLASH_SCAR_CUR or FLASH_SCAR_PRG (otherwise an option byte change error is raised).

- **DMES**

  When this option bit is set, the content of the corresponding secure-only area is erased during an RDP level 1 to 0 regression or a bank erase with protection removal, it is preserved otherwise.

  DMES bits can be set without any restriction. Resetting DMES bit from 1 to 0 can only be performed when an RDP level 1 to 0 regression or a bank erase with protection removal is requested at the same time.

- **Secure DTCM size (ST_RAM_SIZE)**

  These bits selects the size of the secure DTCM, an option that is available only when SECURITY option bit is set. It can be modified only when the CPU is running the ST secure library.

4.4.4 Option bytes overview

Table 18 lists all the user option bytes managed through the embedded Flash memory registers, as well as their default values before the first option byte change (default factory value).

Table 18. Option byte organization

Register	Bitfield															
FLASH_OPTSR_x[31:16]	**31**	**30**	**29**	**28**	**27**	**26**	**25**	**24**	**23**	**22**	**21**	**20**	**19**	**18**	**17**	**16**
	Res.	OPTCHANGEERR	IO_HSLV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECURITY	ST_RAM_SIZE		IWDG_FZ_SDBY	IWDG_FZ_STOP	Res.
Default factory value	*0*	*0*	*0*	*1*	*0*	*1*	*1*	*1*	*1*	*0*	*0*	*1*	*1*	*1*	*1*	*0*
FLASH_OPTSR_x[15:0]	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	RDP[7:0]								NRST_STDY_D1	NRST_STOP_D1	Res.	IWDG1_SW	BOR_LEV		Res.	Res.
Default factory value	*1*	*0*	*1*	*0*	*1*	*0*	*1*	*0*	*1*	*1*	*1*	*1*	*0*	*0*	*0*	*0*
FLASH_OPTSR2_x[15:0]	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CPUFREQ_BOOST	TCM_AXI_SHARED	
Default factory value	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
FLASH_BOOT_x[31:16]	**31**	**30**	**29**	**28**	**27**	**26**	**25**	**24**	**23**	**22**	**21**	**20**	**19**	**18**	**17**	**16**
	BOOT_CM_ADD1[15:0]															
Default factory value	*0x1FF0*															
FLASH_BOOT_x[15:0]	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	BOOT_CM_ADD0[15:0]															
Default factory value	*0x0800*															
FLASH_PRAR_x[31:16]	**31**	**30**	**29**	**28**	**27**	**26**	**25**	**24**	**23**	**22**	**21**	**20**	**19**	**18**	**17**	**16**
	DMEP	Res.	Res.	Res.	PROT_AREA_END											

Table 18. Option byte organization (continued)

Register	Bitfield															
Default factory value	*0*	*0*	*0*	*0*	*0x000*											
FLASH_PRAR_x[15:0]	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	Res.	Res.	Res.	Res.	PROT_AREA_START											
Default factory value	*0*	*0*	*0*	*0*	*0x0FF*											
FLASH_SCAR_x[31:16]	**31**	**30**	**29**	**28**	**27**	**26**	**25**	**24**	**23**	**22**	**21**	**20**	**19**	**18**	**17**	**16**
	DMES	Res.	Res.	Res.	SEC_AREA_END											
Default factory value	*1*	*0*	*0*	*0*	*0x000*											
FLASH_SCAR_x[15:0]	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	Res.	Res.	Res.	Res.	SEC_AREA_START											
Default factory value	*0*	*0*	*0*	*0*	*0x0FF*											
FLASH_WPSN_x[31:16]	**31**	**30**	**29**	**28**	**27**	**26**	**25**	**24**	**23**	**22**	**21**	**20**	**19**	**18**	**17**	**16**
	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
Default factory value	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
FLASH_WPSN_x[15:0]	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRPSn[7:0]							
Default factory value	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*

4.4.5 Description of user and system option bytes

Below the list of the general-purpose option bytes that can be used by the application:

- Watchdog management
  - IWDG_FZ_STOP: independent watchdog (IWDG1) counter active in Stop mode if 1 (stop counting or freeze if 0)
  - IWDG_FZ_SDBY: independent watchdog (IWDG1) counter active in Standby mode if 1 (stop counting or freeze if 0)
  - IWDG1_SW: hardware (0) or software (1) IWDG1 watchdog control selection

Note: If the hardware watchdog "control selection" feature is enabled (set to 0), the watchdog is automatically enabled at power-on, thus generating a reset unless the watchdog key register is written to or the down-counter is reloaded before the end-of-count is reached.

Depending on the configuration of IWDG_STOP and IWDG_STBY options, the IWDG can continue counting (1) or not (0) when the device is in Stop or Standby mode, respectively.

When the IWDG is kept running during Stop or Standby mode, it can wake up the device from these modes.

- Reset management
  - BOR: Brownout level option, indicating the supply level threshold that activates/releases the reset
  - NRST_STDBY_D1: generates a reset when D1 domain enters DStandby mode. It is active low.
  - NRST_STOP_D1: generates a reset when D1 domain enters DStop mode. It is active low.

Note: Whenever a Standby (respectively Stop) mode entry sequence is successfully executed, the device is reset instead of entering Standby (respectively Stop) mode if NRST_STDBY (respectively NRST_STOP) is cleared to 0.

- Device options
  - IO_HSLV: I/O speed optimization at low-voltage if set to 1.

When STMicroelectronics delivers the device, the values programmed in the general-purpose option bytes are the following:

- Watchdog management
  - IWDG1 active in Standby and Stop modes (option byte value = 0x1)
  - IWDG1 not automatically enabled at power-on (option byte value = 0x1)
- Reset management:
  - BOR: brownout level option (reset level) equals brownout reset threshold 0 (option byte value = 0x0)
  - A reset is not generated when D1 domain enters DStandby or DStop low-power mode (option byte value = 0x1)
- Device working in the full voltage range with I/O speed optimization at low-voltage disabled (IO_HSLV=0)

Refer to *Section 4.9: FLASH registers* for details.

4.4.6 Description of data protection option bytes

Below the list of the option bytes that can be used to enhance data protection:

- RDP[7:0]: Readout protection level (see *Section 4.5.3 on page 179* for details).
- WRPSn: sector write- protection (see *Section 4.5.2 on page 178* for details).
- PROT_AREAx: Proprietary code readout protection (refer to *Section 4.5.4 on page 183* for details)
  - PROT_AREA_START (respectively PROT_AREA_END) contains the first (respectively last) 256-byte block of the PCROP zone
  - DMEP: when set to 1, the PCROP area is erased during a RDP protection level regression (change from level 1 to 0) or a bank erase with protection removal.
- SEC_AREAx: secure access only zones definition (refer to *Section 4.5.5 on page 184* for details).
  - SEC_AREA_START (respectively SEC_AREA_END) contains the first (respectively last) 256-byte block of the secure access only zone
  - DMES: when set to 1 the secure access only zone is erased during a RDP protection level regression (change from level 1 to 0), or a bank erase with protection removal.
- SECURITY: this non-volatile option can be used by the application to manage secure access mode, as described in *Section 4.5.5*.
- ST_RAM_SIZE: this non-volatile option defines the amount of DTCM RAM root secure services (RSS) can use during execution when the SECURITY bit is set. The DTCM RAM is always fully available for the application whatever the option byte configuration.

When STMicroelectronics delivers the device, the values programmed in the data protection option bytes are the following:

- RDP level 0 (option byte value = 0xAA)
- Flash bank erase operations do not impact secure-only and PCROP data areas when enabled by the application (DMES=DMEP=0)
- PCROP and secure-only zone protections disabled (start addresses higher than end addresses)
- Write protection disabled (all option byte bits set to 1)
- Secure access mode disabled (SECURITY option byte value= 0)
- RSS can use the full DTCM RAM for executing its services (ST_RAM_SIZE = 11)

Refer to *Section 4.9: FLASH registers* for details.

4.4.7 Description of boot address option bytes

Below the list of option bytes that can be used to configure the appropriate boot address for your application:

- BOOT_CM_ADD0/1: MSB of the Arm® Cortex®-M7 boot address when BOOT pin is low (respectively high)

When STMicroelectronics delivers the device, the values programmed in the boot address option bytes are the following:

- Arm® Cortex®-M7 boot address (MSB): 0x0800 (BOOT pin low for user Flash memory) and 0x1FF0 (BOOT pin high for System Flash memory)

Refer to *Section 4.9: FLASH registers* for details.

4.5 FLASH protection mechanisms

Since sensitive information can be stored in the Flash memory, it is important to protect it against unwanted operations such as reading confidential areas, illegal programming of protected area, or illegal Flash memory erasing.

The embedded Flash memory implements the following protection mechanisms that can be used by end-user applications to manage the security of embedded non-volatile storage:

- Configuration protection
- Global device Readout protection (RDP)
- Write protection
- Proprietary code readout protection (PCROP)
- Secure access mode areas

This section provides a detailed description of all these security mechanisms.

4.5.1 FLASH configuration protection

The embedded Flash memory uses hardware mechanisms to protect the following assets against unwanted or spurious modifications (e.g. software bugs):

- Option bytes change
- Write operations
- Erase commands
- Interrupt masking

More specifically, write operations to embedded Flash memory control registers (FLASH_CR and FLASH_OPTCR) are not allowed after reset.

The following sequence must be used to unlock FLASH_CR register:

1. Program KEY1 to 0x45670123 in FLASH_KEYR key register.
2. Program KEY2 to 0xCDEF89AB in FLASH_KEYR key register.
3. LOCK bit is now cleared and FLASH_CR is unlocked.

The following sequence must be used to unlock FLASH_OPTCR register:

1. Program OPTKEY1 to 0x08192A3B in FLASH_OPTKEYR option key register.
2. Program OPTKEY2 to 0x4C5D6E7F in FLASH_OPTKEYR option key register.
3. OPTLOCK bit is now cleared and FLASH_OPTCR register is unlocked.

Any wrong sequence locks up the corresponding register/bit until the next system reset, and generates a bus error.

The FLASH_CR (respectively FLASH_OPTCR) register can be locked again by software by setting the LOCK bit in FLASH_CR register (respectively OPTLOCK bit in FLASH_OPTCR register).

In addition the FLASH_CR register remains locked and a bus error is generated when the following operations are executed:

- programming a third key value
- writing to a different register than FLASH_KEYR before FLASH_CR has been completely unlocked (KEY1 programmed but KEY2 not yet programmed)
- writing less than 32 bits to KEY1 or KEY2.

Similarly the FLASH_OPTCR register remains locked and a bus error is generated when the following operations are executed:

- programming a third key value
- writing to a different register before FLASH_OPTCR has been completely unlocked (OPTKEY1 programmed but OPTKEY2 not yet programmed)
- writing less than 32 bits to OPTKEY1 or OPTKEY2.

The embedded Flash memory configuration registers protection is summarized in *Table 19*.

Table 19. Flash interface register protection summary

Register Name	Unlocking register	Protected asset
FLASH_ACR	N/A	-
FLASH_KEYR	N/A	-
FLASH_OPTKEYR	N/A	-
FLASH_CR	FLASH_KEYR	Write operations Erase commands Interrupt generation masking sources
FLASH_SR	N/A	-
FLASH_CCR	N/A	-
FLASH_OPTCR	FLASH_OPTKEYR	Option bytes change Mass erase
FLASH_OPTSR_PRG FLASH_OPTSR2_PRG	FLASH_OPTCR	Option bytes change
FLASH_OPTCCR	N/A	-
FLASH_PRAR_PRG	FLASH_OPTCR	Option bytes (PCROP)
FLASH_SCAR_PRG	FLASH_OPTCR	Option bytes (security)
FLASH_WPSN_PRG	FLASH_OPTCR	Option bytes (write protection)
FLASH_BOOT_PRG	FLASH_OPTCR	Option bytes (boot)
FLASH_CRCCR	N/A	-
FLASH_CRCSADDR		-
FLASH_CRCEADDR		-
FLASH_CRCDATAR		-
FLASH_ECC_FAR	N/A	-

4.5.2 Write protection

The purpose of embedded Flash memory write protection is to protect the embedded Flash memory against unwanted modifications of the non-volatile code and/or data.

Any 128-Kbyte Flash sector can be independently write-protected or unprotected by clearing/setting the corresponding WRPSn bit in the FLASH_WPSN_PRG register.

A write-protected sector can neither be erased nor programmed. As a result, a bank erase cannot be performed if one sector is write-protected, unless a bank erase with automatic

protection removal or an RDP level 1 to 0 regression is executed (see *Section : Flash bank erase with automatic protection-removal sequence* for details).

The embedded Flash memory write-protection user option bits can be modified without any restriction when the RDP level is set to level 0 or level 1. When it is set to level 2, the write protection bitfield can no more be changed in the option bytes.

Note: PCROP or secure-only areas are write and erase protected.

Write protection errors are documented in *Section 4.7: FLASH error management*.

4.5.3 Readout protection (RDP)

The embedded Flash memory readout protection is global as it does not apply only to the embedded Flash memory, but also to the other secured regions. This is done by using dedicated security signals.

In this section *other secured regions* are defined as:

- Backup SRAM
- RTC backup registers
- Encrypted regions protected by on-the-fly decryption engine (OTFDEC)

The global readout protection level is set by writing the values given in *Table 20* into the readout protection (RDP) option byte (see *Section 4.4.3: Option byte modification*).

Table 20. RDP value vs readout protection level

RDP option byte value	Global Readout Protection Level
0xAA	Level 0
0xCC	Level 2
Any other value	Level 1(1)

1. Default protection level when RDP option byte is erased.

Definitions of RDP global protection level

RDP Level 0 (no protection)

When the global read protection level 0 is set, all read/program/erase operations from/to the user Flash memory are allowed (if no others protections are set). This is true whatever the boot configuration (boot from user or system flash memory, boot from RAM), and whether the debugger is connected to the device or not. Accesses to the *other secured regions* are also allowed.

RDP Level 1 (Flash memory content protection)

When the global read protection level 1 is set, the below properties apply:

- The embedded flash memory content is protected against debugger and potential malicious code stored in RAM. Hence as soon as any debugger is connected or has been connected, or a boot is configured in embedded RAM (intrusion), the embedded Flash memory prevents any accesses to Flash memory.
- When no intrusion is detected (no boot in RAM, no boot in System Flash memory and no debugger connected), all read/program/erase operations from/to the user Flash

memory are allowed (if no others protections are set). Accesses to the *other secured regions* are also allowed.

- When an intrusion is detected, no accesses to the user Flash memory can be performed. A bus error is generated when a read access is requested to the Flash memory. In addition, no accesses to *other secured regions* (read or write) can be performed.
- When performing an RDP level regression, i.e. programming the RDP protection to level 0, the user Flash memory and the *other secured regions* are mass erased, as described in *RDP protection transitions*.
- When booting from STMicroelectronics non-secure bootloader, only the identification services are available (GET_ID_COMMAND, GET_VER_COMMAND and GET_CMD_COMMAND).

RDP Level 2 (device protection and intrusion prevention)

When the global read protection level 2 is set, the below rules apply:

- All debugging features are disabled.
- Like level 0, all read/write/erase operations from/to the user Flash memory are allowed since the debugger and the boot from RAM and System Flash memory are disabled. Accesses to the *other secured regions* are also allowed.
- Booting from RAM is no more allowed.
- The user option bits described in *Section 4.4* can no longer be changed.

Caution: Memory read protection level 2 is an irreversible operation. When level 2 is activated, the level of protection cannot be changed back to level 0 or level 1.

Note: The JTAG port is permanently disabled when level 2 is active (acting as a JTAG fuse). As a consequence. STMicroelectronics is not able to perform analysis on defective parts on which the level 2 protection has been set.

Apply a power-on reset if the global read protection level 2 is set while the debugger is still connected.

The above RDP global protection is summarized in *Table 21*.

Table 21. Protection vs RDP Level(1)

Boot area	Inputs		Effects				Comment
	RDP	Debugger connected	User Flash memory access(2)	System Flash memory access (3)	Other secured regions	Option Bytes access	
User Flash memory	Level 0	Yes(4)/No	R/W/E	R	R/W	R/W	-
	Level 1	Yes(3)	illegal access(5)	R	no access	R/W	
	Level 1	No	R/W/E	R	R/W	R/W	
	Level 2	No	R/W/ E	R	R/W	R	

Table 21. Protection vs RDP Level(1) (continued)

Boot area	Inputs		Effects				Comment
	RDP	Debugger connected	User Flash memory access(2)	System Flash memory access (3)	Other secured regions	Option Bytes access	
RAM or System Flash memory	Level 0	Yes(3)/No	R/W/E	R	R/W	R/W	-
	Level 1	Yes(3)/No	illegal access(5)	R	no access	R/W	When selected, only ST basic bootloader is executed
	Level 2	No	Not applicable				No boot from RAM or ST system Flash memory in RDP level 2

1. R = read, W =write, E = erase.
2. PCROP (see *Section 4.5.4*) and secure-only access control (see *Section 4.5.5*) applies.
3. Read accesses to secure boot and secure libraries stored in system Flash possible only from STMicroelectronics code.
4. JTAG interface disabled while secure libraries are executed.
5. *Read protection error (RDPERR)* with bus error on read operations, *Write protection error (WRPERR)* on write/erase operations.

RDP protection transitions

Figure 12 shows how to switch from one RDP level to another. The transition is effective after successfully writing the option bytes including RDP (refer to *Section 4.4.3* for details on how to change the option bytes).

Figure 12. RDP protection transition scheme

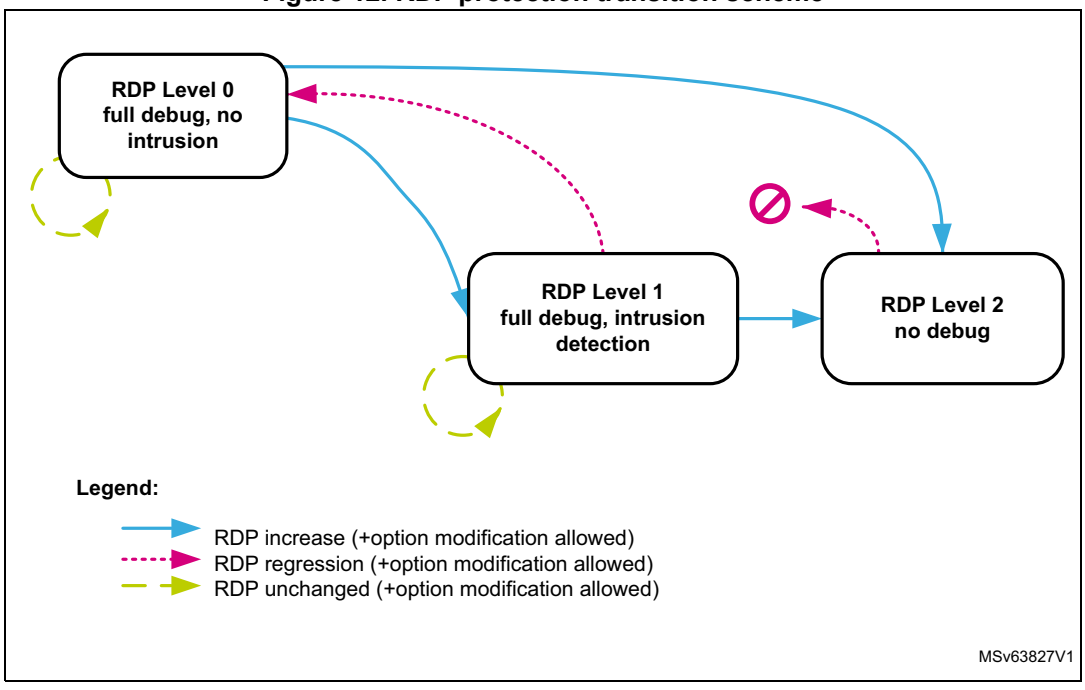


Table 22 details the RDP transitions and their effects on the product.

Table 22. RDP transition and effects

RDP transition		RDP option update	Effect on device		
Level before change	Level after change		Debugger disconnect	Option bytes change	Mass erase
L0	**L1**	not 0xAA and not 0xCC	No	Allowed	No
	L2	0xCC	**Yes**	**Not allowed**	No
L1	**L2**	0xCC	**Yes**	**Not allowed**	No
	L0	0xAA	No	Allowed	**Yes**
L0	**L0**	0xAA	No	Allowed	No
L1	**L1**	not 0xAA and not 0xCC			

When the current RDP level is RDP level 1, requesting a new RDP level 0 causes a full mass erase:

- The user Flash memory area of the embedded Flash memory is mass erased:
  - A partial sector erase occurs if PCROP (respectively secure-only) areas are preserved by the application. It happens when both DMEP bits (respectively DMES bits) are set to 0 in FLASH_PRAR_CUR and FLASH_PRAR_PRG (respectively FLASH_SCAR_CUR and FLASH_SCAR_PRG). The sectors belonging to the preserved area(s) are not erased.
  - A full bank erase occurs when at least one DMEP bit is set to 1 in FLASH_PRAR_CUR or FLASH_PRAR_PRG, and at least one DMES bit is set to 1 in FLASH_SCAR_CUR or FLASH_SCAR_PRG.

Note: Data in write protection area are not preserved during RDP regression.

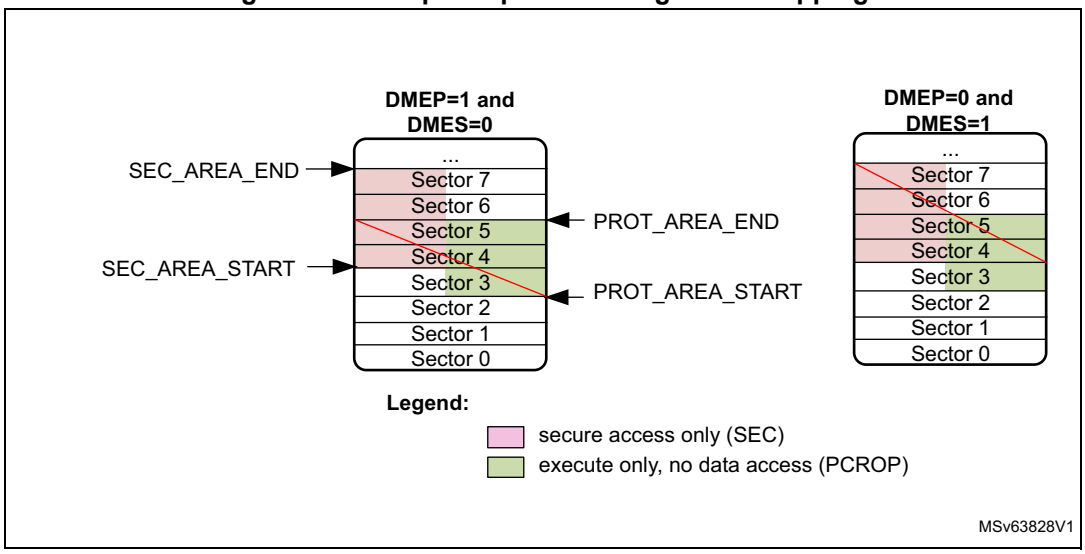
- The *other secured regions* are also erased.

During a level regression, if a PCROP area overlaps with a secure-only area, the embedded Flash memory performs the erase operation depending on the DMES/DMEP options bits (see strike-through areas in red in *Figure 13*). More specifically:

- When DMEP is set in FLASH_PRAR_CUR or FLASH_PRAR_PRG, the PCROP area is erased (overlapped or not with secure-only area).
- When DMES is set in FLASH_SCAR_CUR or FLASH_SCAR_PRG, the secure-only area is erased (overlapped or not with PCROP area).

Note: The sector protections (PCROP, secure-only) are removed only if the protected sector boundaries are modified by the user application.

Figure 13. Example of protected region overlapping



About RDP protection errors

Whatever the RDP level, the corresponding error flag is raised when an illegal read or write access is detected (see *Section 4.7: FLASH error management*).

4.5.4 Proprietary code readout protection (PCROP)

The embedded Flash memory allows the definition of an “executable-only” area in the user area. In this area, only instruction fetch transactions from the system, i.e. no data access (data or literal pool) are allowed. This protection is particularly efficient to protect third party software intellectual property.

Note: Executable-only area usage requires the native code to be compiled accordingly using “execute-only” option.

PCROP area programming

One PCROP area can be defined by setting the PROT_AREA_END and PROT_AREA_START option bytes so that the END address is strictly higher than the START address. PROT_AREA_START and PROT_AREA_END are defined with a granularity of 256 bytes. This means that the actual PCROP area size (in bytes) is defined by:

[(PROT_AREA_END - PROT_AREA_START) + 1] x 256

As an example, to set a PCROP area on the first 4 Kbytes (i.e. from address 0x0800 0000 to address 0x0800 0FFF, both included), the embedded Flash memory must be configured as follows:

- PROT_AREA_START[11:0] = 0x000
- PROT_AREA_END[11:0] = 0x00F

The protected area size defined above is equal to:

[(PROT_AREA_END - PROT_AREA_START) + 1] x 256 = 16 x 256 bytes = 4 Kbytes.

The minimum execute-only PCROP area that can be set is 16 Flash words (or 512 bytes). The maximum area is the whole user Flash memory, configured by setting to the same value the PCROP area START and END addresses.

Note: It is recommended to align the PCROP area size with the Flash sector granularity in order to avoid access right issues.

PCROP area properties

Each valid PCROP area has the following properties:

- Arm® Cortex®-M7 debug events are ignored while executing code in this area.
- Only the CPU can access it (Master ID filtering), using only instruction fetch transactions. In all other cases, accessing the PCROP area is illegal (see below).
- Illegal transactions to a PCROP area (i.e. data read or write, not fetch) are managed as below:
  - Read operations return a zero, write operations are ignored.
  - No bus error is generated but an error flag is raised (RDPERR for read, WRPERR for write).
- A valid PCROP area is erase-protected. As a result:
  - No erase operations to a sector located in this area is possible (including the sector containing the area start address and the end address)
  - No bank erase can be performed if a valid PCROP area is defined, except during regression level or erase with protection removal.
- Only the CPU can modify the PCROP area definition and DMEP bit, as explained in *Changing user option bytes* in *Section 4.4.3*.
- During an RDP level 1 to 0 regression where the PCROP area is not null
  - The PCROP area content is not erased if the DMEP bits are both set to 0 in FLASH_PRAR_CUR and FLASH_PRAR_PRG registers.
  - The PCROP area content is erased if either of the corresponding DMEP bit is set to 1 in FLASH_PRAR_CUR or FLASH_PRAR_PRG register.

For more information on PCROP protection errors, refer to *Section 4.7: FLASH error management*.

4.5.5 Secure access mode

The embedded Flash memory allows the definition of a secure-only area in the user area. This area can be accessed only while the CPU executes secure application code. This feature is available only if the SECURITY option bit is set to 1.

Secure-only areas help isolating secure user code from application non-secure code. As an example, they can be used to protect a customer secure firmware upgrade code, a custom secure boot library or a third party secure library.

Secure-only area programming

One secure-only area can be defined by setting the SEC_AREA_END and SEC_AREA_START option bytes so that the END address is strictly higher than the START address. SEC_AREA_START and SEC_AREA_END are defined with a granularity of 256 bytes. This means that the actual secure-only area size (in bytes) is defined by:

[(SEC_AREA_END - SEC_AREA_START) + 1] x 256

As an example, to set a secure-only area on the first 8 Kbytes (i.e. from address 0x0800 0000 to address 0x0800 1FFF, both included), the embedded Flash memory must be configured as follows:

- SEC_AREA_START[11:0] = 0x000
- SEC_AREA_END[11:0] = 0x01F

The secure-only area size defined above is equal to:

[(SEC_AREA_END - SEC_AREA_START) + 1] x 256 = 32 x 256 bytes = 8 Kbytes.

Note: These option bytes can be modified only by the CPU running ST security library or application secure code, except during regression level or erase with protection removal.

The minimum secure-only area that can be set is 16 Flash words (or 512 bytes). The maximum area is the whole user Flash memory bank, configured by setting to the same value the secure-only area START and END addresses.

Note: It is recommended to align the secure-only area size with Flash sector granularity in order to avoid access right issues.

Secure-only access area properties

- Arm® Cortex®-M7 debug events are ignored while executing code in this area.
- Only the CPU executing ST secure library or user secure application can access it (Master ID filtering). In all other cases, accessing the secure-only area is illegal (see below).
- Illegal transactions to a secure-only area are managed as follows:
  - Data read transactions return zero. Data write transactions are ignored. No bus error is generated but an error flag is raised (RDSERR for read, WRPERR for write).
  - Read instruction transactions generate a bus error and the RDSERR error flag is raised.
- A valid secure-only area is erase-protected. As a result:
  - No erase operations to a sector located in this area are possible (including the sector containing the area start address and the end address), unless the application software is executed from a valid secure-only area.
  - No bank erase can be performed if a valid secure-only area is defined, except during regression level or erase with protection removal.
- Only the CPU can modify the secure-only area definition and DMES bit, as explained in *Changing user option bytes* in *Section 4.4.3*.
- During an RDP level 1 to 0 regression where the secure-only area is not null:
  - the secure-only area content is not erased if the DMES bits are both set to 0 in FLASH_SCAR_CUR and FLASH_SCAR_PRG registers.
  - the secure-only area content is erased if either of the DMES bits is set to 1 in FLASH_SCAR_CUR or FLASH_SCAR_PRG register.

For more information on secure-only protection errors, refer to *Section 4.7: FLASH error management*.

4.6 FLASH low-power modes

4.6.1 Introduction

The table below summarizes the behavior of the embedded Flash memory in the microcontroller low-power modes. The embedded Flash memory belongs to the D1 domain.

Table 23. Effect of low-power modes on the embedded Flash memory

Power mode			D1 domain voltage range	Allowed if FLASH busy	FLASH power mode (in D1 domain)
System state	D1 domain	D2 domain			
Run	DRun	DRun, DStop or DStandby	VOS0/1/2/3	Yes	Run
	DStop	DStop or DStandby	VOS0/1/2/3	No	Off
	DStandby	DStop or DStandby	Off	No	Off
Stop	DStop	DStop or DStandby	SVOS3/4/5	No	Clock gated or Stopped
	DStandby	DStop or DStandby	Off	No	Off
Standby(1)	DStandby	DStandby		No	

1. D3 domain must always be in DStandby mode. When all clocks are stopped and the CPU is in CStop, the VCORE domain is switched off.

When the system state changes or within a given system state, the embedded Flash memory might get a different voltage supply range (VOS) according to the application. The procedure to switch the embedded Flash memory into various power mode (run, clock gated, stopped, off) is described hereafter.

Note: For more information in the microcontroller power states, refer to the Power control section (PWR).

4.6.2 Managing the FLASH domain switching to DStop or DStandby

As explain in *Table 23*, if the embedded Flash memory informs the reset and clock controller (RCC) that it is busy (i.e. BSY, QW, WBNE is set), the microcontroller cannot switch the D1 domain to DStop or DStandby mode.

Note: CRC_BUSY is not taken into account.

There are two ways to release the embedded Flash memory:

- Reset the WBNE busy flag in FLASH_SR register by any of the following actions:
  a) Complete the write buffer with missing data.
  b) Force the write operation without filling the missing data by activating the FW bit in FLASH_CR register. This forces all missing data “high”.
  c) Reset the PG bit in FLASH_CR register. This disables the write buffer and consequently lead to the loss of its content.
- Poll QW busy bits in FLASH_SR register until they are cleared. This will indicate that all recorded write, erase and option change operations are complete.

The microcontroller can then switch the domain to DStop or DStandby mode.

4.7 FLASH error management

4.7.1 Introduction

The embedded Flash memory automatically reports when an error occurs during a read, program or erase operation. A wide range of errors are reported:

- *Write protection error (WRPERR)*
- *Programming sequence error (PGSERR)*
- *Strobe error (STRBERR)*
- *Inconsistency error (INCERR)*
- *Operation error (OPERR)*
- *Error correction code error (SNECCERR/DBECCERR)*
- *Read protection error (RDPERR)*
- *Read secure error (RDSERR)*
- *CRC read error (CRCRDERR)*
- *Option byte change error (OPTCHANGEERR)*

The application software can individually enable the interrupt for each error, as detailed in *Section 4.8: FLASH interrupts*.

Note: For some errors, the application software must clear the error flag before attempting a new operation.

4.7.2 Write protection error (WRPERR)

When an illegal erase/program operation is attempted to the non-volatile memory bank, the embedded Flash memory sets the write protection error flag WRPERR in FLASH_SR register.

An erase operation is rejected and flagged as illegal if it targets one of the following memory areas:

- A sector belonging to a valid PCROP area (even partially)
- A sector belonging to a valid secure-only area (even partially) except if the application software is executed from a valid secure-only area
- A sector write-locked with WRPSn

An program operation is ignored and flagged as illegal if it targets one of the following memory areas:

- A user Flash sector belonging to a valid PCROP area while the device is not executing an ST secure library
- A user Flash sector belonging to a valid secure-only area while the device is not executing user secure code or ST secure library
- A user sector write-locked with WRPSn
- The system Flash memory
- The user main Flash memory when RDP level is 1, a debugger has been detected on the device, or the CPU has not booted from user Flash memory.
- A reserved area

When WRPERR flag is raised, the operation is rejected and nothing is changed in the bank. If a write burst operation was ongoing, WRPERR is raised each time a Flash word write operation is processed by the embedded Flash memory.

Note: WRPERR flag does not block any new erase/program operation.

Not resetting the write protection error flag (WRPERR) does not generate a PGSERR error.

WRPERR flag is cleared by setting CLR_WRPERR bit to 1 in FLASH_CCR register.

If WRPERRIE bit in FLASH_CR register is set to 1, an interrupt is generated when WRPERR flag is raised (see *Section 4.8: FLASH interrupts* for details).

4.7.3 Programming sequence error (PGSERR)

When the programming sequence is incorrect, the embedded Flash memory sets the programming sequence error flag PGSERR in FLASH_SR register.

More specifically, PGSERR flag is set if one of below conditions is met:

- A write operation is requested but the program enable bit (PG) has not been set in FLASH_CR register prior to the request.
- The inconsistency error (INCERR) has not been cleared to 0 before requesting a new write or erase operation.

When PGSERR flag is raised, the current program operation is aborted and nothing is changed. The write data buffer is also flushed. If a write burst operation was ongoing, PGSERR is raised at the end of the burst.

Note: When PGSERR flag is raised, there is a risk that the last write operation performed by the application has been lost because of the above protection mechanism. Hence it is recommended to generate interrupts on PGSERR and verify in the interrupt handler if the last write operation has been successful by reading back the value in the Flash memory.

The PGSERR flag also blocks any new program operation. This means that PGSERR must be cleared before starting a new program operation.

PGSERR flag is cleared by setting CLR_PGSERR bit to 1 in FLASH_CCR register.

If PGSERRIE bit in FLASH_CR register is set to 1, an interrupt is generated when PGSERR flag is raised. See *Section 4.8: FLASH interrupts* for details.

4.7.4 Strobe error (STRBERR)

When the application software writes several times to the same byte write buffer, the embedded Flash memory sets the strobe error flag STRBERR in FLASH_SR register.

When STRBERR flag is raised, the current program operation is not aborted. The application can ignore the error, proceed with the current write operation and request new write operations. If a write burst was ongoing, STRBERR is raised at the end of the burst.

STRBERR flag is cleared by setting CLR_STRBERR bit to 1 in FLASH_CCR register.

If STRBERRIE bit in FLASH_CR register is set to 1, an interrupt is generated when STRBERR flag is raised. See *Section 4.8: FLASH interrupts* for details.

4.7.5 Inconsistency error (INCERR)

When a programming inconsistency is detected, the embedded Flash memory sets the inconsistency error flag INCERR in register FLASH_SR.

More specifically, INCERR flag is set when one of the following conditions is met:

- A write operation is attempted before completion of the previous write operation, e.g.
  - The application software starts a write operation to fill the 256-bit write buffer, but sends a new write burst request to a different Flash memory address before the buffer is full.
  - One master starts a write operation, but before the buffer is full, another master starts a new write operation to the same address or to a different address.
- A wrap burst request issued by a master overlaps two or more 256-bit Flash-word addresses, i.e. wrap bursts must be done within 256-bit Flash-word address boundaries.

Note: INCERR flag must be cleared before starting a new write operation, otherwise a sequence error (PGSERR) is raised.

It is recommended to follow the sequence below to avoid losing data when an inconsistency error occurs:

1. Execute a handler routine when INCERR flag is raised.
2. Stop all write requests to embedded Flash memory.
3. Verify that the write operations that have been requested just before the INCERR event have been successful by reading back the programmed values from the memory.
4. Clear the corresponding INCERR bit.
5. Restart the write operations where they have been interrupted.

INCERR flag is cleared by setting CLR_INCERR bit to 1 in FLASH_CCR register.

If INCERRIE bit in FLASH_CR register is set to 1, an interrupt is generated when INCERR flag is raised (see *Section 4.8: FLASH interrupts* for details).

4.7.6 Operation error (OPERR)

When an error occurred during a write or an erase operation, the embedded Flash memory sets the operation error flag OPERR in FLASH_SR register. This error may be caused by an incorrect non-volatile memory behavior due to cycling issues or to a previous modify operation stopped by a system reset.

When OPERR flag is raised, the current program/erase operation is aborted.

OPERR flag is cleared by setting CLR_OPERR bit to 1 in FLASH_CCR register.

If OPERRIE bit in FLASH_CR register is set to 1, an interrupt is generated when OPERR flag is raised (see *Section 4.8: FLASH interrupts* for details).

4.7.7 Error correction code error (SNECCERR/DBECCERR)

When a single error correction is detected during a read the embedded Flash memory sets the single error correction flag SNECCERR in FLASH_SR register.

When two ECC errors are detected during a read, the embedded Flash memory sets the double error detection flag DBECCERR in FLASH_SR register.When SNECCERR flag is raised, the corrected read data are returned. Hence the application can ignore the error and request new read operations.

If a read burst operation was ongoing, SNECCERR or DBECCERR flag is raised each time a new data is sent back to the requester through the AXI interface.

When SNECCERR or DBECCERR flag is raised, the address of the Flash word that generated the error is saved in the FLASH_ECC_FAR register. This register is automatically cleared when the associated flag that generated the error is reset.

Note: In case of successive single correction or double detection errors, only the address corresponding to the first error is stored in FLASH_ECC_FAR register.

When DBECCERR flag is raised, a bus error is generated. In case of successive double error detections, a bus error is generated each time a new data is sent back to the requester through the AXI interface.

Note: It is not mandatory to clear SNECCERR or DBECCERR flags before starting a new read operation.

SNECCERR (respectively DBECCERR) flag is cleared by setting to 1 CLR_SNECCERR bit in FLASH_CCR register.

If SNECCERR (respectively DBECCERR) bit in FLASH_CR register is set to 1, an interrupt is generated when SNECCERR (respectively DBECCERR) flag is raised. See *Section 4.8: FLASH interrupts* for details.

4.7.8 Read protection error (RDPERR)

When a read operation to a PCROP, a secure-only or a RDP protected area is attempted in non-volatile memory bank, the embedded Flash memory sets the read protection error flag RDPERR in FLASH_SR register.

When RDPERR flag is raised, the current read operation is aborted but the application can request new read operations. If a read burst was ongoing, RDPERR is raised each time a data is sent back to the requester through the AXI interface.

Note: A bus error is raised if a standard application attempts to execute on a secure-only or a RDP protected area.

RDPERR flag is cleared by setting CLR_RDPERR bit to 1 in FLASH_CCR register.

If RDPERRIE bit in FLASH_CR register is set to 1, an interrupt is generated when RDPERR flag is raised (see *Section 4.8: FLASH interrupts* for details).

4.7.9 Read secure error (RDSERR)

When a read operation is attempted to a secure address, the embedded Flash memory sets the read secure error flag RDSERR in FLASH_SR register. For more information, refer to *Section 4.5.5: Secure access mode*.

When RDSERR flag is raised, the current read operation is aborted and the application can request new read operations. If a read burst was ongoing, RDSERR is raised each time a data is sent back to the requester through the AXI interface.

Note: The bus error is raised only if the illegal access is due to an instruction fetch.

RDSERR flag is cleared by setting CLR_RDSERR bit to 1 in FLASH_CCR register.

If RDSERRIE bit in FLASH_CR register is set to 1, an interrupt is generated when RDSERR flag is raised (see *Section 4.8: FLASH interrupts* for details).

4.7.10 CRC read error (CRCRDERR)

After a CRC computation, the embedded Flash memory sets the CRC read error flag CRCRDERR in FLASH_SR register when one or more address belonging to a protected area was read by the CRC module. A protected area corresponds to a PCROP area (see *Section 4.5.4*) or to a secure-only area (see *Section 4.5.5*).

CRCRDERR flag is raised when CRCEND bit is set to 1 (end of CRC calculation). In this case, it is likely that the CRC result is wrong since illegal read operations to protected areas return null values.

CRCRDERR flag is cleared by setting CLR_CRCRDERR bit to 1 in FLASH_CCR register.

If CRCRDERRIE bit in FLASH_CR register is set to 1, an interrupt is generated when CRCRDERR flag is raised together with CRCEND bit (see *Section 4.8: FLASH interrupts* for details).

4.7.11 Option byte change error (OPTCHANGEERR)

When the embedded Flash memory finds an error during an option change operation, it aborts the operation and sets the option byte change error flag OPTCHANGEERR in FLASH_OPTSR_CUR register.

OPTCHANGEERR flag is cleared by setting CLR_OPTCHANGEERR bit to 1 in FLASH_OPTCCR register.

If OPTCHANGEERRIE bit in FLASH_OPTCR register is set to 1, an interrupt is generated when OPTCHANGEERR flag is raised (see *Section 4.8: FLASH interrupts* for details).

4.7.12 Miscellaneous HardFault errors

The following events generate a bus error on the corresponding bus interface:

- On AXI system bus:
  - accesses to user Flash memory while RDP is set to 1 and a illegal condition is detected (boot from system Flash memory, boot from RAM, or debugger connected)
  - fetching to secure-only user Flash memory without the correct access rights
- On AHB configuration bus:
  - wrong key input to FLASH_KEYR or FLASH_OPTKEYR

4.8 FLASH interrupts

The embedded Flash memory can generate a maskable interrupt to signal the following events:

- Read and write errors (see *Section 4.7: FLASH error management*)
  - Single ECC error correction during read operation
  - Double ECC error detection during read operation
  - Write inconsistency error
  - Bad programming sequence
  - Strobe error during write operations
  - Non-volatile memory write/erase error (due to cycling issues)
  - option change operation error
- Security errors (see *Section 4.7: FLASH error management*)
  - Write protection error
  - Read protection error
  - Read secure error
  - CRC computation on PCROP or secure-only area error
- Miscellaneous events (described below)
  - End of programming
  - CRC computation complete

These multiple sources are combined into a single interrupt signal, **flash_it**, which is the only interrupt signal from the embedded Flash memory that drives the NVIC (nested vectored interrupt controller).

You can individually enable or disable embedded Flash memory interrupt sources by changing the mask bits in the FLASH_CR register. Setting the appropriate mask bit to 1 enables the interrupt.

Note: Prior to writing, FLASH_CR register must be unlocked as explained in Section 4.5.1: FLASH configuration protection

Table 24 gives a summary of the available embedded Flash memory interrupt features. As mentioned in the table below, some flags need to be cleared before a new operation is triggered.

Table 24. Flash interrupt request

Interrupt event	Event flag	Enable control bit	Clear flag to resume operation	Bus error
End-of-program event	EOP	EOPIE	N/A	N/A
CRC complete event	CRCEND	CRCENDIE	N/A	N/A
Write protection error	WRPERR	WRPERRIE	No	No
Programming sequence error	PGSERR	PGSERRIE	**Yes**(1)	No
Strobe error	STRBERR	STRBERRIE	No	No
Inconsistency error	INCERR	INCERRIE	**Yes**(1)	No
Operation error	OPERR	OPERRIE	No	No

Table 24. Flash interrupt request (continued)

Interrupt event	Event flag	Enable control bit	Clear flag to resume operation	Bus error
ECC single error correction event	SNECCERR	SNECCERRIE	No	No
ECC double error detection event	DBECCERR	DBECCERRIE	No	**Yes**
Read protection error	RDPERR	RDPERRIE	No	**Yes**(2)
Read secure error	RDSERR	RDSERRIE	No	No (data) **Yes** (fetch)
CRC read error	CRCRDERR	CRCRDERRIE	No	No
Option Bytes operation error	OPTCHANGEERR	OPTCHANGEERRIE	No	No

1. Programming still possible on the AXI interface that did not trigger the inconsistency error, on the Flash bank that does not have the flag bit raised. See *Section 4.7.5: Inconsistency error (INCERR)* for details.
2. Bus error occurs only when accessing RDP protected area, as defined in *Section 4.5.3: Readout protection (RDP)*

The status of the individual maskable interrupt sources described in *Table 24* (except for option byte error) can be read from the FLASH_SR register. They can be cleared by setting to 1 the adequate bit in FLASH_CCR register.

Note: No unlocking mechanism is required to clear an interrupt.

End-of-program event

Setting the end-of-operation interrupt enable bit (EOPIE) in the FLASH_CR register enables the generation of an interrupt at the end of an erase operation, a program operation or an option byte change. The EOP bit in the FLASH_SR register is also set when one of these events occurs.

Setting CLR_EOP bit to 1 in FLASH_CCR register clears EOP flag.

CRC end of calculation event

Setting the CRC end-of-calculation interrupt enable bit (CRCENDIE) in the FLASH_CR register enables the generation of an interrupt at the end of a CRC operation. The CRCEND bit in the FLASH_SR register is also set when this event occurs.

Setting CLR_CRCEND bit to 1 in FLASH_CCR register clears CRCEND flag.

4.9 FLASH registers

4.9.1 FLASH access control register (FLASH_ACR)

Address offset: 0x000

Reset value: 0x0000 0037

For more details, refer to *Section 4.3.8: FLASH read operations* and *Section 4.3.9: FLASH program operations*.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRHIGHFREQ [1:0]		LATENCY[3:0]			
										rw	rw	rw	rw	rw	rw

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:4 **WRHIGHFREQ[1:0]**: Flash signal delay

These bits are used to control the delay between non-volatile memory signals during programming operations. The application software has to program them to the correct value depending on the embedded Flash memory interface frequency. Please refer to *Table 16* for details.

Note: No check is performed by hardware to verify that the configuration is correct.

Bits 3:0 **LATENCY[3:0]**: Read latency

These bits are used to control the number of wait states used during read operations. The application software has to program them to the correct value depending on the embedded Flash memory interface frequency and voltage conditions.

0000: zero wait state used to read a word from non-volatile memory

0001: one wait state used to read a word from non-volatile memory

0010: two wait states used to read a word from non-volatile memory

...

1111: 15 wait states used to read from non-volatile memory

Note: No check is performed by hardware to verify that the configuration is correct.

4.9.2 FLASH key register (FLASH_KEYR)

Address offset: 0x004

Reset value: 0x0000 0000

FLASH_KEYR is a write-only register. The following values must be programmed consecutively to unlock FLASH_CR register:

1. 1^{st} key = 0x4567 0123
2. 2^{nd} key = 0xCDEF 89AB

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **KEY[31:0]**: Non-volatile memory bank configuration access unlock key

4.9.3 FLASH option key register (FLASH_OPTKEYR)

Address offset: 0x008

Reset value: 0x0000 0000

FLASH_OPTKEYR is a write-only register. The following values must be programmed consecutively to unlock FLASH_OPTCR register:

1. 1st key = 0x0819 2A3B
2. 2nd key = 0x4C5D 6E7F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OPTKEY[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OPTKEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **OPTKEY[31:0]**: FLASH option bytes control access unlock key

4.9.4 FLASH control register (FLASH_CR)

Address offset: 0x00C

Reset value: 0x0000 0031

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	CRCRDERRIE	CRCENDIE	DBECCERRIE	SNECCERRIE	RDSERRIE	RDPERRIE	OPERRIE	INCERRIE	Res.	STRBERRIE	PGSERRIE	WRPERRIE	EOPIE
			rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CRC_EN	Res.	Res.	Res.	Res.	SNB[2:0]			START	FW	PSIZE[1:0]		BER	SER	PG	LOCK
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rs

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **CRCRDERRIE**: CRC read error interrupt enable bit

When CRCRDERRIE bit is set to 1, an interrupt is generated when a protected area (PCROP or secure-only) has been detected during the last CRC computation. CRCRDERRIE can be programmed only when LOCK1 is set to 0.

0: no interrupt generated when a CRC read error occurs

1: interrupt generated when a CRC read error occurs

Bit 27 **CRCENDIE**: CRC end of calculation interrupt enable bit

When CRCENDIE bit is set to 1, an interrupt is generated when the CRC computation has completed. CRCENDIE can be programmed only when LOCK1 is set to 0.

0: no interrupt generated when CRC computation complete

1: interrupt generated when CRC computation complete

Bit 26 **DBECCERRIE**: ECC double detection error interrupt enable bit

When DBECCERRIE bit is set to 1, an interrupt is generated when an ECC double detection error occurs during a read operation. DBECCERRIE can be programmed only when LOCK1 is set to 0.

0: no interrupt generated when an ECC double detection error occurs

1: interrupt generated if an ECC double detection error occurs

Bit 25 **SNECCERRIE**: ECC single correction error interrupt enable bit

When SNECCERRIE bit is set to 1, an interrupt is generated when an ECC single correction error occurs during a read operation. SNECCERRIE can be programmed only when LOCK1 is set to 0.

0: no interrupt generated when an ECC single correction error occurs

1: interrupt generated when an ECC single correction error occurs

Bit 24 **RDSERRIE**: Secure error interrupt enable bit

When RDSERRIE bit is set to 1, an interrupt is generated when a secure error (access to a secure-only protected address) occurs during a read operation. RDSERRIE can be programmed only when LOCK1 is set to 0.

0: no interrupt generated when a secure error occurs

1: an interrupt is generated when a secure error occurs

Bit 23 **RDPERRIE**: Read protection error interrupt enable bit

When RDPERRIE bit is set to 1, an interrupt is generated when a read protection error occurs (access to an address protected by PCROP or by RDP level 1) during a read operation. RDPERRIE can be programmed only when LOCK1 is set to 0.

0: no interrupt generated when a read protection error occurs

1: an interrupt is generated when a read protection error occurs

Bit 22 **OPERRIE**: Write/erase error interrupt enable bit

When OPERRIE bit is set to 1, an interrupt is generated when an error is detected during a write/erase operation. OPERRIE can be programmed only when LOCK1 is set to 0.

0: no interrupt generated when a write/erase error occurs

1: interrupt generated when a write/erase error occurs

Bit 21 **INCERRIE**: Inconsistency error interrupt enable bit

When INCERRIE bit is set to 1, an interrupt is generated when an inconsistency error occurs during a write operation. INCERRIE can be programmed only when LOCK1 is set to 0.

0: no interrupt generated when a inconsistency error occurs

1: interrupt generated when a inconsistency error occurs.

Bit 20 Reserved, must be kept at reset value.

Bit 19 **STRBERRIE**: Strobe error interrupt enable bit

When STRBERRIE bit is set to 1, an interrupt is generated when a strobe error occurs (the master programs several times the same byte in the write buffer) during a write operation. STRBERRIE can be programmed only when LOCK1 is set to 0.

0: no interrupt generated when a strobe error occurs

1: interrupt generated when strobe error occurs.

Bit 18 **PGSERRIE**: Programming sequence error interrupt enable bit

When PGSERRIE bit is set to 1, an interrupt is generated when a sequence error occurs during a program operation. PGSERRIE can be programmed only when LOCK1 is set to 0.

0: no interrupt generated when a sequence error occurs

1: interrupt generated when sequence error occurs.

Bit 17 **WRPERRIE**: Write protection error interrupt enable bit

When WRPERRIE bit is set to 1, an interrupt is generated when a protection error occurs during a program operation. WRPERRIE can be programmed only when LOCK1 is set to 0.

0: no interrupt generated when a protection error occurs

1: interrupt generated when a protection error occurs.

Bit 16 **EOPIE**: End-of-program interrupt control bit

Setting EOPIE bit to 1 enables the generation of an interrupt at the end of a program operation. EOPIE can be programmed only when LOCK1 is set to 0.

0: no interrupt generated at the end of a program operation.

1: interrupt enabled when at the end of a program operation.

Bit 15 **CRC_EN**: CRC control bit

Setting CRC_EN bit to 1 enables the CRC calculation. CRC_EN does not start CRC calculation but enables CRC configuration through FLASH_CRCCR register.

When CRC calculation is performed, it can only be disabled by setting CRC_EN bit to 0. Resetting CRC_EN clears CRC configuration and resets the content of FLASH_CRCDATAR register.

Clearing CRC_EN to 0 sets CRCDATA to 0x0.

CRC_EN can be programmed only when LOCK1 is set to 0.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:8 **SNB[2:0]**: Sector erase selection number

These bits are used to select the target sector for a sector erase operation (they are unused otherwise). SNB can be programmed only when LOCK is set to 0.

000: sector 0

001: sector 1

...

111: sector 7

Bit 7 **START**: Erase start control bit

START bit is used to start a sector erase or a bank erase operation. START can be programmed only when LOCK is set to 0.

The embedded Flash memory resets START when the corresponding operation has been acknowledged. The user application cannot access any embedded Flash memory register until the operation is acknowledged.

Bit 6 **FW:** Write forcing control bit

FW forces a write operation even if the write buffer is not full. In this case all bits not written are set to 1 by hardware. FW can be programmed only when LOCK is set to 0.

The embedded Flash memory resets FW when the corresponding operation has been acknowledged. The user application cannot access any embedded Flash memory register until the operation is acknowledged.

Note: Using a force-write operation prevents the application from updating later the missing bits with something else than 1, because it is likely that it will lead to permanent ECC error.

Write forcing is effective only if the write buffer is not empty (in particular, FW does not start several write operations when the force-write operations are performed consecutively).

Bits 5:4 **PSIZE[1:0]**: program size

PSIZE selects the parallelism used by the non-volatile memory during write and erase operations. PSIZE can be programmed only when LOCK is set to 0.

00: programming executed with byte parallelism

01: programming executed with half-word parallelism

10: programming executed with word parallelism

11: programming executed with double word parallelism

Bit 3 **BER**: erase request

Setting BER bit to 1 requests a bank erase operation (user Flash memory only). BER can be programmed only when LOCK is set to 0.

BER has a higher priority than SER: if both are set, the embedded Flash memory executes a bank erase.

0: bank erase not requested

1: bank erase requested

Note: Write protection error is triggered when a bank erase is required and some sectors are protected.

Bit 2 **SER**: sector erase request

Setting SER bit to 1 requests a sector erase. SER can be programmed only when LOCK is set to 0.

BER has a higher priority than SER: if both bits are set, the embedded Flash memory executes a bank erase.

0: sector erase not requested

1: sector erase requested

Note: Write protection error is triggered when a sector erase is required on protected sector(s).

Bit 1 **PG**: internal buffer control bit

Setting PG bit to 1 enables internal buffer for write operations. This allows preparing program operations even if a sector or bank erase is ongoing.

PG can be programmed only when LOCK is set to 0. When PG is reset, the internal buffer is disabled for write operations, and all the data stored in the buffer but not sent to the operation queue are lost.

Bit 0 **LOCK**: configuration lock bit

This bit locks the FLASH_CR register. The correct write sequence to FLASH_KEYR register unlocks this bit. If a wrong sequence is executed, or if the unlock sequence to FLASH_KEYR is performed twice, this bit remains locked until the next system reset.

LOCK can be set by programming it to 1. When set to 1, a new unlock sequence is mandatory to unlock it. When LOCK changes from 0 to 1, the other bits of FLASH_CR register do not change.

0: FLASH_CR register unlocked

1: FLASH_CR register locked

4.9.5 FLASH status register (FLASH_SR)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	CRCRDERR	CRCEND	DBECCERR	SNECCERR	RDSERR	RDPERR	OPERR	INCERR	Res.	STRBERR	PGSERR	WRPERR	EOP
			r	r	r	r	r	r	r	r		r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CRC_BUSY	QW	WBNE	BSY
												r	r	r	r

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **CRCRDERR**: CRC read error flag

CRCRDERR flag is raised when a word is found read protected during a CRC operation. An interrupt is generated if CRCRDIE and CRCEND are set to 1. Writing 1 to CLR_CRCRDERR bit in FLASH_CCR register clears CRCRDERR.

0: no protected area detected inside address read by CRC

1: a protected area has been detected inside address read by CRC. CRC result is very likely incorrect.

Note: This flag is valid only when CRCEND bit is set to 1

Bit 27 **CRCEND**: CRC end of calculation flag

CRCEND bit is raised when the CRC computation has completed. An interrupt is generated if CRCENDIE is set to 1. It is not necessary to reset CRCEND before restarting CRC computation. Writing 1 to CLR_CRCEND bit in FLASH_CCR register clears CRCEND.

0: CRC computation not complete

1: CRC computation complete

Bit 26 **DBECCERR**: ECC double detection error flag

DBECCERR flag is raised when an ECC double detection error occurs during a read operation. An interrupt is generated if DBECCERRIE is set to 1. Writing 1 to CLR_DBECCERR bit in FLASH_CCR register clears DBECCERR.

0: no ECC double detection error occurred

1: ECC double detection error occurred

Bit 25 **SNECCERR**: Single correction error flag

SNECCERR flag is raised when an ECC single correction error occurs during a read operation. An interrupt is generated if SNECCERRIE is set to 1. Writing 1 to CLR_SNECCERR bit in FLASH_CCR register clears SNECCERR.

0: no ECC single correction error occurs

1: ECC single correction error occurs

Bit 24 **RDSERR**: Secure error flag

RDSERR flag is raised when a read secure error (read access to a secure-only protected word) occurs. An interrupt is generated if RDSERRIE is set to 1. Writing 1 to CLR_RDSERR bit in FLASH_CCR register clears RDSERR.

0: no secure error occurs

1: a secure error occurs

Bit 23 **RDPERR:** Read Protection error flag

RDPERR flag is raised when an read protection error (read access to a PCROP-protected or a RDP-protected area) occurs. An interrupt is generated if RDPERRIE is set to 1. Writing 1 to CLR_RDPERR bit in FLASH_CCR register clears RDPERR.

0: no read protection error occurs

1: a read protection error occurs

Bit 22 **OPERR**: Write/erase error flag

OPERR flag is raised when an error occurs during a write/erase. An interrupt is generated if OPERRIE is set to 1. Writing 1 to CLR_OPERR bit in FLASH_CCR register clears OPERR.

0: no write/erase error occurs

1: a write/erase error occurs

Bit 21 **INCERR:** Inconsistency error flag

INCERR flag is raised when a inconsistency error occurs. An interrupt is generated if INCERRIE is set to 1. Writing 1 to CLR_INCERR bit in the FLASH_CCR register clears INCERR.

0: no inconsistency error occurs

1: a inconsistency error occurs

Bit 20 Reserved, must be kept at reset value.

Bit 19 **STRBERR:** Strobe error flag

STRBERR flag is raised when a strobe error occurs (when the master attempts to write several times the same byte in the write buffer). An interrupt is generated if the STRBERRIE bit is set to 1. Writing 1 to CLR_STRBERR bit in FLASH_CCR register clears STRBERR.

0: no strobe error occurs

1: a strobe error occurs

Bit 18 **PGSERR:** Programming sequence error flag

PGSERR flag is raised when a sequence error occurs. An interrupt is generated if the PGSERRIE bit is set to 1. Writing 1 to CLR_PGSERR bit in FLASH_CCR register clears PGSERR.

0: no sequence error occurs

1: a sequence error occurs

Bit 17 **WRPERR**: Write protection error flag

WRPERR flag is raised when a protection error occurs during a program operation. An interrupt is also generated if the WRPERRIE is set to 1. Writing 1 to CLR_WRPERR bit in FLASH_CCR register clears WRPERR.

0: no write protection error occurs

1: a write protection error occurs

Bit 16 **EOP**: End-of-program flag

EOP flag is set when a programming operation completes. An interrupt is generated if the EOPIE is set to 1. It is not necessary to reset EOP before starting a new operation. EOP bit is cleared by writing 1 to CLR_EOP bit in FLASH_CCR register.

0: no programming operation completed

1: a programming operation completed

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **CRC_BUSY**: CRC busy flag

CRC_BUSY flag is set when a CRC calculation is ongoing. This bit cannot be forced to 0. The user must wait until the CRC calculation has completed or disable CRC computation.

0: no CRC calculation ongoing

1: CRC calculation ongoing

Bit 2 **QW**: Wait queue flag

QW flag is set when a write, erase or option byte change operation is pending in the command queue buffer. It is not possible to know what type of programming operation is present in the queue.

This flag is reset by hardware when all write, erase or option byte change operations have been executed and thus removed from the waiting queue(s). This bit cannot be forced to 0. It is reset after a deterministic time if no other operations are requested.

0: no write, erase or option byte change operations waiting in the operation queues

1: at least one write, erase or option byte change operation is waiting in the operation queue

Bit 1 **WBNE**: Write buffer not empty flag

WBNE flag is set when the embedded Flash memory is waiting for new data to complete the write buffer. In this state, the write buffer is not empty. WBNE is reset by hardware each time the write buffer is complete or the write buffer is emptied following one of the event below:

- the application software forces the write operation using FW bit in FLASH_CR
- the embedded Flash memory detects an error that involves data loss
- the application software has disabled write operations

This bit cannot be forced to 0. To reset it, clear the write buffer by performing any of the above listed actions, or send the missing data.

0: write buffer empty or full

1: write buffer waiting data to complete

Bit 0 **BSY**: Busy flag

BSY flag is set when an effective write, erase or option byte change operation is ongoing. It is not possible to know what type of operation is being executed.

BSY cannot be forced to 0. It is automatically reset by hardware every time a step in a write, erase or option byte change operation completes.

0: no programming, erase or option byte change operation being executed

1: programming, erase or option byte change operation being executed

4.9.6 FLASH clear control register (FLASH_CCR)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	CLR_CRCRDERR	CLR_CRCEND	CLR_DBECCERR	CLR_SNECCERR	CLR_RDSERR	CLR_RDPERR	CLR_OPERR	CLR_INCERR	Res.	CLR_STRBERR	CLR_PGSERR	CLR_WRPERR	CLR_EOP
			w	w	w	w	w	w	w	w		w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **CLR_CRCRDERR**: CRCRDERR flag clear bit
Setting this bit to 1 resets to 0 CRCRDERR flag in FLASH_SR register.

Bit 27 **CLR_CRCEND**: CRCEND flag clear bit
Setting this bit to 1 resets to 0 CRCEND flag in FLASH_SR register.

Bit 26 **CLR_DBECCERR**: DBECCERR flag clear bit
Setting this bit to 1 resets to 0 DBECCERR flag in FLASH_SR register. If the SNECCERR flag of FLASH_SR register is set to 0, FLASH_ECC_FAR register is reset to 0 as well.

Bit 25 **CLR_SNECCERR**: SNECCERR flag clear bit
Setting this bit to 1 resets to 0 SNECCERR flag in FLASH_SR register. If the DBECCERR flag of FLASH_SR register is set to 0, FLASH_ECC_FAR register is reset to 0 as well.

Bit 24 **CLR_RDSERR**: RDSERR flag clear bit
Setting this bit to 1 resets to 0 RDSERR flag in FLASH_SR register.

Bit 23 **CLR_RDPERR**: RDPERR flag clear bit
Setting this bit to 1 resets to 0 RDPERR flag in FLASH_SR register.

Bit 22 **CLR_OPERR**: OPERR flag clear bit
Setting this bit to 1 resets to 0 OPERR flag in FLASH_SR register.

Bit 21 **CLR_INCERR**: INCERR flag clear bit
Setting this bit to 1 resets to 0 INCERR flag in FLASH_SR register.

Bit 20 Reserved, must be kept at reset value.

Bit 19 **CLR_STRBERR**: STRBERR flag clear bit
Setting this bit to 1 resets to 0 STRBERR flag in FLASH_SR register.

Bit 18 **CLR_PGSERR**: PGSERR flag clear bit
Setting this bit to 1 resets to 0 PGSERR flag in FLASH_SR register.

Bit 17 **CLR_WRPERR**: WRPERR flag clear bit
Setting this bit to 1 resets to 0 WRPERR flag in FLASH_SR register.

Bit 16 **CLR_EOP**: EOP flag clear bit
Setting this bit to 1 resets to 0 EOP flag in FLASH_SR register.

Bits 15:0 Reserved, must be kept at reset value.

4.9.7 FLASH option control register (FLASH_OPTCR)

Address offset: 0x018

Reset value: 0xX000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	OPTCHANGEERRIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw														

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OPTSTART	OPTLOCK
														w	rs

Bit 31 Reserved, must be kept at reset value.

Bit 30 **OPTCHANGEERRIE**: Option byte change error interrupt enable bit
OPTCHANGEERRIE bit controls if an interrupt has to be generated when an error occurs during an option byte change.
0: no interrupt is generated when an error occurs during an option byte change
1: an interrupt is generated when and error occurs during an option byte change.

Bits 29:5 Reserved, must be kept at reset value.

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **OPTSTART**: Option byte start change option configuration bit

OPTSTART triggers an option byte change operation. The user can set OPTSTART only when the OPTLOCK bit is set to 0. The embedded Flash memory resets OPTSTART when the option byte change operation has been acknowledged.

The user application cannot modify any embedded Flash memory register until the option change operation has been completed.

Before setting this bit, the user has to write the required values in the FLASH_XXX_PRG registers. The FLASH_XXX_PRG registers will be locked until the option byte change operation has been executed in non-volatile memory.

It is not possible to start an option byte change operation if a CRC calculation is ongoing. Trying to set OPTSTART when CRC_BUSY of FLASH_SR register is set has not effect; the option byte change does not start and no error is generated.

Bit 0 **OPTLOCK**: FLASH_OPTCR lock option configuration bit

The OPTLOCK bit locks the FLASH_OPTCR register as well as all _PRG registers. The correct write sequence to FLASH_OPTKEYR register unlocks this bit. If a wrong sequence is executed, or the unlock sequence to FLASH_OPTKEYR is performed twice, this bit remains locked until next system reset.

It is possible to set OPTLOCK by programming it to 1. When set to 1, a new unlock sequence is mandatory to unlock it. When OPTLOCK changes from 0 to 1, the others bits of FLASH_OPTCR register do not change.

0: FLASH_OPTCR register unlocked

1: FLASH_OPTCR register locked.

4.9.8 FLASH option status register (FLASH_OPTSR_CUR)

Address offset: 0x01C

Reset value: 0xXXXX XXXX

Refer to *Table 18: Option byte organization* for details on the reset value.

This read-only register reflects the current values of corresponding option bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	OPTCHANGEERR	IO_HSLV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECURITY	ST_RAM_SIZE[1:0]		IWDG_FZ_SDBY	IWDG_FZ_STOP	Res.
	r	r								r	r	r	r	r	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDP[7:0]								NRST_STDY_D1	NRST_STOP_D1	Res.	IWDG1_SW	BOR_LEV[1:0]		Res.	OPT_BUSY
r	r	r	r	r	r	r	r	r	r		r	r	r		r

Bit 31 Reserved, must be kept at reset value.

Bit 30 **OPTCHANGEERR**: Option byte change error flag

OPTCHANGEERR flag indicates that an error occurred during an option byte change operation. When OPTCHANGEERR is set to 1, the option byte change operation did not successfully complete. An interrupt is generated when this flag is raised if the OPTCHANGEERRIE bit of FLASH_OPTCR register is set to 1.

Writing 1 to CLR_OPTCHANGEERR of register FLASH_OPTCCR clears OPTCHANGEERR.

0: no option byte change errors occurred

1: one or more errors occurred during an option byte change operation.

Bit 29 **IO_HSLV**: I/O high-speed at low-voltage status bit

This bit indicates that the product operates below 2.5 V.

0: Product working in the full voltage range, I/O speed optimization at low-voltage disabled

1: Product operating below 2.5 V, I/O speed optimization at low-voltage feature allowed

Bits 28:26 Reserved, must be kept at reset value.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **SECURITY**: Security enable option status bit

0: Security feature disabled

1: Security feature enabled.

Bits 20:19 **ST_RAM_SIZE[1:0]**: ST RAM size option status

00: 2 Kbytes reserved to ST code

01: 4 Kbytes reserved to ST code

10: 8 Kbytes reserved to ST code

11: 16 Kbytes reserved to ST code

Note: This bitfield is effective only when the security is enabled (SECURITY = 1).

The whole DTCM RAM is always available for the application whatever ST_RAM_SIZE option byte configuration.

Bit 18 **IWDG_FZ_SDBY**: IWDG Standby mode freeze option status bit

When set the independent watchdog IWDG1 is frozen in system Standby mode.

0: Independent watchdog frozen in Standby mode

1: Independent watchdog keep running in Standby mode.

Bit 17 **IWDG_FZ_STOP**: IWDG Stop mode freeze option status bit

When set the independent watchdog IWDG1 is in system Stop mode.

0: Independent watchdog frozen in system Stop mode

1: Independent watchdog keep running in system Stop mode.

Bit 16 Reserved, must be kept at reset value.

Bits 15:8 **RDP[7:0]**: Readout protection level option status byte

0xAA: global readout protection level 0

0xCC: global readout protection level 2

others values: global readout protection level 1.

Bit 7 **NRST_STDY_D1**: D1 domain DStandby entry reset option status bit

0: a reset is generated when entering DStandby mode on D1 domain

1: no reset generated when entering DStandby mode on D1 domain

Bit 6 **NRST_STOP_D1**: D1 domain DStop entry reset option status bit

0: a reset is generated when entering DStop mode on D1 domain

1: no reset generated when entering DStop mode on D1 domain.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **IWDG1_SW**: IWDG1 control mode option status bit
1: IWDG1 watchdog is controlled by software
0: IWDG1 watchdog is controller by hardware.

Bits 3:2 **BOR_LEV[1:0]**: Brownout level option status bit
These bits reflects the power level that generates a system reset.
00: Brownout reset threshold 0 (V_{BOR0})
01: Brownout reset threshold 1 (V_{BOR1})
10: Brownout reset threshold 2 (V_{BOR2})
11: Brownout reset threshold 3 (V_{BOR3})

Bit 1 Reserved, must be kept at reset value.

Bit 0 **OPT_BUSY**: Option byte change ongoing flag
OPT_BUSY indicates if an option byte change is ongoing. When this bit is set to 1, the embedded Flash memory is performing an option change and it is not possible to modify any embedded Flash memory register.
0: no option byte change ongoing
1: an option byte change ongoing and all write accesses to Flash registers are blocked until the option byte change completes.

4.9.9 FLASH option status register (FLASH_OPTSR_PRG)

Address offset: 0x020

Reset value: 0xXXXX XXXX

Refer to *Table 18: Option byte organization* for details on the reset value.

This register is used to program values in corresponding option bits. Values after reset reflects the current values of the corresponding option bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	IO_HSLV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECURITY	ST_RAM_SIZE[1:0]		IWDG_FZ_SDBY	IWDG_FZ_STOP	Res.
		rw								rw	rw	rw	rw	rw	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDP[7:0]								NRST_STDY_D1	NRST_STOP_D1	Res.	IWDG1_SW	BOR_LEV[1:0]		Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw		

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **IO_HSLV**: I/O high-speed at low-voltage configuration bit
This bit indicates that the product operates below 2.5 V.
0: Product working in the full voltage range, I/O speed optimization at low-voltage disabled
1: Product operating below 2.5 V, I/O speed optimization at low-voltage feature allowed

Bits 28:26 Reserved, must be kept at reset value.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **SECURITY**: Security enable option configuration bit
The SECURITY option bit enables the secure access mode of the device during an option byte change. The change will be taken into account at next power-on reset. Once it is enabled, the security feature can be disabled if no areas are protected by PCROP or Secure access mode. If there are secure-only or PCROP protected areas, perform a regression level (from level 1 to 0) and set all the bits to unprotect secure-only areas and PCROP areas.
0: Security feature disabled
1: Security feature enabled.

Bits 20:19 **ST_RAM_SIZE[1:0]**: ST RAM size option configuration bits
00: 2 Kbytes reserved to ST code
01: 4 Kbytes reserved to ST code
10: 8 Kbytes reserved to ST code
11: 16 Kbytes reserved to ST code
Note: This bitfield is effective only when the security is enabled (SECURITY = 1).
The whole DTCM RAM is always available for the application whatever ST_RAM_SIZE option byte configuration.

Bit 18 **IWDG_FZ_SDBY**: IWDG Standby mode freeze option configuration bit
This option bit is used to freeze or not the independent watchdog IWDG1 in system Standby mode.
0: Independent watchdog frozen in Standby mode
1: Independent watchdog keep running in Standby mode.

Bit 17 **IWDG_FZ_STOP**: IWDG Stop mode freeze option configuration bit
This option bit is used to freeze or not the independent watchdog IWDG1 in system Stop mode.
0: Independent watchdog frozen in system Stop mode
1: Independent watchdog keep running in system Stop mode.

Bit 16 Reserved, must be kept at reset value.

Bits 15:8 **RDP[7:0]**: Readout protection level option configuration bits
RDP bits are used to change the readout protection level. This change is possible only when the current protection level is different from level 2. The possible configurations are:
0xAA: global readout protection level 0
0xCC: global readout protection level 2
others values: global readout protection level 1.

Bit 7 **NRST_STDY_D1**: D1 domain DStandby entry reset option configuration bit
0: a reset is generated when entering DStandby mode on D1 domain.
1: no reset generated when entering DStandby mode on D1 domain

Bit 6 **NRST_STOP_D1**: D1 domain DStop entry reset option configuration bit
0: a reset is generated when entering DStop mode on D1 domain.
1: no reset generated when entering DStop mode on D1 domain.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **IWDG1_SW**: IWDG1 control mode option configuration bit

IWDG1_SW option bit is used to select if IWDG1 independent watchdog is controlled by hardware or by software.

1: IWDG1 watchdog is controlled by software.

0: IWDG1 watchdog is controller by hardware.

Bits 3:2 **BOR_LEV[1:0]**: Brownout level option configuration bit

These option bits are used to define the power level that generates a system reset.

00 and 11: the reset level is set to 2.1 V

01: the reset is set to 2.4 V

10: the reset is set to 2.7 V

Bits 1:0 Reserved, must be kept at reset value.

4.9.10 FLASH option clear control register (FLASH_OPTCCR)

Address offset: 0x024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	CLR_OPTCHANGEERR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	w														

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bit 31 Reserved, must be kept at reset value.

Bit 30 **CLR_OPTCHANGEERR**: OPTCHANGEERR reset bit

This bit is used to reset the OPTCHANGEERR flag in FLASH_OPTSR_CUR or FLASH_OPTSR2_CUR register. FLASH_OPTCCR is write-only.

It is reset by programming it to 1.

Bits 29:0 Reserved, must be kept at reset value.

4.9.11 FLASH protection address (FLASH_PRAR_CUR)

Address offset: 0x028

Reset value: 0xXXXX 0XXX

Refer to *Table 18: Option byte organization* for details on the reset value.

This read-only register reflects the current values of corresponding option bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMEP	Res.	Res.	Res.	PROT_AREA_END[11:0]											
r				r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	PROT_AREA_START[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 **DMEP**: PCROP protected erase enable option status bit
If DMEP is set to 1, the PCROP protected area is erased when a protection level regression (change from level 1 to 0) or a bank erase with protection removal occurs.

Bits 30:28 Reserved, must be kept at reset value.

Bits 27:16 **PROT_AREA_END[11:0]**: PCROP area end status bits
These bits contain the last 256-byte block of the PCROP area.
If this address is equal to PROT_AREA_START, the whole bank is PCROP protected.
If this address is lower than PROT_AREA_START, no protection is set.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **PROT_AREA_START[11:0]**: PCROP area start status bits
These bits contain the first 256-byte block of the PCROP area.
If this address is equal to PROT_AREA_END, the whole bank is PCROP protected.
If this address is higher than PROT_AREA_END, no protection is set.

4.9.12 FLASH protection address (FLASH_PRAR_PRG)

Address offset: 0x02C

Reset value: 0xXXXX 0XXX

Refer to *Table 18: Option byte organization* for details on the reset value.

This register is used to program values in corresponding option bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMEP	Res.	Res.	Res.	PROT_AREA_END[11:0]											
rw				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	PROT_AREA_START[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **DMEP**: PCROP protected erase enable option configuration bit
If DMEP is set to 1, the PCROP protected area is erased when a protection level regression (change from level 1 to 0) or a bank erase with protection removal occurs.

Bits 30:28 Reserved, must be kept at reset value.

Bits 27:16 **PROT_AREA_END[11:0]**: PCROP area end configuration bits
These bits contain the last 256-byte block of the PCROP area.
If this address is equal to PROT_AREA_START, the whole bank is PCROP protected.
If this address is lower than PROT_AREA_START, no protection is set.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **PROT_AREA_START[11:0]**: PCROP area start configuration bits
These bits contain the first 256-byte block of the PCROP area.
If this address is equal to PROT_AREA_END, the whole bank is PCROP protected.
If this address is higher than PROT_AREA_END, no protection is set.

4.9.13 FLASH secure address (FLASH_SCAR_CUR)

Address offset: 0x030

Reset value: 0xXXXX 0XXX

Refer to *Table 18: Option byte organization* for details on the reset value.

This read-only register reflects the current values of corresponding option bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMES	Res.	Res.	Res.	SEC_AREA_END[11:0]											
r				r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	SEC_AREA_START[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 **DMES**: secure access protected erase enable option status bit
If DMES is set to 1, the secure access only area is erased when a protection level regression (change from level 1 to 0) or a bank erase with protection removal occurs.

Bits 30:28 Reserved, must be kept at reset value.

Bits 27:16 **SEC_AREA_END[11:0]**: secure-only area end status bits
These bits contain the last 256-byte block of the secure-only area.
If this address is equal to SEC_AREA_START, the whole bank is secure access only.
If this address is lower than SEC_AREA_START, no protection is set.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **SEC_AREA_START[11:0]**: secure-only area start status bits
These bits contain the first 256 bytes of block of the secure-only area.
If this address is equal to SEC_AREA_END, the whole bank is secure access only.
If this address is higher than SEC_AREA_END, no protection is set.

4.9.14 FLASH secure address (FLASH_SCAR_PRG)

Address offset: 0x034

Reset value: 0xXXXX 0XXX

Refer to *Table 18: Option byte organization* for details on the reset value.

This register is used to program values in corresponding option bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMES	Res.	Res.	Res.	SEC_AREA_END[11:0]											
rw				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	SEC_AREA_START[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **DMES**: Secure access protected erase enable option configuration bit
If DMES is set to 1, the secure access only area is erased when a protection level regression (change from level 1 to 0) or a bank erase with protection removal occurs.

Bits 30:28 Reserved, must be kept at reset value.

Bits 27:16 **SEC_AREA_END[11:0]**: Secure-only area end configuration bits
These bits contain the last block of 256 bytes of the secure-only area.
If this address is equal to SEC_AREA_START, the whole bank is secure access only.
If this address is lower than SEC_AREA_START, no protection is set.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **SEC_AREA_START[11:0]**: Secure-only area start configuration bits
These bits contain the first block of 256 bytes of the secure-only area.
If this address is equal to SEC_AREA_END, the whole bank is secure access only.
If this address is higher than SEC_AREA_END, no protection is set.

4.9.15 FLASH write sector protection (FLASH_WPSN_CUR)

Address offset: 0x038

Reset value: 0x0000 00XX

This read-only register reflects the current values of corresponding option bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRPS7	WRPS6	WRPS5	WRPS4	WRPS3	WRPS2	WRPS1	WRPS0
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **WRPSn**: Sector n write protection option status bit (n = 7 to 0)
Each FLASH_WPSN_CUR bit reflects the write protection status of the corresponding sector (0: sector is write protected; 1: sector is not write protected)

4.9.16 FLASH write sector protection (FLASH_WPSN_PRG)

Address offset: 0x03C

Reset value: 0x0000 00XX

This register is used to program values in corresponding option bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRPS7	WRPS6	WRPS5	WRPS4	WRPS3	WRPS2	WRPS1	WRPS0
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **WRPSn**: Sector n write protection option status bit (n = 7 to 0)
Setting WRPSn bit to 0 write protects the corresponding sector (0: sector is write protected; 1: sector is not write protected).

4.9.17 FLASH register boot address for Arm® Cortex®-M7 core (FLASH_BOOT_CUR)

Address offset: 0x040

Reset value: 0xXXXX XXXX

Refer to *Table 18: Option byte organization* for details on the reset value.

This register reflects the current values of corresponding option bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BOOT_CM_ADD1[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BOOT_CM_ADD0[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **BOOT_CM_ADD1[15:0]**: Arm® Cortex®-M7 boot address 1
These bits reflect the MSB of the Arm® Cortex®-M7 boot address when the BOOT pin is high.

Bits 15:0 **BOOT_CM_ADD0[15:0]**: Arm® Cortex®-M7 boot address 0
These bits reflect the MSB of the Arm® Cortex®-M7 boot address when the BOOT pin is low.

4.9.18 FLASH register boot address for Arm® Cortex®-M7 core (FLASH_BOOT_PRG)

Address offset: 0x044

Reset value: 0xXXXX XXXX

Refer to *Table 18: Option byte organization* for details on the reset value.

This register is used to program values in corresponding option bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BOOT_CM_ADD1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BOOT_CM_ADD0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **BOOT_CM_ADD1[15:0]**: Arm® Cortex®-M7 boot address 1 configuration
These bits allow configuring the MSB of the Arm® Cortex®-M7 boot address when the BOOT pin is high.

Bits 15:0 **BOOT_CM_ADD0[15:0]**: Arm® Cortex®-M7 boot address 0 configuration
These bits allow configuring the MSB of the Arm® Cortex®-M7 boot address when the BOOT pin is low.

4.9.19 FLASH CRC control register (FLASH_CRCCR)

Address offset: 0x050

Reset value: 0x001C 0000

This register can be modified only if CRC_EN bit is set to 1 in FLASH_CR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALL_BANK	CRC_BURST[1:0]		Res.	Res.	CLEAN_CRC	START_CRC
									w	rw	rw			rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	CLEAN_SECT	ADD_SECT	CRC_BY_SECT	Res.	Res.	Res.	Res.	Res.	CRC_SECT[2:0]		
					w	w	rw						rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **ALL_BANK**: CRC select bit

When ALL_BANK is set to 1, all bank user sectors are added to list of sectors on which the CRC is calculated.

Bits 21:20 **CRC_BURST[1:0]**: CRC burst size

CRC_BURST bits set the size of the bursts that are generated by the CRC calculation unit.
00: every burst has a size of 4 Flash words (256-bit)
01: every burst has a size of 16 Flash words (256-bit)
10: every burst has a size of 64 Flash words (256-bit)
11: every burst has a size of 256 Flash words (256-bit)

Bits 19:18 Reserved, must be kept at reset value.

Bit 17 **CLEAN_CRC**: CRC clear bit

Setting CLEAN_CRC to 1 clears the current CRC result stored in the FLASH_CRCDATAR register.

Bit 16 **START_CRC**: CRC start bit

START_CRC bit triggers a CRC calculation using the current configuration. No CRC calculation can launched when an option byte change operation is ongoing because all write accesses to embedded Flash memory registers are put on hold until the option byte change operation has completed.

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **CLEAN_SECT**: CRC sector list clear bit

Setting CLEAN_SECT to 1 clears the list of sectors on which the CRC is calculated.

Bit 9 **ADD_SECT**: CRC sector select bit

Setting ADD_SECT to 1 adds the sector whose number is CRC_SECT to the list of sectors on which the CRC is calculated.

Bit 8 **CRC_BY_SECT**: CRC sector mode select bit

When CRC_BY_SECT is set to 1, the CRC calculation is performed at sector level, on the sectors present in the list of sectors. To add a sector to this list, use ADD_SECT and CRC_SECT bits. To clean the list, use CLEAN_SECT bit.
When CRC_BY_SECT is reset to 0, the CRC calculation is performed on all addresses between CRC_START_ADDR and CRC_END_ADDR.

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **CRC_SECT**[2:0]: CRC sector number

CRC_SECT is used to select one or more user Flash sectors to be added to the list of sectors on which the CRC is calculated. The CRC can be computed either between two addresses (using registers FLASH_CRCSADDR and FLASH_CRCEADDR) or on a list of sectors. If this latter option is selected, it is possible to add a sector to the list of sectors by programming the sector number in CRC_SECT and then setting ADD_SECT to 1.
The list of sectors can be erased either by setting CLEAN_SECT bit or by disabling the CRC computation. CRC_SECT can be set only when CRC_EN of FLASH_CR register is set to 1.
000: sector 0
001: sector 1
...
111: sector 7

4.9.20 FLASH CRC start address register (FLASH_CRCSADDR)

Address offset: 0x054

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CRC_START_ADDR[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CRC_START_ADDR[15:2]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:2 **CRC_START_ADDR[19:2]**: CRC start address
CRC_START_ADDR is used when CRC_BY_SECT is set to 0. It must be programmed to the start address of the bank memory area on which the CRC calculation is performed.

Bits 1:0 Reserved, must be kept at reset value.

4.9.21 FLASH CRC end address register (FLASH_CRCEADDR)

Address offset: 0x058

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CRC_END_ADDR[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CRC_END_ADDR[15:2]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:2 **CRC_END_ADDR[19:2]**: CRC end address
CRC_END_ADDR is used when CRC_BY_SECT is set to 0. It must be programmed to the end address of the bank memory area on which the CRC calculation is performed

Bits 1:0 Reserved, must be kept at reset value.

4.9.22 FLASH CRC data register (FLASH_CRCDATAR)

Address offset: 0x05C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CRC_DATA[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CRC_DATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **CRC_DATA[31:0]**: CRC result

CRC_DATA bits contain the result of the last CRC calculation.

4.9.23 FLASH ECC fail address (FLASH_ECC_FAR)

Address offset: 0x060

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	FAIL_ECC_ADDR[14:0]														
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:15 Reserved, must be kept at reset value.

Bits 14:0 **FAIL_ECC_ADDR[14:0]**: ECC error address

When an ECC error occurs (both for single correction or double detection) during a read operation, the FAIL_ECC_ADDR bitfield contains the address that generated the error.

FAIL_ECC_ADDR is reset when the flag error in the FLASH_SR register (CLR_SNECCERR or CLR_DBECCERR) is reset.

The embedded Flash memory programs the address in this register only when no ECC error flags are set. This means that only the first address that generated an ECC error is saved.

The address in FAIL_ECC_ADDR is relative to the Flash area where the error occurred (user Flash, system Flash).

Fail address = FAIL_ECC_ADDR[14:0] * 32 + Flash bank offset

4.9.24 FLASH option status register 2 (FLASH_OPTSR2_CUR)

Address offset: 0x070

Reset value: 0x0000 000X

Refer to *Table 18: Option byte organization* for details on the reset value.

This read-only register reflects the current values of corresponding option bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CPUFREQ_BOOST	TCM_AXI_SHARED[1:0]	
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **CPUFREQ_BOOST:** CPU frequency boost status bit
This bit indicates whether the CPU frequency can be boosted or not. When it is set, the ECC on ITCM and DTCM are no more used.

Bits 1:0 **TCM_AXI_SHARED[1:0]:** TCM RAM sharing status bit
This bitfield contains the ITCM memory size and the AXI system RAM.
00: 64-Kbyte ITCM / 320 Kbyte system AXI
01: 128-Kbyte ITCM / 256-Kbyte system AXI
10: 192-Kbyte ITCM / 192-Kbyte system AXI
11: 256-Kbyte ITCM / 128-Kbyte system AXI

4.9.25 FLASH option status register 2 (FLASH_OPTSR2_PRG)

Address offset: 0x074

Reset value: 0x0000 000X

Refer to *Table 18: Option byte organization* for details on the reset value.

This register is used to program values in corresponding option bits. Values after reset reflects the current values of the corresponding option bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CPUFREQ_BOOST	TCM_AXI_SHARED[1:0]	
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **CPUFREQ_BOOST:** CPU frequency boost status bit

This bit configures whether the CPU frequency can be boosted or not. When it is set, the ECC on ITCM and DTCM are no more used.

Bits 1:0 **TCM_AXI_SHARED[1:0]:** TCM RAM sharing status bit

This bitfield configures the ITCM memory size and the AXI system RAM.

00: 64-Kbyte ITCM / 320 Kbyte system AXI

01: 128-Kbyte ITCM / 256-Kbyte system AXI

10: 192-Kbyte ITCM / 192-Kbyte system AXI

11: 256-Kbyte ITCM / 128-Kbyte system AXI

4.10 FLASH register map and reset values

Table 25. Register map and reset value table

Offset	Register name reset	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	FLASH_ACR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRHIGHFREQ		LATENCY			
	0x00000037																											1	1	0	1	1	1
0x004	FLASH_KEYR	KEYKEYRR																															
	0x00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x008	FLASH_ OPTKEYR	OPTKEYR																															
	0x00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00C	FLASH_CR	Res.	Res.	Res.	CRCRDERRIE	CRCENDIE	DBECCERRIE	SNECCERRIE	RDSERRIE	RDPERRIE	OPERRIE	INCERRIE	Res.	STRBERRIE	PGSERRIE	WRPERRIE	EOPIE	CRC_EN	Res.	Res.	Res.	Res.	SNB			START	FW	PSIZE		BER	SER	PG	LOCK
	0x00000031				0	0	0	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0	1	1	0	0	0	1
0x010	FLASH_SR	Res.	Res.	Res.	CRCRDERR	CRCEND	DBECCERR	SNECCERR	RDSERR	RDPERR	OPERRIE	INCERR	Res.	STRBERR	PGSERR	WRPERR	EOP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CRC_BUSY	QW	WBNE	BSY
	0x00000000				0	0	0	0	0	0	0	0		0	0	0	0													0	0	0	0
0x014	FLASH_CCR	Res.	Res.	Res.	CLR_CRCRDERR	CLR_CRCEND	CLR_DBECCERR	CLR_SNECCERR	CLR_RDSERR	CLR_RDPERR	CLR_OPERRIE	CLR_INCERR	Res.	CLR_STRBERR	CLR_PGSERR	CLR_WRPERR	CLR_EOP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	0x00000000					0	0	0	0	0	0	0		0	0	0	0																
0x018	FLASH_OPTCR	Res.	OPTCHANGEERRIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OPTSTART	OPTLOCK
	0x00000001		0																												0	1
0x01C	FLASH_OPTSR_ CUR	Res.	OPTCHANGEERR	IO_HSLV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECURITY	ST_RAM_SIZE		IWDG_FZ_SDBY	IWDG_FZ_STOP	Res.	RDP[7:0]								NRST_STBY_D1	NRST_STOP_D1	Res.	IWDG1_SW	BOR_LEV		Res.	OPT_BUSY
	0xXXXX XXXX		X	X								X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X		X

Table 25. Register map and reset value table (continued)

Offset	Register name reset	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x020	FLASH_OPTSR_PRG	Res.	Res.	IO_HSLV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECURITY	ST_RAM_SIZE		IWDG_FZ_SDBY	IWDG_FZ_STOP	Res.	RDP[7:0]								NRST_STBY_D1	NRST_STOP_D1	Res.	IWDG1_SW	BOR_LEV		Res.	Res.
	0xXXXX XXXX			X								X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X		
0x024	FLASH_OPTCCR	Res.	CLR_OPTCHANGEERR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	0x00000000		0																														
0x028	FLASH_PRAR_CUR	DMEP	Res.	Res.	Res.	PROT_AREA_END[11:0]												Res.	Res.	Res.	Res.	PROT_AREA_START[11:0]												
	0xXXXX 0XXX	X				X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X
0x02C	FLASH_PRAR_PRG	DMEP	Res.	Res.	Res.	PROT_AREA_END[11:0]												Res.	Res.	Res.	Res.	PROT_AREA_START[11:0]												
	0xXXXX 0XXX	X				X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X
0x030	FLASH_SCAR_CUR	DMES	Res.	Res.	Res.	SEC_AREA_END[11:0]												Res.	Res.	Res.	Res.	SEC_AREA_START[11:0]												
	0xXXXX 0XXX	X				X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X

Table 25. Register map and reset value table (continued)

Offset	Register name reset	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x034	FLASH_SCAR_PRG	DMES	Res.	Res.	Res.	SEC_AREA_END[11:0]												Res.	Res.	Res.	Res.	SEC_AREA_START[11:0]												
	0xXXXX 0XXX	X				X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X
0x038	FLASH_WPSN_CUR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRPSn							
	0x0000 00XX	0																								X	X	X	X	X	X	X	X
0x03C	FLASH_WPSN_PRG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRPSn							
	0x0000 00XX																									X	X	X	X	X	X	X	X
0x040	FLASH_BOOT_CUR	BOOT_CM_ADD1[15:0]																BOOT_CM_ADD0[15:0]															
	0xXXXX XXXX	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x044	FLASH_BOOT_PRG	BOOT_CM_ADD1[15:0]																BOOT_CM_ADD0[15:0]															
	0xXXXX XXXX	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x050	FLASH_CRCCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALL_BANK	CRC_BURST		Res.	Res.	CLEAN_CRC	START_CRC	Res.	Res.	Res.	Res.	Res.	CLEAN_SECT	ADD_SECT	CRC_BY_SECT	Res.	Res.	Res.	Res.	Res.	CRC_SECT		
	0x001C0000										0	0	1			0	0						0	0	0						0	0	0
0x054	FLASH_CRCSADDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CRC_START_ADDR[31:0]																		Res.	Res.
	0x00000000													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
0x058	FLASH_CRCEADDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CRC_END_ADDR[31:0]																		Res.	Res.
	0x00000000													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
0x05C	FLASH_CRCDATAR	CRC_DATA[31:0]																															
	0x00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x060	FLASH_ECC_FAR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FAIL_ECC_ADDR[14:0]														
	0x00000000																		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x070	FLASH_OPTSR2_CUR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CPUFREQ_BOOST	TCM_AXI_SHARED[1:0]	
	0xXXXX 0XXX																																

Table 25. Register map and reset value table (continued)

Offset	Register name reset	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x074	FLASH_OPTSR2_PRG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CPUFREQ_BOOST	TCM_AXI_SHARED[1:0]	
	0xXXXX 0XXX																																

Refer to *Section 2.3 on page 131* for the register boundary addresses.

5 Secure memory management (SMM)

5.1 Introduction

STM32H73x microcontrollers offer a first set of protection mechanisms, which are similar to other STM32 Series:

- Global readout device protection (RDP)
- Write protection (WRP)
- Proprietary code readout protection (PCROP)

A detailed description of these protection mechanisms is given in *Section 4: Embedded Flash memory (FLASH)*.

STM32H73x also offer an additional enhanced protection mode, the Secure access mode, that makes possible the development of user-defined secure services (e.g. secure firmware update or secure boot) and guarantees of a safe execution and protection of both code and data. This mechanism is described in details in *Section 5.3: Secure access mode*, *Section 5.4: Root secure services (RSS)* and *Section 5.5: Secure user software*.

The secure memory management unit is contained inside the D1 domain.

5.2 Glossary

The following terms will be used in herein:

Table 26. List of preferred terms

Term	Description
Device Security Level	
Standard mode	Device state which allows the access to the user Flash memory, the option bytes and the bootloader area.
Secure access mode	Device state which allows the access to all the memory areas of the device.
Memory areas	
System memory	ST reserved memory area used to store ST ROM code.
User Flash memory	Flash memory area used to store user code and data.
Secure user memory/area(1)	This area can be configured to be accessed once after reset and be hidden for the firmware stored in the user Flash memory after the code stored in this area is executed.
Software services	
Bootloader	STMicroelectronics software executed at reset which allows the download of firmware from regular communication ports.
Root secure services (RSS)	STMicroelectronics software which allows the access to secure services.
Secure user software	User software executed once after reset, which can be used to implement secure boot and secure firmware update (SFU). Secure user software is located in secure user memory.

1. Secure user memory/areas are also named secure-hide protected (HDP) memory/areas.

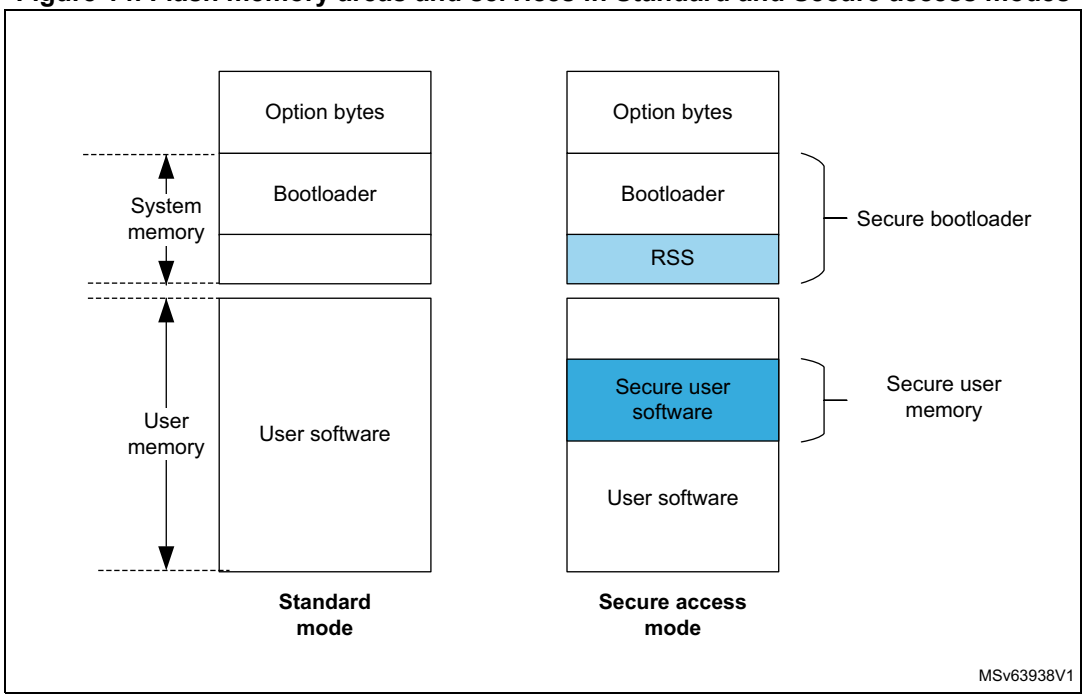
5.3 Secure access mode

Some sensitive functions require safe execution from potential malicious software attacks. Secure firmware update (SFU) software is a good example of code that requires a high level of protection since it handles secret data (such as cryptographic keys) that shall not be retrieved by other processes.

STM32H73x microcontrollers feature secure memory areas with restricted access. They allow building secure services that will be executed prior to any user application. These secure areas, together with the software they contain, are only accessible when configuring the device in Secure access mode.

Figure 14 gives an overview of Flash memory areas and services in Standard and Secure access modes.

Figure 14. Flash memory areas and services in Standard and Secure access modes



1. The protected areas that can only be accessed in Secure access mode are shown in blue.

5.3.1 Associated features

The Secure access mode can be configured through option bytes. When it is set, it enables access to:

- STMicroelectronics root secure services to set secure user areas (see *Section 5.4: Root secure services (RSS)*)
- Secure user memory which embeds secure user code and data.

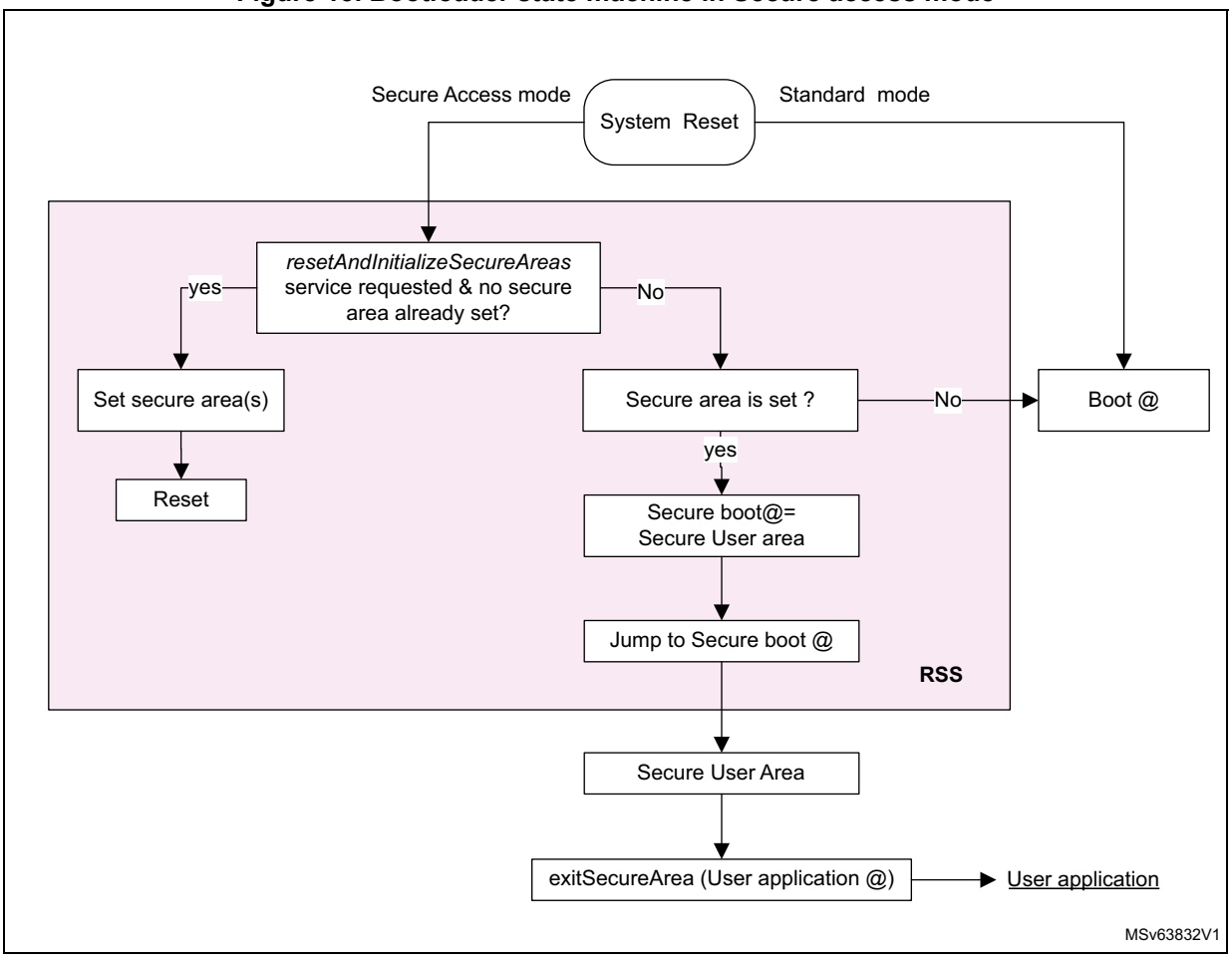
For a summary of access rights for each core, refer to *Section 5.6: Summary of Flash protection mechanisms*.

5.3.2 Boot state machine

In Secure access mode, booting is forced in the RSS whatever the boot configuration (boot pins and boot addresses). The RSS can either set a secure user memory area if one has been requested (see *Section 5.5.2: Setting secure user memory area*) or jump directly to the existing secure user memory. The code located in secure user memory is executed before the main user application and the bootloader. If no service is required and no secure area is defined, the RSS jumps to the boot address selected by BOOT0 pin value.

Figure 15 shows the boot state machine.

Figure 15. Bootloader state machine in Secure access mode



5.3.3 Secure access mode configuration

Enabling Secure access mode

There is no restriction on how to activate Secure access mode on the device. It is configured through the SECURITY option bit in FLASH_OPTSR_CUR register (see *Section 4.9.8: FLASH option status register (FLASH_OPTSR_CUR)*).

The Secure access mode becomes active after a system reset.

Disabling Secure access mode

Disabling Secure access mode is a more sensitive task as it can only be done if no more protected code exists on the device. As a result, to come back to Standard mode, secure user memories and PCROP/execute-only areas shall be removed before clearing the SECURITY option bit in the FLASH_OPTSR_CUR register.

Protected areas can be removed by performing a Flash mass erase (refer to *Section 4.3.10: FLASH erase operations* for more details on mass erase sequence).

5.4 Root secure services (RSS)

5.4.1 Secure area setting service

STMicroelectronics provides a service to perform the initialization of secure areas. This service can be called only once. It is executed after a system reset in Secure access mode prior to any other software stored in the device.

Caution: RSS software cannot be accessed (read, write, execute and debug) when the STM32H73x operate in Standard mode. The service can be automatically accessed with ST programming tool, STM32CubeProgrammer, or called through a direct call to the *resetAndInitializeSecureAreas* function defined below.

resetAndInitializeSecureAreas

Prototype	void *resetAndInitializeSecureAreas*(RSS_SecureArea_t area)
Arguments	Secure user area start and end addresses.
Description	This service sets secure user area boundaries, following the values stored in the option byte registers: – SEC_AREA_START and SEC_AREA_END This service can be used only when a secure area is set for the first time. A system reset is triggered after service completion.

5.4.2 Secure area exiting service

The RSS also provides the *exitSecureArea* service. This service must be called to jump to user application. It allows closing safely the secure user area to guarantee that its content can no more be accessed.

Contrary to the *resetAndInitializeSecureAreas* service, it does not trigger any system reset.

exitSecureArea function is defined below:

exitSecureArea

Prototype	void *exitSecureArea*(unsigned int vectors, unsigned int jtagState)
Arguments	Address of application vectors where to jump after exit and state of JTAG after exit: RSS_ENABLE_JTAG_AT_EXIT: JTAG enabled after exiting the secure area RSS_KEEP_JTAG_DISABLED_AT_EXIT: JTAG disabled after exiting the secure area
Description	This service is used to exit from secure user software and jump to user main application. There is no system reset triggered by this service

5.4.3 OTFDEC encryption service

The RSS includes the *RSS_OTFD_resetAndEncrypt* service to perform in-place encryption of the provided payload in RAM. Refer to AN5281 *"How to use OTFDEC for encryption/decryption in trusted environment on STM32 MCUs* " for more details.

5.5 Secure user software

A secure user software is a trusted piece of code that is executed after device power-on or after a system reset. It allows building secure applications such as:

- code signature or integrity checking (user secure boot).
- software license checking
- secure firmware update
- secure initialization

5.5.1 Access rules

Only accessible in Secure access mode, the secure user software is stored in the secure memory areas.

After secure user software execution, the code shall jump to the main user application and prevent access to the secure user area. This is done by calling *exitSecureArea*s secure service with the application code address given as parameter.

Once in the application code, any access to the secure user area triggers a Flash error.

5.5.2 Setting secure user memory area

The secure area size is configurable from 512 bytes to the full memory size with a granularity of 256 bytes.

The secure area boundaries are configured through SEC_AREA_START and SEC_AREA_END option bits in FLASH_SCAR_CUR (see *Section 4.9.13: FLASH secure address (FLASH_SCAR_CUR)*).

Note: If the secure area start address is equal to the secure area end address, the whole Flash memory is considered as secure protected.

The above option bits can only be initialized through *exitandinitializeSecureAreas* service.

If a secure area already exists, the secure user area code can update its own secure user area size.

5.6 Summary of Flash protection mechanisms

Figure 16 and *Table 27* summarize the access rights of the different Flash memory areas, both in Secure access and Standard modes.

Figure 16. Core access to Flash memory areas

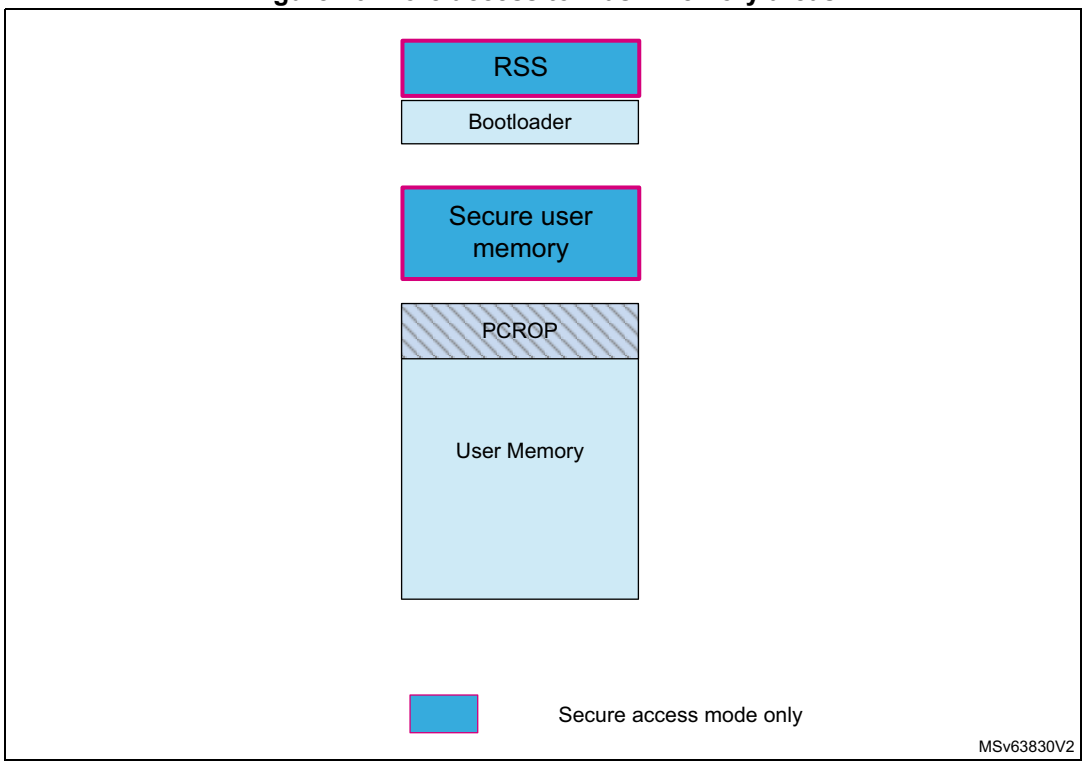


Table 27. Summary of Flash protected areas access rights

Access type	Software area	Security mode	Access
Execution	PCROP	Any	✓
	Secure user software	Secure access	✓ (1)
	Root secure services	Secure access	✓ (1)
Read access	PCROP	Any	No
	Secure user software	Secure access	✓(1)
	Root secure services	Secure access	✓ (1)
Debug access	PCROP	Any	No
	Secure user software	Secure access	No
	Root secure services	Secure access	No

1. Access rights granted after reset until code completion only.

6 Power control (PWR)

6.1 Introduction

The Power control section (PWR) provides an overview of the supply architecture for the different power domains and of the supply configuration controller.

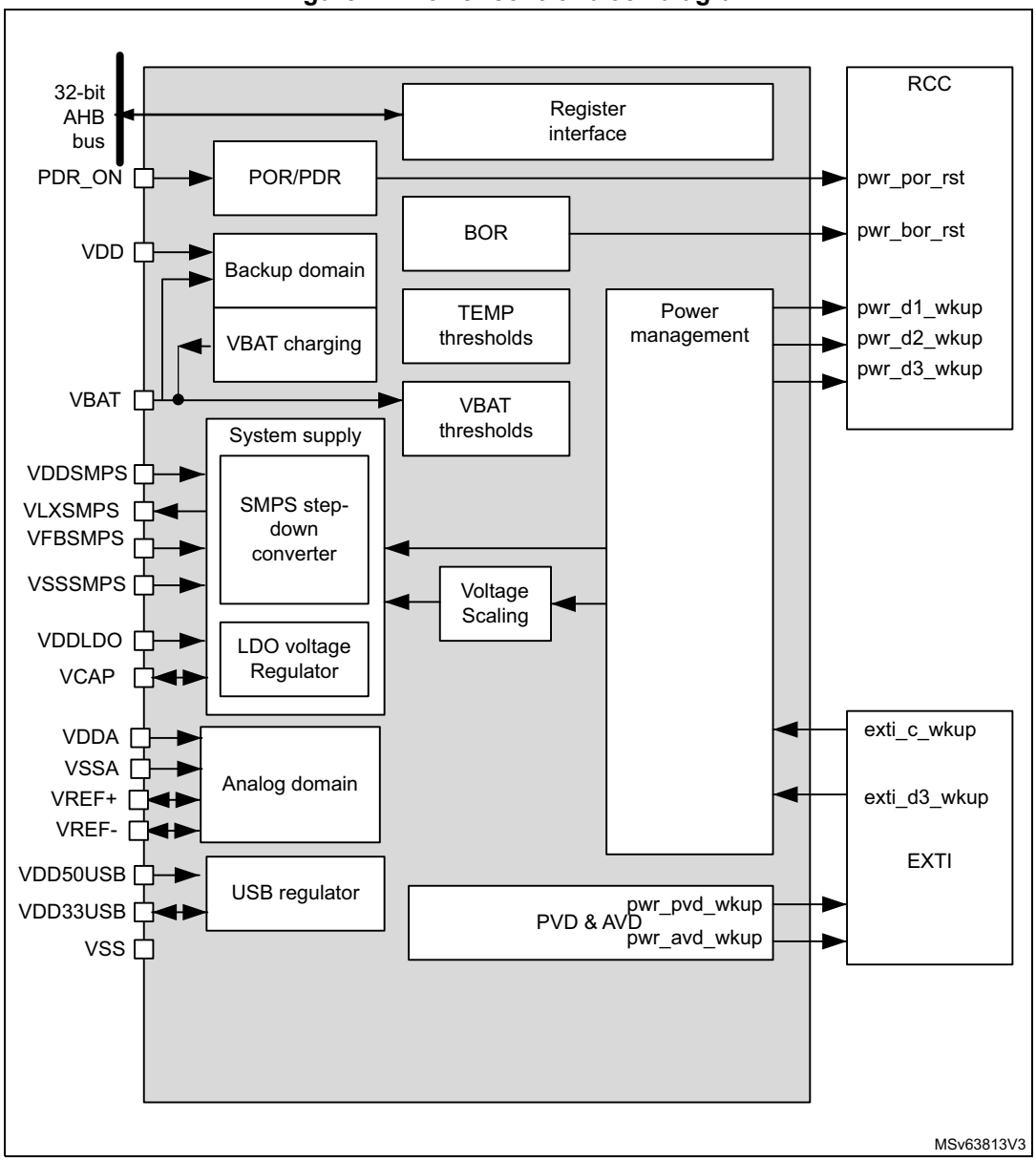
It also describes the features of the power supply supervisors and explains how the V_{CORE} supply domain is configured depending on the operating modes, the selected performance (clock frequency) and the voltage scaling.

6.2 PWR main features

- Power supplies and supply domains
  - Core domains (V_{CORE} = V_{CAP})
  - V_{DD} domain
  - Backup domain (V_{SW}, V_{BKP})
  - Analog domain (V_{DDA})
- System supply voltage regulation
  - Switched-mode power supply power-efficient voltage down-converter (SMPS step-down converter)
  - Voltage regulator (LDO)
- Peripheral supply regulation
  - USB regulator
- Power supply supervision
  - POR/PDR monitor
  - BOR monitor
  - PVD monitor
  - AVD monitor
  - V_{BAT} thresholds
  - Temperature thresholds
- Power management
  - V_{BAT} battery charging
  - Operating modes
  - Voltage scaling control
  - Low-power modes

6.3 PWR block diagram

Figure 17. Power control block diagram



6.3.1 PWR pins and internal signals

Table 28 lists the PWR inputs and output signals connected to package pins or balls, while *Table 29* shows the internal PWR signals.

Table 28. PWR input/output signals connected to package pins or balls

Pin name	Signal type	Description
VDD	Supply input	Main I/O and V_{DD} domain supply input
VDDA	Supply input	External analog power supply for analog peripherals
VREF+,VREF-	Supply input/ output	External reference voltage for ADCs and DAC
VBAT	Supply input/output	Backup battery supply input
VDDSMPS	Supply input	Step-down converter supply input
VLXSMPS	Supply output	Step-down converter supply output
VFBSMPS	Supply input	Step-down converter feedback voltage sense
VSSSMPS	Supply input	Step-down converter ground
VDDLDO(1)	Supply input	Voltage regulator supply input
VCAP	Supply Input/ Outputs	Digital core domain supply
VDD50USB	Supply input	USB regulator supply input
VDD33USB	Supply Input/ Outputs	USB regulator supply output or external USB supply input
VSS	Supply input	Main ground
AHB	Input/output	AHB register interface
PDR_ON	Input	Power Down Reset enable

1. When LDO is available but VDDLDO pin is not present on the package, VDDLDO is internally connected to VDD.

Table 29. PWR internal input/output signals

Signal name	Signal type	Description
AHB	Input/output	AHB register interface
pwr_pvd_wkup	Output	Programmable voltage detector output
pwr_avd_wkup	Output	Analog voltage detector output
pwr_por_rst	Output	Power-on reset
pwr_bor_rst	Output	Brownout reset
exti_c_wkup	Input	CPU wakeup request
exti_d3_wkup	Input	D3 domain wakeup request
pwr_d1_wkup	Output	D1 domain bus matrix clock wakeup request

Table 29. PWR internal input/output signals (continued)

Signal name	Signal type	Description
pwr_d2_wkup	Output	D2 domain bus matrix clock wakeup request
pwr_d3_wkup	Output	D3 domain bus matrix clock wakeup request

6.4 Power supplies

The device requires V_{DD} and V_{DDSMPS} power supplies as well as independent supplies for V_{DDLDO}, V_{DDA}, V_{DDUSB}, and V_{CAP}. It also provides regulated supplies for specific functions (step-down converter, voltage regulator, USB regulator).

- V_{DD}: external power supply for I/Os and system analog blocks such as reset, power management and oscillators
- V_{BAT}: optional external power supply for backup domain when V_{DD} is not present (V_{BAT} mode)

  This power supply must be connected to VDD when no battery is used.
- V_{DDSMPS}: external power supply for the SMPS step-down converter

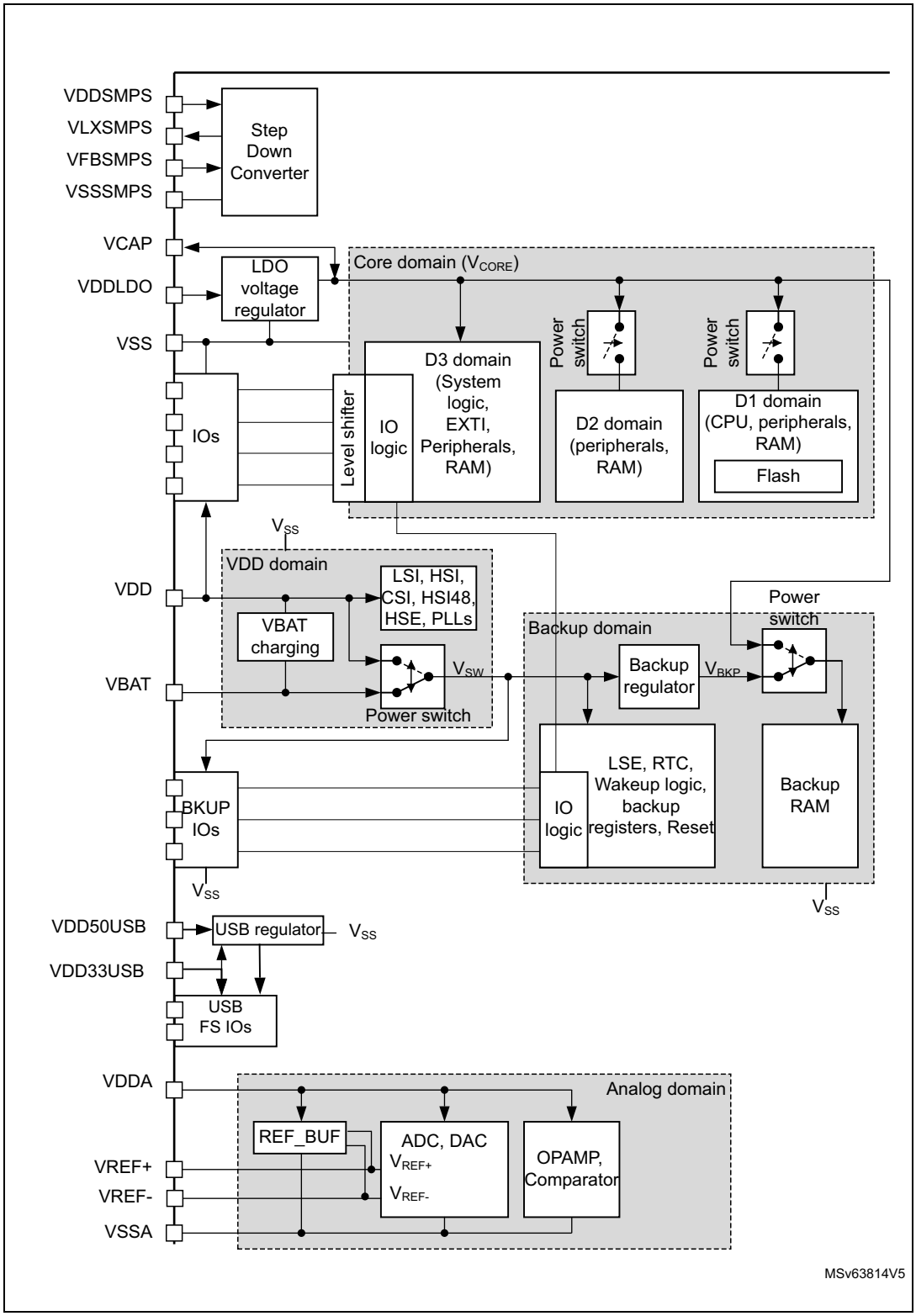
  VDDSMPS must be connected to VDD or tied to VSS when the SMPS is not used.
- V_{LXSMPS}: step-down converter supply output
- V_{FBSMPS}: step-down converter sense feedback
- V_{SSSMPS}: separate step-down converter ground
- V_{DDLDO}: external power supply for voltage regulator
- V_{CAP}: digital core domain supply

  This power supply is independent from all the other power supplies:
  - When the voltage regulator is enabled, V_{CORE} is delivered by the internal voltage regulator.
  - When the voltage regulator is disabled, V_{CORE} is delivered by an external power supply through VCAP pin, or by the SMPS step-down converter.
- V_{DDA}: external analog power supply for ADCs, DACs, OPAMPs, comparators and voltage reference buffers

  This power supply is independent from all the other power supplies.
- V_{REF+}: external reference voltage for ADC and DAC.
  - When the voltage reference buffer is enabled, V_{REF+} and V_{REF-} are delivered by the internal voltage reference buffer.
  - When the voltage reference buffer is disabled, V_{REF+} is delivered by an independent external reference supply.
- V_{SSA}: separate analog and reference voltage ground.
- $V_{DD50USB}$: external power supply for USB regulator.
- $V_{DD33USB}$: USB regulator supply output for USB interface.
  - When the USB regulator is enabled, $V_{DD33USB}$ is delivered by the internal USB regulator.
  - When he USB regulator is disabled, $V_{DD33USB}$ is delivered by an independent external supply input.
- V_{SS}: common ground for all supplies except for step-down converter and analog peripherals.

Note: Depending on the operating power supply range, some peripherals might be used with limited features and performance. For more details, refer to section “General operating conditions” of the device datasheets.

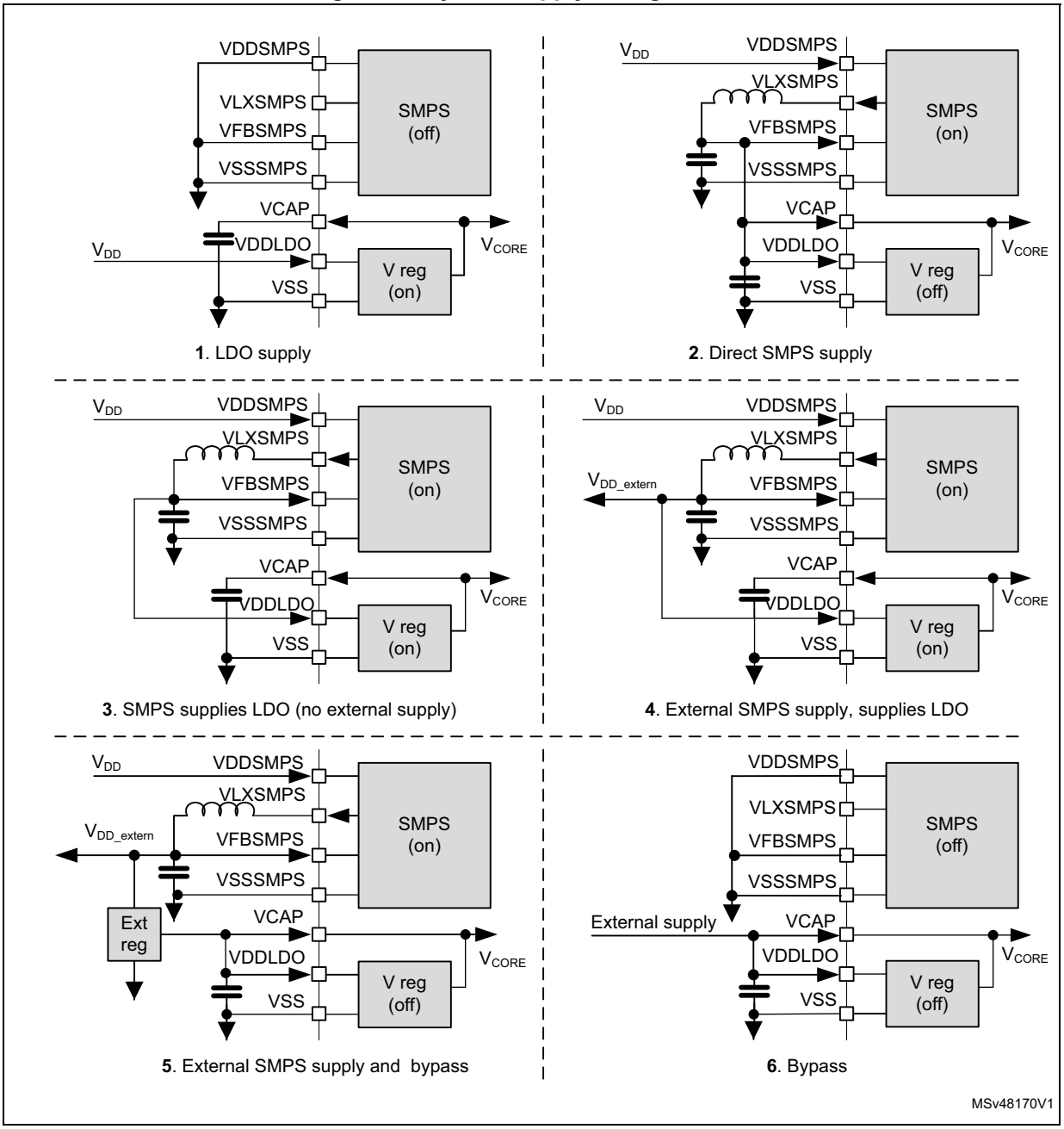
Figure 18. Power supply overview



By configuring the SMPS step-down converter and LDO voltage regulator, the supply configurations shown in *Figure 19* are supported for the V_{CORE} core domain and an external supply.

Note: The SMPS step-down converter is not available on all packages, and the Bypass mode is available only when the SMPS is available.

Figure 19. System supply configurations



The different supply configurations are controlled through the LDOEN, SDEN, SDEXTHP, SDLEVEL and BYPASS bits in *PWR control register 3 (PWR_CR3)* register according to *Table 30*.

Table 30. Supply configuration control

ID	Supply configuration	SDLEVEL	SDEXTHP	SDEN	LDOEN	BYPASS	Description
0	Default configuration	00	0	1	1	0	– V_{CORE} power domains are supplied from the LDO according to VOS. – SMPS step-down converter enabled at 1.36 V, may be used to supply the LDO.
1	LDO supply	x	x	0	1	0	– V_{CORE} power domains are supplied from the LDO according to VOS. – LDO power mode (Main, LP, Off) will follow system low-power modes. – SMPS step-down converter disabled.
2	Direct SMPS step-down converter supply	x	0	1	0	0	– V_{CORE} power domains are supplied from SMPS step-down converter according to VOS. – LDO bypassed. – SMPS step-down converter power mode (MR, LP, Off) will follow system low-power modes.
3	SMPS step-down converter supplies LDO,	01 or 10	0	1	1	0	– V_{CORE} power domains are supplied from the LDO according to VOS – LDO power mode (Main, LP, Off) will follow system low-power modes. – SMPS step-down converter enabled according to SDLEVEL, and supplies the LDO. – SMPS step-down converter power mode (MR, LP, Off) will follow system low-power modes.
4	SMPS step-down converter supplies External and LDO	01 or 10	1	1	1	0	– V_{CORE} power domains are supplied from voltage regulator according to VOS – LDO power mode (Main, LP, Off) will follow system low-power modes. – SMPS step-down converter enabled according to SDLEVEL used to supply external circuits and may supply the LDO. – SMPS step-down converter forced ON in MR mode.
5	SMPS step-down converter supplies external. and LDO Bypass	01 or 10	1	1	0	1	– V_{CORE} supplied from external source – SMPS step-down converter enabled according to SDLEVEL used to supply external circuits and may supply the external source for V_{CORE}. – SMPS step-down converter forced ON in MR mode.

Table 30. Supply configuration control (continued)

ID	Supply configuration	SDLEVEL	SDEXTHP	SDEN	LDOEN	BYPASS	Description
6	SMPS step-down converter disabled and LDO Bypass	x	x	0	0	1	– V_{CORE} supplied from external source – SMPS step-down converter disabled and LDO bypassed, voltage monitoring still active.
NA	Illegal	x	x	0	0	0	– Illegal combination, the default configuration is kept. (write data will be ignored).
		x	x	x	1	1	
		x	0	1	0	1	
		00	x	1	1	0	
		x	1	1	0	0	
		00	1	1	0	1	

6.4.1 System supply startup

The system startup sequence from power-on in different supply configurations is the following (see *Figure 20* and *Figure 21* for LDO supply and Direct SMPS supply, respectively):

1. When the system is powered on, the POR monitors V_{DD} supply. Once V_{DD} is above the POR threshold level, the SMPS step-down converter and voltage regulator are enabled in the default supply configuration:
   – The SMPS step-down converter output level is set at 1.36 V.
   – The voltage regulator output level is set at 1.0 V in accordance with the VOS3 level configured in *PWR D3 domain control register (PWR_D3CR)*.
2. The system is kept in reset mode as long as V_{CORE} is not stable.
3. Once V_{CORE} is stable, the system is taken out of reset and the HSI oscillator is enabled.
4. Once the oscillator is stable, the system is initialized: Flash memory and option bytes are loaded and the CPU starts in limited Run mode (Run*).
5. The software must then initialize the system including supply configuration programming in *PWR control register 3 (PWR_CR3)*. Once the supply configuration has been configured, the ACTVOSRDY bit in *PWR control status register 1 (PWR_CSR1)* must be checked to guarantee valid voltage levels:
   a) As long as ACTVOSRDY indicates that voltage levels are invalid, the system is in Run* mode, write operations to RAM are not allowed, and VOS must not be changed.
   b) Once ACTVOSRDY indicates that voltage levels are valid, the system is in normal Run mode, write accesses to RAMs are allowed and VOS can be changed.

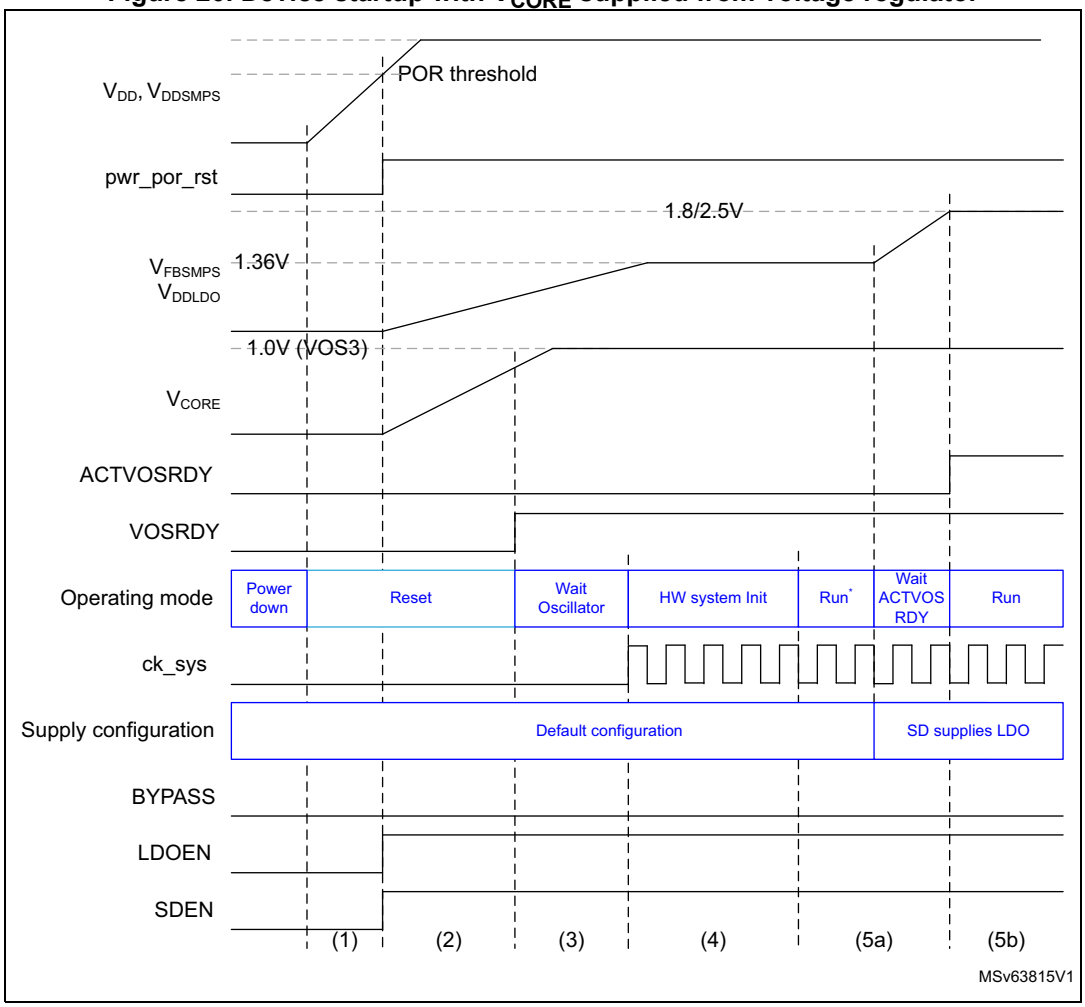
V_{CORE} supplied from the voltage regulator (LDO)

When V_{CORE} is supplied from the voltage regulator (LDO), the V_{CORE} voltage settles directly at VOS3 level. However the SMPS step-down converter V_{FBMPS} output voltage is set at 1.36 V. ACTVOSRDY bit in *PWR control status register 1 (PWR_CSR1)* indicates that the voltage levels are invalid.

The software has to program the supply configuration in *PWR control register 3 (PWR_CR3)*. In addition, the V_{FBSMPS} voltage level must reach the programmed SMPS step-down converter voltage output level (SDLEVEL) so that ACTVOSRDY indicates valid voltage levels (see *Figure 20*).

When exiting from Standby mode, the supply configuration is known by the system since the content of the *PWR control register 3 (PWR_CR3)* is retained. However the software must wait until ACTVOSRDY is set and ACTVOS reflects the awaited value in *PWR control status register 1 (PWR_CSR1)* to indicate VCORE voltage levels are valid, before performing write accesses to RAM or changing VOS level.

Figure 20. Device startup with V_{CORE} supplied from voltage regulator

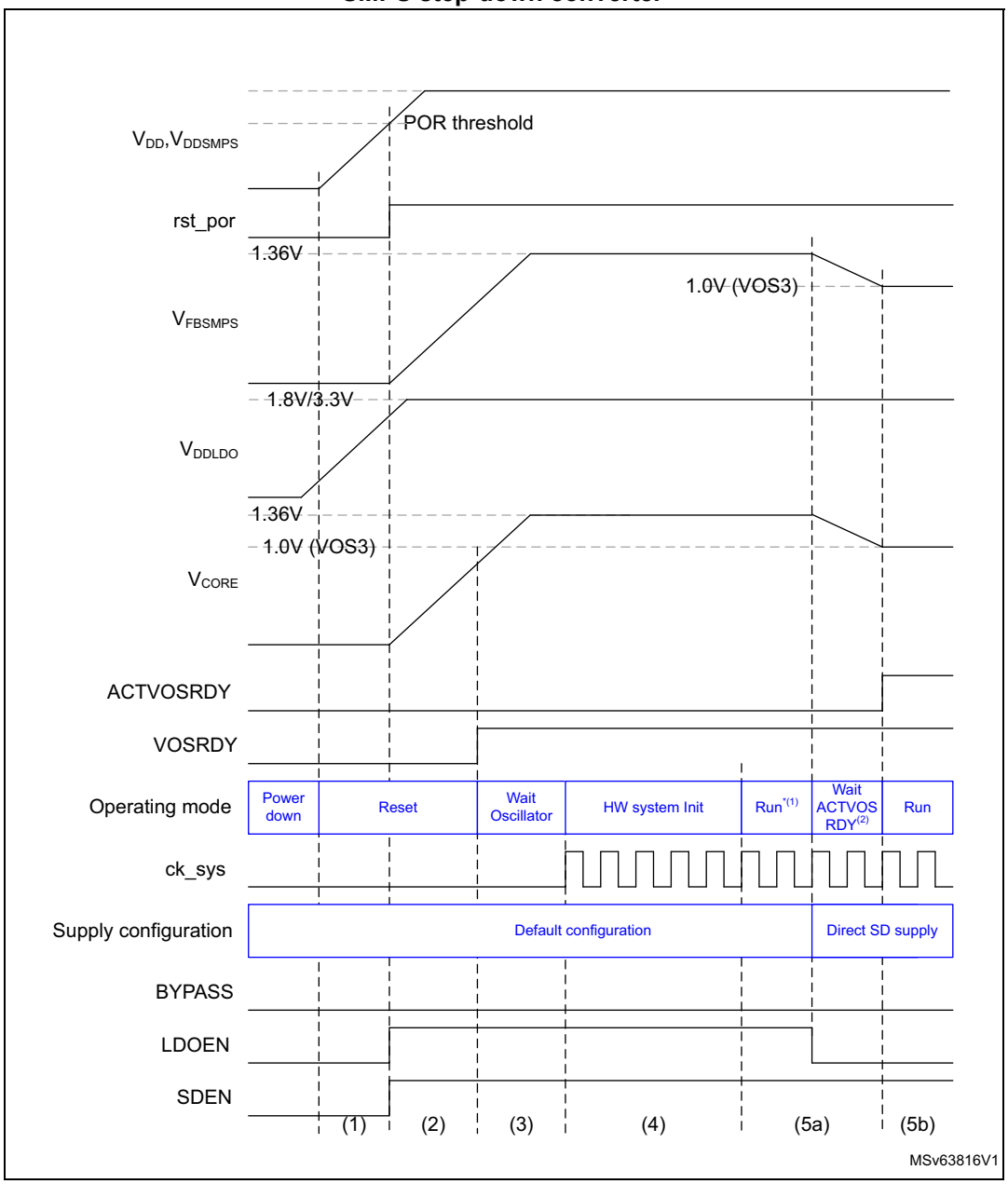


1. In Run* mode, write operations to RAM are not allowed.
2. Write operations to RAM are allowed and VOS can be changed only when ACTVOSRDY is valid.

V_{CORE} directly supplied from the SMPS step-down converter

When V_{CORE} is directly supplied from the SMPS step-down converter, the V_{CORE} voltage first settles at V_{FBSMPS} default level (1.36 V). Due to a too high supply compared to the VOS3 level, the ACTVOSRDY bit in *PWR control status register 1 (PWR_CSR1)* indicates invalid voltage levels. V_{CORE} settles at 1.0 V (VOS3 level) and ACTVODSRDY indicates valid voltage levels only when the supply configuration has been programmed in *PWR control register 3 (PWR_CR3)* (see *Figure 21*).

Figure 21. Device startup with V_{CORE} supplied directly from SMPS step-down converter



1. In Run* mode, write operations to RAM are not allowed.
2. Write operations to RAM are allowed and VOS can be changed only when ACTVOSRDY is valid.

When exiting from Standby mode, the supply configuration is known by the system since the content of *PWR control register 3 (PWR_CR3)* is retained. However the software must still wait for the ACTVOSRDY bit to be set in *PWR control status register 1 (PWR_CSR1)* to indicate V_{CORE} voltage levels are valid, before performing write accesses to RAM or changing VOS.

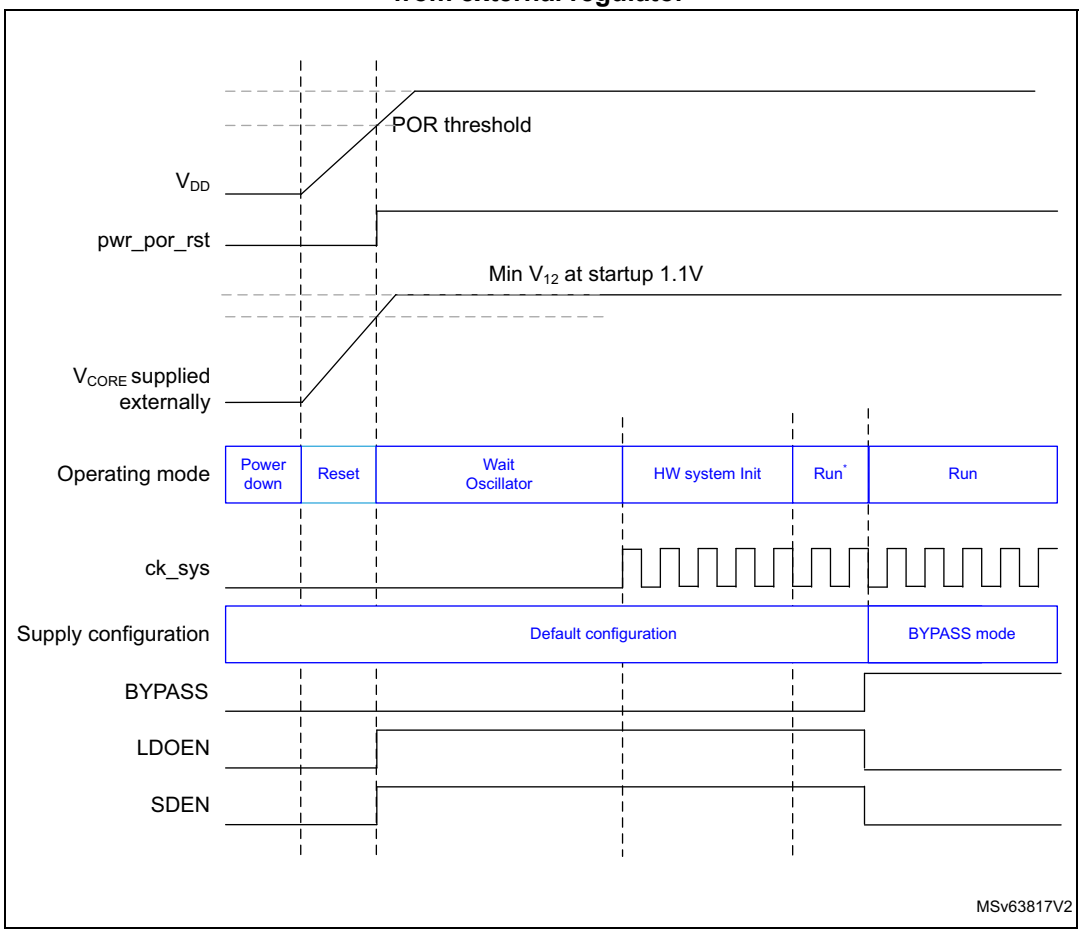
V_{CORE} supplied in Bypass mode (LDO and SMPS OFF)

The devices that feature the SMPS can also be used in Bypass mode.

When V_{CORE} is supplied in Bypass mode (LDO and SMPS OFF), the externally supplied V_{CORE} voltage must first settle at a default level higher than 1.1 V. Due to the LDO default state after power-up (enabled by default), the external V_{CORE} voltage must remain higher than 1.1 V until the LDO is disabled by software.

When the LDO is disabled, the external V_{CORE} voltage can be adjusted according to the user application needs (refer to section *General operating conditions* of the datasheet for details on V_{CORE} level versus the maximum operating frequency).

Figure 22. Device startup with V_{CORE} supplied in Bypass mode from external regulator



How to exit from Run* mode

As the Run* mode does not allow accessing RAM, PWR configuration must be done in the startup file. Below an example of code for SMPS supply that can be adapted for any other mode:

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;
;; Exit Run* mode to Direct SMPS mode
;;
        THUMB
        PUBWEAK ExitRun0ModeToDirectSMPSMode
        SECTION .text:CODE:NOROOT:REORDER(1)
ExitRun0ModeToDirectSMPSMode
        MOV      R1, #0x4804
        MOVT     R1, #0x5802
        LDR      R0,[R1, #+8]
        BIC      R0,R0,#0x2
        STR      R0,[R1, #+8]
wait_actvosrdy:
        LDR      R2,[R1, #+0]
        LSLS     R0,R2,#+18
        BPL.N    wait_actvosrdy
        BX      LR

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;
;; Default interrupt handlers.
;;
        THUMB
        PUBWEAK Reset_Handler
        SECTION .text:CODE:NOROOT:REORDER(2)
Reset_Handler
        LDR     R0, =ExitRun0ModeToDirectSMPSMode
        BLX     R0
        LDR     R0, =SystemInit
        BLX     R0
        LDR     R0, =__iar_program_start
        BX      R0
```

6.4.2 Core domain

The V_{CORE} core domain supply can be provided by the SMPS step-down converter, LDO voltage regulator or by an external supply (V_{CAP}). V_{CORE} supplies all the digital circuitries

except for the backup domain and the Standby circuitry. The V_{CORE} domain is split into 3 sections:

- D1 domain containing the CPU (Cortex®-M7), Flash memory and some peripherals.
- D2 domain containing some peripherals
- D3 domain containing the system control, I/O logic and low-power peripherals.

When a system reset occurs, the voltage regulator is enabled and supplies V_{CORE}. The SMPS step-down converter is also enabled to deliver 1.36 V. This allows the system to start up in any supply configurations (see *Figure 19*).

After a system reset, the software must configure the used supply configuration in *PWR control register 3 (PWR_CR3)* register before changing VOS in *PWR D3 domain control register (PWR_D3CR)* or the RCC ck_sys frequency. The different system supply configurations are controlled as shown in *Table 30*.

Note: The SMPS step-down converter and the LDO are not available on all packages.

LDO voltage regulator

The embedded voltage regulator (LDO) requires external capacitors to be connected to VCAP pins.

The voltage regulator provides three different operating modes: Main (MR), Low-power (LP) or Off. These modes will be used depending on the system operating modes (Run, Stop and Standby).

- Run and Autonomous modes

  The LDO regulator is in Main mode and provides full power to the V_{CORE} domain (core, memories and digital peripherals). The regulator output voltage can be scaled by software to different voltage levels (VOS0, VOS1, VOS2, and VOS3) that are configured through VOS bits in *PWR D3 domain control register (PWR_D3CR)*. The VOS voltage scaling allows optimizing the power consumption when the system is clocked below the maximum frequency. By default VOS3 is selected after system reset. VOS can be changed on-the-fly to adapt to the required system performance.

- Stop mode

  The voltage regulator supplies the V_{CORE} domain to retain the content of registers and internal memories.

  The regulator can be kept in Main mode to allow fast exit from Stop mode, or can be set in LP mode to obtain a lower V_{CORE} supply level and extend the exit-from-Stop latency. The regulator mode is selected through the SVOS and LPDS bits in *PWR control register 1 (PWR_CR1)*. Main mode and LP mode are allowed if SVOS3 voltage scaling is selected, while only LP mode is possible for SVOS4 and SVOS5 scaling. Due to a lower voltage level for SVOS4 and SVOS5 scaling, the Stop mode consumption can be further reduced.

- Standby mode

  The voltage regulator is OFF and the V_{CORE} domains are powered down. The content of the registers and memories is lost except for the Standby circuitry and the backup domain.

Note: The LDO is not available on all packages.

For more details, refer to the voltage regulator section in the datasheets.

SMPS step-down converter regulator

The SMPS step-down converter requires an external coil to be connected between the dedicated VLXSMPS pin and, via a capacitor, to VSS.

The SMPS step-down converter can be used in internal supply mode or external supply mode. The internal supply mode is used to directly supply the V_{CORE} domain, while the external supply mode is used to generate an intermediate supply level (V_{DD_extern} at 1.8 or 2.5 V) which can supply the voltage regulator and optionally an external circuitry.

The SMPS step-down converter works in three different power modes: Main (MR), Low-power (LP) or Off.

When the SMPS step-down converter is used in internal supply mode, the converter operating modes depend on the system modes (Run, Stop, Standby) and are configured through the associated VOS and SVOS levels:

- Run mode

  The SMPS step-down converter operates in MR mode and provides full power to the V_{CORE} domain (core, memories and digital peripherals). The regulator output voltage can be scaled by software to different voltage levels (VOS0, VOS1, VOS2, and VOS3) that are configured through VOS bits in *PWR D3 domain control register (PWR_D3CR)*. The VOS voltage scaling allows optimizing the power consumption when the system is clocked below the maximum frequency. By default VOS3 is selected after system reset. VOS can be changed on-the-fly to adapt to the required system performance.

- Stop mode

  The SMPS step-down converter supplies the V_{CORE} domain to retain the content of registers and internal memories. The regulator can be kept in MR mode to allow fast exit from Stop mode, or can be set in LP mode to achieve a lower V_{CORE} supply level and extend the exit-from-Stop latency. The regulator mode is selected through the SVOS and LPDS bits in *PWR control register 1 (PWR_CR1)*. MR mode or LP mode are allowed if SVOS3 voltage scaling is selected, while only LP mode is possible for SVOS4 and SVOS5 scaling. Due to a lower voltage level for SVOS4 and SVOS5 scaling, the Stop mode consumption can be further reduced.

- Standby mode

  The SMPS step-down converter is OFF and the V_{CORE} domains are powered down. The content of the registers and memories are lost except for the Standby circuitry and the backup domain.

When the SMPS step-down converter supplies an external circuitry by generating an intermediate voltage level, the converter is forced ON and operates in MR mode. The intermediate voltage level is selected through SDLEVEL bits in *PWR control register 3 (PWR_CR3)*. V_{DD_extern} is supplied at all times with full power whatever the system modes (Run, Stop, Standby).

Note: The SMPS step-down converter and the LDO are not available on all packages. When the LDO is not available, the SMPS supplies the voltage regulator and optionally an external circuitry.

6.4.3 PWR external supply

When V_{CORE} is supplied from an external source (Bypass mode), different operating modes can be used depending on the system operating modes (Run, Autonomous, Stop or Standby):

- In Run and D3 Autonomous modes

  The external source supplies full power to the V_{CORE} domain (core, memories and digital peripherals). The external source output voltage is scalable through different voltage levels (VOS0, VOS1, VOS2 and VOS3). The externally applied voltage level must be reflected in the VOS bits of PWR_D3CR register. The RAMs must only be accessed for write operations when the external applied voltage level matches VOS settings.

- In Stop mode

  The external source supplies V_{CORE} domain to retain the content of registers and internal memories. The regulator can select a lower V_{CORE} supply level to reduce the consumption in Stop mode.

- In Standby mode

  The external source must be switched OFF and the V_{CORE} domains powered down. The content of registers and memories is lost except for the Standby circuitry and the backup domain. The external source must be switched ON when exiting Standby mode.

6.4.4 Backup domain

To retain the content of the backup domain (RTC, backup registers and backup RAM) when V_{DD} is turned off, VBAT pin can be connected to an optional voltage which is supplied from a battery or from an another source.

The switching to V_{BAT} is controlled by the power-down reset embedded in the Reset block that monitors the V_{DD} supply.

Warning: **During $t_{RSTTEMPO}$ (temporization at V_{DD} startup) or after a PDR is detected, the power switch between V_{BAT} and V_{DD} remains connected to VBAT.**
During the startup phase, if V_{DD} is established in less than $t_{RSTTEMPO}$ (see the datasheet for the value of $t_{RSTTEMPO}$) and $V_{DD} > V_{BAT} + 0.6$ V, a current may be injected into V_{BAT} through an internal diode connected between V_{DD} and the power switch (V_{BAT}).
If the power supply/battery connected to the VBAT pin cannot support this current injection, it is strongly recommended to connect an external low-drop diode between this power supply and the VBAT pin.

When the V_{DD} supply is present, the backup domain is supplied from V_{DD}. This allows saving V_{BAT} power supply battery life time.

If no external battery is used in the application, it is recommended to connect VBAT externally to VDD, and add a a 100 nF external ceramic capacitor between VBAT and VSS.

When the V_{DD} supply is present and higher than the PDR threshold, the backup domain is supplied by V_{DD} and the following functions are available:

- PC14 and PC15 can be used either as GPIO or as LSE pins.
- PC13 can be used either as GPIO or as RTC_AF1 or RTC_TAMP1 pin assuming they have been configured by the RTC.
- PC1/RTC_TAMP3 when it is configured by the RTC as tamper pins. PC1 can be used either as GPIO or as TAMP_IN3 assuming they have been configured by the RTC tamper.

Note: Since the switch only sinks a limited amount of current, the use of PC13 and PC15 GPIOs is restricted: only one I/O can be used as an output at a time, at a speed limited to 2 MHz with a maximum load of 30 pF. These I/Os must not be used as current sources (e.g. to drive an LED).

In V_{BAT} mode, when the V_{DD} supply is absent and a supply is present on V_{BAT}, the backup domain is supplied by V_{BAT} and the following functions are available:

- PC14 and PC15 can be used as LSE pins only.
- PC13 can be used as RTC_AF1 or RTC_TAMP1 pin assuming they have been configured by the RTC.
- PC1/RTC_TAMP3 when it is configured by the RTC as tamper pins. PC1 can be used as TAMP_IN3 assuming it has been configured by the RTC tamper.

Accessing the backup domain

After reset, the backup domain (RTC registers and RTC backup registers) is protected against possible unwanted write accesses. To enable access to the backup domain, set the DBP bit in the *PWR control register 1 (PWR_CR1)*.

For more detail on RTC and backup RAM access, refer to *Section 8: Reset and clock control (RCC)*.

Backup RAM

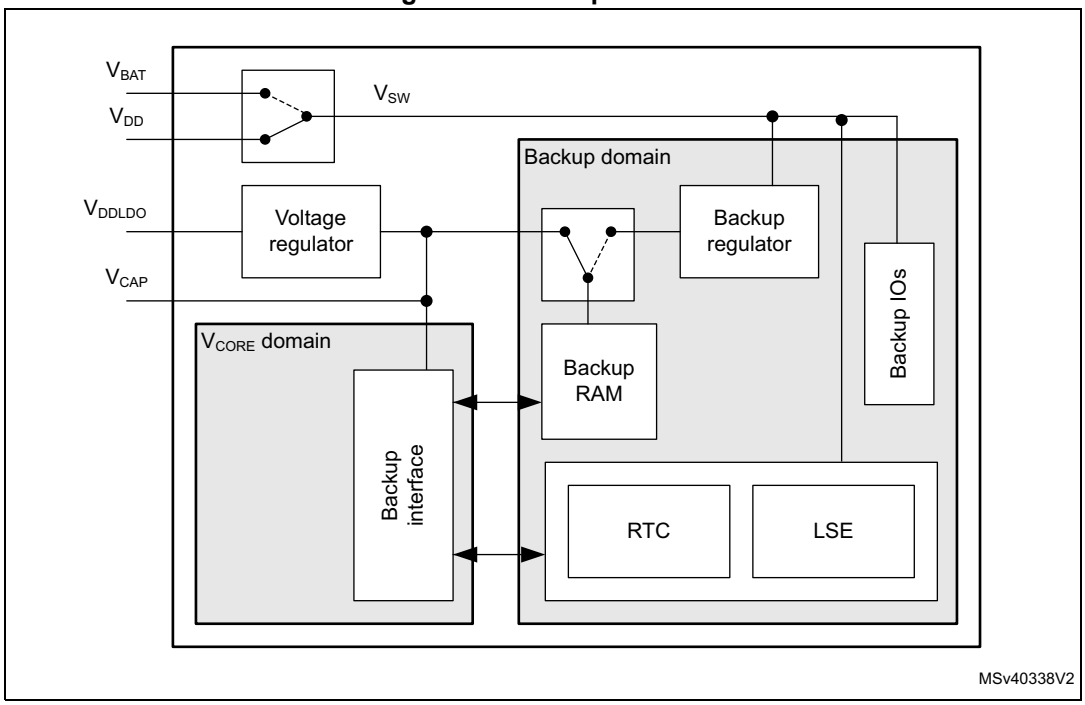
The backup domain includes 4 Kbytes of backup RAM accessible in 32-bit, 16-bit or 8-bit data mode. The backup RAM is supplied from the backup regulator in the backup domain. When the backup regulator is enabled through BREN bit in *PWR control register 2 (PWR_CR2)*, the backup RAM content is retained even in Standby and/or V_{BAT} mode (it can be considered as an internal EEPROM if V_{BAT} is always present.)

The backup regulator can be ON or OFF depending whether the application needs the backup RAM function in Standby or V_{BAT} modes.

After a tamper event, the backup RAM can no more be used until an erase is explicitly requested: reading the backup RAM returns 0x0, and any write different from 0 is not effective. The backup RAM can be erased:

- through the Flash memory interface when an RDP level regression from level 1 to level 0 is requested (refer to *Section 4.5.3: Readout protection (RDP)*) or
- by performing a simple dummy write with zero as data to any address of the backup RAM (this action resets the whole backup RAM when it is performed after a tamper event).

Figure 23. Backup domain



6.4.5 V_{BAT} battery charging

When V_{DD} is present, the external battery connected to VBAT can be charged through an internal resistance.

V_{BAT} charging can be performed either through a 5 kΩ resistor or through a 1.5 kΩ resistor, depending on the VBRS bit value in *PWR control register 3 (PWR_CR3)*.

The battery charging is enabled by setting the VBE bit in *PWR control register 3 (PWR_CR3)*. It is automatically disabled in V_{BAT} mode.

6.4.6 Analog supply

Separate V_{DDA} analog supply

The analog supply domain is powered by dedicated V_{DDA} and V_{SSA} pads that allow the supply to be filtered and shielded from noise on the PCB, thus improving ADC and DAC conversion accuracy:

- The analog supply voltage input is available on a separate VDDA pin.
- An isolated supply ground connection is provided on VSSA pin.

Analog reference voltage V_{REF+}/V_{REF-}

To achieve better accuracy low-voltage signals, the ADC and DAC also have a separate reference voltage, available on $VREF_+$ pin. The user can connect a separate external reference voltage on VREF+.

The VREF+ controls the highest voltage, represented by the full scale value, the lower voltage reference (V_{REF-}) being connected to VSSA.

When enabled by ENVR bit in the VREFBUF control and status register (see *Section 32: Voltage reference buffer (VREFBUF)*), V_{REF+} is provided from the internal voltage reference buffer. The internal voltage reference buffer can also deliver a reference voltage to external components through VREF+/VREF- pins.

When the internal voltage reference buffer is disabled by ENVR, V_{REF+} is delivered by an independent external reference supply voltage.

*Note: VREF+ and VREF- pins are not available on all packages (in this case they are connected internally respectively to VDDA and VSSA). **Do not** enable the internal voltage reference buffer when an external power supply is applied to the VREF+ pin.*

6.4.7 USB regulator

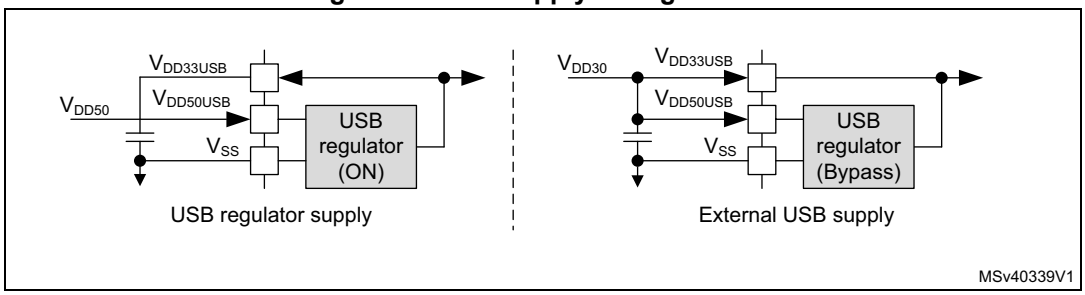
The USB transceivers are supplied from a dedicated $V_{DD33USB}$ supply that can be provided either by the integrated USB regulator, or by an external USB supply.

When enabled by USBREGEN bit in *PWR control register 3 (PWR_CR3)*, the $V_{DD33USB}$ is provided from the USB regulator, which is powered through the VDD50USB pin generally connect to the USB VBUS line. Before using $V_{DD33USB}$, check that it is available by monitoring USB33RDY bit in *PWR control register 3 (PWR_CR3)*. The $V_{DD33USB}$ supply level detector must be enabled through USB33DEN bit in PWR_CR3 register.

When the USB regulator is disabled through USBREGEN bit, $V_{DD33USB}$ can be provided from an external supply. In this case $V_{DD33USB}$ and $V_{DD50USB}$ must be connected together. The $V_{DD33USB}$ supply level detector must be enabled through USB33DEN bit in PWR_CR3 register before using the USB transceivers.

For more information on the USB regulator (see *Section 62: USB on-the-go high-speed (OTG_HS)*).

Figure 24. USB supply configurations



6.5 Power supply supervision

Power supply level monitoring is available on the following supplies:

- V_{DD} (V_{DDSMPS}) can be monitored via POR/PDR (see *Section 6.5.1*), BOR (see *Section 6.5.2*) and PVD monitor (see *Section 6.5.3*)
- V_{DDA} can be monitored via AVD monitor (see *Section 6.5.4*)
- V_{BAT} can be monitored via VBAT threshold (see *Section 6.5.5*)
- V_{SW} can be monitored via rst_vsw, which keeps V_{SW} domain in Reset mode as long as the level is not OK.
- V_{BKP} can be monitored via a BRRDY bit in *PWR control register 2 (PWR_CR2)*.
- V_{FBSMPS} can be monitored via a SDEXTRDY bit in *PWR control register 3 (PWR_CR3)*.
- $V_{DD33USB}$ can be monitored via USBRDY bit in *PWR control register 3 (PWR_CR3)*.

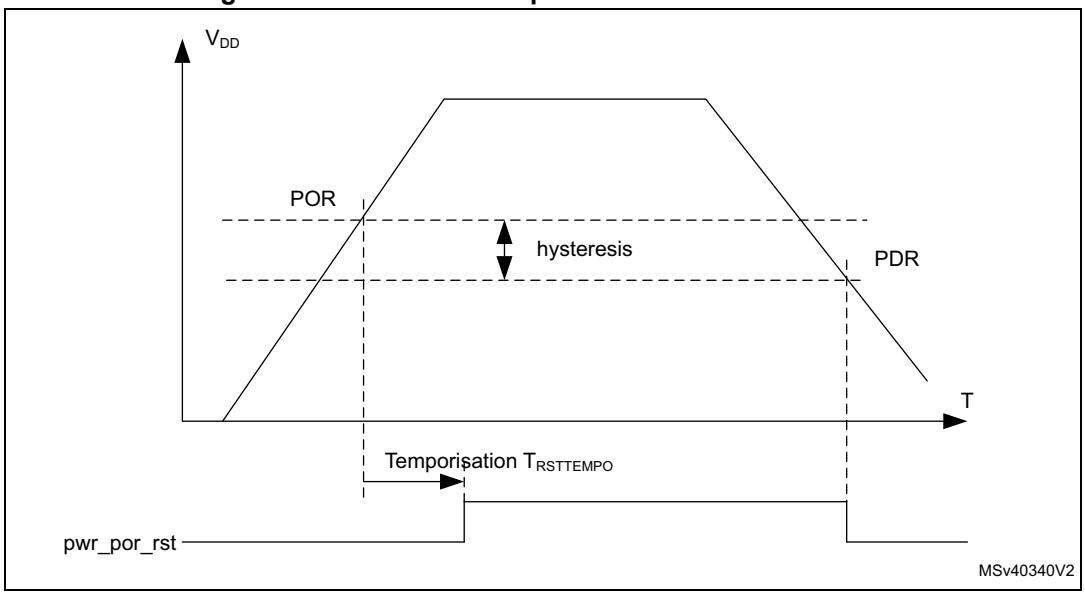
6.5.1 Power-on reset (POR)/power-down reset (PDR)

The system has an integrated POR/PDR circuitry that ensures proper startup operation.

The system remains in Reset mode when V_{DD} is below a specified V_{POR} threshold, without the need for an external reset circuit. Once the V_{DD} supply level is above the V_{POR} threshold, the system is taken out of reset (see *Figure 25*). For more details concerning the power-on/power-down reset threshold, refer to the electrical characteristics section of the datasheets.

The PDR can be enabled/disabled by the device PDR_ON input pin.

Figure 25. Power-on reset/power-down reset waveform



1. For thresholds and hysteresis values, refer to the datasheets.

6.5.2 Brownout reset (BOR)

During power-on, the Brownout reset (BOR) keeps the system under reset until the V_{DD} supply voltage reaches the specified V_{BOR} threshold.

The V_{BOR} threshold is configured through system option bytes. By default, BOR is OFF. The following programmable V_{BOR} thresholds can be selected:

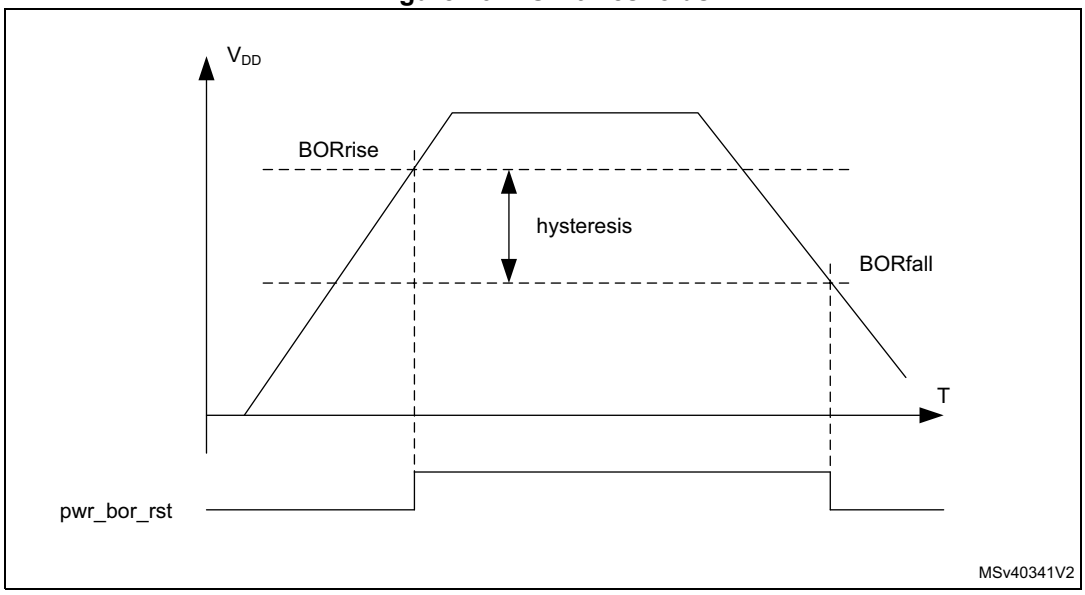
- BOR OFF (V_{BOR0})
- BOR Level 1 (V_{BOR1})
- BOR Level 2 (V_{BOR2})
- BOR Level 3 (V_{BOR3})

For more details on the brown-out reset thresholds, refer to the section “Electrical characteristics” of the product datasheets.

A system reset is generated when the BOR is enabled and V_{DD} supply voltage drops below the selected V_{BOR} threshold.

BOR can be disabled by programming the system option bytes. To disable the BOR function, V_{DD} must have been higher than V_{BOR0} to start the system option byte programming sequence. The power-down is then monitored by the PDR (see *Section 6.5.1*).

Figure 26. BOR thresholds



1. For thresholds and hysteresis values, refer to the datasheets.

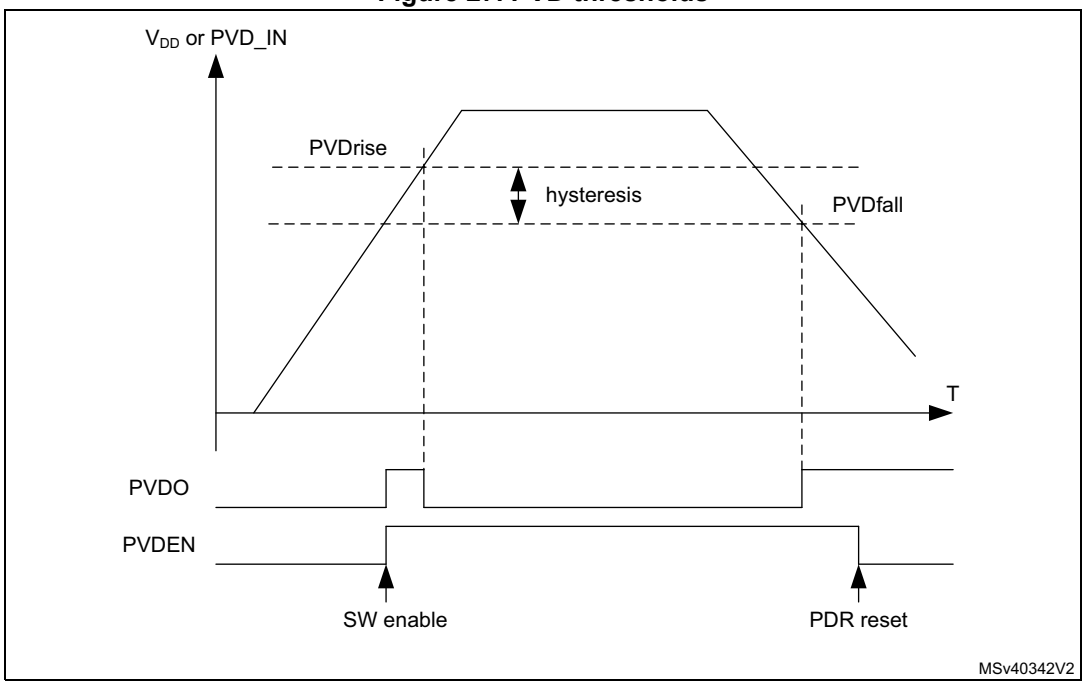
6.5.3 Programmable voltage detector (PVD)

The PVD can be used to monitor the V_{DD} power supply by comparing it to a threshold selected by the PLS[2:0] bits in the *PWR control register 1 (PWR_CR1)*. The PVD can also be used to monitor a voltage level on the PVD_IN pin. In this case PVD_IN voltage is compared to the internal V_{REFINT} level.

The PVD is enabled by setting the PVDE bit in *PWR control register 1 (PWR_CR1)*.

A PVDO flag is available in the *PWR control status register 1 (PWR_CSR1)* to indicate if V_{DD} or PVD_IN voltage is higher or lower than the PVD threshold. This event is internally connected to the EXTI and can generate an interrupt, assuming it has been enabled through the EXTI registers. The PVDO output interrupt can be generated when V_{DD} or PVD_IN voltage drops below the PVD threshold and/or when V_{DD} or PVD_IN voltage rises above the PVD threshold depending on EXTI rising/falling edge configuration. As an example the service routine could perform emergency shutdown tasks.

Figure 27. PVD thresholds



1. For thresholds and hysteresis values, refer to the datasheets.

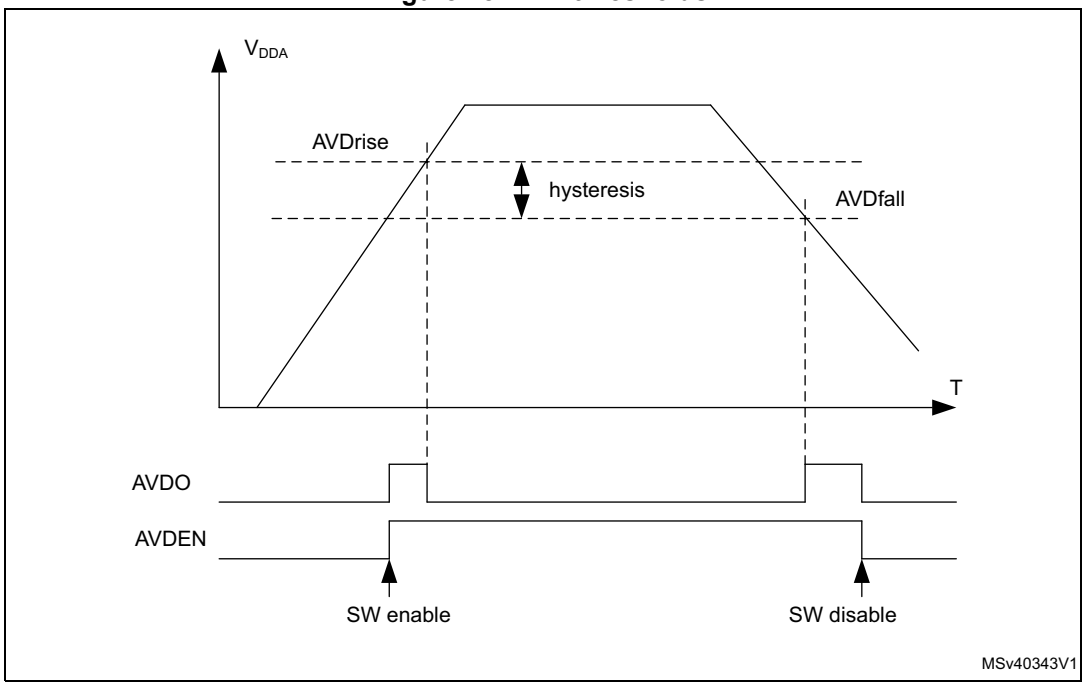
6.5.4 Analog voltage detector (AVD)

The AVD can be used to monitor the V_{DDA} supply by comparing it to a threshold selected by the ALS[1:0] bits in the *PWR control register 1 (PWR_CR1)*.

The AVD is enabled by setting the AVDEN bit in *PWR control register 1 (PWR_CR1)*.

An AVDO flag is available in the *PWR control status register 1 (PWR_CSR1)* to indicate whether V_{DDA} is higher or lower than the AVD threshold. This event is internally connected to the EXTI and can generate an interrupt if enabled through the EXTI registers. The AVDO interrupt can be generated when V_{DDA} drops below the AVD threshold and/or when V_{DDA} rises above the AVD threshold depending on EXTI rising/falling edge configuration. As an example the service routine could indicate when the V_{DDA} supply drops below a minimum level.

Figure 28. AVD thresholds



1. For thresholds and hysteresis values, refer to the datasheets.

6.5.5 Battery voltage thresholds

The battery voltage supply monitors the backup domain V_{SW} level. Vsw is monitored by comparing it with two threshold levels: $V_{BAThigh}$ and V_{BATlow}. VBATH and VBATL flags in the *PWR control register 2 (PWR_CR2)*, indicate if V_{SW} is higher or lower than the threshold.

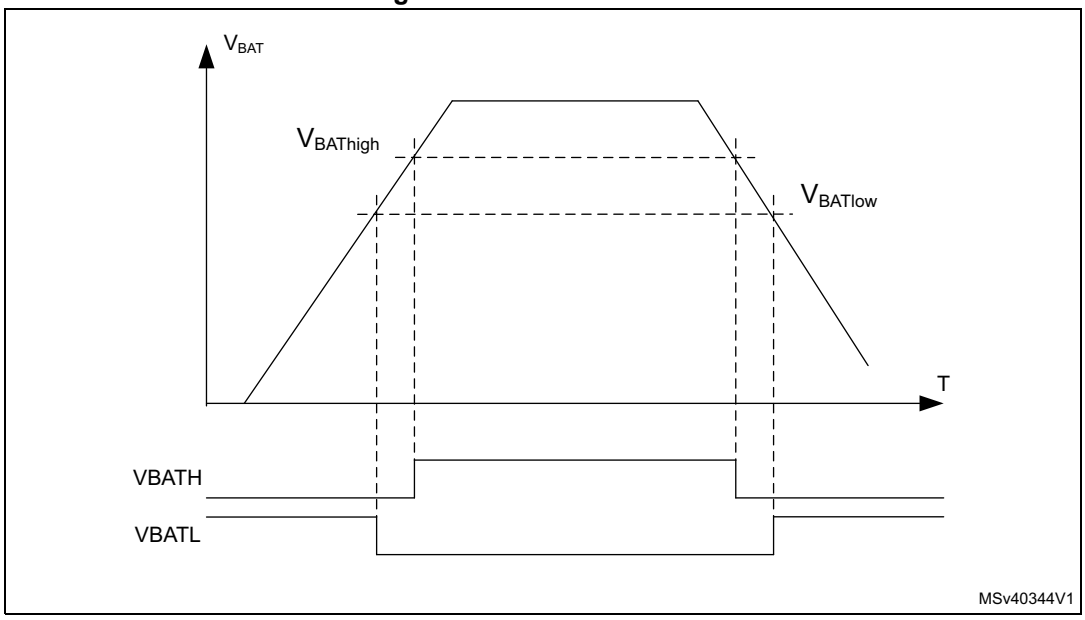
The V_{BAT} supply monitoring can be enabled/disabled via MONEN bit in *PWR control register 2 (PWR_CR2)*. When it is enabled, the battery voltage thresholds increase power consumption. As an example the V_{SW} levels monitoring could be used to trigger a tamper event for an over or under voltage of the RTC power supply domain (available in VBAT mode).

VBATH and VBATL are connected to RTC tamper signals (see *Section 51: Real-time clock (RTC)*).

Note: Battery voltage monitoring is only available when the backup regulator is enabled (BREN bit set in PWR control register 2 (PWR_CR2)).

When the device does not operate in VBAT mode, the battery voltage monitoring checks V_{DD} level. When V_{DD} is available, V_{SW} is connected to V_{DD} through the internal power switch (see Section 6.4.4: Backup domain).

Figure 29. VBAT thresholds



1. For thresholds and hysteresis values, refer to the datasheets.

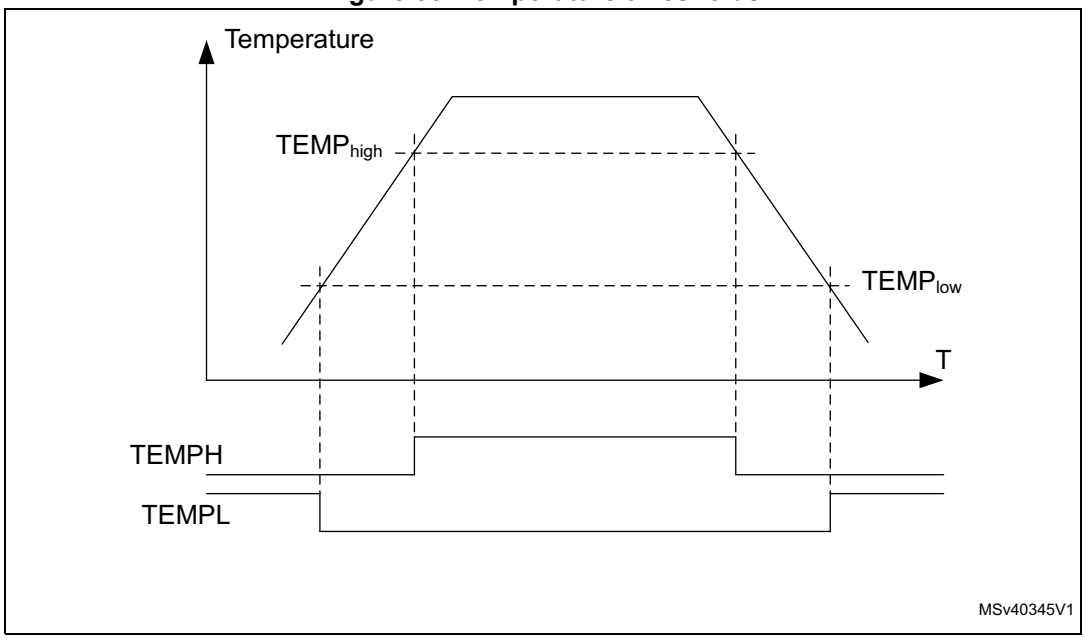
6.5.6 Temperature thresholds

The junction temperature can be monitored by comparing it with two threshold levels, $TEMP_{high}$ and $TEMP_{low}$. TEMPH and TEMPL flags, in the *PWR control register 2 (PWR_CR2)*, indicate whether the device temperature is higher or lower than the threshold. The temperature monitoring can be enabled/disabled via MONEN bit in *PWR control register 2 (PWR_CR2)*. When enabled, the temperature thresholds increase power consumption. As an example the levels could be used to trigger a routine to perform temperature control tasks.

The temperature thresholds are available only when the backup regulator is enabled (BREN bit set in the PWR_CR2 register).

TEMPH and TEMPL wakeup interrupts are available on the RTC tamper signals (see *Section 51: Real-time clock (RTC)*).

Figure 30. Temperature thresholds



1. For thresholds and hysteresis values, refer to the datasheets.

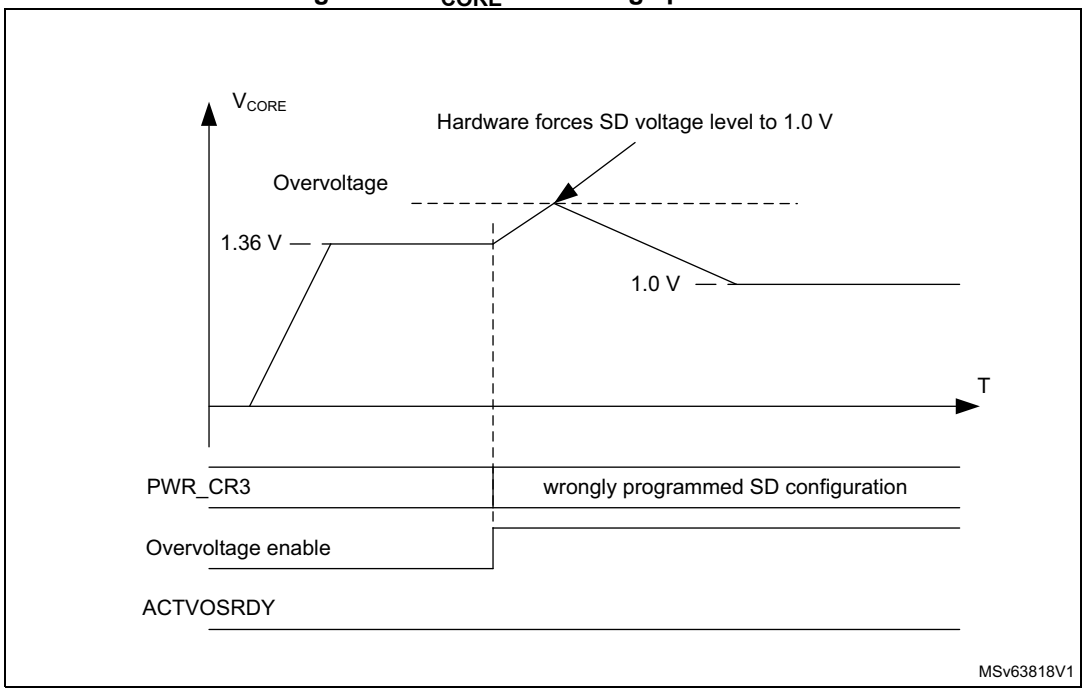
6.5.7 V_{CORE} maximum voltage level detector

V_{CORE} is protected against too high voltages in the direct SMPS step-down converter supply configuration. V_{CORE} overvoltage protection is enabled at startup by hardware once the SMPS step-down converter configuration has been programmed into *PWR control register 3 (PWR_CR3)*:

- V_{CORE} voltage level stays within range:
  - ACTVOSRDY bit in *PWR control status register 1 (PWR_CSR1)* indicate valid voltage levels.
  - The system operates normally and V_{CORE} overvoltage protection is disabled.
- V_{CORE} overvoltage (due to a wrongly programmed SMPS step-down converter configuration):

– The hardware forces the SMPS step-down converter voltage level to 1.0 V.
– The ACTVOSRDY goes on indicating invalid voltage levels. In this case the software must be corrected and re-loaded to program a correct SMPS step-down converter configuration that matches the application supply connections. The system must then be power cycled.

Figure 31. V_{CORE} overvoltage protection



6.6 Power management

The power management block controls the V_{CORE} supply in accordance with the system operation modes (see *Section 6.6.1*).

The V_{CORE} domain is split into the following power domains.

- D1 domain containing some peripherals and the Cortex®-M7 Core.
- D2 domain containing a large part of the peripherals.
- D3 domain containing some peripherals and the system control.

The D1, D2 and system D3 power domains can operate in one of the following operating modes:

- DRun/Run/Run* (power ON, clock ON)
- DStop/Stop (power ON, clock OFF)
- DStandby/Standby (Power OFF, clock OFF).

The operating modes for D1 domain and D2 domain are independent. However system D3 domain power modes depend on D1 and D2 domain modes:

- For system D3 domain to operate in Stop mode, both D1 and D2 domains must be in DStop or DStandby mode.
- For system D3 domain to operate in Standby mode, both D1 and D2 domains must be in DStandby too.

D1, D2 and system D3 domains are supplied from a single regulator at a common V_{CORE} level. The V_{CORE} supply level follows the system operating mode (Run, Stop, Standby). The D1 domain and/or D2 domain supply can be powered down individually when the domains are in DStandby mode.

The following voltage scaling features allow controlling the power with respect to the required system performance (see *Section 6.6.2: Voltage scaling*):

- To obtain a given system performance, the corresponding voltage scaling must be set in accordance with the system clock frequency. To do this, configure the VOS bits to the Run mode voltage scaling.
- To obtain the best trade-off between power consumption and exit-from-Stop mode latency, configure the SVOS bits to Stop mode voltage scaling.

6.6.1 Operating modes

Several system operating modes are available to tune the system according to the performance required, i.e. when the CPU does not need to execute code and are waiting for an external event. It is up to the user to select the operating mode that gives the best compromise between low power consumption, short startup time and available wakeup sources.

The operating modes allow controlling the clock distribution to the different system blocks and powering them. The system operating mode is driven by the CPU subsystem, D2 subsystem and system D3 autonomous wakeup. A CPU subsystem can include multiple domains depending on its peripheral allocation (see *Section 8.5.11: Peripheral clock gating control*).

The following operating modes are available for the different system blocks (see *Table 31*):

- CPU subsystem modes:
  - **CRun**

    CPU and CPU subsystem peripheral allocated via RCC PERxEN bits are clocked.
  - **CSleep**

    The CPU clocks is stalled and the CPU subsystem allocated peripheral(s) clock operate according to RCC PERxLPEN.
  - **CStop**

    CPU and CPU subsystem peripheral clocks are stalled.
- D1 domain mode:
  - **DRun**

    The domain bus matrix is clocked. The CPU subsystem operates in CRun or CSleep mode.
  - **DStop**

    The domain bus matrix clock is stalled.

    The CPU subsystem operates in CStop mode and the PDDS_D1[(a)] bit selects DStop mode.
  - **DStandby**

    The domain is powered down.

    The CPU subsystem operates in CStop mode and the PDDS_D1 bit selects DStandby mode.
- D2 domain mode:
  - **DRun**

    The domain bus matrix is clocked.

    The CPU subsystem has an allocated peripheral in the D2 domain and the CPU subsystem operates in CRun or CSleep mode.

a. The PDDS_Dn bits belong to *PWR CPU control register (PWR_CPUCR)*.

- **DStop**

  The domain bus matrix clock is stalled.

  The CPU subsystem has no peripherals allocated in the D2 domain and PDDS_D2(a) bit selects DStop mode,

  or

  the CPU subsystem has an allocated peripheral in D2 domain, the CPU subsystem operates in CStop mode and PDDS_D2 bit selects DStop mode.

- **DStandby**

  The domain is powered down.

  The CPU subsystem has no peripherals allocated in the D2 domain and PDDS_D2 bit selects DStandby mode,

  or

  the CPU subsystem has an allocated peripheral in the D2 domain, the CPU subsystem operates in CStop mode and PDDS_D2 bit selects DStandby mode.

- System /D3 domain modes
  - **Run/Run***

    The system clock and D3 domain bus matrix clock are running:
    - The CPU subsystem is in CRun or CSleep mode
    or
    - A wakeup signal is active. (i.e. System D3 Autonomous mode)

    The Run* mode is entered after a POR reset and a wakeup from Standby. In Run* mode, the performance is limited and the system supply configuration shall be programmed in *PWR control register 3 (PWR_CR3)*. The system enters Run mode only when the ACTVOSRDY bit in *PWR control status register 1 (PWR_CSR1)* is set to 1.

  - **Stop**

    The system clock and D3 domain bus matrix clock is stalled:
    - The CPU subsystem is in CStop mode.
    and
    - all wakeup signals are inactive.
    and
    - At least one PDDS_Dn(a) bit for any domain select Stop mode.

  - **Standby**

    The system is powered down:
    - The CPU subsystem is in CStop mode
    and
    - all wakeup signals are inactive.
    and
    - All PDDS_Dn(a) bits for all domains select Standby mode.

In Run mode, power consumption can be reduced by one of the following means:

- Lowering the system performance by slowing down the system clocks and reducing the V_{CORE} supply level through VOS voltage scaling bits.
- Gating the clocks to the APBx and AHBx peripherals when they are not used, through PERxEN bits.

Table 31. Summary of the operating mode

System	Domain	CPU	Entry	Wakeup	System oscillator	System clock	Domain bus matrix clk	Peripheral clock	CPU clock	Voltage regulator	Domain supply
Run	DRun(1)	CRun	-	-	ON	ON	ON	ON	ON	ON	ON
		CSleep	WFI or return from ISR or WFE	Any interrupt or event				ON/OFF(2)	OFF		
		CStop	SLEEPDEEP bit + WFI or return from ISR or WFE	Any EXTI interrupt or event				ON/OFF(3)			
	DStop		SLEEPDEEP bit + WFI or return from ISR or WFE				OFF				OFF
	DStandby										
Stop(4)	DStop	CStop	SLEEPDEEP bit + WFI or return from ISR or WFE or Wakeup source cleared(5)		ON/OFF(6)	OFF		OFF			ON
	DStandby										OFF
Standby(7)	DStandby		All PDDS_Dn bit + SLEEPDEEP bit + WFI or return from ISR or WFE or Wakeup source cleared(5)	WKUP pins rising or falling edge, RTC alarm (Alarm A or Alarm B), RTC Wakeup event, RTC tamper events, RTC time stamp event, external reset in NRST pin, IWDG reset	OFF					OFF	

1. In the D2 domain, the CPU subsystem has an allocated peripheral in the domain and operates in CRun or CSleep mode.
2. The CPU subsystem peripherals that have a PERxLPEN bit will operate accordingly.
3. The CPU subsystem peripherals located in the D3 domain that have a PERxAMEN bit operate accordingly.
4. All domains need to be in DStop Or DStandby.
5. When the CPU is in CStop and D3 domain in Autonomous mode, the last EXTI Wakeup source is cleared.
6. When the system oscillator HSI or CSI is used, the state is controlled by HSIKERON and CSIKERON, otherwise the system oscillator is OFF.
7. All domains are in DStandby mode.

6.6.2 Voltage scaling

The D1, D2, and D3 domains are supplied from a single voltage regulator supporting voltage scaling with the following features:

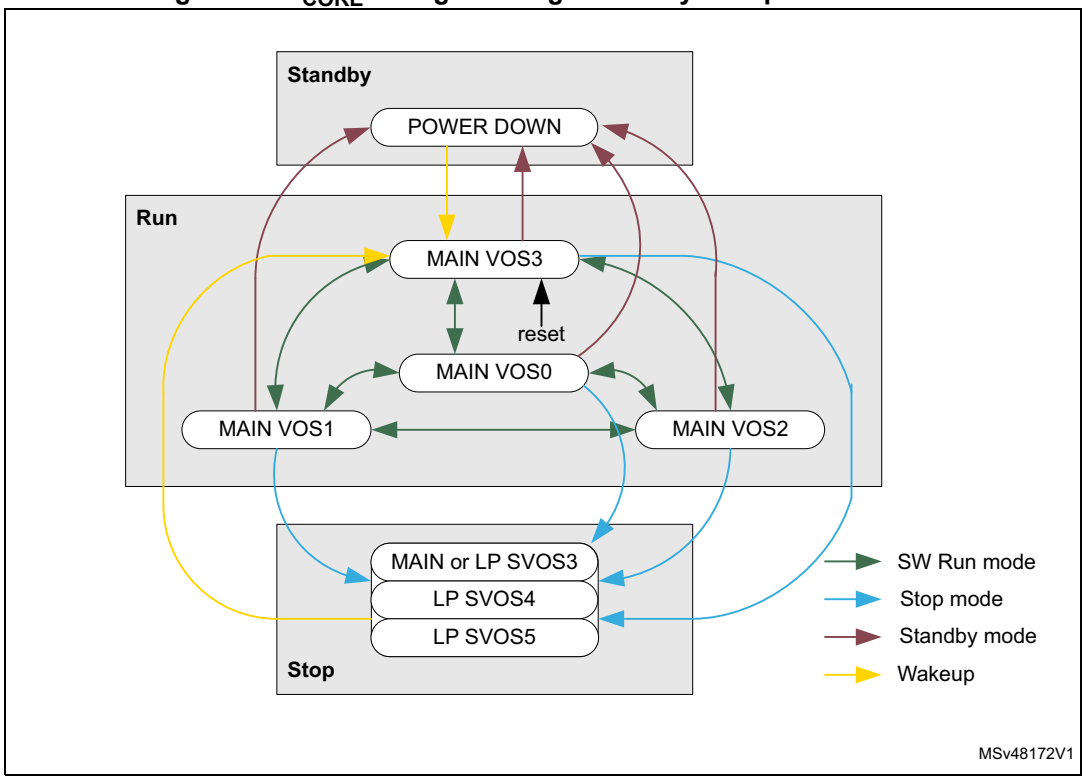
- Run mode voltage scaling
  - VOS0: Scale 0 (V_{CORE} boost)
  - VOS1: Scale 1
  - VOS2: Scale 2
  - VOS3: Scale 3
- Stop mode voltage scaling
  - SVOS3: Scale 3
  - LP-SVOS4: Scale 4
  - LP-SVOS5: Scale 5

For more details on voltage scaling values, refer to the product datasheets.

After reset, the system starts on the lowest Run mode voltage scaling (VOS3). The voltage scaling can then be changed on-the-fly by software by programming VOS bits in *PWR D3 domain control register (PWR_D3CR)* according to the required system performance. When exiting from Stop mode or Standby mode, the Run mode voltage scaling is reset to the default VOS3 value.

Before entering Stop mode, the software can preselect the SVOS level in *PWR control register 1 (PWR_CR1)*. The Stop mode voltage scaling for SVOS4 and SVOS5 also sets the voltage regulator in Low-power (LP) mode to further reduce power consumption. When preselecting SVOS3, the use of the voltage regulator low-power mode (LP) can be selected by LPDS register bit.

Figure 32. V_{CORE} voltage scaling versus system power modes



6.6.3 Power control modes

The power control block handles the V_{CORE} supply for system Run, Stop and Standby modes.

The system operating mode depends on the CPU subsystem modes (CRun, CSleep, CStop), on the domain modes (DRun, DStop, DStandby), and on the system D3 autonomous wakeup:

- In Run mode and Autonomous mode, V_{CORE} is defined by the VOS voltage scaling.
  The CPU subsystem is in CRun or CSleep or an EXTI wakeup is active.
- In Stop mode, V_{CORE} is defined by the SVOS voltage scaling.
  The CPU subsystem is in CStop mode and no EXTI wakeup is pending. The D1 domain and D2 domain are either in DStop or DStandby mode.
- In Standby mode, V_{CORE} supply is switched off.
  The CPU subsystem is in CStop mode and no EXTI wakeup is pending. The D1 domain and D2 domain are both in DStandby mode.

The domain operating mode can depend on the CPU subsystem when peripherals are allocated in the corresponding domain. The domain mode selection between DStop and DStandby is configured via domain dedicated PDDS_Dn bits in *PWR CPU control register (PWR_CPUCR)*. The CPU can choose to keep a domain in DStop, or allow a domain to enter DStandby mode.

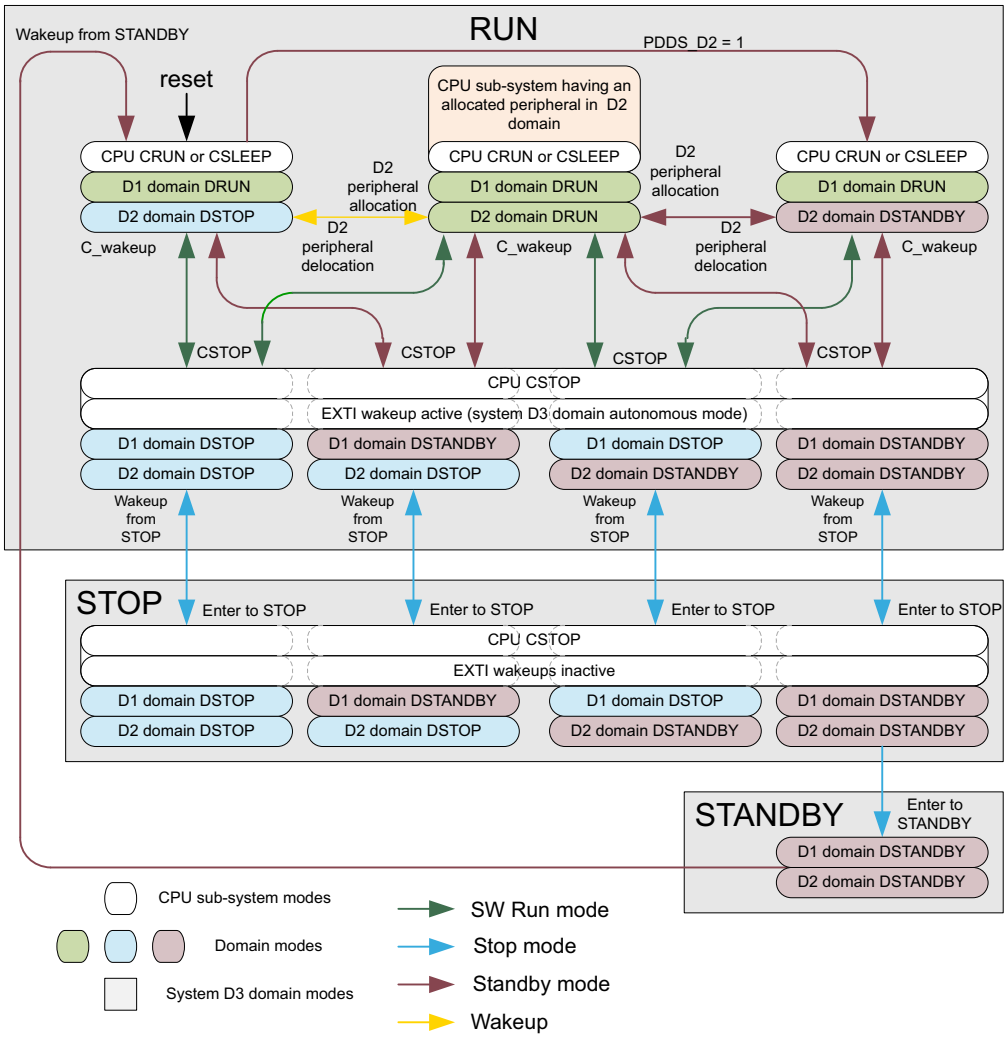
If a domain is in DStandby mode, the corresponding power is switched off.

All the domains can be configured for the system mode (Stop or Standby) through PDDS_Dn bits in *PWR CPU control register (PWR_CPUCR)*. The system enters Standby only when all PDDS_Dn bits for all domains have allowed it.

Table 32. PDDS_Dn low-power mode control

PWR_CPUCR			D1 mode	D2 mode	D3 mode
PDDS_D1	PDDS_D2	PDDS_D3			
0	x	x	DStop	DStop or DStandby	Run or Stop
1			DStandby	DStop or DStandby	any
x	0		any	DStop	Run or Stop
	1		any	DStandby	any
at least one = 0			DStop or DStandby	DStop or DStandby	Stop
1	1	1	DStandby	DStandby	Standby

Figure 33. Power control modes detailed state diagram



After a system reset, the CPU is in CRun mode.

Power control state transitions are initiated by the following events:

- CPU going to CStop mode (state transitions in Run mode are marked in green and red)
  - Green transitions: CPU wakes up as from CSleep.
  - Red transitions: CPU wakes up with domain reset. The SBF_Dn is set.
- Allocating or deallocating a peripheral in a domain (state transitions in Run mode are marked in orange and red)
  - Orange transitions: the domain wakes up from DStop
  - Red transitions: the domain wakes up from DStandby. The SBF_Dn is set.
- The system enters or exits from Stop mode (state transitions marked in blue)
  - Blue transitions the system wakes up from Stop mode. The STOPF is set.
- The system enters or exits from Standby mode (state transitions in Stop and Standby mode are marked in red).
  - When exiting from Standby mode, the SBF is set.

When a domain exits from DStandby, the domain peripherals are reset, while the domain SBF_Dn bit is set (state transitions causing a domain reset are marked in red).

Table 33 shows the flags that indicate from which mode the domain/system exits. The CPU features a set of flags which can be read from *PWR CPU control register (PWR_CPUCR)*.

Table 33. Low-power exit mode flags

System mode	D1 domain mode	D2 domain mode	SBF_D1	SBF_D2	SBF	STOPF	Comment
Run	DRun or DStop	DRun or DStop	0	0	0	0	D1, D2 and system contents retained
Run	DStandby	DStop	1	0	0	0	D1 contents lost, D2 and system contents retained
Run	DRun or DStop	DStandby	0	1	0	0	D2 contents lost, D1 and system contents retained
Run	DStandby	DStandby	1	1	0	0	D1 and D2 contents lost, system contents retained
Stop	DStop	DStop	0	0	0	1	D1, D2 and system contents retained, clock system reset.
Stop	DStandby	DStop	1	0	0	1	D1 contents lost, D2 and system contents retained, clock system reset
Stop	DStop	DStandby	0	1	0	1	D2 contents lost, D1 and system contents retained, clock system reset
Stop	DStandby	DStandby	1	1	0	1	D1 and D2 contents lost, system contents retained, clock system reset
Standby	DStandby	DStandby	0(1)	0(1)	1	0	D1, D2 and system contents lost

1. When returning from Standby, the SBF_D1 and SBF_D2 reflect the reset value.

6.6.4 Power management examples

- *Figure 34* shows V_{CORE} voltage scaling behavior in Run mode.
- *Figure 35* shows V_{CORE} voltage scaling behavior in Stop mode.
- *Figure 36* shows V_{CORE} voltage regulator and voltage scaling behavior in Standby mode.
- *Figure 37* shows V_{CORE} voltage scaling behavior in Run mode with D1 and D2 domains are in DStandby mode

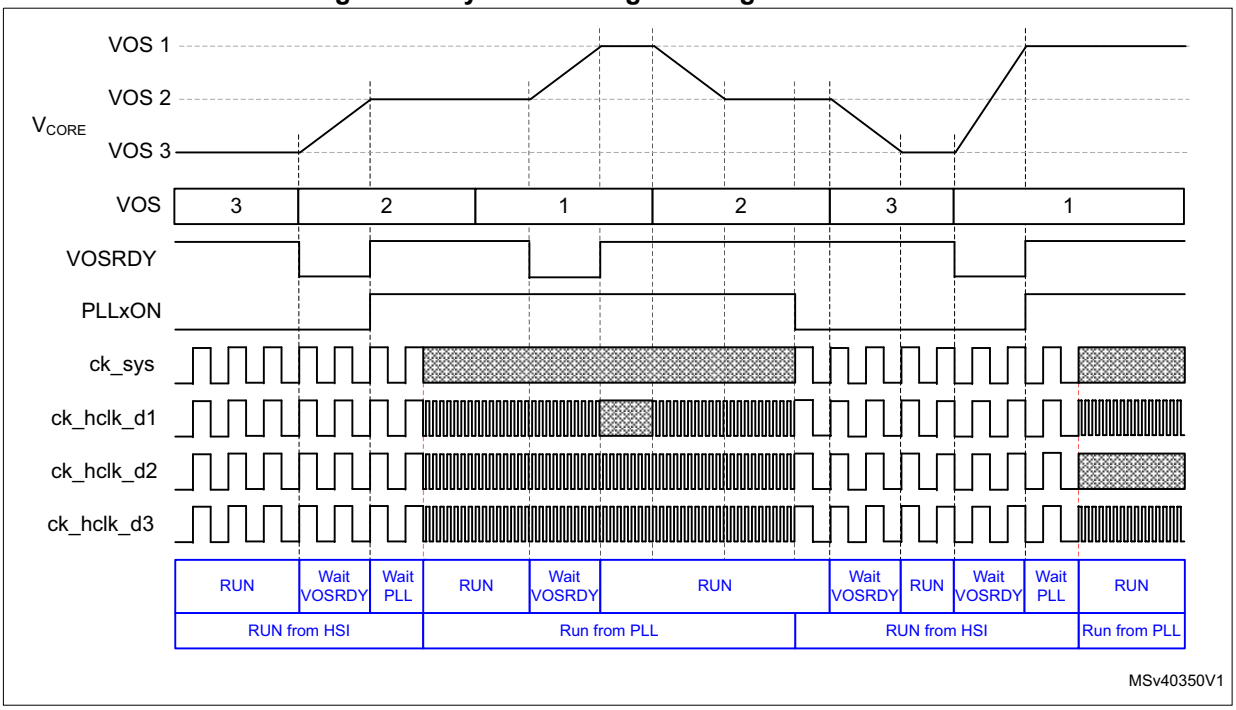
Example of V_{CORE} voltage scaling behavior in Run mode

Figure 34 illustrates the following system operation sequence example:

1. After reset, the system starts from HSI with VOS3.
2. The system performance is first increased to a medium-speed clock from the PLL with voltage scaling VOS2. To do this:
   a) Program the voltage scaling to VOS2.
   b) Once the V_{CORE} supply has reached the required level indicated by VOSRDY, increase the clock frequency by enabling the PLL.
   c) Once the PLL is locked, switch the system clock.
3. The system performance is then increased to high-speed clock from the PLL with voltage scaling VOS1. To do this:
   a) Program the voltage scaling to VOS1.
   b) Once the V_{CORE} supply has reached the required level indicated by VOSRDY, increase the clock frequency.
4. The system performance is then reduced to a medium-speed clock with voltage scaling VOS2. To do this:
   a) First decrease the system frequency.
   b) Then decrease the voltage scaling to VOS2.
5. The next step is to reduce the system performance to HSI clock with voltage scaling VOS3. To do this:
   a) Switch the clock to HSI.
   b) Disable the PLL.
   c) Decrease the voltage scaling to VOS3.
6. The system performance can then be increased to high-speed clock from the PLL. To do this:
   a) Program the voltage scaling to VOS1.
   b) Once the V_{CORE} supply has reached the required level indicated by VOSRDY, increase the clock frequency by enabling the PLL.
   c) Once the PLL is locked, switch the system clock.

When the system performance (clock frequency) is changed, VOS shall be set accordingly. otherwise the system might be unreliable.

Figure 34. Dynamic voltage scaling in Run mode



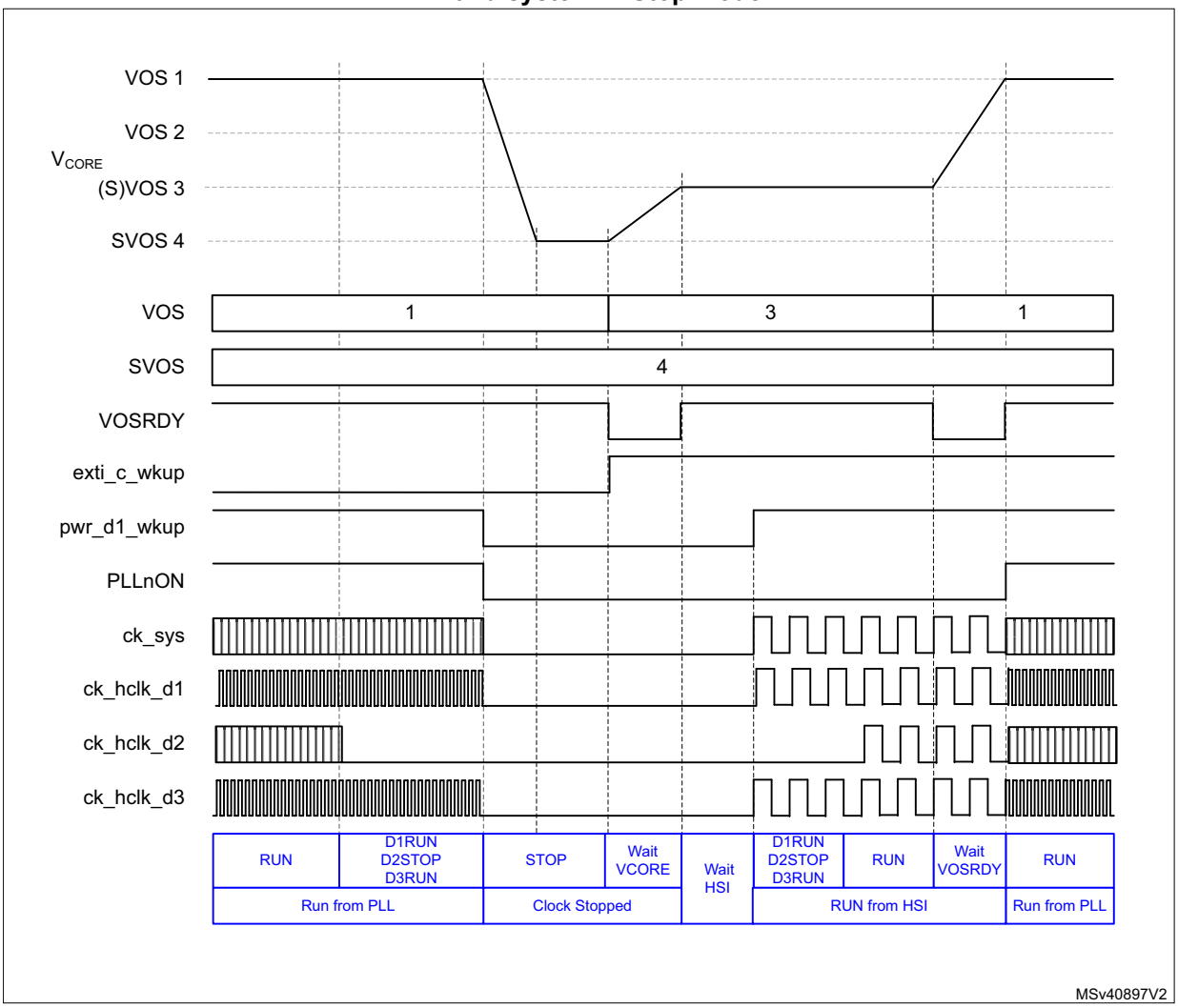
1. The status of the register bits at each step is shown in blue.

Example of V_{CORE} voltage scaling behavior in Stop mode

Figure 35 illustrates the following system operation sequence example:

1. The system is running from the PLL in high-performance mode (VOS1 voltage scaling).
2. The CPU subsystem deallocates all the peripheral in the D2 domain that will first enter DStop mode. D2 system clock is stopped. The system still provides the high-performance system clock, hence the voltage scaling shall stay at VOS1 level.
3. In a second step, the CPU subsystem enters CStop mode, D1 domain enters DStop mode and the system enters Stop mode. The system clock is stopped and the hardware lowers the voltage scaling to the software preselected SVOS4 level.
4. The CPU subsystem is then woken up. The system exits from Stop mode, the D1 domain exits from DStop mode and the CPU subsystem exits from CStop mode. The hardware then sets the voltage scaling to VOS3 level and waits for the requested supply level to be reached before enabling the HSI clock. Once the HSI clock is stable, the system clock and the D1 system clock are enabled.
5. The CPU subsystem allocates a peripheral in the D2 domain. The D2 system clock is enabled.
6. The system performance is then increased. To do this:
   a) The software first sets the voltage scaling to VOS1.
   b) Once the V_{CORE} supply has reached the required level indicated by VOSRDY, the clock frequency can be increased by enabling the PLL.
   c) Once the PLL is locked, the system clock can be switched.

Figure 35. Dynamic voltage scaling behavior with D1, D2 and system in Stop mode



1. The status of the register bits at each step is shown in blue.

Example of V_{CORE} voltage regulator and voltage scaling behavior in Standby mode

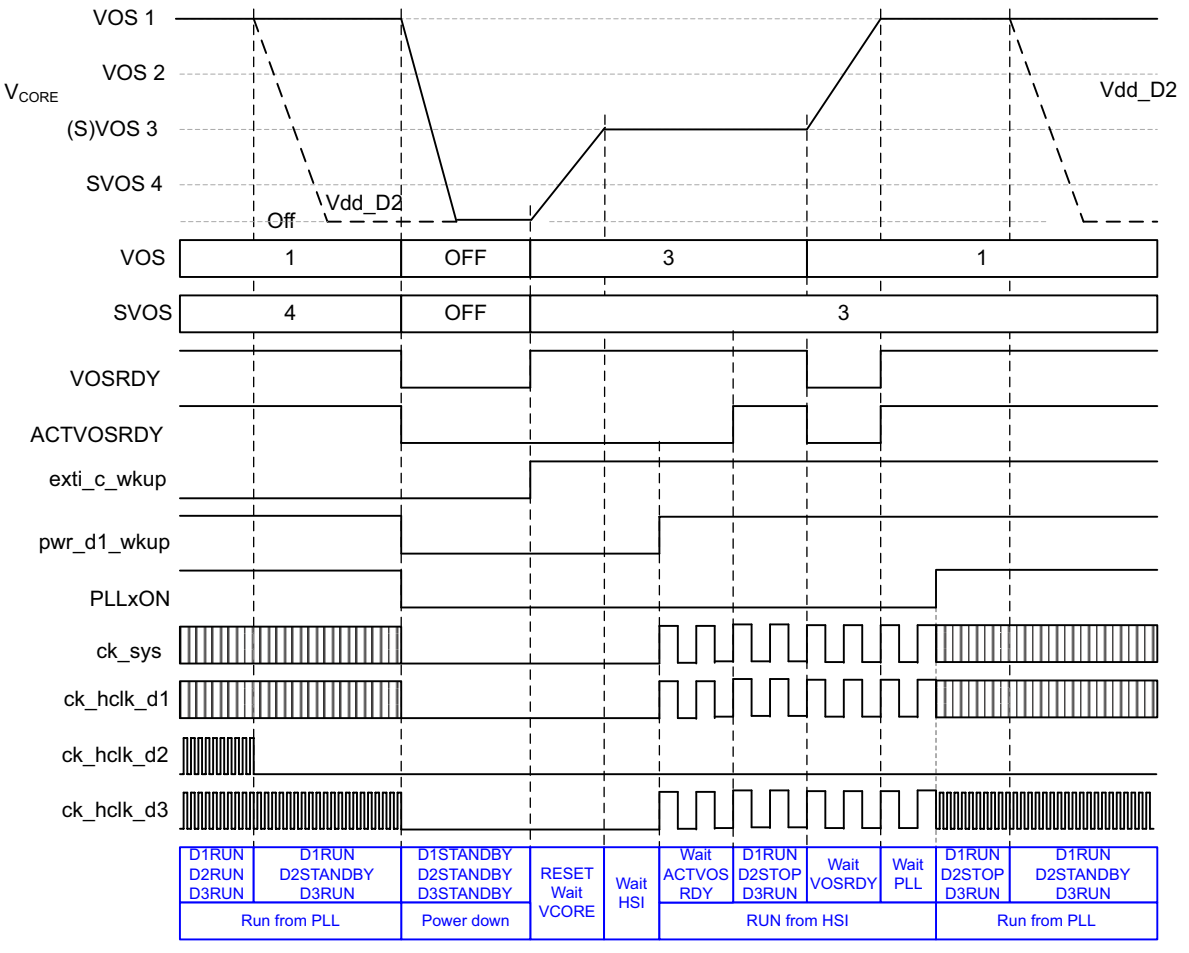
Figure 36 illustrates the following system operation sequence example:

1. The system is running from the PLL in high-performance mode (VOS1 voltage scaling).
2. The CPU subsystem deallocates all the peripherals in the D2 domain that will first enter DStandby mode.The D2 domain bus matrix clock is stopped and the power is switched off. The system performance is unchanged hence the voltage scaling does not change.
3. The CPU subsystem then enters to CStop mode, D1 domain enters DStandby mode and the system enters Standby mode. The system clock is stopped and the voltage regulator switched off.
4. The system is then woken up by a wakeup source. The system exits from Standby mode. The hardware sets the voltage scaling to the default VOS3 level and waits for the requested supply level to be reached before enabling the default HSI oscillator. Once the HSI clock is stable, the system clock and D1 subsystem clock are enabled.

Since there are no allocated peripherals in the D2 domain, this domain remains in DStop mode. The software shall then check the ACTVOSRDY is valid before changing the system performance.

5. In a next step, increase the system performance. To do this:
   a) The software first increases the voltage scaling to VOS1 level
   b) Before enabling the PLL, it waits for the requested supply level to be reached by monitoring VOSRDY bit.
   c) Once the PLL is locked, the system clock can be switched.
6. The CPU subsystem puts the D2 domain in DStandby mode.

Figure 36. Dynamic Voltage Scaling D1, D2, system Standby mode



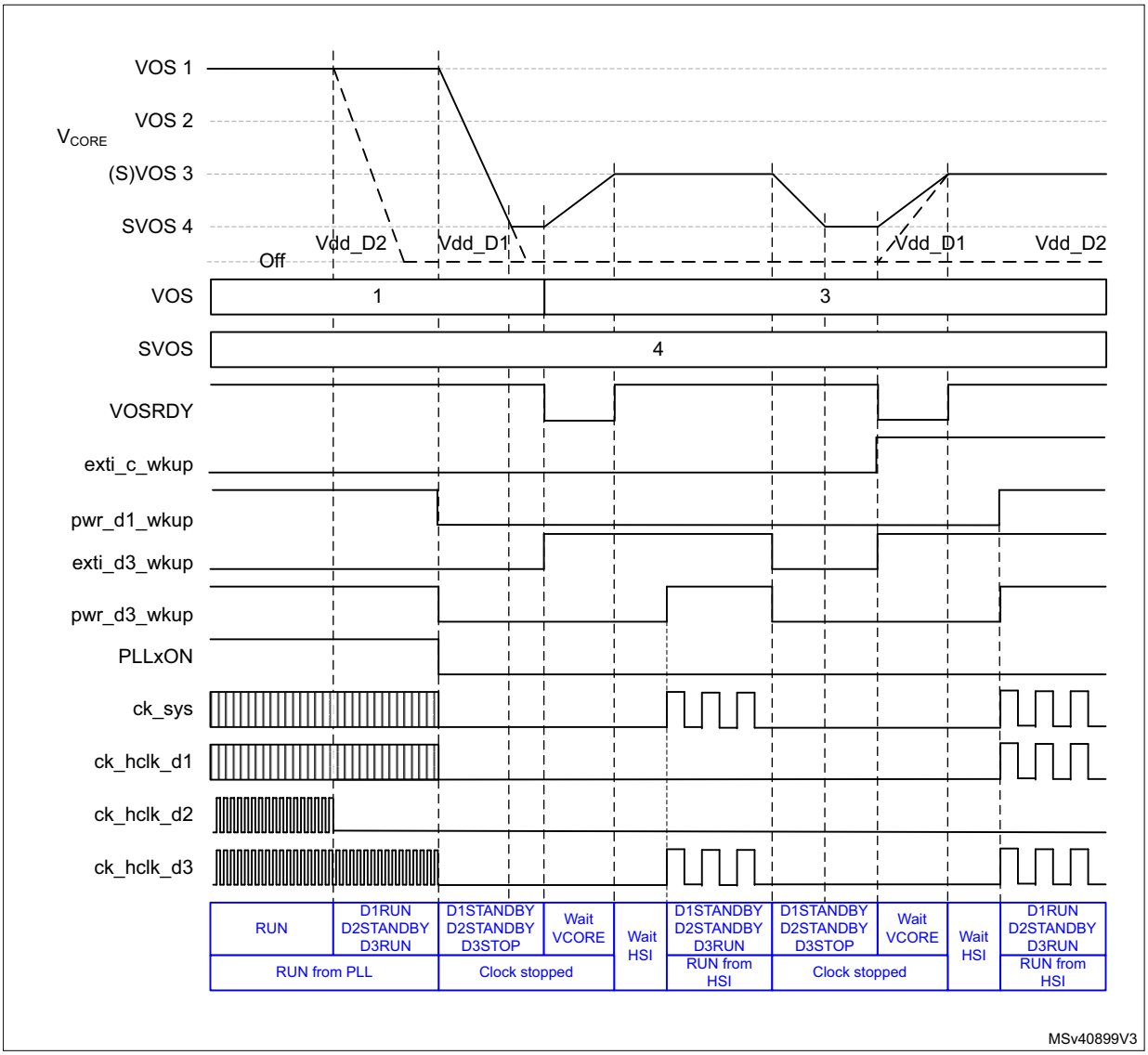
1. The status of the register bits at each step is shown in blue.

Example of V_{CORE} voltage scaling behavior in Run mode with D1 and D2 domains in DStandby mode

Figure 37 illustrates the following system operation sequence example:

1. The system is running from the PLL with system in high performance mode (VOS1 voltage scaling).
2. The CPU subsystem deallocates all the peripherals in the D2 domain that will first enter DStandby mode. The D2 domain bus matrix clock is stopped and its power switched off. The system performance is unchanged hence the voltage scaling does not change.
3. The CPU subsystem then enters CStop mode and the D1 domain enters DStandby mode. The D1 domain bus matrix clock is stopped and its power switched off. At the same time the system enters Stop mode. The system clock is stopped and the hardware lowers the voltage scaling to the software preselected SVOS4 level.
4. The system is then woken up by a D3 Autonomous mode wakeup event. The system exits from Stop mode. The hardware sets the voltage scaling to the default VOS3 level and waits for the requested supply level to be reached before enabling the HSI clock. Once the HSI clock is stable, the system clock is enabled. The system is running in D3 Autonomous mode.
5. The D3 Autonomous mode wakeup source is then cleared, causing the system to enter Stop mode. The system clock is stopped and the voltage scaling is lowered to the software preselected SVOS4 level.
6. The CPU subsystem is then woken up. The system exits from Stop mode, the D1 domain exits from DStandby mode and the CPU subsystem exits from CStop mode. The hardware sets the voltage scaling to the default VOS3 level and waits for the requested supply level to be reached before enabling the default HSI oscillator. Once the HSI clock is stable, the system clock and the D1 subsystem clock are enabled. The D2 domain remains in DStandby mode.

Figure 37. Dynamic voltage scaling behavior with D1 and D2 in DStandby mode and D3 in Autonomous mode



1. The status of the register bits at each step is shown in blue.

6.7 Low-power modes

Several low-power modes are available to save power when the CPU does not need to execute code (i.e. when waiting for an external event). It is up to the user application to select the mode that gives the best compromise between low power consumption, short startup time and available wakeup sources:

- Slowing down system clocks (see *Section 8.5.6: System clock (sys_ck)*)
- Controlling individual peripheral clocks (see *Section 8.5.11: Peripheral clock gating control*)
- Low-power modes
  - CSleep (CPU clock stopped)
  - CStop (CPU subsystem clock stopped)
  - DStop (Domain bus matrix clock stopped)
  - Stop (System clock stopped)
  - DStandby (Domain powered down)
  - Standby (System powered down)

6.7.1 Slowing down system clocks

In Run mode, the speed of the system clock ck_sys can be reduced. For more details refer to *Section 8.5.6: System clock (sys_ck)*.

6.7.2 Controlling peripheral clocks

In Run mode, the HCLKx and PCLKx for individual peripherals can be stopped by configuring at any time PERxEN bit in RCC_C1_xxxxENR or RCC_xxxxENR to reduce power consumption.

To reduce power consumption in CSleep mode, the individual peripheral clocks can be disabled by configuring PERxLPEN bit in RCC_C1_xxxxLPENR or RCC_xxxxLPENR. For the peripherals still receiving a clock in CSleep mode, their clock can be slowed down before entering CSleep mode.

6.7.3 Entering low-power modes

CPU subsystem CSleep and CStop low-power modes are entered by the MCU when executing the WFI (Wait For Interrupt) or WFE (Wait for Event) instructions, or when the SLEEPONEXIT bit in the Cortex®-M System Control register is set on Return from ISR.

The D2 domain enters DStop or DStandby when the CPU subsystem has no peripheral allocated in the domain or is in CStop. The D1 domain enters DStop or DStandby when the CPU subsystem is in CStop.

The system can enter Stop or Standby low-power mode when all EXTI wakeup sources are cleared and the other domains are in DStop or DStandby mode.

6.7.4 Exiting from low-power modes

The CPU subsystem exits from CSleep mode through any interrupt or event depending on how the low-power mode was entered:

- If the WFI instruction or Return from ISR was used to enter to low-power mode, any peripheral interrupt acknowledged by the NVIC can wake up the system.
- If the WFE instruction is used to enter to low-power mode, the CPU exits from low-power mode as soon as an event occurs. The wakeup event can be generated either by:
  - An NVIC IRQ interrupt.

    When SEVONPEND = 0 in the Cortex®-M7 System Control register, the interrupt must be enabled in the peripheral control register and in the NVIC.

    When the MCU resumes from WFE, the peripheral interrupt pending bit and the NVIC peripheral IRQ channel pending bit in the NVIC interrupt clear pending register have to be cleared. Only NVIC interrupts with sufficient priority will wakeup and interrupt the MCU.

    When SEVONPEND = 1 in the Cortex®-M7 System Control register, the interrupt must be enabled in the peripheral control register and optionally in the NVIC. When the MCU resumes from WFE, the peripheral interrupt pending bit and, when enabled, the NVIC peripheral IRQ channel pending bit (in the NVIC interrupt clear pending register) have to be cleared.

    All NVIC interrupts will wakeup the MCU, even the disabled ones.

    Only enabled NVIC interrupts with sufficient priority will wakeup and interrupt the MCU.
  - An event

    An EXTI line must be configured in event mode. When the CPU resumes from WFE, it is not necessary to clear the EXTI peripheral interrupt pending bit or the NVIC IRQ channel pending bit as the pending bits corresponding to the event line is not set. It might be necessary to clear the interrupt flag in the peripheral.

The CPU subsystem exits from CStop, DStop and Stop modes by enabling an EXTI interrupt or event depending on how the low-power mode was entered (see above).

The system can wake up from Stop mode by enabling an EXTI wakeup, without waking up a CPU subsystem. In this case the system will operate in D3 Autonomous mode.

The CPU subsystem exits from DStandby mode by enabling an EXTI interrupt or event, regardless on how DStandby mode was entered. Program execution restarts from CPU local reset (such as a reset vector fetched from System configuration block (SYSCFG).

The D2 domain can exit from DStop or DStandby mode when the CPU allocates a first peripheral in the domain.

The CPU subsystem exits from Standby mode by enabling an external reset (NRST pin), an IWDG reset, a rising edge on one of the enabled WKUPx pins or a RTC event. Program execution restarts in the same way as after a system reset (such as boot pin sampling, option bytes loading or reset vector fetched).

6.7.5 CSleep mode

The CSleep mode applies only to the CPU subsystem. In CSleep mode, the CPU clock is stopped. The CPU subsystem peripheral clocks operate according to the values of PERxLPEN bits in RCC_C1_xxxxENR or RCC_xxxxENR.

Entering CSleep mode

The CSleep mode is entered according to *Section 6.7.3: Entering low-power modes*, when the SLEEPDEEP bit in the Cortex®-M System Control register is cleared.

Refer to *Table 34* for details on how to enter to CSleep mode.

Exiting from CSleep mode

The CSleep mode is exited according to *Section 6.7.4: Exiting from low-power modes*.

Refer to *Table 34* for more details on how to exit from CSleep mode.

Table 34. CSleep mode

CSleep mode	Description
Mode entry	WFI (Wait for Interrupt) or WFE (Wait for Event) while: – SLEEPDEEP = 0 (Refer to the Cortex®-M System Control register.) – CPU NVIC interrupts and events cleared.
	On return from ISR while: – SLEEPDEEP = 0 and – SLEEPONEXIT = 1 (refer to the Cortex®-M System Control register.) – CPU NVIC interrupts and events cleared.
Mode exit	If WFI or return from ISR was used for entry: – Any Interrupt enabled in NVIC: Refer to *Table 140: NVIC* If WFE was used for entry and SEVONPEND = 0: – Any event: Refer to *Section 20.5.3: EXTI CPU wakeup procedure* If WFE was used for entry and SEVONPEND = 1: – Any Interrupt even when disabled in NVIC: refer to *Table 140: NVIC* or any event: refer to *Section 20.5.3: EXTI CPU wakeup procedure*
Wakeup latency	None

6.7.6 CStop mode

The CStop mode applies only to the CPU subsystem. In CStop mode, the CPU clock is stopped. Most CPU subsystem peripheral clocks are stopped too and only the CPU subsystem peripherals having a PERxAMEN bit operate accordingly.

In CStop mode, CPU subsystem peripherals having a kernel clock request can still request their kernel clock. For the peripheral having a PERxAMEN bit, this bit must be set to be able to request the kernel clock.

Entering CStop mode

The CStop mode is entered according to *Section 6.7.3: Entering low-power modes*, when the SLEEPDEEP bit in the Cortex®-M System Control register is set.

Refer to *Table 35* for details on how to enter to CStop mode.

Exiting from CStop mode

The CStop mode is exited according to *Section 6.7.4: Exiting from low-power modes*.

Refer to *Table 35* for more details on how to exit from CStop mode.

Table 35. CStop mode

CStop mode	Description
Mode entry	WFI (Wait for Interrupt) or WFE (Wait for Event) while: – SLEEPDEEP = 1 (Refer to the Cortex®-M System Control register.) – CPU NVIC interrupts and events cleared. – All CPU EXTI Wakeup sources are cleared.
	On return from ISR while: – SLEEPDEEP = 1 and – SLEEPONEXIT = 1 (Refer to the Cortex®-M System Control register.) – CPU NVIC interrupts and events cleared. – All CPU EXTI Wakeup sources are cleared.
Mode exit	If WFI or return from ISR was used for entry: – EXTI Interrupt enabled in NVIC: Refer to *Table 140: NVIC*, for peripheral which are not stopped or powered down. If WFE was used for entry and SEVONPEND = 0: – EXTI event: Refer to *Section 20.5.3: EXTI CPU wakeup procedure*, for peripheral which are not stopped or powered down. If WFE was used for entry and SEVONPEND = 1: – EXTI Interrupt even when disabled in NVIC: refer to *Table 140: NVIC* or EXTI event: refer to *Section 20.5.3: EXTI CPU wakeup procedure*, for peripheral which are not stopped or powered down.
Wakeup latency	EXTI and RCC wakeup synchronization (see *Section 8.4.7: Power-on and wakeup sequences*)

6.7.7 DStop mode

D1 domain and/or D2 domain enters DStop mode only when the CPU subsystem is in CStop mode and has allocated peripheral in the domain (see *Table 36*). In DStop mode the domain bus matrix clock is stopped.

The Flash memory can enter low-power Stop mode when it is enabled through FLPS in PWR_CR1 register. This allows a trade-off between domain DStop restart time and low power consumption.

Table 36. DStop mode overview

Peripheral allocation	CPU	D1 domain	D2 domain	Comment
No peripheral allocated in D2 domain	CRun or CSleep	DRun	DStop	
	CStop	DStop	DStop	
Peripheral allocated in D2 domain	CRun or CSleep	DRun	DRun	CPU subsystem, keep D2 domain active.
	CStop	DStop	DStop	

In DStop mode domain peripherals using the LSI or LSE clock and peripherals having a kernel clock request are still able to operate.

Entering DStop mode

The DStop mode is entered according to *Section 6.7.3: Entering low-power modes*, when at least one PDDS_Dn bit in *PWR CPU control register (PWR_CPUCR)* for the domain select Stop.

Refer to *Table 37* for details on how to enter DStop mode.

If Flash memory programming is ongoing, the DStop mode entry is delayed until the memory access is finished.

If an access to the domain bus matrix is ongoing, the DStop mode entry is delayed until the domain bus matrix access is complete.

Exiting from DStop mode

The DStop mode is exited according to *Section 6.7.4: Exiting from low-power modes*.

Refer to *Table 37* for more details on how to exit from DStop mode.

When exiting from DStop mode, the CPU subsystem clocks, domain(s) bus matrix clocks and voltage scaling depend on the system mode.

- When the system did not enter Stop mode, the CPU subsystem clocks, domain(s) bus matrix clocks and voltage scaling values are the same as when entering DStop mode.
- When the system has entered Stop mode, the CPU subsystem clocks, domain(s) bus matrix clocks and voltage scaling are reset.

Table 37. DStop mode

DStop mode	Description
Mode entry	– The domain CPU subsystem enters CStop. – The CPU subsystem has an allocated peripheral in the D2 domain and enters CStop. – The CPU subsystem deallocated its last peripheral in the D2 domain. – The PDDS_Dn bit for the domain selects Stop mode.

Table 37. DStop mode

DStop mode	Description
Mode exit	– The domain CPU subsystem exits from CStop mode (see *Table 35*) – The CPU subsystem has an allocated peripheral in the D2 domain and exits from CStop mode (see *Table 35*) – The CPU subsystem allocates a first peripheral in the D2 domain.
Wakeup latency	EXTI and RCC wakeup synchronization (see *Section 8.4.7: Power-on and wakeup sequences*).

6.7.8 Stop mode

The system D3 domain enters Stop mode only when the CPU subsystem is in CStop mode, the EXTI wakeup sources are inactive and at least one PDDS_Dn bit in *PWR CPU control register (PWR_CPUCR)* for any domain request Stop. In Stop mode, the system clock including a PLL and the D3 domain bus matrix clocks are stopped.

The HSI or CSI can remain enabled in system Stop mode (HSIKERON and CSIKERON set in RCC_CR register). After exiting Stop mode, the clock is quickly available as kernel clock for peripherals. Other system oscillator sources are stopped and require a starting time after exiting Stop mode.

In system D3 domain Stop mode, D1 domain and D2 domain are either in DStop and/or DStandby mode.

In Stop mode, the domain peripherals that use the LSI or LSE clock, and the peripherals that have a kernel clock request to select HSI or CSI as source, are still able to operate.

In system Stop mode, the following features can be selected to remain active by programming individual control bits:

- Independent watchdog (IWDG)

  The IWDG is started by writing to its Key register or by hardware option. Once started it cannot be stopped except by a Reset (see *Section 50.3* in *Section 50: Independent watchdog (IWDG)*.
- Real-time clock (RTC)

  This is configured via the RTCEN bit in the *RCC backup domain control register (RCC_BDCR)*.
- Internal RC oscillator (LSI RC)

  This is configured via the LSION bit in the *RCC Clock Control and Status Register (RCC_CSR)*.
- External 32.768 kHz oscillator (LSE OSC)

  This is configured via the LSEON bit in the *RCC backup domain control register (RCC_BDCR)*.

- Peripherals capable of running on the LSI or LSE clock.
- Peripherals having a kernel clock request.
- Internal RC oscillators (HSI and CSI)

  This is configured via the HSIKERON and CSIKERON bits in the *RCC Clock Control and Status Register (RCC_CSR)*.
- The ADC or DAC can also consume power during Stop mode, unless they are disabled before entering this mode. To disable them, the ADON bit in the ADC_CR2 register and the ENx bit in the DAC_CR register must both be written to 0.

The selected SVOS4 and SVOS5 levels add an additional startup delay when exiting from system Stop mode (see *Table 38*).

Table 38. Stop mode operation

SVOS	LPDS	Stop mode Voltage regulator operation	Wake-up Latency
SVOS3	0	**Main**	No additional wakeup time.
	1	**LP**	Voltage Regulator wakeup time from LP mode.
SVOS4 or SVOS5	x	**LP**	Voltage Regulator wakeup time from LP mode + voltage level wakeup time for SVOS4 or SVOS5 level to VOS3 level

Entering Stop mode

The Stop mode is entered according to *Section 6.7.3: Entering low-power modes*, when at least one PDDS_Dn bit n *PWR CPU control register (PWR_CPUCR)* for any domain request Stop.

Refer to *Table 39* for details on how to enter Stop mode.

If Flash memory programming is ongoing, the Stop mode entry is delayed until the memory access is finished.

If an access to a bus matrix (AXI, AHB or APB) is ongoing, the Stop mode entry is delayed until the bus matrix access is finished.

To allow peripherals having a kernel clock request to operate in Stop mode, the system must use SVOS3 level.

Note: Use a DSB instruction to ensure that outstanding memory transactions complete before entering stop mode.

Exiting from Stop mode

The Stop mode is exited according to *Section 6.7.4: Exiting from low-power modes*.

Refer to *Table 39* for more details on how to exit from Stop mode.

When exiting from Stop mode, the system clock, D3 domain bus matrix clocks and voltage scaling are reset.

STOPF status flag in *PWR CPU control register (PWR_CPUCR)* indicates that the system has exited from Stop mode (see *Table 33*).

Table 39. Stop mode

Stop mode	Description
Mode entry	– When the CPU is in CStop mode and there is no active EXTI Wakeup source and Run_D3 = 0. – At least one PDDS_Dn bit for any domain select Stop.
Mode exit	– On a EXTI Wakeup.
Wakeup latency	System oscillator startup (when disabled). + EXTI and RCC wakeup synchronization. + Voltage Scaling refer to *Table 38* (see *Section 6.6.2: Voltage scaling*)

I/O states in Stop mode

I/O pin configuration remain unchanged in Stop mode.

6.7.9 DStandby mode

Like DStop mode, DStandby mode is based on the CPU subsystem CStop mode. However the domain V_{CORE} supply is powered off. A domain enters DStandby mode only when the CPU subsystem is in CStop mode if peripherals are allocated in the domain

A domain enters DStandby mode only when the CPU subsystem is in CStop mode if peripherals are allocated in the domain and the PDDS_Dn bit in *PWR CPU control register (PWR_CPUCR)* for the domain is configured accordingly. In DStandby mode, the domain is powered down and the domain RAM and register contents are lost.

Entering DStandby mode

The DStandby mode is entered according to *Section 6.7.3: Entering low-power modes*, when the PDDS_Dn bit in *PWR CPU control register (PWR_CPUCR)* for the Dn domain selects Standby mode.

Refer to *Table 40* for details on how to enter DStandby mode.

If Flash memory programming is ongoing, the DStandby mode entry is delayed until the memory access is finished.

If an access to the domain bus matrix is ongoing, the DStandby mode entry is delayed until the domain bus matrix access is finished.

Note: When the CPU sets the PDDS_D2 bit to select Standby mode, the D2 domain enters DStandby mode (the CPU has no allocated peripherals in the D2 domain).

Exiting from DStandby mode

The DStandby mode is exited according to *Section 6.7.4: Exiting from low-power modes*.

Refer to *Table 40* for more details on how to exit from DStandby mode.

Note: When the D2 domain is in DStandby mode and the CPU sets the domain PDDS_D2 bit to select Stop mode, the D2 domain remains in DStandby mode. The D2 domain will only exit DStandby when the CPU allocates a peripheral in the D2 domain.

When exiting from DStandby mode, the domain CPU and peripherals are reset. However the state of the CPU subsystem clocks, domain(s) bus matrix clocks and voltage scaling depends on the system mode:

- When the system did not enter Stop mode, the CPU subsystem clocks, domain(s) bus matrix clocks and voltage scaling are the same as when entering DStandby mode.
- When the system has entered Stop or Standby mode, the CPU subsystem clocks, domain(s) bus matrix clocks and voltage scaling are reset.

When the D2 domain exits from DStandby mode due to the CPU subsystem (i.e when allocating a first peripheral or when peripherals are allocated in the D2 domain and the CPU subsystem exits from CStop mode), the CPU shall verify that the domain has exited from DStandby mode. To ensure correct operation, it is recommended to follow the sequence below:

1. First check that the domain bus matrix clock is available. The domain bus matrix clock state can be checked in RCC_CR register:
   – When RCC DnCKRDY = 0, the domain bus matrix clock is stalled.
   – If RCC DnCKRDY = 1, the domain bus matrix clock is enabled.
2. Then wait for the domain has exited from DStandby mode. To do this, check the SBF_Dn flag in *PWR CPU control register (PWR_CPUCR)*. The domain is powered and can be accessed only when SBF_Dn is cleared. Below an example of code:

```
Loop
write PWR SBF_Dn = 0 ; try to clear bit.
read PWR SBF_Dn
While 1 ==> loop
```

Table 40. DStandby mode

DStandby mode	Description
Mode entry	– The domain CPU subsystem enters CStop. – The CPU subsystem has an allocated peripheral in D2 domain and enters CStop. – The CPU subsystem deallocated its last peripheral in the D2 domain. – The PDDS_Dn bits for the domain select Standby mode. – All WKUPF bits in Power Control/Status register (PWR_WKUPFR) are cleared.
Mode exit	– The CPU subsystem exits from CStop mode (see *Table 35*) – The CPU subsystem has an allocated peripheral in the D2 domain and exits from CStop mode (see *Table 35*) – The CPU subsystem allocates a first peripheral in the D2 domain.
Wakeup latency	EXTI and RCC wakeup synchronization. + Domain power up and reset. (see *Section 8.4.7: Power-on and wakeup sequences*)

6.7.10 Standby mode

The Standby mode allows achieving the lowest power consumption. Like Stop mode, it is based on CPU subsystem CStop mode. However the V_{CORE} supply regulator is powered off.

The system D3 domain enters Standby mode only when the D1 and D2 domain are in DStandby. When the system D3 domain enters Standby mode, the voltage regulator is disabled. The complete V_{CORE} domain is consequently powered off. The PLLs, HSI oscillator, CSI oscillator, HSI48 and the HSE oscillator are also switched off. SRAM and register contents are lost except for backup domain registers (RTC registers, RTC backup register and backup RAM), and Standby circuitry (see *Section 6.4.4: Backup domain*).

In system Standby mode, the following features can be selected by programming individual control bits:

- Independent watchdog (IWDG)

  The IWDG is started by programming its Key register or by hardware option. Once started, it cannot be stopped except by a reset (see *Section 50.3* in *Section 50: Independent watchdog (IWDG)*.
- Real-time clock (RTC)

  This is configured via the RTCEN bit in the backup domain control register (RCC_BDCR).
- Internal RC oscillator (LSI RC)

  This is configured by the LSION bit in the Control/status register (RCC_CSR).
- External 32.768 kHz oscillator (LSE OSC)

  This is configured by the LSEON bit in the backup domain control register (RCC_BDCR).

Entering Standby mode

The Standby mode is entered according to *Section 6.7.3: Entering low-power modes*, when all PDDS_Dn bits in *PWR CPU control register (PWR_CPUCR)* for all domains request Standby.

Refer to *Table 42* for more details on how to enter to Standby mode.

Exiting from Standby mode

The Standby mode is exited according to *Section 6.7.4: Exiting from low-power modes*.

Refer to *Table 42* for more details on how to exit from Standby mode.

The system exits from Standby mode when an external Reset (NRST pin), an IWDG Reset, a WKUP pin event, a RTC alarm, a tamper event, or a time stamp event is detected. All registers are reset after waking up from Standby except for power control and status registers (*PWR control register 2 (PWR_CR2)*, *PWR control register 3 (PWR_CR3)*), SBF bit in *PWR CPU control register (PWR_CPUCR)*, *PWR wakeup flag register (PWR_WKUPFR)*, and *PWR wakeup enable and polarity register (PWR_WKUPEPR)*.

After waking up from Standby mode, the program execution restarts in the same way as after a system reset (boot option sampling, boot vector reset fetched, etc.). The SBF status flags in *PWR CPU control register (PWR_CPUCR)* registers indicate from which mode the system has exited (see *Table 41*).

Table 41. Standby and Stop flags

SBF_D2	SBF_D1	SBF	STOPF	Description
0	1	0	0	D1 domain exits from DStandby while system stayed in Run
0	1	0	1	D1 domain exits from DStandby, while system has been in or exits from Stop
1	0	0	0	D2 domain exits from DStandby while system stayed in Run
1	0	0	1	D2 domain exits from DStandby while system has been in or exits from Stop
1	1	0	0	D1 and D2 domain exit from DStandby while the system remains in Run mode
1	1	0	1	D1 and D2 domain exit from DStandby while the system is in Stop mode or is exiting this mode.
0	0	0	1	System has been in or exits from Stop
0(1)	0(1)	1	0	System exits from Standby

1. When exiting from Standby the SBF_D1 and SBF_D2 reflect the reset value

Table 42. Standby mode

Standby mode	Description
Mode entry	– The CPU subsystem is in CStop mode, and there is no active EXTI Wakeup source and RUN_D3 = 0. – All PDDS_Dn bits for all domains select Standby. – All WKUPF bits in Power Control/Status register (PWR_WKUPFR) are cleared.
Mode exit	– WKUP pins rising or falling edge, RTC alarm (Alarm A and Alarm B), RTC wakeup, tamper event, time stamp event, external reset in NRST pin, IWDG reset.
Wakeup latency	System reset phase (see *Section 8.4.2: System reset*)

I/O states in Standby mode

In Standby mode, all I/O pins are high impedance without pull, except for:

- Reset pad (still available)
- RTC_AF1 pin if configured for tamper, time stamp, RTC Alarm out, or RTC clock calibration out
- WKUP pins (if enabled). The WKUP pin pull configuration can be defined through WKUPPUPD register bits in *PWR wakeup enable and polarity register (PWR_WKUPEPR)*.

6.7.11 Monitoring low-power modes

The devices feature state monitoring pins to monitor the CPU and Domain state transition to low-power mode (refer to *Table 43* for the list of pins and their description). The GPIO pin corresponding to each monitoring signal has to be programmed in alternate function mode.

This feature is not available in Standby mode since these I/O pins are switched to high impedance.

Table 43. Low-power modes monitoring pin overview

Power state monitoring pins	Description
CSLEEP	Sleeping CPU state
CDSLEEP	Deepsleep CPU state
DxPWREN	Domain (Dx, x= 1 or 2) power enabled

The values of the monitoring pins reflect the state of the CPU and domains. Refer to *Table 44*. for the GPIO state depending on CPU and domain state.

Table 44. GPIO state according to CPU and domain state

Domain DxPWREN	CPU		CPU power state	Domain Dx power state
	CSLEEP	CDSLEEP		
1	0	0	CPU in Run mode	DRun mode
1	1	0	CPU in Sleep mode	
1	0	1	CPU in Run mode	
1	1	1	CPU in Deepsleep mode	DStop mode
0	-	-	-(1)	DStandby mode

1. The full domain is in power off state and the CPU is powered off.

6.8 PWR registers

The PWR registers can be accessed in word, half-word and byte format, unless otherwise specified.

6.8.1 PWR control register 1 (PWR_CR1)

Address offset: 0x000

Reset value: 0xF000 C000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALS[1:0]		AVDEN
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SVOS[1:0]		Res.	Res.	Res.	Res.	FLPS	DBP	PLS[2:0]			PVDE	Res.	Res.	Res.	LPDS
rw	rw					rw	rw	rw	rw	rw	rw				rw

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:17 **ALS[1:0]:** Analog voltage detector level selection

These bits select the voltage threshold detected by the AVD.

00: 1.7 V

01: 2.1 V

10: 2.5 V

11: 2.8 V

Bit 16 **AVDEN:** Peripheral voltage monitor on V_{DDA} enable

0: Peripheral voltage monitor on V_{DDA} disabled.

1: Peripheral voltage monitor on V_{DDA} enabled

Bits 15:14 **SVOS[1:0]:** System Stop mode voltage scaling selection

These bits control the V_{CORE} voltage level in system Stop mode, to obtain the best trade-off between power consumption and performance.

00: Reserved

01: SVOS5 Scale 5

10: SVOS4 Scale 4

11: SVOS3 Scale 3 (default)

Bits 13:10 Reserved, must be kept at reset value.

Bit 9 **FLPS:** Flash low-power mode in DStop mode

This bit allows to obtain the best trade-off between low-power consumption and restart time when exiting from DStop mode.

When it is set, the Flash memory enters low-power mode when D1 domain is in DStop mode.

0: Flash memory remains in normal mode when D1 domain enters DStop (quick restart time).

1: Flash memory enters low-power mode when D1 domain enters DStop mode (low-power consumption).

Bit 8 **DBP:** Disable backup domain write protection

In reset state, the RCC_BDCR register, the RTC registers (including the backup registers), BREN and MOEN bits in PWR_CR2 register, are protected against parasitic write access. This bit must be set to enable write access to these registers.

0: Access to RTC, RTC backup registers and backup SRAM disabled

1: Access to RTC, RTC backup registers and backup SRAM enabled

Note: Depending on the APB1 prescaler, there is a delay between the write to DBP and the effective disable/enable of the backup domain protection. Therefore, a dummy read operation to PWR_CR1 register is required just after writing to the DBP bit.

Bits 7:5 **PLS[2:0]:** Programmable voltage detector level selection

These bits select the voltage threshold detected by the PVD.

000: 1.95 V

001: 2.1 V

010: 2.25 V

011: 2.4 V

100: 2.55 V

101: 2.7 V

110: 2.85 V

111: External voltage level on PVD_IN pin, compared to internal V_{REFINT} level.

Note: Refer to Section "Electrical characteristics" of the product datasheet for more details.

Bit 4 **PVDE:** Programmable voltage detector enable

0: Programmable voltage detector disabled.

1: Programmable voltage detector enabled

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **LPDS:** Low-power Deepsleep with SVOS3 (SVOS4 and SVOS5 always use low-power, regardless of the setting of this bit)

0: Voltage regulator or SMPS step-down converter in Main mode (MR) when SVOS3 is selected for Stop mode

1: Voltage regulator or SMPS step-down converter in Low-power mode (LPR) when SVOS3 is selected for Stop mode

6.8.2 PWR control status register 1 (PWR_CSR1)

Address offset: 0x004

Reset value: 0x0000 4000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AVDO
															r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACTVOS[1:0]		ACTVOSRDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PVDO	Res.	Res.	Res.	Res.
r	r	r									r				

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **AVDO**: Analog voltage detector output on V_{DDA}

This bit is set and cleared by hardware. It is valid only if AVD on V_{DDA} is enabled by the AVDEN bit.

0: V_{DDA} is equal or higher than the AVD threshold selected with the ALS[2:0] bits.

1: V_{DDA} is lower than the AVD threshold selected with the ALS[2:0] bits

Note: Since the AVD is disabled in Standby mode, this bit is equal to 0 after Standby or reset until the AVDEN bit is set.

Bits 15:14 **ACTVOS[1:0]**: VOS currently applied for V_{CORE} voltage scaling selection.

These bits reflect the last VOS value applied to the PMU.

Bit 13 **ACTVOSRDY:** Voltage levels ready bit for currently used VOS and SDLEVEL

This bit is set to 1 by hardware when the voltage regulator and the SMPS step-down converter are both disabled and Bypass mode is selected in PWR control register 3 (PWR_CR3).

0: Voltage level invalid, above or below current VOS and SDLEVEL selected levels.

1: Voltage level valid, at current VOS and SDLEVEL selected levels.

Bits 12:5 Reserved, must be kept at reset value.

Bit 4 **PVDO**: Programmable voltage detect output

This bit is set and cleared by hardware. It is valid only if the PVD has been enabled by the PVDE bit.

0: V_{DD} or PVD_IN voltage is equal or higher than the PVD threshold selected through the PLS[2:0] bits.

1: V_{DD} or PVD_IN voltage is lower than the PVD threshold selected through the PLS[2:0] bits.

Note: since the PVD is disabled in Standby mode, this bit is equal to 0 after Standby or reset until the PVDE bit is set.

Bits 3:0 Reserved, must be kept at reset value.

6.8.3 PWR control register 2 (PWR_CR2)

Address offset: 0x008

Reset value: 0x0000 0000

This register is not reset by wakeup from Standby mode, RESET signal and V_{DD} POR. It is only reset by V_{SW} POR and VSWRST reset.

This register must not be accessed when VSWRST bit in RCC_BDCR register resets the V_{SW} domain.

After reset, PWR_CR2 register is write-protected. Prior to modifying its content, the DBP bit in PWR_CR1 register must be set to disable the write protection.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TEMPH	TEMPL	VBATH	VBATL	Res.	Res.	Res.	BRRDY
								r	r	r	r				r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MONEN	Res.	Res.	Res.	BREN
											rw				rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **TEMPH**: Temperature level monitoring versus high threshold
0: Temperature below high threshold level.
1: Temperature equal or above high threshold level.

Bit 22 **TEMPL**: Temperature level monitoring versus low threshold
0: Temperature above low threshold level.
1: Temperature equal or below low threshold level.

Bit 21 **VBATH**: V_{BAT} level monitoring versus high threshold
0: V_{BAT} level below high threshold level.
1: V_{BAT} level equal or above high threshold level.

Bit 20 **VBATL**: V_{BAT} level monitoring versus low threshold
0: V_{BAT} level above low threshold level.
1: V_{BAT} level equal or below low threshold level.

Bits 19:17 Reserved, must be kept at reset value.

Bit 16 **BRRDY**: Backup regulator ready
This bit is set by hardware to indicate that the backup regulator is ready.
0: Backup regulator not ready.
1: Backup regulator ready.

Bits 15:5 Reserved, must be kept at reset value.

Bit 4 **MONEN:** V_{BAT} and temperature monitoring enable
When set, the V_{BAT} supply and temperature monitoring is enabled.
0: V_{BAT} and temperature monitoring disabled.
1: V_{BAT} and temperature monitoring enabled.
Note: V_{BAT} and temperature monitoring are only available when the backup regulator is enabled (BREN bit set to 1).

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **BREN:** Backup regulator enable
When set, the backup regulator (used to maintain the backup RAM content in Standby and V_{BAT} modes) is enabled.
If BREN is reset, the backup regulator is switched off. The backup RAM can still be used in Run and Stop modes. However, its content will be lost in Standby and V_{BAT} modes.
If BREN is set, the application must wait till the backup regulator ready flag (BRRDY) is set to indicate that the data written into the SRAM will be maintained in Standby and V_{BAT} modes.
0: Backup regulator disabled.
1: Backup regulator enabled.

6.8.4 PWR control register 3 (PWR_CR3)

Address offset: 0x00C

Reset value: 0x0000 0046

This register is reset only by a power-on reset (POR). It is not reset by a wakeup from Standby mode or a the RESET signal.

The lower byte of this register is written once after POR and must be written before changing VOS level or ck_sys clock frequency. No limitation applies to the upper bytes.

Programming data corresponding to an invalid combination of SDLEVEL, SDEXTHP, SDEN, LDOEN and BYPASS bits (see *Table 30*) will be ignored: data will not be written, the written-once mechanism will lock the register and any further write access will be ignored. The default supply configuration will be kept and the ACTVOSRDY bit in *PWR control status register 1 (PWR_CSR1)* will go on indicating invalid voltage levels. The system must be power cycled before writing a new value.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	USB33RDY	USBREGEN	USB33DEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SDEXTRDY
					r	rw	rw								r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	VBRS	VBE	Res.	Res.	SDLEVEL[1:0]		SDEXTHP	SDEN	LDOEN	BYPASS
						rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bit 26 **USB33RDY**: USB supply ready.
0: USB33 supply not ready.
1: USB33 supply ready.

Bit 25 **USBREGEN**: USB regulator enable.
0: USB regulator disabled.
1: USB regulator enabled.

Bit 24 **USB33DEN**: $V_{DD33USB}$ voltage level detector enable.
0: $V_{DD33USB}$ voltage level detector disabled.
1: $V_{DD33USB}$ voltage level detector enabled.

Bits 23:17 Reserved, must be kept at reset value.

Bit 16 **SDEXTRDY**: SMPS step-down converter external supply ready
This bit is set by hardware to indicate that the external supply from the SMPS step-down converter is ready.
0: External supply not ready.
1: External supply ready.

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **VBRS**: V_{BAT} charging resistor selection
0: Charge V_{BAT} through a 5 k Ω resistor.
1: Charge V_{BAT} through a 1.5 k Ω resistor.

Bit 8 **VBE**: V_{BAT} charging enable
0: V_{BAT} battery charging disabled.
1: V_{BAT} battery charging enabled.

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **SDLEVEL[1:0]**: SMPS step-down converter voltage output level selection
This bit is used when both the LDO and SMPS step-down converter are enabled with SDEN and LDOEN enabled or when SDEXTHP is enabled. In this case SDLEVEL has to be written with a value different than 00 at system startup.
00: Reset value
01: 1.8 V
10 and 11: 2.5 V

Note: Illegal combinations of SDLEVEL, SDEXTHP, SDEN, LDOEN and BYPASS are described in Table 30.

Bit 3 **SDEXTHP**: SMPS step-down converter forced ON and in High Power MR mode.
0: SMPS step-down converter in normal operating mode.
1: SMPS step-down converter forced ON and in MR mode.
Note: Illegal combinations of SDLEVEL, SDEXTHP, SDEN, LDOEN and BYPASS are described in Table 30.

Bit 2 **SDEN**: SMPS step-down converter enable
0: SMPS step-down converter disabled
1: SMPS step-down converter enabled. (Default)
Note: Illegal combinations of SDLEVEL, SDEXTHP, SDEN, LDOEN and BYPASS are described in Table 30.
The SMPS step-down converter is not available on all packages.In this case, the SMPS step-down converter is disabled.

Bit 1 **LDOEN**: Low drop-out regulator enable
0: Low drop-out regulator disabled.
1: Low drop-out regulator enabled (default)
Note: Illegal combinations of SDLEVEL, SDEXTHP, SDEN, LDOEN and BYPASS are described in Table 30.

Bit 0 **BYPASS**: Power management unit bypass
0: Power management unit normal operation.
1: Power management unit bypassed, voltage monitoring still active.
Note: Illegal combinations of SDLEVEL, SDEXTHP, SDEN, LDOEN and BYPASS are described in Table 30.

6.8.5 PWR CPU control register (PWR_CPUCR)

This register allows controlling the CPU power.

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	RUN_D3	Res.	CSSF	SBF_D2	SBF_D1	SBF	STOPF	Res.	Res.	PDDS_D3	PDDS_D2	PDDS_D1
				rw		rw	r	r	r	r			rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **RUN_D3:** Keep system D3 domain in Run mode regardless of the CPU subsystems modes
0: D3 domain follows CPU subsystems modes.
1: D3 domain remains in Run mode regardless of CPU subsystems modes.

Bit 10 Reserved, must be kept at reset value.

Bit 9 **CSSF:** Clear D1 domain CPU Standby, Stop and HOLD flags (always read as 0)
This bit is cleared to 0 by hardware.
0: No effect.
1: D1 domain CPU flags (HOLD2F, STOPF, SBF, SBF_D1, and SBF_D2) are cleared.

Bit 8 **SBF_D2:** D2 domain DStandby flag

This bit is set by hardware and cleared by any system reset or by setting the CPU CSSF bit. Once set, this bit can be cleared only when the D2 domain is no longer in DStandby mode.

0: D2 domain has not been in DStandby mode

1: D2 domain has been in DStandby mode.

Bit 7 **SBF_D1:** D1 domain DStandby flag

This bit is set by hardware and cleared by any system reset or by setting the CPU CSSF bit. Once set, this bit can be cleared only when the D1 domain is no longer in DStandby mode.

0: D1 domain has not been in DStandby mode

1: D1 domain has been in DStandby mode.

Bit 6 **SBF:** System Standby flag

This bit is set by hardware and cleared only by a POR (Power-on Reset) or by setting the CPU CSSF bit

0: System has not been in Standby mode

1: System has been in Standby mode

Bit 5 **STOPF:** STOP flag

This bit is set by hardware and cleared only by any reset or by setting the CPU CSSF bit.

0: System has not been in Stop mode

1: System has been in Stop mode

Bits 4:3 Reserved, must be kept at reset value.

Bit 2 **PDDS_D3:** System D3 domain Power Down Deepsleep.

This bit allows CPU to define the Deepsleep mode for System D3 domain.

0: Keep Stop mode when D3 domain enters Deepsleep.

1: Allow Standby mode when D3 domain enters Deepsleep.

Bit 1 **PDDS_D2:** D2 domain Power Down Deepsleep.

This bit allows CPU to define the Deepsleep mode for D2 domain.

0: Keep DStop mode when D2 domain enters Deepsleep.

1: Allow DStandby mode when D2 domain enters Deepsleep.

Bit 0 **PDDS_D1:** D1 domain Power Down Deepsleep selection.

This bit allows CPU to define the Deepsleep mode for D1 domain.

0: Keep DStop mode when D1 domain enters Deepsleep.

1: Allow DStandby mode when D1 domain enters Deepsleep.

6.8.6 PWR D3 domain control register (PWR_D3CR)

This register allows controlling D3 domain power.

Address offset: 0x018

Reset value: 0x0000 4000 (after power up; 0x0000 6000 when regulator is correctly configured and for subsequent resets)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VOS[1:0]		VOSRDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	r													

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:14 **VOS[1:0]:** Voltage scaling selection according to performance

These bits control the V_{CORE} voltage level and allow to obtains the best trade-off between power consumption and performance:

– When increasing the performance, the voltage scaling must be changed before increasing the system frequency.

– When decreasing performance, the system frequency must first be decreased before changing the voltage scaling.

00: Scale 0

01: Scale 3 (default)

10: Scale 2

11: Scale 1

Bit 13 **VOSRDY:** VOS Ready bit for V_{CORE} voltage scaling output selection.

When an internal regulator is used, this bit indicates that all the features allowed by the selected VOS can be used.

When VOS0 voltage scaling is selected, to guarantee that the clock frequency can be increased above the currently used maximum frequency, ACTVOS[1:0] must be equal to VOS[1:0] and ACTVOSRDY must be set.

Note: When Bypass mode is selected in the PWR control register 3 (PWR_CR3), VOSRDY bit is set to 1 by hardware whatever the V_{CORE} level.

0: Not ready, voltage level below VOS selected level.

1: Ready, voltage level at or above VOS selected level.

Bits 12:0 Reserved, must be kept at reset value.

6.8.7 PWR wakeup clear register (PWR_WKUPCR)

Address offset: 0x020

Reset value: 0x0000 0000 (reset only by system reset, not reset by wakeup from Standby mode)

5 wait states are required when writing this register (when clearing a WKUPF bit in PWR_WKUPFR, the AHB write access will complete after the WKUPF has been cleared).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WKUPC6	Res.	WKUPC4	Res.	WKUPC2	WKUPC1
										rc_w1		rc_w1		rc_w1	rc_w1

Bits 31:6, 4, 2 Reserved, must be kept at reset value.

Bits 5, 3, 1:0 **WKUPC[6, 4, 2:1]:** Clear Wakeup pin flag for WKUPn, (n = 6, 4, 2, 1)

These bits are always read as 0.

0: No effect

1: Writing 1 clears the WKUPFn Wakeup pin flag (bit is cleared to 0 by hardware)

6.8.8 PWR wakeup flag register (PWR_WKUPFR)

Address offset: 0x024

Reset value: 0x0000 0000 (reset only by system reset, not reset by wakeup from Standby mode)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WKUPF6	Res.	WKUPF4	Res.	WKUPF2	WKUPF1
										r		r		r	r

Bits 31:6, 4, 2 Reserved, must be kept at reset value.

Bits 5, 3, 1:0 **WKUPF[6, 4, 2:1]:** Wakeup pin WKUPn flag, (n = 6, 4, 2, 1)

This bit is set by hardware and cleared only by a Reset pin or by setting the WKUPCn bit in the *PWR wakeup clear register (PWR_WKUPCR)*.

0: No wakeup event occurred

1: A wakeup event was received from WKUPn pin

6.8.9 PWR wakeup enable and polarity register (PWR_WKUPEPR)

Address offset: 0x028

Reset value: 0x0000 0000 (reset only by system reset, not reset by wakeup from Standby mode)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	WKUPPUPD6[1:0]		Res.	Res.	WKUPPUPD4[1:0]		Res.	Res.	WKUPPUPD2[1:0]		WKUPPUPD1[1:0]	
				rw	rw			rw	rw			rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	WKUPP6	Res.	WKUPP4	Res.	WKUPP2	WKUPP1	Res.	Res.	WKUPEN6	Res.	WKUPEN4	Res.	WKUPEN2	WKUPEN1
		rw		rw		rw	rw			rw		rw		rw	rw

Bits 31:28, 25:24, 21:20 Reserved, must be kept at reset value.

Bits 27:26, 23:22, 19:16 **WKUPPUPD[6, 4, 2:1][1:0]**: Wakeup pin pull configuration for WKUPn, (n = 6, 4, 2, 1)

These bits define the I/O pad pull configuration used when WKUPENn = 1. The associated GPIO port pull configuration must be set to the same value or to 00.

The Wakeup pin pull configuration is kept in Standby mode.

00: No pull-up

01: Pull-up

10: Pull-down

11: Reserved

Bits 15:14 Reserved, must be kept at reset value.

Bits 13, 11, 9:8 **WKUPP[6, 4, 2:1]**: Wakeup pin polarity bit for WKUPn, (n = 6, 4, 2, 1)

These bits define the polarity used for event detection on WKUPn external wakeup pin.

0: Detection on high level (rising edge)

1: Detection on low level (falling edge)

Bits 12, 10, 7:6 Reserved, must be kept at reset value.

Bits 5, 3, 1:0 **WKUPEN[6, 4, 2:1]**: Enable Wakeup Pin WKUPn, (n = n = 6, 4, 2, 1)

Each bit is set and cleared by software.

0: An event on WKUPn pin does not wakeup the system from Standby mode.

1: A rising or falling edge on WKUPn pin wakes-up the system from Standby mode.

Note: An additional wakeup event is detected if WKUPn+1 pin is enabled (by setting the WKUPENn bit) when WKUPn pin level is already high when WKUPPn+1 selects rising edge, or low when WKUPPn selects falling edge.

6.8.10 PWR register map

Table 45. Power control register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**PWR_CR1**	Reserved													ALS		AVDEN	SVOS		Reserved				FLPS	DBP	PLS			PVDE	Reserved			LPDS
	Reset value														0	0	0	1	1					0	0	0	0	0	0				0
0x004	**PWR_CSR1**	Reserved															AVDO	ACTVOS		ACTVOSRDY		Reserved							PVDO	Reserved			
	Reset value																0	0	1	0									0				
0x008	**PWR_CR2**	Reserved								TEMPH	TEMPL	VBATH	VBATL	Reserved			BRRDY	Reserved											MONEN	Reserved			BREN
	Reset value									0	0	0	0				0												0				0
0x00C	**PWR_CR3**	Reserved					USB33RDY	USBREGEN	USB33DEN	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	SDEXTRDY	Reserved						VBRS	VBE	Reserved		SDLEVEL		SDEXTHP	SDEN	LDOEN	BYPASS
	Reset value						0	0	0								0							0	0	0	1	0	0	0	1	1	0
0x010	**PWR_CPUCR**	Reserved																				RUN_D3	Reserved	CSSF	SBF_D2	SBF_D1	SBF	STOPF	Res.	Res.	PDDS_D3	PDDS_D2	PDDS_D1
	Reset value																					0		0	0	0	0	0			0	0	0
0x018	**PWR_D3CR**	Reserved																VOS		VOSRDY	Reserved												
	Reset value																	0	1	0													
0x020	**PWR_WKUPCR**	Reserved																										WKUPC6	Res.	WKUPC4	Res.	WKUPC2	WKUPC1
	Reset value																											0		0		0	0
0x024	**PWR_WKUPFR**	Reserved																										WKUPF6	Res.	WKUPF4	Res.	WKUPF2	WKUPF1
	Reset value																											0		0		0	0
0x028	**PWR_WKUPEPR**	Reserved				WKUPPUPD6	Res.	Res.		WKUPPUPD4	Res.	Res.		WKUPPUPD2		WKUPPUPD1		res.		WKUPP6	Res.	WKUPP4	Res.	WKUPP2	WKUPP1	res.		WKUPEN6	Res.	WKUPEN4	Res.	WKUPEN2	WKUPEN1
	Reset value					0	0			0	0			0	0	0	0			0		0		0	0			0		0		0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

7 Low-power D3 domain application example

This section describes, through an example, how to use the D3 domain to implement low-power applications.

7.1 Introduction

The first part of the description explains how the EXTI, RCC and PWR blocks interact with each other and with the other system blocks. A detailed explanation on how the DMAMUX2 can be used to free the CPU is also provided.

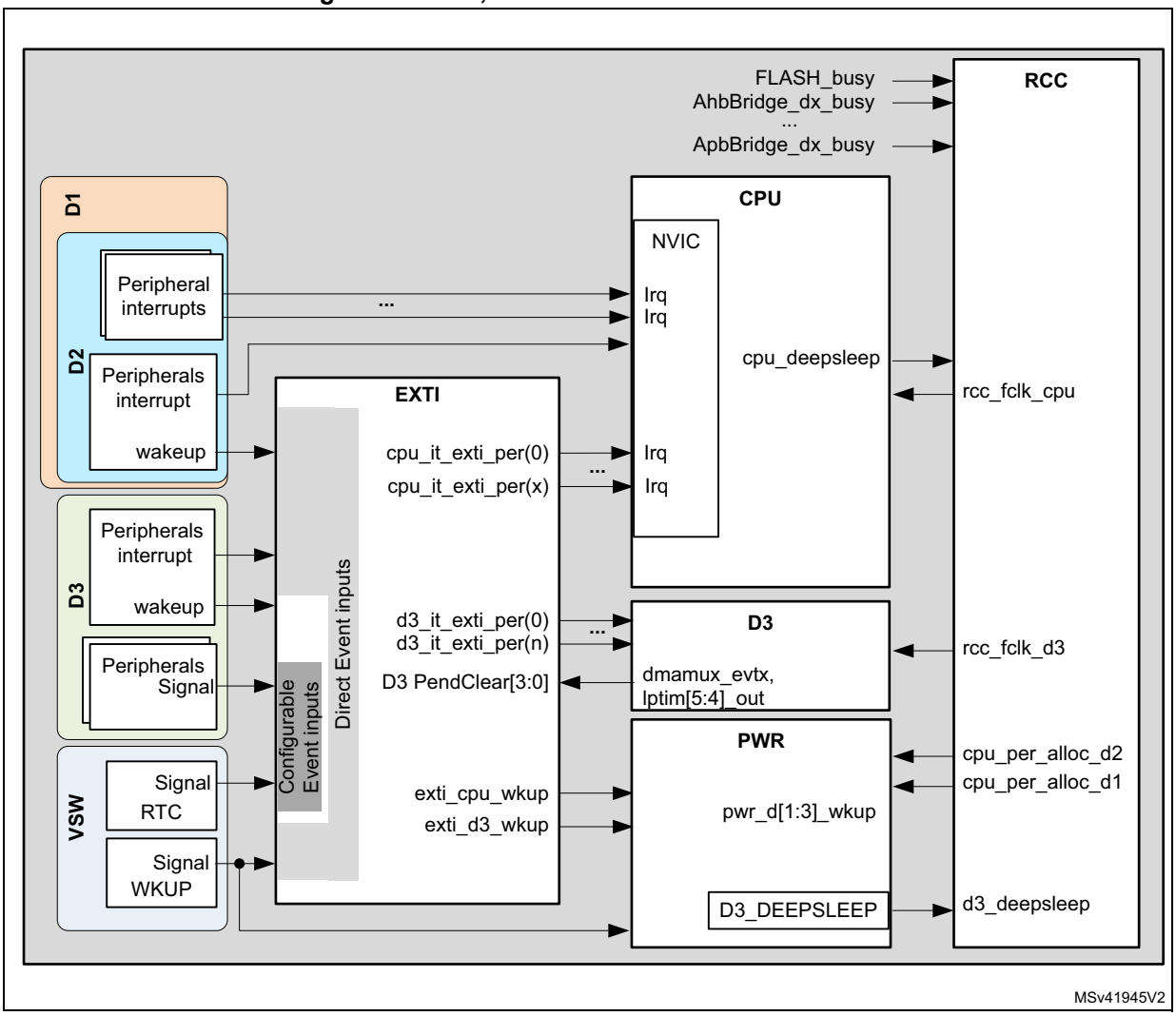
The second part explains how to use the Autonomous mode to perform simple data transfers through an example of LPUART1 transmission.

Register programming is detailed only for the blocks related to the Autonomous mode.

7.2 EXTI, RCC and PWR interconnections

Figure 38 shows the main EXTI, RCC and PWR interconnections.

Figure 38. EXTI, RCC and PWR interconnections



7.2.1 Interrupts and wakeup

Three kinds of signals are exchanged between the peripherals. They can be used to wake up the system from Stop mode:

- **Wakeup events** (or asynchronous interrupts)

  Some peripherals can generate interrupt events, even if their bus interface clock is not present. These interrupt events are called wakeup events (or asynchronous interrupts).

  Example: i2c1_wkup, usart1_wkup and lptim1_wkup.

- **Signals**

  Some peripherals generate a pulse instead of an interrupt signal. These pulses are called signals.

  Examples: lptim2_out and lptim3_out.

- **Interrupts**

  Contrary to signals, the interrupts should be cleared by a CPU or any other bus master, either by clearing the corresponding event bit in the peripheral register or by updating the FIFO interrupt level.

  All the interrupts associated to system peripherals are directly connected to the NVIC, except for the peripherals which are able to wake up the system from Stop mode or the CPU from CStop. In this latter case, the interrupts, signals or wakeup events are connected to the NVIC via the EXTI.

  Example: spi1_it, tim1_brk_it and tim1_upd_it.

The interrupt and wakeup sources that require to be cleared in the peripheral itself are connected to EXTI Direct Event inputs. The EXTI does not manage any CPU status pending bit.

The peripherals signals are connected to EXTI Configurable Event inputs. These EXTI inputs provide a CPU status pending bit which needs to be cleared by the application.

7.2.2 Block interactions

Interaction between EXTI and PWR blocks

The EXTI delivers wakeup requests signals (**exti_c_wkup**, **exti_d3_wkup**) to the PWR controller. These signals are activated according to the state of the interrupts, signals or wakeup events connected to the EXTI. These wakeup requests are used by the PWR controller to supply the domain who needs to handle the activated wakeup event generated by the peripherals.

Interaction between PWR and RCC blocks

The PWR block controls the V_{CORE} supply according to the system operating mode (CRun, CSleep or CStop). The PWR block also controls the power switches (ePODs) that delivers V_{CORE} supply to D1 and D2 domains.

The RCC block controls the clock generation in accordance with the system operating mode. It is also responsible for reset generation.

To synchronize the system mode transitions, the RCC block is tightly coupled with the PWR controller:

- The RCC informs the PWR controller when peripherals located in the Dx domain are allocated by the CPU (**c_per_alloc_d2**, **c_per_alloc_d1**).
- The RCC also warns the PWR block when a domain clock is activated/deactivated. These signals are used in case of domain transition from DRun to DStop or DStandby. In this case, the PWR controller waits until the domain clock has been gated, before switching down this domain.
- Similarly, the PWR controller informs the RCC about the V_{CORE} supply status of each domain (**pwr_d[1:3]_wkup**). This information is used by the RCC when a domain transition from DStop or DStandby to DRun occurs.

Interaction between EXTI and D3 domain

All the wakeup event inputs received by the EXTI from the peripherals located in D3 domain are forwarded back to the D3 domain after system clock re-synchronization. These events are used by the D3 domain to perform autonomous operations without activating the CPU.

The EXTI **D3_PenClear[3:0]** inputs received from the D3 domain are used to acknowledge the ongoing wakeup requests generated by peripherals located in the D3 domain. The **D3_PenClear[3:0]** inputs allow switching the system D3 domain from Run to Stop mode.

7.2.3 Role of DMAMUX2 in D3 domain

The DMAMUX2 implemented in the D3 domain allows chaining BDMA transfers. BDMA requests are synchronized thanks to trigger events (**dmamux2_evtx**) which can be generated when the expected amount of data has been transferred.

These events can also trigger DMAMUX2 request generators (REQ_GEN[3:0]), and thus chain several BDMA transfers. In fact REQ_GEN[3:0] can be triggered indirectly by all the wakeup events generated by all D3 domain peripherals.

Like LPTIM5 and LPTIM4 outputs, dmamux2_evt7 and dmamux2_evt6 events are connected to the EXTI. They can be used to switch the D3 domain from DRun to DStop mode when the task requested by the wakeup event is complete.

7.3 Low-power application example based on LPUART1 transmission

This section illustrates, through an example, the benefit of the D3 domain usage on power consumption. To help the user program the device, only the key register settings are given herein.

Refer to Sections *Reset and clock control (RCC)* and *Power control (PWR)* for additional details.

7.3.1 Memory retention

The D3 domain features 16 Kbytes of SRAM (SRAM4), which can be used to retain data while the D1 and D2 domains enter DStandby mode.

This feature can be used in several use-cases:

- to retain the application code in order to recover properly from DStandby
- to retain the data from/to a sensor when the CPU enters CStop with D1 or D2 domain in DStandby) between two consecutive operations.

Note: SRAM4 remains available as long as the system is not in Standby mode.

If the system is in Standby mode, it is still possible to use the BKUP_SRAM. However, its size is limited to 4 Kbytes.

7.3.2 Memory-to-peripheral transfer using LPUART1 interface

Example description

Figure 39 shows the proposed implementation. At a regular time interval given by LPTIM4, the CPU wakes up from CStop mode (which domain is in DStandby). When the CPU is in Run mode, it prepares the data to be transmitted via LPUART1, transfers them to SRAM4, and goes back to CStop. The D3 domain is configured to perform data transfers via LPUART1 and go back to Stop mode when the transfer is complete.

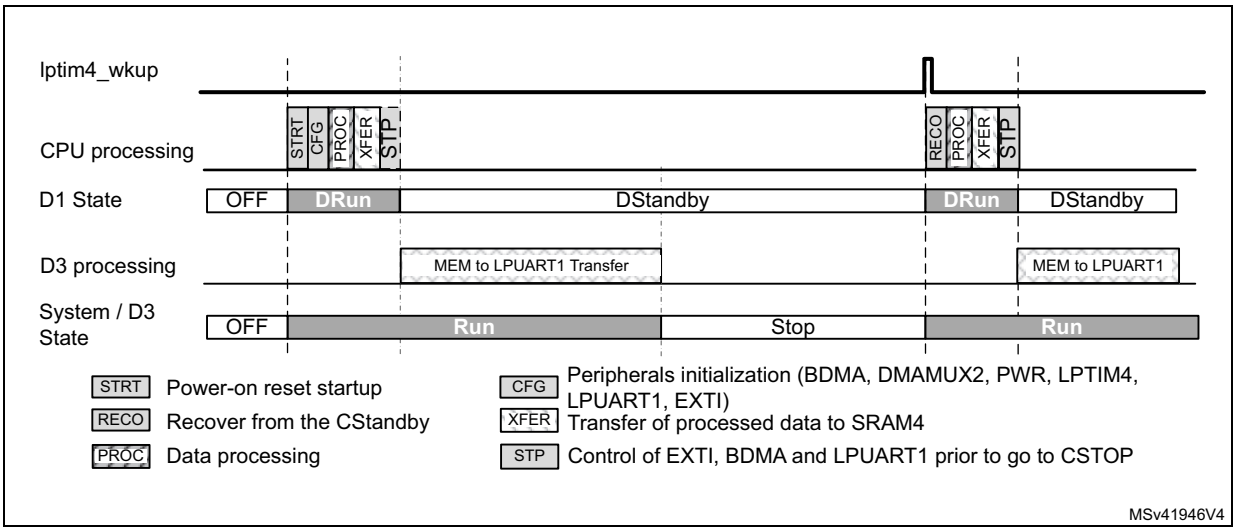
The LPTIM4 interface is used to wake up the system from Standby at regular time intervals. the CPU must then perform the following operations:

1. Recover the application from the system Standby mode (RECO).
2. Process the new data to be sent via LPUART1 (PROC).
3. Transfer the data into SRAM4 (XFER).
4. Configure the DMAMUX2, the BDMA, the LPUART1, and the RCC (CFG).
5. Configure the EXTI (CFG).
6. Configure the PWR block to allow the D1 domain to go to DStandby mode (STP).
7. Set the CPU to Stop mode.

The D3 domain executes the following tasks in Autonomous mode:

1. Transfer the data from SRAM4 to LPUART1, using BDMA.
2. When the LPUART1 interface indicates that the last byte has been transferred, the D3 domain is switched to Stop mode.

Figure 39. Timing diagram of SRAM4-to-LPUART1 transfer with BDMA and D3 domain in Autonomous mode



Note: In the above example described in this section, the D3 domain cannot be kept in Run mode when D1 and D2 domains are in DStop/DStandby by using the RUN_D3 bit of PWR_CPUCR register. RUN_D3 will force the D3 domain to Run mode, but it will not be able to go back to Stop on its own.

If the application needs to toggle the D3 domain between Stop and Run modes, then the Run mode must be triggered by a wakeup event so that the D3 domain can clear this event is needed.

RCC programming

In this example, the CPU sub-system also includes the peripherals of D3 domain that are used for the data transfer, that is BDMA, DMAMUX2, LPUART1 and LPTIM4. These peripherals must be programmed in Autonomous mode, in order to operate even when the CPU is in CStop mode.

LPUART1 can use its own APB clock as kernel clock. Since the system will not enter Stop mode before LPUART1 has completed data transfer, PLLx can be used to provide clocks to the peripherals.

PWR programming

In this example, the PWR block must be programmed in order to:

- prevent system D3 domain to enter Standby mode when the data transfer is complete,
- allow the D1 domain to enter DStandby,
- define the working voltage according to system modes.

Note: D3 domain could enter Standby as well, but in this case the LPTIM4 could not be used to wake up the system and the AWU should be used instead. In addition, everything must be reprogrammed when the system wakes up.

EXTI programming

The EXTI block must be configured to provide the following services:

- Keep D3 domain running when D1 domain is in DStandby. This will be done by a software event.
- Set the device to Stop mode when the data transfer via LPUART1 is complete.
- Wake up the product from Stop when LPTIM4 time interval has elapsed.

The EXTI block is configured once before performing the first data transfer. For incoming data transfers, the programmed configuration remains unchanged; only some events need to be triggered or acknowledged.

Note: The CPU uses the event input number 0 to generate a software event. LPTIM4 wakeup signal is connected to event input number 52 (direct event input).

All other event inputs must be disabled: EXTI_RTSRx_TRy = '0' and EXTI_FTSRx_TRy = '0'.

To generate a wakeup event for D3 domain, the CPU must write SWIER0 bit of EXTI_SWIER1 to '1'.

BDMA and DMAMUX2 programming

Two BDMA channels are required to execute data transfers via LPUART1.

- A BDMA channel, such as channel 0, is used to transfer data from SRAM4 to LPUART1, using the TXE flag.
- The second BDMA channel role is to switch the D3 domain to Stop mode. For that purpose, DMAMUX2 request generator channel 0 (REQ_GEN0) and DMAMUX2 channel 7 synchronization block (SYNC7) are used in conjunction with BDMA channel 7.

BDMA channel 0 does not use DMAMUX2 trigger capabilities. Refer to *Table 46* for initialization details.

BDMA channel 7 uses REQ_GEN0 to generate BDMA requests. The generation of BDMA requests is triggered by the LPUART1 transmit interrupt (**lpuart1_tx_it**). The LPUART1 interface generates lpuart1_tx_it interrupt when the transmit complete event is detected. The BDMA then clears the pending interrupt by performing a write operation to the LPUART1.

The SYNC7 block is programmed in Free-running mode. It generates a pulse on its **dmamux2_evt7** output when the BDMA request generated by the REQ_GEN0 is complete. **dmamux2_evt7** signal is used by the EXTI to switch back the D3 domain to Stop mode.

Figure 40 shows the active signal paths via DMAMUX2. The grayed blocks represent the unused paths.

Figure 40. BDMA and DMAMUX2 interconnection

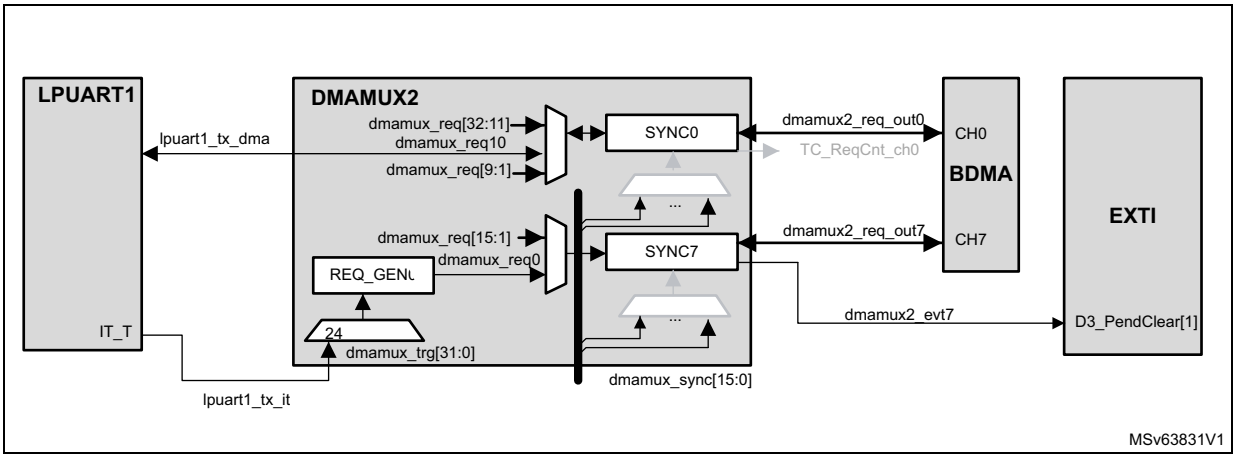


Table 46 explain how to program BDMA and DMAMUX2 key functions. The way errors are handled is not described.

Table 46. BDMA and DMAMUX2 initialization sequence (DMAMUX2_INIT)

Peripherals	Register content	Related actions
DMAMUX2 SYNC0	DMAREQ_ID of DMAMUX2_C0CR = ‘10’ SE of DMAMUX2_C0CR = ‘0’ EGE of DMAMUX2_C0CR = ‘0’ NBREQ of DMAMUX2_C0CR = ‘0’	Selects LPUART_TX BDMA request. Disables block synchronization. No event generation. Generates an event every BDMA transfer (Free-running mode).
DMAMUX2 SYNC7	DMAREQ_ID of DMAMUX2_C7CR = ‘0’ SE of DMAMUX2_C7CR = ‘0’ EGE of DMAMUX2_C7CR = ‘1’ NBREQ of DMAMUX2_C7CR = ‘0’	Selects of REQ_GEN0 as BDMA request. Disables block synchronization. Enables event generation. Generates an event every BDMA transfer (Free-running mode).
DMAMUX2 REQ_GEN0	SIG_ID of DMAMUX2_RG0CR = ‘0d24’ GPOL of DMAMUX2_RG0CR = ‘0b01’ GNBREQ of DMAMUX2_RG0CR = ‘0’ GE of DMAMUX2_RG0CR = ‘1’	Selects LPUART TX interrupt as trigger. Trigger on rising edge of the event. Generates only one BDMA request. Enables generator.

Table 46. BDMA and DMAMUX2 initialization sequence (DMAMUX2_INIT) (continued)

Peripherals	Register content	Related actions
BDMA - CH0	NDT bits of BDMA_CNDTR0 = DatNber	Number of data to transfer.
	PA of BDMA_CPAR0 = &LPUART1_TDR	Address of LPUART1_TDR.
	MA of BDMA_CMAR0 = &DatBuff	Address of memory buffer of SRAM4.
	DIR of BDMA_CCR0 = ‘1’	Read from memory.
	CIRC of BDMA_CCR0 = ‘0’	Circular mode disabled.
	PINC of BDMA_CCR0 = ‘0’	Peripheral increment disabled.
	MINC of BDMA_CCR0 = ‘1’	Memory increment enabled.
	PSIZE of BDMA_CCR0 = ‘0’	Peripheral size = 8 bits.
	MSIZE of BDMA_CCR0 = ‘1’	Memory size = 8 bits.
	MEM2MEM of BDMA_CCR0 = ‘0’	Memory to memory disabled.
BDMA - CH7	NDT bits of BDMA_CNDTR7 = ‘1’	Only one data transferred.
	PA of BDMA_CPAR7 = &LPUART1_ICR	Address of LPUART1_ICR (Interrupt Flag Clear Reg.).
	MA of BDMA_CMAR7 = &DatClrTC	Address of a variable located into SRAM4. This variable must contain 0x0040 in order to clear the TC flag.
	DIR of BDMA_CCR7 = ‘1’	Read from memory.
	CIRC of BDMA_CCR7 = ‘0’	Circular mode disabled.
	PINC of BDMA_CCR7 = ‘0’	Peripheral increment disabled.
	MINC of BDMA_CCR7 = ‘1’	Memory increment disabled.
	PSIZE of BDMA_CCR7 = 2	Peripheral size = 32 bits.
	MSIZE of BDMA_CCR7 = 2	Memory size = 32 bits.
	MEM2MEM of BDMA_CCR7 = ‘0’	Memory to memory disabled.

LPTIM4 programming

When LPTIM4 wakeup event occurs, the CPU reboots and D3 domain mode is also set to Run mode.

An interrupt issued by LPTIM4 is pending on the CPU NVIC. LPTIM4 interrupt handler must acknowledge this LPTIM4 interrupt by writing ARRMCF bit in LPTIM4_ICR register to ‘1’ (LPTIM4_Ack).

LPUART programming

In the use-case described herein, the capability of the LPUART1 to request the kernel clock according to some events is not used.

LPUART1 is programmed so that is generates a BDMA request when its TX-FIFO is not full.

LPUART1 also generates an interrupt when the TX-FIFO and its transmit shift register are empty. This interrupt is used to switch the D3 domain to Stop mode.

Table 47 gives the key settings concerning the handling of Stop mode for LPUART1.

Table 47. LPUART1 Initial programming (LPUART1_INIT)

Register content	Related actions
FIFOEN of LPUART1_CR1 = ‘1’	Enables FIFO. BDMA will then use TXFNF (TXFIFO Not Full) flag for generating the BDMA requests.
TCIE of LPUART1_CR1 = ‘0’	Disables interrupt when the transmit buffer is empty.
UE of LPUART1_CR1 = ‘1’	Enables BDMA.
TE of LPUART1_CR1 = ‘1’	Enables the LPUART1.
TXE of LPUART1_CR1 = ‘1’	Enables transmission.
DMAT of LPUART1_CR3 = ‘1’	Enables the BDMA mode for transmission.

Respect the sequence described in *Table 48* to enable LPUART1.

Table 48. LPUART1 start programming (LPUART1_Start)

Register content	Related actions
TCCF of LPUART1_ICR = ‘1’	Clears the TC flag, to avoid immediate interrupt generation, which would clear the D3_PendClear[1] in EXTI.
TCIE of LPUART1_CR1 = ‘1’	Enables interrupt when the transmit buffer is empty.

7.3.3 Overall description of the low-power application example based on LPUART1 transmission

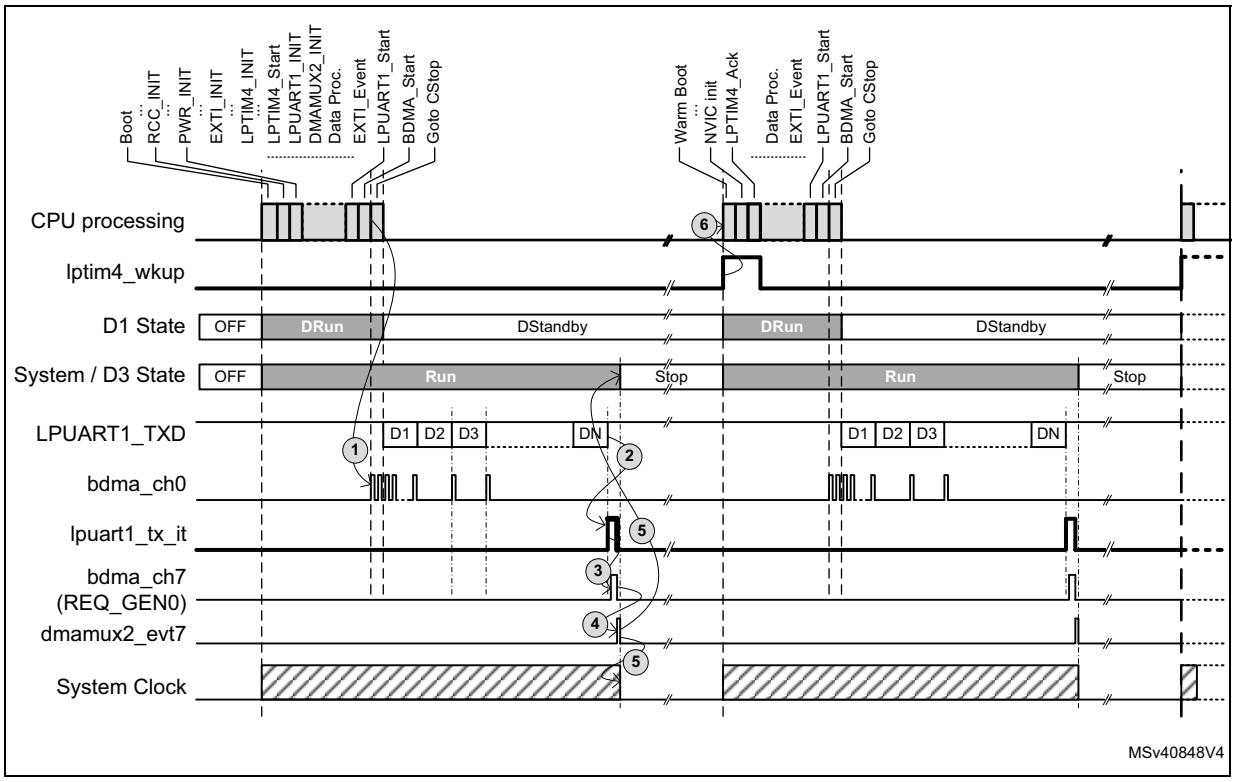
After a Power-on reset, the CPU perform the following operations:

1. Boot sequence (not described here).
2. Full initialization of RCC, PWR, EXTI, LPUART1, GPIOs, LPTIM4, DMAMUX2, BDMA and NVIC.
   Only the relevant steps of RCC, EXTI, PWR, LPUART1, BDMA and DMAMUX2 initialization related to the Autonomous mode are described herein. Refer to the previous sections for additional details.
3. The CPU processes the data to be transferred and copies them to SRAM4.
4. The CPU generates a wakeup event (EXTI_Event) to maintain D3 in Run mode when D1 enters DStandby.
5. The CPU enables the BDMA to start LPUART transmission and goes to Stop mode. As it is allowed to do so, D1 domain enters DStandby while D3 remains in Run mode. The data stored in SRAM4 are retained while the D1 domain is in DStandby mode.
6. As soon as the BDMA is enabled, it serves the request from LPUART1 in order to fill its TX-FIFO. In parallel, serial data transmission can start.
7. When the expected amount of data has been transmitted (NDT bits of BDMA_CNDTR0 set to 0), the BDMA no longer provides data to the LPUART1. The LPUART1 generates an interrupt when the TX-FIFO and the transmit buffer are empty.
8. This interrupt triggers DMAMUX2 REQ_GEN0, thus activating a data transfer via BDMA channel 7 (BDMA_Ch7). This transfer clears LPUART1 TC flag, and the **lpuart1_tx_it** is reset to ‘0’.
9. The end of this transfer triggers a dmamux2_evt7 signal which is used to clear the wakeup request generated by the CPU.
10. As a consequence, the D3 domain (i.e. the system) enters Stop mode and the system clock is gated. LPTIM4 still operates since it uses **ck_lsi** clock.

11. LPTIM4 **lptim4_wkup** interrupt wakes up the system. The device exits from Stop mode with the HSI clock. The CPU must restore the proper clock configuration during the warm re-boot sequence and perform the following tasks:
    a) Acknowledge LPTIM4 wakeup interrupt,
    b) Process the next data block and transfers them to SRAM4,
    c) Generate again a wakeup event for D3 domain,
    d) Start the BDMA.
    e) Go back to CStop mode.

Note: The CPU does not need to initialize BDMA, DMAMUX2 and LPUART1 again.

Figure 41. Timing diagram of LPUART1 transmission with D3 domain in Autonomous mode



7.3.4 Alternate implementations

More power efficient implementations are also possible. As an example the system clock can be stopped once the data have been transferred to LPUART1 TX-FIFO, instead of remaining activated during the whole transmission as in the example presented above. In this case, the LPUART1 must use ck_hsi or ck_csi as kernel clock when the system switches from Run to Stop mode. LPUART1 must be programmed to wake up D3 domain when its TX-FIFO in almost empty. This asynchronous interrupt can be used as trigger by the REQ_GENx of the DMAMUX2, which will perform a given number (e.g. 14) of data transfers to LPUART1_TDR and then switch back the D3 domain to Stop mode. This implementation is possible because the LPUART1 can request the kernel clock as long as the TX-FIFO and transmit buffer are not empty.

7.4 Other low-power applications

Other peripherals located in D3 domain, such as I2C4, SPI6, SAI4 or ADC3, can be used to implement low-power applications.

8 Reset and clock control (RCC)

The RCC block manages the clock and reset generation for the whole microcontroller.

The RCC block is located in the D3 domain (refer to *Section 6: Power control (PWR)* for a detailed description).

The operating modes this section refers to are defined in *Section 6.6.1: Operating modes* of the PWR block.

8.1 RCC main features

Reset block

- Generation of local and system reset
- Bidirectional pin reset allowing to reset the microcontroller or external devices
- WWDG reset supported

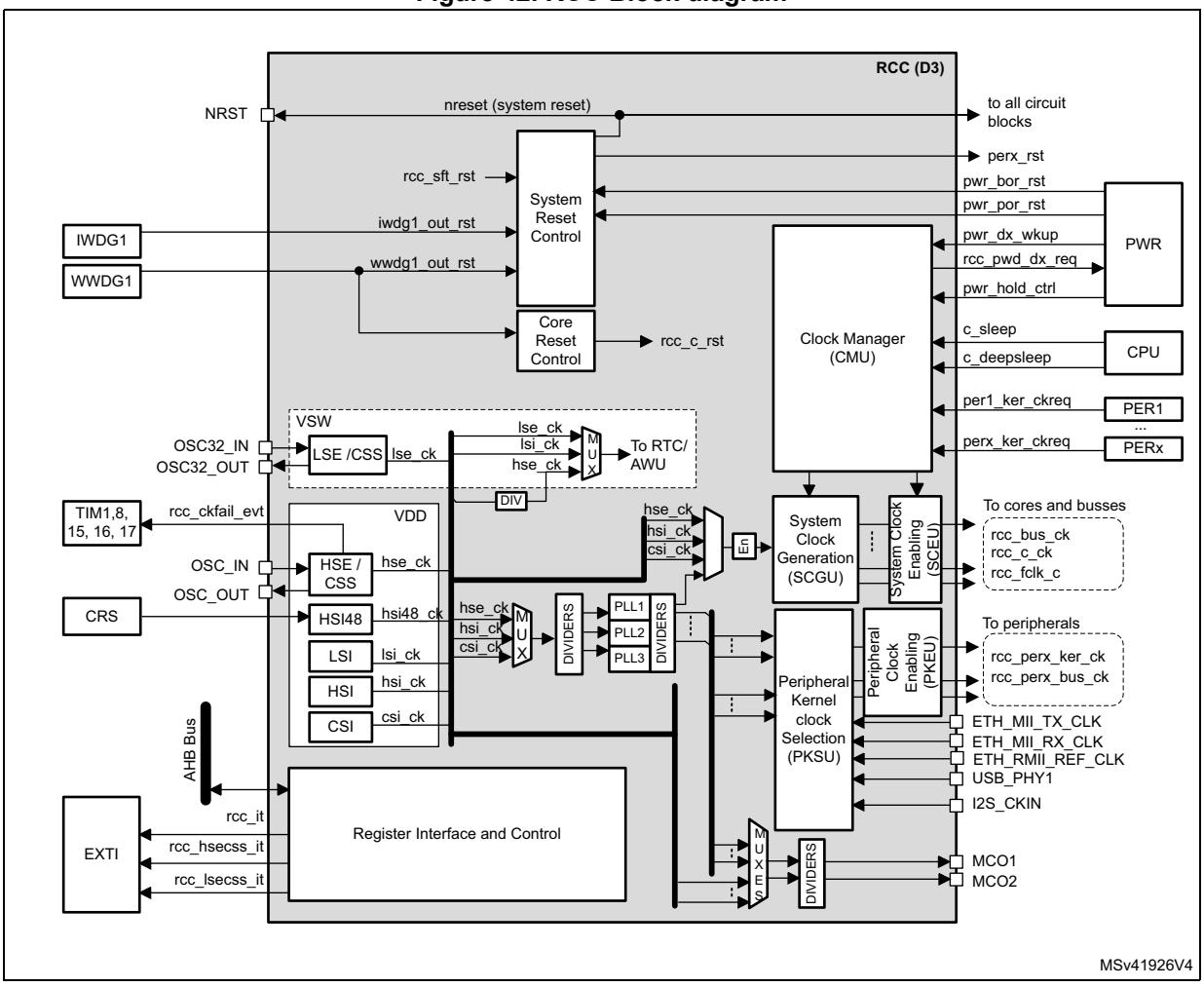
Clock generation block

- Generation and dispatching of clocks for the complete device
- 3 separate PLLs using integer or fractional ratios
- Possibility to change the PLL fractional ratios on-the-fly
- Smart clock gating to reduce power dissipation
- 2 external oscillators:
  - High-speed external oscillator (HSE) supporting a wide range of crystals from 4 to 50 MHz frequency
  - Low-speed external oscillator (LSE) for the 32 kHz crystals
- 4 internal oscillators
  - High-speed internal oscillator (HSI)
  - 48 MHz RC oscillator (HSI48)
  - Low-power Internal oscillator (CSI)
  - Low-speed internal oscillator (LSI)
- Buffered clock outputs for external devices
- Generation of two types of interrupts lines:
  - Dedicated interrupt lines for clock security management
  - One general interrupt line for other events
- Clock generation handling in Stop and Standby mode
- D3 domain Autonomous mode

8.2 RCC block diagram

Figure 42 shows the RCC block diagram.

Figure 42. RCC Block diagram



8.3 RCC pins and internal signals

Table 49 lists the RCC inputs and output signals connected to package pins or balls.

Table 49. RCC input/output signals connected to package pins or balls

Signal name	Signal type	Description
NRST	I/O	System reset, can be used to provide reset to external devices
OSC32_IN	I	32 kHz oscillator input
OSC32_OUT	O	32 kHz oscillator output
OSC_IN	I	System oscillator input

Table 49. RCC input/output signals connected to package pins or balls (continued)

Signal name	Signal type	Description
OSC_OUT	O	System oscillator output
MCO1	O	Output clock 1 for external devices
MCO2	O	Output clock 2 for external devices
I2S_CKIN	I	External kernel clock input for digital audio interfaces: SPI/I2S, SAI, and DFSDM
ETH_MII_TX_CLK	I	External TX clock provided by the Ethernet MII interface
ETH_MII_RX_CLK	I	External RX clock provided by the Ethernet MII interface
ETH_RMII_REF_CLK	I	External reference clock provided by the Ethernet RMII interface
USB_PHY1	I	USB clock input provided by the external USB PHY (OTG_HS_ULPI_CK)

The RCC exchanges a lot of internal signals with all components of the product, for that reason, the *Table 49* only shows the most significant internal signals.

Table 50. RCC internal input/output signals

New Signal name	Signal type	Description
rcc_it	O	General interrupt request line
rcc_hsecss_it	O	HSE clock security failure interrupt
rcc_lsecss_it	O	LSE clock security failure interrupt
rcc_ckfail_evt	O	Event indicating that a HSE clock security failure is detected. This signal is connected to TIMERS
nreset	I/O	System reset
iwdg1_out_rst	I	Reset line driven by the IWDG1, indicating that a timeout occurred.
wwdg1_out_rst	I	Reset line driven by the WWDG1, indicating that a timeout occurred.
pwr_bor_rst	I	Brownout reset generated by the PWR block
pwr_por_rst	I	Power-on reset generated by the PWR block
pwr_vsw_rst	I	Power-on reset of the VSW domain generated by the PWR block
rcc_perx_rst	O	Reset generated by the RCC for the peripherals.
pwr_d[3:1]_wkup	I	Wake-up domain request generated by the PWR. Generally used to restore the clocks a domain when this domain exits from DStop
rcc_pwd_d[3:1]_req	O	Low-Power request generated by the RCC. Generally used to ask to the PWR to set a domain into low-power mode, when a domain is in DStop.
pwr_hold_ctrl	I	Signals generated by the PWR, in order to set the processor into CStop when exiting from system Stop mode.
c_sleep	I	Signal generated by the CPU, indicating if the CPU is in CRun, CSleep or CStop.
c_deepsleep	I	
perx_ker_ckreq	I	Signal generated by some peripherals in order to request the activation of their kernel clock.

Table 50. RCC internal input/output signals (continued)

New Signal name	Signal type	Description
rcc_perx_ker_ck	O	Kernel clock signals generated by the RCC, for some peripherals.
rcc_perx_bus_ck	O	Bus interface clock signals generated by the RCC for peripherals.
rcc_bus_ck	O	Clocks for APB (rcc_apb_ck), AHB (rcc_ahb_ck) and AXI (rcc_axi_ck) bridges generated by the RCC.
rcc_c_ck	O	Clock for the CPU, generated by the RCC.
rcc_fclk_c	O	

8.4 RCC reset block functional description

Several sources can generate a reset:

- An external device via NRST pin
- A failure on the supply voltage applied to V_{DD}
- A watchdog timeout
- A software command

The reset scope depends on the source that generates the reset. Three reset categories exist:

- Power-on/off reset
- System reset
- Local resets

8.4.1 Power-on/off reset

The power-on/off reset (**pwr_por_rst**) is generated by the power controller block (PWR). It is activated when the input voltage (V_{DD}) is below a threshold level. This is the most complete reset since it resets the whole circuit, except the backup domain. The power-on/off reset function can be disabled through PDR_ON pin (see *Section 6.5: Power supply supervision*).

Refer to *Table 51: Reset distribution summary* for details.

8.4.2 System reset

A system reset (**nreset)** resets all registers to their default values unless otherwise specified in the register descriptions.

A system reset can be generated from one of the following sources:

- A reset from NRST pin (external reset)
- A reset from the power-on/off reset block (**pwr_por_rst**)
- A reset from the brownout reset block (**pwr_bor_rst**)

  Refer to *Section 6.5.2: Brownout reset (BOR)* for a detailed description of the BOR function.
- A reset from the independent watchdogs (**iwdg1_out_rst**)
- A software reset from the Cortex®-M7 core

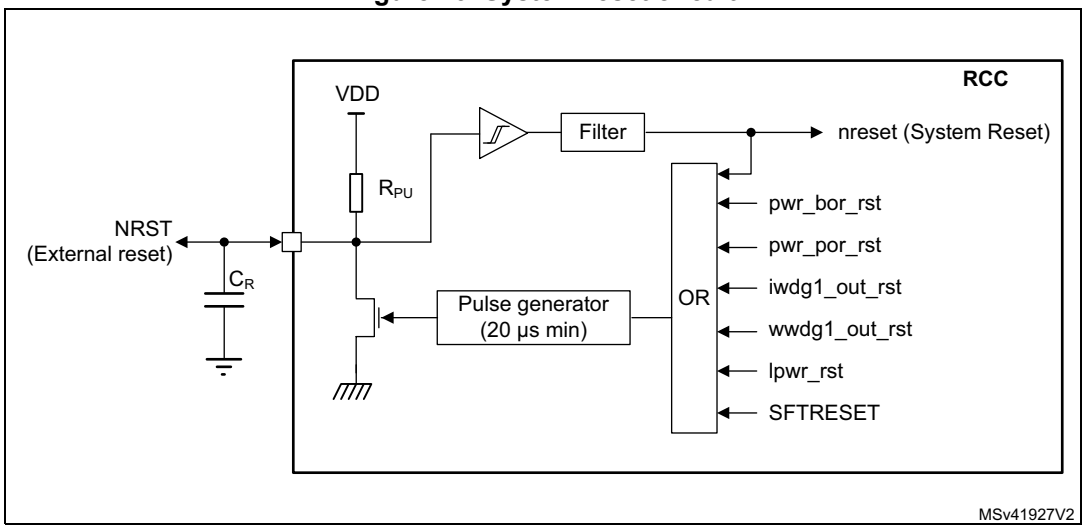
  It is generated via the SYSRESETREQ signal issued by the Cortex®-M7 core. This signal is also named SFTRESET in this document.
- A reset from the window watchdogs depending on WWDG configuration (**wwdg1_out_rst**)
- A reset from the low-power mode security reset, depending on option byte configuration (**lpwr_rst**)

Note: The SYSRESETREQ bit in Cortex®-M7 Application Interrupt and Reset Control Register must be set to force a software reset on the device. Refer to the Cortex®-M7 with FPU technical reference manual for more details (see http://infocenter.arm.com*).*

As shown in *Figure 43*, some internal sources (such as **pwr_por_rst**, **pwr_bor_rst**, **iwdg1_out_rst**) perform a system reset of the circuit, which is also propagated to the NRST pin to reset the connected external devices. The pulse generator guarantees a minimum reset pulse duration of 20 µs for each internal reset source. In case of an external reset, the reset pulse is generated while the NRST pin is asserted Low.

Note: It is not recommended to let the NRST pin unconnected. When it is not used, connect this pin to ground via a 10 to 100 nF *capacitor (C_R in Figure 43*).

Figure 43. System reset circuit



8.4.3 Local resets

CPU reset

The CPU can reset itself by means of the CPURST bit in *RCC AHB3 reset register (RCC_AHB3RSTR)*.

Domain reset

Some resets also dependent on the domain status. For example, when D1 domain exits from DStandby, it is reset (**d1_rst**). The same mechanism applies to D2.

When the system exits from Standby mode, a **stby_rst** reset is applied. The **stby_rst** signal generates a reset of the complete V_{CORE} domain as long the V_{CORE} voltage provided by the internal regulator is not valid.

Table 51 gives a detailed overview of reset sources and scopes.

Table 51. Reset distribution summary

Reset source	Reset name	D1 CPU	D1 Interconnect	D1 Peripherals	D1 Debug	WWDG1	D2 Interconnect	D2 Peripherals	D3 Peripherals	IWDG1	FLASH	RTC domain	Backup RAM	System Supply	NRST pin	Comments
Pin	NRST	x	x	x	-	x	x	x	x	x	-	-	-	-	x	– Resets D1 and D2 domains, and all their peripherals – Resets D3 domain peripherals – Resets V_{DD} domain: IWDG1, LDO... – Debug features, Flash memory, RTC and backup RAM are not reset
PWR	pwr_bor_rst	x	x	x	-	x	x	x	x	x	-	-	-	-	x	– Same as pin reset. The pin is asserted as well.
	pwr_por_rst	x	x	x	x	x	x	x	x	x	x	-	-	x	x	– Same as **pwr_bor_rst** reset, plus: Reset of the Flash memory digital block (including the option byte loading). Reset of the debug block
	lpwr_rst	x	x	x	-	x	x	x	x	x	-	-	-	-	x	– The low-power mode security reset has the same scope than **pwr_por_rst.** Refer to *Section 8.4.5: Low-power mode security reset (lpwr_rst)* for additional information.

Table 51. Reset distribution summary (continued)

Reset source	Reset name	D1 CPU	D1 Interconnect	D1 Peripherals	D1 Debug	WWDG1	D2 Interconnect	D2 Peripherals	D3 Peripherals	IWDG1	FLASH	RTC domain	Backup RAM	System Supply	NRST pin	Comments
RCC	BDRST	-	-	-	-	-	-	-	-	-	-	x	-	-	-	– The backup domain reset can be triggered by software. Refer to *Section 8.4.6: Backup domain reset* for additional information
	d1_rst	x	x	x	x	x	-	-	-	-	-	-	-	-	-	– Resets D1 domain, and all its peripherals, when the domain exits DStandby mode.
	d2_rst	-	-	-	-	-	x	x	-	-	-	-	-	-	-	– Resets D2 domain, and all its peripherals, when the domain exits DStandby mode.
	stby_rst	x	x	x	x	x	x	x	x	-	x	-	-	-	-	– When the device exits Standby mode, a reset of the complete V_{CORE} domain is performed as long the V_{CORE} voltage is not valid. The V_{CORE} is supplied by the internal regulator. NRST signal is not asserted.
	CPURST	x	-	-	-	x	-	-	-	-	-	-	-	-	-	– This reset is generated by software through the bit located into *RCC AHB3 reset register (RCC_AHB3RSTR)*. – Resets the CPU, and the WWDG1 block
CPU	SFTRESET	x	x	x	-	x	x	x	x	x	-	-	-	-	x	– This reset is generated by software when writing SYSRESETREQ bit located into AIRCR register of the Cortex®-M7 core. – Same scope as **pwr_bor_rst** reset.
Backup domain	pwr_vsw_rst	-	-	-	-	-	-	-	-	-	-	x	-	-	-	– This reset is generated by the backup domain when the V_{SW} supply voltage is outside the operating range.
IWDG1	iwdg1_out_rst	x	x	x	-	x	x	x	x	x	-	-	-	-	x	– Same as **pwr_bor_rst** reset.
WWDG1	wwdg1_out_rst	x	x	x	-	x	x	x	x	x	-	-	-	-	x	– Same as **pwr_bor_rst** reset.

8.4.4 Reset source identification

The CPU can identify the reset source by checking the reset flags in the RCC_RSR (or RCC_C1_RSR) register.

The CPU can reset the flags by setting RMVF bit.

Table 52 shows how the status bits of RCC_RSR (or RCC_C1_RSR) register behaves, according to the situation that generated the reset. For example when an IWDG1 timeout occurs (line #8), if the CPU is reading the RCC_RSR (or RCC_C1_RSR) register during the boot phase, both PINRSTF and IWDG1RSTF bits are set, indicating that the IWDG1 also generated a pin reset.

Table 52. Reset source identification (RCC_RSR)(1)

#	Situations Generating a Reset	LPWRRSTF	WWDG1RSTF	IWDG1RSTF	SFTRSTF	PORRSTF	PINRSTF	BORRSTF	D2RSTF	D1RSTF	CPURSTF
1	Power-on reset (pwr_por_rst)	0	0	0	0	1	1	1	1	1	1
2	Pin reset (NRST)	0	0	0	0	0	1	0	0	0	1
3	Brownout reset (pwr_bor_rst)	0	0	0	0	0	1	1	0	0	1
4	System reset generated by CPU (SFTRESET)	0	0	0	1	0	1	0	0	0	1
5	CPU reset (CPURST)	0	0	0	0	0	0	0	0	0	1
6	WWDG1 reset (wwdg1_out_rst)	0	1	0	0	0	**1**	0	0	0	**1**
8	IWDG1 reset (iwdg1_out_rst)	0	0	1	0	0	1	0	0	0	1
10	D1 exits DStandby mode	0	0	0	0	0	0	0	0	1	0
11	D2 exits DStandby mode	0	0	0	0	0	0	0	1	0	0
12	D1 erroneously enters DStandby mode or CPU erroneously enters CStop mode	1	0	0	0	0	1	0	0	0	1

1. Grayed cells highlight the register bits that are set.

8.4.5 Low-power mode security reset (lpwr_rst)

To prevent critical applications from mistakenly enter a low-power mode, two low-power mode security resets are available. When enabled through nRST_STOP_D1 option bytes, a system reset is generated if the following conditions are met:

- CPU accidentally enters CStop mode

  This type of reset is enabled by resetting nRST_STOP_D1 user option byte. In this case, whenever the CPU CStop mode entry sequence is successfully executed, a system reset is generated.
- D1 domain accidentally enters DStandby mode

  This type of reset is enabled by resetting nRST_STDBY_D1 user option byte. In this case, whenever a D1 domain DStandby mode entry sequence is successfully executed, a system reset is generated.

LPWRRSTF bits in *RCC reset status register (RCC_RSR)* indicates that a low-power mode security reset occurred (see line #12 in *Table 52*).

lpwr_rst is activated when a low-power mode security reset due to D1 or CPU occurred.

Refer to *Section 4.4: FLASH option bytes* for additional information.

8.4.6 Backup domain reset

A backup domain reset is generated when one of the following events occurs:

- A software reset, triggered by setting BDRST bit in the *RCC backup domain control register (RCC_BDCR)*. All RTC registers and the RCC_BDCR register are reset to their default values. The backup RAM is not affected.
- V_{SW} voltage is outside the operating range. All RTC registers and the RCC_BDCR register are reset to their default values. In this case the content of the backup RAM is no longer valid.

There are two ways to reset the backup RAM:

- through the Flash memory interface by requesting a protection level change from 1 to 0
- when a tamper event occurs.

Refer to *Section 6.4.1: System supply startup* section of PWR block for additional information.

8.4.7 Power-on and wakeup sequences

For detailed diagrams refer to *Section 6.4.1: System supply startup* in the PWR section.

The time interval between the event which exits the product from a low-power and the moment where the CPU is able to execute code, depends on the system state and on its configuration. *Figure 44* shows the most usual examples.

Power-on wakeup sequence

The power-on wakeup sequence shown in *Figure 44* gives the most significant phases of the power-on sequence. It is the longest sequence since the circuit was not powered. Note that this sequence remains unchanged, whatever V_{BAT} was present or not.

Boot from pin reset

When a pin reset occurs, V_{DD} is still present. As a results:

- The regulator settling time is faster since the reference voltage is already stable.
- The HSI restart delay may be needed if the HSI was not enabled when the NRST occurred, otherwise this restart delay phase is skipped.
- The Flash memory power recovery delay can also be skipped if the Flash memory was enabled when the NRST occurred.

Note: The boot sequence is similar for pwr_bor_rst, lpwr_rst, STFxRESET, iwdg1_out_rst and wwdg1_out_rst (if WW1RSC = 1).

Boot from system Standby

When waking up from system Standby, the reference voltage is stable since V_{DD} has not been removed. As a result, the regulator settling time is fast. Since V_{CORE} was not present, the restart delay for the HSI, the Flash memory power recovery and the option byte reloading cannot be skipped.

Restart from system Stop

When restarting from system Stop, V_{DD} is still present. As a result, the sequence is mainly composed of two steps:

1. Regulator settling time to reach VOS3 (default voltage)
2. HSI/CSI restart delay. This step can be skipped if HSIKERON or CSIKERON bit, in *RCC source control register (RCC_CR)* is set to 1.

Boot from domain DStandby

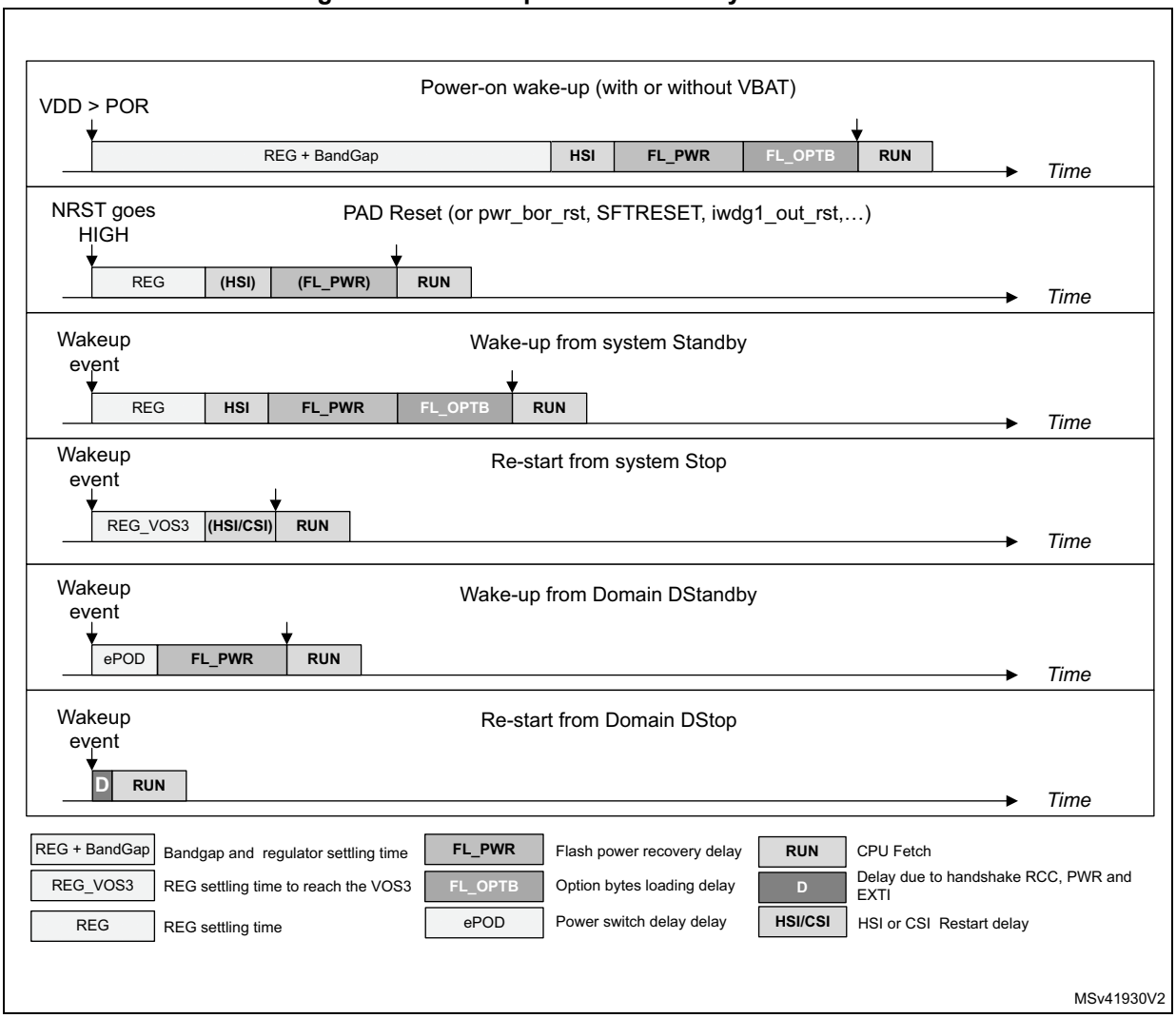
The boot sequence of a domain from domain DStandby is mainly composed of two steps:

1. The power switch settling time (the regulator is already activated).
2. The Flash memory power recovery.

Restart from domain DStop

The restart sequence of a domain from domain DStop is mainly composed of the handshake between the RCC, EXTI and PWR blocks.

Figure 44. Boot sequences versus system states



8.5 RCC clock block functional description

The RCC provides a wide choice of clock generators:

- HSI (High-speed internal oscillator) clock: ~ 8, 16, 32 or 64 MHz
- HSE (High-speed external oscillator) clock: 4 to 48 MHz
- LSE (Low-speed external oscillator) clock: 32 kHz
- LSI (Low-speed internal oscillator) clock: ~ 32 kHz
- CSI (Low-power internal oscillator) clock: ~4 MHz
- HSI48 (High-speed 48 MHz internal oscillator) clock: ~48 MHz

It offers a high flexibility for the application to select the appropriate clock for CPU and peripherals, in particular for peripherals that require a specific clock such as Ethernet, USB OTG-FS and HS, SPI/I2S, SAI and SDMMC.

To optimize the power consumption, each clock source can be switched ON or OFF independently.

The RCC provides up to 3 PLLs; each of them can be configured with integer or fractional ratios.

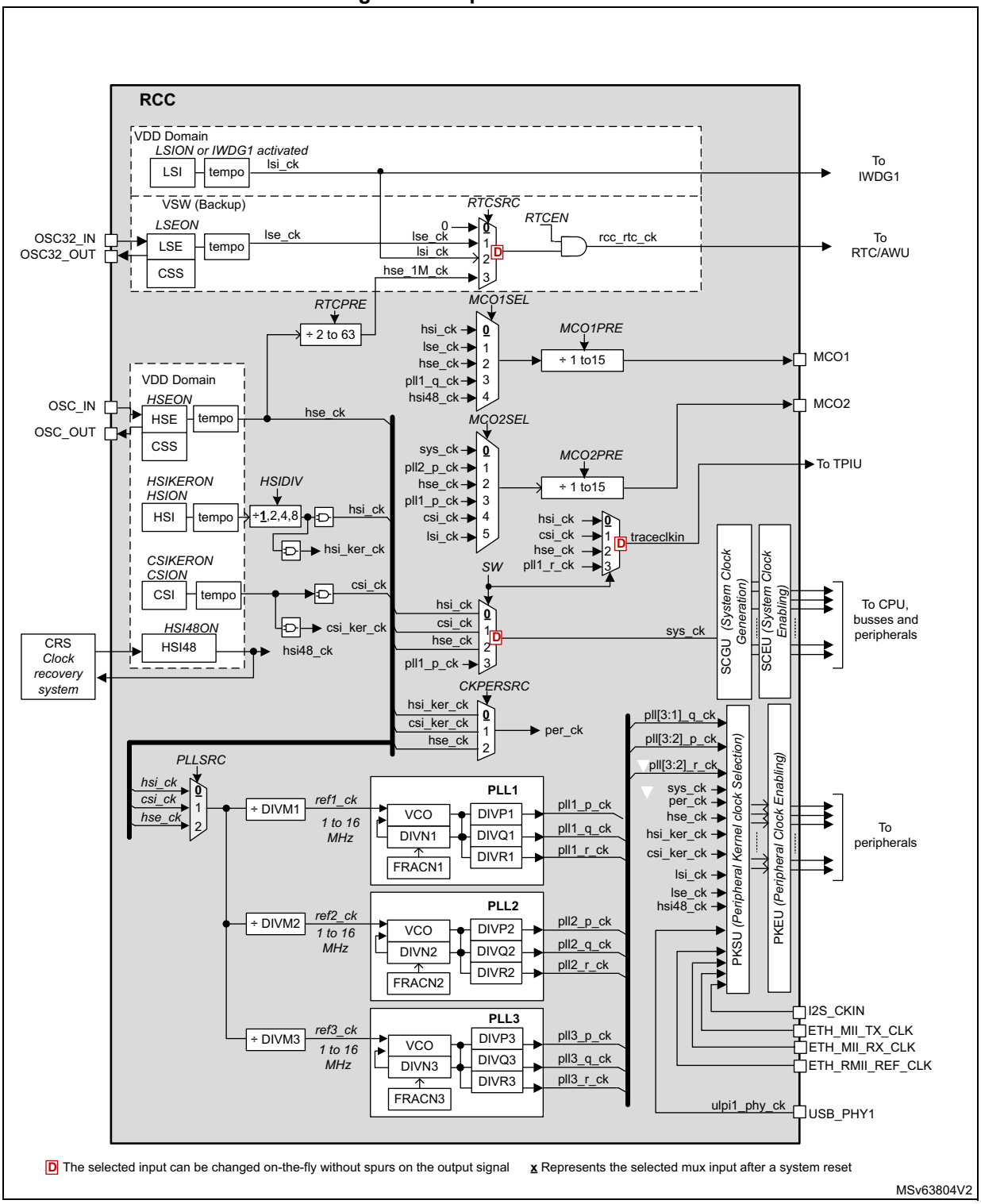
As shown in the *Figure 45*, the RCC offers 2 clock outputs (MCO1 and MCO2), with a great flexibility on the clock selection and frequency adjustment.

The SCGU block (System Clock Generation Unit) contains several prescalers used to configure the CPU and bus matrix clock frequencies.

The PKSU block (Peripheral Kernel clock Selection Unit) provides several dynamic switches allowing a large choice of kernel clock distribution to peripherals.

The PKEU (Peripheral Kernel clock Enable Unit) and SCEU (System Clock Enable Unit) blocks perform the peripheral kernel clock gating, and the bus interface/cores/bus matrix clock gating, respectively.

Figure 45. Top-level clock tree



8.5.1 Clock naming convention

The RCC provides clocks to the complete circuit. To avoid misunderstanding, the following terms are used in this document:

- Peripheral clocks

  The peripheral clocks are the clocks provided by the RCC to the peripherals. Two kinds of clock are available:

  – The bus interface clocks

  – The kernel clocks

  A peripheral receives from the RCC a bus interface clock in order to access its registers, and thus control the peripheral operation. This clock is generally the AHB, APB or AXI clock depending on which bus the peripheral is connected to. Some peripherals only need a bus interface clock (e.g. RNG, TIMx).

  Some peripherals also require a dedicated clock to handle the interface function. This clock is named “kernel clock”. As an example, peripherals such as SAI have to generate specific and accurate master clock frequencies, which require dedicated kernel clock frequencies. Another advantage of decoupling the bus interface clock from the specific interface needs, is that the bus clock can be changed without reprogramming the peripheral.

- CPU clocks

  The CPU clock is the clock provided to the CPU. It is derived from the system clock (**sys_ck**).

- Bus matrix clocks

  The bus matrix clocks are the clocks provided to the different bridges (APB, AHB or AXI). These clocks are derived from the system clock (**sys_ck**).

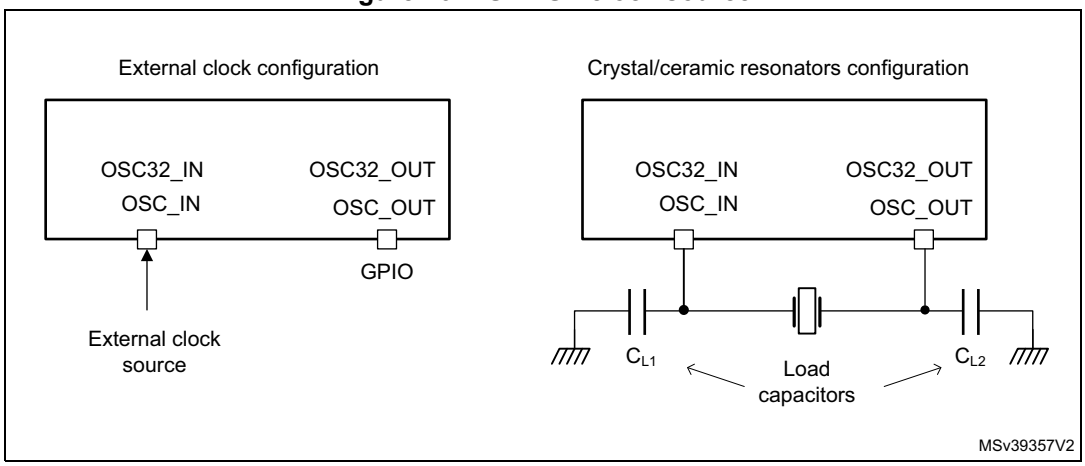
8.5.2 Description of the oscillators

HSE oscillator

The HSE block can generate a clock from two possible sources:

- External crystal/ceramic resonator
- External clock source

Figure 46. HSE/LSE clock source



External clock source (HSE bypass)

In this mode, an external clock source must be provided to OSC_IN pin. This mode is selected by setting the HSEBYP and HSEON bits of the *RCC source control register (RCC_CR)* to 1. The external clock source (square, sinus or triangle) with ~50% duty cycle has to drive the OSC_IN pin.

External crystal/ceramic resonator

The oscillator is enabled by setting the HSEBYP bit to 0 and HSEON bit to 1.

The HSE can be used when the product requires a very accurate high-speed clock.

The associated hardware configuration is shown in *Figure 46*: the resonator and the load capacitors have to be placed as close as possible to the oscillator pins in order to minimize output distortion and startup stabilization time. The loading capacitance values must be adjusted according to the selected crystal or ceramic resonator. Refer to the electrical characteristics section of the datasheet for more details.

The HSERDY flag of the *RCC source control register (RCC_CR)*, indicates whether the HSE oscillator is stable or not. At startup, the **hse_ck** clock is not released until this bit is set by hardware. An interrupt can be generated if enabled in the *RCC clock source interrupt enable register (RCC_CIER)*.

The HSE can be switched ON and OFF through the HSEON bit. Note that the HSE cannot be switched OFF if one of the two conditions is met:

- The HSE is used directly (via software mux) as system clock
- The HSE is selected as reference clock for PLL1, with PLL1 enabled and selected to provide the system clock (via software mux).

In that case the hardware does not allow programming the HSEON bit to 0.

The HSE is automatically disabled by hardware, when the system enters Stop or Standby mode (refer to *Section 8.5.7: Handling clock generators in Stop and Standby mode* for additional information).

In addition, the HSE clock can be driven to the MCO1 and MCO2 outputs and used as clock source for other application components.

LSE oscillator

The LSE block can generate a clock from two possible sources:

- External crystal/ceramic resonator
- External user clock

External clock source (LSE bypass)

In this mode, an external clock source must be provided to OSC32_IN pin. The input clock can have a frequency up to 1 MHz. This mode is selected by setting the LSEBYP and LSEON bits of *RCC backup domain control register (RCC_BDCR)* to 1. The external clock signal (square, sinus or triangle) with ~50% duty cycle has to drive the OSC32_IN pin.

External crystal/ceramic resonator (LSE crystal)

The LSE clock is generated from a 32.768 kHz crystal or ceramic resonator. It has the advantage to provide a low-power highly accurate clock source to the real-time clock (RTC) for clock/calendar or other timing functions.

The LSERDY flag of the *RCC backup domain control register (RCC_BDCR)* indicates whether the LSE crystal is stable or not. At startup, the LSE crystal output clock signal is not released until this bit is set by hardware. An interrupt can be generated if enabled in the *RCC clock source interrupt enable register (RCC_CIER)*.

The LSE oscillator is switched ON and OFF using the LSEON bit. The LSE remains enabled when the system enters Stop or Standby mode.

In addition, the LSE clock can be driven to the MCO1 output and used as clock source for other application components.

The LSE also offers a programmable driving capability (LSEDRV[1:0]) that can be used to modulate the amplifier driving capability. This driving capability must be chosen according to the external crystal/ceramic component requirement to insure a stable oscillation. The driving capability must be set before enabling the LSE oscillator.

HSI oscillator

The HSI block provides the default clock to the product.

The HSI is a high-speed internal RC oscillator which can be used directly as system clock, peripheral clock, or as PLL input. A predivider allows the application to select an HSI output frequency of 8, 16, 32 or 64 MHz. This predivider is controlled by the HSIDIV.

The HSI advantages are the following:

- Low-cost clock source since no external crystal is required
- Faster startup time than HSE (a few microseconds)

The HSI frequency, even with frequency calibration, is less accurate than an external crystal oscillator or ceramic resonator.

The HSI can be switched ON and OFF using the HSION bit. Note that the HSI cannot be switched OFF if one of the two conditions is met:

- The HSI is used directly (via software mux) as system clock
- The HSI is selected as reference clock for PLL1, with PLL1 enabled and selected to provide the system clock (via software mux).

In that case the hardware does not allow programming the HSION bit to 0.

Note that the HSIDIV cannot be changed if the HSI is selected as reference clock for at least one enabled PLL (PLLxON bit set to 1). In that case the hardware does not update the HSIDIV with the new value. However it is possible to change the HSIDIV if the HSI is used directly as system clock.

The HSIRDY flag indicates if the HSI is stable or not. At startup, the HSI output clock is not released until this bit is set by hardware.

The HSI clock can also be used as a backup source (auxiliary clock) if the HSE fails (refer to *Section : CSS on HSE*). The HSI can be disabled or not when the system enters Stop mode, please refer to *Section 8.5.7: Handling clock generators in Stop and Standby mode* for additional information.

In addition, the HSI clock can be driven to the MCO1 output and used as clock source for other application components.

Care must be taken when the HSI is used as kernel clock for communication peripherals, the application must take into account the following parameters:

- the time interval between the moment where the peripheral generates a kernel clock request and the moment where the clock is really available,
- the frequency accuracy.

Note: The HSI can remain enabled when the system is in Stop mode (see Section 8.5.7 for additional information).

HSION, HSIRDY and HSIDIV bits are located in the RCC source control register (RCC_CR).

HSI calibration

RC oscillator frequencies can vary from one chip to another due to manufacturing process variations. That is why each device is factory calibrated by STMicroelectronics to improve accuracy (refer to the product datasheet for more information).

After a power-on reset, the factory calibration value is loaded in the HSICAL[11:0] bits.

If the application is subject to voltage or temperature variations, this may affect the RC oscillator frequency. The user application can trim the HSI frequency using the HSITRIM bits.

CSI oscillator

The CSI is a low-power RC oscillator which can be used directly as system clock, peripheral clock, or PLL input.

The CSI advantages are the following:

- Low-cost clock source since no external crystal is required
- Faster startup time than HSE (a few microseconds)
- Very low-power consumption,

The CSI provides a clock frequency of about 4 MHz, while the HSI is able to provide a clock up to 64 MHz.

CSI frequency, even with frequency calibration, is less accurate than an external crystal oscillator or ceramic resonator.

The CSI can be switched ON and OFF through the CSION bit. The CSIRDY flag indicates whether the CSI is stable or not. At startup, the CSI output clock is not released until this bit is set by hardware.

The CSI cannot be switched OFF if one of the two conditions is met:

- The CSI is used directly (via software mux) as system clock
- The CSI is selected as reference clock for PLL1, with PLL1 enabled and selected to provide the system clock (via software mux).

In that case the hardware does not allow programming the CSION bit to 0.

The CSI can be disabled or not when the system enters Stop mode (refer to *Section 8.5.7: Handling clock generators in Stop and Standby mode* for additional information).

In addition, the CSI clock can be driven to the MCO2 output and used as clock source for other application components.

Even if the CSI settling time is faster than the HSI, care must be taken when the CSI is used as kernel clock for communication peripherals: the application has to take into account the following parameters:

- the time interval between the moment where the peripheral generates a kernel clock request and the moment where the clock is really available,
- the frequency precision.

CSI calibration

RC oscillator frequencies can vary from one chip to another due to manufacturing process variations, this is why each device is factory calibrated by STMicroelectronics to achieve improve (refer to the product datasheet for more information).

After reset, the factory calibration value is loaded in the CSICAL[7:0] bits.

If the application is subject to voltage or temperature variations, this may affect the RC oscillator frequency. The user application can trim the CSI frequency using the CSITRIM bits.

HSI48 oscillator

The HSI48 is an RC oscillator that delivers a 48 MHz clock that can be used directly as kernel clock for some peripherals.

The HSI48 oscillator mainly aims at providing a high precision clock to the USB peripheral by means of a special Clock Recovery System (CRS) circuitry, which could use the USB SOF signal, the LSE, or an external signal, to automatically adjust the oscillator frequency on-the-fly, in very small granularity.

The HSI48 oscillator is disabled as soon as the system enters Stop or Standby mode. When the CRS is not used, this oscillator is free running and thus subject to manufacturing process variations. That is why each device is factory calibrated by STMicroelectronics to achieve an accuracy of ACC_{HSI48} (refer to the product datasheet of the for more information).

For more details on how to configure and use the CRS, please refer to *Section 9: Clock recovery system (CRS)*.

The HSI48RDY flag indicates whether the HSI48 oscillator is stable or not. At startup, the HSI48 output clock is not released until this bit is set by hardware.

The HSI48 can be switched ON and OFF using the HSI48ON bit.

The HSI48 clock can also be driven to the MCO1 multiplexer and used as clock source for other application components.

Note: HSI48ON and HSI48RDY bits are located in the RCC source control register (RCC_CR).

LSI oscillator

The LSI acts as a low-power clock source that can be kept running when the system is in Stop or Standby mode for the independent watchdog (IWDG) and Auto-Wakeup Unit (AWU). The clock frequency is around 32 kHz. For more details, refer to the electrical characteristics section of the datasheet.

The LSI can be switched ON and OFF using the LSION bit. The LSIRDY flag indicates whether the LSI oscillator is stable or not. If an independent watchdog is started either by hardware or software, the LSI is forced ON and cannot be disabled.

The LSI remains enabled when the system enters Stop or Standby mode (refer to *Section 8.5.7: Handling clock generators in Stop and Standby mode* for additional information).

At LSI startup, the clock is not provided until the hardware sets the LSIRDY bit. An interrupt can be generated if enabled in the *RCC clock source interrupt enable register (RCC_CIER)*.

In addition, the LSI clock can be driven to the MCO2 output and used as a clock source for other application components.

Note: Bits LSION and LSIRDY are located into the RCC Clock Control and Status Register (RCC_CSR).

8.5.3 Clock Security System (CSS)

CSS on HSE

The clock security system can be enabled by software via the HSECSSON bit. The HSECSSON bit can be enabled even when the HSEON is set to 0.

The CSS on HSE is enabled by the hardware when the HSE is enabled and ready, and HSECSSON set to 1.

The CSS on HSE is disabled when the HSE is disabled. As a result, this function does not work when the system is in Stop mode.

It is not possible to clear directly the HSECSSON bit by software.

The HSECSSON bit is cleared by hardware when a system reset occurs or when the system enters Standby mode (see *Section 8.4.2: System reset*).

If a failure is detected on the HSE clock, the system automatically switches to the HSI in order to provide a safe clock. The HSE is then automatically disabled, a clock failure event is sent to the break inputs of advanced-control timers (TIM1, TIM8, TIM15, TIM16, and TIM17), and an interrupt is generated to inform the software about the failure (CSS interrupt: ***rcc_hsecss_it***), thus allowing the MCU to perform rescue operations. If the HSE output was used as clock source for PLLs when the failure occurred, the PLLs are also disabled.

If an HSE clock failure occurs when the CSS is enabled, the CSS generates an interrupt which causes the automatic generation of an NMI. The HSECSSF flag in *RCC clock source interrupt flag register (RCC_CIFR)* is set to 1 to allow the application to identify the failure source. The NMI routine is executed indefinitely until the HSECSSF bit is cleared. As a consequence, the application has to clear the HSECSSF flag in the NMI ISR by setting the HSECSSC bit in the *RCC clock source interrupt clear register (RCC_CICR)*.

CSS on LSE

A clock security system on the LSE oscillator can be enabled by software by programming the LSECSSON bit in the *RCC backup domain control register (RCC_BDCR)*.

This bit can be disabled only by hardware when the following conditions are met:

- after a pwr_vsw_rst (V_{SW} software reset)
- or after a failure detection on LSE.

LSECSSON bit must be written after the LSE is enabled (LSEON bit set by software) and ready (LSERDY set by hardware), and after the RTC clock has been selected through the RTCSEL bit.

The CSS on LSE works in all modes (Run, Stop and Standby) except VBAT.

If an LSE failure is detected, the LSE clock is no more delivered to the RTC but the value of RTCSEL, LSECSSON and LSEON bits are not changed by the hardware.

A wakeup is generated in Standby mode. In other modes an interrupt (**rcc_lsecss_it**) can be sent to wake up the software. The software must then disable the LSECSSON bit, stop the defective LSE (clear LSEON bit), and can change the RTC clock source (no clock or LSI or HSE) through RTCSEL bits, or take any required action to secure the application.

8.5.4 Clock output generation (MCO1/MCO2)

Two micro-controller clock output (MCO) pins, MCO1 and MCO2, are available. A clock source can be selected for each output.The selected clock can be divided thanks to configurable prescaler (refer to *Figure 45* for additional information on signal selection).

MCO1 and MCO2 outputs are controlled via MCO1PRE[3:0], MCO1[2:0], MCO2PRE[3:0] and MCO2[2:0] located in the *RCC clock configuration register (RCC_CFGR)*.

The GPIO port corresponding to each MCO pin, has to be programmed in alternate function mode.

The clock provided to the MCOs outputs must not exceed the maximum pin speed (refer to the product datasheet for information on the supported pin speed).

8.5.5 PLL description

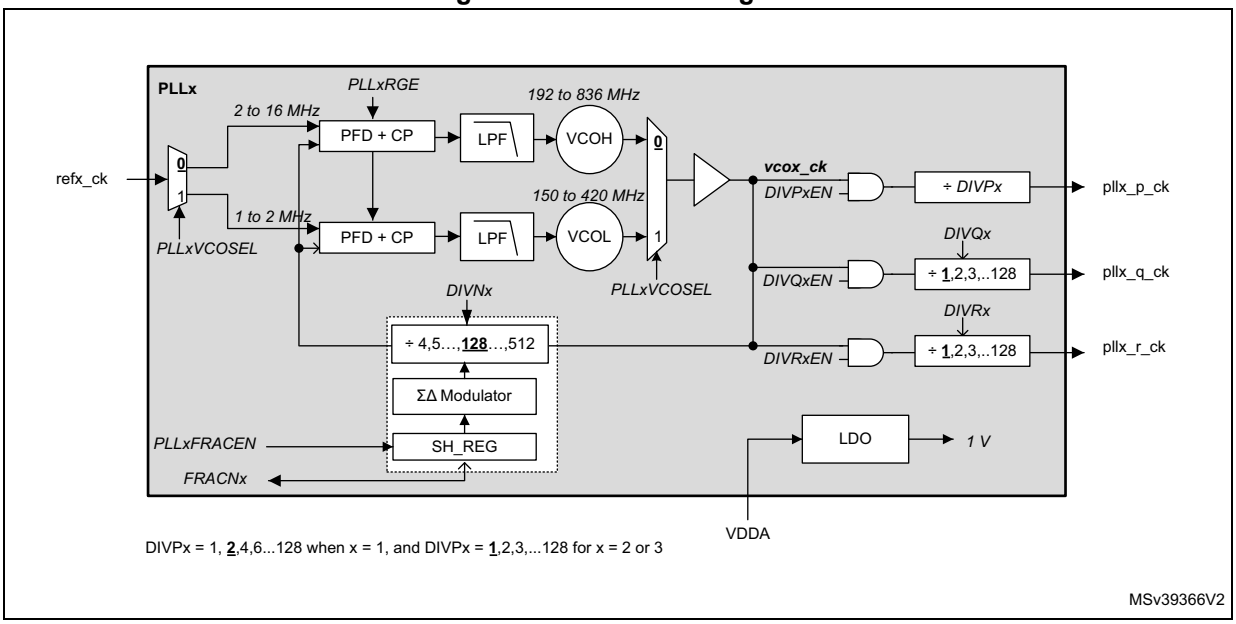
The RCC features three PLLs:

- A main PLL, PLL1, which is generally used to provide clocks to the CPU and to some peripherals.
- Two dedicated PLLs, PLL2 and PLL3, which are used to generate the kernel clock for peripherals.

The PLLs integrated into the RCC are completely independent. They offer the following features:

- Two embedded VCOs:
  - A wide-range VCO (VCOH)
  - A low-frequency VCO (VCOL)
- Input frequency range:
  - 1 to 2 MHz when VCOL is used
  - 2 to 16 MHz when VCOH is used
- Capability to work either in integer or Fractional mode
- 13-bit Sigma-Delta modulator, allowing to fine-tune the VCO frequency by steps of 11 to 0.3 ppm.
- The Sigma-Delta modulator can be updated on-the-fly, without generating frequency overshoots on PLLs outputs.
- Each PLL offer 3 outputs with post-dividers

Figure 47. PLL block diagram



The PLLs are controlled via RCC_PLLxDIVR, RCC_PLLxFRACR, RCC_PLLCFGR and RCC_CR registers.

The frequency of the reference clock provided to the PLLs (**refx_ck**) must range from 1 to 16 MHz. The user application has to program properly the DIVMx dividers of the *RCC PLLs clock source selection register (RCC_PLLCKSELR)* in order to match this condition. In addition, the PLLxRGE of the *RCC PLLs Configuration Register (RCC_PLLCFGR)* field must be set according to the reference input frequency to guarantee an optimal performance of the PLL.

The user application can then configure the proper VCO: if the frequency of the reference clock is lower or equal to 2 MHz, then VCOL must be selected. Otherwise for a frequency equal or higher to 2 MHz, VCOH must be chosen. To reduce the power consumption, it is recommended to configure the VCO output to the lowest frequency.

DIVNx loop divider has to be programmed to achieve the expected frequency at VCO output. In addition, the VCO output range must be respected.

The PLLs operate in integer mode when the value of SH_REG (FRACNx shadow register) is set to 0. The SH_REG is updated with the FRACNx value when PLLxFRACEN bit goes from 0 to 1. The Sigma-Delta modulator is designed in order to minimize the jitter impact while allowing very small frequency steps.

The PLLs can be enabled by setting PLLxON to 1. The bits PLLxRDY indicate that the PLL is ready (i.e. locked).

*Note: Before enabling the PLLs, make sure that the reference frequency (**refx_ck**) provided to the PLL is stable, so the hardware does not allow changing DIVMx when the PLLx is ON and it is also not possible to change PLLSRC when one of the PLL is ON.*

The hardware prevents writing PLL1ON to 0 if the PLL1 is currently used to deliver the system clock. There are other hardware protections on the clock generators (refer to sections HSE oscillator, HSI oscillator and CSI oscillator).

The following PLL parameters cannot be changed once the PLL is enabled: DIVNx, PLLxRGE, PLLxVCOSEL, DIVPx, DIVQx, DIVRx, DIVPxEN, DIVQxEN and DIVRxEN.

To insure an optimal behavior of the PLL when one of the post-divider (DIVP, DIVQ or DIVR) is not used, the application shall set the enable bit (DIVyEN) as well as the corresponding post-divider bits (DIVP, DIVQ or DIVR) to 0.

If the above rules are not respected, the PLL output frequency is not guaranteed.

Output frequency computation

When the PLL is configured in integer mode (SH_REG = 0), the VCO frequency (F_{VCO}) is given by the following expression:

$$F_{VCO} = F_{REF\_CK} \times DIVN$$

$$F_{PLL\_y\_CK} = (F_{VCO} / (DIVy + 1)) \text{ with y = P, Q or R}$$

When the PLL is configured in fractional mode (SH_REG different from 0), the DIVN divider must be initialized before enabling the PLLs. However, it is possible to change the value of FRACNx on-the-fly without disturbing the PLL output.

This feature can be used either to generate a specific frequency from any crystal value with a good accuracy, or to fine-tune the frequency on-the-fly.

For each PLL, the VCO frequency is given by the following formula:

$$F_{VCO} = F_{ref\_ck} \times \left(DIVN + \frac{FRACN}{2^{(13)}} \right)$$

Note: For PLL1, DIVP bitfield can only take odd values or 1 (no division).

The PLLs are disabled by hardware when:

- The system enters Stop or Standby mode.
- An HSE failure occurs when HSE or PLL (clocked by HSE) are used as system clock.

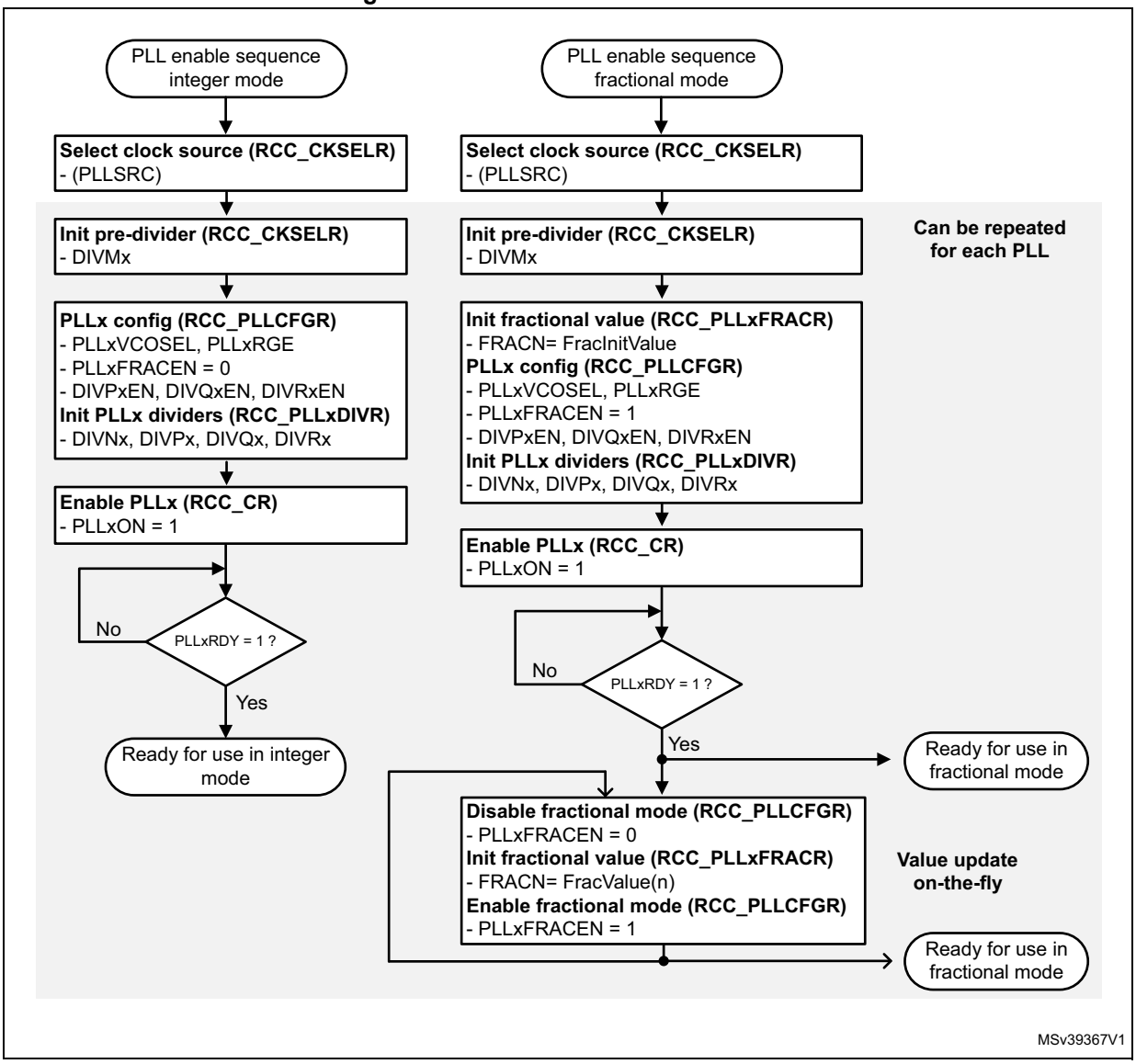
PLL initialization phase

Figure 48 shows the recommended PLL initialization sequence in integer and fractional mode. The PLLx are supposed to be disabled at the start of the initialization sequence:

1. Initialize the PLLs registers according to the required frequency.
   – Set PLLxFRACEN of *RCC PLLs Configuration Register (RCC_PLLCFGR)* to 0 for integer mode.
   – For fractional mode, set FRACN to the required initial value (FracInitValue) and then set PLLxFRACEN to 1.
2. Once the PLLxON bit is set to 1, the user application has to wait until PLLxRDY bit is set to 1. If the PLLx is in fractional mode, the PLLxFRACEN bit must not be set back to 0 as long as PLLxRDY = 0.
3. Once the PLLxRDY bit is set to 1, the PLLx is ready to be used.
4. If the application intends to tune the PLLx frequency on-the-fly (possible only in fractional mode), then:
   a) PLLxFRACEN must be set to 0,
   When PLLxFRACEN = 0, the Sigma-Delta modulator is still operating with the value latched into SH_REG.
   b) A new value must be uploaded into PLLxFRACR (FracValue(n)).
   c) PLLxFRACEN must be set to 1, in order to latch the content of PLLxFRACR into its shadow register.

Note: When the PLLxRDY goes to 1, it means that the difference between the PLLx output frequency and the target value is lower than ±2%.

Figure 48. PLLs Initialization Flowchart



8.5.6 System clock (sys_ck)

System clock selection

After a system reset, the HSI is selected as system clock and all PLLs are switched OFF. When a clock source is used for the system clock, it is not possible for the software to disable the selected source via the xxxON bits.

Of course, the system clock can be stopped by the hardware when the System enters Stop or Standby mode.

When the system is running, the user application can select the system clock (**sys_ck**) among the 4 following sources:

- HSE
- HSI
- CSI or
- pll1_p_ck

This function is controlled by programming the *RCC clock configuration register (RCC_CFGR)*. A switch from one clock source to another occurs only if the target clock source is ready (clock stable after startup delay or PLL locked). If a clock source that is not yet ready is selected, the switch occurs when the clock source is ready.
The SWS status bits in the *RCC clock configuration register (RCC_CFGR)* indicate which clock is currently used as system clock. The other status bits in the RCC_CR register indicate which clock(s) is (are) ready.

System clock generation

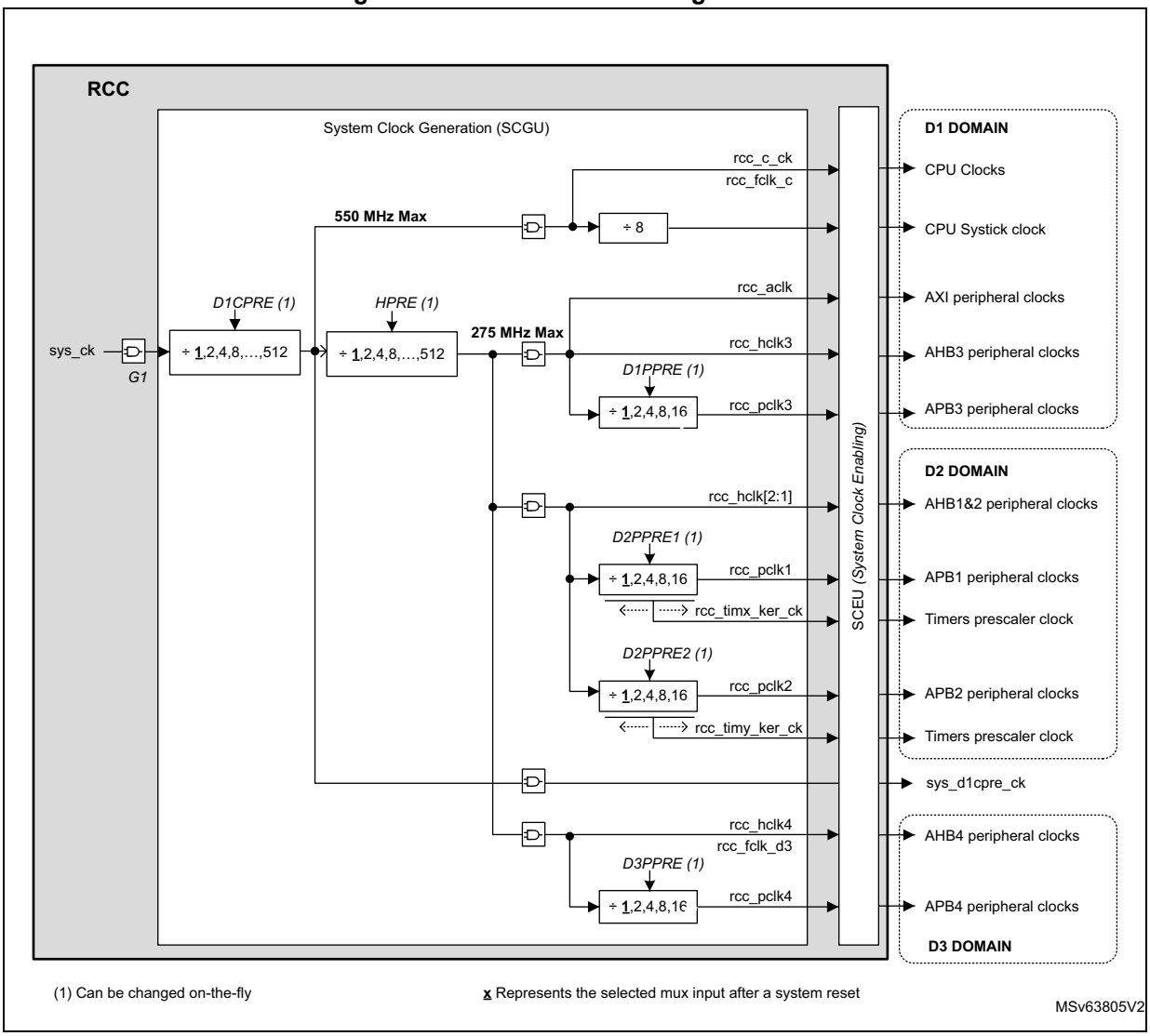
Figure 49 shows a simplified view of the clock distribution for the CPU and busses. All the dividers shown in the block diagram can be changed on-the-fly without generating timing violations. This feature is a very simply solution to adapt the busses frequencies to the application needs, thus optimizing the power consumption.

The D1CPRE divider can be used to adjust the CPU clock. However this also impacts the clock frequency of all bus matrix.

In the same way, HPRE divider can be used to adjust the clock for D1 domain bus matrix, but this also impacts the clock frequency of bus matrix of D2 and D3 domains.

Most of the prescalers are controlled via RCC_D1CFGR, RCC_D2CFGR and RCC_D3CFGR registers.

Figure 49. Core and bus clock generation



This block also provides the clock for the timers (**rcc_timx_ker_ck and rcc_timy_ker_ck**). The frequency of the timers clock depends on the APB prescaler corresponding to the bus to which the timer is connected, and on TIMPRE bit. *Table 53* shows how to select the timer clock frequency.

Table 53. Ratio between clock timer and pclk

D2PPRE1 (1) D2PPRE2	TIMPRE (2)		$F_{rcc\_timx\_ker\_ck}$ $F_{rcc\_timy\_ker\_ck}$	F_{rcc_pclk1} F_{rcc_pclk2}	Comments
0xx	0	→	F_{rcc_hclk1}	F_{rcc_hclk1}	The timer clock is equal to the bus clock.
100	0	→	F_{rcc_hclk1}	F_{rcc_hclk1} / 2	The timer clock is twice as fast as the bus clock.
101	0	→	F_{rcc_hclk1} / 2	F_{rcc_hclk1} / 4	
110	0	→	F_{rcc_hclk1} / 4	F_{rcc_hclk1} / 8	
111	0	→	F_{rcc_hclk1} / 8	F_{rcc_hclk1} / 16	

Table 53. Ratio between clock timer and pclk (continued)

D2PPRE1 (1) D2PPRE2	TIMPRE (2)		$F_{rcc\_timx\_ker\_ck}$ $F_{rcc\_timy\_ker\_ck}$	F_{rcc_pclk1} F_{rcc_pclk2}	Comments
0xx	1	→	F_{rcc_hclk1}	F_{rcc_hclk1}	The timer clock is equal to the bus clock.
100	1	→	F_{rcc_hclk1}	F_{rcc_hclk1} / 2	The timer clock is twice as fast as the bus clock.
101	1	→	F_{rcc_hclk1}	F_{rcc_hclk1} / 4	The timer clock is 4 times faster than the bus clock.
110	1	→	F_{rcc_hclk1} / 2	F_{rcc_hclk1} / 8	
111	1	→	F_{rcc_hclk1} / 4	F_{rcc_hclk1} / 16	

1. D2PPRE1 and D2PPRE2 belong to *RCC domain 2 clock configuration register (RCC_D2CFGR)*.
2. TIMPRE belongs to *RCC clock configuration register (RCC_CFGR)*.

8.5.7 Handling clock generators in Stop and Standby mode

When the whole system enters Stop mode, all the clocks (system and kernel clocks) are stopped as well as the following clock sources:

- CSI, HSI (depending on HSIKERON, and CSIKERON bits)
- HSE
- PLL1, PLL2 and PLL3
- HSI48

The content of the RCC registers is not altered except for PLL1ON, PLL2ON, PLL3ON HSEON and HSI48ON which are set to 0.

Exiting Stop mode

When the microcontroller exits system Stop mode via a wake-up event, the application can select which oscillator (HSI and/or CSI) will be used to restart. The STOPWUCK bit selects the oscillator used as system clock. The STOPKERWUCK bit selects the oscillator used as kernel clock for peripherals. The STOPKERWUCK bit is useful if after a system Stop a peripheral needs a kernel clock generated by an oscillator different from the one used for the system clock.

All these bits belong to the *RCC clock configuration register (RCC_CFGR)*. *Table 54* gives a detailed description of their behavior.

Table 54. STOPWUCK and STOPKERWUCK description

STOPWUCK	STOPKERWUCK		Activated oscillator when the system exits Stop mode	Distributed clocks when System exits Stop mode	
				System Clock	Kernel Clock
0	0	→	HSI	HSI	HSI
	1	→	HSI and CSI		HSI and/or CSI
1	0	→		CSI	
	1	→	CSI		CSI

During Stop mode

There are two specific cases where the HSI or CSI can be enabled during system Stop mode:

- When a dedicated peripheral requests the kernel clock:

  In this case the peripheral will receive the HSI or CSI according to the kernel clock source selected for this peripheral (via PERxSRC).
- When the bits HSIKERON or CSIKERON are set:

  In this case the HSI and CSI are kept running during Stop mode but the outputs are gated. In that way, the clock will be available immediately when the system exits Stop mode or when a peripheral requests the kernel clock (see *Table 55* for details).

HSIKERON and CSIKERON bits belong to *RCC source control register (RCC_CR)*. *Table 55* gives a detailed description of their behavior.

Table 55. HSIKERON and CSIKERON behavior

HSIKERON (CSIKERON)		HSI (CSI) state during Stop mode	HSI (CSI) Setting time
0	→	OFF	$t_{su(HSI)}$ ($t_{su(CSI)}$) (1)
1	→	Running and Gated	Immediate

1. $t_{su(HSI)}$ and $t_{su(CSI)}$ are the startup times of the HSI and CSI oscillators (see refer to the product datasheet for the values of these parameters).

When the microcontroller exists system Standby mode, the HSI is selected as system and kernel clock, the RCC registers are reset to their initial values except for the RCC_RSR (or RCC_C1_RSR) and RCC_BDCR registers.

Note as well that the HSI and CSI outputs provide two clock paths (see *Figure 45*):

- one path for the system clock (**hsi_ck** or **csi_ck**)
- one path for the peripheral kernel clock (**hsi_ker_ck** or **csi_ker_ck**).

When a peripheral requests the kernel clock in system Stop mode, only the path providing the **hsi_ker_ck** or **csi_ker_ck** is activated.

Caution: It is not guaranteed that the CPU will get automatically the same clock frequencies when leaving CStop mode: this mainly depends on the System state. For example If the CPU goes to CStop, while the D3 domain is kept in CRun, when the CPU exits from CStop, the clock settings remain unchanged. If the D3 domain goes to CStop while the CPU is also in CStop, then when the CPU exits from CStop, the CPU will operate with HSI or CSI when it left the CStop mode.

8.5.8 Kernel clock selection

Some peripherals are designed to work with two different clock domains that operate asynchronously:

- a clock domain synchronous with the register and bus interface (**ckg_bus_perx** clock)
- and a clock domain generally synchronous with the peripheral (kernel clock).

The benefit of having peripherals supporting these two clock domains is that the user application has more freedom to choose optimized clock frequency for the CPU, bus matrix and for the kernel part of the peripheral.

As a consequence, the user application can change the bus frequency without reprogramming the peripherals. As an example an on-going transfer with UART will not be disturbed if its APB clock is changed on-the-fly.

Table 56 shows the kernel clock that the RCC can deliver to the peripherals. Each row of *Table 56* represents a MUX and the peripherals connected to its output. The columns starting from number 5 represents the clock sources. Column 3 gives the maximum allowed frequency at each MUX output. It is up to the user to respect these requirements.

Table 56. Kernel clock distribution overview

Peripherals	Clock mux control bits	Maximum allowed frequency [MHz]				Domain	Clock sources																						
		VOS0	VOS1	VOS2	VOS3		pll1_q_ck	pll2_p_ck	pll2_q_ck	pll2_r_ck	pll3_p_ck	pll3_q_ck	pll3_r_ck	sys_ck	bus clocks (1)	hse_ck	hsi_ker_ck	csi_ker_ck	hsi48_ck	lse_ck	lsi_ck	per_ck (2)	I2S_CKIN	USB_PHY1	spdifrx_symb_ck	Disabled
LTDC	-	166	100	75	50	D1							x																
FMC	FMCSEL	275	200	150	100		1			2					0							3							
OCTOSPI	OCTOSPISEL	333	200	150	100		1			2					0							3							
SDMMC1	SDMMCSEL	250(4)	200(4)	150(4)	100(4)		0			1																			
SDMMC2		250	200	150	100	D2																							
DFSDM1 Aclk	SAI1SEL	250	200	150	100		0	1			2											4	3						
DFSDM1 clk	DFSDM1SEL	275	200	150	85									1	0														
FDCAN	FDCANSEL	125	100	75	50		1		2							0													
HDMI-CEC	CECSEL	1	1	1	1													2(3)		0	1								
I2C1,2,3, 5	I2C1235SEL	137.5	100	75	43								1		0		2	3											
LPTIM1	LPTIM1SEL	137.5	100	75	43			1					2		0					3	4	5							
TIM[8:1][17:12]	-	275	200	150	85										x														
RNG	RNGSEL	250	200	150	100		1												0	2	3								
SAI1	SAI1SEL	166	150	113	75		0	1			2											4	3						
SPDIFRX	SPDIFRXSEL	250	200	150	100		0			1			2				3												
SPI(I2S)1,2,3	SPI123SEL	250	180	125	75		0	1			2											4	3						

Table 56. Kernel clock distribution overview (continued)

Peripherals	Clock mux control bits	Maximum allowed frequency [MHz]				Domain	Clock sources																				
		VOS0	VOS1	VOS2	VOS3		pll1_q_ck	pll2_p_ck	pll2_q_ck	pll2_r_ck	pll3_p_ck	pll3_q_ck	pll3_r_ck	sys_ck	bus clocks (1)	hse_ck	hsi_ker_ck	csi_ker_ck	hsi48_ck	lse_ck	lsi_ck	per_ck (2)	I2S_CKIN	USB_PHY1	spdifrx_symb_ck	Disabled
SPI4,5	SPI45SEL	250	180	125	75	D2			1			2			0	5	3	4								
SWPMI	SWPMISEL	137.5	100	75	43										0		1									
USART1,6, 10 UART9	USART16910SEL	137.5	100	75	43				1			2			0		3	4		5						
USART2,3 UART4,5,7,8	USART234578SEL	137.5	100	75	43				1			2			0		3	4		5						
USB1OTG	USBSEL	125	100	50	50		1					2							3							0
USB1ULPI	-	60	60	45	40																		x			
ADC1,2, 3	ADCSEL	160(4)	160(4)	60	40(4)			0					1									2					
I2C4	I2C4SEL	137.5	100	75	43	D3							1		0		2	3								
LPTIM2	LPTIM2SEL	137.5	100	75	43			1					2		0					3	4	5				
LPTIM3,4,5	LPTIM345SEL	137.5	100	75	43			1					2		0					3	4	5				
LPUART1	LPUART1SEL	137.5	100	75	43				1			2			0		3	4		5						
SAI4_A	SAI4ASEL	166	150	113	75		0	1			2											4	3		5	
SAI4_B	SAI4BSEL	166	150	113	75		0	1			2											4	3		5	
SPI(I2S)6	SPI6SEL	250	180	125	75				1			2			0	5	3	4					6			
RTC/AWU	RTCSEL	1				VSW										3(5)				1	2					0

1. The bus clocks are the bus interface clocks to which the peripherals are connected, it can be APB, AHB or AXI clocks.
2. The per_ck clock could be hse_ck, hsi_ker_ck or csi_ker_ck according to CKPERSEL selection.
3. Clock CSI divided by 122.
4. With a duty cycle close to 50%, meaning that DIV[P/Q/R]x values shall be even. For SDMMCx, the duty cycle shall be 50% when supporting DDR.
5. Clock HSE divided by RTCPRE.

Figure 50 to *Figure 60* provide a more detailed description of kernel clock distribution. To simplify the drawings, the bus interface clocks (pclk, hclk) are not represented, even if they are gated with enable signals. Refer to *Section 8.5.11: Peripheral clock gating control* for more details.

To reduce the amount of switches, some peripherals share the same kernel clock source. Nevertheless, all peripherals have their dedicated enable signal.

Peripherals dedicated to audio applications

The audio peripherals generally need specific accurate frequencies, except for SPDIFRX. As shown in *Figure 50* and *Figure 51*, the kernel clock of the SAIs or SPI(I2S)s can be generated by:

- The PLL1 when the amount of active PLLs has to be reduced
- The PLL2 or 3 for optimal flexibility in frequency generation
- HSE, HSI or CSI for use-cases where the current consumption is critical
- I2S_CKIN when an external clock reference need to be used.

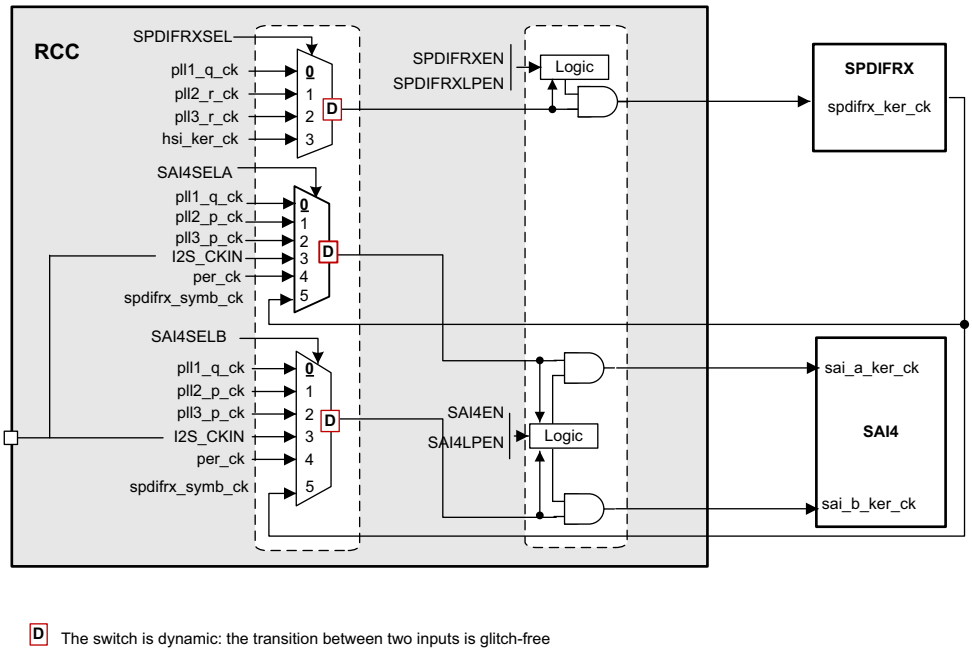
Note: The SPDIFRX does not require a specific frequency, but only a kernel clock frequency high enough to make the peripheral work properly. Refer to the SPDIFRX description for more details.

DFSDM1 can use the same clock as SAI1A. This is useful when DFSDM1 is used for audio applications.

To improve the flexibility, SAI4 can use different clock for each sub-block.

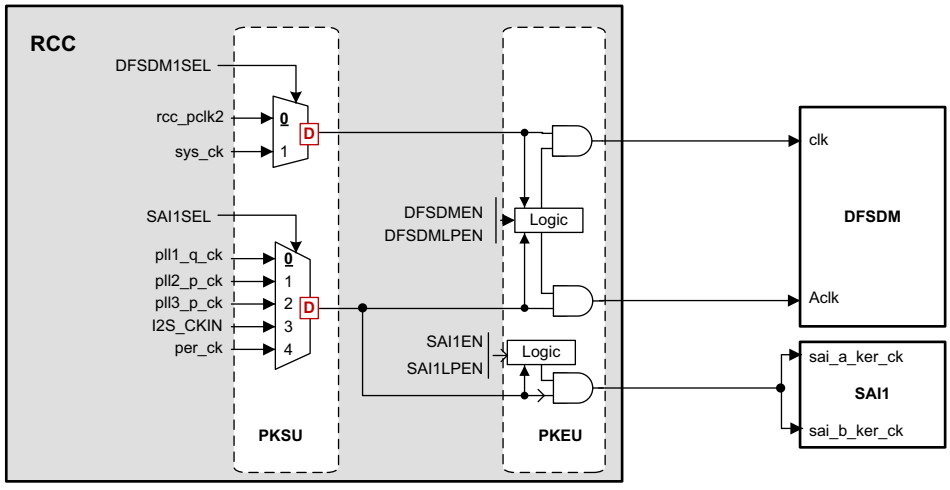
The SPI/I2S1, 2, and 3 share the same kernel clock source (see Figure 52).

Figure 50. Kernel clock distribution for SAIs and SPDIFRX



1. **X** represents the selected MUX input after a system reset.
2. This figure does not show the connection of the bus interface clock to the peripherals. For details on each enable cell, please refer to *Section 8.5.11: Peripheral clock gating control*.

Figure 51. Kernel clock distribution for DFSDM



1. **X** represents the selected MUX input after a system reset.
2. This figure does not show the connection of the bus interface clock to the peripherals. For details on each enable cell, please refer to *Section 8.5.11: Peripheral clock gating control*.

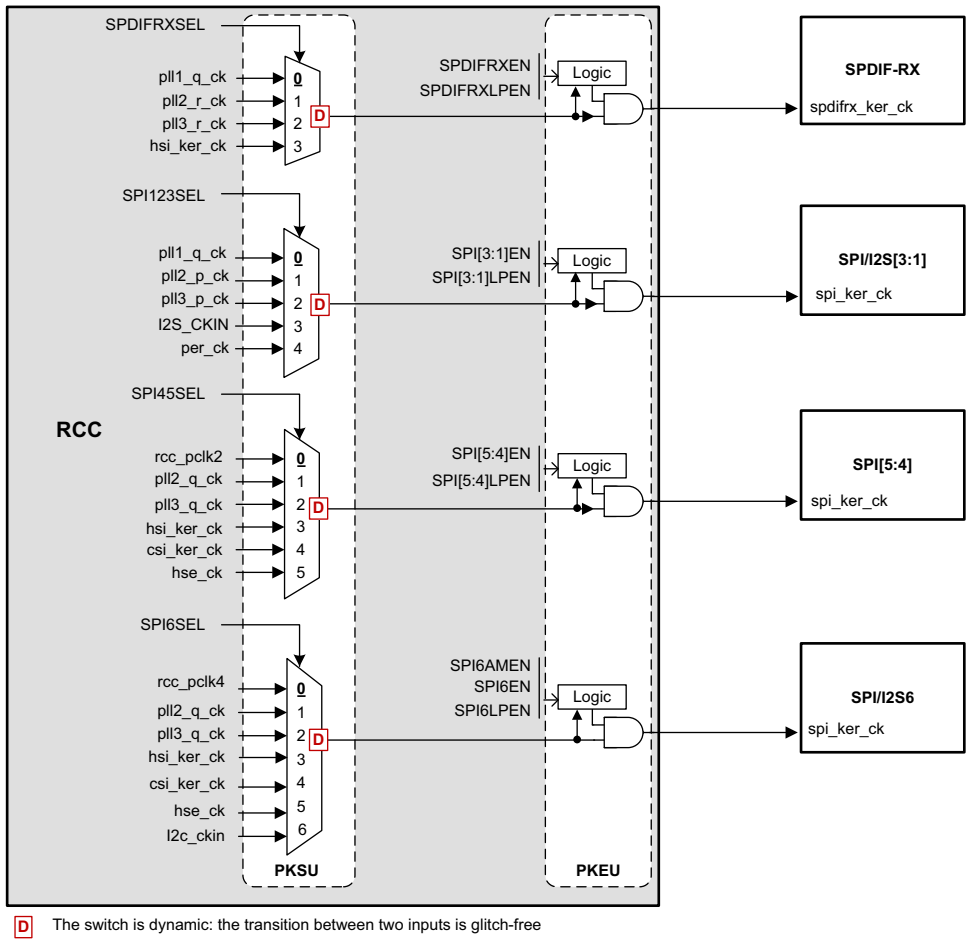
Peripherals dedicated to control and data transfer

Peripherals such as SPIs, I2Cs, UARTs do not need a specific kernel clock frequency but a clock fast enough to generate the correct baud rate, or the required bit clock on the serial interface. For that purpose the source can be selected among:

- PLL1 when the amount of active PLLs has to be reduced
- PLL2 or PLL3 if better flexibility is required. As an example, this solution allows changing the frequency bus via PLL1 without affecting the speed of some serial interfaces.
- HSI or CSI for low-power use-cases or when the peripheral has to quickly wake up from Stop mode (i.e. UART, I2C...).

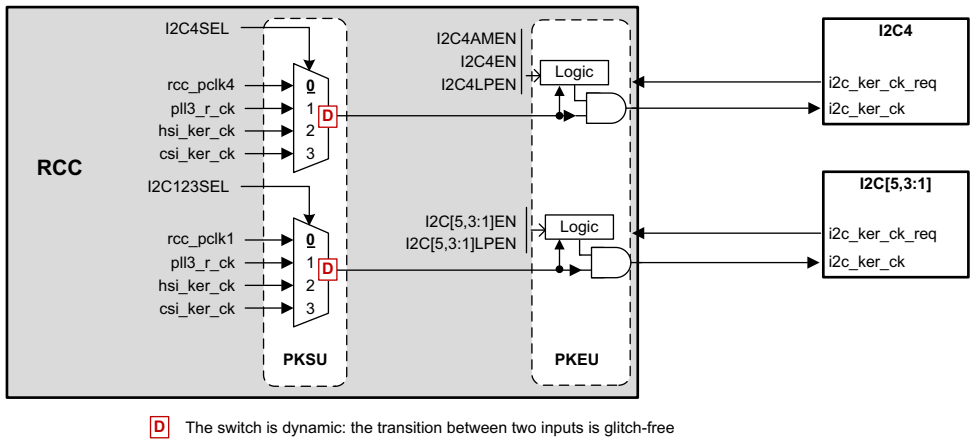
Note: UARTs also need the LSE clock when high baud rates are not required.

Figure 52. Kernel clock distribution for SPIs and SPI/I2S



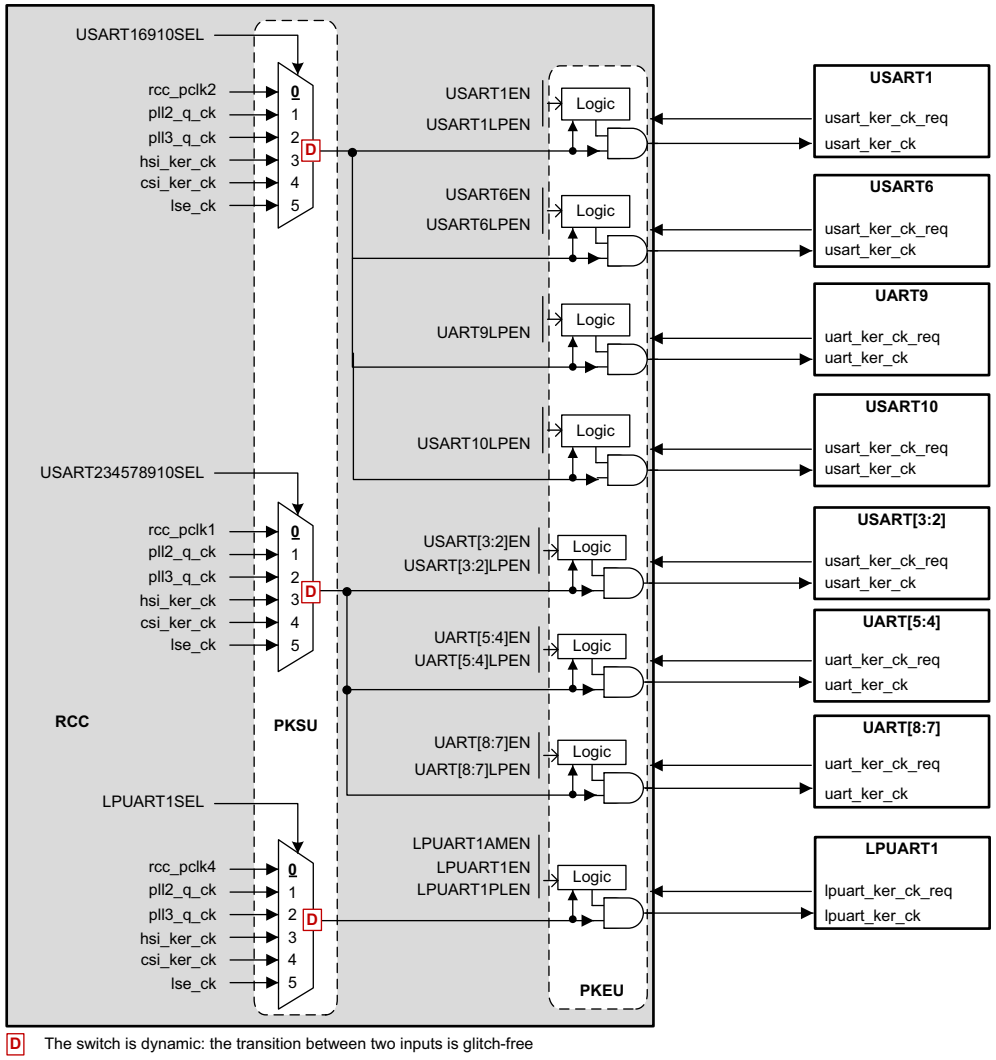
1. **X** represents the selected MUX input after a system reset.
2. This figure does not show the connection of the bus interface clock to the peripheral. or details on each enable cell, please refer to *Section 8.5.11: Peripheral clock gating control*.

Figure 53. Kernel clock distribution for I2Cs



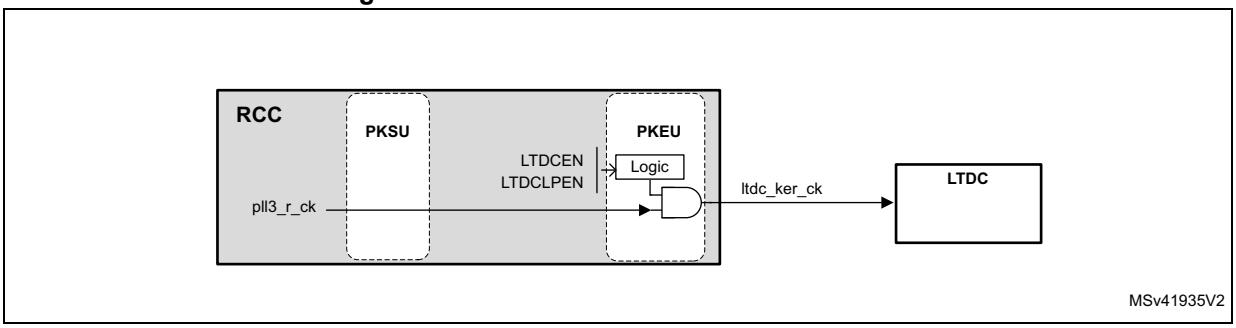
1. **X** represents the selected MUX input after a system reset
2. This figure does not show the connection of the bus interface clock to the peripheral, for details on each enable cell, please refer to *Section 8.5.11: Peripheral clock gating control*.

Figure 54. Kernel clock distribution for UARTs, USARTs and LPUART1



1. **X** represents the selected MUX input after a system reset.
2. This figure does not show the connection of the bus interface clock to the peripheral, for details on each enable cell, please refer to *Section 8.5.11: Peripheral clock gating control*.

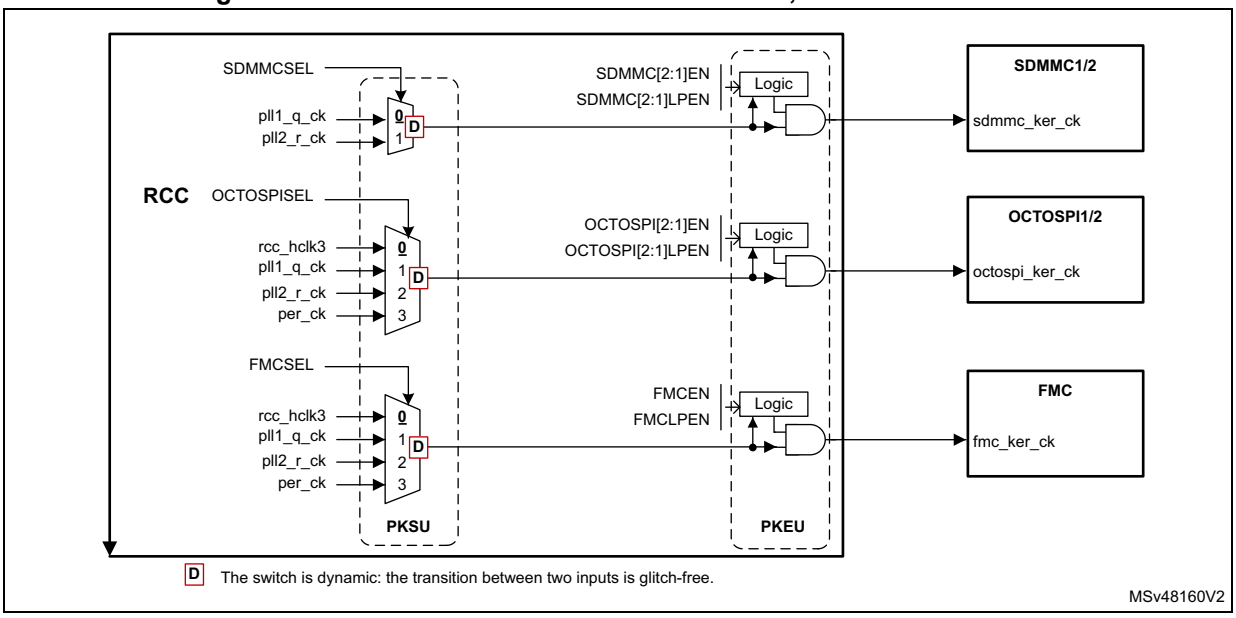
Figure 55. Kernel clock distribution for LTDC



1. **X** represents the selected MUX input after a system reset.
2. This figure does not show the connection of the bus interface clock to the peripheral. For details on each enable cell, please refer to *Section 8.5.11: Peripheral clock gating control*.

The FMC, OCTOSPI and SDMMC1/2 can also use a clock different from the bus interface clock for more flexibility.

Figure 56. Kernel clock distribution for SDMMC, OCTOSPI and FMC

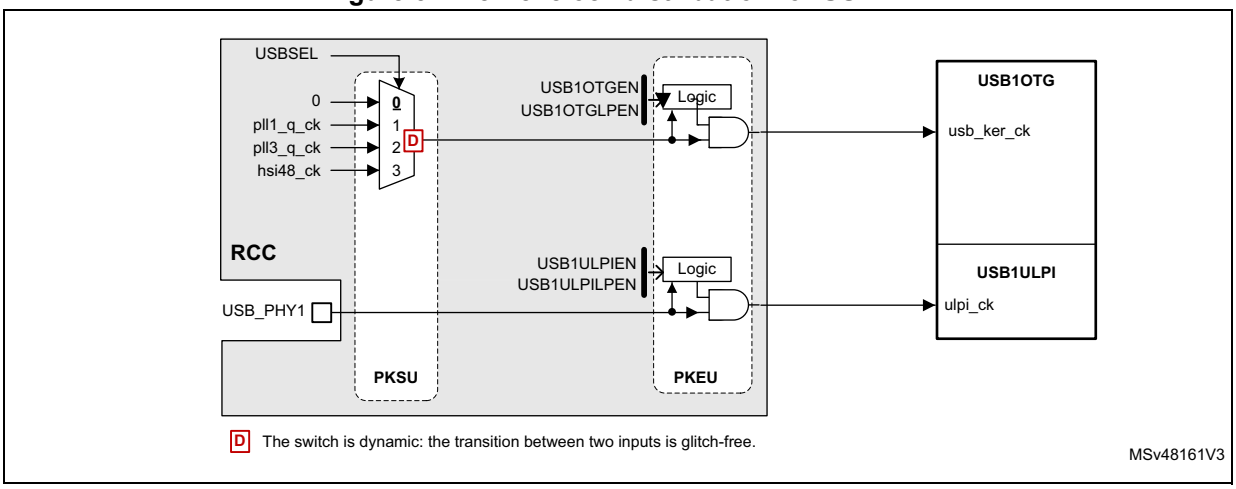


1. **X** represents the selected MUX input after a system reset.
2. This figure does not show the connection of the bus interface clock to the peripheral. For details on each enable cell, please refer to *Section 8.5.11: Peripheral clock gating control*.

Figure 57 shows the clock distribution for the USB blocks. The USB1ULPI block receives its clock from the external PHY.

The USB1OTG block receives the clock for USB communications which can be selected among different sources thanks to the MUX controlled by USBSEL.

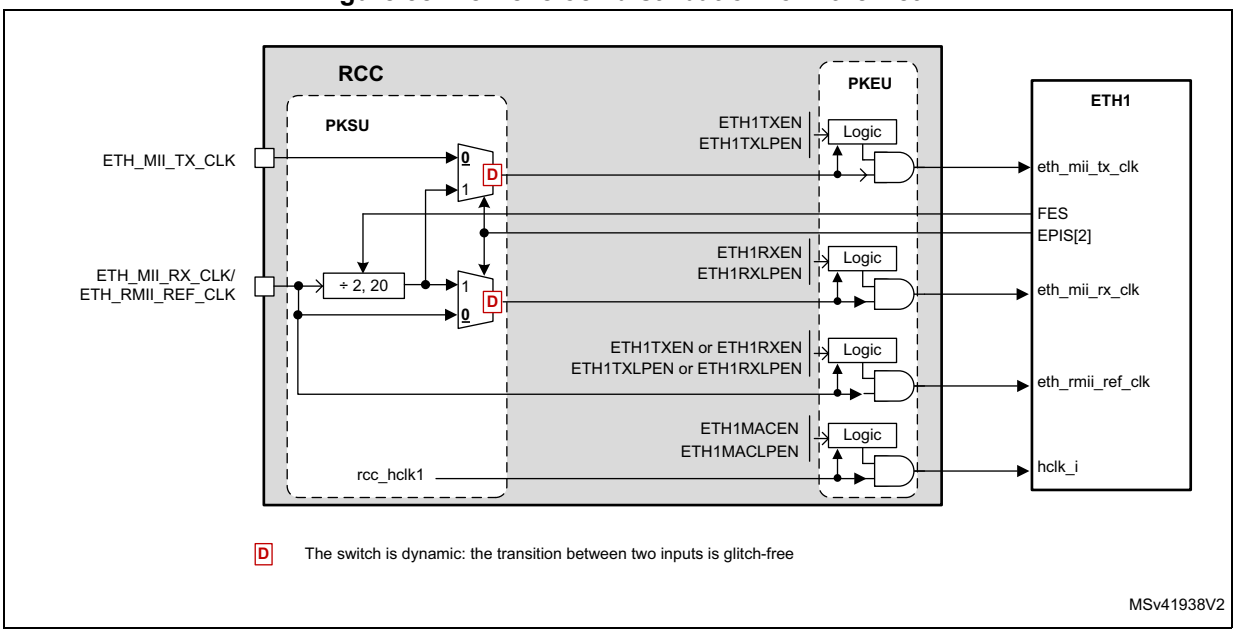
Figure 57. Kernel clock distribution for USB (2)



1. **X** represents the selected MUX input after a system reset.
2. This figure does not show the connection of the bus interface clock to the peripheral. For details on each enable cell, please refer to *Section 8.5.11: Peripheral clock gating control*.

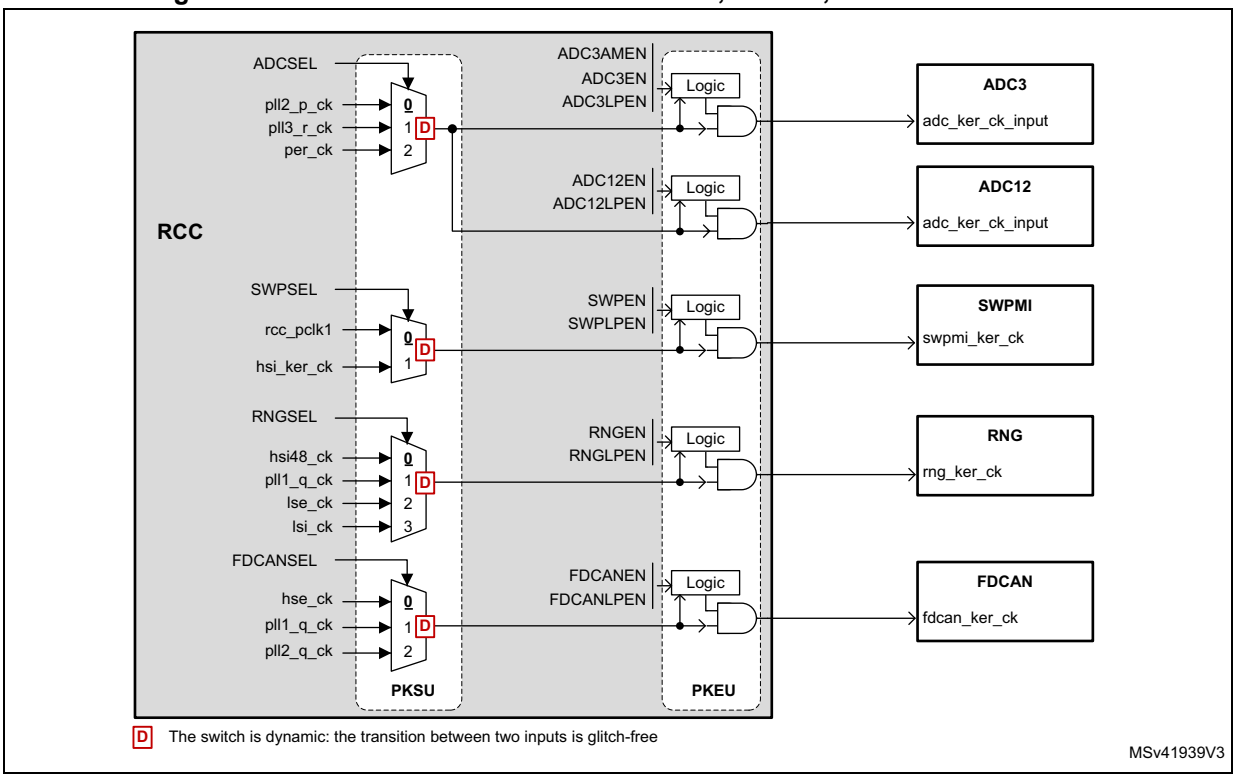
The Ethernet transmit and receive clocks shall be provided from an external Ethernet PHY. The clock selection for the RX and TX path is controlled via the SYSCFG block.

Figure 58. Kernel clock distribution for Ethernet



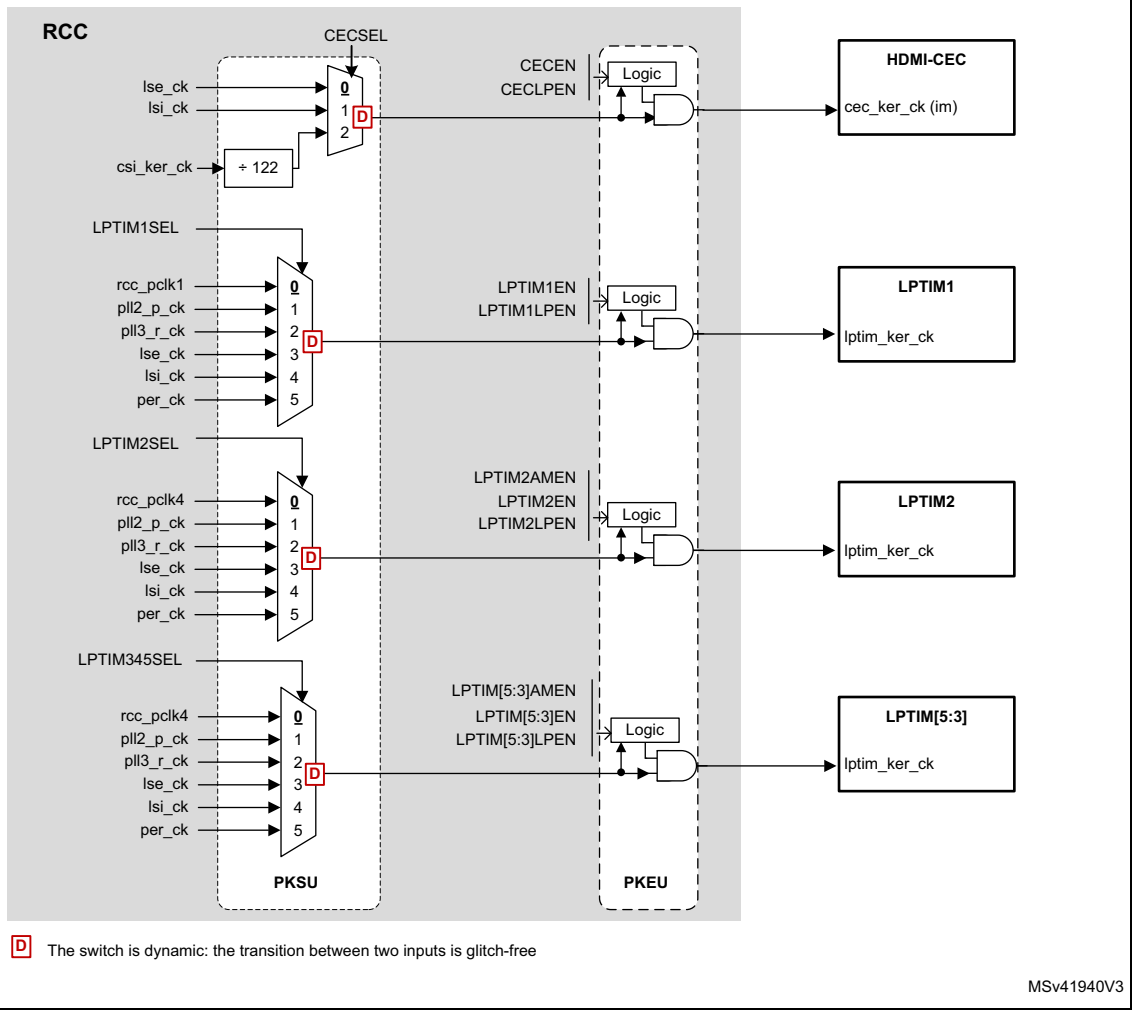
1. **X** represents the selected MUX input after a system reset.
2. This figure does not show the connection of the bus interface clock to the peripheral. For details on each enable cell, please refer to *Section 8.5.11: Peripheral clock gating control*.

Figure 59. Kernel clock distribution for ADCs, SWPMI, RNG and FDCAN (2)



1. **X** represents the selected MUX input after a system reset.
2. This figure does not show the connection of the bus interface clock to the peripheral. For details on each enable cell, please refer to *Section 8.5.11: Peripheral clock gating control*.

Figure 60. Kernel clock distribution for LPTIMs and HDMI-CEC (2)



1. **X** represents the selected MUX input after a system reset
2. This figure does not show the connection of the bus interface clock to the peripheral. For details on each enable cell, please refer to *Section 8.5.11: Peripheral clock gating control*.

RTC/AWU clock

The **rtc_ck** clock source can be:

- the **hse_1M_ck** (**hse_ck** divided by a programmable prescaler)
- the **lse_ck**
- or the **lsi_ck** clock

The source clock is selected by programming the RTCSEL[1:0] bits in the *RCC backup domain control register (RCC_BDCR)* and the RTCPRE[5:0] bits in the *RCC clock configuration register (RCC_CFGR)*.

This selection cannot be modified without resetting the Backup domain.

If the LSE is selected as RTC clock, the RTC will work normally even if the backup or the V_{DD} supply disappears.

The LSE clock is in the Backup domain, whereas the other oscillators are not. As a consequence:

- If LSE is selected as RTC clock, the RTC continues working even if the V_{DD} supply is switched OFF, provided the V_{BAT} supply is maintained.
- If LSI is selected as the RTC clock, the AWU state is not guaranteed if the V_{DD} supply is powered off.
- If the HSE clock is used as RTC clock, the RTC state is not guaranteed if the V_{DD} supply is powered off or if the V_{CORE} supply is powered off.

The **rtc_ck** clock is enabled through RTCEN bit located in the *RCC backup domain control register (RCC_BDCR)*.

The RTC bus interface clock (APB clock) is enabled through RTCAPBEN and RTCAPBLPEN bits located in RCC_APB4ENR/LPENR registers.

Note: To read the RTC calendar register when the APB clock frequency is less than seven times the RTC clock frequency (F_{APB} < 7 x F_{RTCLCK}), the software must read the calendar time and date registers twice. The data are correct if the second read access to RTC_TR gives the same result than the first one. Otherwise a third read access must be performed.

Watchdog clocks

The RCC provides the clock for the four watchdog blocks available on the circuit. The independent watchdog (IWDG1) is connected to the LSI. The window watchdog (WWDG1) are connected to the APB clock.

If an independent watchdog is started by either hardware option or software access, the LSI is forced ON and cannot be disabled. After the LSI oscillator setup delay, the clock is provided to the IWDG.

Caution: Before enabling the WWDG1, the application must set the WW1RSC bit to 1. If the WW1RSC remains to 0, when the WWDG1 is enabled, its the behavior is not guaranteed. The WW1RSC bit is located in *RCC global control register (RCC_GCR)*.

Clock frequency measurement using TIMx

Most of the clock source generator frequencies can be measured by means of the input capture of TIMx.

- Calibrating the HSI or CSI with the LSE

  The primary purpose of having the LSE connected to a TIMx input capture is to be able to accurately measure the HSI or CSI. This requires to use the HSI or CSI as system clock source either directly or via PLL1. The number of system clock counts between consecutive edges of the LSE signal gives a measurement of the internal clock period. Taking advantage of the high precision of LSE crystals (typically a few tens of ppm) we can determine the internal clock frequency with the same resolution, and trim the source to compensate for manufacturing-process and/or temperature- and voltage-related frequency deviations.

  The basic concept consists in providing a relative measurement (e.g. HSI/LSE ratio): the precision is therefore tightly linked to the ratio between the two clock sources. The greater the ratio is, the more accurate the measurement is.

  The HSI and CSI oscillators have dedicated user-accessible calibration bits for this purpose (see *RCC CSI configuration register (RCC_CSICFGR)*) for revision Y devices and *RCC HSI configuration register (RCC_HSICFGR)*/*RCC CSI configuration register*

(RCC_CSICFGR) for revision V devices). When the HSI or CSI are used via the PLLx, the system c*lock can also be fi*ne-tuned by using the fractional divider of the PLLs.

- Calibrating the LSI with the HSI

  The LSI frequency can also be measured: this is useful for applications that do not have a crystal. The ultra-low power LSI oscillator has a large manufacturing process deviation. By measuring it versus the HSI clock source, it is possible to determine its frequency with the precision of the HSI. The measured value can be used to have more accurate RTC time base timeouts (when LSI is used as the RTC clock source) and/or an IWDG timeout with an acceptable accuracy.

8.5.9 General clock concept overview

The RCC handles the distribution of the CPU, bus interface and peripheral clocks for the system (D1, D2 and D3 domains), according to the operating mode of each function (refer to *Section 8.5.1: Clock naming convention* for details on clock definitions).

For each peripheral, the application can control the activation/deactivation of its kernel and bus interface clock. Prior to use a peripheral, the CPU has to enable it (by setting PERxEN to 1), and define if this peripheral remains active in CSleep mode (by setting PERxLPEN to 1). This is called ‘allocation’ of a peripheral to the CPU (refer to *Section 8.5.10: Peripheral allocation* for more details).

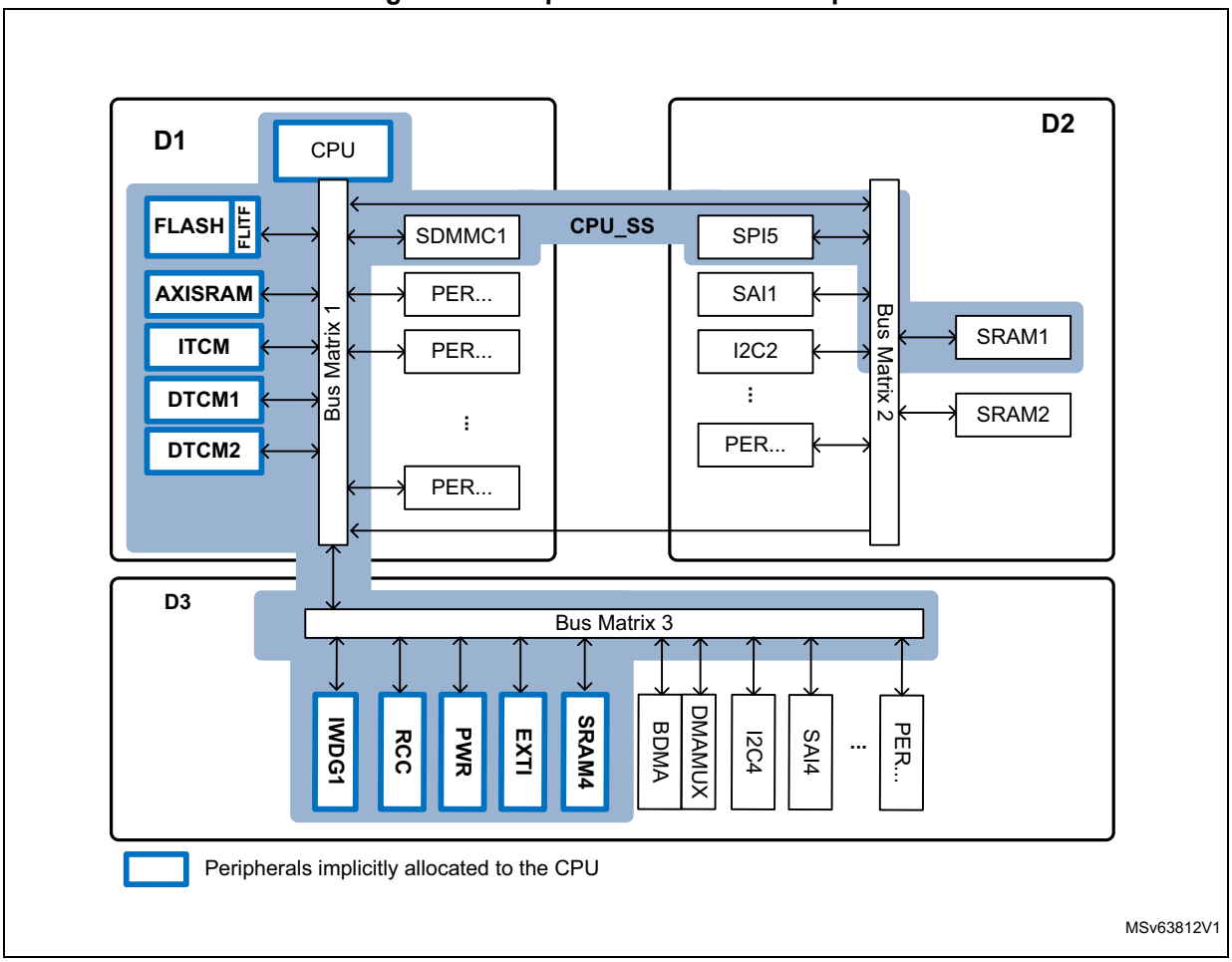
The peripheral allocation is used by the RCC to automatically control the clock gating according to the CPU and domain modes, and by the PWR to control the supply voltages of D1, D2 and D3 domains.

Figure 61 gives an example of peripheral allocation:

- The CPU enabled SDMMC1, SPI5 and SRAM1, AXISRAM, ITCM, DTCM1, DTCM2 and SRAM4 are implicitly allocated to the CPU. The group composed of the CPU, bus matrix 1/2/3 and allocated peripherals makes up a sub-system (CPU_SS).

Note: The FLASH, AXISRAM, ITCM, DTCM1, DTCM2, SRAM4, IWGD1, PWR, EXTI and RCC are common resources and are implicitly allocated to the CPU.

Figure 61. Peripheral allocation example



When the CPU enters CStop mode, the RCC automatically disables the bus interface and kernel clocks of all the peripherals of the CPU_SS as well as the CPU clock. The PLLs, if enabled, are not disabled by the RCC since D3 is still running.

The D3 domain can be kept in DRun mode while the CPU is in CStop mode and D1 and D2 domains are in DStop or DStandby mode. This is done by setting RUN_D3 bit in PWR_CPUCR registers.

- If RUN_D3 is set to 1, then D3 is maintained in DRun mode, independently from the CPU modes (see PWR_CPUCR register in Section *Power control*).
- If RUN_D3 is set to 0, then D3 domain enters DStop or DStandby mode when the CPU enters CStop mode (see *Table 57*).

Note that the CPU can control if D1, D2 or D3 domains are allowed to enter in DStandby when conditions are met, via bits PDDS_D1, PDDS_D2 and PDDS_D3 of PWR_CPUCR.

A wakeup event will be able to exit D1, D2 and D3 domains from DStandby or DStop mode.

In addition, more autonomy can be given to some peripherals located into D3 domain (refer to *Section : D3 domain Autonomous mode* for details).

D3 domain Autonomous mode

The Autonomous mode allows to deliver the peripheral clocks to peripherals located in D3, even if the CPU is in CStop mode. When a peripheral has its autonomous bit enabled, it receives its peripheral clocks according to D3 domain state, if the CPU is in CStop mode:

- If the D3 domain is in DRun mode, peripherals with Autonomous mode activated receive their peripheral clocks,
- If the D3 domain is in DStop mode, no peripheral clock is provided.

The Autonomous mode does not prevent the D3 domain to enter DStop or DStandby mode.

The autonomous bits are located in *RCC D3 Autonomous mode register (RCC_D3AMR)*.

For example, the CPU can enter CStop mode, while the SAI4 is filling the SRAM4 with data received from an external device via BDMA. When the amount of received data is reached, the CPU can be activated by a wakeup event. This can be done by setting the SAI4, the BDMA, and SRAM4 in Autonomous mode, while keeping D3 in DRun mode (RUN_D3 set to 1). In this example, the RCC does not switch off the PLLs as the D3 domain is always in DRun mode.

It is possible to go a step further with power consumption reduction by combining the Autonomous mode with the capability of some peripherals (UARTs, I2Cs) to request the kernel clock on their own, without waking-up the CPU. For example, if the system is expecting messages via I2C4, the whole system can be put in Stop mode. When the I2C4 peripheral detects a START bit, it will generate a “kernel clock request”. This request enables the HSI or CSI, and a kernel clock is provided only to the requester (in our example the I2C4). The I2C4 then decodes the incoming message. Several cases are then possible:

- If the device address of the message does not match, then I2C4 releases its “kernel clock request” until a new START condition is detected.
- If the device address of the incoming message matches, it has to be stored into D3 local memory. I2C4 is able to generate a wakeup event on address match to switch the D3 domain to DRun mode. The message is then transferred into memory via BDMA, and the D3 domain go back to DStop mode without any CPU activation. Note that if the amount of data transferred into memory reached the transfer count, the BDMA can also generate an interrupt to wake-up the CPU.
- If the device address of the incoming message matches and the peripheral is setup to wake up the CPU, then I2C4 generates a wakeup event to activate the CPU.

Please refer to the description of EXTI block in order see which peripheral is able to perform a wake-up event to which domain.

Memory handling

The CPU can access all the memory areas available in the product:

- AXISRAM, ITCM, DTCM1, DTCM2 and FLASH,
- SRAM1 and SRAM2,
- SRAM4 and BKPRAM.

As shown in *Figure 61*, FLASH, AXISRAM, SRAM4, ITCM, DTCM1 and DTCM2 are implicitly allocated to the CPU. As a result, there is no enable bit allowing the CPU to allocate these memories.

If the CPU wants to use memories located into D2 domain (SRAM1 and SRAM2), it has to enable them.

The BKPRAM has a dedicated enable in order to gate the bus interface clock. The CPU needs to enable the BKPRAM prior to use it.

Note: The memory interface clocks (Flash and RAM interfaces) can be stopped by software during CSleep mode (via DxSRAMyLPEN bits).

Refer to *Peripheral clock gating control* and *CPU and bus matrix clock gating control* sections for details on clock enabling.

System states overview

Table 57 gives an overview of the system states with respect to the D1, D2 and D3 domain modes.

- The system remains in Run mode as long as D3 is in DRun mode. Several sub-states of system Run exist that are not detailed here (refer to *Section 6: Power control (PWR)* for more information).
- When the D1 domain is in DRun, the D2 domain can be in DRun, DStop or DStandby. When the D1 domain is in DStop or DStandby, the D2 domain can no longer remain in DRun it will switch to DStop or DStandby according to PDDS_D2 bit.
- D3 can run while D1 and D2 are in DStop/DStandby mode thanks to RUN_D3 bits of PWR_CPUCR registers or when D3 is in Autonomous mode.
- The system remains in Stop mode as long as D3 is in DStop mode. This means implicitly that D1 and D2 are in DStop or DStandby. As soon as D1 or D2 exits DStop or DStandby, D3 switches to DRun mode.
- The system remains in Standby mode as long as D1, D2 and D3 are in DStandby.
- Domain states versus CPU states:
  - When the D1 domain is in DRun mode, it means that its bus matrix is clocked, and the CPU is in CRun mode.
  - When the D2 domain is in DRun mode, it means that its bus matrix is clocked, and the CPU is in CRun mode with at least a peripheral of D2 domain allocated.
  - When the D1 domain is in DStop mode it means that its bus matrix is no longer clocked, and the CPU is in CStop mode.
  - When the D2 domain is in DStop mode it means that its bus matrix is no longer clocked. This situation happens when:

    - the CPU did not allocate peripherals of D2 domain,

    - the CPU allocated peripherals of D2 domain, but the CPU is in CStop or CStandby,
  - When a domain is in DStandby mode, it means that the domain including its CPU are powered down.

Table 57. System states overview

System State	D1 State	D2 State	D3 State
Run	DRun	DRun/DStop/DStandby	DRun
	DStop/DStandby	DStop/DStandby	
Stop	DStop/DStandby	DStop/ DStandby	DStop
Standby	DStandby	DStandby	DStandby

8.5.10 Peripheral allocation

The CPU can allocate a peripheral and hence control its kernel and bus interface clock.

The CPU can allocate a peripheral by setting the dedicated PERxEN bit located into:

- RCC_xxxxENR registers or
- RCC_C1_xxxxENR registers.

The CPU can control the peripheral clocks gating when it is in CSleep mode via the PERxLPEN bits located into:

- RCC_xxxxLPENR registers or
- RCC_C1_xxxxLPENR registers.

Refer to *Section 8.7.1: Register mapping overview* for additional information.

The peripheral allocation bits (PERxEN bits) are used by the hardware to provide the kernel and bus interface clocks to the peripherals. However they are also used to link peripherals to the CPU (CPU sub-system). In this way, the hardware is able to safely gate the peripheral clocks and bus matrix clocks according to CPU states. The PWR block also uses this information to control properly the domain states.

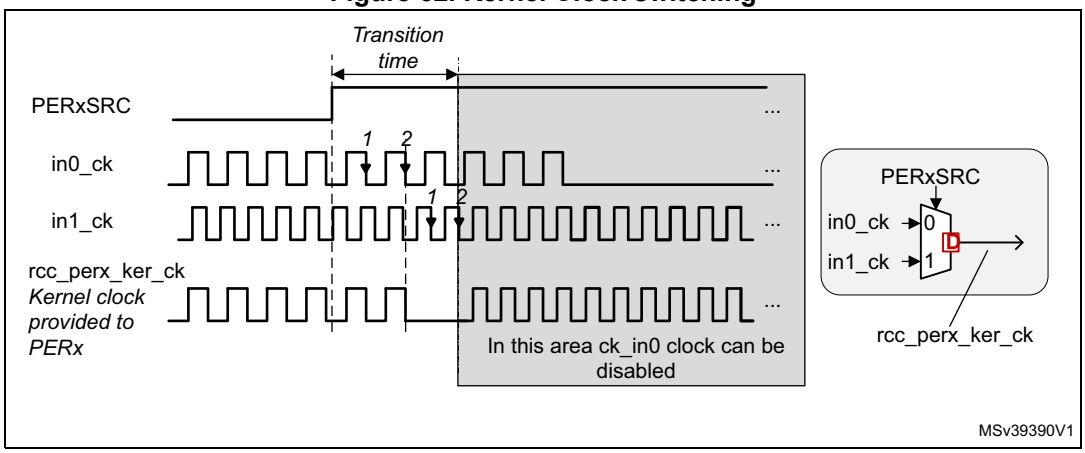
Clock switches and gating

- Clock switching delays

  The input selected by the kernel clock switches can be changed dynamically without generating spurs or timing violation. As a consequence, switching from the original to the new input can only be performed if a clock is present on both inputs. If it not the case, no clock will be provided to the peripheral. To recover from this situation, the user has to provide a valid clock to both inputs.

  During the transition from one input to another, the kernel clock provided to the peripheral will be gated, in the worst case, during 2 clock cycles of the previously selected clock and 2 clock cycles of the new selected clock. As shown in *Figure 62*, both input clocks shall be present during transition time.

Figure 62. Kernel Clock switching



- Clock enabling delays

  In the same way, the clock gating logic synchronizes the enable command (coming generally from a kernel clock request or PERxEN bits) with the selected clock, in order to avoid generation of spurs.

  – A maximum delay of two periods of the enabled clock may occur between the enable command and the first rising edge of the clock. The enable command can be the rising edge of the PERxEN bits of RCC_xxxxENR registers, or a kernel clock request asserted by a peripheral.

  – A maximum delay of 1.5 periods of the disabled clock may occur between the disable command and the last falling edge of the clock. The disable command can be the falling edge of the PERxEN bits of RCC_xxxxENR registers, or a kernel clock request released by a peripheral.

Note: Both the kernel clock and the bus interface clock are affected by this re-synchronization delay.

In addition, the clock enabling delay may strongly increase if the application is enabling for the first time a peripheral which is not located into the same domain. This is due to the fact that the domain where the peripheral is located could be in DStop or DStandby mode. The domain must be switched to DRun mode before the application can use this peripheral.

As an example, if the CPU enables a peripheral located in the D2 domain while the D2 domain is in DStop/DStandby mode, then the power controller (PWR) has first to provide a supply voltage to D2, then the RCC has to wait for an acknowledge from the PWR before enabling the clocks of the D2 domain. To handle properly this situation the RCC and the PWR blocks feature four flags:

– D1CKRDY/D2CKRDY located in *RCC source control register (RCC_CR)*

– SBF_D1 and SBF_D2 located in PWR_CPUCR register.

The following sequence can be followed to avoid this issue:

a) Enable the peripheral clocks (i.e. allocate the peripheral) by writing the corresponding PERxEN bit to 1 in the RCC_xxxxENR register,

b) Read back the RCC_xxxxENR register to make sure that the previous write operation is not pending into a write buffer.

c) If the peripheral is located in a different domain, perform the two next steps:

   Read DxCKRDY until it is set to 1.

   Write SBF_Dx to zero and read-back the value, in order to check if the domain where the peripheral is located is still in DStandby. If the corresponding bit is read at 1, it means that the domain is still in DStandby. Repeat this operation until SBF_Dx is equal to 0, then continue the other steps.

d) Perform a dummy read operation into a register of the enabled peripheral. This operation will take at least 2 clock cycles, which is equal to the max delay of the enable command.

e) The peripheral can then be used.

Note: When the bus interface clock is not active, read or write accesses to the peripheral registers are not supported. A read access will return invalid data. A write access will be ignored and will not create any bus errors.

8.5.11 Peripheral clock gating control

As mentioned previously, each peripheral requires a bus interface clock, named **rcc_perx_bus_ck** (for peripheral ‘x’). This clock can be an APB, AHB or AXI clock, according to which bus the peripheral is connected.

The clocks used as bus interface for peripherals located in D1 domain, could be **rcc_aclk**, **rcc_hclk3** or **rcc_pclk3**, depending on the bus connected to each peripheral. For simplicity sake, these clocks are named **rcc_bus_d1_ck**.

In the same way, the signal named **rcc_bus_d2_ck** represents **rcc_hclk1, rcc_hclk2**, **rcc_pclk1** or **rcc_pclk2**, depending on the bus connected to each peripheral of D2 domain.

Similarly, the signal **rcc_bus_d3_ck** represents **rcc_hclk4** or **rcc_pclk4** for peripherals located in D3.

Some peripherals (SAI, UART...) also require a dedicated clock for their communication interface. This clock is generally asynchronous with respect to the bus interface clock. It is named kernel clock (**perx_ker_ckreq**). Both clocks can be gated according to several conditions detailed hereafter.

As shown in *Figure 63*, enabling the kernel and bus interface clocks of each peripheral depends on several input signals:

- PERxEN and PERxLPEN bits

  PERxEN represents the peripheral enable (allocation) bit for the CPU. The CPU can write these bits to 1 via RCC_C1_xxxxENR or RCC_xxxxENR registers.
- PERxAMEN bits

  The PERxAMEN bits are belong to *RCC D3 Autonomous mode register (RCC_D3AMR)*.
- CPU state (**c_sleep** and **c_deepsleep** signals)
- D3 domain state (**d3_deepsleep** signal)
- The kernel clock request (**perx_ker_ckreq**) of the peripheral itself, when the feature is available.

Refer to *Section 8.5.10: Peripheral allocation* for more details.

Figure 63. Peripheral kernel clock enable logic details

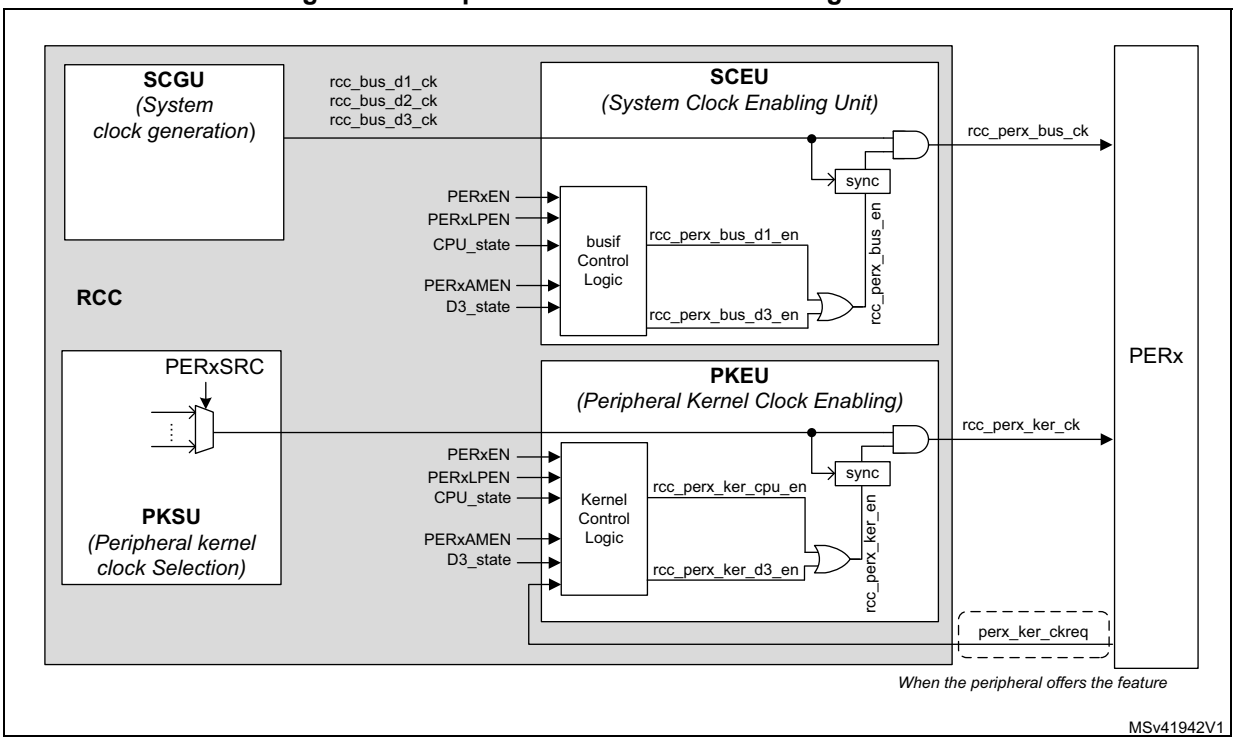


Table 58 gives a detailed description of the enabling logic of the peripheral clocks for peripherals located in D1 or D2 domain and allocated by the CPU.

Table 58. Peripheral clock enabling for D1 and D2 peripherals

PERxEN	PERxLPEN	PERxSRC	perx_ker_ckreq	CPU State	rcc_perx_ker_c_en	rcc_perx_bus_d1_en	Comments
0	X	X	X	X	0	0	No clock provided to the peripheral, because PERxEN=0
1	X	X	X	CRun	1	1	Kernel and bus interface clocks are provided to the peripheral, because the CPU is in CRun, and PERxEN=1
1	0	X	X	CSleep	0	0	No clock provided to the peripheral, because the CPU is in CSleep, and PERxLPEN=0
1	1	X	X		1	1	Kernel and bus interface clocks are provided to the peripheral, because CPU is in CSleep, and PERxLPEN=1
1	0	X	X	CStop	0	0	No clock provided to the peripheral because the PERxLPEN bit is set to 0.
1	1	no lsi_ck and no lse_ck and no hsi_ker_ck and no csi_ker_ck	X		0	0	No clock provided to the peripheral because CPU is in CStop and **lse_ck** or **lsi_ck** or **hsi_ker_ck** or **csi_ker_ck** are not selected.
1	1	lsi_ck or lse_ck	X		1 (1)	0	Kernel clock is provided to the peripheral because PERxEN = PERxLPEN=1 and **lsi_ck** or **lse_ck** are selected. The bus interface clock is no provided as the CPU is in CStop
1	1	hsi_ker_ck or csi_ker_ck	1		1	0	Kernel clock is provided to the peripheral because **req_ker_perx** = 1, and PERxEN = PERxLPEN=1 and **hsi_ker_ck** or **csi_ker_ck** are selected. The bus interface clock is no provided as the CPU is in CStop
1	1	hsi_ker_ck or csi_ker_ck	0		0	0	No clock provided to the peripheral because CPU is in CStop, and no kernel clock request pending

1. For RNG block, the kernel clock is not delivered if the CPU to which it is allocated is in CStop mode, even if the clock selected is lsi_ck or lse_ck.

As a summary, we can state that the kernel clock is provided to the peripherals located on domains D1 and D2 when the following conditions are met:

1. The CPU is in CRun mode, and the peripheral is allocated.
2. The CPU is in CSleep mode, and the peripheral is allocated with PERxLPEN = 1.
3. The CPU is in CStop mode, and the peripheral is allocated with PERxLPEN = 1, and the peripheral generates a kernel clock request, and the selected clock is **hsi_ker_ck** or **csi_ker_ck**.
4. The CPU is in CStop mode, and the peripheral is allocated with PERxLPEN = 1, and the kernel source clock of the peripheral is **lse_ck** or **lsi_ck**.

The bus interface clock will be provided to the peripherals only when conditions 1 or 2 are met.

Table 59 gives a detailed description of the enabling logic of the kernel clock for all peripherals located in D3.

Table 59. Peripheral clock enabling for D3 peripherals

PERxEN	PERxLPEN	PERxAMEN	PERxSRC	perx_ker_ckreq	CPU State	D3 State	rcc_perx_ker_d3_en	rcc_perx_bus_d3_en	Comments
0	X	X	X	X	Any	Any	0	0	No clock provided to the peripheral, as PERxEN=0
1	X	X	X	X	CRun	DRun	1	1	Kernel and bus interface clocks are provided to the peripheral, because the CPU is in CRun, and PERxEN=1
1	0	X	X	X	CSleep		0	0	No clock provided to the peripheral, because the CPU is in CSleep, and PERxLPEN=0
1	1	X	X	X			1	1	Kernel and bus interface clocks are provided to the peripheral, because the CPU is in CSleep, and PERxLPEN=1
1	X	0	X	X	CStop		0	0	As the CPU is in CStop, and PERxEN=1, then the kernel clock gating depends on D3 state and PERxAMEN bits. No clock provided to the peripheral because PERxAMEN = 0.
1	X	1	X	X			1	1	The kernel and bus interface clocks are provided because even if the CPU is in CStop mode, D3 is in DRun mode, with PERxEN and PERxAMEN bits set to 1.
1	X	1	not lse_ck and not lsi_ck	0		DStop	0	0	No clock provided to the peripheral, because D3 is in DStop, **req_ker_perx** = 0, and **lse_ck** or **lsi_ck** are not selected.

Table 59. Peripheral clock enabling for D3 peripherals (continued)

PERxEN	PERxLPEN	PERxAMEN	PERxSRC	perx_ker_ckreq	CPU State	D3 State	rcc_perx_ker_d3_en	rcc_perx_bus_d3_en	Comments
1	X	1	not hsi_ker_ck and not csi_ker_ck and not lse_ck and not lsi_ck	1	CStop	DStop	0	0	No clock provided to the peripheral, because even if **req_ker_perx** = 0, **lse_ck** or **lsi_ck** or **hsi_ker_ck** or **csi_ker_ck** are not selected.
1	X	1	hsi_ker_ck or csi_ker_ck	1			1	0	Kernel clock is provided to the peripheral because **req_ker_perx** = 1, and PERxEN = PERxAMEN=1, and the selected clock is **hsi_ker_ck** or **csi_ker_ck**. The bus interface clock is not provided as D3 is in DStop.
1	X	1	lse_ck or lsi_ck	X			1	0	Kernel clock is provided to the peripheral because PERxEN = PERxAMEN=1 and **lse_ck** or **lsi_ck** are selected, while D3 is in STOP. The bus interface clock is not provided as D3 is in DSTOP.

As a summary, we can state that the kernel clock is provided to the peripherals of D3 if the following conditions are met:

1. The CPU is in CRun mode, and the peripheral is allocated.
2. The CPU is in CSleep mode, and the peripheral is allocated with PERxLPEN = 1.
3. The CPU is in CStop mode, and the peripheral is allocated and D3 domain is in DRun mode with PERxAMEN = 1.
4. The CPU is in CStop mode, and the peripheral is allocated, and D3 domain is in DStop mode with PERxAMEN = 1, and the peripheral is generating a kernel clock request and the kernel clock source is **hsi_ker_ck** or **csi_ker_ck**.
5. The CPU is in CStop mode, and the peripheral is allocated, and D3 domain is in DStop mode with PERxAMEN = 1, and the kernel clock source of the peripheral is **lse_ck** or **lsi_ck**.

The bus interface clock will be provided to the peripherals only when condition 1, 2 or 3 is met.

Note: When they are set to 1, the autonomous bits indicate that the associated peripheral will receive a kernel clock according to D3 state, and not according to the mode of the CPU.

Only I2C, U(S)ART and LPUART peripherals are able to request the kernel clock. This feature gives to the peripheral the capability to transfer data with an optimal power consumption.

The autonomous bits dedicated to some peripherals located in D3 domain allow the data transfer with external devices without activating the CPU.

*In order for the LPTIMER to operate with **lse_ck** or **lsi_ck** when the circuit is in Stop mode, the user application has to select the **lsi_ck** or **lse_ck** input via LPTIMxSEL fields, and set bit LPTIMxAMEN and LPTIMxLPEN to 1.*

8.5.12 CPU and bus matrix clock gating control

For each domain it is possible to control the activation/deactivation of the CPU clock and bus matrix clock.

For information about convention naming, refer to *Section 8.5.11: Peripheral clock gating control*.

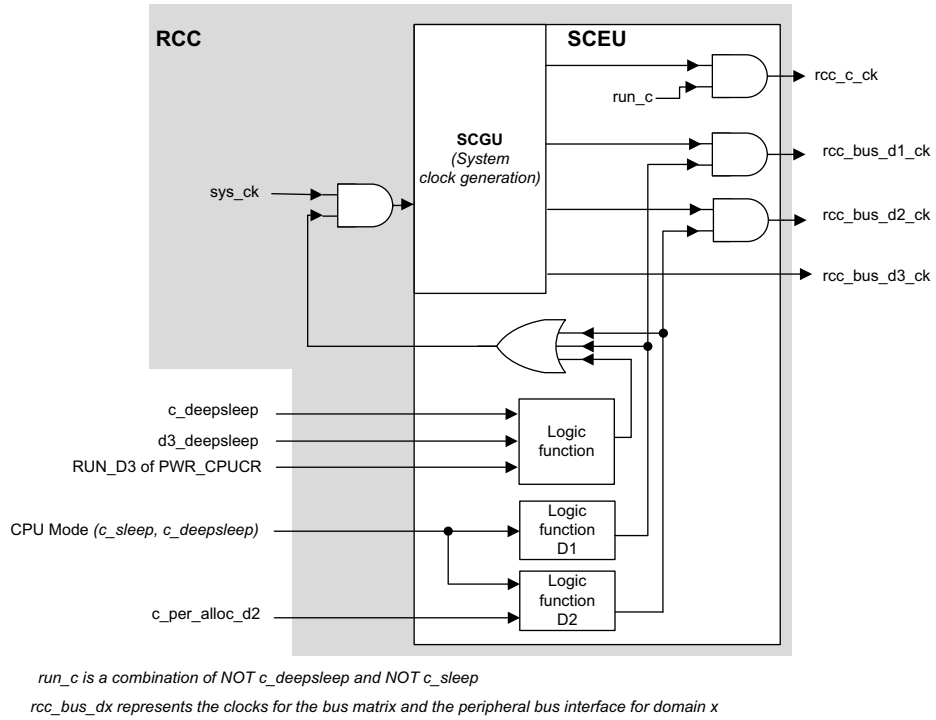
The clocks of the CPU, AHB and AXI bridges and APB busses are enabled according to the rules hereafter:

- The CPU clock **rcc_c_ck** is enabled when the CPU is in CRun mode.
- The AXI bridge clock is enabled when the CPU is in CRun mode.
- The D2 domain AHB bridges clocks are enabled when:
  - The CPU is in CRun or,
  - If the CPU is in CSleep with at least a peripheral (master) connected to this bus having both its PERxEN and PERxLPEN set to 1 or,
  - If the CPU is in CSleep with at least an APB bus having its clock enabled.
- The D3 domain AHB bridge clock is enabled when:
  - The CPU is in CRun or CSleep mode or,
  - When the RUN_D3 bit is set to 1, independently of CPU modes or,
  - When the **d3_deepsleep** signal is inactive (0), independently of CPU modes.
- The APB1,2,3 busses are enabled when:
  - The CPU is in CRun or,
  - If the CPU is in CSleep with at least a peripheral connected to this bus having both its PERxEN and PERxLPEN set to 1.
- The APB4 bus is enabled when: the D3 domain is in DRun.

As shown in the *Figure 64*, the enabling of the core and bus clock of each domain depends on several input signals:

- **c_sleep** and **c_deepsleep** signals from the CPU,
- **d3_sleepdeep** signal,
- RCC_xxxxENR.PERxEN bits of peripherals located on D2 domain

Figure 64. Bus clock enable logic



8.6 RCC Interrupts

The RCC provides 3 interrupt lines:

- **rcc_it**: a general interrupt line, providing events when the PLLs are ready, or when the oscillators are ready.
- **rcc_hsecss_it**: an interrupt line dedicated to the failure detection of the HSE Clock Security System.
- **rcc_lsecss_it**: an interrupt line dedicated to the failure detection of the LSE Clock Security System.

The interrupt enable is controlled via *RCC clock source interrupt enable register (RCC_CIER)*, except for the HSE CSS failure. When the HSE CSS feature is enabled, it not possible to mask the interrupt generation.

The interrupt flags can be checked via *RCC clock source interrupt flag register (RCC_CIFR)*, and those flags can be cleared via *RCC clock source interrupt clear register (RCC_CICR)*.

Note: The interrupt flags are not relevant if the corresponding interrupt enable bit is not set.

Table 60 gives a summary of the interrupt sources, and the way to control them.

Table 60. Interrupt sources and control

Interrupt Source	Description	Interrupt enable	Action to clear interrupt	Interrupt Line
LSIRDYF	LSI ready	LSIRDYIE	Set LSIRDYC to 1	rcc_it
LSERDYF	LSE ready	LSERDYIE	Set LSERDYC to 1	
HSIDRYF	HSI ready	HSIDRYIE	Set HSIRDYC to 1	
HSERDYF	HSE ready	HSERDYIE	Set HSERDYC to 1	
CSIRDYF	CSI ready	CSIRDYIE	Set CSIRDYC to 1	
HSI48RDYF	HSI48 ready	HSI48RDYIE	Set HSI48RDYC to 1	
PLL1RDYF	PLL1 ready	PLL1RDYIE	Set PLL1RDYC to 1	
PLL2RDYF	PLL2 ready	PLL2RDYIE	Set PLL2RDYC to 1	
PLL3RDYF	PLL3 ready	PLL3RDYIE	Set PLL3RDYC to 1	
LSECSSF	LSE Clock security system failure	LSECSSFIE (1)	Set LSECSSC to 1	rcc_lsecss_it
HSECSSF	HSE Clock security system failure	-(2)	Set HSECSSC to 1	rcc_hsecss_it

1. The security system feature must also be enabled (LSECSSON = 1), in order to generate interrupts.
2. It is not possible to mask this interrupt when the security system feature is enabled (HSECSSON = 1).

8.7 RCC registers

8.7.1 Register mapping overview

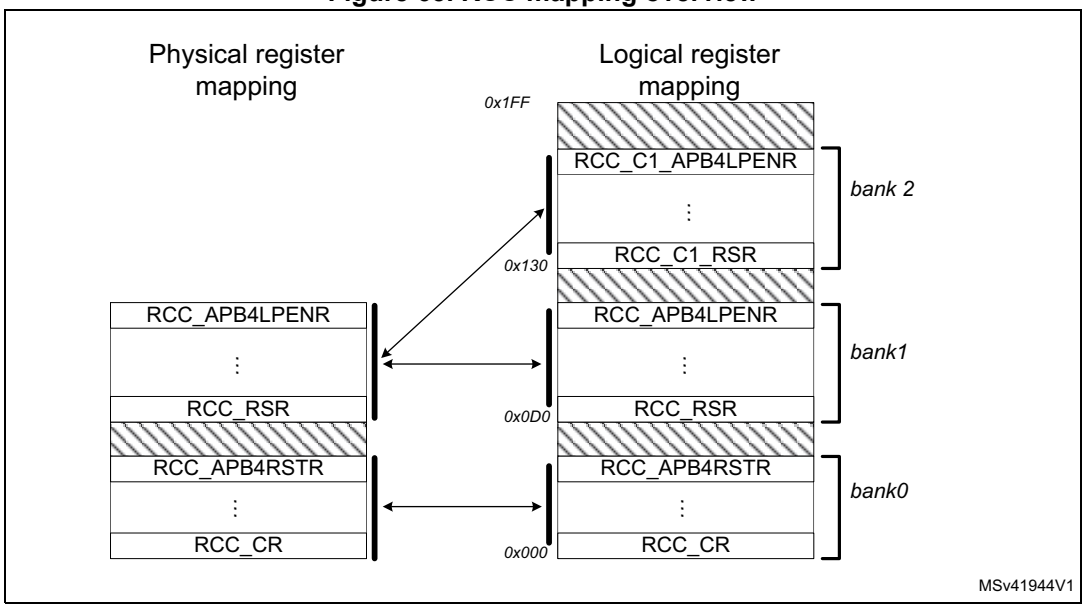
Note that the control of PERxEN and PERxLPEN bits can be performed at two different address offset:0x0D0 and 0x130. So the application can use the registers named:

- RCC_xxxxENR or RCC_C1_xxxxENR to control the PERxEN bits
- RCC_xxxxLPENR or RCC_C1_xxxxLPENR to control the PERxLPEN bits
- RCC_RSR or RCC_C1_RSR to control the reset flag status bits.

This feature is provided to insure the compatibility with other products of this family.

Figure 65 shows the RCC mapping overview.

Figure 65. RCC mapping overview



8.7.2 RCC source control register (RCC_CR)

Address offset: 0x000

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	PLL3RDY	PLL3ON	PLL2RDY	PLL2ON	PLL1RDY	PLL1ON	Res.	Res.	Res.	Res.	HSECSSON	HSEBYP	HSERDY	HSEON
		r	rw	r	rw	r	rw					rs	rw	r	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
D2CKRDY	D1CKRDY	HSI48RDY	HSI48ON	Res.	Res.	CSIKERON	CSIRDY	CSION	Res.	HSIDIVF	HSIDIV[1:0]		HSIRDY	HSIKERON	HSION
r	r	r	rw			rw	r	rw		r	rw	rw	r	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **PLL3RDY**: PLL3 clock ready flag
Set by hardware to indicate that the PLL3 is locked.
0: PLL3 unlocked (default after reset)
1: PLL3 locked

Bit 28 **PLL3ON**: PLL3 enable
Set and cleared by software to enable PLL3.
Cleared by hardware when entering Stop or Standby mode.
0: PLL3 OFF (default after reset)
1: PLL3 ON

Bit 27 **PLL2RDY**: PLL2 clock ready flag
Set by hardware to indicate that the PLL2 is locked.
0: PLL2 unlocked (default after reset)
1: PLL2 locked

Bit 26 **PLL2ON**: PLL2 enable
Set and cleared by software to enable PLL2.
Cleared by hardware when entering Stop or Standby mode.
0: PLL2 OFF (default after reset)
1: PLL2 ON

Bit 25 **PLL1RDY**: PLL1 clock ready flag
Set by hardware to indicate that the PLL1 is locked.
0: PLL1 unlocked (default after reset)
1: PLL1 locked

Bit 24 **PLL1ON**: PLL1 enable
Set and cleared by software to enable PLL1.
Cleared by hardware when entering Stop or Standby mode. Note that the hardware prevents writing this bit to 0, if the PLL1 output is used as the system clock.
0: PLL1 OFF (default after reset)
1: PLL1 ON

Bits 23:20 Reserved, must be kept at reset value.

Bit 19 **HSECSSON**: HSE Clock Security System enable
Set by software to enable Clock Security System on HSE.
This bit is “set only” (disabled by a system reset or when the system enters in Standby mode).
When HSECSSON is set, the clock detector is enabled by hardware when the HSE is ready and disabled by hardware if an oscillator failure is detected.
This bit can be cleared by software, but clearing this bit through software has no impact on the feature.
0: Clock Security System on HSE OFF (Clock detector OFF) (default after reset)
1: Clock Security System on HSE ON (Clock detector ON if the HSE oscillator is stable, OFF if not).

Bit 18 **HSEBYP**: HSE clock bypass
Set and cleared by software to bypass the oscillator with an external clock. The external clock must be enabled with the HSEON bit, to be used by the device.
The HSEBYP bit can be written only if the HSE oscillator is disabled.
0: HSE oscillator not bypassed (default after reset)
1: HSE oscillator bypassed with an external clock

Bit 17 **HSERDY**: HSE clock ready flag
Set by hardware to indicate that the HSE oscillator is stable.
0: HSE clock is not ready (default after reset)
1: HSE clock is ready

Bit 16 **HSEON**: HSE clock enable
Set and cleared by software.
Cleared by hardware to stop the HSE when entering Stop or Standby mode.
This bit cannot be cleared if the HSE is used directly (via SW mux) as system clock or if the HSE is selected as reference clock for PLL1 with PLL1 enabled (PLL1ON bit set to 1).
0: HSE is OFF (default after reset)
1: HSE is ON

Bit 15 **D2CKRDY**: D2 domain clocks ready flag
Set by hardware to indicate that the D2 domain clocks are available.
0: D2 domain clocks are not available (default after reset)
1: D2 domain clocks are available

Bit 14 **D1CKRDY**: D1 domain clocks ready flag
Set by hardware to indicate that the D1 domain clocks (CPU, bus and peripheral) are available.
0: D1 domain clocks are not available (default after reset)
1: D1 domain clocks are available

Bit 13 **HSI48RDY**: HSI48 clock ready flag
Set by hardware to indicate that the HSI48 oscillator is stable.
0: HSI48 clock is not ready (default after reset)
1: HSI48 clock is ready

Bit 12 **HSI48ON**: HSI48 clock enable
Set by software and cleared by software or by the hardware when the system enters to Stop or Standby mode.
0: HSI48 is OFF (default after reset)
1: HSI48 is ON

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **CSIKERON**: CSI clock enable in Stop mode

Set and reset by software to force the CSI to ON, even in Stop mode, in order to be quickly available as kernel clock for some peripherals. This bit has no effect on the value of CSION.

0: no effect on CSI (default after reset)

1: CSI is forced to ON even in Stop mode

Bit 8 **CSIRDY**: CSI clock ready flag

Set by hardware to indicate that the CSI oscillator is stable. This bit is activated only if the RC is enabled by CSION (it is not activated if the CSI is enabled by CSIKERON or by a peripheral request).

0: CSI clock is not ready (default after reset)

1: CSI clock is ready

Bit 7 **CSION**: CSI clock enable

Set and reset by software to enable/disable CSI clock for system and/or peripheral.

Set by hardware to force the CSI to ON when the system leaves Stop mode, if STOPWUCK = 1 or STOPKERWUCK = 1.

This bit cannot be cleared if the CSI is used directly (via SW mux) as system clock or if the CSI is selected as reference clock for PLL1 with PLL1 enabled (PLL1ON bit set to 1).

0: CSI is OFF (default after reset)

1: CSI is ON

Bit 6 Reserved, must be kept at reset value.

Bit 5 **HSIDIVF**: HSI divider flag

Set and reset by hardware.

As a write operation to HSIDIV has not an immediate effect on the frequency, this flag indicates the current status of the HSI divider. HSIDIVF will go immediately to 0 when HSIDIV value is changed, and will be set back to 1 when the output frequency matches the value programmed into HSIDIV.

0: new division ratio not yet propagated to **hsi(_ker)_ck** (default after reset)

1: **hsi(_ker)_ck** clock frequency reflects the new HSIDIV value

Bits 4:3 **HSIDIV[1:0]**: HSI clock divider

Set and reset by software.

These bits allow selecting a division ratio in order to configure the wanted HSI clock frequency. The HSIDIV cannot be changed if the HSI is selected as reference clock for at least one enabled PLL (PLLxON bit set to 1). In that case, the new HSIDIV value is ignored.

00: Division by 1, **hsi(_ker)_ck** = 64 MHz (default after reset)

01: Division by 2, **hsi(_ker)_ck** = 32 MHz

10: Division by 4, **hsi(_ker)_ck** = 16 MHz

11: Division by 8, **hsi(_ker)_ck** = 8 MHz

Bit 2 **HSIRDY**: HSI clock ready flag

Set by hardware to indicate that the HSI oscillator is stable.

0: HSI clock is not ready (default after reset)

1: HSI clock is ready

Bit 1 **HSIKERON**: High Speed Internal clock enable in Stop mode

Set and reset by software to force the HSI to ON, even in Stop mode, in order to be quickly available as kernel clock for peripherals. This bit has no effect on the value of HSION.

0: no effect on HSI (default after reset)

1: HSI is forced to ON even in Stop mode

Bit 0 **HSION**: High Speed Internal clock enable

Set and cleared by software.

Set by hardware to force the HSI to ON when the product leaves Stop mode, if STOPWUCK = 0 or STOPKERWUCK = 0.

Set by hardware to force the HSI to ON when the product leaves Standby mode or in case of a failure of the HSE which is used as the system clock source.

This bit cannot be cleared if the HSI is used directly (via SW mux) as system clock or if the HSI is selected as reference clock for PLL1 with PLL1 enabled (PLL1ON bit set to 1).

0: HSI is OFF

1: HSI is ON (default after reset)

8.7.3 RCC HSI configuration register (RCC_HSICFGR)

Address offset: 0x004

Reset value: 0x4000 0XXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	HSITRIM[6:0]							Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw	rw	rw	rw	rw	rw	rw								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	HSICAL[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:24 **HSITRIM[6:0]**: HSI clock trimming

Set by software to adjust calibration.

HSITRIM field is added to the engineering Option Bytes loaded during reset phase (FLASH_HSI_opt) in order to form the calibration trimming value.

HSICAL = HSITRIM + FLASH_HSI_opt.

Note: The reset value of the field is 0x40.

Bits 23:12 Reserved, must be kept at reset value.

Bits 11:0 **HSICAL[11:0]**: HSI clock calibration

Set by hardware by option byte loading during system reset **nreset**.

Adjusted by software through trimming bits HSITRIM.

This field represents the sum of engineering Option Byte calibration value and HSITRIM bits value.

8.7.4 RCC clock recovery RC register (RCC_CRRCR)

Address offset: 0x008

Reset value: 0x0000 0XXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	HSI48CAL[9:0]									
						r	r	r	r	r	r	r	r	r	r

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:0 **HSI48CAL[9:0]**: Internal RC 48 MHz clock calibration
Set by hardware by option byte loading during system reset **nreset**.
Read-only.

8.7.5 RCC CSI configuration register (RCC_CSICFGR)

Address offset: 0x00C

Reset value: 0x2000 0XXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	CSITRIM[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
		rw	rw	rw	rw	rw	rw								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CSICAL[9:0]									
						r	r	r	r	r	r	r	r	r	r

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:24 **CSITRIM[5:0]**: CSI clock trimming

Set by software to adjust calibration.

CSITRIM bitfield is added to the engineering option bytes loaded during the reset phase (FLASH_CSI_opt) in order to build the calibration trimming value.

CSICAL = CSITRIM + FLASH_CSI_opt.

Note: The reset value of this bitfield is 0x10.

Bits 23:8 Reserved, must be kept at reset value.

Bits 9:0 **CSICAL[9:0]**: CSI clock calibration

Set by hardware by option byte loading during system reset **nreset**.

Adjusted by software through trimming bits CSITRIM.

This bitfield represents the sum of the engineering option byte calibration value and CSITRIM value.

8.7.6 RCC clock configuration register (RCC_CFGR)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MCO2[2:0]			MCO2PRE[3:0]				MCO1[2:0]			MCO1PRE[3:0]				Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TIMPRE	Res.	RTCPRE[5:0]						STOPKERWUCK	STOPWUCK	SWS[2:0]			SW[2:0]		
rw		rw	rw	rw	rw	rw	rw	rw	rw	r	r	r	rw	rw	rw

Bits 31:29 **MCO2[2:0]**: Micro-controller clock output 2

Set and cleared by software. Clock source selection may generate glitches on MCO2.
It is highly recommended to configure these bits only after reset, before enabling the external oscillators and the PLLs.
000: System clock selected (**sys_ck**) (default after reset)
001: PLL2 oscillator clock selected (**pll2_p_ck**)
010: HSE clock selected (**hse_ck**)
011: PLL1 clock selected (**pll1_p_ck**)
100: CSI clock selected (**csi_ck**)
101:LSI clock selected (**lsi_ck**)
others: reserved

Bits 28:25 **MCO2PRE[3:0]**: MCO2 prescaler

Set and cleared by software to configure the prescaler of the MCO2. Modification of this prescaler may generate glitches on MCO2. It is highly recommended to change this prescaler only after reset, before enabling the external oscillators and the PLLs.
0000: prescaler disabled (default after reset)
0001: division by 1 (bypass)
0010: division by 2
0011: division by 3
0100: division by 4
...
1111: division by 15

Bits 24:22 **MCO1[2:0]**: Micro-controller clock output 1

Set and cleared by software. Clock source selection may generate glitches on MCO1.
It is highly recommended to configure these bits only after reset, before enabling the external oscillators and the PLLs.
000: HSI clock selected (**hsi_ck**) (default after reset)
001: LSE oscillator clock selected (**lse_ck**)
010: HSE clock selected (**hse_ck**)
011: PLL1 clock selected (**pll1_q_ck**)
100: HSI48 clock selected (**hsi48_ck**)
others: reserved

Bits 21:18 **MCO1PRE[3:0]**: MCO1 prescaler

Set and cleared by software to configure the prescaler of the MCO1. Modification of this prescaler may generate glitches on MCO1. It is highly recommended to change this prescaler only after reset, before enabling the external oscillators and the PLLs.
0000: prescaler disabled (default after reset)
0001: division by 1 (bypass)
0010: division by 2
0011: division by 3
0100: division by 4
...
1111: division by 15

Bits 17:16 Reserved, must be kept at reset value.

Bit 15 **TIMPRE**: Timers clocks prescaler selection

This bit is set and reset by software to control the clock frequency of all the timers connected to APB1 and APB2 domains.

0: The Timers kernel clock is equal to **rcc_hclk1** if D2PPREx is corresponding to division by 1 or 2, else it is equal to 2 x $F_{rcc\_pclkx\_d2}$ (default after reset)
1: The Timers kernel clock is equal to **rcc_hclk1** if D2PPREx is corresponding to division by 1, 2 or 4, else it is equal to 4 x $F_{rcc\_pclkx\_d2}$
Please refer to *Table 53: Ratio between clock timer and pclk*

Bit 14 Reserved, must be kept at reset value.

Bits 13:8 **RTCPRE[5:0]**: HSE division factor for RTC clock

Set and cleared by software to divide the HSE to generate a clock for RTC.
Caution: The software has to set these bits correctly to ensure that the clock supplied to the RTC is lower than 1 MHz. These bits must be configured if needed before selecting the RTC clock source.
000000: no clock (default after reset)
000001: no clock
000010: HSE/2
000011: HSE/3
000100: HSE/4
...
111110: HSE/62
111111: HSE/63

Bit 7 **STOPKERWUCK**: Kernel clock selection after a wake up from system Stop

Set and reset by software to select the Kernel wakeup clock from system Stop.
0: The HSI is selected as wake up clock from system Stop (default after reset)
1: The CSI is selected as wake up clock from system Stop
See *Section 8.5.7: Handling clock generators in Stop and Standby mode* for details.

Bit 6 **STOPWUCK**: System clock selection after a wake up from system Stop

Set and reset by software to select the system wakeup clock from system Stop.

The selected clock is also used as emergency clock for the Clock Security System on HSE.

0: The HSI is selected as wake up clock from system Stop (default after reset)

1: The CSI is selected as wake up clock from system Stop

See *Section 8.5.7: Handling clock generators in Stop and Standby mode* for details.

Caution: STOPWUCK must not be modified when the Clock Security System is enabled (by HSECSSON bit) and the system clock is HSE (SWS=”10”) or a switch on HSE is requested (SW=”10”).

Bits 5:3 **SWS[2:0]**: System clock switch status

Set and reset by hardware to indicate which clock source is used as system clock.

000: HSI used as system clock (**hsi_ck**) (default after reset)

001: CSI used as system clock (**csi_ck**)

010: HSE used as system clock (**hse_ck**)

011: PLL1 used as system clock (**pll1_p_ck**)

others: Reserved

Bits 2:0 **SW[2:0]**: System clock switch

Set and reset by software to select system clock source (**sys_ck**).

Set by hardware in order to:

– force the selection of the HSI or CSI (depending on STOPWUCK selection) when leaving a system Stop mode

– force the selection of the HSI in case of failure of the HSE when used directly or indirectly as system clock.

000: HSI selected as system clock (**hsi_ck**) (default after reset)

001: CSI selected as system clock (**csi_ck**)

010: HSE selected as system clock (**hse_ck**)

011: PLL1 selected as system clock (**pll1_p_ck**)

others: Reserved

8.7.7 RCC domain 1 clock configuration register (RCC_D1CFGR)

Address offset: 0x018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	D1CPRE[3:0]				Res.	D1PPRE[2:0]			HPRE[3:0]			
				rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:8 **D1CPRE[3:0]**: D1 domain Core prescaler

Set and reset by software to control D1 domain CPU clock division factor.

Changing this division ratio has an impact on the frequency of the CPU clock, and all bus matrix clocks.

The clocks are divided by the new prescaler factor. This factor ranges from 1 to 16 periods of the slowest APB clock among **rcc_pclk[4:1]** after D1CPRE update. The application can check if the new division factor is taken into account by reading back this register.

0xxx: **sys_ck** not divided (default after reset)

1000: **sys_ck** divided by 2

1001: **sys_ck** divided by 4

1010: **sys_ck** divided by 8

1011: **sys_ck** divided by 16

1100: **sys_ck** divided by 64

1101: **sys_ck** divided by 128

1110: **sys_ck** divided by 256

1111: **sys_ck** divided by 512

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **D1PPRE[2:0]**: D1 domain APB3 prescaler

Set and reset by software to control the division factor of **rcc_pclk3**.

The clock is divided by the new prescaler factor from 1 to 16 cycles of **rcc_hclk3** after D1PPRE write.

0xx: **rcc_pclk3** = **rcc_hclk3** (default after reset)

100: **rcc_pclk3** = **rcc_hclk3** / 2

101: **rcc_pclk3** = **rcc_hclk3** / 4

110: **rcc_pclk3** = **rcc_hclk3** / 8

111: **rcc_pclk3** = **rcc_hclk3** / 16

Bits 3:0 **HPRE[3:0]**: D1 domain AHB prescaler

Set and reset by software to control the division factor of **rcc_hclk3** and **rcc_aclk**. Changing this division ratio has an impact on the frequency of all bus matrix clocks.

0xxx: **rcc_hclk3** = **sys_d1cpre_ck** (default after reset)

1000: **rcc_hclk3** = **sys_d1cpre_ck** / 2

1001: **rcc_hclk3** = **sys_d1cpre_ck** / 4

1010: **rcc_hclk3** = **sys_d1cpre_ck** / 8

1011: **rcc_hclk3** = **sys_d1cpre_ck** / 16

1100: **rcc_hclk3** = **sys_d1cpre_ck** / 64

1101: **rcc_hclk3** = **sys_d1cpre_ck** / 128

1110: **rcc_hclk3** = **sys_d1cpre_ck** / 256

1111: **rcc_hclk3** = **sys_d1cpre_ck** / 512

*Note: The clocks are divided by the new prescaler factor from1 to 16 periods of the slowest APB clock among **rcc_pclk[4:1]** after HPRE update.*

*Note: Note also that **rcc_hclk3** = **rcc_aclk**.*

Caution: Care must be taken when using the voltage scaling. Due to the propagation delay of the new division factor, after a prescaler factor change and before lowering the V_{CORE} voltage, this register must be read in order to check that the new prescaler value has been taken into account.

Depending on the clock source frequency and the voltage range, the software application has to program a correct value in HPRE to make sure that the system frequency does not exceed the maximum frequency.

8.7.8 RCC domain 2 clock configuration register (RCC_D2CFGR)

Address offset: 0x01C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	D2PPRE2[2:0]			Res.	D2PPRE1[2:0]			Res.	Res.	Res.	Res.
					rw	rw	rw		rw	rw	rw				

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:8 **D2PPRE2[2:0]**: D2 domain APB2 prescaler

Set and reset by software to control D2 domain APB2 clock division factor.
The clock is divided by the new prescaler factor from 1 to 16 cycles of **rcc_hclk1** after D2PPRE2 write.
0xx: **rcc_pclk2** = **rcc_hclk1** (default after reset)
100: **rcc_pclk2** = **rcc_hclk1** / 2
101: **rcc_pclk2** = **rcc_hclk1** / 4
110: **rcc_pclk2** = **rcc_hclk1** / 8
111: **rcc_pclk2** = **rcc_hclk1** / 16

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **D2PPRE1[2:0]**: D2 domain APB1 prescaler

Set and reset by software to control D2 domain APB1 clock division factor.
The clock is divided by the new prescaler factor from 1 to 16 cycles of **rcc_hclk1** after D2PPRE1 write.
0xx: **rcc_pclk1** = **rcc_hclk1** (default after reset)
100: **rcc_pclk1** = **rcc_hclk1** / 2
101: **rcc_pclk1** = **rcc_hclk1** / 4
110: **rcc_pclk1** = **rcc_hclk1** / 8
111: **rcc_pclk1** = **rcc_hclk1** / 16

Bits 3:0 Reserved, must be kept at reset value.

8.7.9 RCC Domain 3 Clock Configuration Register (RCC_D3CFGR)

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	D3PPRE[2:0]			Res.	Res.	Res.	Res.
									rw	rw	rw				

Bits 31:7 Reserved, must be kept at reset value.

Bits 6:4 **D3PPRE[2:0]**: D3 domain APB4 prescaler

Set and reset by software to control D3 domain APB4 clock division factor.
The clock is divided by the new prescaler factor from 1 to 16 cycles of **rcc_hclk4** after D3PPRE write.
0xx: **rcc_pclk4** = **rcc_hclk4** (default after reset)
100: **rcc_pclk4** = **rcc_hclk4** / 2
101: **rcc_pclk4** = **rcc_hclk4** / 4
110: **rcc_pclk4** = **rcc_hclk4** / 8
111: **rcc_pclk4** = **rcc_hclk4** / 16

Bits 3:0 Reserved, must be kept at reset value.

8.7.10 RCC PLLs clock source selection register (RCC_PLLCKSELR)

Address offset: 0x028

Reset value: 0x0202 0200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	DIVM3[5:0]						Res.	Res.	DIVM2[5:4]	
						rw	rw	rw	rw	rw	rw			rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIVM2[3:0]				Res.	Res.	DIVM1[5:0]						Res.	Res.	PLLSRC[1:0]	
rw	rw	rw	rw			rw	rw	rw	rw	rw	rw			rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:20 **DIVM3[5:0]:** Prescaler for PLL3

Set and cleared by software to configure the prescaler of the PLL3.
The hardware does not allow any modification of this prescaler when PLL3 is enabled (PLL3ON = 1).
In order to save power when PLL3 is not used, the value of DIVM3 must be set to 0.
000000: prescaler disabled (default after reset)
000001: division by 1 (bypass)
000010: division by 2
000011: division by 3
...
100000: division by 32 (default after reset)
...
111111: division by 63

Bits 19:18 Reserved, must be kept at reset value.

Bits 17:12 **DIVM2[5:0]**: Prescaler for PLL2

Set and cleared by software to configure the prescaler of the PLL2.
The hardware does not allow any modification of this prescaler when PLL2 is enabled (PLL2ON = 1).
In order to save power when PLL2 is not used, the value of DIVM2 must be set to 0.
000000: prescaler disabled
000001: division by 1 (bypass)
000010: division by 2
000011: division by 3
...
100000: division by 32 (default after reset)
...
111111: division by 63

Bits 11:10 Reserved, must be kept at reset value.

Bits 9:4 **DIVM1[5:0]**: Prescaler for PLL1

Set and cleared by software to configure the prescaler of the PLL1.
The hardware does not allow any modification of this prescaler when PLL1 is enabled (PLL1ON = 1).
In order to save power when PLL1 is not used, the value of DIVM1 must be set to 0.
000000: prescaler disabled
000001: division by 1 (bypass)
000010: division by 2
000011: division by 3
...
100000: division by 32 (default after reset)
...
111111: division by 63

Bits 3:2 Reserved, must be kept at reset value.

Bits 1:0 **PLLSRC[1:0]:** DIVMx and PLLs clock source selection

Set and reset by software to select the PLL clock source.
These bits can be written only when all PLLs are disabled.
In order to save power, when no PLL is used, the value of PLLSRC must be set to '11'.
00: HSI selected as PLL clock (**hsi_ck**) (default after reset)
01: CSI selected as PLL clock (**csi_ck**)
10: HSE selected as PLL clock (**hse_ck**)
11: No clock send to DIVMx divider and PLLs

8.7.11 RCC PLLs Configuration Register (RCC_PLLCFGR)

Address offset: 0x02C

Reset value: 0x01FF 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIVR3EN	DIVQ3EN	DIVP3EN	DIVR2EN	DIVQ2EN	DIVP2EN	DIVR1EN	DIVQ1EN	DIVP1EN
							rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	PLL3RGE[1:0]		PLL3VCOSEL	PLL3FRACEN	PLL2RGE[[1:0]		PLL2VCOSEL	PLL2FRACEN	PLL1RGE[1:0]		PLL1VCOSEL	PLL1FRACEN
				rw	rw	rw	rw	rw		rw	rw	rw		rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **DIVR3EN**: PLL3 DIVR divider output enable
Set and reset by software to enable the **pll3_r_ck** output of the PLL3.
To save power, DIVR3EN and DIVR3 bits must be set to 0 when the **pll3_r_ck** is not used.
This bit can be written only when the PLL3 is disabled (PLL3ON = 0 and PLL3RDY = 0).
0: **pll3_r_ck** output is disabled
1: **pll3_r_ck** output is enabled (default after reset)

Bit 23 **DIVQ3EN**: PLL3 DIVQ divider output enable
Set and reset by software to enable the **pll3_q_ck** output of the PLL3.
To save power, DIVR3EN and DIVR3 bits must be set to 0 when the **pll3_r_ck** is not used.
This bit can be written only when the PLL3 is disabled (PLL3ON = 0 and PLL3RDY = 0).
0: **pll3_q_ck** output is disabled
1: **pll3_q_ck** output is enabled (default after reset)

Bit 22 **DIVP3EN**: PLL3 DIVP divider output enable
Set and reset by software to enable the **pll3_p_ck** output of the PLL3.
This bit can be written only when the PLL3 is disabled (PLL3ON = 0 and PLL3RDY = 0).
To save power, DIVR3EN and DIVR3 bits must be set to 0 when the **pll3_r_ck** is not used.
0: **pll3_p_ck** output is disabled
1: **pll3_p_ck** output is enabled (default after reset)

Bit 21 **DIVR2EN**: PLL2 DIVR divider output enable
Set and reset by software to enable the **pll2_r_ck** output of the PLL2.
To save power, DIVR2EN and DIVR2 bits must be set to 0 when the **pll2_r_ck** is not used.
This bit can be written only when the PLL2 is disabled (PLL2ON = 0 and PLL2RDY = 0).
0: **pll2_r_ck** output is disabled
1: **pll2_r_ck** output is enabled (default after reset)

Bit 20 **DIVQ2EN**: PLL2 DIVQ divider output enable
Set and reset by software to enable the **pll2_q_ck** output of the PLL2.
To save power, DIVR2EN and DIVR2 bits must be set to 0 when the **pll2_r_ck** is not used.
This bit can be written only when the PLL2 is disabled (PLL2ON = 0 and PLL2RDY = 0).
0: **pll2_q_ck** output is disabled
1: **pll2_q_ck** output is enabled (default after reset)

Bit 19 **DIVP2EN**: PLL2 DIVP divider output enable
Set and reset by software to enable the **pll2_p_ck** output of the PLL2.
This bit can be written only when the PLL2 is disabled (PLL2ON = 0 and PLL2RDY = 0).
To save power, DIVR2EN and DIVR2 bits must be set to 0 when the **pll2_r_ck** is not used.
0: **pll2_p_ck** output is disabled
1: **pll2_p_ck** output is enabled (default after reset)

Bit 18 **DIVR1EN**: PLL1 DIVR divider output enable
Set and reset by software to enable the **pll1_r_ck** output of the PLL1.
To save power, DIVR1EN and DIVR1 bits must be set to 0 when the **pll1_r_ck** is not used.
This bit can be written only when the PLL1 is disabled (PLL1ON = 0 and PLL1RDY = 0).
0: **pll1_r_ck** output is disabled
1: **pll1_r_ck** output is enabled (default after reset)

Bit 17 **DIVQ1EN**: PLL1 DIVQ divider output enable
Set and reset by software to enable the **pll1_q_ck** output of the PLL1.
In order to save power, when the **pll1_q_ck** output of the PLL1 is not used, the **pll1_q_ck** must be disabled.
This bit can be written only when the PLL1 is disabled (PLL1ON = 0 and PLL1RDY = 0).
0: **pll1_q_ck** output is disabled
1: **pll1_q_ck** output is enabled (default after reset)

Bit 16 **DIVP1EN**: PLL1 DIVP divider output enable
Set and reset by software to enable the **pll1_p_ck** output of the PLL1.
This bit can be written only when the PLL1 is disabled (PLL1ON = 0 and PLL1RDY = 0).
In order to save power, when the **pll1_p_ck** output of the PLL1 is not used, the **pll1_p_ck** must be disabled.
0: **pll1_p_ck** output is disabled
1: **pll1_p_ck** output is enabled (default after reset)

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:10 **PLL3RGE[1:0]**: PLL3 input frequency range
Set and reset by software to select the proper reference frequency range used for PLL3.
These bits must be written before enabling the PLL3.
00: The PLL3 input (**ref3_ck**) clock range frequency is between 1 and 2 MHz (default after reset)
01: The PLL3 input (**ref3_ck**) clock range frequency is between 2 and 4 MHz
10: The PLL3 input (**ref3_ck**) clock range frequency is between 4 and 8 MHz
11: The PLL3 input (**ref3_ck**) clock range frequency is between 8 and 16 MHz

Bit 9 **PLL3VCOSEL**: PLL3 VCO selection
Set and reset by software to select the proper VCO frequency range used for PLL3.
This bit must be written before enabling the PLL3.
0: Wide VCO range:192 to 836 MHz (default after reset)
1: Medium VCO range:150 to 420 MHz

Bit 8 **PLL3FRACEN**: PLL3 fractional latch enable
Set and reset by software to latch the content of FRACN3 into the Sigma-Delta modulator.
In order to latch the FRACN3 value into the Sigma-Delta modulator, PLL3FRACEN must be set to 0, then set to 1: the transition 0 to 1 transfers the content of FRACN3 into the modulator. Please refer to *Section : PLL initialization phase* for additional information.

Bits 7:6 **PLL2RGE[1:0]**: PLL2 input frequency range
Set and reset by software to select the proper reference frequency range used for PLL2.
These bits must be written before enabling the PLL2.
00: The PLL2 input (**ref2_ck**) clock range frequency is between 1 and 2 MHz (default after reset)
01: The PLL2 input (**ref2_ck**) clock range frequency is between 2 and 4 MHz
10: The PLL2 input (**ref2_ck**) clock range frequency is between 4 and 8 MHz
11: The PLL2 input (**ref2_ck**) clock range frequency is between 8 and 16 MHz

Bit 5 **PLL2VCOSEL**: PLL2 VCO selection
Set and reset by software to select the proper VCO frequency range used for PLL2.
This bit must be written before enabling the PLL2.
0: Wide VCO range:192 to 836 MHz (default after reset)
1: Medium VCO range:150 to 420 MHz

Bit 4 **PLL2FRACEN**: PLL2 fractional latch enable
Set and reset by software to latch the content of FRACN2 into the Sigma-Delta modulator.
In order to latch the FRACN2 value into the Sigma-Delta modulator, PLL2FRACEN must be set to 0, then set to 1: the transition 0 to 1 transfers the content of FRACN2 into the modulator. Please refer to *Section : PLL initialization phase* for additional information.

Bits 3:2 **PLL1RGE[1:0]**: PLL1 input frequency range
Set and reset by software to select the proper reference frequency range used for PLL1.
This bit must be written before enabling the PLL1.
00: The PLL1 input (**ref1_ck**) clock range frequency is between 1 and 2 MHz (default after reset)
01: The PLL1 input (**ref1_ck**) clock range frequency is between 2 and 4 MHz
10: The PLL1 input (**ref1_ck**) clock range frequency is between 4 and 8 MHz
11: The PLL1 input (**ref1_ck**) clock range frequency is between 8 and 16 MHz

Bit 1 **PLL1VCOSEL**: PLL1 VCO selection
Set and reset by software to select the proper VCO frequency range used for PLL1.
These bits must be written before enabling the PLL1.
0: Wide VCO range: 192 to 836 MHz (default after reset)
1: Medium VCO range: 150 to 420 MHz

Bit 0 **PLL1FRACEN**: PLL1 fractional latch enable
Set and reset by software to latch the content of FRACN1 into the Sigma-Delta modulator.
In order to latch the FRACN1 value into the Sigma-Delta modulator, PLL1FRACEN must be set to 0, then set to 1: the transition 0 to 1 transfers the content of FRACN1 into the modulator. Please refer to *Section : PLL initialization phase* for additional information.

8.7.12 RCC PLL1 dividers configuration register (RCC_PLL1DIVR)

Address offset: 0x030

Reset value: 0x0101 0280

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	DIVR1[6:0]							Res.	DIVQ1[6:0]						
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIVP1[6:0]							DIVN1[8:0]								
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:24 **DIVR1[6:0]**: PLL1 DIVR division factor

Set and reset by software to control the frequency of the **pll1_r_ck** clock.
These bits can be written only when the PLL1 is disabled (PLL1ON = 0 and PLL1RDY = 0).
0000000: **pll1_r_ck** = **vco1_ck**
0000001: **pll1_r_ck** = **vco1_ck** / 2 (default after reset)
0000010: **pll1_r_ck** = **vco1_ck** / 3
0000011: **pll1_r_ck** = **vco1_ck** / 4
...
1111111: **pll1_r_ck** = **vco1_ck** / 128

Bit 23 Reserved, must be kept at reset value.

Bits 22:16 **DIVQ1[6:0]**: PLL1 DIVQ division factor

Set and reset by software to control the frequency of the **pll1_q_ck** clock.
These bits can be written only when the PLL1 is disabled (PLL1ON = 0 and PLL1RDY = 0).
0000000: **pll1_q_ck** = **vco1_ck**
0000001: **pll1_q_ck** = **vco1_ck** / 2 (default after reset)
0000010: **pll1_q_ck** = **vco1_ck** / 3
0000011: **pll1_q_ck** = **vco1_ck** / 4
...
1111111: **pll1_q_ck** = **vco1_ck** / 128

Bits 15:9 **DIVP1[6:0]**: PLL1 DIVP division factor

Set and reset by software to control the frequency of the **pll1_p_ck** clock.
These bits can be written only when the PLL1 is disabled (PLL1ON = 0 and PLL1RDY = 0).

Note that odd division factors are not allowed, except for 1 (no division).

0000000: **pll1_p_ck** = **vco1_ck**
0000001: **pll1_p_ck** = **vco1_ck** / 2 (default after reset)
0000010: Not allowed
0000011: **pll1_p_ck** = **vco1_ck** / 4
...
1111111: **pll1_p_ck** = **vco1_ck** / 128

Bits 8:0 **DIVN1[8:0]**: Multiplication factor for PLL1 VCO

Set and reset by software to control the multiplication factor of the VCO.
These bits can be written only when the PLL is disabled (PLL1ON = 0 and PLL1RDY = 0).
0x003: DIVN1 = 4
0x004: DIVN1 = 5
0x005: DIVN1 = 6
...
0x080: DIVN1 = 129 (default after reset)
...
0x1FF: DIVN1 = 512
Others: wrong configurations

Caution: The software has to set correctly these bits to insure that the VCO output frequency is between its valid frequency range, which is:

- 192 to 836 MHz if PLL1VCOSEL = 0
- 150 to 420 MHz if PLL1VCOSEL = 1
-

VCO output frequency = F_{ref1_ck} x DIVN1, when fractional value 0 has been loaded into FRACN1, with:

- DIVN1 between 4 and 512
- The input frequency F_{ref1_ck} between 1MHz and 16 MHz

8.7.13 RCC PLL1 fractional divider register (RCC_PLL1FRACR)

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FRACN1[12:0]													Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw			

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:3 **FRACN1[12:0]**: Fractional part of the multiplication factor for PLL1 VCO

Set and reset by software to control the fractional part of the multiplication factor of the VCO. These bits can be written at any time, allowing dynamic fine-tuning of the PLL1 VCO.

Caution: The software has to set correctly these bits to insure that the VCO output frequency is between its valid frequency range, which is:

- 192 to 836 MHz if PLL1VCOSEL = 0
- 150 to 420 MHz if PLL1VCOSEL = 1

VCO output frequency = F_{ref1_ck} x $\left(\text{DIVN1} + (\text{FRACN1} / 2^{13})\right)$, with

- DIVN1 shall be between 4 and 512
- FRACN1 can be between 0 and 2^{13}- 1
- The input frequency F_{ref1_ck} shall be between 1 and 16 MHz.

To change the FRACN value on-the-fly even if the PLL is enabled, the application has to proceed as follow:

- set the bit PLL1FRACEN to 0,
- write the new fractional value into FRACN1,
- set the bit PLL1FRACEN to 1.

Bits 2:0 Reserved, must be kept at reset value.

8.7.14 RCC PLL2 dividers configuration register (RCC_PLL2DIVR)

Address offset: 0x038

Reset value: 0x0101 0280

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	DIVR2[6:0]							Res.	DIVQ2[6:0]						
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIVP2[6:0]							DIVN2[8:0]								
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:24 **DIVR2[6:0]**: PLL2 DIVR division factor

Set and reset by software to control the frequency of the **pll2_r_ck** clock.
These bits can be written only when the PLL2 is disabled (PLL2ON = 0 and PLL2RDY = 0).
0000000: **pll2_r_ck** = **vco2_ck**
0000001: **pll2_r_ck** = **vco2_ck** / 2 (default after reset)
0000010: **pll2_r_ck** = **vco2_ck** / 3
0000011: **pll2_r_ck** = **vco2_ck** / 4
...
1111111: **pll2_r_ck** = **vco2_ck** / 128

Bit 23 Reserved, must be kept at reset value.

Bits 22:16 **DIVQ2[6:0]**: PLL2 DIVQ division factor

Set and reset by software to control the frequency of the **pll2_q_ck** clock.
These bits can be written only when the PLL2 is disabled (PLL2ON = 0 and PLL2RDY = 0).
0000000: **pll2_q_ck** = **vco2_ck**
0000001: **pll2_q_ck** = **vco2_ck** / 2 (default after reset)
0000010: **pll2_q_ck** = **vco2_ck** / 3
0000011: **pll2_q_ck** = **vco2_ck** / 4
...
1111111: **pll2_q_ck** = **vco2_ck** / 128

Bits 15:9 **DIVP2[6:0]**: PLL2 DIVP division factor

Set and reset by software to control the frequency of the **pll2_p_ck** clock.
These bits can be written only when the PLL2 is disabled (PLL2ON = 0 and PLL2RDY = 0).

0000000: **pll2_p_ck** = **vco2_ck**
0000001: **pll2_p_ck** = **vco2_ck** / 2 (default after reset)
0000010: **pll2_p_ck** = **vco2_ck** / 3
0000011: **pll2_p_ck** = **vco2_ck** / 4
...
1111111: **pll2_p_ck** = **vco2_ck** / 128

Bits 8:0 **DIVN2[8:0]**: Multiplication factor for PLL2 VCO

Set and reset by software to control the multiplication factor of the VCO.
These bits can be written only when the PLL is disabled (PLL2ON = 0 and PLL2RDY = 0).

Caution: The software has to set correctly these bits to insure that the VCO output frequency is between its valid frequency range, which is:

- 192 to 836 MHz if PLL2VCOSEL = 0
- 150 to 420 MHz if PLL2VCOSEL = 1

VCO output frequency = F_{ref2_ck} x DIVN2, when fractional value 0 has been loaded into FRACN2, with

- DIVN2 between 4 and 512
- The input frequency F_{ref2_ck} between 1MHz and 16MHz

0x003: DIVN2 = 4
0x004: DIVN2 = 5
0x005: DIVN2 = 6
...
0x080: DIVN2 = 129 (default after reset)
...
0x1FF: DIVN2 = 512
Others: wrong configurations

8.7.15 RCC PLL2 fractional divider register (RCC_PLL2FRACR)

Address offset: 0x03C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FRACN2[12:0]													Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw			

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:3 **FRACN2[12:0]**: Fractional part of the multiplication factor for PLL2 VCO

Set and reset by software to control the fractional part of the multiplication factor of the VCO. These bits can be written at any time, allowing dynamic fine-tuning of the PLL2 VCO.

Caution: The software has to set correctly these bits to insure that the VCO output frequency is between its valid frequency range, which is:

- 192 to 836 MHz if PLL2VCOSEL = 0
- 150 to 420 MHz if PLL2VCOSEL = 1

VCO output frequency = F_{ref2_ck} x $\left(DIVN2 + (FRACN2 / 2^{13})\right)$, with

- DIVN2 shall be between 4 and 512
- FRACN2 can be between 0 and $2^{13} - 1$
- The input frequency F_{ref2_ck} shall be between 1 and 16 MHz

In order to change the FRACN value on-the-fly even if the PLL is enabled, the application has to proceed as follow:

- set the bit PLL2FRACEN to 0,
- write the new fractional value into FRACN2,
- set the bit PLL2FRACEN to 1.

Bits 2:0 Reserved, must be kept at reset value.

8.7.16 RCC PLL3 dividers configuration register (RCC_PLL3DIVR)

Address offset: 0x040

Reset value: 0x0101 0280

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	DIVR3[6:0]							Res.	DIVQ3[6:0]						
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIVP3[6:0]							DIVN3[8:0]								
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:24 **DIVR3[6:0]**: PLL3 DIVR division factor

Set and reset by software to control the frequency of the **pll3_r_ck** clock.
These bits can be written only when the PLL3 is disabled (PLL3ON = 0 and PLL3RDY = 0).
0000000: **pll3_r_ck** = **vco3_ck**
0000001: **pll3_r_ck** = **vco3_ck** / 2 (default after reset)
0000010: **pll3_r_ck** = **vco3_ck** / 3
0000011: **pll3_r_ck** = **vco3_ck** / 4
...
1111111: **pll3_r_ck** = **vco3_ck** / 128

Bit 23 Reserved, must be kept at reset value.

Bits 22:16 **DIVQ3[6:0]**: PLL3 DIVQ division factor

Set and reset by software to control the frequency of the **pll3_q_ck** clock.
These bits can be written only when the PLL3 is disabled (PLL3ON = 0 and PLL3RDY = 0).
0000000: **pll3_q_ck** = **vco3_ck**
0000001: **pll3_q_ck** = **vco3_ck** / 2 (default after reset)
0000010: **pll3_q_ck** = **vco3_ck** / 3
0000011: **pll3_q_ck** = **vco3_ck** / 4
...
1111111: **pll3_q_ck** = **vco3_ck** / 128

Bits 15:9 **DIVP3[6:0]**: PLL3 DIVP division factor

Set and reset by software to control the frequency of the **pll3_p_ck** clock.
These bits can be written only when the PLL3 is disabled (PLL3ON = 0 and PLL3RDY = 0).

0000000: **pll3_p_ck** = **vco3_ck**
0000001: **pll3_p_ck** = **vco3_ck** / 2 (default after reset)
0000010: **pll3_p_ck** = **vco3_ck** / 3
0000011: **pll3_p_ck** = **vco3_ck** / 4
...
1111111: pll3_p_ck = **vco3_ck** / 128

Bits 8:0 **DIVN3[8:0]**: Multiplication factor for PLL3 VCO

Set and reset by software to control the multiplication factor of the VCO.
These bits can be written only when the PLL is disabled (PLL3ON = 0 and PLL3RDY = 0).

Caution: The software has to set correctly these bits to insure that the VCO output frequency is between its valid frequency range, which is:

- 192 to 836 MHz if PLL3VCOSEL = 0
- 150 to 420 MHz if PLL3VCOSEL = 1

VCO output frequency = F_{ref3_ck} x DIVN3, when fractional value 0 has been loaded into FRACN3, with

- DIVN3 between 4 and 512
- The input frequency F_{ref3_ck} between 1MHz and 16MHz

0x003: DIVN3 = 4
0x004: DIVN3 = 5
0x005: DIVN3 = 6
...
0x080: DIVN3 = 129 (default after reset)
...
0x1FF: DIVN3 = 512
Others: wrong configurations

8.7.17 RCC PLL3 fractional divider register (RCC_PLL3FRACR)

Address offset: 0x044

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FRACN3[12:0]													Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw			

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:3 **FRACN3[12:0]**: Fractional part of the multiplication factor for PLL3 VCO

Set and reset by software to control the fractional part of the multiplication factor of the VCO. These bits can be written at any time, allowing dynamic fine-tuning of the PLL3 VCO.

Caution: The software has to set correctly these bits to insure that the VCO output frequency is between its valid frequency range, which is:

- 192 to 836 MHz if PLL3VCOSEL = 0
- 150 to 420 MHz if PLL3VCOSEL = 1

VCO output frequency = F_{ref3_ck} x $\left(\text{DIVN3} + (\text{FRACN3} / 2^{13})\right)$, with

- DIVN3 shall be between 4 and 512
- FRACN3 can be between 0 and 2^{13} - 1
- The input frequency F_{ref3_ck} shall be between 1 and 16 MHz

In order to change the FRACN value on-the-fly even if the PLL is enabled, the application has to proceed as follow:

- set the bit PLL1FRACEN to 0,
- write the new fractional value into FRACN1,
- set the bit PLL1FRACEN to 1.

Bits 2:0 Reserved, must be kept at reset value.

8.7.18 RCC domain 1 kernel clock configuration register (RCC_D1CCIPR)

Address offset: 0x04C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	CKPERSEL[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SDMMCSEL
		rw	rw												rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCTOSPISEL[1:0]		Res.	Res.	FMCSEL[1:0]	
										rw	rw			rw	rw

Note: Changing the clock source on-the-fly is allowed and will not generate any timing violation. However the user has to make use that both the previous and the new clock sources are present during the switching, and during the whole transition time. Please refer to Section : Clock switches and gating.

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:28 **CKPERSEL[1:0]**: **per_ck** clock source selection
- 00: **hsi_ker_ck** clock selected as **per_ck** clock (default after reset)
- 01: **csi_ker_ck** clock selected as **per_ck** clock
- 10: **hse_ck** clock selected as **per_ck** clock
- 11: reserved, the **per_ck** clock is disabled

Bits 27:17 Reserved, must be kept at reset value.

Bit 16 **SDMMCSEL**: SDMMC kernel clock source selection
- 0: **pll1_q_ck** clock is selected as kernel peripheral clock (default after reset)
- 1: **pll2_r_ck** clock is selected as kernel peripheral clock

Bits 15:6 Reserved, must be kept at reset value.

Bits 5:4 **OCTOSPISEL[1:0]**: OCTOSPI kernel clock source selection
00: **rcc_hclk3** clock selected as kernel peripheral clock (default after reset)
01: **pll1_q_ck** clock selected as kernel peripheral clock
10: **pll2_r_ck** clock selected as kernel peripheral clock
11: **per_ck** clock selected as kernel peripheral clock

Bits 3:2 Reserved, must be kept at reset value.

Bits 1:0 **FMCSEL[1:0]**: FMC kernel clock source selection
00: **rcc_hclk3** clock selected as kernel peripheral clock (default after reset)
01: **pll1_q_ck** clock selected as kernel peripheral clock
10: **pll2_r_ck** clock selected as kernel peripheral clock
11: **per_ck** clock selected as kernel peripheral clock

8.7.19 RCC domain 2 kernel clock configuration register (RCC_D2CCIP1R)

Address offset: 0x050

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SWPMISEL	Res.	FDCANSEL[1:0]		Res.	Res.	Res.	DFSDM1SEL	Res.	Res.	SPDIFRXSEL[1:0]		Res.	SPI45SEL[2:0]		
rw		rw	rw				rw			rw	rw		rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	SPI123SEL[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SAI1SEL[2:0]		
	rw	rw	rw										rw	rw	rw

Note: Changing the clock source on-the-fly is allowed and will not generate any timing violation. However the user has to make sure that both the previous and the new clock sources are present during the switching, and for the whole transition time. Please refer to Section : Clock switches and gating.

Bit 31 **SWPMISEL**: SWPMI kernel clock source selection
Set and reset by software.
0: **pclk** is selected as SWPMI kernel clock (default after reset)
1: **hsi_ker_ck** clock is selected as SWPMI kernel clock

Bit 30 Reserved, must be kept at reset value.

Bits 29:28 **FDCANSEL[1:0]**: FDCAN kernel clock source selection
Set and reset by software.
00: **hse_ck** clock is selected as FDCAN kernel clock (default after reset)
01: **pll1_q_ck** clock is selected as FDCAN kernel clock
10: **pll2_q_ck** clock is selected as FDCAN kernel clock
11: reserved, the kernel clock is disabled

Bits 27:25 Reserved, must be kept at reset value.

Bit 24 **DFSDM1SEL**: DFSDM1 kernel **Clk** clock source selection
Set and reset by software.
Note: the DFSDM1 Aclk Clock Source Selection is done by SAI1SEL.
0: **rcc_pclk2** is selected as DFSDM1 Clk kernel clock (default after reset)
1: **sys_ck** clock is selected as DFSDM1 Clk kernel clock

Bits 23:22 Reserved, must be kept at reset value.

Bits 21:20 **SPDIFRXSEL[1:0]**: SPDIFRX kernel clock source selection
00: **pll1_q_ck** clock selected as SPDIFRX kernel clock (default after reset)
01: **pll2_r_ck** clock selected as SPDIFRX kernel clock
10: **pll3_r_ck** clock selected as SPDIFRX kernel clock
11: **hsi_ker_ck** clock selected as SPDIFRX kernel clock

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **SPI45SEL[2:0]**: SPI4 and 5 kernel clock source selection
Set and reset by software.
000: APB clock is selected as kernel clock (default after reset)
001: **pll2_q_ck** clock is selected as kernel clock
010: **pll3_q_ck** clock is selected as kernel clock
011: **hsi_ker_ck** clock is selected as kernel clock
100: **csi_ker_ck** clock is selected as kernel clock
101: **hse_ck** clock is selected as kernel clock
others: reserved, the kernel clock is disabled

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **SPI123SEL[2:0]**: SPI/I2S1,2 and 3 kernel clock source selection
Set and reset by software.

Caution: If the selected clock is the external clock and this clock is stopped, it will not be possible to switch to another clock. Refer to *Section : Clock switches and gating* for additional information.

000: **pll1_q_ck** clock selected as SPI/I2S1,2 and 3 kernel clock (default after reset)
001: **pll2_p_ck** clock selected as SPI/I2S1,2 and 3 kernel clock
010: **pll3_p_ck** clock selected as SPI/I2S1,2 and 3 kernel clock
011: I2S_CKIN clock selected as SPI/I2S1,2 and 3 kernel clock
100: **per_ck** clock selected as SPI/I2S1,2 and 3 kernel clock
others: reserved, the kernel clock is disabled

Note: I2S_CKIN is an external clock taken from a pin.

Bits 11:3 Reserved, must be kept at reset value.

Bits 2:0 **SAI1SEL[2:0]**: SAI1 and DFSDM1 kernel **Aclk** clock source selection
Set and reset by software.

Caution: If the selected clock is the external clock and this clock is stopped, it will not be possible to switch to another clock. Refer to *Section : Clock switches and gating* for additional information.

Note: DFSDM1 Clock Source Selection is done by DFSDM1SEL.

000: **pll1_q_ck** clock selected as SAI1 and DFSDM1 **Aclk** kernel clock (default after reset)
001: **pll2_p_ck** clock selected as SAI1 and DFSDM1 **Aclk** kernel clock
010: **pll3_p_ck** clock selected as SAI1 and DFSDM1 **Aclk** kernel clock
011: I2S_CKIN clock selected as SAI1 and DFSDM1 **Aclk** kernel clock
100: **per_ck** clock selected as SAI1 and DFSDM1 **Aclk** kernel clock
others: reserved, the kernel clock is disabled

Note: I2S_CKIN is an external clock taken from a pin.

8.7.20 RCC domain 2 kernel clock configuration register (RCC_D2CCIP2R)

Address offset: 0x054

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	LPTIM1SEL[2:0] (1)			Res.	Res.	Res.	Res.	CECSEL[1:0] (1)		USBSEL[1:0] (1)		Res.	Res.	Res.	Res.
	rw	rw	rw					rw	rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	I2C1235SEL[1:0] (1)		Res.	Res.	RNGSEL[1:0] (1)		Res.	Res.	USART16910SEL[2:0] (1)			USART234578SEL[2:0] (1)		
		rw	rw			rw	rw			rw	rw	rw	rw	rw	rw

1. Changing the clock source on-the-fly is allowed and will not generate any timing violation. However the user has to make sure that both the previous and the new clock sources are present during the switching, and for the whole transition time. Please refer to *Section : Clock switches and gating*.

Bit 31 Reserved, must be kept at reset value.

Bits 30:28 **LPTIM1SEL[2:0]**: LPTIM1 kernel clock source selection
Set and reset by software.
000: **rcc_pclk1** clock selected as kernel peripheral clock (default after reset)
001: **pll2_p_ck** clock selected as kernel peripheral clock
010: **pll3_r_ck** clock selected as kernel peripheral clock
011: **lse_ck** clock selected as kernel peripheral clock
100: **lsi_ck** clock selected as kernel peripheral clock
101: **per_ck** clock selected as kernel peripheral clock
others: reserved, the kernel clock is disabled

Bits 27:24 Reserved, must be kept at reset value.

Bits 23:22 **CECSEL[1:0]**: HDMI-CEC kernel clock source selection
Set and reset by software.
00: **lse_ck** clock is selected as kernel clock (default after reset)
01: **lsi_ck** clock is selected as kernel clock
10: **csi_ker_ck** divided by 122 is selected as kernel clock
11: reserved, the kernel clock is disabled

Bits 21:20 **USBSEL[1:0]**: USBOTG1 kernel clock source selection
Set and reset by software.
00: Disable the kernel clock (default after reset)
01: **pll1_q_ck** clock is selected as kernel clock
10: **pll3_q_ck** clock is selected as kernel clock
11: **hsi48_ck** clock is selected as kernel clock

Bits 19:14 Reserved, must be kept at reset value.

Bits 13:12 **I2C1235SEL[1:0]**: I2C1/2/3/5 kernel clock source selection
Set and reset by software.
00: **rcc_pclk1** clock is selected as kernel clock (default after reset)
01: **pll3_r_ck** clock is selected as kernel clock
10: **hsi_ker_ck** clock is selected as kernel clock
11: **csi_ker_ck** clock is selected as kernel clock

Bits 11:10 Reserved, must be kept at reset value.

Bits 9:8 **RNGSEL[1:0]**: RNG kernel clock source selection
Set and reset by software.
00: **hsi8_ck** clock is selected as kernel clock (default after reset)
01: **pll1_q_ck** clock is selected as kernel clock
10: **lse_ck** clock is selected as kernel clock
11: **lsi_ck** clock is selected as kernel clock

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:3 **USART16910SEL[2:0]**: USART1/6/9/10 kernel clock source selection
Set and reset by software.
000: **rcc_pclk2** clock is selected as kernel clock (default after reset)
001: **pll2_q_ck** clock is selected as kernel clock
010: **pll3_q_ck** clock is selected as kernel clock
011: **hsi_ker_ck** clock is selected as kernel clock
100: **csi_ker_ck** clock is selected as kernel clock
101: **lse_ck** clock is selected as kernel clock
others: reserved, the kernel clock is disabled

Bits 2:0 **USART234578SEL[2:0]**: USART2/3, UART4/5/7/8 (APB1) kernel clock source selection
Set and reset by software.
000: **rcc_pclk1** clock is selected as kernel clock (default after reset)
001: **pll2_q_ck** clock is selected as kernel clock
010: **pll3_q_ck** clock is selected as kernel clock
011: **hsi_ker_ck** clock is selected as kernel clock
100: **csi_ker_ck** clock is selected as kernel clock
101: **lse_ck** clock is selected as kernel clock
others: reserved, the kernel clock is disabled

8.7.21 RCC domain 3 kernel clock configuration register (RCC_D3CCIPR)

Address offset: 0x058

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	SPI6SEL[2:0] (1)			Res.	SAI4BSEL[2:0] (1)			SAI4ASEL[2:0] (1)			Res.	Res.	Res.	ADCSEL[1:0] (1)	
	rw	rw	rw		rw	rw	rw	rw	rw	rw				rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LPTIM345SEL[2:0] (1)			LPTIM2SEL[2:0] (1)			I2C4SEL[1:0] (1)		Res.	Res.	Res.	Res.	Res.	LPUART1SEL[2:0] (1)		
rw	rw	rw	rw	rw	rw	rw	rw						rw	rw	rw

1. Changing the clock source on-the-fly is allowed, and will not generate any timing violation. However the user has to make sure that both the previous and the new clock sources are present during the switching, and for the whole transition time. Please refer to *Section : Clock switches and gating*.

Bit 31 Reserved, must be kept at reset value.

Bits 30:28 **SPI6SEL[2:0]**: SPI6 kernel clock source selection

Set and reset by software.

000: **rcc_pclk4** clock selected as kernel peripheral clock (default after reset)
001: **pll2_q_ck** clock selected as kernel peripheral clock
010: **pll3_q_ck** clock selected as kernel peripheral clock
011: **hsi_ker_ck** clock selected as kernel peripheral clock
100: **csi_ker_ck** clock selected as kernel peripheral clock
101: **hse_ck** clock selected as kernel peripheral clock
110: **i2s_ckin** clock selected as kernel peripheral clock
others: reserved, the kernel clock is disabled

Bit 27 Reserved, must be kept at reset value.

Bits 26:24 **SAI4BSEL[2:0]**: Sub-Block B of SAI4 kernel clock source selection

Set and reset by software.

Caution: If the selected clock is the external clock and this clock is stopped, it will not be possible to switch to another clock. Refer to *Section : Clock switches and gating* for additional information.

000: **pll1_q_ck** clock selected as kernel peripheral clock (default after reset)
001: **pll2_p_ck** clock selected as kernel peripheral clock
010: **pll3_p_ck** clock selected as kernel peripheral clock
011: I2S_CKIN clock selected as kernel peripheral clock
100: **per_ck** clock selected as kernel peripheral clock
101: **spdifrx_symb_ck** clock selected as kernel peripheral clock
others: reserved, the kernel clock is disabled

Note: I2S_CKIN is an external clock taken from a pin.

Bits 23:21 **SAI4ASEL[2:0]**: Sub-Block A of SAI4 kernel clock source selection

Set and reset by software.

Caution: If the selected clock is the external clock and this clock is stopped, it will not be possible to switch to another clock. Refer to *Section : Clock switches and gating* for additional information.

000: **pll1_q_ck** clock selected as kernel peripheral clock (default after reset)
001: **pll2_p_ck** clock selected as kernel peripheral clock
010: **pll3_p_ck** clock selected as kernel peripheral clock
011: I2S_CKIN clock selected as kernel peripheral clock
100: **per_ck** clock selected as kernel peripheral clock
101: **spdifrx_symb_ck** clock selected as kernel peripheral clock
others: reserved, the kernel clock is disabled

Note: I2S_CKIN is an external clock taken from a pin.

Bits 20:18 Reserved, must be kept at reset value.

Bits 17:16 **ADCSEL[1:0]**: SAR ADC kernel clock source selection

Set and reset by software.
00: **pll2_p_ck** clock selected as kernel peripheral clock (default after reset)
01: **pll3_r_ck** clock selected as kernel peripheral clock
10: **per_ck** clock selected as kernel peripheral clock
others: reserved, the kernel clock is disabled

Bits 15:13 **LPTIM345SEL[2:0]**: LPTIM3,4,5 kernel clock source selection

Set and reset by software.
000: **rcc_pclk4** clock selected as kernel peripheral clock (default after reset)
001: **pll2_p_ck** clock selected as kernel peripheral clock
010: **pll3_r_ck** clock selected as kernel peripheral clock
011: **lse_ck** clock selected as kernel peripheral clock
100: **lsi_ck** clock selected as kernel peripheral clock
101: **per_ck** clock selected as kernel peripheral clock
others: reserved, the kernel clock is disabled

Bits 12:10 **LPTIM2SEL[2:0]**: LPTIM2 kernel clock source selection

Set and reset by software.
000: **rcc_pclk4** clock selected as kernel peripheral clock (default after reset)
001: **pll2_p_ck** clock selected as kernel peripheral clock
010: **pll3_r_ck** clock selected as kernel peripheral clock
011: **lse_ck** clock selected as kernel peripheral clock
100: **lsi_ck** clock selected as kernel peripheral clock
101: **per_ck** clock selected as kernel peripheral clock
others: reserved, the kernel clock is disabled

Bits 9:8 **I2C4SEL[1:0]**: I2C4 kernel clock source selection
Set and reset by software.
00: **rcc_pclk4** clock selected as kernel peripheral clock (default after reset)
01: **pll3_r_ck** clock selected as kernel peripheral clock
10: **hsi_ker_ck** clock selected as kernel peripheral clock
11: **csi_ker_ck** clock selected as kernel peripheral clock

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **LPUART1SEL[2:0]**: LPUART1 kernel clock source selection
Set and reset by software.
000: **rcc_pclk_d3** clock is selected as kernel peripheral clock (default after reset)
001: **pll2_q_ck** clock is selected as kernel peripheral clock
010: **pll3_q_ck** clock is selected as kernel peripheral clock
011: **hsi_ker_ck** clock is selected as kernel peripheral clock
100: **csi_ker_ck** clock is selected as kernel peripheral clock
101: **lse_ck** clock is selected as kernel peripheral clock
others: reserved, the kernel clock is disabled

8.7.22 RCC clock source interrupt enable register (RCC_CIER)

Address offset: 0x060

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	LSECSSIE	PLL3RDYIE	PLL2RDYIE	PLL1RDYIE	HSI48RDYIE	CSIRDYIE	HSERDYIE	HSIRDYIE	LSERDYIE	LSIRDYIE
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:10 Reserved, must be kept at reset value.

Bit 9 **LSECSSIE**: LSE clock security system Interrupt Enable

Set and reset by software to enable/disable interrupt caused by the Clock Security System on external 32 kHz oscillator.

0: LSE CSS interrupt disabled (default after reset)

1: LSE CSS interrupt enabled

Bit 8 **PLL3RDYIE**: PLL3 ready Interrupt Enable

Set and reset by software to enable/disable interrupt caused by PLL3 lock.

0: PLL3 lock interrupt disabled (default after reset)

1: PLL3 lock interrupt enabled

Bit 7 **PLL2RDYIE**: PLL2 ready Interrupt Enable

Set and reset by software to enable/disable interrupt caused by PLL2 lock.

0: PLL2 lock interrupt disabled (default after reset)

1: PLL2 lock interrupt enabled

Bit 6 **PLL1RDYIE**: PLL1 ready Interrupt Enable

Set and reset by software to enable/disable interrupt caused by PLL1 lock.

0: PLL1 lock interrupt disabled (default after reset)

1: PLL1 lock interrupt enabled

Bit 5 **HSI48RDYIE**: HSI48 ready Interrupt Enable

Set and reset by software to enable/disable interrupt caused by the HSI48 oscillator stabilization.

0: HSI48 ready interrupt disabled (default after reset)

1: HSI48 ready interrupt enabled

Bit 4 **CSIRDYIE**: CSI ready Interrupt Enable

Set and reset by software to enable/disable interrupt caused by the CSI oscillator stabilization.

0: CSI ready interrupt disabled (default after reset)

1: CSI ready interrupt enabled

Bit 3 **HSERDYIE**: HSE ready Interrupt Enable

Set and reset by software to enable/disable interrupt caused by the HSE oscillator stabilization.

0: HSE ready interrupt disabled (default after reset)

1: HSE ready interrupt enabled

Bit 2 **HSIRDYIE**: HSI ready Interrupt Enable
Set and reset by software to enable/disable interrupt caused by the HSI oscillator stabilization.
0: HSI ready interrupt disabled (default after reset)
1: HSI ready interrupt enabled

Bit 1 **LSERDYIE**: LSE ready Interrupt Enable
Set and reset by software to enable/disable interrupt caused by the LSE oscillator stabilization.
0: LSE ready interrupt disabled (default after reset)
1: LSE ready interrupt enabled

Bit 0 **LSIRDYIE**: LSI ready Interrupt Enable
Set and reset by software to enable/disable interrupt caused by the LSI oscillator stabilization.
0: LSI ready interrupt disabled (default after reset)
1: LSI ready interrupt enabled

8.7.23 RCC clock source interrupt flag register (RCC_CIFR)

Address offset: 0x64

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	HSECSSF	LSECSSF	PLL3RDYF	PLL2RDYF	PLL1RDYF	HSI48RDYF	CSIRDYF	HSERDYF	HSIRDYF	LSERDYF	LSIRDYF
					r	r	r	r	r	r	r	r	r	r	r

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **HSECSSF**: HSE clock security system Interrupt Flag
Reset by software by writing HSECSSC bit.
Set by hardware in case of HSE clock failure.
0: No clock security interrupt caused by HSE clock failure (default after reset)
1: Clock security interrupt caused by HSE clock failure

Bit 9 **LSECSSF**: LSE clock security system Interrupt Flag
Reset by software by writing LSECSSC bit.
Set by hardware when a failure is detected on the external 32 kHz oscillator and LSECSSIE is set.
0: No failure detected on the external 32 kHz oscillator (default after reset)
1: A failure is detected on the external 32 kHz oscillator

Bit 8 **PLL3RDYF**: PLL3 ready Interrupt Flag
Reset by software by writing PLL3RDYC bit.
Set by hardware when the PLL3 locks and PLL3RDYIE is set.
0: No clock ready interrupt caused by PLL3 lock (default after reset)
1: Clock ready interrupt caused by PLL3 lock

Bit 7 **PLL2RDYF**: PLL2 ready Interrupt Flag
Reset by software by writing PLL2RDYC bit.
Set by hardware when the PLL2 locks and PLL2RDYIE is set.
0: No clock ready interrupt caused by PLL2 lock (default after reset)
1: Clock ready interrupt caused by PLL2 lock

Bit 6 **PLL1RDYF**: PLL1 ready Interrupt Flag
Reset by software by writing PLL1RDYC bit.
Set by hardware when the PLL1 locks and PLL1RDYIE is set.
0: No clock ready interrupt caused by PLL1 lock (default after reset)
1: Clock ready interrupt caused by PLL1 lock

Bit 5 **HSI48RDYF**: HSI48 ready Interrupt Flag
Reset by software by writing HSI48RDYC bit.
Set by hardware when the HSI48 clock becomes stable and HSI48RDYIE is set.
0: No clock ready interrupt caused by the HSI48 oscillator (default after reset)
1: Clock ready interrupt caused by the HSI48 oscillator

Bit 4 **CSIRDYF**: CSI ready Interrupt Flag
Reset by software by writing CSIRDYC bit.
Set by hardware when the CSI clock becomes stable and CSIRDYIE is set.
0: No clock ready interrupt caused by the CSI (default after reset)
1: Clock ready interrupt caused by the CSI

Bit 3 **HSERDYF**: HSE ready Interrupt Flag
Reset by software by writing HSERDYC bit.
Set by hardware when the HSE clock becomes stable and HSERDYIE is set.
0: No clock ready interrupt caused by the HSE (default after reset)
1: Clock ready interrupt caused by the HSE

Bit 2 **HSIRDYF**: HSI ready Interrupt Flag
Reset by software by writing HSIRDYC bit.
Set by hardware when the HSI clock becomes stable and HSIRDYIE is set.
0: No clock ready interrupt caused by the HSI (default after reset)
1: Clock ready interrupt caused by the HSI

Bit 1 **LSERDYF**: LSE ready Interrupt Flag
Reset by software by writing LSERDYC bit.
Set by hardware when the LSE clock becomes stable and LSERDYIE is set.
0: No clock ready interrupt caused by the LSE (default after reset)
1: Clock ready interrupt caused by the LSE

Bit 0 **LSIRDYF**: LSI ready Interrupt Flag
Reset by software by writing LSIRDYC bit.
Set by hardware when the LSI clock becomes stable and LSIRDYIE is set.
0: No clock ready interrupt caused by the LSI (default after reset)
1: Clock ready interrupt caused by the LSI

8.7.24 RCC clock source interrupt clear register (RCC_CICR)

Address offset: 0x68

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	HSECSSC	LSECSSC	PLL3RDYC	PLL2RDYC	PLL1RDYC	HSI48RDYC	CSIRDYC	HSERDYC	HSIRDYC	LSERDYC	LSIRDYC
					rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **HSECSSC**: HSE clock security system Interrupt Clear
Set by software to clear HSECSSF.
Reset by hardware when clear done.
0: HSECSSF no effect (default after reset)
1: HSECSSF cleared

Bit 9 **LSECSSC**: LSE clock security system Interrupt Clear
Set by software to clear LSECSSF.
Reset by hardware when clear done.
0: LSECSSF no effect (default after reset)
1: LSECSSF cleared

Bit 8 **PLL3RDYC**: PLL3 ready Interrupt Clear
Set by software to clear PLL3RDYF.
Reset by hardware when clear done.
0: PLL3RDYF no effect (default after reset)
1: PLL3RDYF cleared

Bit 7 **PLL2RDYC**: PLL2 ready Interrupt Clear
Set by software to clear PLL2RDYF.
Reset by hardware when clear done.
0: PLL2RDYF no effect (default after reset)
1: PLL2RDYF cleared

Bit 6 **PLL1RDYC**: PLL1 ready Interrupt Clear
Set by software to clear PLL1RDYF.
Reset by hardware when clear done.
0: PLL1RDYF no effect (default after reset)
1: PLL1RDYF cleared

Bit 5 **HSI48RDYC**: HSI48 ready Interrupt Clear
Set by software to clear HSI48RDYF.
Reset by hardware when clear done.
0: HSI48RDYF no effect (default after reset)
1: HSI48RDYF cleared

Bit 4 **CSIRDYC**: CSI ready Interrupt Clear
Set by software to clear CSIRDYF.
Reset by hardware when clear done.
0: CSIRDYF no effect (default after reset)
1: CSIRDYF cleared

Bit 3 **HSERDYC**: HSE ready Interrupt Clear
Set by software to clear HSERDYF.
Reset by hardware when clear done.
0: HSERDYF no effect (default after reset)
1: HSERDYF cleared

Bit 2 **HSIRDYC**: HSI ready Interrupt Clear
Set by software to clear HSIRDYF.
Reset by hardware when clear done.
0: HSIRDYF no effect (default after reset)
1: HSIRDYF cleared

Bit 1 **LSERDYC**: LSE ready Interrupt Clear
Set by software to clear LSERDYF.
Reset by hardware when clear done.
0: LSERDYF no effect (default after reset)
1: LSERDYF cleared

Bit 0 **LSIRDYC**: LSI ready Interrupt Clear
Set by software to clear LSIRDYF.
Reset by hardware when clear done.
0: LSIRDYF no effect (default after reset)
1: LSIRDYF cleared

8.7.25 RCC backup domain control register (RCC_BDCR)

Address offset: 0x070

Backup domain reset value: 0x0000 0000

Access: 0 ≤ wait state ≤ 7, word, half-word and byte access. Wait states are inserted in case of successive accesses to this register.

After a system reset, the RCC_BDCR register is write-protected. To modify this register, the DBP bit in the PWR control register 1 (PWR_CR1) has to be set to 1. RCC_BDCR bits are only reset after a backup domain reset (see *Section 8.4.6: Backup domain reset*). Any other internal or external reset will not have any effect on these bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BDRST
															rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RTCEN	Res.	Res.	Res.	Res.	Res.	RTCSEL[1:0]		Res.	LSECSSD	LSECSSON	LSEDRV[1:0]		LSEBYP	LSERDY	LSEON
rw						rwo	rwo		r	rs	rw	rw	rw	r	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **BDRST:** Backup domain software reset
Set and reset by software.
0: Reset not activated (default after backup domain reset)
1: Resets the entire VSW domain

Bit 15 **RTCEN**: RTC clock enable
Set and reset by software.
0: **rtc_ck** clock is disabled (default after backup domain reset)
1: **rtc_ck** clock enabled

Bits 14:10 Reserved, must be kept at reset value.

Bits 9:8 **RTCSEL[1:0]**:RTC clock source selection
Set by software to select the clock source for the RTC. These bits can be written only one time (except in case of failure detection on LSE). These bits must be written before LSECSSON is enabled. The BDRST bit can be used to reset them, then it can be written one time again.
If HSE is selected as RTC clock: this clock is lost when the system is in Stop mode or in case of a pin reset (NRST).
00: No clock (default after backup domain reset)
01: LSE clock used as RTC clock
10: LSI clock used as RTC clock
11: HSE clock divided by RTCPRE value is used as RTC clock

Bit 7 Reserved, must be kept at reset value.

Bit 6 **LSECSSD**: LSE clock security system failure detection

Set by hardware to indicate when a failure has been detected by the Clock Security System on the external 32 kHz oscillator.

0: No failure detected on 32 kHz oscillator (default after backup domain reset)

1: Failure detected on 32 kHz oscillator

Bit 5 **LSECSSON**: LSE clock security system enable

Set by software to enable the Clock Security System on 32 kHz oscillator.

LSECSSON must be enabled after LSE is enabled (LSEON enabled) and ready (LSERDY set by hardware), and after RTCSEL is selected.

Once enabled this bit cannot be disabled, except after a LSE failure detection (LSECSSD = 1). In that case the software **must** disable LSECSSON.

0: Clock Security System on 32 kHz oscillator OFF (default after backup domain reset)

1: Clock Security System on 32 kHz oscillator ON

Bits 4:3 **LSEDRV[1:0]**: LSE oscillator driving capability

Set by software to select the driving capability of the LSE oscillator.

00: Lowest drive (default after backup domain reset)

01: Medium low drive

10: Medium high drive

11: Highest drive

Bit 2 **LSEBYP**: LSE oscillator bypass

Set and reset by software to bypass oscillator in debug mode. This bit must not be written when the LSE is enabled (by LSEON) or ready (LSERDY = 1)

0: LSE oscillator not bypassed (default after backup domain reset)

1: LSE oscillator bypassed

Bit 1 **LSERDY**: LSE oscillator ready

Set and reset by hardware to indicate when the LSE is stable. This bit needs 6 cycles of **lse_ck** clock to fall down after LSEON has been set to 0.

0: LSE oscillator not ready (default after backup domain reset)

1: LSE oscillator ready

Bit 0 **LSEON**: LSE oscillator enabled

Set and reset by software.

0: LSE oscillator OFF (default after backup domain reset)

1: LSE oscillator ON

8.7.26 RCC Clock Control and Status Register (RCC_CSR)

Address offset: 0x074

Reset value: 0x0000 0000

Access: 0 ≤ wait state ≤ 7, word, half-word and byte access

Wait states are inserted in case of successive accesses to this register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LSIRDY	LSION
														r	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **LSIRDY**: LSI oscillator ready

Set and reset by hardware to indicate when the Low Speed Internal RC oscillator is stable.
This bit needs 3 cycles of **lsi_ck** clock to fall down after LSION has been set to 0.
This bit can be set even when LSION is not enabled if there is a request for LSI clock by the Clock Security System on LSE or by the Low Speed Watchdog or by the RTC.
0: LSI clock is not ready (default after reset)
1: LSI clock is ready

Bit 0 **LSION**: LSI oscillator enable

Set and reset by software.
0: LSI is OFF (default after reset)
1: LSI is ON

8.7.27 RCC AHB3 reset register (RCC_AHB3RSTR)

Address offset: 0x07C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CPURST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OTFD2RST	OTFD1RST	IOMNGRRST	Res.	OCTOSPI2RST	Res.	Res.	SDMMC1RST
rs								rw	rw	rw		rw			rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	OCTOSPI1RST	Res.	FMCRST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DMA2DRST	Res.	Res.	Res.	MDMARST
	rw		rw								rw				rw

Bit 31 **CPURST**: CPU reset
Set and reset by software.
0: does not reset the CPU (default after reset)
1: resets the CPU

Bits 30:24 Reserved, must be kept at reset value.

Bit 23 **OTFD2RST**: OTFDEC2 reset
Set and reset by software.
0: does not reset OTFDEC2 (default after reset)
1: resets OTFDEC2

Bit 22 **OTFD1RST**: OTFDEC1 reset
Set and reset by software.
0: does not reset OTFDEC1 (default after reset)
1: resets OTFDEC1

Bit 21 **IOMNGRRST**: OCTOSPI I/O manager reset
Set and reset by software.
0: does not reset the OCTOSPI I/O manager (default after reset)
1: resets the OCTOSPI I/O manager

Bit 20 Reserved, must be kept at reset value.

Bit 19 **OCTOSPI2IRST**: OCTOSPI2 and OCTOSPI2 delay block reset
Set and reset by software.
0: does not reset OCTOSPI2 and OCTOSPI2 delay block (default after reset)
1: resets OCTOSPI2 and OCTOSPI2 delay block

Bits 18:17 Reserved, must be kept at reset value.

Bit 16 **SDMMC1RST**: SDMMC1 and SDMMC1 delay block reset
Set and reset by software.
0: does not reset SDMMC1 and SDMMC1 Delay block (default after reset)
1: resets SDMMC1 and SDMMC1 Delay block

Bit 15 Reserved, must be kept at reset value.

Bit 14 **OCTOSPI1RST**: OCTOSPI1 and OCTOSPI1 delay block reset
Set and reset by software.
0: does not reset OCTOSPI1 and OCTOSPI1 delay block (default after reset)
1: resets OCTOSPI1 and OCTOSPI1 delay block

Bit 13 Reserved, must be kept at reset value.

Bit 12 **FMCRST**: FMC block reset
Set and reset by software.
0: does not reset FMC block (default after reset)
1: resets FMC block

Bits 11:5 Reserved, must be kept at reset value.

Bit 4 **DMA2DRST**: DMA2D block reset
Set and reset by software.
0: does not reset DMA2D block (default after reset)
1: resets DMA2D block

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **MDMARST**: MDMA block reset
Set and reset by software.
0: does not reset MDMA block (default after reset)
1: resets MDMA block

8.7.28 RCC AHB1 peripheral reset register(RCC_AHB1RSTR)

Address offset: 0x080

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	USB1OTGRST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
						rw									

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETH1MACRST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADC12RST	Res.	Res.	Res.	DMA2RST	DMA1RST
rw										rw				rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **USB1OTGRST**: USB1OTG (OTG_HS1) block reset
Set and reset by software.
0: does not reset USB1OTG block (default after reset)
1: resets USB1OTG block

Bits 24:16 Reserved, must be kept at reset value.

Bit 15 **ETH1MACRST**: ETH1MAC block reset
Set and reset by software.
0: does not reset ETH1MAC block (default after reset)
1: resets ETH1MAC block

Bits 14:6 Reserved, must be kept at reset value.

Bit 5 **ADC12RST**: ADC1 and 2 block reset
Set and reset by software.
0: does not reset ADC1 and 2 block (default after reset)
1: resets ADC1 and 2 block

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **DMA2RST**: DMA2 block reset
Set and reset by software.
0: does not reset DMA2 block (default after reset)
1: resets DMA2 block

Bit 0 **DMA1RST**: DMA1 block reset
Set and reset by software.
0: does not reset DMA1 block (default after reset)
1: resets DMA1 block

8.7.29 RCC AHB2 peripheral reset register (RCC_AHB2RSTR)

Address offset: 0x084

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CORDICRST	FMACRST
														rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	SDMMC2RST	Res.	Res.	RNGRST	HASHRST	CRYPTRST	Res.	Res.	Res.	DCMI_PSSIRST
						rw			rw	rw	rw				rw

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **CORDICRST**: CORDIC coprocessor block reset
Set and reset by software.
0: does not reset CORDIC block (default after reset)
1: resets CORDIC block

Bit 16 **FMACRST**: FMAC reset
Set and reset by software.
0: does not reset the FMAC (default after reset)
1: resets the FMAC

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **SDMMC2RST**: SDMMC2 and SDMMC2 delay block reset
Set and reset by software.
0: does not reset SDMMC2 and SDMMC2 Delay block (default after reset)
1: resets SDMMC2 and SDMMC2 Delay block

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **RNGRST**: Random Number Generator block reset
Set and reset by software.
0: does not reset RNG block (default after reset)
1: resets RNG block

Bit 5 **HASHRST**: Hash block reset
Set and reset by software.
0: does not reset hash block (default after reset)
1: resets hash block

Bit 4 **CRYPTRST**: Cryptography block reset
Set and reset by software.
0: does not reset cryptography block (default after reset)
1: resets cryptography block

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **DCMI_PSSIRST**: Digital camera interface block reset (DCMI or PSSI, depending which peripheral is active)
Set and reset by software.
0: does not reset the DCMI/PSSI peripheral (default after reset)
1: resets the DCMI/PSSI peripheral

8.7.30 RCC AHB4 peripheral reset register (RCC_AHB4RSTR)

Address offset: 0x088

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	HSEMRST	ADC3RST	Res.	Res.	BDMARST	Res.	CRCRST	Res.	Res.	Res.
						rw	rw			rw		rw			

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	GPIOKRST	GPIOJRST	Res.	GPIOHRST	GPIOGRST	GPIOFRST	GPIOERST	GPIODRST	GPIOCRST	GPIOBRST	GPIOARST
					rw	rw		rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **HSEMRST**: HSEM block reset
Set and reset by software.
0: does not reset the HSEM block (default after reset)
1: resets the HSEM block

Bit 24 **ADC3RST**: ADC3 block reset
Set and reset by software.
0: does not reset the ADC3 block (default after reset)
1: resets the ADC3 block

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **BDMARST**: BDMA block reset
Set and reset by software.
0: does not reset the BDMA block (default after reset)
1: resets the BDMA block

Bit 20 Reserved, must be kept at reset value.

Bit 19 **CRCRST**: CRC block reset
Set and reset by software.
0: does not reset the CRC block (default after reset)
1: resets the CRC block

Bits 18:11 Reserved, must be kept at reset value.

Bit 10 **GPIOKRST**: GPIOK block reset
Set and reset by software.
0: does not reset the GPIOK block (default after reset)
1: resets the GPIOK block

Bit 9 **GPIOJRST**: GPIOJ block reset
Set and reset by software.
0: does not reset the GPIOJ block (default after reset)
1: resets the GPIOJ block

Bit 8 Reserved, must be kept at reset value.

Bit 7 **GPIOHRST**: GPIOH block reset
Set and reset by software.
0: does not reset the GPIOH block (default after reset)
1: resets the GPIOH block

Bit 6 **GPIOGRST**: GPIOG block reset
Set and reset by software.
0: does not reset the GPIOG block (default after reset)
1: resets the GPIOG block

Bit 5 **GPIOFRST**: GPIOF block reset
Set and reset by software.
0: does not reset the GPIOF block (default after reset)
1: resets the GPIOF block

Bit 4 **GPIOERST**: GPIOE block reset
Set and reset by software.
0: does not reset the GPIOE block (default after reset)
1: resets the GPIOE block

Bit 3 **GPIODRST**: GPIOD block reset
Set and reset by software.
0: does not reset the GPIOD block (default after reset)
1: resets the GPIOD block

Bit 2 **GPIOCRST**: GPIOC block reset
Set and reset by software.
0: does not reset the GPIOC block (default after reset)
1: resets the GPIOC block

Bit 1 **GPIOBRST**: GPIOB block reset
Set and reset by software.
0: does not reset the GPIOB block (default after reset)
1: resets the GPIOB block

Bit 0 **GPIOARST**: GPIOA block reset
Set and reset by software.
0: does not reset the GPIOA block (default after reset)
1: resets the GPIOA block

8.7.31 RCC APB3 peripheral reset register (RCC_APB3RSTR)

Address offset: 0x08C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LTDCRST	Res.	Res.	Res.
												rw			

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **LTDCRST**: LTDC block reset
Set and reset by software.
0: does not reset the LTDC block (default after reset)
1: resets the LTDC block

Bits 2:0 Reserved, must be kept at reset value.

8.7.32 RCC APB1 peripheral reset register (RCC_APB1LRSTR)

Address offset: 0x090

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UART8RST	UART7RST	DAC12RST	Res.	CECRST	Res.	I2C5RST	Res.	I2C3RST	I2C2RST	I2C1RST	UART5RST	UART4RST	USART3RST	USART2RST	SPDIFRXRST
rw	rw	rw		rw		rw		rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI3RST	SPI2RST	Res.	Res.	Res.	Res.	LPTIM1RST	TIM14RST	TIM13RST	TIM12RST	TIM7RST	TIM6RST	TIM5RST	TIM4RST	TIM3RST	TIM2RST
rw	rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UART8RST**: UART8 block reset
Set and reset by software.
0: does not reset the UART8 block (default after reset)
1: resets the UART8 block

Bit 30 **UART7RST**: UART7 block reset
Set and reset by software.
0: does not reset the UART7 block (default after reset)
1: resets the UART7 block

Bit 29 **DAC12RST**: DAC1 and 2 Blocks Reset
Set and reset by software.
0: does not reset the DAC1 and 2 blocks (default after reset)
1: resets the DAC1 and 2 blocks

Bit 28 Reserved, must be kept at reset value.

Bit 27 **CECRST**: HDMI-CEC block reset
Set and reset by software.
0: does not reset the HDMI-CEC block (default after reset)
1: resets the HDMI-CEC block

Bit 26 Reserved, must be kept at reset value.

Bit 25 **I2C5RST**: I2C5 block reset
Set and reset by software.
0: does not reset the I2C5 block (default after reset)
1: resets the I2C5 block

Bit 24 Reserved, must be kept at reset value.

Bit 23 **I2C3RST**: I2C3 block reset
Set and reset by software.
0: does not reset the I2C3 block (default after reset)
1: resets the I2C3 block

Bit 22 **I2C2RST**: I2C2 block reset
Set and reset by software.
0: does not reset the I2C2 block (default after reset)
1: resets the I2C2 block

Bit 21 **I2C1RST**: I2C1 block reset
Set and reset by software.
0: does not reset the I2C1 block (default after reset)
1: resets the I2C1 block

Bit 20 **UART5RST**: UART5 block reset
Set and reset by software.
0: does not reset the UART5 block (default after reset)
1: resets the UART5 block

Bit 19 **UART4RST**: UART4 block reset
Set and reset by software.
0: does not reset the UART4 block (default after reset)
1: resets the UART4 block

Bit 18 **USART3RST**: USART3 block reset
Set and reset by software.
0: does not reset the USART3 block (default after reset)
1: resets the USART3 block

Bit 17 **USART2RST**: USART2 block reset
Set and reset by software.
0: does not reset the USART2 block (default after reset)
1: resets the USART2 block

Bit 16 **SPDIFRXRST**: SPDIFRX block reset
Set and reset by software.
0: does not reset the SPDIFRX block (default after reset)
1: resets the SPDIFRX block

Bit 15 **SPI3RST**: SPI3 block reset
Set and reset by software.
0: does not reset the SPI3 block (default after reset)
1: resets the SPI3 block

Bit 14 **SPI2RST**: SPI2 block reset
Set and reset by software.
0: does not reset the SPI2 block (default after reset)
1: resets the SPI2 block

Bits 13:10 Reserved, must be kept at reset value.

Bit 9 **LPTIM1RST**: LPTIM1 block reset
Set and reset by software.
0: does not reset the LPTIM1 block (default after reset)
1: resets the LPTIM1 block

Bit 8 **TIM14RST**: TIM14 block reset
Set and reset by software.
0: does not reset the TIM14 block (default after reset)
1: resets the TIM14 block

Bit 7 **TIM13RST**: TIM13 block reset
Set and reset by software.
0: does not reset the TIM13 block (default after reset)
1: resets the TIM13 block

Bit 6 **TIM12RST**: TIM12 block reset
Set and reset by software.
0: does not reset the TIM12 block (default after reset)
1: resets the TIM12 block

Bit 5 **TIM7RST**: TIM7 block reset
Set and reset by software.
0: does not reset the TIM7 block (default after reset)
1: resets the TIM7 block

Bit 4 **TIM6RST**: TIM6 block reset
Set and reset by software.
0: does not reset the TIM6 block (default after reset)
1: resets the TIM6 block

Bit 3 **TIM5RST**: TIM5 block reset
Set and reset by software.
0: does not reset the TIM5 block (default after reset)
1: resets the TIM5 block

Bit 2 **TIM4RST**: TIM4 block reset
Set and reset by software.
0: does not reset the TIM4 block (default after reset)
1: resets the TIM4 block

Bit 1 **TIM3RST**: TIM3 block reset
Set and reset by software.
0: does not reset the TIM3 block (default after reset)
1: resets the TIM3 block

Bit 0 **TIM2RST**: TIM2 block reset
Set and reset by software.
0: does not reset the TIM2 block (default after reset)
1: resets the TIM2 block

8.7.33 RCC APB1 peripheral reset register (RCC_APB1HRSTR)

Address offset: 0x094

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	TIM24RST	TIM23RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
						rw	rw								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	FDCANRST	Res.	Res.	MDIOSRST	OPAMPRST	Res.	SWPMIRST	CRSRST	Res.
							rw			rw	rw		rw	rw	

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **TIM24RST**: TIM24 block reset
Set and reset by software.
0: does not reset the TIM24 block (default after reset)
1: resets the TIM24 block

Bit 24 **TIM23RST**: TIM23 block reset
Set and reset by software.
0: does not reset the TIM23 block (default after reset)
1: resets the TIM23 block

Bits 23:9 Reserved, must be kept at reset value.

Bit 8 **FDCANRST**: FDCAN block reset
Set and reset by software.
0: does not reset the FDCAN block (default after reset)
1: resets the FDCAN block

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **MDIOSRST**: MDIOS block reset
Set and reset by software.
0: does not reset the MDIOS block (default after reset)
1: resets the MDIOS block

Bit 4 **OPAMPRST**: OPAMP block reset
Set and reset by software.
0: does not reset the OPAMP block (default after reset)
1: resets the OPAMP block

Bit 3 Reserved, must be kept at reset value.

Bit 2 **SWPMIRST**: SWPMI block reset
Set and reset by software.
0: does not reset the SWPMI block (default after reset)
1: resets the SWPMI block

Bit 1 **CRSRST**: Clock Recovery System reset
Set and reset by software.
0: does not reset CRS (default after reset)
1: resets CRS

Bit 0 Reserved, must be kept at reset value.

8.7.34 RCC APB2 peripheral reset register (RCC_APB2RSTR)

Address offset: 0x098

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	DFSDM1RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SAI1RST	Res.	SPI5RST	Res.	TIM17RST	TIM16RST	TIM15RST
	rw								rw		rw		rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	SPI4RST	SPI1RST	Res.	Res.	Res.	Res.	USART10RST	UART9RST	USART6RST	USART1RST	Res.	Res.	TIM8RST	TIM1RST
		rw	rw					rw	rw	rw	rw			rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **DFSDM1RST**: DFSDM1 block reset
Set and reset by software.
0: does not reset DFSDM1 block (default after reset)
1: resets DFSDM1 block

Bits 29:23 Reserved, must be kept at reset value.

Bit 22 **SAI1RST**: SAI1 block reset
Set and reset by software.
0: does not reset the SAI1 (default after reset)
1: resets the SAI1

Bit 21 Reserved, must be kept at reset value.

Bit 20 **SPI5RST**: SPI5 block reset
Set and reset by software.
0: does not reset the SPI5 block (default after reset)
1: resets the SPI5 block

Bit 19 Reserved, must be kept at reset value.

Bit 18 **TIM17RST**: TIM17 block reset
Set and reset by software.
0: does not reset the TIM17 block (default after reset)
1: resets the TIM17 block

Bit 17 **TIM16RST**: TIM16 block reset
Set and reset by software.
0: does not reset the TIM16 block (default after reset)
1: resets the TIM16 block

Bit 16 **TIM15RST**: TIM15 block reset
Set and reset by software.
0: does not reset the TIM15 block (default after reset)
1: resets the TIM15 block

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **SPI4RST**: SPI4 block reset
Set and reset by software.
0: does not reset the SPI4 block (default after reset)
1: resets the SPI4 block

Bit 12 **SPI1RST**: SPI1 block reset
Set and reset by software.
0: does not reset the SPI1 block (default after reset)
1: resets the SPI1 block

Bits 11:8 Reserved, must be kept at reset value.

Bit 7 **USART10RST**: USART10 block reset
Set and reset by software.
0: does not reset the USART10 block (default after reset)
1: resets the USART10 block

Bit 6 **UART9RST**: UART9 block reset
Set and reset by software.
0: does not reset the UART9 block (default after reset)
1: resets the UART9 block

Bit 5 **USART6RST**: USART6 block reset
Set and reset by software.
0: does not reset the USART6 block (default after reset)
1: resets the USART6 block

Bit 4 **USART1RST**: USART1 block reset
Set and reset by software.
0: does not reset the USART1 block (default after reset)
1: resets the USART1 block

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **TIM8RST**: TIM8 block reset
Set and reset by software.
0: does not reset the TIM8 block (default after reset)
1: resets the TIM8 block

Bit 0 **TIM1RST**: TIM1 block reset
Set and reset by software.
0: does not reset the TIM1 block (default after reset)
1: resets the TIM1 block

8.7.35 RCC APB4 peripheral reset register (RCC_APB4RSTR)

Address offset: 0x09C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	DTSRST	Res.	Res.	Res.	Res.	SAI4RST	Res.	Res.	Res.	Res.	Res.
					rw					rw					

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VREFRST	COMP12RST	Res.	LPTIM5RST	LPTIM4RST	LPTIM3RST	LPTIM2RST	Res.	I2C4RST	Res.	SPI6RST	Res.	LPUART1RST	Res.	SYSCFGRST	Res.
rw	rw		rw	rw	rw	rw		rw		rw		rw		rw	

Bits 31:26 Reserved, must be kept at reset value.

Bit 26 **DTSRST**: Digital temperature sensor block reset
Set and reset by software.
0: does not reset the digital temperature sensor block (default after reset)
1: resets the digital temperature sensor block

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **SAI4RST**: SAI4 block reset
Set and reset by software.
0: does not reset the SAI4 block (default after reset)
1: resets the SAI4 block

Bits 20:16 Reserved, must be kept at reset value.

Bit 15 **VREFRST**: VREFBUF block reset
Set and reset by software.
0: does not reset the VREF block (default after reset)
1: resets the VREF block

Bit 14 **COMP12RST**: COMP12 Blocks Reset
Set and reset by software.
0: does not reset the COMP1 and 2 blocks (default after reset)
1: resets the COMP1 and 2 blocks

Bit 13 Reserved, must be kept at reset value.

Bit 12 **LPTIM5RST**: LPTIM5 block reset
Set and reset by software.
0: does not reset the LPTIM5 block (default after reset)
1: resets the LPTIM5 block

Bit 11 **LPTIM4RST**: LPTIM4 block reset
Set and reset by software.
0: does not reset the LPTIM4 block (default after reset)
1: resets the LPTIM4 block

Bit 10 **LPTIM3RST**: LPTIM3 block reset
Set and reset by software.
0: does not reset the LPTIM3 block (default after reset)
1: resets the LPTIM3 block

Bit 9 **LPTIM2RST**: LPTIM2 block reset
Set and reset by software.
0: does not reset the LPTIM2 block (default after reset)
1: resets the LPTIM2 block

Bit 8 Reserved, must be kept at reset value.

Bit 7 **I2C4RST**: I2C4 block reset
Set and reset by software.
0: does not reset the I2C4 block (default after reset)
1: resets the I2C4 block

Bit 6 Reserved, must be kept at reset value.

Bit 5 **SPI6RST**: SPI6 block reset
Set and reset by software.
0: does not reset the SPI6 block (default after reset)
1: resets the SPI6 block

Bit 4 Reserved, must be kept at reset value.

Bit 3 **LPUART1RST**: LPUART1 block reset
Set and reset by software.
0: does not reset the LPUART1 block (default after reset)
1: resets the LPUART1 block

Bit 2 Reserved, must be kept at reset value.

Bit 1 **SYSCFGRST**: SYSCFG block reset
Set and reset by software.
0: does not reset the SYSCFG block (default after reset)
1: resets the SYSCFG block

Bit 0 Reserved, must be kept at reset value.

8.7.36 RCC global control register (RCC_GCR)

Address offset: 0x0A0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WW1RSC
															w

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **WW1RSC**: WWDG1 reset scope control

This bit can be set by software but is cleared by hardware during a system reset
In order to work properly, before enabling the WWDG1, this bit must be set to 1.

8.7.37 RCC D3 Autonomous mode register (RCC_D3AMR)

The Autonomous mode allows providing the peripheral clocks to peripherals located in D3, even if the CPU is in CStop mode. When a peripheral is enabled, and has its autonomous bit enabled, it receives its peripheral clocks according to D3 domain state, if the CPU is in CStop mode.

Address offset: 0x0A8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	SRAM4AMEN	BKPRAMAMEN	Res.	DTSAMEN	Res.	ADC3AMEN	Res.	Res.	SAI4AMEN	Res.	CRCAMEN	Res.	Res.	RTCAMEN
		rw	rw		rw		rw			rw		rw			rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VREFAMEN	COMP12AMEN	Res.	LPTIM5AMEN	LPTIM4AMEN	LPTIM3AMEN	LPTIM2AMEN	Res.	I2C4AMEN	Res.	SPI6AMEN	Res.	LPUART1AMEN	Res.	Res.	BDMAAMEN
rw	rw		rw	rw	rw	rw		rw		rw		rw			rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **SRAM4AMEN**: SRAM4 Autonomous mode enable
Set and reset by software.
0: SRAM4 clock is disabled when the CPU is in CStop (default after reset)
1: SRAM4 peripheral bus clock enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bit 28 **BKPRAMAMEN**: Backup RAM Autonomous mode enable
Set and reset by software.
0: Backup RAM clock is disabled when the CPU is in CStop (default after reset)
1: Backup RAM clock enabling is controlled by D3 domain state.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bit 27 Reserved, must be kept at reset value.

Bit 26 **DTSAMEN**: Digital temperature sensor Autonomous mode enable
Set and reset by software.
0: Digital temperature sensor peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: Digital temperature sensor peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bits 26:25 Reserved, must be kept at reset value.

Bit 24 **ADC3AMEN**: ADC3 Autonomous mode enable
Set and reset by software.
0: ADC3 peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: ADC3 peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **SAI4AMEN**: SAI4 Autonomous mode enable
Set and reset by software.
0: SAI4 peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: SAI4 peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bit 20 Reserved, must be kept at reset value.

Bit 19 **CRCAMEN**: CRC Autonomous mode enable
Set and reset by software.
0: CRC peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: CRC peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bits 18:17 Reserved, must be kept at reset value.

Bit 16 **RTCAMEN**: RTC Autonomous mode enable
Set and reset by software.
0: RTC peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: RTC peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bit 15 **VREFAMEN**: VREF Autonomous mode enable
Set and reset by software.
0: VREF peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: VREF peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bit 14 **COMP12AMEN**: COMP12 Autonomous mode enable
Set and reset by software.
0: COMP12 peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: COMP12 peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bit 13 Reserved, must be kept at reset value.

Bit 12 **LPTIM5AMEN**: LPTIM5 Autonomous mode enable
Set and reset by software.
0: LPTIM5 peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: LPTIM5 peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bit 11 **LPTIM4AMEN**: LPTIM4 Autonomous mode enable
Set and reset by software.
0: LPTIM4 peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: LPTIM4 peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bit 10 **LPTIM3AMEN**: LPTIM3 Autonomous mode enable
Set and reset by software.
0: LPTIM3 peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: LPTIM3 peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bit 9 **LPTIM2AMEN**: LPTIM2 Autonomous mode enable
Set and reset by software.
0: LPTIM2 peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: LPTIM2 peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bit 8 Reserved, must be kept at reset value.

Bit 7 **I2C4AMEN**: I2C4 Autonomous mode enable
Set and reset by software.
0: I2C4 peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: I2C4 peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bit 6 Reserved, must be kept at reset value.

Bit 5 **SPI6AMEN**: SPI6 Autonomous mode enable
Set and reset by software.
0: SPI6 peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: SPI6 peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bit 4 Reserved, must be kept at reset value.

Bit 3 **LPUART1AMEN**: LPUART1 Autonomous mode enable
Set and reset by software.
0: LPUART1 peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: LPUART1 peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

Bits 2:1 Reserved, must be kept at reset value.

Bit 0 **BDMAAMEN**: BDMA and DMAMUX Autonomous mode enable
Set and reset by software.
0: BDMA and DMAMUX peripheral clocks are disabled when the CPU is in CStop (default after reset)
1: BDMA and DMAMUX peripheral clocks enabled when D3 domain is in DRun.
Refer to *Section 8.5.11: Peripheral clock gating control* for additional information

8.7.38 RCC reset status register (RCC_RSR)

This register can be accessed via two different offset address.

Table 61. RCC_RSR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_RSR	0x0D0	0x00FA 0000 (1)
RCC_C1_RSR	0x130	

1. Reset by power-on reset only

Access: 0 ≤ wait state ≤ 7, word, half-word and byte access. Wait states are inserted in case of successive accesses to this register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	LPWRRSTF	Res.	WWDG1RSTF	Res.	IWDG1RSTF	Res.	SFTRSTF	PORRSTF	PINRSTF	BORRSTF	D2RSTF	D1RSTF	Res.	CPURSTF	RMVF
	r		r		r		r	r	r	r	r	r		r	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bit 31 Reserved, must be kept at reset value.

Bit 30 **LPWRRSTF**: Reset due to illegal D1 DStandby or CPU CStop flag
Reset by software by writing the RMVF bit.
Set by hardware when D1 domain goes erroneously in DStandby or when CPU goes erroneously in CStop.
0: No illegal reset occurred (default after power-on reset)
1: Illegal D1 DStandby or CPU CStop reset occurred

Bit 29 Reserved, must be kept at reset value.

Bit 28 **WWDG1RSTF**: Window Watchdog reset flag
Reset by software by writing the RMVF bit.
Set by hardware when a window watchdog reset occurs.
0: No window watchdog reset occurred from WWDG1 (default after power-on reset)
1: window watchdog reset occurred from WWDG1

Bit 27 Reserved, must be kept at reset value.

Bit 26 **IWDG1RSTF**: Independent Watchdog reset flag
Reset by software by writing the RMVF bit.
Set by hardware when an independent watchdog reset occurs.
0: No independent watchdog reset occurred (default after power-on reset)
1: Independent watchdog reset occurred

Bit 25 Reserved, must be kept at reset value.

Bit 24 **SFTRSTF**: System reset from CPU reset flag
Reset by software by writing the RMVF bit.
Set by hardware when the system reset is due to CPU.The CPU can generate a system reset by writing SYSRESETREQ bit of AIRCR register of the CM7.
0: No CPU software reset occurred (default after power-on reset)
1: A system reset has been generated by the CPU

Bit 23 **PORRSTF**: POR/PDR reset flag
Reset by software by writing the RMVF bit.
Set by hardware when a POR/PDR reset occurs.
0: No POR/PDR reset occurred
1: POR/PDR reset occurred (default after power-on reset)

Bit 22 **PINRSTF**: Pin reset flag (NRST)
Reset by software by writing the RMVF bit.
Set by hardware when a reset from pin occurs.
0: No reset from pin occurred
1: Reset from pin occurred (default after power-on reset)

Bit 21 **BORRSTF**: BOR reset flag
Reset by software by writing the RMVF bit.
Set by hardware when a BOR reset occurs (**pwr_bor_rst**).
0: No BOR reset occurred
1: BOR reset occurred (default after power-on reset)

Bit 20 **D2RSTF**: D2 domain power switch reset flag
Reset by software by writing the RMVF bit.
Set by hardware when a D2 domain exits from DStandby or after of power-on reset. Refer to *Table 52* for details.
0: No D2 domain power switch reset occurred
1: A D2 domain power switch (ePOD2) reset occurred (default after power-on reset)

Bit 19 **D1RSTF**: D1 domain power switch reset flag
Reset by software by writing the RMVF bit.
Set by hardware when a D1 domain exits from DStandby or after of power-on reset. Refer to *Table 52* for details.
0: No D1 domain power switch reset occurred
1: A D1 domain power switch (ePOD1) reset occurred (default after power-on reset)

Bit 18 Reserved, must be kept at reset value.

Bit 17 **CPURSTF**: CPU reset flag
Reset by software by writing the RMVF bit.
Set by hardware every time a CPU reset occurs.
0: No CPU reset occurred
1: A CPU reset occurred (default after power-on reset)

Bit 16 **RMVF**: Remove reset flag
Set and reset by software to reset the value of the reset flags.
0: Reset of the reset flags not activated (default after power-on reset)
1: Reset the value of the reset flags

Bits 15:0 Reserved, must be kept at reset value.

8.7.39 RCC AHB3 clock register (RCC_AHB3ENR)

This register can be accessed via two different offset address.

Table 62. RCC_AHB3ENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_AHB3ENR	0x0D4	0x0000 0000
RCC_C1_AHB3ENR	0x134	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OTFD2EN	OTFD1EN	IOMNGREN	Res.	OCTOSP21EN	Res.	Res.	SDMMC1EN
								rw	rw	rw		rw			rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	OCTOSPI1EN	Res.	FMCEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DMA2DEN	Res.	Res.	Res.	MDMAEN
	rw		rw								rw				rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **OTFD2EN**: OTFDEC2 clock enable
Set and reset by software.
0: OTFDEC2 clock disabled (default after reset)
1: OTFDEC2 clock enabled

Bit 22 **OTFD1EN**: OTFDEC1 clock enable
Set and reset by software.
0: OTFDEC1 clock disabled (default after reset)
1: OTFDEC1 clock enabled

Bit 21 **IOMNGREN**: OCTOSPI I/O manager clock enable
Set and reset by software.
0: OCTOSPI I/O manager clock disabled (default after reset)
1: OCTOSPI I/O manager clock enabled

Bit 20 Reserved, must be kept at reset value.

Bit 19 **OCTOSPI2EN**: OCTOSPI2 and OCTOSPI2 delay clock enable
Set and reset by software.
0: OCTOSPI2 and OCTOSPI2 delay clock disabled (default after reset)
1: OCTOSPI2 and OCTOSPI2 delay clock enabled

Bits 18:17 Reserved, must be kept at reset value.

Bit 16 **SDMMC1EN**: SDMMC1 and SDMMC1 Delay Clock Enable
Set and reset by software.
0: SDMMC1 and SDMMC1 Delay clock disabled (default after reset)
1: SDMMC1 and SDMMC1 Delay clock enabled

Bit 15 Reserved, must be kept at reset value.

Bit 14 **OCTOSPI1EN**: OCTOSPI1 and OCTOSPI1 delay clock enable
Set and reset by software.
0: OCTOSPI1 and OCTOSPI1 delay clock disabled (default after reset)
1: OCTOSPI1 and OCTOSPI1 delay clock enabled

Bit 13 Reserved, must be kept at reset value.

Bit 12 **FMCEN**: FMC Peripheral Clocks Enable
Set and reset by software.
0: FMC peripheral clocks disabled (default after reset)
1: FMC peripheral clocks enabled
The peripheral clocks of the FMC are: the kernel clock selected by FMCSEL and provided to fmc_ker_ck input, and the **rcc_hclk3** bus interface clock.

Bits 11:5 Reserved, must be kept at reset value.

Bit 4 **DMA2DEN**: DMA2D Peripheral Clock Enable
Set and reset by software.
0: DMA2D peripheral clock disabled (default after reset)
1: DMA2D peripheral clock enabled

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **MDMAEN**: MDMA Peripheral Clock Enable
Set and reset by software.
0: MDMA peripheral clock disabled (default after reset)
1: MDMA peripheral clock enabled

8.7.40 RCC AHB1 clock register (RCC_AHB1ENR)

This register can be accessed via two different offset address.

Table 63. RCC_AHB1ENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_AHB1ENR	0x0D8	0x0000 0000
RCC_C1_AHB1ENR	0x138	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	USB1OTGHSULPIEN	USB1OTGHSEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETH1RXEN	ETH1TXEN
					rw	rw								rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETH1MACEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADC12EN	Res.	Res.	Res.	DMA2EN	DMA1EN
rw										rw				rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bit 26 **USB1OTGHSULPIEN**: USB_PHY1 Clocks Enable
Set and reset by software.
0: USB1ULPI PHY clocks disabled (default after reset)
1: USB1ULPI PHY clocks enabled

Bit 25 **USB1OTGHSEN**: USB1OTG (OTG_HS1) Peripheral Clocks Enable
Set and reset by software.
0: USB1OTG peripheral clocks disabled (default after reset)
1: USB1OTG peripheral clocks enabled
The peripheral clocks of the USB1OTG are: the kernel clock selected by USBSEL and the **rcc_hclk1** bus interface clock.

Bits 24:18 Reserved, must be kept at reset value.

Bit 17 **ETH1RXEN**: Ethernet Reception Clock Enable
Set and reset by software.
0: Ethernet Reception clock disabled (default after reset)
1: Ethernet Reception clock enabled

Bit 16 **ETH1TXEN**: Ethernet Transmission Clock Enable
Set and reset by software.
0: Ethernet Transmission clock disabled (default after reset)
1: Ethernet Transmission clock enabled

Bit 15 **ETH1MACEN**: Ethernet MAC bus interface Clock Enable
Set and reset by software.
0: Ethernet MAC bus interface clock disabled (default after reset)
1: Ethernet MAC bus interface clock enabled

Bits 14:6 Reserved, must be kept at reset value.

Bit 5 **ADC12EN**: ADC1/2 Peripheral Clocks Enable
Set and reset by software.
0: ADC1 and 2 peripheral clocks disabled (default after reset)
1: ADC1 and 2 peripheral clocks enabled
The peripheral clocks of the ADC1 and 2 are: the kernel clock selected by ADCSEL and provided to adc_ker_ck_input, and the **rcc_hclk1** bus interface clock.

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **DMA2EN**: DMA2 Clock Enable
Set and reset by software.
0: DMA2 clock disabled (default after reset)
1: DMA2 clock enabled

Bit 0 **DMA1EN**: DMA1 Clock Enable
Set and reset by software.
0: DMA1 clock disabled (default after reset)
1: DMA1 clock enabled

8.7.41 RCC AHB2 clock register (RCC_AHB2ENR)

This register can be accessed via two different offset address.

Table 64. RCC_AHB2ENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_AHB2ENR	0x0DC	0x0000 0000
RCC_C1_AHB2ENR	0x13C	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	SRAM2EN	SRAM1EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CORDICEN	FMACEN
	rw	rw												rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	SDMMC2EN	Res.	Res.	RNGEN	HASHEN	CRYPTEN	Res.	Res.	Res.	DCMI_PSSIEN
						rw			rw	rw	rw				rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **SRAM2EN**: SRAM2 block enable

Set and reset by software.

When set, this bit indicates that the SRAM2 is allocated by the CPU. It causes the D2 domain to take into account also the CPU operation modes, i.e. keeping D2 domain in DRun when the CPU is in CRun.

0: SRAM2 interface clock is disabled. (default after reset)

1: SRAM2 interface clock is enabled.

Bit 29 **SRAM1EN**: SRAM1 block enable

Set and reset by software.

When set, this bit indicates that the SRAM1 is allocated by the CPU. It causes the D2 domain to take into account also the CPU operation modes, i.e. keeping D2 domain in DRun when the CPU is in CRun.

0: SRAM1 interface clock is disabled. (default after reset)

1: SRAM1 interface clock is enabled.

Bits 28:18 Reserved, must be kept at reset value.

Bit 17 **CORDICEN**: CORDIC peripheral clock enable

Set and reset by software.

0: CORDIC clock disabled (default after reset)

1: CORDIC clock enabled

Bit 16 **FMACEN**: FMAC peripheral clock enable

Set and reset by software.

0: FMAC clock disabled (default after reset)

1: FMAC clock enabled

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **SDMMC2EN**: SDMMC2 and SDMMC2 delay clock enable
Set and reset by software.
0: SDMMC2 and SDMMC2 Delay clock disabled (default after reset)
1: SDMMC2 and SDMMC2 Delay clock enabled

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **RNGEN**: RNG peripheral clocks enable
Set and reset by software.
0: RNG peripheral clocks disabled (default after reset)
1: RNG peripheral clocks enabled:
The peripheral clocks of the RNG are: the kernel clock selected by RNGSEL and provided to **rng_ker_ck** input, and the **rcc_hclk2** bus interface clock.

Bit 5 **HASHEN**: HASH peripheral clock enable
Set and reset by software.
0: HASH peripheral clock disabled (default after reset)
1: HASH peripheral clock enabled

Bit 4 **CRYPTEN**: CRYPT peripheral clock enable
Set and reset by software.
0: CRYPT peripheral clock disabled (default after reset)
1: CRYPT peripheral clock enabled

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **DCMI_PSSIEN**: Digital camera interface clock enable (DCMI or PSSI, depending which peripheral is active)
Set and reset by software.
0: DCMI/PSSI peripheral clock disabled (default after reset)
1: DCMI/PSSI peripheral clock enabled

8.7.42 RCC AHB4 clock register (RCC_AHB4ENR)

This register can be accessed via two different offset address.

Table 65. RCC_AHB4ENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_AHB4ENR	0x0E0	0x0000 0000
RCC_C1_AHB4ENR	0x140	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	BKPRAMEN	Res.	Res.	HSEMEN	ADC3EN	Res.	Res.	BDMAEN	Res.	CRCEN	Res.	Res.	Res.
			rw			rw	rw			rw		rw			

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	GPIOKEN	GPIOJEN	Res.	GPIOHEN	GPIOGEN	GPIOFEN	GPIOEEN	GPIODEN	GPIOCEN	GPIOBEN	GPIOAEN
					rw	rw		rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **BKPRAMEN**: Backup RAM clock enable
Set and reset by software.
0: Backup RAM clock disabled (default after reset)
1: Backup RAM clock enabled

Bits 27:26 Reserved, must be kept at reset value.

Bit 25 **HSEMEN**: HSEM peripheral clock enable
Set and reset by software.
0: HSEM peripheral clock disabled (default after reset)
1: HSEM peripheral clock enabled

Bit 24 **ADC3EN**: ADC3 Peripheral Clocks Enable
Set and reset by software.
0: ADC3 peripheral clocks disabled (default after reset)
1: ADC3 peripheral clocks enabled
The peripheral clocks of the ADC3 are: the kernel clock selected by ADCSEL and provided to adc_ker_ck_input, and the **rcc_hclk4** bus interface clock.

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **BDMAEN**: BDMA and DMAMUX2 Clock Enable
Set and reset by software.
0: BDMA and DMAMUX2 clock disabled (default after reset)
1: BDMA and DMAMUX2 clock enabled

Bit 20 Reserved, must be kept at reset value.

Bit 19 **CRCEN**: CRC peripheral clock enable
Set and reset by software.
0: CRC peripheral clock disabled (default after reset)
1: CRC peripheral clock enabled

Bits 18:11 Reserved, must be kept at reset value.

Bit 10 **GPIOKEN**: GPIOK peripheral clock enable
Set and reset by software.
0: GPIOK peripheral clock disabled (default after reset)
1: GPIOK peripheral clock enabled

Bit 9 **GPIOJEN**: GPIOJ peripheral clock enable
Set and reset by software.
0: GPIOJ peripheral clock disabled (default after reset)
1: GPIOJ peripheral clock enabled

Bit 8 Reserved, must be kept at reset value.

Bit 7 **GPIOHEN**: GPIOH peripheral clock enable
Set and reset by software.
0: GPIOH peripheral clock disabled (default after reset)
1: GPIOH peripheral clock enabled

Bit 6 **GPIOGEN**: GPIOG peripheral clock enable
Set and reset by software.
0: GPIOG peripheral clock disabled (default after reset)
1: GPIOG peripheral clock enabled

Bit 5 **GPIOFEN**: GPIOF peripheral clock enable
Set and reset by software.
0: GPIOF peripheral clock disabled (default after reset)
1: GPIOF peripheral clock enabled

Bit 4 **GPIOEEN**: GPIOE peripheral clock enable
Set and reset by software.
0: GPIOE peripheral clock disabled (default after reset)
1: GPIOE peripheral clock enabled

Bit 3 **GPIODEN**: GPIOD peripheral clock enable
Set and reset by software.
0: GPIOD peripheral clock disabled (default after reset)
1: GPIOD peripheral clock enabled

Bit 2 **GPIOCEN**: GPIOC peripheral clock enable
Set and reset by software.
0: GPIOC peripheral clock disabled (default after reset)
1: GPIOC peripheral clock enabled

Bit 1 **GPIOBEN**: GPIOB peripheral clock enable
Set and reset by software.
0: GPIOB peripheral clock disabled (default after reset)
1: GPIOB peripheral clock enabled

Bit 0 **GPIOAEN**: GPIOA peripheral clock enable
Set and reset by software.
0: GPIOA peripheral clock disabled (default after reset)
1: GPIOA peripheral clock enabled

8.7.43 RCC APB3 clock register (RCC_APB3ENR)

This register can be accessed via two different offset address.

Table 66. RCC_APB3ENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_APB3ENR	0x0E4	0x0000 0000
RCC_C1_APB3ENR	0x144	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WWDG1EN	Res.	Res.	LTDCEN	Res.	Res.	Res.
									rs			rw			

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **WWDG1EN**: WWDG1 Clock Enable
Set by software, and reset by hardware when a system reset occurs.
Note that in order to work properly, before enabling the WWDG1, the bit WW1RSC must be set to 1.
0: WWDG1 peripheral clock disable (default after reset)
1: WWDG1 peripheral clock enabled

Bits 5:4 Reserved, must be kept at reset value.

Bit 3 **LTDCEN**: LTDC peripheral clock enable
Provides the pixel clock (**ltdc_ker_ck**) to the LTDC block.
Set and reset by software.
0: LTDC peripheral clock disabled (default after reset)
1: LTDC peripheral clock provided to the LTDC block

Bits 2:0 Reserved, must be kept at reset value.

8.7.44 RCC APB1 clock register (RCC_APB1LENR)

This register can be accessed via two different offset address.

Table 67. RCC_APB1ENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_APB1LENR	0x0E8	0x0000 0000
RCC_C1_APB1LENR	0x148	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UART8EN	UART7EN	DAC12EN	Res.	CECEN	Res.	I2C5EN	Res.	I2C3EN	I2C2EN	I2C1EN	UART5EN	UART4EN	USART3EN	USART2EN	SPDIFRXEN
rw	rw	rw		rw		rw		rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI3EN	SPI2EN	Res.	Res.	Res.	Res.	LPTIM1EN	TIM14EN	TIM13EN	TIM12EN	TIM7EN	TIM6EN	TIM5EN	TIM4EN	TIM3EN	TIM2EN
rw	rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UART8EN**: UART8 Peripheral Clocks Enable
Set and reset by software.
0: UART8 peripheral clocks disable (default after reset)
1: UART8 peripheral clocks enabled
The peripheral clocks of the UART8 are: the kernel clock selected by USART234578SEL and provided to usart_ker_ck input, and the **rcc_pclk1** bus interface clock.

Bit 30 **UART7EN**: UART7 Peripheral Clocks Enable
Set and reset by software.
0: UART7 peripheral clocks disable (default after reset)
1: UART7 peripheral clocks enabled
The peripheral clocks of the UART7 are: the kernel clock selected by USART234578SEL and provided to usart_ker_ck input, and the **rcc_pclk1** bus interface clock.

Bit 29 **DAC12EN**: DAC1 and 2 peripheral clock enable
Set and reset by software.
0: DAC1 and 2 peripheral clock disable (default after reset)
1: DAC1 and 2 peripheral clock enabled

Bit 28 Reserved, must be kept at reset value.

Bit 27 **CECEN**: HDMI-CEC peripheral clock enable
Set and reset by software.
0: HDMI-CEC peripheral clock disable (default after reset)
1: HDMI-CEC peripheral clock enabled
The peripheral clocks of the HDMI-CEC are: the kernel clock selected by CECSEL and provided to **cec_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bits 26 Reserved, must be kept at reset value.

Bit 25 **I2C5EN**: I2C5 peripheral clocks enable
Set and reset by software.
0: I2C5 peripheral clocks disable (default after reset)
1: I2C5 peripheral clocks enabled
The peripheral clocks of the I2C3 are: the kernel clock selected by I2C1235SEL and provided to **i2c_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bits 24 Reserved, must be kept at reset value.

Bit 23 **I2C3EN**: I2C3 peripheral clocks enable
Set and reset by software.
0: I2C3 peripheral clocks disable (default after reset)
1: I2C3 peripheral clocks enabled
The peripheral clocks of the I2C3 are: the kernel clock selected by I2C1235SEL and provided to **i2c_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 22 **I2C2EN**: I2C2 Peripheral Clocks Enable
Set and reset by software.
0: I2C2 peripheral clocks disable (default after reset)
1: I2C2 peripheral clocks enabled
The peripheral clocks of the I2C2 are: the kernel clock selected by I2C1235SEL and provided to **i2c_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 21 **I2C1EN**: I2C1 Peripheral Clocks Enable
Set and reset by software.
0: I2C1 peripheral clocks disable (default after reset)
1: I2C1 peripheral clocks enabled
The peripheral clocks of the I2C1 are: the kernel clock selected by I2C1235SEL and provided to **i2c_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 20 **UART5EN**: UART5 Peripheral Clocks Enable
Set and reset by software.
0: UART5 peripheral clocks disable (default after reset)
1: UART5 peripheral clocks enabled
The peripheral clocks of the UART5 are: the kernel clock selected by USART234578SEL and provided to **uart_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 19 **UART4EN**: UART4 Peripheral Clocks Enable
Set and reset by software.
0: UART4 peripheral clocks disable (default after reset)
1: UART4 peripheral clocks enabled
The peripheral clocks of the UART4 are: the kernel clock selected by USART234578SEL and provided to **uart_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 18 **USART3EN**: USART3 Peripheral Clocks Enable
Set and reset by software.
0: USART3 peripheral clocks disable (default after reset)
1: USART3 peripheral clocks enabled
The peripheral clocks of the USART3 are: the kernel clock selected by USART234578SEL and provided to **usart_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 17 **USART2EN**: USART2 Peripheral Clocks Enable
Set and reset by software.
0: USART2 peripheral clocks disable (default after reset)
1: USART2 peripheral clocks enabled
The peripheral clocks of the USART2 are: the kernel clock selected by USART234578SEL and provided to **usart_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 16 **SPDIFRXEN**: SPDIFRX Peripheral Clocks Enable
Set and reset by software.
0: SPDIFRX peripheral clocks disable (default after reset)
1: SPDIFRX peripheral clocks enabled
The peripheral clocks of the SPDIFRX are: the kernel clock selected by SPDIFRXSEL and provided to **spdifrx_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 15 **SPI3EN**: SPI3 Peripheral Clocks Enable
Set and reset by software.
0: SPI3 peripheral clocks disable (default after reset)
1: SPI3 peripheral clocks enabled
The peripheral clocks of the SPI3 are: the kernel clock selected by I2S123SRC and provided to **spi_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 14 **SPI2EN**: SPI2 Peripheral Clocks Enable
Set and reset by software.
0: SPI2 peripheral clocks disable (default after reset)
1: SPI2 peripheral clocks enabled
The peripheral clocks of the SPI2 are: the kernel clock selected by I2S123SRC and provided to **spi_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bits 13:10 Reserved, must be kept at reset value.

Bit 9 **LPTIM1EN**: LPTIM1 Peripheral Clocks Enable
Set and reset by software.
0: LPTIM1 peripheral clocks disable (default after reset)
1: LPTIM1 peripheral clocks enabled
The peripheral clocks of the LPTIM1 are: the kernel clock selected by LPTIM1SEL and provided to **lptim_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 8 **TIM14EN**: TIM14 peripheral clock enable
Set and reset by software.
0: TIM14 peripheral clock disable (default after reset)
1: TIM14 peripheral clock enabled

Bit 7 **TIM13EN**: TIM13 peripheral clock enable
Set and reset by software.
0: TIM13 peripheral clock disable (default after reset)
1: TIM13 peripheral clock enabled

Bit 6 **TIM12EN**: TIM12 peripheral clock enable
Set and reset by software.
0: TIM12 peripheral clock disable (default after reset)
1: TIM12 peripheral clock enabled

Bit 5 **TIM7EN**: TIM7 peripheral clock enable
Set and reset by software.
0: TIM7 peripheral clock disable (default after reset)
1: TIM7 peripheral clock enabled

Bit 4 **TIM6EN**: TIM6 peripheral clock enable
Set and reset by software.
0: TIM6 peripheral clock disable (default after reset)
1: TIM6 peripheral clock enabled

Bit 3 **TIM5EN**: TIM5 peripheral clock enable
Set and reset by software.
0: TIM5 peripheral clock disable (default after reset)
1: TIM5 peripheral clock enabled

Bit 2 **TIM4EN**: TIM4 peripheral clock enable
Set and reset by software.
0: TIM4 peripheral clock disable (default after reset)
1: TIM4 peripheral clock enabled

Bit 1 **TIM3EN**: TIM3 peripheral clock enable
Set and reset by software.
0: TIM3 peripheral clock disable (default after reset)
1: TIM3 peripheral clock enabled

Bit 0 **TIM2EN**: TIM2 peripheral clock enable
Set and reset by software.
0: TIM2 peripheral clock disable (default after reset)
1: TIM2 peripheral clock enabled

8.7.45 RCC APB1 clock register (RCC_APB1HENR)

This register can be accessed via two different offset address.

Table 68. RCC_APB1ENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_APB1HENR	0x0EC	0x0000 0000
RCC_C1_APB1HENR	0x14C	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	TIM24EN	TIM23EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
						rw	rw								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	FDCANEN	Res.	Res.	MDIOSEN	OPAMPEN	Res.	SWPMIEN	CRSEN	Res.
							rw			rw	rw		rw	rw	

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **TIM24EN**: TIM24 peripheral clocks enable
Set and reset by software.
0: TIM24 peripheral clocks disable (default after reset)
1: TIM24 peripheral clocks enabled:

Bit 24 **TIM23EN**: TIM23 peripheral clocks enable
Set and reset by software.
0: TIM23 peripheral clocks disable (default after reset)
1: TIM23 peripheral clocks enabled:

Bits 23:9 Reserved, must be kept at reset value.

Bit 8 **FDCANEN**: FDCAN Peripheral Clocks Enable
Set and reset by software.
0: FDCAN peripheral clocks disable (default after reset)
1: FDCAN peripheral clocks enabled:
The peripheral clocks of the FDCAN are: the kernel clock selected by FDCANSEL and provided to **fdcan_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **MDIOSEN**: MDIOS peripheral clock enable
Set and reset by software.
0: MDIOS peripheral clock disable (default after reset)
1: MDIOS peripheral clock enabled

Bit 4 **OPAMPEN**: OPAMP peripheral clock enable
Set and reset by software.
0: OPAMP peripheral clock disable (default after reset)
1: OPAMP peripheral clock enabled

Bit 3 Reserved, must be kept at reset value.

Bit 2 **SWPMIEN**: SWPMI Peripheral Clocks Enable
Set and reset by software.
0: SWPMI peripheral clocks disable (default after reset)
1: SWPMI peripheral clocks enabled:
The peripheral clocks of the SWPMI are: the kernel clock selected by SWPMISEL and provided to **swpmi_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 1 **CRSEN**: Clock Recovery System peripheral clock enable
Set and reset by software.
0: CRS peripheral clock disable (default after reset)
1: CRS peripheral clock enabled

Bit 0 Reserved, must be kept at reset value.

8.7.46 RCC APB2 clock register (RCC_APB2ENR)

This register can be accessed via two different offset address.

Table 69. RCC_APB2ENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_APB2ENR	0x0F0	0x0000 0000
RCC_C1_APB2ENR	0x150	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	DFSDM1EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SAI1EN	Res.	SPI5EN	Res.	TIM17EN	TIM16EN	TIM15EN
	rw								rw		rw		rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	SPI4EN	SPI1EN	Res.	Res.	Res.	Res.	USART10EN	UART9EN	USART6EN	USART1EN	Res.	Res.	TIM8EN	TIM1EN
		rw	rw					rw	rw	rw	rw			rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **DFSDM1EN**: DFSDM1 Peripheral Clocks Enable
Set and reset by software.
0: DFSDM1 peripheral clocks disabled (default after reset)
1: DFSDM1 peripheral clocks enabled
DFSDM1 peripheral clocks are: the kernel clocks selected by SAI1SEL and DFSDM1SEL and provided to **Aclk** and **clk** inputs respectively, and the **rcc_pclk2** bus interface clock.

Bits 29:23 Reserved, must be kept at reset value.

Bit 22 **SAI1EN**: SAI1 Peripheral Clocks Enable
Set and reset by software.
0: SAI1 peripheral clocks disabled (default after reset)
1: SAI1 peripheral clocks enabled:
The peripheral clocks of the SAI1 are: the kernel clock selected by SAI1SEL and provided to **sai_a_ker_ck** and **sai_b_ker_ck** inputs, and the **rcc_pclk2** bus interface clock.

Bit 21 Reserved, must be kept at reset value.

Bit 20 **SPI5EN**: SPI5 Peripheral Clocks Enable
Set and reset by software.
0: SPI5 peripheral clocks disabled (default after reset)
1: SPI5 peripheral clocks enabled:
The peripheral clocks of the SPI5 are: the kernel clock selected by SPI45SEL and provided to **spi_ker_ck** input, and the **rcc_pclk2** bus interface clock.

Bit 19 Reserved, must be kept at reset value.

Bit 18 **TIM17EN**: TIM17 peripheral clock enable
Set and reset by software.
0: TIM17 peripheral clock disabled (default after reset)
1: TIM17 peripheral clock enabled

Bit 17 **TIM16EN**: TIM16 peripheral clock enable
Set and reset by software.
0: TIM16 peripheral clock disabled (default after reset)
1: TIM16 peripheral clock enabled

Bit 16 **TIM15EN**: TIM15 peripheral clock enable
Set and reset by software.
0: TIM15 peripheral clock disabled (default after reset)
1: TIM15 peripheral clock enabled

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **SPI4EN**: SPI4 Peripheral Clocks Enable
Set and reset by software.
0: SPI4 peripheral clocks disabled (default after reset)
1: SPI4 peripheral clocks enabled:
The peripheral clocks of the SPI4 are: the kernel clock selected by SPI45SEL and provided to **spi_ker_ck** input, and the **rcc_pclk2** bus interface clock.

Bit 12 **SPI1EN**: SPI1 Peripheral Clocks Enable
Set and reset by software.
0: SPI1 peripheral clocks disabled (default after reset)
1: SPI1 peripheral clocks enabled:
The peripheral clocks of the SPI1 are: the kernel clock selected by I2S123SRC and provided to **spi_ker_ck** input, and the **rcc_pclk2** bus interface clock.

Bits 11:8 Reserved, must be kept at reset value.

Bit 7 **USART10EN**: USART10 peripheral clocks enable
Set and reset by software.
0: USART10 peripheral clocks disabled (default after reset)
1: USART10 peripheral clocks enabled:
The peripheral clocks of the USART10 are: the kernel clock selected by USART16910SEL and provided to **usart_ker_ck** input, and the **rcc_pclk2** bus interface clock.

Bit 6 **UART9EN**: UART9 peripheral clocks enable
Set and reset by software.
0: UART9 peripheral clocks disabled (default after reset)
1: UART9 peripheral clocks enabled:
The peripheral clocks of the USART9 are the kernel clock selected by USART16910SEL and provided to **usart_ker_ck** input, and the **rcc_pclk2** bus interface clock.

Bit 5 **USART6EN**: USART6 Peripheral Clocks Enable
Set and reset by software.
0: USART6 peripheral clocks disabled (default after reset)
1: USART6 peripheral clocks enabled:
The peripheral clocks of the USART6 are: the kernel clock selected by USART16910SEL and provided to **usart_ker_ck** input, and the **rcc_pclk2** bus interface clock.

Bit 4 **USART1EN**: USART1 Peripheral Clocks Enable
Set and reset by software.
0: USART1 peripheral clocks disabled (default after reset)
1: USART1 peripheral clocks enabled:
The peripheral clocks of the USART1 are: the kernel clock selected by USART16910SEL and provided to **usart_ker_ck** input, and the **rcc_pclk2** bus interface clock.

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **TIM8EN**: TIM8 peripheral clock enable
Set and reset by software.
0: TIM8 peripheral clock disabled (default after reset)
1: TIM8 peripheral clock enabled

Bit 0 **TIM1EN**: TIM1 peripheral clock enable
Set and reset by software.
0: TIM1 peripheral clock disabled (default after reset)
1: TIM1 peripheral clock enabled

8.7.47 RCC APB4 clock register (RCC_APB4ENR)

This register can be accessed via two different offset address.

Table 70. RCC_APB4ENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_APB4ENR	0x0F4	0x0001 0000
RCC_C1_APB4ENR	0x154	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	DTSEN	Res.	Res.	Res.	Res.	SAI4EN	Res.	Res.	Res.	Res.	RTCAPBEN
					rw					rw					rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VREFEN	COMP12EN	Res.	LPTIM5EN	LPTIM4EN	LPTIM3EN	LPTIM2EN	Res.	I2C4EN	Res.	SPI6EN	Res.	LPUART1EN	Res.	SYSCFGEN	Res.
rw	rw		rw	rw	rw	rw		rw		rw		rw		rw	

Bits 31:27 Reserved, must be kept at reset value.

Bit 26 **DTSEN**: Digital temperature sensor peripheral clock enable
Set and reset by software.
0: Digital temperature sensor peripheral clock disabled (default after reset)
1: Digital temperature sensor peripheral clock enabled

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **SAI4EN**: SAI4 Peripheral Clocks Enable
Set and reset by software.
0: SAI4 peripheral clocks disabled (default after reset)
1: SAI4 peripheral clocks enabled
The peripheral clocks of the SAI4 are: the kernel clocks selected by SAI4ASEL and SAI4BSEL, and provided to **sai_a_ker_ck** and **sai_b_ker_ck** inputs respectively, and the **rcc_pclk4** bus interface clock.

Bits 20:17 Reserved, must be kept at reset value.

Bit 16 **RTCAPBEN**: RTC APB Clock Enable
Set and reset by software.
0: The register clock interface of the RTC (APB) is disabled
1: The register clock interface of the RTC (APB) is enabled (default after reset)

Bit 15 **VREFEN**: VREFBUF peripheral clock enable
Set and reset by software.
0: VREF peripheral clock disabled (default after reset)
1: VREF peripheral clock enabled

Bit 14 **COMP12EN**: COMP1/2 peripheral clock enable
Set and reset by software.
0: COMP1/2 peripheral clock disabled (default after reset)
1: COMP1/2 peripheral clock enabled

Bit 13 Reserved, must be kept at reset value.

Bit 12 **LPTIM5EN**: LPTIM5 Peripheral Clocks Enable
Set and reset by software.
0: LPTIM5 peripheral clocks disabled (default after reset)
1: LPTIM5 peripheral clocks enabled
The peripheral clocks of the LPTIM5 are: the kernel clock selected by LPTIM345SEL and provided to **lptim_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 11 **LPTIM4EN**: LPTIM4 Peripheral Clocks Enable
Set and reset by software.
0: LPTIM4 peripheral clocks disabled (default after reset)
1: LPTIM4 peripheral clocks enabled
The peripheral clocks of the LPTIM4 are: the kernel clock selected by LPTIM345SEL and provided to **lptim_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 10 **LPTIM3EN**: LPTIM3 Peripheral Clocks Enable
Set and reset by software.
0: LPTIM3 peripheral clocks disabled (default after reset)
1: LPTIM3 peripheral clocks enabled
The peripheral clocks of the LPTIM3 are: the kernel clock selected by LPTIM345SEL and provided to **lptim_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 9 **LPTIM2EN**: LPTIM2 Peripheral Clocks Enable
Set and reset by software.
0: LPTIM2 peripheral clocks disabled (default after reset)
1: LPTIM2 peripheral clocks enabled
The peripheral clocks of the LPTIM2 are: the kernel clock selected by LPTIM2SEL and provided to **lptim_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 8 Reserved, must be kept at reset value.

Bit 7 **I2C4EN**: I2C4 Peripheral Clocks Enable
Set and reset by software.
0: I2C4 peripheral clocks disabled (default after reset)
1: I2C4 peripheral clocks enabled
The peripheral clocks of the I2C4 are: the kernel clock selected by I2C4SEL and provided to **i2c_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 6 Reserved, must be kept at reset value.

Bit 5 **SPI6EN**: SPI6 Peripheral Clocks Enable
Set and reset by software.
0: SPI6 peripheral clocks disabled (default after reset)
1: SPI6 peripheral clocks enabled
The peripheral clocks of the SPI6 are: the kernel clock selected by SPI6SEL and provided to **spi_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 4 Reserved, must be kept at reset value.

Bit 3 **LPUART1EN**: LPUART1 Peripheral Clocks Enable
Set and reset by software.
0: LPUART1 peripheral clocks disabled (default after reset)
1: LPUART1 peripheral clocks enabled
The peripheral clocks of the LPUART1 are: the kernel clock selected by LPUART1SEL and provided to **lpuart_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **SYSCFGEN**: SYSCFG peripheral clock enable
Set and reset by software.
0: SYSCFG peripheral clock disabled (default after reset)
1: SYSCFG peripheral clock enabled

Bit 0 Reserved, must be kept at reset value.

8.7.48 RCC AHB3 Sleep clock register (RCC_AHB3LPENR)

This register can be accessed via two different offset address.

Table 71. RCC_AHB3LPENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_AHB3LPENR	0x0FC	0xF0E9 5111
RCC_C1_AHB3LPENR	0x15C	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AXISRAMLPEN	ITCMLPEN	DTCM2LPEN	DTCM1LPEN	Res.	Res.	Res.	Res.	OTFD2LPEN	OTFD1LPEN	IOMNGRLPEN	Res.	OCTO2LPEN	Res.	Res.	SDMMC1LPEN
rw	rw	rw	rw					rw	rw	rw		rw			rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	OCTO1LPEN	Res.	FMCLPEN	Res.	Res.	Res.	FLASHLPEN	Res.	Res.	Res.	DMA2DLPEN	Res.	Res.	Res.	MDMALPEN
	rw		rw				rw				rw				rw

Bit 31 **AXISRAMLPEN**: AXISRAM Block Clock Enable During CSleep mode
Set and reset by software.
0: AXISRAM interface clock disabled during CSleep mode
1: AXISRAM interface clock enabled during CSleep mode (default after reset)

Bit 30 **ITCMLPEN**: D1ITCM Block Clock Enable During CSleep mode
Set and reset by software.
0: D1 ITCM interface clock disabled during CSleep mode
1: D1 ITCM interface clock enabled during CSleep mode (default after reset)

Bit 29 **DTCM2LPEN**: D1 DTCM2 Block Clock Enable During CSleep mode
Set and reset by software.
0: D1 DTCM2 interface clock disabled during CSleep mode
1: D1 DTCM2 interface clock enabled during CSleep mode (default after reset)

Bit 28 **D1DTCM1LPEN**: D1DTCM1 Block Clock Enable During CSleep mode
Set and reset by software.
0: D1DTCM1 interface clock disabled during CSleep mode
1: D1DTCM1 interface clock enabled during CSleep mode (default after reset)

Bits 27:24 Reserved, must be kept at reset value.

Bit 23 **OTFD2LPEN**: OTFDEC2 clock enable during CSleep mode
Set and reset by software.
0: OTFDEC2 clock disabled during CSleep mode
1: OTFDEC2 clock enabled during CSleep mode (default after reset)

Bit 22 **OTFD1LPEN**: OTFDEC1 clock enable during CSleep mode
Set and reset by software.
0: OTFDEC1 clock disabled during CSleep mode
1: OTFDEC1 clock enabled during CSleep mode (default after reset)

Bit 21 **IOMNGRLPEN**: OCTOSPI I/O manager clock enable during CSleep mode
Set and reset by software.
0: OCTOSPI I/O manager clock disabled during CSleep mode
1: OCTOSPI I/O manager clock enabled during CSleep mode (default after reset)

Bit 20 Reserved, must be kept at reset value.

Bit 19 **OCTO2LPEN**: OCTOSPI2 clock enable during CSleep mode
Set and reset by software.
0: OCTOSPI2 clock disabled during CSleep mode
1: OCTOSPI2 clock enabled during CSleep mode (default after reset)

Bits 18:17 Reserved, must be kept at reset value.

Bit 16 **SDMMC1LPEN**: SDMMC1 and SDMMC1 Delay Clock Enable During CSleep Mode
Set and reset by software.
0: SDMMC1 and SDMMC1 Delay clock disabled during CSleep mode
1: SDMMC1 and SDMMC1 Delay clock enabled during CSleep mode (default after reset)

Bit 15 Reserved, must be kept at reset value.

Bit 14 **OCTO1LPEN**: OCTOSPI1 clock enable during CSleep mode
Set and reset by software.
0: OCTOSPI1 clock disabled during CSleep mode
1: OCTOSPI1 clock enabled during CSleep mode (default after reset)

Bit 13 Reserved, must be kept at reset value.

Bit 12 **FMCLPEN**: FMC Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: FMC peripheral clocks disabled during CSleep mode
1: FMC peripheral clocks enabled during CSleep mode (default after reset):
The peripheral clocks of the FMC are: the kernel clock selected by FMCSEL and provided to **fmc_ker_ck** input, and the **rcc_hclk3** bus interface clock.

Bits 11:9 Reserved, must be kept at reset value.

Bit 8 **FLASHLPEN**: Flash interface Clock Enable During CSleep Mode
Set and reset by software.
0: Flash interface clock disabled during CSleep mode
1: Flash interface clock enabled during CSleep mode (default after reset)

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **DMA2DLPEN**: DMA2D Clock Enable During CSleep Mode
Set and reset by software.
0: DMA2D peripheral clock disabled during CSleep mode
1: DMA2D peripheral clock enabled during CSleep mode (default after reset)

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **MDMALPEN**: MDMA Clock Enable During CSleep Mode
Set and reset by software.
0: MDMA peripheral clock disabled during CSleep mode
1: MDMA peripheral clock enabled during CSleep mode (default after reset)

8.7.49 RCC AHB1 Sleep clock register (RCC_AHB1LPENR)

This register can be accessed via two different offset address.

Table 72. RCC_AHB1LPENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_AHB1LPENR	0x100	0x0603 8023
RCC_C1_AHB1LPENR	0x160	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	USB1OTGHSULPILPEN	USB1OTGHSLPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETH1RXLPEN	ETH1TXLPEN
					rw	rw								rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETH1MACLPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADC12LPEN	Res.	Res.	Res.	DMA2LPEN	DMA1LPEN
rw										rw				rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bit 26 **USB1OTGHSULPILPEN**: USB_PHY1 clock enable during CSleep mode
Set and reset by software.
0: USB_PHY1 peripheral clock disabled during CSleep mode
1: USB_PHY1 peripheral clock enabled during CSleep mode (default after reset)

Bit 25 **USB1OTGHSLPEN**: USB1OTG (OTG_HS1) peripheral clock enable during CSleep mode
Set and reset by software.
0: USB1OTG peripheral clock disabled during CSleep mode
1: USB1OTG peripheral clock enabled during CSleep mode (default after reset)
The peripheral clocks of the USB1OTG are: the kernel clock selected by USBSEL and the **rcc_hclk1** bus interface clock.

Bits 24:18 Reserved, must be kept at reset value.

Bit 17 **ETH1RXLPEN**: Ethernet Reception Clock Enable During CSleep Mode
Set and reset by software.
0: Ethernet Reception clock disabled during CSleep mode
1: Ethernet Reception clock enabled during CSleep mode (default after reset)

Bit 16 **ETH1TXLPEN**: Ethernet Transmission Clock Enable During CSleep Mode
Set and reset by software.
0: Ethernet Transmission clock disabled during CSleep mode
1: Ethernet Transmission clock enabled during CSleep mode (default after reset)

Bit 15 **ETH1MACLPEN**: Ethernet MAC bus interface Clock Enable During CSleep Mode
Set and reset by software.
0: Ethernet MAC bus interface clock disabled during CSleep mode
1: Ethernet MAC bus interface clock enabled during CSleep mode (default after reset)

Bits 14:6 Reserved, must be kept at reset value.

Bit 5 **ADC12LPEN**: ADC1/2 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: ADC1/2 peripheral clocks disabled during CSleep mode
1: ADC1/2 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the ADC1 and 2 are: the kernel clock selected by ADCSEL and provided to adc_ker_ck_input, and the **rcc_hclk1** bus interface clock.

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **DMA2LPEN**: DMA2 Clock Enable During CSleep Mode
Set and reset by software.
0: DMA2 clock disabled during CSleep mode
1: DMA2 clock enabled during CSleep mode (default after reset)

Bit 0 **DMA1LPEN**: DMA1 Clock Enable During CSleep Mode
Set and reset by software.
0: DMA1 clock disabled during CSleep mode
1: DMA1 clock enabled during CSleep mode (default after reset)

8.7.50 RCC AHB2 Sleep clock register (RCC_AHB2LPENR)

This register can be accessed via two different offset address.

Table 73. RCC_AHB2LPENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_AHB2LPENR	0x104	0x6003 0271
RCC_C1_AHB2LPENR	0x164	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	SRAM2LPEN	SRAM1LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CORDICLPEN	FMACLPEN
	rw	rw												rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	SDMMC2LPEN	Res.	Res.	RNGLPEN	HASHLPEN	CRYPTLPEN	Res.	Res.	Res.	DCMI_PSSILPEN
						rw			rw	rw	rw				rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **SRAM2LPEN**: SRAM2 Clock Enable During CSleep Mode
Set and reset by software.
0: SRAM2 clock disabled during CSleep mode
1: SRAM2 clock enabled during CSleep mode (default after reset)

Bit 29 **SRAM1LPEN**: SRAM1 Clock Enable During CSleep Mode
Set and reset by software.
0: SRAM1 clock disabled during CSleep mode
1: SRAM1 clock enabled during CSleep mode (default after reset)

Bits 28:18 Reserved, must be kept at reset value.

Bit 17 **CORDICLPEN**: CORDIC clock enable during CSleep mode
Set and reset by software.
0: CORDIC clock disabled during CSleep mode
1: CORDIC clock enabled during CSleep mode (default after reset)

Bit 16 **FMACLPEN**: FMAC clock enable during CSleep mode
Set and reset by software.
0: FMAC clock disabled during CSleep mode
1: FMAC clock enabled during CSleep mode (default after reset)

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **SDMMC2LPEN**: SDMMC2 and SDMMC2 Delay Clock Enable During CSleep Mode
Set and reset by software.
0: SDMMC2 and SDMMC2 Delay clock disabled during CSleep mode
1: SDMMC2 and SDMMC2 Delay clock enabled during CSleep mode (default after reset)

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **RNGLPEN**: RNG peripheral clock enable during CSleep mode
Set and reset by software.
0: RNG peripheral clocks disabled during CSleep mode
1: RNG peripheral clock enabled during CSleep mode (default after reset)
The peripheral clocks of the RNG are: the kernel clock selected by RNGSEL and provided to **rng_ker_ck** input, and the **rcc_hclk2** bus interface clock.

Bit 5 **HASHLPEN**: HASH peripheral clock enable during CSleep mode
Set and reset by software.
0: HASH peripheral clock disabled during CSleep mode
1: HASH peripheral clock enabled during CSleep mode (default after reset)

Bit 4 **CRYPTLPEN**: CRYPT peripheral clock enable during CSleep mode
Set and reset by software.
0: CRYPT peripheral clock disabled during CSleep mode
1: CRYPT peripheral clock enabled during CSleep mode (default after reset)

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **DCMI_PSSILPEN**: Digital camera interface clock enable during CSleep mode (DCMI or PSSI depending which peripheral is active)
Set and reset by software.
0: DCMI/PSSI peripheral clock disabled during CSleep mode
1: DCMI/PSSI peripheral clock enabled during CSleep mode (default after reset)

8.7.51 RCC AHB4 Sleep clock register (RCC_AHB4LPENR)

This register can be accessed via two different offset address.

Table 74. RCC_AHB4LPENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_AHB4LPENR	0x108	0x3128 06FF
RCC_C1_AHB4LPENR	0x168	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	SRAM4LPEN	BKPRAMLPEN	Res.	Res.	Res.	ADC3LPEN	Res.	Res.	BDMALPEN	Res.	CRCLPEN	Res.	Res.	Res.
		rw	rw				rw			rw		rw			

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	GPIOKLPEN	GPIOJLPEN	Res.	GPIOHLPEN	GPIOGLPEN	GPIOFLPEN	GPIOELPEN	GPIODLPEN	GPIOCLPEN	GPIOBLPEN	GPIOALPEN
					rw	rw		rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **SRAM4LPEN**: SRAM4 Clock Enable During CSleep Mode
Set and reset by software.
0: SRAM4 clock disabled during CSleep mode
1: SRAM4 clock enabled during CSleep mode (default after reset)

Bit 28 **BKPRAMLPEN**: Backup RAM Clock Enable During CSleep Mode
Set and reset by software.
0: Backup RAM clock disabled during CSleep mode
1: Backup RAM clock enabled during CSleep mode (default after reset)

Bits 27:25 Reserved, must be kept at reset value.

Bit 24 **ADC3LPEN**: ADC3 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: ADC3 peripheral clocks disabled during CSleep mode
1: ADC3 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the ADC3 are: the kernel clock selected by ADCSEL and provided to adc_ker_ck_input, and the **rcc_hclk4** bus interface clock.

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **BDMALPEN**: BDMA Clock Enable During CSleep Mode
Set and reset by software.
0: BDMA clock disabled during CSleep mode
1: BDMA clock enabled during CSleep mode (default after reset)

Bit 20 Reserved, must be kept at reset value.

Bit 19 **CRCLPEN**: CRC peripheral clock enable during CSleep mode
Set and reset by software.
0: CRC peripheral clock disabled during CSleep mode
1: CRC peripheral clock enabled during CSleep mode (default after reset)

Bits 18:11 Reserved, must be kept at reset value.

Bit 10 **GPIOKLPEN**: GPIOK peripheral clock enable during CSleep mode
Set and reset by software.
0: GPIOK peripheral clock disabled during CSleep mode
1: GPIOK peripheral clock enabled during CSleep mode (default after reset)

Bit 9 **GPIOJLPEN**: GPIOJ peripheral clock enable during CSleep mode
Set and reset by software.
0: GPIOJ peripheral clock disabled during CSleep mode
1: GPIOJ peripheral clock enabled during CSleep mode (default after reset)

Bit 8 Reserved, must be kept at reset value.

Bit 7 **GPIOHLPEN**: GPIOH peripheral clock enable during CSleep mode
Set and reset by software.
0: GPIOH peripheral clock disabled during CSleep mode
1: GPIOH peripheral clock enabled during CSleep mode (default after reset)

Bit 6 **GPIOGLPEN**: GPIOG peripheral clock enable during CSleep mode
Set and reset by software.
0: GPIOG peripheral clock disabled during CSleep mode
1: GPIOG peripheral clock enabled during CSleep mode (default after reset)

Bit 5 **GPIOFLPEN**: GPIOF peripheral clock enable during CSleep mode
Set and reset by software.
0: GPIOF peripheral clock disabled during CSleep mode
1: GPIOF peripheral clock enabled during CSleep mode (default after reset)

Bit 4 **GPIOELPEN**: GPIOE peripheral clock enable during CSleep mode
Set and reset by software.
0: GPIOE peripheral clock disabled during CSleep mode
1: GPIOE peripheral clock enabled during CSleep mode (default after reset)

Bit 3 **GPIODLPEN**: GPIOD peripheral clock enable during CSleep mode
Set and reset by software.
0: GPIOD peripheral clock disabled during CSleep mode
1: GPIOD peripheral clock enabled during CSleep mode (default after reset)

Bit 2 **GPIOCLPEN**: GPIOC peripheral clock enable during CSleep mode
Set and reset by software.
0: GPIOC peripheral clock disabled during CSleep mode
1: GPIOC peripheral clock enabled during CSleep mode (default after reset)

Bit 1 **GPIOBLPEN**: GPIOB peripheral clock enable during CSleep mode
Set and reset by software.
0: GPIOB peripheral clock disabled during CSleep mode
1: GPIOB peripheral clock enabled during CSleep mode (default after reset)

Bit 0 **GPIOALPEN**: GPIOA peripheral clock enable during CSleep mode
Set and reset by software.
0: GPIOA peripheral clock disabled during CSleep mode
1: GPIOA peripheral clock enabled during CSleep mode (default after reset)

8.7.52 RCC APB3 Sleep Clock Register (RCC_APB3LPENR)

This register can be accessed via two different offset address.

Table 75. RCC_APB3LPENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_APB3LPENR	0x10C	0x0000 0048
RCC_C1_APB3LPENR	0x16C	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WWDG1LPEN	Res.	Res.	LTDCLPEN	Res.	Res.	Res.
									rw			rw			

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **WWDG1LPEN**: WWDG1 Clock Enable During CSleep Mode
Set and reset by software.
0: WWDG1 clock disable during CSleep mode
1: WWDG1 clock enabled during CSleep mode (default after reset)

Bits 5:4 Reserved, must be kept at reset value.

Bit 3 **LTDCLPEN**: LTDC peripheral clock enable during CSleep mode
Provides the pixel clock (**ltdc_ker_ck**) to the LTDC block.
Set and reset by software.
0: LTDC clock disabled during CSleep mode
1: LTDC clock provided to the LTDC during CSleep mode (default after reset)

Bits 2:0 Reserved, must be kept at reset value.

8.7.53 RCC APB1 Low Sleep clock register (RCC_APB1LLPENR)

This register can be accessed via two different offset address.

Table 76. RCC_APB1LLPENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_APB1LLPENR	0x110	0xEAFF C3FF
RCC_C1_APB1LLPENR	0x170	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UART8LPEN	UART7LPEN	DAC12LPEN	Res.	CECLPEN	Res.	I2C5LPEN	Res.	I2C3LPEN	I2C2LPEN	I2C1LPEN	UART5LPEN	UART4LPEN	USART3LPEN	USART2LPEN	SPDIFRXLPEN
rw	rw	rw		rw		rw		rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI3LPEN	SPI2LPEN	Res.	Res.	Res.	Res.	LPTIM1LPEN	TIM14LPEN	TIM13LPEN	TIM12LPEN	TIM7LPEN	TIM6LPEN	TIM5LPEN	TIM4LPEN	TIM3LPEN	TIM2LPEN
rw	rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UART8LPEN**: UART8 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: UART8 peripheral clocks disabled during CSleep mode
1: UART8 peripheral clocks enabled during CSleep mode (default after reset):
The peripheral clocks of the UART8 are: the kernel clock selected by USART234578SEL and provided to **usart_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 30 **UART7LPEN**: UART7 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: UART7 peripheral clocks disabled during CSleep mode
1: UART7 peripheral clocks enabled during CSleep mode (default after reset):
The peripheral clocks of the UART7 are: the kernel clock selected by USART234578SEL and provided to **usart_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 29 **DAC12LPEN**: DAC1/2 peripheral clock enable during CSleep mode
Set and reset by software.
0: DAC1/2 peripheral clock disabled during CSleep mode
1: DAC1/2 peripheral clock enabled during CSleep mode (default after reset)

Bit 28 Reserved, must be kept at reset value.

Bit 27 **CECLPEN**: HDMI-CEC Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: HDMI-CEC peripheral clocks disabled during CSleep mode
1: HDMI-CEC peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the HDMI-CEC are: the kernel clock selected by CECSEL and provided to **cec_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 26 Reserved, must be kept at reset value.

Bit 25 **I2C5LPEN**: I2C5 peripheral clocks enable during CSleep mode
Set and reset by software.
0: I2C5 peripheral clocks disabled during CSleep mode
1: I2C5 peripheral clocks enabled during CSleep mode (default after reset):
The peripheral clocks of the I2C3 are: the kernel clock selected by I2C1235SEL and provided to **i2c_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 24 Reserved, must be kept at reset value.

Bit 23 **I2C3LPEN**: I2C3 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: I2C3 peripheral clocks disabled during CSleep mode
1: I2C3 peripheral clocks enabled during CSleep mode (default after reset):
The peripheral clocks of the I2C3 are: the kernel clock selected by I2C1235SEL and provided to **i2c_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 22 **I2C2LPEN**: I2C2 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: I2C2 peripheral clocks disabled during CSleep mode
1: I2C2 peripheral clocks enabled during CSleep mode (default after reset):
The peripheral clocks of the I2C2 are: the kernel clock selected by I2C1235SEL and provided to **i2c_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 21 **I2C1LPEN**: I2C1 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: I2C1 peripheral clocks disabled during CSleep mode
1: I2C1 peripheral clocks enabled during CSleep mode (default after reset):
The peripheral clocks of the I2C1 are: the kernel clock selected by I2C1235SEL and provided to **i2c_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 20 **UART5LPEN**: UART5 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: UART5 peripheral clocks disabled during CSleep mode
1: UART5 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the UART5 are: the kernel clock selected by USART234578SEL and provided to **uart_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 19 **UART4LPEN**: UART4 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: UART4 peripheral clocks disabled during CSleep mode
1: UART4 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the UART4 are: the kernel clock selected by USART234578SEL and provided to **uart_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 18 **USART3LPEN**: USART3 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: USART3 peripheral clocks disabled during CSleep mode
1: USART3 peripheral clocks enabled during CSleep mode (default after reset):
The peripheral clocks of the USART3 are: the kernel clock selected by USART234578SEL and provided to **usart_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 17 **USART2LPEN**: USART2 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: USART2 peripheral clocks disabled during CSleep mode
1: USART2 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the USART2 are: the kernel clock selected by USART234578SEL and provided to **usart_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 16 **SPDIFRXLPEN**: SPDIFRX Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: SPDIFRX peripheral clocks disabled during CSleep mode
1: SPDIFRX peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the SPDIFRX are: the kernel clock selected by SPDIFRXSEL and provided to **spdifrx_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 15 **SPI3LPEN**: SPI3 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: SPI3 peripheral clocks disabled during CSleep mode
1: SPI3 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the SPI3 are: the kernel clock selected by I2S123SRC and provided to **spi_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 14 **SPI2LPEN**: SPI2 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: SPI2 peripheral clocks disabled during CSleep mode
1: SPI2 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the SPI2 are: the kernel clock selected by I2S123SRC and provided to **spi_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bits 13:10 Reserved, must be kept at reset value.

Bit 9 **LPTIM1LPEN**: LPTIM1 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: LPTIM1 peripheral clocks disabled during CSleep mode
1: LPTIM1 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the LPTIM1 are: the kernel clock selected by LPTIM1SEL and provided to **lptim_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 8 **TIM14LPEN**: TIM14 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM14 peripheral clock disabled during CSleep mode
1: TIM14 peripheral clock enabled during CSleep mode (default after reset)

Bit 7 **TIM13LPEN**: TIM13 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM13 peripheral clock disabled during CSleep mode
1: TIM13 peripheral clock enabled during CSleep mode (default after reset)

Bit 6 **TIM12LPEN**: TIM12 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM12 peripheral clock disabled during CSleep mode
1: TIM12 peripheral clock enabled during CSleep mode (default after reset)

Bit 5 **TIM7LPEN**: TIM7 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM7 peripheral clock disabled during CSleep mode
1: TIM7 peripheral clock enabled during CSleep mode (default after reset)

Bit 4 **TIM6LPEN**: TIM6 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM6 peripheral clock disabled during CSleep mode
1: TIM6 peripheral clock enabled during CSleep mode (default after reset)

Bit 3 **TIM5LPEN**: TIM5 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM5 peripheral clock disabled during CSleep mode
1: TIM5 peripheral clock enabled during CSleep mode (default after reset)

Bit 2 **TIM4LPEN**: TIM4 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM4 peripheral clock disabled during CSleep mode
1: TIM4 peripheral clock enabled during CSleep mode (default after reset)

Bit 1 **TIM3LPEN**: TIM3 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM3 peripheral clock disabled during CSleep mode
1: TIM3 peripheral clock enabled during CSleep mode (default after reset)

Bit 0 **TIM2LPEN**: TIM2 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM2 peripheral clock disabled during CSleep mode
1: TIM2 peripheral clock enabled during CSleep mode (default after reset)

8.7.54 RCC APB1 High Sleep clock register (RCC_APB1HLPENR)

This register can be accessed via two different offset address.

Table 77. RCC_APB1HLPENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_APB1HLPENR	0x114	0x0300 0136
RCC_C1_APB1HLPENR	0x174	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	TIM24LPEN	TIM23LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
						rw	rw								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	FDCANLPEN	Res.	Res.	MDIOSLPEN	OPAMPLPEN	Res.	SWPMILPEN	CRSLPEN	Res.
							rw			rw	rw		rw	rw	

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **TIM24LPEN**: TIM24 peripheral clocks enable during CSleep mode
Set and reset by software.
0: TIM24 peripheral clocks disabled during CSleep mode
1: TIM24 peripheral clocks enabled during CSleep mode (default after reset)

Bit 24 **TIM23LPEN**: TIM23 peripheral clocks enable during CSleep mode
Set and reset by software.
0: TIM23 peripheral clocks disabled during CSleep mode
1: TIM23 peripheral clocks enabled during CSleep mode (default after reset)

Bits 23:9 Reserved, must be kept at reset value.

Bit 8 **FDCANLPEN**: FDCAN Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: FDCAN peripheral clocks disabled during CSleep mode
1: FDCAN peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the FDCAN are: the kernel clock selected by FDCANSEL and provided to **fdcan_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **MDIOSLPEN**: MDIOS peripheral clock enable during CSleep mode
Set and reset by software.
0: MDIOS peripheral clock disabled during CSleep mode
1: MDIOS peripheral clock enabled during CSleep mode (default after reset)

Bit 4 **OPAMPLPEN**: OPAMP peripheral clock enable during CSleep mode
Set and reset by software.
0: OPAMP peripheral clock disabled during CSleep mode
1: OPAMP peripheral clock enabled during CSleep mode (default after reset)

Bit 3 Reserved, must be kept at reset value.

Bit 2 **SWPMILPEN**: SWPMI Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: SWPMI peripheral clocks disabled during CSleep mode
1: SWPMI peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the SWPMI are: the kernel clock selected by SWPMISEL and provided to **swpmi_ker_ck** input, and the **rcc_pclk1** bus interface clock.

Bit 1 **CRSLPEN**: Clock Recovery System peripheral clock enable during CSleep mode
Set and reset by software.
0: CRS peripheral clock disabled during CSleep mode
1: CRS peripheral clock enabled during CSleep mode (default after reset)

Bit 0 Reserved, must be kept at reset value.

8.7.55 RCC APB2 Sleep clock register (RCC_APB2LPENR)

This register can be accessed via two different offset address.

Table 78. RCC_APB2LPENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_APB2LPENR	0x118	0x4057 30F3
RCC_C1_APB2LPENR	0x178	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	DFSDM1LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SAI1LPEN	Res.	SPI5LPEN	Res.	TIM17LPEN	TIM16LPEN	TIM15LPEN
	rw								rw		rw		rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	SPI4LPEN	SPI1LPEN	Res.	Res.	Res.	Res.	USART10LPEN	UART9LPEN	USART6LPEN	USART1LPEN	Res.	Res.	TIM8LPEN	TIM1LPEN
		rw	rw					rw	rw	rw	rw			rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **DFSDM1LPEN**: DFSDM1 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: DFSDM1 peripheral clocks disabled during CSleep mode
1: DFSDM1 peripheral clocks enabled during CSleep mode (default after reset)
DFSDM1 peripheral clocks are: the kernel clocks selected by SAI1SEL and DFSDM1SEL and provided to **Aclk** and **clk** inputs respectively, and the **rcc_pclk2** bus interface clock.

Bits 29:23 Reserved, must be kept at reset value.

Bit 22 **SAI1LPEN**: SAI1 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: SAI1 peripheral clocks disabled during CSleep mode
1: SAI1 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the SAI1 are: the kernel clock selected by SAI1SEL and provided to **sai_a_ker_ck** and **sai_b_ker_ck** inputs, and the **rcc_pclk2** bus interface clock.

Bit 21 Reserved, must be kept at reset value.

Bit 20 **SPI5LPEN**: SPI5 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: SPI5 peripheral clocks disabled during CSleep mode
1: SPI5 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the SPI5 are: the kernel clock selected by SPI45SEL and provided to **spi_ker_ck** input, and the **rcc_pclk2** bus interface clock.

Bit 19 Reserved, must be kept at reset value.

Bit 18 **TIM17LPEN**: TIM17 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM17 peripheral clock disabled during CSleep mode
1: TIM17 peripheral clock enabled during CSleep mode (default after reset)

Bit 17 **TIM16LPEN**: TIM16 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM16 peripheral clock disabled during CSleep mode
1: TIM16 peripheral clock enabled during CSleep mode (default after reset)

Bit 16 **TIM15LPEN**: TIM15 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM15 peripheral clock disabled during CSleep mode
1: TIM15 peripheral clock enabled during CSleep mode (default after reset)

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **SPI4LPEN**: SPI4 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: SPI4 peripheral clocks disabled during CSleep mode
1: SPI4 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the SPI4 are: the kernel clock selected by SPI45SEL and provided to **spi_ker_ck** input, and the **rcc_pclk2** bus interface clock.

Bit 12 **SPI1LPEN**: SPI1 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: SPI1 peripheral clocks disabled during CSleep mode
1: SPI1 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the SPI1 are: the kernel clock selected by I2S123SRC and provided to **spi_ker_ck** input, and the **rcc_pclk2** bus interface clock.

Bits 11:8 Reserved, must be kept at reset value.

Bit 7 **USART10LPEN**: USART10 peripheral clocks enable during CSleep mode
Set and reset by software.
0: USART10 peripheral clocks disabled during CSleep mode
1: USART10 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the USART10 are: the kernel clock selected by USART16910SEL and provided to **usart_ker_ck** input, and the **rcc_pclk2** bus interface clock.

Bit 6 **UART9LPEN**: UART9 peripheral clocks enable during CSleep mode
Set and reset by software.
0: UART9 peripheral clocks disabled during CSleep mode
1: UART9 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the UART9 are: the kernel clock selected by USART16910SEL and provided to **usart_ker_ck** input, and the **rcc_pclk2** bus interface clock.

Bit 5 **USART6LPEN**: USART6 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: USART6 peripheral clocks disabled during CSleep mode
1: USART6 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the USART6 are: the kernel clock selected by USART16910SEL and provided to **usart_ker_ck** input, and the **rcc_pclk2** bus interface clock.

Bit 4 **USART1LPEN**: USART1 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: USART1 peripheral clocks disabled during CSleep mode
1: USART1 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the USART1 are: the kernel clock selected by USART16910SEL and provided to **usart_ker_ck** inputs, and the **rcc_pclk2** bus interface clock.

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **TIM8LPEN**: TIM8 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM8 peripheral clock disabled during CSleep mode
1: TIM8 peripheral clock enabled during CSleep mode (default after reset)

Bit 0 **TIM1LPEN**: TIM1 peripheral clock enable during CSleep mode
Set and reset by software.
0: TIM1 peripheral clock disabled during CSleep mode
1: TIM1 peripheral clock enabled during CSleep mode (default after reset)

8.7.56 RCC APB4 Sleep clock register (RCC_APB4LPENR)

This register can be accessed via two different offset address.

Table 79. RCC_APB4LPENR address offset and reset value

Register Name	Address Offset	Reset Value
RCC_APB4LPENR	0x11C	0x0421 DEAA
RCC_C1_APB4LPENR	0x17C	

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	DTSLPEN	Res.	Res.	Res.	Res.	SAI4LPEN	Res.	Res.	Res.	Res.	RTCAPBLPEN
					rw					rw					rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VREFLPEN	COMP12LPEN	Res.	LPTIM5LPEN	LPTIM4LPEN	LPTIM3LPEN	LPTIM2LPEN	Res.	I2C4LPEN	Res.	SPI6LPEN	Res.	LPUART1LPEN	Res.	SYSCFGLPEN	Res.
rw	rw		rw	rw	rw	rw		rw		rw		rw		rw	

Bits 31:26 Reserved, must be kept at reset value.

Bit 26 **DTSLPEN**: Digital temperature sensor peripheral clock enable during CSleep mode
Set and reset by software.
0: Digital temperature sensor peripheral clock disabled during CSleep mode
1: Digital temperature sensor peripheral clock enabled during CSleep mode (default after reset)

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **SAI4LPEN**: SAI4 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: SAI4 peripheral clocks disabled during CSleep mode
1: SAI4 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the SAI4 are: the kernel clocks selected by SAI4ASEL and SAI4BSEL, and provided to **sai_a_ker_ck** and **sai_b_ker_ck** inputs respectively, and the **rcc_pclk4** bus interface clock.

Bits 20:17 Reserved, must be kept at reset value.

Bit 16 **RTCAPBLPEN**: RTC APB Clock Enable During CSleep Mode
Set and reset by software.
0: The register clock interface of the RTC (APB) is disabled during CSleep mode
1: The register clock interface of the RTC (APB) is enabled during CSleep mode (default after reset)

Bit 15 **VREFLPEN**: VREF peripheral clock enable during CSleep mode
Set and reset by software.
0: VREF peripheral clock disabled during CSleep mode
1: VREF peripheral clock enabled during CSleep mode (default after reset)

Bit 14 **COMP12LPEN**: COMP1/2 peripheral clock enable during CSleep mode
Set and reset by software.
0: COMP1/2 peripheral clock disabled during CSleep mode
1: COMP1/2 peripheral clock enabled during CSleep mode (default after reset)

Bit 13 Reserved, must be kept at reset value.

Bit 12 **LPTIM5LPEN**: LPTIM5 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: LPTIM5 peripheral clocks disabled during CSleep mode
1: LPTIM5 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the LPTIM5 are: the kernel clock selected by LPTIM345SEL and provided to **lptim_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 11 **LPTIM4LPEN**: LPTIM4 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: LPTIM4 peripheral clocks disabled during CSleep mode
1: LPTIM4 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the LPTIM4 are: the kernel clock selected by LPTIM345SEL and provided to **lptim_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 10 **LPTIM3LPEN**: LPTIM3 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: LPTIM3 peripheral clocks disabled during CSleep mode
1: LPTIM3 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the LPTIM3 are: the kernel clock selected by LPTIM345SEL and provided to **lptim_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 9 **LPTIM2LPEN**: LPTIM2 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: LPTIM2 peripheral clocks disabled during CSleep mode
1: LPTIM2 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the LPTIM5 are: the kernel clock selected by LPTIM2SEL and provided to **lptim_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 8 Reserved, must be kept at reset value.

Bit 7 **I2C4LPEN**: I2C4 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: I2C4 peripheral clocks disabled during CSleep mode
1: I2C4 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the I2C4 are: the kernel clock selected by I2C4SEL and provided to **i2c_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 6 Reserved, must be kept at reset value.

Bit 5 **SPI6LPEN**: SPI6 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: SPI6 peripheral clocks disabled during CSleep mode
1: SPI6 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the SPI6 are: the kernel clock selected by SPI6SEL and provided to **spi_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 4 Reserved, must be kept at reset value.

Bit 3 **LPUART1LPEN**: LPUART1 Peripheral Clocks Enable During CSleep Mode
Set and reset by software.
0: LPUART1 peripheral clocks disabled during CSleep mode
1: LPUART1 peripheral clocks enabled during CSleep mode (default after reset)
The peripheral clocks of the LPUART1 are: the kernel clock selected by LPUART1SEL and provided to **lpuart_ker_ck** input, and the **rcc_pclk4** bus interface clock.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **SYSCFGLPEN**: SYSCFG peripheral clock enable during CSleep mode
Set and reset by software.
0: SYSCFG peripheral clock disabled during CSleep mode
1: SYSCFG peripheral clock enabled during CSleep mode (default after reset)

Bit 0 Reserved, must be kept at reset value.

8.7.57 RCC register map

Table 80. RCC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**RCC_CR**	Res.	Res.	PLL3RDY	PLL3ON	PLL2RDY	PLL2ON	PLL1RDY	PLL1ON	Res.	Res.	Res.	Res.	HSECSSON	HSEBYP	HSERDY	HSEON	D2CKRDY	D1CKRDY	HSI48RDY	HSI48ON	Res.	Res.	CSIKERON	CSIRDY	CSION	Res.	HSIDIVF	HSIDIV[1:0]		HSIRDY	HSIKERON	HSION
	Reset value			0	0	0	0	0	0					0	0	0	0	0	0	0	0			0	0	0		0	0	0	0	0	1
0x004	**RCC_HSICFGR**	Res.	HSITRIM[6:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSICAL[11:0]											
	Reset value		1	0	0	0	0	0														X	X	X	X	X	X	X	X	X	X	X	X
0x008	**RCC_CRRCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSI48CAL[9:0]									
	Reset value																							-	-	-	-	-	-	-	-	-	-
0x00C	**reserved**	Reserved																															
0x00C	**RCC_CSICFGR**	Res.	Res.	CSITRIM[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSICAL[9:0]									
	Reset value			1	0	0	0	0	0															X	X	X	X	X	X	X	X	X	X
0x010	**RCC_CFGR**	MCO2[2:0]			MCO2PRE[3:0]				MCO1[2:0]				MCO1PRE[3:0]				Res.	Res.	TIMPRE	Res.	RTCPRE[5:0]						STOPKERWUCK	STOPWUCK	SWS[2:0]		SW[2:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0		0	0	0	0	0	0	0	0	0	0	0	0	0
0x014	**reserved**	Reserved																															
0x018	**RCC_D1CFGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	D1CPRE[3:0]					Res.	D1PPRE[2:0]			HPRE[3:0]		
	Reset value																					0	0	0	0		0	0	0	0	0	0	0

Table 80. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x01C	**RCC_D2CFGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	D2PPRE2[2:0]			Res.	D2PPRE1[2:0]			Res.	Res.	Res.	Res.
	Reset value																						0	0	0		0	0	0				
0x020	**RCC_D3CFGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	D3PPRE[2:0]			Res.	Res.	Res.	Res.
	Reset value																										0	0	0				
0x024	**reserved**	Reserved																															
0x028	**RCC_ PLLCKSELR**	Res.	Res.	Res.	Res.	Res.	Res.	DIVM3[5:0]						Res.	Res.	DIVM2[5:0]						Res.	Res.	DIVM1[5:0]						Res.	Res.	PLLSRC[1:0]	
	Reset value							1	0	0	0	0	0			1	0	0	0	0	0			1	0	0	0	0	0			0	0
0x02C	**RCC_PLLCFGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIVR3EN	DIVQ3EN	DIVP3EN	DIVR2EN	DIVQ2EN	DIVP2EN	DIVR1EN	DIVQ1EN	DIVP1EN	Res.	Res.	Res.	Res.	PLL3RGE[1:0]		PLL3VCOSEL	PLL3FRACEN	PLL2RGE[1:0]		PLL2VCOSEL	PLL2FRACEN	PLL1RGE[1:0]		PLL1VCOSEL	PLL1FRACEN
	Reset value								1	1	1	1	1	1	1	1	1					0	0	0	0	0	0	0	0	0	0	0	0
0x030	**RCC_PLL1DIVR**	Res.	DIVR1[6:0]							Res.	DIVQ1[6:0]							DIVP1[6:0]							DIVN1[8:0]								
	Reset value		0	0	0	0	0	0	1		0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
0x034	**RCC_PLL1FRACR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRACN1[12:0]														Res.	Res.	Res.
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x038	**RCC_PLL2DIVR**	Res.	DIVR2[6:0]							Res.	DIVQ2[6:0]							DIVP2[6:0]							DIVN2[8:0]								
	Reset value		0	0	0	0	0	0	1		0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
0x03C	**RCC_PLL2FRACR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRACN2[12:0]														Res.	Res.	Res.
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x040	**RCC_PLL3DIVR**	Res.	DIVR3[6:0]							Res.	DIVQ3[6:0]							DIVP3[6:0]							DIVN3[8:0]								
	Reset value		0	0	0	0	0	0	1		0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
0x044	**RCC_PLL3FRACR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FRACN3[12:0]														Res.	Res.	Res.
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x048	**reserved**	Reserved																															
0x04C	**RCC_D1CCIPR**	Res.	Res.	CKPERSEL[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SDMMCSEL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OCTOSPISEL[1:0]		Res.	Res.	FMCSEL[1:0]	
	Reset value			0	0												0											0	0			0	0

Table 80. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x050	RCC_D2CCIP1R	SWPMISEL	Res.	FDCANSEL[1:0]		Res.	Res.	Res.	DFSDM1SEL	Res.	Res.	SPDIFRXSEL[1:0]		Res.	SPI45SEL[2:0]			Res.	SPI123SEL[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SAI1SEL[2:0]		
	Reset value	0		0	0				0			0	0		0	0	0		0	0	0									0	0	0
0x054	RCC_D2CCIP2R	Res.	LPTIM1SEL[2:0]			Res.	Res.	Res.	Res.	CECSEL[1:0]		USBSEL[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	I2C1235SEL[1:0]		Res.	Res.	RNGSEL[1:0]		Res.	Res.	USART16910SEL[2:0]			USART234578SEL[2:0]		
	Reset value		0	0	0					0	0	0	0							0	0			0	0			0	0	0	0	0	0
0x058	RCC_D3CCIPR	Res.	SPI6SEL[2:0]			Res.	SAI4BSEL[2:0]			SAI4ASEL[2:0]				Res.	Res.	Res.	ADCSEL[1;0]		LPTIM345SEL[2:0]		LPTIM2SEL[2:0]			I2C4SEL[1:0]		Res.	Res.	Res.	Res.	Res.	LPUART1SEL[2:0]		
	Reset value		0	0	0		0	0	0	0	0	0					0	0	0	0	0	0	0	0	0						0	0	0
0x05C	reserved	Reserved																															
0x060	RCC_CIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LSECSSIE	PLL3RDYIE	PLL2RDYIE	PLL1RDYIE	HSI48RDYIE	CSIRDYIE	HSERDYIE	HSIRDYIE	LSERDYIE	LSIRDYIE
	Reset value																							0	0	0	0	0	0	0	0	0	0
0x064	RCC_CIFR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSECSSF	LSECSSF	PLL3RDYF	PLL2RDYF	PLL1RDYF	HSI48RDYF	CSIRDYF	HSERDYF	HSIRDYF	LSERDYF	LSIRDYF
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x068	RCC_CICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSECSSC	LSECSSC	PLL3RDYC	PLL2RDYC	PLL1RDYC	HSI48RDYC	CSIRDYC	HSERDYC	HSIRDYC	LSERDYC	LSIRDYC
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x06C	reserved	Reserved																															
0x070	RCC_BDCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BDRST	RTCEN	Res.	Res.	Res.	Res.	Res.	RTCSEL[1:0]		Res.	LSECSSD	LSECSSON	LSEDRV[1:0]		LSEBYP	LSERDY	LSEON
	Reset value																0	0						0	0		0	0	0	0	0	0	0

Table 80. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x074	**RCC_CSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LSIRDY	LSION
	Reset value																															0	0
0x078	**reserved**	Reserved																															
0x07C	**RCC_ AHB3RSTR**	CPURST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OTFD2RST	OTFD1RST	IOMNGRRST	Res.	OCTOSPI2RST	Res.	Res.	SDMMC1RST	Res.	OCTOSPI1RST	Res.	FMCRST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DMA2DRST	Res.	Res.	Res.	MDMARST
	Reset value	0								0	0	0		0			0		0		0								0				0
0x080	**RCC_ AHB1RSTR**	Res.	Res.	Res.	Res.	Res.	Res.	USB1OTGRST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETH1MACRST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADC12RST	Res.	Res.	Res.	DMA2RST	DMA1RST
	Reset value							0										0										0				0	0
0x084	**RCC_ AHB2RSTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CORDICRST	FMACRST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SDMMC2RST	Res.	Res.	RNGRST	HASHRST	CRYPTRST	Res.	Res.	Res.	DCMI_PSSIRST	
	Reset value													0	0								0			0	0	0					0
0x088	**RCC_ AHB4RSTR**	Res.	Res.	Res.	Res.	Res.	Res.	HSEMRST	ADC3RST	Res.	Res.	BDMARST	Res.	CRCRST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPIOKRST	GPIOJRST	Res.	Res.	GPIOHRST	GPIOGRST	GPIOFRST	GPIOERST	GPIODRST	GPIOCRST	GPIOBRST	GPIOARST
	Reset value							0	0			0		0								0	0			0	0	0	0	0	0	0	0
0x08C	**RCC_ APB3RSTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LTDCRST	Res.	Res.	Res.
	Reset value																													0			
0x090	**RCC_ APB1LRSTR**	UART8RST	UART7RST	DAC12RST	Res.	CECRST	Res.	I2C5RST	Res.	I2C3RST	I2C2RST	I2C1RST	UART5RST	UART4RST	USART3RST	USART2RST	SPDIFRXRST	SPI3RST	SPI2RST	Res.	Res.	Res.	Res.	LPTIM1RST	TIM14RST	TIM13RST	TIM12RST	TIM7RST	TIM6RST	TIM5RST	TIM4RST	TIM3RST	TIM2RST
	Reset value	0	0	0		0		0		0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0
0x094	**RCC_ APB1HRSTR**	Res.	Res.	Res.	Res.	Res.	Res.	TIM24RST	TIM23RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FDCANRST	Res.	Res.	MDIOSRST	OPAMPRST	Res.	SWPMIRST	CRSRST	Res.
	Reset value							0	0																0			0	0		0	0	

Table 80. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x098	**RCC_ APB2RSTR**	Res.	DFSDM1RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SAI1RST	Res.	SPI5RST	Res.	TIM17RST	TIM16RST	TIM15RST	Res.	Res.	SPI4RST	SPI1RST	Res.	Res.	Res.	Res.	UART10RST	UART9RST	USART6RST	USART1RST	Res.	Res.	TIM8RST	TIM1RST
	Reset value		0								0		0		0	0	0			0	0					0	0	0	0			0	0
0x09C	**RCC_ APB4RSTR**	Res.	Res.	Res.	Res.	Res.	DTSRST	Res.	Res.	Res.	Res.	SAI4RST	Res.	Res.	Res.	Res.	Res.	VREFRST	COMP12RST	Res.	LPTIM5RST	LPTIM4RST	LPTIM3RST	LPTIM2RST	Res.	I2C4RST	Res.	SPI6RST	Res.	LPUART1RST	Res.	SYSCFGRST	Res.
	Reset value						0					0						0	0		0	0	0	0		0		0		0		0	
0x0A0	**RCC_GCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WW1RSC
	Reset value																																0
0x0A4	**reserved**	Reserved																															
0x0A8	**RCC_D3AMR**	Res.	Res.	SRAM4AMEN	BKPRAMAMEN	Res.	DTSAMEN	Res.	ADC3AMEN	Res.	Res.	SAI4AMEN	Res.	CRCAMEN	Res.	Res.	RTCAMEN	VREFAMEN	COMP12AMEN	Res.	LPTIM5AMEN	LPTIM4AMEN	LPTIM3AMEN	LPTIM2AMEN	Res.	I2C4AMEN	Res.	SPI6AMEN	Res.	LPUART1AMEN	Res.	Res.	BDMAAMEN
	Reset value			0	0		0		0			0		0			0	0	0		0	0	0	0		0		0		0			0
0x0AC to 0x0CC	**reserved**	Reserved																															
0x0D0	**RCC_RSR**	Res.	LPWRRSTF	Res.	WWDG1RSTF	Res.	IWDG1RSTF	Res.	SFTRSTF	PORRSTF	PINRSTF	BORRSTF	D2RSTF	D1RSTF	Res.	CPURSTF	RMVF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value		0		0		0		0	1	1	1	1	1		1	0																
0x0D4	**RCC_ AHB3ENR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OTFD2EN	OTFD1EN	IOMNGREN	Res.	OCTO2EN	Res.	Res.	SDMMC1EN	Res.	OCTO1EN	Res.	FMCEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DMA2DEN	Res.	Res.	Res.	MDMAEN
	Reset value									0	0	0		0			0		0		0									0				0
0x0D8	**RCC_ AHB1ENR**	Res.	Res.	Res.	Res.	Res.	USB1OTGHSULPIEN	USB1OTGHSEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETH1RXEN	ETH1TXEN	ETH1MACEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADC12EN	Res.	Res.	Res.	DMA2EN	DMA1EN
	Reset value						0	0								0	0	0										0				0	0

Table 80. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0DC	**RCC_ AHB2ENR**	Res.	SRAM2EN	SRAM1EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CORDICEN	FMACEN	Res.	Res.	Res.	Res.	Res.	Res.	SDMMC2EN	Res.	Res.	RNGEN	HASHEN	CRYPTEN	Res.	Res.	Res.	DCMI_PSSIEN
	Reset value		0	0												0	0							0			0	0	0				0
0x0E0	**RCC_ AHB4ENR**	Res.	Res.	Res.	BKPRAMEN	Res.	Res.	HSEMEN	ADC3EN	Res.	Res.	BDMAEN	Res.	CRCEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPIOKEN	GPIOJEN	Res.	GPIOHEN	GPIOGEN	GPIOFEN	GPIOEEN	GPIODEN	GPIOCEN	GPIOBEN	GPIOAEN
	Reset value				0			0	0			0		0									0	0		0	0	0	0	0	0	0	0
0x0E4	**RCC_ APB3ENR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WWDG1EN	Res.	Res.	LTDCEN	Res.	Res.	Res.
	Reset value																										0			0			
0x0E8	**RCC_ APB1LENR**	UART8EN	UART7EN	DAC12EN	Res.	CECEN	Res.	I2C5EN	Res.	I2C3EN	I2C2EN	I2C1EN	UART5EN	UART4EN	USART3EN	USART2EN	SPDIFRXEN	SPI3EN	SPI2EN	Res.	Res.	Res.	Res.	LPTIM1EN	TIM14EN	TIM13EN	TIM12EN	TIM7EN	TIM6EN	TIM5EN	TIM4EN	TIM3EN	TIM2EN
	Reset value	0	0	0		0		0		0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0
0x0EC	**RCC_ APB1HENR**	Res.	Res.	Res.	Res.	Res.	Res.	TIM24EN	TIM23EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FDCANEN	Res.	Res.	MDIOSEN	OPAMPEN	Res.	SWPMIEN	CRSEN	Res.
	Reset value							0	0																0			0	0		0	0	
0x0F0	**RCC_ APB2ENR**	Res.	DFSDM1EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SAI1EN	Res.	SPI5EN	Res.	TIM17EN	TIM16EN	TIM15EN	Res.	Res.	SPI4EN	SPI1EN	Res.	Res.	Res.	Res.	USART10EN	UART9EN	USART6EN	USART1EN	Res.	Res.	TIM8EN	TIM1EN
	Reset value		0								0		0		0	0	0			0	0					0	0	0	0			0	0
0x0F4	**RCC_ APB4ENR**	Res.	Res.	Res.	Res.	Res.	DTSEN	Res.	Res.	Res.	Res.	SAI4EN	Res.	Res.	Res.	Res.	RTCAPBEN	VREFEN	COMP12EN	Res.	LPTIM5EN	LPTIM4EN	LPTIM3EN	LPTIM2EN	Res.	I2C4EN	Reserved	SPI6EN	Res.	LPUART1EN	Res.	SYSCFGEN	Res.
	Reset value						0					0					1	0	0		0	0	0	0		0	0	0		0		0	
0x0F8	**reserved**	Reserved																															
0x0FC	**RCC_ AHB3LPENR**	AXISRAMLPEN	ITCMLPEN	DTCM2LPEN	DTCM1LPEN	Res.	Res.	Res.	Res.	OTFD2LPEN	OTFD1LPEN	IOMNGRLPEN	Res.	SDMMC1LPEN	Res.	Res.	SDMMC1LPEN	Res.	OCTO1LPEN	Res.	FMCLPEN	Res.	Res.	Res.	FLASHLPEN	Res.	Res.	Res.	DMA2DLPEN	Res.	Res.	Res.	MDMALPEN
	Reset value	1	1	1	1					1	1	1		1			1		1		1				1				1				1

Table 80. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x100	**RCC_ AHB1LPENR**	Res.	Res.	Res.	Res.	Res.	USB1OTGHSULPILPEN	USB1OTGHSLPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETH1RXLPEN	ETH1TXLPEN	ETH1MACLPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADC12LPEN	Res.	Res.	Res.	DMA2LPEN	DMA1LPEN
	Reset value						1	1								1	1	1										1				1	1
0x104	**RCC_ AHB2LPENR**	Res.	SRAM2LPEN	SRAM1LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CORDICLPEN	FMACLPEN	Res.	Res.	Res.	Res.	Res.	SDMMC2LPEN	Res.	Res.	Res.	RNGLPEN	HASHLPEN	CRYPTLPEN	Res.	Res.	Res.	DCMI_PSSILPEN
	Reset value		1	1												1	1						1				1	1	1				1
0x108	**RCC_ AHB4LPENR**	Res.	Res.	SRAM4LPEN	BKPRAMLPEN	Res.	Res.	Res.	ADC3LPEN	Res.	Res.	BDMALPEN	Res.	CRCLPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPIOKLPEN	GPIOJLPEN	Res.	GPIOHLPEN	GPIOGLPEN	GPIOFLPEN	GPIOELPEN	GPIODLPEN	GPIOCLPEN	GPIOBLPEN	GPIOALPEN
	Reset value			1	1				1			1		1									1	1		1	1	1	1	1	1	1	1
0x10C	**RCC_ APB3LPENR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WWDG1LPEN	Res.	Res.	LTDCLPEN	Res.	Res.	Res.
	Reset value																										1			1			
0x110	**RCC_ APB1LLPENR**	UART8LPEN	UART7LPEN	DAC12LPEN	Res.	CECLPEN	Res.	I2C5LPEN	Res.	I2C3LPEN	I2C2LPEN	I2C1LPEN	UART5LPEN	UART4LPEN	USART3LPEN	USART2LPEN	SPDIFRXLPEN	SPI3LPEN	SPI2LPEN	Res.	Res.	Res.	Res.	LPTIM1LPEN	TIM14LPEN	TIM13LPEN	TIM12LPEN	TIM7LPEN	TIM6LPEN	TIM5LPEN	TIM4LPEN	TIM3LPEN	TIM2LPEN
	Reset value	1	1	1		1		1		1	1	1	1	1	1	1	1	1	1				1	1	1	1	1	1	1	1	1	1	1
0x114	**RCC_ APB1HLPENR**	Res.	Res.	Res.	Res.	Res.	TIM24LPEN	TIM23LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FDCANLPEN	Res.	Res.	MDIOSLPEN	OPAMPLPEN	Res.	SWPMILPEN	CRSLPEN	Res.
	Reset value						1	1																	1			1	1		1	1	
0x118	**RCC_ APB2LPENR**	Res.	DFSDM1LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SAI1LPEN	Res.	SPI5LPEN	Res.	TIM17LPEN	TIM16LPEN	TIM15LPEN	Res.	Res.	SPI4LPEN	SPI1LPEN	Res.	Res.	Res.	Res.	USART10LPEN	UART9LPEN	USART6LPEN	USART1LPEN	Res.	Res.	TIM8LPEN	TIM1LPEN
	Reset value		1								1		1		1	1	1			1	1					1	1	1	1			1	1

Table 80. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x11C	**RCC_ APB4LPENR**	Res.	Res.	Res.	Res.	Res.	DTSLPEN	Res.	Res.	Res.	Res.	SAI4LPEN	Res.	Res.	Res.	Res.	RTCAPBLPEN	VREFLPEN	COMP12LPEN	Res.	LPTIM5LPEN	LPTIM4LPEN	LPTIM3LPEN	LPTIM2LPEN	Res.	I2C4LPEN	Res.	SPI6LPEN	Res.	LPUART1LPEN	Res.	SYSCFGLPEN	Res.
	Reset value						1					1					1	1	1		1	1	1	1		1		1		1		1	
0x120 to 0x12C	**reserved**	Reserved																															
0x130	**RCC_C1_RSR**	Res.	LPWRRSTF	Res.	WWDG1RSTF	Res.	IWDG1RSTF	Res.	SFTRSTF	PORRSTF	PINRSTF	BORRSTF	D2RSTF	D1RSTF	Res.	CPURSTF	RMVF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value		0		0		0		0	1	1	1	1	1		1	0																
0x134	**RCC_C1_ AHB3ENR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OTFD2EN	OTFD1EN	IOMNGREN	Res.	OCTO2EN	Res.	Res.	SDMMC1EN	Res.	OCTO1EN	Res.	FMCEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DMA2DEN	Res.	Res.	Res.	MDMAEN
	Reset value									0	0	0		0			0		0		0									0				0
0x138	**RCC_C1_ AHB1ENR**	Res.	Res.	Res.	Res.	Res.	USB1OTGHSULPIEN	USB1OTGHSEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETH1RXEN	ETH1TXEN	ETH1MACEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADC12EN	Res.	Res.	Res.	DMA2EN	DMA1EN	
	Reset value						0	0								0	0	0										0				0	0	
0x13C	**RCC_C1_ AHB2ENR**	Res.	SRAM2EN	SRAM1EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CORDICEN	FMACEN	Res.	Res.	Res.	Res.	Res.	Res.	SDMMC2EN	Res.	Res.	RNGEN	HASHEN	CRYPTEN	Res.	Res.	Res.	Res.	DCMI_PSSIEN
	Reset value		0	0												0	0							0			0	0	0				0
0x140	**RCC_C1_ AHB4ENR**	Res.	Res.	Res.	BKPRAMEN	Res.	Res.	HSEMEN	ADC3EN	Res.	Res.	BDMAEN	Res.	CRCEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPIOKEN	GPIOJEN	Res.	GPIOHEN	GPIOGEN	GPIOFEN	GPIOEEN	GPIODEN	GPIOCEN	GPIOBEN	GPIOAEN
	Reset value				0			0	0			0		0								0	0		0	0	0	0	0	0	0	0	0
0x144	**RCC_C1_ APB3ENR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WWDG1EN	Res.	Res.	LTDCEN	Res.	Res.	Res.	Res.
	Reset value																									0			0				

Table 80. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x148	**RCC_C1_ APB1LENR**	UART8EN	UART7EN	DAC12EN	Res.	CECEN	Res.	I2C5EN	Res.	I2C3EN	I2C2EN	I2C1EN	UART5EN	UART4EN	USART3EN	USART2EN	SPDIFRXEN	SPI3EN	SPI2EN	Res.	Res.	Res.	Res.	LPTIM1EN	TIM14EN	TIM13EN	TIM12EN	TIM7EN	TIM6EN	TIM5EN	TIM4EN	TIM3EN	TIM2EN
	Reset value	0	0	0		0		0		0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0
0x14C	**RCC_C1_ APB1HENR**	Res.	Res.	Res.	Res.	Res.	Res.	TIM24EN	TIM23EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FDCANEN	Res.	Res.	MDIOSEN	OPAMPEN	Res.	SWPMIEN	CRSEN	Res.
	Reset value							0	0																0			0	0		0	0	
0x150	**RCC_C1_ APB2ENR**	Res.	DFSDM1EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SAI1EN	Res.	SPI5EN	Res.	TIM17EN	TIM16EN	TIM15EN	Res.	Res.	SPI4EN	SPI1EN	Res.	Res.	Res.	Res.	USART10EN	Res.	UART9EN	USART6EN	USART1EN	Res.	Res.	TIM8EN	TIM1EN
	Reset value		0								0		0		0	0	0			0	0					0		0	0	0			0	0
0x154	**RCC_C1_ APB4ENR**	Res.	Res.	Res.	Res.	Res.	DTSEN	Res.	Res.	Res.	Res.	SAI4EN	Res.	Res.	Res.	Res.	RTCAPBEN	VREFEN	COMP12EN	Res.	LPTIM5EN	LPTIM4EN	LPTIM3EN	LPTIM2EN	Res.	I2C4EN	Reserved	SPI6EN	Res.	LPUART1EN	Res.	SYSCFGEN	Res.	
	Reset value						0					0					1	0	0		0	0	0	0		0	0	0		0		0		
0x158	**reserved**	Reserved																															
0x15C	**RCC_C1_ AHB3LPENR**	AXISRAMLPEN	ITCMLPEN	DTCM2LPEN	DTCM1LPEN	Res.	Res.	Res.	Res.	OTFD2LPEN	OTFD1LPEN	IOMNGRLPEN	Res.	SDMMC1LPEN	Res.	Res.	SDMMC1LPEN	Res.	OCTO1LPEN	Res.	FMCLPEN	Res.	Res.	Res.	FLASHLPEN	Res.	Res.	Res.	DMA2DLPEN	Res.	Res.	Res.	Res.	MDMALPEN
	Reset value	1	1	1	1					1	1	1		1			1		1		1				1				1				1
0x160	**RCC_C1_ AHB1LPENR**	Res.	Res.	Res.	Res.	Res.	USB1OTGHSULPILPEN	USB1OTGHSLPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETH1RXLPEN	ETH1TXLPEN	ETH1MACLPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADC12LPEN	Res.	Res.	DMA2LPEN	DMA1LPEN
	Reset value						1	1								1	1	1											1			1	1
0x164	**RCC_C1_ AHB2LPENR**	Res.	SRAM2LPEN	SRAM1LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CORDICLPEN	FMACLPEN	Res.	Res.	Res.	Res.	Res.	Res.	SDMMC2LPEN	Res.	Res.	RNGLPEN	HASHLPEN	CRYPTLPEN	Res.	Res.	Res.	DCMI_PSSILPEN
	Reset value		1	1												1	1							1			1	1	1				1

Table 80. RCC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x168	**RCC_C1_ AHB4LPENR**	Res.	Res.	SRAM4LPEN	BKPRAMLPEN	Res.	Res.	Res.	ADC3LPEN	Res.	Res.	BDMALPEN	Res.	CRCLPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GPIOKLPEN	GPIOJLPEN	Res.	GPIOHLPEN	GPIOGLPEN	GPIOFLPEN	GPIOELPEN	GPIODLPEN	GPIOCLPEN	GPIOBLPEN	GPIOALPEN
	Reset value			1	1				1			1		1									1	1		1	1	1	1	1	1	1	1
0x16C	**RCC_C1_ APB3LPENR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WWDG1LPEN	Res.	Res.	LTDCLPEN	Res.	Res.	Res.
	Reset value																										1			1			
0x170	**RCC_C1_ APB1LLPENR**	UART8LPEN	UART7LPEN	DAC12LPEN	Res.	CECLPEN	Res.	I2C5LPEN	Res.	I2C3LPEN	I2C2LPEN	I2C1LPEN	UART5LPEN	UART4LPEN	USART3LPEN	USART2LPEN	SPDIFRXLPEN	SPI3LPEN	SPI2LPEN	Res.	Res.	Res.	Res.	LPTIM1LPEN	TIM14LPEN	TIM13LPEN	TIM12LPEN	TIM7LPEN	TIM6LPEN	TIM5LPEN	TIM4LPEN	TIM3LPEN	TIM2LPEN
	Reset value	1	1	1		1		1		1	1	1	1	1	1	1	1	1	1					1	1	1	1	1	1	1	1	1	1
0x174	**RCC_C1_ APB1HLPENR**	Res.	Res.	Res.	Res.	Res.	TIM24LPEN	TIM23LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FDCANLPEN	Res.	Res.	MDIOSLPEN	OPAMPLPEN	Res.	SWPMILPEN	CRSLPEN	Res.
	Reset value						1	1																	1			1	1		1	1	
0x178	**RCC_C1_ APB2LPENR**	Res.	DFSDM1LPEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SAI1LPEN	Res.	SPI5LPEN	Res.	TIM17LPEN	TIM16LPEN	TIM15LPEN	Res.	Res.	SPI4LPEN	SPI1LPEN	Res.	Res.	Res.	Res.	USART10LPEN	UART9LPEN	USART6LPEN	USART1LPEN	Res.	Res.	TIM8LPEN	TIM1LPEN
	Reset value		1								1		1		1	1	1			1	1					1	1	1	1			1	1
0x17C	**RCC_C1_ APB4LPENR**	Res.	Res.	Res.	Res.	Res.	DTSLPEN	Res.	Res.	Res.	Res.	SAI4LPEN	Res.	Res.	Res.	Res.	RTCAPBLPEN	VREFLPEN	COMP12LPEN	Res.	LPTIM5LPEN	LPTIM4LPEN	LPTIM3LPEN	LPTIM2LPEN	Res.	I2C4LPEN	Res.	SPI6LPEN	Res.	LPUART1LPEN	Res.	SYSCFGLPEN	Res.
	Reset value						1					1					1	1	1		1	1	1	1		1		1		1		1	
0x180 to 0x1FC	**reserved**	Reserved																															

Refer to *Section 2.3 on page 131* for the register boundary addresses.

9 Clock recovery system (CRS)

9.1 Introduction

The clock recovery system (CRS) is an advanced digital controller acting on the internal fine-granularity trimmable RC oscillator HSI48. The CRS provides powerful means for oscillator output frequency evaluation, based on comparison with a selectable synchronization signal. It is capable of doing automatic adjustment of oscillator trimming based on the measured frequency error value, while keeping the possibility of a manual trimming.

The CRS is ideally suited to provide a precise clock to the USB peripheral. In such case, the synchronization signal can be derived from the start-of-frame (SOF) packet signalization on the USB bus, which is sent by a USB host at 1 ms intervals.

The synchronization signal can also be derived from the LSE oscillator output or it can be generated by user software.

9.2 CRS main features

- Selectable synchronization source with programmable prescaler and polarity:
  - External pin
  - LSE oscillator output
  - USB SOF packet reception
- Possibility to generate synchronization pulses by software
- Automatic oscillator trimming capability with no need of CPU action
- Manual control option for faster start-up convergence
- 16-bit frequency error counter with automatic error value capture and reload
- Programmable limit for automatic frequency error value evaluation and status reporting
- Maskable interrupts/events:
  - Expected synchronization (ESYNC)
  - Synchronization OK (SYNCOK)
  - Synchronization warning (SYNCWARN)
  - Synchronization or trimming error (ERR)

9.3 CRS implementation

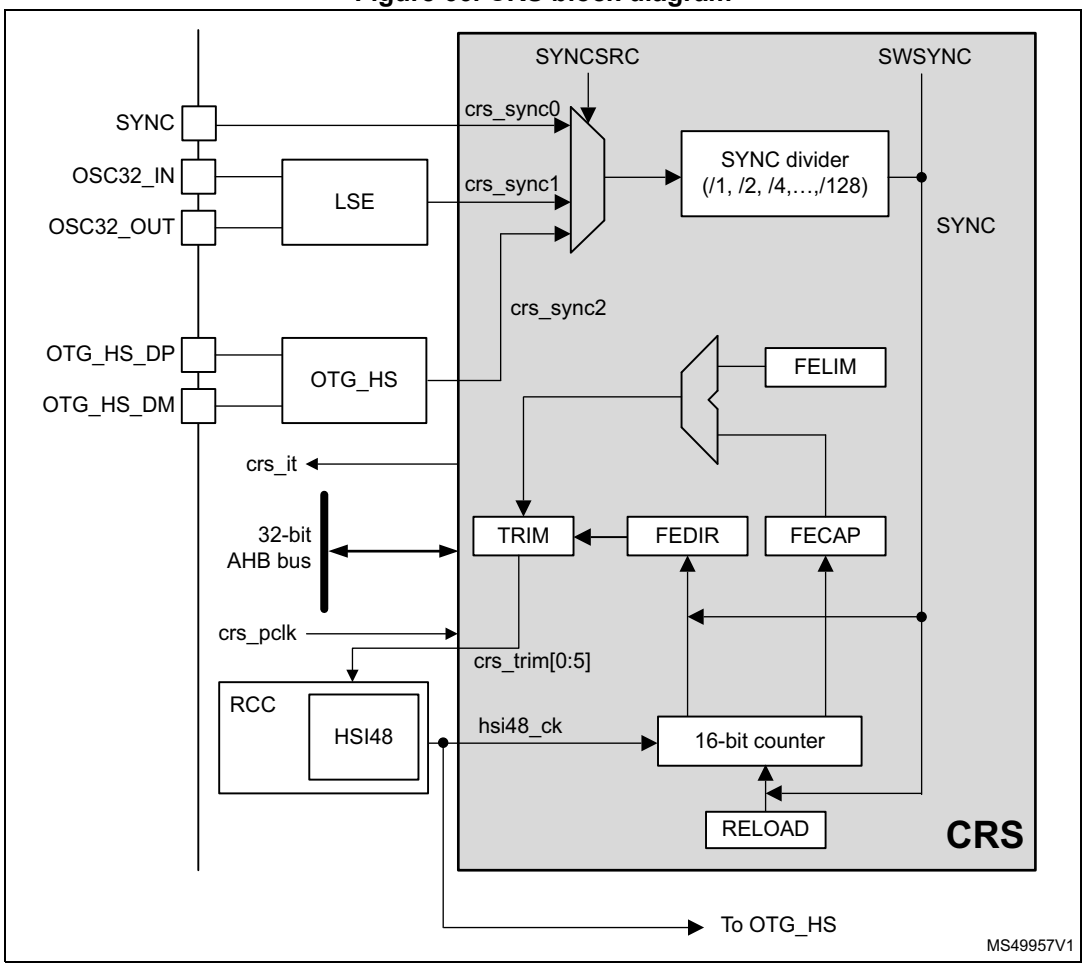
Table 81. CRS features

Feature	CRS1
TRIM width	6 bits

9.4 CRS functional description

9.4.1 CRS block diagram

Figure 66. CRS block diagram



9.5 CRS internal signals

Table 82 gives the list of CRS internal signals.

Table 82. CRS internal input/output signals

Signal name	Signal type	Description
crs_it	Digital output	CRS interrupt
crs_pclk	Digital input	AHB bus clock
hsi48_ck	Digital input	HSI48 oscillator clock

Table 82. CRS internal input/output signals (continued)

Signal name	Signal type	Description
crs_trim[0:5]	Digital output	HSI48 oscillator smooth trimming value
crs_sync0 crs_sync1 crs_sync2	Digital input	SYNC signal source selection (SYNC, LSE or OTG_HS)

9.5.1 Synchronization input

The CRS synchronization (SYNC) source, selectable through the CRS_CFGR register, can be the signal from an external signal (SYNC), the LSE clock,or the OTG HS SOF signal. This source signal also has a configurable polarity and can then be divided by a programmable binary prescaler to obtain a synchronization signal in a suitable frequency range (usually around 1 kHz).

For more information on the CRS synchronization source configuration, refer to *Section 9.8.2: CRS configuration register (CRS_CFGR)*.

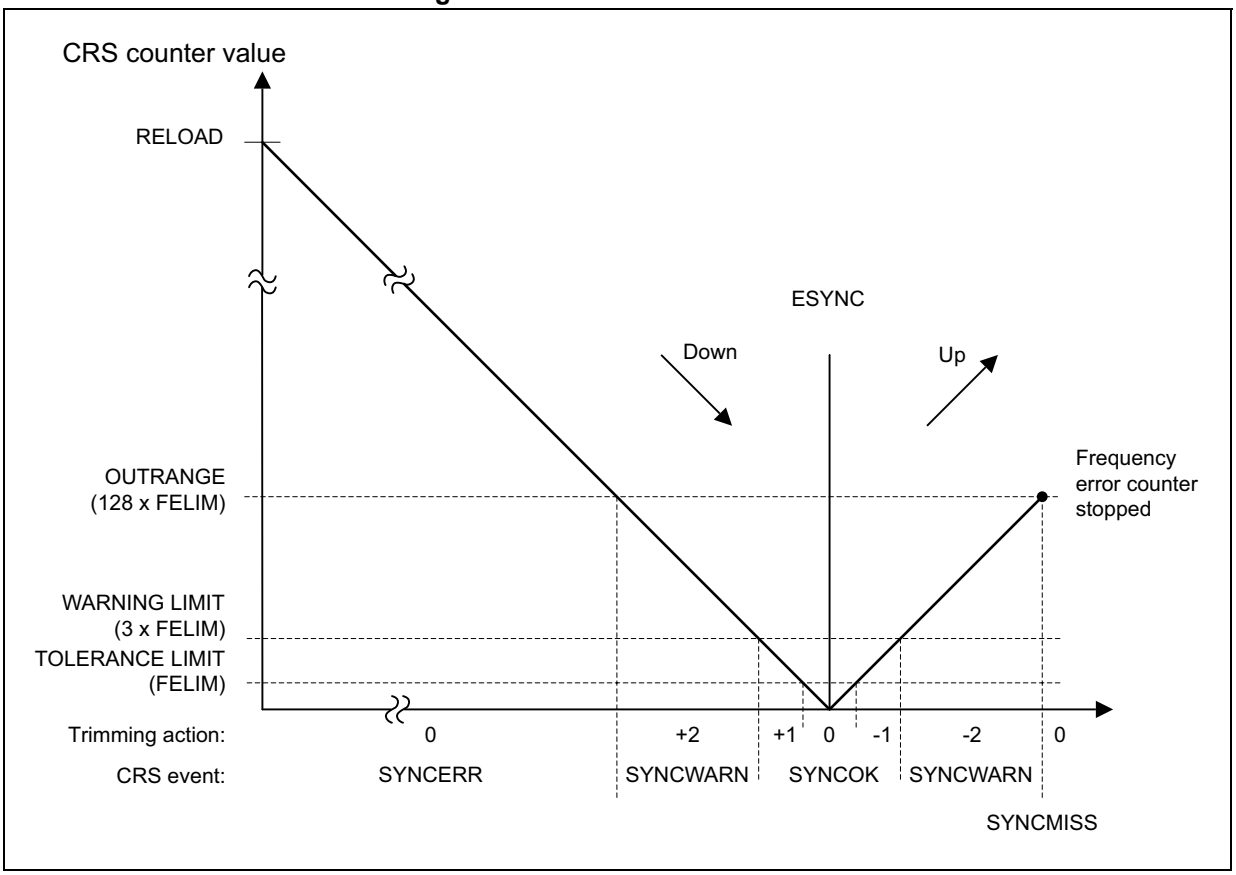
It is also possible to generate a synchronization event by software, by setting the SWSYNC bit in the CRS_CR register.

9.5.2 Frequency error measurement

The frequency error counter is a 16-bit down/up counter which is reloaded with the RELOAD value on each SYNC event. It starts counting down till it reaches the zero value, where the ESYNC (expected synchronization) event is generated. Then it starts counting up to the OUTRANGE limit where it eventually stops (if no SYNC event is received) and generates a SYNCMISS event. The OUTRANGE limit is defined as the frequency error limit (FELIM field of the CRS_CFGR register) multiplied by 128.

When the SYNC event is detected, the actual value of the frequency error counter and its counting direction are stored in the FECAP (frequency error capture) field and in the FEDIR (frequency error direction) bit of the CRS_ISR register. When the SYNC event is detected during the downcounting phase (before reaching the zero value), it means that the actual frequency is lower than the target (and so, that the TRIM value must be incremented), while when it is detected during the upcounting phase it means that the actual frequency is higher (and that the TRIM value must be decremented).

Figure 67. CRS counter behavior



9.5.3 Frequency error evaluation and automatic trimming

The measured frequency error is evaluated by comparing its value with a set of limits:

- TOLERANCE LIMIT, given directly in the FELIM field of the CRS_CFGR register
- WARNING LIMIT, defined as 3 × FELIM value
- OUTRANGE (error limit), defined as 128 × FELIM value

The result of this comparison is used to generate the status indication and also to control the automatic trimming which is enabled by setting the AUTOTRIMEN bit in the CRS_CR register:

- When the frequency error is below the tolerance limit, it means that the actual trimming value in the TRIM field is the optimal one, hence no trimming action is needed.
  - SYNCOK status indicated
  - TRIM value not changed in AUTOTRIM mode
- When the frequency error is below the warning limit but above or equal to the tolerance limit, it means that some trimming action is necessary but that adjustment by one trimming step is enough to reach the optimal TRIM value.
  - SYNCOK status indicated
  - TRIM value adjusted by one trimming step in AUTOTRIM mode

- When the frequency error is above or equal to the warning limit but below the error limit, it means that a stronger trimming action is necessary, and there is a risk that the optimal TRIM value is not reached for the next period.
  - SYNCWARN status indicated
  - TRIM value adjusted by two trimming steps in AUTOTRIM mode
- When the frequency error is above or equal to the error limit, it means that the frequency is out of the trimming range. This can also happen when the SYNC input is not clean or when some SYNC pulse is missing (for example when one USB SOF is corrupted).
  - SYNCERR or SYNCMISS status indicated
  - TRIM value not changed in AUTOTRIM mode

Note: If the actual value of the TRIM field is so close to its limits that the automatic trimming would force it to overflow or underflow, then the TRIM value is set just to the limit and the TRIMOVF status is indicated.

In AUTOTRIM mode (AUTOTRIMEN bit set in the CRS_CR register), the TRIM field of CRS_CR is adjusted by hardware and is read-only.

9.5.4 CRS initialization and configuration

RELOAD value

The RELOAD value must be selected according to the ratio between the target frequency and the frequency of the synchronization source after prescaling. It is then decreased by one to reach the expected synchronization on the zero value. The formula is the following:

$$RELOAD = (f_{TARGET} / f_{SYNC}) - 1$$

The reset value of the RELOAD field corresponds to a target frequency of 48 MHz and a synchronization signal frequency of 1 kHz (SOF signal from USB).

FELIM value

The selection of the FELIM value is closely coupled with the HSI48 oscillator characteristics and its typical trimming step size. The optimal value corresponds to half of the trimming step size, expressed as a number of HSI48 oscillator clock ticks. The following formula can be used:

$$FELIM = (f_{TARGET} / f_{SYNC}) * STEP[\%] / 100\% / 2$$

The result must be always rounded up to the nearest integer value to obtain the best trimming response. If frequent trimming actions are not needed in the application, the hysteresis can be increased by slightly increasing the FELIM value.

The reset value of the FELIM field corresponds to $(f_{TARGET} / f_{SYNC}) = 48000$ and to a typical trimming step size of 0.14%.

Note: The trimming step size depends upon the product, check the datasheet for accurate setting.

Caution: There is no hardware protection from a wrong configuration of the RELOAD and FELIM fields which can lead to an erratic trimming response. The expected operational mode requires proper setup of the RELOAD value (according to the synchronization source frequency), which is also greater than 128 * FELIM value (OUTRANGE limit).

9.6 CRS low-power modes

Table 83. Effect of low-power modes on CRS

Mode	Description
Sleep	No effect. CRS interrupts cause the device to exit the Sleep mode.
Stop	CRS registers are frozen. The CRS stops operating until the Stop mode is exited and the HSI48 oscillator restarted.
Standby	The CRS peripheral is powered down and must be reinitialized after exiting Standby mode.

9.7 CRS interrupts

Table 84. Interrupt control bits

Interrupt event	Event flag	Enable control bit	Clear flag bit
Expected synchronization	ESYNCF	ESYNCIE	ESYNCC
Synchronization OK	SYNCOKF	SYNCOKIE	SYNCOKC
Synchronization warning	SYNCWARNF	SYNCWARNIE	SYNCWARNC
Synchronization or trimming error (TRIMOVF, SYNCMISS, SYNCERR)	ERRF	ERRIE	ERRC

9.8 CRS registers

Refer to *Section 1.2 on page 104* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed only by words (32-bit).

9.8.1 CRS control register (CRS_CR)

Address offset: 0x00

Reset value: 0x0000 2000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	TRIM[5:0]						SW SYNC	AUTO TRIMEN	CEN	Res.	ESYNCIE	ERRIE	SYNC WARNIE	SYNC OKIE
		rw	rw	rw	rw	rw	rw	rt_w1	rw	rw		rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bits 13:8 **TRIM[5:0]**: HSI48 oscillator smooth trimming

These bits provide a user-programmable trimming value to the HSI48 oscillator. They can be programmed to adjust to variations in voltage and temperature that influence the frequency of the HSI48 oscillator.

The default value is 32, which corresponds to the middle of the trimming interval. The trimming step is specified in the product datasheet. A higher TRIM value corresponds to a higher output frequency.

When the AUTOTRIMEN bit is set, this field is controlled by hardware and is read-only.

Bit 7 **SWSYNC**: Generate software SYNC event

This bit is set by software in order to generate a software SYNC event. It is automatically cleared by hardware.

0: No action

1: A software SYNC event is generated.

Bit 6 **AUTOTRIMEN**: Automatic trimming enable

This bit enables the automatic hardware adjustment of TRIM bits according to the measured frequency error between two SYNC events. If this bit is set, the TRIM bits are read-only. The TRIM value can be adjusted by hardware by one or two steps at a time, depending on the measured frequency error value. Refer to *Section 9.5.3* for more details.

0: Automatic trimming disabled, TRIM bits can be adjusted by the user.

1: Automatic trimming enabled, TRIM bits are read-only and under hardware control.

Bit 5 **CEN**: Frequency error counter enable

This bit enables the oscillator clock for the frequency error counter.

0: Frequency error counter disabled

1: Frequency error counter enabled

When this bit is set, the CRS_CFGR register is write-protected and cannot be modified.

Bit 4 Reserved, must be kept at reset value.

Bit 3 **ESYNCIE**: Expected SYNC interrupt enable

0: Expected SYNC (ESYNCF) interrupt disabled

1: Expected SYNC (ESYNCF) interrupt enabled

Bit 2 **ERRIE**: Synchronization or trimming error interrupt enable
0: Synchronization or trimming error (ERRF) interrupt disabled
1: Synchronization or trimming error (ERRF) interrupt enabled

Bit 1 **SYNCWARNIE**: SYNC warning interrupt enable
0: SYNC warning (SYNCWARNF) interrupt disabled
1: SYNC warning (SYNCWARNF) interrupt enabled

Bit 0 **SYNCOKIE**: SYNC event OK interrupt enable
0: SYNC event OK (SYNCOKF) interrupt disabled
1: SYNC event OK (SYNCOKF) interrupt enabled

9.8.2 CRS configuration register (CRS_CFGR)

This register can be written only when the frequency error counter is disabled (CEN bit is cleared in CRS_CR). When the counter is enabled, this register is write-protected.

Address offset: 0x04

Reset value: 0x2022 BB7F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SYNCPOL	Res.	SYNCSRC[1:0]		Res.	SYNCDIV[2:0]			FELIM[7:0]							
rw		rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RELOAD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **SYNCPOL**: SYNC polarity selection
This bit is set and cleared by software to select the input polarity for the SYNC signal source.
0: SYNC active on rising edge (default)
1: SYNC active on falling edge

Bit 30 Reserved, must be kept at reset value.

Bits 29:28 **SYNCSRC[1:0]**: SYNC signal source selection
These bits are set and cleared by software to select the SYNC signal source.
00: CRS_SYNC pin selected as SYNC signal source
01: LSE selected as SYNC signal source
10: OTG HS SOF selected as SYNC signal source (default)
11: Reserved

Note: When using USB LPM (Link Power Management) and the device is in Sleep mode, the periodic USB SOF will not be generated by the host. No SYNC signal will therefore be provided to the CRS to calibrate the HSI48 oscillator on the run. To guarantee the required clock precision after waking up from Sleep mode, the LSE clock or the SYNC pin must be used as SYNC signal.

Bit 27 Reserved, must be kept at reset value.

Bits 26:24 **SYNCDIV[2:0]**: SYNC divider

These bits are set and cleared by software to control the division factor of the SYNC signal.
000: SYNC not divided (default)
001: SYNC divided by 2
010: SYNC divided by 4
011: SYNC divided by 8
100: SYNC divided by 16
101: SYNC divided by 32
110: SYNC divided by 64
111: SYNC divided by 128

Bits 23:16 **FELIM[7:0]**: Frequency error limit

FELIM contains the value to be used to evaluate the captured frequency error value latched in the FECAP[15:0] bits of the CRS_ISR register. Refer to *Section 9.5.3* for more details about FECAP evaluation.

Bits 15:0 **RELOAD[15:0]**: Counter reload value

RELOAD is the value to be loaded in the frequency error counter with each SYNC event. Refer to *Section 9.5.2* for more details about counter behavior.

9.8.3 CRS interrupt and status register (CRS_ISR)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FECAP[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FEDIR	Res.	Res.	Res.	Res.	TRIM OVF	SYNC MISS	SYNC ERR	Res.	Res.	Res.	Res.	ESYNCF	ERRF	SYNC WARNF	SYNC OKF
r					r	r	r					r	r	r	r

Bits 31:16 **FECAP[15:0]**: Frequency error capture

FECAP is the frequency error counter value latched in the time of the last SYNC event. Refer to *Section 9.5.3* for more details about FECAP usage.

Bit 15 **FEDIR**: Frequency error direction

FEDIR is the counting direction of the frequency error counter latched in the time of the last SYNC event. It shows whether the actual frequency is below or above the target.
0: Upcounting direction, the actual frequency is above the target.
1: Downcounting direction, the actual frequency is below the target.

Bits 14:11 Reserved, must be kept at reset value.

Bit 10 **TRIMOVF**: Trimming overflow or underflow

This flag is set by hardware when the automatic trimming tries to over- or under-flow the TRIM value. An interrupt is generated if the ERRIE bit is set in the CRS_CR register. It is cleared by software by setting the ERRC bit in the CRS_ICR register.
0: No trimming error signalized
1: Trimming error signalized

Bit 9 **SYNCMISS**: SYNC missed

This flag is set by hardware when the frequency error counter reached value FELIM * 128 and no SYNC was detected, meaning either that a SYNC pulse was missed or that the frequency error is too big (internal frequency too high) to be compensated by adjusting the TRIM value, and that some other action has to be taken. At this point, the frequency error counter is stopped (waiting for a next SYNC) and an interrupt is generated if the ERRIE bit is set in the CRS_CR register. It is cleared by software by setting the ERRC bit in the CRS_ICR register.

0: No SYNC missed error signalized

1: SYNC missed error signalized

Bit 8 **SYNCERR**: SYNC error

This flag is set by hardware when the SYNC pulse arrives before the ESYNC event and the measured frequency error is greater than or equal to FELIM * 128. This means that the frequency error is too big (internal frequency too low) to be compensated by adjusting the TRIM value, and that some other action has to be taken. An interrupt is generated if the ERRIE bit is set in the CRS_CR register. It is cleared by software by setting the ERRC bit in the CRS_ICR register.

0: No SYNC error signalized

1: SYNC error signalized

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **ESYNCF**: Expected SYNC flag

This flag is set by hardware when the frequency error counter reached a zero value. An interrupt is generated if the ESYNCIE bit is set in the CRS_CR register. It is cleared by software by setting the ESYNCC bit in the CRS_ICR register.

0: No expected SYNC signalized

1: Expected SYNC signalized

Bit 2 **ERRF**: Error flag

This flag is set by hardware in case of any synchronization or trimming error. It is the logical OR of the TRIMOVF, SYNCMISS and SYNCERR bits. An interrupt is generated if the ERRIE bit is set in the CRS_CR register. It is cleared by software in reaction to setting the ERRC bit in the CRS_ICR register, which clears the TRIMOVF, SYNCMISS and SYNCERR bits.

0: No synchronization or trimming error signalized

1: Synchronization or trimming error signalized

Bit 1 **SYNCWARNF**: SYNC warning flag

This flag is set by hardware when the measured frequency error is greater than or equal to FELIM * 3, but smaller than FELIM * 128. This means that to compensate the frequency error, the TRIM value must be adjusted by two steps or more. An interrupt is generated if the SYNCWARNIE bit is set in the CRS_CR register. It is cleared by software by setting the SYNCWARNC bit in the CRS_ICR register.

0: No SYNC warning signalized

1: SYNC warning signalized

Bit 0 **SYNCOKF**: SYNC event OK flag

This flag is set by hardware when the measured frequency error is smaller than FELIM * 3. This means that either no adjustment of the TRIM value is needed or that an adjustment by one trimming step is enough to compensate the frequency error. An interrupt is generated if the SYNCOKIE bit is set in the CRS_CR register. It is cleared by software by setting the SYNCOKC bit in the CRS_ICR register.

0: No SYNC event OK signalized

1: SYNC event OK signalized

9.8.4 CRS interrupt flag clear register (CRS_ICR)

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ESYNCC	ERRC	SYNC WARNC	SYNC OKC
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **ESYNCC**: Expected SYNC clear flag
Writing 1 to this bit clears the ESYNCF flag in the CRS_ISR register.

Bit 2 **ERRC**: Error clear flag
Writing 1 to this bit clears TRIMOVF, SYNCMISS and SYNCERR bits and consequently also the ERRF flag in the CRS_ISR register.

Bit 1 **SYNCWARNC**: SYNC warning clear flag
Writing 1 to this bit clears the SYNCWARNF flag in the CRS_ISR register.

Bit 0 **SYNCOKC**: SYNC event OK clear flag
Writing 1 to this bit clears the SYNCOKF flag in the CRS_ISR register.

9.8.5 CRS register map

Table 85. CRS register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**CRS_CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIM[5:0]						SWSYNC	AUTOTRIMEN	CEN	Res.	ESYNCIE	ERRIE	SYNCWARNIE	SYNCOKIE
	Reset value																			1	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	**CRS_CFGR**	SYNCPOL	Res.	SYNC SRC [1:0]		Res.	SYNC DIV [2:0]			FELIM[7:0]								RELOAD[15:0]															
	Reset value	0		1	0		0	0	0	0	0	1	0	0	0	1	0	1	0	1	1	1	0	1	1	0	1	1	1	1	1	1	1
0x08	**CRS_ISR**	FECAP[15:0]																FEDIR	Res.	Res.	Res.	Res.	TRIMOVF	SYNCMISS	SYNCERR	Res.	Res.	Res.	Res.	ESYNCF	ERRF	SYNCWARNF	SYNCOKF
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0					0	0	0	0

Table 85. CRS register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0C	**CRS_ICR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ESYNCC	ERRC	SYNCWARNC	SYNCOKC
	Reset value																													0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

10 Hardware semaphore (HSEM)

10.1 Introduction

The hardware semaphore block provides 32 (32-bit) register based semaphores.

The semaphores can be used to ensure synchronization between different processes running on the core. The HSEM provides a non blocking mechanism to lock semaphores in an atomic way. The following functions are provided:

- Semaphore lock, in two ways:
  - 2-step lock: by writing MASTERID and PROCID to the semaphore, followed by a read check
  - 1-step lock: by reading the MASTERID from the semaphore
- Interrupt generation when a semaphore is unlocked
  - Each semaphore may generate an interrupt
- Semaphore clear protection
  - A semaphore is only unlocked when MASTERID and PROCID match
- Global semaphore clear per MASTERID

10.2 Main features

The HSEM includes the following features:

- 32 (32-bit) semaphores
- 8-bit PROCID
- 4-bit MASTERID
- 1 interrupt line
- Lock indication

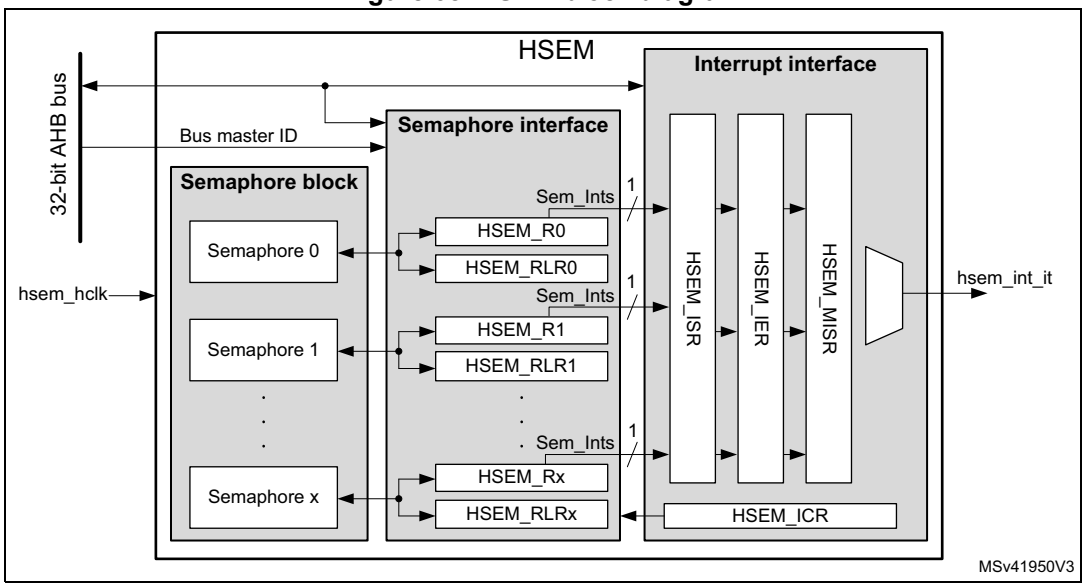
10.3 Functional description

10.3.1 HSEM block diagram

As shown in *Figure 68*, the HSEM is based on three sub-blocks:

- the semaphore block containing the semaphore status and IDs
- the semaphore interface block providing AHB access to the semaphore via the HSEM_Rx and HSEM_RLRx registers
- the interrupt interface block providing control for the interrupts via HSEM_ISR, HSEM_IER, HSEM_MISR, and HSEM_ICR registers.

Figure 68. HSEM block diagram



10.3.2 HSEM internal signals

Table 86. HSEM internal input/output signals

Signal name	Signal type	Description
AHB bus	Digital input/output	AHB register access bus
BusMasterID	Digital input	AHB bus master ID
hsem_int_it	Digital output	Interrupt line

10.3.3 HSEM lock procedures

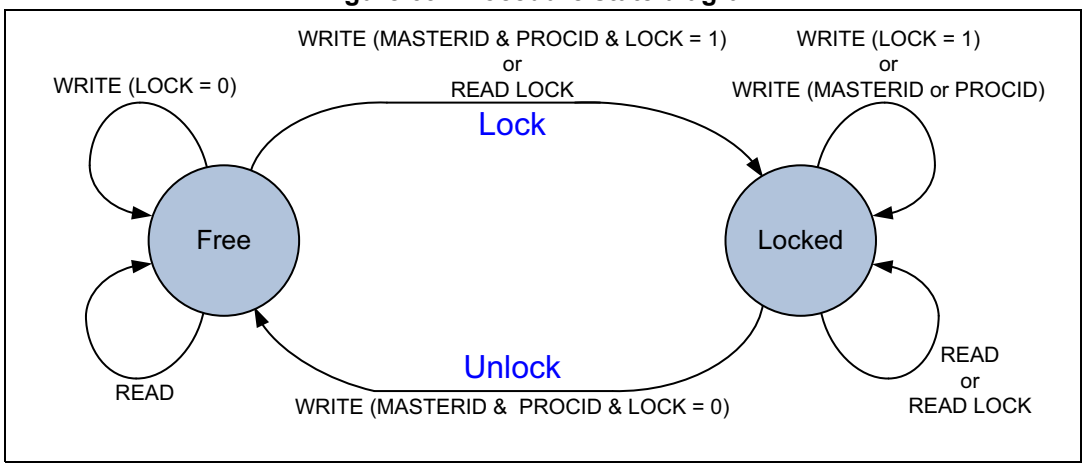
There are two lock procedures, namely 2-step (write) lock and 1-step (read) lock. The two procedures can be used concurrently.

The semaphore is free when its LOCK bit is 0. In this case, the MASTERID and PROCID are also 0. When the LOCK bit is 1, the semaphore is locked and the MASTERID indicates which AHB bus master ID has locked it. The PROCID indicates which process of that AHB bus master ID has locked the semaphore.

When write locking a semaphore, the written MASTERID must match the AHB bus master ID , and the PROCID is written by the AHB bus master software process taking the lock.

When read locking the semaphore, the MASTERID is taken from the AHB bus master ID, and the PROCID is forced to 0 by hardware. There is no PROCID available with read lock.

Figure 69. Procedure state diagram



2-step (write) lock procedure

The 2-step lock procedure consists in a write to lock the semaphore, followed by a read to check if the lock has been successful, carried out from the HSEM_Rx register

- Write semaphore with PROCID and MASTERID, and LOCK = 1. The MASTERID data written by software must match the AHB bus master information. i.e. a AHB bus master ID = 1writes data MASTERID = 1.

  Lock is put in place when the semaphore is free at write time.
- Read-back the semaphore

  The software checks the lock status, if PROCID and MASTERID match the written data, then the lock is confirmed.
- Else retry (the semaphore has been locked by another process).

A semaphore can only be locked when it is free.

A semaphore can be locked when the PROCID = 0.

Consecutive write attempts with LOCK = 1 to a locked semaphore are ignored.

1-step (read) lock procedure

The 1-step procedure consists in a read to lock and check the semaphore in a single step, carried out from the HSEM_RLRx register.

- Read lock semaphore with the AHB bus master MASTERID.
- If read MASTERID matches and PROCID = 0, then lock is put in place. If MASTERID matches and PROCID is not 0, this means that another process from the same MASTERID has locked the semaphore with a 2-step (write) procedure.
- Else retry (the semaphore has been locked by another process).

A semaphore can only be locked when it is free. When read locking a free semaphore, PROCID is 0. Read locking a locked semaphore returns the MASTERID and PROCID that locked it. All read locks, including the first one that locks the semaphore, return the MASTERID that locks or locked the semaphore.

Note: The 1-step procedure must not be used when running multiple processes of the same AHB bus master ID. All processes using the same semaphore read the same status. When only one process locks the semaphore, each process of that AHB bus master ID reads the semaphore as locked by itself with the MASTERID.

10.3.4 HSEM write/read/read lock register address

For each semaphore, two AHB register addresses are provided, separated in two banks of 32-bit semaphore registers, spaced by a 0x80 address offset.

In the first register address bank the semaphore can be written (locked/unlocked) and read through the HSEM_Rx registers.

In the second register address bank the semaphore can be read (locked) through the HSEM_RLRx registers.

10.3.5 HSEM unlock procedures

Unlocking a semaphore is a protected process, to prevent accidental clearing by a AHB bus master ID or by a process not having the semaphore lock right. The procedure consists in writing to the semaphore HSEM_Rx register with the corresponding MASTERID and PROCID and LOCK = 0. When unlocked the semaphore, the MASTERID, and the PROCID are all 0.

When unlocked, an interrupt may be generated to signal the event. To this end, the semaphore interrupt must be enabled.

The unlock procedure consists in a write to the semaphore HSEM_Rx register with matching MASTERID regardless on how the semaphore has been locked (1- or 2-step).

- Write semaphore with PROCID, MASTERID, and LOCK = 0
- If the written data matches the semaphore PROCID and MASTERID and the AHB bus master ID , the semaphore is unlocked and an interrupt may be generated when enabled, else write is ignored, semaphore remains locked and no interrupt is generated (the semaphore is locked by another process or the written data does not match the AHB bus master signaling).

Note: Different processes of the AHB bus master ID can write any PROCID value. Preventing other processes of the AHB bus master ID from unlocking a semaphore must be ensured by software, handling the PROCID correctly.

10.3.6 HSEM MASTERID semaphore clear

All semaphores locked by a MASTERID can be unlocked at once by using the HSEM_CR register. Write MASTERID and correct KEY value in HSEM_CR. All locked semaphores with a matching MASTERID are unlocked, and may generate an interrupt when enabled.

An interrupt may be generated for the unlocked semaphore(s). To this end, the semaphore interrupt must be enabled in the HSEM_IER register.

10.3.7 HSEM interrupts

An interrupt line hsem_int_it allows each semaphore to generate an interrupt.

An interrupt line provides the following features per semaphore:

- interrupt enable
- interrupt clear
- interrupt status
- masked interrupt status

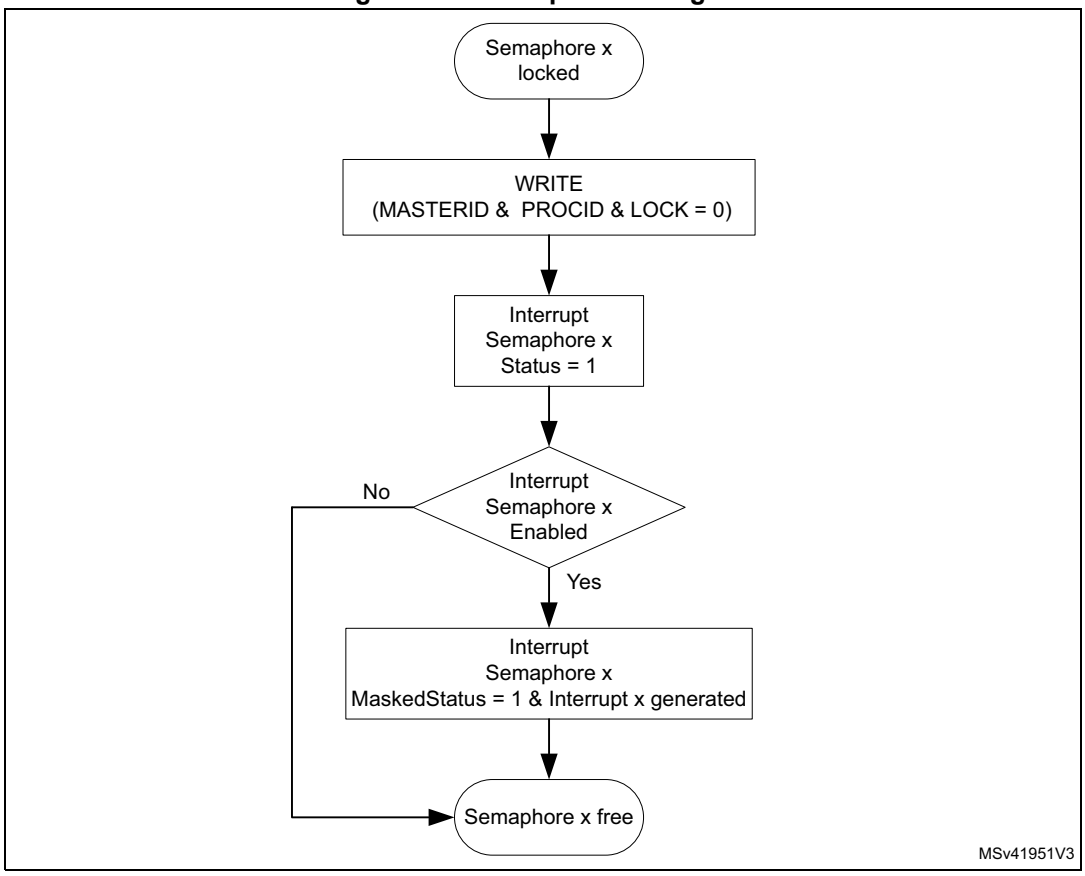
With the interrupt enable (HSEM_IER) the semaphores affecting the interrupt line can be enabled. Disabled (masked) semaphore interrupts do not set the masked interrupt status MISF for that semaphore, and do not generate an interrupt on the interrupt line.

The interrupt clear (HSEM_ICR) clears the interrupt status ISF and masked interrupt status MISF of the associated semaphore for the interrupt line.

The interrupt status (HSEM_ISR) mirrors the semaphore interrupt status ISF before the enable.

The masked interrupt status (HSEM_MISR) only mirrors the semaphore enabled interrupt status MISF on the interrupt line. All masked interrupt status MISF of the enabled semaphores need to be cleared to clear the interrupt line.

Figure 70. Interrupt state diagram



The procedure to get an interrupt when a semaphore becomes free is described hereafter.

Try to lock semaphore x

- If the semaphore lock is obtained, no interrupt is needed.
- If the semaphore lock fails:
- Clear pending semaphore x interrupt status for the interrupt line in HSEM_ICR.
  Re-try to lock the semaphore x again:
  - If the semaphore lock is obtained, no interrupt is needed (semaphore has been freed between first try to lock and clear semaphore interrupt status).
  - If the semaphore lock fails, enable the semaphore x interrupt in HSEM_IER.

On semaphore x free interrupt, try to lock semaphore x

- If the semaphore lock is obtained:
  Disable the semaphore x interrupt in HSEM_IER.
  Clear pending semaphore x interrupt status in HSEM_ICR.
- If the semaphore x lock fails:
  Clear pending semaphore x interrupt status in HSEM_ICR.
  Try again to lock the semaphore x:
  - If the semaphore lock is obtained (semaphore has been freed between first try to lock and semaphore Interrupt status clear), disable the semaphore interrupt in HSEM_IER.

– If the semaphore lock fails, wait for semaphore free interrupt.

Note: An interrupt does not lock the semaphore. After an interrupt, either the AHB bus master or the process must still perform the lock procedure to lock the semaphore.

10.3.8 AHB bus master ID verification

The HSEM allows only authorized AHB bus master ID to lock and unlock semaphores.

- The AHB bus master 2-step lock write access to the semaphore HSEM_Rx register is checked against the valid bus master ID.
  – Accesses from unauthorized AHB bus master IDs are discarded and do not lock the semaphore.
- The AHB bus master 1-step lock read access from the semaphore HSEM_RLRx register is checked against the valid bus master ID.
  – An unauthorized AHB bus master ID read from HSEM_RLRx returns all 0.
- The semaphore unlock write access to the HSEM_CR register is checked against the valid bus master ID. Only the valid bus master ID can write to the HSEM_CR register and unlock any of the MASTERID semaphores.
  – Accesses from unauthorized AHB bus master IDs are discarded and do not clear the MASTERID semaphores.

Table 87 details the relation between bus master/processor and MASTERID.

Table 87. Authorized AHB bus master ID

Bus master 0 (CPU)
MASTERID = 3

Note: Accesses from unauthorized AHB bus master IDs to other registers are granted.

10.4 HSEM registers

Registers must be accessed using word format. Byte and half-word accesses are ignored and have no effect on the semaphores, they generate a bus error.

10.4.1 HSEM register semaphore x (HSEM_Rx)

Address offset: 0x000 + 0x4 * x (x = 0 to 31)

Reset value: 0x0000 0000

The HSEM_Rx must be used to perform a 2-step write lock, read back, and for unlocking a semaphore. Only write accesses with authorized AHB bus master ID is granted. Write accesses with unauthorized AHB bus master IDs are discarded.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LOCK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	MASTERID[3:0]				PROCID[7:0]							
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **LOCK:** Lock indication

This bit can be written and read by software.

0: On write free semaphore (only when MASTERID and PROCID match), on read semaphore is free.

1: On write try to lock semaphore, on read semaphore is locked.

Bits 30:13 Reserved, must be kept at reset value.

Bit 12 Reserved, must be kept at reset value.

Bits 11:8 **MASTERID[3:0]:** Semaphore MASTERID

Written by software

- When the semaphore is free and the LOCK bit is at the same time written to 1 and the MASTERID matches the AHB bus master ID.
- When the semaphore is unlocked (LOCK written to 0 and AHB bus master ID matched MASTERID, the MASTERID is cleared to 0.
- When the semaphore is unlocked (LOCK bit written to 0 or AHB bus master ID does not match MASTERID, the MASTERID is not affected.
- Write when LOCK bit is already 1 (semaphore locked), the MASTERID is not affected.
- An authorized read returns the stored MASTERID value.

Bits 7:0 **PROCID[7:0]:** Semaphore PROCID

Written by software

-When the semaphore is free and the LOCK is written to 1, and the MASTERID matches the AHB bus master ID, PROCID is set to the written data.

- When the semaphore is unlocked, LOCK written to 0 and AHB bus master ID matched MASTERID, the PROCID is cleared to 0.
- When the semaphore is unlocked, LOCK bit written to 0 and AHB bus master ID does not match MASTERID, the PROCID is not affected.
- Write when LOCK bit is already 1 (semaphore locked), the PROCID is not affected.
- An authorized read returns the stored PROCID value.

10.4.2 HSEM read lock register semaphore x (HSEM_RLRx)

Address offset: 0x080 + 0x004 * x (x = 0 to 31)

Reset value: 0x0000 0000

Accesses the same physical bits as HSEM_Rx. The HSEM_RLRx must be used to perform a 1-step read lock. Only read accesses with authorized AHB bus master ID is granted. Read accesses with unauthorized AHB bus master IDs are discarded and return 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LOCK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	MASTERID[3:0]				PROCID[7:0]							
				r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 **LOCK:** Lock indication

This bit is read only by software at this address.

- When the semaphore is free:

A read with a valid AHB bus master ID locks the semaphore and returns 1.

- When the semaphore is locked:

A read with a valid AHB bus master ID returns 1 (the MASTERID and PROCID reflect the already locked semaphore information).

Bits 30:13 Reserved, must be kept at reset value.

Bit 12 Reserved, must be kept at reset value.

Bits 11:8 **MASTERID[3:0]:** Semaphore MASTERID

This field is read only by software at this address.

On a read, when the semaphore is free, the hardware sets the MASTERID to the AHB bus master ID reading the semaphore. The MASTERID of the AHB bus master locking the semaphore is read.

On a read when the semaphore is locked, this field returns the MASTERID of the AHB bus master that has locked the semaphore.

Bits 7:0 **PROCID[7:0]:** Semaphore processor ID

This field is read only by software at this address.

- On a read when the semaphore is free:

A read with a valid AHB bus master ID locks the semaphore and hardware sets the PROCID to 0.

- When the semaphore is locked:

A read with a valid AHB bus master ID returns the PROCID of the AHB bus master that has locked the semaphore.

10.4.3 HSEM interrupt enable register (HSEM_IER)

Address offset: 0x100

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ISE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ISE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ISE[31:0]:** Interrupt semaphore x enable bit (x = 0 to 31)

This bit is read and written by software.

0: Interrupt generation for semaphore x disabled (masked)

1: Interrupt generation for semaphore x enabled (not masked)

10.4.4 HSEM interrupt clear register (HSEM_ICR)

Address offset: 0x104

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ISC[31:16]															
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ISC[15:0]															
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:0 **ISC[31:0]:** Interrupt semaphore x clear bit (x = 0 to 31)

This bit is written by software, and is always read 0.

0: Interrupt semaphore x status ISFx and masked status MISFx not affected.

1: Interrupt semaphore x status ISFx and masked status MISFx cleared.

10.4.5 HSEM interrupt status register (HSEM_ISR)

Address offset: 0x108

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ISF[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ISF[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **ISF[31:0]:** Interrupt semaphore x status bit before enable (mask) (x = 0 to 31)

This bit is set by hardware, and reset only by software. This bit is cleared by software writing the corresponding HSEM_ICR bit.

0: Interrupt semaphore x status, no interrupt pending

1: Interrupt semaphore x status, interrupt pending

10.4.6 HSEM interrupt status register (HSEM_MISR)

Address offset: 0x10C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MISF[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MISF[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **MISF[31:0]:** Masked interrupt semaphore x status bit after enable (mask) (x = 0 to 31)
This bit is set by hardware and read only by software. This bit is cleared by software writing the corresponding HSEM_ICR bit. This bit is read as 0 when semaphore x status is masked in HSEM_IER bit x.
0: interrupt semaphore x status after masking not pending
1: interrupt semaphore x status after masking pending

10.4.7 HSEM clear register (HSEM_CR)

Address offset: 0x140

Reset value: 0x0000 0000

Only write accesses with authorized AHB bus master ID are granted. Write accesses with unauthorized AHB bus master ID are discarded.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	MASTERID[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
				w	w	w	w								

Bits 31:16 **KEY[15:0]:** Semaphore clear key
This field can be written by software and is always read 0.
If this key value does not match HSEM_KEYR.KEY, semaphores are not affected.
If this key value matches HSEM_KEYR.KEY, all semaphores matching the MASTERID are cleared to the free state.

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 Reserved, must be kept at reset value.

Bits 11:8 **MASTERID[3:0]:** MASTERID of semaphores to be cleared
This field can be written by software and is always read 0.
This field indicates the MASTERID for which the semaphores are cleared when writing the HSEM_CR.

Bits 7:0 Reserved, must be kept at reset value.

10.4.8 HSEM interrupt clear register (HSEM_KEYR)

Address offset: 0x144

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
KEY[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:16 **KEY[15:0]:** Semaphore clear key
This field can be written and read by software.
Key value to match when clearing semaphores.

Bits 15:0 Reserved, must be kept at reset value.

10.4.9 HSEM register map

Table 88. HSEM register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**HSEM_R0**	LOCK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MASTERID [3:0]				PROCID[7:0]							
	Reset value	0																				0	0	0	0	0	0	0	0	0	0	0	0
0x004	**HSEM_R1**	LOCK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MASTERID [3:0]				PROCID[7:0]							
	Reset value	0																				0	0	0	0	0	0	0	0	0	0	0	0
⋮																																	
0x07C	**HSEM_R31**	LOCK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MASTERID [3:0]				PROCID[7:0]							
	Reset value	0																				0	0	0	0	0	0	0	0	0	0	0	0
0x080	**HSEM_RLR0**	LOCK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MASTERID [3:0]				PROCID							
	Reset value	0																				0	0	0	0	0	0	0	0	0	0	0	0
0x084	**HSEM_RLR1**	LOCK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MASTERID [3:0]				PROCID[7:0]							
	Reset value	0																				0	0	0	0	0	0	0	0	0	0	0	0
⋮																																	
0x0FC	**HSEM_RLR31**	LOCK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MASTERID [3:0]				PROCID[7:0]							
	Reset value	0																				0	0	0	0	0	0	0	0	0	0	0	0
0x100	**HSEM_IER**	ISE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x104	**HSEM_ICR**	ISC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x108	**HSEM_ISR**	ISF[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10C	**HSEM_MISR**	MISF[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x140	**HSEM_CR**	KEY[15:0]																Res.	Res.	Res.	Res.	MASTERID[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0								
0x144	**HSEM_KEYR**	KEY[15:0]																Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																

Refer to *Section 2.3 on page 131* for the register boundary addresses.

11 General-purpose I/Os (GPIO)

11.1 Introduction

Each general-purpose I/O port has four 32-bit configuration registers (GPIOx_MODER, GPIOx_OTYPER, GPIOx_OSPEEDR and GPIOx_PUPDR), two 32-bit data registers (GPIOx_IDR and GPIOx_ODR) and a 32-bit set/reset register (GPIOx_BSRR). In addition all GPIOs have a 32-bit locking register (GPIOx_LCKR) and two 32-bit alternate function selection registers (GPIOx_AFRH and GPIOx_AFRL).

11.2 GPIO main features

- Output states: push-pull or open drain + pull-up/down
- Output data from output data register (GPIOx_ODR) or peripheral (alternate function output)
- Speed selection for each I/O
- Input states: floating, pull-up/down, analog
- Input data to input data register (GPIOx_IDR) or peripheral (alternate function input)
- Bit set and reset register (GPIOx_ BSRR) for bitwise write access to GPIOx_ODR
- Locking mechanism (GPIOx_LCKR) provided to freeze the I/O port configurations
- Analog function
- Alternate function selection registers
- Fast toggle capable of changing every two clock cycles
- Highly flexible pin multiplexing allows the use of I/O pins as GPIOs or as one of several peripheral functions

11.3 GPIO functional description

Subject to the specific hardware characteristics of each I/O port listed in the datasheet, each port bit of the general-purpose I/O (GPIO) ports can be individually configured by software in several modes:

- Input floating
- Input pull-up
- Input-pull-down
- Analog
- Output open-drain with pull-up or pull-down capability
- Output push-pull with pull-up or pull-down capability
- Alternate function push-pull with pull-up or pull-down capability
- Alternate function open-drain with pull-up or pull-down capability

Each I/O port bit is freely programmable, however the I/O port registers have to be accessed as 32-bit words, half-words or bytes. The purpose of the GPIOx_BSRR register is to allow atomic read/modify accesses to any of the GPIOx_ODR registers. In this way, there is no risk of an IRQ occurring between the read and the modify access.

Figure 71 and *Figure 72* show the basic structures of a standard and a 5-Volt tolerant I/O port bit, respectively. *Table 89* gives the possible port bit configurations.

Figure 71. Basic structure of an I/O port bit

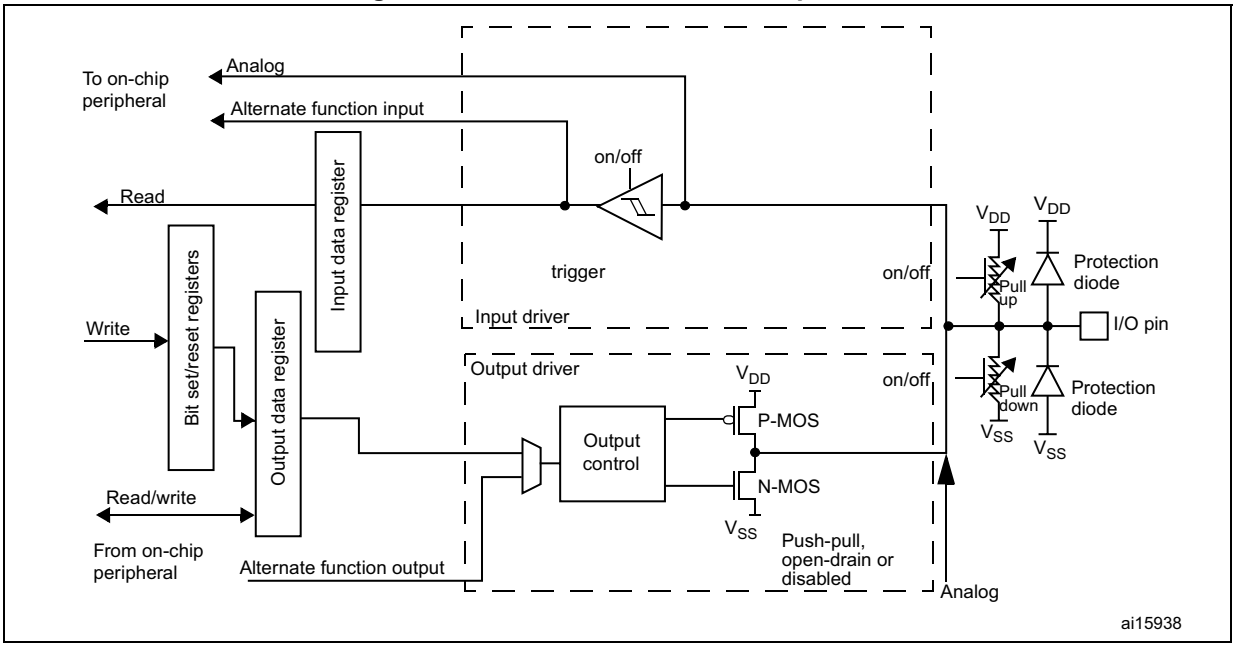
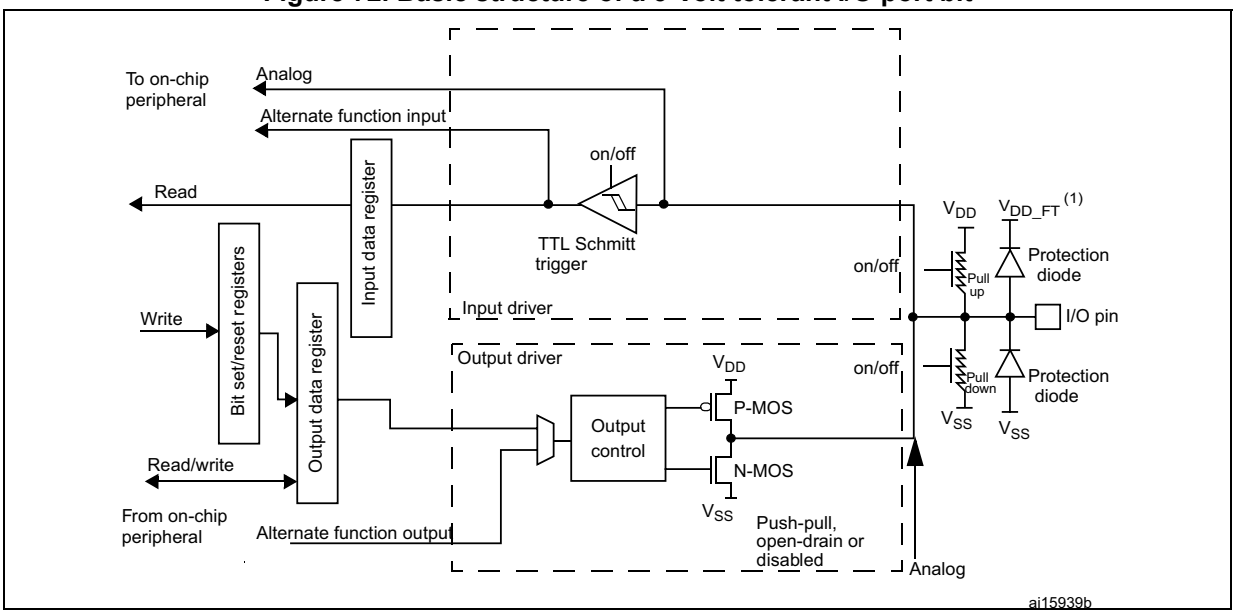


Figure 72. Basic structure of a 5-Volt tolerant I/O port bit



1. V_{DD_FT} is a potential specific to 5-Volt tolerant I/Os and different from V_{DD}.

Table 89. Port bit configuration table(1)

MODE(i) [1:0]	OTYPER(i)	OSPEED(i) [1:0]		PUPD(i) [1:0]		I/O configuration	
01	0	SPEED [1:0]		0	0	GP output	PP
	0			0	1	GP output	PP + PU
	0			1	0	GP output	PP + PD
	0			1	1	Reserved	
	1			0	0	GP output	OD
	1			0	1	GP output	OD + PU
	1			1	0	GP output	OD + PD
	1			1	1	Reserved (GP output OD)	
10	0	SPEED [1:0]		0	0	AF	PP
	0			0	1	AF	PP + PU
	0			1	0	AF	PP + PD
	0			1	1	Reserved	
	1			0	0	AF	OD
	1			0	1	AF	OD + PU
	1			1	0	AF	OD + PD
	1			1	1	Reserved	
00	x	x	x	0	0	Input	Floating
	x	x	x	0	1	Input	PU
	x	x	x	1	0	Input	PD
	x	x	x	1	1	Reserved (input floating)	
11	x	x	x	0	0	Input/output	Analog
	x	x	x	0	1	Reserved	
	x	x	x	1	0		
	x	x	x	1	1		

1. GP = general-purpose, PP = push-pull, PU = pull-up, PD = pull-down, OD = open-drain, AF = alternate function.

11.3.1 General-purpose I/O (GPIO)

During and just after reset, the alternate functions are not active and most of the I/O ports are configured in analog mode.

The debug pins are in AF pull-up/pull-down after reset:

- PA15: JTDI in pull-up
- PA14: JTCK/SWCLK in pull-down
- PA13: JTMS/SWDAT in pull-up
- PB4: NJTRST in pull-up
- PB3: JTDO in floating state

When the pin is configured as output, the value written to the output data register (GPIOx_ODR) is output on the I/O pin. It is possible to use the output driver in push-pull mode or open-drain mode (only the low level is driven, high level is HI-Z).

The input data register (GPIOx_IDR) captures the data present on the I/O pin at every AHB clock cycle.

All GPIO pins have weak internal pull-up and pull-down resistors, which can be activated or not depending on the value in the GPIOx_PUPDR register.

11.3.2 I/O pin alternate function multiplexer and mapping

The device I/O pins are connected to on-board peripherals/modules through a multiplexer that allows only one peripheral alternate function (AF) connected to an I/O pin at a time. In this way, there can be no conflict between peripherals available on the same I/O pin.

Each I/O pin has a multiplexer with up to sixteen alternate function inputs (AF0 to AF15) that can be configured through the GPIOx_AFRL (for pin 0 to 7) and GPIOx_AFRH (for pin 8 to 15) registers:

- After reset the multiplexer selection is alternate function 0 (AF0). The I/Os are configured in alternate function mode through GPIOx_MODER register.
- The specific alternate function assignments for each pin are detailed in the device datasheet.
- Cortex-M7 with FPU EVENTOUT is mapped on AF15

In addition to this flexible I/O multiplexing architecture, each peripheral has alternate functions mapped onto different I/O pins to optimize the number of peripherals available in smaller packages.

To use an I/O in a given configuration, the user has to proceed as follows:

- **Debug function:** after each device reset these pins are assigned as alternate function pins immediately usable by the debugger host
- **System function:** MCOx pins have to be configured in alternate function mode.
- **GPIO:** configure the desired I/O as output, input or analog in the GPIOx_MODER register.
- **Peripheral alternate function:**
  - Connect the I/O to the desired AFx in one of the GPIOx_AFRL or GPIOx_AFRH register.
  - Select the type, pull-up/pull-down and output speed via the GPIOx_OTYPER, GPIOx_PUPDR and GPIOx_OSPEEDER registers, respectively.

  - Configure the desired I/O as an alternate function in the GPIOx_MODER register.
- **Additional functions:**
  - For the ADC and DAC, configure the desired I/O in analog mode in the GPIOx_MODER register and configure the required function in the ADC and DAC registers.
  - For the additional functions like RTC_OUT, RTC_TS, RTC_TAMPx, WKUPx and oscillators, configure the required function in the related RTC, PWR and RCC registers. These functions have priority over the configuration in the standard GPIO registers. For details about I/O control by the RTC, refer to *Section 51.4: RTC functional description on page 1944*.
- EVENTOUT
  - Configure the I/O pin used to output the core EVENTOUT signal by connecting it to AF15.

Refer to the “Alternate function mapping” table in the device datasheet for the detailed mapping of the alternate function I/O pins.

11.3.3 I/O port control registers

Each of the GPIO ports has four 32-bit memory-mapped control registers (GPIOx_MODER, GPIOx_OTYPER, GPIOx_OSPEEDR, GPIOx_PUPDR) to configure up to 16 I/Os. The GPIOx_MODER register is used to select the I/O mode (input, output, AF, analog). The GPIOx_OTYPER and GPIOx_OSPEEDR registers are used to select the output type (push-pull or open-drain) and speed. The GPIOx_PUPDR register is used to select the pull-up/pull-down whatever the I/O direction.

11.3.4 I/O port data registers

Each GPIO has two 16-bit memory-mapped data registers: input and output data registers (GPIOx_IDR and GPIOx_ODR). GPIOx_ODR stores the data to be output, it is read/write accessible. The data input through the I/O are stored into the input data register (GPIOx_IDR), a read-only register.

See *Section 11.4.5: GPIO port input data register (GPIOx_IDR) (x = A to H, J, K)* and *Section 11.4.6: GPIO port output data register (GPIOx_ODR) (x = A to H, J, K)* for the register descriptions.

11.3.5 I/O data bitwise handling

The bit set reset register (GPIOx_BSRR) is a 32-bit register which allows the application to set and reset each individual bit in the output data register (GPIOx_ODR). The bit set reset register has twice the size of GPIOx_ODR.

To each bit in GPIOx_ODR, correspond two control bits in GPIOx_BSRR: BS(i) and BR(i). When written to 1, bit BS(i) **sets** the corresponding ODR(i) bit. When written to 1, bit BR(i) **resets** the ODR(i) corresponding bit.

Writing any bit to 0 in GPIOx_BSRR does not have any effect on the corresponding bit in GPIOx_ODR. If there is an attempt to both set and reset a bit in GPIOx_BSRR, the set action takes priority.

Using the GPIOx_BSRR register to change the values of individual bits in GPIOx_ODR is a “one-shot” effect that does not lock the GPIOx_ODR bits. The GPIOx_ODR bits can always

be accessed directly. The GPIOx_BSRR register provides a way of performing atomic bitwise handling.

There is no need for the software to disable interrupts when programming the GPIOx_ODR at bit level: it is possible to modify one or more bits in a single atomic AHB write access.

11.3.6 GPIO locking mechanism

It is possible to freeze the GPIO control registers by applying a specific write sequence to the GPIOx_LCKR register. The frozen registers are GPIOx_MODER, GPIOx_OTYPER, GPIOx_OSPEEDR, GPIOx_PUPDR, GPIOx_AFRL and GPIOx_AFRH.

To write the GPIOx_LCKR register, a specific write / read sequence has to be applied. When the right LOCK sequence is applied to bit 16 in this register, the value of LCKR[15:0] is used to lock the configuration of the I/Os (during the write sequence the LCKR[15:0] value must be the same). When the LOCK sequence has been applied to a port bit, the value of the port bit can no longer be modified until the next MCU reset or peripheral reset. Each GPIOx_LCKR bit freezes the corresponding bit in the control registers (GPIOx_MODER, GPIOx_OTYPER, GPIOx_OSPEEDR, GPIOx_PUPDR, GPIOx_AFRL and GPIOx_AFRH.

The LOCK sequence (refer to *Section 11.4.8: GPIO port configuration lock register (GPIOx_LCKR) (x = A to H, J, K)*) can only be performed using a word (32-bit long) access to the GPIOx_LCKR register due to the fact that GPIOx_LCKR bit 16 has to be set at the same time as the [15:0] bits.

For more details refer to LCKR register description in *Section 11.4.8: GPIO port configuration lock register (GPIOx_LCKR) (x = A to H, J, K)*.

11.3.7 I/O alternate function input/output

Two registers are provided to select one of the alternate function inputs/outputs available for each I/O. With these registers, the user can connect an alternate function to some other pin as required by the application.

This means that a number of possible peripheral functions are multiplexed on each GPIO using the GPIOx_AFRL and GPIOx_AFRH alternate function registers. The application can thus select any one of the possible functions for each I/O. The AF selection signal being common to the alternate function input and alternate function output, a single channel is selected for the alternate function input/output of a given I/O.

To know which functions are multiplexed on each GPIO pin refer to the device datasheet.

11.3.8 External interrupt/wakeup lines

All ports have external interrupt capability. To use external interrupt lines, the port must be configured in input mode.

Refer to *Section 20: Extended interrupt and event controller (EXTI)* and to *Section 20.3: EXTI functional description.*

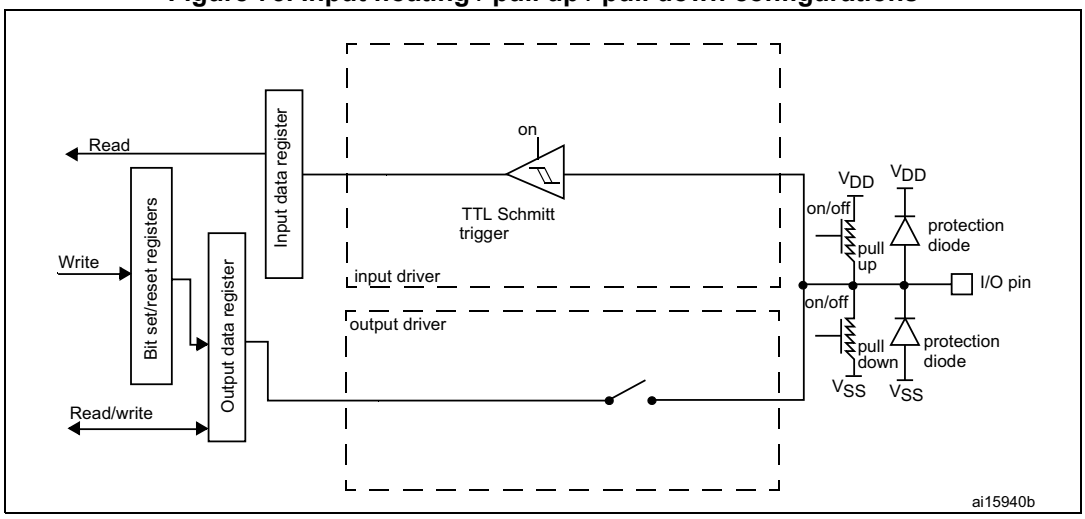
11.3.9 Input configuration

When the I/O port is programmed as input:

- The output buffer is disabled
- The Schmitt trigger input is activated
- The pull-up and pull-down resistors are activated depending on the value in the GPIOx_PUPDR register
- The data present on the I/O pin are sampled into the input data register every AHB clock cycle
- A read access to the input data register provides the I/O state

Figure 73 shows the input configuration of the I/O port bit.

Figure 73. Input floating / pull up / pull down configurations



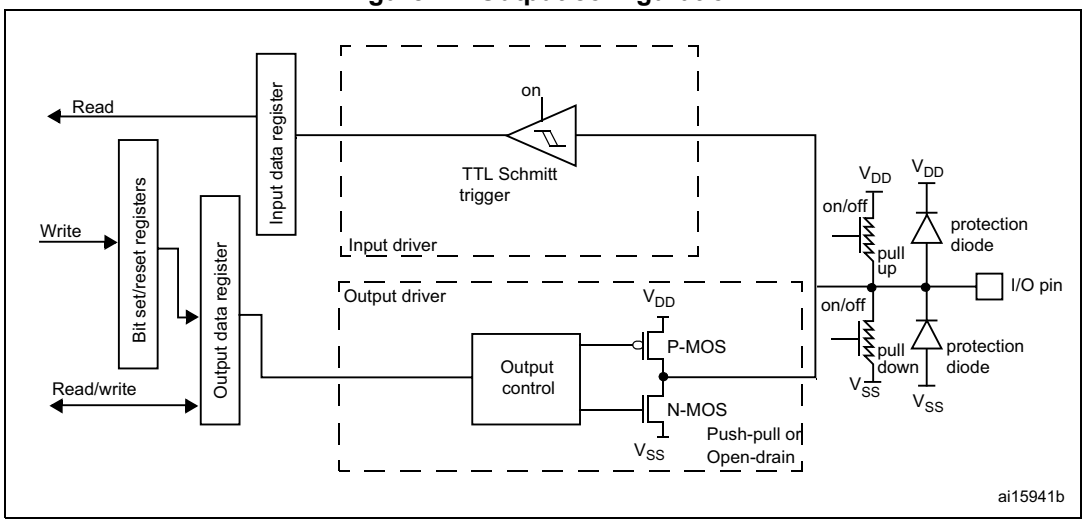
11.3.10 Output configuration

When the I/O port is programmed as output:

- The output buffer is enabled:
  - Open drain mode: A “0” in the Output register activates the N-MOS whereas a “1” in the Output register leaves the port in Hi-Z (the P-MOS is never activated)
  - Push-pull mode: A “0” in the Output register activates the N-MOS whereas a “1” in the Output register activates the P-MOS
- The Schmitt trigger input is activated
- The pull-up and pull-down resistors are activated depending on the value in the GPIOx_PUPDR register
- The data present on the I/O pin are sampled into the input data register every AHB clock cycle
- A read access to the input data register gets the I/O state
- A read access to the output data register gets the last written value

Figure 74 shows the output configuration of the I/O port bit.

Figure 74. Output configuration



11.3.11 I/O compensation cell

This cell is used to control the I/O commutation slew rate (t_{fall} / t_{rise}) to reduce the I/O noise on power supply.

The cell is split into two blocks:

- The first block provides an optimal code for the current PVT. The code stored in this block can be read when the READY flag of the SYSCFG_CCSR is set.
- The second block controls the I/O slew rate.The user selects the code to be applied and programs it by software.

The I/O compensation cell features 2 voltage ranges: 1.62 to 2.0 V and 2.7 to 3.6 V.

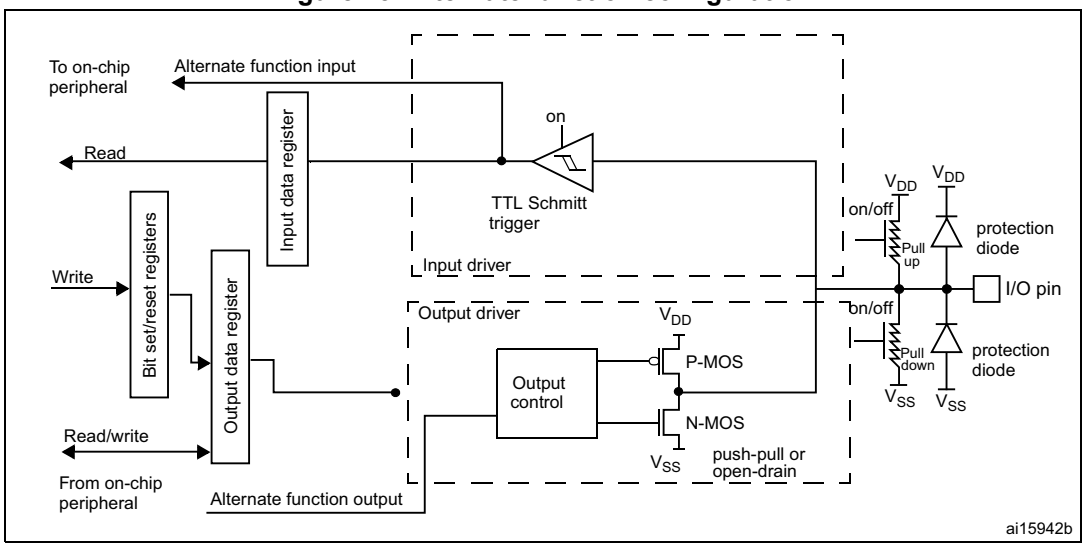
11.3.12 Alternate function configuration

When the I/O port is programmed as alternate function:

- The output buffer can be configured in open-drain or push-pull mode
- The output buffer is driven by the signals coming from the peripheral (transmitter enable and data)
- The Schmitt trigger input is activated
- The weak pull-up and pull-down resistors are activated or not depending on the value in the GPIOx_PUPDR register
- The data present on the I/O pin are sampled into the input data register every AHB clock cycle
- A read access to the input data register gets the I/O state

Figure 75 shows the alternate function configuration of the I/O port bit.

Figure 75. Alternate function configuration



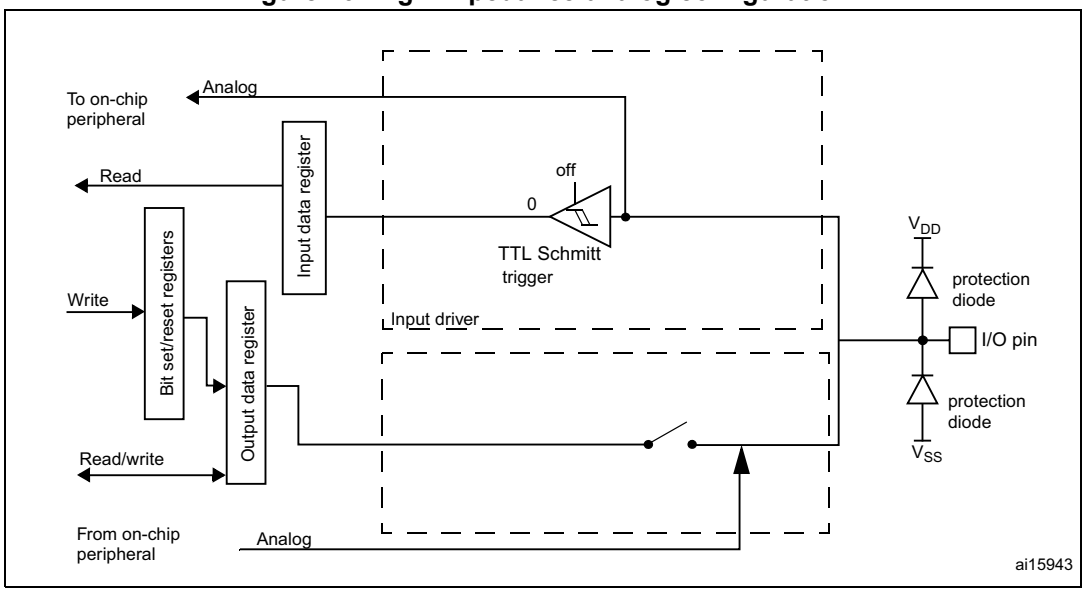
11.3.13 Analog configuration

When the I/O port is programmed as analog configuration:

- The output buffer is disabled
- The Schmitt trigger input is deactivated, providing zero consumption for every analog value of the I/O pin. The output of the Schmitt trigger is forced to a constant value (0).
- The weak pull-up and pull-down resistors are disabled by hardware
- Read access to the input data register gets the value “0”

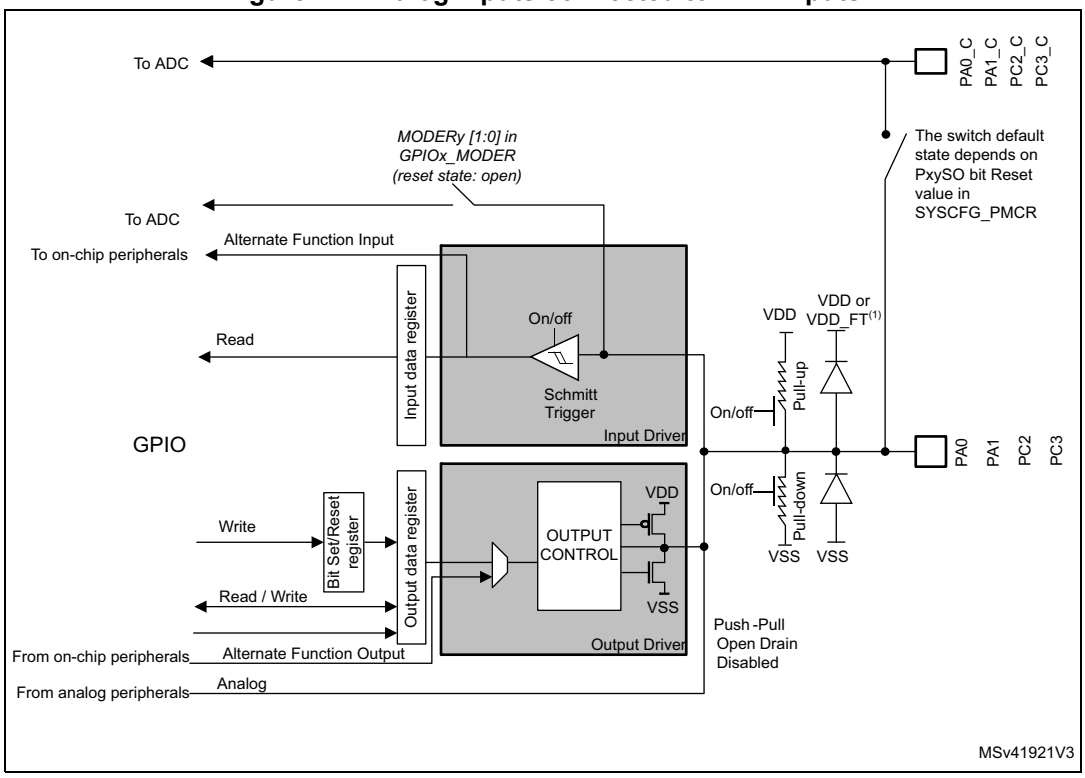
Figure 76 shows the high-impedance, analog-input configuration of the I/O port bits.

Figure 76. High impedance-analog configuration



Some pins/balls are directly connected to PA0_C, PA1_C, PC2_C and PC3_C ADC analog inputs (see *Figure 77*): there is a direct path between Pxy_C and Pxy pins/balls, through an analog switch (refer to *Section 12.4.1: SYSCFG peripheral mode configuration register (SYSCFG_PMCR)* for details on how to configure analog switches).

Figure 77. Analog inputs connected to ADC inputs



1. VDD_FT is a potential specific to 5V tolerant I/Os. It is distinct from VDD.

11.3.14 Using the HSE or LSE oscillator pins as GPIOs

When the HSE or LSE oscillator is switched OFF (default state after reset), the related oscillator pins can be used as normal GPIOs.

When the HSE or LSE oscillator is switched ON (by setting the HSEON or LSEON bit in the RCC_CSR register) the oscillator takes control of its associated pins and the GPIO configuration of these pins has no effect.

When the oscillator is configured in a user external clock mode, only the OSC_IN or OSC32_IN pin is reserved for clock input and the OSC_OUT or OSC32_OUT pin can still be used as normal GPIO.

11.3.15 Using the GPIO pins in the backup supply domain

The PC13/PC14/PC15 GPIO functionality is lost when the core supply domain is powered off (when the device enters Standby mode). In this case, if their GPIO configuration is not bypassed by the RTC configuration, these pins are set in an analog input mode.

11.4 GPIO registers

For a summary of register bits, register address offsets and reset values, refer to *Table 90*.

The peripheral registers can be written in word, half word or byte mode.

11.4.1 GPIO port mode register (GPIOx_MODER) (x = A to H, J, K)

Address offset:0x00

Reset value: 0xABFF FFFF for port A

Reset value: 0xFFFF FEBF for port B

Reset value: 0x00FF 0000 for port J

Reset value: 0x0000 003F for port K

Reset value: 0xFFFF FFFF for other ports

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MODER15[1:0]		MODER14[1:0]		MODER13[1:0]		MODER12[1:0]		MODER11[1:0]		MODER10[1:0]		MODER9[1:0]		MODER8[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MODER7[1:0]		MODER6[1:0]		MODER5[1:0]		MODER4[1:0]		MODER3[1:0]		MODER2[1:0]		MODER1[1:0]		MODER0[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MODER[15:0][1:0]:** Port x configuration I/O pin y (y = 15 to 0)
These bits are written by software to configure the I/O mode.
00: Input mode
01: General purpose output mode
10: Alternate function mode
11: Analog mode (reset state)

11.4.2 GPIO port output type register (GPIOx_OTYPER) (x = A to H, J, K)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OT15	OT14	OT13	OT12	OT11	OT10	OT9	OT8	OT7	OT6	OT5	OT4	OT3	OT2	OT1	OT0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **OT[15:0]:** Port x configuration I/O pin y (y = 15 to 0)
These bits are written by software to configure the I/O output type.
0: Output push-pull (reset state)
1: Output open-drain

11.4.3 GPIO port output speed register (GPIOx_OSPEEDR) (x = A to H, J, K)

Address offset: 0x08

Reset value: 0x0C00 0000 (for port A)

Reset value: 0x0000 00C0 (for port B)

Reset value: 0x0000 0000 (for other ports)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OSPEEDR15 [1:0]		OSPEEDR14 [1:0]		OSPEEDR13 [1:0]		OSPEEDR12 [1:0]		OSPEEDR11 [1:0]		OSPEEDR10 [1:0]		OSPEEDR9 [1:0]		OSPEEDR8 [1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OSPEEDR7 [1:0]		OSPEEDR6 [1:0]		OSPEEDR5 [1:0]		OSPEEDR4 [1:0]		OSPEEDR3 [1:0]		OSPEEDR2 [1:0]		OSPEEDR1 [1:0]		OSPEEDR0 [1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **OSPEEDR[15:0][1:0]**: Port x configuration I/O pin y (y = 15 to 0)
These bits are written by software to configure the I/O output speed.
00: Low speed
01: Medium speed
10: High speed
11: Very high speed

Note: Refer to the product datasheets for the values of OSPEEDRy bits versus V_{DD} range and external load.

11.4.4 GPIO port pull-up/pull-down register (GPIOx_PUPDR) (x = A to H, J, K)

Address offset: 0x0C

Reset value: 0x6400 0000 (for port A)

Reset value: 0x0000 0100 (for port B)

Reset value: 0x0000 0000 (for other ports)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PUPDR15[1:0]		PUPDR14[1:0]		PUPDR13[1:0]		PUPDR12[1:0]		PUPDR11[1:0]		PUPDR10[1:0]		PUPDR9[1:0]		PUPDR8[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PUPDR7[1:0]		PUPDR6[1:0]		PUPDR5[1:0]		PUPDR4[1:0]		PUPDR3[1:0]		PUPDR2[1:0]		PUPDR1[1:0]		PUPDR0[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PUPDR[15:0][1:0]:** Port x configuration I/O pin y (y = 15 to 0)
These bits are written by software to configure the I/O pull-up or pull-down
00: No pull-up, pull-down
01: Pull-up
10: Pull-down
11: Reserved

11.4.5 GPIO port input data register (GPIOx_IDR) (x = A to H, J, K)

Address offset: 0x10

Reset value: 0x0000 XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IDR15	IDR14	IDR13	IDR12	IDR11	IDR10	IDR9	IDR8	IDR7	IDR6	IDR5	IDR4	IDR3	IDR2	IDR1	IDR0
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **IDR[15:0]:** Port x input data I/O pin y (y = 15 to 0)
These bits are read-only. They contain the input value of the corresponding I/O port.

11.4.6 GPIO port output data register (GPIOx_ODR) (x = A to H, J, K)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ODR15	ODR14	ODR13	ODR12	ODR11	ODR10	ODR9	ODR8	ODR7	ODR6	ODR5	ODR4	ODR3	ODR2	ODR1	ODR0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **ODR[15:0]:** Port output data I/O pin y (y = 15 to 0)
These bits can be read and written by software.
Note: For atomic bit set/reset, the ODR bits can be individually set and/or reset by writing to the GPIOx_BSRR register (x = A to H, J, K).

11.4.7 GPIO port bit set/reset register (GPIOx_BSRR) (x = A to H, J, K)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BR15	BR14	BR13	BR12	BR11	BR10	BR9	BR8	BR7	BR6	BR5	BR4	BR3	BR2	BR1	BR0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BS15	BS14	BS13	BS12	BS11	BS10	BS9	BS8	BS7	BS6	BS5	BS4	BS3	BS2	BS1	BS0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:16 **BR[15:0]:** Port x reset I/O pin y (y = 15 to 0)

These bits are write-only. A read to these bits returns the value 0x0000.

0: No action on the corresponding ODRx bit

1: Resets the corresponding ODRx bit

Note: If both BSx and BRx are set, BSx has priority.

Bits 15:0 **BS[15:0]:** Port x set I/O pin y (y = 15 to 0)

These bits are write-only. A read to these bits returns the value 0x0000.

0: No action on the corresponding ODRx bit

1: Sets the corresponding ODRx bit

11.4.8 GPIO port configuration lock register (GPIOx_LCKR) (x = A to H, J, K)

This register is used to lock the configuration of the port bits when a correct write sequence is applied to bit 16 (LCKK). The value of bits [15:0] is used to lock the configuration of the GPIO. During the write sequence, the value of LCKR[15:0] must not change. When the LOCK sequence has been applied on a port bit, the value of this port bit can no longer be modified until the next MCU reset or peripheral reset.

Note: A specific write sequence is used to write to the GPIOx_LCKR register. Only word access (32-bit long) is allowed during this locking sequence.

Each lock bit freezes a specific configuration register (control and alternate function registers).

Address offset: 0x1C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LCKK
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LCK15	LCK14	LCK13	LCK12	LCK11	LCK10	LCK9	LCK8	LCK7	LCK6	LCK5	LCK4	LCK3	LCK2	LCK1	LCK0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **LCKK:** Lock key

This bit can be read any time. It can only be modified using the lock key write sequence.

0: Port configuration lock key not active

1: Port configuration lock key active. The GPIOx_LCKR register is locked until the next MCU reset or peripheral reset.

LOCK key write sequence:

WR LCKR[16] = 1 + LCKR[15:0]

WR LCKR[16] = 0 + LCKR[15:0]

WR LCKR[16] = 1 + LCKR[15:0]

RD LCKR

RD LCKR[16] = 1 (this read operation is optional but it confirms that the lock is active)

Note: During the LOCK key write sequence, the value of LCK[15:0] must not change.

Any error in the lock sequence aborts the lock.

After the first lock sequence on any bit of the port, any read access on the LCKK bit returns 1 until the next MCU reset or peripheral reset.

Bits 15:0 **LCK[15:0]:** Port x lock I/O pin y (y = 15 to 0)

These bits are read/write but can only be written when the LCKK bit is 0.

0: Port configuration not locked

1: Port configuration locked

11.4.9 GPIO alternate function low register (GPIOx_AFRL) (x = A to H, J, K)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AFR7[3:0]				AFR6[3:0]				AFR5[3:0]				AFR4[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AFR3[3:0]				AFR2[3:0]				AFR1[3:0]				AFR0[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **AFR[7:0][3:0]:** Alternate function selection for port x I/O pin y (y = 7 to 0)
These bits are written by software to configure alternate function I/Os.
0000: AF0
0001: AF1
0010: AF2
0011: AF3
0100: AF4
0101: AF5
0110: AF6
0111: AF7
1000: AF8
1001: AF9
1010: AF10
1011: AF11
1100: AF12
1101: AF13
1110: AF14
1111: AF15

11.4.10 GPIO alternate function high register (GPIOx_AFRH) (x = A to H, J, K)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AFR15[3:0]				AFR14[3:0]				AFR13[3:0]				AFR12[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AFR11[3:0]				AFR10[3:0]				AFR9[3:0]				AFR8[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **AFR[15:8][3:0]:** Alternate function selection for port x I/O pin y (y = 15 to 8)
These bits are written by software to configure alternate function I/Os.
0000: AF0
0001: AF1
0010: AF2
0011: AF3
0100: AF4
0101: AF5
0110: AF6
0111: AF7
1000: AF8
1001: AF9
1010: AF10
1011: AF11
1100: AF12
1101: AF13
1110: AF14
1111: AF15

11.4.11 GPIO register map

The following table gives the GPIO register map and reset values.

Table 90. GPIO register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**GPIOA_MODER**	MODER15[1:0]		MODER14[1:0]		MODER13[1:0]		MODER12[1:0]		MODER11[1:0]		MODER10[1:0]		MODER9[1:0]		MODER8[1:0]		MODER7[1:0]		MODER6[1:0]		MODER5[1:0]		MODER4[1:0]		MODER3[1:0]		MODER2[1:0]		MODER1[1:0]		MODER0[1:0]	
	Reset value	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x00	**GPIOB_MODER**	MODER15[1:0]		MODER14[1:0]		MODER13[1:0]		MODER12[1:0]		MODER11[1:0]		MODER10[1:0]		MODER9[1:0]		MODER8[1:0]		MODER7[1:0]		MODER6[1:0]		MODER5[1:0]		MODER4[1:0]		MODER3[1:0]		MODER2[1:0]		MODER1[1:0]		MODER0[1:0]	
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1
0x00	**GPIOx_MODER** (where x = **C..H**)	MODER15[1:0]		MODER14[1:0]		MODER13[1:0]		MODER12[1:0]		MODER11[1:0]		MODER10[1:0]		MODER9[1:0]		MODER8[1:0]		MODER7[1:0]		MODER6[1:0]		MODER5[1:0]		MODER4[1:0]		MODER3[1:0]		MODER2[1:0]		MODER[1:0]		MODER0[1:0]	
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x00	**GPIOJ_MODER**	MODER15[1:0]		MODER14[1:0]		MODER13[1:0]		MODER12[1:0]		MODER11[1:0]		MODER10[1:0]		MODER9[1:0]		MODER8[1:0]		MODER7[1:0]		MODER6[1:0]		MODER5[1:0]		MODER4[1:0]		MODER3[1:0]		MODER2[1:0]		MODER1[1:0]		MODER0[1:0]	
	Reset value	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00	**GPIOK_MODER**	MODER15[1:0]		MODER14[1:0]		MODER13[1:0]		MODER12[1:0]		MODER11[1:0]		MODER10[1:0]		MODER9[1:0]		MODER8[1:0]		MODER7[1:0]		MODER6[1:0]		MODER5[1:0]		MODER4[1:0]		MODER3[1:0]		MODER2[1:0]		MODER1[1:0]		MODER0[1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
0x04	**GPIOx_OTYPER** (where x = **A to H, J, K**)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OT15	OT14	OT13	OT12	OT11	OT10	OT9	OT8	OT7	OT6	OT5	OT4	OT3	OT2	OT1	OT0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	**GPIOA_OSPEEDR**	OSPEEDR15[1:0]		OSPEEDR14[1:0]		OSPEEDR13[1:0]		OSPEEDR12[1:0]		OSPEEDR11[1:0]		OSPEEDR10[1:0]		OSPEEDR9[1:0]		OSPEEDR8[1:0]		OSPEEDR7[1:0]		OSPEEDR6[1:0]		OSPEEDR5[1:0]		OSPEEDR4[1:0]		OSPEEDR3[1:0]		OSPEEDR2[1:0]		OSPEEDR1[1:0]		OSPEEDR0[1:0]	
	Reset value	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	**GPIOB_OSPEEDR**	OSPEEDR15[1:0]		OSPEEDR14[1:0]		OSPEEDR13[1:0]		OSPEEDR12[1:0]		OSPEEDR11[1:0]		OSPEEDR10[1:0]		OSPEEDR9[1:0]		OSPEEDR8[1:0]		OSPEEDR7[1:0]		OSPEEDR6[1:0]		OSPEEDR5[1:0]		OSPEEDR4[1:0]		OSPEEDR3[1:0]		OSPEEDR2[1:0]		OSPEEDR1[1:0]		OSPEEDR0[1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0

Table 90. GPIO register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x08	**GPIOx_OSPEEDR** (where x = **C..H, J, K**)	OSPEEDR15[1:0]		OSPEEDR14[1:0]		OSPEEDR13[1:0]		OSPEEDR12[1:0]		OSPEEDR11[1:0]		OSPEEDR10[1:0]		OSPEEDR9[1:0]		OSPEEDR8[1:0]		OSPEEDR7[1:0]		OSPEEDR6[1:0]		OSPEEDR5[1:0]		OSPEEDR4[1:0]		OSPEEDR3[1:0]		OSPEEDR2[1:0]		OSPEEDR1[1:0]		OSPEEDR0[1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	**GPIOA_PUPDR**	PUPDR15[1:0]		PUPDR14[1:0]		PUPDR13[1:0]		PUPDR12[1:0]		PUPDR11[1:0]		PUPDR10[1:0]		PUPDR9[1:0]		PUPDR8[1:0]		PUPDR7[1:0]		PUPDR6[1:0]		PUPDR5[1:0]		PUPDR4[1:0]		PUPDR3[1:0]		PUPDR2[1:0]		PUPDR1[1:0]		PUPDR0[1:0]	
	Reset value	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	**GPIOB_PUPDR**	PUPDR15[1:0]		PUPDR14[1:0]		PUPDR13[1:0]		PUPDR12[1:0]		PUPDR11[1:0]		PUPDR10[1:0]		PUPDR9[1:0]		PUPDR8[1:0]		PUPDR7[1:0]		PUPDR6[1:0]		PUPDR5[1:0]		PUPDR4[1:0]		PUPDR3[1:0]		PUPDR2[1:0]		PUPDR1[1:0]		PUPDR0[1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0x0C	**GPIOx_PUPDR** (where x = **C..H, J, K**)	PUPDR15[1:0]		PUPDR14[1:0]		PUPDR13[1:0]		PUPDR12[1:0]		PUPDR11[1:0]		PUPDR10[1:0]		PUPDR9[1:0]		PUPDR8[1:0]		PUPDR7[1:0]		PUPDR6[1:0]		PUPDR5[1:0]		PUPDR4[1:0]		PUPDR3[1:0]		PUPDR2[1:0]		PUPDR1[1:0]		PUPDR0[1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	**GPIOx_IDR** (where x = **A to H, J, K**)	Res.		Res.		Res.		Res.		Res.		Res.		Res.		Res.		IDR15	IDR14	IDR13	IDR12	IDR11	IDR10	IDR9	IDR8	IDR7	IDR6	IDR5	IDR4	IDR3	IDR2	IDR1	IDR0
	Reset value																	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
0x14	**GPIOx_ODR** (where x = **A to H, J, K**)	Res.		Res.		Res.		Res.		Res.		Res.		Res.		Res.		ODR15	ODR14	ODR13	ODR12	ODR11	ODR10	ODR9	ODR8	ODR7	ODR6	ODR5	ODR4	ODR3	ODR2	ODR1	ODR0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	**GPIOx_BSRR** (where x = **A to H, J, K**)	BR15	BR14	BR13	BR12	BR11	BR10	BR9	BR8	BR7	BR6	BR5	BR4	BR3	BR2	BR1	BR0	BS15	BS14	BS13	BS12	BS11	BS10	BS9	BS8	BS7	BS6	BS5	BS4	BS3	BS2	BS1	BS0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	**GPIOx_LCKR** (where x = **A to H, J, K**)	Res.		Res.		Res.		Res.		Res.		Res.		Res.		Res.	LCKK	LCK15	LCK14	LCK13	LCK12	LCK11	LCK10	LCK9	LCK8	LCK7	LCK6	LCK5	LCK4	LCK3	LCK2	LCK1	LCK0
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	**GPIOx_AFRL** (where x = **A to H, J, K**)	AFR7[3:0]				AFR6[3:0]				AFR5[3:0]				AFR4[3:0]				AFR3[3:0]				AFR2[3:0]				AFR1[3:0]				AFR0[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x24	**GPIOx_AFRH** (where x = **A to H, J, K**)	AFR15[3:0]				AFR14[3:0]				AFR13[3:0]				AFR12[3:0]				AFR11[3:0]				AFR10[3:0]				AFR9[3:0]				AFR8[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

12 System configuration controller (SYSCFG)

12.1 Introduction

The devices feature a set of configuration registers. The objectives of this section is to describe in details the system configuration controller.

12.2 SYSCFG main features

The system configuration controller main functions are the following:

- Analog switch configuration management
- I2C Fm+ configuration
- Selection of the Ethernet PHY interface.
- Management of the external interrupt line connection to the GPIOs
- Management of the I/O compensation cell
- Getting readout protection
- Management of boot sequences and boot addresses
- Management BOR reset level
- Management of Flash memory secured and protected sector status
- Management Flash memory write protections status
- Management of DTCM secured section status
- Management of independent watchdog behavior (hardware or software / freeze)
- Reset generation in Stop and Standby mode
- Secure mode enabling/disabling status
- Management timer break input lock.

12.3 Management of timer break input lock

This feature allows, in addition to HSE break detection, to disable the timer output when an internal SRAM or Flash memory ECC double error, or when a PVD or core lockup occurs. This is particularly useful when timers are used to drive motors. The type of lockup can be selected through the SYSCFG_CFGR register in addition to the HSE break detection.

12.4 SYSCFG registers

12.4.1 SYSCFG peripheral mode configuration register (SYSCFG_PMCR)

Address offset: 0x04

Reset value: 0x0X00 0000

Note: 'X' correspond to PC3, PC2, PA1 and PA0 switch open bit reset value (PXnSO). PXnSO reset value is 0 when the corresponding PXn_C pin is available on the package but PXn is not, otherwise it is 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	PC3SO	PC2SO	PA1SO	PA0SO	EPIS[2:0]			Res.	Res.	Res.	Res.	Res.
				rw	rw	rw	rw	rw	rw	rw					

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	I2C5 FMP	BOOSTV DDSEL	BOOSTE	PB9 FMP	PB8 FMP	PB7 FMP	PB6 FMP	I2C4 FMP	I2C3 FMP	I2C2 FMP	I2C1 FMP
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **PC3SO**: PC3 switch open
This bit controls the analog switch between PC3 and PC3_C (dual pad)
0: Analog switch closed (pads are connected through the analog switch)
1: Analog switch open (2 separated pads)

Bit 26 **PC2SO**: PC2 switch open
This bit controls the analog switch between PC2 and PC2_C (dual pad)
0: Analog switch closed (pads are connected through the analog switch)
1: Analog switch open (2 separated pads)

Bit 25 **PA1SO**: PA1 switch open
This bit controls the analog switch between PA1 and PA1_C (dual pad)
0: Analog switch closed (pads are connected through the analog switch)
1: Analog switch open (2 separated pads)

Bit 24 **PA0SO**: PA0 switch open
This bit controls the analog switch between PA0 and PA0_C (dual pad)
0: Analog switch closed (pads are connected through the analog switch)
1: Analog switch open (2 separated pads)

Bits 23:21 **EPIS[2:0]**: Ethernet PHY interface selection
These bits select the Ethernet PHY interface.
000: MII
100: RMII
Others: Reserved, must not be used

Bits 20:11 Reserved, must be kept at reset value.

Bit 10 **I2C5FMP**: I2C5 Fm+
This bit enables Fm+ on I2C5.
0: Fm+ disabled
1: Fm+ enabled

Bit 9 **BOOSTVDDSEL**: Analog switch supply voltage selection (V_{DD}/V_{DDA}/booster)

To avoid current consumption due to booster activation when V_{DDA} < 2.7 V and V_{DD} > 2.7 V, V_{DD} can be selected as supply voltage for analog switches. In this case, the BOOSTE bit should be cleared to avoid unwanted power consumption.

When both V_{DD} < 2.7 V and V_{DDA} < 2.7 V, the booster is required to obtain full AC performance from I/O analog switches.

0: V_{DDA} selected as analog switch supply voltage (when BOOSTE bit is cleared)

1: V_{DD} selected as analog switch supply voltage

Bit 8 **BOOSTE**: Booster enable

This bit enables the booster to reduce the total harmonic distortion of the analog switch when the supply voltage is lower than 2.7 V.

Activating the booster allows to guaranty the analog switch AC performance when the supply voltage is below 2.7 V: in this case, the analog switch performance is the same on the full voltage range.

0: Booster disabled

1: Booster enabled

Bit 7 **PB9FMP**: PB(9) Fm+

This bit enables I2C Fm+ on PB(9).

0: Fm+ disabled

1: Fm+ enabled

Bit 6 **PB8FMP**: PB(8) Fm+

This bit enables I2C Fm+ on PB(8).

0: Fm+ disabled

1: Fm+ enabled

Bit 5 **PB7FMP**: PB(7) Fm+

this bit enables I2C Fm+ on PB(7).

0: Fm+ disabled

1: Fm+ enabled

Bit 4 **PB6FMP**: PB(6) Fm+

This bit enables I2C Fm+ on PB(6).

0: Fm+ disabled

1: Fm+ enabled

Bit 3 **I2C4FMP**: I2C4 Fm+

This bit enables Fm+ on I2C4.

0: Fm+ disabled

1: Fm+ enabled

Bit 2 **I2C3FMP**: I2C3 Fm+

This bit enables Fm+ on I2C3.

0: Fm+ disabled

1: Fm+ enabled

Bit 1 **I2C2FMP**: I2C2 Fm+

This bit enables Fm+ on I2C2.

0: Fm+ disabled

1: Fm+ enabled

Bit 0 **I2C1FMP**: I2C1 Fm+

This bit enables Fm+ on I2C1.

0: Fm+ disabled

1: Fm+ enabled

12.4.2 SYSCFG external interrupt configuration register 1 (SYSCFG_EXTICR1)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTI3[3:0]				EXTI2[3:0]				EXTI1[3:0]				EXTI0[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **EXTI[3:0][3:0]**: EXTI x configuration (x = 0 to 3)

These bits are written by software to select the source input for the EXTI input for external interrupt / event detection.

0000: PA[x] pin
0001: PB[x] pin
0010: PC[x] pin
0011: PD[x] pin
0100: PE[x] pin
0101: PF[x] pin
0110: PG[x] pin
0111: PH[x] pin
1001: PJ[x] pin
1010: PK[x] pin
Others: Reserved, must not be used

Note: PJ[3:0] and PK[3] are not used.

12.4.3 SYSCFG external interrupt configuration register 2 (SYSCFG_EXTICR2)

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTI7[3:0]				EXTI6[3:0]				EXTI5[3:0]				EXTI4[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **EXTI[7:4][3:0]**: EXTI x configuration (x = 4 to 7)

These bits are written by software to select the source input for the EXTI input for external interrupt / event detection.

0000: PA[x] pin
0001: PB[x] pin
0010: PC[x] pin
0011: PD[x] pin
0100: PE[x] pin
0101: PF[x] pin
0110: PG[x] pin
0111: PH[x] pin
1001: PJ[x] pin
1010: PK[x] pin
Others: Reserved, must not be used

Note: PJ[7:4] and PK[7:4] are not used.

12.4.4 SYSCFG external interrupt configuration register 3 (SYSCFG_EXTICR3)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTI11[3:0]				EXTI10[3:0]				EXTI9[3:0]				EXTI8[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **EXTI[11:8][3:0]**: EXTI x configuration (x = 8 to 11)

These bits are written by software to select the source input for the EXTI input for external interrupt / event detection.

0000: PA[x] pin
0001: PB[x] pin
0010: PC[x] pin
0011: PD[x] pin
0100: PE[x] pin
0101: PF[x] pin
0110: PG[x] pin
0111: PH[x] pin
1001: PJ[x] pin
1010: PK[x] pin
Others: Reserved, must not be used

Note: PK[11:8] are not used.

12.4.5 SYSCFG external interrupt configuration register 4 (SYSCFG_EXTICR4)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTI15[3:0]				EXTI14[3:0]				EXTI13[3:0]				EXTI12[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **EXTI[5:12][3:0]**: EXTI x configuration (x = 12 to 15)

These bits are written by software to select the source input for the EXTI input for external interrupt / event detection.

0000: PA[x] pin
0001: PB[x] pin
0010: PC[x] pin
0011: PD[x] pin
0100: PE[x] pin
0101: PF[x] pin
0110: PG[x] pin
0111: PH[x] pin
1001: PJ[x] pin
1010: PK[x] pin
Others: Reserved, must not be used

Note: PJ[15:12] and PK[15:12] are not used.

12.4.6 SYSCFG timer break lockup register (SYSCFG_CFGR)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AXIRAML	ITCML	DTCML	SRAM1L	SRAM2L	Res.	SRAM4L	Res.	BKRAML	CM7L	Res.	Res.	FLASHL	PVDL	Res.	Res.
rw	rw	rw	rw	rw		rw		rw	rw			rw	rw		

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **AXIRAML**: D1 AXI-SRAM ECC double error lock bit
This bit is set by software and cleared by reset system only.
This is bit is used to enable and lock the D1 AXI-SRAM ECC double error connection to TIM1/8/15/16 /17 Break inputs
0: D1 AXI-SRAM ECC double error signal disconnected
1: D1 AXI-SRAM ECC double error signal connected

Bit 14 **ITCML**: D1 ITCM-RAM ECC double error lock bit
This bit is set by software and cleared by reset system only.
This is bit is used to enable and lock the D1 ITCM-RAM ECC double error connection to TIM1/8/15/16 /17 Break inputs
0: D1 ITCM-RAM ECC double error signal disconnected
1: D1 ITCM-RAM ECC double error signal connected

Bit 13 **DTCML**: D1 DTCM ECC double error lock bit
This bit is set by software and cleared by reset system only.
This is bit is used to enable and lock the D1 DTCM ECC double error connection to TIM1/8/15/16 /17 Break inputs
0: D1 DTCM ECC double error signal disconnected
1: D1 DTCM ECC double error signal connected

Bit 12 **SRAM1L**: D2 SRAM1 ECC double error lockup bit
This bit is set by software and cleared by reset system only.
This is bit is used to enable and lock the D2 SRAM1 ECC double error connection to TIM1/8/15/16 /17 Break inputs
0: D2 SRAM1 ECC double error signal disconnected
1: D2 SRAM1 ECC double error signal connected

Bit 11 **SRAM2L**: D2 SRAM2 ECC double error lockup bit
This bit is set by software and cleared by reset system only.
This is bit is used to enable and lock the D2 SRAM2 ECC double error connection to TIM1/8/15/16 /17 Break inputs
0: D2 SRAM2 ECC double error signal disconnected
1: D2 SRAM2 ECC double error signal connected

Bit 10 Reserved, must be kept at reset value.

Bit 9 **SRAM4L**: D3 SRAM4 ECC double error Lockup bit
This bit is set by software and cleared by reset system only.
This is bit is used to enable and lock the D3 SRAM4 ECC double error connection to TIM1/8/15/16 /17 Break
inputs
0: D3 SRAM4 ECC double error signal disconnected
1: D3 SRAM4 ECC double error signal connected

Bit 8 Reserved, must be kept at reset value.

Bit 7 **BKRAML**: D3 backup SRAM ECC double error lockup bit
This bit is set by software and cleared by reset system only.
This is bit is used to enable and lock the D3 backup SRAM ECC double error connection to TIM1/8/15/16 /17 Break inputs
0: D3 backup SRAM ECC double error signal disconnected
1: D3 backup SRAM ECC double error signal connected

Bit 6 **CM7L**: CPU lockup bit
This bit is set by software and cleared by reset system only.
This is bit is used to enable and lock the CPU lockup connection to TIM1/8/15/16 /17 Break inputs
0: CPU lockup signal disconnected
1: CPU lockup signal connected

Bits 5:4 Reserved, must be kept at reset value.

Bit 3 **FLASHL**: FLASH double ECC error lockup bit
This bit is set by software and cleared by reset system only.
This is bit is used to enable and lock the FLASH double ECC error connection to TIM1/8/15/16 /17 Break inputs
0: FLASH double ECC error signal disconnected
1: FLASH double ECC error signal connected

Bit 2 **PVDL**: Programmable voltage detector lockup bit
This bit is set by software and cleared by reset system only.
This is bit is used to enable and lock the PVD connection to TIM1/8/15/16 /17 Break inputs
0: PVD signal disconnected
1: PVD signal connected

Bits 1:0 Reserved, must be kept at reset value.

12.4.7 SYSCFG compensation cell control/status register (SYSCFG_CCCSR)

Address offset: 0x20

Reset value: 0x0000 0000

Refer to *Section 11.3.11: I/O compensation cell* for a detailed description of I/O compensation mechanism.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSLV
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	READY	Res.	Res.	Res.	Res.	Res.	Res.	CS	EN
							r							rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **HSLV:** High-speed at low-voltage

This bit is written by software to optimize the I/O speed when the product voltage is low.

This bit is active only if IO_HSLV user option bit is set. It must be used only if the product supply voltage is below 2.5 V. Setting this bit when V_{DD} is higher than 2.5 V might be destructive.

0: No I/O speed optimization

1: I/O speed optimization

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **READY:** Compensation cell ready flag

This bit provides the status of the compensation cell.

0: I/O compensation cell not ready

1: I/O compensation cell ready

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **CS:** Code selection

This bit selects the code to be applied for the I/O compensation cell.

0: Code from the cell (available in the SYSCFG_CCVR)

1: Code from the SYSCFG compensation cell code register (SYSCFG_CCCR)

Bit 0 **EN:** O compensation cell enable

This bit enables the I/O compensation cell.

0: I/O compensation cell disabled

1: I/O compensation cell enabled

12.4.8 SYSCFG compensation cell value register (SYSCFG_CCVR)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCV[3:0]				NCV[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **PCV[3:0]:** PMOS compensation value

This value is provided by the cell and can be used by the CPU to compute an I/O compensation cell code for PMOS transistors. This code is applied to the I/O compensation cell when the CS bit of the SYSCFG_CCCSR is reset.

Bits 3:0 **NCV[3:0]:** NMOS compensation value

This value is provided by the cell and can be used by the CPU to compute an I/O compensation cell code for NMOS transistors. This code is applied to the I/O compensation cell when the CS bit of the SYSCFG_CCCSR is reset.

12.4.9 SYSCFG compensation cell code register (SYSCFG_CCCR)

Address offset: 0x28

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCC[3:0]				NCC[3:0]			
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **PCC[3:0]:** PMOS compensation code

These bits are written by software to define an I/O compensation cell code for PMOS transistors. This code is applied to the I/O compensation cell when the CS bit of the SYSCFG_CCCSR is set.

Bits 3:0 **NCC[3:0]:** NMOS compensation code

These bits are written by software to define an I/O compensation cell code for NMOS transistors. This code is applied to the I/O compensation cell when the CS bit of the SYSCFG_CCCSR is set.

12.4.10 SYSCFG ADC2 internal input alternate connection register (SYSCFG_ADC2ALT)

Address offset: 0x30

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADC2_ ROUT1	ADC2_ ROUT0
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **ADC2_ROUT1:** ADC2 V_{INP}[17] alternate connection
0: dac1_out2 connected to ADC2 V_{INP}[17] (default)
1: Internal reference voltage (V_{REFINT}) connected to ADC2 V_{INP}[17]

Bit 0 **ADC2_ROUT0:** ADC2 V_{INP}[16] alternate connection
0: dac1_out1 connected to ADC2 V_{INP}[16] (default)
1: V_{BAT}/4 connected to ADC2 V_{INP}[16]

12.4.11 SYSCFG package register (SYSCFG_PKGR)

Address offset: 0x124

Reset value: 0x000X 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKG[3:0			
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **PKG[3:0]:** Package

These bits indicate the device package.
0000: VFQFPN68 Industrial
0001: LQFP100 Legacy / TFBGA100 Legacy
0010: LQFP100 Industrial
0011: TFBGA100 Industrial
0100: WLCSP115 Industrial
0101: LQFP144 Legacy
0110: UFBGA144 Legacy
0111: LQFP144 Industrial
1000: UFBGA169 Industrial
1001: UFBGA176+25 Industrial
1010: LQFP176 Industrial
Other configurations: all pads enabled

12.4.12 SYSCFG user register 0 (SYSCFG_UR0)

Address offset: 0x300

Reset value: 0x00XX 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDP[7:0]							
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **RDP[7:0]:** Readout protection

These bits indicate the readout protection level.
0xAA: Level 0 (no protection)
0xCC: Level 2 (Flash memory readout protected, full debug features, boot from SRAM and boundary scan disabled)
Other configurations: Level 1 (Flash memory readout protected, limited debug features and boundary scan enabled)

Bits 15:0 Reserved, must be kept at reset value.

12.4.13 SYSCFG user register 2 (SYSCFG_UR2)

Address offset: 0x308

Reset value: 0xXXXX 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BOOT_ADD0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BORH[1:0]	
														r	r

Bits 31:16 **BOOT_ADD0[15:0]:** Cortex-M7 boot address 0

These bits define the MSB of the Cortex-M7 core boot address when BOOT pin is low.

Bits 15:2 Reserved, must be kept at reset value.

Bits 1:0 **BORH[1:0]:** BOR_LEV Brownout reset threshold level

These bits indicate the Brownout reset high level.
00: BOR OFF
01: BOR Level 1
10: BOR Level 2
11: BOR Level 3

12.4.14 SYSCFG user register 3 (SYSCFG_UR3)

Address offset: 0x30C

Reset value: 0x0000 XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BOOT_ADD1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **BOOT_ADD1[15:0]:** Cortex-M7 boot address 1
These bits define the MSB of the core boot address when BOOT pin is high.

12.4.15 SYSCFG user register 4 (SYSCFG_UR4)

Address offset: 0x310

Reset value: 0x000X 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MEPAD_1
															r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **MEPAD_1:** PCROP protected erase enable option configuration bit
If MEPAD_1 is set to 1, the PCROP protected area is erased when a protection level regression (change from level 1 to 0) or a bank erase with protection removal occurs.

Bits 15:0 Reserved, must be kept at reset value.

12.4.16 SYSCFG user register 5 (SYSCFG_UR5)

Address offset: 0x314

Reset value: 0x00XX 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRPN_1[7:0]							
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MESAD_1
															r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **WRPN_1[7:0]:** Sector 7 to 0 write protection option status bit
Setting WRPN_1[n] bit to 0 write protects the corresponding bank sector (0: sector is write protected; 1: sector is not write protected).

Bits 15:1 Reserved, must be kept at reset value.

Bit 0 **MESAD_1:** Secure access protected erase enable option configuration bit
If MESAD_1 is set to 1, the secure access only area is erased when a protection level regression (change from level 1 to 0) or a bank erase with protection removal occurs.

12.4.17 SYSCFG user register 6 (SYSCFG_UR6)

Address offset: 0x318

Reset value: 0x0XXX 0XXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	PA_END_1[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	PA_BEG_1[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **PA_END_1[11:0]:** PCROP area end configuration bits
These bits contain the last 256-byte block of the PCROP area.
If this address is equal to PA_BEG_1, the whole bank is PCROP protected.
If this address is lower than PA_BEG_1, no protection is set.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **PA_BEG_1[11:0]:** PCROP area start configuration bits
These bits contain the first 256-byte block of the PCROP area.
If this address is equal to PA_END_1, the whole bank is PCROP protected.
If this address is higher than PA_END_1, no protection is set.

12.4.18 SYSCFG user register 7 (SYSCFG_UR7)

Address offset: 0x31C

Reset value: 0x0XXX 0XXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	SA_END_1[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	SA_BEG_1[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **SA_END_1[11:0]:** Secure-only area end configuration bits
These bits contain the last block of 256 bytes of the secure-only area.
If this address is equal to SA_START_1, the whole bank is secure access only.
If this address is lower than SA_START_1, no protection is set.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **SA_BEG_1[11:0]:** Secure-only area start configuration bits
These bits contain the first block of 256 bytes of the secure-only area.
If this address is equal to SA_END_1, the whole bank is secure access only.
If this address is higher than SA_END_1, no protection is set.

12.4.19 SYSCFG user register 11 (SYSCFG_UR11)

Address offset: 0x32C

Reset value: 0x000X 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IWDG1M
															r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **IWDG1M:** Independent Watchdog 1 mode
This bit indicates the control mode of the Independent Watchdog 1 (IWDG1).
0: IWDG1 controlled by hardware
1: IWDG1 controlled by software

Bits 15:0 Reserved, must be kept at reset value.

12.4.20 SYSCFG user register 12 (SYSCFG_UR12)

Address offset: 0x330

Reset value: 0x000X 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECURE
															r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **SECURE:** Secure mode (SECURITY)
This bit indicates the Secure mode status.
0: Secure mode disabled
1: Secure mode enabled

Bits 15:0 Reserved, must be kept at reset value.

12.4.21 SYSCFG user register 13 (SYSCFG_UR13)

Address offset: 0x334

Reset value: 0x000X 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	D1SBRST
															rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SDRS[1:0]	
														r	r

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **D1SBRST:** D1 Standby reset
This bit indicates if a reset is generated when D1 domain enters DStandby mode.
0: A reset is generated by entering D1 Standby mode
1: D1 Standby mode is entered without reset generation

Bits 15:2 Reserved, must be kept at reset value.

Bits 1:0 **SDRS[1:0]:** Secured DTCM-RAM size
These bits indicates the size of the secured DTCM-RAM.
00: 2 Kbytes
01: 4 Kbytes
10: 8 Kbytes
11: 16 Kbytes

12.4.22 SYSCFG user register 14 (SYSCFG_UR14)

Address offset: 0x338

Reset value: 0x000X 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	D1STPRST
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **D1STPRST:** D1 Stop Reset

This bit indicates if a reset is generated when D1 domain enters in DStop mode.

0: A reset is generated entering D1 Stop mode

1: D1 Stop mode is entered without reset generation

12.4.23 SYSCFG user register 15 (SYSCFG_UR15)

Address offset: 0x33C

Reset value: 0x000X 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FZIWDGSTB
															r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **FZIWDGSTB:** Freeze independent watchdog in Standby mode
This bit indicates if the independent watchdog is frozen in Standby mode.
0: Independent Watchdog frozen in Standby mode
1: Independent Watchdog running in Standby mode

Bits 15:0 Reserved, must be kept at reset value.

12.4.24 SYSCFG user register 16 (SYSCFG_UR16)

Address offset: 0x340

Reset value: 0x000X 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKP
															r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FZIWDG STP
															r

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **PKP:** Private key programmed
This bit indicates if the device private key is programmed.
0: Private key not programmed
1: Private key programmed

Bits 15:1 Reserved, must be kept at reset value.

Bit 0 **FZIWDGSTP:** Freeze independent watchdog in Stop mode
This bit indicates if the independent watchdog is frozen in Stop mode.
0: Independent Watchdog frozen in Stop mode
1: Independent Watchdog running in Stop mode

12.4.25 SYSCFG user register 17 (SYSCFG_UR17)

Address offset: 0x344

Reset value: 0x0000 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCM_AXI_SHARED_CFG[1:0]	
														r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IO_HSLV
															r

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:16 **TCM_AXI_SHARED_CFG[1:0]**: ITCM-RAM / AXI-SRAM size
00: 64-Kbyte ITCM-RAM / 320-Kbyte AXI-SRAM
01: 128-Kbyte ITCM-RAM / 256-Kbyte AXI-SRAM
10: 192-Kbyte ITCM-RAM / 192-Kbyte AXI-SRAM
11: 256-Kbyte ITCM-RAM / 128-Kbyte AXI-SRAM

Bit 0 **IO_HSLV:** I/O high speed / low voltage
This bit indicates that the IO_HSLV option bit is set.
0: Product is working on the full voltage range
1: Product is working below 2.5 V

12.4.26 SYSCFG user register 18 (SYSCFG_UR18)

Address offset: 0x348

Reset value: 0x0000 000X

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CPU_FREQ_BOOST
															r

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **CPU_FREQ_BOOST**: CPU maximum frequency boost enable
When this bit is set, the CPU maximum frequency is boosted and the ECC on ITCM-RAM and DTCM-RAM are no more used.
0: CPU maximum frequency feature disabled.
1: CPU operates at a boosted maximum frequency (no more ECC on I/DTCM)

12.4.27 SYSCFG register maps

The following table gives the SYSCFG register map and the reset values.

Table 91. SYSCFG register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	Reserved	Reserved																															
0x04	SYSCFG_PMCR	Res.	Res.	Res.	Res.	PC3SO	PC2SO	PA1SO	PA0SO	EPIS[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	I2C5FMP	BOOSTVDDSEL	BOOSTE	PB9FMP	PB8FMP	PB7FMP	PB6FMP	I2C4FMP	I2C3FMP	I2C2FMP	I2C1FMP
	Reset value					X	X	X	0	0	0	0											0	0	0	0	0	0	0	0	0	0	0
0x08	SYSCFG_ EXTICR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EXTI3[3:0]				EXTI2[3:0]				EXTI1[3:0]				EXTI0[3:0]			
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	SYSCFG_ EXTICR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EXTI7[3:0]				EXTI6[3:0]				EXTI5[3:0]				EXTI4[3:0]			
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	SYSCFG_ EXTICR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EXTI11[3:0]				EXTI10[3:0]				EXTI9[3:0]				EXTI8[3:0]			
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	SYSCFG_ EXTICR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EXTI15[3:0]				EXTI14[3:0]				EXTI13[3:0]				EXTI12[3:0]			
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	SYSCFG_ EXTICR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EXTI15[3:0]				EXTI14[3:0]				EXTI13[3:0]				EXTI12[3:0]			
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	SYSCFG_CFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AXISRAML	ITCML	DTCML	SRAM1L	SRAM2L	Res.	SRAM4L	Res.	BKRAML	CM7L	Res.	Res.	FLASHL	PVDL	Res.	CM4L
	Reset value																	0	0	0	0	0		0		0	0			0	0		0
0x20	SYSCFG_ CCCSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSLV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	READY	Res.	Res.	Res.	Res.	Res.	CS	EN
	Reset value																0									0						0	0
0x24	SYSCFG_CCVR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCV[3:0]				NCV[3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0x28	SYSCFG_CCCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCC[3:0]				NCC[3:0]			
	Reset value																									0	0	0	0	0	0	0	0
0x30	SYSCFG_ ADC2ALT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADC2_ROUT1	ADC2_ROUT0
	Reset value																															0	0
0x34-0x120	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x124	SYSCFG_PKGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKG[3:0]			
	Reset value																													X	X	X	X

Table 91. SYSCFG register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x128 - 0x2FC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x300	SYSCFG_UR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDP[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BKS
	Reset value									x	x	x	x	x	x	x	x																0
0x304	Reserved	Reserved																															
0x308	SYSCFG_UR2	BOOT_ADD0[15:0]																Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BORH[1:0]	
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X															X	X
0x30C	SYSCFG_UR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BOOT_ADD1[15:0]															
	Reset value																	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x310	SYSCFG_UR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MEPAD_1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																X																
0x314	SYSCFG_UR5	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRPN_1[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MESAD_1
	Reset value									X	X	X	X	X	X	X	X																X
0x318	SYSCFG_UR6	Res.	Res.	Res.	Res.	PA_END_1[11:0]												Res.	Res.	Res.	Res.	PA_BEG_1[11:0]											
	Reset value					X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X
0x31C	SYSCFG_UR7	Res.	Res.	Res.	Res.	SA_END_1[11:0]												Res.	Res.	Res.	Res.	SA_BEG_1[11:0]											
	Reset value					X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X
0x320 to 0x328	Reserved	Reserved																															
0x32C	SYSCFG_UR11	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IWDG1M	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																X																
0x330	SYSCFG_UR12	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SECURE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																X																
0x334	SYSCFG_UR13	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	D1SBRST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SDRS[1:0]	
	Reset value																X															X	X
0x338	SYSCFG_UR14	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	D1STPRST
	Reset value																																X

Table 91. SYSCFG register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x33C	SYSCFG_UR15	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FZIWDGSTB	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.
	Reset value																X																
0x340	SYSCFG_UR16	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKP	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	FZIWDGST
	Reset value																X																X
0x344	SYSCFG_UR17	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCM_AXI_SHARED_CFG		RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	RES.	IO_HSLV
	Reset value															0	0																X

Refer to *Section 2.3 on page 131* for the register boundary addresses.

13 Block interconnect

13.1 Peripheral interconnect

13.1.1 Introduction

Several peripherals have direct connections between them.

This enables autonomous communication and synchronization between peripherals, thus saving CPU resources and power consumption.

These hardware connections remove software latency, allow the design of a predictable system and result in a reduction of the number of pins and GPIOs.

13.1.2 Connection overview

There are several types of connections.

- Asynchronous connections (A)

  The source output signal is sampled by the destination clock, leading to introduction of a possible jitter in the latency between the source output event and the destination event detection
- Synchronous connections (S)

  Both source and destination are synchronous (they run on the same clock), and the latency from the source to the destination is deterministic. No jitter is introduced.
- Immediate connections (I)

  Either the source or the destination is an analog signal.
- Break/fault connection for TIM outputs (B)

  The source output signal disables the timer outputs through a pure combinational logic path, without any latency.

Table 92. Peripherals interconnect matrix (D2 domain) (1) (2)

Source			Destination																												
			D2 domain																					D3 domain							
			APB1											APB2						AHB1			AHB4	APB4							
			TIM2	TIM3	TIM4	TIM5	TIM12	TIM23	TIM24	LPTIM1	DAC	CRS	CAN	TIM1	TIM8	TIM15	TIM16	TIM17	DFSDM1	ADC1	ADC2	ETHERNET	ADC3	LPTIM2	LPTIM3	LPTIM4	LPTIM5	COMP1	COMP2	DTS
D2 domain	APB1	TIM2	-	S	S	-	-	S	S	-	S	-	A	S	S	S	-	-	-	S	S	A	S	-	-	-	-	I	I	-
		TIM3	S	-	S	S	-	S	S	-	-	-	A	S		S	-	-	S	S	S	A	S	-	-	-	-	I	I	-
		TIM4	S	S	-	S	S	S	S	-	S	-	-	S	S	S	-	-	S	S	S	-	S	-	-	-	-	-	-	-
		TIM5	-	-	-	-	S	S	S	-	S	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		TIM6	-	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-	S	S	S	-	S	-	-	-	-	-	-	-
		TIM7	-	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-
		TIM12	-	-	-	-	-	S	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		TIM13	-	-	-	-	S	S	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		TIM14	-	-	-	-	S	S	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		TIM23	S	S	S	S	S	-	S	-	S	-	-	S	S	S	-	-	S	S	S	-	S	-	-	-	-	-	-	-
		TIM24	S	S	S	S	S	S	-	-	S	-	-	S	S	S	-	-	S	S	S	-	S	-	-	-	-	-	-	-
		LPTIM1	-	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	A	A	A		A	-	-	-	-	-	-	S
		SPDIFRX	-	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		OPAMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		CAN	-	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-
	APB2	TIM1	S	S	S	S	-	S	S	-	S	-	-	-	S	S	-	-	S	S	S	-	S	-	-	-	-	I	I	-
		TIM8	S	-	S	S	-	S	S	-	S	-	-	-	-	-	-	-	S	S	S	-	S	-	-	-	-	I	I	-
		TIM15	-	S	-	-	-	S	S	-	S	-	-	S	-	-	-	-		S	S	-	S	-	-	-	-	I	I	-
		TIM16	-	-	-	-	-	S	S	-	-	-	-	-	-	S	-	-	S	-	-	-	-	-	-	-	-	-	-	-
		TIM17	-	-	-	-	-	S	S	-	-	-	-	-	-	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		SAI1	A	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-	-
		DFSDM1	-	-	-	-	-	-	-	-	-	-	-	B	B	B	B	B	-	-	-	-	-	-	-	-	-	-	-	-
	AHB1	ADC1	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		ADC2	-	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		ETH	A	A	-	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		USB1 (OTG_ HS1)	A	-	-	A	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

1. Letters in the table correspond to the type of connection described in *Section 13.1.2: Connection overview*
2. The "-" symbol in a gray cell means no interconnect.

Table 93. Peripherals interconnect matrix (D3 domain) (1) (2)

Source			Destination																									
			D2 domain																				D3 domain AHB4 APB4					
			APB1									APB2								AHB1									
			TIM2	TIM3	TIM4	TIM5	TIM12	LPTIM1	DAC	CRS	CAN	TIM1	TIM8	TIM15	TIM16	TIM17	TIM23	TIM24	DFSDM1	ADC1	ADC2	ETHERNET	ADC3	LPTIM2	LPTIM3	LPTIM4	LPTIM5	DTS
D3 Domain	APB4	EXTI	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	A	A	A	-	-	-	-	-	-	S
		LPTIM2	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	A	A	A	-	A	-	A	A	A	S
		LPTIM3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	-	A	-	-	A	A	S
		LPTIM4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-	A	-
		LPTIM5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	A	-	-
		COMP1	A	A	-	-	-	A	-	-	-	A/B	A/B	B	B	B	-	-	-	-	-	-	-	A	-	-	-	-
		COMP2	A	A	-	-	-	A	-	-	-	A/B	A/B	B	B	B	-	-	-	-	-	-	-	A	-	-	-	-
		SAI4	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	A	-	-	-	-	-	-	A	A	A	-
		RTC	-	-	-	-	-	A	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	A	-	-	-	-
	AHB4	ADC3	-	-	-	-	-	-	-	-	-	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		RCC	A	-	-	-	-	-	-	A	-	-	-	A	A	A	-	-	-	-	-	-	-	-	-	-	-	-

1. Letters in the table correspond to the type of connection described in *Section 13.1.2: Connection overview*.
2. The “-” symbol in a gray cell means no interconnect.

Table 94. Peripherals interconnect matrix details(1)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D2	APB2	TIM1	TRGO	ITR0	TIM2	APB1	D2	S	-
		TIM8	TRGO	ITR1				S	-
	APB1	TIM3	TRGO	ITR2				S	-
		TIM4	TRGO	ITR3				S	-
		TIM23	TRGO	ITR12				S	-
		TIM24	TRGO	ITR13				S	-
	AHB1	ETH	eth_ptp_pps_out	ITR4				A	-
		USB1	SOF	ITR5				A	-
D3	APB4	COMP1	comp1_out	ETR1				I	-
		COMP2	comp2_out	ETR2				I	-
		RCC	lse_ck	ETR3				A	-
D2	APB2	SAI1	SAI1_FS_A	ETR4				A	-
		SAI1	SAI1_FS_B	ETR5				A	-
D3	APB4	COMP1	comp1_out	TI4_1				I	-
		COMP2	comp2_out	TI4_2				I	-
		COMP1 or COMP2(2)	comp1_out or comp2_out	TI4_3				I	-
D2	APB2	TIM1	TRGO	ITR0	TIM3	APB1	D2	S	-
	APB1	TIM2	TRGO	ITR1				S	-
	APB2	TIM15	TRGO	ITR2				S	-
	APB1	TIM4	TRGO	ITR3				S	-
	AHB1	ETH	eth_ptp_pps_out	ITR4				A	-
	APB1	TIM23	TRGO	ITR12				S	-
	APB1	TIM24	TRGO	ITR13				S	-
D3	APB4	COMP1	comp1_out	ETR1				I	-
		COMP1	comp1_out	TI1_1				I	-
		COMP2	comp2_out	TI1_2				I	-
		COMP1 or COMP2(2)	comp1_out or comp2_out	TI1_3				I	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D2	APB2	TIM1	TRGO	ITR0	TIM4	APB1	D2	S	-
	APB1	TIM2	TRGO	ITR1				S	-
		TIM3	TRGO	ITR2				S	-
	APB2	TIM8	TRGO	ITR3				S	-
	APB1	TIM23	TRGO	ITR12				S	-
		TIM24	TRGO	ITR13				S	-
	APB2	TIM1	TRGO	ITR0	TIM5		D2	S	-
		TIM8	TRGO	ITR1				S	-
	APB1	TIM3	TRGO	ITR2				S	-
		TIM4	TRGO	ITR3				S	-
		CAN	SOC	ITR6				A	-
	AHB1	USB1	SOF	ITR7				A	-
	APB1	TIM23	TRGO	ITR12				S	-
		TIM24	TRGO	ITR13				S	-
	APB4	SAI4	SAI4_FS_A	ETR1				A	-
		SAI4	SAI4_FS_B	ETR2				A	
	APB1	CAN	TMP	TI1_1				A	-
		CAN	RTP	TI1_2				A	-
D2	APB1	TIM4	TRGO	ITR0	TIM12	APB1	D2	S	-
		TIM5	TRGO	ITR1				S	-
		TIM13	OC1	ITR2				S	-
		TIM14	OC1	ITR3				S	-
		TIM23	TRGO	ITR12				S	-
		TIM24	TRGO	ITR13				S	-
		SPDIFRX	FS	TI_1				S	-
	AHB1	USB1	SOF	crs_sync2	CRS	APB1	D2	A	-
D3	AHB4	RCC	lse_ck	crs_sync1	CRS	APB1	D2	A	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D2	APB2	TIM15	TRGO	ITR0	TIM1	APB2	D2	S	-
	APB1	TIM2	TRGO	ITR1				S	-
		TIM3	TRGO	ITR2				S	-
		TIM4	TRGO	ITR3				S	-
		TIM23	TRGO	ITR12				S	-
		TIM24	TRGO	ITR13				S	-
D3	APB4	COMP1	comp1_out	ETR1				I	-
		COMP2	comp2_out	ETR2				I	-
D2	AHB1	ADC1	adc1_awd1	ETR3				A	-
		ADC1	adc1_awd2	ETR4				A	-
		ADC1	adc1_awd3	ETR5				A	-
D3	AHB4	ADC3	adc3_awd1	ETR6				A	-
		ADC3	adc3_awd2	ETR7				A	-
		ADC3	adc3_awd3	ETR8				A	-
	APB4	COMP1	comp1_out	TI1_1				I	-
		COMP1	comp1_out	BRK_1				B	-
		COMP2	comp2_out	BRK_2				B	-
D2	APB2	DFSDM1	dfsdm1_break0	BRK_8				B	-
D3	APB4	COMP1	comp1_out	BRK2_1				B	-
		COMP2	comp2_out	BRK2_2				B	-
D2	APB2	DFSDM1	dfsdm1_break1	BRK2_8				B	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D2	APB2	TIM1	TRGO	ITR0	TIM8	APB2	D2	S	-
	APB1	TIM2	TRGO	ITR1				S	-
		TIM4	TRGO	ITR2				S	-
		TIM5	TRGO	ITR3				S	-
		TIM23	TRGO	ITR12				S	-
		TIM24	TRGO	ITR13				S	-
D3	APB4	COMP1	comp1_out	ETR1				I	-
		COMP2	comp2_out	ETR2				I	-
D2	AHB1	ADC2	adc2_awd1	ETR3				A	-
		ADC2	adc2_awd2	ETR4				A	-
		ADC2	adc2_awd3	ETR5				A	-
D3	AHB4	ADC3	adc3_awd1	ETR6				A	-
		ADC3	adc3_awd2	ETR7				A	-
		ADC3	adc3_awd3	ETR8				A	-
	APB4	COMP2	comp2_out	TI1_1				I	-
		COMP1	comp1_out	BRK_1				B	-
		COMP2	comp2_out	BRK_2				B	-
D2	APB2	DFSDM1	dfsdm1_ break2	BRK_8				B	-
D3	APB4	COMP1	comp1_out	BRK2_1				B	-
		COMP2	comp2_out	BRK2_2				B	-
D2	APB2	DFSDM1	dfsdm1_ break3	BRK2_8				B	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D2	APB2	TIM1	TRGO	ITR0	TIM15	APB2	D2	S	-
	APB1	TIM3	TRGO	ITR1				S	-
	APB2	TIM16	OC1	ITR2				S	-
		TIM17	OC1	ITR3				S	-
	APB1	TIM23	TRGO	ITR12				S	-
		TIM24	TRGO	ITR13				S	-
	APB1	TIM2	CH1	TI1_1				A	-
		TIM3	CH1	TI1_2				A	-
		TIM4	CH1	TI1_3				A	-
D3	AHB4	RCC	lse_ck	TI1_4				A	-
		RCC	csi_ck	TI1_5				A	-
		RCC	MCO2	TI1_6				A	-
D2	APB1	TIM2	CH2	TI2_1				A	-
		TIM3	CH2	TI2_2				A	-
		TIM4	CH2	TI2_3				A	-
D3	APB4	COMP1	comp1_out	BRK_1				B	-
		COMP2	comp2_out	BRK_2				B	-
D2	APB2	DFSDM1	dfsdm_ break0	BRK_8				B	-
D3	AHB4	RCC	lsi_ck	TI1_1	TIM16	APB2	D2	A	-
		RCC	lse_ck	TI1_2				A	-
	APB4	RTC	WKUP_IT	TI1_3				A	-
		COMP1	comp1_out	BRK_1				B	-
		COMP2	comp2_out	BRK_2				B	-
D2	APB2	DFSDM1	dfsdm_ break1	BRK_8				B	-
D3	AHB4	RCC	HSE_1MHZ	TI1_2	TIM17	APB2	D2	A	-
		RCC	MCO1	TI1_3				A	-
	APB4	COMP1	comp1_out	BRK_1				B	-
		COMP2	comp2_out	BRK_2				B	-
D2	APB2	DFSDM1	dfsdm_ break2	BRK_8				B	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D2	APB2	TIM1	TRGO	ITR0	TIM23	APB1	D2	S	-
	APB1	TIM2	TRGO	ITR1				S	-
		TIM3	TRGO	ITR2				S	-
		TIM4	TRGO	ITR3				S	-
		TIM5	TRGO	ITR4				S	-
	APB2	TIM8	TRGO	ITR5				S	-
	APB1	TIM12	TRGO	ITR6				S	-
		TIM13	OC1	ITR7				S	-
		TIM14	OC1	ITR8				S	-
	APB2	TIM15	TRGO	ITR9				S	-
		TIM16	OC1	ITR10				S	-
		TIM17	OC1	ITR11				S	-
	APB1	TIM24	TRGO	ITR13				S	-
D3	APB4	COMP1	comp1_out	ETR1				B	-
		COMP2	comp2_out	ETR2				B	-
		COMP1	comp1_out	TI4_1				B	-
		COMP2	comp2_out	TI4_2				B	-
		COMP1 or COMP2(2)	comp1_out or comp2_out	TI4_3				B	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D2	APB2	TIM1	TRGO	ITR0	TIM24	APB1	D2	S	-
	APB1	TIM2	TRGO	ITR1				S	-
		TIM3	TRGO	ITR2				S	-
		TIM4	TRGO	ITR3				S	-
		TIM5	TRGO	ITR4				S	-
	APB2	TIM8	TRGO	ITR5				S	-
	APB1	TIM12	TRGO	ITR6				S	-
		TIM13	OC1	ITR7				S	-
		TIM14	OC1	ITR8				S	-
	APB2	TIM15	TRGO	ITR9				S	-
		TIM16	OC1	ITR10				S	-
		TIM17	OC1	ITR11				S	-
	APB1	TIM23	TRGO	ITR12				S	-
D3	APB4	SAI4	SAI4_FS_A	ETR1				A	-
		SAI4	SAI4_FS_B	ETR2				A	
D2	APB2	SAI1	SAI1_FS_A	ETR3				A	
		SAI1	SAI1_FS_B	ETR4				A	
	APB1	CAN	TMP	TI1_1				A	-
		CAN	RTP	TI1_2				A	-
		CAN	SOC	TI1_3				A	-
D3	APB4	RTC	rtc_alarm_a_evt	lptim1_ext_trg1	LPTIM1	APB1	D2	A	-
		RTC	rtc_alarm_b_evt	lptim1_ext_trg2				A	-
		RTC	rtc_tamp1_evt	lptim1_ext_trg3				A	-
		RTC	rtc_tamp3_evt	lptim1_ext_trg5				A	-
		COMP1	comp1_out	lptim1_ext_trg6				I	-
		COMP2	comp2_out	lptim1_ext_trg7				I	-
		COMP1	comp1_out	lptim1_in1_mux1				I	-
		COMP2	comp2_out	lptim1_in2_mux1				I	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D3	APB4	RTC	rtc_alarm_a_evt	lptim2_ext_trg1	LPTIM2	APB4	D3	A	-
		RTC	rtc_alarm_b_evt	lptim2_ext_trg2				A	-
		RTC	rtc_tamp1_evt	lptim2_ext_trg3				A	-
		RTC	rtc_tamp3_evt	lptim2_ext_trg5				A	-
		COMP1	comp1_out	lptim2_ext_trg6				I	-
		COMP2	comp2_out	lptim2_ext_trg7				I	-
		COMP1	comp1_out	lptim2_in1_mux1				I	-
		COMP2	comp2_out	lptim2_in1_mux2				I	-
		COMP1 or COMP2 (2)	comp1_out or comp2_out	lptim2_in1_mux3				I	-
		COMP2	comp2_out	lptim2_in2_mux1				I	-
D3	APB4	LPTIM2	lptim2_out	lptim3_ext_trg0	LPTIM3	APB4	D3	S	If same kernel clock source
		LPTIM4	lptim4_out	lptim3_ext_trg2				S	If same kernel clock source
		LPTIM5	lptim5_out	lptim3_ext_trg3				S	If same kernel clock source
D2	APB2	SAI1	SAI1_FS_A	lptim3_ext_trg4				A	-
		SAI1	SAI1_FS_B	lptim3_ext_trg5				A	-
D3	APB4	SAI4	SAI4_FS_A	lptim3_in1_mux1				A	-
		SAI4	SAI4_FS_B	lptim3_in1_mux2				A	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D3	APB4	LPTIM2	lptim2_out	lptim4_ext_trg0	LPTIM4	APB4	D3	S	If same kernel clock source
		LPTIM3	lptim3_out	lptim4_ext_trg1				S	If same kernel clock source
		LPTIM5	lptim5_out	lptim4_ext_trg3				S	If same kernel clock source
		SAI4	SAI4_FS_A	lptim4_ext_trg4				A	-
		SAI4	SAI4_FS_B	lptim4_ext_trg5				A	-
D3	APB4	LPTIM2	lptim2_out	lptim5_ext_trg0	LPTIM5	APB4	D3	S	If same kernel clock source
		LPTIM3	lptim3_out	lptim5_ext_trg1				S	If same kernel clock source
		LPTIM4	lptim4_out	lptim5_ext_trg2				S	If same kernel clock source
		SAI4	SAI4_FS_A	lptim5_ext_trg3				A	-
		SAI4	SAI4_FS_B	lptim5_ext_trg4				A	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D2	APB2	TIM1	TRGO	dac_ch1/2_trg1	DAC channel 1/channel 2	APB1	D2	S	-
	APB1	TIM2	TRGO	dac_ch1/2_trg2				S	-
		TIM4	TRGO	dac_ch1/2_trg3				S	-
		TIM5	TRGO	dac_ch1/2_trg4				S	-
		TIM6	TRGO	dac_ch1/2_trg5				S	-
		TIM7	TRGO	dac_ch1/2_trg6				S	-
	APB2	TIM8	TRGO	dac_ch1/2_trg7				S	-
		TIM15	TRGO	dac_ch1/2_trg8				S	-
	APB1	LPTIM1	lptim1_out	dac_ch1/2_trg11				S	-
		LPTIM2	lptim2_out	dac_ch1/2_trg12				S	-
D3	APB4	SYSCFG	EXTI9	dac_ch1/2_trg13				S	-
D2	APB1	TIM23	TRGO	dac_ch1/2_trg14				S	-
		TIM24	TRGO	dac_ch1/2_trg15				S	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D2	APB2	TIM1	TRGO	TRG0	DFSDM1	APB2	D2	S	-
		TIM1	TRGO2	TRG1				S	-
		TIM8	TRGO	TRG2				S	-
		TIM8	TRGO2	TRG3				S	-
	APB1	TIM3	TRGO	TRG4				S	-
		TIM4	TRGO	TRG5				S	-
	APB2	TIM16	OC1	TRG6				S	-
	APB1	TIM6	TRGO	TRG7				S	-
		TIM7	TRGO	TRG8				S	-
		TIM23	TRGO	TRG11				S	-
		TIM24	TRGO	TRG12				S	-
D3	APB4	SYSCFG	EXTI11	TRG24				A	-
		SYSCFG	EXTI15	TRG25				A	-
D2	APB1	LPTIM1	lptim1_out	TRG26				A	-
D3	APB4	LPTIM2	lptim2_out	TRG27				A	-
		LPTIM3	lptim3_out	TRG28				A	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D2	APB2	TIM1	OC1	adc_ext_trg0	ADC1 / ADC2	AHB1	D2	S	-
		TIM1	OC2	adc_ext_trg1				S	-
		TIM1	OC3	adc_ext_trg2				S	-
	APB1	TIM2	OC2	adc_ext_trg3				S	-
		TIM3	TRGO	adc_ext_trg4				S	-
		TIM4	OC4	adc_ext_trg5				S	-
D3	APB4	SYSCFG	EXTI11	adc_ext_trg6				A	-
D2	APB2	TIM8	TRGO	adc_ext_trg7				S	-
		TIM8	TRGO2	adc_ext_trg8				S	-
		TIM1	TRGO	adc_ext_trg9				S	-
		TIM1	TRGO2	adc_ext_trg10				S	-
	APB1	TIM2	TRGO	adc_ext_trg11				S	-
		TIM4	TRGO	adc_ext_trg12				S	-
		TIM6	TRGO	adc_ext_trg13				S	-
	APB2	TIM15	TRGO	adc_ext_trg14				S	-
	APB1	TIM3	OC4	adc_ext_trg15				S	-
	APB2	LPTIM1	lptim1_out	adc_ext_trg18				A	-
D3	APB4	LPTIM2	lptim2_out	adc_ext_trg19				A	-
		LPTIM3	lptim3_out	adc_ext_trg20				A	-
D2	APB1	TIM23	TRGO	adc_jext_trg21				A	-
		TIM24	TRGO	adc_jext_trg22				A	-
	APB2	TIM1	TRGO	adc_jext_trg0				S	-
		TIM1	OC4	adc_jext_trg1				S	-
	APB1	TIM2	TRGO	adc_jext_trg2				S	-
		TIM2	OC1	adc_jext_trg3				S	-
		TIM3	OC4	adc_jext_trg4				S	-
		TIM4	TRGO	adc_jext_trg5				S	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D3	APB4	SYSCFG	EXTI15	adc_jext_trg6	ADC1 / ADC2	AHB1	D2	A	-
D2	APB2	TIM8	OC4	adc_jext_trg7				S	-
		TIM1	TRGO2	adc_jext_trg8				S	-
		TIM8	TRGO	adc_jext_trg9				S	-
		TIM8	TRGO2	adc_jext_trg10				S	-
	APB1	TIM3	OC3	adc_jext_trg11				S	-
		TIM3	TRGO	adc_jext_trg12				S	-
		TIM3	OC1	adc_jext_trg13				S	-
		TIM6	TRGO	adc_jext_trg14				S	-
	APB2	TIM15	TRGO	adc_jext_trg15				S	-
	APB1	LPTIM1	lptim1_out	adc_jext_trg18				A	-
D3	APB4	LPTIM2	lptim2_out	adc_jext_trg19				A	-
		LPTIM3	lptim3_out	adc_jext_trg20				A	-
D2	APB1	TIM23	TRGO	adc_jext_trg21				A	-
		TIM24	TRGO	adc_jext_trg22				A	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D2	APB2	TIM1	OC1	adc_ext_trg0	ADC3	AHB4	D3	S	-
		TIM1	OC2	adc_ext_trg1				S	-
		TIM1	OC3	adc_ext_trg2				S	-
	APB1	TIM2	OC2	adc_ext_trg3				S	-
		TIM3	TRGO	adc_ext_trg4				S	-
		TIM4	OC4	adc_ext_trg5				S	-
D3	APB4	SYSCFG	EXTI11	adc_ext_trg6				A	-
D2	APB2	TIM8	TRGO	adc_ext_trg7				S	-
		TIM8	TRGO2	adc_ext_trg8				S	-
		TIM1	TRGO	adc_ext_trg9				S	-
		TIM1	TRGO2	adc_ext_trg10				S	-
	APB1	TIM2	TRGO	adc_ext_trg11				S	-
		TIM4	TRGO	adc_ext_trg12				S	-
		TIM6	TRGO	adc_ext_trg13					
	APB2	TIM15	TRGO	adc_ext_trg14				S	-
	APB1	TIM3	OC4	adc_ext_trg15				A	-
		LPTIM1	lptim1_out	adc_ext_trg18					
D3	APB4	LPTIM2	lptim2_out	adc_ext_trg19				A	-
		LPTIM3	lptim3_out	adc_ext_trg20				A	-
D2	APB1	TIM23	TRGO	adc_ext_trg21				A	-
		TIM24	TRGO	adc_ext_trg22				A	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D2	APB2	TIM1	TRGO	adc_jext_trg0	ADC3	AHB4	D3	SI	-
		TIM1	OC4	adc_jext_trg1				S	-
	APB1	TIM2	TRGO	adc_jext_trg2				S	-
		TIM2	OC1	adc_jext_trg3				S	-
		TIM3	OC4	adc_jext_trg4				S	-
		TIM4	TRGO	adc_jext_trg5				S	-
D3	APB4	SYSCFG	EXTI15	adc_jext_trg6				A	-
D2	APB2	TIM8	OC4	adc_jext_trg7				S	-
		TIM1	TRGO2	adc_jext_trg8				S	-
		TIM8	TRGO	adc_jext_trg9				S	-
		TIM8	TRGO2	adc_jext_trg10				S	-
	APB1	TIM3	OC3	adc_jext_trg11				S	-
		TIM3	TRGO	adc_jext_trg12				S	-
		TIM3	OC1	adc_jext_trg13				S	-
		TIM6	TRGO	adc_jext_trg14				S	-
	APB2	TIM15	TRGO	adc_jext_trg15				S	-
	APB1	LPTIM1	lptim1_out	adc_jext_trg18				A	-
D3	APB4	LPTIM2	lptim2_out	adc_jext_trg19				A	-
		LPTIM3	lptim3_out	adc_jext_trg20				A	-
	APB1	TIM23	TRGO	adc_jext_trg21				A	-
		TIM24	TRGO	adc_jext_trg22				A	-
D2	APB2	TIM1	OC5	comp_blk1	COMP1 / COMP2	APB4	D3	I	-
	APB1	TIM2	OC3	comp_blk2				I	-
		TIM3	OC3	comp_blk3				I	-
		TIM3	OC4	comp_blk4				I	-
	APB2	TIM8	OC5	comp_blk5				I	-
		TIM15	OC1	comp_blk6				I	-
D2	APB1	LPTIM1	lptim1_out	ts1_trg0	DTS	APB4	D3	S	-
	APB4	LPTIM2	lptim2_out	ts1_trg1				S	-
		LPTIM3	lptim3_out	ts1_trg2				S	-
		SYSCFG	EXTI3	ts1_trg3				S	-

Table 94. Peripherals interconnect matrix details(1) (continued)

Source				Destination				Type	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain		
D2	APB1	TIM2	TRGO	SWT0	FDCAN	APB1	D2	A	-
		TIM3	TRGO	SWT1				A	-
	AHB1	ETH	eth_ptp_pps_out	SWT2				A	-
	APB1	TIM2	TRGO	EVT0				A	-
		TIM3	TRGO	EVT1				A	-
	AHB1	ETH	eth_ptp_pps_out	EVT2				A	-
	APB1	TIM2	TRGO	eth_ptp_trg0	ETH	AHB1	D2	A	-
		TIM3	TRGO	eth_ptp_trg1				A	-
	APB1	CAN	TMP	eth_ptp_trg3				A	-

1. Letters in the table correspond to the type of connection described in *Section 13.1.2: Connection overview*.
2. comp1_out and comp2_out are connected to the inputs of an OR gate. The output of this OR gate is connected to the The lptim2_in1_mux3 input.

13.2 Wakeup from low power modes

The Extended interrupt and event controller module (EXTI) allows to wake up the system from Stop mode and/or a CPU from CStop mode. Wakeup events are coming from peripherals.

These events are handled by the EXTI either as Configurable events (**C**), or as Direct events (**D**). See *Type* column in *Table 95*. Refer to *Section 20: Extended interrupt and event controller (EXTI)* for further details.

Three types of peripheral output signals are connected to the EXTI input events:

- The wake up signals. These signals can be generated by the peripheral without any bus interface clock, they are referred to as xxx_wkup in *Table 95*. Some peripherals do not have this capability.
- The interrupt signals. These signals can be generated only if the peripheral bus interface clock is running. These interrupt signals are generally directly connected to the NVIC of CPU. They are referred to as xxx_it.
- The signals, i.e. the pulses generated by the peripheral. Once a peripheral has generated a signal, no action (flag clearing) is required at peripheral level.

Each EXTI input event has a different wakeup capability or possible target (see *Target* column in *Table 95*):

- CPU wakeup (**CPU**): the input event can be enabled to wake up the CPU
- CPU and D3 domain wakeup for autonomous Run mode (**ANY**): the input event can be enabled to wake up the CPU or the D3 domain only for an autonomous Run mode phase.

Table 95. EXTI wakeup inputs(1)

Source				Destination		Type	Target	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral			
D3	APB4	SYSCFG	exti0_wkup	WKUP0	EXTI	C	ANY	-
			exti1_wkup	WKUP1				-
			exti2_wkup	WKUP2				-
			exti3_wkup	WKUP3				-
			exti4_wkup	WKUP4				-
			exti5_wkup	WKUP5				-
			exti6_wkup	WKUP6				-
			exti7_wkup	WKUP7				-
			exti8_wkup	WKUP8				-
			exti9_wkup	WKUP9				-
			exti10_wkup	WKUP10				-
			exti11_wkup	WKUP11				-
			exti12_wkup	WKUP12				-
			exti13_wkup	WKUP13				-
			exti14_wkup	WKUP14				-
			exti15_wkup	WKUP15				-
D3	AHB4	PWR	pvd_avd_wkup	WKUP16		C	CPU	-
D3	APB4	RTC	ALARMS	WKUP17		C	CPU	-
D3	APB4	RTC	TAMPER TIMESTAMP	WKUP18		C	CPU	-
D3	AHB4	RCC	CSS_LSE					-
D3	APB4	RTC	WKUP	WKUP19		C	ANY	-
D3	APB4	COMP1	comp1_out	WKUP20		C	ANY	-
D3	APB4	COMP2	comp2_out	WKUP21		C	ANY	-
D2	APB1	I2C1	i2c1_wkup	WKUP22		C	CPU	-
D2	APB1	I2C2	i2c2_wkup	WKUP23		D	CPU	-
D2	APB1	I2C3	i2c3_wkup	WKUP24		D	CPU	-
D2	APB1	I2C4	i2c4_wkup	WKUP25		D	ANY	-
D2	APB2	USART1	usart1_wkup	WKUP26		D	CPU	-
D2	APB1	USART2	usart2_wkup	WKUP27		D	CPU	-

Table 95. EXTI wakeup inputs(1) (continued)

Source				Destination		Type	Target	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral			
D2	APB1	USART3	usart3_wkup	WKUP28	EXTI	D	CPU	-
D2	APB2	USART6	usart6_wkup	WKUP29		D	CPU	-
D2	APB1	UART4	uart4_wkup	WKUP30		D	CPU	-
D2	APB1	UART5	uart5_wkup	WKUP31		D	CPU	-
D2	APB1	UART7	uart7_wkup	WKUP32		D	CPU	-
D2	APB1	UART8	uart8_wkup	WKUP33		D	CPU	-
D3	APB4	LPUART	lpuart_rx_wkup	WKUP34		D	ANY	-
D3	APB4	LPUART	lpuart_tx_wkup	WKUP35		D	ANY	-
D2	APB2	SPI1	spi1_wkup	WKUP36		D	CPU	-
D2	APB1	SPI2	spi2_wkup	WKUP37		D	CPU	-
D2	APB1	SPI3	spi3_wkup	WKUP38		D	CPU	-
D2	APB2	SPI4	spi4_wkup	WKUP39		D	CPU	-
D2	APB2	SPI5	spi5_wkup	WKUP40		D	CPU	-
D3	APB4	SPI6	spi6_wkup	WKUP41		D	ANY	-
D2	APB1	MDIOS	mdios_wkup	WKUP42		D	CPU	-
D2	AHB1	USB1	usb1_wkup	WKUP43		D	CPU	-
D2	APB1	LPTIM1	lptim1_wkup	WKUP47		D	CPU	-
D3	APB4	LPTIM2	lptim2_wkup	WKUP48		D	ANY	-
D3	APB4	LPTIM2	lptim2_out	WKUP49		C	ANY	(2)
D3	APB4	LPTIM3	lptim3_wkup	WKUP50		D	ANY	-
D3	APB4	LPTIM3	lptim3_out	WKUP51		C	ANY	(2)
D3	APB4	LPTIM4	lptim4_wkup	WKUP52		D	ANY	-
D3	APB4	LPTIM5	lptim5_wkup	WKUP53		D	ANY	-
D2	APB1	SWPMI	swpmi_wkup	WKUP54		D	CPU	-

Table 95. EXTI wakeup inputs(1) (continued)

Source				Destination		Type	Target	Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral			
D3	AHB4	PWR	pwr_wkup1_wkup	WKUP55	EXTI	D	CPU	-
			pwr_wkup2_wkup	WKUP56				-
			pwr_wkup4_wkup	WKUP58				-
			pwr_wkup6_wkup	WKUP60				-
D3	AHB4	RCC	rcc_it	WKUP61		D	CPU	-
D3	APB4	I2C4	i2c4_ev_it	WKUP62		D	CPU	(1)
		I2C4	i2c4_err_it	WKUP63		D	CPU	(1)
D3	APB4	LPUART1	lpuart1_it	WKUP64		D	CPU	(1)
D3	APB4	SPI6	spi6_it	WKUP64		D	CPU	(1)
D3	AHB4	BDMA	bdma_ch0_it	WKUP66		D	CPU	(1)
			bdma_ch1_it	WKUP67		D	CPU	(1)
			bdma_ch2_it	WKUP68		D	CPU	(1)
			bdma_ch3_it	WKUP69		D	CPU	(1)
			bdma_ch4_it	WKUP70		D	CPU	(1)
			bdma_ch5_it	WKUP71		D	CPU	(1)
			bdma_ch6_it	WKUP72		D	CPU	(1)
			bdma_ch7_it	WKUP73		D	CPU	(1)
D3	AHB4	DMAMUX2	dmamux2_it	WKUP74			CPU	(1)
D3	AHB4	ADC3	adc3_it	WKUP75		D	CPU	(1)
D3	APB4	SAI4	sai4_gbl_it	WKUP76		D	CPU	(1)
D3	AHB4	HSEM	hsem_int_it	WKUP77		D	CPU	(1)
-	-	NC	NC	WKUP81		-	-	-
-	-	NC	NC	WKUP83		-	-	-
D1	APB1	CEC	cec_wkup	WKUP85		C	CPU	-
D2	AHB1	ETH	eth	WKUP86		C	CPU	-
D3	AHB4	RCC	hse_css_rcc_wkup	WKUP87		D	CPU	-
D3	APB4	TEMP	temp_wkup	WKUP88		D	ANY	-
D2	APB2	UART9	uart9_wkup	WKUP89		D	CPU	-
		USART10	usart10_wkup	WKUP90		D	CPU	-
D2	APB1	I2C5	i2c5_wkup	WKUP91		D	CPU	-

1. The source peripheral needs its bus clock in order to generate the event. This is either PCLK4 or HCLK4 in D3 domain, PCLK3 in D1 domain.
2. The source peripheral signal is not connected to the NVIC.

The Extended Interrupt and Event Controller (EXTI) module event inputs able to wake up the D3 domain for autonomous Run mode have a pending request logic that can be cleared by 4 different input sources (*Table 96*). Refer to *Section 20: Extended interrupt and event controller (EXTI)* for further details.

Table 96. EXTI pending requests clear inputs

Source				Destination				Comment
Domain	**Bus**	**Peripheral**	**Signal**	**Signal**	**Peripheral**	**Bus**	**Domain**	
D3	AHB4	DMAMUX2	dmamux2_evt6	d3_pendclear_in[0]	EXTI	APB4	D3	-
			dmamux2_evt7	d3_pendclear_in[1]				-
	APB4	LPTIM4	lptim4_out	d3_pendclear_in[2]				-
		LPTIM5	lptim5_out	d3_pendclear_in[3]				-

13.3 DMA

In D1 domain, the MDMA allows the memory to transfer data. It can be triggered by software or by hardware, according to the connections described in *Section 13.3.1*.

DMA Multiplexer in D2 domain (DMAMUX1) allows to map any peripheral DMA request to any stream of the DMA1 or the DMA2. In addition to this, The DMAMUX provides two other functionalities:

- It's possible to synchronize a peripheral DMA request with a timer, with an external pin or with a DMA transfer complete of another stream.
- DMA requests can be generated on a stream by the DMAMUX1 itself. This event can be triggered by a timer, by an external pin event, or by a DMA transfer complete of another stream. The number of DMA requests generated is configurable.

The connections on DMAMUX1 and DMA1/DMA2 are described in *Section 17: DMA request multiplexer (DMAMUX)*, *Section 15: Direct memory access controller (DMA)* and *Section 16: Basic direct memory access controller (BDMA)*.

DMA Multiplexer in D3 domain (DMAMUX2) has the same functionality of DMAMUX1, it is connected to the basic DMA (BDMA).

The connections on DMAMUX2 and BDMA are described in *Section 13.3.3: DMAMUX2, BDMA (D3 domain)*. Refer to *Section 13.3.3: DMAMUX2, BDMA (D3 domain)* and *Section 16: Basic direct memory access controller (BDMA)* for more details.

13.3.1 MDMA (D1 domain)

Table 97. MDMA

Source				Destination				Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain	
D2	AHB1	DMA1	dma1_tcif0	mdma_str0	MDMA	AXI	D1	DMA1 stream 0 transfer complete
			dma1_tcif1	mdma_str1				DMA1 stream 1 transfer complete
			dma1_tcif2	mdma_str2				DMA1 stream 2 transfer complete
			dma1_tcif3	mdma_str3				DMA1 stream 3 transfer complete
			dma1_tcif4	mdma_str4				DMA1 stream 4 transfer complete
			dma1_tcif5	mdma_str5				DMA1 stream 5 transfer complete flag
			dma1_tcif6	mdma_str6				DMA1 stream 6 transfer complete
			dma1_tcif7	mdma_str7				DMA1 stream 7 transfer complete
D2	AHB1	DMA2	dma2_tcif0	mdma_str8				DMA2 stream 0 transfer complete
			dma2_tcif1	mdma_str9				DMA2 stream 1 transfer complete
			dma2_tcif2	mdma_str10				DMA2 stream 2 transfer complete
			dma2_tcif3	mdma_str11				DMA2 stream 3 transfer complete
			dma2_tcif4	mdma_str12				DMA2 stream 4 transfer complete
			dma2_tcif5	mdma_str13				DMA2 stream 5 transfer complete
			dma2_tcif6	mdma_str14				DMA2 stream 6 transfer complete
			dma2_tcif7	mdma_str15				DMA2 stream 7 transfer complete
D1	APB3	LTDC	ltdc_li_it	mdma_str16				LTDC line interrupt

Table 97. MDMA (continued)

Source				Destination				Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain	
D1	AHB3	OCTOSPI1	octospi1_ft_trg	mdma_str22	MDMA	AXI	D1	OCTOSPI1 FIFO threshold
			octospi1_tc_trg	mdma_str23				OCTOSPI1 transfer complete
D1	AHB3	DMA2D	dma2d_clut_trg	mdma_str24				DMA2D CLUT transfer complete
			dma2d_tc_trg	mdma_str25				DMA2D transfer complete
			dma2d_tw_trg	mdma_str26				DMA2D transfer watermark
D1	AHB3	SDMMC1	sdmmc1_ dataend_trg	mdma_str29				End of data
			sdmmc1_ buffend_trg	mdma_str30				End of buffer
			sdmmc1_ cmdend_trg	mdma_str31				End of command
		OCTOSPI2	octospi2_ft_trg	mdma_str32				OCTOSPI2 FIFO threshold
			octospi2_fc_trg	mdma_str33				OCTOSPI2 transfer complete

13.3.2 DMAMUX1, DMA1 and DMA2 (D2 domain)

Table 98. DMAMUX1, DMA1 and DMA2 connections(1)

Source				Destination				Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain	
D3	AHB4	dmamux1 internal (Request generator)		dmamux1_req_in1	DMAMUX1	AHB1	D2	Requests
				dmamux1_req_in2				
				dmamux1_req_in3				
				dmamux1_req_in4				
				dmamux1_req_in5				
				dmamux1_req_in6				
				dmamux1_req_in7				
				dmamux1_req_in8				
D2	AHB1	ADC1	adc1_dma	dmamux1_req_in9				
D2	AHB1	ADC2	adc2_dma	dmamux1_req_in10				
D2	APB2	TIM1	tim1_ch1_dma	dmamux1_req_in11				
			tim1_ch2_dma	dmamux1_req_in12				
			tim1_ch3_dma	dmamux1_req_in13				
			tim1_ch4_dma	dmamux1_req_in14				
			tim1_up_dma	dmamux1_req_in15				
			tim1_trig_dma	dmamux1_req_in16				
			tim1_com_dma	dmamux1_req_in17				
D2	APB1	TIM2	tim2_ch1_dma	dmamux1_req_in18				
			tim2_ch2_dma	dmamux1_req_in19				
			tim2_ch3_dma	dmamux1_req_in20				
			tim2_ch4_dma	dmamux1_req_in21				
			tim2_up_dma	dmamux1_req_in22				
D2	APB1	TIM3	tim3_ch1_dma	dmamux1_req_in23				
			tim3_ch2_dma	dmamux1_req_in24				
			tim3_ch3_dma	dmamux1_req_in25				
			tim3_ch4_dma	dmamux1_req_in26				
			tim3_up_dma	dmamux1_req_in27				
			tim3_trig_dma	dmamux1_req_in28				
D2	APB1	TIM4	tim4_ch1_dma	dmamux1_req_in29				
			tim4_ch2_dma	dmamux1_req_in30				
			tim4_ch3_dma	dmamux1_req_in31				
			tim4_up_dma	dmamux1_req_in32				

Table 98. DMAMUX1, DMA1 and DMA2 connections(1) (continued)

Source				Destination				Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain	
D2	APB1	I2C1	i2c1_rx_dma	dmamux1_req_in33	DMAMUX1	AHB1	D2	Requests
			i2c1_tx_dma	dmamux1_req_in34				
D2	APB1	I2C2	i2c2_rx_dma	dmamux1_req_in35				
			i2c2_tx_dma	dmamux1_req_in36				
D2	APB2	SPI1	spi1_rx_dma	dmamux1_req_in37				
			spi1_tx_dma	dmamux1_req_in38				
D2	APB1	SPI2	spi2_rx_dma	dmamux1_req_in39				
			spi2_tx_dma	dmamux1_req_in40				
D2	APB2	USART1	usart1_rx_dma	dmamux1_req_in41				
			usart1_tx_dma	dmamux1_req_in42				
D2	APB1	USART2	usart2_rx_dma	dmamux1_req_in43				
			usart2_tx_dma	dmamux1_req_in44				
D2	APB1	USART3	usart3_rx_dma	dmamux1_req_in45				
			usart3_tx_dma	dmamux1_req_in46				
D2	APB2	TIM8	tim8_ch1_dma	dmamux1_req_in47				
			tim8_ch2_dma	dmamux1_req_in48				
			tim8_ch3_dma	dmamux1_req_in49				
			tim8_ch4_dma	dmamux1_req_in50				
			tim8_up_dma	dmamux1_req_in51				
			tim8_trig_dma	dmamux1_req_in52				
			tim8_com_dma	dmamux1_req_in53				
-	-	NC	NC	NC				
D1	APB1	TIM3	tim5_ch1_dma	dmamux1_req_in55				
			tim5_ch2_dma	dmamux1_req_in56				
			tim5_ch3_dma	dmamux1_req_in57				
			tim5_ch4_dma	dmamux1_req_in58				
			tim5_up_dma	dmamux1_req_in59				
			tim5_trig_dma	dmamux1_req_in60				
D2	APB1	SPI3	spi3_rx_dma	dmamux1_req_in61				
			spi3_tx_dma	dmamux1_req_in62				
D1	APB1	UART4	uart4_rx_dma	dmamux1_req_in63				
			uart4_tx_dma	dmamux1_req_in64				

Table 98. DMAMUX1, DMA1 and DMA2 connections(1) (continued)

Source				Destination				Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain	
D1	APB1	UART5	uart5_rx_dma	dmamux1_req_in65	DMAMUX1	AHB1	D2	Requests
			uart5_tx_dma	dmamux1_req_in66				
D2	APB1	DAC1	dac_ch1_dma	dmamux1_req_in67				
D2	APB1	DAC2	dac_ch2_dma	dmamux1_req_in68				
D2	APB1	TIM6	tim6_up_dma	dmamux1_req_in69				
D2	APB1	TIM7	tim7_up_dma	dmamux1_req_in70				
D2	APB2	USART6	usart6_rx_dma	dmamux1_req_in71				
			usart6_tx_dma	dmamux1_req_in72				
D2	APB1	I2C3	i2c3_rx_dma	dmamux1_req_in73				
			i2c3_tx_dma	dmamux1_req_in74				
D2	AHB2	DCMI	dcmi_dma	dmamux1_req_in75				
D2	AHB2	CRYP	cryp_in_dma	dmamux1_req_in76				
			cryp_out_dma	dmamux1_req_in77				
D2	AHB2	HASH	hash_in_dma	dmamux1_req_in78				
D2	APB1	UART7	uart7_rx_dma	dmamux1_req_in79				
			uart7_tx_dma	dmamux1_req_in80				
D2	APB1	UART8	uart8_rx_dma	dmamux1_req_in81				
			uart8_tx_dma	dmamux1_req_in82				
D2	APB2	SPI4	spi4_rx_dma	dmamux1_req_in83				
			spi4_tx_dma	dmamux1_req_in84				
D2	APB2	SPI5	spi5_rx_dma	dmamux1_req_in85				
			spi5_tx_dma	dmamux1_req_in86				
D2	APB2	SAI1	sai1_a_dma	dmamux1_req_in87				
			sai1_b_dma	dmamux1_req_in88				
D2	APB1	SWPMI	swpmi_rx_dma	dmamux1_req_in91				
			swpmi_tx_dma	dmamux1_req_in92				
D2	APB1	SPDIFRX	spdifrx_dt_dma	dmamux1_req_in93				
			spdifrx_cs_dma	dmamux1_req_in94				

Table 98. DMAMUX1, DMA1 and DMA2 connections(1) (continued)

Source				Destination				Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain	
D2	APB2	DFSDM1	dfsdm1_dma0	dmamux1_req_in101	DMAMUX1	AHB1	D2	Requests
			dfsdm1_dma1	dmamux1_req_in102				
			dfsdm1_dma2	dmamux1_req_in103				
			dfsdm1_dma3	dmamux1_req_in104				
D2	APB2	TIM15	tim15_ch1_dma	dmamux1_req_in105				
			tim15_up_dma	dmamux1_req_in106				
			tim15_trig_dma	dmamux1_req_in107				
			tim15_com_dma	dmamux1_req_in108				
D2	APB2	TIM16	tim16_ch1_dma	dmamux1_req_in109				
			tim16_up_dma	dmamux1_req_in110				
D2	APB2	TIM17	tim17_ch1_mda	dmamux1_req_in111				
			tim17_up_dma	dmamux1_req_in112				
D3	AHB4	ADC3	adc3_dma	dmamux1_req_in115				
D2	APB2	UART9	uart9_rx_dma	dmamux1_req_in116				
			uart9_tx_dma	dmamux1_req_in117				
		USART10	usart10_rx_dma	dmamux1_req_in118				
			usart10_tx_dma	dmamux1_req_in119				
D2	AHB2	FMAC	fmac_rd_dma	dmamux1_req_in120				
			fmac_wr_dma	dmamux1_req_in121				
		CORDIC	cordic_rd_dma	dmamux1_req_in122				
			cordic_wr_dma	dmamux1_req_in123				
	APB1	I2C5	i2c5_rx_dma	dmamux1_req_in124				
			i2c5_tx_dma	dmamux1_req_in125				
		TIM23	tim23_ch1_dma	dmamux1_req_in126				
			tim23_ch2_dma	dmamux1_req_in127				
			tim23_ch3_dma	dmamux1_req_in128				
			tim23_ch4_dma	dmamux1_req_in129				
			tim23_up_dma	dmamux1_req_in130				
			tim23_trig_dma	dmamux1_req_in131				

Table 98. DMAMUX1, DMA1 and DMA2 connections(1) (continued)

Source				Destination				Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain	
D2	APB1	TIM24	tim24_ch1_dma	dmamux1_req_in132	DMAMUX1	AHB1	D2	Requests
			tim24_ch2_dma	dmamux1_req_in133				
			tim24_ch3_dma	dmamux1_req_in134				
			tim24_ch4_dma	dmamux1_req_in135				
			tim24_up_dma	dmamux1_req_in136				
			tim24_trig_dma	dmamux1_req_in137				
D2	AHB1	DMAMUX1	dmamux1_evt0	dmamux1_gen0	DMAMUX1	AHB1	D2	Request generation triggers
			dmamux1_evt1	dmamux1_gen1				
			dmamux1_evt2	dmamux1_gen2				
D2	APB1	LPTIM1	lptim1_out	dmamux1_gen3				
D2	APB1	LPTIM2	lptim2_out	dmamux1_gen4				
D2	APB1	LPTIM3	lptim3_out	dmamux1_gen5				
D3	APB4	EXTI	exti_exti0_it	dmamux1_gen6				
D2	APB1	TIM12	tim12_trgo	dmamux1_gen7				
D2	AHB1	DMAMUX1	dmamux1_evt0	dmamux1_trg0	DMAMUX1	AHB1	D2	Synchroni-zation inputs
			dmamux1_evt1	dmamux1_trg1				
			dmamux1_evt2	dmamux1_trg2				
D2	APB1	LPTIM1	lptim1_out	dmamux1_trg3				
D2	APB1	LPTIM2	lptim2_out	dmamux1_trg4				
D2	APB1	LPTIM3	lptim3_out	dmamux1_trg5				
D3	APB4	EXTI	exti_exti0_it	dmamux1_trg6				
D2	APB1	TIM12	tim12_trgo	dmamux1_trg7				

Table 98. DMAMUX1, DMA1 and DMA2 connections(1) (continued)

Source				Destination				Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain	
D2	AHB1	DMAMUX1	dmamux1_req_out0	dma1_str0	DMA1	AHB1	D2	Requests out
			dmamux1_req_out1	dma1_str1				
			dmamux1_req_out2	dma1_str2				
			dmamux1_req_out3	dma1_str3				
			dmamux1_req_out4	dma1_str4				
			dmamux1_req_out5	dma1_str5				
			dmamux1_req_out6	dma1_str6				
			dmamux1_req_out7	dma1_str7				
			dmamux1_req_out8	dma2_str0	DMA2	AHB1	D2	
			dmamux1_req_out9	dma2_str1				
			dmamux1_req_out10	dma2_str2				
			dmamux1_req_out11	dma2_str3				
			dmamux1_req_out12	dma2_str4				
			dmamux1_req_out13	dma2_str5				
			dmamux1_req_out14	dma2_str6				
			dmamux1_req_out15	dma2_str7				

1. The “-” symbol in grayed cells means no interconnect.

13.3.3 DMAMUX2, BDMA (D3 domain)

Table 99. DMAMUX2 and BDMA connections

Source				Destination				Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain	
D3	AHB4	dmamux2 internal (Request generator)		dmamux2_req_in1	DMAMUX2	AHB4	D3	Requests
				dmamux2_req_in2				
				dmamux2_req_in3				
				dmamux2_req_in4				
				dmamux2_req_in5				
				dmamux2_req_in6				
				dmamux2_req_in7				
				dmamux2_req_in8				
D3	APB4	LPUART	dma_rx_lpuart	dmamux2_req_in9				
			dma_tx_lpuart	dmamux2_req_in10				
D3	APB4	SPI6	dma_rx_spi6	dmamux2_req_in11				
			dma_tx_spi6	dmamux2_req_in12				
D2	APB1	I2C4	dma_rx_i2c4	dmamux2_req_in13				
			dma_tx_i2c4	dmamux2_req_in14				
D3	APB4	SAI4	dma_a_sai4	dmamux2_req_in15				
			dma_b_sai4	dmamux2_req_in16				
D3	APB4	ADC3	dma_adc3	dmamux2_req_in17				

Table 99. DMAMUX2 and BDMA connections (continued)

Source				Destination				Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain	
D3	AHB4	DMAMUX2	dmamux2_evt0	dmamux2_gen0	DMAMUX2	AHB4	D3	Request generation triggers
			dmamux2_evt1	dmamux2_gen1				
			dmamux2_evt2	dmamux2_gen2				
			dmamux2_evt3	dmamux2_gen3				
			dmamux2_evt4	dmamux2_gen4				
			dmamux2_evt5	dmamux2_gen5				
			dmamux2_evt6	dmamux2_gen6				
D3	APB4	EXTI	exti_lpuart_rx_it	dmamux2_gen7				
			exti_lpuart_tx_it	dmamux2_gen8				
			exti_lptim2_wkup	dmamux2_gen9				
			exti_lptim2_out	dmamux2_gen10				
			exti_lptim3_wkup	dmamux2_gen11				
			exti_lptim3_out	dmamux2_gen12				
			exti_lptim4_wkup	dmamux2_gen13				
			exti_lptim5_wkup	dmamux2_gen14				
			exti_i2c4_wkup	dmamux2_gen15				
			exti_spi6_wkup	dmamux2_gen16				
			exti_comp1_out	dmamux2_gen17				
			exti_comp2_out	dmamux2_gen18				
			exti_rtc_wkup	dmamux2_gen19				
			exti_syscfg_exti0	dmamux2_gen20				
			exti_syscfg_exti2	dmamux2_gen21				
D3	APB4	I2C4	it_evt_i2c4	dmamux2_gen22				
D3	APB4	SPI6	it_spi6/spi6_wkup	dmamux2_gen23				
D3	APB4	LPUART	it_tx_lpuart1	dmamux2_gen24				
			it_rx_lpuart1	dmamux2_gen25				
D3	AHB4	ADC3	it_adc3	dmamux2_gen26				
			out_awd1_adc3	dmamux2_gen27				
D3	AHB4	BDMA	it_ch0_bdma	dmamux2_gen28				
			it_ch1_bdma	dmamux2_gen29				

Table 99. DMAMUX2 and BDMA connections (continued)

Source				Destination				Comment
Domain	Bus	Peripheral	Signal	Signal	Peripheral	Bus	Domain	
D3	AHB4	DMAMUX2	dmamux2_evt0	dmamux2_trg0	DMAMUX2	AHB4	D3	Synchroni-zation inputs
			dmamux2_evt1	dmamux2_trg1				
			dmamux2_evt2	dmamux2_trg2				
			dmamux2_evt3	dmamux2_trg3				
			dmamux2_evt4	dmamux2_trg4				
			dmamux2_evt5	dmamux2_trg5				
D3	APB4	EXTI	it_exti_tx_lpuart1	dmamux2_trg6				
			it_exti_rx_lpuart1	dmamux2_trg7				
			it_exti_out_lptim2	dmamux2_trg8				
			it_exti_out_lptim3	dmamux2_trg9				
			it_exti_wkup_i2c4	dmamux2_trg10				
			it_exti_wkup_spi6	dmamux2_trg11				
			it_exti_out_comp1	dmamux2_trg12				
			it_exti_wkup_rtc	dmamux2_trg13				
			it_exti_exti0_syscfg	dmamux2_trg14				
			it_exti_exti2_syscfg	dmamux2_trg15				
D3	AHB4	DMAMUX2	dmamux1_req_out0	bdma_ch0	BDMA	AHB4	D3	Requests out
			dmamux1_req_out1	bdma_ch1				
			dmamux1_req_out2	bdma_ch2				
			dmamux1_req_out3	bdma_ch3				
			dmamux1_req_out4	bdma_ch4				
			dmamux1_req_out5	bdma_ch5				
			dmamux1_req_out6	bdma_ch6				
			dmamux1_req_out7	bdma_ch7				

14 MDMA controller (MDMA)

14.1 MDMA introduction

The master direct memory access (MDMA) is used in order to provide high-speed data transfer between memory and memory, or between peripherals and memory. Data can be quickly moved by the MDMA without any CPU action. This keeps the CPU resources free for other operations.

The MDMA controller provides a master AXI interface for main memory and peripheral register access (system access port) and a master AHB interface only for Cortex-M7 TCM memory access (TCM access port).

The MDMA works in conjunction with the standard DMA controllers (DMA1 or DMA2). It offers up to 16 channels, each dedicated to manage memory access requests from one of the DMA stream memory buffer or other peripherals (w/ integrated FIFO).

14.2 MDMA main features

- AXI/AHB master bus architecture, one dedicated to main memory/peripheral accesses and one dedicated to Cortex-M7 AHBS port (only for TCM accesses).
- 16 channels
- Up to 34 hardware trigger sources
- Each channel request can be selected among any of the request sources. This selection is software-configurable and allows several peripherals to initiate DMA requests. The trigger selection can be automatically changed at the end of one block transfer.
- All channels are identical and can be connected either to a standard DMA or a peripheral request (acknowledge by data read/write) system
- Each channel also supports software trigger.
- One 256-level memory buffer, split in two 128-level first-in, first-out (FIFO), that is used to store temporary the data to be transferred (in burst or single transfer mode), for one or two consecutive buffers. The FIFO stores the data that are transferred during the current channel block transfer (up to the block transfer size). The second FIFO can be used for the next buffer to be transferred, either for the same channel or for the next channel transfer.
- The priorities between DMA channels are software-programmable (four levels consisting of very-high, high, medium, low) or hardware in case of equality (for example, channel 0 has priority over channel 1)
- Independent source and destination transfer width (byte, half-word, word, double-word): when the data widths of the source and destination are not equal, the MDMA can pack/unpack the necessary data to optimize the bandwidth.
- The size and address increment for both source and destination can be independently selected.

Note: Based on this separation, some more advanced packing/unpacking operations are available at software level. As an example, 2 x 16-bit data blocks can be interleaved together using two MDMA channels, in the destination memory, by simply programming the two channels with an increment step of 4 bytes and a data size of 16 bits + a start address shifted by two between the two channels.

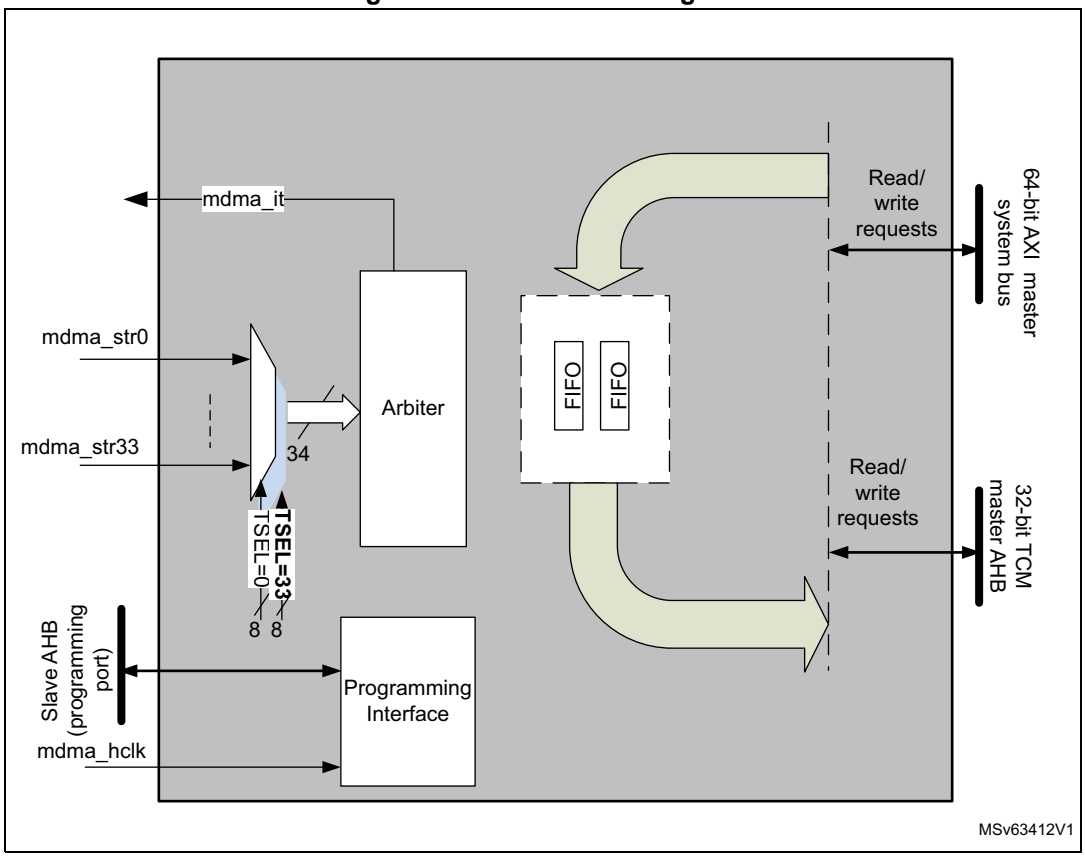
- Incrementing, decrementing or non incrementing/fixed addressing for source and destination
- Data packing/unpacking is always done respecting the little endian convention: lower address in a data entity (double-word, word, or half-word) contains always the lowest significant byte. This is independent of the address increment/decrement mode of both source and destination.
- Supports incremental burst transfers. The size of the burst is software-configurable, up to 128 bytes. For larger data sizes the burst length is limited, as to respect the maximum 128 bytes data burst size (such as 16 x 64 bits or 32 x 32 bits).
- For the TCM memory accesses, the burst access is only allowed when the increment and data size are identical and lower than or equal to 32 bits.
- Five event flags (MDMA channel transfer complete, MDMA block transfer complete, MDMA block repeat transfer Complete, MDMA buffer transfer Complete, MDMA transfer error) are available and can generate interrupts.

14.3 MDMA functional description

14.3.1 MDMA block diagram

The figure below shows the block diagram of the MDMA.

Figure 78. MDMA block diagram



14.3.2 MDMA internal signals

The table below shows the internal MDMA signals.

Table 100. MDMA internal input/output signals

Signal name	Signal type	Description
mdma_hclk	Digital input	MDMA AHB clock
mdma_it	Digital output	MDMA interrupt
mdma_str[0:31]	Digital input	MDMA stream request

14.3.3 MDMA overview

The MDMA performs a direct memory transfer: as an AXI/AHB master, the MDMA can take the control of the AXI/AHB bus matrix to initiate AXI/AHB transactions.

The MDMA can carry out the following transactions:

- memory-to-memory (software triggered)
- peripheral-to-memory
- memory-to-peripheral

For the last two transaction types, the memory can also be replaced by a memory-mapped peripheral, which has no control over the MDMA flow. When these types of transaction are used and the request comes from a standard DMA (DMA1 or DMA2), the peripheral register access is replaced by a memory access to the memory buffer used by this DMA.

Note: Non-incrementing/decrementing mode is not used for memory accesses.

The source and destination are simply defined by the address (peripherals being memory-mapped also).

The AHB slave port is used to program the MDMA (it supports 8-,16-, and 32-bit accesses).

The size of the data array to be transferred for a single request is one of the following:

- buffer transfer size
- block size
- repeated block
- complete channel data (until the linked-list pointer for the channel is null)

The choice of the size is done through the TRGM[1:0] (Trigger mode) selection field.

The user must choose one of them based on the data array size available (usually in the DMA1/2 memory buffer) and the “real time” requirements for other MDMA channels (knowing that a buffer transfer is the minimum data aggregate to be transferred by the MDMA without doing a new arbitration between MDMA channel requests).

For each channel, there are three key data array sizes:

- Burst size: this is the length of the data transfer which can be performed in burst mode. This burst length defines the maximum transfer length which cannot be interrupted at bus arbitration level and can block other masters from accessing the bus.
- Buffer transfer size: this is the length of the data array to be transferred, on a channel, before checking for MDMA requests on other channels. This is the data array transfer lengths which cannot be interrupted at MDMA level (from other channel requests).
- Block size: this value has two meanings which can be used together:
  - main: this is length of the data block which is described in a block structure of the MDMA linked list (corresponds to one entry in the linked list)
  - selectable: when TRGM[1:0] equals 01, this is the length of the data array which is transferred on a single MDMA request activation (for the respective channel)

14.3.4 MDMA channel

Each MDMA channel provides an unidirectional transfer link between a source and a destination.

Each channel can perform transfer of the following types:

- Single block transfer: one block is transferred. At the end of the block, the MDMA channel is disabled and an end-of-channel transfer interrupt is generated.
- Repeated block transfer: a number of blocks is transferred before disabling the channel.
- Linked-list transfer: when the transfer of the current data block (or last block in a repeat) is completed, a new block control structure is loaded from memory and a new block transfer is started.

The minimum amount of data to be transferred for each request (buffer size, up to 128 bytes) is programmable. The total amount of data in a block, is programmable up to 64 Kbytes. This value is decremented after each transfer. When this counter reaches zero, the end of the block is reached and an action is taken based on the repeat counter (for repeated block transfer) and/or linked-list structure value.

Note: If the block length is not a multiple of the buffer length, the last buffer transfer in the block is shorter, covering the remaining bytes to be transferred in the current block.

If the link structure address points to a valid memory address, the MDMA reloads the whole channel descriptor structure register contents from memory at this address. Then, a new block transfer is then executed (on the next MDMA channel request) based on this information.

If the link structure address is 0x0, at the end of the current/repeated block transfer, the MDMA channel is disabled and the end-of-channel transfer interrupt is generated.

14.3.5 Source, destination and transfer modes

Both source and destination transfers can address peripherals and memories in the entire 4-Gbyte area, at addresses comprised between 0x0000 0000 and 0xFFFF FFFF.

The source/destination addresses can be fixed (such as FIFO/single data register peripherals) or incremented/decremented. The transfer can be done in single access or in burst mode (programmable).

14.3.6 Pointer update

The source and destination memory pointers can optionally be automatically post-incremented/decremented, or kept constant after each transfer depending on the SINC[1:0] and DINC[1:0] bitfields in the MDMA_CxCR register.

Disabling the increment mode is useful when the peripheral source or destination data are accessed through a single register/FIFO mode.

If the increment/decrement mode is enabled, the address of the next data transfer is the address of the previous one incremented/decrement by 1, 2, 4 or 8 depending on the increment size programmed in SINCOS[1:0] or DINCOS[1:0] in MDMA_CxCR.

In order to optimize the packing operation, the increment offset size and the data size are programmable independently.

14.3.7 MDMA buffer transfer

This is the minimum logical amount of data (up to 128 bytes) which is transferred on an MDMA request event, on one channel.

An MDMA buffer transfer consists of a sequence of a given number of data transfers (done as single or burst data transfers). The number of data items to be transferred and their width (8, 16, 32, or 64 bits) are software programmable. The length of the burst used for data transfers is also programmable, independently.

After an event requiring a data array to be transferred, the DMA/peripheral sends a request signal to the MDMA, which serves the request depending on the channel priorities.

The request is acknowledged by writing the mask data value to the address given mask address, when these registers are set.

If the mask address register is not set (0x00 value), the request can be reset by simply reading/writing the data to the peripheral. In this case, if the request is done by a destination peripheral, the write must be set as non bufferable, in order to avoid a false new MDMA request.

The total amount of data to be transferred, on the current channel, following a MDMA request, is determined by the TRGM[1:0] field.

If TRGM[1:0] equals 00, a single buffer is transferred, then the MDMA waits for another request on the same channel.

Note: In this case, the hardware request for the currently active channel (data in the FIFO) is not considered again until the end of the write phase for this channel. Even if the channel is still active at the end of the read phase, another channel (even with lower priority) can start the read phase. Lower priority channels can be interleaved with current channel transfer.

If TRGM[1:0] is different from 00 (multiple buffers need to be transferred), the mdma_strx for the current channel remains active (internally memorized) until the whole transfer defined by TRGM (block, repeated block or whole channel/linked list data) is completed.
After transferring an individual buffer, the MDMA enters in a new arbitration phase (between new external requests and internally memorized ones). If no other higher priority, the channel request is active, and a new buffer transfer is started for the same channel.

Note: When TRGM[1:0] is different from 00, a larger array of data is transferred for a single request. But, as the channel arbitration is done after each buffer transfer, no higher level MDMA requests are blocked for the more than a buffer transfer period, on any lower priority channel.

14.3.8 Request arbitration

An arbiter manages the MDMA channel requests based on their priority. When the MDMA is idle and after the end of each buffer transfer, all MDMA requests (hardware or software) are checked for all enabled channels.

Priorities are managed in two stages:

- Software: each stream priority can be configured in the MDMA_CxCR register. There are four levels:
  - Very high priority
  - High priority
  - Medium priority
  - Low priority
- Hardware: at hardware level, the channel priority is fixed. If two requests have the same software priority level, the channel with the lower number takes priority over the stream with the higher number. For example, Channel 2 takes priority over Channel 4 when they have the same software priority level.

14.3.9 FIFO

A FIFO structure is used to temporarily store data coming from the source before writing them to the destination. There is a central FIFO structure which is used for all channels.

In order to maximize data bandwidth and bus usage, the following mechanisms are used, allowing multiple read/write operation to be executed in parallel.

- During a buffer transfer, as soon as the FIFO contains enough data for a destination burst transfer, the write operation starts.
- When the complete data for a buffer transfer has been read into the FIFO, the arbitration procedure is started. Following that, the next buffer data to be transferred can be read to the FIFO.

When an active channel is disabled due to an error, during a buffer transfer, the remaining data in the internal FIFO is discarded.

14.3.10 Block transfer

A block is a “contiguous” array of data, up to 64 Kbytes, which is transferred by successive buffer transfers.

Each block of data is defined by the start address and the block length. When a block transfer is completed, one of the following three actions can be executed:

- The block is part of a repeated block transfer: the block length is reloaded and new block start address is computed (based on the information in MDMA_CxBRUR).
- It is a single block or the last block in a repeated block transfer: the next block information is loaded from the memory (using the linked list address information, from MDMA_CxLAR).
- It is the last block which needs to be transferred for the current MDMA channel (MDMA_CxLAR = 0): the channel is disabled and no further MDMA requests are accepted for this channel.

14.3.11 Block repeat mode

The block repeat mode is used to repeat a block transfer, with different start addresses for source and destination.

When the repeat block mode is active (repeat counter ≠ 0), at the end of the current block transfer, the block parameters are updated (BNDT value reloaded and SAR/DAR values updated according to BRSUM/BRDUM configuration), and the repeat counter decremented by one.

When the repeat block counter reaches 0, this last block is treated as a single block transfer.

14.3.12 Linked-list mode

The linked-list mode allows a new MDMA configuration to be loaded (MDMA_CxTCR, MDMA_CxBNDTR, MDMA_CxSAR, MDMA_CxDAR, MDMA_CxBRUR, MDMA_CxLAR, MDMA_CxTBR, MDMA_CxMAR and MDMA_CxMDR registers), from the address given in MDMA_CxLAR. This address must address a memory mapped on the AXI system bus.

Following this operation, the channel is ready to accept new requests, as defined in the block/repeated block modes above, or continue the transfer if TRGM[1:0] = 11.

The trigger source can be automatically changed, when loading the MDMA_CxTBR value.

The TRGM and SWRM values must not be changed when TRGM[1:0] = 11.

14.3.13 MDMA transfer completion

Different events can generate an end of transfer by setting the CTCIF bit in the status register (MDMA_CxISR):

- The MDMA_CxBNDTR counter has reached zero, the Block Repeat Counter is 0 and the Link list pointer address is 0
- The channel is disabled before the end of transfer (by clearing the EN bit in MDMA_CxCR) and all the remaining data have been transferred from the FIFO to the destination

14.3.14 MDMA transfer suspension

At any time, a MDMA transfer can be suspended in order to be to be restarted later on or to be definitively disabled before the end of the MDMA transfer.

There are two cases:

- The channel is disabled, with no later-on restart from the point where it was stopped. There is no particular action to do, besides clearing the EN bit in the MDMA_CxCR register to disable the channel. The stream can take time to be disabled (on going buffer transfer is completed first). The transfer complete interrupt flag is set in order to indicate the end of transfer. The value of the EN bit in MDMA_CxCR is now 0 to confirm the channel interruption. The MDMA_CxNDTR register contains the number of remaining data items when the channel was stopped. The software can then determine how many data items have been transferred before the channel was interrupted.
- The channel is suspended before the number of remaining bytes to be transferred in the MDMA_CxBNDTR register reaches zero. The aim is to restart the transfer later by re-enabling the channel. The channel transfer complete interrupt flag CTCIF is set in order to indicate the end of transfer. If the MDMA_CxBNDTR, MDMA_CxSAR and

MDMA_CxDAR registers are not modified by software, the transfer continues when the channel is re-enabled. CTCIF must also be reset before restarting the channel.

Note: If the completed buffer is the last of the block, the configuration registers are also updated before disabling the channel, in order to be correctly prepared for a soft restart.

Before reprogramming the channel, the software must wait the MDMA_CTCIF register is set, in order to guarantee that any ongoing operation has been completed.

14.3.15 Error management

The MDMA can detect the following errors and the transfer error interrupt flag (TEIF) is set:

- when a bus error occurs during a MDMA read/write access
- when an address alignment does not correspond to the data size
- when the block size is not a multiple of the data size (for source and/or destination): this error is activated on the last transfer and the error address points to the last transfer (which cannot be done)

14.4 MDMA interrupts

For each MDMA channel, an interrupt can be produced on the following events:

- Channel transfer completed
- Block-transfer completed
- Block-transfer repeat completed
- Buffer transfer completed
- Transfer error

Separate interrupt enable control bits are available for flexibility as shown in the table below.

Table 101. MDMA interrupt requests

Interrupt event	Event flag	Enable control bit
Channel transfer completed	CTCIF	CTCIE
Block-transfer repeat completed	BTRIF	BTRIE
Block-transfer completed	BTIF	BTIE
Buffer transfer completed	TCIF	TCIE
Transfer error	TEIF	TEIE

Note: Before setting an enable control bit to 1, the corresponding event flag must be cleared, otherwise an interrupt may be immediately generated, if the bit is already set.

When at least one interrupt flag and the respective enable control bit are set, the channel interrupt bit is set in the MDMA_GISR. The interrupt output is also activated. This generates an interrupt if the respective interrupt channel is enabled in the NVIC.

14.5 MDMA registers

The MDMA registers can be accessed in word/half-word or byte format.

14.5.1 MDMA global interrupt/status register (MDMA_GISR0)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GIF15	GIF14	GIF13	GIF12	GIF11	GIF10	GIF9	GIF8	GIF7	GIF6	GIF5	GIF4	GIF3	GIF2	GIF1	GIF0
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **GIF[15:0]**: Channel x global interrupt flag (x = 15 to 0)

This bit is set and reset by hardware. It is a logical OR of all the channel x interrupt flags (CTCIF, BTIF, BRTIF, TEIF) which are enabled in the interrupt mask register (MDMA_CTCIEx, MDMA_BTIEx, MDMA_BRTIEx, MDMA_TEIEx)

0: No interrupt generated by channel x

1: Interrupt generated by channel x

14.5.2 MDMA channel x interrupt/status register (MDMA_CxISR)

Address offset: 0x40 + 0x40 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CRQA
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCIF	BTIF	BRTIF	CTCIF	TEIF
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **CRQA**: Channel x request active flag

This bit is set by software writing 1 to SWRQx in MDMA_CxCR, in order to request a MDMA transfer, and the channel x is enabled.

It is also set by hardware when the channel request becomes active and the channel is enabled. The hardware request memorized until it is served.

It is cleared by hardware, when the channel x request is completed (after the source write phase of the last buffer transfer due for the current request).

0: The MDMA transfer mdma_strx is inactive for channel x.

1: The MDMA transfer mdma_strx is active for channel x

Note: This bit is also reset by hardware when the channel is disabled (in case of transfer error or when reaching the end of the channel data transfer - repeat block = 0 and linked list pointer null - or by software programming the channel enable bit to 0 before that).

Bits 15:5 Reserved, must be kept at reset value.

Bit 4 **TCIF**: Channel x buffer transfer complete interrupt flag

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in MDMA_IFCRy.

0: No buffer transfer complete event on channel x

1: A buffer transfer complete event occurred on channel x

TC is set when a single buffer was transferred. It is activated on each channel transfer request.

This can be used as a debug feature (without interrupt), indicating that (at least) an MDMA buffer transfer had been generated since the last flag reset.

Bit 3 **BTIF**: Channel x block transfer complete interrupt flag

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in MDMA_IFCRy.

0: No block transfer complete event on channel x

1: A block transfer complete event occurred on channel x

Bit 2 **BRTIF**: Channel x block repeat transfer complete interrupt flag

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in MDMA_IFCRy.

0: No block repeat transfer complete event on channel x

1: A block repeat transfer complete event occurred on channel x

Bit 1 **CTCIF**: Channel x channel transfer complete interrupt flag

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in MDMA_IFCRy.

0: No channel transfer complete event on channel x

1: A channel transfer complete event occurred on channel x

CTC is set when the last block was transferred and the channel has been automatically disabled.

CTC is also set when the channel is suspended, as a result of writing EN bit to 0.

Bit 0 **TEIF**: Channel x transfer error interrupt flag

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in MDMA_IFCRy.

0: No transfer error on stream x

1: A transfer error occurred on stream x

14.5.3 MDMA channel x interrupt flag clear register (MDMA_CxIFCR)

Address offset: 0x44 + 0x40 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLTCIF	CBTIF	CBR TIF	CCT CIF	CTEIF
											w	w	w	w	w

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **CLTCIF**: Clear buffer transfer complete Interrupt flag for channel x
Writing 1 into this bit clears TCIF in MDMA_ISRy.

Bit 3 **CBTIF**: Channel x clear block transfer complete interrupt flag
Writing 1 into this bit clears BTIF in MDMA_ISRy.

Bit 2 **CBRTIF**: Channel x clear block repeat transfer complete interrupt flag
Writing 1 into this bit clears BRTIF in MDMA_ISRy.

Bit 1 **CCTCIF**: Clear channel transfer complete interrupt flag for channel x
Writing 1 into this bit clears CTCIF in MDMA_ISRy.

Bit 0 **CTEIF**: Channel x clear transfer error interrupt flag
Writing 1 into this bit clears TEIF in MDMA_ISRy.

14.5.4 MDMA channel x error status register (MDMA_CxESR)

Address offset: 0x48 + 0x40 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	BSE	ASE	TEMD	TELD	TED	TEA[6:0]						
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **BSE**: Block size error
This bit is set by hardware, when the block size is not an integer multiple of the data size either for source or destination. TED indicates whether the problem is on the source or destination.
This bit is cleared by software writing 1 to CTEIF in MDMA_IFCRy.
0: No block size error.
1: Programmed block size is not an integer multiple of the data size.

Bit 10 **ASE**: Address/size error

This bit is set by hardware, when the programmed address is not aligned with the data size. TED indicates whether the problem is on the source or destination.

It is cleared by software writing 1 to CTEIF in MDMA_IFCRy.

0: No address/size error.

1: Programmed address is not coherent with the data size.

Bit 9 **TEMD**: Transfer error mask data

This bit is set by hardware, in case of a transfer error while writing the mask data.

It is cleared by software writing 1 to CTEIF in MDMA_IFCRy.

0: No mask write access error.

1: The last transfer error on the channel was a related to a write of the mask data.

Bit 8 **TELD**: Transfer error link data

This bit is set by hardware, in case of a transfer error while reading the block link data structure. It is cleared by software writing 1 to CTEIF in MDMA_IFCRy.

0: No link data read access error.

1: The last transfer error on the channel was a related to a read of the link data structure.

Bit 7 **TED**: Transfer error direction

This bit is set and cleared by hardware, in case of an MDMA data transfer error.

0: The last transfer error on the channel was a related to a read access.

1: The last transfer error on the channel was a related to a write access.

Bits 6:0 **TEA[6:0]**: Transfer error address

These bits are set and cleared by hardware, in case of an MDMA data transfer error. They are used in conjunction with TED.

This field indicates the 7 LSB bits of the address which generated a transfer/access error.

It can be used by software to retrieve the failing address, by adding this value (truncated to the buffer transfer length size) to the current SAR/DAR value.

Note: The SAR/DAR current value does not reflect this last address due to the FIFO management system. The SAR/DAR are only updated at the end of a (buffer) transfer (of TLEN+1 bytes).

This field is not set in case of a link data error.

14.5.5 MDMA channel x control register (MDMA_CxCR)

This register is used to control the concerned channel.

Address offset: 0x4C + 0x40 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWRQ
															w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	WEX	HEX	BEX	Res.	Res.	Res.	Res.	PL[1:0]		TCIE	BTIE	BRTIE	CTCIE	TEIE	EN
	rw	rw	rw					rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **SWRQ**: Software request

Writing 1 into this bit sets the CRQA in MDMA_ISRy, activating the request on channel x.

Note: Either the whole MDMA_CxCR register or the 8-bit/16-bit register at the address offset: 0x4E + 0x40 × channel number, can be used for SWRQ activation.

In case of software request, acknowledge is not generated (neither hardware signal, nor MDMA_CxMAR write access).

Bit 15 Reserved, must be kept at reset value.

Bit 14 **WEX**: Word endianness exchange

This bit is set and cleared by software.

0: Little endianness preserved for words

1: word order exchanged in double word

When this bit is set, the word order in the destination double word is reversed: higher address word contains the data read from the lower address of the source.

If destination is not a double word, do not care of the value of this bit.

Note: This bit is protected and can be written only if EN is 0.

Bit 13 **HEX**: Half word endianness exchange

This bit is set and cleared by software.

0: Little endianness preserved for half words

1: half-word order exchanged in each word

When this bit is set, the half-word order in each destination word is reversed: higher address half-word contains the data read from the lower address of the source.

If destination length is shorter than word, do not care of the value of this bit.

Note: This bit is protected and can be written only if EN is 0.

Bit 12 **BEX**: Byte endianness exchange

This bit is set and cleared by software.

0: Little endianness preserved for bytes

1: byte order exchanged in each half-word

When this bit is set, the byte order in each destination Half Word is reversed: higher address word contains the data read from the lower address of the source.

If destination is byte, do not care of the value of this bit.

Note: This bit is protected and can be written only if EN is 0.

Bits 11:9 Reserved, must be kept at reset value.

Bit 8 Reserved, must be kept at reset value.

Bits 7:6 **PL[1:0]**: Priority level

These bits are set and cleared by software.

00: Low

01: Medium

10: High

11: Very high

Note: These bits are protected and can be written only if EN is 0.

Bit 5 **TCIE**: buffer Transfer complete interrupt enable

This bit is set and cleared by software.

0: TC interrupt disabled

1: TC interrupt enabled

Bit 4 **BTIE**: Block transfer interrupt enable

This bit is set and cleared by software.

0: BT complete interrupt disabled

1: BT complete interrupt enabled

Bit 3 **BRTIE**: Block repeat transfer interrupt enable
This bit is set and cleared by software.
0: BT interrupt disabled
1: BT interrupt enabled

Bit 2 **CTCIE**: Channel transfer complete interrupt enable
This bit is set and cleared by software.
0: TC interrupt disabled
1: TC interrupt enabled

Bit 1 **TEIE**: Transfer error interrupt enable
This bit is set and cleared by software.
0: TE interrupt disabled
1: TE interrupt enabled

Bit 0 **EN**: Channel enable/flag channel ready when read low
This bit is set and cleared by software.
0: Channel disabled
1: Channel enabled
This bit can be cleared by hardware:
- on a MDMA end of transfer (stream ready to be configured)
- if a transfer error occurs on the AHB/AXI master buses (bus error/hard fault)
- if another error condition is encountered (data alignment, block/data size incompatibility)

When this bit is reset by software, the ongoing buffer transfer (if any) is completed. All status/configuration registers keep their current values. If the channel is re enabled without writing these registers, the channel continues from the point where it was interrupted.
When this bit is read as 0, the software is allowed to program the configuration registers. It is forbidden to write these registers when the EN bit is read as 1 (writes are ignored).

Note: When this bit is reset by software, it is recommended to wait for the CTCIF = 1, in order to ensure that any ongoing buffer transfer has been completed, before reprogramming the channel.

14.5.6 MDMA channel x transfer configuration register (MDMA_CxTCR)

This register is used to configure the concerned channel. In linked-list mode, at the end of a block (single or last block in repeated block transfer mode), this register is loaded from memory (from address given by current LAR[31:0] + 0x00).

Address offset: 0x50 + 0x40 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BWM	SWRM	TRGM[1:0]		PAM[1:0]		PKE	TLEN[6:0]							DBURST[2:1]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DBURST [0]	SBURST[2:0]			DINCOS[1:0]		SINCOS[1:0]		DSIZE[1:0]		SSIZE[1:0]		DINC[1:0]		SINC[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **BWM**: Bufferable write mode

This bit is set and cleared by software.

0: The destination write operation is non-bufferable.

1: The destination write operation is bufferable.

Note: This bit is protected and can be written only if EN is 0.

All MDMA destination accesses are non-cacheable.

Bit 30 **SWRM**: Software request mode

This bit is set and cleared by software. If a hardware or software request is currently active, the bit change is delayed until the current transfer is completed.

0: hardware request are taken into account: the transfer is initiated as defined by TRGM value and acknowledged by the MDMA ACKx signal.

If the MDMA_CxMAR contains a valid address, the MDMA_CxMDR value is also written at MDMA_CxMAR address.

1: hardware request are ignored. Transfer is triggered by software writing 1 to the SWRQ bit.

Note: This bit is protected and can be written only if EN is 0.

Bits 29:28 **TRGM[1:0]**: Trigger mode

These bits are set and cleared by software.

00: Each MDMA request (software or hardware) triggers a buffer transfer.

01: Each MDMA request (software or hardware) triggers a block transfer.

10: Each MDMA request (software or hardware) triggers a repeated block transfer (if the block repeat is 0, a single block is transferred).

11: Each MDMA request (software or hardware) triggers the transfer of the whole data for the respective channel (e.g. linked list) until the channel reach the end and it is disabled.

Note: If TRGM is 11 for the current block, all the values loaded at the end of the current block through the linked list mechanism must keep the same value (TRGM = 11) and the same SWRM value, otherwise the result is undefined.

These bits are protected and can be written only if EN is 0.

Bits 27:26 **PAM[1:0]**: Padding/alignment mode

These bits are set and cleared by software.

00: Right aligned, padded w/ 0s (default)

if source data is larger than destination size, only the LSBs part of the source is written to the destination address. The reminder part is discarded.

01: Right aligned, sign extended

10: Left aligned (padded with 0s)

if source data is larger than destination size, only the MSBs part of the source is written to the destination address. The reminder part is discarded.

11: Reserved

Note: When PKE = 1 or DSIZE=SSIZE, these bits are ignored.

These bits are protected and can be written only if EN is 0.

Bit 25 **PKE**: Pack enable

This bit is set and cleared by software.

0: The source data is written to the destination as is.

If the source size is smaller than the destination, it is padded according to the PAM value.

If the source data size is larger than the destination one, it is truncated. The alignment is done according to the PAM[1:0] value.

1: The source data is packed/unpacked into the destination data size. All data are right aligned, in little endian mode.

Note: This bit is protected and can be written only if EN is 0

Bits 24:18 **TLEN[6:0]**: Buffer transfer length (number of bytes - 1)

These bits are set and cleared by software.

The value of TLEN + 1 represents the number of bytes to be transferred in a single transfer.

The transfer length must be a multiple of the data size (for both source and destination)

When the source/destination sizes are different and padding/truncation is used, the TLEN + 1 refers to the source data array size.

Note: These bits are protected and can be written only if EN is 0

DBURST value must be programmed in order to ensure that the burst size is lower than the transfer size.

Bits 17:15 **DBURST[2:0]**: Destination burst transfer configuration

These bits are set and cleared by software.

000: single transfer

N: burst of 2^N beats

These bits are protected and can be written only if EN is 0

DBURST value must be programmed as to ensure that the burst size is lower than the Transfer Length. If this is not ensured, the result is unpredictable.

Note: When the destination bus is TCM/AHB (DBUS = 1) and DINCOS = 11 or DINC = 00 or DINCOS/=DSIZE, DBURST must be programmed to 000 (single transfer), else the result is unpredictable.

When the destination bus is system/AXI bus (DBUS = 0) and DINC = 00, DBURST must be maximum 100 (burst of 16), else the result is unpredictable.

Bits 14:12 **SBURST[2:0]**: Source burst transfer configuration

These bits are set and cleared by software.

000: single transfer

N: burst of 2^N beats

These bits are protected and can be written only if EN is 0

SBURST value must be programmed as to ensure that the burst size is lower than the transfer length. If this is not ensured, the result is unpredictable.

Note: When the source bus is TCM (SBUS = 1) and SINCOS = 11 or SINC = 00 or SINCOS/=SSIZE, SBURST must be programmed to 000 (single transfer), else the result is unpredictable.

When the source bus is system/AXI bus (SBUS = 0) and SINC = 00, SBURST must be maximum 100 (burst of 16), else the result is unpredictable.

Bits 11:10 **DINCOS[1:0]**: Destination increment offset size

These bits are set and cleared by software.

00: byte (8-bit)

01: half-word (16-bit)

10: word (32-bit)

11: Double-Word (64-bit) -

This bits have no meaning if bit DINC[1:0] = 00.

Note: These bits are protected and can be written only if EN = 0.

If DINCOS < DSIZE and DINC /= 00, the result is unpredictable.

If destination is AHB and DBURST =/ 000, destination address must be aligned with DINCOS size, else the result is unpredictable.

Bits 9:8 **SINCOS[1:0]**: Source increment offset size

These bits are set and cleared by software.

00: byte (8-bit)

01: half-word (16-bit)

10: word (32-bit)

11: Double-Word (64-bit) -

This bits have no meaning if bit SINC[1:0] = 00.

Note: These bits are protected and can be written only if EN = 0.

If SINCOS < SSIZE and SINC /= 00, the result is unpredictable.

If source is TCM/AHB and SBURST =/ 000, source address must be aligned with SINCOS size, else the result is unpredictable.

Bits 7:6 **DSIZE[1:0]**: Destination data size

These bits are set and cleared by software.

00: byte (8-bit)

01: half-word (16-bit)

10: word (32-bit)

11: Double-Word (64-bit) -

These bits are protected and can be written only if EN = 0.

Note: If a value of 11 is programmed for the TCM access/AHB port, a transfer error occurs (TEIF bit set)

If DINCOS < DSIZE and DINC /= 00, the result is unpredictable.

DSIZE = 11 (double-word) is forbidden when destination is TCM/AHB bus (DBUS = 1).

Bits 5:4 **SSIZE[1:0]**: Source data size

These bits are set and cleared by software.

00: Byte (8-bit)

01: Half-word (16-bit)

10: Word (32-bit)

11: Double-Word (64-bit)

Note: These bits are protected and can be written only if EN is 0

If a value of 11 is programmed for the TCM access/AHB port, a transfer error occurs (TEIF bit set)

If SINCOS < SSIZE and SINC /= 00, the result is unpredictable.

SSIZE = 11 (double-word) is forbidden when source is TCM/AHB bus (SBUS = 1).

Bits 3:2 **DINC[1:0]**: Destination increment mode

These bits are set and cleared by software.

00: Destination address pointer is fixed

10: Destination address pointer is incremented after each data transfer (increment is done according to DINCOS)

11: Destination address pointer is decremented after each data transfer (increment is done according to DINCOS)

Note: These bits are protected and can be written only if EN = 0.

When destination is AHB (DBUS=1), DINC = 00 is forbidden.

Bits 1:0 **SINC[1:0]**: Source increment mode

These bits are set and cleared by software.

00: Source address pointer is fixed

10: Source address pointer is incremented after each data transfer (increment is done according to SINCOS)

11: Source address pointer is decremented after each data transfer (decrement is done according to SINCOS)

Note: These bits are protected and can be written only if EN = 0.

When source is AHB (SBUS = 1), SINC = 00 is forbidden.

14.5.7 MDMA channel x block number of data register (MDMA_CxBNDTR)

In linked-list mode, at the end of a block (single or last block in repeated block transfer mode), this register is loaded from memory (from address given by current LAR[31:0] + 0x04).

Address offset: 0x54 + 0x40 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BRC[11:0]												BRDUM	BRSUM	Res.	BNDT[16]
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BNDT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 **BRC[11:0]**: Block repeat count

This field contains the number of repetitions of the current block (0 to 4095). When the channel is enabled, this register is read-only, indicating the remaining number of blocks, excluding the current one. This register decrements after each complete block transfer.

Once the last block transfer has completed, this register can either stay at zero or be reloaded automatically from memory (in linked-list mode, meaning link address valid).

Note: These bits are protected and can be written only if EN = 0.

Bit 19 **BRDUM**: Block repeat destination address update mode

0: At the end of a block transfer, the MDMA_DAR register is updated by adding the DUV to the current DAR value (current destination address).

1: At the end of a block transfer, the MDMA_DAR register is updated by subtracting the DUV from the current DAR value (current destination address).

Note: These bits are protected and can be written only if EN = 0.

Bit 18 **BRSUM**: Block repeat source address update mode

0: At the end of a block transfer, the MDMA_SAR register is updated by adding the SUV to the current SAR value (current source address).

1: At the end of a block transfer, the MDMA_SAR register is updated by subtracting the SUV from the current SAR value (current source address).

Note: These bits are protected and can be written only if EN = 0.

Bit 17 Reserved, must be kept at reset value.

Bits 16:0 **BNDT[16:0]**: Block number of data bytes to transfer

Number of bytes to be transferred (0 up to 65536) in the current block. When the channel is enabled, this register is read-only, indicating the remaining data items to be transmitted. During the channel activity, this register decrements, indicating the number of data items remaining in the current block.

Once the block transfer has completed, this register can either stay at zero or be reloaded automatically with the previously programmed value if the channel is configured in block repeat mode.

If the value of this register is zero, no transaction can be served even if the stream is enabled.

Note: These bits are protected and can be written only if EN = 0.

If the BNDT value is not an integer multiple of the TLEN + 1 value, the last transfer is shorter and contains only the remaining data in the block.

The block size must be a multiple of the source and destination data size. If this is not true, an error is set and the no data are written.

14.5.8 MDMA channel x source address register (MDMA_CxSAR)

In linked-list mode, at the end of a block (single or last block in repeated block transfer mode), this register is loaded from memory (from address given by current LAR[31:0] + 0x08).

Address offset: 0x58 + 0x40 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SAR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SAR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SAR[31:0]**: Source address

These bits represent the base address of the peripheral data register from/to which the data is read. They must be aligned with the SSIZE (SAR[1:0] = 00 when SSIZE = 10), but may be unaligned with the SINCOS.

When source is TCM/AHB, if address is not aligned with SINCOS, the access must be programmed as single (SBURST = 000).

During the channel activity, this register is updated, reflecting the current address from which the data is read next.

When the block repeat mode is active, when a block transfer is completed, the source address is updated by adding/subtracting the SAU value to the current value (already updated after the last transfer in the block).

When the linked-list mode is active, at the end of a block (repeated or not) transfer, the SAR value is loaded from memory (from address LSA + m).

Note: These bits are write-protected and can be written only when bit EN = 0.

14.5.9 MDMA channel x destination address register (MDMA_CxDAR)

In linked-list mode, at the end of a block (single or last block in repeated block transfer mode), this register is loaded from memory (from address given by current LAR[31:0] + 0x0C).

Address offset: 0x5C + 0x40 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DAR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DAR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DAR[31:0]**: Destination address

Base address of the destination address to which the data is written.

Must be aligned with the DSIZE (e.g. DAR[0] = 0 when DSIZE=01), but may be unaligned with the DINCOS.

When destination is AHB, if address is not aligned with DINCOS, access must be programmed as single (DBURST = 000).

During the channel activity, this register is updated, reflecting the current address to which the data is written next.

When the block repeat mode is active, when a block transfer is completed, the Destination address is updated by adding/subtracting the DAU value to the current value (after the last transfer in the block).

When the linked-list mode is active, at the end of a block (repeated or not) transfer, the DAR value is loaded from memory (from address LSA + m).

Note: These bits are write-protected and can be written only when bit EN = 0.

14.5.10 MDMA channel x block repeat address update register (MDMA_CxBRUR)

In linked-list mode, at the end of a block (single or last block in repeated block transfer mode), this register is loaded from memory (from address given by current LAR[31:0] + 0x10).

Address offset: 0x60 + 0x40 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DUV[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SUV[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **DUV[15:0]**: Destination address update value

This value is used to update (by addition or subtraction) the current destination address at the end of a block transfer. It must be an integer multiple of DSIZE, in order to keep DAR aligned to DSIZE (DAR[1:0] = 00 when DSIZ E =10).

If this value is 0, the next repetition of the block transfer continues to the next address.

When the block repeat mode is not active (BRC = 0), this field is ignored.

Note: These bits are write-protected and can be written only when bit EN = 0.

This field must be programmed to 0 when DINC[1:0] = 00.

Bits 15:0 **SUV[15:0]**: Source address update value

This value is used to update (by addition or subtraction) the current source address at the end of a block Transfer. It must be an integer multiple of SSIZE, in order to keep SAR aligned to SSIZE (SAR[1:0] = 00 when SSIZE = 10).

If this value is 0, the next repetition of the block transfer continues from the next address.

When the block repeat mode is not active (BRC=0), this field is ignored.

Note: These bits are write-protected and can be written only when bit EN = 0.

This field must be programmed to 0 when SINC[1:0] = 00.

14.5.11 MDMA channel x link address register (MDMA_CxLAR)

In linked-list mode, at the end of a block (single or last block in repeated block transfer mode), this register is loaded from memory (from address given by current LAR[31:0] + 0x14).

Note: The new value is only taken into account after all registers are updated, for the next end of block.

Address offset: 0x64 + 0x40 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LAR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LAR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r	r

Bits 31:0 **LAR[31:0]**: Link address register

At the end of a (repeated) block transfer, the current channel configuration registers (MDMA_CxTCR, MDMA_CxBNDTR, MDMA_CxSAR, MDMA_CxDAR, MDMA_CxBRUR, MDMA_CxMAR, MDMA_CxMDR and MDMA_CxLAR itself) are loaded with the data structure found at this address.

If the value of this register is 0, no register update takes place, the channel is disabled and CTCIF is set, indicating the end of the transfer for this channel.

The channel configuration (LAR address) must be in the AXI address space.

LAR value must be aligned at a double-word address (LAR[2:0] = 0x0).

Note: These bits are write-protected and can be written only when bit EN = 0.

14.5.12 MDMA channel x trigger and bus selection register (MDMA_CxTBR)

In linked-list mode, at the end of a block (single or last block in repeated block transfer mode), this register is loaded from memory (from address given by current LAR[31:0] + 0x18).

Address offset: 0x68 + 0x40 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBUS	SBUS
														rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSEL[5:0]					
										rw	rw	rw	rw	rw	rw

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **DBUS**: Destination bus select

0: The system/AXI bus is used as destination (write operation) on channel x.
1: The AHB bus/TCM is used as destination (write operation) on channel x.

Note: This bit is protected and can be written only if EN is 0.

Bit 16 **SBUS**: Source bus select

0: The system/AXI bus is used as source (read operation) on channel x.
1: The AHB bus/TCM is used as source (read operation) on channel x.

Note: This bit is protected and can be written only if EN is 0.

Bits 15:6 Reserved, must be kept at reset value.

Bits 5:0 **TSEL[5:0]**: Trigger selection

This field selects the hardware trigger (RQ) input for channel x. The ACK is sent on the ACK output having the same index value.

When SWRM bit is set (software request selected), this bit field is ignored.

Note: These bits are write-protected and can be written only when bit EN = 0.

If multiple channels are triggered by the same event (have the same TSEL value), all of them are triggered in parallel. Only the channel with the lowest index acknowledges the request .

14.5.13 MDMA channel x mask address register (MDMA_CxMAR)

In linked-list mode, at the end of a block (single or last block in repeated block transfer mode), this register is loaded from memory (from address given by current LAR[31:0] + 0x20).

Address offset: 0x70 + 0x40 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MAR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MAR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MAR[31:0]**: Mask address

A write of the MDR value is also done to this address. This allows to clear the RQ signal generated by the DMA2 by writing to its Interrupt Clear register.

If the value of this register is 0, this function is disabled. These bits are write-protected and can be written only when bit EN = '0' in the MDMA_CxCR register.

14.5.14 MDMA channel x mask data register (MDMA_CxMDR)

In Linked List mode, at the end of a block (single or last block in repeated block transfer mode), this register is loaded from memory (from address given by current LAR[31:0] + 0x24).

Address offset: 0x74 + 0x40 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MDR[31:0]**: Mask Data

A write of the MDR value is also done to the address defined by the MDMA_MAR register. This is used to clear the RQ signal generated by the DMA2 by writing to its interrupt clear register.

Note: These bits are write-protected and can be written only when bit EN = 0.

14.5.15 MDMA register map

Table 102. MDMA register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	MDMA_GISR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GIF15	GIF14	GIF13	GIF12	GIF11	GIF10	GIF9	GIF8	GIF7	GIF6	GIF5	GIF4	GIF3	GIF2	GIF1	GIF0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04 - 0x3C	Reserved	Reserved																															
0x40 + 0x40 × channel number	MDMA_CxISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCIF	BTIF	BRTIF	CTCIF	TEIF
	Reset value																												0	0	0	0	0
0x44 + 0x40 × channel number	MDMA_CxIFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLTCIF	CBTIF	CBRTIF	CCTCIF	CTEIF
	Reset value																												0	0	0	0	0
0x48 + 0x40 × channel number	MDMA_CxESR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BSE	ASE	TEMD	TELD	TED	TEA[6:0]						
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x4C + 0x40 × channel number	MDMA_CxCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWRQ	Res.	WEX	HEX	BEX	Res.	Res.	Res.	Res.	PL[1:0]		TCIE	BTIE	BRTIE	CTCIE	TEIE	EN
	Reset value																0		0	0	0					0	0	0	0	0	0	0	0
0x50 + 0x40 × channel number	MDMA_CxTCR	BWM	SWRM	TRGM[1:0]		PAM[1:0]		PKE	TLEN[6:0].							DBURST[2:0]		SBURST[2:0]			DINCOS[1:0]		SINCOS[1:0]		DSIZE[1:0]		SSIZE[1:0]		DINC[1:0]		SINC[1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x54 + 0x40 × channel number	MDMA_CxBNDTR	BRC[11:0]												BRDUM	BRSUM	Res.	BNDT[16:0]																
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x58 + 0x40 × channel number	MDMA_CxSAR	SAR[31:0].																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x5C + 0x40 × channel number	MDMA_CxDAR	DAR[31:0].																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x60 + 0x40 × channel number	MDMA_CxBRUR	DUV[15:0].																SUV[15:0].															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x64 + 0x40 × channel number	MDMA_CxLAR	LAR[31:0].																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x68 + 0x40 × channel number	MDMA_CxTBR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBUS	SBUS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSEL[5:0]					
	Reset value															0	0											0	0	0	0	0	0
0x6C+ 0x40 × channel number	Reserved	Reserved																															
0x70 + 0x40 × channel number	MDMA_CxMAR	MAR[31:0].																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x74 + 0x40 × channel number	MDMA_CxMDR	MDR[31:0].																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3* for the register boundary addresses.

15 Direct memory access controller (DMA)

15.1 DMA introduction

Direct memory access (DMA) is used in order to provide high-speed data transfer between peripherals and memory and between memory and memory. Data can be quickly moved by DMA without any CPU action. This keeps CPU resources free for other operations.

The DMA controller combines a powerful dual AHB master bus architecture with independent FIFO to optimize the bandwidth of the system, based on a complex bus matrix architecture.

The two DMA controllers (DMA1, DMA2) have 8 streams each, dedicated to managing memory access requests from one or more peripherals.

Each DMA stream is driven by one DMAMUX1 output channel (request). Any DMAMUX1 output request can be individually programmed in order to select the DMA request source signal, from any of the 115 available request input signals.

Refer to the *Section 17.3: DMAMUX implementation* for more information about the DMA requests and streams mapping.

Each DMA controller has an arbiter for handling the priority between DMA requests.

15.2 DMA main features

The main DMA features are:

- Dual AHB master bus architecture, one dedicated to memory accesses and one dedicated to peripheral accesses
- AHB slave programming interface supporting only 32-bit accesses
- 8 streams for each DMA controller, up to 115 channels (requests) per stream
- Four-word depth 32 first-in, first-out memory buffers (FIFOs) per stream, that can be used in FIFO mode or direct mode:
  - FIFO mode: with threshold level software selectable between 1/4, 1/2 or 3/4 of the FIFO size
  - Direct mode: each DMA request immediately initiates a transfer from/to the memory. When it is configured in direct mode (FIFO disabled), to transfer data in memory-to-peripheral mode, the DMA preloads only one data from the memory to the internal FIFO to ensure an immediate data transfer as soon as a DMA request is triggered by a peripheral.
- Each stream can be configured to be:
  - a regular channel that supports peripheral-to-memory, memory-to-peripheral and memory-to-memory transfers
  - a double buffer channel that also supports double buffering on the memory side
- Priorities between DMA stream requests are software-programmable (four levels consisting of very high, high, medium, low) or hardware in case of equality (for example, request 0 has priority over request 1)
- Each stream also supports software trigger for memory-to-memory transfers

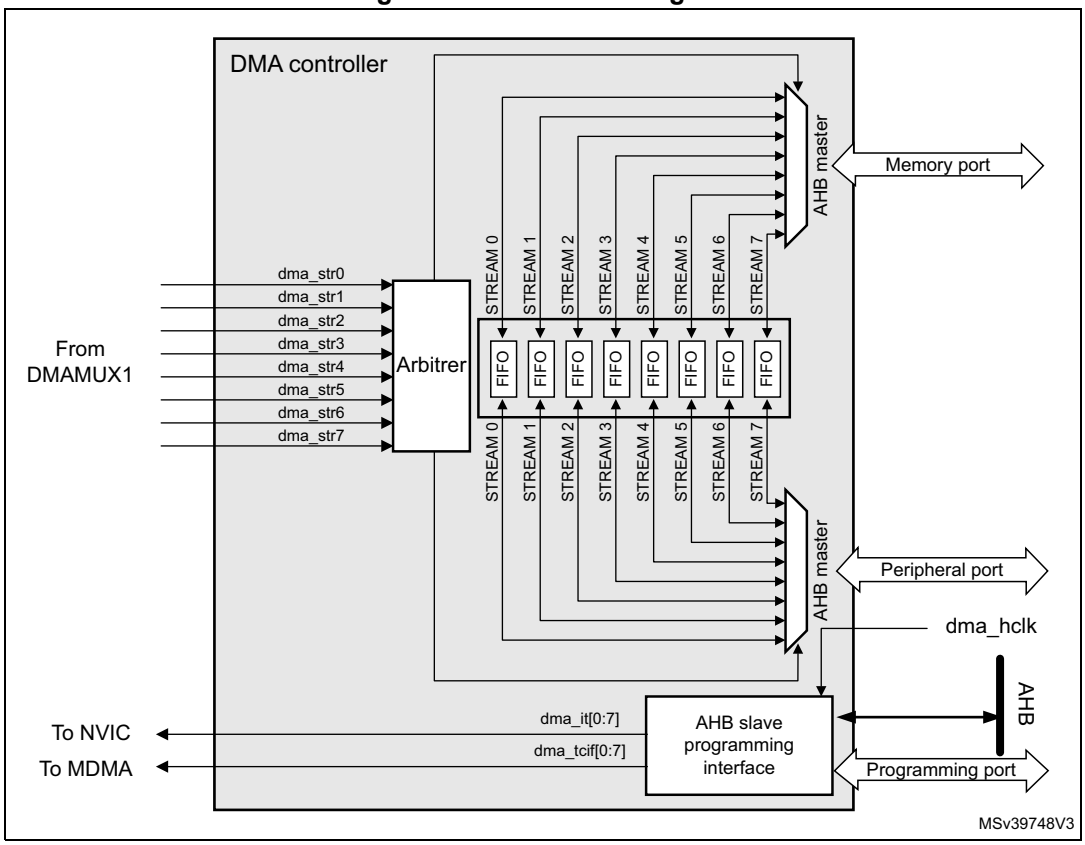
- Each stream request can be selected among up to 115 possible channel requests. This selection is software-configurable by the DMAMUX1 and allows 107 peripherals to initiate DMA requests
- The number of data items to be transferred can be managed either by the DMA controller or by the peripheral:
  - DMA flow controller: the number of data items to be transferred is software-programmable from 1 to 65535
  - Peripheral flow controller: the number of data items to be transferred is unknown and controlled by the source or the destination peripheral that signals the end of the transfer by hardware
- Independent source and destination transfer width (byte, half-word, word): when the data widths of the source and destination are not equal, the DMA automatically packs/unpacks the necessary transfers to optimize the bandwidth. This feature is only available in FIFO mode
- Incrementing or non-incrementing addressing for source and destination
- Supports incremental burst transfers of 4, 8 or 16 beats. The size of the burst is software-configurable, usually equal to half the FIFO size of the peripheral
- Each stream supports circular buffer management
- 5 event flags (DMA half transfer, DMA transfer complete, DMA transfer error, DMA FIFO error, direct mode error) logically ORed together in a single interrupt request for each stream

15.3 DMA functional description

15.3.1 DMA block diagram

The figure below shows the block diagram of a DMA.

Figure 79. DMA block diagram



15.3.2 DMA internal signals

The table below shows the internal DMA signals.

Table 103. DMA internal input/output signals

Signal name	Signal type	Description
dma_hclk	Digital input	DMA AHB clock
dma_it[0:7]	Digital outputs	DMA stream [0:7] global interrupts
dma_tcif[0:7]	Digital outputs	MDMA triggers
dma_str[0:7]	Digital input	DMA stream [0:7] requests

15.3.3 DMA overview

The DMA controller performs direct memory transfer: as an AHB master, the DMA controller can take the control of the AHB bus matrix to initiate AHB transactions.

The DMA controller carries out the following transactions:

- peripheral-to-memory
- memory-to-peripheral
- memory-to-memory

The DMA controller provides two AHB master ports: the AHB memory port, intended to be connected to memories and the AHB peripheral port, intended to be connected to peripherals. However, to allow memory-to-memory transfers, the AHB peripheral port must also have access to the memories.

The AHB slave port is used to program the DMA controller (it supports only 32-bit accesses).

15.3.4 DMA transactions

A DMA transaction consists of a sequence of a given number of data transfers. The number of data items to be transferred and their width (8-bit, 16-bit or 32-bit) are software-programmable.

Each DMA transfer consists of three operations:

- a loading from the peripheral data register or a location in memory, addressed through the DMA_SxPAR or DMA_SxM0AR register
- a storage of the data loaded to the peripheral data register or a location in memory addressed through the DMA_SxPAR or DMA_SxM0AR register
- a post-decrement of the DMA_SxNDTR register, containing the number of transactions that still have to be performed

After an event, the peripheral sends a request signal to the DMA controller. The DMA controller serves the request depending on the channel priorities. As soon as the DMA controller accesses the peripheral, an Acknowledge signal is sent to the peripheral by the DMA controller. The peripheral releases its request as soon as it gets the Acknowledge signal from the DMA controller. Once the request has been deasserted by the peripheral, the DMA controller releases the Acknowledge signal. If there are more requests, the peripheral can initiate the next transaction.

15.3.5 DMA request mapping

The DMA request mapping from peripherals to DMA streams is described in *Section 17.3: DMAMUX implementation*.

15.3.6 Arbiter

An arbiter manages the 8 DMA stream requests based on their priority for each of the two AHB master ports (memory and peripheral ports) and launches the peripheral/memory access sequences.

Priorities are managed in two stages:

- Software: each stream priority can be configured in the DMA_SxCR register. There are four levels:
  - Very high priority
  - High priority
  - Medium priority
  - Low priority
- Hardware: If two requests have the same software priority level, the stream with the lower number takes priority over the stream with the higher number. For example, stream 2 takes priority over stream 4.

15.3.7 DMA streams

Each of the eight DMA controller streams provides a unidirectional transfer link between a source and a destination.

Each stream can be configured to perform:

- Regular type transactions: memory-to-peripherals, peripherals-to-memory or memory-to-memory transfers
- Double-buffer type transactions: double buffer transfers using two memory pointers for the memory (while the DMA is reading/writing from/to a buffer, the application can write/read to/from the other buffer).

The amount of data to be transferred (up to 65535) is programmable and related to the source width of the peripheral that requests the DMA transfer connected to the peripheral AHB port. The register that contains the amount of data items to be transferred is decremented after each transaction.

15.3.8 Source, destination and transfer modes

Both source and destination transfers can address peripherals and memories in the entire 4-Gbyte area, at addresses comprised between 0x0000 0000 and 0xFFFF FFFF.

The direction is configured using the DIR[1:0] bits in the DMA_SxCR register and offers three possibilities: memory-to-peripheral, peripheral-to-memory or memory-to-memory transfers.

The table below describes the corresponding source and destination addresses.

Table 104. Source and destination address

Bits DIR[1:0] of the DMA_SxCR register	Direction	Source address	Destination address
00	Peripheral-to-memory	DMA_SxPAR	DMA_SxM0AR
01	Memory-to-peripheral	DMA_SxM0AR	DMA_SxPAR

Table 104. Source and destination address (continued)

Bits DIR[1:0] of the DMA_SxCR register	Direction	Source address	Destination address
10	Memory-to-memory	DMA_SxPAR	DMA_SxM0AR
11	Reserved	-	-

When the data width (programmed in the PSIZE or MSIZE bits in the DMA_SxCR register) is a half-word or a word, respectively, the peripheral or memory address written into the DMA_SxPAR or DMA_SxM0AR/M1AR registers has to be aligned on a word or half-word address boundary, respectively.

Peripheral-to-memory mode

Figure 80 describes this mode.

When this mode is enabled (by setting the bit EN in the DMA_SxCR register), each time a peripheral request occurs, the stream initiates a transfer from the source to fill the FIFO.

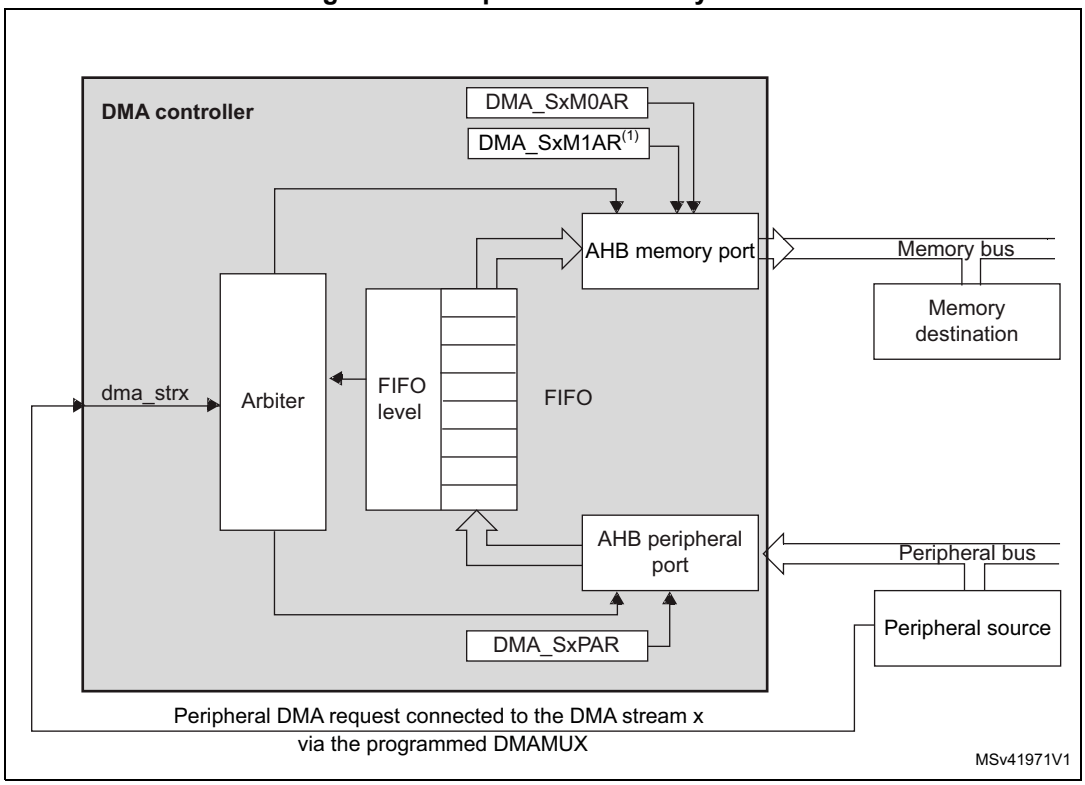
When the threshold level of the FIFO is reached, the contents of the FIFO are drained and stored into the destination.

The transfer stops once the DMA_SxNDTR register reaches zero, when the peripheral requests the end of transfers (in case of a peripheral flow controller) or when the EN bit in the DMA_SxCR register is cleared by software.

In direct mode (when the DMDIS value in the DMA_SxFCR register is 0), the threshold level of the FIFO is not used: after each single data transfer from the peripheral to the FIFO, the corresponding data are immediately drained and stored into the destination.

The stream has access to the AHB source or destination port only if the arbitration of the corresponding stream is won. This arbitration is performed using the priority defined for each stream using the PL[1:0] bits in the DMA_SxCR register.

Figure 80. Peripheral-to-memory mode



1. For double-buffer mode.

Memory-to-peripheral mode

Figure 81 describes this mode.

When this mode is enabled (by setting the EN bit in the DMA_SxCR register), the stream immediately initiates transfers from the source to entirely fill the FIFO.

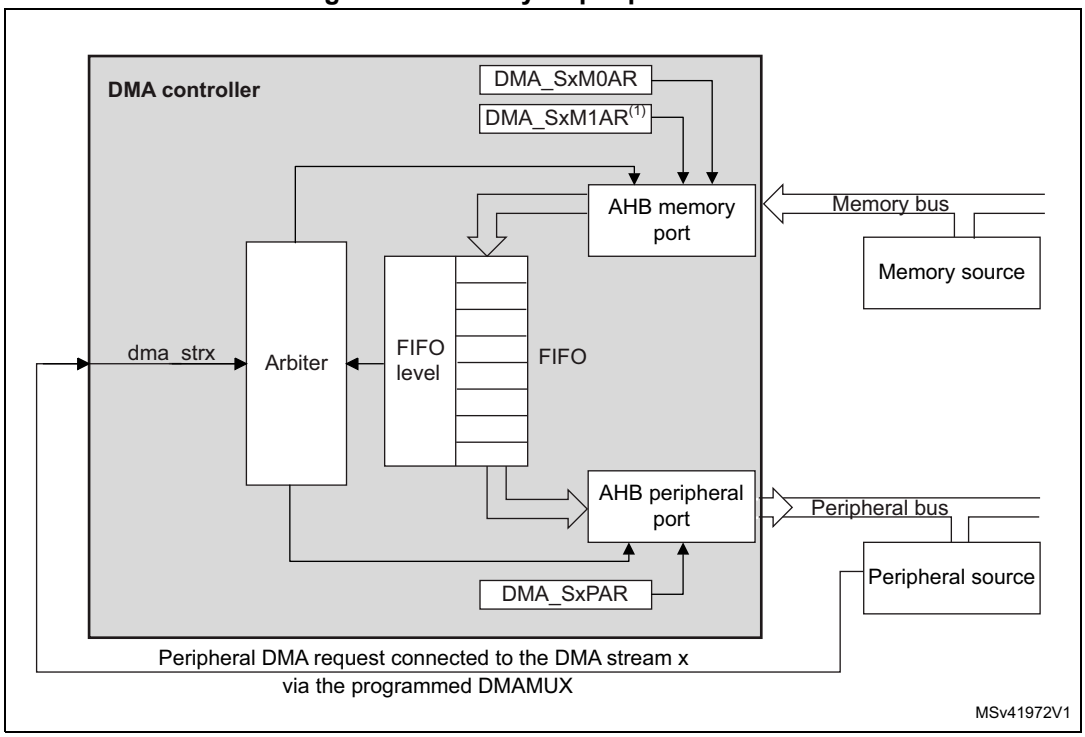
Each time a peripheral request occurs, the contents of the FIFO are drained and stored into the destination. When the level of the FIFO is lower than or equal to the predefined threshold level, the FIFO is fully reloaded with data from the memory.

The transfer stops once the DMA_SxNDTR register reaches zero, when the peripheral requests the end of transfers (in case of a peripheral flow controller) or when the EN bit in the DMA_SxCR register is cleared by software.

In direct mode (when the DMDIS value in the DMA_SxFCR register is 0), the threshold level of the FIFO is not used. Once the stream is enabled, the DMA preloads the first data to transfer into an internal FIFO. As soon as the peripheral requests a data transfer, the DMA transfers the preloaded value into the configured destination. It then reloads again the empty internal FIFO with the next data to be transfer. The preloaded data size corresponds to the value of the PSIZE bitfield in the DMA_SxCR register.

The stream has access to the AHB source or destination port only if the arbitration of the corresponding stream is won. This arbitration is performed using the priority defined for each stream using the PL[1:0] bits in the DMA_SxCR register.

Figure 81. Memory-to-peripheral mode



1. For double-buffer mode.

Memory-to-memory mode

The DMA channels can also work without being triggered by a request from a peripheral. This is the memory-to-memory mode, described in *Figure 82*.

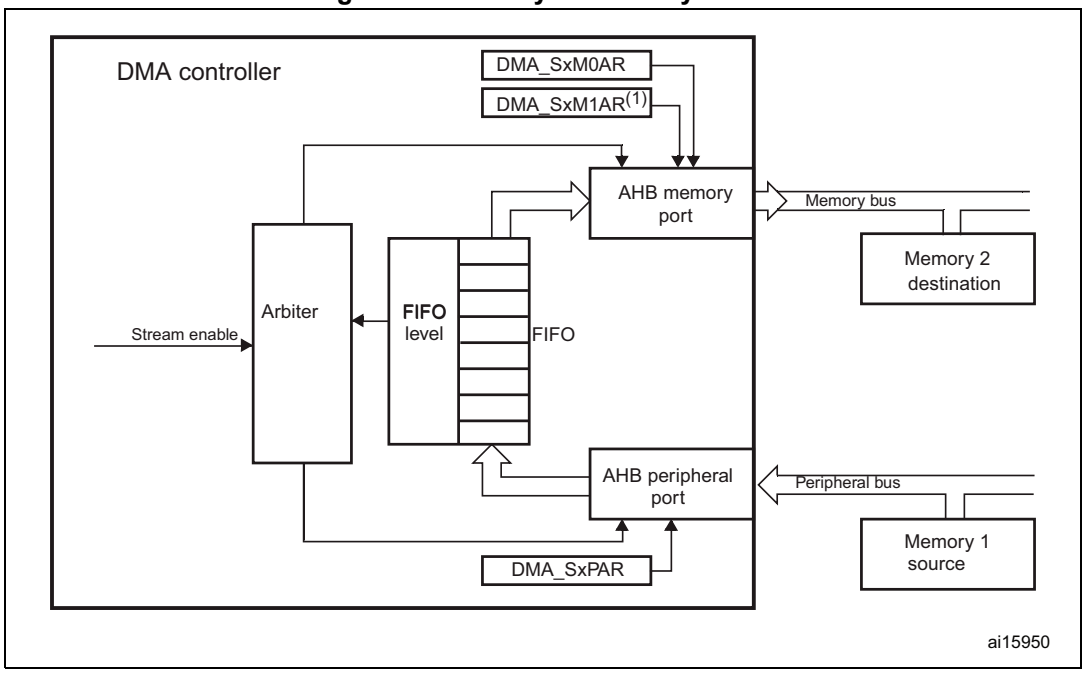
When the stream is enabled by setting the Enable bit (EN) in the DMA_SxCR register, the stream immediately starts to fill the FIFO up to the threshold level. When the threshold level is reached, the FIFO contents are drained and stored into the destination.

The transfer stops once the DMA_SxNDTR register reaches zero or when the EN bit in the DMA_SxCR register is cleared by software.

The stream has access to the AHB source or destination port only if the arbitration of the corresponding stream is won. This arbitration is performed using the priority defined for each stream using the PL[1:0] bits in the DMA_SxCR register.

Note: When memory-to-memory mode is used, the circular and direct modes are not allowed.

Figure 82. Memory-to-memory mode



1. For double-buffer mode.

15.3.9 Pointer incrementation

Peripheral and memory pointers can optionally be automatically post-incremented or kept constant after each transfer depending on the PINC and MINC bits in the DMA_SxCR register.

Disabling the increment mode is useful when the peripheral source or destination data is accessed through a single register.

If the increment mode is enabled, the address of the next transfer is the address of the previous one incremented by 1 (for bytes), 2 (for half-words) or 4 (for words) depending on the data width programmed in the PSIZE or MSIZE bits in the DMA_SxCR register.

In order to optimize the packing operation, it is possible to fix the increment offset size for the peripheral address whatever the size of the data transferred on the AHB peripheral port. The PINCOS bit in the DMA_SxCR register is used to align the increment offset size with the data size on the peripheral AHB port, or on a 32-bit address (the address is then incremented by 4). The PINCOS bit has an impact on the AHB peripheral port only.

If the PINCOS bit is set, the address of the following transfer is the address of the previous one incremented by 4 (automatically aligned on a 32-bit address), whatever the PSIZE value. The AHB memory port, however, is not impacted by this operation.

15.3.10 Circular mode

The circular mode is available to handle circular buffers and continuous data flows (e.g. ADC scan mode). This feature can be enabled using the CIRC bit in the DMA_SxCR register.

When the circular mode is activated, the number of data items to be transferred is automatically reloaded with the initial value programmed during the stream configuration phase, and the DMA requests continue to be served.

Note: In the circular mode, it is mandatory to respect the following rule in case of a burst mode configured for memory:

DMA_SxNDTR = Multiple of ((Mburst beat) × (Msize)/(Psize)), where:

- *(Mburst beat) = 4, 8 or 16 (depending on the MBURST bits in the DMA_SxCR register)*
- *((Msize)/(Psize)) = 1, 2, 4, 1/2 or 1/4 (Msize and Psize represent the MSIZE and PSIZE bits in the DMA_SxCR register. They are byte dependent)*
- *DMA_SxNDTR = Number of data items to transfer on the AHB peripheral port*

For example: Mburst beat = 8 (INCR8), MSIZE = 00 (byte) and PSIZE = 01 (half-word), in this case: DMA_SxNDTR must be a multiple of (8 × 1/2 = 4).

If this formula is not respected, the DMA behavior and data integrity are not guaranteed.

NDTR must also be a multiple of the Peripheral burst size multiplied by the peripheral data size, otherwise this could result in a bad DMA behavior.

15.3.11 Double-buffer mode

This mode is available for all the DMA1 and DMA2 streams.

The double-buffer mode is enabled by setting the DBM bit in the DMA_SxCR register.

A double-buffer stream works as a regular (single buffer) stream with the difference that it has two memory pointers. When the double-buffer mode is enabled, the circular mode is automatically enabled (CIRC bit in DMA_SxCR is not relevant) and at each end of transaction, the memory pointers are swapped.

In this mode, the DMA controller swaps from one memory target to another at each end of transaction. This allows the software to process one memory area while the second memory area is being filled/used by the DMA transfer. The double-buffer stream can work in both directions (the memory can be either the source or the destination) as described in *Table 105: Source and destination address registers in double-buffer mode (DBM = 1)*.

*Note: In double-buffer mode, it is possible to update the base address for the AHB memory port on-the-fly (*DMA_SxM0AR or DMA_SxM1AR*) when the stream is enabled, by respecting the following conditions:*

- *When the CT bit is 0 in the DMA_SxCR register, the DMA_SxM1AR register can be written. Attempting to write to this register while CT = 1 sets an error flag (TEIF) and the stream is automatically disabled.*
- *When the CT bit is 1 in the DMA_SxCR register, the DMA_SxM0AR register can be written. Attempting to write to this register while CT = 0, sets an error flag (TEIF) and the stream is automatically disabled.*

To avoid any error condition, it is advised to change the base address as soon as the TCIF flag is asserted because, at this point, the targeted memory must have changed from

memory 0 to 1 (or from 1 to 0) depending on the value of CT in the DMA_SxCR register in accordance with one of the two above conditions.

For all the other modes (except the double-buffer mode), the memory address registers are write-protected as soon as the stream is enabled.

Table 105. Source and destination address registers in double-buffer mode (DBM = 1)

Bits DIR[1:0] of the DMA_SxCR register	Direction	Source address	Destination address
00	Peripheral-to-memory	DMA_SxPAR	DMA_SxM0AR / DMA_SxM1AR
01	Memory-to-peripheral	DMA_SxM0AR / DMA_SxM1AR	DMA_SxPAR
10	Not allowed(1)		
11	Reserved	-	-

1. When the double-buffer mode is enabled, the circular mode is automatically enabled. Since the memory-to-memory mode is not compatible with the circular mode, when the double-buffer mode is enabled, it is not allowed to configure the memory-to-memory mode.

15.3.12 Programmable data width, packing/unpacking, endianness

The number of data items to be transferred has to be programmed into DMA_SxNDTR (number of data items to transfer bit, NDT) before enabling the stream (except when the flow controller is the peripheral, PFCTRL bit in DMA_SxCR is set).

When using the internal FIFO, the data widths of the source and destination data are programmable through the PSIZE and MSIZE bits in the DMA_SxCR register (can be 8-, 16- or 32-bit).

When PSIZE and MSIZE are not equal:

- The data width of the number of data items to transfer, configured in the DMA_SxNDTR register is equal to the width of the peripheral bus (configured by the PSIZE bits in the DMA_SxCR register). For instance, in case of peripheral-to-memory, memory-to-peripheral or memory-to-memory transfers and if the PSIZE[1:0] bits are configured for half-word, the number of bytes to be transferred is equal to 2 × NDT.
- The DMA controller only copes with little-endian addressing for both source and destination. This is described in *Table 106: Packing/unpacking and endian behavior (bit PINC = MINC = 1)*.

This packing/unpacking procedure may present a risk of data corruption when the operation is interrupted before the data are completely packed/unpacked. So, to ensure data coherence, the stream may be configured to generate burst transfers: in this case, each group of transfers belonging to a burst are indivisible (refer to *Section 15.3.13: Single and burst transfers*).

In direct mode (DMDIS = 0 in the DMA_SxFCR register), the packing/unpacking of data is not possible. In this case, it is not allowed to have different source and destination transfer data widths: both are equal and defined by the PSIZE bits in the DMA_SxCR register. MSIZE bits are not relevant.

Table 106. Packing/unpacking and endian behavior (bit PINC = MINC = 1)

AHB memory port width	AHB peripheral port width	Number of data items to transfer (NDT)	Memory transfer number	Memory port address / byte lane	Peripheral transfer number	Peripheral port address / byte lane	
						PINCOS = 1	PINCOS = 0
8	8	4	1 2 3 4	0x0 / B0[7:0] 0x1 / B1[7:0] 0x2 / B2[7:0] 0x3 / B3[7:0]	1 2 3 4	0x0 / B0[7:0] 0x4 / B1[7:0] 0x8 / B2[7:0] 0xC / B3[7:0]	0x0 / B0[7:0] 0x1 / B1[7:0] 0x2 / B2[7:0] 0x3 / B3[7:0]
8	16	2	1 2 3 4	0x0 / B0[7:0] 0x1 / B1[7:0] 0x2 / B2[7:0] 0x3 / B3[7:0]	1 2	0x0 / B1|B0[15:0] 0x4 / B3|B2[15:0]	0x0 / B1|B0[15:0] 0x2 / B3|B2[15:0]
8	32	1	1 2 3 4	0x0 / B0[7:0] 0x1 / B1[7:0] 0x2 / B2[7:0] 0x3 / B3[7:0]	1	0x0 / B3|B2|B1|B0[31:0]	0x0 / B3|B2|B1|B0[31:0]
16	8	4	1 2	0x0 / B1|B0[15:0] 0x2 / B3|B2[15:0]	1 2 3 4	0x0 / B0[7:0] 0x4 / B1[7:0] 0x8 / B2[7:0] 0xC / B3[7:0]	0x0 / B0[7:0] 0x1 / B1[7:0] 0x2 / B2[7:0] 0x3 / B3[7:0]
16	16	2	1 2	0x0 / B1|B0[15:0] 0x2 / B1|B0[15:0]	1 2	0x0 / B1|B0[15:0] 0x4 / B3|B2[15:0]	0x0 / B1|B0[15:0] 0x2 / B3|B2[15:0]
16	32	1	1 2	0x0 / B1|B0[15:0] 0x2 / B3|B2[15:0]	1	0x0 / B3|B2|B1|B0[31:0]	0x0 / B3|B2|B1|B0[31:0]
32	8	4	1	0x0 / B3|B2|B1|B0[31:0]	1 2 3 4	0x0 / B0[7:0] 0x4 / B1[7:0] 0x8 / B2[7:0] 0xC / B3[7:0]	0x0 / B0[7:0] 0x1 / B1[7:0] 0x2 / B2[7:0] 0x3 / B3[7:0]
32	16	2	1	0x0 /B3|B2|B1|B0[31:0]	1 2	0x0 / B1|B0[15:0] 0x4 / B3|B2[15:0]	0x0 / B1|B0[15:0] 0x2 / B3|B2[15:0]
32	32	1	1	0x0 /B3|B2|B1|B0 [31:0]	1	0x0 / B3|B2|B1|B0 [31:0]	0x0 / B3|B2|B1|B0[31:0]

Note: Peripheral port may be the source or the destination (it can also be the memory source in the case of memory-to-memory transfer).

PSIZE, MSIZE and NDT[15:0] must be configured so as to ensure that the last transfer is not incomplete. This can occur when the data width of the peripheral port (PSIZE bits) is lower than the data width of the memory port (MSIZE bits). This constraint is summarized in the table below.

Table 107. Restriction on NDT versus PSIZE and MSIZE

PSIZE[1:0] of DMA_SxCR	MSIZE[1:0] of DMA_SxCR	NDT[15:0] of DMA_SxNDTR
00 (8-bit)	01 (16-bit)	Must be a multiple of 2.
00 (8-bit)	10 (32-bit)	Must be a multiple of 4.
01 (16-bit)	10 (32-bit)	Must be a multiple of 2.

15.3.13 Single and burst transfers

The DMA controller can generate single transfers or incremental burst transfers of 4, 8 or 16 beats.

The size of the burst is configured by software independently for the two AHB ports by using the MBURST[1:0] and PBURST[1:0] bits in the DMA_SxCR register.

The burst size indicates the number of beats in the burst, not the number of bytes transferred.

To ensure data coherence, each group of transfers that form a burst are indivisible: AHB transfers are locked and the arbiter of the AHB bus matrix does not degrant the DMA master during the sequence of the burst transfer.

Depending on the single or burst configuration, each DMA request initiates a different number of transfers on the AHB peripheral port:

- When the AHB peripheral port is configured for single transfers, each DMA request generates a data transfer of a byte, half-word or word depending on the PSIZE[1:0] bits in the DMA_SxCR register
- When the AHB peripheral port is configured for burst transfers, each DMA request generates 4,8 or 16 beats of byte, half word or word transfers depending on the PBURST[1:0] and PSIZE[1:0] bits in the DMA_SxCR register.

The same as above has to be considered for the AHB memory port considering the MBURST and MSIZE bits.

In direct mode, the stream can only generate single transfers and the MBURST[1:0] and PBURST[1:0] bits are forced by hardware.

The address pointers (DMA_SxPAR or DMA_SxM0AR registers) must be chosen so as to ensure that all transfers within a burst block are aligned on the address boundary equal to the size of the transfer.

The burst configuration has to be selected in order to respect the AHB protocol, where bursts **must not** cross the 1 Kbyte address boundary because the minimum address space that can be allocated to a single slave is 1 Kbyte. This means that the 1-Kbyte address boundary **must not** be crossed by a burst block transfer, otherwise an AHB error is generated, that is not reported by the DMA registers.

15.3.14 FIFO

FIFO structure

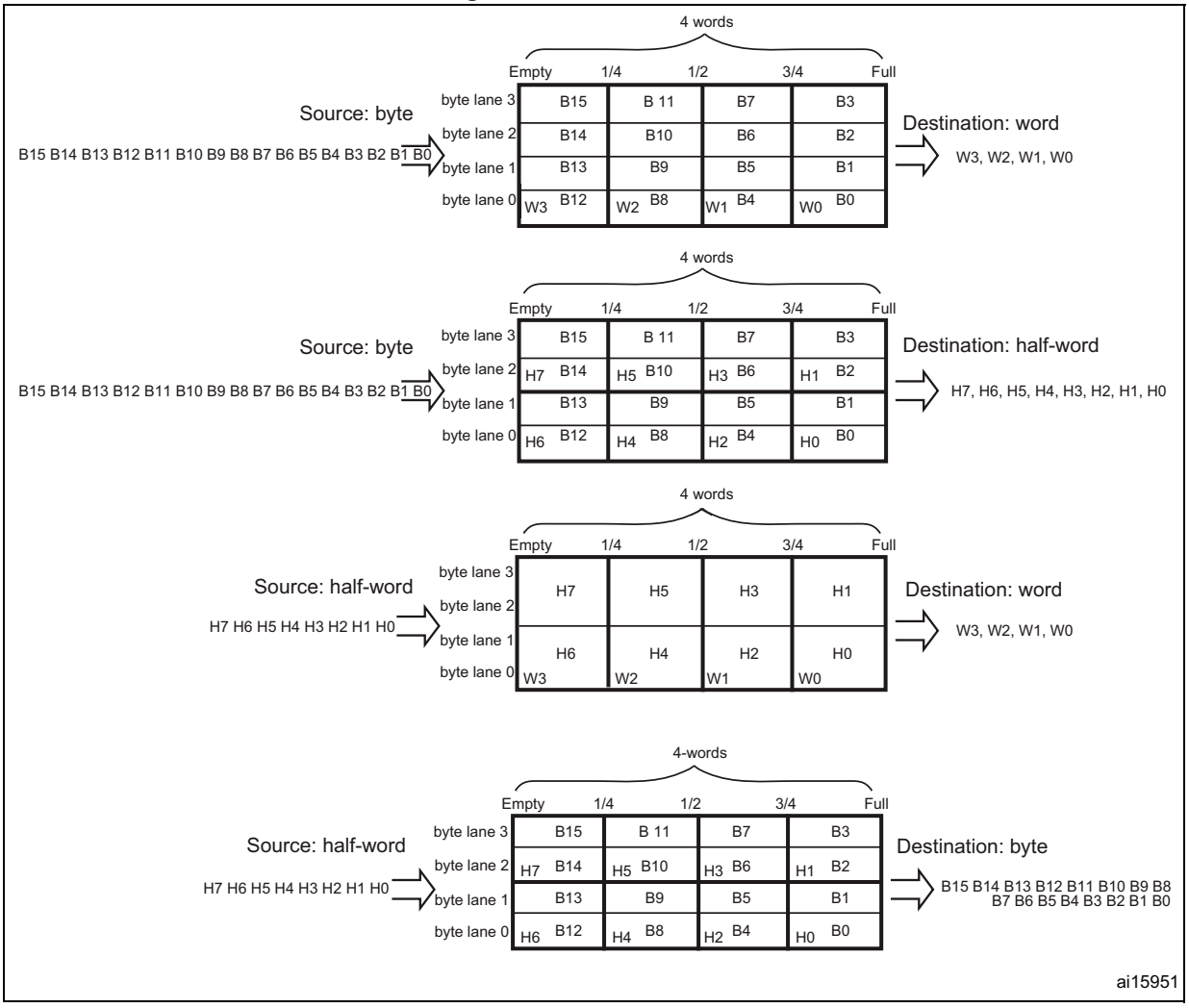
The FIFO is used to temporarily store data coming from the source before transmitting them to the destination.

Each stream has an independent 4-word FIFO and the threshold level is software-configurable between 1/4, 1/2, 3/4 or full.

To enable the use of the FIFO threshold level, the direct mode must be disabled by setting the DMDIS bit in the DMA_SxFCR register.

The structure of the FIFO differs depending on the source and destination data widths, and is described in the figure below.

Figure 83. FIFO structure



FIFO threshold and burst configuration

Caution is required when choosing the FIFO threshold (bits FTH[1:0] of the DMA_SxFCR register) and the size of the memory burst (MBURST[1:0] of the DMA_SxCR register): The content pointed by the FIFO threshold must exactly match an integer number of memory burst transfers. If this is not in the case, a FIFO error (flag FEIFx of the DMA_HISR or DMA_LISR register) is generated when the stream is enabled, then the stream is automatically disabled. The allowed and forbidden configurations are described in the table below. The forbidden configurations are highlighted in gray in the table.

Table 108. FIFO threshold configurations

MSIZE	FIFO level	MBURST = INCR4	MBURST = INCR8	MBURST = INCR16
Byte	1/4	1 burst of 4 beats	Forbidden	Forbidden
	1/2	2 bursts of 4 beats	1 burst of 8 beats	
	3/4	3 bursts of 4 beats	Forbidden	
	Full	4 bursts of 4 beats	2 bursts of 8 beats	1 burst of 16 beats
Half-word	1/4	Forbidden	Forbidden	Forbidden
	1/2	1 burst of 4 beats		
	3/4	Forbidden		
	Full	2 bursts of 4 beats	1 burst of 8 beats	
Word	1/4	Forbidden	Forbidden	
	1/2			
	3/4			
	Full	1 burst of 4 beats		

In all cases, the burst size multiplied by the data size must not exceed the FIFO size (data size can be: 1 (byte), 2 (half-word) or 4 (word)).

Incomplete burst transfer at the end of a DMA transfer may happen if one of the following conditions occurs:

- For the AHB peripheral port configuration: the total number of data items (set in the DMA_SxNDTR register) is not a multiple of the burst size multiplied by the data size.
- For the AHB memory port configuration: the number of remaining data items in the FIFO to be transferred to the memory is not a multiple of the burst size multiplied by the data size.

In such cases, the remaining data to be transferred is managed in single mode by the DMA, even if a burst transaction is requested during the DMA stream configuration.

Note: When burst transfers are requested on the peripheral AHB port and the FIFO is used (DMDIS = 1 in the DMA_SxCR register), it is mandatory to respect the following rule to avoid permanent underrun or overrun conditions, depending on the DMA stream direction:

If (PBURST × PSIZE) = FIFO_SIZE (4 words), FIFO_Threshold = 3/4 is forbidden with PSIZE = 1, 2 or 4 and PBURST = 4, 8 or 16.

This rule ensures that enough FIFO space at a time is free to serve the request from the peripheral.

FIFO flush

The FIFO can be flushed when the stream is disabled by resetting the EN bit in the DMA_SxCR register and when the stream is configured to manage peripheral-to-memory or memory-to-memory transfers. If some data are still present in the FIFO when the stream is disabled, the DMA controller continues transferring the remaining data to the destination (even though stream is effectively disabled). When this flush is completed, the transfer complete status bit (TCIFx) in the DMA_LISR or DMA_HISR register is set.

The remaining data counter DMA_SxNDTR keeps the value in this case to indicate how many data items are currently available in the destination memory.

Note that during the FIFO flush operation, if the number of remaining data items in the FIFO to be transferred to memory (in bytes) is less than the memory data width (for example 2 bytes in FIFO while MSIZE is configured to word), data is sent with the data width set in the MSIZE bit in the DMA_SxCR register. This means that memory is written with an undesired value. The software may read the DMA_SxNDTR register to determine the memory area that contains the good data (start address and last address).

If the number of remaining data items in the FIFO is lower than a burst size (if the MBURST bits in DMA_SxCR register are set to configure the stream to manage burst on the AHB memory port), single transactions are generated to complete the FIFO flush.

Direct mode

By default, the FIFO operates in direct mode (DMDIS bit in the DMA_SxFCR is reset) and the FIFO threshold level is not used. This mode is useful when the system requires an immediate and single transfer to or from the memory after each DMA request.

When the DMA is configured in direct mode (FIFO disabled), to transfer data in memory-to-peripheral mode, the DMA preloads one data from the memory to the internal FIFO to ensure an immediate data transfer as soon as a DMA request is triggered by a peripheral.

To avoid saturating the FIFO, it is recommended to configure the corresponding stream with a high priority.

This mode is restricted to transfers where:

- the source and destination transfer widths are equal and both defined by the PSIZE[1:0] bits in DMA_SxCR (MSIZE[1:0] bits are not relevant)
- burst transfers are not possible (PBURST[1:0] and MBURST[1:0] bits in DMA_SxCR are don’t care)

Direct mode must not be used when implementing memory-to-memory transfers.

15.3.15 DMA transfer completion

Different events can generate an end of transfer by setting the TCIFx bit in the DMA_LISR or DMA_HISR status register:

- In DMA flow controller mode:
  - The DMA_SxNDTR counter has reached zero in the memory-to-peripheral mode.
  - The stream is disabled before the end of transfer (by clearing the EN bit in the DMA_SxCR register) and (when transfers are peripheral-to-memory or memory-

to-memory) all the remaining data have been flushed from the FIFO into the memory.

- In Peripheral flow controller mode:
  - The last external burst or single request has been generated from the peripheral and (when the DMA is operating in peripheral-to-memory mode) the remaining data have been transferred from the FIFO into the memory
  - The stream is disabled by software, and (when the DMA is operating in peripheral-to-memory mode) the remaining data have been transferred from the FIFO into the memory

Note: The transfer completion is dependent on the remaining data in FIFO to be transferred into memory only in the case of peripheral-to-memory mode. This condition is not applicable in memory-to-peripheral mode.

If the stream is configured in non-circular mode, after the end of the transfer (that is when the number of data to be transferred reaches zero), the DMA is stopped (EN bit in DMA_SxCR register is cleared by Hardware) and no DMA request is served unless the software reprograms the stream and re-enables it (by setting the EN bit in the DMA_SxCR register).

15.3.16 DMA transfer suspension

At any time, a DMA transfer can be suspended to be restarted later on or to be definitively disabled before the end of the DMA transfer.

There are two cases:

- The stream disables the transfer with no later-on restart from the point where it was stopped. There is no particular action to do, except to clear the EN bit in the DMA_SxCR register to disable the stream. The stream may take time to be disabled (ongoing transfer is completed first). The transfer complete interrupt flag (TCIF in the DMA_LISR or DMA_HISR register) is set in order to indicate the end of transfer. The value of the EN bit in DMA_SxCR is now 0 to confirm the stream interruption. The DMA_SxNDTR register contains the number of remaining data items at the moment when the stream was stopped so that the software can determine how many data items have been transferred before the stream was interrupted.
- The stream suspends the transfer before the number of remaining data items to be transferred in the DMA_SxNDTR register reaches 0. The aim is to restart the transfer later by re-enabling the stream. In order to restart from the point where the transfer was stopped, the software has to read the DMA_SxNDTR register after disabling the stream by writing the EN bit in DMA_SxCR register (and then checking that it is at 0) to know the number of data items already collected. Then:
  - The peripheral and/or memory addresses have to be updated in order to adjust the address pointers
  - The SxNDTR register has to be updated with the remaining number of data items to be transferred (the value read when the stream was disabled)
  - The stream may then be re-enabled to restart the transfer from the point it was stopped

Note: A transfer complete interrupt flag (TCIF in DMA_LISR or DMA_HISR) is set to indicate the end of transfer due to the stream interruption.

15.3.17 Flow controller

The entity that controls the number of data to be transferred is known as the flow controller. This flow controller is configured independently for each stream using the PFCTRL bit in the DMA_SxCR register.

The flow controller can be:

- The DMA controller: in this case, the number of data items to be transferred is programmed by software into the DMA_SxNDTR register before the DMA stream is enabled.
- The peripheral source or destination: this is the case when the number of data items to be transferred is unknown. The peripheral indicates by hardware to the DMA controller when the last data are being transferred. This feature is only supported for peripherals that are able to signal the end of the transfer.

When the peripheral flow controller is used for a given stream, the value written into the DMA_SxNDTR has no effect on the DMA transfer. Actually, whatever the value written, it is forced by hardware to 0xFFFF as soon as the stream is enabled, to respect the following schemes:

- Anticipated stream interruption: EN bit in DMA_SxCR register is reset to 0 by the software to stop the stream before the last data hardware signal (single or burst) is sent by the peripheral. In such a case, the stream is switched off and the FIFO flush is triggered in the case of a peripheral-to-memory DMA transfer. The TCIFx flag of the corresponding stream is set in the status register to indicate the DMA completion. To know the number of data items transferred during the DMA transfer, read the DMA_SxNDTR register and apply the following formula:
  – Number_of_data_transferred = 0xFFFF – DMA_SxNDTR
- Normal stream interruption due to the reception of a last data hardware signal: the stream is automatically interrupted when the peripheral requests the last transfer (single or burst) and when this transfer is complete. the TCIFx flag of the corresponding stream is set in the status register to indicate the DMA transfer completion. To know the number of data items transferred, read the DMA_SxNDTR register and apply the same formula as above.
- The DMA_SxNDTR register reaches 0: the TCIFx flag of the corresponding stream is set in the status register to indicate the forced DMA transfer completion. The stream is automatically switched off even though the last data hardware signal (single or burst) has not been yet asserted. The already transferred data is not lost. This means that a maximum of 65535 data items can be managed by the DMA in a single transaction, even in peripheral flow control mode.

Note: When configured in memory-to-memory mode, the DMA is always the flow controller and the PFCTRL bit is forced to 0 by hardware.

The circular mode is forbidden in the peripheral flow controller mode.

15.3.18 Summary of the possible DMA configurations

The table below summarizes the different possible DMA configurations. The forbidden configurations are highlighted in gray in the table.

Table 109. Possible DMA configurations

DMA transfer mode	Source	Destination	Flow controller	Circular mode	Transfer type	Direct mode	Double-buffer mode
Peripheral-to-memory	AHB peripheral port	AHB memory port	DMA	Possible	single	Possible	Possible
					burst	Forbidden	
			Peripheral	Forbidden	single	Possible	Forbidden
					burst	Forbidden	
Memory-to-peripheral	AHB memory port	AHB peripheral port	DMA	Possible	single	Possible	Possible
					burst	Forbidden	
			Peripheral	Forbidden	single	Possible	Forbidden
					burst	Forbidden	
Memory-to-memory	AHB peripheral port	AHB memory port	DMA only	Forbidden	single	Forbidden	Forbidden
					burst		

15.3.19 Stream configuration procedure

The following sequence must be followed to configure a DMA stream x (where x is the stream number):

1. If the stream is enabled, disable it by resetting the EN bit in the DMA_SxCR register, then read this bit in order to confirm that there is no ongoing stream operation. Writing this bit to 0 is not immediately effective since it is actually written to 0 once all the current transfers are finished. When the EN bit is read as 0, this means that the stream is ready to be configured. It is therefore necessary to wait for the EN bit to be cleared before starting any stream configuration. All the stream dedicated bits set in the status register (DMA_LISR and DMA_HISR) from the previous data block DMA transfer must be cleared before the stream can be re-enabled.
2. Set the peripheral port register address in the DMA_SxPAR register. The data is moved from/ to this address to/ from the peripheral port after the peripheral event.
3. Set the memory address in the DMA_SxMA0R register (and in the DMA_SxMA1R register in the case of a double-buffer mode). The data is written to or read from this memory after the peripheral event.
4. Configure the total number of data items to be transferred in the DMA_SxNDTR register. After each peripheral event or each beat of the burst, this value is decremented.
5. Use DMAMUX1 to route a DMA request line to the DMA channel.
6. If the peripheral is intended to be the flow controller and if it supports this feature, set the PFCTRL bit in the DMA_SxCR register.
7. Configure the stream priority using the PL[1:0] bits in the DMA_SxCR register.
8. Configure the FIFO usage (enable or disable, threshold in transmission and reception)

9. Configure the data transfer direction, peripheral and memory incremented/fixed mode, single or burst transactions, peripheral and memory data widths, circular mode, double-buffer mode and interrupts after half and/or full transfer, and/or errors in the DMA_SxCR register.
10. Activate the stream by setting the EN bit in the DMA_SxCR register.

As soon as the stream is enabled, it can serve any DMA request from the peripheral connected to the stream.

Once half the data have been transferred on the AHB destination port, the half-transfer flag (HTIF) is set and an interrupt is generated if the half-transfer interrupt enable bit (HTIE) is set. At the end of the transfer, the transfer complete flag (TCIF) is set and an interrupt is generated if the transfer complete interrupt enable bit (TCIE) is set.

Warning: **To switch off a peripheral connected to a DMA stream request, it is mandatory to, first, switch off the DMA stream to which the peripheral is connected, then to wait for EN bit = 0. Only then can the peripheral be safely disabled.**

15.3.20 Error management

The DMA controller can detect the following errors:

- **Transfer error**: the transfer error interrupt flag (TEIFx) is set when:
  - a bus error occurs during a DMA read or a write access
  - a write access is requested by software on a memory address register in double-buffer mode whereas the stream is enabled and the current target memory is the one impacted by the write into the memory address register (refer to *Section 15.3.11: Double-buffer mode*)
- **FIFO error**: the FIFO error interrupt flag (FEIFx) is set if:
  - a FIFO underrun condition is detected
  - a FIFO overrun condition is detected (no detection in memory-to-memory mode because requests and transfers are internally managed by the DMA)
  - the stream is enabled while the FIFO threshold level is not compatible with the size of the memory burst (refer to *Table 108: FIFO threshold configurations*)
- **Direct mode error**: the direct mode error interrupt flag (DMEIFx) can only be set in the peripheral-to-memory mode while operating in direct mode and when the MINC bit in the DMA_SxCR register is cleared. This flag is set when a DMA request occurs while the previous data have not yet been fully transferred into the memory (because the memory bus was not granted). In this case, the flag indicates that two data items were be transferred successively to the same destination address, which could be an issue if the destination is not able to manage this situation

In direct mode, the FIFO error flag can also be set under the following conditions:

- In the peripheral-to-memory mode, the FIFO can be saturated (overrun) if the memory bus is not granted for several peripheral requests.
- In the memory-to-peripheral mode, an underrun condition may occur if the memory bus has not been granted before a peripheral request occurs.

If the TEIFx or the FEIFx flag is set due to incompatibility between burst size and FIFO threshold level, the faulty stream is automatically disabled through a hardware clear of its EN bit in the corresponding stream configuration register (DMA_SxCR).

If the DMEIFx or the FEIFx flag is set due to an overrun or underrun condition, the faulty stream is not automatically disabled and it is up to the software to disable or not the stream by resetting the EN bit in the DMA_SxCR register. This is because there is no data loss when this kind of errors occur.

When the stream's error interrupt flag (TEIF, FEIF, DMEIF) in the DMA_LISR or DMA_HISR register is set, an interrupt is generated if the corresponding interrupt enable bit (TEIE, FEIE, DMIE) in the DMA_SxCR or DMA_SxFCR register is set.

Note: When a FIFO overrun or underrun condition occurs, the data is not lost because the peripheral request is not acknowledged by the stream until the overrun or underrun condition is cleared. If this acknowledge takes too much time, the peripheral itself may detect an overrun or underrun condition of its internal buffer and data might be lost.

15.4 DMA interrupts

For each DMA stream, an interrupt can be produced on the following events:

- Half-transfer reached
- Transfer complete
- Transfer error
- FIFO error (overrun, underrun or FIFO level error)
- Direct mode error

Separate interrupt enable control bits are available for flexibility as shown in the table below.

Table 110. DMA interrupt requests

Interrupt event	Event flag	Enable control bit
Half-transfer	HTIF	HTIE
Transfer complete	TCIF	TCIE
Transfer error	TEIF	TEIE
FIFO overrun/underrun	FEIF	FEIE
Direct mode error	DMEIF	DMEIE

Note: Before setting an enable control bit EN = 1, the corresponding event flag must be cleared, otherwise an interrupt is immediately generated.

15.5 DMA registers

The DMA registers have to be accessed by words (32 bits).

15.5.1 DMA low interrupt status register (DMA_LISR)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TCIF3	HTIF3	TEIF3	DMEIF3	Res.	FEIF3	TCIF2	HTIF2	TEIF2	DMEIF2	Res.	FEIF2
				r	r	r	r		r	r	r	r	r		r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TCIF1	HTIF1	TEIF1	DMEIF1	Res.	FEIF1	TCIF0	HTIF0	TEIF0	DMEIF0	Res.	FEIF0
				r	r	r	r		r	r	r	r	r		r

Bits 31:28, 15:12 Reserved, must be kept at reset value.

Bits 27, 21, 11, 5 **TCIF[3:0]**: stream x transfer complete interrupt flag (x = 3 to 0)
This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA_LIFCR register.
0: no transfer complete event on stream x
1: a transfer complete event occurred on stream x

Bits 26, 20, 10, 4 **HTIF[3:0]**: stream x half transfer interrupt flag (x = 3 to 0)
This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA_LIFCR register.
0: no half transfer event on stream x
1: a half transfer event occurred on stream x

Bits 25, 19, 9, 3 **TEIF[3:0]**: stream x transfer error interrupt flag (x = 3 to 0)
This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA_LIFCR register.
0: no transfer error on stream x
1: a transfer error occurred on stream x

Bits 24, 18, 8, 2 **DMEIF[3:0]**: stream x direct mode error interrupt flag (x = 3 to 0)
This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA_LIFCR register.
0: No direct mode error on stream x
1: a direct mode error occurred on stream x

Bits 23, 17, 7, 1 Reserved, must be kept at reset value.

Bits 22, 16, 6, 0 **FEIF[3:0]**: stream x FIFO error interrupt flag (x = 3 to 0)
This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA_LIFCR register.
0: no FIFO error event on stream x
1: a FIFO error event occurred on stream x

15.5.2 DMA high interrupt status register (DMA_HISR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TCIF7	HTIF7	TEIF7	DMEIF7	Res.	FEIF7	TCIF6	HTIF6	TEIF6	DMEIF6	Res.	FEIF6
				r	r	r	r		r	r	r	r	r		r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TCIF5	HTIF5	TEIF5	DMEIF5	Res.	FEIF5	TCIF4	HTIF4	TEIF4	DMEIF4	Res.	FEIF4
				r	r	r	r		r	r	r	r	r		r

Bits 31:28, 15:12 Reserved, must be kept at reset value.

Bits 27, 21, 11, 5 **TCIF[7:4]**: stream x transfer complete interrupt flag (x = 7 to 4)

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA_HIFCR register.

0: no transfer complete event on stream x

1: a transfer complete event occurred on stream x

Bits 26, 20, 10, 4 **HTIF[7:4]**: stream x half transfer interrupt flag (x = 7 to 4)

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA_HIFCR register.

0: no half transfer event on stream x

1: a half transfer event occurred on stream x

Bits 25, 19, 9, 3 **TEIF[7:4]**: stream x transfer error interrupt flag (x = 7 to 4)

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA_HIFCR register.

0: no transfer error on stream x

1: a transfer error occurred on stream x

Bits 24, 18, 8, 2 **DMEIF[7:4]**: stream x direct mode error interrupt flag (x = 7 to 4)

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA_HIFCR register.

0: no direct mode error on stream x

1: a direct mode error occurred on stream x

Bits 23, 17, 7, 1 Reserved, must be kept at reset value.

Bits 22, 16, 6, 0 **FEIF[7:4]**: stream x FIFO error interrupt flag (x = 7 to 4)

This bit is set by hardware. It is cleared by software writing 1 to the corresponding bit in the DMA_HIFCR register.

0: no FIFO error event on stream x

1: a FIFO error event occurred on stream x

15.5.3 DMA low interrupt flag clear register (DMA_LIFCR)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	CTCIF3	CHTIF3	CTEIF3	CDMEIF3	Res.	CFEIF3	CTCIF2	CHTIF2	CTEIF2	CDMEIF2	Res.	CFEIF2
				w	w	w	w		w	w	w	w	w		w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	CTCIF1	CHTIF1	CTEIF1	CDMEIF1	Res.	CFEIF1	CTCIF0	CHTIF0	CTEIF0	CDMEIF0	Res.	CFEIF0
				w	w	w	w		w	w	w	w	w		w

Bits 31:28, 15:12 Reserved, must be kept at reset value.

Bits 27, 21, 11, 5 **CTCIF[3:0]**: stream x clear transfer complete interrupt flag (x = 3 to 0)
Writing 1 to this bit clears the corresponding TCIFx flag in the DMA_LISR register.

Bits 26, 20, 10, 4 **CHTIF[3:0]**: stream x clear half transfer interrupt flag (x = 3 to 0)
Writing 1 to this bit clears the corresponding HTIFx flag in the DMA_LISR register

Bits 25, 19, 9, 3 **CTEIF[3:0]**: Stream x clear transfer error interrupt flag (x = 3 to 0)
Writing 1 to this bit clears the corresponding TEIFx flag in the DMA_LISR register.

Bits 24, 18, 8, 2 **CDMEIF[3:0]**: stream x clear direct mode error interrupt flag (x = 3 to 0)
Writing 1 to this bit clears the corresponding DMEIFx flag in the DMA_LISR register.

Bits 23, 17, 7, 1 Reserved, must be kept at reset value.

Bits 22, 16, 6, 0 **CFEIF[3:0]**: stream x clear FIFO error interrupt flag (x = 3 to 0)
Writing 1 to this bit clears the corresponding CFEIFx flag in the DMA_LISR register.

15.5.4 DMA high interrupt flag clear register (DMA_HIFCR)

Address offset: 0x00C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	CTCIF7	CHTIF7	CTEIF7	CDMEIF7	Res.	CFEIF7	CTCIF6	CHTIF6	CTEIF6	CDMEIF6	Res.	CFEIF6
				w	w	w	w		w	w	w	w	w		w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	CTCIF5	CHTIF5	CTEIF5	CDMEIF5	Res.	CFEIF5	CTCIF4	CHTIF4	CTEIF4	CDMEIF4	Res.	CFEIF4
				w	w	w	w		w	w	w	w	w		w

Bits 31:28, 15:12 Reserved, must be kept at reset value.

Bits 27, 21, 11, 5 **CTCIF[7:4]**: stream x clear transfer complete interrupt flag (x = 7 to 4)
Writing 1 to this bit clears the corresponding TCIFx flag in the DMA_HISR register.

Bits 26, 20, 10, 4 **CHTIF[7:4]**: stream x clear half transfer interrupt flag (x = 7 to 4)
Writing 1 to this bit clears the corresponding HTIFx flag in the DMA_HISR register.

Bits 25, 19, 9, 3 **CTEIF[7:4]**: stream x clear transfer error interrupt flag (x = 7 to 4)
Writing 1 to this bit clears the corresponding TEIFx flag in the DMA_HISR register.

Bits 24, 18, 8, 2 **CDMEIF[7:4]**: stream x clear direct mode error interrupt flag (x = 7 to 4)
Writing 1 to this bit clears the corresponding DMEIFx flag in the DMA_HISR register.

Bits 23, 17, 7, 1 Reserved, must be kept at reset value.

Bits 22, 16, 6, 0 **CFEIF[7:4]**: stream x clear FIFO error interrupt flag (x = 7 to 4)
Writing 1 to this bit clears the corresponding CFEIFx flag in the DMA_HISR register.

15.5.5 DMA stream x configuration register (DMA_SxCR)

This register is used to configure the concerned stream.

Address offset: 0x010 + 0x018 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	MBURST[1:0]		PBURST[1:0]		TR BUFF	CT	DBM	PL[1:0]	
							rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PINCOS	MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR[1:0]		PFCTRL	TCIE	HTIE	TEIE	DMEIE	EN
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 24:23 **MBURST[1:0]**: memory burst transfer configuration
These bits are set and cleared by software.
00: single transfer
01: INCR4 (incremental burst of 4 beats)
10: INCR8 (incremental burst of 8 beats)
11: INCR16 (incremental burst of 16 beats)
These bits are protected and can be written only if EN = 0.
In direct mode, these bits are forced to 0x0 by hardware as soon as bit EN = 1.

Bits 22:21 **PBURST[1:0]**: peripheral burst transfer configuration
These bits are set and cleared by software.
00: single transfer
01: INCR4 (incremental burst of 4 beats)
10: INCR8 (incremental burst of 8 beats)
11: INCR16 (incremental burst of 16 beats)
These bits are protected and can be written only if EN = 0.
In direct mode, these bits are forced to 0x0 by hardware.

Bit 20 **TRBUFF**: Enable the DMA to handle bufferable transfers.
0: bufferable transfers not enabled
1: bufferable transfers enabled
Note: This bit must be set to 1 if the DMA stream manages UART/USART/LPUART transfers.

Bit 19 **CT**: current target (only in double-buffer mode)

This bit is set and cleared by hardware. It can also be written by software.
0: current target memory is Memory 0 (addressed by the DMA_SxM0AR pointer)
1: current target memory is Memory 1 (addressed by the DMA_SxM1AR pointer)
This bit can be written only if EN = 0 to indicate the target memory area of the first transfer. Once the stream is enabled, this bit operates as a status flag indicating which memory area is the current target.

Bit 18 **DBM**: double-buffer mode

This bit is set and cleared by software.
0: no buffer switching at the end of transfer
1: memory target switched at the end of the DMA transfer
This bit is protected and can be written only if EN = 0.

Bits 17:16 **PL[1:0]**: priority level

These bits are set and cleared by software.
00: low
01: medium
10: high
11: very high
These bits are protected and can be written only if EN = 0.

Bit 15 **PINCOS**: peripheral increment offset size

This bit is set and cleared by software
0: The offset size for the peripheral address calculation is linked to the PSIZE
1: The offset size for the peripheral address calculation is fixed to 4 (32-bit alignment).
This bit has no meaning if bit PINC = 0.
This bit is protected and can be written only if EN = 0.
This bit is forced low by hardware when the stream is enabled (EN = 1) if the direct mode is selected or if PBURST are different from 00.

Bits 14:13 **MSIZE[1:0]**: memory data size

These bits are set and cleared by software.
00: byte (8-bit)
01: half-word (16-bit)
10: word (32-bit)
11: reserved
These bits are protected and can be written only if EN = 0.
In direct mode, MSIZE is forced by hardware to the same value as PSIZE as soon as EN = 1.

Bits 12:11 **PSIZE[1:0]**: peripheral data size

These bits are set and cleared by software.
00: byte (8-bit)
01: half-word (16-bit)
10: word (32-bit)
11: reserved
These bits are protected and can be written only if EN = 0.

Bit 10 **MINC**: memory increment mode

This bit is set and cleared by software.
0: memory address pointer is fixed
1: memory address pointer is incremented after each data transfer (increment is done according to MSIZE)
This bit is protected and can be written only if EN = 0.

Bit 9 **PINC**: peripheral increment mode
This bit is set and cleared by software.
0: peripheral address pointer fixed
1: peripheral address pointer incremented after each data transfer (increment done according to PSIZE)
This bit is protected and can be written only if EN = 0.

Bit 8 **CIRC**: circular mode
This bit is set and cleared by software and can be cleared by hardware.
0: circular mode disabled
1: circular mode enabled
When the peripheral is the flow controller (bit PFCTRL = 1) and the stream is enabled (EN = 1), then this bit is automatically forced by hardware to 0.
It is automatically forced by hardware to 1 if the DBM bit is set, as soon as the stream is enabled (EN = 1).

Bits 7:6 **DIR[1:0]**: data transfer direction
These bits are set and cleared by software.
00: peripheral-to-memory
01: memory-to-peripheral
10: memory-to-memory
11: reserved
These bits are protected and can be written only if EN = 0.

Bit 5 **PFCTRL**: peripheral flow controller
This bit is set and cleared by software.
0: DMA is the flow controller.
1: The peripheral is the flow controller.
This bit is protected and can be written only if EN = 0.
When the memory-to-memory mode is selected (bits DIR[1:0]=10), then this bit is automatically forced to 0 by hardware.

Bit 4 **TCIE**: transfer complete interrupt enable
This bit is set and cleared by software.
0: TC interrupt disabled
1: TC interrupt enabled

Bit 3 **HTIE**: half transfer interrupt enable
This bit is set and cleared by software.
0: HT interrupt disabled
1: HT interrupt enabled

Bit 2 **TEIE**: transfer error interrupt enable
This bit is set and cleared by software.
0: TE interrupt disabled
1: TE interrupt enabled

Bit 1 **DMEIE**: direct mode error interrupt enable
This bit is set and cleared by software.
0: DME interrupt disabled
1: DME interrupt enabled

Bit 0 **EN**: stream enable / flag stream ready when read low

This bit is set and cleared by software.

0: stream disabled

1: stream enabled

This bit may be cleared by hardware:

- on a DMA end of transfer (stream ready to be configured)
- if a transfer error occurs on the AHB master buses
- when the FIFO threshold on memory AHB port is not compatible with the size of the burst

When this bit is read as 0, the software is allowed to program the configuration and FIFO bits registers. It is forbidden to write these registers when the EN bit is read as 1.

Note: Before setting EN bit to 1 to start a new transfer, the event flags corresponding to the stream in DMA_LISR or DMA_HISR register must be cleared.

15.5.6 DMA stream x number of data register (DMA_SxNDTR)

Address offset: 0x014 + 0x018 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NDT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **NDT[15:0]**: number of data items to transfer (0 up to 65535)

This register can be written only when the stream is disabled. When the stream is enabled, this register is read-only, indicating the remaining data items to be transmitted. This register decrements after each DMA transfer.

Once the transfer is completed, this register can either stay at zero (when the stream is in normal mode) or be reloaded automatically with the previously programmed value in the following cases:

- when the stream is configured in circular mode.
- when the stream is enabled again by setting EN bit to 1.

If the value of this register is zero, no transaction can be served even if the stream is enabled.

15.5.7 DMA stream x peripheral address register (DMA_SxPAR)

Address offset: 0x018 + 0x018 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PAR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PAR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PAR[31:0]**: peripheral address

Base address of the peripheral data register from/to which the data is read/written.
These bits are write-protected and can be written only when bit EN = 0 in DMA_SxCR.

15.5.8 DMA stream x memory 0 address register (DMA_SxM0AR)

Address offset: 0x01C + 0x018 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
M0A[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
M0A[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **M0A[31:0]**: memory 0 address

Base address of memory area 0 from/to which the data is read/written.
These bits are write-protected. They can be written only if:

- the stream is disabled (EN = 0 in DMA_SxCR) or
- the stream is enabled (EN = 1 in DMA_SxCR) and CT = 1 in DMA_SxCR (in double-buffer mode).

15.5.9 DMA stream x memory 1 address register (DMA_SxM1AR)

Address offset: 0x020 + 0x018 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
M1A[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
M1A[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **M1A[31:0]**: memory 1 address (used in case of double-buffer mode)
Base address of memory area 1 from/to which the data is read/written.
This register is used only for the double-buffer mode.
These bits are write-protected. They can be written only if:
– the stream is disabled (EN = 0 in DMA_SxCR) or
– the stream is enabled (EN = 1 in DMA_SxCR) and bit CT = 0 in DMA_SxCR .

15.5.10 DMA stream x FIFO control register (DMA_SxFCR)

Address offset: 0x024 + 0x018 * x, (x = 0 to 7)

Reset value: 0x0000 0021

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FEIE	Res.	FS[2:0]			DMDIS	FTH[1:0]	
								rw		r	r	r	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **FEIE**: FIFO error interrupt enable
This bit is set and cleared by software.
0: FE interrupt disabled
1: FE interrupt enabled

Bit 6 Reserved, must be kept at reset value.

Bits 5:3 **FS[2:0]**: FIFO status
These bits are read-only.
000: 0 < fifo_level < 1/4
001: 1/4 ≤ fifo_level < 1/2
010: 1/2 ≤ fifo_level < 3/4
011: 3/4 ≤ fifo_level < full
100: FIFO is empty
101: FIFO is full
others: no meaning
These bits are not relevant in the direct mode (DMDIS = 0).

Bit 2 **DMDIS**: direct mode disable
This bit is set and cleared by software. It can be set by hardware.
0: direct mode enabled
1: direct mode disabled
This bit is protected and can be written only if EN = 0.
This bit is set by hardware if the memory-to-memory mode is selected (DIR bit in DMA_SxCR are 10) and the EN = 1 in DMA_SxCR because the direct mode is not allowed in the memory-to-memory configuration.

Bits 1:0 **FTH[1:0]**: FIFO threshold selection
These bits are set and cleared by software.
00: 1/4 full FIFO
01: 1/2 full FIFO
10: 3/4 full FIFO
11: full FIFO
These bits are not used in the direct mode when the DMIS = 0.
These bits are protected and can be written only if EN = 0.

15.5.11 DMA register map

Table 111. DMA register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**DMA_LISR**	Res.	Res.	Res.	Res.	TCIF3	HTIF3	TEIF3	DMEIF3	Res.	FEIF3	TCIF2	HTIF2	TEIF2	DMEIF2	Res.	FEIF2	Res.	Res.	Res.	Res.	TCIF1	HTIF1	TEIF1	DMEIF1	Res.	FEIF1	TCIF0	HTIF0	TEIF0	DMEIF0	Res.	FEIF0
	Reset value					0	0	0	0		0	0	0	0	0		0					0	0	0	0		0	0	0	0	0		0
0x004	**DMA_HISR**	Res	Res	Res	Res	TCIF7	HTIF7	TEIF7	DMEIF7		FEIF7	TCIF6	HTIF6	TEIF6	DMEIF6	Res	FEIF6	Res	Res	Res	Res	TCIF5	HTIF5	TEIF5	DMEIF5	Res	FEIF5	TCIF4	HTIF4	TEIF4	DMEIF4	Res	FEIF4
	Reset value					0	0	0	0		0	0	0	0	0		0					0	0	0	0		0	0	0	0	0		0
0x008	**DMA_LIFCR**	Res	Res	Res	Res	CTCIF3	CHTIF3	TEIF3	CDMEIF3	Res	CFEIF3	CTCIF2	CHTIF2	CTEIF2	CDMEIF2	Res	CFEIF2	Res	Res	Res	Res	CTCIF1	CHTIF1	CTEIF1	CDMEIF1	Res	CFEIF1	CTCIF0	CHTIF0	CTEIF0	CDMEIF0	Res	CFEIF0
	Reset value					0	0	0	0		0	0	0	0	0		0					0	0	0	0		0	0	0	0	0		0
0x00C	**DMA_HIFCR**	Res	Res	Res	Res	CTCIF7	CHTIF7	CTEIF7	CDMEIF7	Res	CFEIF7	CTCIF6	CHTIF6	CTEIF6	CDMEIF6	Res	CFEIF6	Res	Res	Res	Res	CTCIF5	CHTIF5	CTEIF5	CDMEIF5	Res	CFEIF5	CTCIF4	CHTIF4	CTEIF4	CDMEIF4	Res	CFEIF4
	Reset value					0	0	0	0		0	0	0	0	0		0					0	0	0	0		0	0	0	0	0		0
0x010	**DMA_S0CR**	Res	Res	Res	Res	Res	Res	Res	MBURST[1:0]		PBURST[1:0]		TRBUFF	CT	DBM	PL[1:0]		PINCOS	MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR[1:0]		PFCTRL	TCIE	HTIE	TEIE	DMEIE	EN
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014	**DMA_S0NDTR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	NDT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x018	**DMA_S0PAR**	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x01C	**DMA_S0M0AR**	M0A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	**DMA_S0M1AR**	M1A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	**DMA_S0FCR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	FEIE	Res	FS[2:0]			DMDIS	FTH[1:0]	
	Reset value																									0		1	0	0	0	0	1
0x028	**DMA_S1CR**	Res	Res	Res	Res	Res	Res	Res	MBURST[1:0]		PBURST[1:0]		TRBUFF	CT	DBM	PL[1:0]		PINCOS	MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR[1:0]		PFCTRL	TCIE	HTIE	TEIE	DMEIE	EN
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x02C	**DMA_S1NDTR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	NDT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x030	**DMA_S1PAR**	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 111. DMA register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x034	**DMA_S1M0AR**	M0A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x038	**DMA_S1M1AR**	M1A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x03C	**DMA_S1FCR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	FEIE	Res	FS[2:0]			DMDIS	FTH[1:0]	
	Reset value																									0		1	0	0	0	0	1
0x040	**DMA_S2CR**	Res	Res	Res	Res	Res	Res	Res	MBURST[1:0]		PBURST[1:0]		TRBUFF	CT	DBM	PL[1:0]		PINCOS	MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR[1:0]		PFCTRL	TCIE	HTIE	TEIE	DMEIE	EN
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x044	**DMA_S2NDTR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	NDT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x048	**DMA_S2PAR**	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04C	**DMA_S2M0AR**	M0A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x050	**DMA_S2M1AR**	M1A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x054	**DMA_S2FCR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	FEIE	Res	FS[2:0]			DMDIS	FTH[1:0]	
	Reset value																									0		1	0	0	0	0	1
0x058	**DMA_S3CR**	Res	Res	Res	Res	Res	Res	Res	MBURST[1:0]		PBURST[1:0]		TRBUFF	CT	DBM	PL[1:0]		PINCOS	MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR[1:0]		PFCTRL	TCIE	HTIE	TEIE	DMEIE	EN
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x05C	**DMA_S3NDTR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	NDT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x060	**DMA_S3PAR**	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x064	**DMA_S3M0AR**	M0A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x068	**DMA_S3M1AR**	M1A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 111. DMA register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x06C	**DMA_S3FCR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	FEIE	Res	FS[2:0]			DMDIS	FTH[1:0]	
	Reset value																									0		1	0	0	0	0	1
0x070	**DMA_S4CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MBURST[1:0]		PBURST[1:0]		TRBUFF	CT	DBM	PL[1:0]		PINCOS	MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR[1:0]		PFCTRL	TCIE	HTIE	TEIE	DMEIE	EN
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x074	**DMA_S4NDTR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	NDT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x078	**DMA_S4PAR**	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x07C	**DMA_S4M0AR**	M0A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x080	**DMA_S4M1AR**	M1A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x084	**DMA_S4FCR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	FEIE	Res	FS[2:0]			DMDIS	FTH[1:0]	
	Reset value																									0		1	0	0	0	0	1
0x088	**DMA_S5CR**	Res	Res	Res	Res	Res	Res	Res	MBURST[1:0]		PBURST[1:0]		TRBUFF	CT	DBM	PL[1:0]		PINCOS	MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR[1:0]		PFCTRL	TCIE	HTIE	TEIE	DMEIE	EN
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08C	**DMA_S5NDTR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	NDT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x090	**DMA_S5PAR**	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x094	**DMA_S5M0AR**	M0A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x098	**DMA_S5M1AR**	M1A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x09C	**DMA_S5FCR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	FEIE	Res	FS[2:0]			DMDIS	FTH[1:0]	
	Reset value																									0		1	0	0	0	0	1

Table 111. DMA register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0A0	**DMA_S6CR**	Res	Res	Res	Res	Res	Res	Res	MBURST[1:0]		PBURST[1:0]		TRBUFF	CT	DBM	PL[1:0]		PINCOS	MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR[1:0]		PFCTRL	TCIE	HTIE	TEIE	DMEIE	EN
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A4	**DMA_S6NDTR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	NDT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A8	**DMA_S6PAR**	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0AC	**DMA_S6M0AR**	M0A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B0	**DMA_S6M1AR**	M1A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B4	**DMA_S6FCR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	FEIE	Res	FS[2:0]			DMDIS	FTH[1:0]	
	Reset value																									0		1	0	0	0	0	1
0x0B8	**DMA_S7CR**	Res	Res	Res	Res	Res	Res	Res	MBURST[1:0]		PBURST[1:0]		TRBUFF	CT	DBM	PL[1:0]		PINCOS	MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR[1:0]		PFCTRL	TCIE	HTIE	TEIE	DMEIE	EN
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0BC	**DMA_S7NDTR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	NDT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C0	**DMA_S7PAR**	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C4	**DMA_S7M0AR**	M0A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C8	**DMA_S7M1AR**	M1A[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0CC	**DMA_S7FCR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	FEIE	Res	FS[2:0]			DMDIS	FTH[1:0]	
	Reset value																									0		1	0	0	0	0	1

Refer to *Section 2.3* for the register boundary addresses.

16 Basic direct memory access controller (BDMA)

16.1 Introduction

The basic direct memory access (BDMA) controller is a bus master and system peripheral.

The BDMA is used to perform programmable data transfers between memory-mapped peripherals and/or memories, upon the control of an off-loaded CPU.

The BDMA controller features a single AHB master architecture.

There is one instance of BDMA with 8 channels.

Each channel is dedicated to managing memory access requests from one or more peripherals. The BDMA includes an arbiter for handling the priority between DMA requests.

16.2 BDMA main features

- Single AHB master
- Peripheral-to-memory, memory-to-peripheral, memory-to-memory and peripheral-to-peripheral data transfers
- Access to D3 domain SRAM and AHB/APB peripherals (BDMA)
- All BDMA channels independently configurable:
  - Each channel is associated either with a DMA request signal coming from a peripheral, or with a software trigger in memory-to-memory transfers. This configuration is done by software.
  - Priority between the requests is programmable by software (4 levels per channel: very high, high, medium, low) and by hardware in case of equality (such as request to channel 1 has priority over request to channel 2).
  - Transfer size of source and destination are independent (byte, half-word, word), emulating packing and unpacking. Source and destination addresses must be aligned on the data size.
  - Support of transfers from/to peripherals to/from memory with circular buffer management
  - Programmable number of data to be transferred: 0 to 2^{16} - 1
- Generation of an interrupt request per channel. Each interrupt request is caused from any of the three DMA events: transfer complete, half transfer, or transfer error.

16.3 BDMA implementation

16.3.1 BDMA

BDMA is implemented with the hardware configuration parameters shown in the table below.

Table 112. BDMA implementation

Feature	BDMA
Number of channels (double-buffer)	8

16.3.2 BDMA request mapping

The BDMA controller is connected to DMA requests from the AHB/APB peripherals through the DMAMUX peripheral.

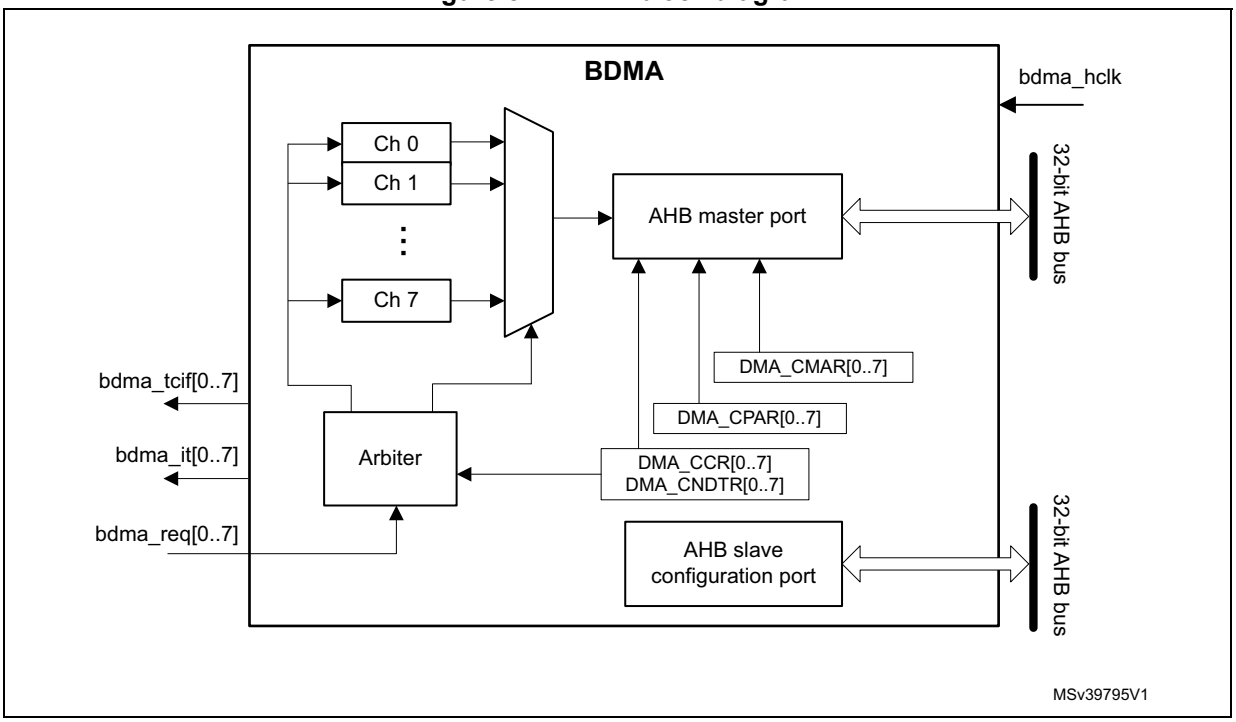
For the mapping of the different requests, refer to the *Section 17.3: DMAMUX implementation*.

16.4 BDMA functional description

16.4.1 BDMA block diagram

The BDMA block diagram is shown in the figure below.

Figure 84. BDMA block diagram



The BDMA controller performs direct memory transfer by sharing the AHB system bus with other system masters. The bus matrix implements round-robin scheduling. DMA requests may stop the CPU access to the system bus for a number of bus cycles, when CPU and BDMA target the same destination (memory or peripheral).

The BDMA controller is connected to DMA requests from the AHB/APB peripherals through the DMAMUX peripheral.

According to its configuration through the AHB slave interface, the BDMA controller arbitrates between the DMA channels and their associated received requests. The BDMA controller also schedules the DMA data transfers over the single AHB port master.

The BDMA controller generates an interrupt per channel to the interrupt controller.

16.4.2 BDMA pins and internal signals

Table 113. BDMA internal input/output signals

Signal name	Signal type	Description
bdma_req[x]	Input	BDMA channel x request
bdma_ack[x]	Output	BDMA channel x acknowledge
bdma_it[x]	Output	BDMA channel x interrupt

16.4.3 BDMA transfers

The software configures the BDMA controller at channel level, in order to perform a block transfer, composed of a sequence of AHB bus transfers.

A BDMA block transfer may be requested from a peripheral, or triggered by the software in case of memory-to-memory transfer.

After an event, the following steps of a single BDMA transfer occur:

1. The peripheral sends a single DMA request signal to the BDMA controller.
2. The BDMA controller serves the request, depending on the priority of the channel associated to this peripheral request.
3. As soon as the BDMA controller grants the peripheral, an acknowledge is sent to the peripheral by the BDMA controller.
4. The peripheral releases its request as soon as it gets the acknowledge from the BDMA controller.
5. Once the request is deasserted by the peripheral, the BDMA controller releases the acknowledge.

The peripheral may order a further single request and initiate another single BDMA transfer.

The request/acknowledge protocol is used when a peripheral is either the source or the destination of the transfer. For example, in case of memory-to-peripheral transfer, the peripheral initiates the transfer by driving its single request signal to the BDMA controller. The BDMA controller reads then a single data in the memory and writes this data to the peripheral.

For a given channel x, a BDMA block transfer consists of a repeated sequence of:

- a single BDMA transfer, encapsulating two AHB transfers of a single data, over the BDMA AHB bus master:
  - a single data read (byte, half-word or word) from the peripheral data register or a location in the memory, addressed through an internal current peripheral/memory address register.
    The start address used for the first single transfer is the base address of the peripheral or memory, and is programmed in the BDMA_CPARx or BDMA_CM0/1ARx register.
  - a single data write (byte, half-word or word) to the peripheral data register or a location in the memory, addressed through an internal current peripheral/memory address register.
    The start address used for the first transfer is the base address of the peripheral or memory, and is programmed in the BDMA_CPARx or BDMA_CM0/1ARx register.
- post-decrementing of the programmed BDMA_CNDTRx register
  This register contains the remaining number of data items to transfer (number of AHB ‘read followed by write’ transfers).

This sequence is repeated until BDMA_CNDTRx is null.

Note: The AHB master bus source/destination address must be aligned with the programmed size of the transferred single data to the source/destination.

16.4.4 BDMA arbitration

The BDMA arbiter manages the priority between the different channels.

When an active channel x is granted by the arbiter (hardware requested or software triggered), a single BDMA transfer is issued (such as a AHB ‘read followed by write’ transfer of a single data). Then, the arbiter considers again the set of active channels and selects the one with the highest priority.

The priorities are managed in two stages:

- software: priority of each channel is configured in the BDMA_CCRx register, to one of the four different levels:
  - very high
  - high
  - medium
  - low
- hardware: if two requests have the same software priority level, the channel with the lowest index gets priority. For example, channel 2 gets priority over channel 4.

When a channel x is programmed for a block transfer in memory-to-memory mode, re arbitration is considered between each single BDMA transfer of this channel x. Whenever there is another concurrent active requested channel, the BDMA arbiter automatically alternates and grants the other highest-priority requested channel, which may be of lower priority than the memory-to-memory channel.

16.4.5 BDMA channels

Each channel may handle a BDMA transfer between a peripheral register located at a fixed address, and a memory address. The amount of data items to transfer is programmable.

The register that contains the amount of data items to transfer is decremented after each transfer.

A DMA channel is programmed at block transfer level.

Programmable data sizes

The transfer sizes of a single data (byte, half-word, or word) to the peripheral and memory are programmable through, respectively, the PSIZE[1:0] and MSIZE[1:0] fields of the BDMA_CCRx register.

Pointer incrementation

The peripheral and memory pointers may be automatically incremented after each transfer, depending on the PINC and MINC bits of the BDMA_CCRx register.

If the **incremented mode** is enabled (PINC or MINC set to 1), the address of the next transfer is the address of the previous one incremented by 1, 2 or 4, depending on the data size defined in PSIZE[1:0] or MSIZE[1:0]. The first transfer address is the one programmed in the BDMA_CPARx or BDMA_CM0/1ARx register. During transfers, these registers keep the initially programmed value. The current transfer addresses (in the current internal peripheral/memory address register) are not accessible by software.

If the channel x is configured in **non-circular mode**, no DMA request is served after the last data transfer (once the number of single data to transfer reaches zero). The DMA channel must be disabled in order to reload a new number of data items into the BDMA_CNDTRx register.

Note: If the channel x is disabled, the BDMA registers are not reset. The DMA channel registers (BDMA_CCRx, BDMA_CPARx and BDMA_CM0ARx) retain the initial values programmed during the channel configuration phase.

In **circular mode**, after the last data transfer, the BDMA_CNDTRx register is automatically reloaded with the initially programmed value. The current internal address registers are reloaded with the base address values from the BDMA_CPARx and BDMA_CM0/1ARx registers.

Channel configuration procedure

The following sequence is needed to configure a DMA channel x:

1. Set the peripheral register address in the BDMA_CPARx register.
   The data is moved from/to this address to/from the memory after the peripheral event, or after the channel is enabled in memory-to-memory mode.
2. Set the memory address in the BDMA_CM0ARx register.
   The data is written to/read from the memory after the peripheral event or after the channel is enabled in memory-to-memory mode.
3. Configure the total number of data to transfer in the BDMA_CNDTRx register.
   After each data transfer, this value is decremented.
4. Configure the parameters listed below in the BDMA_CCRx register:
   – the channel priority
   – the data transfer direction
   – the circular mode
   – the double-buffer mode
   – the peripheral and memory incremented mode
   – the peripheral and memory data size
   – the interrupt enable at half and/or full transfer and/or transfer error
5. Activate the channel by setting the EN bit in the BDMA_CCRx register.

A channel, as soon as enabled, may serve any BDMA request from the peripheral connected to this channel, or may start a memory-to-memory block transfer.

Note: The two last steps of the channel configuration procedure may be merged into a single access to the BDMA_CCRx register, to configure and enable the channel.

Channel state and disabling a channel

A channel x in active state is an enabled channel (read BDMA_CCRx.EN = 1). An active channel x is a channel that must have been enabled by the software (BDMA_CCRx.EN set to 1) and afterwards with no occurred transfer error (BDMA_ISR.TEIFx = 0). In case there is a transfer error, the channel is automatically disabled by hardware (BDMA_CCRx.EN = 0).

The three following use cases may happen:

- Suspend and resume a channel

  This corresponds to the two following actions:
  – An active channel is disabled by software (writing BDMA_CCRx.EN = 0 whereas BDMA_CCRx.EN = 1).
  – The software enables the channel again (BDMA_CCRx.EN set to 1) without reconfiguring the other channel registers (such as BDMA_CNDTRx, BDMA_CPARx and BDMA_CM0/1ARx).

  This case is not supported by the BDMA hardware, that does not guarantee that the remaining data transfers are performed correctly.
- Stop and abort a channel

  If the application does not need any more the channel, this active channel can be disabled by software. The channel is stopped and aborted but the BDMA_CNDTRx

register content may not correctly reflect the remaining data transfers versus the aborted source and destination buffer/register.

- Abort and restart a channel

  This corresponds to the software sequence: disable an active channel, then reconfigure the channel and enable it again.

  This is supported by the hardware if the following conditions are met:

  – The application guarantees that, when the software is disabling the channel, a DMA data transfer is not occurring at the same time over its master port. For example, the application can first disable the peripheral in DMA mode, in order to ensure that there is no pending hardware DMA request from this peripheral.

  – The software must operate separated write accesses to the same BDMA_CCRx register: First disable the channel. Second reconfigure the channel for a next block transfer including the BDMA_CCRx if a configuration change is needed. There are read-only BDMA_CCRx register fields when BDMA_CCRx.EN=1. Finally enable again the channel.

When a channel transfer error occurs, the EN bit of the BDMA_CCRx register is cleared by hardware. This EN bit can not be set again by software to re-activate the channel x, until the TEIFx bit of the BDMA_CxISR register is set.

Circular mode (in memory-to-peripheral/peripheral-to-memory transfers)

The circular mode is available to handle circular buffers and continuous data flows (such as ADC scan mode). This feature is enabled using the CIRC bit in the BDMA_CCRx register.

Note: The circular mode must not be used in memory-to-memory mode. Before enabling a channel in circular mode (CIRC = 1), the software must clear the MEM2MEM bit of the BDMA_CCRx register. When the circular mode is activated, the amount of data to transfer is automatically reloaded with the initial value programmed during the channel configuration phase, and the DMA requests continue to be served.

In order to stop a circular transfer, the software needs to stop the peripheral from generating DMA requests (such as quit the ADC scan mode), before disabling the DMA channel. The software must explicitly program the BDMA_CNDTRx value before starting/enabling a transfer, and after having stopped a circular transfer.

Memory-to-memory mode

The BDMA channels may operate without being triggered by a request from a peripheral. This mode is called memory-to-memory mode, and is initiated by software.

If the MEM2MEM bit in the BDMA_CCRx register is set, the channel, if enabled, initiates transfers. The transfer stops once the BDMA_CNDTRx register reaches zero.

Note: The memory-to-memory mode must not be used in circular mode. Before enabling a channel in memory-to-memory mode (MEM2MEM = 1), the software must clear the CIRC bit of the BDMA_CCRx register.

Double-buffer mode (in memory-to-peripheral and peripheral-to memory transfers)

The BDMA channels can operate in double-buffer mode.

The difference compared to a regular operation is that the BDMA controller toggles between two memory address pointers at the end of each BDMA transfer, thus accessing two memory areas in an alternate way. This allows the software to access one of the two

memory areas while the BDMA controller accesses the other one. The double-buffer mode transfer operates in both directions, so the target memory can be either the source or the destination.

The double-buffer mode is configured by setting both the DBM and CIRC bits of the BDMA_CCRx register.

Note: The double-buffer mode must not be used in memory-to-memory mode. Before enabling a channel in double-buffer mode (DBM = 1), the software has to configure appropriately the MEM2MEM bit (MEM2MEM = 0).

The steps described below allow the configuration of a BDMA channel x in double-buffer mode:

- Set the DBM and CIRC bits and clear the MEM2MEM bit of the BDMA_CCRx register. The circular mode is then activated for the swap mechanism to occur.
- Configure the second memory address register BDMA_CM1ARx.
- Continue with the regular channel configuration procedure, and lastly, activate the channel by setting the EN bit of the BDMA_CCRx register. The first BDMA transfer target memory of the corresponding BDMA channel x, is given by the CT bit of the BDMA_CCRx register.

Note: Independently from the value of DBM bit of the BDMA_CCRx register, if CT = 1, the memory address pointer for the BDMA transfer is defined by BDMA_CM1ARx, and not by BDMA_CM0ARx.

Peripheral-to-peripheral mode

Any BDMA channel can operate in peripheral-to-peripheral mode:

- when the hardware request from a peripheral is selected to trigger the BDMA channel

  This peripheral is the BDMA initiator and paces the data transfer from/to this peripheral to/from a register belonging to another memory-mapped peripheral (this one being not configured in DMA mode).
- when no peripheral request is selected and connected to the BDMA channel

  The software configures a register-to-register transfer by setting the MEM2MEM bit of the BDMA_CCRx register.

Programming transfer direction, assigning source/destination

The value of the DIR bit of the BDMA_CCRx register sets the direction of the transfer, and consequently, it identifies the source and the destination, regardless the source/destination type (peripheral or memory):

- **DIR = 1** defines typically a memory-to-peripheral transfer. More generally, if DIR = 1:
  - The **source** attributes are defined by the BDMA_MARx register, the MSIZE[1:0] field and MINC bit of the BDMA_CCRx register.
    Regardless of their usual naming, these ‘memory’ register, field and bit are used to define the source peripheral in peripheral-to-peripheral mode.
  - The **destination** attributes are defined by the BDMA_PARx register, the PSIZE[1:0] field and PINC bit of the BDMA_CCRx register.

Regardless of their usual naming, these ‘peripheral’ register, field and bit are used to define the destination memory in memory-to-memory mode.

- **DIR = 0** defines typically a peripheral-to-memory transfer. More generally, if DIR = 0:
  - The **source** attributes are defined by the BDMA_PARx register, the PSIZE[1:0] field and PINC bit of the BDMA_CCRx register.
    Regardless of their usual naming, these ‘peripheral’ register, field and bit are used to define the source memory in memory-to-memory mode
  - The **destination** attributes are defined by the BDMA_MARx register, the MSIZE[1:0] field and MINC bit of the BDMA_CCRx register.
    Regardless of their usual naming, these ‘memory’ register, field and bit are used to define the destination peripheral in peripheral-to-peripheral mode.

16.4.6 BDMA data width, alignment and endianness

When PSIZE[1:0] and MSIZE[1:0] are not equal, the BDMA controller performs some data alignments as described in the table below.

Table 114. Programmable data width and endian behavior (when PINC = MINC = 1)

Source port width (MSIZE if DIR = 1, else PSIZE)	Destination port width (PSIZE if DIR = 1, else MSIZE)	Number of data items to transfer (NDT)	Source content: address / data (BDMA_CM0/1ARx if DIR = 1, else BDMA_CPARx)	DMA transfers	Destination content: address / data (BDMA_CPARx if DIR = 1, else BDMA_CM0/1ARx)
8	8	8	@0x0 / B0 @0x1 / B1 @0x2 / B2 @0x3 / B3	1: read B0[7:0] @0x0 then write B0[7:0] @0x0 2: read B1[7:0] @0x1 then write B1[7:0] @0x1 3: read B2[7:0] @0x2 then write B2[7:0] @0x2 4: read B3[7:0] @0x3 then write B3[7:0] @0x3	@0x0 / B0 @0x1 / B1 @0x2 / B2 @0x3 / B3
8	16	4	@0x0 / B0 @0x1 / B1 @0x2 / B2 @0x3 / B3	1: read B0[7:0] @0x0 then write 00B0[15:0] @0x0 2: read B1[7:0] @0x1 then write 00B1[15:0] @0x2 3: read B2[7:0] @0x2 then write 00B2[15:0] @0x4 4: read B3[7:0] @0x3 then write 00B3[15:0] @0x6	@0x0 / 00B0 @0x2 / 00B1 @0x4 / 00B2 @0x6 / 00B3
8	32	4	@0x0 / B0 @0x1 / B1 @0x2 / B2 @0x3 / B3	1: read B0[7:0] @0x0 then write 000000B0[31:0] @0x0 2: read B1[7:0] @0x1 then write 000000B1[31:0] @0x4 3: read B2[7:0] @0x2 then write 000000B2[31:0] @0x8 4: read B3[7:0] @0x3 then write 000000B3[31:0] @0xC	@0x0 / 000000B0 @0x4 / 000000B1 @0x8 / 000000B2 @0xC / 000000B3
16	8	4	@0x0 / B1B0 @0x2 / B3B2 @0x4 / B5B4 @0x6 / B7B6	1: read B1B0[15:0] @0x0 then write B0[7:0] @0x0 2: read B3B2[15:0] @0x2 then write B2[7:0] @0x1 3: read B5B4[15:0] @0x4 then write B4[7:0] @0x2 4: read B7B6[15:0] @0x6 then write B6[7:0] @0x3	@0x0 / B0 @0x1 / B2 @0x2 / B4 @0x3 / B6
16	16	4	@0x0 / B1B0 @0x2 / B3B2 @0x4 / B5B4 @0x6 / B7B6	1: read B1B0[15:0] @0x0 then write B1B0[15:0] @0x0 2: read B3B2[15:0] @0x2 then write B3B2[15:0] @0x2 3: read B5B4[15:0] @0x4 then write B5B4[15:0] @0x4 4: read B7B6[15:0] @0x6 then write B7B6[15:0] @0x6	@0x0 / B1B0 @0x2 / B3B2 @0x4 / B5B4 @0x6 / B7B6
16	32	4	@0x0 / B1B0 @0x2 / B3B2 @0x4 / B5B4 @0x6 / B7B6	1: read B1B0[15:0] @0x0 then write 0000B1B0[31:0] @0x0 2: read B3B2[15:0] @0x2 then write 0000B3B2[31:0] @0x4 3: read B5B4[15:0] @0x4 then write 0000B5B4[31:0] @0x8 4: read B7B6[15:0] @0x6 then write 0000B7B6[31:0] @0xC	@0x0 / 0000B1B0 @0x4 / 0000B3B2 @0x8 / 0000B5B4 @0xC / 0000B7B6
32	8	4	@0x0 / B3B2B1B0 @0x4 / B7B6B5B4 @0x8 / BBBAB9B8 @0xC / BFBEBDBC	1: read B3B2B1B0[31:0] @0x0 then write B0[7:0] @0x0 2: read B7B6B5B4[31:0] @0x4 then write B4[7:0] @0x1 3: read BBBAB9B8[31:0] @0x8 then write B8[7:0] @0x2 4: read BFBEBDBC[31:0] @0xC then write BC[7:0] @0x3	@0x0 / B0 @0x1 / B4 @0x2 / B8 @0x3 / BC

Table 114. Programmable data width and endian behavior (when PINC = MINC = 1) (continued)

Source port width (MSIZE if DIR = 1, else PSIZE)	Destination port width (PSIZE if DIR = 1, else MSIZE)	Number of data items to transfer (NDT)	Source content: address / data (BDMA_CM0/1ARx if DIR = 1, else BDMA_CPARx)	DMA transfers	Destination content: address / data (BDMA_CPARx if DIR = 1, else BDMA_CM0/1ARx)
32	16	4	@0x0 / B3B2B1B0 @0x4 / B7B6B5B4 @0x8 / BBBAB9B8 @0xC / BFBEBDBC	1: read B3B2B1B0[31:0] @0x0 then write B1B0[15:0] @0x0 2: read B7B6B5B4[31:0] @0x4 then write B5B4[15:0] @0x2 3: read BBBAB9B8[31:0] @0x8 then write B9B8[15:0] @0x4 4: read BFBEBDBC[31:0] @0xC then write BDBC[15:0] @0x6	@0x0 / B1B0 @0x2 / B5B4 @0x4 / B9B8 @0x6 / BDBC
32	32	4	@0x0 / B3B2B1B0 @0x4 / B7B6B5B4 @0x8 / BBBAB9B8 @0xC / BFBEBDBC	1: read B3B2B1B0[31:0] @0x0 then write B3B2B1B0[31:0] @0x0 2: read B7B6B5B4[31:0] @0x4 then write B7B6B5B4[31:0] @0x4 3: read BBBAB9B8[31:0] @0x8 then write BBBAB9B8[31:0] @0x8 4: read BFBEBDBC[31:0] @0xC then write BFBEBDBC[31:0] @0xC	@0x0 / B3B2B1B0 @0x4 / B7B6B5B4 @0x8 / BBBAB9B8 @0xC / BFBEBDBC

Addressing AHB peripherals not supporting byte/half-word write transfers

When the BDMA controller initiates an AHB byte or half-word write transfer, the data are duplicated on the unused lanes of the AHB master 32-bit data bus (HWDATA[31:0]).

When the AHB slave peripheral does not support byte or half-word write transfers and does not generate any error, the BDMA controller writes the 32 HWDATA bits as shown in the two examples below:

- To write the half-word 0xABCD, the BDMA controller sets the HWDATA bus to 0xABCDABCD with a half-word data size (HSIZE = HalfWord in AHB master bus).
- To write the byte 0xAB, the BDMA controller sets the HWDATA bus to 0xABABABAB with a byte data size (HSIZE = Byte in the AHB master bus).

Assuming the AHB/APB bridge is an AHB 32-bit slave peripheral that does not take into account the HSIZE data, any AHB byte or half-word transfer is changed into a 32-bit APB transfer as described below:

- An AHB byte write transfer of 0xB0 to one of the 0x0, 0x1, 0x2 or 0x3 addresses, is converted to an APB word write transfer of 0xB0B0B0B0 to the 0x0 address.
- An AHB half-word write transfer of 0xB1B0 to the 0x0 or 0x2 addresses, is converted to an APB word write transfer of 0xB1B0B1B0 to the 0x0 address.

16.4.7 BDMA error management

A BDMA transfer error is generated when reading from or writing to a reserved address space. When a BDMA transfer error occurs during a BDMA read or write access, the faulty channel x is automatically disabled through a hardware clear of its EN bit in the corresponding BDMA_CCRx register.

The TEIFx bit of the BDMA_ISR register is set. An interrupt is then generated if the TEIE bit of the BDMA_CCRx register is set.

The EN bit of the BDMA_CCRx register can not be set again by software (channel x re-activated) until the TEIFx bit of the BDMA_ISR register is cleared (by setting the CTEIFx bit of the BDMA_IFCR register).

When the software is notified with a transfer error over a channel which involves a peripheral, the software has first to stop this peripheral in DMA mode, in order to disable any pending or future DMA request. Then software may normally reconfigure both BDMA and the peripheral in DMA mode for a new transfer.

16.5 BDMA interrupts

An interrupt can be generated on a half transfer, transfer complete or transfer error for each DMA channel x. Separate interrupt enable bits are available for flexibility.

Table 115. BDMA interrupt requests

Interrupt request	Interrupt event	Event flag	Interrupt enable bit
Channel x interrupt	Half transfer on channel x	HTIFx	HTIEx
	Transfer complete on channel x	TCIFx	TCIEx
	Transfer error on channel x	TEIFx	TEIEx
	Half transfer or transfer complete or transfer error on channel x	GIFx	-

16.6 BDMA registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions.

The BDMA registers have to be accessed by words (32-bit).

16.6.1 BDMA interrupt status register (BDMA_ISR)

Address offset: 0x00

Reset value: 0x0000 0000

Every status bit is cleared by hardware when the software sets the corresponding clear bit or the corresponding global clear bit CGIFx, in the BDMA_IFCR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TEIF7	HTIF7	TCIF7	GIF7	TEIF6	HTIF6	TCIF6	GIF6	TEIF5	HTIF5	TCIF5	GIF5	TEIF4	HTIF4	TCIF4	GIF4
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TEIF3	HTIF3	TCIF3	GIF3	TEIF2	HTIF2	TCIF2	GIF2	TEIF1	HTIF1	TCIF1	GIF1	TEIF0	HTIF0	TCIF0	GIF0
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 **TEIF7**: transfer error (TE) flag for channel 7
0: no TE event
1: a TE event occurred

Bit 30 **HTIF7**: half transfer (HT) flag for channel 7
0: no HT event
1: a HT event occurred

Bit 29 **TCIF7**: transfer complete (TC) flag for channel 7
0: no TC event
1: a TC event occurred

Bit 28 **GIF7**: global interrupt flag for channel 7
0: no TE, HT or TC event
1: a TE, HT or TC event occurred

Bit 27 **TEIF6**: transfer error (TE) flag for channel 6
0: no TE event
1: a TE event occurred

Bit 26 **HTIF6**: half transfer (HT) flag for channel 6
0: no HT event
1: a HT event occurred

Bit 25 **TCIF6**: transfer complete (TC) flag for channel 6
0: no TC event
1: a TC event occurred

Bit 24 **GIF6**: global interrupt flag for channel 6
0: no TE, HT or TC event
1: a TE, HT or TC event occurred

Bit 23 **TEIF5**: transfer error (TE) flag for channel 5
0: no TE event
1: a TE event occurred

Bit 22 **HTIF5**: half transfer (HT) flag for channel 5
0: no HT event
1: a HT event occurred

Bit 21 **TCIF5**: transfer complete (TC) flag for channel 5
0: no TC event
1: a TC event occurred

Bit 20 **GIF5**: global interrupt flag for channel 5
0: no TE, HT or TC event
1: a TE, HT or TC event occurred

Bit 19 **TEIF4**: transfer error (TE) flag for channel 4
0: no TE event
1: a TE event occurred

Bit 18 **HTIF4**: half transfer (HT) flag for channel 4
0: no HT event
1: a HT event occurred

Bit 17 **TCIF4**: transfer complete (TC) flag for channel 4
0: no TC event
1: a TC event occurred

Bit 16 **GIF4**: global interrupt flag for channel 4
0: no TE, HT or TC event
1: a TE, HT or TC event occurred

Bit 15 **TEIF3**: transfer error (TE) flag for channel 3
0: no TE event
1: a TE event occurred

Bit 14 **HTIF3**: half transfer (HT) flag for channel 3
0: no HT event
1: a HT event occurred

Bit 13 **TCIF3**: transfer complete (TC) flag for channel 3
0: no TC event
1: a TC event occurred

Bit 12 **GIF3**: global interrupt flag for channel 3
0: no TE, HT or TC event
1: a TE, HT or TC event occurred

Bit 11 **TEIF2**: transfer error (TE) flag for channel 2
0: no TE event
1: a TE event occurred

Bit 10 **HTIF2**: half transfer (HT) flag for channel 2
0: no HT event
1: a HT event occurred

Bit 9 **TCIF2**: transfer complete (TC) flag for channel 2
0: no TC event
1: a TC event occurred

Bit 8 **GIF2**: global interrupt flag for channel 2
0: no TE, HT or TC event
1: a TE, HT or TC event occurred

Bit 7 **TEIF1**: transfer error (TE) flag for channel 1
0: no TE event
1: a TE event occurred

Bit 6 **HTIF1**: half transfer (HT) flag for channel 1
0: no HT event
1: a HT event occurred

Bit 5 **TCIF1**: transfer complete (TC) flag for channel 1
0: no TC event
1: a TC event occurred

Bit 4 **GIF1**: global interrupt flag for channel 1
0: no TE, HT or TC event
1: a TE, HT or TC event occurred

Bit 3 **TEIF0**: transfer error (TE) flag for channel 0
0: no TE event
1: a TE event occurred

Bit 2 **HTIF0**: half transfer (HT) flag for channel 0
0: no HT event
1: a HT event occurred

Bit 1 **TCIF0**: transfer complete (TC) flag for channel 0
0: no TC event
1: a TC event occurred

Bit 0 **GIF0**: global interrupt flag for channel 0
0: no TE, HT or TC event
1: a TE, HT or TC event occurred

16.6.2 BDMA interrupt flag clear register (BDMA_IFCR)

Address offset: 0x04

Reset value: 0x0000 0000

Setting the global clear bit CGIFx of the channel x in this BDMA_IFCR register, causes the BDMA hardware to clear the corresponding GIFx bit and any individual flag among TEIFx, HTIFx, TCIFx, in the BDMA_ISR register.

Setting any individual clear bit among CTEIFx, CHTIFx, CTCIFx in this BDMA_IFCR register, causes the BDMA hardware to clear the corresponding individual flag and the global flag GIFx in the BDMA_ISR register, provided that none of the two other individual flags is set.

Writing 0 into any flag clear bit has no effect.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CTEIF7	CHTIF7	CTCIF7	CGIF7	CTEIF6	CHTIF6	CTCIF6	CGIF6	CTEIF5	CHTIF5	CTCIF5	CGIF5	CTEIF4	CHTIF4	CTCIF4	CGIF4
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CTEIF3	CHTIF3	CTCIF3	CGIF3	CTEIF2	CHTIF2	CTCIF2	CGIF2	CTEIF1	CHTIF1	CTCIF1	CGIF1	CTEIF0	CHTIF0	CTCIF0	CGIF0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bit 31 **CTEIF7**: transfer error flag clear for channel 7

Bit 30 **CHTIF7**: half transfer flag clear for channel 7

Bit 29 **CTCIF7**: transfer complete flag clear for channel 7

Bit 28 **CGIF7**: global interrupt flag clear for channel 7

Bit 27 **CTEIF6**: transfer error flag clear for channel 6

Bit 26 **CHTIF6**: half transfer flag clear for channel 6

Bit 25 **CTCIF6**: transfer complete flag clear for channel 6

Bit 24 **CGIF6**: global interrupt flag clear for channel 6

Bit 23 **CTEIF5**: transfer error flag clear for channel 5

Bit 22 **CHTIF5**: half transfer flag clear for channel 5

Bit 21 **CTCIF5**: transfer complete flag clear for channel 5

Bit 20 **CGIF5**: global interrupt flag clear for channel 5

Bit 19 **CTEIF4**: transfer error flag clear for channel 4

Bit 18 **CHTIF4**: half transfer flag clear for channel 4

Bit 17 **CTCIF4**: transfer complete flag clear for channel 4

Bit 16 **CGIF4**: global interrupt flag clear for channel 4

Bit 15 **CTEIF3**: transfer error flag clear for channel 3

Bit 14 **CHTIF3**: half transfer flag clear for channel 3

Bit 13 **CTCIF3**: transfer complete flag clear for channel 3

Bit 12 **CGIF3**: global interrupt flag clear for channel 3

Bit 11 **CTEIF2**: transfer error flag clear for channel 2

Bit 10 **CHTIF2**: half transfer flag clear for channe2

Bit 9 **CTCIF2**: transfer complete flag clear for channel 2

Bit 8 **CGIF2**: global interrupt flag clear for channel 2

Bit 7 **CTEIF1**: transfer error flag clear for channel 1

Bit 6 **CHTIF1**: half transfer flag clear for channel 1

Bit 5 **CTCIF1**: transfer complete flag clear for channel 1

Bit 4 **CGIF1**: global interrupt flag clear for channel 0

Bit 3 **CTEIF0**: transfer error flag clear for channel 0

Bit 2 **CHTIF0**: half transfer flag clear for channel 0

Bit 1 **CTCIF0**: transfer complete flag clear for channel 0

Bit 0 **CGIF0**: global interrupt flag clear for channel 0

16.6.3 BDMA channel x configuration register (BDMA_CCRx)

Address offset: 0x08 + 0x14 * x, (x = 0 to 7)

Reset value: 0x0000 0000

The register fields/bits CT, DBM, MEM2MEM, PL[1:0], MSIZE[1:0], PSIZE[1:0], MINC, PINC, and DIR are read-only when EN = 1.

The states of MEM2MEM and CIRC bits must not be both high at the same time.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CT
															rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DBM	MEM2MEM	PL[1:0]		MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR	TEIE	HTIE	TCIE	EN
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **CT**: current target memory of DMA transfer in double-buffer mode

This bit is toggled by hardware at the end of each channel transfer in double-buffer mode.

0: memory 0 (addressed by the BDMA_CM0AR pointer)

1: memory 1 (addressed by the BDMA_CM1AR pointer)

Note: this bit is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is read-only when the channel is enabled (EN = 1).

Bit 15 **DBM**: double-buffer mode

This bit must be set only in memory-to-peripheral and peripheral-to-memory transfers (MEM2MEM=0). The CIRC bit must also be set in double buffer mode.

0: disabled (no memory address switch at the end of the BDMA transfer)

1: enabled (memory address switched at the end of the BDMA transfer)

Note: this bit is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is not read-only when the channel is enabled (EN = 1).

Bit 14 **MEM2MEM**: memory-to-memory mode

0: disabled

1: enabled

Note: this bit is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is read-only when the channel is enabled (EN = 1).

Bits 13:12 **PL[1:0]**: priority level

00: low

01: medium

10: high

11: very high

Note: this field is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is read-only when the channel is enabled (EN = 1).

Bits 11:10 **MSIZE[1:0]**: memory size

Defines the data size of each DMA transfer to the identified memory.

In memory-to-memory mode, this field identifies the memory source if DIR = 1 and the memory destination if DIR = 0.

In peripheral-to-peripheral mode, this field identifies the peripheral source if DIR = 1 and the peripheral destination if DIR = 0.

00: 8 bits

01: 16 bits

10: 32 bits

11: reserved

Note: this field is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is read-only when the channel is enabled (EN = 1).

Bits 9:8 **PSIZE[1:0]**: peripheral size

Defines the data size of each DMA transfer to the identified peripheral.

In memory-to-memory mode, this field identifies the memory destination if DIR = 1 and the memory source if DIR = 0.

In peripheral-to-peripheral mode, this field identifies the peripheral destination if DIR = 1 and the peripheral source if DIR = 0.

00: 8 bits

01: 16 bits

10: 32 bits

11: reserved

Note: this field is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is read-only when the channel is enabled (EN = 1).

Bit 7 **MINC**: memory increment mode

Defines the increment mode for each DMA transfer to the identified memory.

In memory-to-memory mode, this field identifies the memory source if DIR = 1 and the memory destination if DIR = 0.

In peripheral-to-peripheral mode, this field identifies the peripheral source if DIR = 1 and the peripheral destination if DIR = 0.

0: disabled

1: enabled

Note: this bit is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is read-only when the channel is enabled (EN = 1).

Bit 6 **PINC**: peripheral increment mode

Defines the increment mode for each DMA transfer to the identified peripheral.

n memory-to-memory mode, this field identifies the memory destination if DIR = 1 and the memory source if DIR = 0.

In peripheral-to-peripheral mode, this field identifies the peripheral destination if DIR = 1 and the peripheral source if DIR = 0.

0: disabled

1: enabled

Note: this bit is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is read-only when the channel is enabled (EN = 1).

Bit 5 **CIRC**: circular mode

0: disabled

1: enabled

Note: this bit is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is not read-only when the channel is enabled (EN = 1).

Bit 4 **DIR**: data transfer direction

This bit must be set only in memory-to-peripheral and peripheral-to-memory modes.

0: read from peripheral

- Source attributes are defined by PSIZE and PINC, plus the BDMA_CPARx register. This is still valid in a memory-to-memory mode.
- Destination attributes are defined by MSIZE and MINC, plus the BDMA_CM0/1ARx register. This is still valid in a peripheral-to-peripheral mode.

1: read from memory

- Destination attributes are defined by PSIZE and PINC, plus the BDMA_CPARx register. This is still valid in a memory-to-memory mode.
- Source attributes are defined by MSIZE and MINC, plus the BDMA_CM0/1ARx register. This is still valid in a peripheral-to-peripheral mode.

Note: this bit is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is read-only when the channel is enabled (EN = 1).

Bit 3 **TEIE**: transfer error interrupt enable

0: disabled

1: enabled

Note: this bit is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is not read-only when the channel is enabled (EN = 1).

Bit 2 **HTIE**: half transfer interrupt enable

0: disabled

1: enabled

Note: this bit is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is not read-only when the channel is enabled (EN = 1).

Bit 1 **TCIE**: transfer complete interrupt enable

0: disabled

1: enabled

Note: this bit is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is not read-only when the channel is enabled (EN = 1).

Bit 0 **EN**: channel enable

When a channel transfer error occurs, this bit is cleared by hardware. It can not be set again by software (channel x re-activated) until the TEIFx bit of the BDMA_ISR register is cleared (by setting the CTEIFx bit of the BDMA_IFCR register).

0: disabled

1: enabled

Note: this bit is set and cleared by software.

16.6.4 BDMA channel x number of data to transfer register (BDMA_CNDTRx)

Address offset: 0x0C + 0x14 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NDT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **NDT[15:0]**: number of data to transfer (0 to 2^{16} - 1)

This field is updated by hardware when the channel is enabled:

- It is decremented after each single BDMA 'read followed by write' transfer, indicating the remaining amount of data items to transfer.
- It is kept at zero when the programmed amount of data to transfer is reached, if the channel is not in circular mode (CIRC = 0 in the BDMA_CCRx register).
- It is reloaded automatically by the previously programmed value, when the transfer is complete, if the channel is in circular mode (CIRC = 1).

If this field is zero, no transfer can be served whatever the channel status (enabled or not).

Note: this field is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is read-only when the channel is enabled (EN = 1).

16.6.5 BDMA channel x peripheral address register (BDMA_CPARx)

Address offset: 0x10 + 0x14 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PA[31:0]**: peripheral address

It contains the base address of the peripheral data register from/to which the data is read/written.

When PSIZE[1:0] = 01 (16 bits), bit 0 of PA[31:0] is ignored. Access is automatically aligned to a half-word address.

When PSIZE = 10 (32 bits), bits 1 and 0 of PA[31:0] are ignored. Access is automatically aligned to a word address.

In memory-to-memory mode, this register identifies the memory destination address if DIR = 1 and the memory source address if DIR = 0.

In peripheral-to-peripheral mode, this register identifies the peripheral destination address DIR = 1 and the peripheral source address if DIR = 0.

Note: this register is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is not read-only when the channel is enabled (EN = 1).

16.6.6 BDMA channel x memory 0 address register (BDMA_CM0ARx)

Address offset: 0x14 + 0x14 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MA[31:0]**: peripheral address

It contains the base address of the memory from/to which the data is read/written.

When MSIZE[1:0] = 01 (16 bits), bit 0 of MA[31:0] is ignored. Access is automatically aligned to a half-word address.

When MSIZE = 10 (32 bits), bits 1 and 0 of MA[31:0] are ignored. Access is automatically aligned to a word address.

In memory-to-memory mode, this register identifies the memory source address if DIR = 1 and the memory destination address if DIR = 0.

In peripheral-to-peripheral mode, this register identifies the peripheral source address DIR = 1 and the peripheral destination address if DIR = 0.

Note: this register is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is not read-only when the channel is enabled (EN = 1).

16.6.7 BDMA channel x memory 1 address register (BDMA_CM1ARx)

Address offset: 0x18 + 0x14 * x, (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MA[31:0]**: peripheral address

It contains the base address of the memory from/to which the data is read/written.

When MSIZE[1:0] = 01 (16 bits), bit 0 of MA[31:0] is ignored. Access is automatically aligned to a half-word address.

When MSIZE = 10 (32 bits), bits 1 and 0 of MA[31:0] are ignored. Access is automatically aligned to a word address.

In memory-to-memory mode, this register identifies the memory source address if DIR = 1 and the memory destination address if DIR = 0.

In peripheral-to-peripheral mode, this register identifies the peripheral source address DIR = 1 and the peripheral destination address if DIR = 0.

Note: this register is set and cleared by software.
It must not be written when the channel is enabled (EN = 1).
It is not read-only when the channel is enabled (EN = 1).

16.6.8 BDMA register map

The table below gives the BDMA register map and reset values.

Table 116. BDMA register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	BDMA_ISR	TEIF7	HTIF7	TCIF7	GIF7	TEIF6	HTIF6	TCIF6	GIF6	TEIF5	HTIF5	TCIF5	GIF5	TEIF4	HTIF4	TCIF4	GIF4	TEIF3	HTIF3	TCIF3	GIF3	TEIF2	HTIF2	TCIF2	GIF2	TEIF1	HTIF1	TCIF1	GIF1	TEIF0	HTIF0	TCIF0	GIF0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x004	BDMA_IFCR	CTEIF7	CHTIF7	CTCIF7	CGIF7	CTEIF6	CHTIF6	CTCIF6	CGIF6	CTEIF5	CHTIF5	CTCIF5	CGIF5	CTEIF4	CHTIF4	CTCIF4	CGIF4	CTEIF3	CHTIF3	CTCIF3	CGIF3	CTEIF2	CHTIF2	CTCIF2	CGIF2	CTEIF1	CHTIF1	CTCIF1	CGIF1	CTEIF0	CHTIF0	CTCIF0	CGIF0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x008	BDMA_CCR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CT	DBM	MEM2MEM	PL[1:0]		MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR	TEIE	HTIE	TCIE	EN
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00C	BDMA_CNDTR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NDTR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x010	BDMA_CPAR0	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x014	BDMA_CM0AR0	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x018	BDMA_CM1AR0	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 116. BDMA register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x01C	BDMA_CCR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CT	DBM	MEM2MEM	PL[1:0]		MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR	TEIE	HTIE	TCIE	EN
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	BDMA_CNDTR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NDTR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	BDMA_CPAR1	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x028	BDMA_CM0AR1	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x02C	BDMA_CM1AR1	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x030	BDMA_CCR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CT	DBM	MEM2MEM	PL[1:0]		MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR	TEIE	HTIE	TCIE	EN
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x034	BDMA_CNDTR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NDTR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x038	BDMA_CPAR2	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x03C	BDMA_CM0AR2	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x040	BDMA_CM1AR2	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x044	BDMA_CCR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CT	DBM	MEM2MEM	PL[1:0]		MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR	TEIE	HTIE	TCIE	EN
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x048	BDMA_CNDTR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NDTR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04C	BDMA_CPAR3	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x050	BDMA_CM0AR3	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x054	BDMA_CM1AR3	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x058	BDMA_CCR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CT	DBM	MEM2MEM	PL[1:0]		MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR	TEIE	HTIE	TCIE	EN
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x05C	BDMA_CNDTR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NDTR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x060	BDMA_CPAR4	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x064	BDMA_CM0AR4	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x068	BDMA_CM1AR4	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 116. BDMA register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x06C	BDMA_CCR5	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CT	DBM	MEM2MEM	PL[1:0]		MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR	TEIE	HTIE	TCIE	EN
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x070	BDMA_CNDTR5	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NDTR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x074	BDMA_CPAR5	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x078	BDMA_CM0AR5	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x07C	BDMA_CM1AR5	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x080	BDMA_CCR6	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CT	DBM	MEM2MEM	PL[1:0]		MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR	TEIE	HTIE	TCIE	EN
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x084	BDMA_CNDTR6	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NDTR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x088	BDMA_CPAR6	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08C	BDMA_CM0AR6	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x090	BDMA_CM1AR6	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x094	BDMA_CCR7	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CT	DBM	MEM2MEM	PL[1:0]		MSIZE[1:0]		PSIZE[1:0]		MINC	PINC	CIRC	DIR	TEIE	HTIE	TCIE	EN
	Reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x098	BDMA_CNDTR7	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NDTR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x09C	BDMA_CPAR7	PA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A0	BDMA_CM0AR7	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A4	BDMA_CM1AR7	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

17 DMA request multiplexer (DMAMUX)

17.1 Introduction

A peripheral indicates a request for DMA transfer by setting its DMA request signal. The DMA request is pending until it is served by the DMA controller that generates a DMA acknowledge signal, and the corresponding DMA request signal is deasserted.

In this document, the set of control signals required for the DMA request/acknowledge protocol is not explicitly shown or described, and it is referred to as DMA request line.

The DMAMUX request multiplexer enables routing a DMA request line between the peripherals and the DMA controllers of the product. The routing function is ensured by a programmable multi-channel DMA request line multiplexer. Each channel selects a unique DMA request line, unconditionally or synchronously with events from its DMAMUX synchronization inputs. The DMAMUX may also be used as a DMA request generator from programmable events on its input trigger signals.

The number of DMAMUX instances and their main characteristics are specified in *Section 17.3.1*.

The assignment of DMAMUX request multiplexer inputs to the DMA request lines from peripherals and to the DMAMUX request generator outputs, the assignment of DMAMUX request multiplexer outputs to DMA controller channels, and the assignment of DMAMUX synchronizations and trigger inputs to internal and external signals depend on the product implementation, and are detailed in *Section 17.3.2*.

17.2 DMAMUX main features

- Up to 16-channel programmable DMA request line multiplexer output
- Up to 8-channel DMA request generator
- Up to 32 trigger inputs to DMA request generator
- Up to 16 synchronization inputs
- Per DMA request generator channel:
  - DMA request trigger input selector
  - DMA request counter
  - Event overrun flag for selected DMA request trigger input
- Per DMA request line multiplexer channel output:
  - Up to 129 input DMA request lines from peripherals
  - One DMA request line output
  - Synchronization input selector
  - DMA request counter
  - Event overrun flag for selected synchronization input
  - One event output, for DMA request chaining

17.3 DMAMUX implementation

17.3.1 DMAMUX1 and DMAMUX2 instantiation

The product integrates two instances of DMA request multiplexer:

- DMAMUX1 for DMA1 and DMA2 (D2 domain)
- DMAMUX2 for BDMA (D3 domain)

DMAMUX1 and DMAMUX2are instantiated with the hardware configuration parameters listed in the following table.

Table 117. DMAMUX1 and DMAMUX2 instantiation

Feature	DMAMUX1	DMAMUX2
Number of DMAMUX output request channels	16	8
Number of DMAMUX request generator channels	8	8
Number of DMAMUX request trigger inputs	8	32
Number of DMAMUX synchronization inputs	8	16
Number of DMAMUX peripheral request inputs	129	12

17.3.2 DMAMUX1 mapping

The mapping of resources to DMAMUX1 is hardwired.

DMAMUX1 is used with DMA1 and DMA2 in D2 domain

- DMAMUX1 channels 0 to 7 are connected to DMA1 channels 0 to 7
- DMAMUX1 channels 8 to 15 are connected to DMA2 channels 0 to 7

Table 118. DMAMUX1: assignment of multiplexer inputs to resources

DMA request MUX input	Resource	DMA request MUX input	Resource	DMA request MUX input	Resource
1	dmamux1_req_gen0	47	TIM8_CH1	93	spdifrx_dat_dma
2	dmamux1_req_gen1	48	TIM8_CH2	94	spdifrx_ctrl_dma
3	dmamux1_req_gen2	49	TIM8_CH3	95	Reserved
4	dmamux1_req_gen3	50	TIM8_CH4	96	Reserved
5	dmamux1_req_gen4	51	TIM8_UP	97	Reserved
6	dmamux1_req_gen5	52	TIM8_TRIG	98	Reserved
7	dmamux1_req_gen6	53	TIM8_COM	99	Reserved
8	dmamux1_req_gen7	54	Reserved	100	Reserved
9	adc1_dma	55	TIM5_CH1	101	dfsdm1_dma0
10	adc2_dma	56	TIM5_CH2	102	dfsdm1_dma1
11	TIM1_CH1	57	TIM5_CH3	103	dfsdm1_dma2
12	TIM1_CH2	58	TIM5_CH4	104	dfsdm1_dma3
13	TIM1_CH3	59	TIM5_UP	105	TIM15_CH1
14	TIM1_CH4	60	TIM5_TRIG	106	TIM15_UP
15	TIM1_UP	61	spi3_rx_dma	107	TIM15_TRIG
16	TIM1_TRIG	62	spi3_tx_dma	108	TIM15_COM
17	TIM1_COM	63	uart4_rx_dma	109	TIM16_CH1
18	TIM2_CH1	64	uart4_tx_dma	110	TIM16_UP
19	TIM2_CH2	65	uart5_rx_dma	111	TIM17_CH1
20	TIM2_CH3	66	uart5_tx_dma	112	TIM17_UP
21	TIM2_CH4	67	dac_ch1_dma	113	Reserved
22	TIM2_UP	68	dac_ch2_dma	114	Reserved
23	TIM3_CH1	69	TIM6_UP	115	adc3_dma
24	TIM3_CH2	70	TIM7_UP	116	uart9_rx_dma
25	TIM3_CH3	71	usart6_rx_dma	117	uart9_tx_dma
26	TIM3_CH4	72	usart6_tx_dma	118	uart10_rx_dma
27	TIM3_UP	73	i2c3_rx_dma	119	uart10_tx_dma
28	TIM3_TRIG	74	i2c3_tx_dma	120	FMAC_RD
29	TIM4_CH1	75	dcmi_dma	121	FMAC_WR
30	TIM4_CH2	76	cryp_in_dma	122	CORDIC_RD
31	TIM4_CH3	77	cryp_out_dma	123	CORDIC_WR
32	TIM4_UP	78	hash_in_dma	124	i2c5_rx_dma
33	i2c1_rx_dma	79	uart7_rx_dma	125	i2c5_tx_dma
34	i2c1_tx_dma	80	uart7_tx_dma	126	TIM23_CH1
35	i2c2_rx_dma	81	uart8_rx_dma	127	TIM23_CH2
36	i2c2_tx_dma	82	uart8_tx_dma	128	TIM23_CH3

Table 118. DMAMUX1: assignment of multiplexer inputs to resources (continued)

DMA request MUX input	Resource	DMA request MUX input	Resource	DMA request MUX input	Resource
37	spi1_rx_dma	83	spi4_rx_dma	129	TIM23_CH4
38	spi1_tx_dma	84	spi4_tx_dma	130	TIM23_UP
39	spi2_rx_dma	85	spi5_rx_dma	131	TIM23_TRIG
40	spi2_tx_dma	86	spi5_tx_dma	132	TIM24_CH1
41	usart1_rx_dma	87	sai1a_dma	133	TIM24_CH2
42	usart1_tx_dma	88	sai1b_dma	134	TIM24_CH3
43	usart2_rx_dma	89	Reserved	135	TIM24_CH4
44	usart2_tx_dma	90	Reserved	136	TIM24_UP
45	usart3_rx_dma	91	swpmi_rx_dma	137	TIM24_TRIG
46	usart3_tx_dma	92	swpmi_tx_dma	-	-

Table 119. DMAMUX1: assignment of trigger inputs to resources

Trigger input	Resource	Trigger input	Resource
0	dmamux1_evt0	4	lptim2_out
1	dmamux1_evt1	5	lptim3_out
2	dmamux1_evt2	6	extit0
3	lptim1_out	7	TIM12_TRGO

Table 120. DMAMUX1: assignment of synchronization inputs to resources

Sync. input	Resource	Sync. input	Resource
0	dmamux1_evt0	4	lptim2_out
1	dmamux1_evt1	5	lptim3_out
2	dmamux1_evt2	6	extit0
3	lptim1_out	7	TIM12_TRGO

17.3.3 DMAMUX2 mapping

DMAMUX2 channels 0 to 7 are connected to BDMA channels 0 to 7.

Table 121. DMAMUX2: assignment of multiplexer inputs to resources

DMA request MUX input	Resource	DMA request MUX input	Resource
1	dmamux2_req_gen0	17	adc3_dma
2	dmamux2_req_gen1	18	Reserved
3	dmamux2_req_gen2	19	Reserved
4	dmamux2_req_gen3	20	Reserved
5	dmamux2_req_gen4	21	Reserved

Table 121. DMAMUX2: assignment of multiplexer inputs to resources (continued)

DMA request MUX input	Resource	DMA request MUX input	Resource
6	dmamux2_req_gen5	22	Reserved
7	dmamux2_req_gen6	23	Reserved
8	dmamux2_req_gen7	24	Reserved
9	lpuart1_rx_dma	25	Reserved
10	lpuart1_tx_dma	26	Reserved
11	spi6_rx_dma	27	Reserved
12	spi6_tx_dma	28	Reserved
13	i2c4_rx_dma	29	Reserved
14	i2c4_tx_dma	30	Reserved
15	sai4_a_dma	31	Reserved
16	sai4_b_dma	32	Reserved

Table 122. DMAMUX2: assignment of trigger inputs to resources

Trigger input	Resource	Trigger input	Resource
0	dmamux2_evt0	16	spi6_wkup
1	dmamux2_evt1	17	Comp1_out
2	dmamux2_evt2	18	Comp2_out
3	dmamux2_evt3	19	RTC_wkup
4	dmamux2_evt4	20	Syscfg_exti0_mux
5	dmamux2_evt5	21	Syscfg_exti2_mux
6	dmamux2_evt6	22	I2c4_event_it
7	lpuart_rx_wkup	23	spi6_it
8	lpuart_tx_wkup	24	Lpuart1_it_T
9	lptim2_wkup	25	Lpuart1_it_R
10	lptim2_out	26	adc3_it
11	lptim3_wkup	27	adc3_awd1
12	lptim3_out	28	bdma_ch0_it
13	Lptim4_ait	29	bdma_ch1_it
14	Lptim5_ait	30	Reserved
15	I2c4_wkup	31	Reserved

Table 123. DMAMUX2: assignment of synchronization inputs to resources

Sync input	Resource	Sync input	Resource
0	dmamux2_evt0	16	Reserved
1	dmamux2_evt1	17	Reserved
2	dmamux2_evt2	18	Reserved

Table 123. DMAMUX2: assignment of synchronization inputs to resources

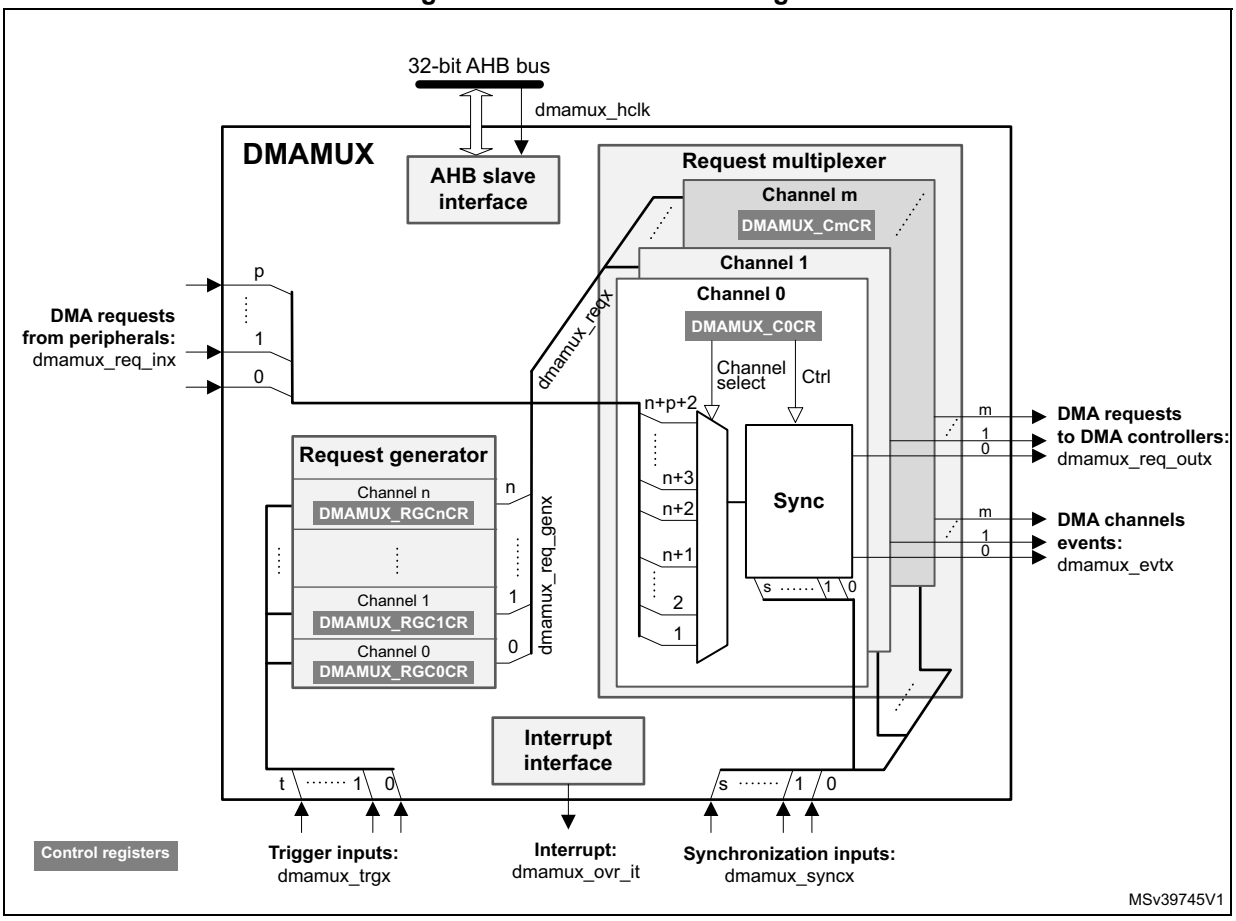
Sync input	Resource	Sync input	Resource
3	dmamux2_evt3	19	Reserved
4	dmamux2_evt4	20	Reserved
5	dmamux2_evt5	21	Reserved
6	lpuart1_rx_wkup	22	Reserved
7	lpuart1_tx_wkup	23	Reserved
8	Lptim2_out	24	Reserved
9	Lptim3_out	25	Reserved
10	I2c4_wkup	26	Reserved
11	spi6_wkup	27	Reserved
12	Comp1_out	28	Reserved
13	RTC_wkup	29	Reserved
14	Syscfg_exti0_mux	30	Reserved
15	Syscfg_exti2_mux	31	Reserved

17.4 DMAMUX functional description

17.4.1 DMAMUX block diagram

Figure 85 shows the DMAMUX block diagram.

Figure 85. DMAMUX block diagram



DMAMUX features two main sub-blocks: the request line multiplexer and the request line generator.

The implementation assigns:

- DMAMUX request multiplexer sub-block inputs (dmamux_reqx) from peripherals (dmamux_req_inx) and from channels of the DMAMUX request generator sub-block (dmamux_req_genx)
- DMAMUX request outputs to channels of DMA controllers (dmamux_req_outx)
- Internal or external signals to DMA request trigger inputs (dmamux_trgx)
- Internal or external signals to synchronization inputs (dmamux_syncx)

17.4.2 DMAMUX signals

Table 124 lists the DMAMUX signals.

Table 124. DMAMUX signals

Signal name	Description
dmamux_hclk	DMAMUX AHB clock
dmamux_req_inx	DMAMUX DMA request line inputs from peripherals
dmamux_trgx	DMAMUX DMA request triggers inputs (to request generator sub-block)
dmamux_req_genx	DMAMUX request generator sub-block channels outputs
dmamux_reqx	DMAMUX request multiplexer sub-block inputs (from peripheral requests and request generator channels)
dmamux_syncx	DMAMUX synchronization inputs (to request multiplexer sub-block)
dmamux_req_outx	DMAMUX requests outputs (to DMA controllers)
dmamux_evtx	DMAMUX events outputs
dmamux_ovr_it	DMAMUX overrun interrupts

17.4.3 DMAMUX channels

A DMAMUX channel is a DMAMUX request multiplexer channel that may include, depending on the selected input of the request multiplexer, an additional DMAMUX request generator channel.

A DMAMUX request multiplexer channel is connected and dedicated to one single channel of DMA controller(s).

Channel configuration procedure

Follow the sequence below to configure both a DMAMUX x channel and the related DMA channel y:

1. Set and configure completely the DMA channel y, except enabling the channel y.
2. Set and configure completely the related DMAMUX y channel.
3. Last, activate the DMA channel y by setting the EN bit in the DMA y channel register.

17.4.4 DMAMUX request line multiplexer

The DMAMUX request multiplexer with its multiple channels ensures the actual routing of DMA request/acknowledge control signals, named DMA request lines.

Each DMA request line is connected in parallel to all the channels of the DMAMUX request line multiplexer.

A DMA request is sourced either from the peripherals or from the DMAMUX request generator.

The DMAMUX request line multiplexer channel x selects the DMA request line number as configured by the DMAREQ_ID field in the DMAMUX_CxCR register.

Note: The null value in the field DMAREQ_ID corresponds to no DMA request line selected.

Caution: A same non-null DMAREQ_ID must not be programmed to different x and y DMAMUX request multiplexer channels (via DMAMUX_CxCR and DMAMUX_CyCR), except if application guarantees that the two connected DMA channels are not simultaneously active.

On top of the DMA request selection, the synchronization mode and/or the event generation may be configured and enabled, if required.

Synchronization mode and channel event generation

Each DMAMUX request line multiplexer channel x can be individually synchronized by setting the synchronization enable (SE) bit in the DMAMUX_CxCR register.

DMAMUX has multiple synchronization inputs. The synchronization inputs are connected in parallel to all the channels of the request multiplexer.

The synchronization input is selected via the SYNC_ID field in the DMAMUX_CxCR register of a given channel x.

When a channel is in this synchronization mode, the selected input DMA request line is propagated to the multiplexer channel output, once is detected a programmable rising/falling edge on the selected input synchronization signal, via the SPOL[1:0] field of the DMAMUX_CxCR register.

Additionally, there is a programmable DMA request counter, internally to the DMAMUX request multiplexer, which may be used for the channel request output generation and also possibly for an event generation. An event generation on the channel x output is enabled through the EGE bit (event generation enable) of the DMAMUX_CxCR register.

As shown in *Figure 87*, upon the detected edge of the synchronization input, the pending selected input DMA request line is connected to the DMAMUX multiplexer channel x output.

Note: If a synchronization event occurs while there is no pending selected input DMA request line, it is discarded. The following asserted input request lines is not connected to the DMAMUX multiplexer channel output until a synchronization event occurs again.

From this point on, each time the connected DMAMUX request is served by the DMA controller (a served request is deasserted), the DMAMUX request counter is decremented. At its underrun, the DMA request counter is automatically loaded with the value in NBREQ field of the DMAMUX_CxCR register and the input DMA request line is disconnected from the multiplexer channel x output.

Thus, the number of DMA requests transferred to the multiplexer channel x output following a detected synchronization event, is equal to the value in NBREQ field, plus one.

Note: The NBREQ field value shall only be written by software when both synchronization enable bit SE and event generation enable EGE bit of the corresponding multiplexer channel x are disabled.

Figure 86. Synchronization mode of the DMAMUX request line multiplexer channel

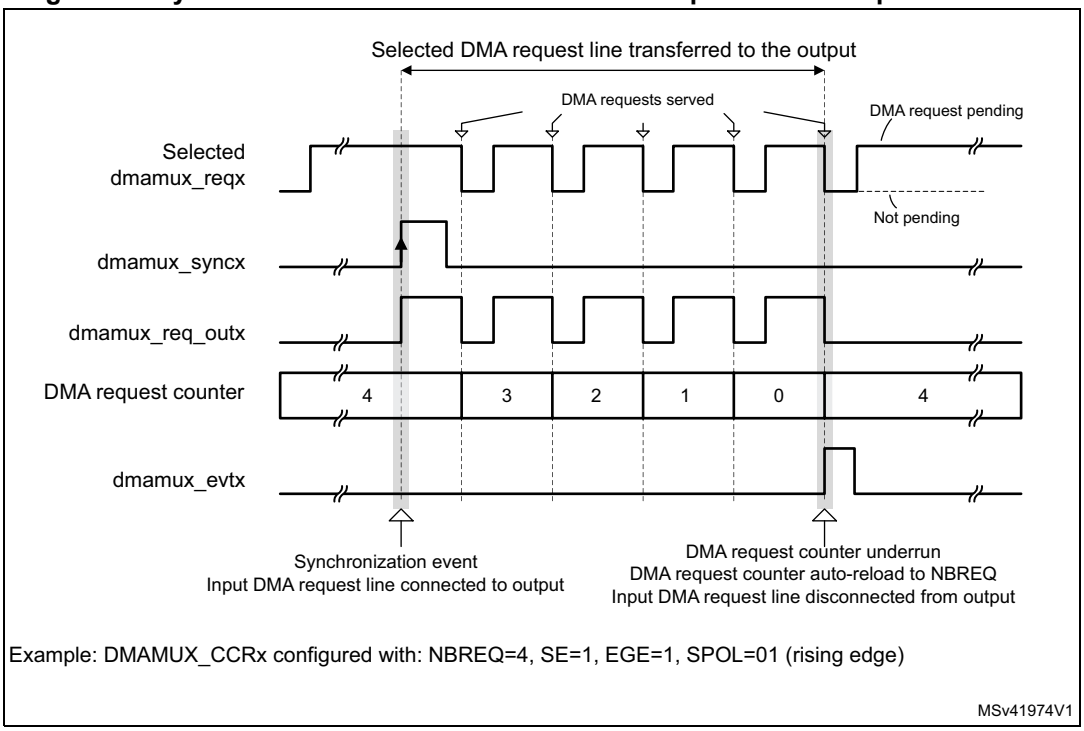
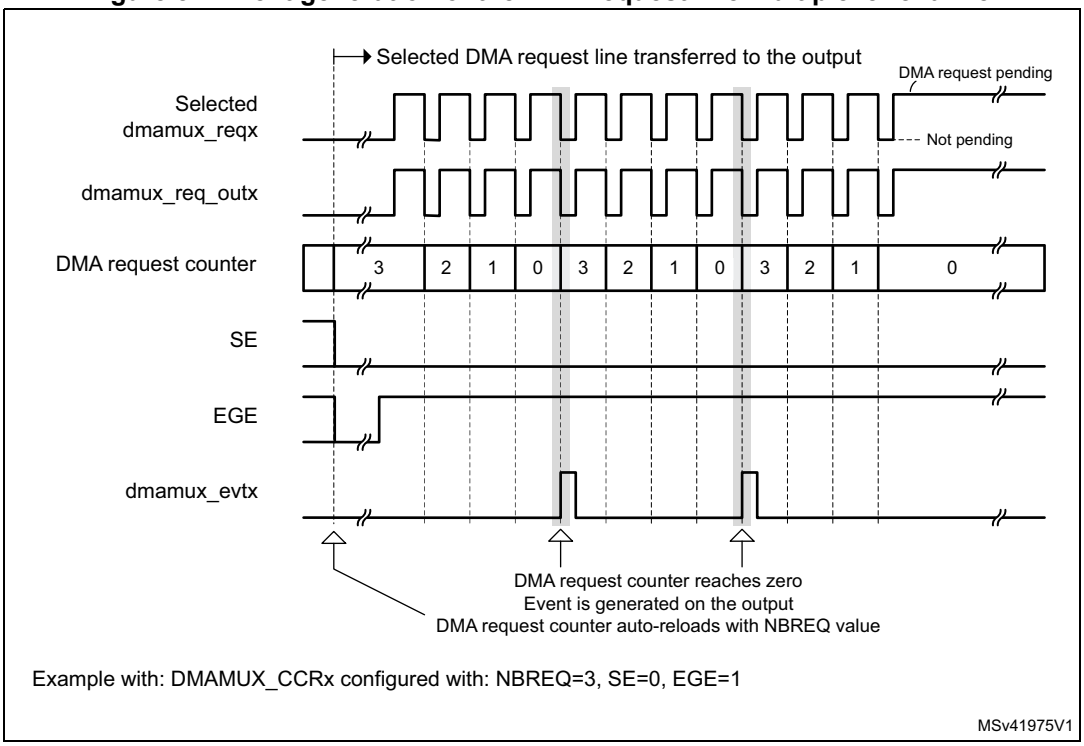


Figure 87. Event generation of the DMA request line multiplexer channel



If EGE is enabled, the multiplexer channel generates a channel event, as a pulse of one AHB clock cycle, when its DMA request counter is automatically reloaded with the value of the programmed NBREQ field, as shown in *Figure 86* and *Figure 87*.

Note: If EGE is enabled and NBREQ = 0, an event is generated after each served DMA request.

Note: A synchronization event (edge) is detected if the state following the edge remains stable for more than two AHB clock cycles.

Upon writing into DMAMUX_CxCR register, the synchronization events are masked during three AHB clock cycles.

Synchronization overrun and interrupt

If a new synchronization event occurs before the request counter underrun (the internal request counter programmed via the NBREQ field of the DMAMUX_CxCR register), the synchronization overrun flag bit SOFx is set in the DMAMUX_CSR status register.

Note: The request multiplexer channel x synchronization must be disabled (DMAMUX_CxCR.SE = 0) at the completion of the use of the related channel of the DMA controller. Else, upon a new detected synchronization event, there is a synchronization overrun due to the absence of a DMA acknowledge (that is, no served request) received from the DMA controller.

The overrun flag SOFx is reset by setting the associated clear synchronization overrun flag bit CSOFx in the DMAMUX_CFR register.

Setting the synchronization overrun flag generates an interrupt if the synchronization overrun interrupt enable bit SOIE is set in the DMAMUX_CxCR register.

17.4.5 DMAMUX request generator

The DMAMUX request generator produces DMA requests following trigger events on its DMA request trigger inputs.

The DMAMUX request generator has multiple channels. DMA request trigger inputs are connected in parallel to all channels.

The outputs of DMAMUX request generator channels are inputs to the DMAMUX request line multiplexer.

Each DMAMUX request generator channel x has an enable bit GE (generator enable) in the corresponding DMAMUX_RGxCR register.

The DMA request trigger input for the DMAMUX request generator channel x is selected through the SIG_ID (trigger signal ID) field in the corresponding DMAMUX_RGxCR register.

Trigger events on a DMA request trigger input can be rising edge, falling edge or either edge. The active edge is selected through the GPOL (generator polarity) field in the corresponding DMAMUX_RGxCR register.

Upon the trigger event, the corresponding generator channel starts generating DMA requests on its output. Each time the DMAMUX generated request is served by the connected DMA controller (a served request is deasserted), a built-in (inside the DMAMUX request generator) DMA request counter is decremented. At its underrun, the request generator channel stops generating DMA requests and the DMA request counter is automatically reloaded to its programmed value upon the next trigger event.

Thus, the number of DMA requests generated after the trigger event is GNBREQ + 1.

Note: The GNBREQ field value must be written by software only when the enable GE bit of the corresponding generator channel x is disabled.

There is no hardware write protection.

A trigger event (edge) is detected if the state following the edge remains stable for more than two AHB clock cycles.

Upon writing into DMAMUX_RGxCR register, the trigger events are masked during three AHB clock cycles.

Trigger overrun and interrupt

If a new DMA request trigger event occurs before the DMAMUX request generator counter underrun (the internal counter programmed via the GNBREQ field of the DMAMUX_RGxCR register), and if the request generator channel x was enabled via GE, then the request trigger event overrun flag bit OFx is asserted by the hardware in the status DMAMUX_RGSR register.

Note: The request generator channel x must be disabled (DMAMUX_RGxCR.GE = 0) at the completion of the usage of the related channel of the DMA controller. Else, upon a new detected trigger event, there is a trigger overrun due to the absence of an acknowledge (that is, no served request) received from the DMA.

The overrun flag OFx is reset by setting the associated clear overrun flag bit COFx in the DMAMUX_RGCFR register.

Setting the DMAMUX request trigger overrun flag generates an interrupt if the DMA request trigger event overrun interrupt enable bit OIE is set in the DMAMUX_RGxCR register.

17.5 DMAMUX interrupts

An interrupt can be generated upon:

- a synchronization event overrun in each DMA request line multiplexer channel
- a trigger event overrun in each DMA request generator channel

For each case, per-channel individual interrupt enable, status and clear flag register bits are available.

Table 125. DMAMUX interrupts

Interrupt signal	Interrupt event	Event flag	Clear bit	Enable bit
dmamuxovr_it	Synchronization event overrun on channel x of the DMAMUX request line multiplexer	SOFx	CSOFx	SOIE
	Trigger event overrun on channel x of the DMAMUX request generator	OFx	COFx	OIE

17.6 DMAMUX registers

Refer to the table containing register boundary addresses for the DMAMUX1 and DMAMUX2 base address.

DMAMUX registers may be accessed per (8-bit) byte, (16-bit) half-word, or (32-bit) word. The address must be aligned with the data size.

17.6.1 DMAMUX1 request line multiplexer channel x configuration register (DMAMUX1_CxCR)

Address offset: 0x000 + 0x04 * x (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	SYNC_ID[2:0]			NBREQ[4:0]					SPOL[1:0]		SE
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
						rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bits 26:24 **SYNC_ID[2:0]**: Synchronization identification

Selects the synchronization input (see *Table 120: DMAMUX1: assignment of synchronization inputs to resources*).

Bits 23:19 **NBREQ[4:0]**: Number of DMA requests minus 1 to forward

Defines the number of DMA requests to forward to the DMA controller after a synchronization event, and/or the number of DMA requests before an output event is generated.

This field shall only be written when both SE and EGE bits are low.

Bits 18:17 **SPOL[1:0]**: Synchronization polarity

Defines the edge polarity of the selected synchronization input:

00: No event, i.e. no synchronization nor detection.

01: Rising edge

10: Falling edge

11: Rising and falling edges

Bit 16 **SE**: Synchronization enable

0: Synchronization disabled

1: Synchronization enabled

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **EGE**: Event generation enable

0: Event generation disabled

1: Event generation enabled

Bit 8 **SOIE**: Synchronization overrun interrupt enable

0: Interrupt disabled

1: Interrupt enabled

Bit 7 Reserved, must be kept at reset value.

Bits 6:0 **DMAREQ_ID[6:0]**: DMA request identification

Selects the input DMA request. See the DMAMUX table about assignments of multiplexer inputs to resources.

17.6.2 DMAMUX2 request line multiplexer channel x configuration register (DMAMUX2_CxCR)

Address offset: 0x000 + 0x04 * x, where x = 0 to 7

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	SYNC_ID[4:0]					NBREQ[4:0]					SPOL[1:0]		SE
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	Res.	Res.	DMAREQ_ID[4:0]				
						rw	rw				rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:24 **SYNC_ID[4:0]**: Synchronization identification

Selects the synchronization input (see *Table 123: DMAMUX2: assignment of synchronization inputs to resources*)

Bits 23:19 **NBREQ[4:0]**: Number of DMA requests minus 1 to forward

Defines the number of DMA requests to forward to the DMA controller after a synchronization event, and/or the number of DMA requests before an output event is generated.
This field shall only be written when both SE and EGE bits are low.

Bits 18:17 **SPOL[1:0]**: Synchronization polarity

Defines the edge polarity of the selected synchronization input:
00: no event, i.e. no synchronization nor detection.
01: rising edge
10: falling edge
11: rising and falling edges

Bit 16 **SE**: Synchronization enable

0: synchronization disabled
1: synchronization enabled

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **EGE**: Event generation enable

0: event generation disabled
1: event generation enabled

Bit 8 **SOIE**: Synchronization overrun interrupt enable

0: interrupt disabled
1: interrupt enabled

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **DMAREQ_ID[4:0]**: DMA request identification

Selects the input DMA request. (see the DMAMUX table about assignments of multiplexer inputs to resources).

17.6.3 DMAMUX1 request line multiplexer interrupt channel status register (DMAMUX1_CSR)

Address offset: 0x080

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SOF15	SOF14	SOF13	SOF12	SOF11	SOF10	SOF9	SOF8	SOF7	SOF6	SOF5	SOF4	SOF3	SOF2	SOF1	SOF0
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **SOF[15:0]**: Synchronization overrun event flag

The flag is set when a synchronization event occurs on a DMA request line multiplexer channel x, while the DMA request counter value is lower than NBREQ.

The flag is cleared by writing 1 to the corresponding CSOFx bit in DMAMUX_CFR register.

For DMAMUX2 bits 15:8 are reserved, keep them at reset value.

17.6.4 DMAMUX2 request line multiplexer interrupt channel status register (DMAMUX2_CSR)

Address offset: 0x080

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SOF7	SOF6	SOF5	SOF4	SOF3	SOF2	SOF1	SOF0
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **SOF[7:0]**: Synchronization overrun event flag

The flag is set when a new synchronization event occurs on a DMA request line multiplexer channel x before the request counter underrun (the internal request counter programmed via the NBREQ field of the DMAMUX_CxCR register).

The flag is cleared by writing 1 to the corresponding CSOFx bit in DMAMUX2_CFR register.

17.6.5 DMAMUX1 request line multiplexer interrupt clear flag register (DMAMUX1_CFR)

Address offset: 0x084

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CSOF 15	CSOF 14	CSOF 13	CSOF 12	CSOF 11	CSOF 10	CSOF 9	CSOF 8	CSOF 7	CSOF 6	CSOF 5	CSOF 4	CSOF 3	CSOF 2	CSOF 1	CSOF 0
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **CSOF[15:0]**: Clear synchronization overrun event flag

Writing 1 in each bit clears the corresponding overrun flag SOFx in the DMAMUX_CSR register.

17.6.6 DMAMUX2 request line multiplexer interrupt clear flag register (DMAMUX2_CFR)

Address offset: 0x084

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSOF6	CSOF6	CSOF5	CSOF4	CSOF3	CSOF2	CSOF1	CSOF0
								w	w	w	w	w	w	w	w

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **CSOF[7:0]**: Clear synchronization overrun event flag

Writing 1 in each bit clears the corresponding overrun flag SOFx in the DMAMUX2_CSR register.

17.6.7 DMAMUX1 request generator channel x configuration register (DMAMUX1_RGxCR)

Address offset: 0x100 + 0x04 * x (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GNBREQ[4:0]					GPOL[1:0]		GE
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OIE	Res.	Res.	Res.	Res.	Res.	SIG_ID[2:0]		
							rw						rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:19 **GNBREQ[4:0]**: Number of DMA requests to be generated (minus 1)

Defines the number of DMA requests to be generated after a trigger event. The actual number of generated DMA requests is GNBREQ +1.

Note: This field must be written only when GE bit is disabled.

Bits 18:17 **GPOL[1:0]**: DMA request generator trigger polarity

Defines the edge polarity of the selected trigger input

00: No event, i.e. no trigger detection nor generation.

01: Rising edge

10: Falling edge

11: Rising and falling edges

Bit 16 **GE**: DMA request generator channel x enable

0: DMA request generator channel x disabled

1: DMA request generator channel x enabled

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **OIE**: Trigger overrun interrupt enable

0: Interrupt on a trigger overrun event occurrence is disabled

1: Interrupt on a trigger overrun event occurrence is enabled

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **SIG_ID[2:0]**: Signal identification

Selects the DMA request trigger input used for the channel x of the DMA request generator

17.6.8 DMAMUX2 request generator channel x configuration register (DMAMUX2_RGxCR)

Address offset: 0x100 + 0x04 * x (x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GNBREQ[4:0]					GPOL[1:0]		GE
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OIE	Res.	Res.	Res.	SIG_ID[4:0]				
							rw				rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:19 **GNBREQ[4:0]**: Number of DMA requests to be generated (minus 1)

Defines the number of DMA requests to be generated after a trigger event. The actual number of generated DMA requests is GNBREQ+1.

Note: This field shall only be written when GE bit is disabled.

Bits 18:17 **GPOL[1:0]**: DMA request generator trigger polarity

Defines the edge polarity of the selected trigger input
00: no event. I.e. none trigger detection nor generation.
01: rising edge
10: falling edge
11: rising and falling edge

Bit 16 **GE**: DMA request generator channel x enable

0: DMA request generator channel x disabled
1: DMA request generator channel x enabled

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **OIE**: Trigger overrun interrupt enable

0: interrupt on a trigger overrun event occurrence is disabled
1: interrupt on a trigger overrun event occurrence is enabled

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **SIG_ID[4:0]**: Signal identification

Selects the DMA request trigger input used for the channel x of the DMA request generator

17.6.9 DMAMUX1 request generator interrupt status register (DMAMUX1_RGSR)

Address offset: 0x140

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OF7	OF6	OF5	OF4	OF3	OF2	OF1	OF0
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **OF[:0]**: Trigger overrun event flag

The flag is set when a new trigger event occurs on DMA request generator channel x, before the request counter underrun (the internal request counter programmed via the GNBREQ field of the DMAMUX_RGxCR register).

The flag is cleared by writing 1 to the corresponding COFx bit in the DMAMUX_RGCFR register.

17.6.10 DMAMUX2 request generator interrupt status register (DMAMUX2_RGSR)

Address offset: 0x140

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OF7	OF6	OF5	OF4	OF3	OF2	OF1	OF0
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **OF[7:0]**: Trigger overrun event flag

The flag is set when a new trigger event occurs on DMA request generator channel x.

The flag is cleared by writing 1 to the corresponding COFx bit in the DMAMUX2_RGCFR register.

17.6.11 DMAMUX1 request generator interrupt clear flag register (DMAMUX1_RGCFR)

Address offset: 0x144

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COF7	COF6	COF5	COF4	COF3	COF2	COF1	COF0
								w	w	w	w	w	w	w	w

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **COF[7:0]**: Clear trigger overrun event flag

Writing 1 in each bit clears the corresponding overrun flag OFx in the DMAMUX_RGSR register.

17.6.12 DMAMUX2 request generator interrupt clear flag register (DMAMUX2_RGCFR)

Address offset: 0x144

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COF7	COF6	COF5	COF4	COF3	COF2	COF1	COF0
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **COF[7:0]**: Clear trigger overrun event flag

Writing 1 in each bit clears the corresponding overrun flag OFx in the DMAMUX2_RGSR register.

17.6.13 DMAMUX register map

The following table summarizes the DMAMUX registers and reset values. Refer to the register boundary address table for the DMAMUX register base address.

Table 126. DMAMUX register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	DMAMUX_C0CR[1][2]	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x004	DMAMUX_C1CR[1]	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x008	DMAMUX_C2CR[1]	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x00C	DMAMUX_C3CR[1]	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x010	DMAMUX_C4CR[1]	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x014	DMAMUX_C5CR[1]	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x018	DMAMUX_C6CR[1]	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x01C	DMAMUX_C7CR[1]	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x020	DMAMUX_C8CR[3]	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x024	DMAMUX_C9CR[4]	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x028	DMAMUX_C10CR	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x02C	DMAMUX_C11CR	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x030	DMAMUX_C12CR	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x034	DMAMUX_C13CR	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x038	DMAMUX_C14CR	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x03C	DMAMUX_C15CR	Res.	Res.	Res.	Res.	Res.	SYNC_ID [2:0]			NBREQ[4:0]					SPOL [1:0]		SE	Res.	Res.	Res.	Res.	Res.	Res.	EGE	SOIE	Res.	DMAREQ_ID[6:0]						
	Reset value						0	0	0	0	0	0	0	0	0	0	0							0	0		0	0	0	0	0	0	0
0x040 - 0x07C	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Table 126. DMAMUX register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x080	DMAMUX_CSR(4)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SOF15	SOF14	SOF13	SOF12	SOF11	SOF10	SOF9	SOF8	SOF7	SOF6	SOF5	SOF4	SOF3	SOF2	SOF1	SOF0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x084	DMAMUX_CFR(4)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSOF15	CSOF14	CSOF13	CSOF12	CSOF11	CSOF10	CSOF9	CSOF8	CSOF7	CSOF6	CSOF5	CSOF4	CSOF3	CSOF2	CSOF1	CSOF0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x088 - 0x0FC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x100	DMAMUX_RG0CR(5)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GNBREQ[4:0]					GPOL [1:0]		GE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OIE	Res.	Res.	Res.	Res.	Res.	SIG_ID [2:0]		
	Reset value									0	0	0	0	0	0	0	0								0						0	0	0
0x104	DMAMUX_RG1CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GNBREQ[4:0]					GPOL [1:0]		GE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OIE	Res.	Res.	Res.	Res.	Res.	SIG_ID [2:0]		
	Reset value									0	0	0	0	0	0	0	0								0						0	0	0
0x108	DMAMUX_RG2CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GNBREQ[4:0]					GPOL [1:0]		GE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OIE	Res.	Res.	Res.	Res.	Res.	SIG_ID [2:0]		
	Reset value									0	0	0	0	0	0	0	0								0						0	0	0
0x10C	DMAMUX_RG3CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GNBREQ[4:0]					GPOL [1:0]		GE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OIE	Res.	Res.	Res.	Res.	Res.	SIG_ID [2:0]		
	Reset value									0	0	0	0	0	0	0	0								0						0	0	0
0x140	DMAMUX_RGSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OF15	OF14	OF13	OF12	OF11	OF10	OF9	OF8	OF7	OF6	OF5	OF4	OF3	OF2	OF1	OF0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x144	DMAMUX_RGCFR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COF15	COF14	COF13	COF12	COF11	COF10	COF9	COF8	COF7	COF6	COF5	COF4	COF3	COF2	COF1	COF0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x140	DMAMUX_RGSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OF7	OF6	OF5	OF4	OF3	OF2	OF1	OF0
	Reset value																									0	0	0	0	0	0	0	0
0x144	DMAMUX_RGCFR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COF7	COF6	COF5	COF4	COF3	COF2	COF1	COF0
	Reset value																									0	0	0	0	0	0	0	0
0x148 - 0x3FC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

1. For DMAMUX2 bits 6:5 are reserved.
2. For DMAMUX2 bits 28:24 correspond to SYNC_ID[4:0].
3. Only applies to DMAMUX1. For DMAMUX2 the word is reserved.
4. For DMAMUX2 bits 15:8 are reserved.
5. Valid for DMAMUX1. For DMAMUX2 bits 4:0 are for SIG_ID[4:0].

Refer to *Section 2.3 on page 131* for the register boundary addresses.

18 Chrom-Art Accelerator controller (DMA2D)

18.1 DMA2D introduction

The Chrom-Art Accelerator (DMA2D) is a specialized DMA dedicated to image manipulation. It can perform the following operations:

- Filling a part or the whole of a destination image with a specific color
- Copying a part or the whole of a source image into a part or the whole of a destination image
- Copying a part or the whole of a source image into a part or the whole of a destination image with a pixel format conversion
- Blending a part and/or two complete source images with different pixel format and copy the result into a part or the whole of a destination image with a different color format.

All the classical color coding schemes are supported from 4-bit up to 32-bit per pixel with indexed or direct color mode, including block based YCbCr to handle JPEG decoder output. The DMA2D has its own dedicated memories for CLUTs (color look-up tables).

18.2 DMA2D main features

The main DMA2D features are:

- Single AXI master bus architecture.
- AHB slave programming interface supporting 8/16/32-bit accesses (except for CLUT accesses which are 32-bit).
- User programmable working area size
- User programmable offset for sources and destination areas
- User programmable sources and destination addresses on the whole memory space
- Up to 2 sources with blending operation
- Alpha value can be modified (source value, fixed value or modulated value)
- User programmable source and destination color format
- Up to 11 color formats supported from 4-bit up to 32-bit per pixel with indirect or direct color coding
- Block based (8x8) YCbCr support with 4:4:4, 4:2:2 and 4:2:0 chroma sub-sampling factors
- 2 internal memories for CLUT storage in indirect color mode
- Automatic CLUT loading or CLUT programming via the CPU
- User programmable CLUT size
- Internal timer to control AXI bandwidth
- 6 operating modes: register-to-memory, memory-to-memory, memory-to-memory with pixel format conversion, memory-to-memory with pixel format conversion and blending, memory-to memory with pixel format conversion, blending and fixed color foreground,

and memory-to memory with pixel format conversion, blending and fixed color background.

- Area filling with a fixed color
- Copy from an area to another
- Copy with pixel format conversion between source and destination images
- Copy from two sources with independent color format and blending
- Output buffer byte swapping to support refresh of displays through parallel interface
- Abort and suspend of DMA2D operations
- Watermark interrupt on a user programmable destination line
- Interrupt generation on bus error or access conflict
- Interrupt generation on process completion

18.3 DMA2D functional description

18.3.1 General description

The DMA2D controller performs direct memory transfer. As an AXI master, it can take the control of the AXI bus matrix to initiate AXI transactions.

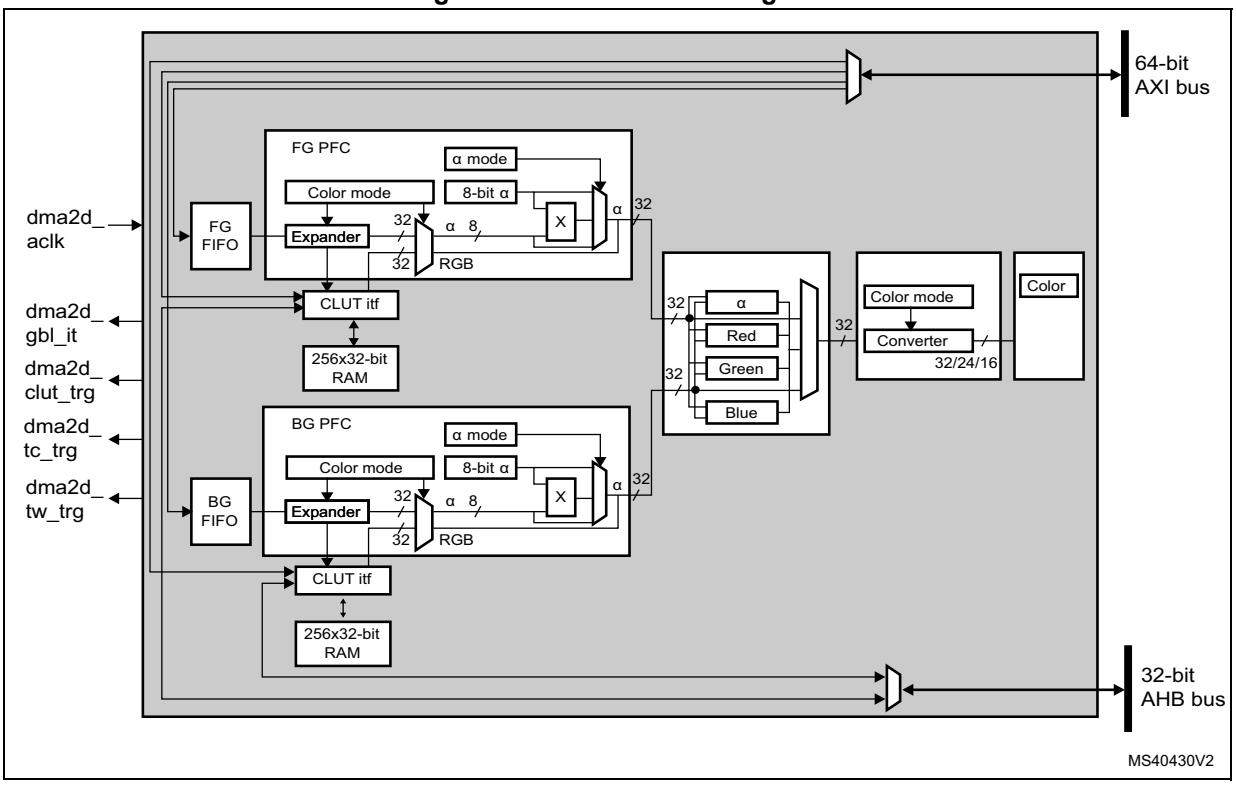
The DMA2D can operate in the following modes:

- Register-to-memory
- Memory-to-memory
- Memory-to-memory with Pixel Format Conversion
- Memory-to-memory with Pixel Format Conversion and Blending
- Memory-to memory with pixel format conversion, blending and fixed color foreground

The AHB slave port is used to program the DMA2D controller.

The block diagram of the DMA2D is shown in *Figure 88: DMA2D block diagram*.

Figure 88. DMA2D block diagram



18.3.2 DMA2D internal signals

The table below lists the DMA2D internal signals.

Table 127. DMA2D internal input/output signals

Signal name	Signal type	Description
dma2d_aclk	Input	64-bit AXI bus clock
dma2d_gbl_it	Output	DMA2D global interrupt
dma2d_clut_trg	Output	CLUT transfer complete (to MDMA)
dma2d_tc_trg	Output	Transfer complete (to MDMA)
dma2d_tw_trg	Output	Transfer watermark (to MDMA)

18.3.3 DMA2D control

The DMA2D controller is configured through the DMA2D Control Register (DMA2D_CR) which allows selecting:

The user application can perform the following operations:

- Select the operating mode
- Enable/disable the DMA2D interrupt
- Start/suspend/abort ongoing data transfers

18.3.4 DMA2D foreground and background FIFOs

The DMA2D foreground (FG) FG FIFO and background (BG) FIFO fetch the input data to be copied and/or processed.

The FIFOs fetch the pixels according to the color format defined in their respective pixel format converter (PFC).

They are programmed through a set of control registers:

- DMA2D foreground memory address register (DMA2D_FGMAR)
- DMA2D foreground offset register (DMA2D_FGOR)
- DMA2D background memory address register (DMA2D_BGMAR)
- DMA2D background offset register (DMA2D_BGBOR)
- DMA2D number of lines register (number of lines and pixel per lines) (DMA2D_NLR)

When the DMA2D operates in register-to-memory mode, none of the FIFOs is activated.

When the DMA2D operates in memory-to-memory mode (no pixel format conversion nor blending operation), only the FG FIFO is activated and acts as a buffer.

When the DMA2D operates in memory-to-memory operation with pixel format conversion (no blending operation), the BG FIFO is not activated.

18.3.5 DMA2D foreground and background pixel format converter (PFC)

DMA2D foreground pixel format converter (PFC) and background pixel format converter perform the pixel format conversion to generate a 32-bit per pixel value. The PFC can also modify the alpha channel.

The first stage of the converter converts the color format. The original color format of the foreground pixel and background pixels are configured through the CM[3:0] bits of the DMA2D_FGPFCCR and DMA2D_BGPFCCR, respectively.

The supported input formats are given in *Table 128: Supported color mode in input*.

Table 128. Supported color mode in input

CM[3:0]	Color mode
0000	ARGB8888
0001	RGB888
0010	RGB565
0011	ARGB1555
0100	ARGB4444

Table 128. Supported color mode in input

CM[3:0]	Color mode
0101	L8
0110	AL44
0111	AL88
1000	L4
1001	A8
1010	A4
1011	YCbCr (only for foreground)

The color format are coded as follows:

- Alpha value field: transparency
  0xFF value corresponds to an opaque pixel and 0x00 to a transparent one.
- R field for Red
- G field for Green
- B field for Blue
- L field: luminance
  This field is the index to a CLUT to retrieve the three/four RGB/ARGB components.

If the original format was direct color mode, then the extension to 8-bit per channel is performed by copying the MSBs into the LSBs. This ensures a perfect linearity of the conversion.

If the original format does not include an alpha channel, the alpha value is automatically set to 0xFF (opaque).

If the original format is indirect color mode, a CLUT is required and each pixel format converter is associated with a 256 entry 32-bit CLUT.

For the specific alpha mode A4 and A8, no color information is stored nor indexed. The color to be used for the image generation is fixed and is defined in the DMA2D_FGCOLR for foreground pixels and in the DMA2D_BGCOLR register for background pixels.

The order of the fields in the system memory is defined in *Table 129: Data order in memory*.

Table 129. Data order in memory

Color Mode	@ + 3	@ + 2	@ + 1	@ + 0
ARGB8888	A_0[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
RGB888	B_1[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
	G_2[7:0]	B_2[7:0]	R_1[7:0]	G_1[7:0]
	R_3[7:0]	G_3[7:0]	B_3[7:0]	R_2[7:0]
RGB565	R_1[4:0]G_1[5:3]	G_1[2:0]B_1[4:0]	R_0[4:0]G_0[5:3]	G_0[2:0]B_0[4:0]
ARGB1555	A_1[0]R_1[4:0]G_1[4:3]	G_1[2:0]B_1[4:0]	A_0[0]R_0[4:0]G_0[4:3]	G_0[2:0]B_0[4:0]
ARGB4444	A_1[3:0]R_1[3:0]	G_1[3:0]B_1[3:0]	A_0[3:0]R_0[3:0]	G_0[3:0]B_0[3:0]
L8	L_3[7:0]	L_2[7:0]	L_1[7:0]	L_0[7:0]
AL44	A_3[3:0]L_3[3:0]	A_2[3:0]L_2[3:0]	A_1[3:0]L_1[3:0]	A_0[3:0]L_0[3:0]
AL88	A_1[7:0]	L_1[7:0]	A_0[7:0]	L_0[7:0]
L4	L_7[3:0]L_6[3:0]	L_5[3:0]L_4[3:0]	L_3[3:0]L_2[3:0]	L_1[3:0]L_0[3:0]
A8	A_3[7:0]	A_2[7:0]	A_1[7:0]	A_0[7:0]
A4	A_7[3:0]A_6[3:0]	A_5[3:0]A_4[3:0]	A_3[3:0]A_2[3:0]	A_1[3:0]A_0[3:0]

The 24-bit RGB888 aligned on 32-bit is supported through the ARGB8888 mode.

Once the 32-bit value is generated, the alpha channel can be modified according to the AM[1:0] field of the DMA2D_FGPFCCR/DMA2D_BGPFCCR registers as shown in *Table 130: Alpha mode configuration*.

The alpha channel can be:

- kept as it is (no modification),
- replaced by the ALPHA[7:0] value of DMA2D_FGPFCCR/DMA2D_BGPFCCR,
- or replaced by the original alpha value multiplied by the ALPHA[7:0] value of DMA2D_FGPFCCR/DMA2D_BGPFCCR divided by 255.

Table 130. Alpha mode configuration

AM[1:0]	Alpha mode
00	No modification
01	Replaced by value in DMA2D_xxPFCCR
10	Replaced by original value multiplied by the value in DMA2D_xxPFCCR / 255
11	Reserved

Note: To support the alternate format, the incoming alpha value can be inverted setting the AI bit of the DMA2D_FGPFCCR/DMA2D_BGPFCCR registers. This applies also to the Alpha value stored in the DMA2D_FGPFCCR/DMA2D_BGPFCCR and in the CLUT.

The R and B fields can also be swapped setting the RBS bit of the DMA2D_FGPFCCR/DMA2D_BGPFCCR registers. This applies also to the RGB order used in the CLUT and in the DMA2D_FGCOLR/DMA2D_BGCOLR registers.

18.3.6 DMA2D foreground and background CLUT interface

The CLUT interface manages the CLUT memory access and the automatic loading of the CLUT.

Three kinds of accesses are possible:

- CLUT read by the PFC during pixel format conversion operation
- CLUT accessed through the AHB slave port when the CPU is reading or writing data into the CLUT
- CLUT written through the AXI master port when an automatic loading of the CLUT is performed

The CLUT memory loading can be done in two different ways:

- Automatic loading

  The following sequence should be followed to load the CLUT:

  a) Program the CLUT address into the DMA2D_FGCMAR register (foreground CLUT) or DMA2D_BGCMAR register (background CLUT)

  b) Program the CLUT size in the CS[7:0] field of the DMA2D_FGPFCCR register (foreground CLUT) or DMA2D_BGPFCCR register (background CLUT).

  c) Set the START bit of the DMA2D_FGPFCCR register (foreground CLUT) or DMA2D_BGPFCCR register (background CLUT) to start the transfer. During this automatic loading process, the CLUT is not accessible by the CPU. If a conflict occurs, a CLUT access error interrupt is raised assuming CAEIE is set to '1' in DMA2D_CR.

- Manual loading

  The application has to program the CLUT manually through the DMA2D AHB slave port to which the local CLUT memory is mapped.The foreground CLUT is located at address offset 0x0400 and the background CLUT at address offset 0x0800.

The CLUT format can be 24 or 32 bits. It is configured through the CCM bit of the DMA2D_FGPFCCR register (foreground CLUT) or DMA2D_BGPFCCR register (background CLUT) as shown in *Table 131: Supported CLUT color mode*.

Table 131. Supported CLUT color mode

CCM	CLUT color mode
0	32-bit ARGB8888
1	24-bit RGB888

The way the CLUT data are organized in the system memory is specified in *Table 132: CLUT data order in memory*.

Table 132. CLUT data order in memory

CLUT Color Mode	@ + 3	@ + 2	@ + 1	@ + 0
ARGB8888	A_0[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
RGB888	B_1[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
	G_2[7:0]	B_2[7:0]	R_1[7:0]	G_1[7:0]
	R_3[7:0]	G_3[7:0]	B_3[7:0]	R_2[7:0]

18.3.7 DMA2D blender

The DMA2D blender blends the source pixels by pair to compute the resulting pixel.

The blending is performed according to the following equation:

$$\text{with } \alpha_{Mult} = \frac{\alpha_{FG} \cdot \alpha_{BG}}{255}$$

$$\alpha_{OUT} = \alpha_{FG} + \alpha_{BG} - \alpha_{Mult}$$

$$C_{OUT} = \frac{C_{FG}.\alpha_{FG} + C_{BG}.\alpha_{BG} - C_{BG}.\alpha_{Mult}}{\alpha_{OUT}} \quad \text{with C = R or G or B}$$

Division is rounded to the nearest lower integer

No configuration register is required by the blender. The blender usage depends on the DMA2D operating mode defined in MODE[1:0] field of the DMA2D_CR register.

18.3.8 DMA2D output PFC

The output PFC performs the pixel format conversion from 32 bits to the output format defined in the CM[2:0] field of the DMA2D output pixel format converter configuration register (DMA2D_OPFCCR).

The supported output formats are given in *Table 133: Supported color mode in output*

Table 133. Supported color mode in output

CM[2:0]	Color mode
000	ARGB8888
001	RGB888
010	RGB565
011	ARGB1555
100	ARGB4444

Note: To support the alternate format, the calculated alpha value can be inverted setting the AI bit of the DMA2D_OPFCCR registers. This applies also to the Alpha value used in the DMA2D_OCOLR.

The R and B fields can also be swapped setting the RBS bit of the DMA2D_OPFCCR registers. This applies also to the RGB order used in the DMA2D_OCOLR.

18.3.9 DMA2D output FIFO

The output FIFO programs the pixels according to the color format defined in the output PFC.

The destination area is defined through a set of control registers:

- DMA2D output memory address register (DMA2D_OMAR)
- DMA2D output offset register (DMA2D_OOR**)**
- DMA2D number of lines register (number of lines and pixel per lines) (DMA2D_NLR**)**

If the DMA2D operates in register-to-memory mode, the configured output rectangle is filled by the color specified in the DMA2D output color register (DMA2D_OCOLR) which contains a fixed 32-bit, 24-bit or 16-bit value. The format is selected by the CM[2:0] field of the DMA2D_OPFCCR register.

The data are stored into the memory in the order defined in *Table 134: Data order in memory*

Table 134. Data order in memory

Color mode	@ + 3	@ + 2	@ + 1	@ + 0
ARGB8888	A_0[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
RGB888	B_1[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
	G_2[7:0]	B_2[7:0]	R_1[7:0]	G_1[7:0]
	R_3[7:0]	G_3[7:0]	B_3[7:0]	R_2[7:0]
RGB565	R_1[4:0]G_1[5:3]	G_1[2:0]B_1[4:0]	R_0[4:0]G_0[5:3]	G_0[2:0]B_0[4:0]
ARGB1555	A_1[0]R_1[4:0]G_1[4:3]	G_1[2:0]B_1[4:0]	A_0[0]R_0[4:0]G_0[4:3]	G_0[2:0]B_0[4:0]
ARGB4444	A_1[3:0]R_1[3:0]	G_1[3:0]B_1[3:0]	A_0[3:0]R_0[3:0]	G_0[3:0]B_0[3:0]

The RGB888 aligned on 32-bit is supported through the ARGB8888 mode.

18.3.10 DMA2D output FIFO byte reordering

The output FIFO bytes can be reordered to support display frame buffer update through a parallel interface (F(S)MC) directly from the DMA2D.

The reordering of bytes can be done using:

- RBS bit to swap red and blue component
- SB bit to swap byte two by two in the output FIFO

When the byte swapping is activated (SB field of the DMA2D_OPFCR is set), the number of pixel per line (PL field of the DMA2D_NLR) must be even and the output memory address (MA field of the DMA2D_OMAR) must be even, and the output line offset computed in bytes (resulting from LOM field of DMA2D_CR and LO field of DMA2D_OOR values) must be even. If not a configuration error is detected.

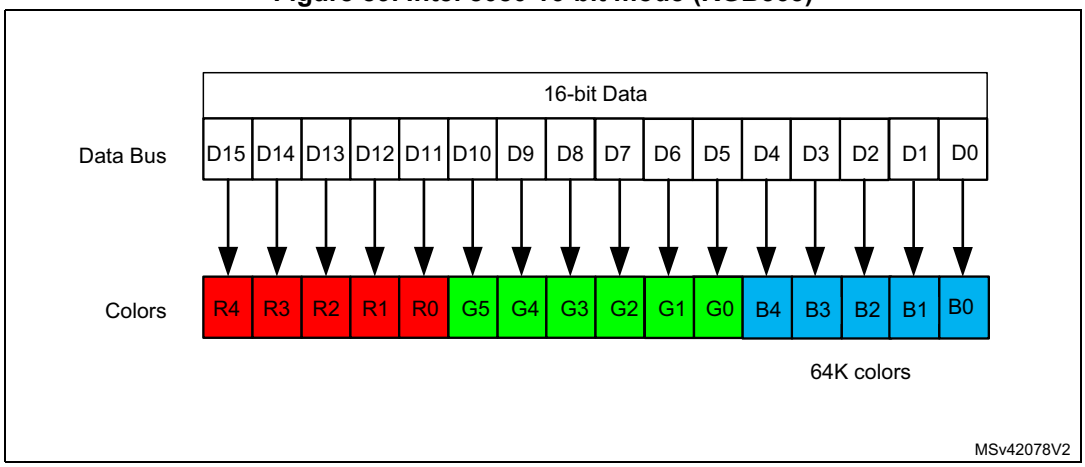
Table 135. Standard data order in memory

Color Mode	@ + 3	@ + 2	@ + 1	@ + 0
RGB888	B_1[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
	G_2[7:0]	B_2[7:0]	R_1[7:0]	G_1[7:0]
	R_3[7:0]	G_3[7:0]	B_3[7:0]	R_2[7:0]
RGB565	R_1[4:0]G_1[5:3]	G_1[2:0]B_1[4:0]	R_0[4:0]G_0[5:3]	G_0[2:0]B_0[4:0]

16-bit mode (RGB565)

This mode is supported without byte reordering by the DMA2D.

Figure 89. Intel 8080 16-bit mode (RGB565)



18/24-bit mode (RGB888)

This mode needs data reordering.

1. The red and the blue have to be swapped (setting the RBS bit)
2. The MSB and the LSB bytes of an half-word as to be swapped (setting the SB bit)

Figure 90. Intel 8080 18/24-bit mode (RGB888)

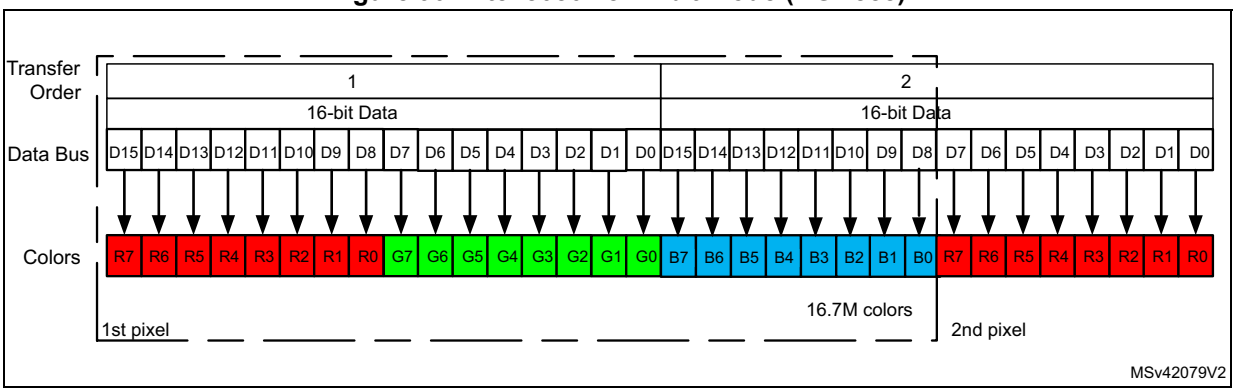


Table 136. Output FIFO byte reordering steps

Steps	@ + 3	@ + 2	@ + 1	@ + 0
Original data ordering	B_1[7:0]	R_0[7:0]	G_0[7:0]	B_0[7:0]
	G_2[7:0]	B_2[7:0]	R_1[7:0]	G_1[7:0]
	R_3[7:0]	G_3[7:0]	B_3[7:0]	R_2[7:0]
Setting the RBS bit				
Data ordering after red and blue swap (RBS set)	R_1[7:0]	B_0[7:0]	G_0[7:0]	R_0[7:0]
	G_2[7:0]	R_2[7:0]	B_1[7:0]	G_1[7:0]
	B_3[7:0]	G_3[7:0]	R_3[7:0]	B_2[7:0]
Setting the SB bit				
Data ordering after byte swapping (SB set)	B_0[7:0]	R_1[7:0]	R_0[7:0]	G_0[7:0]
	R_2[7:0]	G_2[7:0]	G_1[7:0]	B_1[7:0]
	G_3[7:0]	B_3[7:0]	B_2[7:0]	R_3[7:0]

18.3.11 DMA2D AXI master port timer

An 8-bit timer is embedded into the AXI master port to provide an optional limitation of the bandwidth on the crossbar.

This timer is clocked by the AXI clock and counts a dead time between two consecutive accesses. This limits the bandwidth usage.

The timer enabling and the dead time value are configured through the AXI master port timer configuration register (DMA2D_AMPTCR).

18.3.12 DMA2D transactions

DMA2D transactions consist of a sequence of a given number of data transfers. The number of data and the width can be programmed by software.

Each DMA2D data transfer is composed of up to 4 steps:

1. Data loading from the memory location pointed by the DMA2D_FGMAR register and pixel format conversion as defined in DMA2D_FGCR.
2. Data loading from a memory location pointed by the DMA2D_BGMAR register and pixel format conversion as defined in DMA2D_BGCR.
3. Blending of all retrieved pixels according to the alpha channels resulting of the PFC operation on alpha values.
4. Pixel format conversion of the resulting pixels according to the DMA2D_OCR register and programming of the data to the memory location addressed through the DMA2D_OMAR register.

18.3.13 DMA2D configuration

Both source and destination data transfers can target peripherals and memories in the whole 4-Gbyte memory area, at addresses ranging between 0x0000 0000 and 0xFFFF FFFF.

The DMA2D can operate in any of the four following modes selected through MODE[1:0] bits of the DMA2D_CR register:

- Register-to-memory
- Memory-to-memory
- Memory-to-memory with PFC
- Memory-to-memory with PFC and blending
- Memory-to-memory with PFC, blending and fixed FG color

Register-to-memory

The register-to-memory mode is used to fill a user defined area with a predefined color.

The color format is set in the DMA2D_OPFCCR.

The DMA2D does not perform any data fetching from any source. It just writes the color defined in the DMA2D_OCOLR register to the area located at the address pointed by the DMA2D_OMAR and defined in the DMA2D_NLR and DMA2D_OOR.

Memory-to-memory

In memory-to-memory mode, the DMA2D does not perform any graphical data transformation. The foreground input FIFO acts as a buffer and the data are transferred from the source memory location defined in DMA2D_FGMAR to the destination memory location pointed by DMA2D_OMAR.

The color mode programmed in the CM[3:0] bits of the DMA2D_FGPFCCR register defines the number of bits per pixel for both input and output.

The size of the area to be transferred is defined by the DMA2D_NLR and DMA2D_FGOR registers for the source, and by DMA2D_NLR and DMA2D_OOR registers for the destination.

Memory-to-memory with PFC

In this mode, the DMA2D performs a pixel format conversion of the source data and stores them in the destination memory location.

The size of the areas to be transferred are defined by the DMA2D_NLR and DMA2D_FGOR registers for the source, and by DMA2D_NLR and DMA2D_OOR registers for the destination.

Data are fetched from the location defined in the DMA2D_FGMAR register and processed by the foreground PFC. The original pixel format is configured through the DMA2D_FGPFCCR register.

If the original pixel format is direct color mode, then the color channels are all expanded to 8 bits.

If the pixel format is indirect color mode, the associated CLUT has to be loaded into the CLUT memory.

The CLUT loading can be done automatically by following the sequence below:

1. Set the CLUT address into the DMA2D_FGCMAR.
2. Set the CLUT size in the CS[7:0] bits of the DMA2D_FGPFCCR register.
3. Set the CLUT format (24 or 32 bits) in the CCM bit of the DMA2D_FGPFCCR register.
4. Start the CLUT loading by setting the START bit of the DMA2D_FGPFCCR register.

Once the CLUT loading is complete, the CTCIF flag of the DMA2D_IFR register is raised, and an interrupt is generated if the CTCIE bit is set in DMA2D_CR. The automatic CLUT loading process can not work in parallel with classical DMA2D transfers.

The CLUT can also be filled by the CPU or by any other master through the AHB port. The access to the CLUT is not possible when a DMA2D transfer is ongoing and uses the CLUT (indirect color format).

In parallel to the color conversion process, the alpha value can be added or changed depending on the value programmed in the DMA2D_FGPFCCR register. If the original image does not have an alpha channel, a default alpha value of 0xFF is automatically added to obtain a fully opaque pixel. The alpha value can be modified according to the AM[1:0] bits of the DMA2D_FGPFCCR register:

- It can be unchanged.
- It can be replaced by the value defined in the ALPHA[7:0] value of the DMA2D_FGPFCCR register.
- It can be replaced by the original value multiplied by the ALPHA[7:0] value of the DMA2D_FGPFCCR register divided by 255.

The resulting 32-bit data are encoded by the OUT PFC into the format specified by the CM[2:0] field of the DMA2D_OPFCCR register. The output pixel format cannot be the indirect mode since no CLUT generation process is supported.

The processed data are written into the destination memory location pointed by DMA2D_OMAR.

Memory-to-memory with PFC and blending

In this mode, 2 sources are fetched in the foreground FIFO and background FIFO from the memory locations defined by DMA2D_FGMAR and DMA2D_BGMAR.

The two pixel format converters have to be configured as described in the memory-to-memory mode. Their configurations can be different as each pixel format converter are independent and have their own CLUT memory.

Once each pixel has been converted into 32 bits by their respective PFCs, they are blended according to the equation below:

$$\text{with } \alpha_{Mult} = \frac{\alpha_{FG} \cdot \alpha_{BG}}{255}$$

$$\alpha_{OUT} = \alpha_{FG} + \alpha_{BG} - \alpha_{Mult}$$

$$C_{OUT} = \frac{C_{FG}.\alpha_{FG} + C_{BG}.\alpha_{BG} - C_{BG}.\alpha_{Mult}}{\alpha_{OUT}} \quad \text{with C = R or G or B}$$

Division are rounded to the nearest lower integer

The resulting 32-bit pixel value is encoded by the output PFC according to the specified output format, and the data are written into the destination memory location pointed by DMA2D_OMAR.

Memory-to-memory with PFC, blending and fixed color FG

In this mode, only 1 source is fetched in the background FIFO from the memory location defined by DMA2D_BGMAR.

The value of the foreground color is given by the DMA2D_FGCOLR register and the alpha value is set to 0xFF (opaque).

The alpha value can be replaced or modified according to the AM[1:0] and ALPHA[7:0] fields of the DMA2D_FGPFCCR.

The two pixel format converters have to be configured as described in the memory-to-memory mode. Their configurations can be different as each pixel format converter are independent and have their own CLUT memory

Once each pixel has been converted into 32 bits by their respective PFCs, they are blended together, and the resulting 32-bit pixel value is encoded by the output PFC according to the specified output format, and the data are written into the destination memory location pointed by DMA2D_OMAR.

Memory-to-memory with PFC, blending and fixed color BG

In this mode, only 1 source is fetched in the foreground FIFO from the memory location defined by DMA2D_FGMAR.

The value of the background color is given by the DMA2D_BGCOLR register and the alpha value is set to 0xFF (opaque).

The alpha value can be replaced or modified according to the AM[1:0] and ALPHA[7:0] fields of the DMA2D_BGPFCCR.

The two pixel format converters have to be configured as described in the memory-to-memory mode. Their configurations can be different as each pixel format converter are independent and have their own CLUT memory

Once each pixel has been converted into 32 bits by their respective PFCs, they are blended together, and the resulting 32-bit pixel value is encoded by the output PFC according to the specified output format, and the data are written into the destination memory location pointed by DMA2D_OMAR.

Configuration error detection

The DMA2D checks that the configuration is correct before any transfer. The configuration error interrupt flag is set by hardware when a wrong configuration is detected when a new transfer/automatic loading starts. An interrupt is then generated if the CEIE bit of the DMA2D_CR is set.

The wrong configurations that can be detected are listed below:

- Foreground CLUT automatic loading: MA bits of DMA2D_FGCMAR are not aligned with CCM of DMA2D_FGPFCCR.
- Background CLUT automatic loading: MA bits of DMA2D_BGCMAR are not aligned with CCM of DMA2D_BGPFCCR
- Memory transfer (except in register-to-memory mode and except in memory-to-memory mode with blending and fixed color FG): MA bits of DMA2D_FGMAR are not aligned with CM of DMA2D_FGPFCCR
- Memory transfer (except in register-to-memory mode and except in memory-to-memory mode with blending and fixed color FG): CM bits of DMA2D_FGPFCCR are invalid
- Memory transfer (except in register-to-memory mode and except in memory-to-memory mode with blending and fixed color FG): PL bits of DMA2D_NLR are odd while CM of DMA2D_FGPFCCR is A4 or L4
- Memory transfer (except in register-to-memory mode and except in memory-to-memory mode with blending and fixed color FG): LO bits of DMA2D_FGOR are odd while CM of DMA2D_FGPFCCR is A4 or L4 and LOM bit of the DMA2D_CR is pixel mode
- Memory transfer (only in blending mode and except in memory-to-memory mode with blending and fixed color FG): MA bits of DMA2D_BGMAR are not aligned with the CM of DMA2D_BGPFCCR
- Memory transfer: (only in blending mode and in blending with fixed color FG mode) CM bits of DMA2D_BGPFCCR are invalid
- Memory transfer (only in blending mode and in blending with fixed color FG mode): PL bits of DMA2D_NLR odd while CM of DMA2D_BGPFCCR is A4 or L4
- Memory transfer (only in blending mode and in blending with fixed color FG mode): LO bits of DMA2D_BGOR are odd while CM of DMA2D_BGPFCCR is A4 or L4 and LOM bit of the DMA2D_CR is pixel mode
- Memory transfer (except in memory to memory mode): MA bits of DMA2D_OMAR are not aligned with CM bits of DMA2D_OPFCCR.
- Memory transfer (except in memory to memory mode): CM bits of DMA2D_OPFCCR are invalid
- Memory transfer with byte swapping: PL bits of DMA2D_NLR are odd or MA bits of the DMA2D_OMAR are odd or LO in bytes (resulting from LOM bit of the DMA2D_CR and LO bits of DMA2D_OOR values) are odd while SB bit of DMA2D_OPFCCR is set
- Memory transfer: NL bits of DMA2D_NLR = 0
- Memory transfer: PL bits of DMA2D_NLR = 0
- Memory transfer: MODE bits of DMA2D_CR are invalid
- YCbCr format: when a CLUT loading starts setting the START bit of the DMA2D_FGPFCCR.
- YCbCr format: when the memory-to-memory mode is selected.
- YCbCr format: when YCbCR4:4:4 is selected and the sum of the number of pixel (PL) and the line offset LO is not a multiple of 8 pixels.
- YCbCr format: when YCbCr4:2:2 or YCbCr4:2:0 is selected and the sum of the number of pixel (PL) and the line offset LO is not a multiple of 16 pixels.

18.3.14 YCbCr support

The DMA2D foreground plane can support 8x8 block based YCbCr as output by the JPEG decoder with different chroma sub-sampling factors:

The memory organization follows the standard JFIF rules:

- Each of the three color component must be coded on 8-bit
- Each component must be arranged by blocks of 8x8 (64 bytes) called MCU

Depending of the chroma sub-sampling factor the MCU must be arranged in the memory as described in *Table 137: MCU order in memory*.

Table 137. MCU order in memory

Sub-sampling	@	@ + 64	@ + 128	@+192	@+256	@ + 320
4:4:4	Y_1	Cb_1	Cr_1	Y_2	Cb_2	Cr_2
4:2:2	Y_1	Y_2	Cb_{12}	Cr_{12}	Y_3	Y_4
4:2:0	Y_1	Y_2	Y_3	Y_4	Cb_{1234}	Cr_{1234}

The chroma sub-sampling factor is configured through the CSS field of the DMA2D_FGPFCCR register.

Once the DMA2D has started with the foreground configured in YCbCr color mode, the first 2 chroma MCU are loaded in the foreground CLUT. Once the chroma MCU are loaded, the DMA2D performs the loading of the Y MCU as for a classical color mode.

18.3.15 DMA2D transfer control (start, suspend, abort and completion)

Once the DMA2D is configured, the transfer can be launched by setting the START bit of the DMA2D_CR register. Once the transfer is completed, the START bit is automatically reset and the TCIF flag of the DMA2D_ISR register is raised. An interrupt can be generated if the TCIE bit of the DMA2D_CR is set.

The user application can suspend the DMA2D at any time by setting the SUSP bit of the DMA2D_CR register. The transaction can then be aborted by setting the ABORT bit of the DMA2D_CR register or can be restarted by resetting the SUSP bit of the DMA2D_CR register.

The user application can abort at any time an ongoing transaction by setting the ABORT bit of the DMA2D_CR register. In this case, the TCIF flag is not raised.

Automatic CLUT transfers can also be aborted or suspended by using their own START bits in the DMA2D_FGPFCCR and DMA2D_BGPFCCR registers.

18.3.16 Watermark

A watermark can be programmed to generate an interrupt when the last pixel of a given line has been written to the destination memory area.

The line number is defined in the LW[15:0] field of the DMA2D_LWR register.

When the last pixel of this line has been transferred, the TWIF flag of the DMA2D_ISR register is raised and an interrupt is generated if the TWIE bit of the DMA2D_CR is set.

18.3.17 Error management

Two kind of errors can be triggered:

- AXI master port errors signaled by the TEIF flag of the DMA2D_ISR register.
- Conflicts caused by CLUT access (CPU trying to access the CLUT while a CLUT loading or a DMA2D transfer is ongoing) signaled by the CAEIF flag of the DMA2D_ISR register.

Both flags are associated to their own interrupt enable flag in the DMA2D_CR register to generate an interrupt if need be (TEIE and CAEIE).

18.3.18 AXI dead time

To limit the AXI bandwidth usage, a dead time between two consecutive AXI accesses can be programmed.

This feature can be enabled by setting the EN bit in the DMA2D_AMTCR register.

The dead time value is stored in the DT[7:0] field of the DMA2D_AMTCR register. This value represents the guaranteed minimum number of cycles between two consecutive transactions on the AXI bus.

The update of the dead time value while the DMA2D is running is taken into account for the next AXI transfer.

18.4 DMA2D interrupts

An interrupt can be generated on the following events:

- Configuration error
- CLUT transfer complete
- CLUT access error
- Transfer watermark reached
- Transfer complete
- Transfer error

Separate interrupt enable bits are available for flexibility.

Table 138. DMA2D interrupt requests

Interrupt event	Event flag	Enable control bit
Configuration error	CEIF	CEIE
CLUT transfer complete	CTCIF	CTCIE
CLUT access error	CAEIF	CAEIE
Transfer watermark	TWF	TWIE
Transfer complete	TCIF	TCIE
Transfer error	TEIF	TEIE

18.5 DMA2D registers

18.5.1 DMA2D control register (DMA2D_CR)

Address offset: 0x0000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE[2:0]		
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	CEIE	CTCIE	CAEIE	TWIE	TCIE	TEIE	Res.	LOM	Res.	Res.	Res.	ABORT	SUSP	START
		rw	rw	rw	rw	rw	rw		rw				rs	rw	rs

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **MODE[2:0]**: DMA2D mode

This bit is set and cleared by software. It cannot be modified while a transfer is ongoing.
000: Memory-to-memory (FG fetch only)
001: Memory-to-memory with PFC (FG fetch only with FG PFC active)
010: Memory-to-memory with blending (FG and BG fetch with PFC and blending)
011: Register-to-memory (no FG nor BG, only output stage active)
100: Memory-to-memory with Blending and fixed color FG (BG fetch only with FG and BG PFC active)
101: Memory-to-memory with Blending and fixed color BG (BG fetch only with FG and BG PFC active)
others: meaningless

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **CEIE**: Configuration Error Interrupt Enable

This bit is set and cleared by software.
0: CE interrupt disable
1: CE interrupt enable

Bit 12 **CTCIE**: CLUT transfer complete interrupt enable

This bit is set and cleared by software.
0: CTC interrupt disable
1: CTC interrupt enable

Bit 11 **CAEIE**: CLUT access error interrupt enable

This bit is set and cleared by software.
0: CAE interrupt disable
1: CAE interrupt enable

Bit 10 **TWIE**: Transfer watermark interrupt enable

This bit is set and cleared by software.
0: TW interrupt disable
1: TW interrupt enable

Bit 9 **TCIE**: Transfer complete interrupt enable
This bit is set and cleared by software.
0: TC interrupt disable
1: TC interrupt enable

Bit 8 **TEIE**: Transfer error interrupt enable
This bit is set and cleared by software.
0: TE interrupt disable
1: TE interrupt enable

Bit 7 Reserved, must be kept at reset value.

Bit 6 **LOM**: Line Offset Mode
This bit configures how is expressed the line offset (pixels or bytes) for the foreground, background and output.
This bit is set and cleared by software. It can not be modified while a transfer is on going.
0: Line offsets are expressed in pixels
1: Line offsets are expressed in bytes

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **ABORT**: Abort
This bit can be used to abort the current transfer. This bit is set by software and is automatically reset by hardware when the START bit is reset.
0: No transfer abort requested
1: Transfer abort requested

Bit 1 **SUSP**: Suspend
This bit can be used to suspend the current transfer. This bit is set and reset by software. It is automatically reset by hardware when the START bit is reset.
0: Transfer not suspended
1: Transfer suspended

Bit 0 **START**: Start
This bit can be used to launch the DMA2D according to the parameters loaded in the various configuration registers. This bit is automatically reset by the following events:
- At the end of the transfer
- When the data transfer is aborted by the user application by setting the ABORT bit in DMA2D_CR
- When a data transfer error occurs
- When the data transfer has not started due to a configuration error or another transfer operation already ongoing (automatic CLUT loading).

18.5.2 DMA2D interrupt status register (DMA2D_ISR)

Address offset: 0x0004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CEIF	CTCIF	CAEIF	TWIF	TCIF	TEIF
										r	r	r	r	r	r

Bits 31:6 Reserved, must be kept at reset value.

Bit 5 **CEIF**: Configuration error interrupt flag

This bit is set when the START bit of DMA2D_CR, DMA2DFGPFCCR or DMA2D_BGPFCCR is set and a wrong configuration has been programmed.

Bit 4 **CTCIF**: CLUT transfer complete interrupt flag

This bit is set when the CLUT copy from a system memory area to the internal DMA2D memory is complete.

Bit 3 **CAEIF**: CLUT access error interrupt flag

This bit is set when the CPU accesses the CLUT while the CLUT is being automatically copied from a system memory to the internal DMA2D.

Bit 2 **TWIF**: Transfer watermark interrupt flag

This bit is set when the last pixel of the watermarked line has been transferred.

Bit 1 **TCIF**: Transfer complete interrupt flag

This bit is set when a DMA2D transfer operation is complete (data transfer only).

Bit 0 **TEIF**: Transfer error interrupt flag

This bit is set when an error occurs during a DMA transfer (data transfer or automatic CLUT loading).

18.5.3 DMA2D interrupt flag clear register (DMA2D_IFCR)

Address offset: 0x0008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCEIF	CCTCIF	CAECIF	CTWIF	CTCIF	CTEIF
										rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:6 Reserved, must be kept at reset value.

Bit 5 **CCEIF**: Clear configuration error interrupt flag
Programming this bit to 1 clears the CEIF flag in the DMA2D_ISR register

Bit 4 **CCTCIF**: Clear CLUT transfer complete interrupt flag
Programming this bit to 1 clears the CTCIF flag in the DMA2D_ISR register

Bit 3 **CAECIF**: Clear CLUT access error interrupt flag
Programming this bit to 1 clears the CAEIF flag in the DMA2D_ISR register

Bit 2 **CTWIF**: Clear transfer watermark interrupt flag
Programming this bit to 1 clears the TWIF flag in the DMA2D_ISR register

Bit 1 **CTCIF**: Clear transfer complete interrupt flag
Programming this bit to 1 clears the TCIF flag in the DMA2D_ISR register

Bit 0 **CTEIF**: Clear Transfer error interrupt flag
Programming this bit to 1 clears the TEIF flag in the DMA2D_ISR register

18.5.4 DMA2D foreground memory address register (DMA2D_FGMAR)

Address offset: 0x000C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MA[31:0]**: Memory address

Address of the data used for the foreground image. This register can only be written when data transfers are disabled. Once the data transfer has started, this register is read-only.

The address alignment must match the image format selected e.g. a 32-bit per pixel format must be 32-bit aligned, a 16-bit per pixel format must be 16-bit aligned and a 4-bit per pixel format must be 8-bit aligned.

18.5.5 DMA2D foreground offset register (DMA2D_FGOR)

Address offset: 0x0010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LO[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **LO[15:0]**: Line offset

The line offset used for the foreground image, expressed in pixel when the LOM bit is reset and in byte when the LOM bit is set.

When expressed in pixels, only LO[13:0] bits are considered, LO[15:14] bits are ignored.

This value is used for the address generation. It is added at the end of each line to determine the starting address of the next line.

These bits can only be written when data transfers are disabled. Once the data transfer has started, they become read-only.

If the image format is 4-bit per pixel, the line offset must be even.

18.5.6 DMA2D background memory address register (DMA2D_BGMAR)

Address offset: 0x0014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MA[31:0]**: Memory address

Address of the data used for the background image. This register can only be written when data transfers are disabled. Once a data transfer has started, this register is read-only.

The address alignment must match the image format selected e.g. a 32-bit per pixel format must be 32-bit aligned, a 16-bit per pixel format must be 16-bit aligned and a 4-bit per pixel format must be 8-bit aligned.

18.5.7 DMA2D background offset register (DMA2D_BGOR)

Address offset: 0x0018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LO[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **LO[15:0]**: Line offset

The line offset used for the background image, expressed in pixel when the LOM bit is reset and in byte when the LOM bit is set.

When expressed in pixels, only LO[13:0] bits are considered, LO[15:14] bits are ignored.

This value is used for the address generation. It is added at the end of each line to determine the starting address of the next line.

These bits can only be written when data transfers are disabled. Once the data transfer has started, they become read-only.

If the image format is 4-bit per pixel, the line offset must be even.

18.5.8 DMA2D foreground PFC control register (DMA2D_FGPFCCR)

Address offset: 0x001C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALPHA[7:0]								Res.	Res.	RBS	AI	CSS[1:0]		AM[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CS[7:0]								Res.	Res.	START	CCM	CM[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw			rc_w1	rw	rw	rw	rw	rw

Bits 31:24 **ALPHA[7:0]**: Alpha value

These bits define a fixed alpha channel value which can replace the original alpha value or be multiplied by the original alpha value according to the alpha mode selected through the AM[1:0] bits.
These bits can only be written when data transfers are disabled. Once a transfer has started, they become read-only.

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **RBS**: Red Blue Swap

This bit allows to swap the R & B to support BGR or ABGR color formats. Once the transfer has started, this bit is read-only.
0: Regular mode (RGB or ARGB)
1: Swap mode (BGR or ABGR)

Bit 20 **AI**: Alpha Inverted

This bit inverts the alpha value. Once the transfer has started, this bit is read-only.
0: Regular alpha
1: Inverted alpha

Bits 19:18 **CSS[1:0]**: Chroma Sub-Sampling

These bits define the chroma sub-sampling mode for YCbCr color mode. Once the transfer has started, these bits are read-only.
00: 4:4:4 (no chroma sub-sampling)
01: 4:2:2
10: 4:2:0
others: meaningless

Bits 17:16 **AM[1:0]**: Alpha mode

These bits select the alpha channel value to be used for the foreground image. They can only be written data the transfer are disabled. Once the transfer has started, they become read-only.
00: No modification of the foreground image alpha channel value
01: Replace original foreground image alpha channel value by ALPHA[7: 0]
10: Replace original foreground image alpha channel value by ALPHA[7:0] multiplied with original alpha channel value
other configurations are meaningless

Bits 15:8 **CS[7:0]**: CLUT size

These bits define the size of the CLUT used for the foreground image. Once the CLUT transfer has started, this field is read-only.
The number of CLUT entries is equal to CS[7:0] + 1.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **START**: Start

This bit can be set to start the automatic loading of the CLUT. It is automatically reset:

- at the end of the transfer
- when the transfer is aborted by the user application by setting the ABORT bit in DMA2D_CR
- when a transfer error occurs
- when the transfer has not started due to a configuration error or another transfer operation already ongoing (data transfer or automatic background CLUT transfer).

Bit 4 **CCM**: CLUT color mode

This bit defines the color format of the CLUT. It can only be written when the transfer is disabled. Once the CLUT transfer has started, this bit is read-only.
0: ARGB8888
1: RGB888

Bits 3:0 **CM[3:0]**: Color mode

These bits defines the color format of the foreground image. They can only be written when data transfers are disabled. Once the transfer has started, they are read-only.
0000: ARGB8888
0001: RGB888
0010: RGB565
0011: ARGB1555
0100: ARGB4444
0101: L8
0110: AL44
0111: AL88
1000: L4
1001: A8
1010: A4
1011: YCbCr
others: meaningless

18.5.9 DMA2D foreground color register (DMA2D_FGCOLR)

Address offset: 0x0020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RED[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GREEN[7:0]								BLUE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **RED[7:0]**: Red value

These bits defines the red value for the A4 or A8 mode of the foreground image. They can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Used also for fixed color FG in memory-to-memory with blending and fixed color FG (BG fetch only with FG and BG PFC active) mode.

Bits 15:8 **GREEN[7:0]**: Green value

These bits defines the green value for the A4 or A8 mode of the foreground image. They can only be written when data transfers are disabled. Once the transfer has started, They are read-only.

Used also for fixed color FG in memory-to-memory with blending and fixed color FG (BG fetch only with FG and BG PFC active) mode.

Bits 7:0 **BLUE[7:0]**: Blue value

These bits defines the blue value for the A4 or A8 mode of the foreground image. They can only be written when data transfers are disabled. Once the transfer has started, They are read-only.

Used also for fixed color FG in memory-to-memory with blending and fixed color FG (BG fetch only with FG and BG PFC active) mode.

18.5.10 DMA2D background PFC control register (DMA2D_BGPFCCR)

Address offset: 0x0024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALPHA[7:0]								Res.	Res.	RBS	AI	Res.	Res.	AM[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw			rw	rw			rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CS[7:0]								Res.	Res.	START	CCM	CM[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw			rc_w1	rw	rw	rw	rw	rw

Bits 31:24 **ALPHA[7:0]**: Alpha value

These bits define a fixed alpha channel value which can replace the original alpha value or be multiplied with the original alpha value according to the alpha mode selected with bits AM[1: 0]. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **RBS**: Red Blue Swap

This bit allows to swap the R & B to support BGR or ABGR color formats. Once the transfer has started, this bit is read-only.

0: Regular mode (RGB or ARGB)

1: Swap mode (BGR or ABGR)

Bit 20 **AI**: Alpha Inverted

This bit inverts the alpha value. Once the transfer has started, this bit is read-only.

0: Regular alpha

1: Inverted alpha

Bits 19:18 Reserved, must be kept at reset value.

Bits 17:16 **AM[1:0]**: Alpha mode

These bits define which alpha channel value to be used for the background image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

00: No modification of the foreground image alpha channel value

01: Replace original background image alpha channel value by ALPHA[7: 0]

10: Replace original background image alpha channel value by ALPHA[7:0] multiplied with original alpha channel value

others: meaningless

Bits 15:8 **CS[7:0]**: CLUT size

These bits define the size of the CLUT used for the BG. Once the CLUT transfer has started, this field is read-only.

The number of CLUT entries is equal to CS[7:0] + 1.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **START**: Start

This bit is set to start the automatic loading of the CLUT. This bit is automatically reset:

- at the end of the transfer
- when the transfer is aborted by the user application by setting the ABORT bit in the DMA2D_CR
- when a transfer error occurs
- when the transfer has not started due to a configuration error or another transfer operation already on going (data transfer or automatic BackGround CLUT transfer).

Bit 4 **CCM**: CLUT Color mode

These bits define the color format of the CLUT. This register can only be written when the transfer is disabled. Once the CLUT transfer has started, this bit is read-only.

0: ARGB8888

1: RGB888

Bits 3:0 **CM[3:0]**: Color mode

These bits define the color format of the foreground image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

0000: ARGB8888
0001: RGB888
0010: RGB565
0011: ARGB1555
0100: ARGB4444
0101: L8
0110: AL44
0111: AL88
1000: L4
1001: A8
1010: A4
others: meaningless

18.5.11 DMA2D background color register (DMA2D_BGCOLR)

Address offset: 0x0028

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RED[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GREEN[7:0]								BLUE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **RED[7:0]**: Red value

These bits define the red value for the A4 or A8 mode of the background. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Used also for fixed color BG in memory-to-memory with blending and fixed color BG (FG fetch only with FG and BG PFC active) mode.

Bits 15:8 **GREEN[7:0]**: Green value

These bits define the green value for the A4 or A8 mode of the background. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Used also for fixed color BG in memory-to-memory with blending and fixed color BG (FG fetch only with FG and BG PFC active) mode.

Bits 7:0 **BLUE[7:0]**: Blue value

These bits define the blue value for the A4 or A8 mode of the background. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Used also for fixed color BG in memory-to-memory with blending and fixed color BG (FG fetch only with FG and BG PFC active) mode.

18.5.12 DMA2D foreground CLUT memory address register (DMA2D_FGCMAR)

Address offset: 0x002C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MA[31:0]**: Memory Address

Address of the data used for the CLUT address dedicated to the foreground image. This register can only be written when no transfer is ongoing. Once the CLUT transfer has started, this register is read-only.

If the foreground CLUT format is 32-bit, the address must be 32-bit aligned.

18.5.13 DMA2D background CLUT memory address register (DMA2D_BGCMAR)

Address offset: 0x0030

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MA[31:0]**: Memory address

Address of the data used for the CLUT address dedicated to the background image. This register can only be written when no transfer is on going. Once the CLUT transfer has started, this register is read-only.

If the background CLUT format is 32-bit, the address must be 32-bit aligned.

18.5.14 DMA2D output PFC control register (DMA2D_OPFCCR)

Address offset: 0x0034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RBS	AI	Res.	Res.	Res.	Res.
										rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	SB	Res.	Res.	Res.	Res.	Res.	CM[2:0]		
							rw						rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **RBS**: Red Blue Swap
This bit allows to swap the R & B to support BGR or ABGR color formats. Once the transfer has started, this bit is read-only.
0: Regular mode (RGB or ARGB)
1: Swap mode (BGR or ABGR)

Bit 20 **AI**: Alpha Inverted
This bit inverts the alpha value. Once the transfer has started, this bit is read-only.
0: Regular alpha
1: Inverted alpha

Bits 19:9 Reserved, must be kept at reset value.

Bit 8 **SB**: Swap Bytes
When set, the bytes in the output FIFO are swapped two by two.
When this bit is set, the number of pixel per line (PL) must be even, and the output memory address (OMAR) must be even.
This register can only be written when the transfer is disabled. Once the transfer has started, this register is read-only.
0: Bytes in regular order in the output FIFO
1: Bytes are swapped two by two in the output FIFO

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **CM[2:0]**: Color mode
These bits define the color format of the output image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.
000: ARGB8888
001: RGB888
010: RGB565
011: ARGB1555
100: ARGB4444
others: meaningless

18.5.15 DMA2D output color register (DMA2D_OCOLR)

Address offset: 0x0038

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALPHA[7:0]								RED[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GREEN[7:0]								BLUE[7:0]							
RED[4:0]					GREEN[5:0]						BLUE[4:0]				
A	RED[4:0]				GREEN[4:0]						BLUE[4:0]				
ALPHA[3:0]				RED[3:0]				GREEN[3:0]				BLUE[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

ARGB8888 or RGB888 color mode

Bits 31:24 **ALPHA[7:0]**: Alpha channel value in ARGB8888 mode otherwise reserved
These bits define the alpha channel of the output color. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Bits 23:16 **RED[7:0]**: Red value in ARGB8888 or RGB888 mode otherwise reserved
These bits define the red value of the output image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Bits 15:8 **GREEN[7:0]**: Green value in ARGB8888 or RGB888
These bits define the green value of the output image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Bits 7:0 **BLUE[7:0]**: Blue value in ARGB8888 or RGB888
These bits define the blue value of the output image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

RGB565 color mode

Bits 15:11 **RED[4:0]**: Red value in RGB565 mode
These bits define the red value of the output image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Bits 12:5 **GREEN[5:0]**: Green value in RGB565 mode
These bits define the green value of the output image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Bits 4:0 **BLUE[4:0]**: Blue value in RGB565 mode
These bits define the blue value of the output image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

ARGB1555 color mode

Bit 15 **A**: Alpha channel value in ARGB1555 mode
This bit defines the alpha channel of the output color. This bit can only be written when data transfers are disabled. Once the transfer has started, it is read-only.

Bits 14:10 **RED[4:0]**: Red value in ARGB1555 mode
These bits define the red value of the output image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Bits 9:5 **GREEN[4:0]**: Green value in ARGB1555 mode
These bits define the green value of the output image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Bits 4:0 **BLUE[4:0]**: Blue value in ARGB1555 mode
These bits define the blue value of the output image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

ARGB4444 color mode

Bits 15:12 **ALPHA[3:0]**: Alpha channel value in ARGB4444
This bit defines the alpha channel of the output color. This bit can only be written when data transfers are disabled. Once the transfer has started, it is read-only.

Bits 11:8 **RED[3:0]**: Red value in ARGB4444 mode

These bits define the red value of the output image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Bits 7:4 **GREEN[3:0]**: Green value in ARGB4444 mode

These bits define the green value of the output image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

Bits 3:0 **BLUE[3:0]**: Blue value in ARGB4444 mode

These bits define the blue value of the output image. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

18.5.16 DMA2D output memory address register (DMA2D_OMAR)

Address offset: 0x003C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31: 0 **MA[31:0]**: Memory address

Address of the data used for the output FIFO. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

The address alignment must match the image format selected e.g. a 32-bit per pixel format must be 32-bit aligned and a 16-bit per pixel format must be 16-bit aligned.

18.5.17 DMA2D output offset register (DMA2D_OOR)

Address offset: 0x0040

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LO[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **LO[15:0]**: Line offset

The line offset used for the output expressed in pixel when the LOM bit is reset and in byte when the LOM bit is set.
When expressed in pixels, only LO[13:0] is considered, LO[15:14] are ignored.
This value is used for the address generation. It is added at the end of each line to determine the starting address of the next line.
These bits can only be written when data transfers are disabled. Once data transfer has started, they become read-only.

18.5.18 DMA2D number of line register (DMA2D_NLR)

Address offset: 0x0044

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	PL[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:16 **PL[13:0]**: Pixel per lines

Number of pixels per lines of the area to be transferred. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.
If any of the input image format is 4-bit per pixel, pixel per lines must be even.

Bits 15:0 **NL[15:0]**: Number of lines

Number of lines of the area to be transferred. These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

18.5.19 DMA2D line watermark register (DMA2D_LWR)

Address offset: 0x0048

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LW[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **LW[15:0]**: Line watermark

These bits allow to configure the line watermark for interrupt generation.
An interrupt is raised when the last pixel of the watermarked line has been transferred.
These bits can only be written when data transfers are disabled. Once the transfer has started, they are read-only.

18.5.20 DMA2D AXI master timer configuration register (DMA2D_AMTCR)

Address offset: 0x004C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DT[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	EN
rw	rw	rw	rw	rw	rw	rw	rw								rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **DT[7:0]**: Dead time

Dead time value in the AXI clock cycle inserted between two consecutive accesses on the AXI master port. These bits represent the minimum guaranteed number of cycles between two consecutive AXI accesses.

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **EN**: Enable

Enables the dead time functionality.

18.5.21 DMA2D foreground CLUT (DMA2D_FGCLUT[y])

Address offset: 0x0400 + 4*y, (y = 0 to 255)

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALPHA<y>[7:0]								RED<y>[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GREEN<y>[7:0]								BLUE<y>[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **ALPHA<y>[7:0]**: Alpha <y>
Alpha value for index <y> for the foreground.

Bits 23:16 **RED<y>[7:0]**: Red <y>
Red value for index <y> for the foreground.

Bits 15:8 **GREEN<y>[7:0]**: Green <y>
Green value for index <y> for the foreground.

Bits 7:0 **BLUE<y>[7:0]**: Blue <y>
Blue value for index <y> for the foreground.

18.5.22 DMA2D background CLUT (DMA2D_BGCLUT[y])

Address offset: 0x0800 + 4*y, (y = 0 to 255)

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALPHA<y>[7:0]								RED<y>[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GREEN<y>[7:0]								BLUE<y>[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **ALPHA<y>[7:0]**: Alpha <y>
Alpha value for index <y> for the background.

Bits 23:16 **RED<y>[7:0]**: Red <y>
Red value for index <y> for the background.

Bits 15:8 **GREEN<y>[7:0]**: Green <y>
Green value for index <y> for the background.

Bits 7:0 **BLUE<y>[7:0]**: Blue <y>
Blue value for index <y> for the background.

18.5.23 DMA2D register map

The following table summarizes the DMA2D registers. Refer to *Section 2.3 on page 131* for the DMA2D register base address.

Table 139. DMA2D register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0000	DMA2D_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE[2:0]			Res.	Res.	CEIE	CTCIE	CAEIE	TWIE	TCIE	TEIE	Res.	LOM	Res.	Res.	Res.	ABORT	SUSP	START
	Reset value														0	0	0			0	0	0	0	0	0		0				0	0	0
0x0004	DMA2D_ISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CEIF	CTCIF	CAEIF	TWIF	TCIF	TEIF
	Reset value																											0	0	0	0	0	0
0x0008	DMA2D_IFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCEIF	CCTCIF	CAECIF	CTWIF	CTCIF	CTEIF
	Reset value																											0	0	0	0	0	0
0x000C	DMA2D_FGMAR	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0010	DMA2D_FGOR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LO[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0014	DMA2D_BGMAR	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0018	DMA2D_BGOR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LO[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x001C	DMA2D_FGPFCCR	ALPHA[7:0]								Res.	Res.	RBS	AI	CSS[1:0]		AM[1:0]		CS[7:0]								Res.	Res.	START	CCM	CM[3:0]			
	Reset value	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0
0x0020	DMA2D_FGCOLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RED[7:0]								GREEN[7:0]								BLUE[7:0]							
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0024	DMA2D_BGPFCCR	ALPHA[7:0]								Res.	Res.	RBS	AI	Res.	Res.	AM[1:0]		CS[7:0]								Res.	Res.	START	CCM	CM[3:0]			
	Reset value	0	0	0	0	0	0	0	0			0	0			0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0
0x0028	DMA2D_BGCOLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RED[7:0]								GREEN[7:0]								BLUE[7:0]							
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x002C	DMA2D_FGCMAR	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0030	DMA2D_BGCMAR	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0034	DMA2D_OPFCCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RBS	AI	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SB	Res.	Res.	Res.	Res.	Res.	CM[2:0]		
	Reset value											0	0												0						0	0	0

Table 139. DMA2D register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0038	DMA2D_OCOLR	ALPHA[7:0]								RED[7:0]								GREEN[7:0]								BLUE[7:0]							
		Res.																RED[4:0]					GREEN[6:0]				BLUE[4:0]						
		Res.																A	RED[4:0]				GREEN[4:0]				BLUE[4:0]						
		Res.																ALPHA[3:0]				RED[3:0]				GREEN[3:0]				BLUE[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x003C	DMA2D_OMAR	MA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0040	DMA2D_OOR	Res.																LO[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0044	DMA2D_NLR	Res.	Res.	PL[13:0]														NL[15:0]															
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0048	DMA2D_LWR	Res.																LW[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x004C	DMA2D_AMTCR	Res.																DT[7:0]								Res.							EN
	Reset value																	0	0	0	0	0	0	0	0								0
0x0050-0x03FC	Reserved	Res.																															
0x0400-0x07FC	DMA2D_FGCLUT	ALPHA<y>[7:0]								RED<y>[7:0]								GREEN<y>[7:0]								BLUE<y>[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x0800-0x0BFC	DMA2D_BGCLUT	ALPHA<y>[7:0]								RED<y>[7:0]								GREEN<y>[7:0]								BLUE<y>[7:0]							
	Reset value	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x0C00-0x0FFC	Reserved	Res.																															

Refer to *Section 2.3 on page 131* for the register boundary addresses.

19 Nested vectored interrupt controller (NVIC)

19.1 NVIC features

The NVIC includes the following features:

- up to 140 maskable interrupt channels for STM32H7xxx (not including the 16 interrupt lines of Cortex®-M7 with FPU)
- 16 programmable priority levels (4 bits of interrupt priority are used)
- low-latency exception and interrupt handling
- power management control
- implementation of system control registers

The NVIC and the processor core interface are closely coupled, which enables low latency interrupt processing and efficient processing of late arriving interrupts.

All interrupts, including the core exceptions, are managed by the NVIC.

For more information on exceptions and NVIC programming, refer to PM0253 programming manual for Cortex®-M7.

19.1.1 SysTick calibration value register

The SysTick calibration value (SYST_CALIB) is fixed to 0x3E8. It provides a reference timebase of 1 ms based when the SysTick clock frequency is 1 MHz. To match the 1 ms timebase whatever the application frequency, the SysTick reload value must be programmed as follows in the SYST_RVR register:

- The SysTick clock source is the 100 MHz CPU clock (HCLK):

$$\text{reload value} = (F_{HCLK} \times \text{SYST\_CALIB}) - 1$$

- or the SysTick clock source is an external clock:

$$\text{reload value} = ((F_{HCLK}/8) \times \text{SYST\_CALIB}) - 1$$

  where F_{HCLK} refers to the AHB frequency expressed in MHz.

For example, to achieve a timebase of 1 ms when the SysTick clock source is the 100 MHz HCLK:

$$\text{reload value} = (100 \times \text{SYST\_CALIB}) - 1 = 0\text{x}1869\text{F}$$

19.1.2 Interrupt and exception vectors

The exception vectors connected to the NVIC are the following: reset, NMI, HardFault, MemManage, Bus Fault, UsageFault, SVCall, DebugMonitor, PendSV, SysTick.

Table 140. NVIC(1)

Signal(s)	Priority	NVIC position	Acronym	Description	Address
-	-	-	-	Reserved	0x0000 0000
-	-3	-	Reset	Reset	0x0000 0004
-	-2	-	NMI	Non maskable interrupt. The HSE clock security system (CSS) is linked to the NMI vector.	0x0000 0008
-	-1	-	HardFault	All class of fault	0x0000 000C
-	0	-	MemManage	Memory management	0x0000 0010
-	1	-	BusFault	Prefetch fault, memory access fault	0x0000 0014
-	2	-	UsageFault	Undefined instruction or illegal state	0x0000 0018
-	-	-	-	Reserved	0x0000 001C - 0x0000 002B
-	3	-	SVCall	System service call via SWI instruction	0x0000 002C
-	4	-	Debug Monitor	Debug Monitor	0x0000 0030
-	-	-	-	Reserved	0x0000 0034
-	5	-	PendSV	Pendable request for system service	0x0000 0038
-	6	-	SysTick	SystemTick timer	0x0000 003C
wwdg1_it	7	0	WWDG1	Window watchdog interrupt	0x0000 0040
exti_pwr_pvd_wkup	8	1	PVD_PVM	PVD detection interrupt through the EXTI line	0x0000 0044
exti_tamp_rtc_wkup	9	2	RTC_TAMP_ STAMP_CSS_ LSE	RTC tamper and timestamp interrupts through the EXTI line	0x0000 0048
lsecss_rcc_it				LSE clock security system interrupt	
exti_wkup_rtc_wkup	10	3	RTC_WKUP	RTC Wakeup interrupt through the EXTI line	0x0000 004C
flash_it	11	4	FLASH	Flash memory interface	0x0000 0050
rcc_it	12	5	RCC	RCC global interrupt	0x0000 0054
exti_exti0_wkup	13	6	EXTI0	EXTI line 0 interrupt	0x0000 0058
exti_exti1_wkup	14	7	EXTI1	EXTI line 1 interrupt	0x0000 005C
exti_exti2_wkup	15	8	EXTI2	EXTI line 2 interrupt	0x0000 0060
exti_exti3_wkup	16	9	EXTI3	EXTI line 3 interrupt	0x0000 0064
exti_exti4_wkup	17	10	EXTI4	EXTI line 4 interrupt	0x0000 0068

Table 140. NVIC(1) (continued)

Signal(s)	Priority	NVIC position	Acronym	Description	Address
dma1_it0	18	11	DMA1_STR0	DMA1 stream0 global interrupt	0x0000 006C
dma1_it1	19	12	DMA1_STR1	DMA1 stream1 global interrupt	0x0000 0070
dma1_it2	20	13	DMA1_STR2	DMA1 stream2 global interrupt	0x0000 0074
dma1_it3	21	14	DMA1_STR3	DMA1 stream3 global interrupt	0x0000 0078
dma1_it4	22	15	DMA1_STR4	DMA1 stream4 global interrupt	0x0000 007C
dma1_it5	23	16	DMA1_STR5	DMA1 stream5 global interrupt	0x0000 0080
dma1_it6	24	17	DMA1_STR6	DMA1 stream6 global interrupt	0x0000 0084
adc1_it adc2_it	25	18	ADC1_2	ADC1 and ADC2 global interrupt	0x0000 0088
ttfdcan_intr0_it	26	19	FDCAN1_IT0	FDCAN1 interrupt line 0	0x0000 008C
fdcan_intr0_it	27	20	FDCAN2_IT0	FDCAN2 interrupt line 0	0x0000 0090
ttfdcan_intr1_it	28	21	FDCAN1_IT1	FDCAN1 interrupt line 1	0x0000 0094
fdcan_intr1_it	29	22	FDCAN2_IT1	FDCAN2 interrupt line 1	0x0000 0098
exti_exti9_wkup exti_exti8_wkup exti_exti7_wkup exti_exti6_wkup exti_exti5_wkup	30	23	EXTI9_5	EXTI Line[9:5] interrupts	0x0000 009C
tim1_brk_it	31	24	TIM1_BRK	TIM1 break interrupt	0x0000 00A0
tim1_upd_it	32	25	TIM1_UP	TIM1 update interrupt	0x0000 00A4
tim1_trg_it	33	26	TIM1_TRG_COM	TIM1 trigger and commutation interrupts	0x0000 00A8
tim1_cc_it	34	27	TIM1_CC	TIM1 capture/compare interrupt	0x0000 00AC
tim2_it	35	28	TIM2	TIM2 global interrupt	0x0000 00B0
tim3_it	36	29	TIM3	TIM3 global interrupt	0x0000 00B4
tim4_it	37	30	TIM4	TIM4 global interrupt	0x0000 00B8
i2c1_ev_it exti_i2c1_ev_wkup	38	31	I2C1_EV	I2C1 event interrupt	0x0000 00BC
i2c1_err_it	39	32	I2C1_ER	I2C1 global error interrupt	0x0000 00C0
i2c2_ev_it exti_i2c2_ev_wkup	40	33	I2C2_EV	I2C2 global event interrupt	0x0000 00C4
i2c2_err_it	41	34	I2C2_ER	I2C 2 global error interrupt	0x0000 00C8
spi1_it exti_spi1_it	42	35	SPI1	SPI1 global interrupt	0x0000 00CC

Table 140. NVIC(1) (continued)

Signal(s)	Priority	NVIC position	Acronym	Description	Address
spi2_it	43	36	SPI2	SPI2 global interrupt	0x0000 00D0
exti_spi2_it					
usart1_gbl_it	44	37	USART1	USART1 global interrupt	0x0000 00D4
exti_usart1_wkup					
usart2_gbl_it	45	38	USART2	USART2 global interrupt	0x0000 00D8
exti_usart2_wkup					
usart3_gbl_it	46	39	USART3	USART3 global interrupt	0x0000 00DC
exti_usart3_wkup					
exti_exti15_wkup	47	40	EXTI15_10	EXTI Line[15:10] interrupts	0x0000 00E0
exti_exti14_wkup					
exti_exti13_wkup					
exti_exti12_wkup					
exti_exti11_wkup					
exti_exti10_wkup					
exti_rtc_al	48	41	RTC_ALARM	RTC alarms (A and B) through EXTI lines	0x0000 00E4
-	-	-	-	Reserved	0x0000 00E8
tim8_brk_it	50	43	TIM8_BRK_ TIM12	TIM8 Break interrupt and TIM12 global interrupt	0x0000 00EC
tim12_gbl_it					
tim8_upd_it	51	44	TIM8_UP_TIM13	TIM8 Update interrupt and TIM13 global interrupt	0x0000 00F0
tim13_gbl_it					
tim8_trg_it	52	45	TIM8_TRG_ COM_TIM14	TIMER8 trigger/commutation interrupt and TIM14 global interrupt	0x0000 00F4
tim14_gbl_it					
tim8_cc_it	53	46	TIM8_CC	TIM8 capture/compare interrupt	0x0000 00F8
dma1_it7	54	47	DMA1_STR7	DMA1 stream7 global interrupt	0x0000 00FC
fmc_gbl_it	55	48	FMC	FMC global interrupt	0x0000 0100
sdmmc_it	56	49	SDMMC1	SDMMC1 global interrupt	0x0000 0104
tim5_gbl_it	57	50	TIM5	TIM5 global interrupt	0x0000 0108
spi3_it	58	51	SPI3	SPI3 global interrupt	0x0000 010C
exti_spi3_wkup					
uart4_gbl_it	59	52	UART4	UART4 global interrupt	0x0000 0110
exti_uart4_wkup					
uart5_gbl_it	60	53	UART5	UART 5 global interrupt	0x0000 0114
exti_uart5_wkup					

Table 140. NVIC(1) (continued)

Signal(s)	Priority	NVIC position	Acronym	Description	Address
tim6_gbl_it dac_unr_it	61	54	TIM6_DAC	TIM6 global interrupt, DAC1 and DAC2 interrupts	0x0000 0118
tim7_gbl_it	62	55	TIM7	TIM7 global interrupt	0x0000 011C
dma2_it0	63	56	DMA2_STR0	DMA2 stream0 global interrupt	0x0000 0120
dma2_it1	64	57	DMA2_STR1	DMA2 stream1 global interrupt	0x0000 0124
dma2_it2	65	58	DMA2_STR2	DMA2 stream2 global interrupt	0x0000 0128
dma2_it3	66	59	DMA2_STR3	DMA2 stream3 global interrupt	0x0000 012C
dma2_it4	67	60	DMA2_STR4	DMA2 stream4 global interrupt	0x0000 0130
eth_sbd_intr_it	68	61	ETH	Ethernet interrupt	0x0000 0134
exti_eth_wkup	69	62	ETH_WKUP	ETHERNET wakeup interrupt through EXTI line	0x0000 0138
fdcan_cal_it	70	63	FDCAN_CAL	FDCAN calibration interrupt	0x0000 013C
-	-	-	-	Reserved	0x0000 0140
-	-	-	-	Reserved	0x0000 0144
-	-	-	-	Reserved	0x0000 0148
-	-	-	-	Reserved	0x0000 014C
dma2_it5	75	68	DMA2_STR5	DMA2 stream5 global interrupt	0x0000 0150
dma2_it6	76	69	DMA2_STR6	DMA2 stream6 global interrupt	0x0000 0154
dma2_it7	77	70	DMA2_STR7	DMA2 stream7 global interrupt	0x0000 0158
usart6_gbl_it exti_usart6_wkup	78	71	USART6	USART6 global interrupt	0x0000 015C
i2c3_ev_it exti_i2c3_ev_wkup	79	72	I2C3_EV	I2C3 event interrupt	0x0000 0160
i2c3_err_it	80	73	I2C3_ER	I2C3 error interrupt	0x0000 0164
usb1_out_it	81	74	OTG_HS_EP1_OUT	USB OTG_HS OUT endpoint1 global interrupt	0x0000 0168
usb1_in_it	82	75	OTG_HS_EP1_IN	USB OTG_HS IN endpoint1 global interrupt	0x0000 016C
exti_usb1_wkup	83	76	OTG_HS_WKUP	USB OTG_HS wakeup Interrupt through EXTI line	0x0000 0170
usb1_gbl_it	84	77	OTG_HS	USB OTG_HS global interrupt	0x0000 0174
dcmi_pssi_it	85	78	DCMI_PSSI	DCMI/PSSI global interrupt	0x0000 0178
cryp_it	86	79	CRYP	CRYP global interrupt	0x0000 017C
hash_rng_it	87	80	HASH_RNG	HASH OR RNG interrupt	0x0000 0180
cpu_fpu_it	88	81	FPU	CPU FPU global interrupt	0x0000 0184

Table 140. NVIC(1) (continued)

Signal(s)	Priority	NVIC position	Acronym	Description	Address
uart7_gbl_it	89	82	UART7	UART7 global interrupt	0x0000 0188
exti_uart7_wkup					
uart8_gbl_it	90	83	UART8	UART8 global interrupt	0x0000 018C
exti_uart8_wkup					
spi4_it	91	84	SPI4	SPI4 global interrupt	0x0000 0190
exti_spi4_wkup					
spi5_it	92	85	SPI5	SPI5 global interrupt	
exti_spi5_wkup					0x0000 0194
spi6_it	93	86	SPI6	SPI6 global interrupt	0x0000 0198
exti_spi6_wkup					
sai1_it	94	87	SAI1	SAI1 global interrupt	0x0000 019C
ltdc_it	95	88	LTDC	LCD-TFT global interrupt	0x0000 01A0
ltdc_err_it	96	89	LTDC_ERR	LCD-TFT global Error interrupt	0x0000 01A4
dma2d_gbl_it	97	90	DMA2D	DMA2D global interrupt	0x0000 01A8
-	-	-	-	Reserved	0x0000 01AC
octospi1_it	99	92	OCTOSPI1	OCTOSPI1 global interrupt	0x0000 01B0
lptim1_it	100	93	LPTIM1	LPTIM1 global interrupt	0x0000 01B4
exti_lptim1_wkup					
cec_it	101	94	CEC	HDMI-CEC global interrupt	0x0000 01B8
exti_cec_wkup					
i2c4_ev_it	102	95	I2C4_EV	I2C4 event interrupt	0x0000 01BC
exti_i2c4_wkup					
i2c4_evrrit	103	96	I2C4_ER	I2C4 error interrupt	0x0000 01C0
spdifrx_it	104	97	SPDIF	SPDIFIRX global interrupt	0x0000 01C4
-	-	-	-	Reserved	0x0000 01C8
-	-	-	-	Reserved	0x0000 01CC
-	-	-	-	Reserved	0x0000 01D0
-	-	-	-	Reserved	0x0000 01D4
dmamux1_ovr_it	109	102	DMAMUX1_OV	DMAMUX1 overrun interrupt	0x0000 01D8
-	-	-	-	Reserved	0x0000 01DC
-	-	-	-	Reserved	0x0000 01E0
-	-	-	-	Reserved	0x0000 01E4
-	-	-	-	Reserved	0x0000 01E8
-	-	-	-	Reserved	0x0000 01EC

Table 140. NVIC(1) (continued)

Signal(s)	Priority	NVIC position	Acronym	Description	Address
-	-	-	-	Reserved	0x0000 01F0
-	-	-	-	Reserved	0x0000 01F4
dfsdm1_it0	117	110	DFSDM1_FLT0	DFSDM1 filter 0 interrupt	0x0000 01F8
dfsdm1_it1	118	111	DFSDM1_FLT1	DFSDM1 filter 1 interrupt	0x0000 01FC
dfsdm1_it2	119	112	DFSDM1_FLT2	DFSDM1 filter 2 interrupt	0x0000 0200
dfsdm1_it3	120	113	DFSDM1_FLT3	DFSDM1 filter 3 interrupt	0x0000 0204
-	-	-	-	Reserved	0x0000 0208
swpmi_gbl_it exti_swpmi_wup	122	115	SWPMI1	SWPMI global interrupt OR Slave Resume asynchronous interrupt	0x0000 020C
tim15_gbl_it	123	116	TIM15	TIM15 global interrupt	0x0000 0210
tim16_gbl_it	124	117	TIM16	TIM16 global interrupt	0x0000 0214
tim17_gbl_it	125	118	TIM17	TIM17 global interrupt	0x0000 0218
exti_mdios_wkup	126	119	MDIOS_WKUP	MDIOS wakeup interrupt through EXTI line	0x0000 021C
mdios_it	127	120	MDIOS	MDIO global interrupt	0x0000 0220
-	-	-	-	Reserved	0x0000 0224
mdma_it	129	122	MDMA	MDMA global interrupt	0x0000 0228
-	-	-	-	Reserved	0x0000 022C
sdmmc_it	131	124	SDMMC2	SDMMC2 global interrupt	0x0000 0230
hsem1_it	132	125	HSEM0	HSEM global interrupt 1	0x0000 0234
-	-	-	-	Reserved	0x0000 0238
adc3_it	134	127	ADC3	ADC3 global interrupt	0x0000 023C
dmamux2_ovr_it	135	128	DMAMUX2_OVR	DMAMUX2 overrun interrupt	0x0000 0240
bdma_ch0_it	136	129	BDMA_CH0	BDMA channel 0 interrupt	0x0000 0244
bdma_ch1_it	137	130	BDMA_CH1	BDMA channel 1 interrupt	0x0000 0248
bdma_ch2_it	138	131	BDMA_CH2	BDMA channel 2 interrupt	0x0000 024C
bdma_ch3_it	139	132	BDMA_CH3	BDMA channel 3 interrupt	0x0000 0250
bdma_ch4_it	140	133	BDMA_CH4	BDMA channel 4 interrupt	0x0000 0254
bdma_ch5_it	141	134	BDMA_CH5	BDMA channel 5 interrupt	0x0000 0258
bdma_ch6_it	142	135	BDMA_CH6	BDMA channel 6 interrupt	0x0000 025C
bdma_ch7_it	143	136	BDMA_CH7	BDMA channel 7 interrupt	0x0000 0260
comp_gbl_it exti_comp1_wkup exti_comp2_wkup	144	137	COMP	COMP1 and COMP2 global Interrupt	0x0000 0264

Table 140. NVIC(1) (continued)

Signal(s)	Priority	NVIC position	Acronym	Description	Address
lptim2_it	145	138	LPTIM2	LPTIM2 global interrupt	0x0000 0268
exti_lptim2_wkup					
lptim3_it	146	139	LPTIM3	LPTIM3 global interrupt	0x0000 026C
exti_lptim3_wkup					
lptim4_it	147	140	LPTIM4	LPTIM4 global interrupt	0x0000 0270
exti_lptim4_wkup					
lptim5_it	148	141	LPTIM5	LPTIM5 global interrupt	0x0000 0274
exti_lptim5_wkup					
lpuart_gbl_it	149	142	LPUART	LPUART1 global interrupt	0x0000 0278
exti_lpuart_rx_it					
exti_lpuart_tx_it					
-	-	-	-	Reserved	0x0000 027C
crs_it	151	144	CRS	Clock recovery global interrupt	0x0000 0280
ecc_it	152	145	ECC_DIAG_IT	ECC diagnostic global interrupt	0x0000 0284
sai4_it	153	146	SAI4	SAI4 global interrupt	0x0000 0288
temp_it	154	147	TEMP_IT	Temperature sensor global interrupt	0x0000 028C
exti_temp_wkup					
-	-	-	-	Reserved	0x0000 0290
exti_wkup1_wkup	156	149	WKUP	Interrupt for 4 wakeup pins (1, 2, 4, 6) through EXTI line	0x0000 0294
exti_wkup2_wkup					
exti_wkup4_wkup					
exti_wkup6_wkup					
octospi2_it	157	150	OCTOSPI2	OCTOSPI2 global interrupt	0x0000 0298
otfdec1_it	158	151	OTFDEC1	OTFDEC1 interrupt	0x0000 029C
otfdec2_it	159	152	OTFDEC2	OTFDEC2 interrupt	0x0000 02A0
fmac_it	160	153	FMAC	FMAC interrupt	0x0000 02A4
cordic_it	161	154	CORDIC_IT	CORDIC interrupt	0x0000 02A8
exti_uart9_wkup	162	155	UART9	UART9 interrupt	0x0000 02AC
usart10_gbl_it	163	156	USART10	USART10 interrupt	0x0000 02B0
exti_usart10_wkup					
i2c5_ev_it	164	157	I2C5_EV	I2C5 event interrupt	0x0000 02B4
exti_i2c5_ev_wkup					
i2c5_err_it	165	158	I2C5_ER	I2C5 error interrupt	0x0000 02B8
ttfdcan_intr2_it	166	159	FDCAN3_IT0	FDCAN3 interrupt line 0	0x0000 02BC

Table 140. NVIC(1) (continued)

Signal(s)	Priority	NVIC position	Acronym	Description	Address
fdcan_intr2_it	167	160	FDCAN3_IT1	FDCAN3 interrupt line 1	0x0000 02C0
tim23_it	168	161	TIM23	TIM23 global interrupt	0x0000 02C4
tim24_it	169	162	TIM24	TIM24 global interrupt	0x0000 02C8

1. When different signals are connected to the same NVIC interrupt line, they are ORed.

20 Extended interrupt and event controller (EXTI)

The Extended Interrupt and event controller (EXTI) manages wakeup through configurable and direct event inputs. It provides wakeup requests to the Power Control, and generates interrupt requests to the CPU NVIC and to the D3 domain DMAMUX2, and events to the CPU event input.

The EXTI wakeup requests allow the system to be woken up from Stop mode, and the CPU to be woken up from CStop mode.

Both the interrupt request and event request generation can also be used in Run modes.

20.1 EXTI main features

The EXTI main features are the following:

- All Event inputs allow the CPU to wakeup and to generate a CPU interrupt and/or CPU event
- Some Event inputs allow the user to wakeup the D3 domain for autonomous Run mode and generate an interrupt to the D3 domain, i.e. the DMAMUX2

The asynchronous event inputs are classified in 2 groups:

- Configurable events (signals from I/Os or peripherals able to generate a pulse), they have the following features:
  - Selectable active trigger edge
  - Interrupt pending status register bit
  - Individual Interrupt and Event generation mask
  - SW trigger possibility
  - Configurable System D3 domain wakeup events have a D3 Pending mask and status register and may have a D3 interrupt signal.
- Direct events (interrupt and wakeup sources from other peripherals, requiring to be cleared in the peripheral), they feature
  - Fixed rising edge active trigger
  - No interrupt pending status register bit in the EXTI (the interrupt pending status is provided by the peripheral generating the event)
  - Individual Interrupt and Event generation mask
  - No SW trigger possibility
  - Direct system D3 domain wakeup events have a D3 Pending mask and status register and may have a D3 interrupt signal

20.2 EXTI block diagram

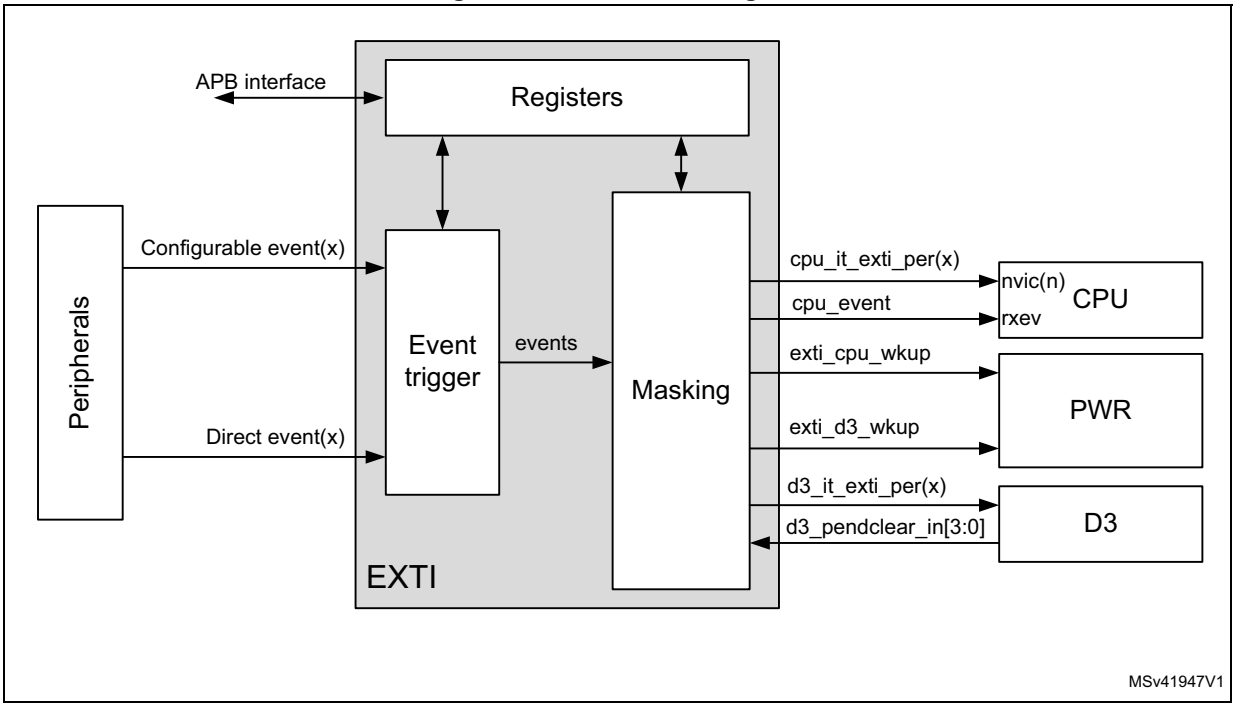
As shown in *Figure 91*, the EXTI consists of a Register block accessed via an APB interface, an Event input Trigger block, and a Masking block.

The Register block contains all EXTI registers.

The Event input trigger block provides Event input edge triggering logic.

The Masking block provides the Event input distribution to the different wakeup, interrupt and event outputs, and their masking.

Figure 91. EXTI block diagram



20.2.1 EXTI connections between peripherals, CPU, and D3 domain

The peripherals able to generate wakeup events when the system is in Stop mode or the CPU is in CStop mode are connected to an EXTI Configurable event input or Direct Event input:

- Peripheral signals that generate a pulse are connected to an EXTI Configurable Event input. For these events the EXTI provides a CPU status pending bit that has to be cleared.
- Peripheral Interrupt and Wakeup sources that have to be cleared in the peripheral are connected to an EXTI Direct Event input. There is no CPU status pending bit within the EXTI. The Interrupt or Wakeup is cleared by the CPU in the peripheral.

The Event inputs able to wakeup D3 for autonomous Run mode are provided with a D3 domain pending request function, that has to be cleared. This clearing request is taken care of by the signal selected by the Pending clear selection.

The CPU interrupts are connected to their respective CPU NVIC, and, similarly, the CPU event is connected to the CPU rxev input.

The EXTI Wakeup signals are connected to the PWR block, and are used to wakeup the D3 domain and/or the CPU.

The D3 domain interrupts allow the system to trigger events for D3 domain autonomous Run mode operation.

20.3 EXTI functional description

Depending on the EXTI Event input type and wakeup target(s), different logic implementations are used. The applicable features are controlled from register bits:

- Active trigger edge enable, by *EXTI rising trigger selection register (EXTI_RTSR1)*, *EXTI rising trigger selection register (EXTI_RTSR2)*, *EXTI rising trigger selection register (EXTI_RTSR3)*, and *EXTI falling trigger selection register (EXTI_FTSR1)*, *EXTI falling trigger selection register (EXTI_FTSR2)*, *EXTI falling trigger selection register (EXTI_FTSR3)*
- Software trigger, by *EXTI software interrupt event register (EXTI_SWIER1)*, *EXTI software interrupt event register (EXTI_SWIER2)*, *EXTI software interrupt event register (EXTI_SWIER3)*
- CPU Interrupt enable, by *EXTI interrupt mask register (EXTI_CPUIMR1)*, *EXTI interrupt mask register (EXTI_CPUIMR2)*, *EXTI interrupt mask register (EXTI_CPUIMR3)*
- CPU Event enable, by *EXTI event mask register (EXTI_CPUEMR1)*, *EXTI event mask register (EXTI_CPUEMR2)*, *EXTI event mask register (EXTI_CPUEMR3)*
- D3 domain wakeup pending, by *EXTI D3 pending mask register (EXTI_D3PMR1)*, *EXTI D3 pending mask register (EXTI_D3PMR2)*, *EXTI D3 pending mask register (EXTI_D3PMR3)*

Table 141. EXTI Event input configurations and register control(1)

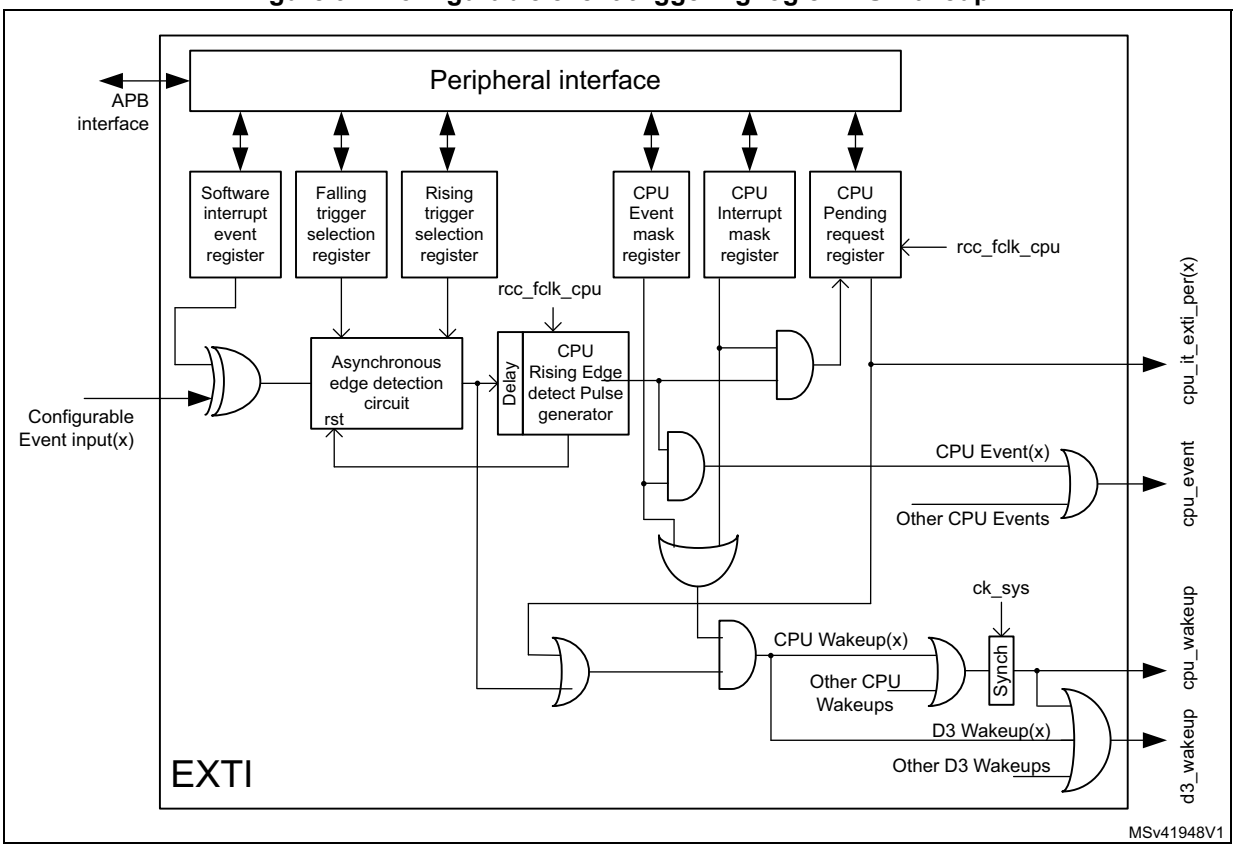
Event input type	Wakeup target(s)	Logic implementation	EXTI_RTSR	EXTI_FTSR	EXTI_SWIER	EXTI_CPUIMR	EXTI_CPUEMR	EXTI_D3PMR
Configurable	CPU	Configurable event input, CPU wakeup logic	X	X	X	X	X	-
	Any(2)	Configurable event input, Any wakeup logic						X
Direct	CPU	Direct event input, CPU wakeup logic	-	-	-	X	X	-
	Any(2)	Direct event input, Any wakeup logic						X

1. X indicates that functionality is available.
2. Waking-up D3 domain for autonomous Run mode, and/or CPU.

20.3.1 EXTI configurable event input - CPU wakeup

Figure 93 is a detailed representation of the logic associated with Configurable Event inputs which will always wake up the CPU.

Figure 92. Configurable event triggering logic CPU wakeup



The Software interrupt event register allows the system to trigger Configurable events by software, writing the *EXTI software interrupt event register (EXTI_SWIER1)*, the *EXTI software interrupt event register (EXTI_SWIER2)*, or the *EXTI software interrupt event register (EXTI_SWIER3)* register bit.

The rising edge *EXTI rising trigger selection register (EXTI_RTSR1)*, *EXTI rising trigger selection register (EXTI_RTSR2)*, *EXTI rising trigger selection register (EXTI_RTSR3)*, and falling edge *EXTI falling trigger selection register (EXTI_FTSR1)*, *EXTI falling trigger selection register (EXTI_FTSR2)*, *EXTI falling trigger selection register (EXTI_FTSR3)* selection registers allow the system to enable and select the Configurable event active trigger edge or both edges.

The devices feature dedicated interrupt mask registers, namely *EXTI interrupt mask register (EXTI_CPUIMR1)* and *EXTI interrupt mask register (EXTI_CPUIMR2)*, *EXTI interrupt mask register (EXTI_CPUIMR3)*, and *EXTI pending register (EXTI_CPUPR1)*, *EXTI pending register (EXTI_CPUPR2)*, *EXTI pending register (EXTI_CPUPR3)* for Configurable events pending request registers. The CPU pending register will only be set for an unmasked CPU interrupt. Each event provides a individual CPU interrupt to the CPU NVIC. The Configurable events interrupts need to be acknowledged by software in the EXTI_CPUPR register.

The devices feature dedicated event mask registers, i.e. *EXTI event mask register (EXTI_CPUEMR1)*, *EXTI event mask register (EXTI_CPUEMR2)*, and *EXTI event mask register (EXTI_CPUEMR3)*. The enabled event then generates an event on the CPU. All events for a CPU are OR-ed together into a single CPU event signal. The CPU Pending register (EXTI_CPUPR) will not be set for an unmasked CPU event.

When a CPU interrupt or CPU event is enabled, the Asynchronous edge detection circuit is reset by the clocked Delay and Rising edge detect pulse generator. This guarantees that the CPU clock is woken up before the Asynchronous edge detection circuit is reset.

Note: A detected Configurable event, enabled by the CPU, is only cleared when the CPU wakes up.

20.3.2 EXTI configurable event input - any wakeup

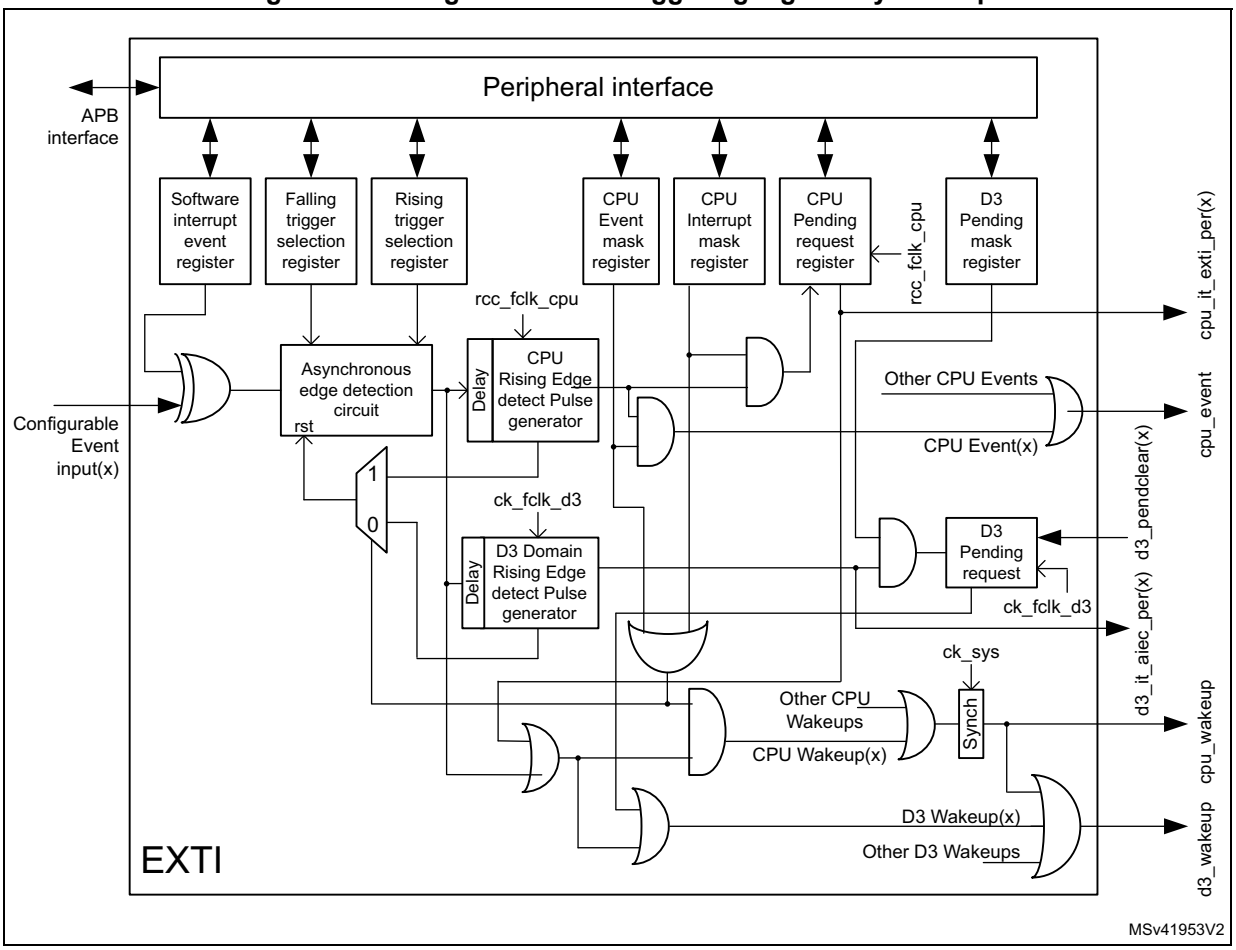
Figure 93 is a detailed representation of the logic associated with Configurable Event inputs that can wakeup D3 domain for autonomous Run mode and/or CPU (“Any” target). It provides the same functionality as the Configurable event input CPU wakeup, with additional functionality to wake up the D3 domain independently.

When all CPU interrupts and CPU events are disabled, the Asynchronous edge detection circuit is reset by the D3 domain clocked Delay and Rising edge detect pulse generator. This guarantees that the D3 domain clock is woken up before the Asynchronous edge detection circuit is reset.

Table 142. Configurable event input asynchronous edge detector reset

EXTI_C1IMR	EXTI_C1EMR	Asynchronous edge detector reset by
Both = 0		D3 domain clock rising edge detect pulse generator
At least one = 1		CPU clock rising edge detect pulse generator

Figure 93. Configurable event triggering logic - any wakeup



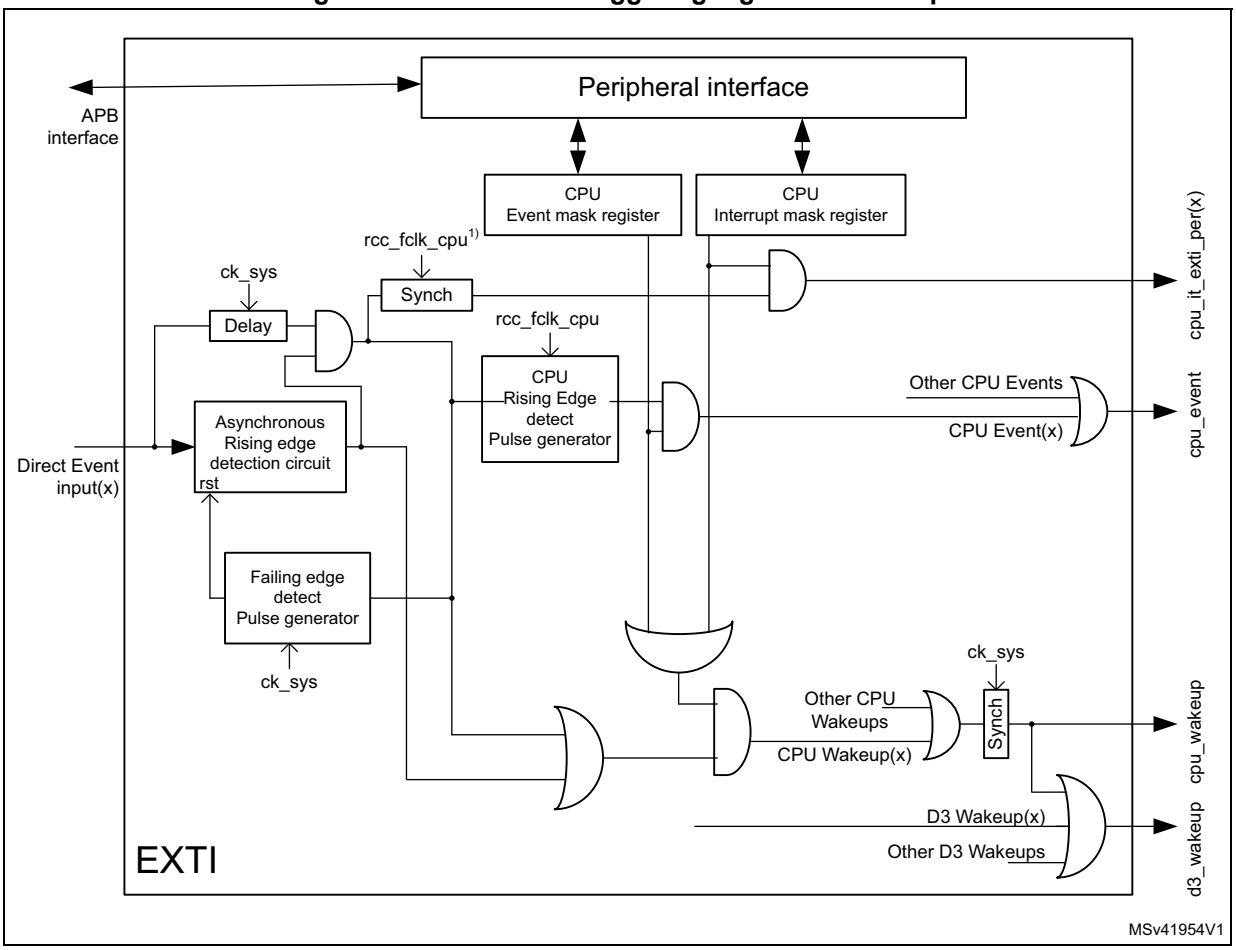
The event triggering logic for “Any” target has additional D3 Pending mask register *EXTI D3 pending mask register (EXTI_D3PMR1)*, *EXTI D3 pending mask register (EXTI_D3PMR2)*, *EXTI D3 pending mask register (EXTI_D3PMR3)*and D3 Pending request logic. The D3 Pending request logic will only be set for unmasked D3 Pending events. The D3 Pending request logic keeps the D3 domain in Run mode until the D3 Pending request logic is cleared by the selected D3 domain pendclear source.

20.3.3 EXTI direct event input - CPU wakeup

Figure 94 is a detailed representation of the logic associated with Direct Event inputs waking up the CPU.

Direct events only provide CPU interrupt enable and CPU event enable functionality.

Figure 94. Direct event triggering logic CPU wakeup

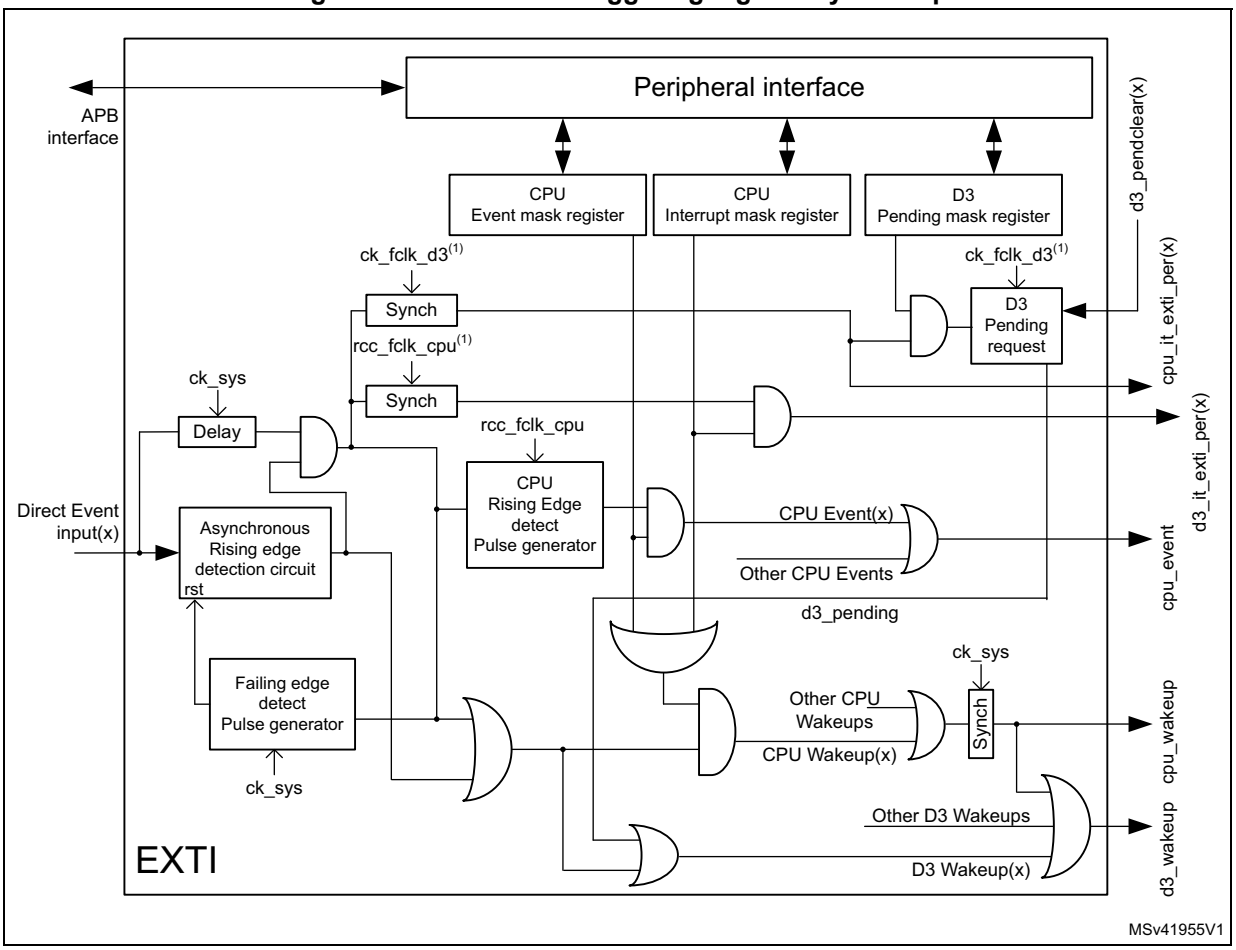


1. The CPU interrupt for asynchronous Direct Event inputs (peripheral Wakeup signals) is synchronized with the CPU clock. The synchronous Direct Event inputs (peripheral interrupt signals), after the asynchronous edge detection, are directly sent to the CPU interrupt without resynchronization.

20.3.4 EXTI direct event input - any wakeup

Figure 95 is a detailed representation of the logic associated with Direct Event inputs waking up D3 domain for autonomous Run mode and/or CPU, (“Any” target). It provides the same functionality as the Direct event input CPU wakeup, plus additional functionality to wakeup the D3 domain independently.

Figure 95. Direct event triggering logic - any wakeup



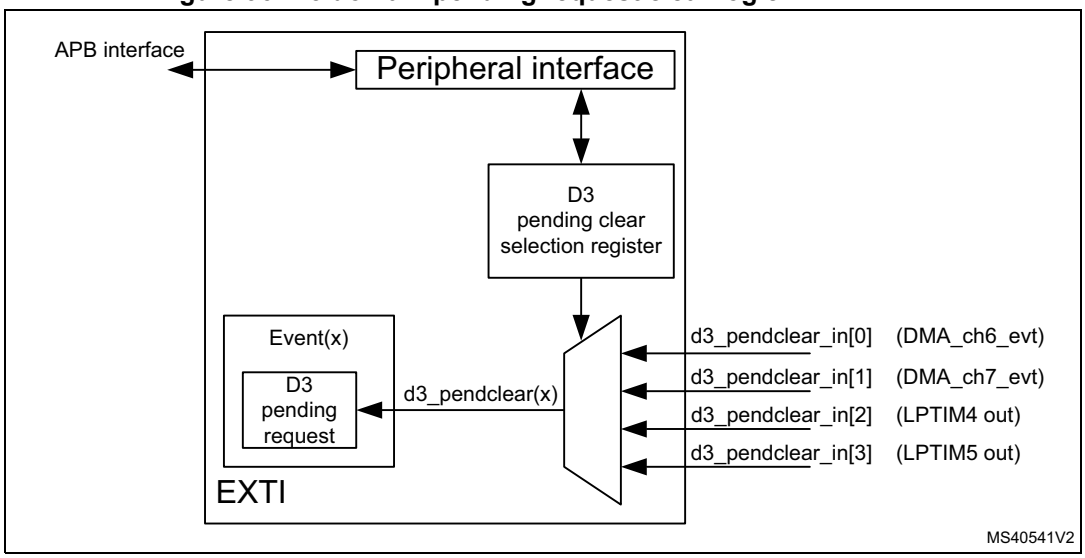
1. The CPU interrupt and D3 domain interrupt for asynchronous Direct Event inputs (peripheral Wakeup signals) are synchronized, respectively, with the CPU clock and the D3 domain clock. The synchronous Direct Event inputs (peripheral interrupt signals), after the asynchronous edge detection, are directly sent to the CPU interrupt and the D3 domain interrupt without resynchronization in the EXTI.

20.3.5 EXTI D3 pending request clear selection

Event inputs able to wake up D3 domain for autonomous Run mode have D3 Pending request logic that can be cleared by the selected D3 pendclear source. For each D3 Pending request a D3 domain pendclear source can be selected from four different inputs.

Figure 96 is a detailed representation of the logic selecting the D3 pendclear source.

Figure 96. D3 domain pending request clear logic



The D3 Pending request clear selection registers *EXTI D3 pending clear selection register low (EXTI_D3PCR1L)*, *EXTI D3 pending clear selection register high (EXTI_D3PCR1H)*, *EXTI D3 pending clear selection register low (EXTI_D3PCR2L)*, *EXTI D3 pending clear selection register high (EXTI_D3PCR2H)*, *EXTI D3 pending clear selection register low (EXTI_D3PCR2L)* and *EXTI D3 pending clear selection register high (EXTI_D3PCR3H)* allow the system to select the source to reset the D3 Pending request.

20.4 EXTI event input mapping

For the sixteen GPIO Event inputs the associated IOPORT pin has to be selected in the SYSCFG register SYSCFG_EXTICRn. The same pin from each IOPORT maps to the corresponding EXTI Event input.

The wakeup capabilities of each Event input are detailed in *Table 143*. An Event input can either wake up the CPU, and in the case of “Any” can also wake up D3 domain for autonomous Run mode.

The EXTI Event inputs with a connection to the CPU NVIC are indicated in the *Connection to NVIC* column. For the EXTI events not having a connection to the NVIC, the peripheral interrupt is directly connected to the NVIC in parallel with the connection to the EXTI.

All EXTI Event inputs are OR-ed together and connected to the CPU event input (rxev).

Table 143. EXTI Event input mapping

Event input	Source	Event input type	Wakeup target(s)	Connection to NVIC
0 - 15	EXTI[15:0]	Configurable	Any	Yes
16	PVD and AVD(1)	Configurable	CPU only	Yes
17	RTC alarms	Configurable	CPU only	Yes
18	RTC tamper, RTC timestamp, RCC LSECSS(2)	Configurable	CPU only	Yes
19	RTC wakeup timer	Configurable	Any	Yes
20	COMP1	Configurable	Any	Yes
21	COMP2	Configurable	Any	Yes
22	I2C1 wakeup	Direct	CPU only	Yes
23	I2C2 wakeup	Direct	CPU only	Yes
24	I2C3 wakeup	Direct	CPU only	Yes
25	I2C4 wakeup	Direct	Any	Yes
26	USART1 wakeup	Direct	CPU only	Yes
27	USART2 wakeup	Direct	CPU only	Yes
28	USART3 wakeup	Direct	CPU only	Yes
29	USART6 wakeup	Direct	CPU only	Yes
30	UART4 wakeup	Direct	CPU only	Yes
31	UART5 wakeup	Direct	CPU only	Yes
32	UART7 wakeup	Direct	CPU only	Yes
33	UART8 wakeup	Direct	CPU only	Yes
34	LPUART1 RX wakeup	Direct	Any	Yes
35	LPUART1 TX wakeup	Direct	Any	Yes
36	SPI1 wakeup	Direct	CPU only	Yes
37	SPI2 wakeup	Direct	CPU only	Yes
38	SPI3 wakeup	Direct	CPU only	Yes
39	SPI4 wakeup	Direct	CPU only	Yes
40	SPI5 wakeup	Direct	CPU only	Yes
41	SPI6 wakeup	Direct	Any	Yes
42	MDIO wakeup	Direct	CPU only	Yes
43	USB1 wakeup	Direct	CPU only	Yes
44	Reserved	-	-	-
45	Reserved	-	-	-
46	Reserved	-	-	-
47	LPTIM1 wakeup	Direct	CPU only	Yes
48	LPTIM2 wakeup	Direct	Any	Yes

Table 143. EXTI Event input mapping (continued)

Event input	Source	Event input type	Wakeup target(s)	Connection to NVIC
49	LPTIM2 output	Configurable	Any	No(3)
50	LPTIM3 wakeup	Direct	Any	Yes
51	LPTIM3 output	Configurable	Any	No(3)
52	LPTIM4 wakeup	Direct	Any	Yes
53	LPTIM5 wakeup	Direct	Any	Yes
54	SWPMI wakeup	Direct	CPU only	Yes
55	WKUP1	Direct	CPU only	Yes
56	WKUP2	Direct	CPU only	Yes
57	Reserved	-	-	-
58	WKUP4	Direct	CPU only	Yes
59	Reserved	-	-	-
60	WKUP6	Direct	CPU only	Yes
61	RCC interrupt	Direct	CPU only	No(4)
62	I2C4 Event interrupt	Direct	CPU only	No(4)
63	I2C4 Error interrupt	Direct	CPU only	No(4)
64	LPUART1 global Interrupt	Direct	CPU only	No(4)
65	SPI6 interrupt	Direct	CPU only	No(4)
66	BDMA CH0 interrupt	Direct	CPU only	No(4)
67	BDMA CH1 interrupt	Direct	CPU only	No(4)
68	BDMA CH2 interrupt	Direct	CPU only	No(4)
69	BDMA CH3 interrupt	Direct	CPU only	No(4)
70	BDMA CH4 interrupt	Direct	CPU only	No(4)
71	BDMA CH5 interrupt	Direct	CPU only	No(4)
72	BDMA CH6 interrupt	Direct	CPU only	No(4)
73	BDMA CH7 interrupt	Direct	CPU only	No(4)
74	DMAMUX2 interrupt	Direct	CPU only	No(4)
75	ADC3 interrupt	Direct	CPU only	No(4)
76	SAI4 interrupt	Direct	CPU only	No(4)
77	HSEM0 interrupt	Direct	CPU only	No
78	Reserved	-	-	-
79	Reserved	-	-	-
80	Reserved	-	-	-
81	Reserved	-	-	-
82	Reserved	-	-	-
83	Reserved	-	-	-

Table 143. EXTI Event input mapping (continued)

Event input	Source	Event input type	Wakeup target(s)	Connection to NVIC
84	Reserved	-	-	-
85	HDMI-CEC wakeup	Configurable	CPU only	Yes
86	ETHERNET wakeup	Configurable	CPU only	Yes
87	HSECSS interrupt	Direct	CPU only	No(4)
88	TEMP wakeup	Direct	Any	Yes
89	UART9 wakeup	Direct	CPU only	Yes
90	USART10 wakeup	Direct	CPU only	Yes
91	I2C5 wakeup	Direct	CPU only	Yes

1. PVD and AVD signals are OR-ed together on the same EXTI event input.
2. RTC Tamper, RTC timestamp and RCC LSECSS signals are OR-ed together on the same EXTI event input.
3. Not available on CPU NVIC, to be used for system wakeup only or CPU event input (rxev).
4. Available on CPU NVIC directly from the peripheral

20.5 EXTI functional behavior

The Direct event inputs are enabled in the respective peripheral generating the event. The Configurable events are enabled by enabling at least one of the trigger edges.

When in Stop mode an event will always wake up the D3 domain. In system Run and Stop modes an event will always generate an associated D3 domain interrupt. An event will only wake up the CPU when the event associated CPU interrupt is unmasked and/or the CPU event is unmasked.

Table 144. Masking functionality

CPU		Configurable event inputs PRx bits of EXTI_CPUPR	CPU			D3 domain wakeup
Interrupt enable MRx bits of EXTI_CPUIMR	Event enable MRx bits of EXTI_CPUEMR		Interrupt	Event	Wakeup	
0	0	No	Masked	Masked	Masked	Yes(1) / Masked(2)
0	1	No	Masked	Yes	Yes	Yes
1	0	Status latched	Yes	Masked	Yes	Yes
1	1	Status latched	Yes	Yes	Yes	Yes

1. Only for Event inputs that allow the system to wakeup D3 domain for autonomous Run mode (Any target).
2. For Event inputs that will always wake up CPU.

For Configurable event inputs, when the enabled edge(s) occur on the event input, an event request is generated. When the associated CPU interrupt is unmasked, the corresponding pending PRx bit in EXTI_CPUPR is set and the CPU interrupt signal is activated. EXTI_CPUPR PRx pending bit shall be cleared by software writing it to ‘1’. This will clear the CPU interrupt.

For Direct event inputs, when enabled in the associated peripheral, an event request is generated on the rising edge only. There is no corresponding CPU pending bit. When the associated CPU interrupt is unmasked the corresponding CPU interrupt signal is activated.

The CPU event has to be unmasked to generate an event. When the enabled edge(s) occur on the Event input a CPU event pulse is generated. There is no CPU event pending bit.

Both a CPU interrupt and a CPU event may be enabled on the same Event input. They will both trigger the same Event input condition(s).

For the Configurable Event inputs an event input request can be generated by software when writing a ‘1’ in the software interrupt/event register EXTI_SWIER.

Whenever an Event input is enabled and a CPU interrupt and/or CPU event is unmasked, the Event input will also generate a D3 domain wakeup next to the CPU wakeup.

Some Event inputs are able to wakeup the D3 domain autonomous Run mode, in this case the CPU interrupt and CPU event are masked, preventing the CPU to be woken up. Two D3 domain autonomous Run mode wakeup mechanisms are supported:

- D3 domain wakeup without pending (EXTI_D3PMR = 0)
  - On a Configurable Event input this mechanism will wake up D3 domain and clear the D3 domain wakeup signal automatically after the Delay + Rising Edge detect Pulse generator.
  - On a Direct Event input this mechanism will wake up D3 domain and clear the D3 domain wakeup signal after the Direct Event input signal is cleared.
- D3 domain wakeup with pending (EXTI_D3PMR = 1)
  - On a Configurable Event input this mechanism will wake up D3 domain and clear the D3 domain wakeup signal after the Delay + Rising Edge detect Pulse generator and when the D3 Pending request is cleared.
  - On a Direct Event input this mechanism will wake up D3 domain and clear the D3 domain wakeup signal after the Direct Event input signal is cleared and when the D3 Pending request is cleared.

20.5.1 EXTI CPU interrupt procedure

- Unmask the Event input interrupt by setting the corresponding mask bits in the EXTI_CPUIMR register.
- For Configurable Event inputs, enable the event input by setting either one or both the corresponding trigger edge enable bits in EXTI_RTSR and EXTI_FTSR registers.
- Enable the associated interrupt source in the CPU NVIC or use the SEVONPEND, so that an interrupt coming from the CPU interrupt signal is detectable by the CPU after a WFI/WFE instruction.
  - For Configurable event inputs the associated EXTI pending bit needs to be cleared.

20.5.2 EXTI CPU event procedure

- Unmask the Event input by setting the corresponding mask bits of the EXTI_CPUEMR register.
- For Configurable Event inputs, enable the event input by setting either one or both the corresponding trigger edge enable bits in EXTI_RTSR and EXTI_FTSR registers.
- The CPU event signal is detected by the CPU after a WFE instruction.
  - For Configurable event inputs there is no EXTI pending bit to clear.

20.5.3 EXTI CPU wakeup procedure

- Unmask the Event input by setting at least one of the corresponding mask bits in the EXTI_CPUIMR and/or EXTI_CPUEMR registers. The CPU wakeup is generated at the same time as the unmasked CPU interrupt and/or CPU event.
- For Configurable Event inputs, enable the event input by setting either one or both the corresponding trigger edge enable bits in EXTI_RTSR and EXTI_FTSR registers.
- Direct Events will automatically generate a CPU wakeup.

20.5.4 EXTI D3 domain wakeup for autonomous Run mode procedure

- Mask the Event input for waking up the CPU, by clearing both the corresponding mask bits in the EXTI_CPUIMR and/or EXTI_CPUEMR registers.
- For Configurable Event inputs, enable the event input by setting either one or both the corresponding trigger edge enable bits in EXTI_RTSR and EXTI_FTSR registers.
- Direct Events will automatically generate a D3 domain wakeup.
- Select the D3 domain wakeup mechanism in EXTI_D3PMR.
  - When D3 domain wakeup without pending (EXTI_PMR = 0) is selected, the Wakeup will be cleared automatically following the clearing of the Event input.
  - When D3 domain wakeup with pending (EXTI_PMR = 1) is selected the Wakeup needs to be cleared by a selected D3 domain pendclear source.
    A pending D3 domain wakeup signal can also be cleared by FW clearing the associated EXTI_D3PMR register bit.
- After the D3 domain wakeup a D3 domain interrupt is generated.
  - Configurable Event inputs will generate a pulse on D3 domain interrupt.
  - Direct Event inputs will activate the D3 domain interrupt until the event input is cleared in the peripheral.

20.5.5 EXTI software interrupt/event trigger procedure

Any of the Configurable Event inputs can be triggered from the software interrupt/event register (the associated CPU interrupt and/or CPU event shall be enabled by their respective procedure).

- Enable the Event input by setting at least one of the corresponding edge trigger bits in the EXTI_RTSR and/or EXTI_FTSR registers.
- Unmask the software interrupt/event trigger by setting at least one of the corresponding mask bits in the EXTI_CPUIMR and/or EXTI_CPUEMR registers.
- Trigger the software interrupt/event by writing “1” to the corresponding bit in the EXTI_SWIER register.
- The Event input may be disabled by clearing the EXTI_RTSR and EXTI_FTSR register bits.

Note: An edge on the Configurable event input will also trigger an interrupt/event.

A software trigger can be used to set the D3 Pending request logic, keeping the D3 domain in Run until the D3 Pending request logic is cleared.

20.6 EXTI registers

Every register can only be accessed with 32-bit (word). A byte or half-word cannot be read or written.

20.6.1 EXTI rising trigger selection register (EXTI_RTSR1)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TR21	TR20	TR19	TR18	TR17	TR16
										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TR15	TR14	TR13	TR12	TR11	TR10	TR9	TR8	TR7	TR6	TR5	TR4	TR3	TR2	TR1	TR0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:0 **TR[21:0]:** Rising trigger event configuration bit of Configurable Event input x.(1)

0: Rising trigger disabled (for Event and Interrupt) for input line

1: Rising trigger enabled (for Event and Interrupt) for input line

1. The Configurable event inputs are edge triggered, no glitch must be generated on these inputs.
If a rising edge on the Configurable event input occurs during writing of the register, the associated pending bit will not be set.
Rising and falling edge triggers can be set for the same Configurable Event input. In this case, both edges generate a trigger.

20.6.2 EXTI falling trigger selection register (EXTI_FTSR1)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TR21	TR20	TR19	TR18	TR17	TR16
										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TR15	TR14	TR13	TR12	TR11	TR10	TR9	TR8	TR7	TR6	TR5	TR4	TR3	TR2	TR1	TR0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:0 **TR[21:0]:** Falling trigger event configuration bit of Configurable Event input x.(1)

0: Falling trigger disabled (for Event and Interrupt) for input line

1: Falling trigger enabled (for Event and Interrupt) for input line.

1. The Configurable event inputs are edge triggered, no glitch must be generated on these inputs.
If a falling edge on the Configurable event input occurs during writing of the register, the associated pending bit will not be set.
Rising and falling edge triggers can be set for the same Configurable Event input. In this case, both edges generate a trigger.

20.6.3 EXTI software interrupt event register (EXTI_SWIER1)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWIER 21	SWIER 20	SWIER 19	SWIER 18	SWIER 17	SWIER 16
										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SWIER 15	SWIER 14	SWIER 13	SWIER 12	SWIER 11	SWIER 10	SWIER 9	SWIER 8	SWIER 7	SWIER 6	SWIER 5	SWIER 4	SWIER 3	SWIER 2	SWIER 1	SWIER 0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:0 **SWIER[21:0]:** Software interrupt on line x

This bitfield alway returns 0 when read.

0: Writing 0 has no effect.

1: Writing a 1 to this bit will trigger an event on line x. This bit is auto cleared by HW.

20.6.4 EXTI D3 pending mask register (EXTI_D3PMR1)

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	MR25	Res.	Res.	Res.	MR21	MR20	MR19	Res.	Res.	Res.
						rw				rw	rw	rw			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MR15	MR14	MR13	MR12	MR11	MR10	MR9	MR8	MR7	MR6	MR5	MR4	MR3	MR2	MR1	MR0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **MR25:** D3 Pending Mask on Event input x

0: D3 Pending request from Line x is masked. Writing this bit to 0 will also clear the D3 Pending request.

1: D3 Pending request from Line x is unmasked. The D3 domain pending signal when triggered will keep D3 domain wakeup active until cleared.

Bits 24:22 Reserved, must be kept at reset value.

Bits 21:19 **MR[21:19]:** D3 Pending Mask on Event input x

0: D3 Pending request from Line x is masked. Writing this bit to 0 will also clear the D3 Pending request.

1: D3 Pending request from Line x is unmasked. The D3 domain pending signal when triggered will keep D3 domain wakeup active until cleared.

Bits 18:16 Reserved, must be kept at reset value.

Bits 15:0 **MR[15:0]:** D3 Pending Mask on Event input x

0: D3 Pending request from Line x is masked. Writing this bit to 0 will also clear the D3 Pending request.

1: D3 Pending request from Line x is unmasked. The D3 domain pending signal when triggered will keep D3 domain wakeup active until cleared.

20.6.5 EXTI D3 pending clear selection register low (EXTI_D3PCR1L)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PCS15[1:0]		PCS14[1:0]		PCS13[1:0]		PCS12[1:0]		PCS11[1:0]		PCS10[1:0]		PCS9[1:0]		PCS8[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PCS7[1:0]		PCS6[1:0]		PCS5[1:0]		PCS4[1:0]		PCS3[1:0]		PCS2[1:0]		PCS1[1:0]		PCS0[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PCS[15:0][1:0]:** D3 Pending request clear input signal selection on Event input x = truncate (n/2)

00: DMA ch6 event selected as D3 domain pendclear source

01: DMA ch7 event selected as D3 domain pendclear source

10: LPTIM4 out selected as D3 domain pendclear source

11: LPTIM5 out selected as D3 domain pendclear source

20.6.6 EXTI D3 pending clear selection register high (EXTI_D3PCR1H)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCS25[1:0]		Res.	Res.
												rw	rw		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	PCS21[1:0]		PCS20[1:0]		PCS19[1:0]		Res.	Res.	Res.	Res.	Res.	Res.
				rw	rw	rw	rw	rw	rw						

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:18 **PCS25[1:0]:** D3 Pending request clear input signal selection on Event input 25 = truncate ((n+32)/2)
00: DMA ch6 event selected as D3 domain pendclear source
01: DMA ch7 event selected as D3 domain pendclear source
10: LPTIM4 out selected as D3 domain pendclear source
11: LPTIM5 out selected as D3 domain pendclear source

Bits 17:12 Reserved, must be kept at reset value.

Bits 11:6 **PCS[21:19][1:0]:** D3 Pending request clear input signal selection on Event input x = truncate ((n+32)/2) (x = 21 to 19)
00: DMA ch6 event selected as D3 domain pendclear source
01: DMA ch7 event selected as D3 domain pendclear source
10: LPTIM4 out selected as D3 domain pendclear source
11: LPTIM5 out selected as D3 domain pendclear source

Bits 5:0 Reserved, must be kept at reset value.

20.6.7 EXTI rising trigger selection register (EXTI_RTSR2)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TR51	Res.	TR49	Res.
												rw		rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **TR51:** Rising trigger event configuration bit of Configurable Event input x+32.(1)
0: Rising trigger disabled (for Event and Interrupt) for input line
1: Rising trigger enabled (for Event and Interrupt) for input line

Bit 18 Reserved, must be kept at reset value.

Bit 17 **TR49:** Rising trigger event configuration bit of Configurable Event input x+32.(1)
0: Rising trigger disabled (for Event and Interrupt) for input line
1: Rising trigger enabled (for Event and Interrupt) for input line

Bits 16:0 Reserved, must be kept at reset value.

1. The Configurable event inputs are edge triggered, no glitch must be generated on these inputs.
If a rising edge on the Configurable event input occurs during writing of the register, the associated pending bit will not be set.
Rising and falling edge triggers can be set for the same Configurable Event input. In this case, both edges generate a trigger.

20.6.8 EXTI falling trigger selection register (EXTI_FTSR2)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TR51	Res.	TR49	Res.
												rw		rw	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **TR51:** Falling trigger event configuration bit of Configurable Event input x+32.(1)
0: Falling trigger disabled (for Event and Interrupt) for input line
1: Falling trigger enabled (for Event and Interrupt) for input line

Bit 18 Reserved, must be kept at reset value.

Bit 17 **TR49:** Falling trigger event configuration bit of Configurable Event input x+32.(1)
0: Falling trigger disabled (for Event and Interrupt) for input line
1: Falling trigger enabled (for Event and Interrupt) for input line

Bits 16:0 Reserved, must be kept at reset value.

1. The Configurable event inputs are edge triggered, no glitch must be generated on these inputs.
If a falling edge on the Configurable event input occurs during writing of the register, the associated pending bit will not be set.
Rising and falling edge triggers can be set for the same Configurable Event input. In this case, both edges generate a trigger.

20.6.9 EXTI software interrupt event register (EXTI_SWIER2)

Address offset: 0x28

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWIER 51	Res.	SWIER 49	Res.
												rw		rw	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **SWIER51:** Software interrupt on line x+32
Will alway return 0 when read.
0: Writing 0 has no effect.
1: Writing a 1 to this bit will trigger an event on line x. This bit is auto cleared by HW.

Bit 18 Reserved, must be kept at reset value.

Bit 17 **SWIER49:** Software interrupt on line x+32
Will alway return 0 when read.
0: Writing 0 has no effect.
1: Writing a 1 to this bit will trigger an event on line x. This bit is auto cleared by HW.

Bits 16:0 Reserved, must be kept at reset value.

20.6.10 EXTI D3 pending mask register (EXTI_D3PMR2)

Address offset: 0x2C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MR53	MR52	MR51	MR50	MR49	MR48
										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	MR41	Res.	Res.	Res.	Res.	Res.	MR35	MR34	Res.	Res.
						rw						rw	rw		

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:16 **MR[53:48]:** D3 Pending Mask on Event input x+32
0: D3 Pending request from Line x+32 is masked. Writing this bit to 0 will also clear the D3 Pending request.
1: D3 Pending request from Line x+32 is unmasked. The D3 domain pending signal when triggered will keep D3 domain wakeup active until cleared.

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **MR41:** D3 Pending Mask on Event input x+32
0: D3 Pending request from Line x+32 is masked. Writing this bit to 0 will also clear the D3 Pending request.
1: D3 Pending request from Line x+32 is unmasked. The D3 domain pending signal when triggered will keep D3 domain wakeup active until cleared.

Bits 8:4 Reserved, must be kept at reset value.

Bits 3:2 **MR[35:34]:** D3 Pending Mask on Event input x+32
0: D3 Pending request from Line x+32 is masked. Writing this bit to 0 will also clear the D3 Pending request.
1: D3 Pending request from Line x+32 is unmasked. The D3 domain pending signal when triggered will keep D3 domain wakeup active until cleared.

Bits 1:0 Reserved, must be kept at reset value.

20.6.11 EXTI D3 pending clear selection register low (EXTI_D3PCR2L)

Address offset: 0x30

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCS41[1:0]		Res.	Res.
												rw	rw		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCS35[1:0]		PCS34[1:0]		Res.	Res.	Res.	Res.
								rw	rw	rw	rw				

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:18 **PCS41[1:0]:** D3 Pending request clear input signal selection on Event input x = truncate ((n+64)/2)

00: DMA ch6 event selected as D3 domain pendclear source
01: DMA ch7 event selected as D3 domain pendclear source
10: LPTIM4 out selected as D3 domain pendclear source
11: LPTIM5 out selected as D3 domain pendclear source

Bits 17:8 Reserved, must be kept at reset value.

Bits 7:4 **PCS[35:34][1:0]:** D3 Pending request clear input signal selection on Event input x= truncate ((n+64)/2)

00: DMA ch6 event selected as D3 domain pendclear source
01: DMA ch7 event selected as D3 domain pendclear source
10: LPTIM4 out selected as D3 domain pendclear source
11: LPTIM5 out selected as D3 domain pendclear source

Bits 3:0 Reserved, must be kept at reset value.

20.6.12 EXTI D3 pending clear selection register high (EXTI_D3PCR2H)

Address offset: 0x34

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	PCS53[1:0]		PCS52[1:0]		PCS51[1:0]		PCS50[1:0]		PCS49[1:0]		PCS48[1:0]	
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **PCS[53:48][1:0]:** D3 Pending request clear input signal selection on Event input x= truncate ((n+96)/2)

00: DMA ch6 event selected as D3 domain pendclear source
01: DMA ch7 event selected as D3 domain pendclear source
10: LPTIM4 out selected as D3 domain pendclear source
11: LPTIM5 out selected as D3 domain pendclear source

20.6.13 EXTI rising trigger selection register (EXTI_RTSR3)

Address offset: 0x40

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TR86	TR85	Res.	Res.	Res.	Res.	Res.
									rw	rw					
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:21 **TR[86:85]:** Rising trigger event configuration bit of Configurable Event input x+64.(1)

0: Rising trigger disabled (for Event and Interrupt) for input line
1: Rising trigger enabled (for Event and Interrupt) for input line

Bits 20:0 Reserved, must be kept at reset value.

1. The Configurable event inputs are edge triggered, no glitch must be generated on these inputs.
If a rising edge on the Configurable event input occurs during writing of the register, the associated pending bit will not be set.
Rising and falling edge triggers can be set for the same Configurable Event input. In this case, both edges generate a trigger.

20.6.14 EXTI falling trigger selection register (EXTI_FTSR3)

Address offset: 0x44

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TR86	TR85	Res.	Res.	Res.	Res.	Res.
									rw	rw					
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:21 **TR[86:85]:** Falling trigger event configuration bit of Configurable Event input x+64.(1)
0: Falling trigger disabled (for Event and Interrupt) for input line
1: Falling trigger enabled (for Event and Interrupt) for input line

Bits 20:0 Reserved, must be kept at reset value.

1. The Configurable event inputs are edge triggered, no glitch must be generated on these inputs.
If a falling edge on the Configurable event input occurs during writing of the register, the associated pending bit will not be set.
Rising and falling edge triggers can be set for the same Configurable Event input. In this case, both edges generate a trigger.

20.6.15 EXTI software interrupt event register (EXTI_SWIER3)

Address offset: 0x48

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWIER 86	SWIER 85	Res.	Res.	Res.	Res.	Res.
									rw	rw					

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:21 **SWIER[86:85]:** Software interrupt on line x+64
Will alway return 0 when read.
0: Writing 0 has no effect.
1: Writing a 1 to this bit will trigger an event on line x. This bit is auto cleared by HW.

Bits 20:0 Reserved, must be kept at reset value.

20.6.16 EXTI D3 pending mask register (EXTI_D3PMR3)

Address offset: 0x4C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	MR88	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
							rw								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **MR88:** D3 Pending Mask on Event input x+64

0: D3 Pending request from Line x+64 is masked. Writing this bit to 0 will also clear the D3 Pending request.
1: D3 Pending request from Line x+64 is unmasked. The D3 domain pending signal when triggered will keep D3 domain wakeup active until cleared.

Bits 23:0 Reserved, must be kept at reset value.

20.6.17 EXTI D3 pending clear selection register high (EXTI_D3PCR3H)

Address offset: 0x54

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCS88[1:0]	
														rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:16 **PCS88[1:0]:** D3 Pending request clear input signal selection on Event input x= truncate ((n+160)/2)

00: DMA ch6 event selected as D3 domain pendclear source
01: DMA ch7 event selected as D3 domain pendclear source
10: LPTIM4 out selected as D3 domain pendclear source
11: LPTIM5 out selected as D3 domain pendclear source

Bits 15:0 Reserved, must be kept at reset value.

20.6.18 EXTI interrupt mask register (EXTI_CPUIMR1)

Address offset: 0x80

Reset value: 0xFFC0 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MR31	MR30	MR29	MR28	MR27	MR26	MR25	MR24	MR23	MR22	MR21	MR20	MR19	MR18	MR17	MR16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MR15	MR14	MR13	MR12	MR11	MR10	MR9	MR8	MR7	MR6	MR5	MR4	MR3	MR2	MR1	MR0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 **MR[31:22]:** CPU interrupt Mask on Direct Event input x(1)
0: Interrupt request from Line x is masked
1: Interrupt request from Line x is unmasked

Bits 21:0 **MR[21:0]:** CPU interrupt Mask on Configurable Event input x (2)
0: Interrupt request from Line x is masked
1: Interrupt request from Line x is unmasked

1. The reset value for Direct Event inputs is set to '1' in order to enable the interrupt by default.
2. The reset value for Configurable Event inputs is set to '0' in order to disable the interrupt by default.

20.6.19 EXTI event mask register (EXTI_CPUEMR1)

Address offset: 0x84

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MR31	MR30	MR29	MR28	MR27	MR26	MR25	MR24	MR23	MR22	MR21	MR20	MR19	MR18	MR17	MR16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MR15	MR14	MR13	MR12	MR11	MR10	MR9	MR8	MR7	MR6	MR5	MR4	MR3	MR2	MR1	MR0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MR[31:0]:** CPU Event mask on Event input x
0: Event request from Line x is masked
1: Event request from Line x is unmasked

20.6.20 EXTI pending register (EXTI_CPUPR1)

Address offset: 0x88

Reset value: undefined

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PR21	PR21	PR19	PR18	PR17	PR16
										rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PR15	PR14	PR13	PR12	PR11	PR10	PR9	PR8	PR7	PR6	PR5	PR4	PR3	PR2	PR1	PR0
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:0 **PR[21:0]:** Configurable event inputs x Pending bit
0: No trigger request occurred
1: selected trigger request occurred
This bit is set when the selected edge event arrives on the external interrupt line. This bit is cleared by writing a 1 into the bit or by changing the sensitivity of the edge detector.

20.6.21 EXTI interrupt mask register (EXTI_CPUIMR2)

Address offset: 0x90

Reset value: 0xFFF5 FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MR63	MR62	MR61	MR60	Res.	MR58	Res.	MR56	MR55	MR54	MR53	MR52	MR51	MR50	MR49	MR48
rw	rw	rw	rw		rw	1	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MR47	Res.	Res.	Res.	MR43	MR42	MR41	MR40	MR39	MR38	MR37	MR36	MR35	MR34	MR33	MR32
rw	1	1	1	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 **MR[63:60]:** CPU Interrupt Mask on Direct Event input x+32[1] (x = 63 to 60)
0: Interrupt request from Line x is masked
1: Interrupt request from Line x is unmasked

Bit 27 Reserved, must be kept at reset value[1].

Bit 26 **MR58:** CPU Interrupt Mask on Direct Event input 58+32[1]
0: Interrupt request from Line 58 is masked
1: Interrupt request from Line 58 is unmasked

Bit 25 Reserved, must be kept at reset value[1].

Bits 24:20 **MR[56:52]:** CPU Interrupt Mask on Direct Event input x+32[1] (x = 56 to 52)
0: Interrupt request from Line x is masked
1: Interrupt request from Line x is unmasked

Bit 19 **MR51:** CPU interrupt Mask on Configurable Event input 51+32 [2]
0: Interrupt request from Line 51 is masked
1: Interrupt request from Line 51 is unmasked

Bit 18 **MR50:** CPU Interrupt Mask on Direct Event input 50+32 [1]
0: Interrupt request from Line 50 is masked
1: Interrupt request from Line 50 is unmasked

Bit 17 **MR49:** CPU interrupt Mask on Configurable Event input 49+32 [2]
0: Interrupt request from Line 49 is masked
1: Interrupt request from Line 49 is unmasked

Bits 16:15 **MR[48:47]:** CPU Interrupt Mask on Direct Event input x+32 [1] (x = 48 to 47)
0: Interrupt request from Line x is masked
1: Interrupt request from Line x is unmasked

Bits 14:12 Reserved, must be kept at reset value[1].

Bits 11:0 **MR[43:32]:** CPU Interrupt Mask on Direct Event input x+32 [1] (x = 43 to 32)
0: Interrupt request from Line x is masked
1: Interrupt request from Line x is unmasked

1. The reset value for Direct Event inputs is set to ‘1’ in order to enable the interrupt by default.
2. The reset value for Configurable Event inputs is set to ‘0’ in order to disable the interrupt by default.

20.6.22 EXTI event mask register (EXTI_CPUEMR2)

Address offset: 0x94

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MR63	MR62	MR61	MR60	Res.	MR58	Res.	MR56	MR55	MR54	MR53	MR52	MR51	MR50	MR49	MR48
rw	rw	rw	rw		rw	0	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MR47	Res.	Res.	Res.	MR43	MR42	MR41	MR40	MR39	MR38	MR37	MR36	MR35	MR34	MR33	MR32
rw	0	0	0	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 **MR[63:60]:** CPU Event mask on Event input x+32 (x = 63 to 60)
0: Event request from Line x is masked
1: Event request from Line x is unmasked

Bit 27 Reserved, must be kept at reset value.

Bit 26 **MR[58]:** CPU Event mask on Event input 58+32
0: Event request from Line 58 is masked
1: Event request from Line 58 is unmasked

Bit 25 Reserved, must be kept at reset value.

Bits 24:14 **MR[56:47]:** CPU Event mask on Event input x+32 (x = 56 to 47)
0: Event request from Line x is masked
1: Event request from Line x is unmasked

Bits 14:12 Reserved, must be kept at reset value.

Bits 11:0 **MR[43:0]:** CPU Event mask on Event input x+32 (x = 43 to 0)
0: Event request from Line x is masked
1: Event request from Line x is unmasked

20.6.23 EXTI pending register (EXTI_CPUPR2)

Address offset: 0x98

Reset value: undefined

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PR51	Res.	PR49	Res.
												rc_w1		rc_w1	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **PR51:** Configurable event inputs 51+32 Pending bit
0: No trigger request occurred
1: selected trigger request occurred
This bit is set when the selected edge event arrives on the external interrupt line. This bit is cleared by writing a 1 into the bit or by changing the sensitivity of the edge detector.

Bit 18 Reserved, must be kept at reset value.

Bit 17 **PR49:** Configurable event inputs 49+32 Pending bit
0: No trigger request occurred
1: selected trigger request occurred
This bit is set when the selected edge event arrives on the external interrupt line. This bit is cleared by writing a 1 into the bit or by changing the sensitivity of the edge detector.

Bits 16:0 Reserved, must be kept at reset value.

20.6.24 EXTI interrupt mask register (EXTI_CPUIMR3)

Address offset: 0xA0

Reset value: 0x0F8B FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	MR91	MR90	MR89	MR88	MR87	MR86	MR85	Res.	Res.	Res.	Res.	MR80
				rw	rw	rw	rw	rw	rw	rw					rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	MR78	MR77	MR76	MR75	MR74	MR73	MR72	MR71	MR70	MR69	MR68	MR67	MR66	MR65	MR64
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:23 **MR[91:87]:** CPU Interrupt Mask on Direct Event input x+64 (1) (x = 91 to 87)
0: Interrupt request from Line x is masked
1: Interrupt request from Line x is unmasked

Bits 22:21 **MR[86:85]:** CPU interrupt Mask on Configurable Event input x+64 (2) (x = 86 to 85)
0: Interrupt request from Line x is masked
1: Interrupt request from Line x is unmasked

Bits 20:17 Reserved, must be kept at reset value.

Bit 16 **MR16:** CPU Interrupt Mask on Direct Event input 80+64 (1)
0: Interrupt request from Line 80 is masked
1: Interrupt request from Line 80 is unmasked

Bit 15 Reserved, must be kept at reset value.

Bits 14:0 **MR[78: 64]:** CPU Interrupt Mask on Direct Event input x+64 (1) (x = 78 to 64)
0: Interrupt request from Line x is masked
1: Interrupt request from Line x is unmasked

1. The reset value for Direct Event inputs is set to ‘1’ in order to enable the interrupt by default.
2. The reset value for Configurable Event inputs is set to ‘0’ in order to disable the interrupt by default.

20.6.25 EXTI event mask register (EXTI_CPUEMR3)

Address offset: 0xA4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	MR91	MR90	MR89	MR88	MR87	MR86	MR85	Res.	Res.	Res.	Res.	MR80
				rw	rw	rw	rw	rw	rw	rw					rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	MR78	MR77	MR76	MR75	MR74	MR73	MR72	MR71	MR70	MR69	MR68	MR67	MR66	MR65	MR64
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:21 **MR[91:21]:** CPU Event mask on Event input x+64 (x = 91 to 21)
0: Event request from Line x is masked
1: Event request from Line x is unmasked

Bits 20:17 Reserved, must be kept at reset value.

Bit 16 **MR80:** CPU Event mask on Event input 80+64
0: Event request from Line 80 is masked
1: Event request from Line 80 is unmasked

Bit 15 Reserved, must be kept at reset value.

Bits 14:0 **MR[78:64]:** CPU Event mask on Event input x+64 (x = 78to 64)
0: Event request from Line x is masked
1: Event request from Line x is unmasked

20.6.26 EXTI pending register (EXTI_CPUPR3)

Address offset: 0xA8

Reset value: undefined

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PR86	PR85	PR84	Res.	Res.	Res.	Res.
									rc_w1	rc_w1	rc_w1				

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:0 **PR[86:84]:** Configurable event inputs x+64 Pending bit (x = 86 to 84)
0: No trigger request occurred
1: selected trigger request occurred
This bit is set when the selected edge event arrives on the external interrupt line. This bit is cleared by writing a 1 into the bit or by changing the sensitivity of the edge detector.

20.6.27 EXTI register map

The following table gives the EXTI register map and the reset values.

Table 145. Asynchronous interrupt/event controller register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**EXTI_RTSR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TR[21:0]																					
	Reset value											0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	**EXTI_FTSR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TR[21:0]																					
	Reset value											0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	**EXTI_SWIER1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWIER[21:0]																					
	Reset value											0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	**EXTI_D3PMR1**	Res.	Res.	Res.	Res.	Res.	Res.	MR[25]	Res.	Res.	Res.	MR[21:19]			Res.	Res.	Res.	MR[15:0]															
	Reset value							0				0	0	0				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	**EXTI_D3PCR1L**	PCS[15]		PCS[14]		PCS[13]		PCS[12]		PCS[11]		PCS[10]		PCS[9]		PCS[8]		PCS[7]		PCS[6]		PCS[5]		PCS[4]		PCS[3]		PCS[2]		PCS[1]		PCS[0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	**EXTI_D3PCR1H**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCS[25]		Res.	Res.	Res.	Res.	Res.	Res.	PCS[21]		PCS[20]		PCS[19]		Res.	Res.	Res.	Res.	Res.	Res.
	Reset value													0	0							0	0	0	0	0	0						
0x20	**EXTI_RTSR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TR[51]	Res.	TR[49]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value													0		0																	
0x24	**EXTI_FTSR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TR[51]	Res.	TR[49]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value													0		0																	
0x28	**EXTI_SWIER2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWIER[51]	Res.	SWIER[49]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value													0		0																	
0x2C	**EXTI_D3PMR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MR[53:48]						Res.	Res.	Res.	Res.	Res.	Res.	MR[41]	Res.	Res.	Res.	Res.	Res.	MR[35]	MR[34]	Res.	Res.
	Reset value											0	0	0	0	0	0							0						0	0		
0x30	**EXTI_D3PCR2L**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCS[41]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCS[35]		PCS[34]		Res.	Res.	Res.	Res.
	Reset value													0	0											0	0	0	0				
0x34	**EXTI_D3PCR2H**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCS[53]		PCS[52]		PCS[51]		PCS[50]		PCS[49]		PCS[48]	
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x40	**EXTI_RTSR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TR[86]	TR[85]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value										0	0																					

Table 145. Asynchronous interrupt/event controller register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x44	**EXTI_FTSR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TR[86]	TR[85]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value										0	0																					
0x48	**EXTI_SWIER3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWIER[86]	SWIER[85]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value										0	0																					
0x4C	**EXTI_D3PMR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MR[88]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value								0																								
0x50	**EXTI_D3PCR3L**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																																
0x54	**EXTI_D3PCR3H**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCS[88]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value															0	0																
0x58-0x7C	Reserved																																
0x80	**EXTI_CPUIMR1**	MR[31:22]										MR[21:0]																					
	Reset value	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x84	**EXTI_CPUCPUEMR1**	MR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x88	**EXTI_CPUPR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PR[21:0]																					
	Reset value											0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x90	**EXTI_CPUIMR2**	MR[63:52]				Res.	MR[58]	Res.	MR[56:52]					MR[51]	MR[50]	MR[49]	MR[48:47]		Res.	Res.	Res.	MR[43:32]												
	Reset value	1	1	1	1		1		1	1	1	1	1	0	1	0	1	1				1	1	1	1	1	1	1	1	1	1	1	1
0x94	**EXTI_CPUEMR2**	MR[63:60]				Res.	MR[58]	Res.	MR[56:47]										Res.	Res.	Res.	MR[43:32]												
	Reset value	0	0	0	0		0		0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0
0x98	**EXTI_CPUPR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PR[51]	Res.	PR[49]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value													0		0																	
0xA0	**EXTI_CPUIMR3**	Res.	Res.	Res.	Res.	MR[91:85]						Res.	Res.	Res.	Res.	Res.	MR[80]	Res.	MR[78:64]															
	Reset value					1	1	1	1	1	0	0					1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0xA4	**EXTI_CPUEMR3**	Res.	Res.	Res.	Res.	MR[91:85]						Res.	Res.	Res.	Res.	Res.	MR[80]	Res.	MR[78:64]															
	Reset value								0	0	0	0			0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 145. Asynchronous interrupt/event controller register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xA8	**EXTI_CPUPR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PR[86]	PR[85]	PR[84]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value										0	0	0																				
0xAC-0xBC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Refer to *Section 2.3 on page 131* for the register boundary addresses.

21 Cyclic redundancy check calculation unit (CRC)

21.1 Introduction

The CRC (cyclic redundancy check) calculation unit is used to get a CRC code from 8-, 16- or 32-bit data word and a generator polynomial.

Among other applications, CRC-based techniques are used to verify data transmission or storage integrity. In the scope of the functional safety standards, they offer a means of verifying the Flash memory integrity. The CRC calculation unit helps compute a signature of the software during runtime, to be compared with a reference signature generated at link time and stored at a given memory location.

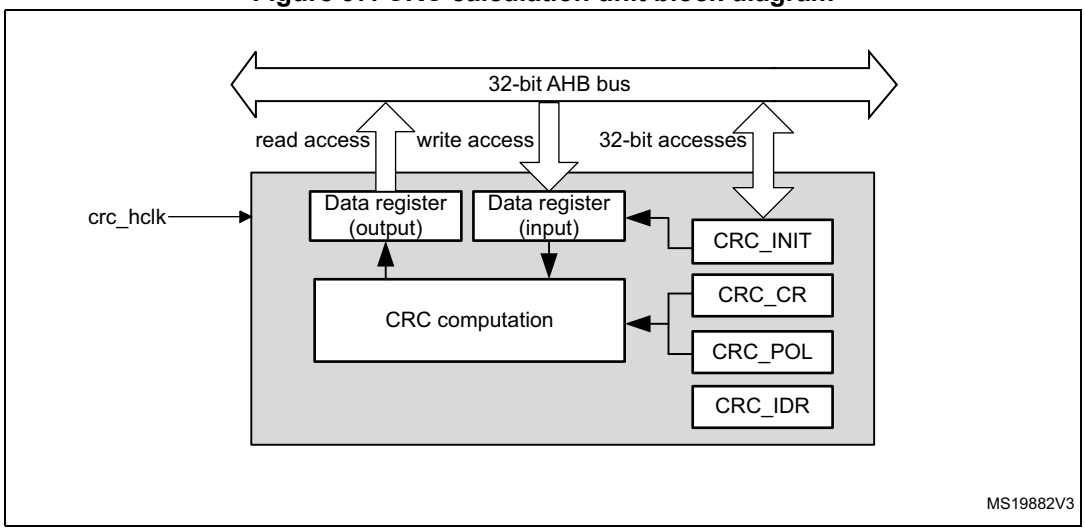
21.2 CRC main features

- Uses CRC-32 (Ethernet) polynomial: 0x4C11DB7
  $X^{32} + X^{26} + X^{23} + X^{22} + X^{16} + X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^5 + X^4 + X^2 + X + 1$
- Alternatively, uses fully programmable polynomial with programmable size (7, 8, 16, 32 bits)
- Handles 8-,16-, 32-bit data size
- Programmable CRC initial value
- Single input/output 32-bit data register
- Input buffer to avoid bus stall during calculation
- CRC computation done in 4 AHB clock cycles (HCLK) for the 32-bit data size
- General-purpose 8-bit register (can be used for temporary storage)
- Reversibility option on I/O data
- Accessed through AHB slave peripheral by 32-bit words only, with the exception of CRC_DR register that can be accessed by words, right-aligned half-words and right-aligned bytes

21.3 CRC functional description

21.3.1 CRC block diagram

Figure 97. CRC calculation unit block diagram



21.3.2 CRC internal signals

Table 146. CRC internal input/output signals

Signal name	Signal type	Description
crc_hclk	Digital input	AHB clock

21.3.3 CRC operation

The CRC calculation unit has a single 32-bit read/write data register (CRC_DR). It is used to input new data (write access), and holds the result of the previous CRC calculation (read access).

Each write operation to the data register creates a combination of the previous CRC value (stored in CRC_DR) and the new one. CRC computation is done on the whole 32-bit data word or byte by byte depending on the format of the data being written.

The CRC_DR register can be accessed by word, right-aligned half-word and right-aligned byte. For the other registers only 32-bit access is allowed.

The duration of the computation depends on data width:

- 4 AHB clock cycles for 32 bits
- 2 AHB clock cycles for 16 bits
- 1 AHB clock cycles for 8 bits

An input buffer allows a second data to be immediately written without waiting for any wait states due to the previous CRC calculation.

The data size can be dynamically adjusted to minimize the number of write accesses for a given number of bytes. For instance, a CRC for 5 bytes can be computed with a word write followed by a byte write.

The input data can be reversed, to manage the various endianness schemes. The reversing operation can be performed on 8 bits, 16 bits and 32 bits depending on the REV_IN[1:0] bits in the CRC_CR register.

For example: input data 0x1A2B3C4D is used for CRC calculation as:

- 0x58D43CB2 with bit-reversal done by byte
- 0xD458B23C with bit-reversal done by half-word
- 0xB23CD458 with bit-reversal done on the full word

The output data can also be reversed by setting the REV_OUT bit in the CRC_CR register.

The operation is done at bit level: for example, output data 0x11223344 is converted into 0x22CC4488.

The CRC calculator can be initialized to a programmable value using the RESET control bit in the CRC_CR register (the default value is 0xFFFFFFFF).

The initial CRC value can be programmed with the CRC_INIT register. The CRC_DR register is automatically initialized upon CRC_INIT register write access.

The CRC_IDR register can be used to hold a temporary value related to CRC calculation. It is not affected by the RESET bit in the CRC_CR register.

Polynomial programmability

The polynomial coefficients are fully programmable through the CRC_POL register, and the polynomial size can be configured to be 7, 8, 16 or 32 bits by programming the POLYSIZE[1:0] bits in the CRC_CR register. Even polynomials are not supported.

Note: The type of an even polynomial is $X+X^2+..+X^n$, while the type of an odd polynomial is $1+X+X^2+..+X^n$.

If the CRC data is less than 32-bit, its value can be read from the least significant bits of the CRC_DR register.

To obtain a reliable CRC calculation, the change on-fly of the polynomial value or size can not be performed during a CRC calculation. As a result, if a CRC calculation is ongoing, the application must either reset it or perform a CRC_DR read before changing the polynomial.

The default polynomial value is the CRC-32 (Ethernet) polynomial: 0x4C11DB7.

21.4 CRC registers

The CRC_DR register can be accessed by words, right-aligned half-words and right-aligned bytes. For the other registers only 32-bit accesses are allowed.

21.4.1 CRC data register (CRC_DR)

Address offset: 0x00

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DR[31:0]:** Data register bits

This register is used to write new data to the CRC calculator.
It holds the previous CRC calculation result when it is read.
If the data size is less than 32 bits, the least significant bits are used to write/read the correct value.

21.4.2 CRC independent data register (CRC_IDR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IDR[31:0]**: General-purpose 32-bit data register bits

These bits can be used as a temporary storage location for four bytes.
This register is not affected by CRC resets generated by the RESET bit in the CRC_CR register

21.4.3 CRC control register (CRC_CR)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REV_OUT	REV_IN[1:0]		POLYSIZE[1:0]		Res.	Res.	RESET
								rw	rw	rw	rw	rw			rs

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **REV_OUT**: Reverse output data

This bit controls the reversal of the bit order of the output data.
0: Bit order not affected
1: Bit-reversed output format

Bits 6:5 **REV_IN[1:0]**: Reverse input data

These bits control the reversal of the bit order of the input data
00: Bit order not affected
01: Bit reversal done by byte
10: Bit reversal done by half-word
11: Bit reversal done by word

Bits 4:3 **POLYSIZE[1:0]**: Polynomial size

These bits control the size of the polynomial.
00: 32 bit polynomial
01: 16 bit polynomial
10: 8 bit polynomial
11: 7 bit polynomial

Bits 2:1 Reserved, must be kept at reset value.

Bit 0 **RESET**: RESET bit

This bit is set by software to reset the CRC calculation unit and set the data register to the value stored in the CRC_INIT register. This bit can only be set, it is automatically cleared by hardware

21.4.4 CRC initial value (CRC_INIT)

Address offset: 0x10

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CRC_INIT[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CRC_INIT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CRC_INIT[31:0]**: *Programmable initial CRC value*

This register is used to write the CRC initial value.

21.4.5 CRC polynomial (CRC_POL)

Address offset: 0x14

Reset value: 0x04C1 1DB7

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
POL[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
POL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **POL[31:0]**: Programmable polynomial

This register is used to write the coefficients of the polynomial to be used for CRC calculation.

If the polynomial size is less than 32 bits, the least significant bits have to be used to program the correct value.

21.4.6 CRC register map

Table 147. CRC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**CRC_DR**	DR[31:0]																															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x04	**CRC_IDR**	IDR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	**CRC_CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REV_OUT	REV_IN[1:0]		POLYSIZE[1:0]		Res.	Res.	RESET
	Reset value																									0	0	0	0	0			0
0x10	**CRC_INIT**	CRC_INIT[31:0]																															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x14	**CRC_POL**	POL[31:0]																															
	Reset value	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	0	1	1	1	0	1	1	0	1	1	0	1	1	1

Refer to *Section 2.3 on page 131* for the register boundary addresses.

22 CORDIC co-processor (CORDIC)

22.1 CORDIC introduction

The CORDIC co-processor provides hardware acceleration of mathematical functions (mainly trigonometric ones) commonly used in motor control, metering, signal processing and many other applications.

It speeds up the calculation of these functions compared to a software implementation, making it possible the use of a lower operating frequency, or freeing up processor cycles in order to perform other tasks.

22.2 CORDIC main features

- 24-bit CORDIC rotation engine
- Circular and Hyperbolic modes
- Rotation and Vectoring modes
- Functions: sine, cosine, sinh, cosh, atan, atan2, atanh, modulus, square root, natural logarithm
- Programmable precision
- Low latency AHB slave interface
- Results can be read as soon as ready, without polling or interrupt
- DMA read and write channels
- Multiple register read/write by DMA

22.3 CORDIC functional description

22.3.1 General description

The CORDIC is a cost-efficient successive approximation algorithm for evaluating trigonometric and hyperbolic functions.

In trigonometric (circular) mode, the sine and cosine of an angle θ are determined by rotating the unit vector [1, 0] through decreasing angles until the cumulative sum of the rotation angles equals the input angle θ. The x and y cartesian components of the rotated vector then correspond, respectively, to the cosine and sine of θ. Inversely, the angle of a vector [x, y] corresponding to arctangent (y / x), is determined by rotating [x, y] through successively decreasing angles to obtain the unit vector [1, 0]. The cumulative sum of the rotation angles gives the angle of the original vector.

The CORDIC algorithm can also be used for calculating hyperbolic functions (sinh, cosh, atanh), by replacing the successive circular rotations by steps along a hyperbole.

Other functions can be derived from the basic functions described above.

22.3.2 CORDIC functions

The first step when using the co-processor is to select the required function, by programming the FUNC field of the CORDIC_CR register accordingly.

Table 148 lists the functions supported by the CORDIC co-processor.

Table 148. CORDIC functions

Function	Primary argument (ARG1)	Secondary argument (ARG2)	Primary result (RES1)	Secondary result (RES2)
Cosine	angle θ	modulus m	$m \cdot \cos\theta$	$m \cdot \sin\theta$
Sine	angle θ	modulus m	$m \cdot \sin\theta$	$m \cdot \cos\theta$
Phase	x	y	atan2(y,x)	$\sqrt{x^2 + y^2}$
Modulus	x	y	$\sqrt{x^2 + y^2}$	atan2(y,x)
Arctangent	x	none	$\tan^{-1} x$	none
Hyperbolic cosine	x	none	cosh x	sinh x
Hyperbolic sine	x	none	sinh x	cosh x
Hyperbolic arctangent	x	none	$\tanh^{-1} x$	none
Natural logarithm	x	none	ln x	none
Square root	x	none	$\sqrt{x}$	none

Several functions take two input arguments (ARG1 and ARG2) and some generate two results (RES1 and RES2) simultaneously. This is a side-effect of the algorithm and means that only one operation is needed to obtain two values. This is the case, for example, when performing polar-to-rectangular conversion: sin θ also generates cos θ, cos θ also generates sin θ. Similarly for rectangular-to-polar conversion (phase(x,y), modulus(x,y)) and for hyperbolic functions (cosh θ, sinh θ).

Note: The exponential function, exp x, can be obtained as the sum of sinh x and cosh x. Furthermore, base N logarithms, $\log_N x$, can be derived by multiplying ln x by a constant K, where K = 1/ln N.

For certain functions (atan, log, sqrt) a scaling factor (see *Section 22.3.4*) can be applied to extend the range of the function beyond the maximum [-1, 1] supported by the q1.31 fixed point format. The scaling factor must be set to 0 for all other circular functions, and to 1 for hyperbolic functions.

Cosine

Table 149. Cosine parameters

Parameter	Description	Range
ARG1	Angle θ in radians, divided by π	[-1, 1]
ARG2	Modulus m	[0, 1]
RES1	m · cos θ	[-1, 1]

Table 149. Cosine parameters (continued)

Parameter	Description	Range
RES2	m · sin θ	[-1, 1]
SCALE	Not applicable	0

This function calculates the cosine of an angle in the range -π to π. It can also be used to perform polar to rectangular conversion.

The primary argument is the angle θ in radians. It must be divided by π before programming ARG1.

The secondary argument is the modulus m. If m is greater than 1, a scaling must be applied in software to adapt it to the q1.31 range of ARG2.

The primary result, RES1, is the cosine of the angle, multiplied by the modulus.

The secondary result, RES2, is the sine of the angle, multiplied by the modulus.

Sine

Table 150. Sine parameters

Parameter	Description	Range
ARG1	Angle θ in radians, divided by π	[-1, 1]
ARG2	Modulus m	[0, 1]
RES1	m · sin θ	[-1, 1]
RES2	m · cos θ	[-1, 1]
SCALE	Not applicable	0

This function calculates the sine of an angle in the range -π to π. It can also be used to perform polar to rectangular conversion.

The primary argument is the angle θ in radians. It must be divided by π before programming ARG1.

The secondary argument is the modulus m. If m is greater than 1, a scaling must be applied in software to adapt it to the q1.31 range of ARG2.

The primary result, RES1, is the sine of the angle, multiplied by the modulus.

The secondary result, RES2, is the cosine of the angle, multiplied by the modulus.

Phase

Table 151. Phase parameters

Parameter	Description	Range
ARG1	x coordinate	[-1, 1]
ARG2	y coordinate	[-1, 1]
RES1	Phase angle θ in radians, divided by π	[-1, 1]

Table 151. Phase parameters (continued)

Parameter	Description	Range
RES2	Modulus m	[0, 1]
SCALE	Not applicable	0

This function calculates the phase angle in the range -π to π of a vector **v** = [x y] (also known as atan2(y,x). It can also be used to perform rectangular to polar conversion.

The primary argument is the x coordinate, that is, the magnitude of the vector in the direction of the x axis. If |x| > 1, a scaling must be applied in software to adapt it to the q1.31 range of ARG1.

The secondary argument is the y coordinate, that is, the magnitude of the vector in the direction of the y axis. If |y| > 1, a scaling must be applied in software to adapt it to the q1.31 range of ARG2.

The primary result, RES1, is the phase angle θ of the vector **v**. RES1 must be multiplied by π to obtain the angle in radians. Note that values close to π may sometimes wrap to -π due to the circular nature of the phase angle.

The secondary result, RES2, is the modulus, given by: $|v| = \sqrt{x^2 + y^2}$. If |**v**| > 1 the result in RES2 is saturated to 1.

Modulus

Table 152. Modulus parameters

Parameter	Description	Range
ARG1	x coordinate	[-1, 1]
ARG2	y coordinate	[-1, 1]
RES1	Modulus m	[0, 1]
RES2	Phase angle θ	[-1, 1]
SCALE	Not applicable	0

This function calculates the magnitude, or modulus, of a vector **v** = [x y]. It can also be used to perform rectangular to polar conversion.

The primary argument is the x coordinate, that is, the magnitude of the vector in the direction of the x axis. If |x| > 1, a scaling must be applied in software to adapt it to the q1.31 range of ARG1.

The secondary argument is the y coordinate, that is, the magnitude of the vector in the direction of the y axis. If |y| > 1, a scaling must be applied in software to adapt it to the q1.31 range of ARG2.

The primary result, RES1, is the modulus, given by: $|v| = \sqrt{x^2 + y^2}$. If |**v**| > 1 the result in RES1 is saturated to 1.

The secondary result, RES2, is the phase angle θ of the vector **v**. RES2 must be multiplied by π to obtain the angle in radians. Note that values close to π may sometimes wrap to -π due to the circular nature of the phase angle.

Arctangent

Table 153. Arctangent parameters

Parameter	Description	Range
ARG1	$x \cdot 2^{-n}$	[-1, 1]
ARG2	Not applicable	-
RES1	$2^{-n} \cdot \tan^{-1} x$, in radians, divided by p	[-1, 1]
RES2	Not applicable	-
SCALE	n	[0 7]

This function calculates the arctangent, or inverse tangent, of the input argument x.

The primary argument, ARG1, is the input value, $x = \tan \theta$. If $|x| > 1$, a scaling factor of 2^{-n} must be applied in software such that $-1 < x \cdot 2^{-n} < 1$. The scaled value $x \cdot 2^{-n}$ is programmed in ARG1 and the scale factor n must be programmed in the SCALE parameter.

Note that the maximum input value allowed is $\tan \theta = 128$, which corresponds to an angle $\theta = 89.55$ degrees. For $|x| > 128$, a software method must be used to find $\tan^{-1} x$.

The secondary argument, ARG2, is unused.

The primary result, RES1, is the angle $\theta = \tan^{-1} x$. RES1 must be multiplied by $2^n \cdot \pi$ to obtain the angle in radians.

The secondary result, RES2, is unused.

Hyperbolic cosine

Table 154. Hyperbolic cosine parameters

Parameter	Description	Range
ARG1	$x \cdot 2^{-n}$	[-0.559 0.559]
ARG2	Not applicable	-
RES1	$2^{-n} \cdot \cosh x$	[0.5 0.846]
RES2	$2^{-n} \cdot \sinh x$	[-0.683 0.683]
SCALE	n	1

This function calculates the hyperbolic cosine of a hyperbolic angle x. It can also be used to calculate the exponential functions $e^x = \cosh x + \sinh x$, and $e^{-x} = \cosh x - \sinh x$.

The primary argument is the hyperbolic angle x. Only values of x in the range -1.118 to +1.118 are supported. Since the minimum value of cosh x is 1, which is beyond the range of the q1.31 format, a scaling factor of 2^{-n} must be applied in software. The factor n = 1 must be programmed in the SCALE parameter.

The secondary argument is not used.

The primary result, RES1, is the hyperbolic cosine, cosh x. RES1 must be multiplied by 2 to obtain the correct result.

The secondary result, RES2, is the hyperbolic sine, sinh x. RES2 must be multiplied by 2 to obtain the correct result.

Hyperbolic sine

Table 155. Hyperbolic sine parameters

Parameter	Description	Range
ARG1	$x \cdot 2^{-n}$	[-0.559, 0.559]
ARG2	Not applicable	-
RES1	$2^{-n} \cdot \sinh x$	[-0.683, 0.683]
RES2	$2^{-n} \cdot \cosh x$	[0.5, 0.846]
SCALE	n	1

This function calculates the hyperbolic sine of a hyperbolic angle x. It can also be used to calculate the exponential functions e^x = cosh x + sinh x, and e^{-x} = cosh x- sinh x.

The primary argument is the hyperbolic angle x. Only values of x in the range -1.118 to +1.118 are supported. For all input values, a scaling factor of 2^{-n} must be applied in software, where n = 1. The scaled value x · 0.5 is programmed in ARG1 and the factor n = 1 must be programmed in the SCALE parameter.

The secondary argument is not used.

The primary result, RES1, is the hyperbolic sine, sinh x. RES1 must be multiplied by 2 to obtain the correct result.

The secondary result, RES2, is the hyperbolic cosine, cosh x. RES2 must be multiplied by 2 to obtain the correct result.

Hyperbolic arctangent

Table 156. Hyperbolic arctangent parameters

Parameter	Description	Range
ARG1	$x \cdot 2^{-n}$	[-0.403 0.403]
ARG2	Not applicable	-
RES1	$2^{-n} \cdot \text{atanh } x$	[-0.559 0.559]
RES2	Not applicable	-
SCALE	n	1

This function calculates the hyperbolic arctangent of the input argument x.

The primary argument is the input value x. Only values of x in the range -0.806 to +0.806 are supported. The value x must be scaled by a factor 2^{-n}, where n = 1. The scaled value

$x \cdot 0.5$ is programmed in ARG1 and the factor n = 1 must be programmed in the SCALE parameter.

The secondary argument is not used.

The primary result is the hyperbolic arctangent, atanh x. RES1 must be multiplied by 2 to obtain the correct value.

The secondary result is not used.

Natural logarithm

Table 157. Natural logarithm parameters

Parameter	Description	Range
ARG1	$x \cdot 2^{-n}$	[0.054 0.875]
ARG2	Not applicable	-
RES1	$2^{-(n+1)}.\ln x$	[-0.279 0.137]
RES2	Not applicable	-
SCALE	n	[1 4]

This function calculates the natural logarithm of the input argument x.

The primary argument is the input value x. Only values of x in the range 0.107 to 9.35 are supported. The value x must be scaled by a factor 2^{-n}, such that $x \cdot 2^{-n} < 1-2^{-n}$. The scaled value $x \cdot 2^{-n}$ is programmed in ARG1 and the factor n must be programmed in the SCALE parameter.

Table 158 lists the valid scaling factors, n, and the corresponding ranges of x and ARG1.

Table 158. Natural log scaling factors and corresponding ranges

n	x range	ARG1 range
1	$0.107 \leq x < 1$	$0.0535 \leq ARG1 < 0.5$
2	$1 \leq x < 3$	$0.25 \leq ARG1 < 0.75$
3	$3 \leq x < 7$	$0.375 \leq ARG1 < 0.875$
4	$7 \leq x \leq 9.35$	$0.4375 \leq ARG1 < 0.584$

The secondary argument is not used.

The primary result is the natural logarithm, ln x. RES1 must be multiplied by $2^{(n+1)}$ to obtain the correct value.

The secondary result is not used.

Square root

Table 159. Square root parameters

Parameter	Description	Range
ARG1	$x \cdot 2^{-n}$	[0.027 0.875]
ARG2	Not applicable	-
RES1	$2^{-n}\sqrt{x}$	[0.04 1]
RES2	Not applicable	-
SCALE	n	[0 2]

This function calculates the square root of the input argument x.

The primary argument is the input value x. Only values of x in the range 0.027 to 2.34 are supported. The value x must be scaled by a factor 2^{-n}, such that $x \cdot 2^{-n} < (1 - 2^{(-n-2)})$.

The scaled value $x \cdot 2^{-n}$ is programmed in ARG1 and the factor n must be programmed in the SCALE parameter.

Table 160 lists the valid scaling factors, n, and the corresponding ranges of x and ARG1.

Table 160. Square root scaling factors and corresponding ranges

n	x range	ARG1 range
0	$0.027 \leq x < 0.75$	0.027 ≤ ARG1 < 0.75
1	$0.75 \leq x < 1.75$	0.375 ≤ ARG1 < 0.875
2	$1.75 \leq x \leq 2.341$	0.4375 ≤ ARG1 ≤ 0.585

The secondary argument is not used.

The primary result is the square root of x. RES1 must be multiplied by 2^n to obtain the correct value.

The secondary result is not used.

22.3.3 Fixed point representation

The CORDIC operates in fixed point signed integer format. Input and output values can be either q1.31 or q1.15.

In q1.31 format, numbers are represented by one sign bit and 31 fractional bits (binary decimal places). The numeric range is therefore -1 (0x80000000) to $1 - 2^{-31}$ (0x7FFFFFFF).

In q1.15 format, the numeric range is 1 (0x8000) to $1 - 2^{-15}$ (0x7FFF). This format has the advantage that two input arguments can be packed into a single 32-bit write, and two results can be fetched in one 32-bit read.

22.3.4 Scaling factor

Several of the functions listed in *Section 22.3.2* specify a scaling factor, SCALE. This allows the function input range to be extended to cover the full range of values supported by the CORDIC, without saturating the input, output or internal registers. If the scaling factor is

required, it has to be calculated in software and programmed into the SCALE field of the CORDIC_CSR register. The input arguments must be scaled accordingly before programming the scaled values in the CORDIC_WDATA register. The scaling must also be undone on the results read from the CORDIC_RDATA register.

Note: The scaling factor entails a loss of precision due to truncation of the scaled value.

22.3.5 Precision

The precision of the result is dependent on the number of CORDIC iterations. The algorithm converges at a constant rate of one binary digit per iteration for trigonometric functions (sine, cosine, phase, modulus), see *Figure 98*.

For hyperbolic functions (hyperbolic sine, hyperbolic cosine, natural logarithm), the convergence rate is less constant due to the peculiarities of the CORDIC algorithm (see *Figure 99*). The square root function converges at roughly twice the speed of the hyperbolic functions (see *Figure 100*).

Figure 98. CORDIC convergence for trigonometric functions

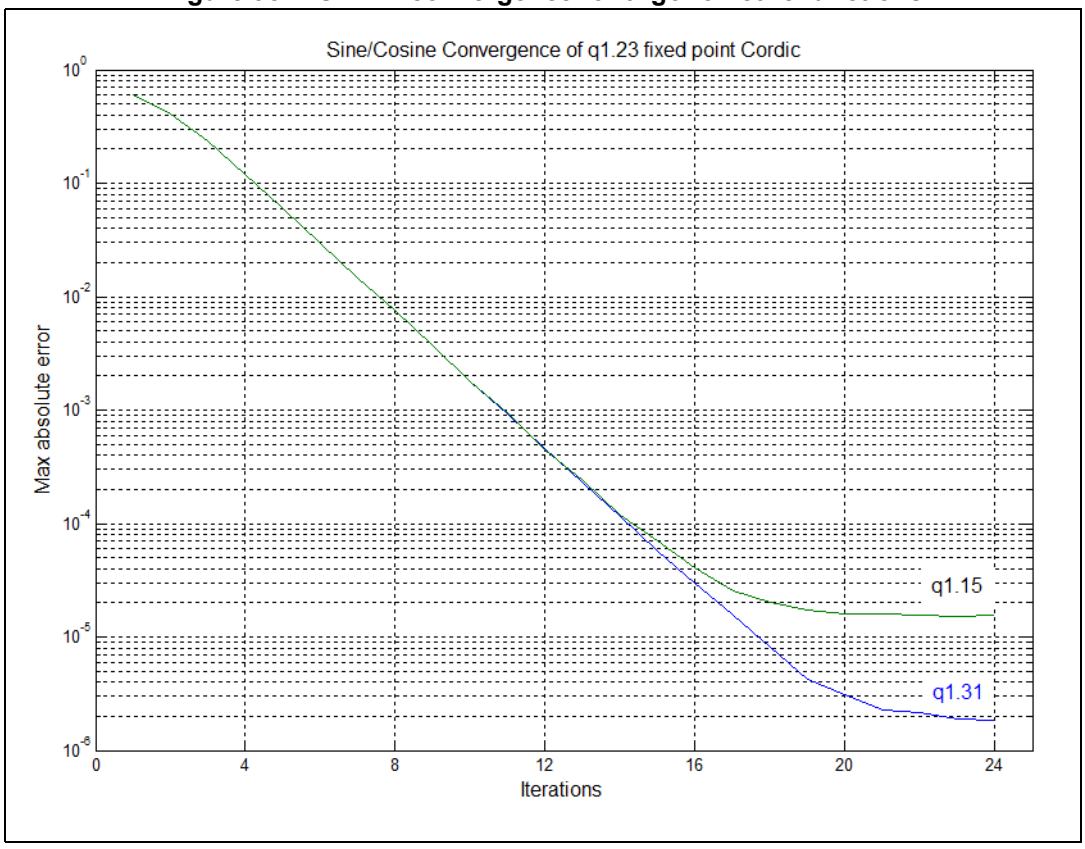


Figure 99. CORDIC convergence for hyperbolic functions

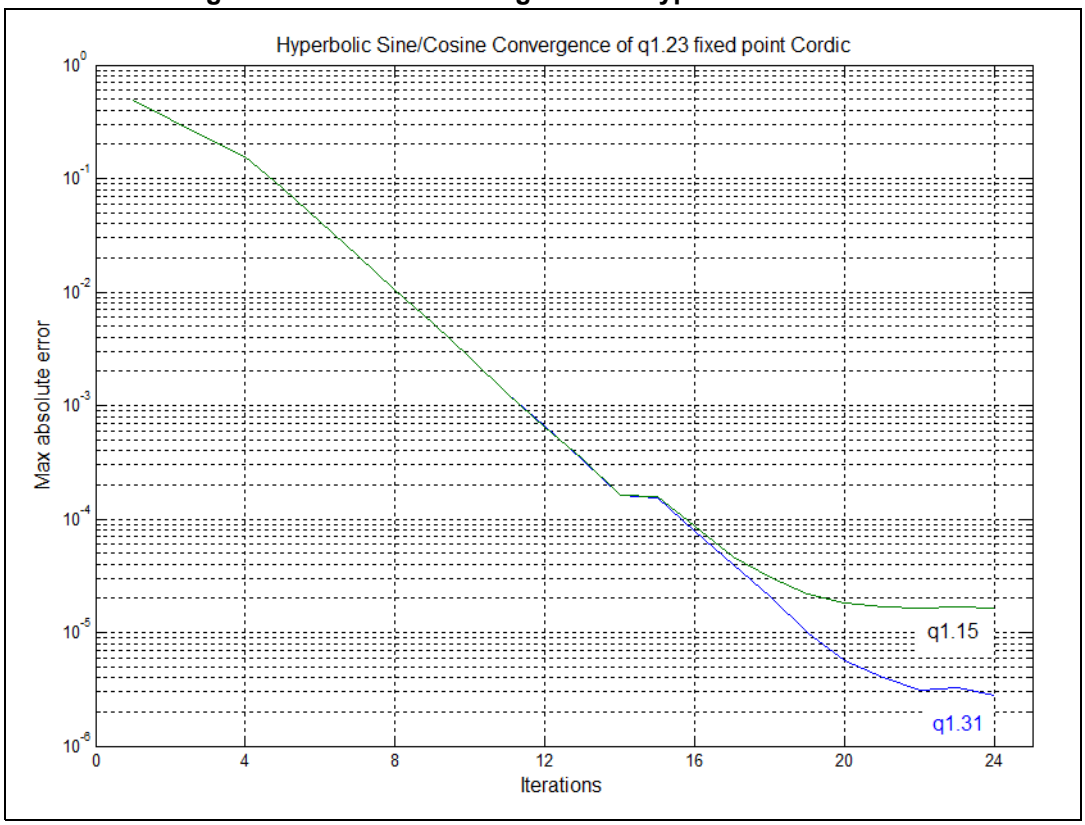
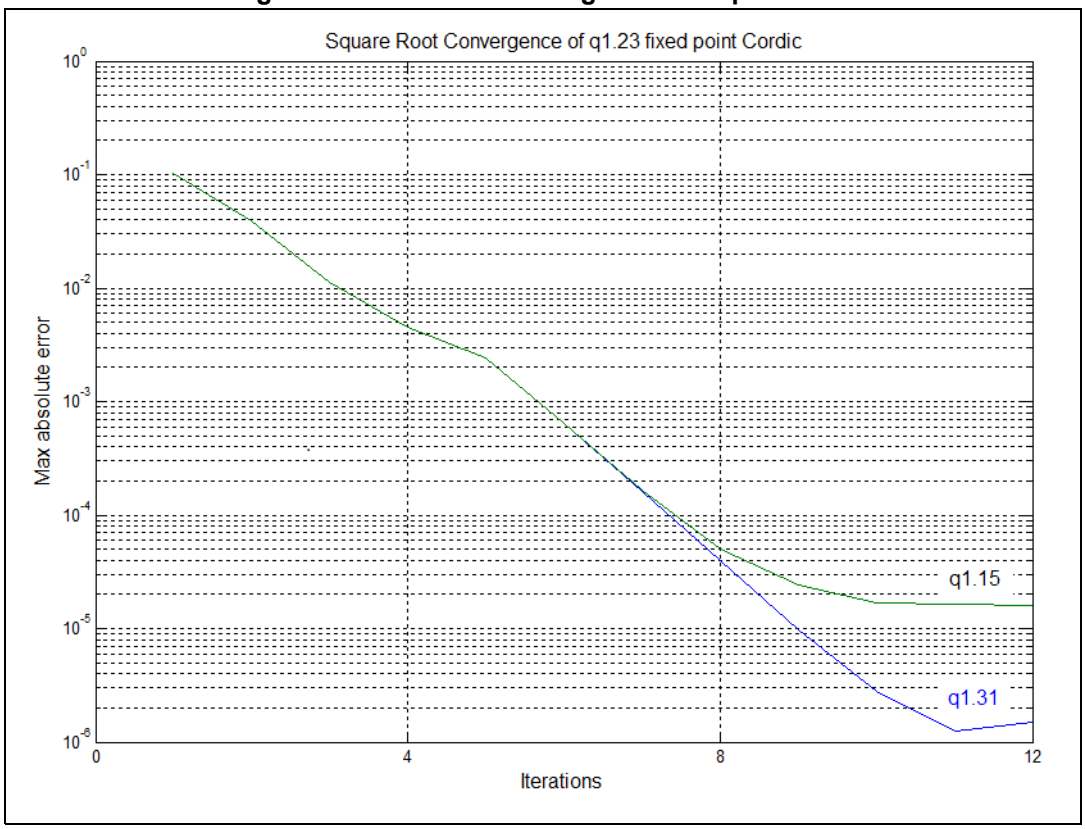


Figure 100. CORDIC convergence for square root



Note: The convergence rate decreases as the quantization error starts to become significant.

The CORDIC can perform four iterations per clock cycle. For each function, the maximum error remaining after every four iterations is shown in *Table 161*, together with the number of clock cycles required to reach that precision. From this table, the desired number of cycles can be determined and programmed in the PRECISION field of the CORDIC_CR register. The co-processor stops as soon as the programmed number of iterations has completed, and the result can be read immediately.

Table 161. Precision vs. number of iterations

Function	Number of iterations	Number of cycles	Max residual error(1)	
			q1.31 format	q1.15 format
Sin, Cos, Phase(2), Mod, Atan(4)	4	1	2^{-3}	2^{-3}
	8	2	2^{-7}	2^{-7}
	12	3	2^{-11}	2^{-11}
	16	4	2^{-15}	2^{-15}
	20	5	2^{-18}	2^{-16}
	24	6	2^{-19}	2^{-16}

Table 161. Precision vs. number of iterations (continued)

Function	Number of iterations	Number of cycles	Max residual error(1)	
			q1.31 format	q1.15 format
Sinh, Cosh, Atanh, Ln(3)	4	1	2^{-2}	2^{-2}
	8	2	2^{-6}	2^{-6}
	12	3	2^{-10}	2^{-10}
	16	4	2^{-13}	2^{-13}
	20	5	2^{-17}	2^{-15}
	24	6	2^{-18}	2^{-15}
Sqrt(4)	4	1	2^{-7}	2^{-7}
	8	2	2^{-14}	2^{-14}
	12	3	2^{-19}	2^{-15}

1. Max residual error is the maximum error remaining after the given number of iterations, compared to the identical calculation performed in double precision floating point. An additional rounding error may be incurred, of up to 2^{-16} for q15 format or 2^{-20} for q31 format.
2. For modulus > 0.5. The achievable precision reduces proportionally to the magnitude of the modulus, as quantization error becomes significant.
3. SCALE = 1. If a higher scaling factor is used, the achievable precision is reduced proportionally.
4. SCALE = 0. If a higher scaling factor is used, the achievable precision is reduced proportionally.

22.3.6 Zero-overhead mode

The fastest way to use the co-processor is to pre-program the CORDIC_CSR register with the function to be performed (FUNC), the desired number of clock cycles (PRECISION), the size of the input and output values (ARGSIZE, RESSIZE), the number of input arguments (NARGS) and/or results (NRES), and the scaling factor (SCALE), if applicable.

Subsequently, a calculation is triggered by writing the input arguments to the CORDIC_WDATA register. As soon as the correct number of input arguments has been written (and any ongoing calculation has finished) a new calculation is launched using these input arguments and the current CORDIC_CSR settings. There is no need to re-program the CORDIC_CSR register if there is no change.

If a dual 32-bit input argument is needed (ARGSIZE = 0, NARGS = 1), the primary input argument, ARG1, must be written first, followed by the secondary argument, ARG2. If the secondary argument remains unchanged for a series of calculations, the second write can be avoided, by reprogramming the number of arguments to one (NARGS = 0), once the first calculation has started. The secondary argument retains its programmed value as long as the function is not changed.

Note: ARG2 is set to +1 (0x7FFFFFFF) after a reset.

If two 16-bit arguments are used (ARGSIZE = 1) they must be packed into a 32-bit word, with ARG1 in the least significant half-word and ARG2 in the most significant half-word. The packed 32-bit word is then written to the CORDIC_WDATA register. Only one write is needed in this case (NARGS = 0).

For functions taking only one input argument, ARG1, it is recommended to set NARGS = 0. If NARGS = 1, a second write to CORDIC_WDATA must be performed to trigger the calculation. The ARG2 data in this case is not used.

Once the calculation starts, any attempt to read the CORDIC_RDATA register inserts bus wait states until the calculation is completed, before returning the result. Hence it is possible for the software to write the input and immediately read the result without polling to see if it is valid. Alternatively, the processor can wait for the appropriate number of clock cycles before reading the result. This time can be used to program the CORDIC_CSR register for the next calculation and prepare the next input data, if needed. The CORDIC_CSR register can be re-programmed while a calculation is in progress, without affecting the result of the ongoing calculation. In the same way, the CORDIC_WDATA register can be updated with the next argument(s) once the previous arguments have been taken into account. The next arguments and settings remain pending until the previous calculation has completed.

When a calculation is finished, the result(s) can be read from the CORDIC_RDATA register. If two 32-bit results are expected (NRES = 1, RESSIZE = 0), the primary result (RES1) is read out first, followed by the secondary result (RES2). If only one 32-bit result is expected (NRES = 0, RESSIZE = 0), then RES1 is output on the first read.

If 16-bit results are expected (RESSIZE = 1), a single read to CORDIC_RDATA fetches both results packed into a 32-bit word. RES1 is in the lower half-word, and RES2 in the upper half-word. In this case, it is recommended to program NRES = 0. IF NRES = 1, a second read of CORDIC_RDATA must be performed in order to free up the CORDIC for the next operation. The data from this second read must be discarded.

The next calculation starts when the expected number of results has been read, provided the expected number of arguments has been written. This means that at any time, there can be one calculation in progress, or waiting for the results to be read, and one operation pending. Any further access to CORDIC_WDATA while an operation is pending, cancels the pending operation and overwrite the data.

The following sequence summarizes the use of the CORDIC_IP in zero-overhead mode:

1. Program the CORDIC_CSR register with the appropriate settings
2. Program the argument(s) for the first calculation in the CORDIC_WDATA register. This launches the first calculation.
3. If needed, update the CORDIC_CSR register settings for the next calculation.
4. Program the argument(s) for the next calculation in the CORDIC_WDATA register.
5. Read the result(s) from the CORDIC_RDATA register. This triggers the next calculation.
6. Go to step *3*.

22.3.7 Polling mode

When a new result is available in the CORDIC_RDATA register, the RRDY flag is set in the CORDIC_CSR register. The flag can be polled by reading the register. It is reset by reading the CORDIC_RDATA register (once or twice depending on the NRES field of the CORDIC_CSR register).

Polling the RRDY flag takes slightly longer than reading the CORDIC_RDATA register directly, since the result is not read as soon as it is available. However the processor and bus interface are not stalled while reading the CORDIC_CSR register, so this mode may be of interest if stalling the processor is not acceptable (e.g. if low latency interrupts must be serviced).

22.3.8 Interrupt mode

By setting the interrupt enable (IE) bit in the CORDIC_CSR register, an interrupt is generated whenever the RRDY flag is set. The interrupt is cleared when the flag is reset.

This mode allows the result of the calculation to be read under interrupt service routine, and hence given a priority relative to other tasks. However it is slower than directly reading the result, or polling the flag, due to the interrupt handling delays.

22.3.9 DMA mode

If the DMA write enable (DMAWEN) bit is set in the CORDIC_CSR register, and no operation is pending, a DMA write channel request is generated. The DMA controller can transfer a primary input argument (ARG1) from memory into the CORDIC_WDATA register. Writing into the register deasserts the DMA request. If NARGS = 1 in the CORDIC_CSR register, a second DMA write channel request is generated to transfer the secondary input argument (ARG2) into the CORDIC_WDATA register. When all input arguments have been written, and any ongoing calculation has been completed (by reading the results), a new calculation is started and another DMA write channel request is generated.

If the DMA read enable (DMAREN) bit is set in the CORDIC_CSR register, the RRDY flag going active generates a DMA read channel request. The DMA controller can then transfer the primary result (RES1) from the CORDIC_RDATA register to memory. Reading the register deasserts the DMA request. If NRES = 1 in the CORDIC_CSR register, a second DMA request is generated to read out the secondary result (RES2). When all results have been read, the RRDY flag is deasserted.

The DMA read and write channels can be enabled separately. If both channels are enabled, the CORDIC can autonomously perform repeated calculations on a buffer of data without processor intervention.This allows the processor to perform other tasks. The DMA controller is operating in memory-to-peripheral mode for the write channel, and peripheral-to-memory mode for the read channel. Note that the sequence is started by the processor setting the DMAWEN flag. Thereafter the DMA read and write requests are generated as fast as the CORDIC can process the data.

In some cases, the input data may be stored in memory, and the output is transferred at regular intervals to another peripheral, such as a digital-to-analog converter. In this case, the destination peripheral generates a DMA request each time it needs a new data. The DMA controller can directly fetch the next sample from the CORDIC_RDATA register (in this case the DMA controller is operating in memory-to-peripheral mode, even though the source is a peripheral register). The act of reading the result allows the CORDIC to start a new calculation, which in turn generates a DMA write channel request, and the DMA controller transfers the next input value to the CORDIC_WDATA register. The DMA write channel is enabled (DMAWEN = 1), but the read channel must not be enabled.

In a similar way, data coming from another peripheral, such as an ADC, can be transferred directly to the CORDIC_WDATA register (in peripheral-to-memory mode). The DMA write channel must not be enabled. The CORDIC processes the input data and generate a DMA read request when complete, if DMAREN = 1. The DMA controller then transfers the result from CORDIC_RDATA register to memory (peripheral-to-memory mode).

Note: No DMA request is generated to program the CORDIC_CSR register. DMA mode is therefore only useful when repeatedly performing the same function with the same settings. The scale factor cannot be changed during a series of DMA transfers.

Note: Each DMA request must be acknowledged, as a result of the DMA performing an access to the CORDIC_WDATA or CORDIC_RDATA register. If an extraneous access to the relevant register occurs before this, the acknowledge is asserted prematurely, and could block the DMA channel. Therefore, when the DMA read channel is enabled, CPU access to the CORDIC_RDATA register must be avoided. Similarly, the processor must avoid accessing the CORDIC_WDATA register when the DMA write channel is enabled.

22.4 CORDIC registers

The CORDIC registers can only be accessed in 32-bit word format

22.4.1 CORDIC control/status register (CORDIC_CSR)

Address offset: 0x00

Reset value: 0x0000 0050

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RRDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARG SIZE	RES SIZE	NARG S	NRES	DMA WEN	DMA REN	IEN
r									rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	SCALE[2:0]			PRECISION[3:0]				FUNC[3:0]			
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **RRDY**: Result ready flag

0: No new result in output register

1: CORDIC_RDATA register contains new data.

This bit is set by hardware when a CORDIC operation completes. It is reset by hardware when the CORDIC_RDATA register is read (NRES+1) times.

When this bit is set, if the IEN bit is also set, the CORDIC interrupt is asserted. If the DMAREN bit is set, a DMA read channel request is generated. While this bit is set, no new calculation is started.

Bits 30:23 Reserved, must be kept at reset value.

Bit 22 **ARGSIZE**: Width of input data

0: 32-bit

1: 16-bit

ARGSIZE selects the number of bits used to represent input data.

If 32-bit data is selected, the CORDIC_WDATA register expects arguments in q1.31 format.

If 16-bit data is selected, the CORDIC_WDATA register expects arguments in q1.15 format. The primary argument (ARG1) is written to the least significant half-word, and the secondary argument (ARG2) to the most significant half-word.

Bit 21 **RESSIZE**: Width of output data

0: 32-bit

1: 16-bit

RESSIZE selects the number of bits used to represent output data.

If 32-bit data is selected, the CORDIC_RDATA register contains results in q1.31 format.

If 16-bit data is selected, the least significant half-word of CORDIC_RDATA contains the primary result (RES1) in q1.15 format, and the most significant half-word contains the secondary result (RES2), also in q1.15 format.

Bit 20 **NARGS**: Number of arguments expected by the CORDIC_WDATA register

0: Only one 32-bit write (or two 16-bit values if ARGSIZE = 1) is needed for the next calculation.

1: Two 32-bit values must be written to the CORDIC_WDATA register to trigger the next calculation.

Reads return the current state of the bit.

Bit 19 **NRES**: Number of results in the CORDIC_RDATA register

0: Only one 32-bit value (or two 16-bit values if RESSIZE = 1) is transferred to the CORDIC_RDATA register on completion of the next calculation. One read from CORDIC_RDATA resets the RRDY flag.

1: Two 32-bit values are transferred to the CORDIC_RDATA register on completion of the next calculation. Two reads from CORDIC_RDATA are necessary to reset the RRDY flag.

Reads return the current state of the bit.

Bit 18 **DMAWEN**: Enable DMA write channel

0: Disabled. No DMA write requests are generated.

1: Enabled. Requests are generated on the DMA write channel whenever no operation is pending

This bit is set and cleared by software. A read returns the current state of the bit.

Bit 17 **DMAREN**: Enable DMA read channel

0: Disabled. No DMA read requests are generated.

1: Enabled. Requests are generated on the DMA read channel whenever the RRDY flag is set.

This bit is set and cleared by software. A read returns the current state of the bit.

Bit 16 **IEN**: Enable interrupt.

0: Disabled. No interrupt requests are generated.

1: Enabled. An interrupt request is generated whenever the RRDY flag is set.

This bit is set and cleared by software. A read returns the current state of the bit.

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:8 **SCALE[2:0]**: Scaling factor

The value of this field indicates the scaling factor applied to the arguments and/or results. A value n implies that the arguments have been multiplied by a factor 2^{-n}, and/or the results need to be multiplied by 2^{n}. Refer to *Section 22.3.2* for the applicability of the scaling factor for each function and the appropriate range.

Bits 7:4 **PRECISION[3:0]**: Precision required (number of iterations)

0: reserved

1 to 15: (Number of iterations)/4

To determine the number of iterations needed for a given accuracy refer to *Table 161*.

Note that for most functions, the recommended range for this field is 3 to 6.

Bits 3:0 **FUNC[3:0]**: Function

0: Cosine
1: Sine
2: Phase
3: Modulus
4: Arctangent
5: Hyperbolic cosine
6: Hyperbolic sine
7: Arctanh
8: Natural logarithm
9: Square Root
10 to 15: reserved

22.4.2 CORDIC argument register (CORDIC_WDATA)

Address offset: 0x04

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ARG[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARG[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **ARG[31:0]**: Function input arguments

This register is programmed with the input arguments for the function selected in the CORDIC_CSR register FUNC field.

If 32-bit format is selected (CORDIC_CSR.ARGSIZE = 0) and two input arguments are required (CORDIC_CSR.NARGS = 1), two successive writes are required to this register. The first writes the primary argument (ARG1), the second writes the secondary argument (ARG2).

If 32-bit format is selected and only one input argument is required (NARGS = 0), only one write is required to this register, containing the primary argument (ARG1).

If 16-bit format is selected (CORDIC_CSR.ARGSIZE = 1), one write to this register contains both arguments. The primary argument (ARG1) is in the lower half, ARG[15:0], and the secondary argument (ARG2) is in the upper half, ARG[31:16]. In this case, NARGS must be set to 0.

Refer to *Section 22.3.2* for the arguments required by each function, and their permitted range.

When the required number of arguments has been written, the CORDIC evaluates the function designated by CORDIC_CSR.FUNC using the supplied input arguments, provided any previous calculation has completed. If a calculation is ongoing, the ARG1 and ARG 2 values are held pending until the calculation is completed and the results read. During this time, a write to the register cancels the pending operation and overwrite the argument data.

22.4.3 CORDIC result register (CORDIC_RDATA)

Address offset: 0x8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RES[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RES[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RES[31:0]**: Function result

If 32-bit format is selected (CORDIC_CSR.RESSIZE = 0) and two output values are expected (CORDIC_CSR.NRES = 1), this register must be read twice when the RRDY flag is set. The first read fetches the primary result (RES1). The second read fetches the secondary result (RES2) and resets RRDY.

If 32-bit format is selected and only one output value is expected (NRES = 0), only one read of this register is required to fetch the primary result (RES1) and reset the RRDY flag.

If 16-bit format is selected (CORDIC_CSR.RESSIZE = 1), this register contains the primary result (RES1) in the lower half, RES[15:0], and the secondary result (RES2) in the upper half, RES[31:16]. In this case, NRES must be set to 0, and only one read performed.

A read from this register resets the RRDY flag in the CORDIC_CSR register.

22.4.4 CORDIC register map

Table 162. CORDIC register map and reset value

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	CORDIC_CSR	RRDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARGSIZE	RESSIZE	NARGS	NRES	DMAWEN	DMAREN	IEN	Res.	Res.	Res.	Res.	SCALE [2:0]				PRECISION [3:0]				FUNC [3:0]			
	Reset value	0									0	0	0	0	0	0	0					0	0	0	0	0	1	0	1	0	0	0	0
0x04	CORDIC_WDATA	ARG[31:0]																															
	Reset value	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
0x08	CORDIC_RDATA	RES[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3* for the register boundary addresses.

23 Filter math accelerator (FMAC)

23.1 FMAC introduction

The filter math accelerator unit performs arithmetic operations on vectors. It comprises a multiplier/accumulator (MAC) unit, together with address generation logic which allows it to index vector elements held in local memory.

The unit includes support for circular buffers on input and output, which allows digital filters to be implemented. Both finite and infinite impulse response filters can be realized.

The unit allows frequent or lengthy filtering operations to be offloaded from the CPU, freeing up the processor for other tasks. In many cases it can accelerate such calculations compared to a software implementation, resulting in a speed-up of time critical tasks.

23.2 FMAC main features

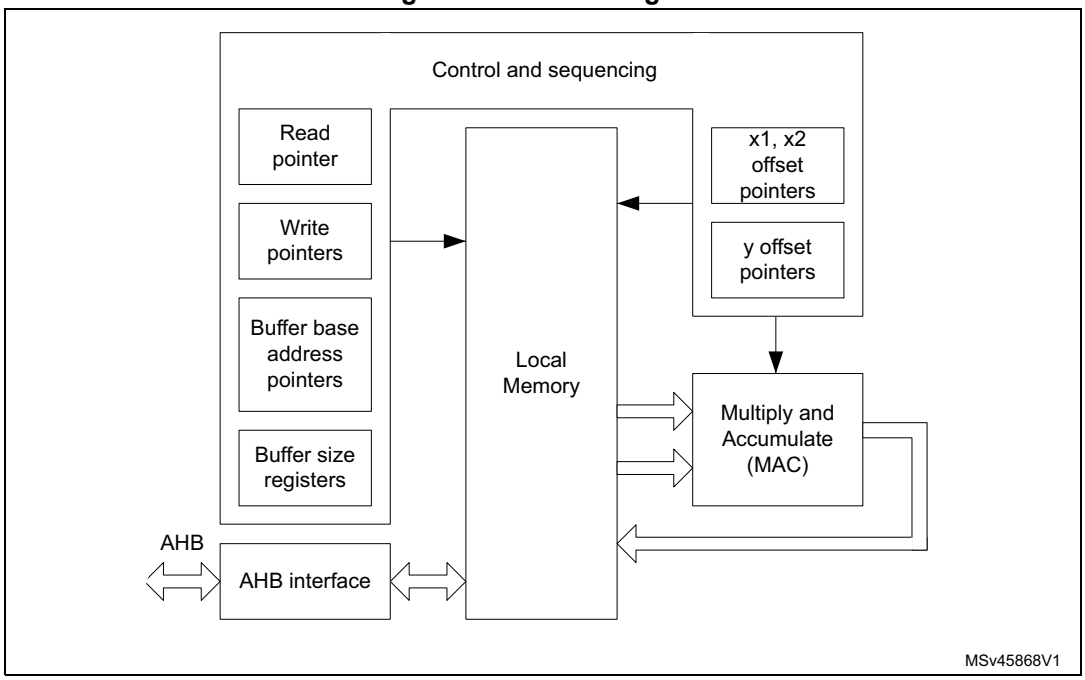
- 16 x 16-bit multiplier
- 24 + 2-bit accumulator with addition and subtraction
- 16-bit input and output data
- 256 x 16-bit local memory
- Up to three areas can be defined in memory for data buffers (two input, one output), defined by programmable base address pointers and associated size registers
- Input and output buffers can be circular
- Filter functions: FIR, IIR (direct form 1)
- Vector functions: Dot product, convolution, correlation
- AHB slave interface
- DMA read and write data channels

23.3 FMAC functional description

23.3.1 General description

The FMAC is shown in *Figure 101*.

Figure 101. Block diagram



The unit is built around a fixed point multiplier and accumulator (MAC). The MAC can take two 16-bit input signed values from memory, multiply them together and add them to the contents of the accumulator. The address of the input values in memory is determined using a set of pointers. These pointers can be loaded, incremented, decremented or reset by the internal hardware. The pointer and MAC operations are controlled by a built-in sequencer in order to execute the requested operation.

To calculate a dot product, the two input vectors are loaded into the local memory by the processor or DMA controller, and the requested operation is selected and started. Each pair of input vector elements is fetched from memory, multiplied together and accumulated. When all the vector elements have been processed, the contents of the accumulator are stored in the local memory, from where they can be read out by the processor or DMA.

The finite impulse response (FIR) filter operation (also known as convolution) consists in repeatedly calculating the dot product of the coefficient vector and a vector of input samples, the latter being shifted by one sample delay, with the least recent sample being discarded and a new sample added, at each repetition.

The infinite impulse response (IIR) filter operation is the convolution of the feedback coefficients with the previous output samples, added to the result of the FIR convolution.

A more detailed description of the filter operations is given in *Section 23.3.6: Filter functions*.

23.3.2 Local memory and buffers

The unit contains a 256 x 16-bit read/write memory which is used for local storage:

- Input values (the elements of the input vectors) are stored in two buffers, X1 and X2.
- Output values (the results of the operations) are stored in another buffer, Y.
- The locations and sizes of the buffers are designated as follows:
  - x1_base: the base address of the X1 buffer
  - x2_base: the base address of the X2 buffer
  - y_base: the base address of the Y buffer
  - x1_buf_size: the number of 16-bit addresses allocated to the X1 buffer
  - x2_buf_size: the number of 16-bit addresses allocated to the X2 buffer
  - y_buf_size: the number of 16-bit addresses allocated to the Y buffer.

These parameters are programmed in the corresponding registers when configuring the unit.

The CPU (or DMA controller) can initialize the contents of each buffer using the Initialization functions (*Section 23.3.5: Initialization functions*) and writing to the write data register. The data is transferred to the location within the target buffer indicated by a write pointer. After each new write, the write pointer is incremented. When the write pointer reaches the end of the allocated buffer space, it wraps back to the base address. This feature is used to load the elements of a vector prior to an operation, or to initialize a filter and load filter coefficients.

Buffer configuration

The buffer sizes and base address offsets must be configured in the X1, X2 and Y buffer configuration registers. For each function, the required buffer size is specified in the function description in *Section 23.3.6: Filter functions*. The base addresses can be chosen anywhere in internal memory, provided that all buffers fit within the internal memory address range (0x00 to 0xFF), that is, base address + buffer size must be less than 256.

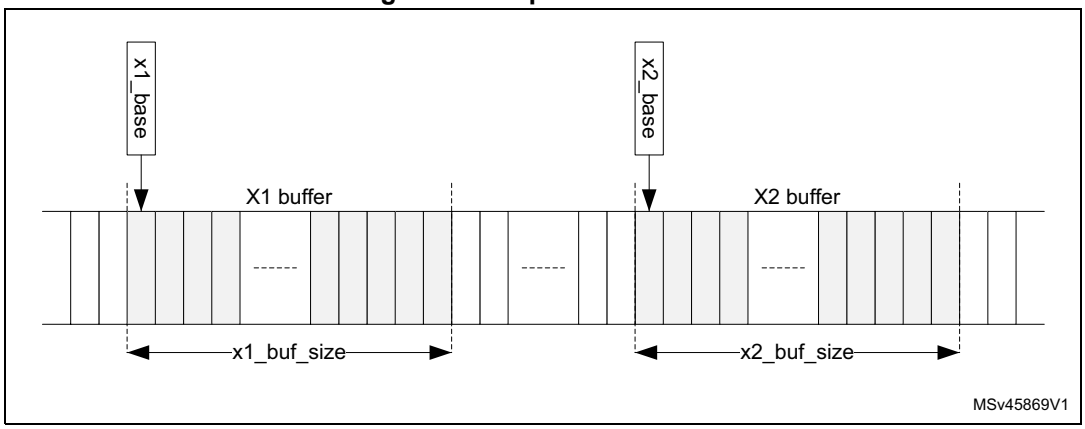
There is no constraint on the size and location of the buffers (they can overlap or even coincide exactly). For filter functions it is recommended not to overlap buffers as this can lead to erroneous behavior.

When circular buffer operation is required, an optional “headroom”, d, can be added to the buffer size. Furthermore, a watermark level can be set, to regulate the CPU or DMA activity. The value of d and the watermark level should be chosen according to the application performance requirements. For maximum throughput, the input buffer should never go empty, so d should be somewhat greater than the watermark level, allowing for any interrupt or DMA latency. On the other hand, if the input data can not be provided as fast as the unit can process them, the buffer can be allowed to empty waiting for the next data to be written, so d can be equal to the watermark level (to ensure that no overflow occurs on the input).

23.3.3 Input buffers

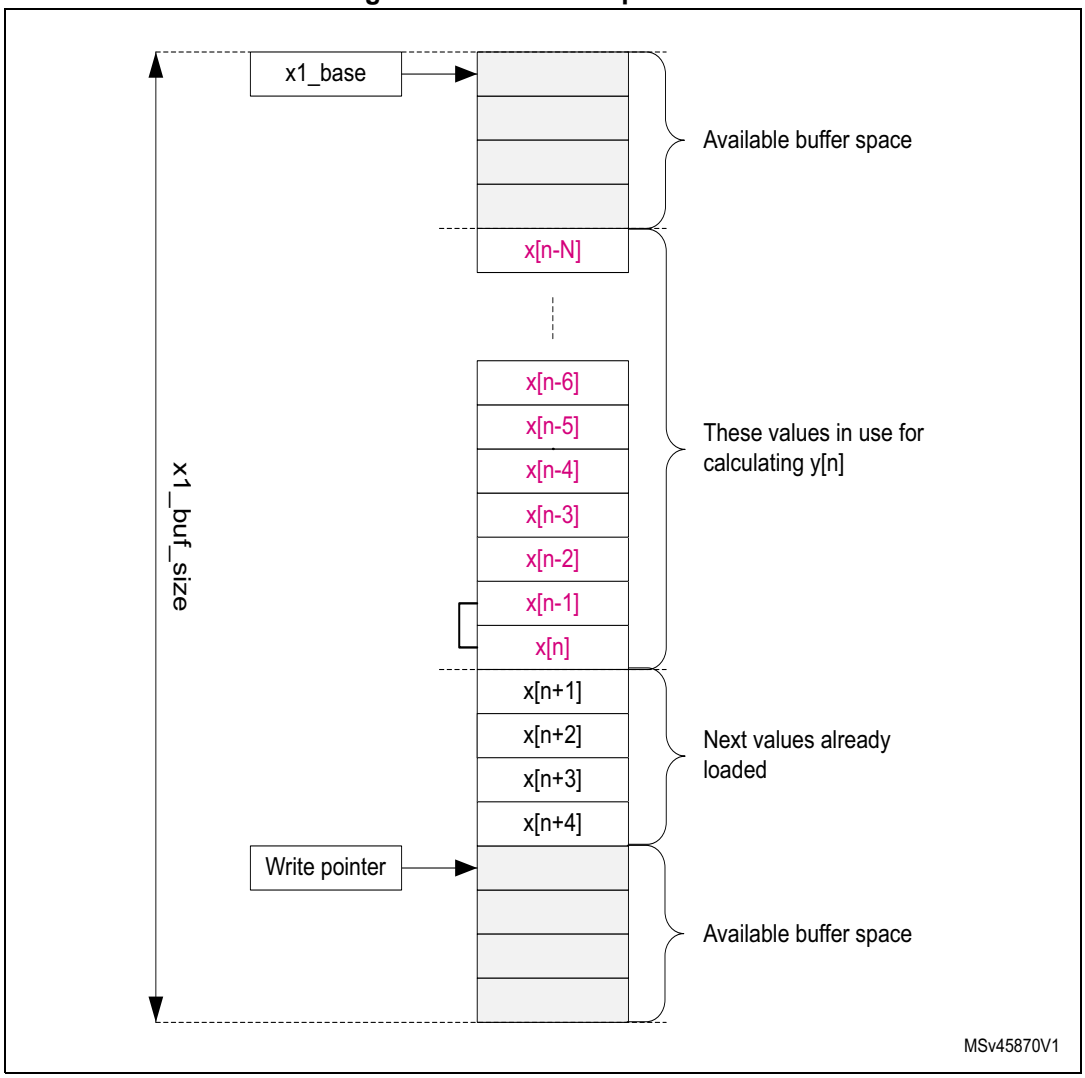
The X1 and X2 buffers are used to store data for input to the MAC. Each multiplication takes a value from the X1 buffer and a value from the X2 buffer and multiplies them together. A pointer in the control unit generates the read address offset (relative to the buffer base address) for each value. The pointers are managed by hardware according to the current function.

Figure 102. Input buffer areas



The X1 buffer can be used as a circular buffer, in which case new data are continually transferred into the input buffer whenever space is available. Pre-loading this buffer is optional for digital filters, since if no input samples have been written in the buffer when the operation is started, it is flagged as empty, which triggers the CPU or DMA to load new samples until there are enough to begin operation. Pre-loading is nevertheless useful in the case of a vector operation, that is, the input data is already available in system memory and circular operation is not required.

Figure 103. Circular input buffer



The X2 buffer can only be used in vector mode (that is not circular), and needs to be pre-loaded, except if the contents of the buffer do not change from one operation to the next. For filter functions, the X2 buffer is used to store the filter coefficients.

When operating as a circular buffer, the space allocated to the buffer (x1_buf_size) should generally be bigger than the number of elements in use for the current calculation, so that there are always new values available in the buffer. *Figure 103* illustrates the layout of the buffer for a filter operation. While calculating an output sample y[n], the unit uses a set of N+1 input samples, x[n-N] to x[n]. When this is finished, the unit starts the calculation of y[n+1], using the set of input samples x[n-N+1] to x[n+1]. The least-recent input sample, x[n-N], drops out of the input set, and a new sample, x[n+1], is added to it.

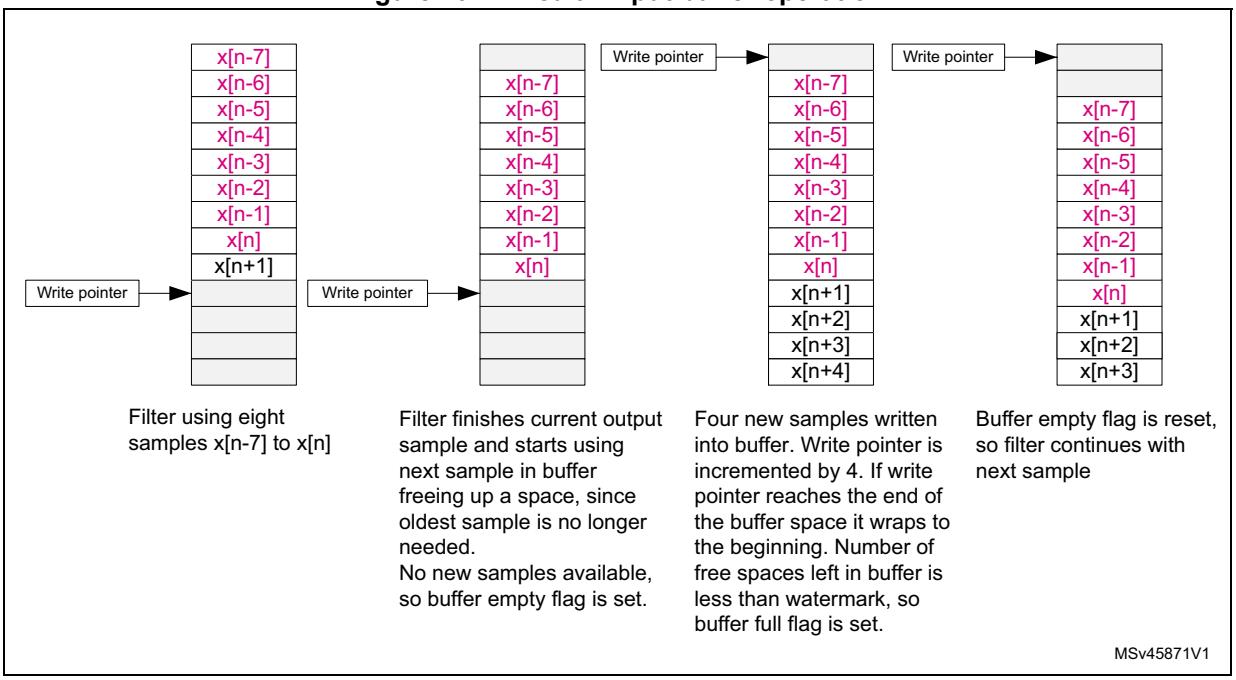
The processor, or DMA controller, must ensure that the new sample x[n+1] is available in the buffer space when required. If not, the buffer is flagged as empty, which stalls the execution of the unit until a new sample is added. No underflow condition is signaled on the X1 buffer.

Note: If the flow of samples is controlled by a timer or other peripheral such as an ADC, the buffer regularly goes empty, since the filter processes each new sample faster than the source can provide it. This is an essential feature of filter operation.

If the number of free spaces in the buffer is less than the watermark threshold programmed in the FULL_WM bitfield of the FMAC_X1BUFCFG register, the buffer is flagged as full. As long as the full flag is not set, interrupts are generated, if enabled, to request more data for the buffer. The watermark allows several data to be transferred under one interrupt, without danger of overflow. Nevertheless, if an overflow does occur, the OVFL error flag is set and the write data is ignored. The write pointer is not incremented in the event of an overflow.

The operation of the X1 buffer during a filtering operation is illustrated in *Figure 104*. This example shows an 8-tap FIR filter with a watermark set to four.

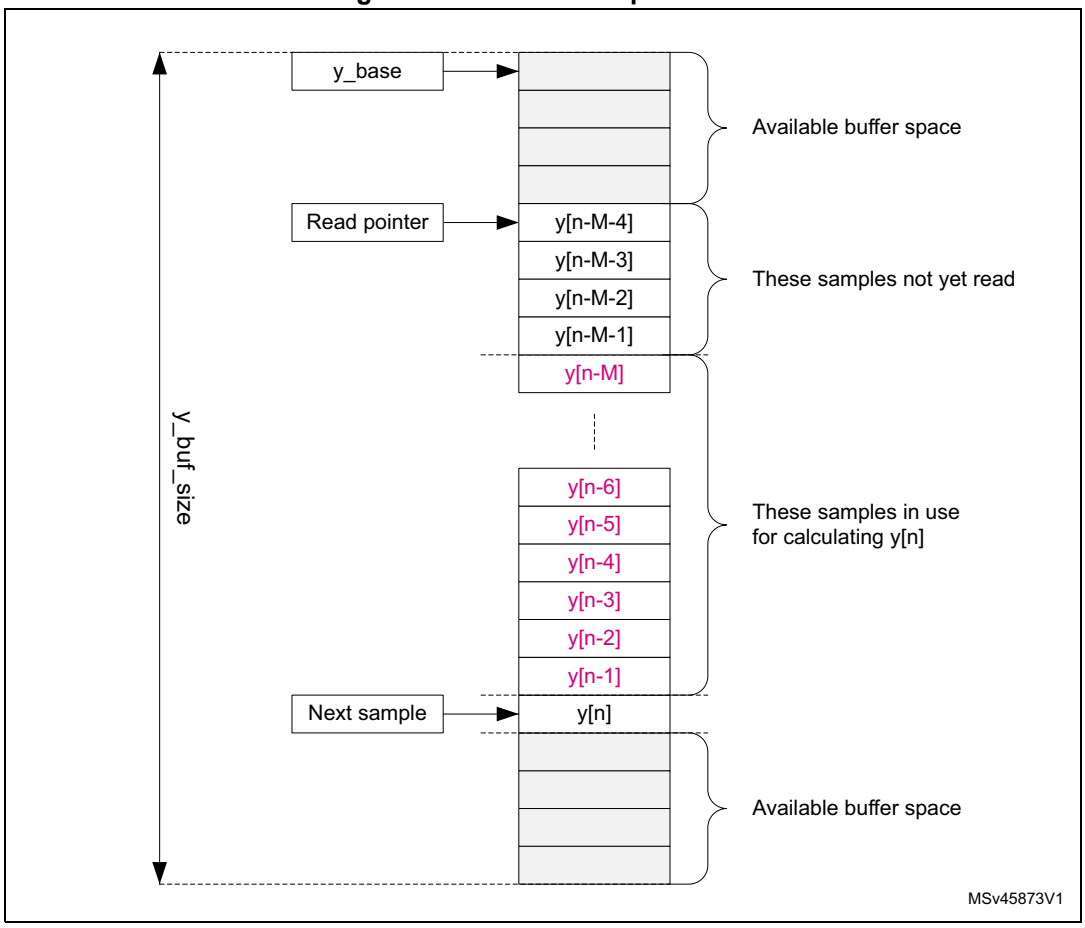
Figure 104. Circular input buffer operation



23.3.4 Output buffer

The Y (output) buffer is used to store the output of an accumulation. Each new output value is stored in the buffer until it is read by the processor or DMA controller. Each time a read access is made to the read data register, the read data is fetched from the address indicated by the read pointer. This pointer is incremented after each read, and wraps back to the base address when it reaches the end of the allocated Y buffer space.

Figure 105. Circular output buffer



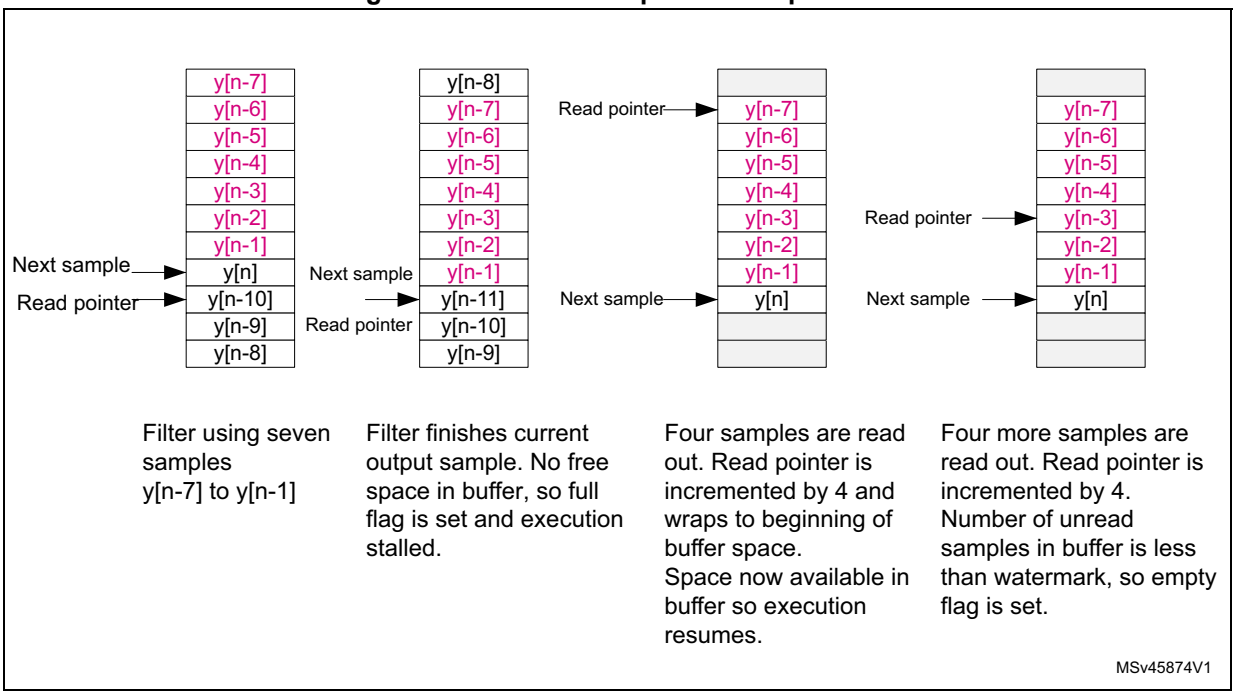
The Y buffer can also operate as a circular buffer. If the address for the next output value is the same as that indicated by the read pointer (an unread sample), then the buffer is flagged as full and execution stalled until the sample is read.

In the case of IIR filters, the Y buffer is used to store the set of M previous output samples, y[n-M] to y[n-1], used for calculating the next output sample y[n]. Each time a new sample is added to the set, the least recent sample y[n-M] drops out.

If the number of unread data in the buffer is less than the watermark threshold programmed in the EMPTY_WM bitfield of the FMAC_YBUFCFG register, the buffer is flagged as empty. As long as the empty flag is not set, interrupts or DMA requests are generated, if enabled, to request reads from the buffer. The watermark allows several data to be transferred under one interrupt, without danger of underflow. Nevertheless, if an underflow does occur, the UNFL error flag is set. In this case, the read pointer is not incremented and the read operation returns the content of the memory at the read pointer address.

The operation of the Y buffer in circular mode is illustrated in *Figure 106*. This example shows a 7-tap IIR filter with a watermark set to four.

Figure 106. Circular output buffer operation



23.3.5 Initialization functions

The following functions initialize the FMAC unit. They are triggered by writing the appropriate value in the FUNC bitfield of the FMAC_PARAM register, with the START bit set. The P and Q bitfields must also contain the appropriate parameter values for each function as detailed below. The R bitfield is not used. When the function completes, the START bit is automatically reset by hardware.

During initialization, it is recommended that the DMA requests and interrupts be disabled. The transfer of data into the FMAC memory can be done by software or by memory-to-memory DMA transfers, since no flow control is required.

Load X1 buffer

This function pre-loads the X1 buffer with N values, starting from the address in X1_BASE. Successive writes to the FMAC_WDATA register load the write data into the X1 buffer and increment the write address. The write pointer points to the address X1_BASE + N when the function completes.

The function can be used to pre-load the buffer with the elements of a vector, or to initialize the input storage elements of a filter.

Parameters

- The parameter P contains the number of values, N, to be loaded into the X1 buffer.
- The parameters Q and R are not used.

The function completes when N writes have been performed to the FMAC_WDATA register.

Load X2 buffer

This function pre-loads the X2 buffer with N + M values, starting from the address in X2_BASE. Successive writes to the FMAC_WDATA register load the write data into the X2 buffer and increment the write address.

The function can be used to pre-load the buffer with the elements of a vector, or the coefficients of a filter. In the case of an IIR, the N feed-forward and M feed-back coefficients are concatenated and loaded together into the X2 buffer. The total number of coefficients is equal to N + M. For an FIR, there are no feedback coefficients, so M = 0.

Parameters

- The parameter P contains the number of values, N, to be loaded into the X2 buffer starting from address X2_BASE.
- The parameter Q contains the number of values, M, to be loaded into the X2 buffer starting from address X2_BASE + N.
- The parameter R is not used.

The function completes when N + M writes have been performed to the FMAC_WDATA register.

Load Y buffer

This function pre-loads the Y buffer with N values, starting from the address in Y_BASE. Successive writes to the FMAC_WDATA register load the write data into the Y buffer and increment the write address. The read pointer points to the address Y_BASE + N when the function completes.

The function can be used to pre-load the feedback storage elements of an IIR filter.

Parameters

- The parameter P contains the number of values to be loaded into the Y buffer.
- The parameters Q and R are not used.

The function completes when N writes have been performed to the FMAC_WDATA register.

23.3.6 Filter functions

The following filter functions are supported by the FMAC unit. These functions are triggered by writing the corresponding value in the FUNC bitfield of the FMAC_PARAM register with the START bit set. The P, Q and R bitfields must also contain the appropriate parameter values for each function as detailed below. The filter functions continue to run until the START bit is reset by software.

Convolution (FIR filter)

Y = **B***__X__

$$y_n = 2^R \cdot \sum_{k=0}^{N} b_k x_{n-k}$$

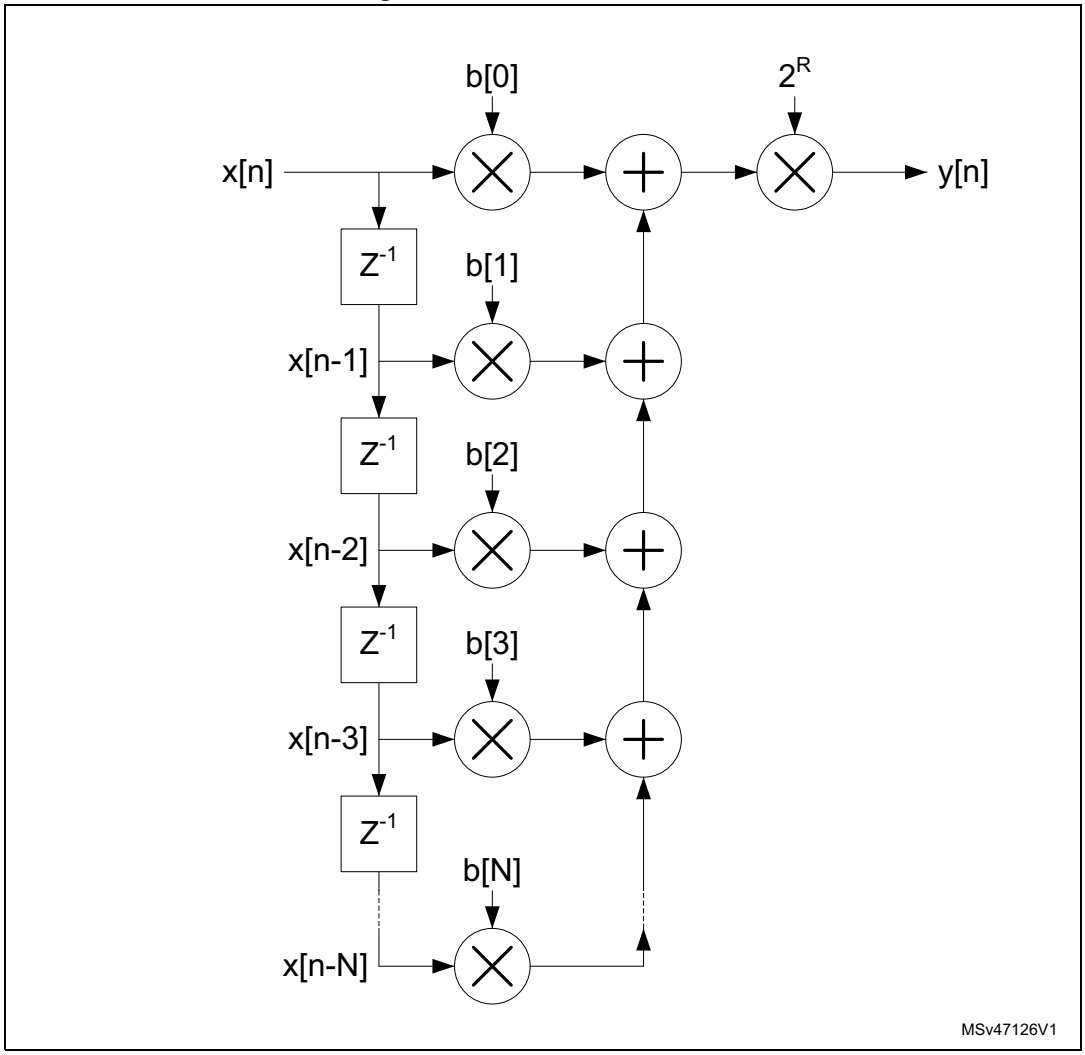
This function performs a convolution of a vector **B** of length N+1 and a vector **X** of indefinite length. The elements of **Y** for incrementing values of n are calculated as the dot product,

$y_n = \underline{\mathbf{B}}.\underline{\mathbf{X}}_{\mathbf{n}}$, where $\underline{\mathbf{X}}_{\mathbf{n}} = [x_{n-N},...,x_n]$ is composed of the N+1 elements of $\underline{\mathbf{X}}$ at indexes n - N to n.

This function corresponds to a finite impulse response (FIR) filter, where vector **B** contains the filter coefficients and vector **X** the sampled data.

The structure of the filter (direct form) is shown in *Figure 107*.

Figure 107. FIR filter structure



Note that the cross correlation vector can be calculated by reversing the order of the coefficient vector **B**.

Input:

- X1 buffer contains the elements of vector **X**. It is a circular buffer of length N + 1 + d.
- X2 buffer contains the elements of vector **B**. It is a fixed buffer of length N + 1.

Output:

- Y buffer contains the output values, y_n. It is a circular buffer of length d.

Parameters:

- The parameter P contains the length, N+1, of the coefficient vector **B** in the range [2:127].
- The parameter R contains the gain to be applied to the accumulator output. The value output to the Y buffer is multiplied by 2^R, where R is in the range [0:7]
- The parameter Q is not used.

The function completes when the START bit in the FMAC_PARAM register is reset by software.

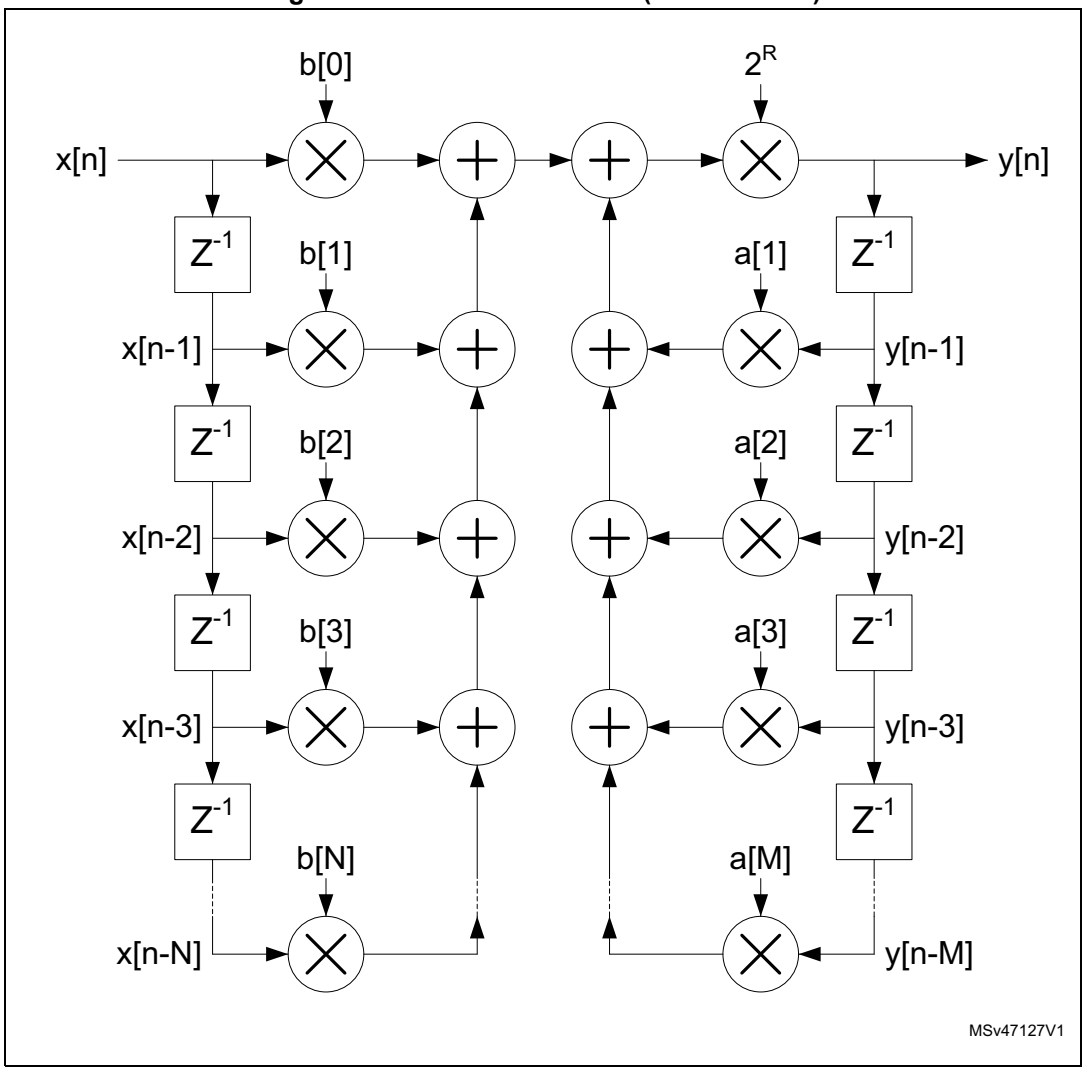
IIR filter

Y = **B*****X**+**A*****Y'**

$$y_n = 2^R \cdot \left(\sum_{k=0}^{N} b_k x_{n-k} + \sum_{k=1}^{M} a_k y_{n-k} \right)$$

This function implements an infinite impulse response (IIR) filter. The filter output vector **Y** is the convolution of a coefficient vector **B** of length N+1 and a vector **X** of indefinite length, plus the convolution of the delayed output vector **Y'** with a second coefficient vector **A**, of length M. The elements of **Y** for incrementing values of n are calculated as y_n = **B**.$\mathbf{X_n}$ + **A**.$\mathbf{Y_{n-1}}$, where $\mathbf{X_n}$ = $[x_{n-N},...,x_n]$ comprises the N+1 elements of **X** at indexes n - N to n, while $\mathbf{Y_{n-1}}$ = $[y_{n-M},...,y_{n-1}]$ comprises the M elements of **Y** at indexes n - M to n - 1. The structure of the filter (direct form 1) is shown in *Figure 108*.

Figure 108. IIR filter structure (direct form 1)



Input:

- X1 buffer contains the elements of vector **X**. It is a circular buffer of length N + 1+ d.
- X2 buffer contains the elements of coefficient vectors **B** and **A** concatenated (b_0, b_1, b_2..., b_N, a_1, a_2, ..., a_M). It is a fixed buffer of length M+N+1.

Output:

- Y buffer contains the output values, y_n. It is a circular buffer of length M + d.

Parameters

- The parameter P contains the length, N + 1, of the coefficient vector **B** in the range [2:64].
- The parameter Q contains the length, M, of the coefficient vector **A** in the range [1:63].
- The parameter R contains the gain to be applied to the accumulator output. The value output to the Y buffer is multiplied by 2^R, where R is in the range [0:7].

The function completes when the START bit in the FMAC_PARAM register is reset by software.

23.3.7 Fixed point representation

The FMAC operates in fixed point signed integer format. Input and output values are q1.15.

In q1.15 format, numbers are represented by one sign bit and 15 fractional bits (binary decimal places). The numeric range is therefore -1 (0x8000) to 1 - 2^{-15} (0x7FFF).

The accumulator has 26 bits, of which 22 are fractional and 4 are integer/sign (q4.22). This allows it to support partial accumulation sums in the range -8 (0x2000000) to +7.99999976 (0x1FFFFFF). A programmable gain from 0dB to 42dB in steps of 6dB can be applied at the output of the accumulator.

Note that the content of the accumulator is not saturated if the numeric range is exceeded. Partial sums whose value is greater than +7.99999976 or less than -8, wrap but this is harmless provided subsequent accumulations undo the wrapping. Nevertheless, the SAT flag in the FMAC_SR register is set if wrapping occurs, and generates an interrupt if the SATIEN bit is set in the FMAC_CR register. This helps in debugging the filter.

The data output by the accumulator can optionally be saturated, after application of the programmable gain, by setting the CLIPEN bit in the FMAC_CR register. If this bit is set, then any value which exceeds the numeric range of the q1.15 output, is set to 1 - 2^{-15} or -1, according to the sign. If clipping is not enabled, the unused accumulator bits after applying the gain is simply truncated.

23.3.8 Implementing FIR filters with the FMAC

The FMAC supports FIR filters of length N, where N is the number of taps or coefficients. The minimum local memory requirement for a FIR filter of length N is 2N + 1:

– N coefficients
– N input samples
– 1 output sample

Since the local memory size is 256, the maximum value for N is 127.

If maximum throughput is required, it may be necessary to allocate a small amount of extra space, d1 and d2, to the input and output sample buffers respectively, to ensure that the filter never stalls waiting for a new input sample, or waiting for the output sample to be read. In this case, the local memory requirement is 2N + d1 + d2.

The buffers should be configured as follows:

- X1_BUF_SIZE = N + d1;
- X2_BUF_SIZE = N;
- Y_BUF_SIZE = d2 (or 1 if no extra space is required)

The buffer base addresses can be allocated anywhere, but the X2 buffer must not overlap with the others, or else the coefficients are overwritten. An example configuration could be:

- X2_BASE = 0;
- X1_BASE = N;
- Y_BASE = 2N + d1

However, if the memory space is limited, the X1 and Y buffer areas can be overlapped, such that each output sample takes the place of the oldest input sample, which is no longer required:

- X2_BASE = 0;
- X1_BASE = N;
- Y_BASE = N

In this case, Y_BUF_SIZE = X1_BUF_SIZE = N + d1, so that the buffers remain in sync.

Note: The FULL_WM bitfield of X1 buffer configuration register must be programmed with a value less than or equal to $log_2(d1)$, otherwise the buffer is flagged full before N input samples have been written, and no more samples are requested. Similarly, the EMPTY_WM bitfield of the Y buffer configuration register must be less than or equal to $log_2(d2)$.

The filter coefficients **must** be pre-loaded into the X2 buffer, using the Load X2 Buffer function. The X1 buffer can optionally be pre-loaded with any number of samples up to a maximum of N. There is no point in pre-loading the Y buffer, since for the FIR filter there is no feedback path.

After configuring and initializing the buffers, the FMAC_CR register should be programmed according to the method used for writing and reading data to and from the FMAC memory.

Three methods are supported:

- Polling: No DMA request or Interrupt request is generated. Software must check that the X1_FULL flag is low before writing to WDATA, or that the Y_EMPTY flag is low before reading from RDATA.
- Interrupt: The interrupt request is asserted while the X1_FULL flag is low, for writes, or when the Y_EMPTY flag is low, for reads.
- DMA: DMA requests are asserted on the DMA write channel while the X1_FULL flag is low, and on the read channel while the Y_EMPTY flag is low.

Different methods can be used for read and for write. However it is not recommended to use both interrupts and DMA requests for the same operation[(a)]. The valid combinations are listed in *Table 163*.

Table 163. Valid combinations for read and write methods

WIEN	RIEN	DMAWEN	DMAREN	Write	Read
0	0	0	0	Polling	Polling
0	1	0	0	Polling	Interrupt
1	0	0	0	Interrupt	Polling
1	1	0	0	Interrupt	Interrupt
0	0	0	1	Polling	DMA
0	0	1	0	DMA	Polling
0	0	1	1	DMA	DMA
0	1	1	0	DMA	Interrupt
1	0	0	1	Interrupt	DMA

a. If both interrupts and DMA requests are enabled then only DMA should perform the transfer.

The filter is started by writing to the FMAC_PARAM register with the following bitfield values:

- FUNC = 8 (FIR filter);
- P = N (number of coefficients);
- Q = “Don’t care”;
- R = Gain;
- START = 1;

If less than N + d - 2^{FULL_WM} values have been pre-loaded in the X1 buffer, the X1FULL flag remains low. If the WIEN bit is set in the FMAC_CR register, then the interrupt request is asserted immediately to request the processor to write 2^{FULL_WM} additional samples into the buffer, via the FMAC_WDATA register. It remains asserted until the X1FULL flag goes high in the FMAC_SR register. The interrupt service routine should check the X1FULL flag after every 2^{FULL_WM} writes to the FMAC_WDATA register, and repeat the transfer until the flag goes high. Similarly, if the DMAWEN bit is set in the FMAC_CR register, DMA write channel requests are generated until the X1FULL flag goes high.

The filter calculates the first output sample when at least N samples have been written into the X1 buffer (including any pre-loaded samples).

When 2^{EMPTY_WM} output samples have been written into the Y buffer, the YEMPTY flag in the FMAC_SR register goes low. If the RIEN bit is set in the FMAC_CR register, the interrupt request is asserted to request the processor to read 2^{EMPTY_WM} samples from the buffer, via the FMAC_RDATA register. It remains asserted until the YEMPTY flag goes high. The interrupt service routine should check the YEMPTY flag after every 2^{EMPTY_WM} reads from the FMAC_RDATA register, and repeat the transfer until the flag goes high. If the DMAREN bit is set in the FMAC_CR, DMA read channel requests are generated until the YEMPTY flag goes high.

The filter continues to operate in this fashion until it is stopped by the software resetting the START bit.

23.3.9 Implementing IIR filters with the FMAC

The FMAC supports IIR filters of length N, where N is the number of feed-forward taps or coefficients. The number of feedback coefficients, M, can be any value from 1 to N-1. Only direct form 1 implementations can be realized, so filters designed for other forms need to be converted.

The minimum memory requirement for an IIR filter with N feed-forward coefficients and M feed-back coefficients is 2N + 2M:

- N + M coefficients
- N input samples
- M output samples

If M = N-1, then the maximum filter length that can be implemented is N = 64.

As for the FIR, for maximum throughput a small amount of additional space, d1 and d2, should be allowed in the input and output buffer size respectively, making the total memory requirement 2M + 2N + d1 + d2.

The buffers must be configured as follows:

- X1_BUF_SIZE = N + d1;
- X2_BUF_SIZE = N + M;
- Y_BUF_SIZE = M + d2;

The buffer base addresses can be allocated anywhere, but must not overlap. An example configuration is given below:

- X2_BASE = 0;
- X1_BASE = N + M;
- Y_BASE = 2N + M + d1;

Note: The FULL_WM bitfield of X1 buffer configuration register must be programmed with a value less than or equal to $log_2(d1)$, otherwise the buffer is flagged full before N input samples have been written, and no more samples are requested. Similarly, the EMPTY_WM bitfield of the Y buffer configuration register must be less than or equal to $log_2(d2)$.

The filter coefficients (N feed-forward followed by M feedback) **must** be pre-loaded into the X2 buffer, using the Load X2 Buffer function. The X1 buffer can optionally be pre-loaded with any number of samples up to a maximum of N. The Y buffer can optionally be pre-loaded with any number of values up to a maximum of M. This has the effect of initializing the feedback delay line.

After configuring the buffers, the FMAC_CR register should be programmed in the same way as for the FIR filter (see *Section 23.3.8: Implementing FIR filters with the FMAC*).

The filter is started by writing to the FMAC_PARAM register with the following bitfield values:

- FUNC = 9 (IIR filter);
- P = N (number of feed-forward coefficients);
- Q = M (number of feed-back coefficients);
- R = Gain;
- START = 1;

If less than $N + d - 2^{FULL\_WM}$ values have been pre-loaded in the X1 buffer, the X1FULL flag remains low. If the WIEN bit is set in the FMAC_CR register, then the interrupt request is asserted immediately to request the processor to write 2^{FULL_WM} additional samples into the buffer, via the FMAC_WDATA register. It remains asserted until the X1FULL flag goes high in the FMAC_SR register. The interrupt service routine should check the X1FULL flag after every 2^{FULL_WM} writes to the FMAC_WDATA register, and repeat the transfer until the flag goes high. Similarly, if the DMAWEN bit is set in the FMAC_CR register, DMA write channel requests are generated until the X1FULL flag goes high.

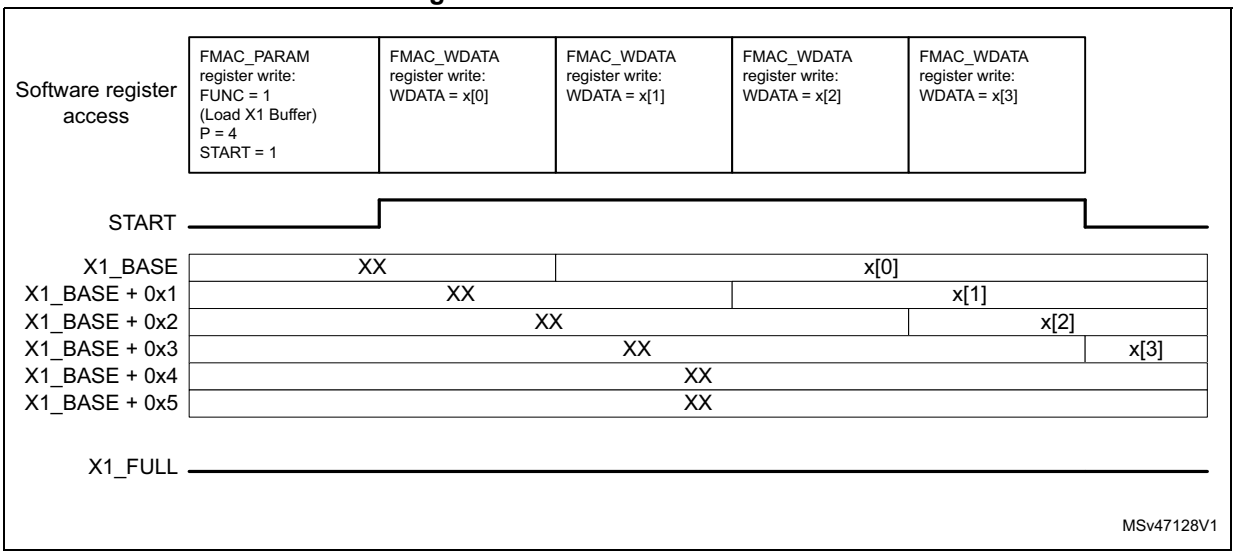
The filter calculates the first output sample when at least N samples have been written into the X1 buffer (including any pre-loaded samples). The first sample is calculated using the first N samples in the X1 buffer, and the first M samples in the Y buffer (whether or not they are preloaded. The first output sample is written into the Y buffer at Y_BASE + M.

When 2^{EMPTY_WM} new output samples have been written into the Y buffer, the YEMPTY flag in the FMAC_SR register goes low. If the RIEN bit is set in the FMAC_CR register, the interrupt request is asserted to request the processor to read 2^{EMPTY_WM} samples from the buffer, via the FMAC_RDATA register. It remains asserted until the YEMPTY flag goes high. The interrupt service routine should check the YEMPTY flag after every 2^{EMPTY_WM} reads from the FMAC_RDATA register, and repeat the transfer until the flag goes high. If the DMAREN bit is set in the FMAC_CR, DMA read channel requests are generated until the YEMPTY flag goes high

The filter continues to operate in this fashion until it is stopped by the software resetting the START bit.

23.3.10 Examples of filter initialization

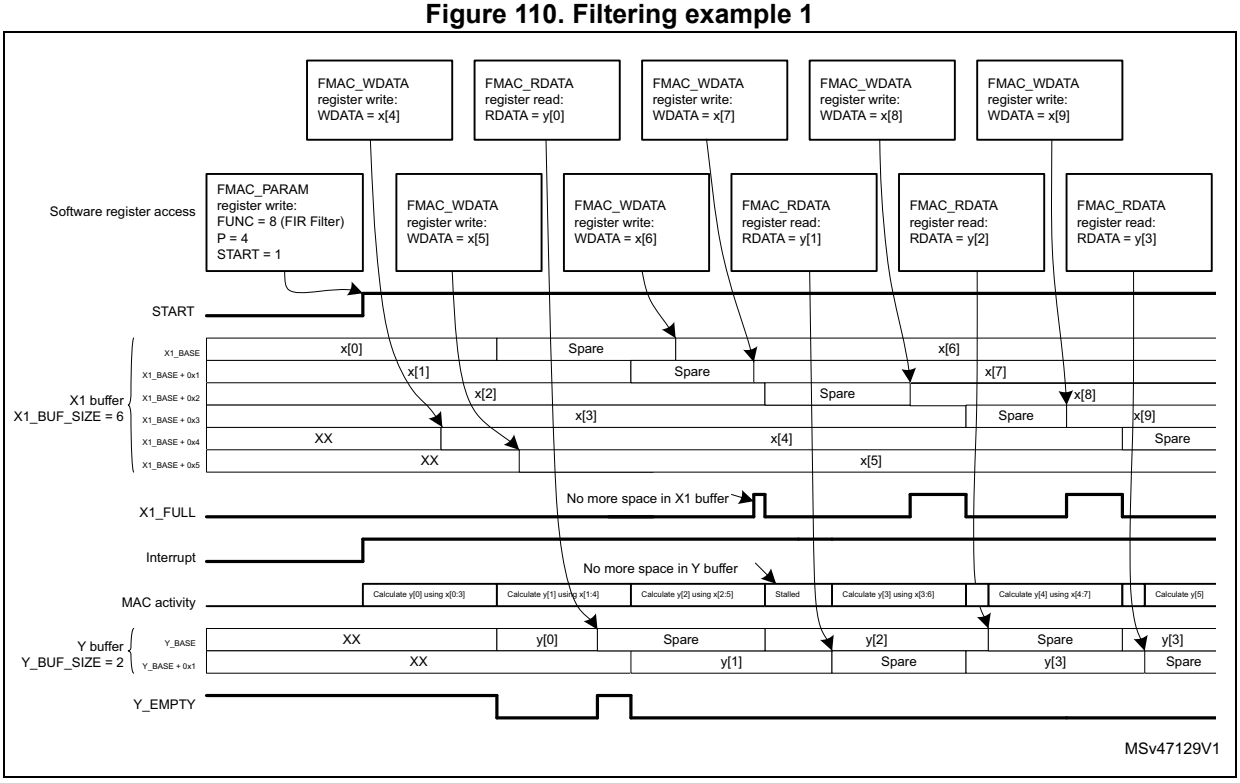
Figure 109. X1 buffer initialization



The example in *Figure 109* illustrates a X1 buffer pre-load with four samples (P = 4). The buffer size is six (X1_BUF_SIZE = 6). The initialization is launched by programming the FMAC_PARAM register with the START bit set. The four samples are then written to FMAC_WDATA, and transferred into local memory from X1_BASE onwards. The START bit resets after the fourth sample has been written. At this point, the X1 buffer contains the four samples, in order of writing, and the write pointer (next empty space) is at X1_BASE + 0x4.

23.3.11 Examples of filter operation

Figure 110. Filtering example 1



The example in *Figure 110* illustrates the beginning of a filter operation. The filter has four taps (P=4). The X1 buffer size is six and the Y buffer size is two. The FULL_WM and EMPTY_WM bitfields are both set to 0. Prior to starting the filter, the X1 buffer has been pre-loaded with four samples, x[0:3] as in *Figure 109*. So the filter starts calculating the first output sample, y[0], immediately after the START bit is set. Since the X1FULL flag is not set (due to two uninitialized spaces in the X1 buffer), the interrupt is asserted straight away, to request new data. The processor writes two new samples, x[4] and x[5], to the FMAC_WDATA register, which are transferred to the empty locations in the X1 buffer.

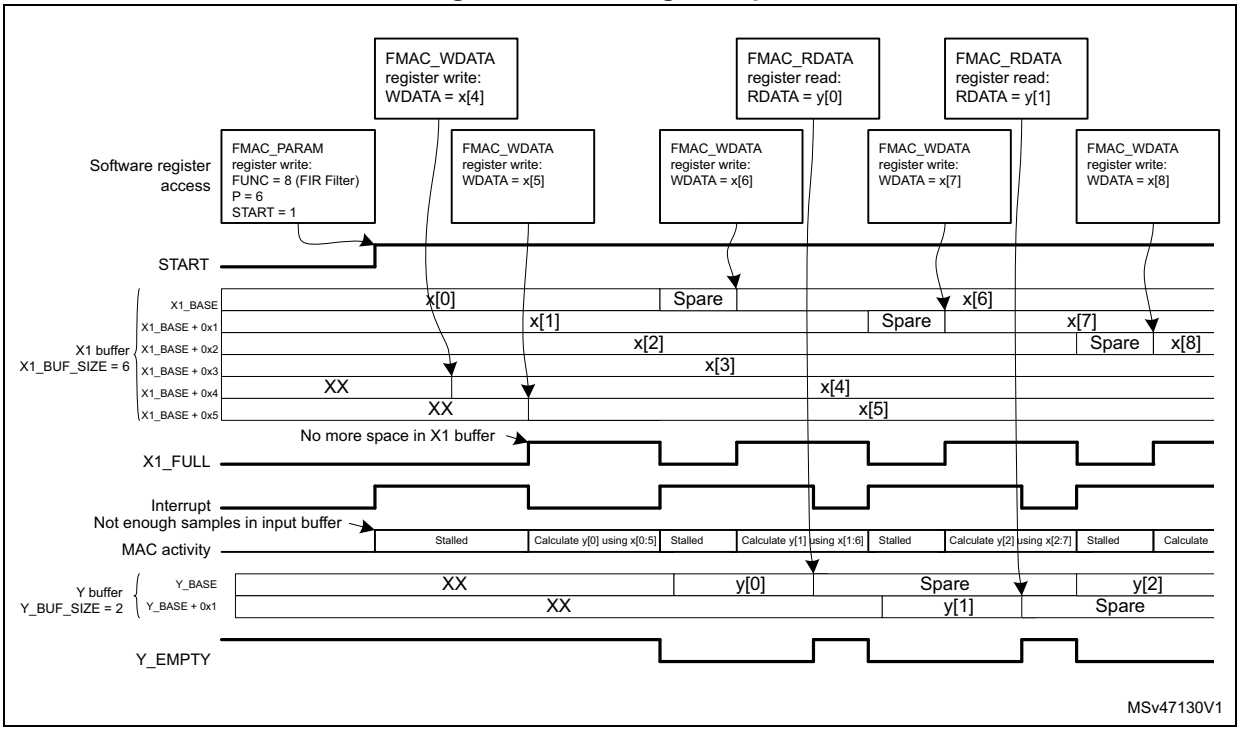
In the mean time, the FMAC finishes calculating the first output sample, y[0], and writes it into the Y buffer, causing the Y_EMPTY flag to go low. At the same time, the x[0] sample is discarded, as it is no longer required, freeing up its location in memory (at X1_BASE). The FMAC can immediately start work on the second output sample, y[1], since all the required input samples x[1:5] are present in the X1 buffer.

Since the Y_EMPTY flag is low, the interrupt remains active after the processor finishes writing x[5]. The processor reads y[0] from the FMAC_RDATA register, freeing up its location in the Y buffer. There are now no samples in the output buffer since y[1] is still being calculated, so the Y_EMPTY flag goes high. Nevertheless, the interrupt remains active, because there is still free space in the X1 buffer, which the processor next fills with x[6], and so on.

Note: In this example, the processor can fill the input buffer more quickly than the FMAC can process them, so the X1_full flag regularly goes active. However, it struggles to read the Y buffer fast enough, so the FMAC stalls regularly waiting for space to be freed up in the Y buffer. This means the filter is not executing at maximum throughput. The reason is that the

filter length is small and the processor relatively slow, in this example. So increasing the Y buffer size would not help.

Figure 111. Filtering example 2



The example in *Figure 111* illustrates the beginning of the same filter operation, but this time the filter has six taps (P=6). The X1 buffer size is six and the Y buffer size is two. The FULL_WM and EMPTY_WM bitfields are both set to 0. Prior to starting the filter, the X1 buffer has been pre-loaded with four samples, x[0:3] as in *Figure 109*. Because there are not enough samples in the input buffer, the X1FULL flag is not set, so the interrupt is asserted straight away, to request new data. The FMAC is stalled.

The processor writes two new samples, x[4] and x[5], to the FMAC_WDATA register, which are transferred to the empty locations in the X1 buffer. As soon as there are six unused samples in the X1 buffer, the X1_FULL flag goes active (since the buffer size is six), causing the interrupt to go inactive. The FMAC starts calculating the first output sample, y[0]. Since this requires all six input samples, there are no free spaces in the X1 buffer and so the X1_FULL flag remains active. Only when the FMAC finishes calculating y[0] and writes it into the Y buffer, can x[0] be discarded, freeing up a space in the X1 buffer, and deasserting X1_FULL. At the same time, the Y_EMPTY flag goes inactive. Both these flag states cause the interrupt to be asserted, requesting the processor to write a new input sample, first of all, and then read the output sample just calculated. The FMAC remains stalled until a new input sample is written.

In this example, the processor has to wait for the FMAC to finish calculating the current output sample, before it can write a new input sample, and therefore the X1 buffer regularly goes empty, stalling the FMAC. This can be avoided by allowing some extra space in the input buffer.

23.3.12 Filter design tips

The FMAC architecture imposes some constraints detailed below, on the design of digital filters.

1. Implementation of direct form 2, or transposed forms, is not efficient. Filters which have been designed for such forms should be converted to direct form 1.
2. Cascaded filters must either be combined into a single stage, or implemented as separate filters. In the latter case, multiple sets of filter coefficients can be pre-loaded into the memory, one set per stage, and only the X2_BASE address changed to select which set is used. The most efficient method of implementing a multi-stage filter is to pre-load a large X1 buffer with input samples, run the IIR filter function on it using the first stage coefficients, and store the output samples back in memory. Then change the X2_BASE pointer to point to the 2nd stage coefficients, and reload the input buffer with the output of the first stage (with a gain if required), before running the IIR function again. The procedure is repeated for all stages. Once the final stage samples have been transferred back into system memory, the input buffer can be loaded with the next set of input samples, and a new round of calculations started. Note that the N sample input buffer of each stage must be pre-loaded first of all with the N-1 last inputs from the previous round, plus one new sample, in order to keep continuity between each round. Similarly, the output buffer of each stage must be loaded with the last M samples from the previous round, for the same reason.
3. The use of direct form 1 for IIR designs can lead to large positive or negative partial sums in the accumulator, if for example a large step occurs on the input, or some of the filter coefficients' absolute values are >1. Since the accumulator is limited to 26 bits, the biggest value that it can handle without wrapping (changing sign) is 0x1FFFFFF positive or 0x2000000 negative. This corresponds to 3.99999988 and -4 respectively in q3.23 fixed point format. Wrapping does not represent a problem provided the wrapping is "undone" before the end of the accumulation. However this is not always the case when a filter is starting up and can lead to unexpected results. Consider pre-loading the output buffer with suitable values to avoid this.
4. The IIR filter has feed-forward (numerator) coefficients $[b_0, b_1, ..., b_{N-1}]$, and feed-back (denominator) coefficients $[1, a_1, ..., a_M]$. Many IIR filters require some of the denominator coefficients to have an absolute value greater than 1 to achieve a steep roll-off in the frequency response. Given that the coefficients are coded in fixed point q1.15 format, this is not possible. Nevertheless, by scaling the denominator coefficients by a factor 2^{-R}, such that $2^{-R}.[1, a_1, ..., a_M]$ are all less than 1, such filters can be implemented. However an inverse gain of 2^R must be applied at the output of the accumulator to compensate the scaling. This has an adverse effect on the signal-to-noise ratio.

23.4 FMAC registers

23.4.1 FMAC X1 buffer configuration register (FMAC_X1BUFCFG)

Address offset: 0x00

Reset value: 0x0000 0000

Access: word access

This register can only be modified if START = 0 in the FMAC_PARAM register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	FULL_WM[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
						rw	rw								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
X1_BUF_SIZE[7:0]								X1_BASE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:24 **FULL_WM[1:0]**: Watermark for buffer full flag

Defines the threshold for setting the X1 buffer full flag when operating in circular mode. The flag is set if the number of free spaces in the buffer is less than 2^{FULL_WM}.

0: Threshold = 1

1: Threshold = 2

2: Threshold = 4

3: Threshold = 8

Setting a threshold greater than 1 allows several data to be transferred into the buffer under one interrupt.

Threshold should be set to 1 if DMA write requests are enabled (DMAWEN = 1 in FMAC_CR register).

Bits 23:16 Reserved, must be kept at reset value.

Bits 15:8 **X1_BUF_SIZE[7:0]**: Allocated size of X1 buffer in 16-bit words

The minimum buffer size is the number of feed-forward taps in the filter (+ the watermark threshold - 1).

Bits 7:0 **X1_BASE[7:0]**: Base address of X1 buffer

23.4.2 FMAC X2 buffer configuration register (FMAC_X2BUFCFG)

Address offset: 0x04

Reset value: 0x0000 0000

Access: word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
X2_BUF_SIZE[7:0]								X2_BASE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **X2_BUF_SIZE[7:0]**: Size of X2 buffer in 16-bit words
This bitfield can not be modified when a function is ongoing (START = 1).

Bits 7:0 **X2_BASE[7:0]**: Base address of X2 buffer
The X2 buffer base address can be modified while START=1, for example to change coefficient values. The filter should be stalled when doing this, since changing the coefficients while a calculation is ongoing affects the result.

23.4.3 FMAC Y buffer configuration register (FMAC_YBUFCFG)

Address offset: 0x08

Reset value: 0x0000 0000

Access: word access

This register can only be modified if START = 0 in the FMAC_PARAM register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	EMPTY_WM[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
						rw	rw								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Y_BUF_SIZE[7:0]								Y_BASE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:24 **EMPTY_WM[1:0]**: Watermark for buffer empty flag
Defines the threshold for setting the Y buffer empty flag when operating in circular mode. The flag is set if the number of unread values in the buffer is less than 2^{EMPTY_WM}.
0: Threshold = 1
1: Threshold = 2
2: Threshold = 4
3: Threshold = 8
Setting a threshold greater than 1 allows several data to be transferred from the buffer under one interrupt.
Threshold should be set to 1 if DMA read requests are enabled (DMAREN = 1 in FMAC_CR register).

Bits 23:16 Reserved, must be kept at reset value.

Bits 15:8 **Y_BUF_SIZE[7:0]**: Size of Y buffer in 16-bit words
For FIR filters, the minimum buffer size is 1 (+ the watermark threshold). For IIR filters the minimum buffer size is the number of feedback taps (+ the watermark threshold).

Bits 7:0 **Y_BASE[7:0]**: Base address of Y buffer

23.4.4 FMAC parameter register (FMAC_PARAM)

Address offset: 0x0C

Reset value: 0x0000 0000

Access: word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
START	FUNC[6:0]							R[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Q[7:0]								P[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **START**: Enable execution
0: Stop execution
1: Start execution
Setting this bit triggers the execution of the function selected in the FUNC bitfield. Resetting it by software stops any ongoing function. For initialization functions, this bit is reset by hardware.

Bits 30:24 **FUNC[6:0]**: Function
0: Reserved
1: Load X1 buffer
2: Load X2 buffer
3: Load Y buffer
4 to 7: Reserved
8: Convolution (FIR filter)
9: IIR filter (direct form 1)
10 to 127: Reserved
This bitfield can not be modified when a function is ongoing (START = 1)

Bits 23:16 **R[7:0]**: Input parameter R.
The value of this parameter is dependent on the function.
This bitfield can not be modified when a function is ongoing (START = 1)

Bits 15:8 **Q[7:0]**: Input parameter Q.
The value of this parameter is dependent on the function.
This bitfield can not be modified when a function is ongoing (START = 1)

Bits 7:0 **P[7:0]**: Input parameter P.
The value of this parameter is dependent on the function
This bitfield can not be modified when a function is ongoing (START = 1)

23.4.5 FMAC control register (FMAC_CR)

Address offset: 0x10

Reset value: 0x0000 0000

Access: word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RESET
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CLIP EN	Res.	Res.	Res.	Res.	Res.	DMA WEN	DMA REN	Res.	Res.	Res.	SAT IEN	UNFL IEN	OVFL IEN	WIEN	RIEN
rw						rw	rw				rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **RESET**: Reset FMAC unit

This resets the write and read pointers, the internal control logic, the FMAC_SR register and the FMAC_PARAM register, including the START bit if active. Other register settings are not affected. This bit is reset by hardware.

0: Reset inactive

1: Reset active

Bit 15 **CLIPEN**: Enable clipping

0: Clipping disabled. Values at the output of the accumulator which exceed the q1.15 range, wrap.

1: Clipping enabled. Values at the output of the accumulator which exceed the q1.15 range are saturated to the maximum positive or negative value (+1 or -1) according to the sign.

Bits 14:10 Reserved, must be kept at reset value.

Bit 9 **DMAWEN**: Enable DMA write channel requests

0: Disable. No DMA requests are generated

1: Enable. DMA requests are generated while the X1 buffer is not full.

This bit can only be modified when START= 0 in the FMAC_PARAM register. A read returns the current state of the bit.

Bit 8 **DMAREN**: Enable DMA read channel requests

0: Disable. No DMA requests are generated

1: Enable. DMA requests are generated while the Y buffer is not empty.

This bit can only be modified when START= 0 in the FMAC_PARAM register. A read returns the current state of the bit.

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **SATIEN**: Enable saturation error interrupts

0: Disabled. No interrupts are generated upon saturation detection.

1: Enabled. An interrupt request is generated if the SAT flag is set

This bit is set and cleared by software. A read returns the current state of the bit.

Bit 3 **UNFLIEN**: Enable underflow error interrupts

0: Disabled. No interrupts are generated upon underflow detection.

1: Enabled. An interrupt request is generated if the UNFL flag is set

This bit is set and cleared by software. A read returns the current state of the bit.

Bit 2 **OVFLIEN**: Enable overflow error interrupts
0: Disabled. No interrupts are generated upon overflow detection.
1: Enabled. An interrupt request is generated if the OVFL flag is set
This bit is set and cleared by software. A read returns the current state of the bit.

Bit 1 **WIEN**: Enable write interrupt
0: Disabled. No write interrupt requests are generated.
1: Enabled. An interrupt request is generated while the X1 buffer FULL flag is not set.
This bit is set and cleared by software. A read returns the current state of the bit.

Bit 0 **RIEN**: Enable read interrupt
0: Disabled. No read interrupt requests are generated.
1: Enabled. An interrupt request is generated while the Y buffer EMPTY flag is not set.
This bit is set and cleared by software. A read returns the current state of the bit.

23.4.6 FMAC status register (FMAC_SR)

Address offset: 0x14

Reset value: 0x0000 0001

Access: word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	SAT	UNFL	OVFL	Res.	Res.	Res.	Res.	Res.	Res.	X1 FULL	Y EMPTY
					r	r	r							r	r

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **SAT**: Saturation error flag
Saturation occurs when the result of an accumulation exceeds the numeric range of the accumulator.
0: No saturation detected
1: Saturation detected. If the SATIEN bit is set, an interrupt is generated.
This flag is cleared by a reset of the unit.

Bit 9 **UNFL**: Underflow error flag
An underflow occurs when a read is made from FMAC_RDATA when no valid data is available in the Y buffer.
0: No underflow detected
1: Underflow detected. If the UNFLIEN bit is set, an interrupt is generated.
This flag is cleared by a reset of the unit.

Bit 8 **OVFL**: Overflow error flag
An overflow occurs when a write is made to FMAC_WDATA when no free space is available in the X1 buffer.
0: No overflow detected
1: Overflow detected. If the OVFLIEN bit is set, an interrupt is generated.
This flag is cleared by a reset of the unit.

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **X1FULL**: X1 buffer full flag

The buffer is flagged as full if the number of available spaces is less than the FULL_WM threshold. The number of available spaces is the difference between the write pointer and the least recent sample currently in use.

0: X1 buffer not full. If the WIEN bit is set, the interrupt request is asserted until the flag is set. If DMAWEN is set, DMA write channel requests are generated until the flag is set.

1: X1 buffer full.

This flag is set and cleared by hardware, or by a reset.

Note: after the last available space in the X1 buffer is filled there is a delay of 3 clock cycles before the X1FULL flag goes high. To avoid any risk of overflow it is recommended to insert a software delay after writing to the X1 buffer before reading the FMAC_SR. Alternatively, a FULL_WM threshold of 2 can be used.

Bit 0 **YEMPTY**: Y buffer empty flag

The buffer is flagged as empty if the number of unread data is less than the EMPTY_WM threshold. The number of unread data is the difference between the read pointer and the current output destination address.

0: Y buffer not empty. If the RIEN bit is set, the interrupt request is asserted until the flag is set. If DMAREN is set, DMA read channel requests are generated until the flag is set.

1: Y buffer empty.

This flag is set and cleared by hardware, or by a reset.

Note: after the last sample is read from the Y buffer there is a delay of 3 clock cycles before the YEMPTY flag goes high. To avoid any risk of underflow it is recommended to insert a software delay after reading from the Y buffer before reading the FMAC_SR. Alternatively, an EMPTY_WM threshold of 2 can be used.

23.4.7 FMAC write data register (FMAC_WDATA)

Address offset: 0x18

Reset value: 0x0000 0000

Access: word and half-word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WDATA[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **WDATA[15:0]**: Write data

When a write access to this register occurs, the write data are transferred to the address offset indicated by the write pointer. The pointer address is automatically incremented after each write access.

23.4.8 FMAC read data register (FMAC_RDATA)

Address offset: 0x1C

Reset value: 0x0000 0000

Access: word and half-word access

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **RDATA[15:0]**: Read data

When a read access to this register occurs, the read data are the contents of the Y output buffer at the address offset indicated by the READ pointer. The pointer address is automatically incremented after each read access.

23.4.9 FMAC register map

Table 164.FMAC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	FMAC_X1BUFCFG	Res.	Res.	Res.	Res.	Res.	Res.	FULL_WM[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	X1_BUF_SIZE[7:0]								X1_BASE[7:0]							
	Reset value							0	0									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	FMAC_X2BUFCFG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	X2_BUF_SIZE[7:0]								X2_BASE[7:0]							
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	FMAC_YBUFCFG	Res.	Res.	Res.	Res.	Res.	Res.	EMPTY_WM[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Y_BUF_SIZE[7:0]								Y_BASE[7:0]							
	Reset value							0	0									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	FMAC_PARAM	START	FUNC[6:0]							R[7:0]								Q[7:0]								P[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	FMAC_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RESET	CLIPEN	Res.	Res.	Res.	Res.	Res.	DMAWEN	DMAREN	Res.	Res.	Res.	SATIEN	UNFLIEN	OVFLIEN	WIEN	RIEN
	Reset value																0	0						0	0				0	0	0	0	0
0x14	FMAC_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SAT	UNFL	OVFL	Res.	Res.	Res.	Res.	Res.	Res.	X1FULL	YEMPTY
	Reset value																						0	0	0							0	1
0x18	FMAC_WDATA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDATA[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	FMAC_RDATA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDATA[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3* for the register boundary addresses.

24 Flexible memory controller (FMC)

The flexible memory controller (FMC) includes three memory controllers:

- The NOR/PSRAM memory controller
- The NAND memory controller
- The Synchronous DRAM (SDRAM/Mobile LPSDR SDRAM) controller

24.1 FMC main features

The FMC functional block makes the interface with: synchronous and asynchronous static memories, SDRAM memories, and NAND flash memory. Its main purposes are:

- to translate AXI transactions into the appropriate external device protocol
- to meet the access time requirements of the external memory devices

All external memories share the addresses, data and control signals with the controller. Each external device is accessed by means of a unique Chip Select. The FMC performs only one access at a time to an external device.

The main features of the FMC controller are the following:

- Interface with static-memory mapped devices including:
  - Static random access memory (SRAM)
  - NOR Flash memory/OneNAND Flash memory
  - PSRAM (4 memory banks)
  - NAND Flash memory with ECC hardware to check up to 8 Kbytes of data
- Interface with synchronous DRAM (SDRAM/Mobile LPSDR SDRAM) memories
- Burst mode support for faster access to synchronous devices such as NOR Flash memory, PSRAM and SDRAM)
- Programmable continuous clock output for asynchronous and synchronous accesses
- 8-,16- or 32-bit wide data bus
- Independent Chip Select control for each memory bank
- Independent configuration for each memory bank
- Write enable and byte lane select outputs for use with PSRAM, SRAM and SDRAM devices
- External asynchronous wait control
- Write FIFO with 16 x32-bit depth

  The Write FIFO is common to all memory controllers and consists of:
  - a Write Data FIFO which stores the data to be written to the memory
  - a Write Address FIFO which stores the address (up to 28 bits) plus the data size (up to 2 bits). When operating in Burst mode, only the start address is stored except when crossing a page boundary (for PSRAM and SDRAM). In this case, the burst is broken into two FIFO entries.
- Cacheable Read FIFO with 6 x64-bit depth (6 x14-bit address tag) for SDRAM controller.

At startup the FMC pins must be configured by the user application. The FMC I/O pins which are not used by the application can be used for other purposes.

The FMC registers that define the external device type and associated characteristics are set at boot time and do not change until the next reset or power-up. However, only a few bits can be changed on-the-fly:

- ECCEN and PBKEN bits in the FMC_PCR register
- IFS, IRS and ILS bits in the FMC_SR register
- MODE[2:0], CTB1/CTB2, NRFS and MRD bits in the FMC_SDCMR register
- REIE and CRE bits in the FMC_SDRTR register.

Follow the below sequence to modify parameters while the FMC is enabled:

1. First disable the FMC controller to prevent further accesses to any memory controller while the register is modified.
2. Update all required configurations.
3. Enable the FMC controller again.

When the SDRAM controller is used, if the SDCLK Clock ratio or refresh rate has to be modified after initialization phase, the following procedure must be followed.

1. Put the SDRAM device in Self-refresh mode.
2. Disable the FMC controller by resetting the FMCEN bit in the FMC_BCR1 register.
3. Update the required parameters.
4. Enable the FMC controller once all parameters have been updated.
5. Then, send the Clock Configuration Enable command to exit Self-fresh mode.

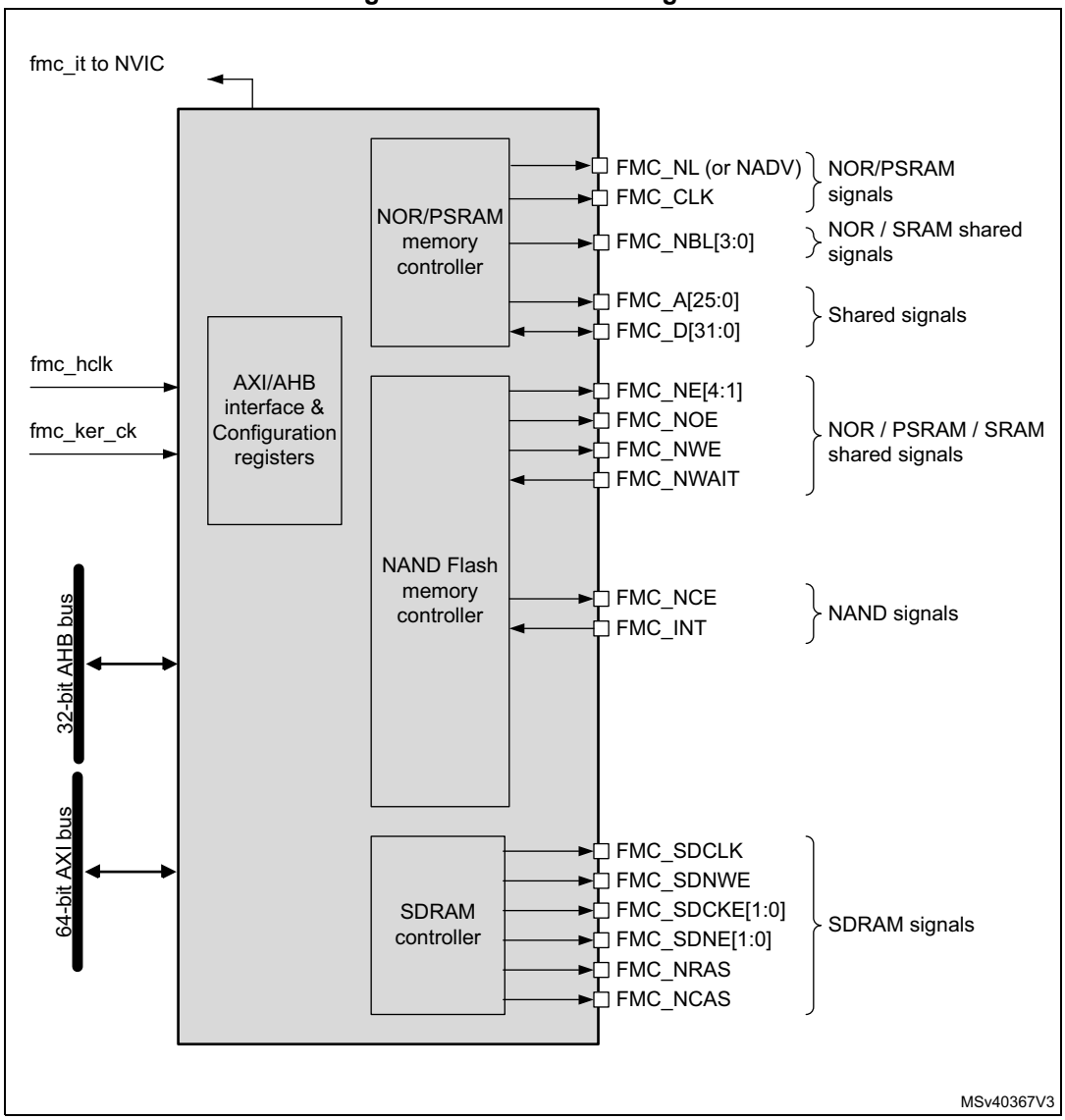
24.2 FMC block diagram

The FMC consists of the following main blocks:

- The NOR Flash/PSRAM/SRAM controller
- The NAND controller
- The SDRAM controller
- The AXI interface
- The AHB interface (including the FMC configuration registers)

The block diagram is shown in the figure below.

Figure 112. FMC block diagram



24.3 FMC internal signals

Table 165 gives the list of FMC internal signals. FMC pins (or external signals) are described in *Section 24.7.1: External memory interface signals*.

Table 165. FMC pins

Names	Signal type	Description
fmc_it	Digital output	FMC interrupt
fmc_ker_ck	Digital input	FMC kernel clock
fmc_hclk	Digital input	FMC interface clock

24.4 AHB interface

The AHB slave interface allows internal CPUs to configure the FMC registers.

The AHB clock (fmc_hclk) is the reference clock for the FMC register accesses.

24.5 AXI interface

The AXI slave interface allows internal CPUs and other bus master peripherals to access the external memories.

AXI transactions are translated into the external device protocol. As the AXI data bus is 64-bit wide, the AXI transactions might be split into several consecutive 32-, 16- or 8-bit accesses according to data size accesses. The FMC Chip Select (FMC_NEx) does not toggle between consecutive accesses except in case of accesses in mode D when the Extended mode is enabled.

The FMC generates an AXI slave error when one of the following conditions is met:

- Reading or writing to an FMC bank (Bank 1 to 4) which is not enabled.
- Reading or writing to the NOR Flash bank while the FACCEN bit is reset in the FMC_BCRx register.
- Writing to a write protected SDRAM bank (WP bit set in the FMC_SDCRx register).
- Violation of the SDRAM address range (access to reserved address range)
- Attempting to read/write access from/to SDRAM bank when it is not yet initialized

The FMC generates an AXI decoder error when ADDR[31:28] address bits are not supported by the FMC bank base address following the BMAP[1:0] bits configuration.

The kernel clock for the FMC controller is the asynchronous fmc_ker_ck clock (refer to *Section 32: Reset and Clock Control (RCC)* for fmc_ker_ck clock source selection).

24.5.1 Supported memories and transactions

General transaction rules

The requested AXI transaction data size can be 8-, 16-, 32- or 64-bit wide whereas the accessed external device has a fixed data width. The best performance is always achieved with aligned AXI transactions whose size matches the external device data width.

When AXI transaction data size is different from the device data width, the result depends on the following factors:

- AXI transaction data size is greater than the device data width:
  - Read/Write transactions: the FMC splits the AXI transaction into smaller consecutive accesses matching the external device data width.
- AXI transaction data size is smaller than the external device data width and the device supports byte selection (SRAM, PSRAM, SDRAM):
  - Write transactions, the FMC manages the transaction using the byte lane signals.
  - Read transactions, the FMC returns all bytes according to the external device data width. The useless bytes are discarded by the system.
- AXI transaction data size is smaller than the external device data width and the device does not support byte selection (NOR and NAND Flash memories):
  - Write transactions: the FMC writes some irrelevant bytes which may corrupt the external device
  - Read transactions: the FMC returns all bytes according to the external device data width. The useless bytes are discarded by the system.

Caution: Address alignment

- Read transactions with unaligned addresses (such as half-word starting at an odd address) are not supported by the FMC.
- Write transactions with unaligned addresses

  Their support depends on byte selection availability on the external device:
  - If the device does not support byte selection (NOR and NAND Flash memories), narrow write transactions and/or unaligned write transaction are not supported since the FMC would write irrelevant bytes and corrupt the external device.

Wrap support for NOR Flash/PSRAM and SDRAM

The synchronous memories must be configured in Linear burst mode of undefined length as not all masters can issue wrap transactions.

If a master generates a wrap transaction:

- The read is split into two linear burst transactions.
- The write is split into two linear burst transactions if the write FIFO is enabled and into several linear burst transactions if the write FIFO is disabled.

Configuration registers

The FMC can be configured through a set of registers. Refer to *Section 24.7.6*, for a detailed description of the NOR Flash/PSRAM controller registers. Refer to *Section 24.8.7*, for a detailed description of the NAND Flash registers and to *Section 24.9.5* for a detailed description of the SDRAM controller registers.

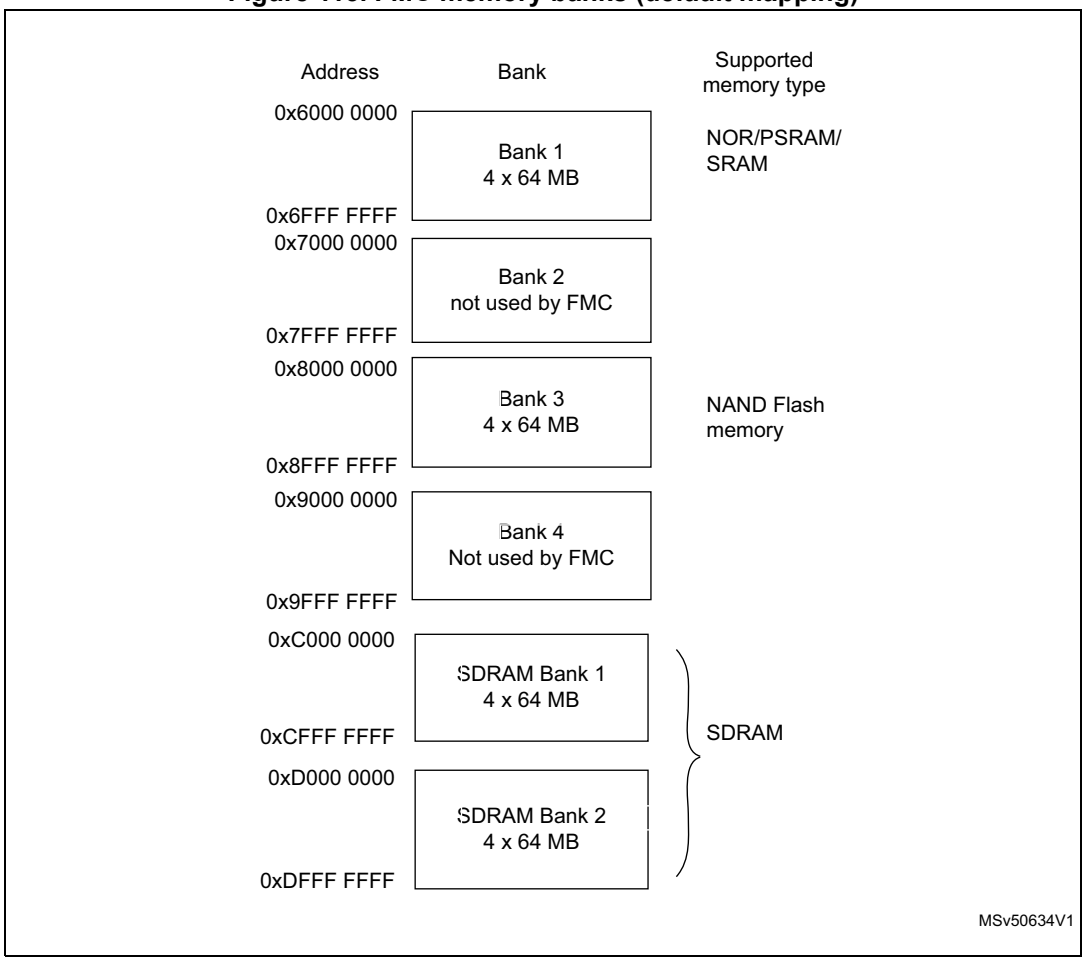
24.6 External device address mapping

From the FMC point of view, the external memory is divided into fixed-size banks of 256 Mbytes each (see *Figure 113*):

- Bank 1 is used to address up to 4 NOR Flash memory or PSRAM devices. This bank is split into 4 NOR/PSRAM subbanks with 4 dedicated Chip Selects, as follows:
  - Bank 1 - NOR/PSRAM 1
  - Bank 1 - NOR/PSRAM 2
  - Bank 1 - NOR/PSRAM 3
  - Bank 1 - NOR/PSRAM 4
- Bank 2 and Bank 4 are not used by the FMC.
- Bank 3 is used to address NAND Flash memory devices.The MPU memory attribute for this space must be reconfigured by software to Device.
- Bank 5 and 6 are used to address SDRAM devices (1 device per bank).

For each bank the type of memory to be used can be configured by the user application through the Configuration register.

Figure 113. FMC memory banks (default mapping)



The FMC bank mapping can be modified through the BMAP[1:0] bits in the FMC_BCR1 register. *Table 166* shows the configuration to swap the NOR/PSRAM bank with SDRAM banks.

Table 166. FMC bank mapping options

Start -End address	BMAP[1:0]=00 (Default mapping)	BMAP[1:0]=01 NOR/PSRAM and SDRAM banks swapped
0x6000 0000 - 0x6FFF FFFF	NOR/PSRAM bank	SDRAM bank1
0x7000 0000 - 0x7FFF FFFF	Not used by FMC	
0x8000 0000 - 0x8FFF FFFF	NAND bank	NAND bank
0x9000 0000 - 0x9FFF FFFF	Not used by FMC	
0xC000 0000 - 0xCFFF FFFF	SDRAM bank1	NOR/PSRAM bank
0xD000 0000 - 0xDFFF FFFF	SDRAM bank2	SDRAM bank2

24.6.1 NOR/PSRAM address mapping

ADDR[27:26] bits are used to select one of the four memory banks as shown in *Table 167*.

Table 167. NOR/PSRAM bank selection

ADDR[27:26](1)	Selected bank
00	Bank 1 - NOR/PSRAM 1
01	Bank 1 - NOR/PSRAM 2
10	Bank 1 - NOR/PSRAM 3
11	Bank 1 - NOR/PSRAM 4

1. ADDR are internal address lines that are translated to external memory.

The ADDR[25:0] bits contain the external memory address. Since ADDR is a byte address whereas the memory is addressed at word level, the address actually issued to the memory varies according to the memory data width, as shown in the following table.

Table 168. NOR/PSRAM External memory address

Memory width(1)	Data address issued to the memory	Maximum memory capacity (bits)
8-bit	ADDR[25:0]	64 Mbytes x 8 = 512 Mbit
16-bit	ADDR[25:1] >> 1	64 Mbytes/2 x 16 = 512 Mbit
32-bit	ADDR[25:2] >> 2	64 Mbytes/4 x 32 = 512 Mbit

1. In case of a 16-bit external memory width, the FMC will internally use ADDR[25:1] to generate the address for external memory FMC_A[24:0]. In case of a 32-bit memory width, the FMC will internally use ADDR[25:2] to generate the external address.
Whatever the external memory width, FMC_A[0] should be connected to external memory address A[0].

24.6.2 NAND Flash memory address mapping

The NAND bank is divided into memory areas as indicated in *Table 169*.

Table 169. NAND memory mapping and timing registers

Start address	End address	FMC bank	Memory space	Timing register
0x8800 0000	0x8BFF FFFF	Bank 3 - NAND Flash	Attribute	FMC_PATT (0x8C)
0x8000 0000	0x83FF FFFF		Common	FMC_PMEM (0x88)

For NAND Flash memory, the common and attribute memory spaces are subdivided into three sections (see in *Table 170* below) located in the lower 256 Kbytes:

- Data section (first 64 Kbytes in the common/attribute memory space)
- Command section (second 64 Kbytes in the common / attribute memory space)
- Address section (next 128 Kbytes in the common / attribute memory space)

Table 170. NAND bank selection

Section name	ADDR[17:16]	Address range
Address section	1X	0x020000-0x03FFFF
Command section	01	0x010000-0x01FFFF
Data section	00	0x000000-0x0FFFF

The application software uses the 3 sections to access the NAND Flash memory:

- **To send a command to NAND Flash memory**, the software must write the command value to any memory location in the command section.
- **To specify the NAND Flash address that must be read or written**, the software must write the address value to any memory location in the address section. Since an address can be 4 or 5 bytes long (depending on the actual memory size), several consecutive write operations to the address section are required to specify the full address.
- **To read or write data,** the software reads or writes the data from/to any memory location in the data section.

Since the NAND Flash memory automatically increments addresses, there is no need to increment the address of the data section to access consecutive memory locations.

24.6.3 SDRAM address mapping

Two SDRAM banks are available as indicated in *Table 171*.

Table 171. SDRAM bank selection

Selected bank	Control register	Timing register
SDRAM Bank1	FMC_SDCR1	FMC_SDTR1
SDRAM Bank2	FMC_SDCR2	FMC_SDTR2

Table 172 shows SDRAM mapping for a 13-bit row and an 11-bit column configuration.

Table 172. SDRAM address mapping

Memory width(1)	Internal bank	Row address	Column address(2)	Maximum memory capacity (Mbytes)
8-bit	ADDR[25:24]	ADDR[23:11]	ADDR[10:0]	64 Mbytes: 4 x 8K x 2K
16-bit	ADDR[26:25]	ADDR[24:12]	ADDR[11:1]	128 Mbytes: 4 x 8K x 2K x 2
32-bit	ADDR[27:26]	ADDR[25:13]	ADDR[12:2]	256 Mbytes: 4 x 8K x 2K x 4

1. When interfacing with a 16-bit memory, the FMC internally uses the ADDR[11:1] internal address lines to generate the external address. When interfacing with a 32-bit memory, the FMC internally uses ADDR[12:2] lines to generate the external address. Whatever the memory width, FMC_A[0] has to be connected to the external memory address A[0].
2. The AutoPrecharge is not supported. FMC_A[10] must be connected to the external memory address A[10] but it will be always driven low.

The ADDR[27:0] bits are translated into an external SDRAM address depending on the SDRAM controller configuration:

- Data size:8, 16 or 32 bits
- Row size:11, 12 or 13 bits
- Column size: 8, 9, 10 or 11 bits
- Number of internal banks: two or four internal banks

The following tables show the SDRAM address mapping versus the SDRAM controller configuration.

Table 173. SDRAM address mapping with 8-bit data bus width(1)(2)

<table>
<tr><th rowspan="2">Row size configuration</th><th colspan="28">ADDR(Internal Address Lines)</th></tr>
<tr><th>27</th><th>26</th><th>25</th><th>24</th><th>23</th><th>22</th><th>21</th><th>20</th><th>19</th><th>18</th><th>17</th><th>16</th><th>15</th><th>14</th><th>13</th><th>12</th><th>11</th><th>10</th><th>9</th><th>8</th><th>7</th><th>6</th><th>5</th><th>4</th><th>3</th><th>2</th><th>1</th><th>0</th></tr>
<tr><td rowspan="4">11-bit row size configuration</td><td colspan="8">Res.</td><td colspan="2">Bank [1:0]</td><td colspan="10">Row[10:0]</td><td colspan="8">Column[7:0]</td></tr>
<tr><td colspan="7">Res.</td><td colspan="2">Bank [1:0]</td><td colspan="10">Row[10:0]</td><td colspan="8">Column[8:0]</td></tr>
<tr><td colspan="6">Res.</td><td colspan="2">Bank [1:0]</td><td colspan="10">Row[10:0]</td><td colspan="8">Column[9:0]</td></tr>
<tr><td colspan="5">Res.</td><td colspan="2">Bank [1:0]</td><td colspan="10">Row[10:0]</td><td colspan="8">Column[10:0]</td></tr>
</table>

Table 173. SDRAM address mapping with 8-bit data bus width(1)(2) (continued)

Row size configuration	ADDR(Internal Address Lines)																											
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
12-bit row size configuration	Res.						Bank [1:0]		Row[11:0]										Column[7:0]									
	Res.						Bank [1:0]		Row[11:0]										Column[8:0]									
	Res.						Bank [1:0]		Row[11:0]										Column[9:0]									
	Res.						Bank [1:0]		Row[11:0]										Column[10:0]									
13-bit row size configuration	Res.						Bank [1:0]		Row[12:0]										Column[7:0]									
	Res.						Bank [1:0]		Row[12:0]										Column[8:0]									
	Res.						Bank [1:0]		Row[12:0]										Column[9:0]									
	Res.						Bank [1:0]		Row[12:0]										Column[10:0]									

1. BANK[1:0] are the Bank Address BA[1:0]. When only 2 internal banks are used, BA1 must always be set to ‘0’.
2. Access to Reserved (Res.) address range generates an AXI slave error.

Table 174. SDRAM address mapping with 16-bit data bus width(1)(2)

Row size Configuration	ADDR(address Lines)																											
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
11-bit row size configuration	Res.						Bank [1:0]		Row[10:0]										Column[7:0]									BM0 (3)
	Res.						Bank [1:0]		Row[10:0]										Column[8:0]									BM0
	Res.						Bank [1:0]		Row[10:0]										Column[9:0]									BM0
	Res.						Bank [1:0]		Row[10:0]										Column[10:0]									BM0
12-bit row size configuration	Res.						Bank [1:0]		Row[11:0]										Column[7:0]									BM0
	Res.						Bank [1:0]		Row[11:0]										Column[8:0]									BM0
	Res.						Bank [1:0]		Row[11:0]										Column[9:0]									BM0
	Res.						Bank [1:0]		Row[11:0]										Column[10:0]									BM0

Table 174. SDRAM address mapping with 16-bit data bus width(1)(2)

Row size Configuration	ADDR(address Lines)																										
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
13-bit row size configuration	Res.				Bank [1:0]		Row[12:0]													Column[7:0]								BM0
	Res.				Bank [1:0]		Row[12:0]													Column[8:0]								BM0
	Res.				Bank [1:0]		Row[12:0]													Column[9:0]								BM0
	Res.				Bank [1:0]		Row[12:0]													Column[10:0]								BM0

1. BANK[1:0] are the Bank Address BA[1:0]. When only 2 internal banks are used, BA1 must always be set to '0'.
2. Access to Reserved space (Res.) generates an AXI Slave error.
3. BM0: is the byte mask for 16-bit access.

Table 175. SDRAM address mapping with 32-bit data bus width(1)(2)

Row size configuration	ADDR(address Lines)																										
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
11-bit row size configuration	Res.					Bank [1:0]		Row[10:0]											Column[7:0]								BM[1:0](3)	
	Res.					Bank [1:0]		Row[10:0]											Column[8:0]								BM[1:0	
	Res.					Bank [1:0]		Row[10:0]											Column[9:0]								BM[1:0	
	Res.					Bank [1:0]		Row[10:0]											Column[10:0]								BM[1:0	
12-bit row size configuration	Res.					Bank [1:0]		Row[11:0]											Column[7:0]								BM[1:0	
	Res.					Bank [1:0]		Row[11:0]											Column[8:0]								BM[1:0	
	Res.					Bank [1:0]		Row[11:0]											Column[9:0]								BM[1:0	
	Res.					Bank [1:0]		Row[11:0]											Column[10:0]								BM[1:0	
13-bit row size configuration	Res.					Bank [1:0]		Row[12:0]											Column[7:0]								BM[1:0	
	Res.					Bank [1:0]		Row[12:0]											Column[8:0]								BM[1:0	
	Res.					Bank [1:0]		Row[12:0]											Column[9:0]								BM[1:0	
	Bank [1:0]					Row[12:0]													Column[10:0]								BM[1:0	

1. BANK[1:0] are the Bank Address BA[1:0]. When only 2 internal banks are used, BA1 must always be set to '0'.
2. Access to Reserved space (Res.) generates an AXI slave error.
3. BM[1:0]: is the byte mask for 32-bit access.

24.7 NOR Flash/PSRAM controller

The FMC generates the appropriate signal timings to drive the following types of memories:

- Asynchronous SRAM and ROM
  - 8 bits
  - 16 bits
  - 32 bits
- PSRAM (Cellular RAM)
  - Asynchronous mode
  - Burst mode for synchronous accesses with configurable option to split burst access when crossing boundary page for CRAM 1.5.
  - Multiplexed or non-multiplexed
- NOR Flash memory
  - Asynchronous mode
  - Burst mode for synchronous accesses
  - Multiplexed or non-multiplexed

The FMC outputs a unique Chip Select signal, NE[4:1], per bank. All the other signals (addresses, data and control) are shared.

The FMC supports a wide range of devices through a programmable timings among which:

- Programmable wait states (up to 15)
- Programmable bus turnaround cycles (up to 15)
- Programmable output enable and write enable delays (up to 15)
- Independent read and write timings and protocol to support the widest variety of memories and timings
- Programmable continuous clock (FMC_CLK) output.

The FMC output Clock (FMC_CLK) is a sub-multiple of the fmc_ker_ck clock. It can be delivered to the selected external device either during synchronous accesses only or during asynchronous and synchronous accesses depending on the CCKEN bit configuration in the FMC_BCR1 register:

- If the CCLKEN bit is reset, the FMC generates the clock (FMC_CLK) only during synchronous accesses (Read/write transactions).
- If the CCLKEN bit is set, the FMC generates a continuous clock during asynchronous and synchronous accesses. To generate the FMC_CLK continuous clock, Bank 1 must be configured in Synchronous mode (see *Section 24.7.6: NOR/PSRAM controller registers*). Since the same clock is used for all synchronous memories, when a continuous output clock is generated and synchronous accesses are performed, the AXI data size has to be the same as the memory data width (MWID) otherwise the FMC_CLK frequency will be changed depending on AXI data transaction (refer to *Section 24.7.5: Synchronous transactions* for FMC_CLK divider ratio formula).

The size of each bank is fixed and equal to 64 Mbytes. Each bank is configured through dedicated registers (see *Section 24.7.6: NOR/PSRAM controller registers*).

The programmable memory parameters include access times (see *Table 176*) and support for wait management (for PSRAM and NOR Flash memory accessed in Burst mode).

Table 176. Programmable NOR/PSRAM access parameters

Parameter	Function	Access mode	Unit	Min.	Max.
Address setup	Duration of the address setup phase	Asynchronous	FMC clock cycle (fmc_ker_ck)	0	15
Address hold	Duration of the address hold phase	Asynchronous, muxed I/Os	FMC clock cycle (fmc_ker_ck)	1	15
Data setup	Duration of the data setup phase	Asynchronous	FMC clock cycle (fmc_ker_ck)	1	256
Bust turn	Duration of the bus turnaround phase	Asynchronous and synchronous read	FMC clock cycle (fmc_ker_ck)	0	15
Clock divide ratio	Number of FMC clock cycles (fmc_ker_ck) to build one memory clock cycle (CLK)	Synchronous	FMC clock cycle (fmc_ker_ck)	2	16
Data latency	Number of clock cycles to issue to the memory before the first data of the burst	Synchronous	Memory clock cycle (fmc_ker_ck)	2	17

24.7.1 External memory interface signals

Table 177, *Table 178* and *Table 179* list the signals that are typically used to interface with NOR Flash memory, SRAM and PSRAM.

Note: The prefix “N” identifies the signals which are active low.

NOR Flash memory, non-multiplexed I/Os

Table 177. Non-multiplexed I/O NOR Flash memory

FMC pin name	I/O	Function
CLK	O	Clock (for synchronous access)
A[25:0]	O	Address bus
D[31:0]	I/O	Bidirectional data bus
NE[x]	O	Chip Select, x = 1..4
NOE	O	Output enable
NWE	O	Write enable
NL(=NADV)	O	Latch enable (this signal is called address valid, NADV, by some NOR Flash devices)
NWAIT	I	NOR Flash wait input signal to the FMC

The maximum capacity is 512 Mbits (26 address lines).

NOR Flash memory, 16-bit multiplexed I/Os

Table 178. 16-bit multiplexed I/O NOR Flash memory

FMC pin name	I/O	Function
CLK	O	Clock (for synchronous access)
A[25:16]	O	Address bus
AD[15:0]	I/O	16-bit multiplexed, bidirectional address/data bus (the 16-bit address A[15:0] and data D[15:0] are multiplexed on the databus)
NE[x]	O	Chip Select, x = 1..4
NOE	O	Output enable
NWE	O	Write enable
NL(=NADV)	O	Latch enable (this signal is called address valid, NADV, by some NOR Flash devices)
NWAIT	I	NOR Flash wait input signal to the FMC

The maximum capacity is 512 Mbits.

PSRAM/SRAM, non-multiplexed I/Os

Table 179. Non-multiplexed I/Os PSRAM/SRAM

FMC pin name	I/O	Function
CLK	O	Clock (only for PSRAM synchronous access)
A[25:0]	O	Address bus
D[31:0]	I/O	Data bidirectional bus
NE[x]	O	Chip Select, x = 1..4 (called NCE by PSRAM (Cellular RAM i.e. CRAM))
NOE	O	Output enable
NWE	O	Write enable
NL(= NADV)	O	Address valid only for PSRAM input (memory signal name: NADV)
NWAIT	I	PSRAM wait input signal to the FMC
NBL[3:0]	O	Byte lane output. Byte 0 to Byte 3 control (Upper and lower byte enable)

The maximum capacity is 512 Mbits.

PSRAM, 16-bit multiplexed I/Os

Table 180. 16-Bit multiplexed I/O PSRAM

FMC pin name	I/O	Function
CLK	O	Clock (for synchronous access)
A[25:16]	O	Address bus
AD[15:0]	I/O	16-bit multiplexed, bidirectional address/data bus (the 16-bit address A[15:0] and data D[15:0] are multiplexed on the databus)

Table 180. 16-Bit multiplexed I/O PSRAM (continued)

FMC pin name	I/O	Function
NE[x]	O	Chip Select, x = 1..4 (called NCE by PSRAM (Cellular RAM i.e. CRAM))
NOE	O	Output enable
NWE	O	Write enable
NL(= NADV)	O	Address valid PSRAM input (memory signal name: NADV)
NWAIT	I	PSRAM wait input signal to the FMC
NBL[1:0]	O	Byte lane output. Byte 0 and Byte 1 control (upper and lower byte enable)

The maximum capacity is 512 Mbits (26 address lines).

24.7.2 Supported memories and transactions

Table 181 below shows an example of the supported devices, access modes and transactions when the memory data bus is 16-bit wide for NOR Flash memory, PSRAM and SRAM. The transactions not allowed (or not supported) by the FMC are shown in gray in this example.

Table 181. NOR Flash/PSRAM: Example of supported memories and transactions(1)

Device	Mode	R/W	AXI data size	Memory data size	Allowed/ not allowed	Comments
NOR Flash (muxed I/Os and non-multiplexed I/Os)	Asynchronous	R	8	16	Y	
	Asynchronous	W	8	16	N	
	Asynchronous	R	16	16	Y	
	Asynchronous	W	16	16	Y	
	Asynchronous	R	32	16	Y	Split into 2 FMC accesses
	Asynchronous	W	32	16	Y	Split into 2 FMC accesses
	Asynchronous	R	64	16	Y	Split into 4 FMC accesses
	Asynchronous	W	64	16	Y	Split into 4 FMC accesses
	Asynchronous page	R	-	16	N	Mode is not supported
	Synchronous	R	8	16	N	
	Synchronous	R	16	16	Y	
	Synchronous	R	32/64	16	Y	

Table 181. NOR Flash/PSRAM: Example of supported memories and transactions(1) (continued)

Device	Mode	R/W	AXI data size	Memory data size	Allowed/ not allowed	Comments
PSRAM (multiplexed I/Os and non-multiplexed I/Os)	Asynchronous	R	8	16	Y	
	Asynchronous	W	8	16	Y	Use of byte lanes NBL[1:0]
	Asynchronous	R	16	16	Y	
	Asynchronous	W	16	16	Y	
	Asynchronous	R	32	16	Y	Split into 2 FMC accesses
	Asynchronous	W	32	16	Y	Split into 2 FMC accesses
	Asynchronous	R	64	16	Y	Split into 4 FMC accesses
	Asynchronous	W	64	16	Y	Split into 4 FMC accesses
	Asynchronous page	R	-	16	N	Mode is not supported
	Synchronous	R	8	16	N	
	Synchronous	R	16	16	Y	
	Synchronous	R	32/64	16	Y	
	Synchronous	W	8	16	Y	Use of byte lanes NBL[1:0]
	Synchronous	W	16/32/64	16	Y	
SRAM and ROM	Asynchronous	R	8/16	16	Y	
	Asynchronous	W	8/16	16	Y	Use of byte lanes NBL[1:0]
	Asynchronous	R	32	16	Y	Split into 2 FMC accesses
	Asynchronous	W	32	16	Y	Split into 2 FMC accesses Use of byte lanes NBL[1:0]
	Asynchronous	R	64	16	Y	Split into 4 FMC accesses
	Asynchronous	W	64	16	Y	Split into 4 FMC accesses Use of byte lanes NBL[1:0]

1. NBL[1:0] are also driven by AXI write strobes.

24.7.3 General timing rules

Signal synchronization is performed as follows:

- All controller output signals change on the rising edge of the fmc_ker_ck clock.
- In Synchronous read and write modes, all output signals change on the rising edge of fmc_ker_ck clock. Whatever the CLKDIV value, all outputs change as follows:
  - NOEL/NWEL/ NEL/NADVL/ NADVH /NBLL/ Address valid outputs change on the falling edge of FMC_CLK clock.
  - NOEH/ NWEH / NEH/ NOEH/NBLH/ Address invalid outputs change on the rising edge of FMC_CLK clock.

24.7.4 NOR Flash/PSRAM controller asynchronous transactions

Asynchronous transactions on static memories (NOR Flash memory, PSRAM, SRAM) are performed as follows:

- Signals are synchronized by the internal clock. This clock is not issued to the memory.
- The FMC always samples the data before deasserting the Chip Select signal. This guarantees that the memory data hold timing constraint is met (minimum Chip Enable high to data transition is usually 0 ns)
- If the Extended mode is enabled (EXTMOD bit is set in the FMC_BCRx register), up to four extended modes (A, B, C and D) are available. It is possible to mix A, B, C and D modes for read and write operations. For example, read operation can be performed in mode A and write in mode B.
- If the Extended mode is disabled (EXTMOD bit is reset in the FMC_BCRx register), the FMC can operate in Mode1 or Mode2 as follows:
  - Mode 1 is the default mode when SRAM/PSRAM memory type is selected (MTYP = 0x0 or 0x01 in the FMC_BCRx register)
  - Mode 2 is the default mode when NOR memory type is selected (MTYP = 0x10 in the FMC_BCRx register).

Mode 1 - SRAM/PSRAM (CRAM)

The next figures show the read and write transactions for the supported modes followed by the required configuration of FMC_BCRx, and FMC_BTRx/FMC_BWTRx registers.

Figure 114. Mode 1 read access waveforms

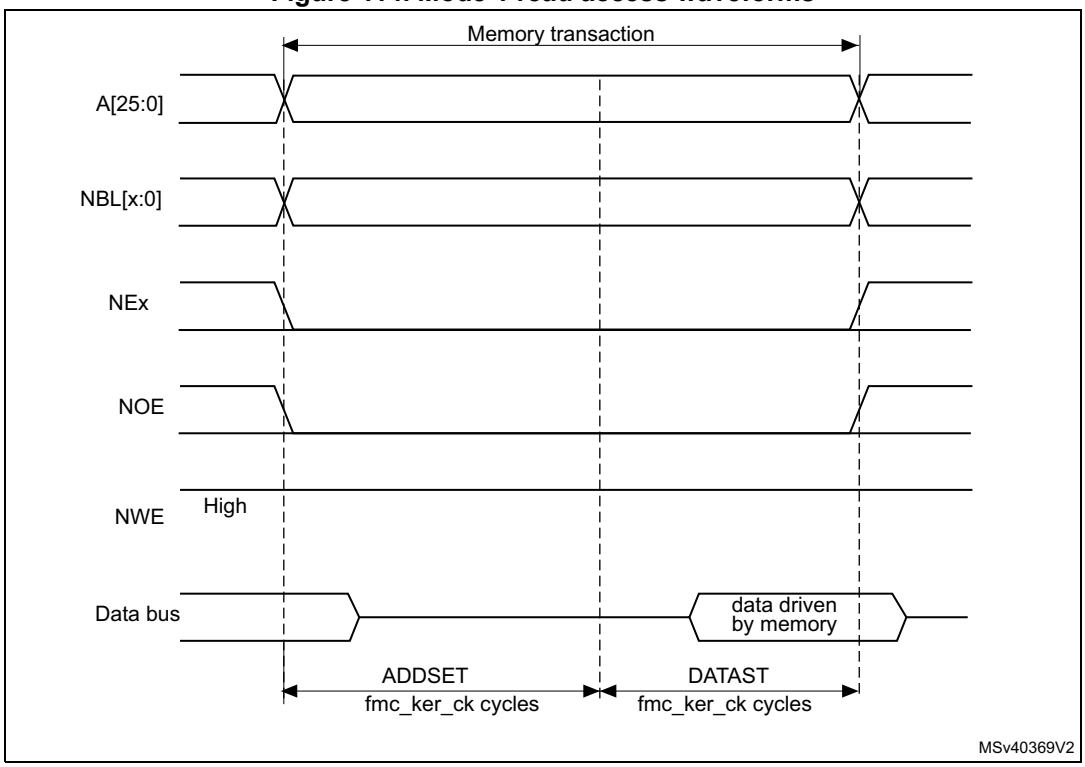
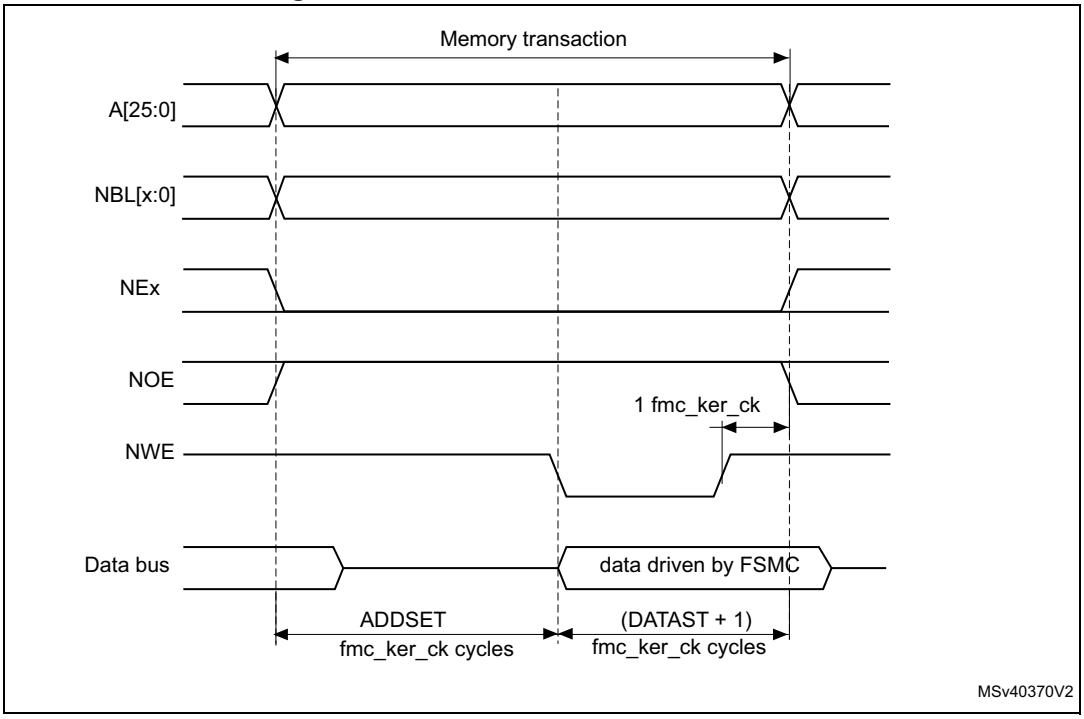


Figure 115. Mode 1 write access waveforms



The fmc_ker_ck cycle at the end of the write transaction helps guarantee the address and data hold time after the NWE rising edge. Due to the presence of this fmc_ker_ck cycle, the DATAST value must be greater than zero (DATAST > 0).

Table 182. FMC_BCRx bitfields (mode 1)

Bit number	Bit name	Value to set
31	FMCEN	0x1
30:26	Reserved	0x000
25:24	BMAP	As needed
23:22	Reserved	0x000
21	WFDIS	As needed
20	CCLKEN	As needed
19	CBURSTRW	0x0 (no effect in Asynchronous mode)
18:16	CPSIZE	0x0 (no effect in Asynchronous mode)
15	ASYNCWAIT	Set to 1 if the memory supports this feature. Otherwise keep at 0.
14	EXTMOD	0x0
13	WAITEN	0x0 (no effect in Asynchronous mode)
12	WREN	As needed
11	WAITCFG	Don’t care
10	Reserved	0x0

Table 182. FMC_BCRx bitfields (mode 1) (continued)

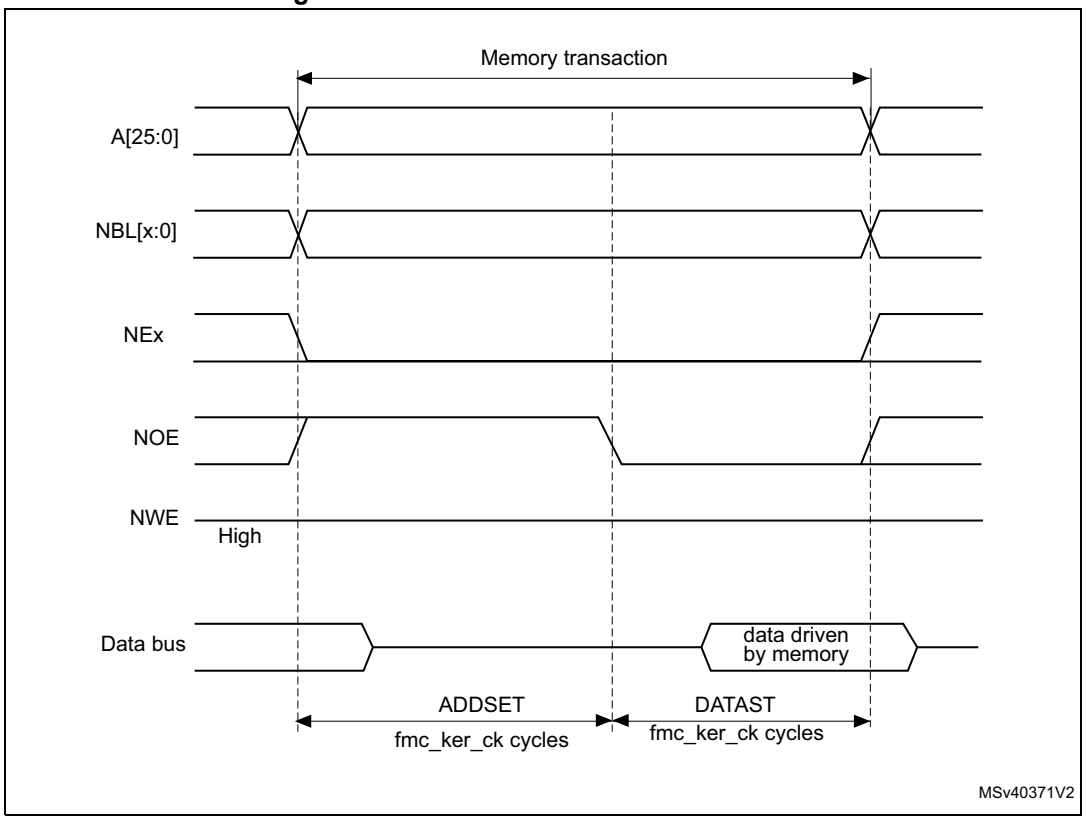
Bit number	Bit name	Value to set
9	WAITPOL	Meaningful only if bit 15 is 1
8	BURSTEN	0x0
7	Reserved	0x1
6	FACCEN	Don’t care
5:4	MWID	As needed
3:2	MTYP	As needed, exclude 0x2 (NOR Flash memory)
1	MUXE	0x0
0	MBKEN	0x1

Table 183. FMC_BTRx bitfields (mode 1)

Bit number	Bit name	Value to set
31:30	Reserved	0x0
29:28	ACCMOD	Don’t care
27:24	DATLAT	Don’t care
23:20	CLKDIV	Don’t care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN fmc_ker_ck)
15:8	DATAST	Duration of the second access phase (DATAST+1 fmc_ker_ck cycles for write accesses, DATAST fmc_ker_ck cycles for read accesses).
7:4	ADDHLD	Don’t care
3:0	ADDSET	Duration of the first access phase (ADDSET fmc_ker_ck cycles). Minimum value for ADDSET is 0.

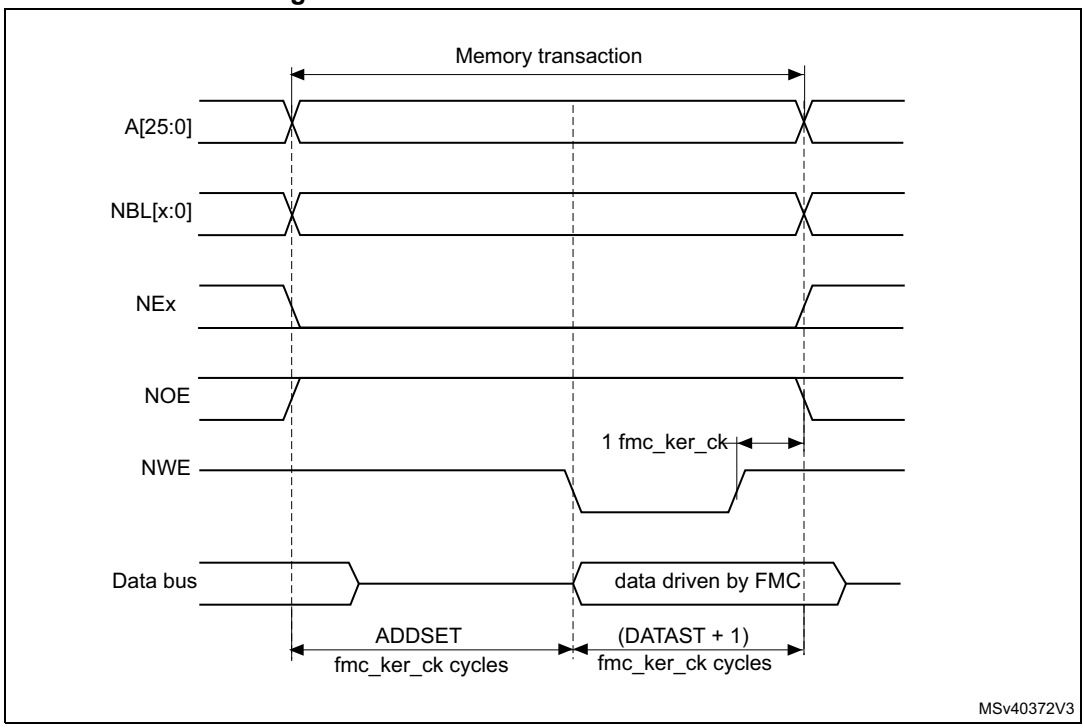
Mode A - SRAM/PSRAM (CRAM) OE toggling

Figure 116. Mode A read access waveforms



1. NBL[3:0] are driven low during the read access

Figure 117. Mode A write access waveforms



The differences compared with Mode1 are the toggling of NOE and the independent read and write timings.

Table 184. FMC_BCRx bitfields (mode A)

Bit number	Bit name	Value to set
31	FMCEN	0x1
30:26	Reserved	0x000
25:24	BMAP	As needed
23:22	Reserved	0x000
21	WFDIS	As needed
20	CCLKEN	As needed
19	CBURSTRW	0x0 (no effect in Asynchronous mode)
18:16	CPSIZE	0x0 (no effect in Asynchronous mode)
15	ASYNCWAIT	Set to 1 if the memory supports this feature. Otherwise keep at 0.
14	EXTMOD	0x1
13	WAITEN	0x0 (no effect in Asynchronous mode)
12	WREN	As needed
11	WAITCFG	Don’t care
10	Reserved	0x0

Table 184. FMC_BCRx bitfields (mode A) (continued)

Bit number	Bit name	Value to set
9	WAITPOL	Meaningful only if bit 15 is 1
8	BURSTEN	0x0
7	Reserved	0x1
6	FACCEN	Don't care
5:4	MWID	As needed
3:2	MTYP	As needed, exclude 0x2 (NOR Flash memory)
1	MUXEN	0x0
0	MBKEN	0x1

Table 185. FMC_BTRx bitfields (mode A)

Bit number	Bit name	Value to set
31:30	Reserved	0x0
29:28	ACCMOD	0x0
27:24	DATLAT	Don't care
23:20	CLKDIV	Don't care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN fmc_ker_ck)
15:8	DATAST	Duration of the second access phase (DATAST fmc_ker_ck cycles) for read accesses.
7:4	ADDHLD	Don't care
3:0	ADDSET	Duration of the first access phase (ADDSET fmc_ker_ck cycles) for read accesses. Minimum value for ADDSET is 0.

Table 186. FMC_BWTRx bitfields (mode A)

Bit number	Bit name	Value to set
31:30	Reserved	0x0
29:28	ACCMOD	0x0
27:24	DATLAT	Don't care
23:20	CLKDIV	Don't care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN fmc_ker_ck)
15:8	DATAST	Duration of the second access phase (DATAST fmc_ker_ck cycles) for write accesses.
7:4	ADDHLD	Don't care
3:0	ADDSET	Duration of the first access phase (ADDSET fmc_ker_ck cycles) for write accesses. Minimum value for ADDSET is 0.

Mode 2/B - NOR Flash

Figure 118. Mode 2 and mode B read access waveforms

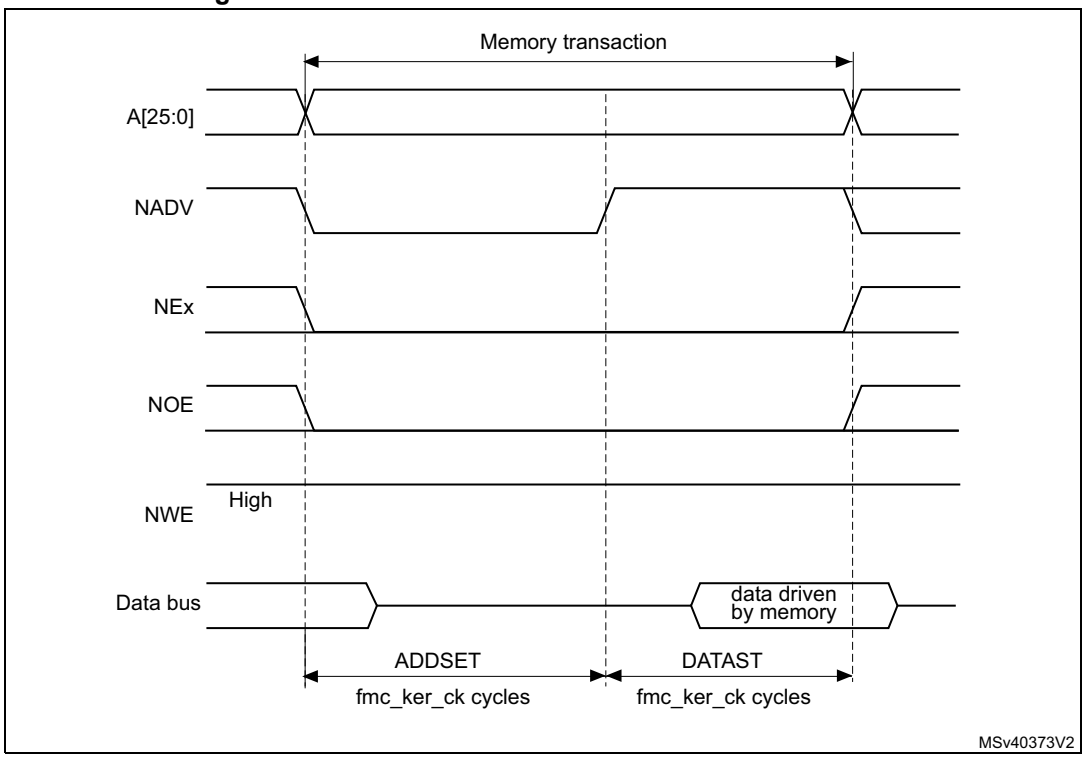


Figure 119. Mode 2 write access waveforms

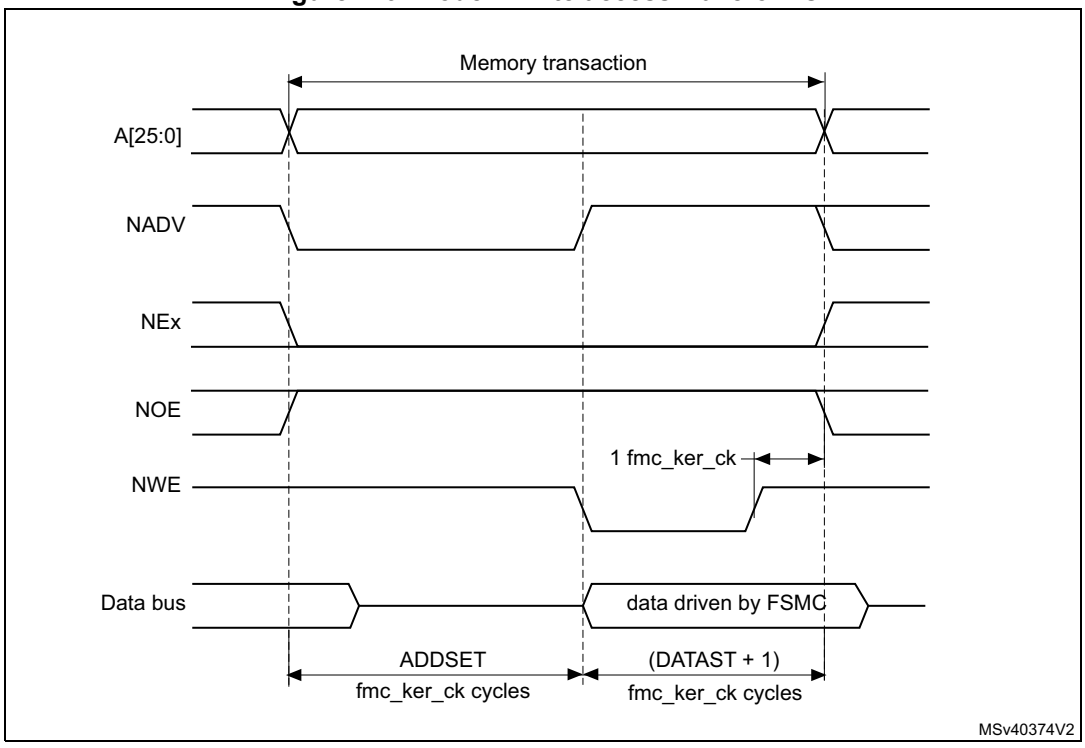
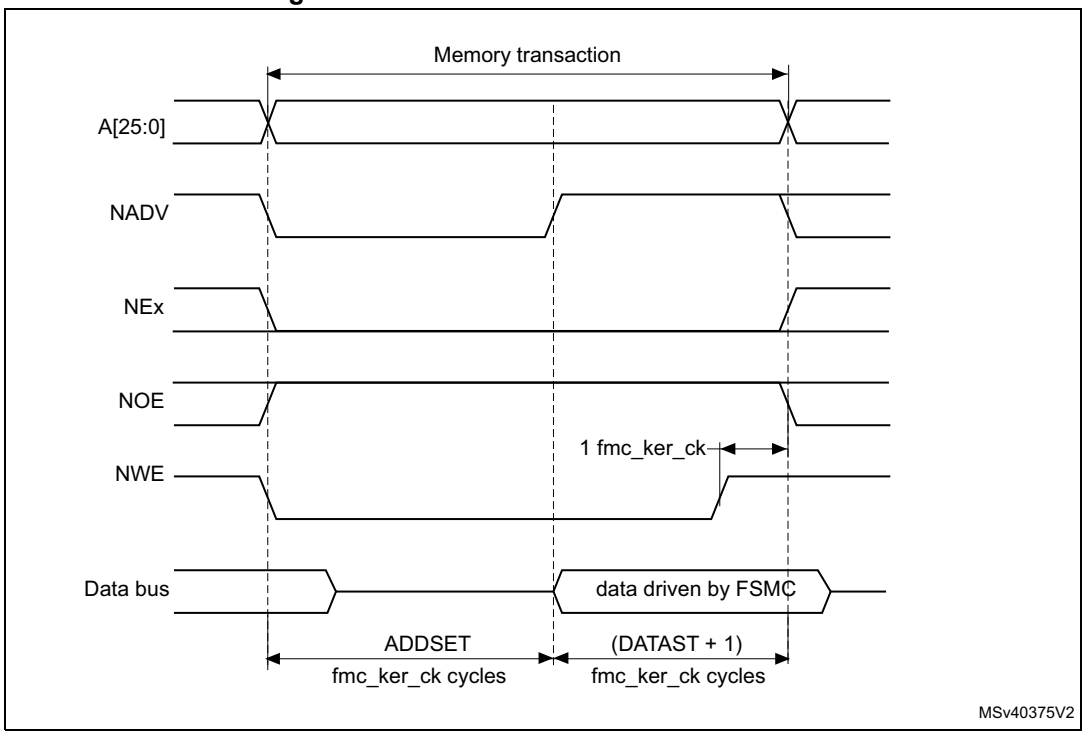


Figure 120. Mode B write access waveforms



The differences with Mode1 are the toggling of NWE and the independent read and write timings when extended mode is set (mode B).

Table 187. FMC_BCRx bitfields (mode 2/B)

Bit number	Bit name	Value to set
31	FMCEN	0x1
30:26	Reserved	0x000
25:24	BMAP	As needed
23:22	Reserved	0x000
21	WFDIS	As needed
20	CCLKEN	As needed
19	CBURSTRW	0x0 (no effect in Asynchronous mode)
18:16	CPSIZE	0x0 (no effect in Asynchronous mode)
15	ASYNCWAIT	Set to 1 if the memory supports this feature. Otherwise keep at 0.
14	EXTMOD	0x1 for mode B, 0x0 for mode 2
13	WAITEN	0x0 (no effect in Asynchronous mode)
12	WREN	As needed
11	WAITCFG	Don’t care
10	Reserved	0x0

Table 187. FMC_BCRx bitfields (mode 2/B) (continued)

Bit number	Bit name	Value to set
9	WAITPOL	Meaningful only if bit 15 is 1
8	BURSTEN	0x0
7	Reserved	0x1
6	FACCEN	0x1
5:4	MWID	As needed
3:2	MTYP	0x2 (NOR Flash memory)
1	MUXEN	0x0
0	MBKEN	0x1

Table 188. FMC_BTRx bitfields (mode 2/B)

Bit number	Bit name	Value to set
31:30	Reserved	0x0
29:28	ACCMOD	0x1 if Extended mode is set
27:24	DATLAT	Don’t care
23:20	CLKDIV	Don’t care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN fmc_ker_ck)
15:8	DATAST	Duration of the access second phase (DATAST fmc_ker_ck cycles) for read accesses.
7:4	ADDHLD	Don’t care
3:0	ADDSET	Duration of the access first phase (ADDSET fmc_ker_ck cycles) for read accesses. Minimum value for ADDSET is 0.

Table 189. FMC_BWTRx bitfields (mode 2/B)

Bit number	Bit name	Value to set
31:30	Reserved	0x0
29:28	ACCMOD	0x1 if Extended mode is set
27:24	DATLAT	Don’t care
23:20	CLKDIV	Don’t care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN fmc_ker_ck)
15:8	DATAST	Duration of the access second phase (DATAST fmc_ker_ck cycles) for write accesses.
7:4	ADDHLD	Don’t care
3:0	ADDSET	Duration of the access first phase (ADDSET fmc_ker_ck cycles) for write accesses. Minimum value for ADDSET is 0.

Note: The FMC_BWTRx register is valid only if the Extended mode is set (mode B), otherwise its content is don't care.

Mode C - NOR Flash - OE toggling

Figure 121. Mode C read access waveforms

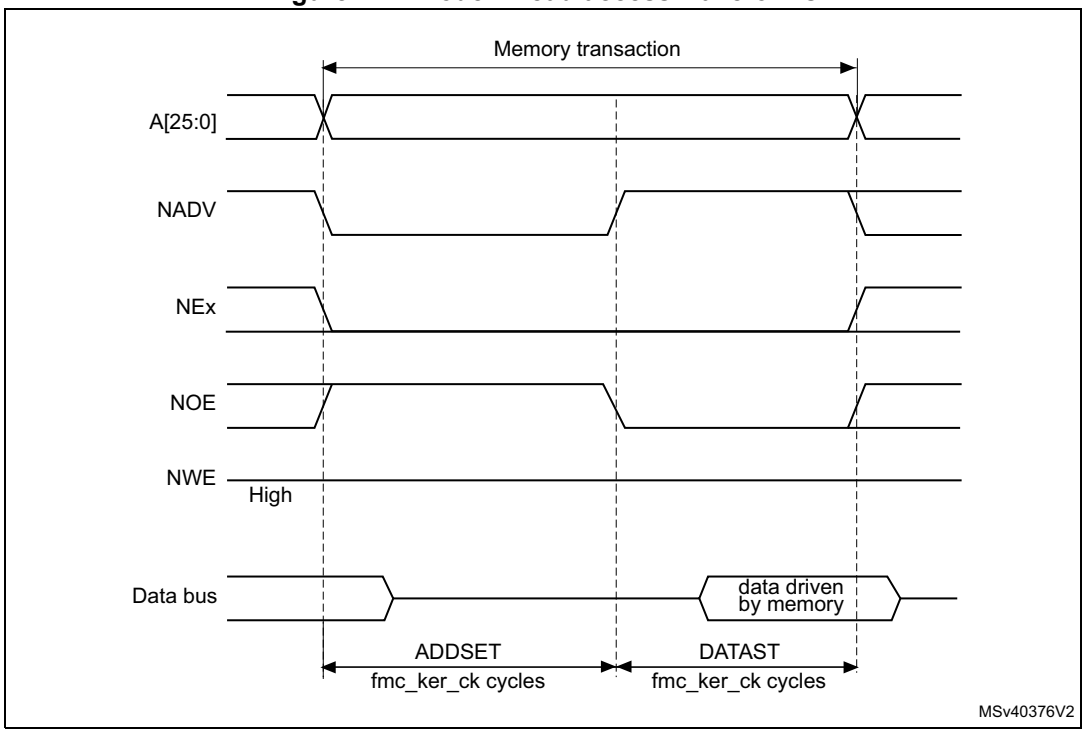
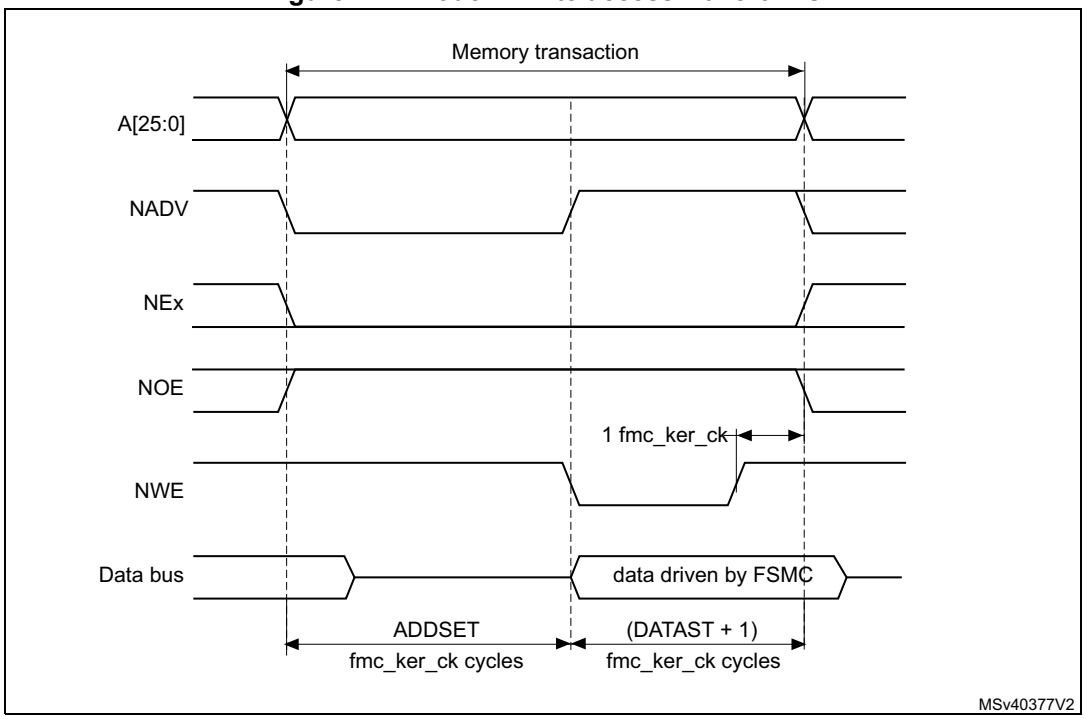


Figure 122. Mode C write access waveforms



The differences compared with Mode1 are the toggling of NOE and the independent read and write timings.

Table 190. FMC_BCRx bitfields (mode C)

Bit No.	Bit name	Value to set
31	FMCEN	0x1
30:26	Reserved	0x000
25:24	BMAP	As needed
23:22	Reserved	0x000
21	WFDIS	As needed
20	CCLKEN	As needed
19	CBURSTRW	0x0 (no effect in Asynchronous mode)
18:16	CPSIZE	0x0 (no effect in Asynchronous mode)
15	ASYNCWAIT	Set to 1 if the memory supports this feature. Otherwise keep at 0.
14	EXTMOD	0x1
13	WAITEN	0x0 (no effect in Asynchronous mode)
12	WREN	As needed
11	WAITCFG	Don’t care
10	Reserved	0x0
9	WAITPOL	Meaningful only if bit 15 is 1
8	BURSTEN	0x0
7	Reserved	0x1
6	FACCEN	0x1
5:4	MWID	As needed
3:2	MTYP	0x02 (NOR Flash memory)
1	MUXEN	0x0
0	MBKEN	0x1

Table 191. FMC_BTRx bitfields (mode C)

Bit number	Bit name	Value to set
31:30	Reserved	0x0
29:28	ACCMOD	0x2
27:24	DATLAT	0x0
23:20	CLKDIV	0x0
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN fmc_ker_ck)
15:8	DATAST	Duration of the second access phase (DATAST fmc_ker_ck cycles) for read accesses.
7:4	ADDHLD	Don’t care
3:0	ADDSET	Duration of the first access phase (ADDSET fmc_ker_ck cycles) for read accesses. Minimum value for ADDSET is 0.

Table 192. FMC_BWTRx bitfields (mode C)

Bit number	Bit name	Value to set
31:30	Reserved	0x0
29:28	ACCMOD	0x2
27:24	DATLAT	Don’t care
23:20	CLKDIV	Don’t care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN fmc_ker_ck)
15:8	DATAST	Duration of the second access phase (DATAST fmc_ker_ck cycles) for write accesses.
7:4	ADDHLD	Don’t care
3:0	ADDSET	Duration of the first access phase (ADDSET fmc_ker_ck cycles) for write accesses. Minimum value for ADDSET is 0.

Mode D - asynchronous access with extended address

Figure 123. Mode D read access waveforms

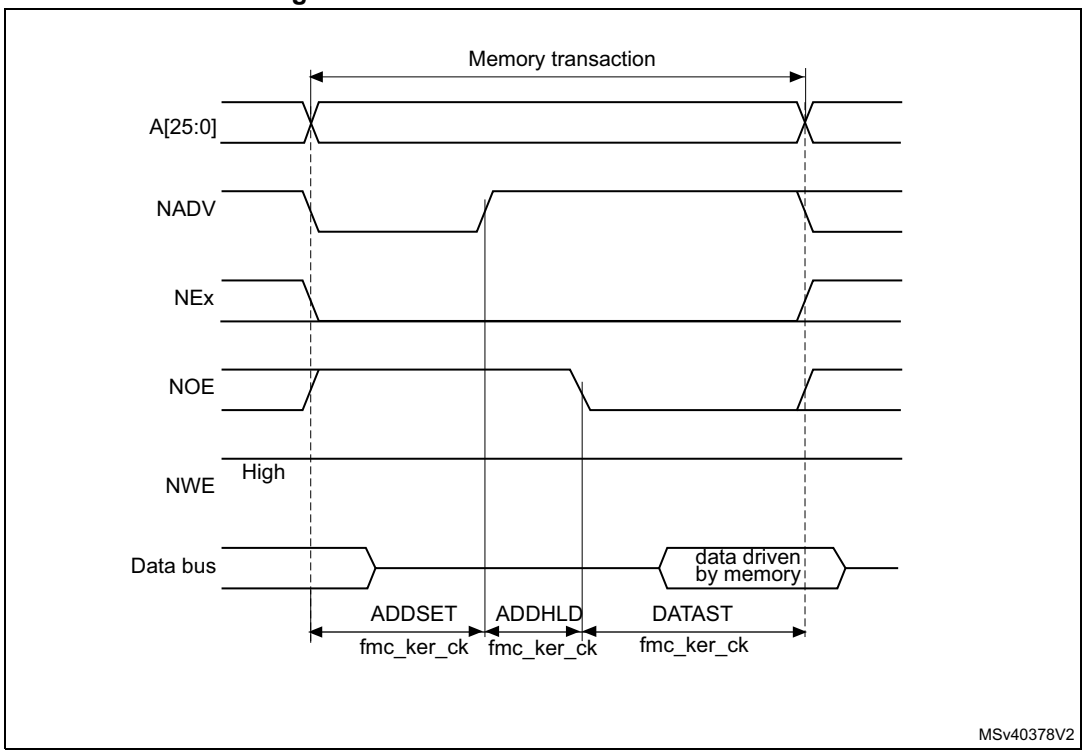
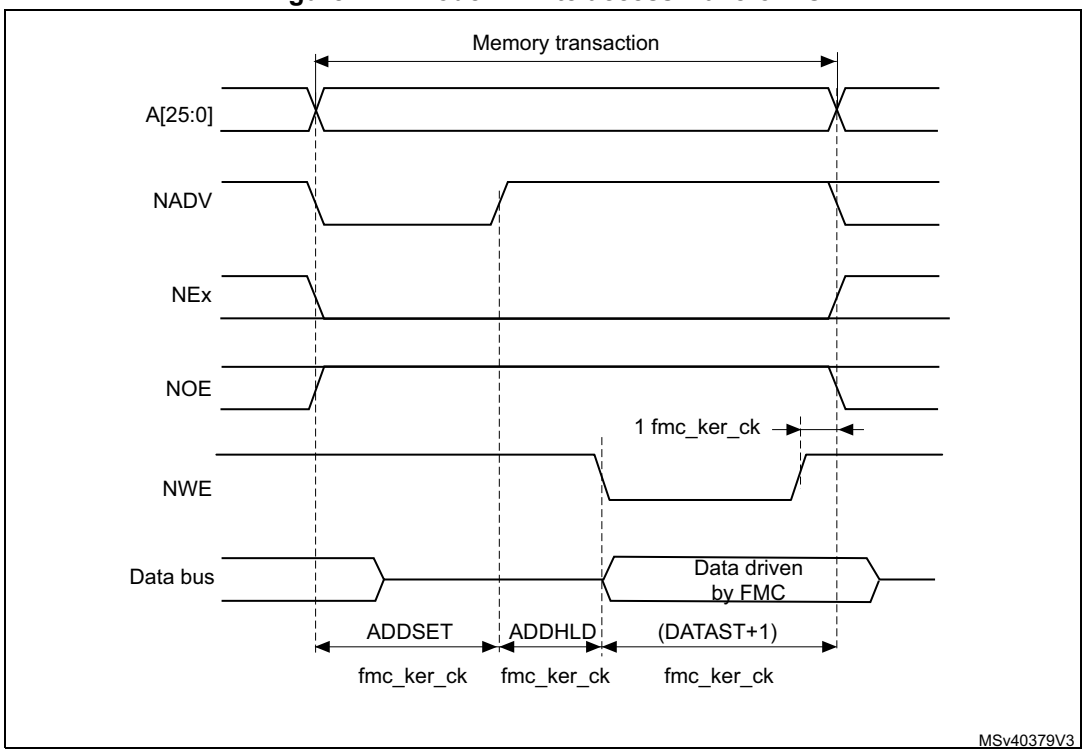


Figure 124. Mode D write access waveforms



The differences with Mode1 are the toggling of NOE that goes on toggling after NADV changes and the independent read and write timings.

Table 193. FMC_BCRx bitfields (mode D)

Bit No.	Bit name	Value to set
31	FMCEN	0x1
30:26	Reserved	0x000
25:24	BMAP	As needed
23:22	Reserved	0x000
21	WFDIS	As needed
20	CCLKEN	As needed
19	CBURSTRW	0x0 (no effect in Asynchronous mode)
18:16	CPSIZE	0x0 (no effect in Asynchronous mode)
15	ASYNCWAIT	Set to 1 if the memory supports this feature. Otherwise keep at 0.
14	EXTMOD	0x1
13	WAITEN	0x0 (no effect in Asynchronous mode)
12	WREN	As needed
11	WAITCFG	Don’t care
10	Reserved	0x0
9	WAITPOL	Meaningful only if bit 15 is 1
8	BURSTEN	0x0
7	Reserved	0x1
6	FACCEN	Set according to memory support
5:4	MWID	As needed
3:2	MTYP	As needed
1	MUXEN	0x0
0	MBKEN	0x1

Table 194. FMC_BTRx bitfields (mode D)

Bit number	Bit name	Value to set
31:30	Reserved	0x0
29:28	ACCMOD	0x3
27:24	DATLAT	Don’t care
23:20	CLKDIV	Don’t care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN fmc_ker_ck)
15:8	DATAST	Duration of the second access phase (DATAST fmc_ker_ck cycles) for read accesses.

Table 194. FMC_BTRx bitfields (mode D) (continued)

Bit number	Bit name	Value to set
7:4	ADDHLD	Duration of the middle phase of the read access (ADDHLD fmc_ker_ck cycles)
3:0	ADDSET	Duration of the first access phase (ADDSET fmc_ker_ck cycles) for read accesses. Minimum value for ADDSET is 1.

Table 195. FMC_BWTRx bitfields (mode D)

Bit number	Bit name	Value to set
31:30	Reserved	0x0
29:28	ACCMOD	0x3
27:24	DATLAT	Don’t care
23:20	CLKDIV	Don’t care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN fmc_ker_ck)
15:8	DATAST	Duration of the second access phase (DATAST + 1 fmc_ker_ck cycles) for write accesses.
7:4	ADDHLD	Duration of the middle phase of the write access (ADDHLD fmc_ker_ck cycles)
3:0	ADDSET	Duration of the first access phase (ADDSET fmc_ker_ck cycles) for write accesses. Minimum value for ADDSET is 1.

Muxed mode - multiplexed asynchronous access to NOR Flash memory

Figure 125. Muxed read access waveforms

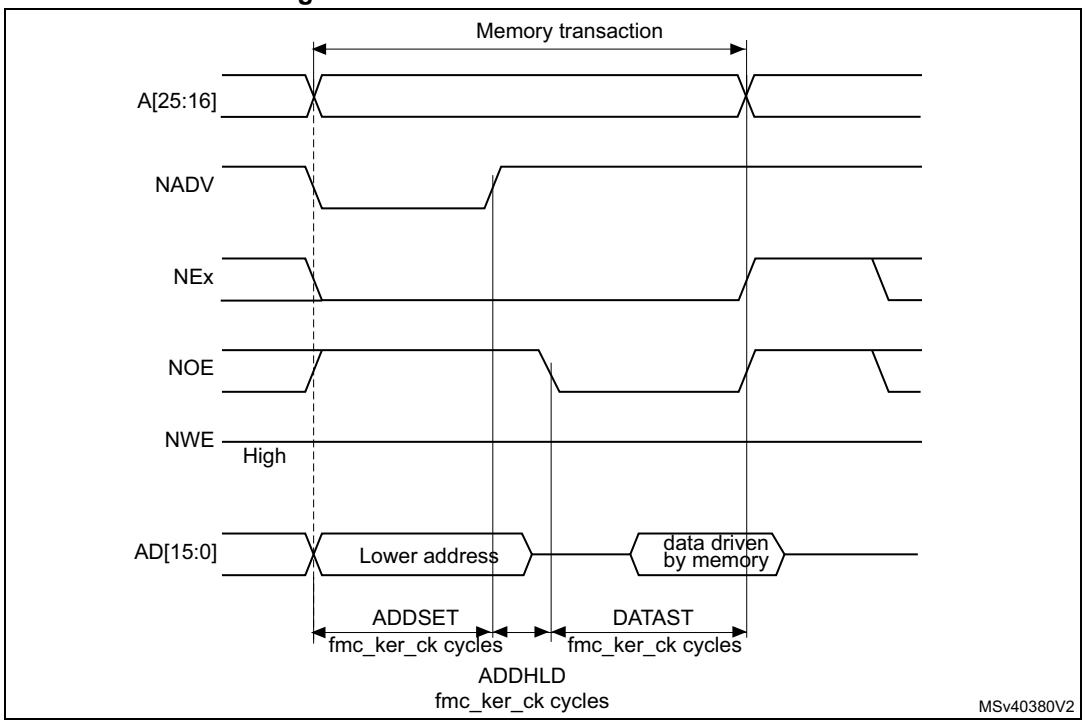
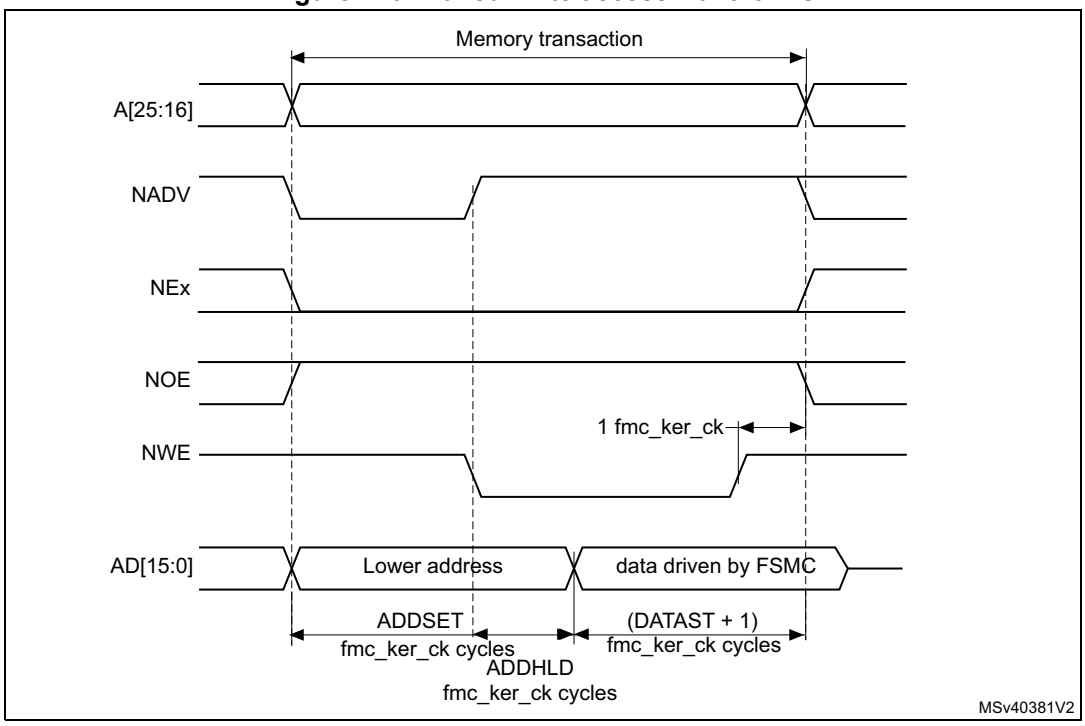


Figure 126. Muxed write access waveforms



The difference with Mode D is the drive of the lower address byte(s) on the data bus.

Table 196. FMC_BCRx bitfields (Muxed mode)

Bit No.	Bit name	Value to set
31	FMCEN	0x1
30:26	Reserved	0x000
25:24	BMAP	As needed
23:22	Reserved	0x000
21	WFDIS	As needed
20	CCLKEN	As needed
19	CBURSTRW	0x0 (no effect in Asynchronous mode)
18:16	CPSIZE	0x0 (no effect in Asynchronous mode)
15	ASYNCWAIT	Set to 1 if the memory supports this feature. Otherwise keep at 0.
14	EXTMOD	0x0
13	WAITEN	0x0 (no effect in Asynchronous mode)
12	WREN	As needed
11	WAITCFG	Don’t care
10	Reserved	0x0
9	WAITPOL	Meaningful only if bit 15 is 1
8	BURSTEN	0x0
7	Reserved	0x1
6	FACCEN	0x1
5:4	MWID	As needed
3:2	MTYP	0x2 (NOR Flash memory)
1	MUXEN	0x1
0	MBKEN	0x1

Table 197. FMC_BTRx bitfields (Muxed mode)

Bit number	Bit name	Value to set
31:30	Reserved	0x0
29:28	ACCMOD	0x0
27:24	DATLAT	Don’t care
23:20	CLKDIV	Don’t care
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN fmc_ker_ck)
15:8	DATAST	Duration of the second access phase (DATAST fmc_ker_ck cycles for read accesses and DATAST+1 fmc_ker_ck cycles for write accesses).

Table 197. FMC_BTRx bitfields (Muxed mode) (continued)

Bit number	Bit name	Value to set
7:4	ADDHLD	Duration of the middle phase of the access (ADDHLD fmc_ker_ck cycles).
3:0	ADDSET	Duration of the first access phase (ADDSET fmc_ker_ck cycles). Minimum value for ADDSET is 1.

WAIT management in asynchronous accesses

If the asynchronous memory asserts the WAIT signal to indicate that it is not yet ready to accept or to provide data, the ASYNCWAIT bit has to be set in FMC_BCRx register.

If the WAIT signal is active (high or low depending on the WAITPOL bit), the second access phase (Data setup phase), programmed by the DATAST bits, is extended until WAIT becomes inactive. Unlike the data setup phase, the first access phases (Address setup and Address hold phases), programmed by the ADDSET and ADDHLD bits, are not WAIT sensitive and so they are not prolonged.

The data setup phase must be programmed so that WAIT can be detected 4 fmc_ker_ck cycles before the end of the memory transaction. The following cases must be considered:

1. The memory asserts the WAIT signal aligned to NOE/NWE which toggles:

$$DATAST \geq (4 \times fmc\_ker\_ck) + max\_wait\_assertion\_time$$

2. The memory asserts the WAIT signal aligned to NEx (or NOE/NWE not toggling):

   if

$$max\_wait\_assertion\_time > address\_phase + hold\_phase$$

   then:

$$DATAST \geq (4 \times fmc\_ker\_ck) + (max\_wait\_assertion\_time - address\_phase - hold\_phase)$$

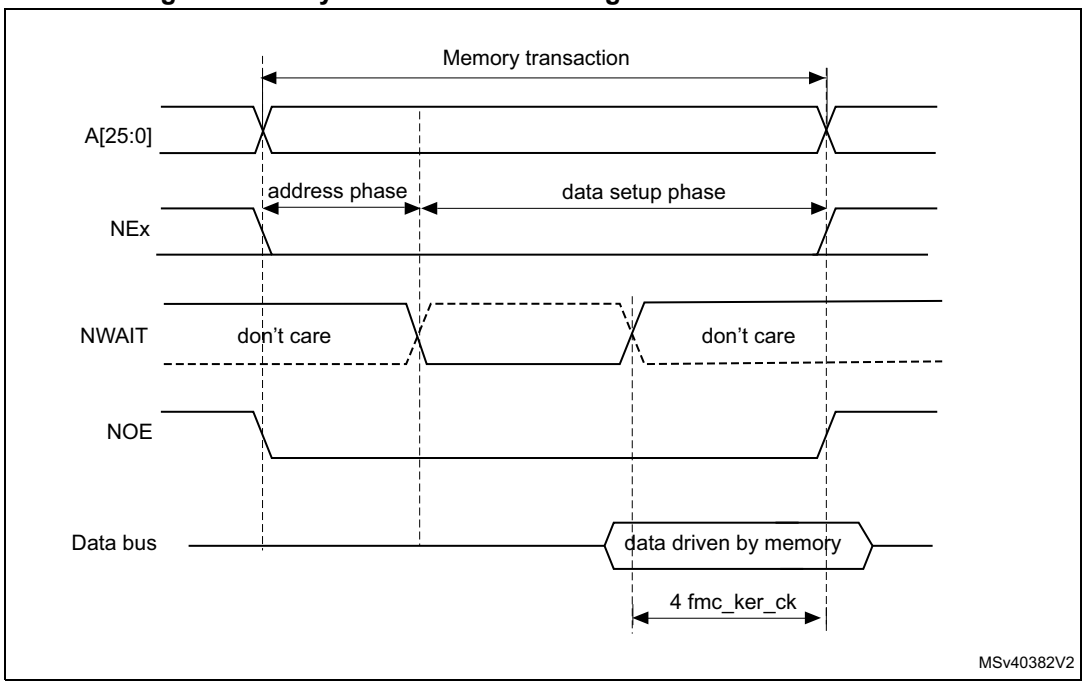
   otherwise

$$DATAST \geq (4 \times fmc\_ker\_ck)$$

   where max_wait_assertion_time is the maximum time taken by the memory to assert the WAIT signal once NEx/NOE/NWE is low.

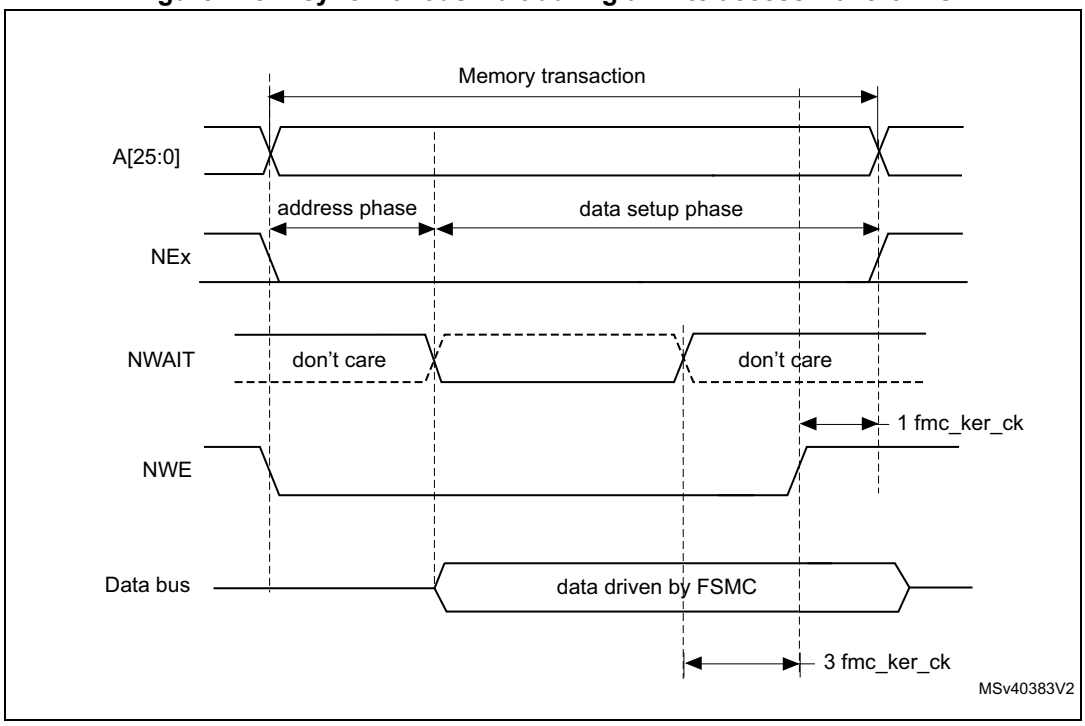
Figure 127 and *Figure 128* show the number of fmc_ker_ck clock cycles that are added to the memory access phase after WAIT is released by the asynchronous memory (independently of the above cases).

Figure 127. Asynchronous wait during a read access waveforms



1. NWAIT polarity depends on WAITPOL bit setting in FMC_BCRx register.

Figure 128. Asynchronous wait during a write access waveforms



1. NWAIT polarity depends on WAITPOL bit setting in FMC_BCRx register.

24.7.5 Synchronous transactions

The memory clock, FMC_CLK, is a sub-multiple of fmc_ker_ck. It depends on the value of CLKDIV and the MWID/ AXI data size, following the formula given below:

$$\text{FMC\_CLK divider ratio} = \max(\text{CLKDIV} + 1, \text{MWID}(\text{AXI data size}))$$

If MWID is 16 or 8-bit, the FMC_CLK divider ratio is always defined by the programmed CLKDIV value.

If MWID is 32-bit, the FMC_CLK divider ratio depends also on AXI data size.

Example:

- If CLKDIV=1, MWID = 32 bits, AXI data size=8 bits, FMC_CLK=fmc_ker_ck/4.
- If CLKDIV=1, MWID = 16 bits, AXI data size=8 bits, FMC_CLK=fmc_ker_ck/2.

NOR Flash memories specify a minimum time from NADV assertion to FMC_CLK high. To meet this constraint, the FMC does not issue the clock to the memory during the first internal clock cycle of the synchronous access (before NADV assertion). This guarantees that the rising edge of the memory clock occurs in the middle of the NADV low pulse.

For some PSRAM memories which must be configured to Synchronous mode, during the BCR register writing, the memory attribute space must be configured to device or strongly-ordered. Once PSRAM BCR register is configured, the memory attribute of PSRAM address space can be programmed to cacheable.

Data latency versus NOR memory latency

The data latency is the number of cycles to wait before sampling the data. The DATLAT value must be consistent with the latency value specified in the NOR Flash configuration register. The FMC does not include the clock cycle when NADV is low in the data latency count.

Caution: Some NOR Flash memories include the NADV Low cycle in the data latency count, so that the exact relation between the NOR Flash latency and the FMC DATLAT parameter can be either:

- NOR Flash latency = (DATLAT + 2) FMC_CLK clock cycles
- or NOR Flash latency = (DATLAT + 3) FMC_CLK clock cycles

Some recent memories assert NWAIT during the latency phase. In such cases DATLAT can be set to its minimum value. As a result, the FMC samples the data and waits long enough to evaluate if the data are valid. Thus the FMC detects when the memory exits latency and real data are processed.

Other memories do not assert NWAIT during latency. In this case the latency must be set correctly for both the FMC and the memory, otherwise invalid data are mistaken for good data, or valid data are lost in the initial phase of the memory access.

Single-burst transfer

When the selected bank is configured in Burst mode for synchronous accesses, if for example a single-burst transaction is requested on 16-bit memories, the FMC performs a burst transaction of length 1 (if the AXI transfer is 16 bits), or length 2 (if the AXI transfer is 32 bits) and deassert the Chip Select signal when the last data is strobed.

Such transfers are not the most efficient in terms of cycles compared to asynchronous read operations. Nevertheless, a random asynchronous access would first require to re-program the memory access mode, which would altogether last longer.

Cross boundary page for Cellular RAM 1.5

Cellular RAM 1.5 does not allow burst access to cross the page boundary. The FMC controller allows to split automatically the burst access when the memory page size is reached by configuring the CPSIZE bits in the FMC_BCR1 register following the memory page size.

Wait management

For synchronous NOR Flash memories, NWAIT is evaluated after the programmed latency period, which corresponds to (DATLAT+2) FMC_CLK clock cycles.

If NWAIT is active (low level when WAITPOL = 0, high level when WAITPOL = 1), wait states are inserted until NWAIT is inactive (high level when WAITPOL = 0, low level when WAITPOL = 1).

When NWAIT is inactive, the data is considered valid either immediately (bit WAITCFG = 1) or on the next clock edge (bit WAITCFG = 0).

During wait-state insertion via the NWAIT signal, the controller continues to send clock pulses to the memory, keeping the Chip Select and output enable signals valid. It does not consider the data as valid.

In Burst mode, there are two timing configurations for the NOR Flash NWAIT signal:

- The Flash memory asserts the NWAIT signal one data cycle before the wait state (default after reset).
- The Flash memory asserts the NWAIT signal during the wait state

The FMC supports both NOR Flash wait state configurations, for each Chip Select, thanks to the WAITCFG bit in the FMC_BCRx registers (x = 0..3).

Figure 129. Wait configuration waveforms

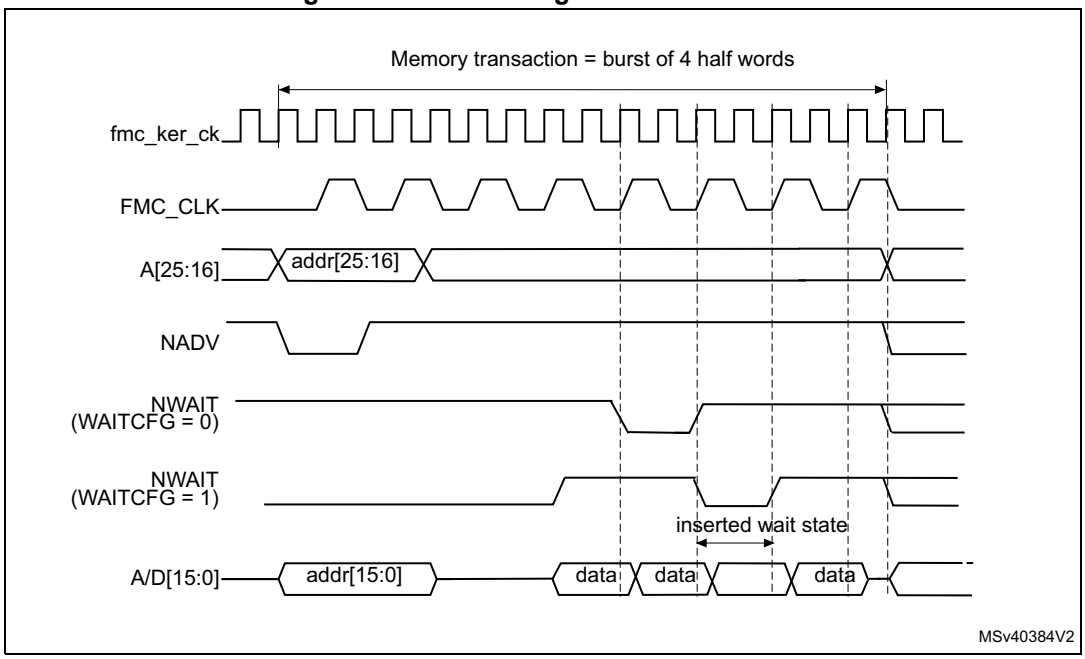
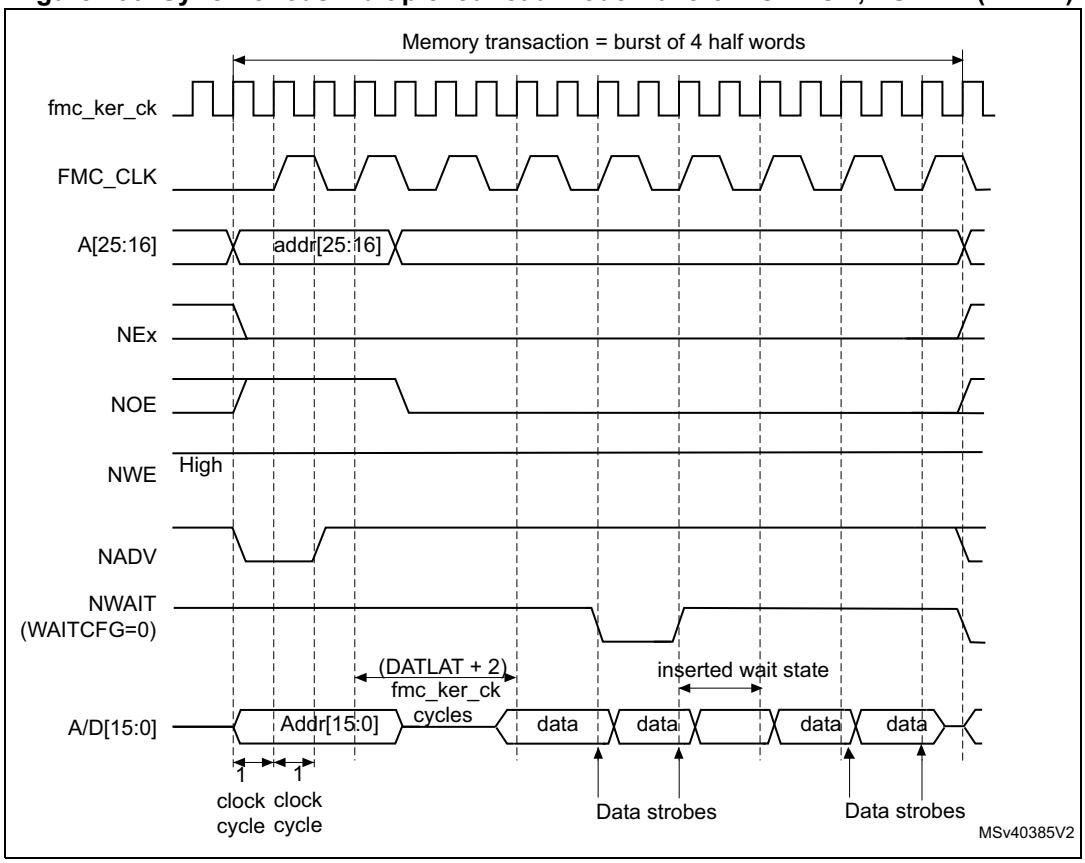


Figure 130. Synchronous multiplexed read mode waveforms - NOR, PSRAM (CRAM)



1. Byte lane outputs (NBL are not shown; for NOR access, they are held high, and, for PSRAM (CRAM) access, they are held low.

Table 198. FMC_BCRx bitfields (Synchronous multiplexed read mode)

Bit No.	Bit name	Value to set
31	MC	0x1
30:26	Reserved	0x000
25:24	BMAP	As needed
23:22	Reserved	0x000
21	WFDIS	As needed
20	CCLKEN	As needed
19	CBURSTRW	No effect on synchronous read
18:16	CPSIZE	As needed. (0x1 when using CRAM 1.5)
15	ASYNCWAIT	0x0
14	EXTMOD	0x0
13	WAITEN	to be set to 1 if the memory supports this feature, to be kept at 0 otherwise
12	WREN	no effect on synchronous read
11	WAITCFG	to be set according to memory
10	Reserved	0x0
9	WAITPOL	to be set according to memory
8	BURSTEN	0x1
7	Reserved	0x1
6	FACCEN	Set according to memory support (NOR Flash memory)
5:4	MWID	As needed
3:2	MTYP	0x1 or 0x2
1	MUXEN	As needed
0	MBKEN	0x1

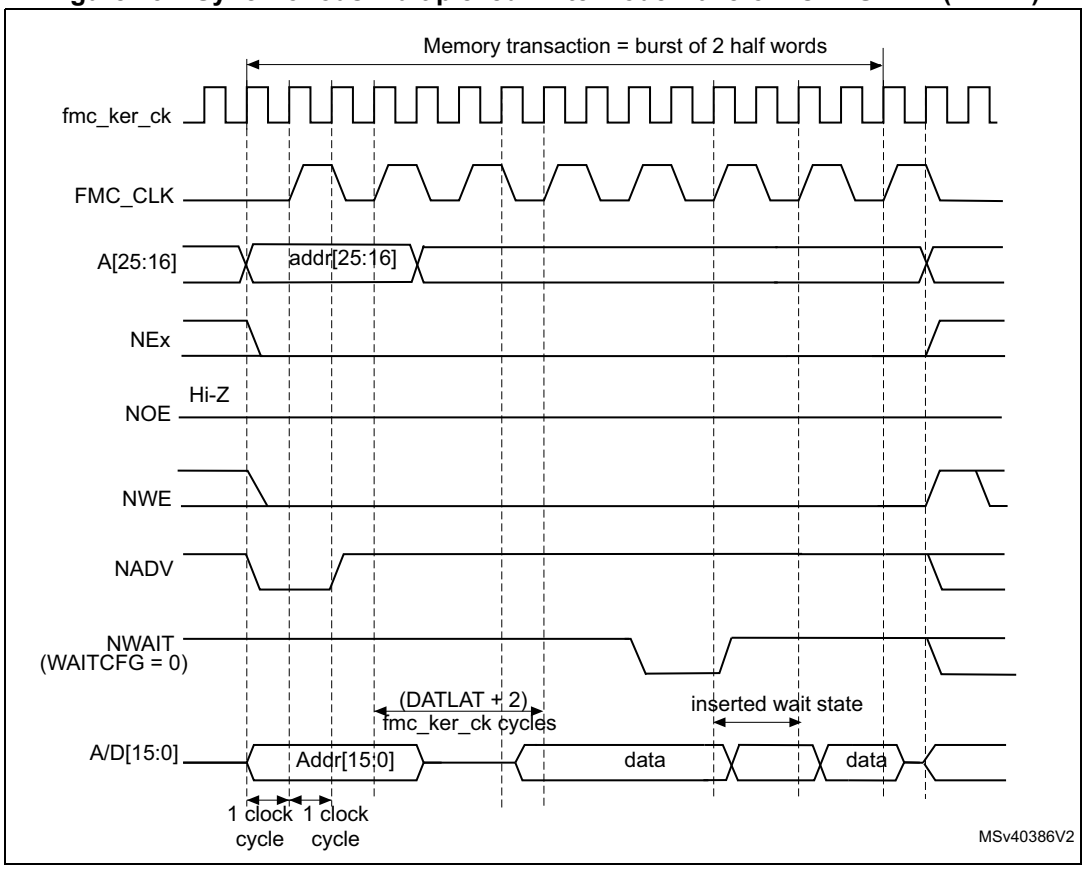
Table 199. FMC_BTRx bitfields (Synchronous multiplexed read mode)

Bit number	Bit name	Value to set
31:30	Reserved	0x0
29:28	ACCMOD	0x0
27:24	DATLAT	Data latency
27:24	DATLAT	Data latency
23:20	CLKDIV	0x0 to get CLK = fmc_ker_ck 0x1 to get CLK = 2 × fmc_ker_ck ..
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN fmc_ker_ck)
15:8	DATAST	Don’t care

Table 199. FMC_BTRx bitfields (Synchronous multiplexed read mode) (continued)

Bit number	Bit name	Value to set
7:4	ADDHLD	Don't care
3:0	ADDSET	Don't care

Figure 131. Synchronous multiplexed write mode waveforms - PSRAM (CRAM)



1. The memory must issue NWAIT signal one cycle in advance, accordingly WAITCFG must be programmed to 0.
2. Byte Lane (NBL) outputs are not shown, they are held low while NEx is active.

Table 200. FMC_BCRx bitfields (Synchronous multiplexed write mode)

Bit No.	Bit name	Value to set
31	FMCEN	0x1
30:26	Reserved	0x000
25:24	BMAP	As needed
23:22	Reserved	0x000
21	WFDIS	As needed
20	CCLKEN	As needed
19	CBURSTRW	No effect on synchronous read

Table 200. FMC_BCRx bitfields (Synchronous multiplexed write mode) (continued)

Bit No.	Bit name	Value to set
18:16	CPSIZE	As needed. (0x1 when using CRAM 1.5)
15	ASYNCWAIT	0x0
14	EXTMOD	0x0
13	WAITEN	to be set to 1 if the memory supports this feature, to be kept at 0 otherwise.
12	WREN	0x1
11	WAITCFG	0x0
10	Reserved	0x0
9	WAITPOL	to be set according to memory
8	BURSTEN	no effect on synchronous write
7	Reserved	0x1
6	FACCEN	Set according to memory support
5:4	MWID	As needed
3:2	MTYP	0x1
1	MUXEN	As needed
0	MBKEN	0x1

Table 201. FMC_BTRx bitfields (Synchronous multiplexed write mode)

Bit number	Bit name	Value to set
31:30	Reserved	0x0
29:28	ACCMOD	0x0
27:24	DATLAT	Data latency
23:20	CLKDIV	0x0 to get CLK = fmc_ker_ck 0x1 to get CLK = 2 × fmc_ker_ck
19:16	BUSTURN	Time between NEx high to NEx low (BUSTURN fmc_ker_ck)
15:8	DATAST	Don’t care
7:4	ADDHLD	Don’t care
3:0	ADDSET	Don’t care

24.7.6 NOR/PSRAM controller registers

SRAM/NOR-Flash chip-select control registers for bank x (FMC_BCRx)

Address offset: 8 * (x - 1), (x = 1 to 4)

Reset value: Block 1: 0x0000 30DB

Reset value: Block 2: 0x0000 30D2

Reset value: Block 3: 0x0000 30D2

Reset value: Block 4: 0x0000 30D2

This register contains the control information of each memory bank, used for SRAMs, PSRAM and NOR Flash memories.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FMCEN	Res.	Res.	Res.	Res.	Res.	BMAP[1:0]		Res.	Res.	WFDIS	CCLKEN	CBURSTRW	CPSIZE[2:0]		
rw						rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ASYNCWAIT	EXTMOD	WAITEN	WREN	WAITCFG	Res.	WAITPOL	BURSTEN	Res.	FACCEN	MWID		MTYP		MUXEN	MBKEN
rw	rw	rw	rw	rw		rw	rw		rw	rw	rw	rw	rw	rw	rw

Bit 31 **FMCEN:** FMC controller Enable

This bit enables/disables the FMC controller.

0: Disable the FMC controller

1: Enable the FMC controller

Note: The FMCEN bit of the FMC_BCR2..4 registers is don't care. It is only enabled through the FMC_BCR1 register.

Bits 30:26 Reserved, must be kept at reset value.

Bits 25:24 **BMAP[1:0]:** FMC bank mapping

These bits allow different remap or swap of the FMC NOR/PSRAM and SDRAM banks (refer to *Table 166*).

00: Default mapping (refer to *Figure 113* and *Table 166*).

01: NOR/PSRAM bank and SDRAM bank 1 are swapped.

10: Reserved

11: Reserved.

Note: The BMAP bits of the FMC_BCR2..4 registers are don't care. It is only enabled through the FMC_BCR1 register.

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **WFDIS:** Write FIFO Disable

This bit disables the Write FIFO used by the FMC controller.

0: Write FIFO enabled (Default after reset)

1: Write FIFO disabled

Note: The WFDIS bit of the FMC_BCR2..4 registers is don't care. It is only enabled through the FMC_BCR1 register.

Bit 20 **CCLKEN:** Continuous Clock Enable

This bit enables the FMC_CLK clock output to external memory devices.

0: The FMC_CLK is only generated during the synchronous memory access (read/write transaction). The FMC_CLK clock ratio is specified by the programmed CLKDIV value in the FMC_BCRx register (default after reset).

1: The FMC_CLK is generated continuously during asynchronous and synchronous access. The FMC_CLK clock is activated when the CCLKEN is set.

Note: The CCLKEN bit of the FMC_BCR2..4 registers is don't care. It is only enabled through the FMC_BCR1 register. Bank 1 must be configured in Synchronous mode to generate the FMC_CLK continuous clock.

If CCLKEN bit is set, the FMC_CLK clock ratio is specified by CLKDIV value in the FMC_BTR1 register. CLKDIV in FMC_BWTR1 is don't care.

If the Synchronous mode is used and CCLKEN bit is set, the synchronous memories connected to other banks than Bank 1 are clocked by the same clock (the CLKDIV value in the FMC_BTR2..4 and FMC_BWTR2..4 registers for other banks has no effect.)

Bit 19 **CBURSTRW:** Write burst enable

For PSRAM (CRAM) operating in Burst mode, the bit enables synchronous accesses during write operations. The enable bit for synchronous read accesses is the BURSTEN bit in the FMC_BCRx register.

0: Write operations are always performed in Asynchronous mode

1: Write operations are performed in Synchronous mode.

Bits 18:16 **CPSIZE[2:0]**: CRAM Page Size

These are used for Cellular RAM 1.5 which does not allow burst access to cross the address boundaries between pages. When these bits are configured, the FMC controller splits automatically the burst access when the memory page size is reached (refer to memory datasheet for page size).

000: No burst split when crossing page boundary (default after reset).

001: 128 bytes

010: 256 bytes

100: 1024 bytes

Other configuration: reserved.

Bit 15 **ASYNCWAIT**: Wait signal during asynchronous transfers

This bit enables/disables the FMC to use the wait signal even during an asynchronous protocol.

0: NWAIT signal is not taken in to account when running an asynchronous protocol (default after reset)

1: NWAIT signal is taken in to account when running an asynchronous protocol

Bit 14 **EXTMOD**: Extended mode enable.

This bit enables the FMC to program the write timings for asynchronous accesses inside the FMC_BWTR register, thus resulting in different timings for read and write operations.

0: values inside FMC_BWTR register are not taken into account (default after reset)

1: values inside FMC_BWTR register are taken into account

Note: When the Extended mode is disabled, the FMC can operate in Mode1 or Mode2 as follows:

- *Mode 1 is the default mode when the SRAM/PSRAM memory type is selected (MTYP =0x0 or 0x01)*
- *Mode 2 is the default mode when the NOR memory type is selected (MTYP = 0x10).*

Bit 13 **WAITEN**: Wait enable bit

This bit enables/disables wait-state insertion via the NWAIT signal when accessing the memory in Synchronous mode.

0: NWAIT signal is disabled (its level not taken into account, no wait state inserted after the programmed Flash latency period)

1: NWAIT signal is enabled (its level is taken into account after the programmed latency period to insert wait states if asserted) (default after reset)

Bit 12 **WREN**: Write enable bit

This bit indicates whether write operations are enabled/disabled in the bank by the FMC:

0: Write operations are disabled in the bank by the FMC, an AXI slave error is reported

1: Write operations are enabled for the bank by the FMC (default after reset).

Bit 11 **WAITCFG**: Wait timing configuration

The NWAIT signal indicates whether the data from the memory are valid or if a wait state must be inserted when accessing the memory in Synchronous mode. This configuration bit determines if NWAIT is asserted by the memory one clock cycle before the wait state or during the wait state:

0: NWAIT signal is active one data cycle before wait state (default after reset)

1: NWAIT signal is active during wait state (not used for PSRAM).

Bit 10 Reserved, must be kept at reset value.

Bit 9 **WAITPOL**: Wait signal polarity bit

This bit defines the polarity of the wait signal from memory used for either in Synchronous or Asynchronous mode:

0: NWAIT active low (default after reset)

1: NWAIT active high.

Bit 8 **BURSTEN**: Burst enable bit

This bit enables/disables synchronous accesses during read operations. It is valid only for synchronous memories operating in Burst mode:

0: Burst mode disabled (default after reset). Read accesses are performed in Asynchronous mode

1: Burst mode enable. Read accesses are performed in Synchronous mode.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **FACCEN**: Flash access enable

This bit enables NOR Flash memory access operations.

0: Corresponding NOR Flash memory access is disabled

1: Corresponding NOR Flash memory access is enabled (default after reset)

Bits 5:4 **MWID[1:0]:** Memory data bus width

Defines the external memory device width, valid for all type of memories.
00: 8 bits
01: 16 bits (default after reset)
10: 32 bits
11: reserved

Bits 3:2 **MTYP[1:0]:** Memory type

These bits define the type of external memory attached to the corresponding memory bank:
00: SRAM (default after reset for Bank 2...4)
01: PSRAM (CRAM)
10: NOR Flash/OneNAND Flash (default after reset for Bank 1)
11: reserved

Bit 1 **MUXEN:** Address/data multiplexing enable bit

When this bit is set, the address and data values are multiplexed on the data bus, valid only with NOR and PSRAM memories:
0: Address/Data non-multiplexed
1: Address/Data multiplexed on databus (default after reset)

Bit 0 **MBKEN:** Memory bank enable bit

This bit enables the memory bank. After reset Bank1 is enabled, all others are disabled. Accessing a disabled bank causes an ERROR on AXI bus.
0: Corresponding memory bank is disabled
1: Corresponding memory bank is enabled

SRAM/NOR-Flash chip-select timing registers for bank x (FMC_BTRx)

Address offset: 0x04 + 8 * (x - 1), (x = 1 to 4)

Reset value: 0x0FFF FFFF

This register contains the control information of each memory bank, used for SRAMs, PSRAM and NOR Flash memories.If the EXTMOD bit is set in the FMC_BCRx register, then this register is partitioned for write and read access, that is, 2 registers are available: one to configure read accesses (this register) and one to configure write accesses (FMC_BWTRx registers).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	ACCMOD		DATLAT				CLKDIV				BUSTURN			
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATAST								ADDHLD				ADDSET			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:28 **ACCMOD[1:0]:** Access mode

These bits specify the Asynchronous access modes as shown in the timing diagrams. They are taken into account only when the EXTMOD bit in the FMC_BCRx register is 1.

00: access mode A

01: access mode B

10: access mode C

11: access mode D

Bits 27:24 **DATLAT[3:0]:** (see note below bit descriptions): Data latency for synchronous memory

For synchronous access with read/write Burst mode enabled (BURSTEN / CBURSTRW bits set), these bits define the number of memory clock cycles (+2) to issue to the memory before reading/writing the first data:

This timing parameter is not expressed in fmc_ker_ck periods, but in FMC_CLK periods.

For asynchronous access, this value is don't care.

0000: Data latency of 2 FMC_CLK clock cycles for first burst access

1111: Data latency of 17 FMC_CLK clock cycles for first burst access (default value after reset)

Bits 23:20 **CLKDIV[3:0]:** Clock divide ratio (for FMC_CLK signal)

These bits define the period of FMC_CLK clock output signal, expressed in number of fmc_ker_ck cycles:

0000: FMC_CLK period = 1 x fmc_ker_ck period

0001: FMC_CLK period = 2 × fmc_ker_ck periods

0010: FMC_CLK period = 3 × fmc_ker_ck periods

1111: FMC_CLK period = 16 × fmc_ker_ck periods (default value after reset)

In asynchronous NOR Flash, SRAM or PSRAM accesses, this value is don't care.

Note: Refer to Section 24.7.5: Synchronous transactions for FMC_CLK divider ratio formula)

Bits 19:16 **BUSTURN:** Bus turnaround phase duration

These bits are written by software to add a delay at the end of a write-to-read (and read-to-write) transaction. This delay allows to match the minimum time between consecutive transactions (t_{EHEL} from NEx high to NEx low) and the maximum time needed by the memory to free the data bus after a read access (t_{EHQZ}). The programmed bus turnaround delay is inserted between an asynchronous read (muxed or mode D) or write transaction and any other asynchronous /synchronous read or write to or from a static bank. The bank can be the same or different in case of read, in case of write the bank can be different except for muxed or mode D.

In some cases, whatever the programmed BUSTURN values, the bus turnaround delay is fixed

as follows:

- The bus turnaround delay is not inserted between two consecutive asynchronous write transfers to the same static memory bank except for muxed and D modes.
- There is a bus turnaround delay of 1 FMC clock cycle between:
  - –Two consecutive asynchronous read transfers to the same static memory bank except for muxed and D modes.
  - –An asynchronous read to an asynchronous or synchronous write to any static bank or dynamic bank except for muxed and D modes.
  - –An asynchronous (modes 1, 2, A, B or C) read and a read from another static bank.
- There is a bus turnaround delay of 2 FMC clock cycle between:
  - –Two consecutive synchronous writes (burst or single) to the same bank.
  - –A synchronous write (burst or single) access and an asynchronous write or read transfer to or from static memory bank (the bank can be the same or different for the case of read.
  - –Two consecutive synchronous reads (burst or single) followed by any synchronous/asynchronous read or write from/to another static memory bank.
- There is a bus turnaround delay of 3 FMC clock cycle between:
  - –Two consecutive synchronous writes (burst or single) to different static bank.
  - –A synchronous write (burst or single) access and a synchronous read from the same or a different bank.

0000: BUSTURN phase duration = 0 fmc_ker_ck clock cycle added

...

1111: BUSTURN phase duration = 15 x fmc_ker_ck clock cycles added (default value after reset)

Bits 15:8 **DATAST:** Data-phase duration

These bits are written by software to define the duration of the data phase (refer to *Figure 114* to *Figure 126*), used in asynchronous accesses:

0000 0000: Reserved

0000 0001: DATAST phase duration = 1 × fmc_ker_ck clock cycles

0000 0010: DATAST phase duration = 2 × fmc_ker_ck clock cycles

...

1111 1111: DATAST phase duration = 255 × fmc_ker_ck clock cycles (default value after reset)

For each memory type and access mode data-phase duration, please refer to the respective figure (*Figure 114* to *Figure 126*).

Example: Mode1, write access, DATAST = 1: Data-phase duration = DATAST+1 = 1 x fmc_ker_ck clock cycles.

Note: In synchronous accesses, this value is don't care.

Bits 7:4 **ADDHLD:** Address-hold phase duration

These bits are written by software to define the duration of the *address hold* phase (refer to *Figure 114* to *Figure 126*), used in mode D or multiplexed accesses:
0000: Reserved
0001: ADDHLD phase duration =1 × fmc_ker_ck clock cycle
0010: ADDHLD phase duration = 2 × fmc_ker_ck clock cycle
...
1111: ADDHLD phase duration = 15 × fmc_ker_ck clock cycles (default value after reset)
For each access mode address-hold phase duration, please refer to the respective figure (*Figure 114* to *Figure 126*).

Note: In synchronous accesses, this value is not used, the address hold phase is always 1 memory clock period duration.

Bits 3:0 **ADDSET:** Address setup phase duration

These bits are written by software to define the duration of the *address setup* phase (refer to *Figure 114* to *Figure 126*), used in SRAMs, ROMs and asynchronous NOR Flash:
0000: ADDSET phase duration = 0 × fmc_ker_ck clock cycle
...
1111: ADDSET phase duration = 15 × fmc_ker_ck clock cycles (default value after reset)
For each access mode address setup phase duration, please refer to the respective figure (refer to *Figure 114* to *Figure 126*).

Note: In synchronous accesses, this value is don't care.
In Muxed mode or mode D, the minimum value for ADDSET is 1.
In mode 1 and PSRAM memory, the minimum value for ADDSET is 1.

Note: PSRAMs (CRAMs) have a variable latency due to internal refresh. Therefore these memories issue the NWAIT signal during the whole latency phase to extend the latency as needed.
On PSRAMs (CRAMs) the filled DATLAT must be set to 0, so that the FMC exits its latency phase soon and starts sampling NWAIT from memory, then starts to read or write when the memory is ready.
This method can be used also with the latest generation of synchronous Flash memories that issue the NWAIT signal, unlike older Flash memories (check the datasheet of the specific Flash memory being used).

SRAM/NOR-Flash write timing registers for bank x (FMC_BWTRx)

Address offset: 0x104 + 8 * (x - 1), (x = 1 to 4)

Reset value: 0x0FFF FFFF

This register contains the control information of each memory bank. It is used for SRAMs, PSRAMs and NOR Flash memories. When the EXTMOD bit is set in the FMC_BCRx register, then this register is active for write access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	ACCMOD		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSTURN			
		rw	rw									rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATAST								ADDHLD				ADDSET[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:28 **ACCMOD:** Access mode.

These bits specify the asynchronous access modes as shown in the next timing diagrams.These bits are taken into account only when the EXTMOD bit in the FMC_BCRx register is 1.

00: access mode A

01: access mode B

10: access mode C

11: access mode D

Bits 27:20 Reserved, must be kept at reset value.

Bits 19:16 **BUSTURN**: Bus turnaround phase duration

These bits are written by software to add a delay at the end of a write transaction to match the minimum time between consecutive transactions (t_{EHEL} from ENx high to ENx low):

(BUSTRUN + 1) fmc_ker_ck period ≥ $t_{EHELmin}$.

The programmed bus turnaround delay is inserted between an asynchronous write transfer and any other asynchronous /synchronous read or write transfer to or from a static bank. The bank can be the same or different in case of read, in case of write the bank can be different expect for muxed or mode D.

In some cases, whatever the programmed BUSTURN values, the bus turnaround delay is fixed as follows:

- The bus turnaround delay is not inserted between two consecutive asynchronous write transfers to the same static memory bank except for muxed and D modes.
- There is a bus turnaround delay of 2 FMC clock cycle between:
  - –Two consecutive synchronous writes (burst or single) to the same bank.
  - –A synchronous write (burst or single) transfer and an asynchronous write or read transfer to or from static memory bank.
- There is a bus turnaround delay of 3 FMC clock cycle between:
  - –Two consecutive synchronous writes (burst or single) to different static bank.
  - –A synchronous write (burst or single) transfer and a synchronous read from the same or a different bank.

0000: BUSTURN phase duration = 0 fmc_ker_ck clock cycle added

...

1111: BUSTURN phase duration = 15 fmc_ker_ck clock cycles added (default value after reset)

Bits 15:8 **DATAST:** Data-phase duration.

These bits are written by software to define the duration of the data phase (refer to *Figure 114* to *Figure 126*), used in asynchronous SRAM, PSRAM and NOR Flash memory accesses:

0000 0000: Reserved

0000 0001: DATAST phase duration = 1 × fmc_ker_ck clock cycles

0000 0010: DATAST phase duration = 2 × fmc_ker_ck clock cycles

...

1111 1111: DATAST phase duration = 255 × fmc_ker_ck clock cycles (default value after reset)

Bits 7:4 **ADDHLD:** Address-hold phase duration.

These bits are written by software to define the duration of the *address hold* phase (refer to *Figure 114* to *Figure 126*), used in asynchronous multiplexed accesses:

0000: Reserved

0001: ADDHLD phase duration = 1 × fmc_ker_ck clock cycle

0010: ADDHLD phase duration = 2 × fmc_ker_ck clock cycle

...

1111: ADDHLD phase duration = 15 × fmc_ker_ck clock cycles (default value after reset)

Note: In synchronous NOR Flash accesses, this value is not used, the address hold phase is always 1 Flash clock period duration.

Bits 3:0 **ADDSET:** Address setup phase duration.

These bits are written by software to define the duration of the *address setup* phase in fmc_ker_ck cycles (refer to *Figure 114* to *Figure 126*), used in asynchronous accesses:

0000: ADDSET phase duration = 0 × fmc_ker_ck clock cycle

...

1111: ADDSET phase duration = 15 × fmc_ker_ck clock cycles (default value after reset)

Note: In synchronous accesses, this value is not used, the address setup phase is always 1 Flash clock period duration. In muxed mode, the minimum ADDSET value is 1.

24.8 NAND Flash controller

The FMC generates the appropriate signal timings to drive 8- and 16-bit NAND Flash memories.

The NAND bank is configured through dedicated registers (*Section 24.8.7*). The programmable memory parameters include access timings (shown in *Table 202*) and ECC configuration.

Table 202. Programmable NAND Flash access parameters

Parameter	Function	Access mode	Unit	Min.	Max.
Memory setup time	Number of clock cycles (fmc_ker_ck) required to set up the address before the command assertion	Read/Write	AHB clock cycle (fmc_ker_ck)	1	255
Memory wait	Minimum duration (in fmc_ker_ck clock cycles) of the command assertion	Read/Write	AHB clock cycle (fmc_ker_ck)	2	255
Memory hold	Number of clock cycles (fmc_ker_ck) during which the address must be held (as well as the data if a write access is performed) after the command deassertion	Read/Write	AHB clock cycle (fmc_ker_ck)	1	254
Memory databus high-Z	Number of clock cycles (fmc_ker_ck) during which the data bus is kept in high-Z state after a write access has started	Write	AHB clock cycle (fmc_ker_ck)	0	254

24.8.1 External memory interface signals

The following tables list the signals that are typically used to interface NAND Flash memories.

Note: The prefix “N” identifies the signals which are active low.

8-bit NAND Flash memory

Table 203. 8-bit NAND Flash memory

FMC pin name	I/O	Function
A[17]	O	NAND Flash address latch enable (ALE) signal
A[16]	O	NAND Flash command latch enable (CLE) signal
D[7:0]	I/O	8-bit multiplexed, bidirectional address/data bus
NCE	O	Chip Select
NOE(= NRE)	O	Output enable (memory signal name: read enable, NRE)
NWE	O	Write enable
NWAIT/INT	I	NAND Flash ready/busy input signal to the FMC

Theoretically, there is no capacity limitation as the FMC can manage as many address cycles as needed.

16-bit NAND Flash memory

Table 204. 16-bit NAND Flash memory

FMC pin name	I/O	Function
A[17]	O	NAND Flash address latch enable (ALE) signal
A[16]	O	NAND Flash command latch enable (CLE) signal
D[15:0]	I/O	16-bit multiplexed, bidirectional address/data bus
NCE	O	Chip Select
NOE(= NRE)	O	Output enable (memory signal name: read enable, NRE)
NWE	O	Write enable
NWAIT/INT	I	NAND Flash ready/busy input signal to the FMC

Note: Theoretically, there is no capacity limitation as the FMC can manage as many address cycles as needed.

24.8.2 NAND Flash supported memories and transactions

Table 205 shows the supported devices, access modes and transactions. Transactions not allowed (or not supported) by the NAND Flash controller are shown in gray.

Table 205. Supported memories and transactions

Device	Mode	R/W	AXI data size	Memory data size	Allowed/ not allowed	Comments
NAND 8-bit	Asynchronous	R	8	8	Y	-
	Asynchronous	W	8	8	Y	-
	Asynchronous	R	16	8	Y	Split into 2 FMC accesses
	Asynchronous	W	16	8	Y	Split into 2 FMC accesses
	Asynchronous	R	32	8	Y	Split into 4 FMC accesses
	Asynchronous	W	32	8	Y	Split into 4 FMC accesses
	Asynchronous	R	32	8	Y	Split into 8 FMC accesses
	Asynchronous	W	32	8	Y	Split into 8 FMC accesses

Table 205. Supported memories and transactions (continued)

Device	Mode	R/W	AXI data size	Memory data size	Allowed/ not allowed	Comments
NAND 16-bit	Asynchronous	R	8	16	Y	-
	Asynchronous	W	8	16	N	-
	Asynchronous	R	16	16	Y	-
	Asynchronous	W	16	16	Y	-
	Asynchronous	R	32	16	Y	Split into 2 FMC accesses
	Asynchronous	W	32	16	Y	Split into 2 FMC accesses
	Asynchronous	R	32	16	Y	Split into 4 FMC accesses
	Asynchronous	W	32	16	Y	Split into 4 FMC accesses

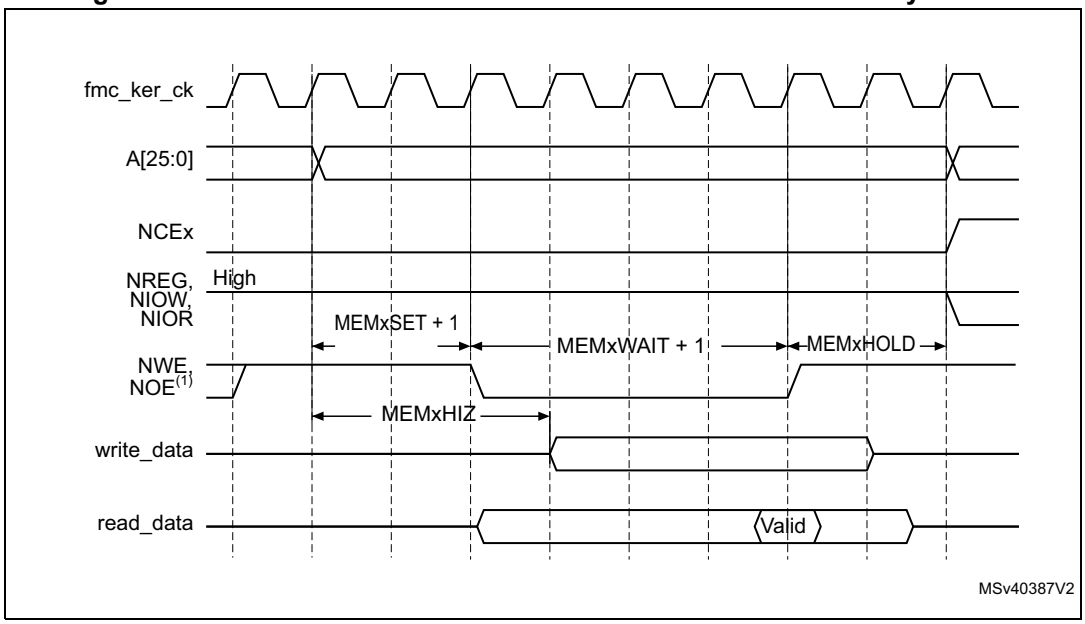
24.8.3 Timing diagrams for NAND Flash memories

The NAND Flash memory bank is managed through a set of registers:

- Control register: FMC_PCR
- Interrupt status register: FMC_SR
- ECC register: FMC_ECCR
- Timing register for Common memory space: FMC_PMEM
- Timing register for Attribute memory space: FMC_PATT

Each timing configuration register contains three parameters used to define the number of fmc_ker_ck cycles for the three phases of any NAND Flash access, plus one parameter that defines the timing to start driving the data bus when a write access is performed. *Figure 132* shows the timing parameter definitions for common memory accesses, knowing that Attribute memory space access timings are similar.

Figure 132. NAND Flash controller waveforms for common memory access



1. NOE remains high (inactive) during write accesses. NWE remains high (inactive) during read accesses.
2. For write accesses, the hold phase delay is (MEMHOLD) fmc_ker_ck cycles and for read access is (MEMHOLD + 1) fmc_ker_ck cycles.

24.8.4 NAND Flash operations

The command latch enable (CLE) and address latch enable (ALE) signals of the NAND Flash memory device are driven by address signals from the FMC controller. This means that to send a command or an address to the NAND Flash memory, the CPU has to perform a write to a specific address in its memory space.

A typical page read operation from the NAND Flash device requires the following steps:

1. Program and enable the corresponding memory bank by configuring the FMC_PCR and FMC_PMEM (and for some devices, FMC_PATT, see *Section 24.8.5: NAND Flash prewait feature*) registers according to the characteristics of the NAND Flash memory (PWID bits for the data bus width of the NAND Flash memory, PWAITEN = 0 or 1 as needed, see *Section 24.6.2: NAND Flash memory address mapping* for timing configuration).
2. The CPU performs a byte write to the common memory space, with data byte equal to one Flash command byte (for example 0x00 for Samsung NAND Flash devices). The LE input of the NAND Flash memory is active during the write strobe (low pulse on NWE), thus the written byte is interpreted as a command by the NAND Flash memory. Once the command is latched by the memory device, it does not need to be written again for the following page read operations.
3. The CPU can send the start address (STARTAD) for a read operation by writing four bytes (or three for smaller capacity devices), STARTAD[7:0], STARTAD[16:9], STARTAD[24:17] and finally STARTAD[25] (for 64 Mb x 8 bit NAND Flash memories) in the common memory or attribute space. The ALE input of the NAND Flash device is active during the write strobe (low pulse on NWE), thus the written bytes are interpreted as the start address for read operations. Using the attribute memory space makes it possible to use a different timing configuration of the FMC, which can be used

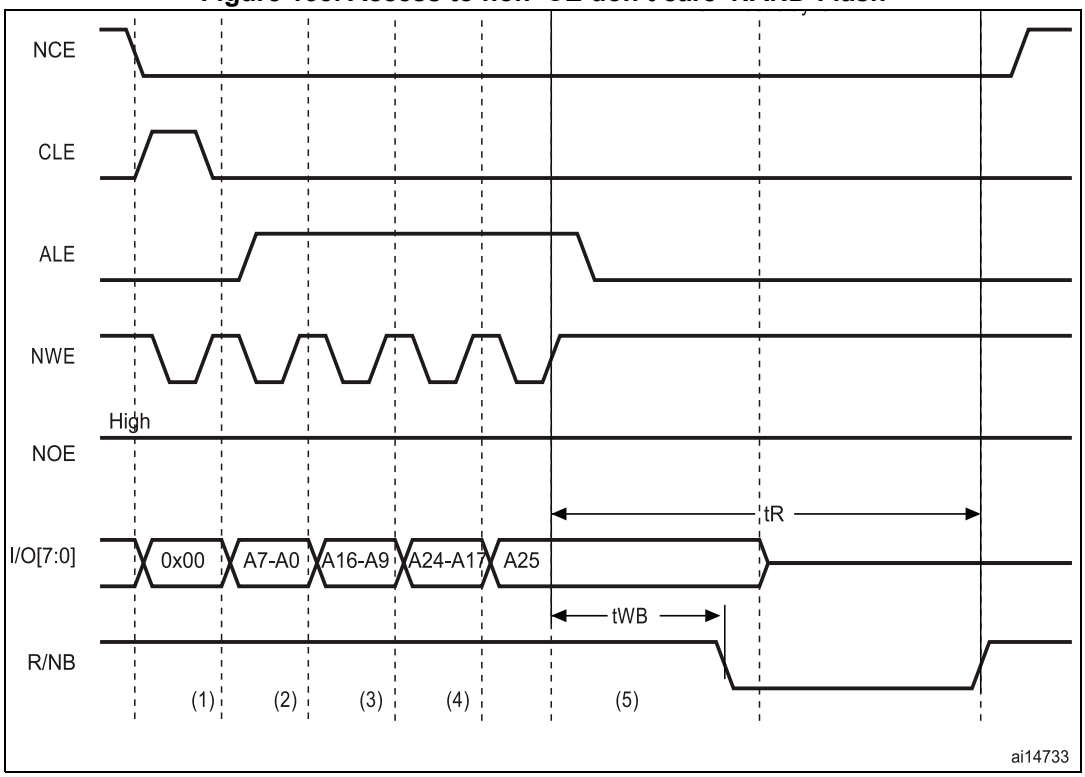
to implement the prewait functionality needed by some NAND Flash memories (see details in *Section 24.8.5: NAND Flash prewait feature*).

4. The controller waits for the NAND Flash memory to be ready (R/NB signal high), before starting a new access to the same or another memory bank. While waiting, the controller holds the NCE signal active (low).
5. The CPU can then perform byte read operations from the common memory space to read the NAND Flash page (data field + Spare field) byte by byte.
6. The next NAND Flash page can be read without any CPU command or address write operation. This can be done in three different ways:
   – by simply performing the operation described in step 5
   – a new random address can be accessed by restarting the operation at step 3
   – a new command can be sent to the NAND Flash device by restarting at step 2

24.8.5 NAND Flash prewait feature

Some NAND Flash devices require that, after writing the last part of the address, the controller waits for the R/NB signal to go low. (see *Figure 133*).

Figure 133. Access to non 'CE don't care' NAND-Flash



1. CPU wrote byte 0x00 at address 0x7001 0000.
2. CPU wrote byte A7~A0 at address 0x7002 0000.
3. CPU wrote byte A16~A9 at address 0x7002 0000.
4. CPU wrote byte A24~A17 at address 0x7002 0000.
5. CPU wrote byte A25 at address 0x8802 0000: FMC performs a write access using FMC_PATT2 timing definition, where ATTHOLD ≥ 7 (providing that (7+1) × fmc_ker_ck = 112 ns > t_{WB} max). This guarantees that NCE remains low until R/NB goes low and high again (only requested for NAND Flash memories where NCE is not don't care).

When this function is required, it can be performed by programming the MEMHOLD value to meet the t_{WB} timing. However, any CPU read access to NAND Flash memory has a hold delay of (MEMHOLD + 1) fmc_ker_ck cycles, and any CPU write access has a hold delay of (MEMHOLD) fmc_ker_ck cycles that is inserted between the rising edge of the NWE signal and the next access.

To cope with this timing constraint, the attribute memory space can be used by programming its timing register with an ATTHOLD value that meets the t_{WB} timing, and by keeping the MEMHOLD value at its minimum value. The CPU must then use the common memory space for all NAND Flash read and write accesses, except when writing the last address byte to the NAND Flash device, where the CPU must write to the attribute memory space.

24.8.6 Computation of the error correction code (ECC) in NAND Flash memory

The FMC controller includes an error correction code computation hardware block. It reduces the host CPU workload when processing the ECC by software.The ECC block is associated with NAND bank.

The ECC algorithm implemented in the FMC can perform 1-bit error correction and 2-bit error detection per 256, 512, 1 024, 2 048, 4 096 or 8 192 bytes read or written from/to the NAND Flash memory. It is based on the Hamming coding algorithm and consists in calculating the row and column parity.

The ECC modules monitor the NAND Flash data bus and read/write signals (NCE and NWE) each time the NAND Flash memory bank is active.

The ECC operates as follows:

- When accessing NAND Flash bank, the data present on the D[15:0] bus is latched and used for ECC computation.
- When accessing any other address in NAND Flash memory, the ECC logic is idle, and does not perform any operation. As a result, write operations to define commands or addresses to the NAND Flash memory are not taken into account for ECC computation.

Once the desired number of bytes has been read/written from/to the NAND Flash memory by the host CPU, the FMC_ECCR registers must be read to retrieve the computed value. Once read, they should be cleared by resetting the ECCEN bit to ‘0’. To compute a new data block, the ECCEN bit must be set to one in the FMC_PCR registers.

Execute below the sequence to perform an ECC computation:

1. Enable the ECCEN bit in the FMC_PCR register.
2. Write data to the NAND Flash memory page. While the NAND page is written, the ECC block computes the ECC value.
3. Wait until the ECC code is ready (FIFO empty).
4. Read the ECC value available in the FMC_ECCR register and store it in a variable.
5. Clear the ECCEN bit and then enable it in the FMC_PCR register before reading back the written data from the NAND page. While the NAND page is read, the ECC block computes the ECC value.
6. Read the new ECC value available in the FMC_ECCR register.
7. If the two ECC values are the same, no correction is required, otherwise there is an ECC error and the software correction routine returns information on whether the error can be corrected or not.

24.8.7 NAND Flash controller registers

NAND Flash control registers (FMC_PCR)

Address offset: 0x80

Reset value: 0x0000 0018

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCPS			TAR3
												rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TAR2	TAR1	TAR0	TCLR				Res.	Res.	ECCEN	PWID		Res.	PBKEN	PWAITEN	Res.
rw	rw	rw	rw	rw	rw	rw			rw	rw	rw		rw	rw	

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:17 **ECCPS:** ECC page size.
These bits define the page size for the extended ECC:
000: 256 bytes
001: 512 bytes
010: 1024 bytes
011: 2048 bytes
100: 4096 bytes
101: 8192 bytes

Bits 16:13 **TAR:** ALE to RE delay.
These bits set time from ALE low to RE low in number of fmc_ker_ck clock cycles.
Time is: t_ar = (TAR + SET + 2) × $t_{fmc\_ker\_ck}$ where $t_{fmc\_ker\_ck}$ is the FMC clock period
0000: 1 x fmc_ker_ck cycle (default)
1111: 16 x fmc_ker_ck cycles
Note: Set is MEMSET or ATTSET according to the addressed space.

Bits 12:9 **TCLR:** CLE to RE delay.
These bits set time from CLE low to RE low in number of fmc_ker_ck clock cycles. The time is give by the following formula:
t_clr = (TCLR + SET + 2) × $t_{fmc\_ker\_ck}$ where $t_{fmc\_ker\_ck}$ is the fmc_ker_ck clock period
0000: 1 x fmc_ker_ck cycle (default)
1111: 16 x fmc_ker_ck cycles
Note: Set is MEMSET or ATTSET according to the addressed space.

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **ECCEN:** ECC computation logic enable bit
0: ECC logic is disabled and reset (default after reset),
1: ECC logic is enabled.

Bits 5:4 **PWID:** Data bus width.
These bits define the external memory device width.
00: 8 bits
01: 16 bits (default after reset).
10: reserved.
11: reserved.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **PBKEN:** NAND Flash memory bank enable bit.
This bit enables the memory bank. Accessing a disabled memory bank causes an ERROR on AXI bus
0: Corresponding memory bank is disabled (default after reset)
1: Corresponding memory bank is enabled

Bit 1 **PWAITEN:** Wait feature enable bit.
This bit enables the Wait feature for the NAND Flash memory bank:
0: disabled
1: enabled

Bit 0 Reserved, must be kept at reset value.

FIFO status and interrupt register (FMC_SR)

Address offset: 0x84

Reset value: 0x0000 0040

This register contains information about the FIFO status and interrupt. The FMC features a FIFO that is used when writing to memories to transfer up to 16 words of data.

This is used to quickly write to the FIFO and free the AXI bus for transactions to peripherals other than the FMC, while the FMC is draining its FIFO into the memory. One of these register bits indicates the status of the FIFO, for ECC purposes.

The ECC is calculated while the data are written to the memory. To read the correct ECC, the software must consequently wait until the FIFO is empty.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FEMPT	IFEN	ILEN	IREN	IFS	ILS	IRS
									r	rw	rw	rw	rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **FEMPT:** FIFO empty.

Read-only bit that provides the status of the FIFO
0: FIFO not empty
1: FIFO empty

Bit 5 **IFEN:** Interrupt falling edge detection enable bit

0: Interrupt falling edge detection request disabled
1: Interrupt falling edge detection request enabled

Bit 4 **ILEN:** Interrupt high-level detection enable bit

0: Interrupt high-level detection request disabled
1: Interrupt high-level detection request enabled

Bit 3 **IREN:** Interrupt rising edge detection enable bit

0: Interrupt rising edge detection request disabled
1: Interrupt rising edge detection request enabled

Bit 2 **IFS:** Interrupt falling edge status

The flag is set by hardware and reset by software.
0: No interrupt falling edge occurred
1: Interrupt falling edge occurred

Note: If this bit is written by software to 1 it will be set.

Bit 1 **ILS:** Interrupt high-level status

The flag is set by hardware and reset by software.
0: No Interrupt high-level occurred
1: Interrupt high-level occurred

Bit 0 **IRS:** Interrupt rising edge status

The flag is set by hardware and reset by software.
0: No interrupt rising edge occurred
1: Interrupt rising edge occurred

Note: If this bit is written by software to 1 it will be set.

Common memory space timing register (FMC_PMEM)

Address offset: Address: 0x88

Reset value: 0xFCFC FCFC

The FMC_PMEM read/write register contains the timing information for NAND Flash memory bank. This information is used to access either the common memory space of the NAND Flash for command, address write access and data read/write access.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MEMHIZ								MEMHOLD							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MEMWAIT								MEMSET							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **MEMHIZ:** Common memory x data bus Hi-Z time

These bits define the number of fmc_ker_ck clock cycles during which the data bus is kept Hi-Z after the start of a NAND Flash write access to common memory space. This is only valid for write transactions:
0000 0000: 0 x fmc_ker_ck cycle
1111 1110: 254 x fmc_ker_ck cycles
1111 1111: reserved.

Bits 23:16 **MEMHOLD:** Common memory hold time

These bits define the number of fmc_ker_ck clock cycles for write accesses and fmc_ker_ck+1 clock cycles for read accesses during which the address is held (and data for write accesses) after the command is deasserted (NWE, NOE), for NAND Flash read or write access to common memory space:
0000 0000: reserved.
0000 0001: 1 fmc_ker_ck cycle for write access / 3 fmc_ker_ck cycle for read access
1111 1110: 254 fmc_ker_ck cycles for write access / 257 fmc_ker_ck cycles for read access
1111 1111: reserved.

Bits 15:8 **MEMWAIT:** Common memory wait time

These bits define the minimum number of fmc_ker_ck (+1) clock cycles to assert the command (NWE, NOE), for NAND Flash read or write access to common memory space. The duration of command assertion is extended if the wait signal (NWAIT) is active (low) at the end of the programmed value of fmc_ker_ck:
0000 0000: reserved
0000 0001: x fmc_ker_ck cycles (+ wait cycle introduced by deasserting NWAIT)
1111 1110: 255 x fmc_ker_ck cycles (+ wait cycle introduced by deasserting NWAIT)
1111 1111: reserved.

Bits 7:0 **MEMSET:** Common memory x setup time

These bits define the number of fmc_ker_ck (+1) clock cycles to set up the address before the command assertion (NWE, NOE), for NAND Flash read or write access to common memory space:
0000 0000: fmc_ker_ck cycles
1111 1110: 255 x fmc_ker_ck cycles
1111 1111: reserved

Attribute memory space timing registers (FMC_PATT)

Address offset: 0x8C

Reset value: 0xFCFC FCFC

The FMC_PATT read/write register contains the timing information for NAND Flash memory bank. It is used for 8-bit accesses to the attribute memory space of the NAND Flash for the last address write access if the timing must differ from that of previous accesses (for Ready/Busy management, refer to *Section 24.8.5: NAND Flash prewait feature*).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ATTHIZ								ATTHOLD							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ATTWAIT								ATTSET							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **ATTHIZ:** Attribute memory data bus Hi-Z time

These bits define the number of fmc_ker_ck clock cycles during which the data bus is kept in Hi-Z after the start of a NAND Flash write access to attribute memory space on socket. Only valid for writ transaction:
0000 0000: 0 x fmc_ker_ck cycle
1111 1110: 254 x fmc_ker_ck cycles
1111 1111: reserved.

Bits 23:16 **ATTHOLD:** Attribute memory hold time

These bits define the number of fmc_ker_ck clock cycles during which the address is held (and data for write access) after the command deassertion (NWE, NOE), for NAND Flash read or write access to attribute memory space:
0000 0000: reserved
0000 0001: 1 x fmc_ker_ck cycle
1111 1110: 254 x fmc_ker_ck cycles
1111 1111: reserved.

Bits 15:8 **ATTWAIT:** Attribute memory wait time

These bits define the minimum number of x fmc_ker_ck (+1) clock cycles to assert the command (NWE, NOE), for NAND Flash read or write access to attribute memory space. The duration for command assertion is extended if the wait signal (NWAIT) is active (low) at the end of the programmed value of fmc_ker_ck:
0000 0000: reserved
0000 0001: 2 x fmc_ker_ck cycles (+ wait cycle introduced by deassertion of NWAIT)
1111 1110: 255 x fmc_ker_ck cycles (+ wait cycle introduced by deasserting NWAIT)
1111 1111: reserved.

Bits 7:0 **ATTSET:** Attribute memory setup time

These bits define the number of fmc_ker_ck (+1) clock cycles to set up address before the command assertion (NWE, NOE), for NAND Flash read or write access to attribute memory space:
0000 0000: 1 x fmc_ker_ck cycle
1111 1110: 255 x fmc_ker_ck cycles
1111 1111: reserved.

ECC result registers (FMC_ECCR)

Address offset: 0x94

Reset value: 0x0000 0000

This register contain the current error correction code value computed by the ECC computation modules of the FMC NAND controller. When the CPU reads/writes the data from a NAND Flash memory page at the correct address (refer to *Section 24.8.6: Computation of the error correction code (ECC) in NAND Flash memory*), the data read/written from/to the NAND Flash memory are processed automatically by the ECC computation module. When X bytes have been read (according to the ECCPS field in the FMC_PCR registers), the CPU must read the computed ECC value from the FMC_ECC registers. It then verifies if these computed parity data are the same as the parity value recorded in the spare area, to determine whether a page is valid, and, to correct it otherwise. The FMC_ECCR register should be cleared after being read by setting the ECCEN bit to ‘0’. To compute a new data block, the ECCEN bit must be set to ’1’.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ECC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ECC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **ECC[31:0]:** ECC result

This field contains the value computed by the ECC computation logic. *Table 206* describes the contents of these bitfields.

Table 206. ECC result relevant bits

ECCPS[2:0]	Page size in bytes	ECC bits
000	256	ECC[21:0]
001	512	ECC[23:0]
010	1024	ECC[25:0]
011	2048	ECC[27:0]
100	4096	ECC[29:0]
101	8192	ECC[31:0]

24.9 SDRAM controller

24.9.1 SDRAM controller main features

The main features of the SDRAM controller are the following:

- Two SDRAM banks with independent configuration
- 8-bit, 16-bit, 32-bit data bus width
- 13-bits Address Row, 11-bits Address Column, 4 internal banks: 4x16Mx32bit (256 MB), 4x16Mx16bit (128 MB), 4x16Mx8bit (64 MB)
- Word, half-word, byte access
- SDRAM clock can be fmc_ker_ck/2 or fmc_ker_ck/3
- Automatic row and bank boundary management
- Multibank ping-pong access
- Programmable timing parameters
- Automatic Refresh operation with programmable Refresh rate
- Self-refresh mode
- Power-down mode
- SDRAM power-up initialization by software
- CAS latency of 1,2,3
- Cacheable Read FIFO with depth of 6 lines x32-bit (6 x14-bit address tag)

24.9.2 SDRAM External memory interface signals

At startup, the SDRAM I/O pins used to interface the FMC SDRAM controller with the external SDRAM devices must configured by the user application. The SDRAM controller I/O pins which are not used by the application, can be used for other purposes.

Table 207. SDRAM signals

SDRAM signal	I/O type	Description	Alternate function
SDCLK	O	SDRAM clock	-
SDCKE[1:0]	O	SDCKE0: SDRAM Bank 1 Clock Enable SDCKE1: SDRAM Bank 2 Clock Enable	-
SDNE[1:0]	O	SDNE0: SDRAM Bank 1 Chip Enable SDNE1: SDRAM Bank 2 Chip Enable	-
A[12:0]	O	Address	FMC_A[12:0]
D[31:0]	I/O	Bidirectional data bus	FMC_D[31:0]
BA[1:0]	O	Bank Address	FMC_A[15:14]
NRAS	O	Row Address Strobe	-
NCAS	O	Column Address Strobe	-
SDNWE	O	Write Enable	-
NBL[3:0]	O	Output Byte Mask for write accesses (memory signal name: DQM[3:0]	FMC_NBL[3:0]

24.9.3 SDRAM controller functional description

All SDRAM controller outputs (signals, address and data) change on the falling edge of the memory clock (FMC_SDCLK).

SDRAM initialization

The initialization sequence is managed by software. If the two banks are used, the initialization sequence must be generated simultaneously to Bank 1and Bank 2 by setting the Target Bank bits CTB1 and CTB2 in the FMC_SDCMR register:

1. Program the memory device features into the FMC_SDCRx register. The SDRAM clock frequency, RBURST and RPIPE must be programmed in the FMC_SDCR1 register.
2. Program the memory device timing into the FMC_SDTRx register. The TRP and TRC timings must be programmed in the FMC_SDTR1 register.
3. Set MODE bits to ‘001’ and configure the Target Bank bits (CTB1 and/or CTB2) in the FMC_SDCMR register to start delivering the clock to the memory (SDCKE is driven high).
4. Wait during the prescribed delay period. Typical delay is around 100 µs (refer to the SDRAM datasheet for the required delay after power-up).
5. Set MODE bits to ‘010’ and configure the Target Bank bits (CTB1 and/or CTB2) in the FMC_SDCMR register to issue a “Precharge All” command.
6. Set MODE bits to ‘011’, and configure the Target Bank bits (CTB1 and/or CTB2) as well as the number of consecutive Auto-refresh commands (NRFS) in the FMC_SDCMR register. Refer to the SDRAM datasheet for the number of Auto-refresh commands that should be issued. Typical number is 8.
7. Configure the MRD field, set the MODE bits to ‘100’, and configure the Target Bank bits (CTB1 and/or CTB2) in the FMC_SDCMR register to issue a “Load Mode Register” command and program the SDRAM device. In particular the Burst Length (BL) has to be set to ‘1’) and the CAS latency has to be selected. If the Mode Register is not the same for both SDRAM banks, this step has to be repeated twice, once for each bank and the Target Bank bits set accordingly. For mobile SDRAM devices, the MRD field is also used to configure the extended mode register while issuing the Load Mode Register”
8. Program the refresh rate in the FMC_SDRTR register

   The refresh rate corresponds to the delay between refresh cycles. Its value must be adapted to SDRAM devices.

At this stage the SDRAM device is ready to accept commands. If a system reset occurs during an ongoing SDRAM access, the data bus might still be driven by the SDRAM device. Therefor the SDRAM device must be first reinitialized after reset before issuing any new access by the NOR Flash/PSRAM/SRAM or NAND Flash controller.

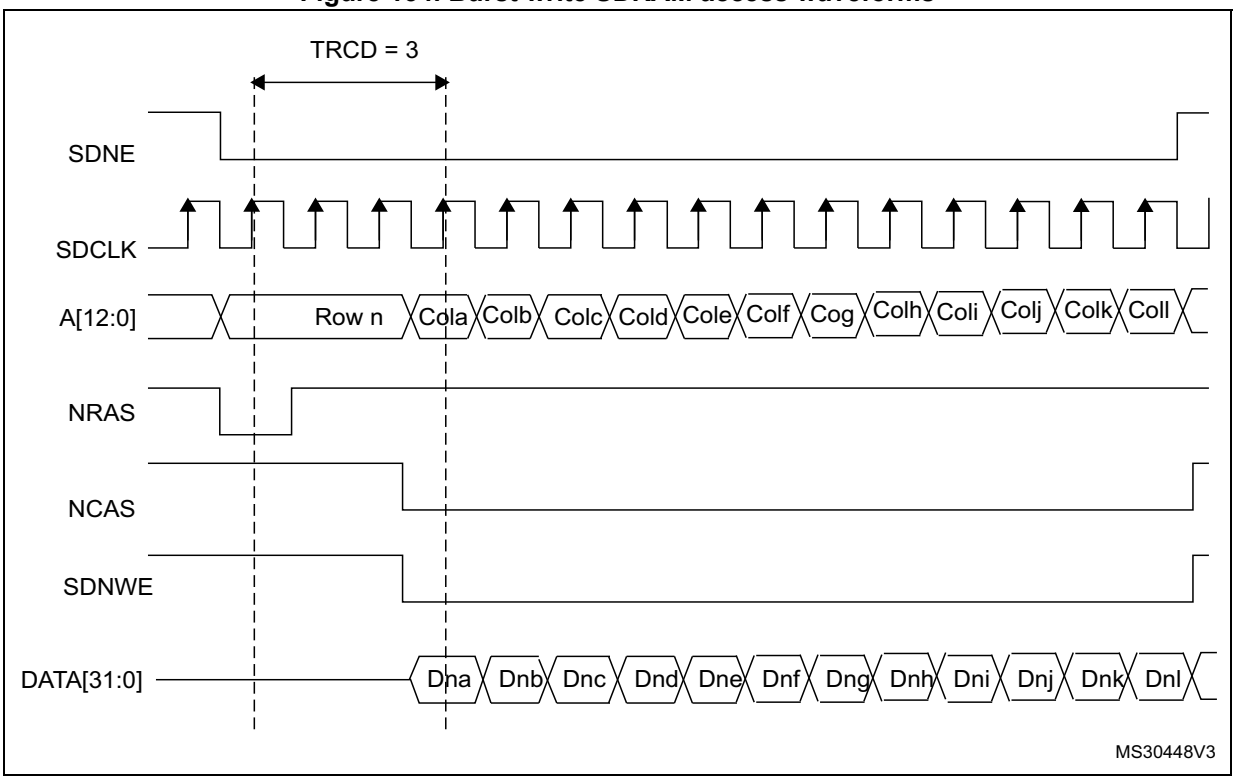
Note: If two SDRAM devices are connected to the FMC, all the accesses performed at the same time to both devices by the Command Mode register (Load Mode Register command) are issued using the timing parameters configured for SDRAM Bank 1 (TMRD andTRAS timings) in the FMC_SDTR1 register.

SDRAM controller write cycle

The SDRAM controller accepts single and burst write requests and translates them into single memory accesses. In both cases, the SDRAM controller keeps track of the active row for each bank to be able to perform consecutive write accesses to different banks (Multibank ping-pong access).

Before performing any write access, the SDRAM bank write protection must be disabled by clearing the WP bit in the FMC_SDCRx register.

Figure 134. Burst write SDRAM access waveforms



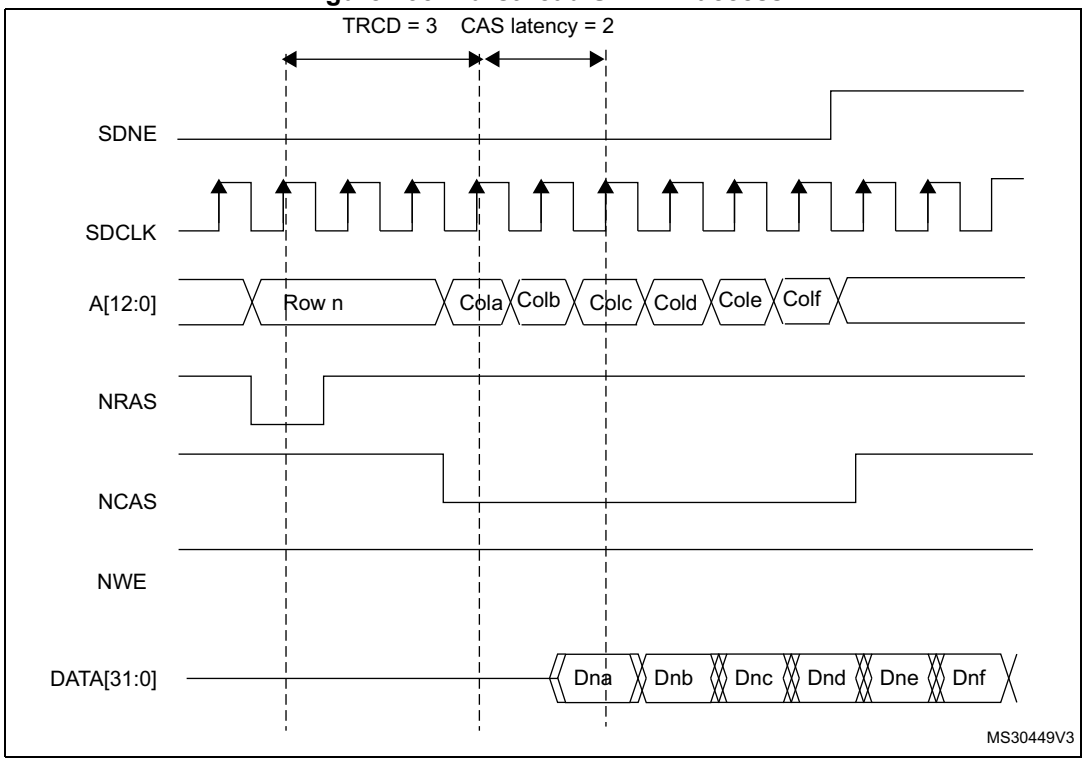
The SDRAM controller always checks the next access.

- If the next access is in the same row or in another active row, the write operation is carried out,
- if the next access targets another row (not active), the SDRAM controller generates a precharge command, activates the new row and initiates a write command.

SDRAM controller read cycle

The SDRAM controller accepts single and burst read requests and translates them into single memory accesses. In both cases, the SDRAM controller keeps track of the active row in each bank to be able to perform consecutive read accesses in different banks (Multibank ping-pong access).

Figure 135. Burst read SDRAM access



The FMC SDRAM controller features a Cacheable read FIFO (6 lines x 32 bits). It is used to store data read in advance during the CAS latency period (up to 3 memory clock cycles, programmed FMC_SDCRx) and during the RPIPE delay when set to 2xfmc_ker_ck clock cycles as configured in FMC_SDCR1) following this formula: CAS Latency + 1 + (RPIPE DIV2). The RBURST bit must be set in the FMC_SDCR1 register to anticipate the next read access.

Examples:

- CAS=3, RPIPE= 2xfmc_ker_ck. In this case, 5 data (not committed) are stored in the FIFO (4 data during CAS latency and 1 data during RPIPE delay)
- CAS=3, RPIPE= 1xfmc_ker_ck. In this case, 4 data (not committed) are stored in the FIFO (4 data during CAS latency)

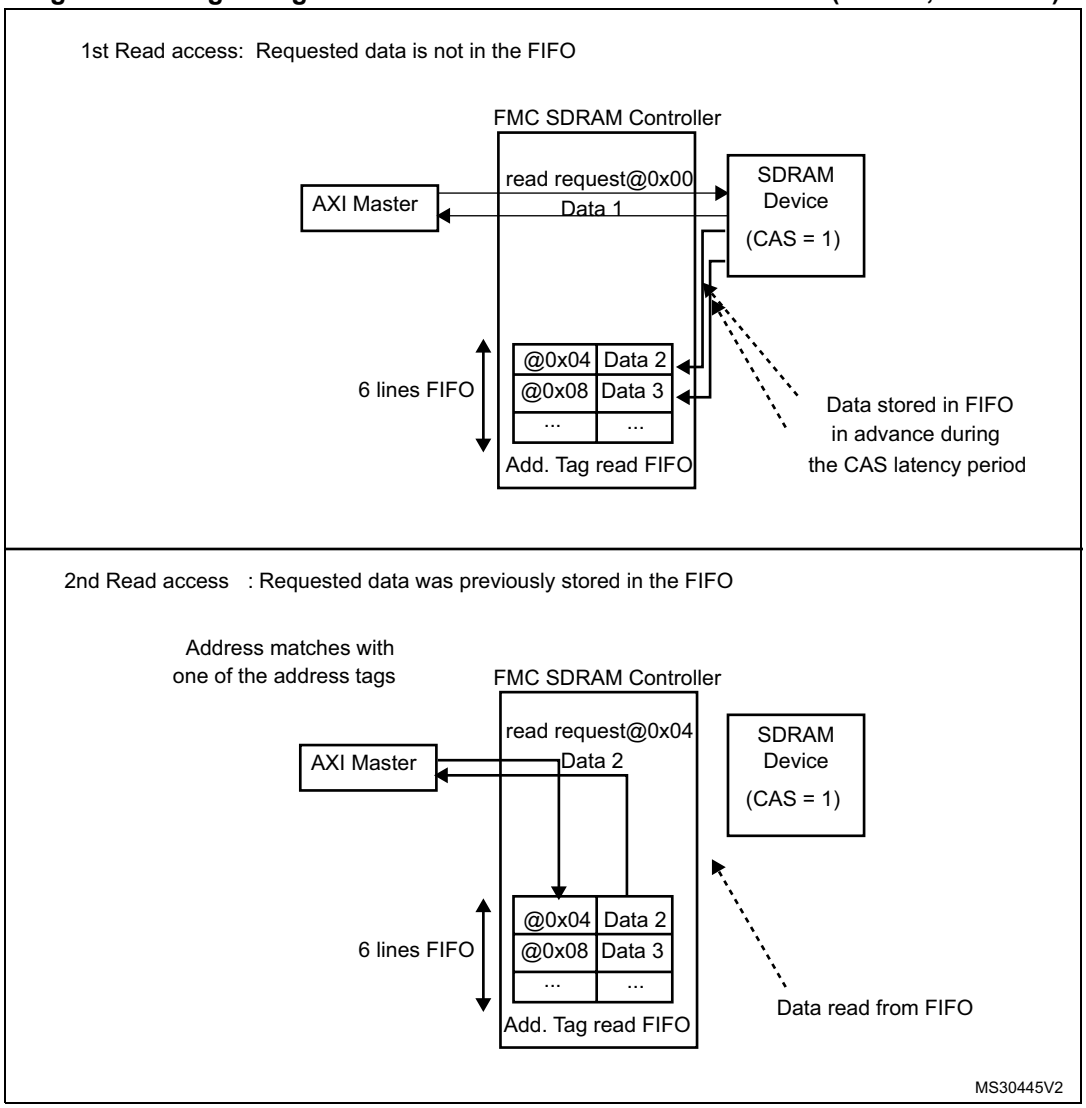
The read FIFO features a 14-bit address tag to each line to identify its content: 11 bits for the column address, 2 bits to select the internal bank and the active row, and 1 bit to select the SDRAM device

When the end of the row is reached in advance during an burst read transaction, the data read in advance (not committed) are not stored in the read FIFO. For single read access, data are correctly stored in the FIFO.

Each time a read request occurs, the SDRAM controller checks:

- If the address matches one of the address tags, data are directly read from the FIFO and the corresponding address tag/ line content is cleared and the remaining data in the FIFO are compacted to avoid empty lines.
- Otherwise, a new read command is issued to the memory and the FIFO is updated with new data. If the FIFO is full, the older data are lost.

Figure 136. Logic diagram of Read access with RBURST bit set (CAS=2, RPIPE=0)



During a write access or a Precharge command, the read FIFO is flushed and ready to be filled with new data.

After the first read request, if the current access was not performed to a row boundary, the SDRAM controller anticipates the next read access during the CAS latency period and the RPIPE delay (if configured). This is done by incrementing the memory address. The following condition must be met:

- RBURST control bit should be set to ‘1’ in the FMC_SDCR1 register.

The address management depends on the next AXI request:

- Next request is sequential (Burst access)

  In this case, the SDRAM controller increments the address.
- Next request is not sequential
  - If the new read request targets the same row or another active row, the new address is passed to the memory and the master is stalled for the CAS latency period, waiting for the new data from memory.
  - If the new read request does not target an active row, the SDRAM controller generates a Precharge command, activates the new row, and initiates a read command.

If the RBURST is reset, the read FIFO is not used.

Row and bank boundary management

When a read or write access crosses a row boundary, if the next read or write access is sequential and the current access was performed to a row boundary, the SDRAM controller executes the following operations:

1. Precharge of the active row,
2. Activation of the new row
3. Start of a read/write command.

At a row boundary, the automatic activation of the next row is supported for all columns and data bus width configurations.

If necessary, the SDRAM controller inserts additional clock cycles between the following commands:

- Between Precharge and Active commands to match TRP parameter (only if the next access is in a different row in the same bank),
- Between Active and Read commands to match the TRCD parameter.

These parameters are defined into the FMC_SDTRx register.

Refer to *Figure 134* and *Figure 135* for read and burst write access crossing a row boundary.

Figure 137. Read access crossing row boundary

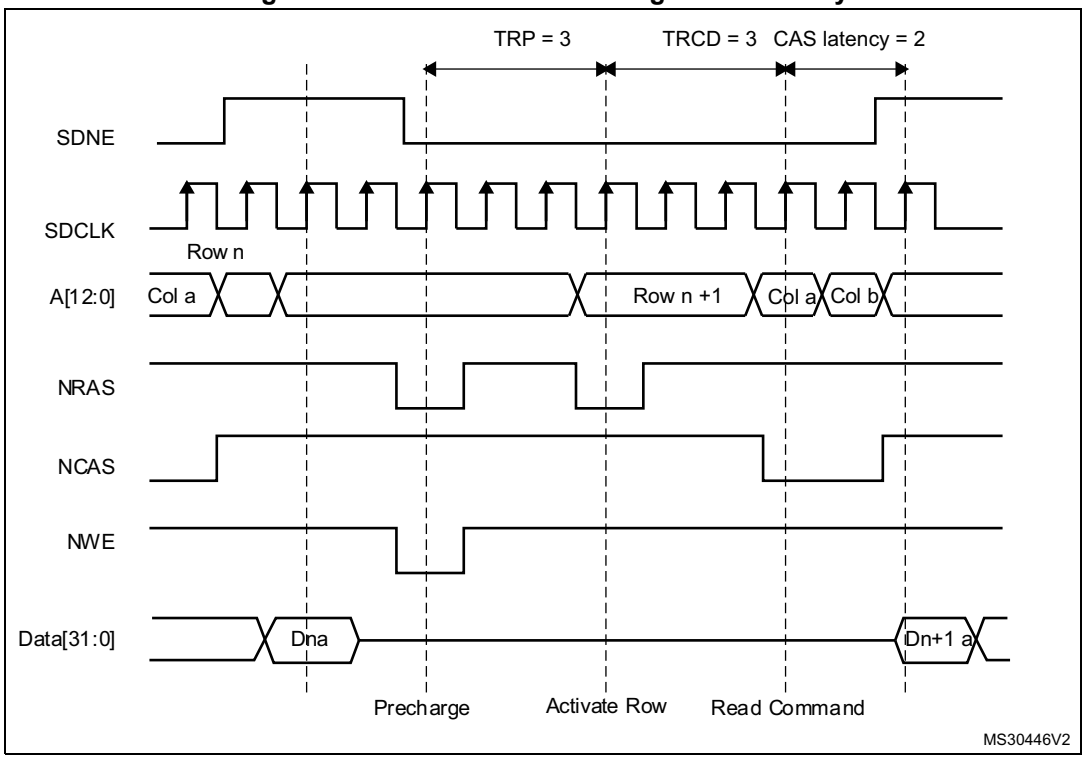
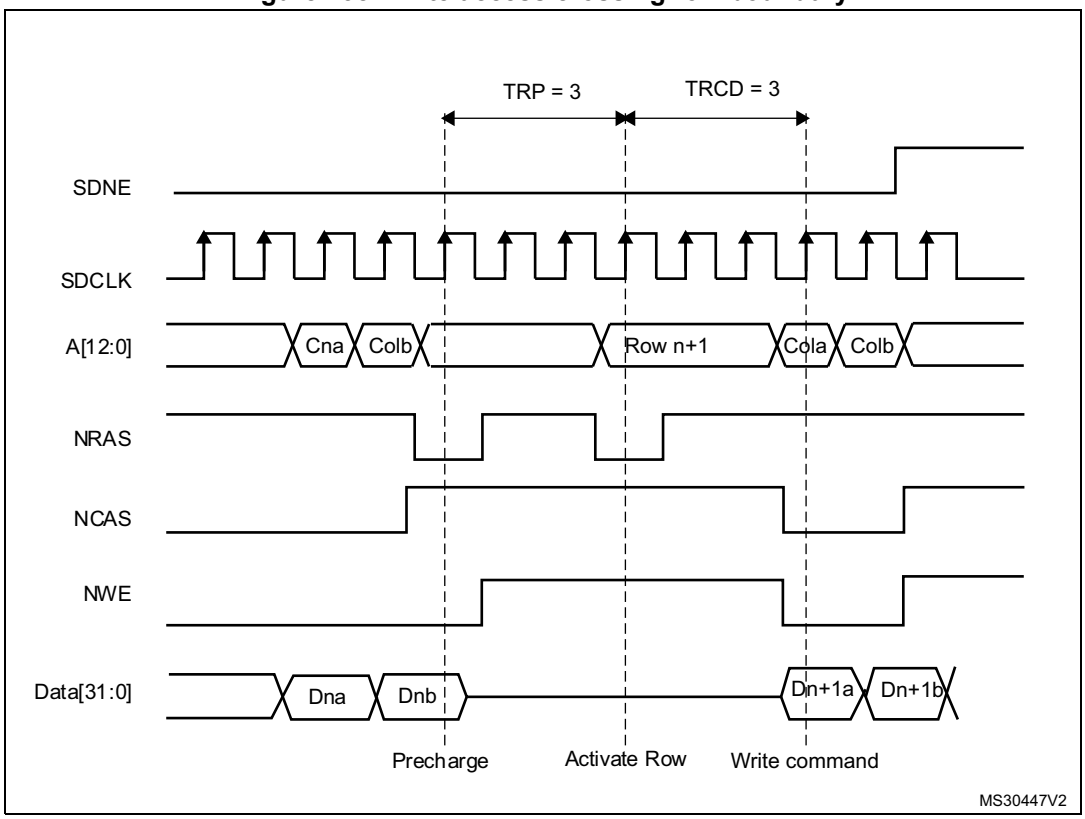


Figure 138. Write access crossing row boundary



If the next access is sequential and the current access crosses a bank boundary, the SDRAM controller activates the first row in the next bank and initiates a new read/write command. Two cases are possible:

- If the current bank is not the last one, the active row in the new bank must be precharged.At a bank boundary, the automatic activation of the next row is supported for all rows/columns and data bus width configuration.
- If the current bank is the last one, the automatic activation of the next row is supported only when addressing 13-bit rows, 11-bit columns, 4 internal banks and 32-bit data bus SDRAM devices. Otherwise, the SDRAM address range is violated and an AXI slave error is generated.
- In case of 13-bit row address, 11-bit column address, 4 internal banks and bus width 32-bit SDRAM memories, at boundary bank, the SDRAM controller continues to read/write from the second SDRAM device (assuming it has been initialized):
  a) The SDRAM controller activates the first row (after precharging the active row, if there is already an active row in the first internal bank, and initiates a new read/write command.
  b) If the first row is already activated, the SDRAM controller just initiates a read/write command.

SDRAM controller refresh cycle

The Auto-refresh command is used to refresh the SDRAM device content. The SDRAM controller periodically issues auto-refresh commands. An internal counter is loaded with the COUNT value in the register FMC_SDRTR. This value defines the number of memory clock cycles between the refresh cycles (refresh rate). When this counter reaches zero, an internal pulse is generated.

If a memory access is ongoing, the auto-refresh request is delayed. However, if the memory access and the auto-refresh requests are generated simultaneously, the auto-refresh request takes precedence.

If the memory access occurs during an auto-refresh operation, the request is buffered and processed when the auto-refresh is complete.

If a new auto-refresh request occurs while the previous one was not served, the RE (Refresh Error) bit is set in the Status register. An Interrupt is generated if it has been enabled (REIE = ‘1’).

If SDRAM lines are not in idle state (not all row are closed), the SDRAM controller generates a PALL (Precharge ALL) command before the auto-refresh.

If the Auto-refresh command is generated by the FMC_SDCMR Command Mode register (Mode bits = ‘011’), a PALL command (Mode bits =’ 010’) must be issued first.

24.9.4 Low-power modes

Two low-power modes are available:

- Self-refresh mode

  The auto-refresh cycles are performed by the SDRAM device itself to retain data without external clocking.
- Power-down mode

  The auto-refresh cycles are performed by the SDRAM controller.

Self-refresh mode

This mode is selected by setting the MODE bits to ‘101’ and by configuring the Target Bank bits (CTB1 and/or CTB2) in the FMC_SDCMR register.

The SDRAM clock stops running after a TRAS delay and the internal refresh timer stops counting only if one of the following conditions is met:

- A Self-refresh command is issued to both devices
- One of the devices is not activated (SDRAM bank is not initialized).

Before entering Self-Refresh mode, the SDRAM controller automatically issues a PALL command.

If the Write data FIFO is not empty, all data are sent to the memory before activating the Self-refresh mode and the BUSY status flag remains set.

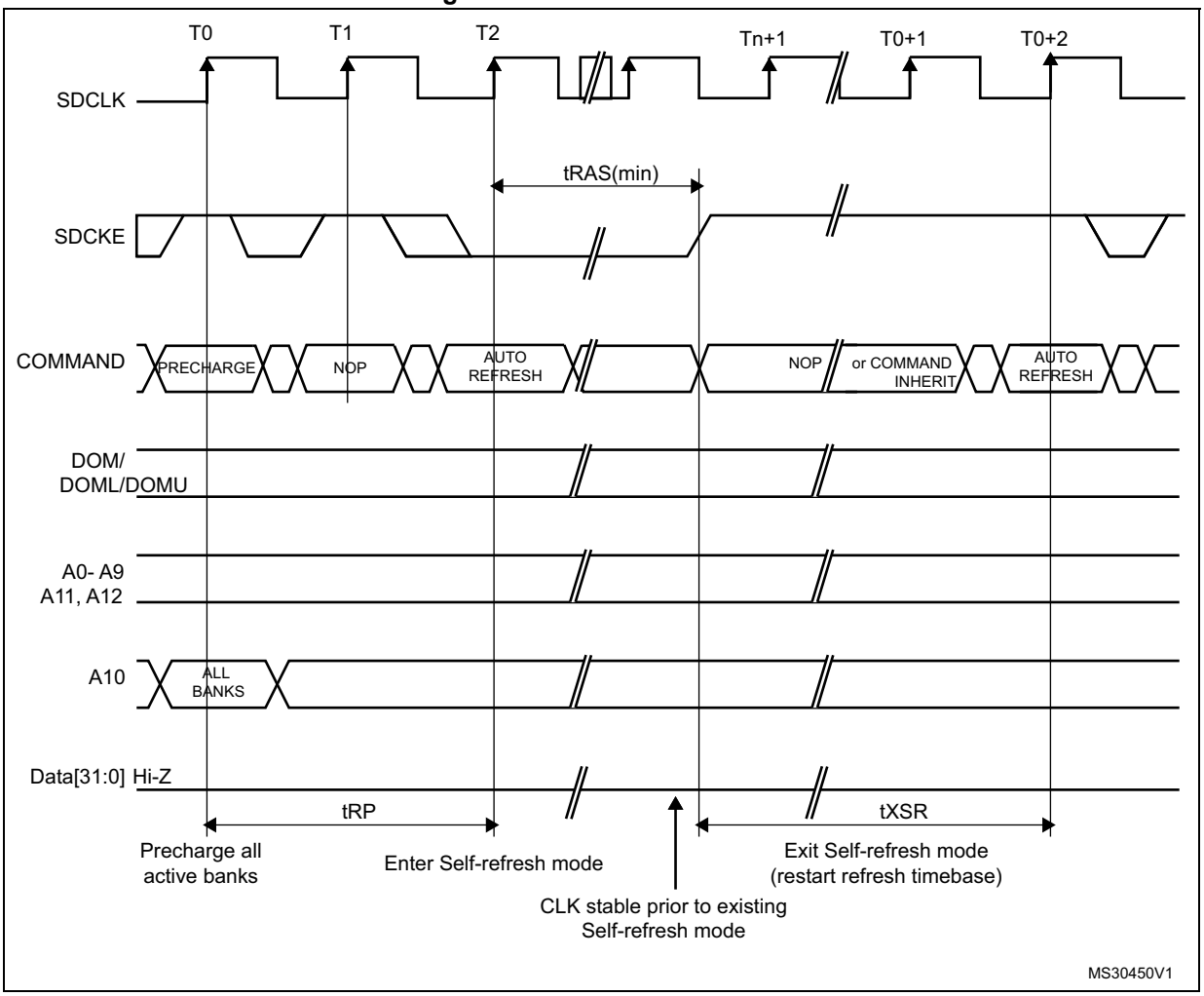
In Self-refresh mode, all SDRAM device inputs become don’t care except for SDCKE which remains low.

The SDRAM device must remain in Self-refresh mode for a minimum period of time of TRAS and can remain in Self-refresh mode for an indefinite period beyond that. To guarantee this minimum period, the BUSY status flag remains high after the Self-refresh activation during a TRAS delay.

As soon as an SDRAM device is selected, the SDRAM controller generates a sequence of commands to exit from Self-refresh mode. After the memory access, the selected device remains in Normal mode.

To exit from Self-refresh, the MODE bits must be set to ‘000’ (Normal mode) and the Target Bank bits (CTB1 and/or CTB2) must be configured in the FMC_SDCMR register.

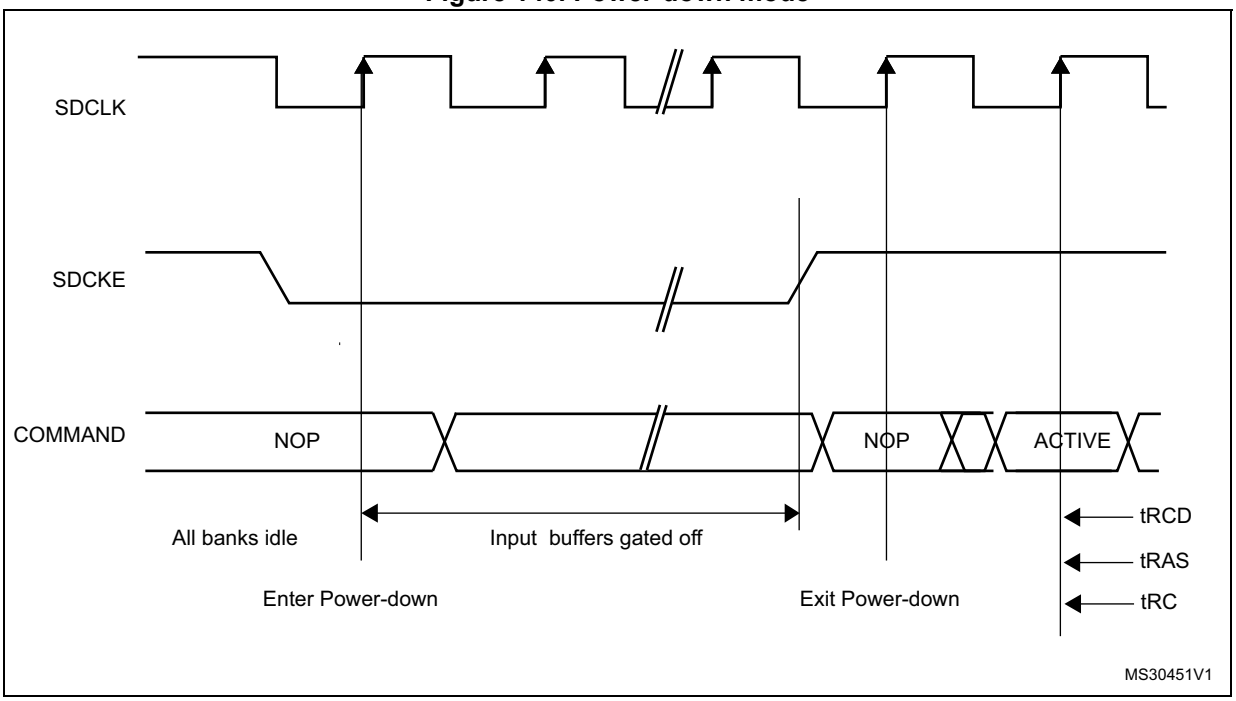
Figure 139. Self-refresh mode



Power-down mode

This mode is selected by setting the MODE bits to ‘110’ and by configuring the Target Bank bits (CTB1 and/or CTB2) in the FMC_SDCMR register.

Figure 140. Power-down mode



If the Write data FIFO is not empty, all data are sent to the memory before activating the Power-down mode.

As soon as an SDRAM device is selected, the SDRAM controller exits from the Power-down mode. After the memory access, the selected SDRAM device remains in Normal mode.

During Power-down mode, all SDRAM device input and output buffers are deactivated except for the SDCKE which remains low.

The SDRAM device cannot remain in Power-down mode longer than the refresh period and cannot perform the Auto-refresh cycles by itself. Therefore, the SDRAM controller carries out the refresh operation by executing the operations below:

1. Exit from Power-down mode and drive the SDCKE high
2. Generate the PALL command only if a row was active during Power-down mode
3. Generate the auto-refresh command
4. Drive SDCKE low again to return to Power-down mode.

To exit from Power-down mode, the MODE bits must be set to ‘000’ (Normal mode) and the Target Bank bits (CTB1 and/or CTB2) must be configured in the FMC_SDCMR register.

24.9.5 SDRAM controller registers

SDRAM Control registers for SDRAM memory bank x (FMC_SDCRx)

Address offset: 0x140+ 4* (x - 1), (x = 1 to 2)

Reset value: 0x0000 02D0

This register contains the control parameters for each SDRAM memory bank

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	RPIPE[1:0]		RBURST	SDCLK[1:0]		WP	CAS[1:0]		NB	MWID[1:0]		NR[1:0]		NC[1:0]	
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:15 Reserved, must be kept at reset value.

Bits 14:13 **RPIPE[1:0]:** Read pipe

These bits define the delay, in fmc_ker_ck clock cycles, for reading data after CAS latency.
00: No fmc_ker_ck clock cycle delay
01: One fmc_ker_ck clock cycle delay
10: Two fmc_ker_ck clock cycle delay
11: reserved.

Note: The corresponding bits in the FMC_SDCR2 register is read only.

Bit 12 **RBURST:** Burst read

This bit enables Burst read mode. The SDRAM controller anticipates the next read commands during the CAS latency and stores data in the Read FIFO.
0: single read requests are not managed as bursts
1: single read requests are always managed as bursts

Note: The corresponding bit in the FMC_SDCR2 register is read only.

Bits 11:10 **SDCLK[1:0]:** SDRAM clock configuration

These bits define the SDRAM clock period for both SDRAM banks and allow disabling the clock before changing the frequency. In this case the SDRAM must be re-initialized.
00: SDCLK clock disabled
01: Reserved
10: SDCLK period = 2 x fmc_ker_ck periods
11: SDCLK period = 3 x fmc_ker_ck periods

Note: The corresponding bits in the FMC_SDCR2 register is read only.

Bit 9 **WP:** Write protection

This bit enables Write mode access to the SDRAM bank.
0: Write accesses allowed
1: Write accesses ignored

Bits 8:7 **CAS[1:0]:** CAS Latency
This bits sets the SDRAM CAS latency in number of memory clock cycles
00: reserved.
01: 1 cycle
10: 2 cycles
11: 3 cycles

Bit 6 **NB:** Number of internal banks
This bit sets the number of internal banks.
0: Two internal Banks
1: Four internal Banks

Bits 5:4 **MWID[1:0]:** Memory data bus width.
These bits define the memory device width.
00: 8 bits
01: 16 bits
10: 32 bits
11: reserved.

Bits 3:2 **NR[1:0]:** Number of row address bits
These bits define the number of bits of a row address.
00: 11 bit
01: 12 bits
10: 13 bits
11: reserved.

Bits 1:0 **NC[1:0]:** Number of column address bits
These bits define the number of bits of a column address.
00: 8 bits
01: 9 bits
10: 10 bits
11: 11 bits.

Note: Before modifying the RBURST or RPIPE settings or disabling the SDCLK clock, the user must first send a PALL command to make sure ongoing operations are complete.

SDRAM Timing registers for SDRAM memory bank x (FMC_SDTRx)

Address offset: 0x148 + 4 * (x - 1), (x = 1 to 2)

Reset value: 0x0FFF FFFF

This register contains the timing parameters of each SDRAM bank

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TRCD				TRP				TWR			
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRC				TRAS				TXSR				TMRD			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **TRCD[3:0]:** Row to column delay

These bits define the delay between the Activate command and a Read/Write command in number of memory clock cycles.
0000: 1 cycle.
0001: 2 cycles
....
1111: 16 cycles

Bits 23:20 **TRP[3:0]:** Row precharge delay

These bits define the delay between a Precharge command and another command in number of memory clock cycles. The TRP timing is only configured in the FMC_SDTR1 register. If two SDRAM devices are used, the TRP must be programmed with the timing of the slowest device.
0000: 1 cycle
0001: 2 cycles
....
1111: 16 cycles

Note: The corresponding bits in the FMC_SDTR2 register are don't care.

Bits 19:16 **TWR[3:0]:** Recovery delay

These bits define the delay between a Write and a Precharge command in number of memory clock cycles.
0000: 1 cycle
0001: 2 cycles
....
1111: 16 cycles

Note: TWR must be programmed to match the write recovery time (t_{WR}) defined in the SDRAM datasheet, and to guarantee that:

TWR ³ TRAS - TRCD and TWR ³TRC - TRCD - TRP

Example: TRAS= 4 cycles, TRCD= 2 cycles. So, TWR >= 2 cycles. TWR must be programmed to 0x1.

If two SDRAM devices are used, the FMC_SDTR1 and FMC_SDTR2 must be programmed with the same TWR timing corresponding to the slowest SDRAM device.
If only one SDRAM device is used, the TWR timing must be kept at reset value (0xF) for the not used bank.

Bits 15:12 **TRC[3:0]:** Row cycle delay

These bits define the delay between the Refresh command and the Activate command, as well as the delay between two consecutive Refresh commands. It is expressed in number of memory clock cycles. The TRC timing is only configured in the FMC_SDTR1 register. If two SDRAM devices are used, the TRC must be programmed with the timings of the slowest device.
0000: 1 cycle
0001: 2 cycles
....
1111: 16 cycles

Note: TRC must match the TRC and TRFC (Auto Refresh period) timings defined in the SDRAM device datasheet.

Note: The corresponding bits in the FMC_SDTR2 register are don't care.

Bits 11:8 **TRAS[3:0]:** Self refresh time

These bits define the minimum Self-refresh period in number of memory clock cycles.
0000: 1 cycle
0001: 2 cycles
....
1111: 16 cycles

Bits 7:4 **TXSR[3:0]:** Exit Self-refresh delay

These bits define the delay from releasing the Self-refresh command to issuing the Activate command in number of memory clock cycles.
0000: 1 cycle
0001: 2 cycles
....
1111: 16 cycles

Note: If two SDRAM devices are used, the FMC_SDTR1 and FMC_SDTR2 must be programmed with the same TXSR timing corresponding to the slowest SDRAM device.

Bits 3:0 **TMRD[3:0]:** Load Mode Register to Active

These bits define the delay between a Load Mode Register command and an Active or Refresh command in number of memory clock cycles.
0000: 1 cycle
0001: 2 cycles
....
1111: 16 cycles

Note: If two SDRAM devices are connected, all the accesses performed simultaneously to both devices by the Command Mode register (Load Mode Register command) are issued using the timing parameters configured for Bank 1 (TMRD and TRAS timings) in the FMC_SDTR1 register.

The TRP and TRC timings are only configured in the FMC_SDTR1 register. If two SDRAM devices are used, the TRP and TRC timings must be programmed with the timings of the slowest device.

SDRAM Command mode register (FMC_SDCMR)

Address offset: 0x150

Reset value: 0x0000 0000

This register contains the command issued when the SDRAM device is accessed. This register is used to initialize the SDRAM device, and to activate the Self-refresh and the Power-down modes. As soon as the MODE field is written, the command will be issued only to one or to both SDRAM banks according to CTB1 and CTB2 command bits. This register is the same for both SDRAM banks.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MRD						
									rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MRD							NRFS				CTB1	CTB2	MODE		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:9 **MRD[13:0]:** Mode Register definition

This 14-bit field defines the SDRAM Mode Register content. The Mode Register is programmed using the Load Mode Register command. The MRD[13:0] bits are also used to program the extended mode register for mobile SDRAM.

Bits 8:5 **NRFS[3:0]:** Number of Auto-refresh

These bits define the number of consecutive Auto-refresh commands issued when MODE = '011'.
0000: 1 Auto-refresh cycle
0001: 2 Auto-refresh cycles
....
1110: 15 Auto-refresh cycles
1111: 16 Auto-refresh cycles

Bit 4 **CTB1:** Command Target Bank 1

This bit indicates whether the command will be issued to SDRAM Bank 1 or not.
0: Command not issued to SDRAM Bank 1
1: Command issued to SDRAM Bank 1

Bit 3 **CTB2:** Command Target Bank 2

This bit indicates whether the command will be issued to SDRAM Bank 2 or not.
0: Command not issued to SDRAM Bank 2
1: Command issued to SDRAM Bank 2

Bits 2:0 **MODE[2:0]:** Command mode

These bits define the command issued to the SDRAM device.
000: Normal Mode
001: Clock Configuration Enable
010: PALL ("All Bank Precharge") command
011: Auto-refresh command
100: Load Mode Register
101: Self-refresh command
110: Power-down command
111: Reserved

Note: When a command is issued, at least one Command Target Bank bit (CTB1 or CTB2) must be set otherwise the command will be ignored.

Note: If two SDRAM banks are used, the Auto-refresh and PALL command must be issued simultaneously to the two devices with CTB1 and CTB2 bits set otherwise the command will be ignored.

Note: If only one SDRAM bank is used and a command is issued with it's associated CTB bit set, the other CTB bit of the unused bank must be kept to 0.

SDRAM refresh timer register (FMC_SDRTR)

Address offset: 0x154

Reset value: 0x0000 0000

This register sets the refresh rate in number of SDCLK clock cycles between the refresh cycles by configuring the Refresh Timer Count value.

$$\text{Refresh rate} = (\text{COUNT} + 1) \times \text{SDRAM clock frequency}$$

$$\text{COUNT} = (\text{SDRAM refresh period} / \text{Number of rows}) - 20$$

Below an example of refresh rate calculation:

$$\text{Refresh rate} = 64\ \text{ms} / (8196\text{rows}) = 7.81\mu\text{s}$$

where 64 ms is the SDRAM refresh period.

$$7.81\mu\text{s} \times 60\text{MHz} = 468.6$$

The refresh rate must be increased by 20 SDRAM clock cycles (as in the above example) to obtain a safe margin if an internal refresh request occurs when a read request has been accepted. It corresponds to a COUNT value of '0000111000000' (448).

This 13-bit field is loaded into a timer which is decremented using the SDRAM clock. This timer generates a refresh pulse when zero is reached. The COUNT value must be set at least to 41 SDRAM clock cycles.

As soon as the FMC_SDRTR register is programmed, the timer starts counting. If the value programmed in the register is '0', no refresh is carried out. This register must not be reprogrammed after the initialization procedure to avoid modifying the refresh rate.

Each time a refresh pulse is generated, this 13-bit COUNT field is reloaded into the counter.

If a memory access is in progress, the Auto-refresh request is delayed. However, if the memory access and Auto-refresh requests are generated simultaneously, the Auto-refresh takes precedence. If the memory access occurs during a refresh operation, the request is buffered to be processed when the refresh is complete.

This register is common to SDRAM bank 1 and bank 2.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	REIE	COUNT													CRE
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w

Bits 31: 15 Reserved, must be kept at reset value.

Bit 14 **REIE:** RES Interrupt Enable
0: Interrupt is disabled
1: An Interrupt is generated if RE = 1

Bits 13:1 **COUNT[12:0]:** Refresh Timer Count
This 13-bit field defines the refresh rate of the SDRAM device. It is expressed in number of memory clock cycles. It must be set at least to 41 SDRAM clock cycles (0x29).
Refresh rate = (COUNT + 1) x SDRAM frequency clock
COUNT = (SDRAM refresh period / Number of rows) - 20

Bit 0 **CRE:** Clear Refresh error flag
This bit is used to clear the Refresh Error Flag (RE) in the Status Register.
0: no effect
1: Refresh Error flag is cleared

Note: The programmed COUNT value must not be equal to the sum of the following timings: TWR+TRP+TRC+TRCD+4 memory clock cycles .

SDRAM Status register (FMC_SDSR)

Address offset: 0x158

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODES2		MODES1		RE
											r	r	r	r	r

Bits 31:5 Reserved, must be kept at reset value.

Bits 4:3 **MODES2:** Status Mode for Bank 2
These bits define the Status Mode of SDRAM Bank 2.
00: Normal Mode
01: Self-refresh mode
10: Power-down mode

Bits 2:1 **MODES1:** Status Mode for Bank 1
These bits define the Status Mode of SDRAM Bank 1.
00: Normal Mode
01: Self-refresh mode
10: Power-down mode

Bit 0 **RE:** Refresh error flag
0: No refresh error has been detected
1: A refresh error has been detected
An interrupt is generated if REIE = 1 and RE = 1

24.9.6 FMC register map

The following table summarizes the FMC registers.

Table 208. FMC register map

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**FMC_BCR1**	FMCEN	Res.	Res.	Res.	Res.	Res.	BMAP[1:0]		Res.	Res.	WFDIS	CCLKEN	CBURSTRW	CPSIZE[2:0]			ASYNCWAIT	EXTMOD	WAITEN	WREN	WAITCFG	Res.	WAITPOL	BURSTEN	Res.	FACCEN	MWID		MTYP		MUXEN	MBKEN
0x08	**FMC_BCR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CBURSTRW	CPSIZE [2:0]			ASYNCWAIT	EXTMOD	WAITEN	WREN	WAITCFG	Res.	WAITPOL	BURSTEN	Res.	FACCEN	MWID [1:0]		MTYP [1:0]		MUXEN	MBKEN
	Reset value													0	0	0	0	0	0	1	1	0		0	0		1	0	1	0	0	1	0
0x10	**FMC_BCR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CBURSTRW	CPSIZE [2:0]			ASYNCWAIT	EXTMOD	WAITEN	WREN	WAITCFG	Res.	WAITPOL	BURSTEN	Res.	FACCEN	MWID [1:0]		MTYP [1:0]		MUXEN	MBKEN
	Reset value													0	0	0	0	0	0	1	1	0		0	0		1	0	1	0	0	1	0

Table 208. FMC register map (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x18	**FMC_BCR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CBURSTRW	CPSIZE [2:0]			ASYNCWAIT	EXTMOD	WAITEN	WREN	WAITCFG	Res.	WAITPOL	BURSTEN	Res.	FACCEN	MWID [1:0]		MTYP [1:0]		MUXEN	MBKEN
	Reset value													0	0	0	0	0	0	1	1	0		0	0		1	0	1	0	0	1	0
0x04	**FMC_BTR1**	Res.	Res.	ACCMOD[1:0]		DATLAT[3:0]				CLKDIV[3:0]				BUSTURN[3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value			0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0C	**FMC_BTR2**	Res.	Res.	ACCMOD[1:0]		DATLAT[3:0]				CLKDIV[3:0]				BUSTURN[3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value			0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x14	**FMC_BTR3**	Res.	Res.	ACCMOD[1:0]		DATLAT[3:0]				CLKDIV[3:0]				BUSTURN[3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value			0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x1C	**FMC_BTR4**	Res.	Res.	ACCMOD[1:0]		DATLAT[3:0]				CLKDIV[3:0]				BUSTURN[3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value			0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x104	**FMC_BWTR1**	Res.	Res.	ACCMOD[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSTURN[3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value			0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x10C	**FMC_BWTR2**	Res.	Res.	ACCMOD[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSTURN[3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value			0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x114	**FMC_BWTR3**	Res.	Res.	ACCMOD[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSTURN[3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value			0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x11C	**FMC_BWTR4**	Res.	Res.	ACCMOD[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSTURN[3:0]				DATAST[7:0]								ADDHLD[3:0]				ADDSET[3:0]			
	Reset value			0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x80	**FMC_PCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ECCPS [2:0]				TAR[3:0]				TCLR[3:0]				Res.	Res.	ECCEN	PWID [1:0]		Res.	PBKEN	PWAITEN	Res.
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0			0	0	1	1	0	0	
0x84	**FMC_SR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FEMPT	IFEN	ILEN	IREN	IFS	ILS	IRS
	Reset value																										1	0	0	0	0	0	0
0x88	**FMC_PMEM**	MEMHIZx[7:0]								MEMHOLDx[7:0]								MEMWAITx[7:0]								MEMSETx[7:0]							
	Reset value	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0
0x8C	**FMC_PATT**	ATTHIZ[7:0]								ATTHOLD[7:0]								ATTWAIT[7:0]								ATTSET[7:0]							
	Reset value	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0
0x94	**FMC_ECCR**	ECC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x140	**FMC_SDCR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RPIPE[1:0]		RBURST	SDCLK [1:0]		WP	CAS [1:0]		NB	MWID [1:0]		NR[1:0]		NC	
	Reset value																		0	0	0	1	1	0	1	0	0	1	0	0	0	0	0
0x144	**FMC_SDCR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RPIPE [1:0]		RBURST	SDCLK [1:0]		WP	CAS [1:0]		NB	MWID [1:0]		NR[1:0]		NC	
	Reset value																		0	0	0	1	1	0	1	0	0	1	0	0	0	0	0
0x148	**FMC_SDTR1**	Res.	Res.	Res.	Res.	TRCD[3:0]				TRP[3:0]				TWR[3:0]				TRC[3:0]				TRAS[3:0]				TXSR[3:0]				TMRD[3:0]			
	Reset value					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 208. FMC register map (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x14C	**FMC_SDTR2**	Res.	Res.	Res.	Res.	TRCD[3:0]				TRP[3:0]				TWR[3:0]				TRC[3:0]				TRAS[3:0]				TXSR[3:0]				TMRD[3:0]			
	Reset value					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x150	**FMC_SDCMR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MRD														NRFS[3:0]				CTB1	CTB2	MODE[2:0]		
	Reset value											0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x154	**FMC_SDRTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REIE	COUNT[12:0]													CRE
	Reset value																		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x158	**FMC_SDSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODES2[1:0]		MODES1[1:0]		RE
	Reset value																												0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

25 Octo-SPI interface (OCTOSPI)

25.1 Introduction

The OCTOSPI supports most external serial memories such as serial PSRAMs, serial NAND and serial NOR Flash memories, HyperRAM™ and HyperFlash™ memories, with the following functional modes:

- Indirect mode: all the operations are performed using the OCTOSPI registers to preset commands, addresses, data and transfer parameters.
- Automatic status-polling mode: the external memory status register is periodically read and an interrupt can be generated in case of flag setting.
- Memory-mapped mode: the external memory is memory mapped and it is seen by the system as if it was an internal memory, supporting both read and write operations.

The OCTOSPI supports the following protocols with associated frame formats:

- the Regular-command frame format with the command, address, alternate byte, dummy cycles and data phase
- the HyperBus™ frame format

25.2 OCTOSPI main features

- Functional modes: Indirect, Automatic status-polling, and Memory-mapped
- Read and write support in Memory-mapped mode
- External (P)SRAM memory support
- Support for single, dual, quad and octal communication
- Dual-quad configuration, where eight bits can be sent/received simultaneously by accessing two quad memories in parallel
- SDR (single-data rate) and DTR (double-transfer rate) support
- Data strobe support
- Fully programmable opcode
- Fully programmable frame format
- Support wrapped-type access to memory in read direction
- HyperBus support
- Integrated FIFO for reception and transmission
- Asynchronous bus clock versus kernel clock support
- 8-, 16-, and 32-bit data accesses allowed
- DMA channel for Indirect mode operations
- Interrupt generation on FIFO threshold, timeout, operation complete, and access error
- AXI interface with transaction acceptance limited to one: the interface accepts the next transfer on AXI bus only once the previous is completed on memory side.

25.3 OCTOSPI implementation

Table 209. OCTOSPI implementation

OCTOSPI feature	OCTOSPI1/2
HyperBus standard compliant	X
Xcella standard compliant	X
XSPI (JEDEC251ES) standard compliant	X
AMBA® AXI compliant data interface	X
Asynchronous AXI clock versus kernel clock	X
Functional modes: Indirect, Automatic status-polling, and Memory-mapped	X
Read and write support in Memory-mapped mode	X
Dual-quad configuration	X
SDR (single-data rate) and DTR (double-transfer rate)	X
Data strobe (DS,DQS)	X
Fully programmable opcode	X
Fully programmable frame format	X
Integrated FIFO for reception and transmission	X
8-, 16-, and 32-bit data accesses	X
Interrupt on FIFO threshold, timeout, operation complete, and access error	X
Compliant with dual-OCTOSPI arbiter (communication regulation)	X
Extended CSHT timeout	X
Memory-mapped write	X
Refresh counter	X

25.4 OCTOSPI functional description

25.4.1 OCTOSPI block diagram

Figure 141. OCTOSPI block diagram in octal configuration

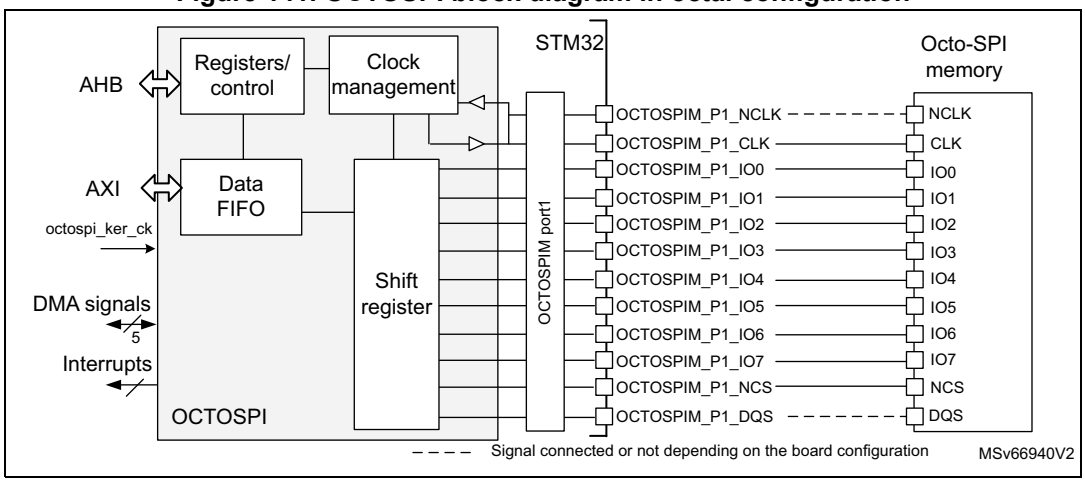


Figure 142. OCTOSPI block diagram in quad configuration

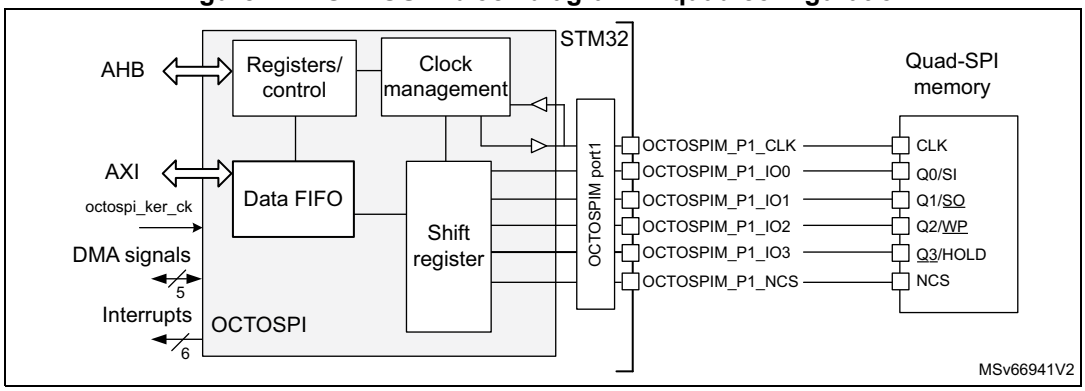
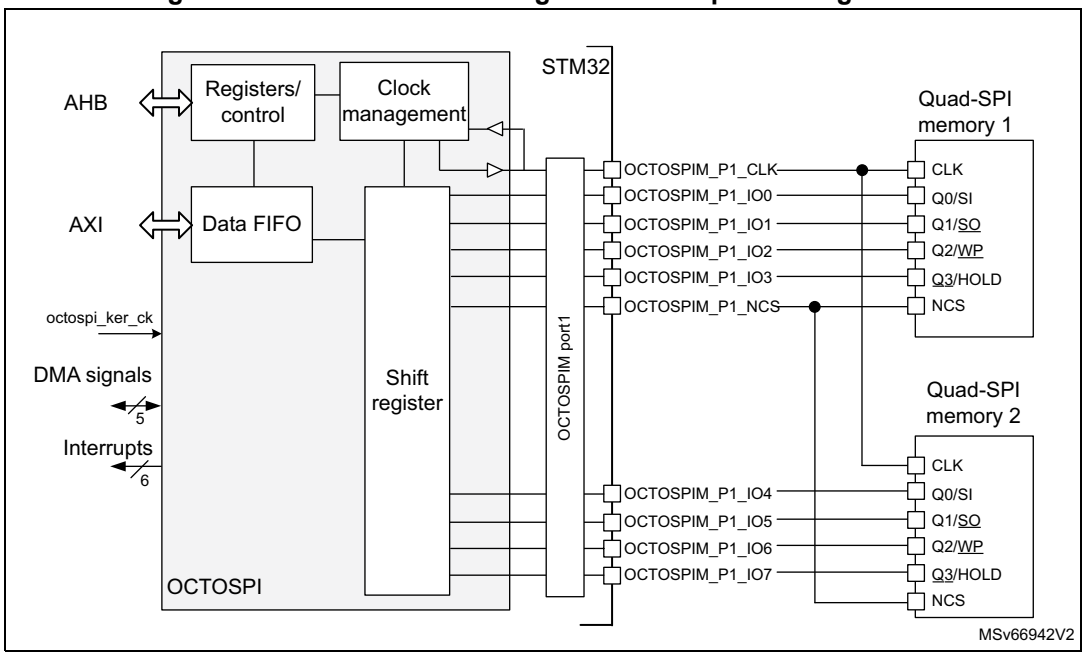


Figure 143. OCTOSPI block diagram in dual-quad configuration



25.4.2 OCTOSPI interface to memory modes

The OCTOSPI supports the following protocols:

- Regular-command protocol
- HyperBus protocol

The OCTOSPI uses from 6 to 12 signals to interface with a memory, depending on the functional mode:

- NCS: chip-select
- CLK: communication clock
- NCLK: inverted clock used only in the 1.8 V HyperBus protocol
- DQS: data strobe used only in Regular-command protocol as input only
- IO[3:0]: data bus LSB
- IO[7:4]: data bus MSB used in dual-quad and octal configurations

25.4.3 OCTOSPI Regular-command protocol

When in Regular-command protocol, the OCTOSPI communicates with the external device using commands. Each command can include the following phases:

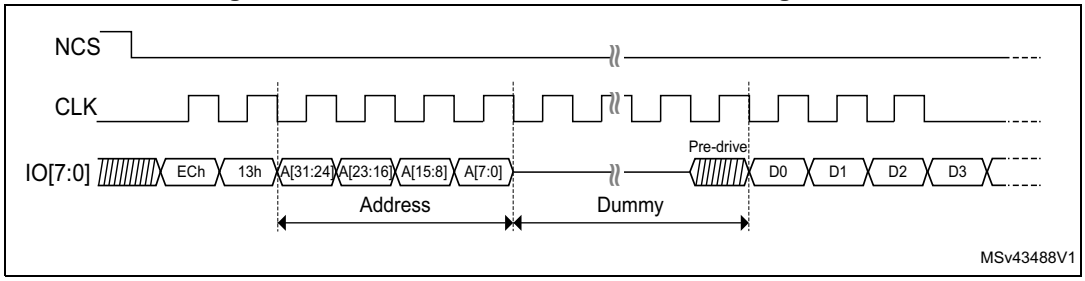
- Instruction phase
- Address phase
- Alternate-byte phase
- Dummy-cycle phase
- Data phase

Any of these phases can be configured to be skipped but, in case of single-phase command, the only use case supported is instruction-phase-only.

The NCS falls before the start of each command and rises again after each command finishes.

In Memory-mapped mode, both read and write operations are supported: as a consequence, some of the configuration registers are duplicated to specify write operations (read operations are configured using regular registers).

Figure 144. SDR read command in octal configuration



The specific Regular-command protocol features are configured through the registers in the 0x0100-0x01FC offset range.

Instruction phase

During this phase, a 1- to 4-byte instruction is sent to the external device specifying the type of operation to be performed. The size of the instruction to be sent is configured in ISIZE[1:0] of OCTOSPI_CCR and the instruction is programmed in INSTRUCTION[31:0] of OCTOSPI_IR.

The instruction phase can optionally send:

- 1 bit at a time from the IO0/SO signal (single-SPI mode)
- 2 bits at a time (over IO0/IO1 in dual-SPI mode)
- 4 bits at a time (over IO0 to IO3 in quad-SPI mode)
- 8 bits at a time (over IO0 to IO7 in octal-SPI mode).

This can be configured using IMODE[2:0] of OCTOSPI_CCR.

The instruction can be sent in DTR (double-transfer rate) mode on each rising and falling edge of the clock, by setting IDTR in OCTOSPI_CCR.

When IMODE[2:0] = 000 in OCTOSPI_CCR, the instruction phase is skipped, and the command sequence starts with the address phase, if present.

In Memory-mapped mode, the instruction used for the write operation is specified in OCTOSPI_WIR and the instruction format is specified in OCTOSPI_WCCR. The instruction used for the read operation and the instruction format are specified in OCTOSPI_IR and OCTOSPI_CCR.

Address phase

In the address phase, 1 to 4 bytes are sent to the external device, to indicate the address of the operation. The number of address bytes to be sent is configured in ADSIZE[1:0] of OCTOSPI_CCR.

In Indirect and Automatic status-polling modes, the address bytes to be sent are specified in ADDRESS[31:0] of OCTOSPI_AR. In Memory-mapped mode, the address is given directly via the AXI (from any master in the system).

The address phase can send:

- 1 bit at a time (over SOI in single-SPI mode)
- 2 bits at a time (over IO0/IO1 in dual-SPI mode)
- 4 bits at a time (over IO0 to IO3 in quad-SPI mode)
- 8 bits at a time (over IO0 to IO7 in octal-SPI mode)

This can be configured using ADMODE[2:0] of OCTOSPI_CCR.

The address can be sent in DTR mode (on each rising and falling edge of the clock) setting ADDTR of OCTOSPI_CCR.

When ADMODE[2:0] = 000, the address phase is skipped and the command sequence proceeds directly to the next phase, if any.

In Memory-mapped mode, the address format for the write operation is specified in OCTOSPI_WCCR. The address format for the read operation is specified in OCTOSPI_CCR.

Alternate-bytes phase

In the alternate-bytes phase, 1 to 4 bytes are sent to the external device, generally to control the mode of operation. The number of alternate bytes to be sent is configured in ABSIZE[1:0] of OCTOSPI_CCR. The bytes to be sent are specified in OCTOSPI_ABR.

The alternate-byte phase can send:

- 1 bit at a time (over SOI in single-SPI mode)
- 2 bits at a time (over IO0/IO1 in dual-SPI mode)
- 4 bits at a time (over IO0 to IO3 in quad-SPI mode)
- 8 bits at a time (over IO0 to IO7 in octal-SPI mode)

This can be configured using ABMODE[2:0] of OCTOSPI_CCR.

The alternate bytes can be sent in DTR mode (on each rising and falling edge of the clock) setting ABDTR of OCTOSPI_CCR.

When ABMODE[2:0] = 000, the alternate-bytes phase is skipped and the command sequence proceeds directly to the next phase, if any.

There may be times when only a single nibble needs to be sent during the alternate-byte phase rather than a full byte, such as when the dual-SPI mode is used and only two cycles are used for the alternate bytes.

In this case, the firmware can use the quad-SPI mode (ABMODE[2:0] = 011) and send a byte with bits 7 and 3 of ALTERNATE[31:0] set to 1 (keeping the IO3 line high), and bits 6 and 2 set to 0 (keeping the IO2 line low), in OCTOSPI_IR.

The upper two bits of the nibble to be sent are then placed in bits 4:3 of ALTERNATE[31:0] while the lower two bits are placed in bits 1:0. For example, if the nibble 2 (0010) is to be sent over IO0/IO1, then ALTERNATE[31:0] must be set to 0x8A (1000_1010).

In Memory-mapped mode, the alternate bytes used for the write operation are specified in OCTOSPI_WABR and the alternate byte format is specified in OCTOSPI_WCCR. The alternate bytes used for read operation and the alternate byte format are specified in OCTOSPI_ABR and OCTOSPI_CCR.

Dummy-cycle phase

In the dummy-cycle phase, 1 to 31 cycles are given without any data being sent or received, in order to give the external device, the time to prepare for the data phase when the higher clock frequencies are used. The number of cycles given during this phase is specified in DCYC[4:0] of OCTOSPI_TCR. In both SDR and DTR modes, the duration is specified as a number of full CLK cycles.

When DCYC[4:0] = 00000, the dummy-cycle phase is skipped, and the command sequence proceeds directly to the data phase, if present.

In order to assure enough “turn-around” time for changing the data signals from the output mode to the input mode, there must be at least one dummy cycle when using the dual-SPI, the quad-SPI or the octal-SPI mode, to receive data from the external device.

In Memory-mapped mode, the dummy cycles for the write operations are specified in OCTOSPI_WTCR. The dummy cycles for the read operation are specified in OCTOSPI_TCR.

Data phase

During the data phase, any number of bytes can be sent to or received from the external device.

In Indirect mode, the number of bytes to be sent/received is specified in OCTOSPI_DLR. In this mode, the data to be sent to the external device must be written to OCTOSPI_DR, while in Indirect-read mode the data received from the external device is obtained by reading OCTOSPI_DR.

In Automatic status-polling mode, the number of bytes to be received is specified in OCTOSPI_DLR and the data received from the external device can be obtained by reading OCTOSPI_DR.

In Memory-mapped mode, the data read or written, is sent or received directly over the AXI to the Cortex core or to a DMA.

The data phase can send/receive:

- 1 bit at a time (over SO/SI in single-SPI mode)
- 2 bits at a time (over IO0/IO1 in dual-SPI mode)
- 4 bits at a time (over IO0 to IO3 in quad-SPI mode)
- 8 bits at a time (over IO0 to IO7 in octal-SPI mode)

This can be configured using DMODE[2:0] of OCTOSPI_CCR.

The data can be sent or received in DTR mode (on each rising and falling edge of the clock) setting DDTR of OCTOSPI_CCR.

When DMODE[2:0] = 000, the data phase is skipped, and the command sequence finishes immediately by raising the NCS. This configuration must be used only in Indirect-write mode.

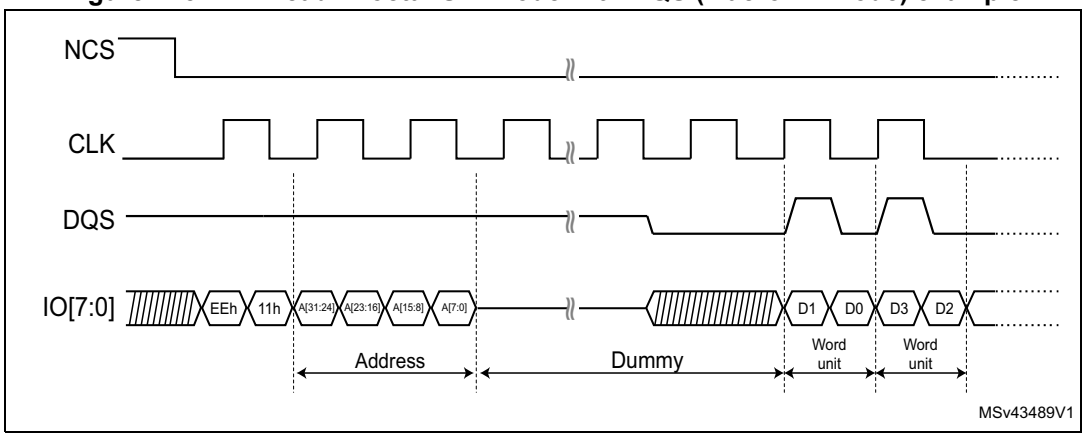
In Memory-mapped mode, the data format for the write operation is specified in OCTOSPI_WCCR. The data format for the read operation is specified in OCTOSPI_CCR.

DQS usage

The DQS signal can be used for data strobing during the read transactions when the device toggles the DQS aligned with the data.

The DQS management can be enabled by setting DQSE of OCTOSPI_CCR.

Figure 145. DTR read in octal-SPI mode with DQS (Macronix mode) example



25.4.4 OCTOSPI Regular-command protocol signal interface

Single-SPI mode

The legacy SPI mode allows just a single bit to be sent/received serially. In this mode, the data is sent to the external device over the SO signal (whose I/Os are shared with IO0). The data received from the external device arrives via SI (whose I/Os are shared with IO1).

The different phases can each be configured separately to use this single-SPI mode by setting to 001 the IMODE, ADMODE, ABMODE, and DMODE fields in OCTOSPI_CCR and OCTOSPI_WCCR.

In each phase configured in single-SPI mode:

- IO0 (SO) is in output mode.
- IO1 (SI) is in input mode (high impedance).
- IO2 is in output mode and forced to 0 (to deactivate the “write protect” function).
- IO3 is in output mode and forced to 1 (to deactivate the “hold” function).
- IO4 to IO7 are in output mode and forced to 0.

This is the case even for the dummy phase if DMODE[2:0] = 001.

Dual-SPI mode

In dual-SPI mode, two bits are sent/received simultaneously over the IO0/IO1 signals.

The different phases can each be configured separately to use dual-SPI mode by setting to 010 the IMODE,ADMODE, ABMODE, and DMODE fields in OCTOSPI_CCR and OCTOSPI_WCCR.

In each phase configured in dual-SPI mode:

- IO0/IO1 are at high-impedance (input) during the data phase for the read operations, and outputs in all other cases.
- IO2 is in output mode and forced to 0.
- IO3 is in output mode and forced to 1.
- IO4 to IO7 are in output mode and forced to 0.

In the dummy phase when DMODE[2:0] = 010, IO0/IO1 are always high-impedance.

Quad-SPI mode

In quad-SPI mode, four bits are sent/received simultaneously over the IO0/IO1/IO2/IO3 signals.

The different phases can each be configured separately to use the quad-SPI mode by setting to 011 the IMODE,ADMODE, ABMODE, and DMODE fields in OCTOSPI_CCR and OCTOSPI_WCCR.

In each phase configured in quad-SPI mode:

- IO0 to IO3 are all at high-impedance (inputs) during the data phase for the read operations, and outputs in all other cases.
- IO4 to IO7 are in output mode and forced to 0.

In the dummy phase when DMODE[2:0] = 011, IO0 to IO3 are all high-impedance.

IO2 and IO3 are used only in quad-SPI mode. If none of the phases are configured to use the quad-SPI mode, then the pins corresponding to IO2 and IO3 can be used for other functions even while the OCTOSPI is active.

Octal-SPI mode

In regular octal-SPI mode, the eight bits are sent/received simultaneously over the IO[0:7] signals.

The different phases can each be configured separately to use the octal-SPI mode by setting to 100 the IMODE,ADMODE, ABMODE, and DMODE fields in OCTOSPI_CCR and OCTOSPI_WCCR.

In each phase that is configured in octal-SPI mode, IO[0:7] are all at high-impedance (input) during the data phase for read operations, and outputs in all other cases.

In the dummy phase when DMODE[2:0] = 100, IO[0:7] are all high-impedance.

IO[4:7] are used only in Octal-SPI mode. If none of the phases are configured to use octal-SPI mode, then the pins corresponding to IO[4:7] can be used for other functions even while the OCTOSPI is active.

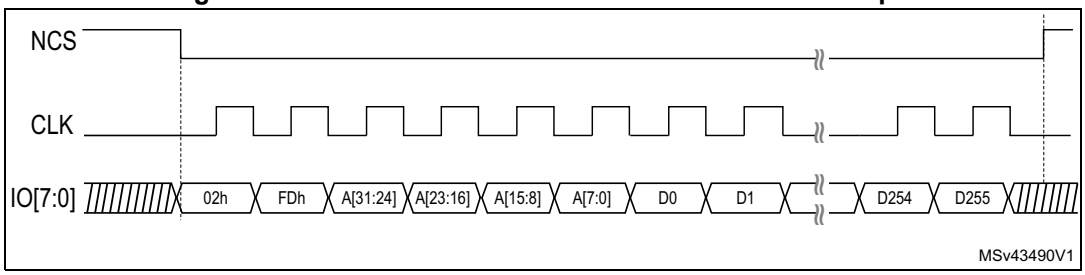
Single-data rate (SDR) mode

By default, all the phases operate in single-data rate (SDR) mode.

In SDR mode, when the OCTOSPI drives the IO0/SO, IO1 to IO7 signals, these signals transition only with the falling edge of CLK.

When receiving data in SDR mode, the OCTOSPI assumes that the external devices also send the data using CLK falling edge. By default (when SSHIFT = 0 in OCTOSPI_TCR), the signals are sampled using the following (rising) edge of CLK.

Figure 146. SDR write command in octo-SPI mode example



Note: Due to internal synchronization, up to six extra dummy clock cycles may be generated by the Octo-SPI interface after the last data is read.

Double-transfer rate (DTR) mode

Each of the instruction, address, alternate-byte and data phases can be configured to operate in DTR mode setting IDTR, ADDTR, ABDTR, and DDTR in OCTOSPI_CCR.

In Memory-mapped mode, the DTR mode for each phase of the write operations is specified in OCTOSPI_WCCR. The DTR mode for each phase of the read operations is specified in OCTOSPI_CCR.

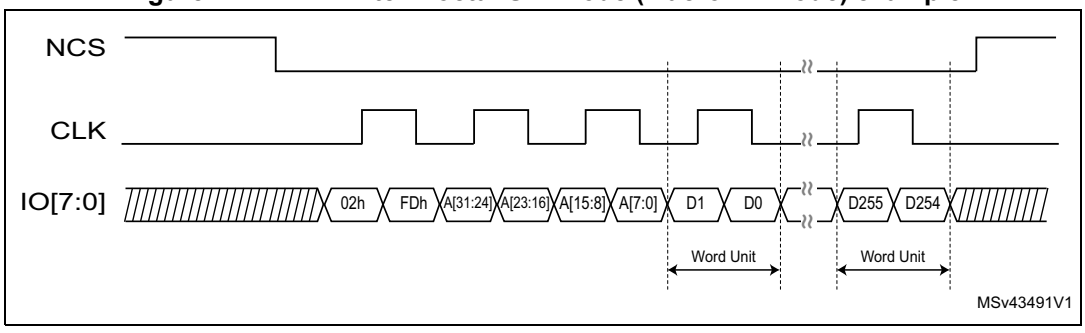
In DTR mode, when the OCTOSPI drives the IO0/SO and IO1to IO7 signals in the instruction, address, and alternate-byte phases, a bit is sent or received on each of the falling and rising edges of CLK.

When receiving data in DTR mode, the OCTOSPI assumes that the external devices also send the data using both CLK rising and falling edges. When DDTR = 1 in OCTOSPI_CCR, the software must clear SSHIFT in OCTOSPI_TCR. Thus, the signals are sampled one half of a CLK cycle later (on the following, opposite edge).

In DTR mode, it is recommended to set DHQC of OCTOSPI_TCR, to shift the outputs by a quarter of cycle and avoid to hold issues on the memory side.

Note: DHQC must not be set when the prescaler value is 0, as this action leads to unpredictable behavior.

Figure 147. DTR write in octal-SPI mode (Macronix mode) example



Note: Due to internal synchronization, up to six extra dummy clock cycles may be generated by the Octo-SPI interface after the last data is read.

Dual-quad configuration

When DMM = 1 in OCTOSPI_CR, the OCTOSPI is in dual-memory configuration: if DMODE = 100,two external Quad-SPI devices (device A and device B) are used in order to

send/receive eight bits (or 16 bits in DTR mode) every cycle, effectively doubling the throughput.

Each device (A or B) uses the same CLK and NCS signals, but each has separate IO0 to IO3 signals.

The dual-quad configuration can be used in conjunction with the single-SPI, dual-SPI, and quad-SPI modes, as well as with either the SDR or DTR mode.

The device size, as specified in DEVSIZE[4:0] of OCTOSPI_DCR1, must reflect the total external device capacity, that is the double of the size of one individual component.

If address X is even, then the byte that the OCTOSPI gives for address X is the byte at the address X/2 of device A, and the byte that the OCTOSPI gives for address X + 1 is the byte at the address X/2 of device B. In other words, the bytes at even addresses are all stored in device A and the bytes at odd addresses are all stored in device B.

When reading the status registers of the devices in dual-quad configuration, twice as many bytes must be read compared to the same read in Regular-command protocol: if each device gives eight valid bits after the instruction for fetching the status register, then the OCTOSPI must be configured with a data length of 2 bytes (16 bits), and the OCTOSPI receives one byte from each device.

If each device gives a status of 16 bits, then the OCTOSPI must be configured to read 4 bytes to get all the status bits of both devices in dual-quad configuration. The least-significant byte of the result (in the data register) is the least-significant byte of device A status register. The next byte is the least-significant byte of device B status register. Then, the third byte of the data register is the device A second byte. The forth byte is the device B second byte (if devices have 16-bit status registers).

An even number of bytes must always be accessed in dual-quad configuration. For this reason, bit 0 of DL[31:0] in OCTOSPI_DLR is stuck at 1 when DMM = 1.

In dual-quad configuration, the behavior of device A interface signals is basically the same as in normal mode. Device B interface signals have exactly the same waveforms as device A ones during the instruction, address, alternate-byte, and dummy-cycle phases. In other words, each device always receives the same instruction and the same address.

Then, during the data phase, the AIOx and the BIOx buses both transfer data in parallel, but the data that is sent to (or received from) device A is distinct than the one from device B.

25.4.5 HyperBus protocol

The OCTOSPI can communicate with the external device using the HyperBus protocol.

The HyperBus uses 11 to 12 pins depending on the operating voltage:

- IO[7:0] as bidirectional data bus
- RWDS for read and write data strobe and latency insertion (mapped on DQS pin)
- NCS
- CLK
- NCLK for 1.8 V operations (to support this mode, the device must be powered with 1.8 V)

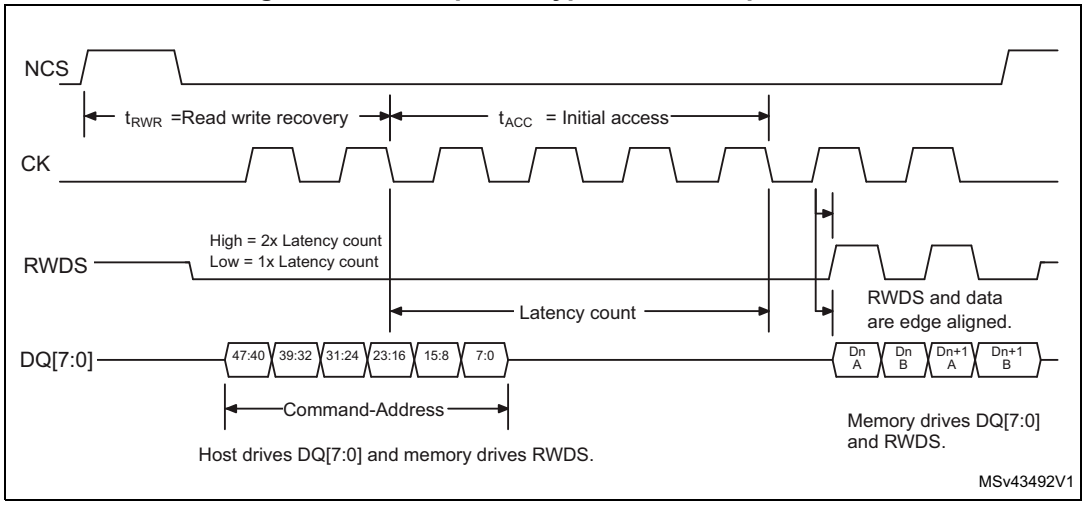
The HyperBus does not require any command specification nor any alternate bytes. As a consequence, a separate register set is used to define the timing of the transaction.

The HyperBus frame is composed of the following phases:

- Command/address phase
- Data phase

The NCS falls before the start of a transaction and rises again after each transaction finishes.

Figure 148. Example of HyperBus read operation



Note: Due to internal synchronization, up to six extra dummy clock cycles may be generated by the Octo-SPI interface after the last data is read.

The specific HyperBus features are configured through the registers in the 0x0200-0x02FC offset range.

Command/address phase

During this initial phase, the OCTOSPI sends 48 bits over IO[7:0] to specify the operations to be performed with the external device.

Table 210. Command/address phase description

CA bit	Bit name	Description
47	R/W#	Identifies the transaction as a read or a write.
46	Address space	Indicates if the transaction accesses the memory or the register space.
45	Burst type	Indicates if the burst is linear or wrapped.
44-16	Row and upper column address	Selects the row and the upper column addresses.
15-3	Reserved	-
2-0	Lower column address	Selects the starting 16-bit word within the half page.

The address space is configured through the memory type MTYP[2:0] of OCTOSPI_DCR1.

The total size of the device is configured in DEVSIZE[4:0] of OCTOSPI_DCR1. In case of multi-chip product (MCP), the device size is the sum of all the sizes of all the MCP dies.

Read/write operation with initial latency

The HyperBus read and write operations need to respect two timings:

- t_{RWR}: minimal read/write recovery time for the device (defined in TRWR[7:0] of OCTOSPI_HLCR)
- t_{ACC}: access time for the device (defined in TAC[7:0] of OCTOSPI_HLCR)

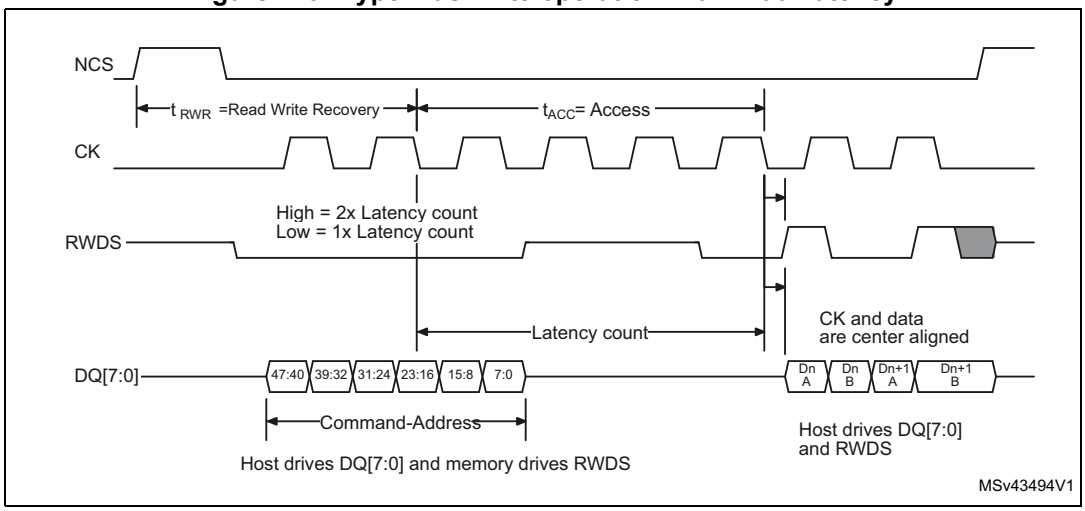
During the read operation, the RWDS is used by the device, in two ways (see *Figure 148*):

- during the command/address phase, to request an additional latency
- during the data phase, for data strobing

During the write operation the RWDS is used:

- by the device, during the command/address phase, to request an additional latency.
- by the OCTOSPI, during the data phase, for write data masking.

Figure 149. HyperBus write operation with initial latency



Read/write operation with additional latency

If the device needs an additional latency (during refresh period of a SDRAM for example), RWDS must be tied to one during one of the RWDS signals, during the command/address phase.

An additional t_{ACC} duration is added by the OCTOSPI to meet the device request.

Figure 150. HyperBus read operation with additional latency

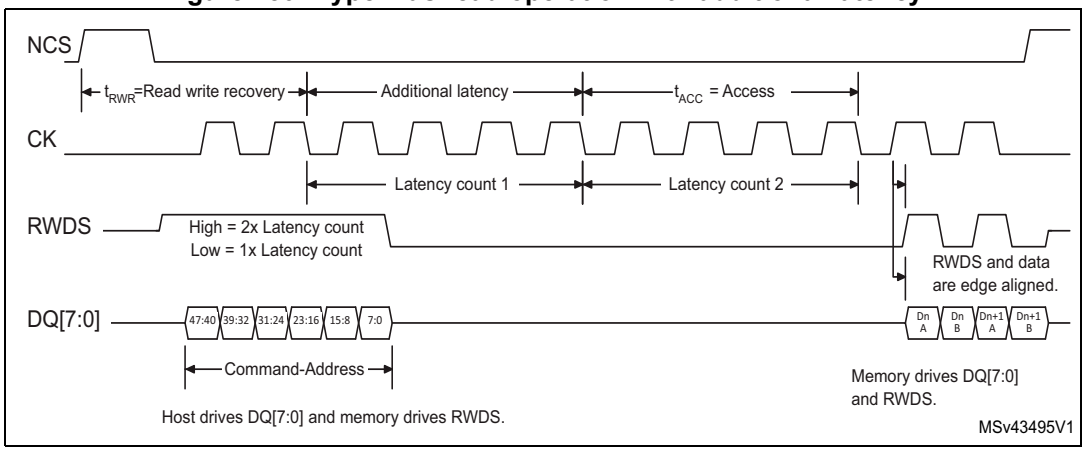
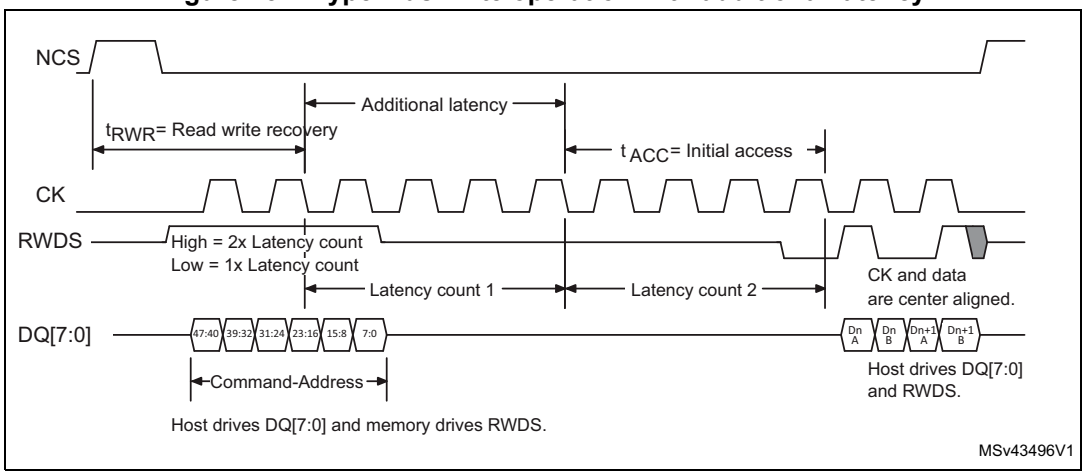


Figure 151. HyperBus write operation with additional latency



Fixed-latency mode

Some devices or some applications may not want to operate with a variable latency time as described above.

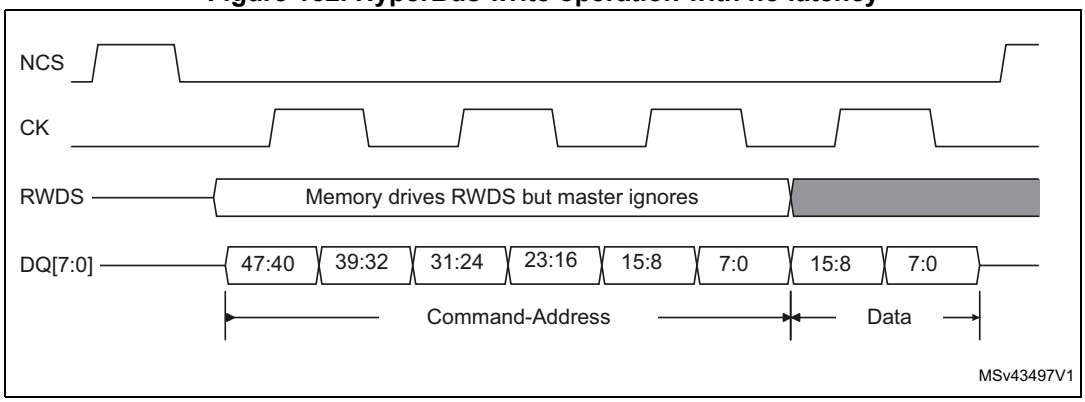
The latency can be forced to 2 x t_{ACC} by setting LM of OCTOSPI_HLCR.

In this OCTOSPI latency mode, the state of the RWDS signal is not taken into account by the OCTOSPI and an additional latency is always added, leading to a fixed 2 x t_{ACC} latency time.

Write operation with no latency

Some devices can also require a zero latency for the write operations. This write-zero latency can be forced by setting WZL in OCTOSPI_HLCR.

Figure 152. HyperBus write operation with no latency

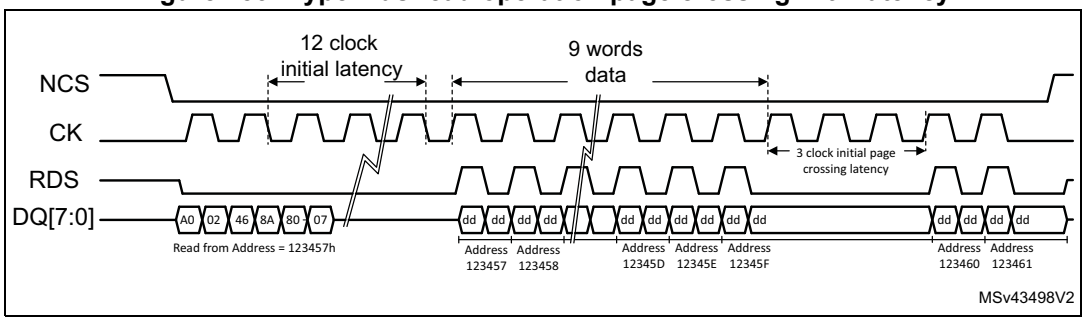


Latency on page-crossing during the read operations

An additional latency can be needed by some devices for the read operation when crossing pages.

The initial latency must be respected for any page access, as a consequence, when the first access is close to the page boundary, a latency is automatically added at the page crossing to respect the t_{ACC} time.

Figure 153. HyperBus read operation page crossing with latency



25.4.6 Specific features

The OCTOSPI supports some specific features, such as:

- Wrap support
- NCS boundary and refresh
- Communication regulation

Wrap support

The OCTOSPI supports an hybrid wrap as defined by the HyperBus protocol. An hybrid wrap is also supported in the Regular-command protocol.

In hybrid wrap, the transaction can continue after the initial wrap with an incremental access.

The wrap size supported by the target memory is configured by WRAPSIZE in OCTOSPI_DCR2.

Wrap is supported only in memory-read direction and only for data size = 8 bytes. Wrapped reads are supported for both HyperBus and Regular-command protocols. To enable wrapped-read accesses, the dedicated registers OCTOSPI_WPxxx must be programmed according to the wrapped-read access characteristics. The dedicated OCTOSPI_WPxxx registers apply for both HyperBus and Regular-command protocols.

If the target memory is not supporting the hybrid wrap, WRAPSIZE must be set to 0.

NCS boundary and refresh

Two processes can be activated to regulate the OCTOSPI transactions:

- NCS boundary
- Refresh

The NCS boundary feature limits a transaction to a boundary of aligned addresses. The size of the address to be aligned with, is configured in CSBOUND[4:0] of OCTOSPI_DCR3 and it is equal to $2^{CSBOUND}$.

As an example, if CSBOUND(4:0] = 0x4, the boundary is set to 2^4 = 16 bytes. As a consequence, the NCS is released each time that the LSB address is equal to 0xF and each time that a new transaction is issued to address the next data.

If CSBOUND[4:0] = 0, the feature is disabled and a minimum value of 3 is recommended.

The NCS boundary feature cannot be used for Flash memory devices in write mode since a command is necessary to program another page of the Flash memory.

The refresh feature limits the duration of the transactions to the value programmed in REFRESH[31:0] of OCTOSPI_DCR4. The duration is expressed in number of cycles. This allows an external RAM to perform its internal refresh operation regularly.

The refresh value must be greater than the minimal transaction size in terms of number of cycles including the command/address/alternate/dummy phases.

If NCS boundary and refresh are enabled at the same time, the NCS is released on the first condition met.

Communication regulation

The communication regulation feature limits the maximum length of a transaction to the value programmed in MAXTRAN[7:0] of OCTOSPI_DCR3.

If the number of clock cycles reach the MAXTRAN + 1 value, and if the second OCTOSPI requests an access, the NCS is released and a new transaction is issued to address the next data. If the second OCTOSPI does not request an access, the transaction is not stopped and the NCS is not released.

If MAXTRAN[7:0] = 0, no limitation occurs.

The MAXTRAN[7:0] value must be greater than the minimal transaction size in terms of number of cycles including the command, address, alternate, and dummy phases.

Note: The communication regulation feature cannot be used in write mode for the Flash memory devices that require extra command to re-enable the write operation after the NCS is active again.

If NCS boundary, refresh and communication regulation are enabled at the same time, the NCS is released on the first condition met.

Re-starting after an interrupted transfer

When a read or write operation is interrupted by a timeout or communication regulation feature, the Octo-SPI interface, as soon as possible after getting back the port ownership, re-issues the initial command sequence together with the address following the last address actually accessed before interruption. The transfer initially set goes on and ends seamlessly.

25.4.7 OCTOSPI operating modes introduction

The OCTOSPI has the following operating modes regardless of the low-level protocol used (either Regular-command or HyperBus):

- Indirect mode (read or write)
- Automatic status-polling mode
- Memory-mapped mode

25.4.8 OCTOSPI Indirect mode

In Indirect mode, the commands are started by writing to the OCTOSPI registers and the data is transferred by writing or reading the data register, in a similar way to other communication peripherals.

When FMODE[1:0] = 0 in OCTOSPI_CR, the OCTOSPI is in Indirect-write mode: bytes are sent to the external device during the data phase. Data is provided by writing to OCTOSPI_DR.

When FMODE[1:0] = 01, the OCTOSPI is in Indirect-read mode: bytes are received from the external device during the data phase. Data is recovered by reading OCTOSPI_DR.

In Indirect mode, when the OCTOSPI is configured in DTR mode over eight lanes with DQS disabled, the given starting address and the data length must be even.

Note: The OCTOSPI_AR register must be updated even if the start address is the same as the start address of the previous indirect access

The number of bytes to be read/written is specified in OCTOSPI_DLR:

- If DL[31:0] = 0xFFFF FFFF, the data length is considered undefined and the OCTOSPI simply continues to transfer data until it reaches the end of the external device (as defined by DEVSIZE). If no bytes are to be transferred, DMODE[2:0] must be set to 0 in OCTOSPI_CCR.
- If DL[31:0] = 0xFFFF FFFFF and DEVSIZE[4:0] = 0x1F (its maximum value indicating at 4-Gbyte device), the transfers continue indefinitely, stopping only after an abort request or after the OCTOSPI is disabled. After the last memory address is read (at address 0xFFFF FFFF), reading continues with address = 0x0000 0000.

When the programmed number of bytes to be transmitted or received is reached, TCF bit is set in OCTOSPI_SR and an interrupt is generated if TCIE = 1 in OCTOSPI_CR. In the case of an undefined number of data, TCF is set when the limit of the external SPI memory is reached, according to the device size defined in OCTOSPI_DCR1.

Triggering the start of a transfer in Regular-command protocol

Depending on the OCTOSPI configuration, there are three different ways to trigger the start of a transfer in Indirect mode when using Regular-command protocol. In general, the start of transfer is triggered as soon as the software gives the last information that is necessary for the command. More specifically in Indirect mode, a transfer starts when one of the following sequence of events occurs:

- if no address is necessary (ADMODE[2:0] = 000) and if no data needs to be provided by the software (FMODE[1:0] = 01 or DMODE[2:0] = 000), and at the moment when a write is performed to INSTRUCTION[31:0] in OCTOSPI_IR
- if an address is necessary (when ADMODE[2:0] ≠ 000) and if no data needs to be provided by the software (when FMODE[1:0] = 01 or DMODE[2:0] = 000), and at the moment when a write is performed to ADDRESS[31:0] in OCTOSPI_AR
- if an address is necessary (when ADMODE[2:0] ≠ 000) and if data needs to be provided by the software (when FMODE[1:0] = 00 and DMODE[2:0] ≠ 000), and at the moment when a write is performed to DATA[31:0] in OCTOSPI_DR

A write to OCTOSPI_ABR never triggers the communication start. If alternate bytes are required, they must have been programmed before.

As soon as a command is started, the BUSY bit is automatically set in OCTOSPI_SR.

Triggering the start of a transfer in HyperBus protocol

Depending on the OCTOSPI configuration, there are different ways to trigger the start of a command in Indirect mode. In general, it is triggered as soon as the firmware gives the last information that is necessary for the transfer to start, and more specifically, a communication in Indirect mode is triggered by one of the following register settings, when it is the last one to be executed:

- when a write is performed to ADDRESS[31:0] (OCTOSPI_AR) in Indirect-read mode (when FMODE = 01).
- when a write is performed to DATA[31:0] (OCTOSPI_DR) in Indirect-write mode (when FMODE = 00).
- when a write is performed to INSTRUCTION[31:0] (OCTOSPI_IR) for both Indirect read and write modes

Note: In case of HyperBus, a (dummy) write to OCTOSPI_IR is required to trigger the transfer, as for Regular-command protocol.

As soon as a transfer is started, the BUSY bit (OCTOSPI_SR[5]) is automatically set.

FIFO and data management

Data in Indirect mode passes through a 32-byte FIFO that is internal to the OCTOSPI. FLEVEL in OCTOSPI_SR indicates how many bytes are currently being held in the FIFO.

In Indirect-write mode (FMODE[1:0] = 00), the software adds data to the FIFO when it writes in OCTOSPI_DR. A word write adds 4 bytes to the FIFO, a half-word write adds 2 bytes, and a byte write adds only 1 byte. If the software adds too many bytes to the FIFO (more than indicated in DL[31:0]), the extra bytes are flushed from the FIFO at the end of the write operation (when TCF is set).

The byte/half-word accesses to OCTOSPI_DR must be done only to the least significant byte/halfword of the 32-bit register.

FTHRES is used to define a FIFO threshold after which point the FIFO threshold flag, FTF, gets set. In Indirect-read mode, FTF is set when the number of valid bytes to be read from the FIFO is above the threshold. FTF is also set if there is any data left in the FIFO after the last byte is read from the external device, regardless of FTHRES setting. In Indirect-write mode, the FTF is set when the number of empty bytes in the FIFO is above the threshold.

If FTIE = 1, there is an interrupt when the FTF is set. If DMAEN = 1, a DMA transfer is initiated when the FTF is set. The FTF is cleared by hardware as soon as the threshold condition is no longer true (after enough data has been transferred by the CPU or DMA).

The last data read in RX FIFO remains valid as long as there is no request for the next line. This means that, when the application reads several times in a row at the same location, the data is provided from the RX FIFO and not read again from the distant memory.

25.4.9 OCTOSPI Automatic status-polling mode

In Automatic status-polling mode, the OCTOSPI periodically starts a command to read a defined number of status bytes (up to four). The received bytes can be masked to isolate some status bits and an interrupt can be generated when the selected bits have a defined value.

The access to the device begins in the same manner as in Indirect-read mode. BUSY in OCTOSPI_SR goes high at this point and stays high even between the periodic accesses.

The content of MASK[31:0] in OCTOSPI_PSMAR is used to mask the data from the external device in Automatic status-polling mode:

- If the MASK[n] = 0, then bit n of the result is masked and not considered.
- If MASK[n] = 1, and the content of bit[n] is the same as MATCH[n] in OCTOSPI_PSMAR, then there is a match for bit n.

If PMM = 0 in OCTOSPI_CR, the AND-match mode is activated: SMF is set in OCTOSPI_SR only when there is a match on all of the unmasked bits.

If PMM = 1 in OCTOSPI_CR, the OR-match mode is activated: SMF gets set if there is a match on any of the unmasked bits.

An interrupt is called when SMF = 1 if SMIE = 1.

If APMS is set in OCTOSPI_CR, the operation stops and BUSY goes to 0 as soon as a match is detected. Otherwise, BUSY stays at 1 and the periodic accesses continue until there is an abort or until the OCTOSPI is disabled (EN = 0).

OCTOSPI_DR contains the latest received status bytes (FIFO deactivated). The content of this register is not affected by the masking used in the matching logic. FTF in OCTOSPI_SR is set as soon as a new reading of the status is complete. FTF is cleared as soon as the data is read.

In Automatic status-polling mode, variable latency is not supported. As a consequence, the memory must be configured in fixed latency.

25.4.10 OCTOSPI Memory-mapped mode

When configured in Memory-mapped mode, the external SPI device is seen as an internal memory.

Note: No more than 256 Mbytes can be addressed even if the external device capacity is larger.

If an access is made to an address outside of the range defined by DEVSIZE[4:0] but still within the 256 Mbytes range, then an AXI error is given. The effect of this error depends on the AXI master that attempted the access:

- If it is the Cortex CPU, a hard-fault interrupt is generated.
- If it is a DMA, a DMA transfer error is generated and the corresponding DMA channel is automatically disabled.

Byte, half-word, and word access types are all supported.

A support for execute in place (XIP) operation is implemented, where the OCTOSPI continues to load the bytes to the addresses following the most recent access. If subsequent accesses are continuous to the bytes that follow, then these operations ends up quickly since their results were pre-fetched.

By default, the OCTOSPI never stops its prefetch operation, it either keeps the previous read operation active with the NCS maintained low or it relaunches a new transfer, even if no access to the external device occurs for a long time.

Since external devices tend to consume more when the NCS is held low, the application may want to activate the timeout counter (TCEN = 1 in OCTOSPI_CR): the NCS is released after a period defined by TIMEOUT[15:0] in OCTOSPI_LPTR, when x cycles have elapsed without an access since the clock is inactive.

BUSY goes high as soon as the first memory-mapped access occurs. Because of the prefetch operations, BUSY does not fall until there is an abort, or the peripheral is disabled.

25.4.11 OCTOSPI configuration introduction

The OCTOSPI configuration is done in three steps:

1. OCTOSPI system configuration
2. OCTOSPI device configuration
3. OCTOSPI mode configuration

25.4.12 OCTOSPI system configuration

The OCTOSPI is configured using OCTOSPI_CR. The user must program:

- Functional mode with FMODE[1:0]
- Automatic status-polling mode behavior if needed with PMM and APMS
- FIFO level with FTHRES
- DMA usage with DMAEN
- Timeout counter usage with TCEN
- Dual-quad configuration, if needed, with DMM (only for quad-SPI mode)

In case of an interrupt usage, the respective enable bit can also be set during this phase.

If the timeout counter is used, the timeout value is programmed in OCTOSPI_LPTR.

The DMA channel must not be enabled during the OCTOSPI configuration: it must be enabled only when the operation is fully configured, to avoid any unexpected request generation.

The DMA and OCTOSPI must be configured in a coherent manner regarding data length: FTHRES value must reflect the DMA burst size.

25.4.13 OCTOSPI device configuration

The parameters related to the external device targeted are configured through OCTOSPI_DCR1 and OCTOSPI_DCR2.The user must program:

- Device size with DEVSIZE[4:0]
- Chip-select minimum high time with CSHT[5:0]
- Clock mode with FRCK and CKMODE
- Device frequency with PRESCALER[7:0]

MTYP[2:0] defines the memory type to be used for 8-line modes:

- Micron mode with D0/D1 ordering in 8-data-bit mode (DMODE[2:0] = 100)
- Macronix mode with D1/D0 ordering in 8-data-bit mode (DMODE[2:0] = 100)
- HyperBus memory mode: the protocol follows the HyperBus specification, and an 8-data-bit DTR mode must be selected.
- HyperBus register mode, addressing register space: the memory-mapped accesses in this mode must be non-cacheable, or the Indirect read/write modes must be used.

DEVSIZE[4:0] defines the size of external memory using the following formula:

$$\text{Number of bytes in the device} = 2^{[\text{DEVSIZE}+1]}$$

where DEVSIZE+1 is the number of address bits required to address the external device. The external device capacity can go up to 4 Gbytes (addressed using 32 bits) in Indirect mode, but the addressable space in Memory-mapped mode is limited to 256 Mbytes.

If DMM = 1, DEVSIZE[4:0] indicates the total capacity of the two devices together.

When the OCTOSPI executes two commands, one immediately after the other, it raises the chip-select signal (NCS) high between the two commands for only one CLK cycle by default.

If the external device requires more time between commands, the chip-select high time CSHT[5:0] can be used to specify the minimum number of CLK cycles for which the NCS must remain high.

CKMODE indicates the level that the CLK takes between commands (when NCS = 1).

In HyperBus protocol, the device timing (t_{ACC} and t_{RWR}) and the Latency mode must be configured in OCTOSPI_HLCR.

25.4.14 OCTOSPI Regular-command mode configuration

Indirect mode configuration

When FMODE[1:0] = 00, the Indirect-write mode is selected and data can be sent to the external device. When FMODE[1:0] = 01, the Indirect-read mode is selected and data can be read from the external device.

When the OCTOSPI is used in Indirect mode, the frames are constructed in the following way:

1. Specify a number of data bytes to read or write in OCTOSPI_DLR.
2. Specify the frame timing in OCTOSPI_TCR.
3. Specify the frame format in OCTOSPI_CCR.
4. Specify the instruction in OCTOSPI_IR.
5. Specify the optional alternate byte to be sent right after the address phase in OCTOSPI_ABR.
6. Specify the targeted address in OCTOSPI_AR.
7. Enable the DMA channel if needed.
8. Read/write the data from/to the FIFO through OCTOSPI_DR (if no DMA usage).

If neither the address register (OCTOSPI_AR) nor the data register (OCTOSPI_DR) need to be updated for a particular command, then the command sequence starts as soon as OCTOSPI_IR is written. This is the case when both ADMODE[2:0] and DMODE[2:0] equal 000, or if just ADMODE[2:0] = 000 when in Indirect-read mode (FMODE[1:0] = 01).

When an address is required (ADMODE[2:0] ≠ 000) and the data register does not need to be written (FMODE[1:0] = 01 or DMODE[2:0] = 000), the command sequence starts as soon as the address is updated with a write to OCTOSPI_AR.

In case of data transmission (FMODE[1:0] = 00 and DMODE[2:0] ≠ 000), the communication start is triggered by a write in the FIFO through OCTOSPI_DR.

Automatic status-polling mode configuration

The Automatic status-polling mode is enabled by setting FMODE[1:0] = 10. In this mode, the programmed frame is sent and the data is retrieved periodically.

The maximum amount of data read in each frame is 4 bytes. If more data is requested in OCTOSPI_DLR, it is ignored and only 4 bytes are read.The periodicity is specified in OCTOSPI_PIR.

Once the status data has been retrieved, the following can be processed:

- Set SMF (an interrupt is generated if enabled).
- Stop automatically the periodic retrieving of the status bytes.

The received value can be masked with the value stored in OCTOSPI_PSMKR, and can be ORed or ANDed with the value stored in OCTOSPI_PSMAR.

In case of a match, SMF is set and an interrupt is generated if enabled; The OCTOSPI can be automatically stopped if AMPS is set. In any case, the latest retrieved value is available in OCTOSPI_DR.

When the OCTOSPI is used in Automatic status-polling mode, the frames are constructed in the following way:

1. Specify the input mask in OCTOSPI_PSMKR.
2. Specify the comparison value in OCTOSPI_PSMAR.
3. Specify the read period in OCTOSPI_PIR.
4. Specify a number of data bytes to read in OCTOSPI_DLR.
5. Specify the frame timing in OCTOSPI_TCR.
6. Specify the frame format in OCTOSPI_CCR.
7. Specify the instruction in OCTOSPI_IR.
8. Specify the optional alternate byte to be sent right after the address phase in OCTOSPI_ABR.
9. Specify the optional targeted address in OCTOSPI_AR.

If the address register (OCTOSPI_AR) does not need to be updated for a particular command, then the command sequence starts as soon as OCTOSPI_CCR is written. This is the case when ADMODE[2:0] = 000.

When an address is required (ADMODE[2:0] ≠ 000), the command sequence starts as soon as the address is updated with a write to OCTOSPI_AR.

Memory-mapped mode configuration

In Memory-mapped mode, the external device is seen as an internal memory but with some latency during accesses. Read and write operations are allowed to the external device in this mode.

It is not recommended to program the Flash memory using memory-mapped writes, as the internal flags for erase or programming status have to be polled.

Memory-mapped mode is entered by setting FMODE[1:0] = 11 in OCTOSPI_CR.

The programmed instruction and frame are sent when an AXI master accesses the memory mapped space.

The FIFO is used as a prefetch buffer to anticipate any linear reads. Any access to OCTOSPI_DR in this mode returns zero.

The data length register (OCTOSPI_DLR) has no meaning in Memory-mapped mode.

When the OCTOSPI is used in Memory-mapped mode, the frames are constructed in the following way:

1. Specify the frame timing in OCTOSPI_TCR for read operation.
2. Specify the frame format in OCTOSPI_CCR for read operation.
3. Specify the instruction in OCTOSPI_IR.
4. Specify the optional alternate byte to be sent right after the address phase in OCTOSPI_ABR for read operation.
5. Specify the frame timing in OCTOSPI_WTCR for write operation.
6. Specify the frame format in OCTOSPI_WCCR for write operation.
7. Specify the instruction in OCTOSPI_WIR.
8. Specify the optional alternate byte to be sent right after the address phase in OCTOSPI_WABR for read operation.

All the configuration operations must be completed (ensured by checking BUSY = 0) before the first access to the memory area: any register write operation when BUSY = 1 have no effect and is not signaled with an error response. On the first access, the OCTOSPI becomes busy, and no further configuration is allowed.

OCTOSPI delayed data sampling when no DQS is used

By default, when no DQS is used, the OCTOSPI samples the data driven by the external device one half of a CLK cycle after the external device drives the signal.

In case of any external signal delays, it may be useful to sample the data later. Using SSHIFT in OCTOSPI_TCR, the sampling of the data can be shifted by half of a CLK cycle.

The firmware must clear SSHIFT when the data phase is configured in DTR mode (DDTR = 1).

OCTOSPI delayed data sampling when DQS is used

When external DQS is used as a sampling clock, it can be shifted in time to compensate the data propagation delay. This shift is performed by an external delay block located outside the OCTOSPI. The control of this feature depends on the device implementation (see the product reference manual for more details).

In configurations where delay does not need to be compensated, the external delay block can be bypassed by setting DLYBYP in OCTOSPI_DCR1.

Sending the instruction only once (SIOO)

A Flash memory can provide a mode where an instruction must be sent only with the first command sequence, while subsequent commands start directly with the address. The user can take advantage of this type of features using SIOO in OCTOSPI_CCR.

SIOO is valid for Memory-mapped mode only. If this bit is set, the instruction is sent only for the first command following a write to OCTOSPI_CCR.

Subsequent command sequences skip the instruction phase, until there is a write to OCTOSPI_CCR. SIOO has no effect when IMODE[1:0] = 00 (no instruction).

SIOO mode is not supported when any of the communication regulation, NCS boundary or refresh features are used.

25.4.15 OCTOSPI HyperBus protocol configuration

Indirect mode configuration

When FMODE[1:0] = 00, the Indirect-write mode is selected and data can be sent to the external device. When FMODE[1:0] = 01, the Indirect-read mode is selected where data can be read from the external device.

When the OCTOSPI is used in Indirect mode, the frames are constructed in the following way:

1. Specify a number of data bytes to read or write in OCTOSPI_DLR.
2. Specify the targeted address in OCTOSPI_AR.
3. Make a write operation in OCTOSPI_IR and enable the DMA channel if needed.
4. Read/write the data from/to the FIFO through OCTOSPI_DR (if no DMA usage).

In Indirect-read mode, the command sequence starts as soon as the address is updated with a write to OCTOSPI_AR.

In Indirect-write mode, the communication start is triggered by a write in the FIFO through OCTOSPI_DR.

Automatic status-polling mode configuration

The Automatic status-polling mode is enabled setting FMODE[1:0] = 10. In this mode, the programmed frame is sent and the data is retrieved periodically.

The maximum amount of data read in each frame is 4 bytes. If more data is requested in OCTOSPI_DLR, it is ignored and only 4 bytes are read. The periodicity is specified in OCTOSPI_PIR.

Once the status data has been retrieved, it can be internally processed to:

- Set SMF (an interrupt is generated if enabled).
- Stop automatically the periodic retrieving of the status bytes.

The received value can be masked with the value stored in OCTOSPI_PSMKR and can be ORed or ANDed with the value stored in OCTOSPI_PSMAR.

In case of a match, SMF is set and an interrupt is generated if enabled. The OCTOSPI can be automatically stopped if AMPS is set.

In any case, the latest retrieved value is available in OCTOSPI_DR.

When the OCTOSPI is used in Automatic status-polling mode, the frames are constructed in the following way:

1. Specify the input mask in OCTOSPI_PSMKR.
2. Specify the comparison value in OCTOSPI_PSMAR.
3. Specify the read period in OCTOSPI_PIR.
4. Specify a number of data bytes to read in OCTOSPI_DLR.
5. Specify the targeted address in OCTOSPI_AR.

The command sequence starts as soon as the address is updated with a write to OCTOSPI_AR.

Memory-mapped mode configuration

In Memory-mapped mode, the external device is seen as an internal memory but with some latency during the accesses. Read and write operations are allowed to the external device in this mode.

The Memory-mapped mode is entered by setting FMODE[1:0] = 11. The programmed instruction and frame is sent when an AXI master accesses the memory mapped space.

The FIFO is used as a prefetch buffer to anticipate any linear reads. Any access to OCTOSPI_DR in this mode returns zero.

The data length register (OCTOSPI_DLR) has no meaning in Memory-mapped mode.

All the configuration operation must be completed prior to the first access to the memory area. On the first access, the OCTOSPI becomes busy, and no configuration is allowed.

25.4.16 OCTOSPI error management

A error can be generated in the following cases:

- in Indirect or Automatic status-polling mode, when a wrong address has been programmed in OCTOSPI_AR (according to the device size defined by DEVSIZE[4:0]). This sets TEF and an interrupt is generated if enabled.
- in Indirect mode, if the address plus the data length exceed the device size. TEF is set as soon as the access is triggered.
- in Memory-mapped mode when an out-of-range access is done by an AXI master. This generates an AXI error as a response to the faulty AXI request.
- when the Memory-mapped mode is disabled. An access to the memory-mapped area generates an AXI error as a response to the faulty AXI request.

The OCTOSPI generates an AXI slave error in the following situations:

- Memory-mapped mode is disabled and an AXI read request occurs.
- Read or write address exceeds the size of the external memory.
- Abort is received while a read or write burst is ongoing.
- OCTOSPI is disabled while a read or write burst is ongoing.
- Write wrap burst is received.
- Write request is received while DQSE = 0 in OCTOSPI_WCCR, which means that the DQS output is disabled.
- Write request is received while DMODE[2:0] = 000 (no data phase), except when MTYP[2:0] is HyperBus.
- Illegal access size when wrap read burst. This means the ARSIZE is different from 8 bytes (only for Memory-mapped mode).
- Illegal wrap size when receiving read wrap burst with size different from 8 bytes (only for Memory-mapped mode).

25.4.17 OCTOSPI BUSY and ABORT

Once the OCTOSPI starts an operation with the external device, BUSY is automatically set in OCTOSPI_SR.

In Indirect mode, BUSY is reset once the OCTOSPI has completed the requested command sequence and the FIFO is empty.

In Automatic status-polling mode, BUSY goes low only after the last periodic access is complete, due to a match when APMS = 1 or due to an abort.

After the first access in Memory-mapped mode, BUSY goes low only on an abort.

Any operation can be aborted by setting ABORT in OCTOSPI_CR. Once the abort is completed, BUSY and ABORT are automatically reset, and the FIFO is flushed.

Before setting ABORT, the software must ensure that all the current transactions are finished using the synchronization barriers.

Note: Some devices may misbehave if a write operation to a status register is aborted.

25.4.18 OCTOSPI reconfiguration or deactivation

Prior to any OCTOSPI reconfiguration, the software must ensure that all the transactions are completed:

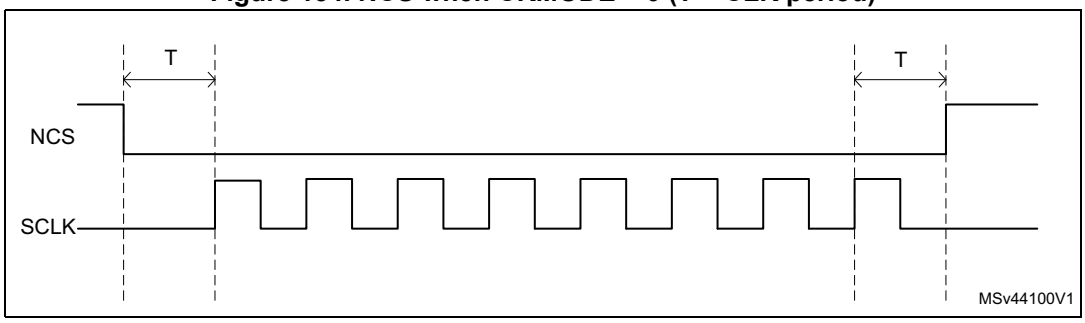
- After a Memory-mapped write, the software must perform a dummy read followed by a synchronization barrier, then an abort.
- After a Memory-mapped read, the software must perform a synchronization barrier then an abort.

25.4.19 NCS behavior

By default, NCS is high, deselecting the external device. NCS falls before an operation begins and rises as soon as it finishes.

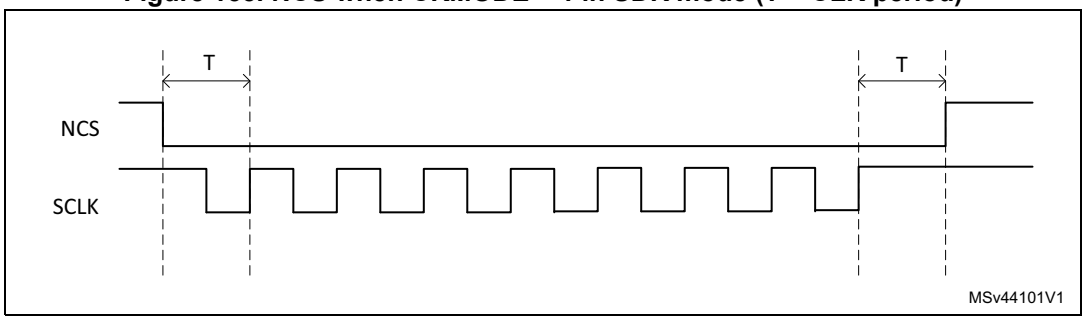
When CKMODE = 0 (clock mode 0: CLK stays low when no operation is in progress), NCS falls one CLK cycle before an operation first rising CLK edge, and NCS rises one CLK cycle after the operation final rising CLK edge (see the figure below).

Figure 154. NCS when CKMODE = 0 (T = CLK period)



When CKMODE = 1 (clock mode 3: CLK goes high when no operation is in progress) and when in SDR mode, NCS falls one CLK cycle before an operation first rising CLK edge, and NCS rises one CLK cycle after the operation final rising CLK edge (see the figure below).

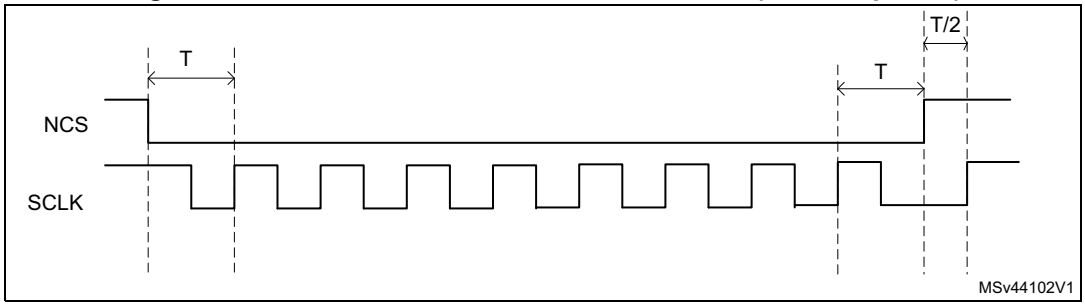
Figure 155. NCS when CKMODE = 1 in SDR mode (T = CLK period)



When the CKMODE = 1 (clock mode 3) and DDTR = 1 (data DTR mode), NCS falls one CLK cycle before an operation first rising CLK edge, and NCS rises one CLK cycle after the operation final active rising CLK edge (see the figure below). Because the DTR operations

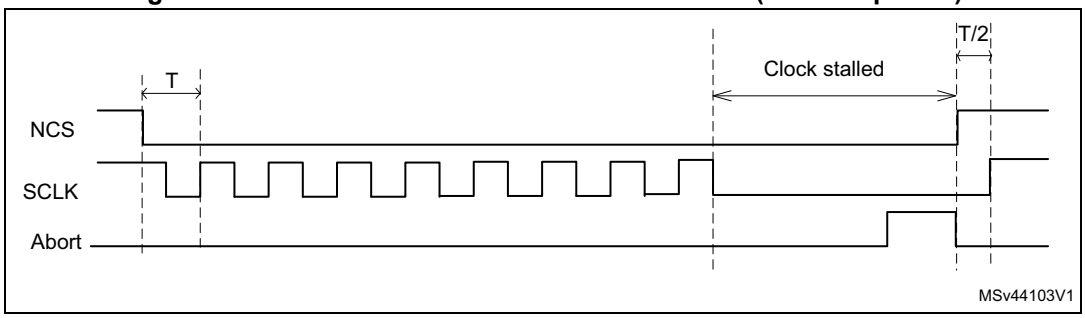
must finish with a falling edge, CLK is low when NCS rises, and CLK rises back up one half of a CLK cycle afterwards.

Figure 156. NCS when CKMODE = 1 in DTR mode (T = CLK period)



When the FIFO stays full during a read operation, or if the FIFO stays empty during a write operation, the operation stalls and CLK stays low until the software services the FIFO. If an abort occurs when an operation is stalled, NCS rises just after the abort is requested and then CLK rises one half of a CLK cycle later (see the figure below).

Figure 157. NCS when CKMODE = 1 with an abort (T = CLK period)



25.5 Address alignment and data number

The following table summarizes the effect of the address alignment and programmed data number depending on the use case.

Table 211. Address alignment cases

Memory type	Transaction type	Constraint on address(1)	Impact if constraint on address not respected	Constraint on number of bytes(1)	Impact if constraint on bytes not respected
Single, dual, quad Flash or SRAM (DMM = 0)	IND(2) read	None	None	None	None
	MM(3) read				
	IND write				
	MM write				

Table 211. Address alignment cases (continued)

Memory type	Transaction type	Constraint on address(1)	Impact if constraint on address not respected	Constraint on number of bytes(1)	Impact if constraint on bytes not respected
Single, dual, quad Flash or SRAM (DMM = 1)	IND read	Even	ADDR[0] is set to 0.	Even	DLR[0] is set to 1.
	MM read	None	None	None	None
	IND write	Even	ADDR[0] is set to 0.	Even	DLR[0] is set to 1.
	MM write	Even	Slave error	Even	Last byte is lost.
Octal Flash in SDR mode	IND read	None	None	None	None
	MM read				
	IND write				
	MM write				
Octal Flash or RAM in DTR mode without RDS nor WDM(4)	IND read	Even	ADDR[0] is set to 0.	Even	DLR[0] is set to 1.
	MM read	None	None	None	None
	IND write	Even	ADDR[0] is set to 0.	Even	DLR[0] is set to 1.
	MM write	Even	Slave error	Even	Last byte is lost.
Octal Flash or RAM in DTR mode with RDS or WDM	IND read	Even	ADDR[0] is set to 0.	Even	DLR[0] is set to 1.
	MM read	None	None	None	None
	IND write				
	MM write				
HyperBus	IND read	Even	ADDR[0] is set to 0.	Even	DLR[0] is set to 1.
	MM read	None	None	None	None
	IND write				
	MM write				

1. To be respected by the software.
2. IND = Indirect mode.
3. MM = Memory-mapped mode
4. RDS = read data strobe, WDM = write data mask.

25.6 OCTOSPI interrupts

An interrupt can be produced on the following events:

- Timeout
- Status match
- FIFO threshold
- Transfer complete
- Transfer error

Separate interrupt enable bits are available to provide more flexibility.

Table 212. OCTOSPI interrupt requests

Interrupt event	Event flag	Enable control bit
Timeout	TOF	TOIE
Status match	SMF	SMIE
FIFO threshold	FTF	FTIE
Transfer complete	TCF	TCIE
Transfer error	TEF	TEIE

25.7 OCTOSPI registers

25.7.1 OCTOSPI control register (OCTOSPI_CR)

Address offset: 0x0000

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	FMODE[1:0]		Res.	Res.	Res.	Res.	PMM	APMS	Res.	TOIE	SMIE	FTIE	TCIE	TEIE
		rw	rw					rw	rw		rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	FTHRES[4:0]					FSEL	DMM	Res.	Res.	TCEN	DMAEN	ABORT	EN
			rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:28 **FMODE[1:0]**: Functional mode

This field defines the OCTOSPI functional mode of operation.
00: Indirect-write mode
01: Indirect-read mode
10: Automatic status-polling mode
11: Memory-mapped mode
If DMAEN = 1 already, then the DMA controller for the corresponding channel must be disabled before changing the FMODE[1:0] value. If FMODE[1:0] and FTHRES[4:0] are wrongly updated while DMAEN = 1, the DMA request signal automatically goes to inactive state.

Bits 27:24 Reserved, must be kept at reset value.

Bit 23 **PMM**: Polling match mode

This bit indicates which method must be used to determine a match during the Automatic status-polling mode.
0: AND-match mode, SMF is set if all the unmasked bits received from the device match the corresponding bits in the match register.
1: OR-match mode, SMF is set if any of the unmasked bits received from the device matches its corresponding bit in the match register.

Bit 22 **APMS**: Automatic status-polling mode stop
This bit determines if the Automatic status-polling mode is stopped after a match.
0: Automatic status-polling mode is stopped only by abort or by disabling the OCTOSPI.
1: Automatic status-polling mode stops as soon as there is a match.

Bit 21 Reserved, must be kept at reset value.

Bit 20 **TOIE**: Timeout interrupt enable
This bit enables the timeout interrupt.
0: Interrupt disabled
1: Interrupt enabled

Bit 19 **SMIE**: Status match interrupt enable
This bit enables the status match interrupt.
0: Interrupt disabled
1: Interrupt enabled

Bit 18 **FTIE**: FIFO threshold interrupt enable
This bit enables the FIFO threshold interrupt.
0: Interrupt disabled
1: Interrupt enabled

Bit 17 **TCIE**: Transfer complete interrupt enable
This bit enables the transfer complete interrupt.
0: Interrupt disabled
1: Interrupt enabled

Bit 16 **TEIE**: Transfer error interrupt enable
This bit enables the transfer error interrupt.
0: Interrupt disabled
1: Interrupt enabled

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **FTHRES[4:0]**: FIFO threshold level
This field defines, in Indirect mode, the threshold number of bytes in the FIFO that causes the FIFO threshold flag FTF in OCTOSPI_SR, to be set.
00000: FTF is set if there are one or more free bytes available to be written to in the FIFO in Indirect-write mode, or if there are one or more valid bytes can be read from the FIFO in Indirect-read mode.
00001: FTF is set if there are two or more free bytes available to be written to in the FIFO in Indirect-write mode, or if there are two or more valid bytes can be read from the FIFO in Indirect-read mode.
...
11111: FTF is set if there are 32 free bytes available to be written to in the FIFO in Indirect-write mode, or if there are 32 valid bytes can be read from the FIFO in Indirect-read mode.
Note: If DMAEN = 1, the DMA controller for the corresponding channel must be disabled before changing the FTHRES[4:0] value.

Bit 7 **FSEL**: Flash select
This bit selects the Flash memory to be addressed in single-, dual-, quad-SPI mode in single-memory configuration (when DMM = 0).
0: FLASH 1 selected (data exchanged over IO[3:0])
1: FLASH 2 selected (data exchanged over IO[7:4])
This bit is ignored when DMM = 1 or when octal-SPI mode is selected.

Bit 6 **DMM**: Dual-memory configuration

This bit activates the dual-memory configuration, where two external devices are used simultaneously to double the throughput and the capacity

0: Dual-quad configuration disabled

1: Dual-quad configuration enabled

Bits 5:4 Reserved, must be kept at reset value.

Bit 3 **TCEN**: Timeout counter enable

This bit is valid only when the Memory-mapped mode (FMODE[1:0] = 11) is selected. This bit enables the timeout counter.

0: Timeout counter is disabled, and thus the chip-select (NCS) remains active indefinitely after an access in Memory-mapped mode.

1: Timeout counter is enabled, and thus the chip-select is released in the Memory-mapped mode after TIMEOUT[15:0] cycles of external device inactivity.

Bit 2 **DMAEN**: DMA enable

In Indirect mode, the DMA can be used to input or output data via OCTOSPI_DR. DMA transfers are initiated when FTF is set.

0: DMA disabled for Indirect mode

1: DMA enabled for Indirect mode

Note: Resetting the DMAEN bit while a DMA transfer is ongoing, breaks the handshake with the DMA. Do not write this bit during DMA operation.

Bit 1 **ABORT**: Abort request

This bit aborts the ongoing command sequence. It is automatically reset once the abort is completed. This bit stops the current transfer.

0: No abort requested

1: Abort requested

Note: This bit is always read as 0.

Bit 0 **EN**: Enable

This bit enables the OCTOSPI.

0: OCTOSPI disabled

1: OCTOSPI enabled

Note: The DMA request can be aborted without having received the ACK in case this EN bit is cleared during the operation.
In case this bit is set to 0 during a DMA transfer, the REQ signal to DMA returns to inactive state without waiting for the ACK signal from DMA to be active.

25.7.2 OCTOSPI device configuration register 1 (OCTOSPI_DCR1)

Address offset: 0x0008

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	MTYP[2:0]			Res.	Res.	Res.	DEVSIZE[4:0]				
					rw	rw	rw				rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	CSHT[5:0]						Res.	Res.	Res.	Res.	DLY BYP	Res.	FRCK	CKMODE
		rw	rw	rw	rw	rw	rw					rw		rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bits 26:24 **MTYP[2:0]**: Memory type

This bit indicates the type of memory to be supported.

000: Micron mode, D0/D1 ordering in DTR 8-data-bit mode. Regular-command protocol in single-, dual-, quad- and octal-SPI modes.

Note: In this mode, DQS signal polarity is inverted with respect to the memory clock signal. This is the default value and care must be taken to change MTYP[2:0] for memories different from Micron.

001: Macronix mode, D1/D0 ordering in DTR 8-data-bit mode. Regular-command protocol in single-, dual-, quad- and octal-SPI modes.

010: Standard mode

011: Macronix RAM mode, D1/D0 ordering in DTR 8-data-bit mode. Regular-command protocol in single-, dual-, quad- and octal-SPI modes with dedicated address mapping.

100: HyperBus memory mode, the protocol follows the HyperBus specification. 8-data-bit DTR mode must be selected.

101: HyperBus register mode, addressing register space. The memory-mapped accesses in this mode must be non-cacheable, or Indirect read/write modes must be used.

Others: Reserved

Bits 23:21 Reserved, must be kept at reset value.

Bits 20:16 **DEVSIZE[4:0]**: Device size

This field defines the size of the external device using the following formula:

Number of bytes in device = $2^{[DEVSIZE+1]}$.

DEVSIZE+1 is effectively the number of address bits required to address the external device. The device capacity can be up to 4 Gbytes (addressed using 32-bits) in Indirect mode, but the addressable space in Memory-mapped mode is limited to 256 Mbytes.

In Regular-command protocol, if DMM = 1, DEVSIZE[4:0] indicates the capacity of one of the two external devices.

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:8 **CSHT[5:0]**: Chip-select high time

CSHT + 1 defines the minimum number of CLK cycles where the chip-select (NCS) must remain high between commands issued to the external device.

0x0: NCS stays high for at least 1 cycle between external device commands.

0x1: NCS stays high for at least 2 cycles between external device commands.

...

0x3F: NCS stays high for at least 64 cycles between external device commands.

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **DLYBYP**: Delay block bypass

0: The internal sampling clock (called feedback clock) or the DQS data strobe external signal is delayed by the delay block (for more details on this block, refer to the dedicated section of the reference manual as it is not part of the OCTOSPI peripheral).

1: The delay block is bypassed, so the internal sampling clock or the DQS data strobe external signal is not affected by the delay block. The delay is shorter than when the delay block is not bypassed, even with the delay value set to minimum value in delay block.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **FRCK**: Free running clock

This bit configures the free running clock.

0: CLK is not free running.

1: CLK is free running (always provided).

Note: Free running clock mode is intended for delay calibration only. No memory or other device access is possible when FRCK is set.

Bit 0 **CKMODE**: Clock mode 0/mode 3

This bit indicates the level taken by the CLK between commands (when NCS = 1).

0: CLK must stay low while NCS is high (chip-select released). This is referred to as clock mode 0.

1: CLK must stay high while NCS is high (chip-select released). This is referred to as clock mode 3.

25.7.3 OCTOSPI device configuration register 2 (OCTOSPI_DCR2)

Address offset: 0x000C

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRAPSIZE[2:0]		
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **WRAPSIZE[2:0]**: Wrap size

This field indicates the wrap size to which the memory is configured. For memories which have a separate command for wrapped instructions, this field indicates the wrap-size associated with the command held in the OCTOSPI1_WPIR register.

000: Wrapped reads are not supported by the memory.

001: Reserved

010: External memory supports wrap size of 16 bytes.

011: External memory supports wrap size of 32 bytes.

100: External memory supports wrap size of 64 bytes.

101: External memory supports wrap size of 128 bytes.

110-111: Reserved

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **PRESCALER[7:0]**: Clock prescaler

This field defines the scaler factor for generating the CLK based on the kernel clock (value + 1).

0: $F_{CLK} = F_{KERNEL}$, kernel clock used directly as OCTOSPI CLK (prescaler bypassed). In this case, if the DTR mode is used, it is mandatory to provide to the OCTOSPI a kernel clock that has 50% duty-cycle.

1: $F_{CLK} = F_{KERNEL}/2$

2: $F_{CLK} = F_{KERNEL}/3$

...

255: $F_{CLK} = F_{KERNEL}/256$

For odd clock division factors, the CLK duty cycle is not 50 %. The clock signal remains low one cycle longer than it stays high.

25.7.4 OCTOSPI device configuration register 3 (OCTOSPI_DCR3)

Address offset: 0x0010

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSBOUND[4:0]				
											rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MAXTRAN[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:16 **CSBOUND[4:0]**: NCS boundary

This field enables the transaction boundary feature. When active, a minimum value of 3 is recommended.

The NCS is released on each boundary of $2^{CSBOUND}$ bytes.

0: NCS boundary disabled

others: NCS boundary set to $2^{CSBOUND}$ bytes

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **MAXTRAN[7:0]**: Maximum transfer

This field enables the communication regulation feature.

The NCS is released every MAXTRAN+1 clock cycles when the other OCTOSPI request the access to the bus.

0: Maximum communication disabled

others: Maximum communication is set to MAXTRAN + 1 bytes.

25.7.5 OCTOSPI device configuration register 4 (OCTOSPI_DCR4)

Address offset: 0x0014

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REFRESH[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REFRESH[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **REFRESH[31:0]**: Refresh rate

This field enables the refresh rate feature.

The NCS is released every REFRESH + 1 clock cycles for writes, and REFRESH + 4 clock cycles for reads.

Note: These two values can be extended with few clock cycles when refresh occurs during a byte transmission in single-, dual- or quad-SPI mode, because the byte transmission must be completed.

0: Refresh disabled

others: Maximum communication length is set to REFRESH + 1 clock cycles.

Note: REFRESH count is based on the divided clock period: if OCTOSPI_DCR2 PRESCALER field is changed, the REFRESH field must be updated accordingly.

25.7.6 OCTOSPI status register (OCTOSPI_SR)

Address offset: 0x0020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	FLEVEL[5:0]						Res.	Res.	BUSY	TOF	SMF	FTF	TCF	TEF
		r	r	r	r	r	r			r	r	r	r	r	r

Bits 31:14 Reserved, must be kept at reset value.

Bits 13:8 **FLEVEL[5:0]**: FIFO level

This field gives the number of valid bytes that are being held in the FIFO. FLEVEL = 0 when the FIFO is empty, and 32 when it is full.

In Automatic status-polling mode, FLEVEL is zero.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **BUSY**: Busy

This bit is set when an operation is ongoing. It is cleared automatically when the operation with the external device is finished and the FIFO is empty.

Bit 4 **TOF**: Timeout flag

This bit is set when timeout occurs. It is cleared by writing 1 to CTOF.

Bit 3 **SMF**: Status match flag

This bit is set in Automatic status-polling mode when the unmasked received data matches the corresponding bits in the match register (OCTOSPI_PSMAR).
It is cleared by writing 1 to CSMF.

Bit 2 **FTF**: FIFO threshold flag

In Indirect mode, this bit is set when the FIFO threshold has been reached, or if there is any data left in the FIFO after the reads from the external device are complete.
It is cleared automatically as soon as the threshold condition is no longer true.
In Automatic status-polling mode, this bit is set every time the status register is read, and the bit is cleared when the data register is read.

Bit 1 **TCF**: Transfer complete flag

This bit is set in Indirect mode when the programmed number of data has been transferred or in any mode when the transfer has been aborted.It is cleared by writing 1 to CTCF.

Bit 0 **TEF**: Transfer error flag

This bit is set in Indirect mode when an invalid address is being accessed in Indirect mode.
It is cleared by writing 1 to CTEF.

25.7.7 OCTOSPI flag clear register (OCTOSPI_FCR)

Address offset: 0x0024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CTOF	CSMF	Res.	CTCF	CTEF
											w	w		w	w

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **CTOF**: Clear timeout flag

Writing 1 clears the TOF flag in the OCTOSPI_SR register.

Bit 3 **CSMF**: Clear status match flag

Writing 1 clears the SMF flag in the OCTOSPI_SR register.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CTCF**: Clear transfer complete flag

Writing 1 clears the TCF flag in the OCTOSPI_SR register.

Bit 0 **CTEF**: Clear transfer error flag

Writing 1 clears the TEF flag in the OCTOSPI_SR register.

25.7.8 OCTOSPI data length register (OCTOSPI_DLR)

Address offset: 0x0040

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DL[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DL[31: 0]**: Data length

Number of data to be retrieved (value+1) in Indirect and Automatic status-polling modes. A value not greater than three (indicating 4 bytes) must be used for Automatic status-polling mode.

All 1’s in Indirect mode means undefined length, where OCTOSPI continues until the end of the memory, as defined by DEVSIZE.

0x0000_0000: 1 byte is to be transferred.

0x0000_0001: 2 bytes are to be transferred.

0x0000_0002: 3 bytes are to be transferred.

0x0000_0003: 4 bytes are to be transferred.

...

0xFFFF_FFFD: 4,294,967,294 (4G-2) bytes are to be transferred.

0xFFFF_FFFE: 4,294,967,295 (4G-1) bytes are to be transferred.

0xFFFF_FFFF: undefined length; all bytes, until the end of the external device, (as defined by DEVSIZE) are to be transferred. Continue reading indefinitely if DEVSIZE = 0x1F.

DL[0] is stuck at 1 in dual-memory configuration (DMM = 1) even when 0 is written to this bit, thus assuring that each access transfers an even number of bytes.

This field has no effect in Memory-mapped mode.

25.7.9 OCTOSPI address register (OCTOSPI_AR)

Address offset: 0x0048

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADDRESS[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDRESS[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ADDRESS[31:0]**: Address

Address to be sent to the external device. In HyperBus protocol, this field must be even as this protocol is 16-bit word oriented. In dual-memory configuration, AR[0] is forced to 1.
Writes to this field are ignored when BUSY = 1 or when FMODE = 11 (Memory-mapped mode).

25.7.10 OCTOSPI data register (OCTOSPI_DR)

Address offset: 0x0050

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DATA[31: 0]**: Data

Data to be sent/received to/from the external SPI device
In Indirect-write mode, data written to this register is stored on the FIFO before it is sent to the external device during the data phase. If the FIFO is too full, a write operation is stalled until the FIFO has enough space to accept the amount of data being written.
In Indirect-read mode, reading this register gives (via the FIFO) the data that was received from the external device. If the FIFO does not have as many bytes as requested by the read operation and if BUSY = 1, the read operation is stalled until enough data is present or until the transfer is complete, whichever happens first.
In Automatic status-polling mode, this register contains the last data read from the external device (without masking).
Word, half-word, and byte accesses to this register are supported. In Indirect-write mode, a byte write adds 1 byte to the FIFO, a half-word write 2 bytes, and a word write 4 bytes.
Similarly, in Indirect-read mode, a byte read removes 1 byte from the FIFO, a halfword read 2 bytes, and a word read 4 bytes. Accesses in Indirect mode must be aligned to the bottom of this register: A byte read must read DATA[7:0] and a half-word read must read DATA[15:0].

25.7.11 OCTOSPI polling status mask register (OCTOSPI_PSMKR)

Address offset: 0x0080

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MASK[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MASK[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MASK[31:0]**: Status mask

Mask to be applied to the status bytes received in Automatic status-polling mode

For bit n:

0: Bit n of the data received in Automatic status-polling mode is masked and its value is not considered in the matching logic.

1: Bit n of the data received in Automatic status-polling mode is unmasked and its value is considered in the matching logic.

25.7.12 OCTOSPI polling status match register (OCTOSPI_PSMAR)

Address offset: 0x0088

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MATCH[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MATCH[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MATCH[31: 0]**: Status match

Value to be compared with the masked status register to get a match

25.7.13 OCTOSPI polling interval register (OCTOSPI_PIR)

Address offset: 0x0090

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INTERVAL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **INTERVAL[15: 0]**: Polling interval

Number of CLK cycle between a read during the Automatic status-polling phases

25.7.14 OCTOSPI communication configuration register (OCTOSPI_CCR)

Address offset: 0x0100

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SIOO	Res.	DQSE	Res.	DDTR	DMODE[2:0]			Res.	Res.	ABSIZE[1:0]		ABDTR	ABMODE[2:0]		
rw		rw		rw	rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	ADSIZE[1:0]		AD DTR	ADMODE[2:0]			Res.	Res.	ISIZE[1:0]		IDTR	IMODE[2:0]		
		rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bit 31 **SIOO**: Send instruction only once mode
This bit has no effect when IMODE = 00 (see *Sending the instruction only once (SIOO)*).
0: Send instruction on every transaction
1: Send instruction only for the first command

Bit 30 Reserved, must be kept at reset value.

Bit 29 **DQSE**: DQS enable
This bit enables the data strobe management.
0: DQS disabled
1: DQS enabled

Bit 28 Reserved, must be kept at reset value.

Bit 27 **DDTR**: Data double transfer rate
This bit sets the DTR mode for the data phase.
0: DTR mode disabled for data phase
1: DTR mode enabled for data phase

Bits 26:24 **DMODE[2:0]**: Data mode
This field defines the data phase mode of operation.
000: No data
001: Data on a single line
010: Data on two lines
011: Data on four lines
100: Data on eight lines
101-111: Reserved

Bits 23:22 Reserved, must be kept at reset value.

Bits 21:20 **ABSIZE[1:0]**: Alternate bytes size
This bit defines alternate bytes size.
00: 8-bit alternate bytes
01: 16-bit alternate bytes
10: 24-bit alternate bytes
11: 32-bit alternate bytes

Bit 19 **ABDTR**: Alternate bytes double transfer rate
This bit sets the DTR mode for the alternate bytes phase.
0: DTR mode disabled for alternate bytes phase
1: DTR mode enabled for alternate bytes phase
This field can be written only when BUSY = 0.

Bits 18:16 **ABMODE[2:0]**: Alternate-byte mode
This field defines the alternate-byte phase mode of operation.
000: No alternate bytes
001: Alternate bytes on a single line
010: Alternate bytes on two lines
011: Alternate bytes on four lines
100: Alternate bytes on eight lines
101-111: Reserved

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:12 **ADSIZE[1:0]**: Address size
This field defines address size.
00: 8-bit address
01: 16-bit address
10: 24-bit address
11: 32-bit address

Bit 11 **ADDTR**: Address double transfer rate
This bit sets the DTR mode for the address phase.
0: DTR mode disabled for address phase
1: DTR mode enabled for address phase

Bits 10:8 **ADMODE[2:0]**: Address mode
This field defines the address phase mode of operation.
000: No address
001: Address on a single line
010: Address on two lines
011: Address on four lines
100: Address on eight lines
101-111: Reserved

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **ISIZE[1:0]**: Instruction size
This bit defines instruction size.
00: 8-bit instruction
01: 16-bit instruction
10: 24-bit instruction
11: 32-bit instruction

Bit 3 **IDTR**: Instruction double transfer rate
This bit sets the DTR mode for the instruction phase.
0: DTR mode disabled for instruction phase
1: DTR mode enabled for instruction phase

Bits 2:0 **IMODE[2:0]**: Instruction mode
This field defines the instruction phase mode of operation.
000: No instruction
001: Instruction on a single line
010: Instruction on two lines
011: Instruction on four lines
100: Instruction on eight lines
101-111: Reserved

25.7.15 OCTOSPI timing configuration register (OCTOSPI_TCR)

Address offset: 0x0108

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	SSHIFT	Res.	DHQC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw		rw												
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCYC[4:0]				
											rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **SSHIFT**: Sample shift
By default, the OCTOSPI samples data 1/2 of a CLK cycle after the data is driven by the external device.
This bit allows the data to be sampled later in order to consider the external signal delays.
0: No shift
1: 1/2 cycle shift
The software must ensure that SSHIFT = 0 when the data phase is configured in DTR mode (when DDTR = 1.)

Bit 29 Reserved, must be kept at reset value.

Bit 28 **DHQC**: Delay hold quarter cycle
0: No delay hold
1: 1/4 cycle hold

Bits 27:5 Reserved, must be kept at reset value.

Bits 4:0 **DCYC[4:0]**: Number of dummy cycles
This field defines the duration of the dummy phase.
In both SDR and DTR modes, it specifies a number of CLK cycles (0-31).
It is recommended to have at least six dummy cycles when using memories with DQS activated.

25.7.16 OCTOSPI instruction register (OCTOSPI_IR)

Address offset: 0x0110

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
INSTRUCTION[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INSTRUCTION[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **INSTRUCTION[31:0]**: Instruction
Instruction to be sent to the external SPI device

25.7.17 OCTOSPI alternate bytes register (OCTOSPI_ABR)

Address offset: 0x0120

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALTERNATE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ALTERNATE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ALTERNATE[31: 0]**: Alternate bytes
Optional data to be sent to the external SPI device right after the address.

25.7.18 OCTOSPI low-power timeout register (OCTOSPI_LPTR)

Address offset: 0x00130

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TIMEOUT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **TIMEOUT[15: 0]**: Timeout period

After each access in Memory-mapped mode, the OCTOSPI prefetches the subsequent bytes and hold them in the FIFO.

This field indicates how many CLK cycles the OCTOSPI waits after the clock becomes inactive and until it raises the NCS, putting the external device in a lower-consumption state.

25.7.19 OCTOSPI wrap communication configuration register (OCTOSPI_WPCCR)

Address offset: 0x0140

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	DQSE	Res.	DDTR	DMODE[2:0]			Res.	Res.	ABSIZE[1:0]		ABDTR	ABMODE[2:0]		
		rw		rw	rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	ADSIZE[1:0]		AD DTR	ADMODE[2:0]			Res.	Res.	ISIZE[1:0]		IDTR	IMODE[2:0]		
		rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **DQSE**: DQS enable

This bit enables the data strobe management.

0: DQS disabled

1: DQS enabled

Bit 28 Reserved, must be kept at reset value.

Bit 27 **DDTR**: Data double transfer rate

This bit sets the DTR mode for the data phase.

0: DTR mode disabled for data phase

1: DTR mode enabled for data phase

Bits 26:24 **DMODE[2:0]**: Data mode
This field defines the data phase mode of operation.
000: No data
001: Data on a single line
010: Data on two lines
011: Data on four lines
100: Data on eight lines
101-111: Reserved

Bits 23:22 Reserved, must be kept at reset value.

Bits 21:20 **ABSIZE[1:0]**: Alternate bytes size
This bit defines alternate bytes size.
00: 8-bit alternate bytes
01: 16-bit alternate bytes
10: 24-bit alternate bytes
11: 32-bit alternate bytes

Bit 19 **ABDTR**: Alternate bytes double transfer rate
This bit sets the DTR mode for the alternate bytes phase.
0: DTR mode disabled for alternate bytes phase
1: DTR mode enabled for alternate bytes phase

Bits 18:16 **ABMODE[2:0]**: Alternate-byte mode
This field defines the alternate byte phase mode of operation.
000: No alternate bytes
001: Alternate bytes on a single line
010: Alternate bytes on two lines
011: Alternate bytes on four lines
100: Alternate bytes on eight lines
101-111: Reserved

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:12 **ADSIZE[1:0]**: Address size
This field defines address size.
00: 8-bit address
01: 16-bit address
10: 24-bit address
11: 32-bit address

Bit 11 **ADDTR**: Address double transfer rate
This bit sets the DTR mode for the address phase.
0: DTR mode disabled for address phase
1: DTR mode enabled for address phase

Bits 10:8 **ADMODE[2:0]**: Address mode
This field defines the address phase mode of operation.
000: No address
001: Address on a single line
010: Address on two lines
011: Address on four lines
100: Address on eight lines
101-111: Reserved

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **ISIZE[1:0]**: Instruction size
This field defines instruction size.
00: 8-bit instruction
01: 16-bit instruction
10: 24-bit instruction
11: 32-bit instruction

Bit 3 **IDTR**: Instruction double transfer rate
This bit sets the DTR mode for the instruction phase.
0: DTR mode disabled for instruction phase
1: DTR mode enabled for instruction phase

Bits 2:0 **IMODE[2:0]**: Instruction mode
This field defines the instruction phase mode of operation.
000: No instruction
001: Instruction on a single line
010: Instruction on two lines
011: Instruction on four lines
100: Instruction on eight lines
101-111: Reserved

25.7.20 OCTOSPI wrap timing configuration register (OCTOSPI_WPTCR)

Address offset: 0x0148

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	SSHIFT	Res.	DHQC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw		rw												

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCYC[4:0]				
											rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **SSHIFT**: Sample shift
By default, the OCTOSPI samples data 1/2 of a CLK cycle after the data is driven by the external device.
This bit allows the data to be sampled later in order to consider the external signal delays.
0: No shift
1: 1/2 cycle shift
The firmware must assure that SSHIFT=0 when the data phase is configured in DTR mode (when DDTR = 1).

Bit 29 Reserved, must be kept at reset value.

Bit 28 **DHQC**: Delay hold quarter cycle
Add a quarter cycle delay on the outputs in DTR communication to match hold requirement.
0: No quarter cycle delay
1: Quarter cycle delay inserted

Bits 27:5 Reserved, must be kept at reset value.

Bits 4:0 **DCYC[4:0]**: Number of dummy cycles
This field defines the duration of the dummy phase.
In both SDR and DTR modes, it specifies a number of CLK cycles (0-31). It is recommended to have at least 5 dummy cycles when using memories with DQS activated.

25.7.21 OCTOSPI wrap instruction register (OCTOSPI_WPIR)

Address offset: 0x0150

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
INSTRUCTION[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INSTRUCTION[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **INSTRUCTION[31: 0]**: Instruction
Instruction to be sent to the external SPI device

25.7.22 OCTOSPI wrap alternate bytes register (OCTOSPI_WPABR)

Address offset: 0x0160

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALTERNATE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ALTERNATE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ALTERNATE[31: 0]**: Alternate bytes
Optional data to be sent to the external SPI device right after the address

25.7.23 OCTOSPI write communication configuration register (OCTOSPI_WCCR)

Address offset: 0x0180

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	DQSE	Res.	DDTR	DMODE[2:0]			Res.	Res.	ABSIZE[1:0]		ABDTR	ABMODE[2:0]		
		rw		rw	rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	ADSIZE[1:0]		ADDTR	ADMODE[2:0]			Res.	Res.	ISIZE[1:0]		IDTR	IMODE[2:0]		
		rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **DQSE**: DQS enable
This bit enables the data strobe management.
0: DQS disabled
1: DQS enabled

Bit 28 Reserved, must be kept at reset value.

Bit 27 **DDTR**: data double transfer rate
This bit sets the DTR mode for the data phase.
0: DTR mode disabled for data phase
1: DTR mode enabled for data phase

Bits 26:24 **DMODE[2:0]**: Data mode
This field defines the data phase mode of operation.
000: No data
001: Data on a single line
010: Data on two lines
011: Data on four lines
100: Data on eight lines
101-111: Reserved

Bits 23:22 Reserved, must be kept at reset value.

Bits 21:20 **ABSIZE[1:0]**: Alternate bytes size
This field defines alternate bytes size:
00: 8-bit alternate bytes
01: 16-bit alternate bytes
10: 24-bit alternate bytes
11: 32-bit alternate bytes

Bit 19 **ABDTR**: Alternate bytes double transfer rate
This bit sets the DTR mode for the alternate-bytes phase.
0: DTR mode disabled for alternate-bytes phase
1: DTR mode enabled for alternate-bytes phase

Bits 18:16 **ABMODE[2:0]**: Alternate-byte mode
This field defines the alternate-byte phase mode of operation.
000: No alternate bytes
001: Alternate bytes on a single line
010: Alternate bytes on two lines
011: Alternate bytes on four lines
100: Alternate bytes on eight lines
101-111: Reserved

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:12 **ADSIZE[1:0]**: Address size
This field defines address size.
00: 8-bit address
01: 16-bit address
10: 24-bit address
11: 32-bit address

Bit 11 **ADDTR**: Address double transfer rate
This bit sets the DTR mode for the address phase.
0: DTR mode disabled for address phase
1: DTR mode enabled for address phase

Bits 10:8 **ADMODE[2:0]**: Address mode
This field defines the address phase mode of operation.
000: No address
001: Address on a single line
010: Address on two lines
011: Address on four lines
100: Address on eight lines
101-111: Reserved

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **ISIZE[1:0]**: Instruction size
This bit defines instruction size:
00: 8-bit instruction
01: 16-bit instruction
10: 24-bit instruction
11: 32-bit instruction

Bit 3 **IDTR**: Instruction double transfer rate
This bit sets the DTR mode for the instruction phase.
0: DTR mode disabled for instruction phase
1: DTR mode enabled for instruction phase

Bits 2:0 **IMODE[2:0]**: Instruction mode
This field defines the instruction phase mode of operation.
000: No instruction
001: Instruction on a single line
010: Instruction on two lines
011: Instruction on four lines
100: Instruction on eight lines
101-111: Reserved

25.7.24 OCTOSPI write timing configuration register (OCTOSPI_WTCR)

Address offset: 0x0188

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCYC[4:0]				
											rw	rw	rw	rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bits 4:0 **DCYC[4:0]**: Number of dummy cycles

This field defines the duration of the dummy phase.
In both SDR and DTR modes, it specifies a number of CLK cycles (0-31). It is recommended to have at least 5 dummy cycles when using memories with DQS activated.

25.7.25 OCTOSPI write instruction register (OCTOSPI_WIR)

Address offset: 0x0190

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
INSTRUCTION[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INSTRUCTION[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **INSTRUCTION[31:0]**: Instruction

Instruction to be sent to the external SPI device

25.7.26 OCTOSPI write alternate bytes register (OCTOSPI_WABR)

Address offset: 0x01A0

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ALTERNATE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ALTERNATE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ALTERNATE[31: 0]**: Alternate bytes

Optional data to be sent to the external SPI device right after the address

25.7.27 OCTOSPI HyperBus latency configuration register (OCTOSPI_HLCR)

Address offset: 0x0200

Reset value: 0x0000 0000

This register can be modified only when BUSY = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRWR[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TACC[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	WZL	LM
rw	rw	rw	rw	rw	rw	rw	rw							rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **TRWR[7:0]:** Read write recovery time

Device read write recovery time expressed in number of communication clock cycles

Bits 15:8 **TACC[7: 0]**: Access time

Device access time expressed in number of communication clock cycles

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **WZL:** Write zero latency

This bit enables zero latency on write operations.

0: Latency on write accesses

1: No latency on write accesses

Bit 0 **LM:** Latency mode

This bit selects the Latency mode.

0: Variable initial latency

1: Fixed latency

25.7.28 OCTOSPI register map

Table 213. OCTOSPI register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0000	OCTOSPI_CR	Res.	Res.	FMDOE[1:0]		Res.	Res.	Res.	Res.	PMM	APMS	Res.	TOIE	SMIE	FTIE	TCIE	TEIE	Res.	Res.	Res.	FTHRES[4:0]					FSEL	DMM	Res.	Res.	TCEN	DMAEN	ABORT	EN
	Reset value			0	0					0	0		0	0	0	0	0				0	0	0	0	0	0	0			0	0	0	0
0x0004	Reserved	Reserved																															
0x0008	OCTOSPI_DCR1	Res.	Res.	Res.	Res.	Res.	MTYP [2:0]			Res.	Res.	Res.	DEVSIZE[4:0]					Res.	Res.	CSHT[5:0]						Res.	Res.	Res.	Res.	DLYBYP	Res.	FRCK	CKMODE
	Reset value						0	0	0				0	0	0	0	0			0	0	0	0	0	0					0		0	0
0x000C	OCTOSPI_DCR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WRAPSIZE [2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[7:0]							
	Reset value														0	0	0									0	0	0	0	0	0	0	0
0x0010	OCTOSPI_DCR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSBOUND[4:0]					Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MAXTRAN[7:0]							
	Reset value												0	0	0	0	0									0	0	0	0	0	0	0	0
0x0014	OCTOSPI_DCR4	REFRESH[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0018-0x001C	Reserved	Reserved																															
0x0020	OCTOSPI_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLEVEL[5:0]						Res.	Res.	BUSY	TOF	SMF	FTF	TCF	TEF
	Reset value																			0	0	0	0	0	0			0	0	0	0	0	0
0x0024	OCTOSPI_FCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CTOF	CSMF	Res.	CTCF	CTEF
	Reset value																												0	0		0	0
0x0028-0x003C	Reserved	Reserved																															
0x0040	OCTOSPI_DLR	DL[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 213. OCTOSPI register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0044	Reserved	Reserved																															
0x0048	OCTOSPI_AR	ADDRESS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x004C	Reserved	Reserved																															
0x0050	OCTOSPI_DR	DATA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0054-0x007C	Reserved	Reserved																															
0x0080	OCTOSPI_PSMKR	MASK[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0084	Reserved	Reserved																															
0x0088	OCTOSPI_PSMAR	MATCH[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x008C	Reserved	Reserved																															
0x0090	OCTOSPI_PIR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INTERVAL[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0094-0x00FC	Reserved	Reserved																															
0x0100	OCTOSPI_CCR	SIOO	Res.	DQSE	Res.	DDTR	DMODE [2:0]			Res.	Res.	ABSIZE [1:0]		ABDTR	ABMODE [2:0]			Res.	Res.	ADSIZE [1:0]		ADDTR	ADMODE [2:0]			Res.	Res.	ISIZE[1:0]		IDTR	IMODE [2:0]		
	Reset value	0		0		0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0
0x0104	Reserved	Reserved																															
0x0108	OCTOSPI_TCR	Res.	SSHIFT	Res.	DHQC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCYC[4:0]				
	Reset value		0		0																								0	0	0	0	0
0x010C	Reserved	Reserved																															
0x0110	OCTOSPI_IR	INSTRUCTION[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0114-0x011C	Reserved	Reserved																															
0x0120	OCTOSPI_ABR	ALTERNATE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0124-0x012C	Reserved	Reserved																															
0x0130	OCTOSPI_LPTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TIMEOUT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0134-0x013C	Reserved	Reserved																															

Table 213. OCTOSPI register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0140	OCTOSPI_WPCCR	Res.	Res.	DQSE	Res.	DDTR	DMODE[2:0]			Res.	Res.	ABSIZE[1:0]		ABDTR	ABMODE[2:0]			Res.	Res.	ADSIZE[1:0]		ADDTR	ADMODE[2:0]			Res.	Res.	ISIZE[1:0]		IDTR	IMODE[2:0]		
	Reset value	0		0		0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0
0x0144	Reserved	Reserved																															
0x0148	OCTOSPI_WPTCR	Res.	SSHIFT	Res.	DHQC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCYC[4:0]				
	Reset value		0		0																								0	0	0	0	0
0x014C	Reserved	Reserved																															
0x0150	OCTOSPI_WPIR	INSTRUCTION[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0154-0x015C	Reserved	Reserved																															
0x0160	OCTOSPI_WPABR	ALTERNATE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0164-0x017C	Reserved	Reserved																															
0x0180	OCTOSPI_WCCR	Res.	Res.	DQSE	Res.	DDTR	DMODE[2:0]			Res.	Res.	ABSIZE[1:0]		ABDTR	ABMODE[2:0]			Res.	Res.	ADSIZE[1:0]		ADDTR	ADMODE[2:0]			Res.	Res.	ISIZE[1:0]		IDTR	IMODE[2:0]		
	Reset value	0		0		0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0
0x0184	Reserved	Reserved																															
0x0188	OCTOSPI_WTCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCYC[4:0]				
	Reset value																												0	0	0	0	0
0x018C	Reserved	Reserved																															
0x0190	OCTOSPI_WIR	INSTRUCTION[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0194-0x019C	Reserved	Reserved																															
0x01A0	OCTOSPI_WABR	ALTERNATE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x01A4-0x01FC	Reserved	Reserved																															
0x0200	OCTOSPI_HLCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRWR[7:0]								TACC[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	WZL	LM
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0							0	0

Refer to *Section 2.3* for the register boundary addresses.

26 OCTOSPI I/O manager (OCTOSPIM)

26.1 Introduction

The OCTOSPI I/O manager is a low-level interface that enables an efficient OCTOSPI pin assignment with a full I/O matrix (before alternate function map) and multiplex of single/dual/quad/octal SPI interfaces over the same bus.

26.2 OCTOSPIM main features

- Supports up to two single/dual/quad/octal SPI interfaces
- Supports up to two ports for pin assignment
- Fully programmable I/O matrix for pin assignment by function (data/control/clock)

26.3 OCTOSPIM implementation

The table below describes the OCTOSPIM implementation.

Table 214. OCTOSPIM implementation

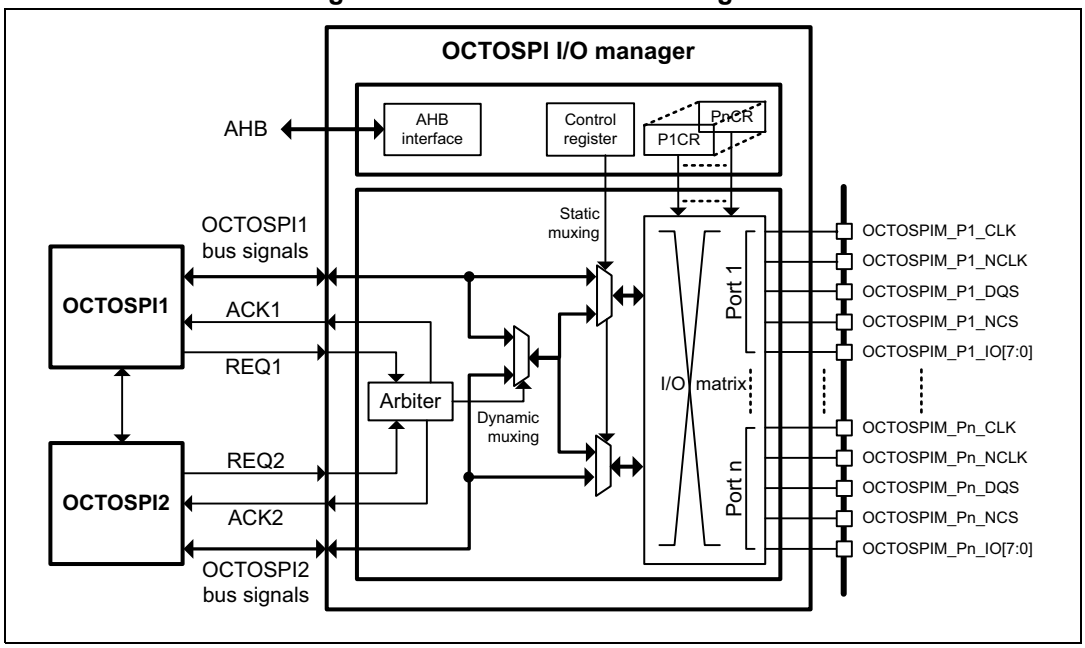
OCTOSPI feature	Available on the devices
Supports up to two single/dual/quad interfaces	X
Fully I/O multiplexing capability	X
Supports time-multiplexed mode	X
Supports high-speed interface	-
Chip select selection if OCTOSPI provides dual chip select	-
Supports 16-bit data interface and dual-octal mode	-

26.4 OCTOSPIM functional description

26.4.1 OCTOSPIM block diagram

The block diagram of the OCTOSPI I/O manager is shown in *Figure 158*.

Figure 158. OCTOSPIM block diagram



1. The number of ports (n) is 2.
2. Arbitration is possible for both I/O matrix input ports.

26.4.2 OCTOSPIM matrix

The OCTOSPI I/O manager matrix allows the user to set a fully programmable pre-mapping of functions:

- Any OCTOSPIM_Pn_CLK / OCTOSPIM_Pn_NCLK pair can be mapped independently to OCTOSPI1_CLK/OCTOSPI1_NCLK or OCTOSPI2_CLK/OCTOSPI2_NCLK
- Any OCTOSPIM_Pn_DQS can be mapped independently to OCTOSPI1_DQS or OCTOSPI2_DQS
- Any OCTOSPIM_Pn_NCS can be mapped independently to OCTOSPI1_NCS or OCTOSPI2_NCS
- Any OCTOSPIM_Pn_IO[3:0] and OCTOSPIM_Pn_IO[7:4] can be mapped independently to OCTOSPI1_IO[3:0], OCTOSPI1_IO[7:4], OCTOSPI2_IO1[3:0] or OCTOSPI2_IO[7:4]

For each OCTOSPI I/O manager port, individual signal enables and mapping are configured through the corresponding OCTOSPI I/O manager Port n configuration register (OCTOSPIM_PnCR).

When several I/O pins have the same configuration and are enabled at the same time, the result can be unpredictable.

In the default out-of-reset configuration, all the OCTOSPI1 and OCTOSPI2 signals are mapped, respectively, on Port 1 and on Port 2.

The OCTOSPIM configuration can be changed only when all OCTOSPIs are disabled.

26.4.3 OCTOSPIM multiplexed mode

When this mode is set the OCTOSPIs are time-multiplexed over the same bus. They get the ownership of the bus (in turn) through a request/acknowledge protocol with REQ/ACK signals.

The time-multiplexing is enabled by setting the MUXEN bit of the configuration register OCTOSPIM_CR.

The fairness counter (MAXTRAN) of each OCTOSPI can be used to accurately manage the maximum duration for which a given OCTOSPI takes the bus: this feature ensures a maximum bus access latency for the other OCTOSPI(s). When the bus is released by one OCTOSPI, an arbitration phase occurs, which is round-robin: when another OCTOSPI requests the bus, it gets it.

When the multiplexed mode is enabled, either the fairness counter or the refresh timeout counter of both OCTOSPI interfaces must be activated.

OCTOSPIn_NCS are not part of the multiplexing.Only OCTOSPIn_IOs, OCTOSPIn_DQS and OCTOSPIn_CLK / OCTOSPIn_NCLK are multiplexed.

When the multiplexed mode is used, only clock mode 0 is supported on the OCTOSPIs.

Due to arbitration and bus sharing, the auto polling interval time of the OCTOSPI, when used, may be increased.

Minimum switching duration

The minimum number of cycles needed to switch from an OCTOSPI to another can be configured.

This internal timer guarantees a latency between the falling edge of the REQ signal of the active OCTOSPI (the active one releases the bus), and the rising edge of the ACK signal to the requesting OCTOSPI (the bus is granted to the requesting one).

The duration is defined by the REQ2ACK_TIME field of the configuration register OCTOSPIM_CR.

Pin mapping in Multiplexed mode

In Multiplexed mode, the mapping of the bus is done as described below:

- OCTOSPI1_NCS and OCTOSPI2_NCS work in the same way, then in Non-multiplexed mode they have to be assigned to their respective OCTOSPIM_Pn_NCS.
- All the other signals are seen by the I/O matrix as if they were seen from OCTOSPI1.

26.5 OCTOSPIM registers

26.5.1 OCTOSPIM control register (OCTOSPIM_CR)

Address offset: 0x0000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REQ2ACK_TIME[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MUXEN
															rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **REQ2ACK_TIME[7:0]**: REQ to ACK time
In Multiplexed mode (MUXEN = 1), this field defines the time between two transactions.
The value is the number of OCTOSPI clock cycles - 1

Bits 15:1 Reserved, must be kept at reset value.

Bit 0 **MUXEN**: Multiplexed mode enable
This bit enables the multiplexing of the two OCTOSPIs.
0: No multiplexing, hence no arbitration
1: OCTOSPI1 and OCTOSPI2 are multiplexed over the same bus.

26.5.2 OCTOSPIM Port n configuration register (OCTOSPIM_PnCR)

Address offset: 0x0000 + 0x04*n (n=1 to 2)

Reset value: 0x0301 0111, 0x0705 0333

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	IOHSRC[1:0]		IOHEN	Res.	Res.	Res.	Res.	Res.	IOLSRC[1:0]		IOLEN
					rw	rw	rw						rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	NCSSRC	NCSEN	Res.	Res.	DQSSRC	DQSEN	Res.	Res.	CLKSRC	CLKEN
						rw	rw			rw	rw			rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bits 26:25 **IOHSRC[1:0]**: IO[7:4] source for Port n
This bits select the source of Port n IO[7:4].
00: OCTOSPI1_IO[3:0] in non multiplexed mode / multiplexed_IO[3:0] in multiplexed mode
01: OCTOSPI1_IO[7:4] in non multiplexed mode / multiplexed_IO[7:4] in multiplexed mode
10: OCTOSPI2_IO[3:0] in non multiplexed mode / unused in multiplexed mode
11: OCTOSPI2_IO[7:4] in non multiplexed mode / unused in multiplexed mode

Bit 24 **IOHEN**: IO[7:4] enable for Port n
This bit enables the Port n IO[7:4].
0: IO[7:4] for Port n disabled
1: IO[7:4] for Port n enabled

Bits 23:19 Reserved, must be kept at reset value.

Bits 18:17 **IOLSRC[1:0]**: IO[3:0] source for Port n
This bits select the source of Port n IO[3:0].
00: OCTOSPI1_IO[3:0] in non multiplexed mode / multiplexed_IO[3:0] in multiplexed mode
01: OCTOSPI1_IO[7:4] in non multiplexed mode / multiplexed_IO[7:4] in multiplexed mode
10: OCTOSPI2_IO[3:0] in non multiplexed mode / unused in multiplexed mode
11: OCTOSPI2_IO[7:4] in non multiplexed mode / unused in multiplexed mode

Bit 16 **IOLEN**: IO[3:0] enable for Port n
This bit enables the Port n IO[3:0].
0: IO[3:0] for Port n disabled
1: IO[3:0] for Port n enabled

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **NCSSRC**: NCS source for Port n
This bit selects the source of Port n NCS.
0: OCTOSPI1_NCS
1: OCTOSPI2_NCS

Bit 8 **NCSEN**: NCS enable for Port n
This bit enables the Port n NCS.
0: NCS for Port n is disabled
1: NCS for Port n is enabled

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **DQSSRC**: DQS source for Port n
This bit selects the source of Port n DQS.
0: OCTOSPI1_DQS in non multiplexed mode / multiplexed_DQS in multiplexed mode
1: OCTOSPI2_DQS in non multiplexed mode / unused port in multiplexed mode

Bit 4 **DQSEN**: DQS enable for Port n
This bit enables the Port n DQS.
0: DQS for Port n is disabled
1: DQS for Port n is enabled

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **CLKSRC**: CLK/NCLK source for Port n
This bit selects the source of Port n CLK/NCLK.
0: OCTOSPI1_CLK/NCLK in non multiplexed mode / multiplexed_CLK/CLKn in multiplexed mode
1: OCTOSPI2_CLK/NCLK in non multiplexed mode / unused port in multiplexed mode

Bit 0 **CLKEN**: CLK/NCLK enable for Port n
This bit enables the Port n CLK/NCLK.
0: CLK/NCLK for Port n is disabled
1: CLK/NCLK for Port n is enabled

26.5.3 OCTOSPIM register map

The following table summarizes the OCTOSPI I/O manager registers.

Table 215. OCTOSPIM register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0000	**OCTOSPIM _CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REQ2ACK_TIME[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MUXEN
	Reset value									0	0	0	0	0	0	0	0																0
0x0004	**OCTOSPIM _P1CR**	Res.	Res.	Res.	Res.	Res.	IOHSRC [1:0]		IOHEN	Res.	Res.	Res.	Res.	Res.	IOLSRC [1:0]		IOLEN	Res.	Res.	Res.	Res.	Res.	Res.	NCSSRC	NCSEN	Res.	Res.	DQSSRC	DQSEN	Res.	Res.	CLKSRC	CLKEN
	Reset value						0	1	1						0	0	1							0	1			0	1			0	1
0x0008	**OCTOSPIM _P2CR**	Res.	Res.	Res.	Res.	Res.	IOHSRC [1:0]		IOHEN	Res.	Res.	Res.	Res.	Res.	IOLSRC [1:0]		IOLEN	Res.	Res.	Res.	Res.	Res.	Res.	NCSSRC	NCSEN	Res.	Res.	DQSSRC	DQSEN	Res.	Res.	CLKSRC	CLKEN
	Reset value						1	1	1						1	0	1							1	1			1	1			1	1

Refer to *Section 2.3 on page 131* for the register boundary addresses.

27 Delay block (DLYB)

27.1 Introduction

The delay block (DLYB) is used to generate an output clock that is dephased from the input clock. The phase of the output clock must be programmed by the user application. The output clock is then used to clock the data received by another peripheral such as an SDMMC or Octo-SPI interface.

The delay is voltage- and temperature-dependent, that may require the application to re-configure and recenter the output clock phase with the receive data.

27.2 DLYB main features

The delay block has the following features:

- Input clock frequency ranging from 25 MHz to the maximum frequency supported by the communication interface (see datasheet)
- Up to 12 oversampling phases.

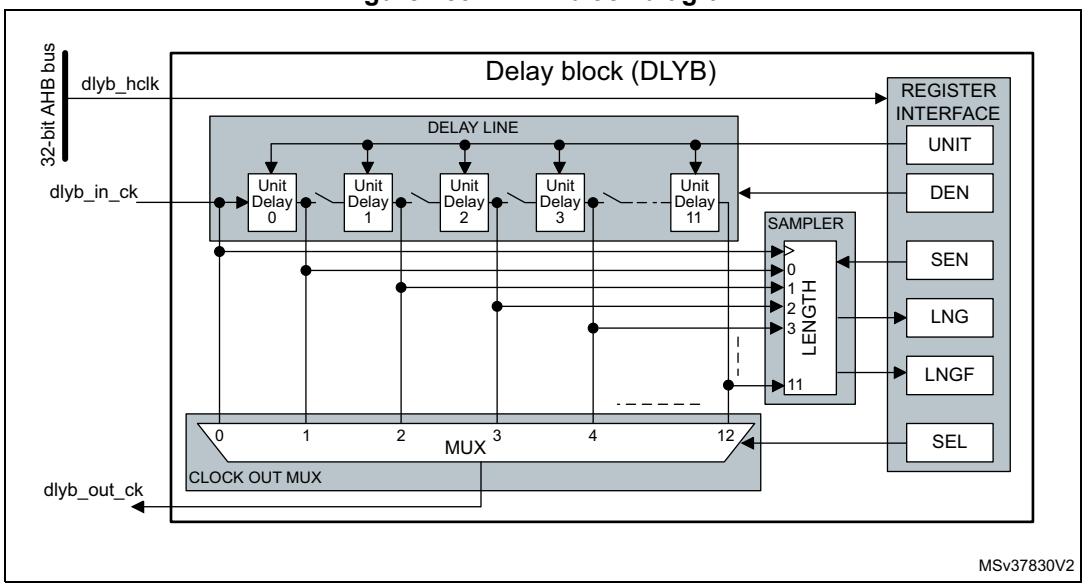
27.3 DLYB functional description

27.3.1 DLYB diagram

The delay block includes the following sub-blocks (shown in the figure below):

- register interface block providing AHB access to the DLYB registers
- delay line supporting the unit delays
- delay line length sampling
- output clock selection multiplexer

Figure 159. DLYB block diagram



27.3.2 DLYB pins and internal signals

Table 216 lists the DLYB internal signals.

Table 216. DLYB internal input/output signals

Signal name	Signal type	Description
dlyb_hclk	Digital input	Delay block register interface clock
dlyb_in_ck	Digital input	Delay block input clock
dlyb_out_ck	Digital output	Delay block output clock

Table 217. DLYB interconnection

Signal name	Source/destination			
	SDMMC1	SDMMC2	OCTOSPI1	OCTOSPI2
dlyb_in_ck	sdmmc_io_in_ck		DQS	
dlyb_out_ck	sdmmc_fb_ck		DQS delayed for data sampling	

27.3.3 General description

The delay block is enabled by setting the DEN bit in the DLYB control register (DLYB_CR). The length sampler is enabled through the SEN bit in DLYB_CR register.

When the delay block is enabled, the delay added by a unit delay is defined by the UNIT[6:0] field in the DLYB configuration register (DLYB_CFGR).

Note: UNIT[6:0] can be programmed only when the output clock is disabled (SEN = 1).

When the delay block is enabled, the output clock phase is selected through the SEL[3:0] field in DLYB_CFGR register.

Note: SEL can be programmed only when the output clock is disabled (SEN = 1).

The output clock can be de-phased over one input clock period by configuring the delay line length to span one period. The delay line length can be configured by enabling the length sampler through the SEN bit, that gives access to the delay line length (LNG[11:0]) and length valid flag (LNGF) in DLYB_CFGR.

If an output clock delay smaller than one input clock period is needed the delay line length can be reduced. This allows a smaller unit delay providing higher resolution.

Once the delay line length is configured, a dephased output clock can be selected by the output clock multiplexer. This is done through SEL[3:0]. The output clock is only available on the selected phase when SEN is set to 0.

The table below gives a summary of the delay block control.

Table 218. Delay block control

DEN	SEN	UNIT	SEL	LNG	LNGF	Output clock
0	0	Don’t care	Don’t care	Don’t care	Don’t care	Enabled (= Input clock)

Table 218. Delay block control

DEN	SEN	UNIT	SEL	LNG	LNGF	Output clock
x	1	Unit delay	Output clock phase	Length	Length flag	Disabled
1	0	Unit delay(1)	Output clock phase(2)	Don't care	Don't care	Enabled (= selected phase)

1. The unit delay can only be changed when SEN = 1.
2. The output clock phase can only be changed when SEN = 1.

27.3.4 Delay line length configuration procedure

LNG[11:0] is used to determine the delay line length with respect to the input clock period. The length must be configured so that one full input clock period is covered by the delay line length.

Note that despite the delay line has 12 unit delay elements, the following procedure description returns a length between 0 and 10, as the upper delay output value is used to ensure that the delay is calibrated over one full input clock cycle. Depending on the clock frequency and UNIT value, unit delay element 10 may also be truncated from the clock cycle length.

A clock input (free running clock) must be present during the whole tuning procedure.

To configure the delay line length to one period of the Input clock, follow the sequence below:

1. Enable the delay block by setting DEN bit to 1.
2. Enable the length sampling by setting SEN bit to 1.
3. Enable all delay cells by setting SEL[3:0] to 12.
4. For UNIT[6:0] = 0 to 127 (this step must be repeated until the delay line length is configured):
   a) Update the UNIT[6:0] value and wait till the length flag LNGF is set to 1.
   b) Read LNG[11:0].

   If (LNG[10:0] > 0) and (LNG[11] or LNG[10] = 0), the delay line length is configured to one input clock period.
5. Determine how many unit delays (N) span one input clock period: for N = 0 to 10, if LNG[N] = 1, the number of unit delays spanning the input clock period = N.
6. Disable the length sampling by clearing SEN to 0.

If an output clock delay smaller than one input clock period is needed the delay line length can be reduced smaller than one input clock period. This allows a smaller unit delay, providing a higher resolution spanning a shorter time interval.

27.3.5 Output clock phase configuration procedure

When the delay line length is configured to one input clock period, the output clock phase can be selected between the unit delays spanning one Input clock period.

Follow the steps below to select the output clock phase:

1. Disable the output clock and enable the access to the phase selection SEL[3:0] bits by setting SEN bit to 1.
2. Program SEL[3:0] with the desired output clock phase value.
3. Enable the output clock on the selected phase by clearing SEN to 0.

QUAD/OCTOSPI use case:

The delay block is used in conjunction with QUADSPI or OCTOSPI interfaces to allow shifting the input data sampling signal. This sampling signal can be the feedback clock or the data strobe (DQS) signal, which is delivered by certain type of devices. Note that in case DQS is used, the calibration procedure shall be performed beforehand with a free running clock, as DQS is a discontinuous signal.

In case of SDR (single data rate) mode the user shall typically shift the sampling signal by half period, so that the sampling edges are positioned in the middle of the valid data phase.

In case of DDR (dual data rate) mode, for which data are transitioning at start and middle of period, typical value shall be close to N/4, once the calibration is completed.

In case of high frequencies and tight timing constraints, the delay setting granularity (10) might be too coarse. Since in most cases it is not necessary to have a possible delay value covering the whole sampling clock period, the "Unit" value can be overridden by application in order to improve the accuracy of the sampling edge position (example: providing a twice as small "Unit" gives twice better timing accuracy. The counterpart being that the maximum possible delay is divided by 2).

SDMMC use case:

The delay block is used in conjunction with SDMMC interface variable delay. For correct sampling point tuning the delay value must cover a whole SDMMC_CK clock period. After having tuned the delay line length the individual delays are used in the sampling point tuning to find the optimal sampling point.

27.4 DLYB registers

All registers can be accessed in word, half-word and byte access.

27.4.1 DLYB control register (DLYB_CR)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEN	DEN
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **SEN:** Sampler length enable bit

0: Sampler length and register access to UNIT[6:0] and SEL[3:0] disabled, output clock enabled.

1: Sampler length and register access to UNIT[6:0] and SEL[3:0] enabled, output clock disabled.

Bit 0 **DEN:** Delay block enable bit

0: DLYB disabled.

1: DLYB enabled.

27.4.2 DLYB configuration register (DLYB_CFGR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LNGF	Res.	Res.	Res.	LNG[11:0]											
r				r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	UNIT[6:0]							Res.	Res.	Res.	Res.	SEL[3:0]			
	rw	rw	rw	rw	rw	rw	rw					rw	rw	rw	rw

Bit 31 **LNGF:** Length valid flag

This flag indicates when the delay line length value contained in LNG[11:0] is valid after UNIT[6:0] bits changed.

0: Length value in LNG is not valid.

1: Length value in LNG is valid.

Bits 30:28 Reserved, must be kept at reset value.

Bits 27:16 **LNG[11:0]:** Delay line length value

These bits reflect the 12 unit delay values sampled at the rising edge of the input clock. The value is only valid when LNGF = 1.

Bit 15 Reserved, must be kept at reset value.

Bits 14:8 **UNIT[6:0]:** Delay of a unit delay cell.

These bits can only be written when SEN = 1.

Unit delay = initial delay + UNIT[6:0] x delay step

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **SEL[3:0]:** Phase for the output clock.

These bits can only be written when SEN = 1.

Output clock phase = input clock + SEL[3:0] x unit delay

27.4.3 DLYB register map

Table 219. DLYB register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**DLYB_CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEN	DEN
	Reset value																															0	0
0x004	**DLYB_CFGR**	LNGF	Res	Res	Res	LNG												Res	UNIT							Res	Res	Res	Res	SEL			
	Reset value	0				0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0					0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

28 Analog-to-digital converters (ADC1/ADC2)

28.1 Introduction

This section describes the ADC implementation:

- ADC1 and ADC2 are tightly coupled and can operate in dual mode (ADC1 is master).

Each ADC consists of a 16-bit successive approximation analog-to-digital converter.

Each ADC has up to 20 multiplexed channels. A/D conversion of the various channels can be performed in single, continuous, scan or discontinuous mode. The result of the ADC is stored in a left-aligned or right-aligned 32-bit data register.

The ADCs are mapped on the AHB bus to allow fast data handling.

The analog watchdog features allow the application to detect if the input voltage goes outside the user-defined high or low thresholds.

A built-in hardware oversampler allows to improve analog performances while off-loading the related computational burden from the CPU.

An efficient low-power mode is implemented to allow very low consumption at low frequency.

28.2 ADC main features

- High-performance features
  - Up to 2x ADCs which can operate in dual mode
  - 16, 14, 12, 10 or 8-bit configurable resolution
  - ADC conversion time is independent from the AHB bus clock frequency
  - Faster conversion time by lowering resolution
  - Can manage Single-ended or differential inputs (programmable per channels)
  - AHB slave bus interface to allow fast data handling
  - Self-calibration (both offset and linearity)
  - Channel-wise programmable sampling time
  - Up to four injected channels (analog inputs assignment to regular or injected channels is fully configurable)
  - Hardware assistant to prepare the context of the injected channels to allow fast context switching
  - Data alignment with in-built data coherency
  - Data can be managed by GP-DMA for regular channel conversions with FIFO
  - Data can be routed to DFSDM for post processing
  - 4 dedicated data registers for the injected channels
- Oversampler
  - 32-bit data register
  - Oversampling ratio adjustable from 2 to 1024x
  - Programmable data right and left shift
- Low-power features
  - Speed adaptive low-power mode to reduce ADC consumption when operating at low frequency
  - Allows slow bus frequency application while keeping optimum ADC performance
  - Provides automatic control to avoid ADC overrun in low AHB bus clock frequency application (auto-delayed mode)
- Each ADC features an external analog input channel
  - Up to 6 fast channels from dedicated GPIO pads
  - Up to 14 slow channels from dedicated GPIO pads
- In addition, there are 4 internal dedicated channels
  - Internal reference voltage (V_{REFINT})
  - V_{BAT} monitoring channel ($V_{BAT}/4$)
  - Connection to DAC internal channels
- Start-of-conversion can be initiated:
  - by software for both regular and injected conversions
  - by hardware triggers with configurable polarity (internal timers events or GPIO input events) for both regular and injected conversions
- Conversion modes
  - Each ADC can convert a single channel or can scan a sequence of channels
  - Single mode converts selected inputs once per trigger

  - Continuous mode converts selected inputs continuously
  - Discontinuous mode
- Dual ADC mode
- Interrupt generation at ADC ready, the end of sampling, the end of conversion (regular or injected), end of sequence conversion (regular or injected), analog watchdog 1, 2 or 3 or overrun events
- 3 analog watchdogs per ADC
- ADC input range: $V_{REF-} \leq V_{IN} \leq V_{REF+}$

Figure 160 shows the block diagram of one ADC.

28.3 ADC implementation

Table 220. ADC features

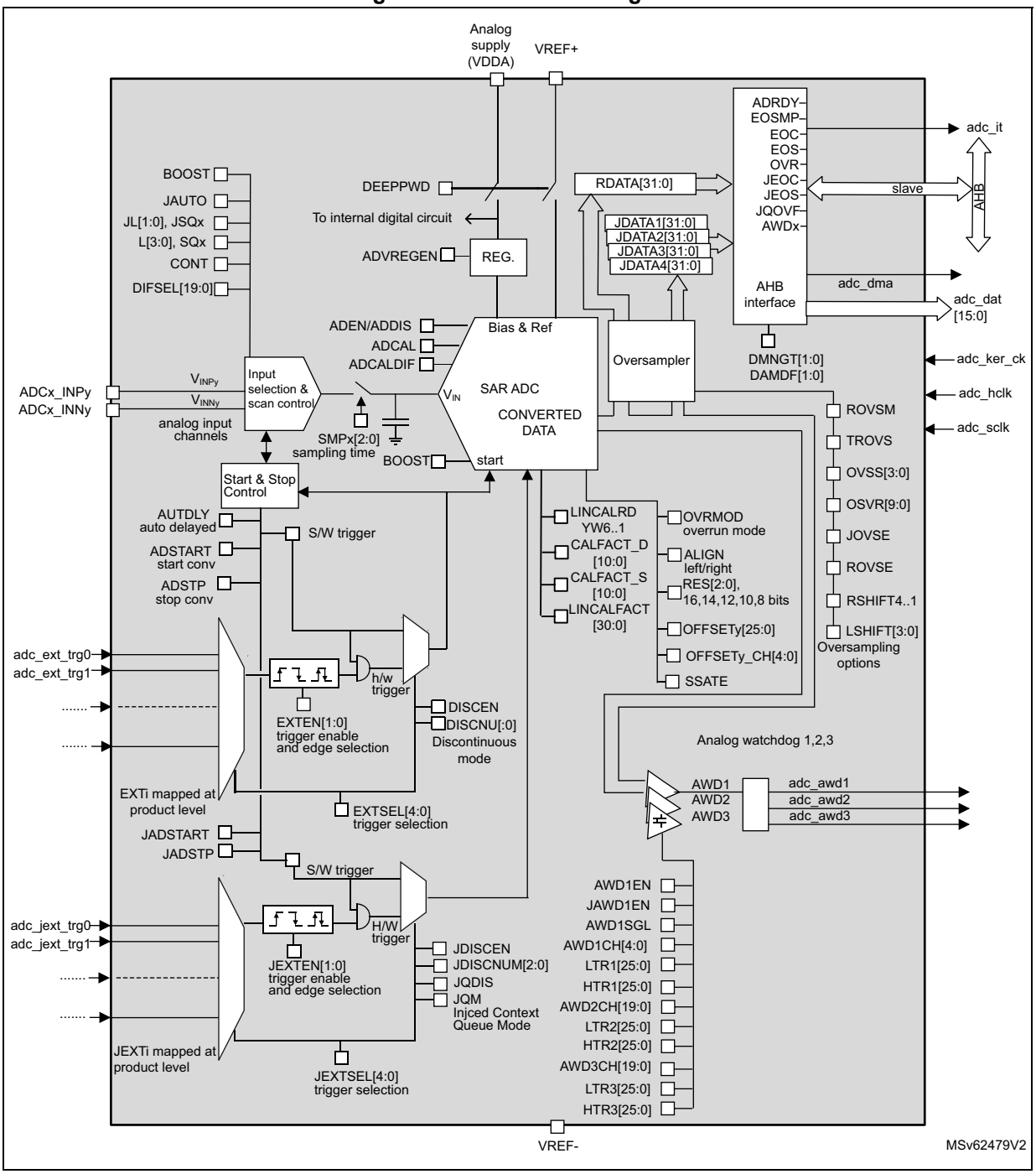
ADC modes/features	ADC1, ADC2	ADC3
Resolution	16bit	12 bit
Maximum sampling speed	3.6 Msps (16-bit resolution)	5 Msps (12-bit resolution)
Dual mode operation	X	-
Hardware offset calibration	X	X
Hardware linearity calibration	X	-
Single end input	X	X
Differential input	X	X
Injected channel conversion	X	X
Oversampling	up to x1024	up to x256
Data register	32 bits	16 bits
DMA support	X	X
Parallel data output to DSFSDM	X	X
Offset compensation	X	X
Gain compensation	-	-
Number of Analog watchdog	3	3

28.4 ADC functional description

28.4.1 ADC block diagram

Figure 160 shows the ADC block diagram and *Table 221* gives the ADC pin description.

Figure 160. ADC block diagram



28.4.2 ADC pins and internal signals

Table 221. ADC input/output pins

Name	Signal type	Description
VREF+	Input, analog reference positive	The higher/positive reference voltage for the ADC.
VDDA	Input, analog supply	Analog power supply equal V_{DDA}
VREF-	Input, analog reference negative	The lower/negative reference voltage for the ADC.
VSSA	Input, analog supply ground	Ground for analog power supply equal to V_{SS}
ADCx_INPy	External analog inputs	Up to 20 analog input channels (x = ADC number= 1 to 2): – ADCx_INP[0:5] fast channels – ADCx_INP[6:19] slow channels
ADCx_INNy		Up to 20 analog input channels (x = ADC number= 1 to 2): – ADCx_INN[0:5] fast channels – ADCx_INN[6:19] slow channels

Table 222. ADC internal input/output signals

Internal signal name	Signal type	Description
V_{INP}[y]	Analog inputs	Positive input analog channels for each ADC, connected either to ADCx_INP*i* external channels or to internal channels.
V_{INN}[y]	Analog inputs	Negative input analog channels for each ADC, connected either to V_{REF-} or to ADCx_INN*i* external channels
adc_ext_trgy	Inputs	Up to 23 external trigger inputs for the regular conversions (can be connected to on-chip timers). These inputs are shared between the ADC master and the ADC slave.
adc_jext_trgy	Inputs	Up to 23 external trigger inputs for the injected conversions (can be connected to on-chip timers). These inputs are shared between the ADC master and the ADC slave.
adc_awd1 adc_awd2 adc_awd3	Outputs	Internal analog watchdog output signal connected to on-chip timers. (x = Analog watchdog number 1,2,3)
adc_it	Output	ADC interrupt
adc_hclk	Input	AHB clock
adc_sclk	Input	ADC synchronous clock input from RCC
adc_ker_ck_input	Input	ADC kernel clock input from RCC
adc_dma	Output	ADC DMA requests
adc_dat[15:0]	Outputs	ADC data outputs

Table 223. ADC interconnection

Signal name	Source/destination
ADC2 $V_{INP}[17]$(1)	V_{REFINT} (output voltage from internal reference voltage)
ADC2 $V_{INP}[16]$(2)	$V_{BAT}/4$ (external battery voltage supply voltage)
ADC2 $V_{INP}[16]$(2)	dac1_out1
ADC2 $V_{INP}[17]$(1)	dac1_out2
adc_dat[15:0]	dfsdm_dat_adc[15:0]

1. ADC2 $V_{INP}[17]$ alternate connection can be switched though SYSCFG_ADC2ALT register.
2. ADC2 $V_{INP}[16]$ alternate connection can be switched though SYSCFG_ADC2ALT register.

28.4.3 ADC clocks

Dual clock domain architecture

The dual clock-domain architecture means that the ADC clock is independent from the AHB bus clock.

The input clock is the same for all ADCs and can be selected between two different clock sources (see *Figure 161: ADC Clock scheme*):

1. The ADC clock can be a specific clock source, named adc_ker_ck_input which is independent and asynchronous with the AHB clock.

   It can be configured in the RCC (refer to RCC Section for more information on how to generate the ADC clock (adc_ker_ck_input) dedicated clock).

   To select this scheme, CKMODE[1:0] bits of the ADCx_CCR register must be reset.
2. The ADC clock can be derived from the system clock or system clock divided by two (adc_sclk). In this mode, a programmable divider factor can be selected (/1, 2 or 4 according to bits CKMODE[1:0]).

   To select this scheme, CKMODE[1:0] bits of the ADCx_CCR register must be different from “00”. adc_sclk is equal to sys_ck when HPRE is set to 0, otherwise it corresponds to sys_ck/2.

In both case, the clock divider factor of 2 is applied to the clock provided to the ADC analog block ($f_{adc\_ker\_ck}$).

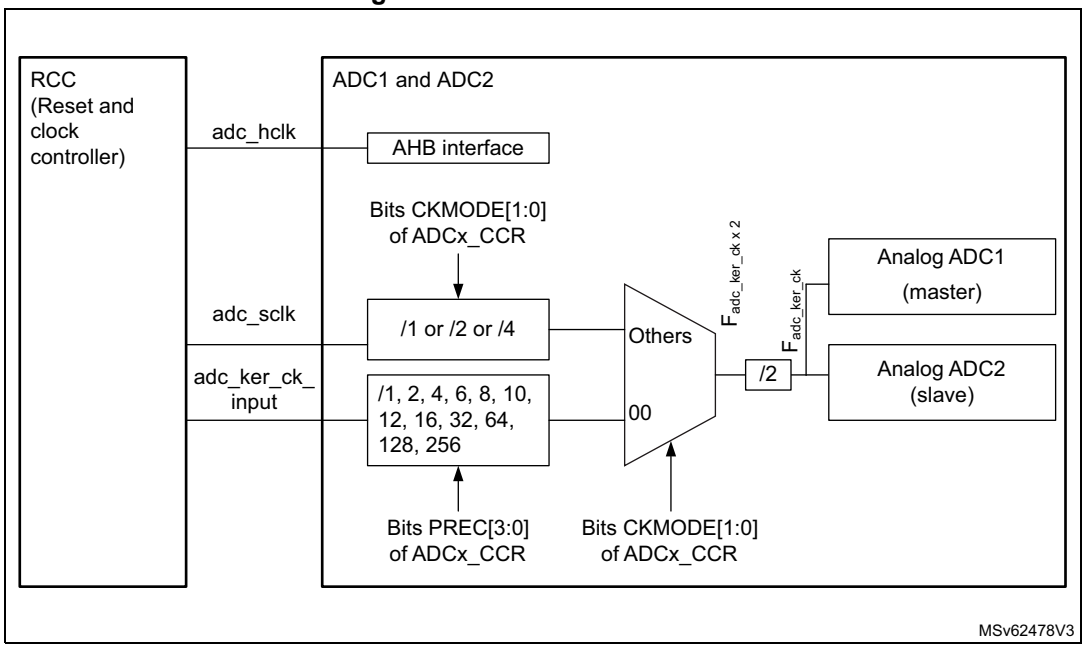
Option 1) has the advantage of reaching the maximum ADC clock frequency whatever the AHB clock scheme selected. The ADC clock can eventually be divided by the following ratio: 1, 2, 4, 6, 8, 10, 12, 16, 32, 64, 128, 256; using the prescaler configured with bits PRESC[3:0] in the ADCx_CCR register.

Option 2) has the advantage of using the system without additional PLL. In addition, when adc_sclk is twice faster than the adc_hclk clock, the latency between the trigger and the start of conversion is fixed. This can be useful when the ADC is triggered by a timer and if the application requires that the ADC is precisely triggered without any uncertainty (otherwise, an uncertainty of the trigger instant is added by the resynchronizations between the two clock domains).

The clock configured through CKMODE[1:0] bits must be compliant with the analog ADC operating frequency specified in the product datasheet.

Note: adc_sclk is the system clock or system clock divided by two: when the ABH prescaler is set to 1 (HPRE[3:0] = 0XXX in RCC_CFGR register), adc_sclk is equal to sys_clk, otherwise adc_sclk corresponds to sys_clk/2.

Figure 161. ADC Clock scheme



1. Refer to the RCC section to see how adc_hclk and adc_ker_ck_input can be generated.

Clock ratio constraint between ADC clock and AHB clock

There are generally no constraints to be respected for the ratio between the ADC clock and the AHB clock except if some injected channels are programmed. In this case, it is mandatory to respect the following ratio:

- $F_{adc\_hclk} \geq F_{adc\_ker\_ck} / 4$ if the resolution of all channels are 16-bit, 14-bit,12-bit or 10-bit
- $F_{adc\_hclk} \geq F_{adc\_ker\_ck} / 3$ if there are some channels with resolutions equal to 8-bit (and none with lower resolutions)

Constraints between ADC clocks

When several ADC interfaces are used simultaneously, it is mandatory to use the same clock source from the RCC block without prescaler ratio, for all ADC interfaces.

BOOST control

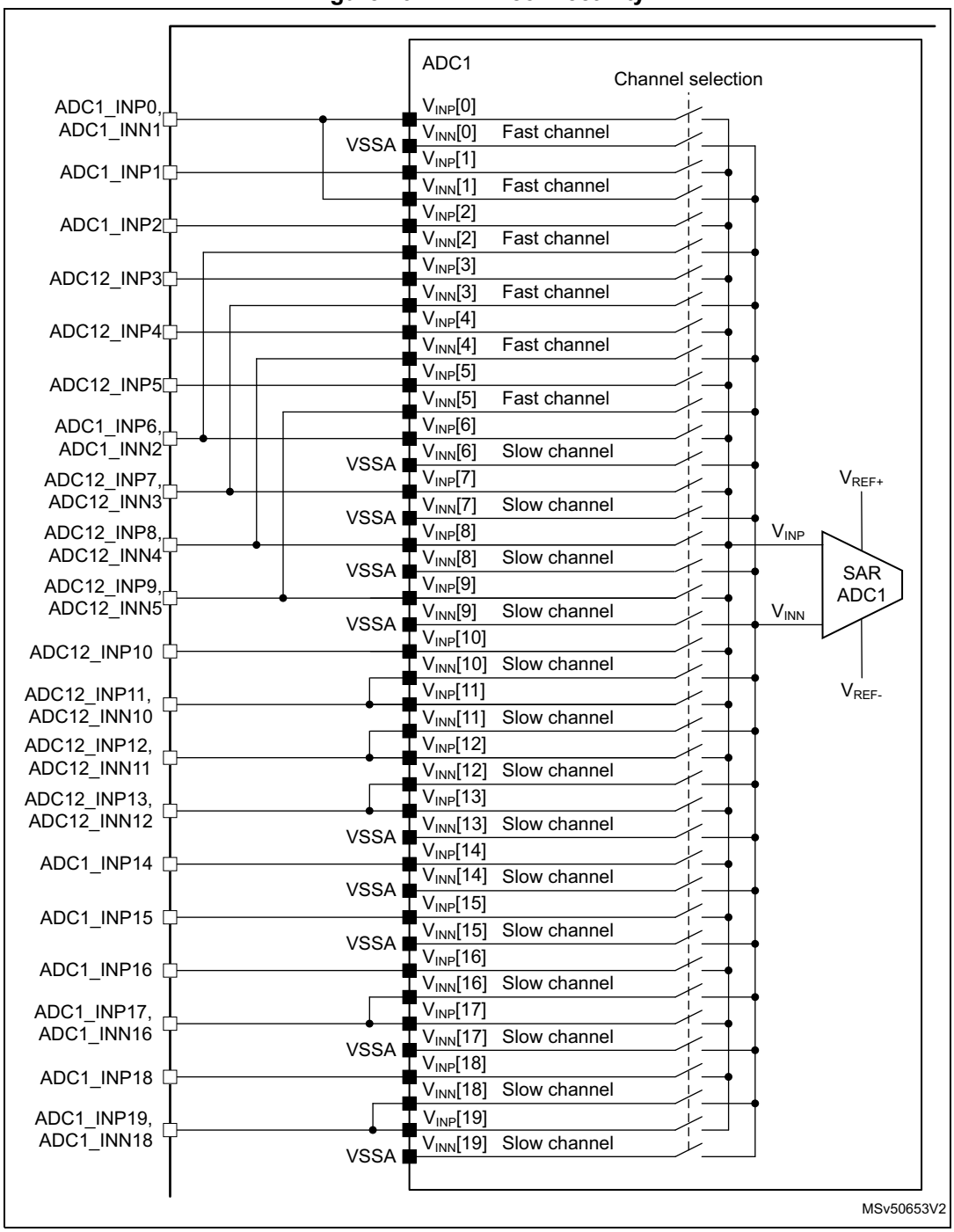
The ADC Boost mode can be controlled through the BOOST bitfield in the ADC_CR register.

This bitfield must be set according to the ADC clock setting. Refer to the ADC_CR register description.

28.4.4 ADC1/2 connectivity

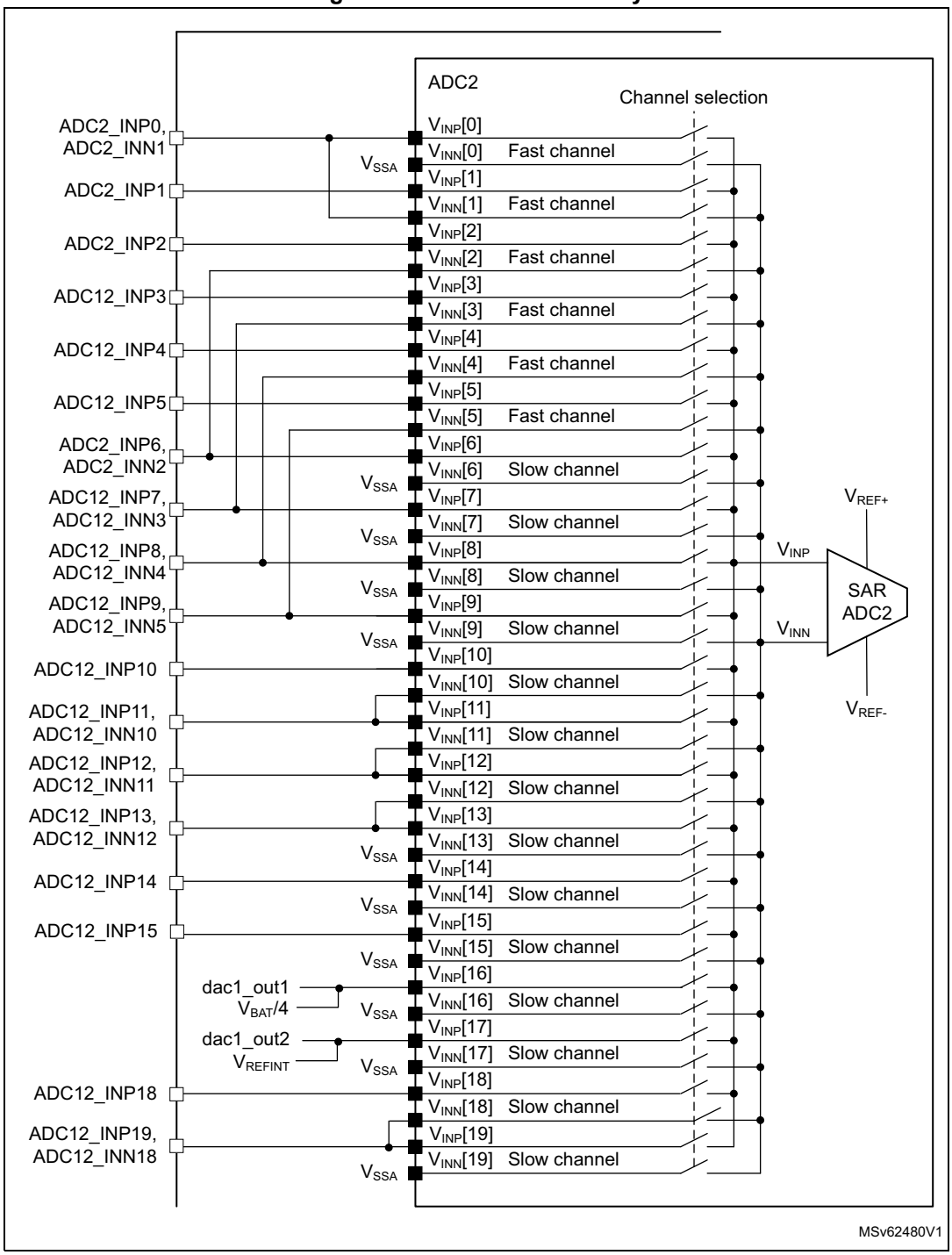
ADC1 and ADC2 are tightly coupled and share some external channels as described in the following figures.

Figure 162. ADC1 connectivity



1. ADCx_INNy signal can only be used when the corresponding ADC input channel is configured as differential mode.

Figure 163. ADC2 connectivity



28.4.5 Slave AHB interface

The ADCs implement an AHB slave port for control/status register and data access. The features of the AHB interface are listed below:

- Word (32-bit) accesses
- Single cycle response
- Response to all read/write accesses to the registers with zero wait states.

The AHB slave interface does not support split/retry requests, and never generates AHB errors.

28.4.6 ADC deep-power-down mode (DEEPPWD) and ADC voltage regulator (ADVREGEN)

By default, the ADC is in deep-power-down mode where its supply is internally switched off to reduce the leakage currents (the reset state of bit DEEPPWD is 1 in the ADC_CR register).

To start ADC operations, it is first needed to exit deep-power-down mode by clearing bit DEEPPWD=0.

Then, it is mandatory to enable the ADC internal voltage regulator by setting the bit ADVREGEN=1 into ADC_CR register. The software must wait for the startup time of the ADC voltage regulator ($T_{ADCVREG\_STUP}$) before launching a calibration or enabling the ADC. This delay must be implemented by software.

The LDO status can be verified by checking the LDORDY bit in ADC_ISR register (refer to *Section 28.3: ADC implementation* for the availability of the LDO regulator status).

For the startup time of the ADC voltage regulator, refer to device datasheet for $T_{ADCVREG\_STUP}$ parameter.

After ADC operations are complete, the ADC can be disabled (ADEN=0). It is possible to save power by also disabling the ADC voltage regulator. This is done by writing bit ADVREGEN=0.

Then, to save more power by reducing the leakage currents, it is also possible to re-enter in ADC deep-power-down mode by setting bit DEEPPWD=1 into ADC_CR register. This is particularly interesting before entering Stop mode.

Note: Writing DEEPPWD=1 automatically disables the ADC voltage regulator and bit ADVREGEN is automatically cleared.

Note: When the internal voltage regulator is disabled (ADVREGEN=0), the internal analog calibration is kept.

In ADC deep-power-down mode (DEEPPWD=1), the internal analog calibration is lost and it is necessary to either relaunch a calibration or apply again the calibration factor which was previously saved (refer to *Section 28.4.8: Calibration (ADCAL, ADCALDIF, ADCALLIN, ADC_CALFACT)*).

28.4.7 Single-ended and differential input channels

Channels can be configured to be either single-ended input or differential input by writing into bits DIFSEL[19:0] in the ADC_DIFSEL register. This configuration must be written while the ADC is disabled (ADEN=0).

In single-ended input mode, the analog voltage to be converted for channel “i” is the difference between the external voltage $V_{INP[i]}$ (positive input) and V_{REF-} (negative input).

In differential input mode, the analog voltage to be converted for channel “i” is the difference between the external voltage $V_{INP[i]}$ (positive input) and $V_{INN[i]}$ (negative input).

The output data for the differential mode is an unsigned data. When $V_{INP[i]}$ equals V_{REF-}, $V_{INN[i]}$ equals V_{REF+} and the output data is 0x0000 (16-bit resolution mode). When $V_{INP[i]}$ equals V_{REF+}, $V_{INN[i]}$ equals V_{REF-} and the output data is 0xFFFF.

$$\text{Converted value} = \frac{\text{ADC\_Full\_Scale}}{2} \times \left[1 + \frac{V_{INP} - V_{INN}}{V_{REF+}}\right]$$

When ADC is configured as differential mode, both input should be biased at V_{REF+} / 2 voltage.

The input signal are supposed to be differential (common mode voltage should be fixed).

For a complete description of how the input channels are connected for each ADC, refer to *Section 28.4.4: ADC1/2 connectivity*.

Caution: When configuring the channel “i” in differential input mode, its negative input voltage is connected to $V_{INN[i]}$. As a consequence, channel “*i+n*”, which is connected to $V_{INN[i]}$, should not be converted at same time by different ADCs. Some channels are shared between ADC1/ADC2: this can make the channel on the other ADC unusable.

28.4.8 Calibration (ADCAL, ADCALDIF, ADCALLIN, ADC_CALFACT)

Each ADC provides an automatic calibration procedure which drives all the calibration sequence including the power-on/off sequence of the ADC. During the procedure, the ADC calculates a calibration factor which is 11-bits of offset or 160-bits of linearity and which is applied internally to the ADC until the next ADC power-off. During the calibration procedure, the application must not use the ADC and must wait until calibration is complete.

The calibration is preliminary to any ADC operation. It removes the systematic errors which may vary from chip to chip and allows to compensate offset and linearity deviation.

The calibration factor for the offset to be applied for single-ended input conversions is different from the factor to be applied for differential input conversions:

- Write ADCALDIF=0 before launching a calibration which will be applied for single-ended input conversions.
- Write ADCALDIF=1 before launching a calibration which will be applied for differential input conversions.

The linearity correction must be done once only, regardless of single / differential configuration.

- Write ADCALLIN=1 before launching a calibration which will run the linearity calibration same time as the offset calibration.
- Write ADCALLIN=0 before launching a calibration which will not run the linearity calibration but only the offset calibration.

The calibration is then initiated by software by setting bit ADCAL=1. It can be initiated only when the ADC is disabled (when ADEN=0). ADCAL bit stays at 1 during all the calibration sequence. It is then cleared by hardware as soon the calibration completes. At this time, the associated calibration factor is stored internally in the analog ADC and also in the bits CALFACT_S[10:0] or CALFACT_D[10:0] of ADC_CALFACT register (depending on single-ended or differential input calibration). The 160-bit linearity calibration factor can be accessed using the ADC_CALFACT2 register with ADEN set to 1.

The internal analog calibration is kept if the ADC is disabled (ADEN=0). However, if the ADC is disabled for extended periods, it is recommended that a new offset calibration cycle is run before enabling again the ADC.

The internal analog calibration is lost each time the power of the ADC is removed (example, when the product enters in STANDBY or VBAT mode). In this case, to avoid spending time recalibrating the ADC, it is possible to re-write the calibration factor into the ADC_CALFACT and ADC_CALFACT2 register without recalibrating, supposing that the software has previously saved the calibration factor delivered during the previous calibration.

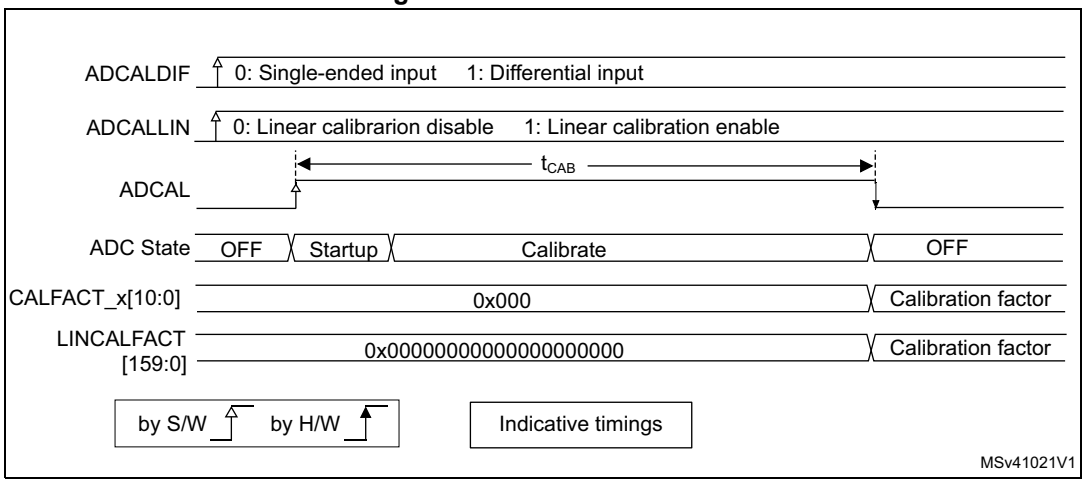
The calibration factor can be written if the ADC is enabled but not converting (ADEN=1 and ADSTART=0 and JADSTART=0). Then, at the next start of conversion, the calibration factor will automatically be injected into the analog ADC. This loading is transparent and does not add any cycle latency to the start of the conversion. It is recommended to recalibrate when V_{REF+} voltage changed more than 10%.

Refer to the datasheets for the clock cycle requirement for both linear and offset calibration.

Software procedure to calibrate the ADC

1. Ensure DEEPPWD=0, ADVREGEN=1 and verify that the ADC voltage regulator startup time has elapsed by checking the LDORDY bit in ADC_ISR (refer to *Section 28.3: ADC implementation* for the availability of the LDO regulator status).
2. Ensure that ADEN=0.
3. Select the input mode for this calibration by setting ADCALDIF=0 (Single-ended input) or ADCALDIF=1 (Differential input). Select if Linearity calibration enable or not by ADCALLIN=1(enabled) or ADCALLIN=0(disabled).
4. Set ADCAL=1.
5. Wait until ADCAL=0.
6. The offset calibration factor can be read from ADC_CALFACT register.
7. The linearity calibration factor can be read from ADC_CALFACT2 register, following the procedure described in *Section : Linearity calibration reading procedure* (ADEN must be set to 1 prior to accessing ADC_CALFACT2 register).

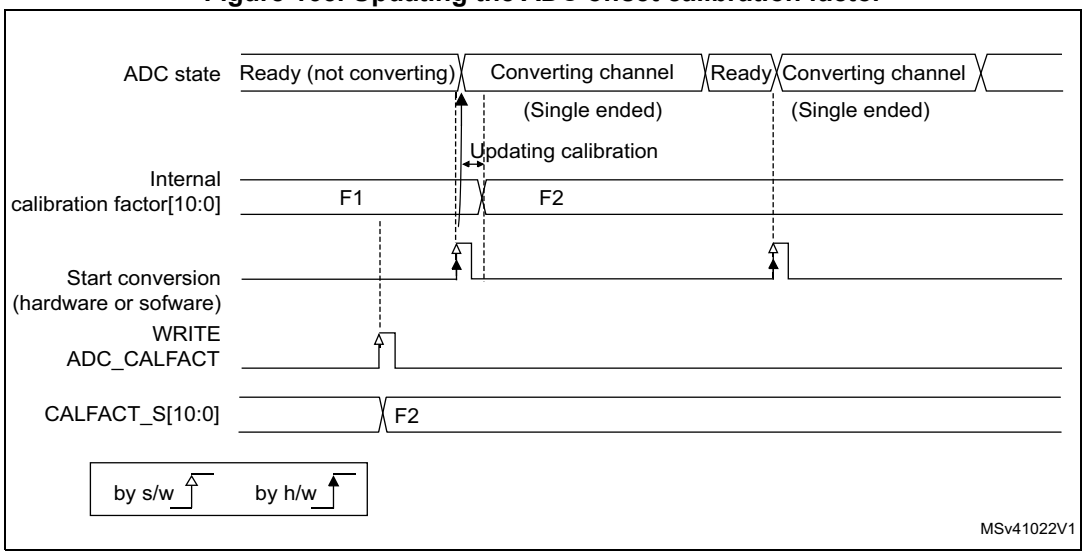
Figure 164. ADC calibration



Software procedure to re-inject a calibration factor into the ADC

1. Ensure ADEN=1 and ADSTART=0 and JADSTART=0 (ADC enabled and no conversion is ongoing).
2. Write CALFACT_S and CALFACT_D with the new offset calibration factors.
3. Write LINCALFACT bits with the new linearity calibration factors, following the procedure described in *Section : Linearity calibration writing procedure*.
4. When a conversion is launched, the calibration factor will be injected into the analog ADC only if the internal analog calibration factor differs from the one stored in bits CALFACT_S for single-ended input channel or bits CALFACT_D for differential input channel.

Figure 165. Updating the ADC offset calibration factor

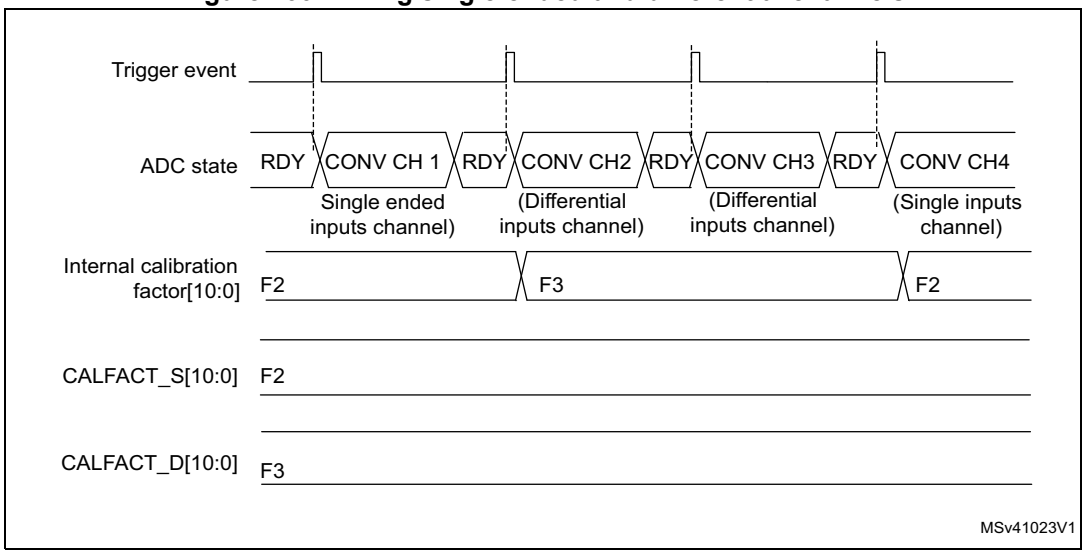


Calibrating single-ended and differential analog inputs with a single ADC

If the ADC is supposed to convert both differential and single-ended inputs, two calibrations must be performed, one with ADCALDIF=0 and one with ADCALDIF=1. The procedure is the following:

1. Disable the ADC.
2. Calibrate the ADC in single-ended input mode (with ADCALDIF=0) and Linearity calibration enable (with ADCALLIN=1). This updates the registers CALFACT_S[10:0] and LINCALFACT[159:0].
3. Calibrate the ADC in Differential input modes (with ADCALDIF=1) and Linearity calibration disable (with ADCALLIN=0). This updates the register CALFACT_D[10:0].
4. Enable the ADC, configure the channels and launch the conversions. Each time there is a switch from a single-ended to a differential inputs channel (and vice-versa), the calibration will automatically be injected into the analog ADC.

Figure 166. Mixing single-ended and differential channels



Linearity calibration reading procedure

Once the calibration is done (ADCAL bit cleared by hardware) with ADCALLIN=1, the 160-bit linearity correction factor can be read using the ADC_CALFACT2 30-bit registers (6 read accesses are necessary).

The six LINCALRDYW1..6 control/status bits in ADC_CR are set when the calibration is complete. When ADEN is set to 1, clearing one of these bits launches the transfer of part of the linearity factor into the LINCALFACT[29:0] of the ADC_CALFACT2 register. The bit will be reset by hardware when the ADC_CALFACT2 register can be read (software must poll the bit until it is cleared). The complete procedure is as following:

1. Ensure DEEPPWD=0, ADVREGEN=1 and that the ADC voltage regulator startup time has elapsed by checking the LDORDY bit in ADC_ISR (refer to *Section 28.3: ADC implementation* for the availability of the LDO regulator status).
2. Set ADEN = 1 and wait until ADRDY=1.
3. Clear LINCALRDYW6 bit (Linearity calibration ready Word 6).
4. Poll LINCALRDYW6 bit until returned value is zero, indicating linearity correction bits[159:150] are available in ADC_CALFACT2[29:0].
5. Read ADC_CALFACT2[29:0].
6. Clear LINCALRDYW5 bit.
7. Poll LINCALRDYW5 bit until returned value is zero, indicating linearity correction bits[149:120] are available in ADC_CALFACT2[29:0].
8. Read ADC_CALFACT2[29:0].
9. Clear LINCALRDYW4 bit.
10. Poll LINCALRDYW4 bit until returned value is zero, indicating linearity correction bits[119:90] are available in ADC_CALFACT2[29:0].
11. Read ADC_CALFACT2[29:0].
12. Clear LINCALRDYW3 bit.
13. Poll LINCALRDYW3 bit until returned value is zero, indicating linearity correction bits[89:60] are available in ADC_CALFACT2[29:0].
14. Read ADC_CALFACT2[29:0].
15. Clear LINCALRDYW2 bit.
16. Poll LINCALRDYW2 bit until returned value is zero, indicating linearity correction bits[59:30] are available in ADC_CALFACT2[29:0].
17. Read ADC_CALFACT2[29:0].
18. Clear LINCALRDYW1 bit.
19. Poll LINCALRDYW1 bit until returned value is zero, indicating linearity correction bits[29:0] are available in ADC_CALFACT2[29:0].
20. Read ADC_CALFACT2[29:0].

Note: The software is allowed to toggle a single LINCALRDYWx bit at once (other bits left unchanged), otherwise causing unexpected behavior.

The software can access the linearity calibration factor by writing LINCALRDYW1..6 bits only when ADEN=1 and ADSTART=0 and JADSTART=0 (ADC enabled and no conversion is ongoing).

Linearity calibration writing procedure

The six LINCALRDYW1..6 control/status bits in ADC_CR are reset when the calibration has not yet been done or a new linearity calibration factor have been rewritten. It is possible to force directly a linearity calibration factor or re-inject it using the following procedure:

1. Ensure DEEPPWD=0, ADVREGEN=1 and that ADC voltage regulator startup time has elapsed by checking the LDORDY bit in ADC_ISR (refer to *Section 28.3: ADC implementation* for the availability of the LDO regulator status).
2. Set ADEN = 1 and wait until ADRDY=1.
3. Write ADC_CALFACT2[9:0] with previously saved linearity correction factor bits[159:150].
4. Set LINCALRDYW6 bit.
5. Poll LINCALRDYW6 bit until returned value is one, indicating linearity correction bits[159:150] have been effectively written.
6. Write ADC_CALFACT2[29:0] with previously saved linearity correction factor bits[149:120].
7. Set LINCALRDYW5 bit.
8. Poll LINCALRDYW5 bit until returned value is one, indicating linearity correction bits[149:120] have been effectively written.
9. Write ADC_CALFACT2[29:0] with previously saved linearity correction factor bits[119:90].
10. Set LINCALRDYW4 bit.
11. Poll LINCALRDYW4 bit until returned value is one, indicating linearity correction bits[119:90] have been effectively written.
12. Write ADC_CALFACT2[29:0] with previously saved linearity correction factor bits[89:60].
13. Set LINCALRDYW3 bit.
14. Poll LINCALRDYW3 bit until returned value is one, indicating linearity correction bits[89:60] have been effectively written.
15. Write ADC_CALFACT2[29:0] with previously saved linearity correction factor bits[59:30].
16. Set LINCALRDYW2 bit.
17. Poll LINCALRDYW2 bit until returned value is one, indicating linearity correction bits[59:30] have been effectively written.
18. Write ADC_CALFACT2[29:0] with previously saved linearity correction factor bits[29:0].
19. Set LINCALRDYW1 bit.
20. Poll LINCALRDYW1 bit until returned value is one, indicating linearity correction bits[29:0] have been effectively written.

Note: The software is allowed to toggle a single LINCALRDYWx bit at once (other bits left unchanged), otherwise causing unexpected behavior.

The software is allowed to update the linearity calibration factor by writing LINCALRDYW1..6 bits only when ADEN=1 and ADSTART=0 and JADSTART=0 (ADC enabled and no conversion is ongoing).

28.4.9 ADC on-off control (ADEN, ADDIS, ADRDY)

First of all, follow the procedure explained in *Section 28.4.6: ADC deep-power-down mode (DEEPPWD) and ADC voltage regulator (ADVREGEN)*).

Once DEEPPWD = 0 and ADVREGEN = 1, the ADC can be enabled and the ADC needs a stabilization time of t_{STAB} before it starts converting accurately, as shown in *Figure 167*. Two control bits enable or disable the ADC:

- ADEN=1 enables the ADC. The flag ADRDY will be set once the ADC is ready for operation.
- ADDIS=1 disables the ADC. ADEN and ADDIS are then automatically cleared by hardware as soon as the analog ADC is effectively disabled.

Regular conversion can then start either by setting ADSTART=1 (refer to *Section 28.4.19: Conversion on external trigger and trigger polarity (EXTSEL, EXTEN, JEXTSEL, JEXTEN)*) or when an external trigger event occurs, if triggers are enabled.

Injected conversions start by setting JADSTART=1 or when an external injected trigger event occurs, if injected triggers are enabled.

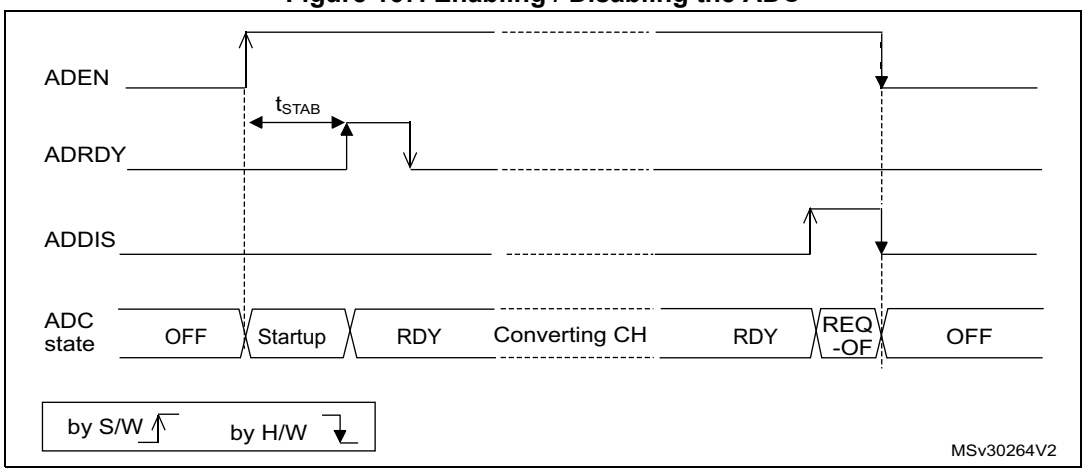
Software procedure to enable the ADC

1. Clear the ADRDY bit in the ADC_ISR register by writing ‘1’.
2. Set ADEN=1.
3. Wait until ADRDY=1 (ADRDY is set after the ADC startup time). This can be done using the associated interrupt (setting ADRDYIE=1).
4. Clear the ADRDY bit in the ADC_ISR register by writing ‘1’ (optional).

Software procedure to disable the ADC

1. Check that both ADSTART=0 and JADSTART=0 to ensure that no conversion is ongoing. If required, stop any regular and injected conversion ongoing by setting ADSTP=1 and JADSTP=1 and then wait until ADSTP=0 and JADSTP=0.
2. Set ADDIS=1.
3. If required by the application, wait until ADEN=0, until the analog ADC is effectively disabled (ADDIS will automatically be reset once ADEN=0).

Figure 167. Enabling / Disabling the ADC



28.4.10 Constraints when writing the ADC control bits

The software can write the RCC control bits to configure and enable the ADC clock (refer to RCC Section), the control bits DIFSEL in the ADC_DIFSEL register, ADCx_CCR register and the control bits ADCAL and ADEN in the ADC_CR register, only if the ADC is disabled (ADEN must be equal to 0).

The software is then allowed to write the control bits ADSTART, JADSTART and ADDIS of the ADC_CR register only if the ADC is enabled and there is no pending request to disable the ADC (ADEN must be equal to 1 and ADDIS to 0).

For all the other control bits of the ADC_CFGR, ADC_SMPRy, ADC_TRy, ADC_SQRy, ADC_JDRy, ADC_OFRy and ADC_IER registers:

- For control bits related to configuration of regular conversions, the software is allowed to write them only if the ADC is enabled (ADEN=1) and if there is no regular conversion ongoing (ADSTART must be equal to 0).
- For control bits related to configuration of injected conversions, the software is allowed to write them only if the ADC is enabled (ADEN=1) and if there is no injected conversion ongoing (JADSTART must be equal to 0).

The software can write ADSTP or JADSTP control bits in the ADC_CR register only if the ADC is enabled and eventually converting and if there is no pending request to disable the ADC (ADSTART or JADSTART must be equal to 1 and ADDIS to 0).

The software can write the register ADC_JSQR at any time, when the ADC is enabled (ADEN=1).

The software is allowed to write the ADC_JSQR register only when JADSTART is cleared to 0 (no injected conversion is ongoing) unless the context queue is enabled (JQDIS=0 in ADC_CFGR register).

Note: There is no hardware protection to prevent these forbidden write accesses and ADC behavior may become in an unknown state. To recover from this situation, the ADC must be disabled (clear ADEN=0 as well as all the bits of ADC_CR register).

28.4.11 Channel selection (SQRx, JSQRx)

There are up to 20 multiplexed channels per ADC:

- 6 fast analog inputs coming from Analog PADs and GPIO pads (ADCx_INP/INN[0..5])
- Up to 14 slow analog inputs coming from GPIO pads (ADCx_INP/INN[6..19]).
- The ADCs are connected to 4 internal analog inputs:
  - the internal reference voltage (V_{REFINT})
  - the V_{BAT} monitoring channel ($V_{BAT}/4$)
  - DAC internal channels

Refer to *Table ADC interconnection* in *Section 28.4.2: ADC pins and internal signals* for the connection of the above internal analog inputs to external ADC pins or internal signals.

It is possible to organize the conversions in two groups: regular and injected. A group consists of a sequence of conversions that can be done on any channel and in any order. For instance, it is possible to implement the conversion sequence in the following order:

ADCx_INP/INN3, ADCx_INP/INN8, ADCx_INP/INN2, ADCx_INP/INN2, ADCx_INP/INN0, ADCx_INP/INN2, ADCx_INP/INN2, ADCx_INP/INN15.

- A **regular group** is composed of up to 16 conversions. The regular channels and their order in the conversion sequence must be selected in the ADC_SQRy registers. The total number of conversions in the regular group must be written in the L[3:0] bits in the ADC_SQR1 register.
- An **injected group** is composed of up to 4 conversions. The injected channels and their order in the conversion sequence must be selected in the ADC_JSQR register. The total number of conversions in the injected group must be written in the L[1:0] bits in the ADC_JSQR register.

ADC_SQRy registers must not be modified while regular conversions can occur. For this, the ADC regular conversions must be first stopped by writing ADSTP=1 (refer to *Section 28.4.18: Stopping an ongoing conversion (ADSTP, JADSTP)*).

The software is allowed to modify on-the-fly the ADC_JSQR register when JADSTART is set to 1 only when the context queue is enabled (JQDIS=0 in ADC_CFGR register).

V_{REFINT} and V_{BAT} internal channels

The internal reference voltage (V_{REFINT}), and the V_{BAT} channel are connected to ADC internal channels. Refer to *Table ADC interconnection* in *Section 28.4.2: ADC pins and internal signals* for details.

Note: To convert one of the internal analog channels, enable the corresponding analog sources by programming VREFEN and VBATEN bits in the ADC3_CCR registers, and select the multiplexer by SYSCFG_ADC2ALT register.

28.4.12 Channel preselection register (ADC_PCSEL)

For each channel selected through SQRx or JSQRx, the corresponding ADC_PCSEL bit must be previously configured.

This ADC_PCSEL bit controls the analog switch integrated in the I/O level. The ADC input MUX selects the ADC input according to the SQRx and JSQRx with very high speed, the analog switch integrated in the IO cannot react as fast as ADC mux does. To avoid the delay on analog switch control on IO, it is necessary to pre select the input channels which will be selected in the SQRx, JSQRx.

The selection is based on the $V_{INP[i]}$ of each ADC input. If ADC1 converts the ADC12_INP2($V_{INP[2]}$) as differential mode, ADC12_INP6($V_{INP[6]}$) also needs to be selected in ADC_PCSEL.

Some I/Os are connected to several $V_{INP[i]}$ of the ADCx. The control inputs of the analog switch are ORed with the corresponding ADC_PCSEL register bits.

28.4.13 Channel-wise programmable sampling time (SMPR1, SMPR2)

Before starting a conversion, the ADC must establish a direct connection between the voltage source under measurement and the embedded sampling capacitor of the ADC. This sampling time must be enough for the input voltage source to charge the embedded capacitor to the input voltage level.

Each channel can be sampled with a different sampling time which is programmable using the SMP[2:0] bits in the ADC_SMPR1 and ADC_SMPR2 registers. It is therefore possible to select among the following sampling time values:

- SMP = 000: 1.5 ADC clock cycles
- SMP = 001: 2.5 ADC clock cycles
- SMP = 010: 8.5 ADC clock cycles
- SMP = 011: 16.5 ADC clock cycles
- SMP = 100: 32.5 ADC clock cycles
- SMP = 101: 64.5 ADC clock cycles
- SMP = 110: 387.5 ADC clock cycles
- SMP = 111: 810.5 ADC clock cycles

The total conversion time is calculated as follows:

T_{CONV} = Sampling time + 7.5 ADC clock cycles

Example:

With $F_{adc\_ker\_ck}$ = 24 MHz and a sampling time of 1.5 ADC clock cycles (14-bit mode):

T_{CONV} = (1.5 + 7.5) ADC clock cycles = 9 ADC clock cycles = 0.375 µs (14 bit mode for fast channels)

The ADC notifies the end of the sampling phase by setting the status bit EOSMP (only for regular conversion).

Constraints on the sampling time for fast and slow channels

For each channel, SMP[2:0] bits must be programmed to respect a minimum sampling time as specified in the ADC characteristics section of the datasheets.

I/O analog switches voltage booster

The I/O analog switches resistance increases when the V_{DDA} voltage is too low. This requires to have the sampling time adapted accordingly (refer to the datasheet for electrical characteristics). This resistance can be minimized at low V_{DDA} by enabling an internal voltage booster with BOOSTE bit in the SYSCFG_PMCR register.

28.4.14 Single conversion mode (CONT=0)

In Single conversion mode, the ADC performs once all the conversions of the channels. This mode is started with the CONT bit at 0 by either:

- Setting the ADSTART bit in the ADC_CR register (for a regular channel, with software trigger selected)
- Setting the JADSTART bit in the ADC_CR register (for an injected channel, with software trigger selected)
- External hardware trigger event (for a regular or injected channel)

  ADSTART bit or JADSTART bit must be set before triggering an external event.

Inside the regular sequence, after each conversion is complete:

- The converted data are stored into the 32-bit ADC_DR register
- The EOC (end of regular conversion) flag is set
- An interrupt is generated if the EOCIE bit is set

Inside the injected sequence, after each conversion is complete:

- The converted data are stored into one of the four 32-bit ADC_JDRy registers
- The JEOC (end of injected conversion) flag is set
- An interrupt is generated if the JEOCIE bit is set

After the regular sequence is complete:

- The EOS (end of regular sequence) flag is set
- An interrupt is generated if the EOSIE bit is set

After the injected sequence is complete:

- The JEOS (end of injected sequence) flag is set
- An interrupt is generated if the JEOSIE bit is set

Then the ADC stops until a new external regular or injected trigger occurs or until bit ADSTART or JADSTART is set again.

Note: To convert a single channel, program a sequence with a length of 1.

28.4.15 Continuous conversion mode (CONT=1)

This mode applies to regular channels only.

In continuous conversion mode, when a software or hardware regular trigger event occurs, the ADC performs once all the regular conversions of the channels and then automatically re-starts and continuously converts each conversions of the sequence. This mode is started with the CONT bit at 1 either by external trigger or by setting the ADSTART bit in the ADC_CR register.

Inside the regular sequence, after each conversion is complete:

- The converted data are stored into the 32-bit ADC_DR register
- The EOC (end of conversion) flag is set
- An interrupt is generated if the EOCIE bit is set

After the sequence of conversions is complete:

- The EOS (end of sequence) flag is set
- An interrupt is generated if the EOSIE bit is set

Then, a new sequence restarts immediately and the ADC continuously repeats the conversion sequence.

Note: To convert a single channel, program a sequence with a length of 1.

It is not possible to have both discontinuous mode and continuous mode enabled: it is forbidden to set both DISCEN=1 and CONT=1.

Injected channels cannot be converted continuously. The only exception is when an injected channel is configured to be converted automatically after regular channels in continuous mode (using JAUTO bit), refer to Auto-injection mode section).

28.4.16 Starting conversions (ADSTART, JADSTART)

Software starts ADC regular conversions by setting ADSTART=1.

When ADSTART is set, the conversion starts:

- Immediately: if EXTEN = 0x0 (software trigger)
- At the next active edge of the selected regular hardware trigger: if EXTEN /= 0x0

Software starts ADC injected conversions by setting JADSTART=1.

When JADSTART is set, the conversion starts:

- Immediately, if JEXTEN = 0x0 (software trigger)
- At the next active edge of the selected injected hardware trigger: if JEXTEN /= 0x0

Note: In auto-injection mode (JAUTO=1), use ADSTART bit to start the regular conversions followed by the auto-injected conversions (JADSTART must be kept cleared).

ADSTART and JADSTART also provide information on whether any ADC operation is currently ongoing. It is possible to re-configure the ADC while ADSTART=0 and JADSTART=0 are both true, indicating that the ADC is idle.

ADSTART is cleared by hardware:

- In single mode with software trigger (CONT=0, EXTEN=0x0)
  - at any end of conversion sequence (EOS =1)
- In discontinuous mode with software trigger (CONT=0, DISCEN=1, EXTEN=0x0)
  - at end of conversion (EOC=1)
- In all other cases (CONT=x, EXTEN=x)
  - after execution of the ADSTP procedure asserted by the software.

Note: In continuous mode (CONT=1), ADSTART is not cleared by hardware with the assertion of EOS because the sequence is automatically relaunched.

When a hardware trigger is selected in single mode (CONT=0 and EXTEN /=0x00), ADSTART is not cleared by hardware with the assertion of EOS to help the software which does not need to reset ADSTART again for the next hardware trigger event. This ensures that no further hardware triggers are missed.

JADSTART is cleared by hardware:

- in single mode with software injected trigger (JEXTEN=0x0)
  - at any end of injected conversion sequence (JEOS assertion) or at any end of sub-group processing if JDISCEN=1
- in all cases (JEXTEN=x)
  - after execution of the JADSTP procedure asserted by the software.

Note: When the software trigger is selected, ADSTART bit should not be set if the EOC flag is still high.

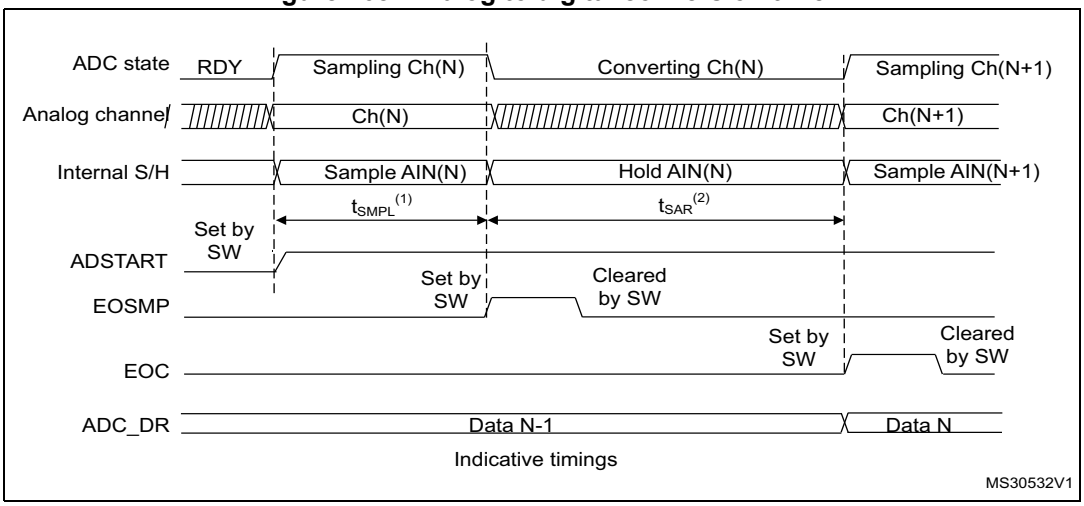
28.4.17 Timing

The elapsed time between the start of a conversion and the end of conversion is the sum of the configured sampling time plus the successive approximation time depending on data resolution:

$T_{CONV} = T_{SMPL} + T_{SAR} = [1.5\ _{|min} + 7.5\ _{|14bit}] \times T_{adc\_ker\_ck}$

$T_{CONV} = T_{SMPL} + T_{SAR} = 62.5\ ns\ _{|min} + 312.5\ ns\ _{|14bit} = 375.0\ ns$ (for $F_{adc\_ker\_ck} = 24$ MHz)

Figure 168. Analog to digital conversion time



1. T_{SMPL} depends on SMP[2:0]
2. T_{SAR} depends on RES[2:0]

28.4.18 Stopping an ongoing conversion (ADSTP, JADSTP)

The software can decide to stop regular conversions ongoing by setting ADSTP=1 and injected conversions ongoing by setting JADSTP=1.

Stopping conversions will reset the ongoing ADC operation. Then the ADC can be reconfigured (ex: changing the channel selection or the trigger) ready for a new operation.

Note that it is possible to stop injected conversions while regular conversions are still operating and vice-versa. This allows, for instance, re-configuration of the injected conversion sequence and triggers while regular conversions are still operating (and vice-versa).

When the ADSTP bit is set by software, any ongoing regular conversion is aborted with partial result discarded (ADC_DR register is not updated with the current conversion).

When the JADSTP bit is set by software, any ongoing injected conversion is aborted with partial result discarded (ADC_JDRy register is not updated with the current conversion). The scan sequence is also aborted and reset (meaning that relaunching the ADC would re-start a new sequence).

Once this procedure is complete, bits ADSTP/ADSTART (in case of regular conversion), or JADSTP/JADSTART (in case of injected conversion) are cleared by hardware and the software must poll ADSTART (or JADSTART) until the bit is reset before assuming the ADC is completely stopped.

Note: In auto-injection mode (JAUTO=1), setting ADSTP bit aborts both regular and injected conversions (JADSTP must not be used).

Figure 169. Stopping ongoing regular conversions

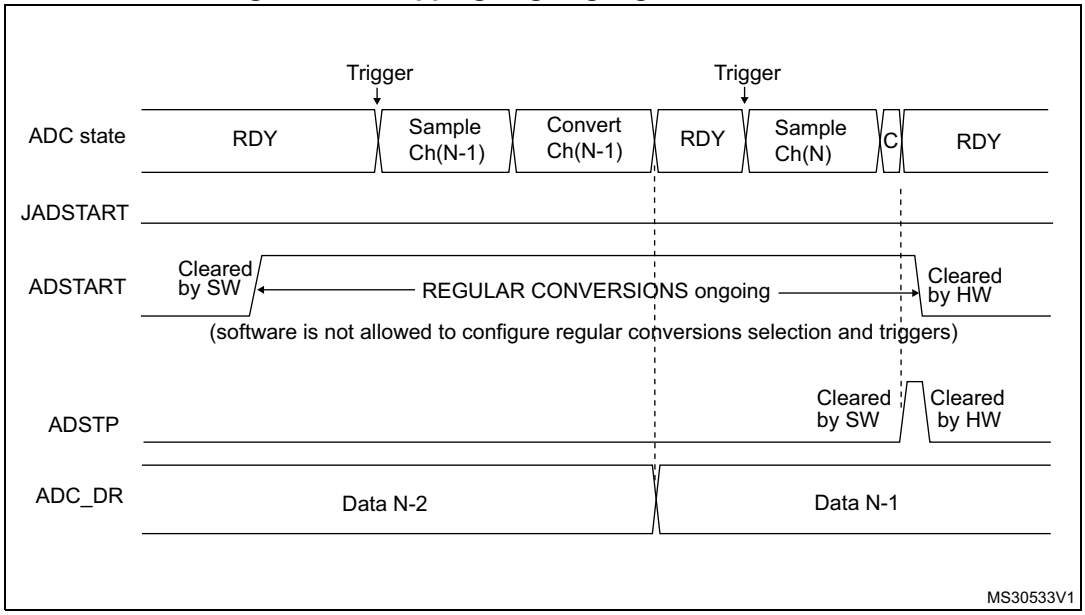
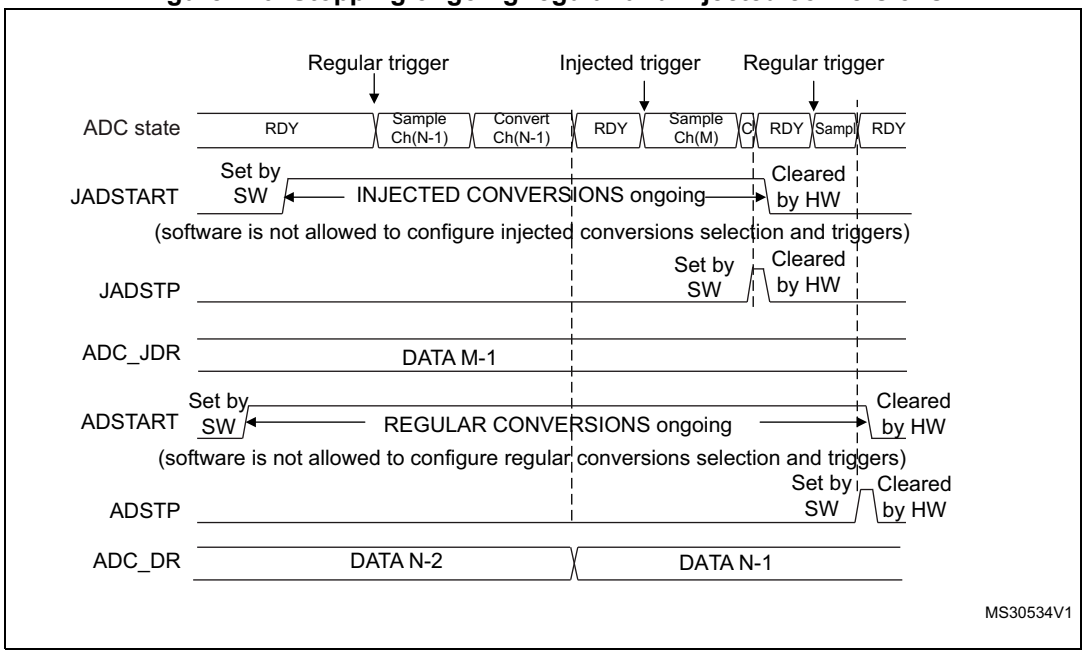


Figure 170. Stopping ongoing regular and injected conversions



28.4.19 Conversion on external trigger and trigger polarity (EXTSEL, EXTEN, JEXTSEL, JEXTEN)

A conversion or a sequence of conversions can be triggered either by software or by an external event (e.g. timer capture, input pins). If the EXTEN[1:0] control bits (for a regular conversion) or JEXTEN[1:0] bits (for an injected conversion) are different from 0b00, then external events are able to trigger a conversion with the selected polarity.

When the Injected Queue is enabled (bit JQDIS=0), injected software triggers are not possible.

The regular trigger selection is effective once software has set bit ADSTART=1 and the injected trigger selection is effective once software has set bit JADSTART=1.

Any hardware triggers which occur while a conversion is ongoing are ignored.

- If bit ADSTART=0, any regular hardware triggers which occur are ignored.
- If bit JADSTART=0, any injected hardware triggers which occur are ignored.

Table 224 provides the correspondence between the EXTEN[1:0] and JEXTEN[1:0] values and the trigger polarity.

Table 224. Configuring the trigger polarity for regular external triggers

EXTEN[1:0]	Source
00	Hardware Trigger detection disabled, software trigger detection enabled
01	Hardware Trigger with detection on the rising edge
10	Hardware Trigger with detection on the falling edge
11	Hardware Trigger with detection on both the rising and falling edges

Note: The polarity of the regular trigger cannot be changed on-the-fly.

Table 225. Configuring the trigger polarity for injected external triggers

JEXTEN[1:0]	Source
00	– If JQDIS=1 (Queue disabled): Hardware trigger detection disabled, software trigger detection enabled – If JQDIS=0 (Queue enabled), Hardware and software trigger detection disabled
01	Hardware Trigger with detection on the rising edge
10	Hardware Trigger with detection on the falling edge
11	Hardware Trigger with detection on both the rising and falling edges

Note: The polarity of the injected trigger can be anticipated and changed on-the-fly when the queue is enabled (JQDIS=0). Refer to Section 28.4.22: Queue of context for injected conversions.

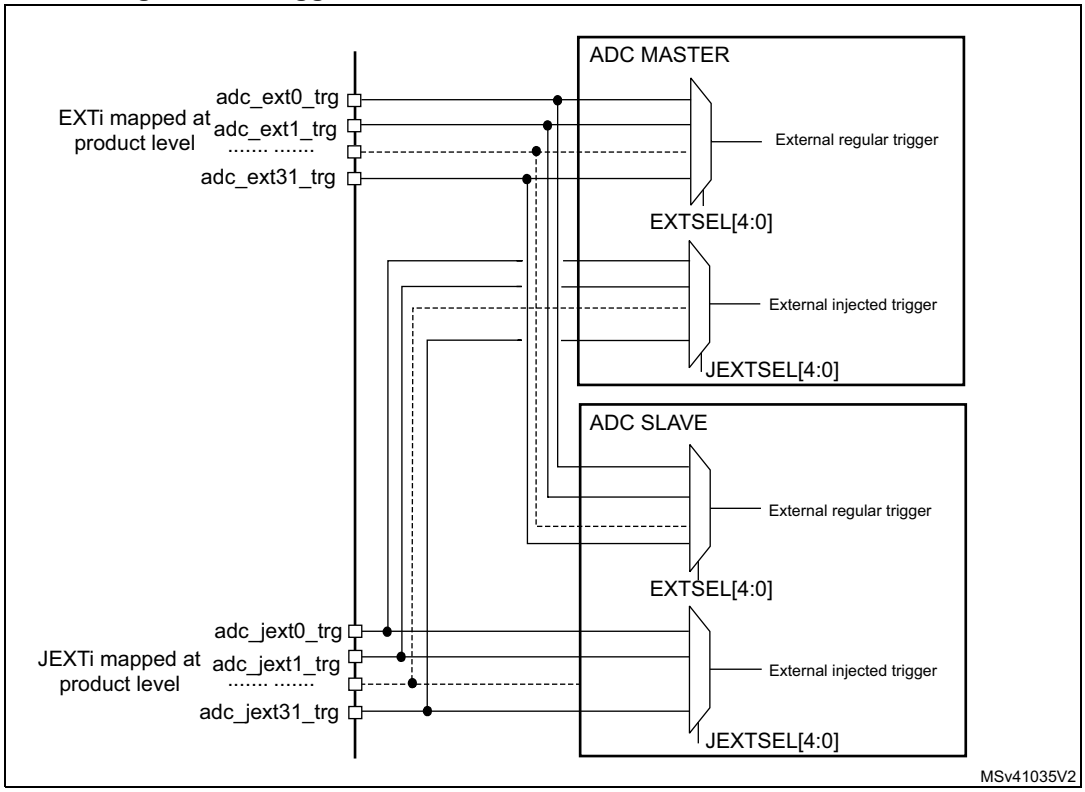
The EXTSEL[4:0] and JEXTSEL[4:0] control bits select which out of 23 possible events can trigger conversion for the regular and injected groups.

A regular group conversion can be interrupted by an injected trigger.

Note: The regular trigger selection cannot be changed on-the-fly.
The injected trigger selection can be anticipated and changed on-the-fly. Refer to Section 28.4.22: Queue of context for injected conversions on page 1005

Each ADC master shares the same input triggers with its ADC slave as described in *Figure 171*.

Figure 171. Triggers are shared between ADC master and ADC slave



give all the possible external triggers of the three ADCs for regular and injected conversion.

Table 226. ADC1 and ADC2- External triggers for regular channels

Name	Source	Type	EXTSEL[4:0]
adc_ext_trg0	tim1_oc1	Internal signal from on-chip timers	00000
adc_ext_trg1	tim1_oc2	Internal signal from on-chip timers	00001
adc_ext_trg2	tim1_oc3	Internal signal from on-chip timers	00010
adc_ext_trg3	tim2_oc2	Internal signal from on-chip timers	00011
adc_ext_trg4	tim3_trgo	Internal signal from on-chip timers	00100
adc_ext_trg5	tim4_oc4	Internal signal from on-chip timers	00101
adc_ext_trg6	exti11	External pin	00110
adc_ext_trg7	tim8_trgo	Internal signal from on-chip timers	00111
adc_ext_trg8	tim8_trgo2	Internal signal from on-chip timers	01000
adc_ext_trg9	tim1_trgo	Internal signal from on-chip timers	01001

Table 226. ADC1 and ADC2- External triggers for regular channels (continued)

Name	Source	Type	EXTSEL[4:0]
adc_ext_trg10	tim1_trgo2	Internal signal from on-chip timers	01010
adc_ext_trg11	tim2_trgo	Internal signal from on-chip timers	01011
adc_ext_trg12	tim4_trgo	Internal signal from on-chip timers	01100
adc_ext_trg13	tim6_trgo	Internal signal from on-chip timers	01101
adc_ext_trg14	tim15_trgo	Internal signal from on-chip timers	01110
adc_ext_trg15	tim3_oc4	Internal signal from on-chip timers	01111
adc_ext_trg16	reserved	-	10000
adc_ext_trg17	reserved	-	10001
adc_ext_trg18	lptim1_out	Internal signal from on-chip timers	10010
adc_ext_trg19	lptim2_out	Internal signal from on-chip timers	10011
adc_ext_trg20	lptim3_out	Internal signal from on-chip timers	10100
adc_ext_trg21	tim23_trgo	Internal signal from on-chip timers	10101
adc_ext_trg22	tim24_trgo	Internal signal from on-chip timers	10110
adc_ext_trg23	Reserved	-	10111
adc_ext_trg24	Reserved	-	11000
adc_ext_trg25	Reserved	-	11001
adc_ext_trg26	Reserved	-	11010
adc_ext_trg27	Reserved	-	11011
adc_ext_trg28	Reserved	-	11100
adc_ext_trg29	Reserved	-	11101
adc_ext_trg30	Reserved	-	11110
adc_ext_trg31	Reserved	-	11111

Table 227. ADC1 and ADC2 - External triggers for injected channels

Name	Source	Type	JEXTSEL[4:0]
adc_jext_trg0	tim1_trgo	Internal signal from on-chip timers	00000
adc_jext_trg1	tim1_oc4	Internal signal from on-chip timers	00001
adc_jext_trg2	tim2_trgo	Internal signal from on-chip timers	00010
adc_jext_trg3	tim2_oc1	Internal signal from on-chip timers	00011
adc_jext_trg4	tim3_oc4	Internal signal from on-chip timers	00100
adc_jext_trg5	tim4_trgo	Internal signal from on-chip timers	00101
adc_jext_trg6	exti15	External pin	00110
adc_jext_trg7	tim8_oc4	Internal signal from on-chip timers	00111
adc_jext_trg8	tim1_trgo2	Internal signal from on-chip timers	01000
adc_jext_trg9	tim8_trgo	Internal signal from on-chip timers	01001

Table 227. ADC1 and ADC2 - External triggers for injected channels (continued)

Name	Source	Type	JEXTSEL[4:0]
adc_jext_trg10	tim8_trgo2	Internal signal from on-chip timers	01010
adc_jext_trg11	tim3_oc3	Internal signal from on-chip timers	01011
adc_jext_trg12	tim3_trgo	Internal signal from on-chip timers	01100
adc_jext_trg13	tim3_oc1	Internal signal from on-chip timers	01101
adc_jext_trg14	tim6_trgo	Internal signal from on-chip timers	01110
adc_jext_trg15	tim15_trgo	Internal signal from on-chip timers	01111
adc_jext_trg16	Reserved	-	10000
adc_jext_trg17	Reserved	-	10001
adc_jext_trg18	lptim1_out	Internal signal from on-chip timers	10010
adc_jext_trg19	lptim2_out	Internal signal from on-chip timers	10011
adc_jext_trg20	lptim3_out	Internal signal from on-chip timers	10100
adc_jext_trg21	tim23_trgo	Internal signal from on-chip timers	10101
adc_jext_trg22	tim24_trgo	Internal signal from on-chip timers	10110
adc_jext_trg23	Reserved	-	10111
adc_jext_trg24	Reserved	-	11000
adc_jext_trg25	Reserved	-	11001
adc_jext_trg26	Reserved	-	11010
adc_jext_trg27	Reserved	-	11011
adc_jext_trg28	Reserved	-	11100
adc_jext_trg29	Reserved	-	11101
adc_jext_trg30	Reserved	-	11110
adc_jext_trg31	Reserved	-	11111

28.4.20 Injected channel management

Triggered injection mode

To use triggered injection, the JAUTO bit in the ADC_CFGR register must be cleared.

1. Start the conversion of a group of regular channels either by an external trigger or by setting the ADSTART bit in the ADC_CR register.
2. If an external injected trigger occurs, or if the JADSTART bit in the ADC_CR register is set during the conversion of a regular group of channels, the current conversion is

reset and the injected channel sequence switches are launched (all the injected channels are converted once).

3. Then, the regular conversion of the regular group of channels is resumed from the last interrupted regular conversion.
4. If a regular event occurs during an injected conversion, the injected conversion is not interrupted but the regular sequence is executed at the end of the injected sequence. *Figure 172* shows the corresponding timing diagram.

Note: When using triggered injection, one must ensure that the interval between trigger events is longer than the injection sequence. For instance, if the sequence length is 20 ADC clock cycles (that is two conversions with a sampling time of 1.5 clock periods), the minimum interval between triggers must be 21 ADC clock cycles.

Auto-injection mode

If the JAUTO bit in the ADC_CFGR register is set, then the channels in the injected group are automatically converted after the regular group of channels. This can be used to convert a sequence of up to 20 conversions programmed in the ADC_SQRy and ADC_JSQR registers.

In this mode, the ADSTART bit in the ADC_CR register must be set to start regular conversions, followed by injected conversions (JADSTART must be kept cleared). Setting the ADSTP bit aborts both regular and injected conversions (JADSTP bit must not be used).

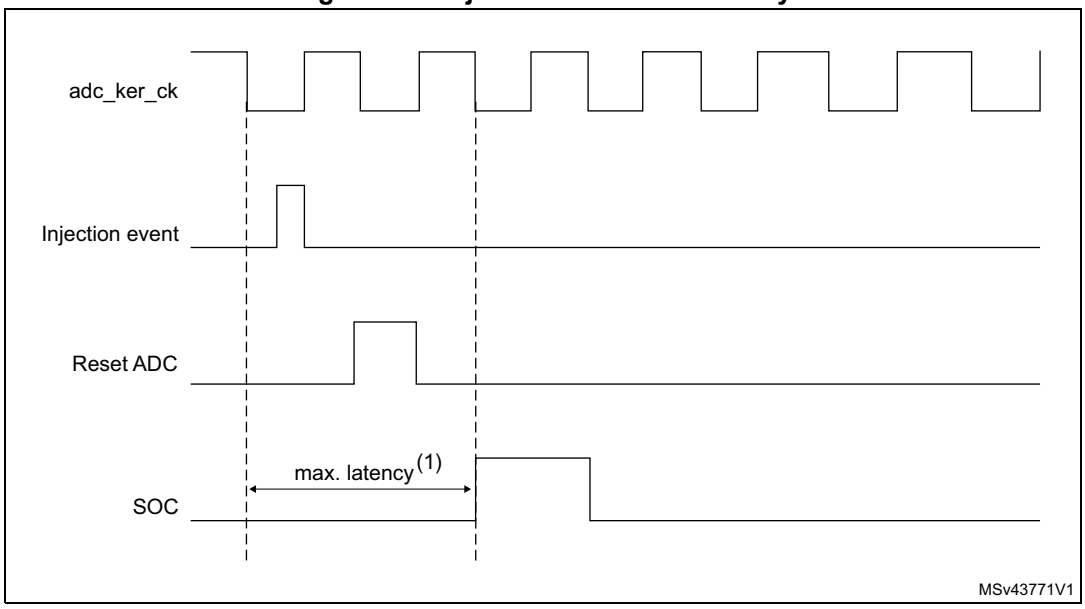
In this mode, external trigger on injected channels must be disabled.

If the CONT bit is also set in addition to the JAUTO bit, regular channels followed by injected channels are continuously converted.

Note: It is not possible to use both the auto-injected and discontinuous modes simultaneously.

When the DMA is used for exporting regular sequencer's data in JAUTO mode, it is necessary to program it in circular mode (CIRC bit set in DMA_CCRx register). If the CIRC bit is reset (single-shot mode), the JAUTO sequence will be stopped upon DMA Transfer Complete event.

Figure 172. Injected conversion latency



1. The maximum latency value can be found in the electrical characteristics of the device datasheet.

28.4.21 Discontinuous mode (DISCEN, DISCNUM, JDISCEN)

Regular group mode

This mode is enabled by setting the DISCEN bit in the ADC_CFGR register.

It is used to convert a short sequence (sub-group) of n conversions (n ≤ 8) that is part of the sequence of conversions selected in the ADC_SQRy registers. The value of n is specified by writing to the DISCNUM[2:0] bits in the ADC_CFGR register.

When an external trigger occurs, it starts the next n conversions selected in the ADC_SQR registers until all the conversions in the sequence are done. The total sequence length is defined by the L[3:0] bits in the ADC_SQR1 register.

Example:

- DISCEN=1, n=3, channels to be converted = 1, 2, 3, 6, 7, 8, 9, 10, 11
  - 1st trigger: channels converted are 1, 2, 3 (an EOC event is generated at each conversion).
  - 2nd trigger: channels converted are 6, 7, 8 (an EOC event is generated at each conversion).
  - 3rd trigger: channels converted are 9, 10, 11 (an EOC event is generated at each conversion) and an EOS event is generated after the conversion of channel 11.
  - 4th trigger: channels converted are 1, 2, 3 (an EOC event is generated at each conversion).
  - ...
- DISCEN=0, channels to be converted = 1, 2, 3, 6, 7, 8, 9, 10,11
  - 1st trigger: the complete sequence is converted: channel 1, then 2, 3, 6, 7, 8, 9, 10 and 11. Each conversion generates an EOC event and the last one also generates an EOS event.
  - all the next trigger events will relaunch the complete sequence.

Note: When a regular group is converted in discontinuous mode, no rollover occurs (the last subgroup of the sequence can have less than n conversions).

When all subgroups are converted, the next trigger starts the conversion of the first subgroup. In the example above, the 4th trigger reconverts the channels 1, 2 and 3 in the 1st subgroup.

It is not possible to have both discontinuous mode and continuous mode enabled. In this case (if DISCEN=1, CONT=1), the ADC behaves as if continuous mode was disabled.

Injected group mode

This mode is enabled by setting the JDISCEN bit in the ADC_CFGR register. It converts the sequence selected in the ADC_JSQR register, channel by channel, after an external injected trigger event. This is equivalent to discontinuous mode for regular channels where ‘n’ is fixed to 1.

When an external trigger occurs, it starts the next channel conversions selected in the ADC_JSQR registers until all the conversions in the sequence are done. The total sequence length is defined by the JL[1:0] bits in the ADC_JSQR register.

Example:

- JDISCEN=1, channels to be converted = 1, 2, 3
  - 1st trigger: channel 1 converted (a JEOC event is generated)
  - 2nd trigger: channel 2 converted (a JEOC event is generated)
  - 3rd trigger: channel 3 converted and a JEOC event + a JEOS event are generated
  - ...

Note: When all injected channels have been converted, the next trigger starts the conversion of the first injected channel. In the example above, the 4th trigger reconverts the 1st injected channel 1.

It is not possible to use both auto-injected mode and discontinuous mode simultaneously: the bits DISCEN and JDISCEN must be kept cleared by software when JAUTO is set.

28.4.22 Queue of context for injected conversions

A queue of context is implemented to anticipate up to 2 contexts for the next injected sequence of conversions. JQDIS bit of ADC_CFGR register must be reset to enable this feature. Only hardware-triggered conversions are possible when the context queue is enabled.

This context consists of:

- Configuration of the injected triggers (bits JEXTEN[1:0] and JEXTSEL[4:0] in ADC_JSQR register)
- Definition of the injected sequence (bits JSQx[4:0] and JL[1:0] in ADC_JSQR register)

All the parameters of the context are defined into a single register ADC_JSQR and this register implements a queue of 2 buffers, allowing the bufferization of up to 2 sets of parameters:

- The ADC_JSQR register can be written at any moment even when injected conversions are ongoing.
- Each data written into the JSQR register is stored into the Queue of context.
- At the beginning, the Queue is empty and the first write access into the JSQR register immediately changes the context and the ADC is ready to receive injected triggers.
- Once an injected sequence is complete, the Queue is consumed and the context changes according to the next JSQR parameters stored in the Queue. This new context is applied for the next injected sequence of conversions.
- A Queue overflow occurs when writing into register JSQR while the Queue is full. This overflow is signaled by the assertion of the flag JQOVF. When an overflow occurs, the write access of JSQR register which has created the overflow is ignored and the queue of context is unchanged. An interrupt can be generated if bit JQOVFIE is set.
- Two possible behaviors are possible when the Queue becomes empty, depending on the value of the control bit JQM of register ADC_CFGR:
  - If JQM=0, the Queue is empty just after enabling the ADC, but then it can never be empty during run operations: the Queue always maintains the last active context and any further valid start of injected sequence will be served according to the last active context.
  - If JQM=1, the Queue can be empty after the end of an injected sequence or if the Queue is flushed. When this occurs, there is no more context in the queue and hardware triggers are disabled. Therefore, any further hardware injected triggers are ignored until the software re-writes a new injected context into JSQR register.
- Reading JSQR register returns the current JSQR context which is active at that moment. When the JSQR context is empty, JSQR is read as 0x0000.
- The Queue is flushed when stopping injected conversions by setting JADSTP=1 or when disabling the ADC by setting ADDIS=1:
  - If JQM=0, the Queue is maintained with the last active context.
  - If JQM=1, the Queue becomes empty and triggers are ignored.

Note: When configured in discontinuous mode (bit JDISCEN=1), only the last trigger of the injected sequence changes the context and consumes the Queue.The 1st trigger only consumes the queue but others are still valid triggers as shown by the discontinuous mode example below (length = 3 for both contexts):

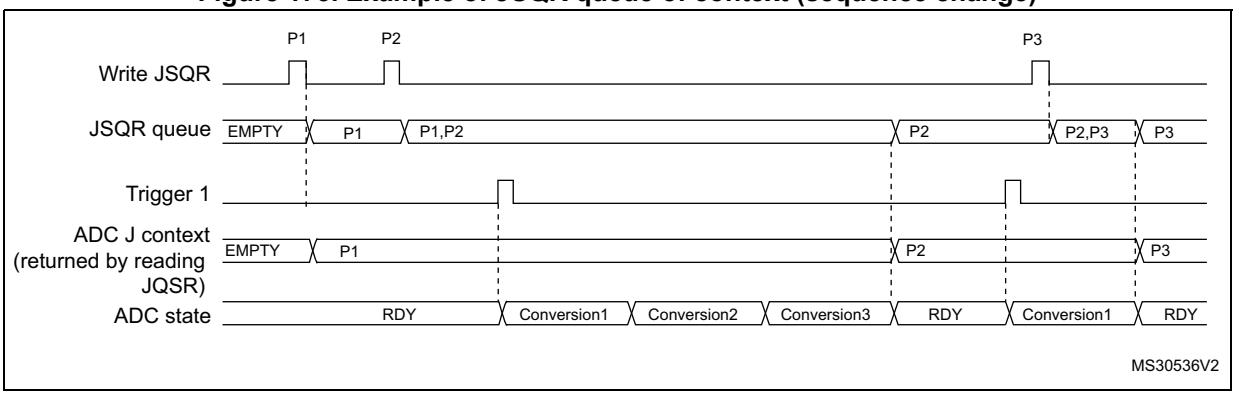
- *1st trigger, discontinuous. Sequence 1: context 1 consumed, 1st conversion carried out*
- *2nd trigger, disc. Sequence 1: 2nd conversion.*
- *3rd trigger, discontinuous. Sequence 1: 3rd conversion.*
- *4th trigger, discontinuous. Sequence 2: context 2 consumed, 1st conversion carried out.*
- *5th trigger, discontinuous. Sequence 2: 2nd conversion.*
- *6th trigger, discontinuous. Sequence 2: 3rd conversion.*

Note: When queue of context enabled (bit JQDIS=0), only hardware trigger can be used.

Behavior when changing the trigger or sequence context

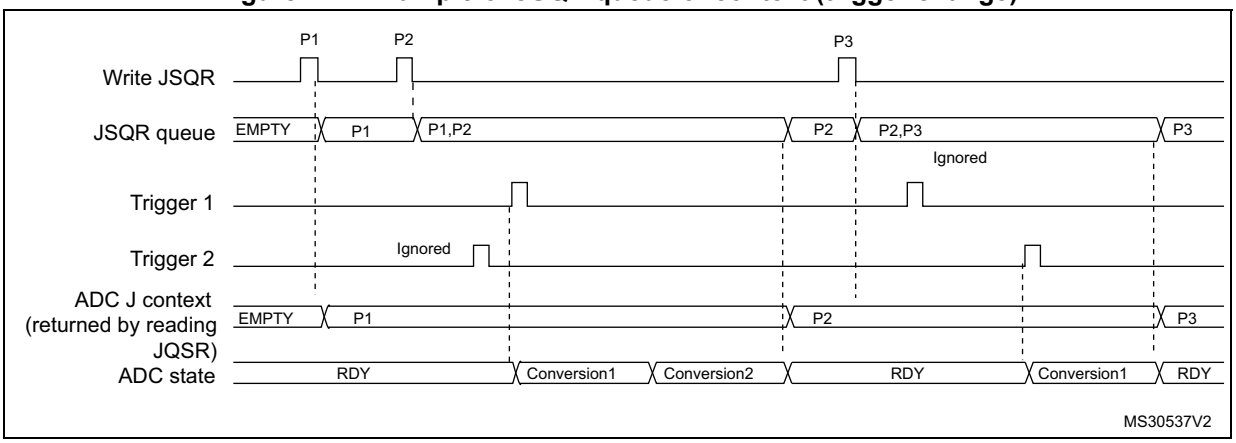
The *Figure 173* and *Figure 174* show the behavior of the context Queue when changing the sequence or the triggers.

Figure 173. Example of JSQR queue of context (sequence change)



1. Parameters:
   P1: sequence of 3 conversions, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 4 conversions, hardware trigger 1

Figure 174. Example of JSQR queue of context (trigger change)

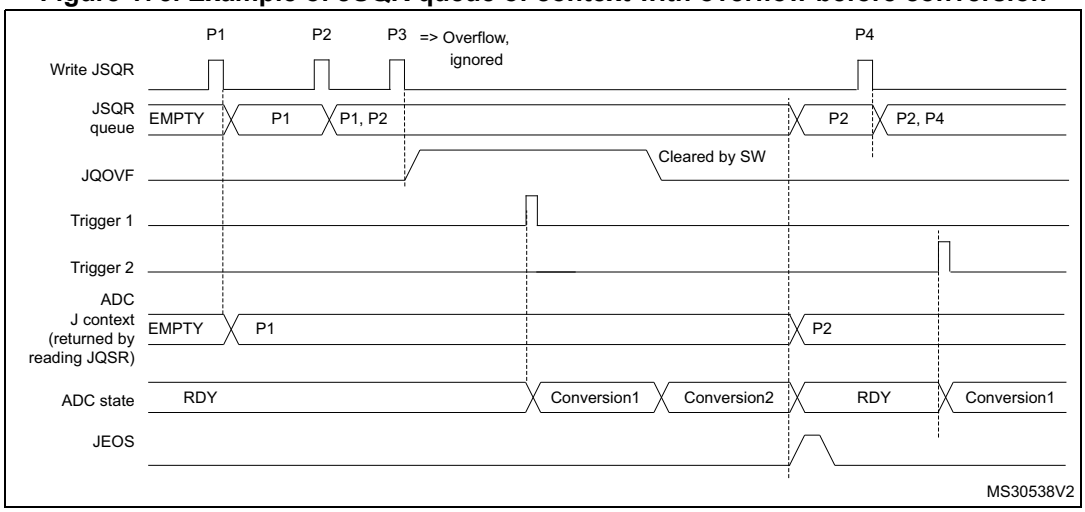


1. Parameters:
   P1: sequence of 2 conversions, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 2
   P3: sequence of 4 conversions, hardware trigger 1

Queue of context: Behavior when a queue overflow occurs

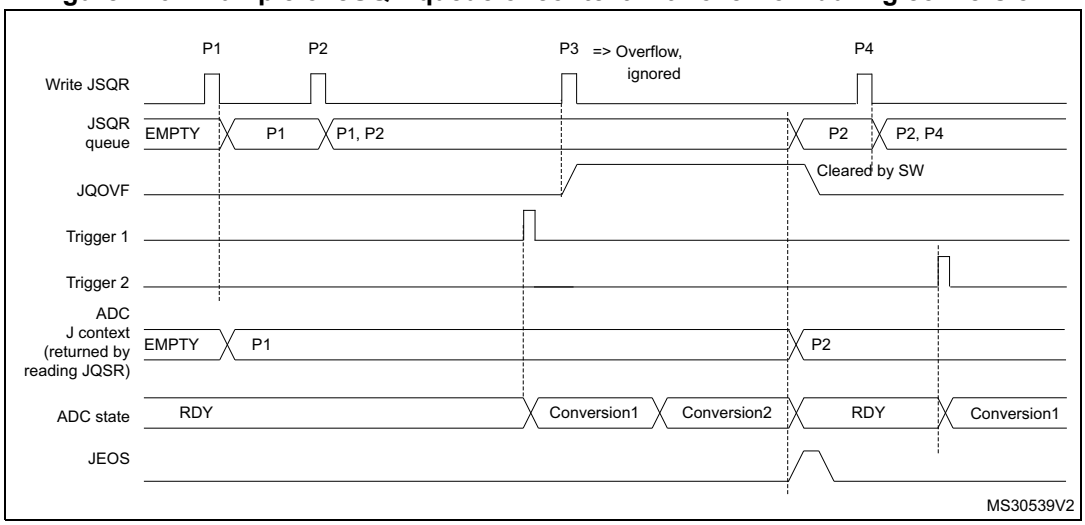
The *Figure 175* and *Figure 176* show the behavior of the context Queue if an overflow occurs before or during a conversion.

Figure 175. Example of JSQR queue of context with overflow before conversion



1. Parameters:
   P1: sequence of 2 conversions, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 2
   P3: sequence of 3 conversions, hardware trigger 1
   P4: sequence of 4 conversions, hardware trigger 1

Figure 176. Example of JSQR queue of context with overflow during conversion



1. Parameters:
   P1: sequence of 2 conversions, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 2
   P3: sequence of 3 conversions, hardware trigger 1
   P4: sequence of 4 conversions, hardware trigger 1

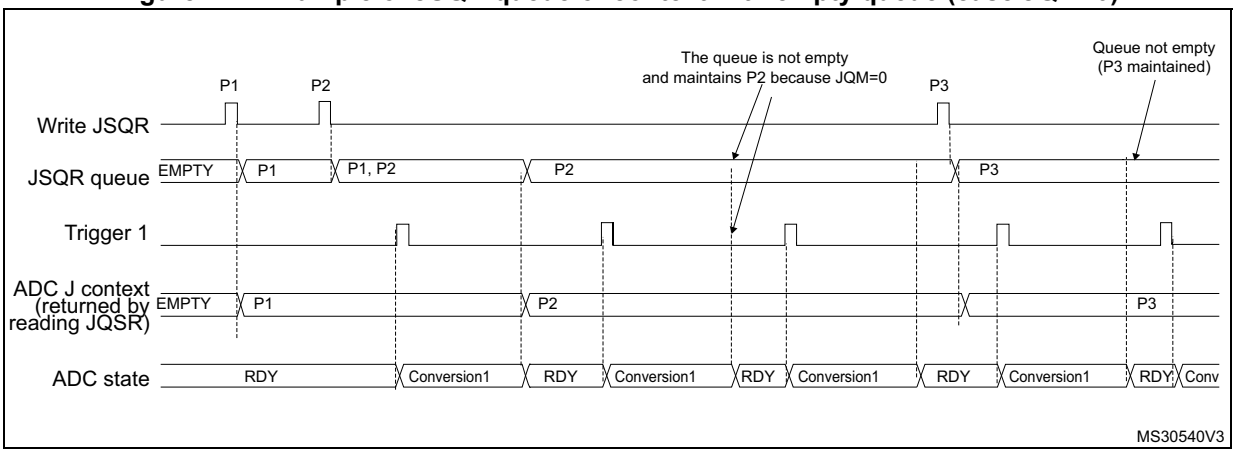
It is recommended to manage the queue overflows as described below:

- After each P context write into JSQR register, flag JQOVF shows if the write has been ignored or not (an interrupt can be generated).
- Avoid Queue overflows by writing the third context (P3) only once the flag JEOS of the previous context P2 has been set. This ensures that the previous context has been consumed and that the queue is not full.

Queue of context: Behavior when the queue becomes empty

Figure 177 and *Figure 178* show the behavior of the context Queue when the Queue becomes empty in both cases JQM=0 or 1.

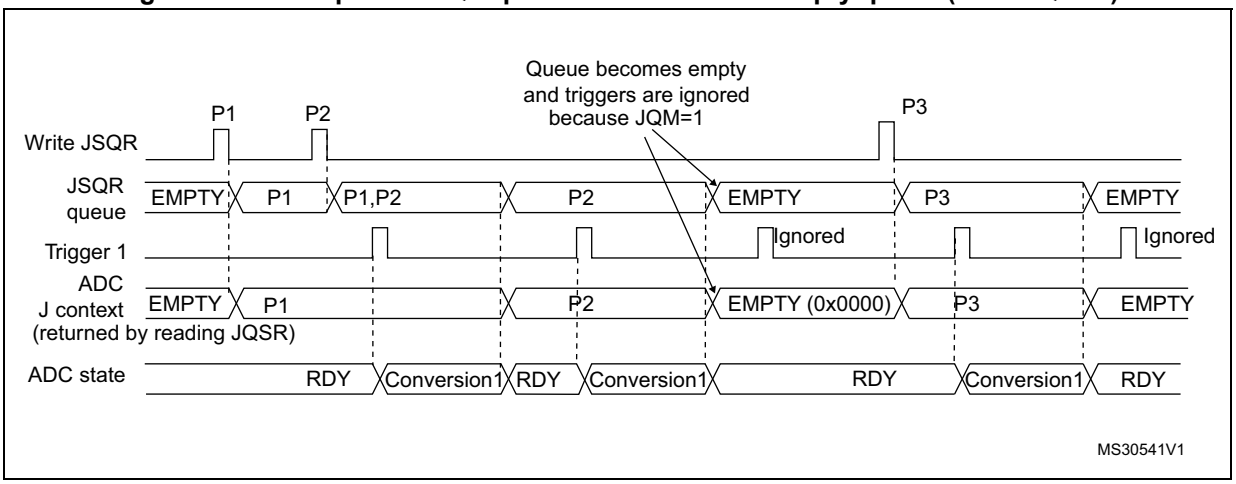
Figure 177. Example of JSQR queue of context with empty queue (case JQM=0)



1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Note: When writing P3, the context changes immediately. However, because of internal resynchronization, there is a latency and if a trigger occurs just after or before writing P3, it can happen that the conversion is launched considering the context P2. To avoid this situation, the user must ensure that there is no ADC trigger happening when writing a new context that applies immediately.

Figure 178. Example of JSQR queue of context with empty queue (case JQM=1)

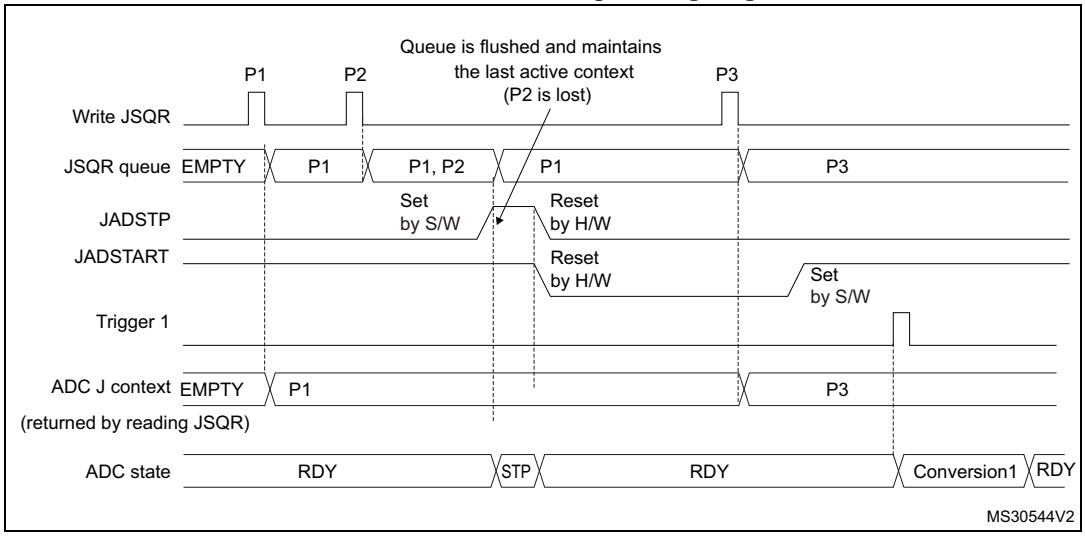


1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Flushing the queue of context

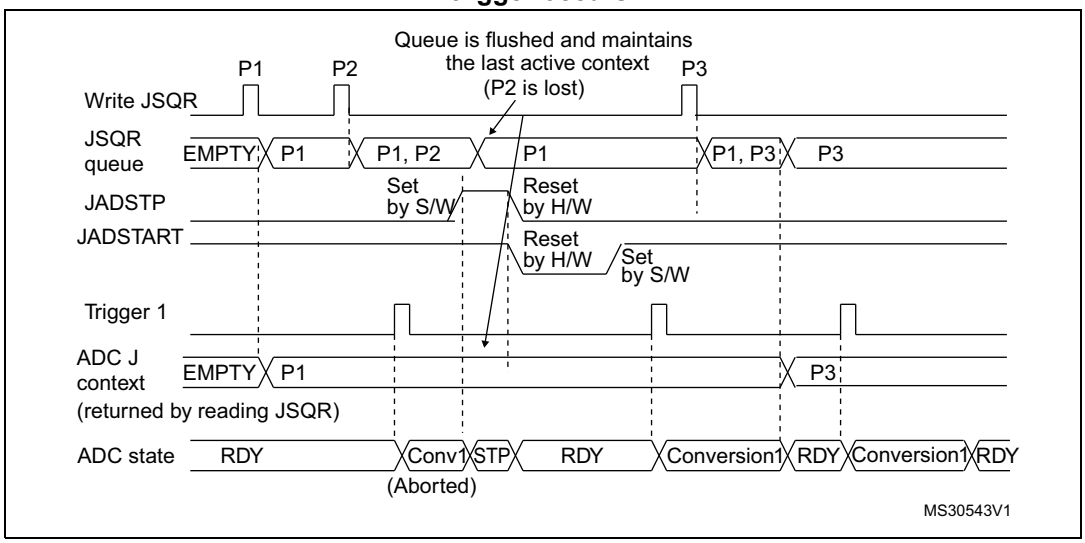
The figures below show the behavior of the context Queue in various situations when the queue is flushed.

Figure 179. Flushing JSQR queue of context by setting JADSTP=1 (JQM=0). Case when JADSTP occurs during an ongoing conversion.



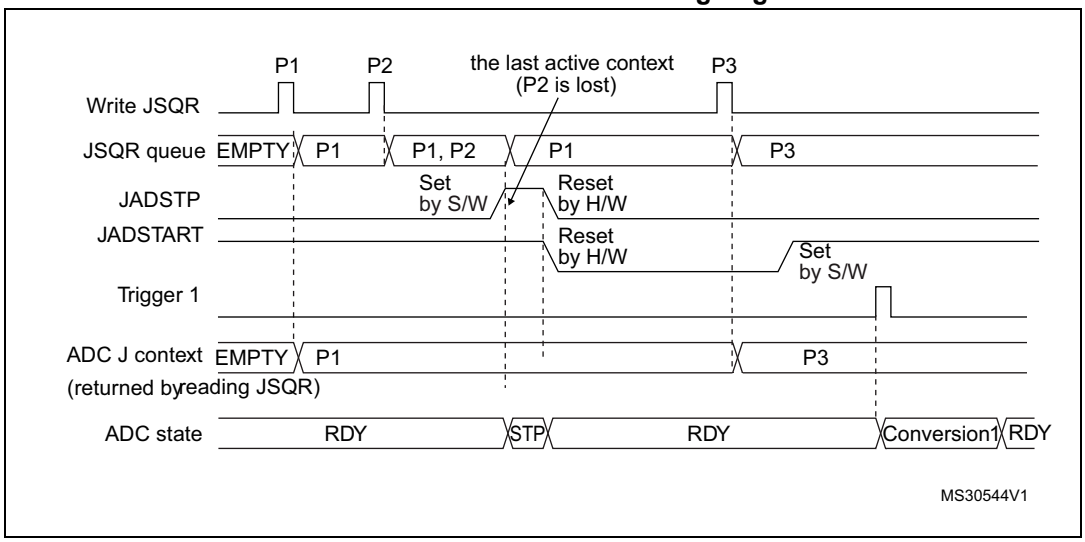
1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 180. Flushing JSQR queue of context by setting JADSTP=1 (JQM=0). Case when JADSTP occurs during an ongoing conversion and a new trigger occurs.



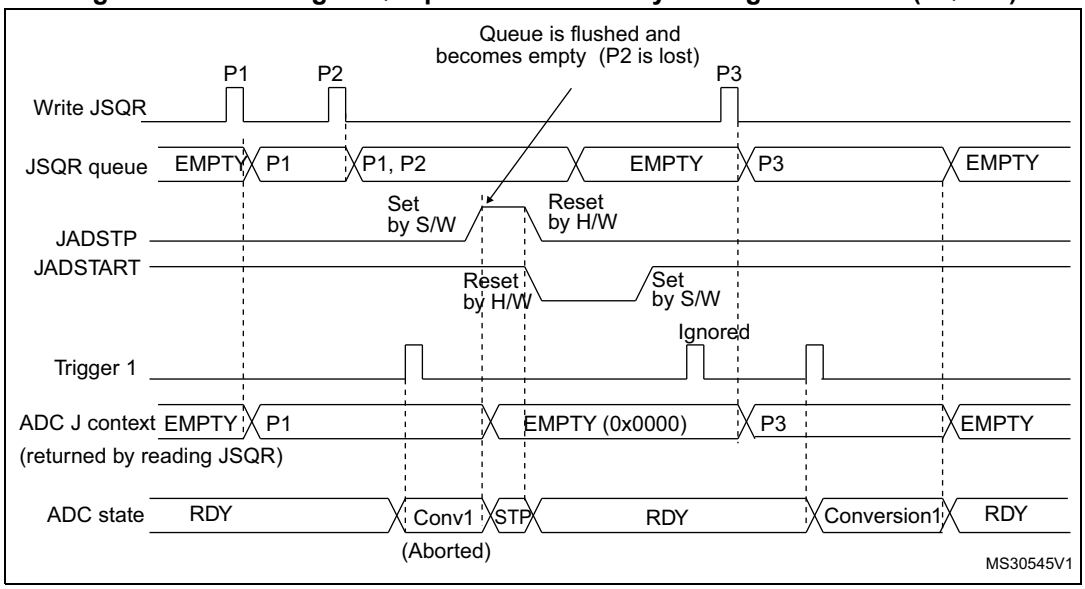
1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 181. Flushing JSQR queue of context by setting JADSTP=1 (JQM=0). Case when JADSTP occurs outside an ongoing conversion



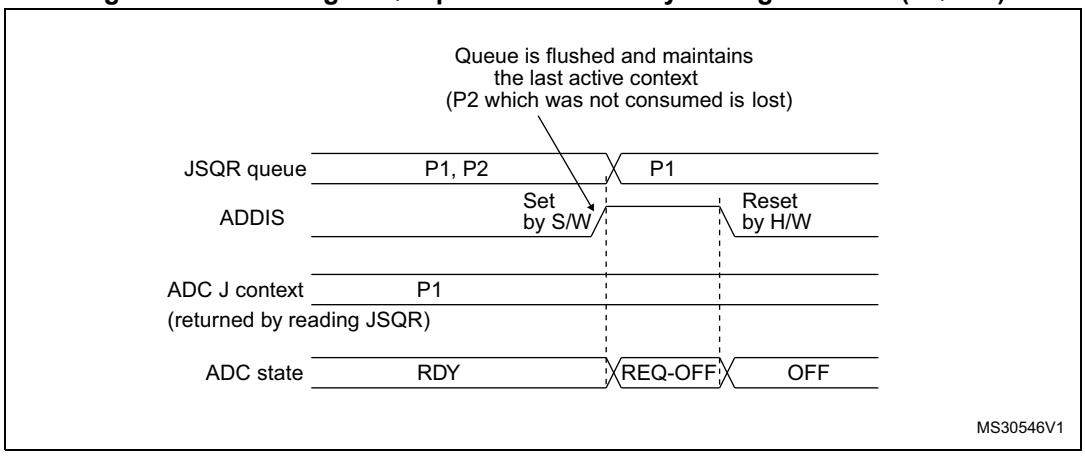
1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 182. Flushing JSQR queue of context by setting JADSTP=1 (JQM=1)



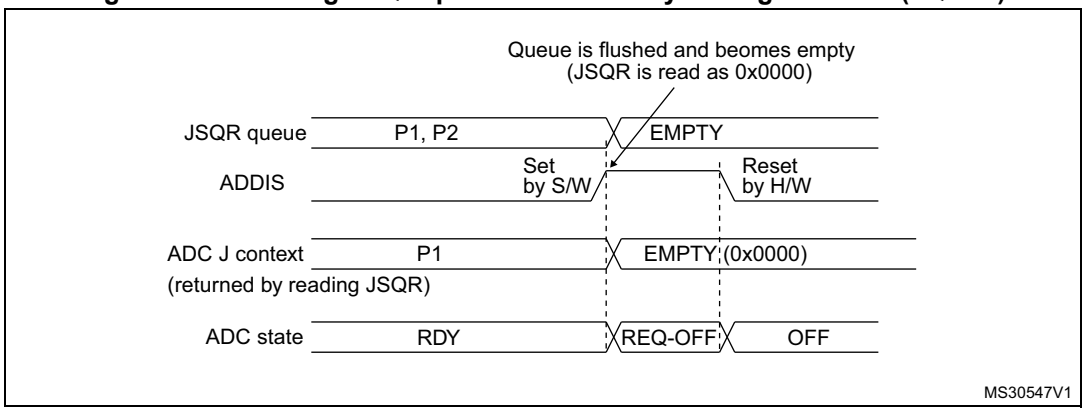
1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 183. Flushing JSQR queue of context by setting ADDIS=1 (JQM=0)



1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 184. Flushing JSQR queue of context by setting ADDIS=1 (JQM=1)



1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Queue of context: Starting the ADC with an empty queue

The following procedure must be followed to start ADC operation with an empty queue, in case the first context is not known at the time the ADC is initialized. This procedure is only applicable when JQM bit is reset:

5. Write a dummy JSQR with JEXTEN not equal to 0 (otherwise triggering a software conversion)
6. Set JADSTART
7. Set JADSTP
8. Wait until JADSTART is reset
9. Set JADSTART.

Disabling the queue

It is possible to disable the queue by setting bit JQDIS=1 into the ADC_CFGR register.

Queue of context: Programming of the register ADC_JSQR

When the injected conversion queue of context is enabled (JQDIS=0), the ADC_JSQR must be programmed at one register write access. As JL[1:0] register define the number of the injected sequence, corresponding JSQ1 to JSQ4 must be written at same time. If ADC_JSQR is reprogrammed before the injected conversion start, reprogrammed data is put on the queue. When queue of context is empty, ADC_JSQR read back as 0x0000. Register access should not use the ‘read modify write’ sequence.

When ADC_JSQR is programmed when already 2 contexts are queued, it will raise JQOVF flag and generate the interrupt.

28.4.23 Programmable resolution (RES) - fast conversion mode

It is possible to perform faster conversion by reducing the ADC resolution.

The resolution can be configured to be either 16, 14, 12, 10, 8 bits by programming the control bits RES[1:0]. *Figure 189*, *Figure 190*, *Figure 191* and *Figure 192* show the conversion result format with respect to the resolution as well as to the data alignment.

Lower resolution allows faster conversion time for applications where high-data precision is not required. It reduces the conversion time spent by the successive approximation steps according to *Table 228*.

Table 228. T_{SAR} timings depending on resolution

RES [2:0]	T_{SAR} (ADC clock cycles)	T_{SAR} (ns) at $F_{adc\_ker\_ck}$=24 MHz	$T_{adc\_ker\_ck}$ (ADC clock cycles) (with Sampling Time= 1.5 ADC clock cycles)	$T_{adc\_ker\_ck}$ (ns) at $F_{adc\_ker\_ck}$=24 MHz
16 bits	8.5 ADC clock cycles	354.2	10 ADC clock cycles	416.7
14 bits	7.5 ADC clock cycles	312.5	9 ADC clock cycles	375
12 bits	6.5 ADC clock cycles	270.8	8 ADC clock cycles	333.3
10 bits	5.5 ADC clock cycles	229.2	7 ADC clock cycles	291.7
8 bits	4.5 ADC clock cycles	187.5	6 ADC clock cycles	250.0

28.4.24 End of conversion, end of sampling phase (EOC, JEOC, EOSMP)

The ADC notifies the application for each end of regular conversion (EOC) event and each injected conversion (JEOC) event.

The ADC sets the EOC flag as soon as a new regular conversion data is available in the ADC_DR register. An interrupt can be generated if bit EOCIE is set. EOC flag is cleared by the software either by writing 1 to it or by reading ADC_DR.

The ADC sets the JEOC flag as soon as a new injected conversion data is available in one of the ADC_JDRy register. An interrupt can be generated if bit JEOCIE is set. JEOC flag is cleared by the software either by writing 1 to it or by reading the corresponding ADC_JDRy register.

The ADC also notifies the end of Sampling phase by setting the status bit EOSMP (for regular conversions only). EOSMP flag is cleared by software by writing 1 to it. An interrupt can be generated if bit EOSMPIE is set.

28.4.25 End of conversion sequence (EOS, JEOS)

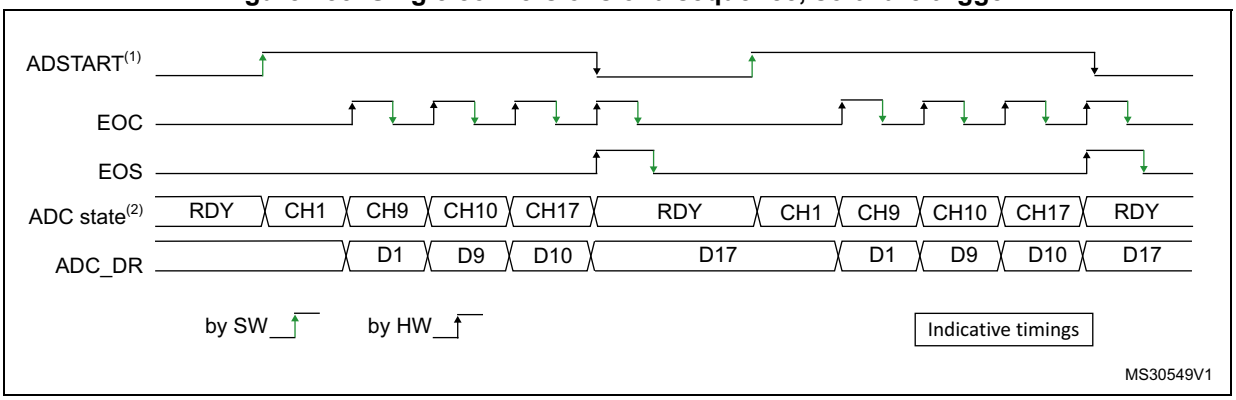
The ADC notifies the application for each end of regular sequence (EOS) and for each end of injected sequence (JEOS) event.

The ADC sets the EOS flag as soon as the last data of the regular conversion sequence is available in the ADC_DR register. An interrupt can be generated if bit EOSIE is set. EOS flag is cleared by the software either by writing 1 to it.

The ADC sets the JEOS flag as soon as the last data of the injected conversion sequence is complete. An interrupt can be generated if bit JEOSIE is set. JEOS flag is cleared by the software either by writing 1 to it.

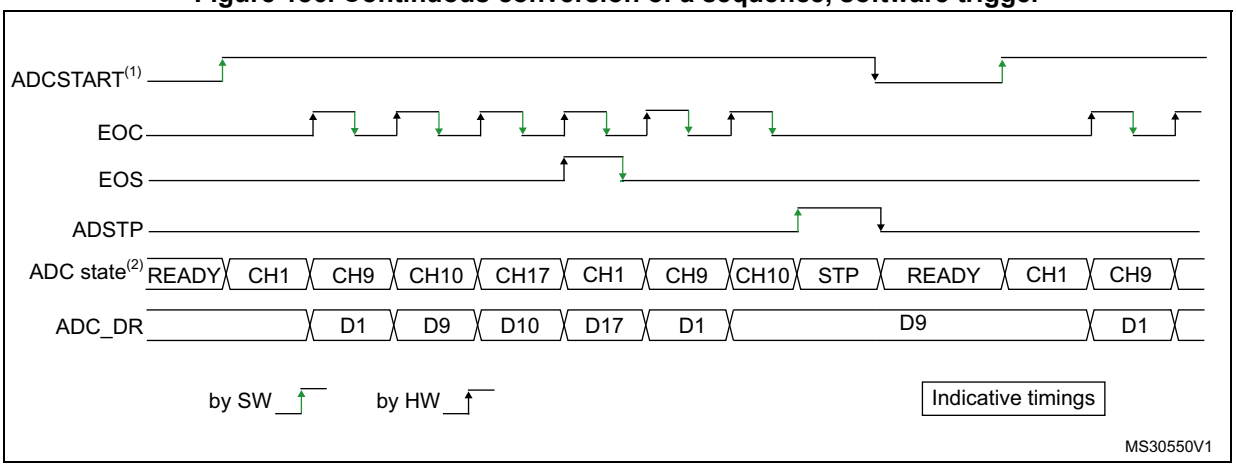
28.4.26 Timing diagrams example (single/continuous modes, hardware/software triggers)

Figure 185. Single conversions of a sequence, software trigger



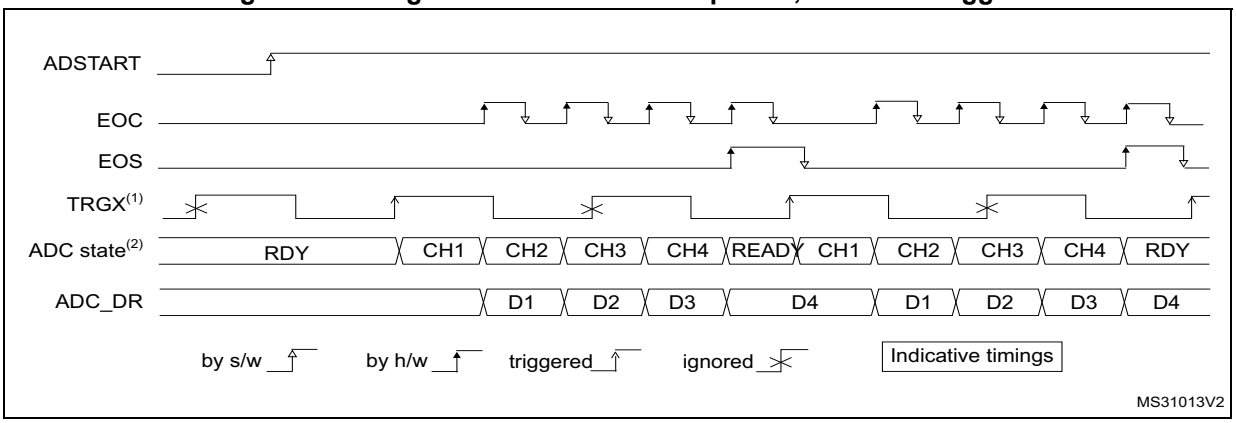
1. EXTEN=0x0, CONT=0
2. Channels selected = 1,9, 10, 17; AUTDLY=0.

Figure 186. Continuous conversion of a sequence, software trigger



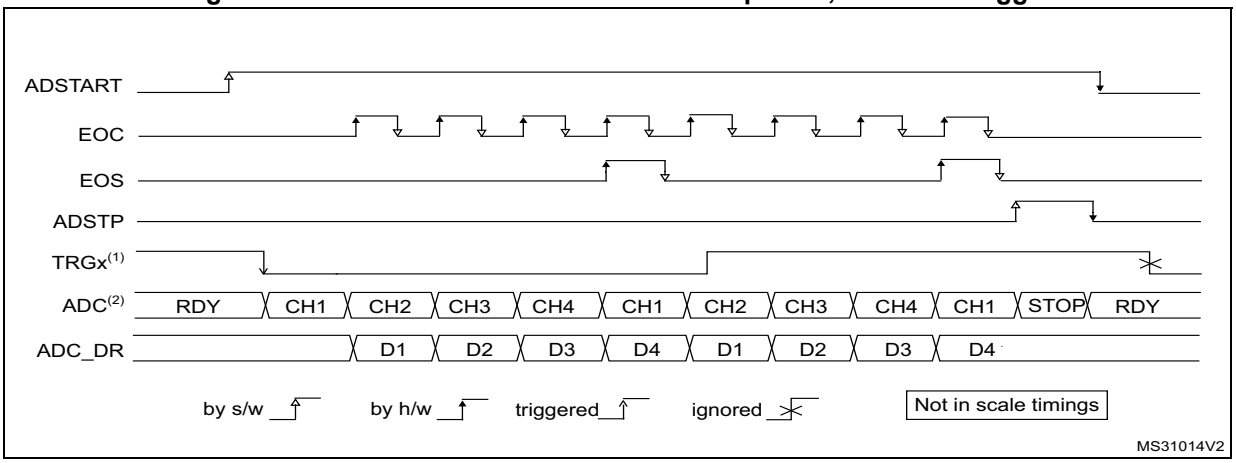
1. EXTEN=0x0, CONT=1
2. Channels selected = 1,9, 10, 17; AUTDLY=0.

Figure 187. Single conversions of a sequence, hardware trigger



1. TRGx (over-frequency) is selected as trigger source, EXTEN = 01, CONT = 0
2. Channels selected = 1, 2, 3, 4; AUTDLY=0.

Figure 188. Continuous conversions of a sequence, hardware trigger



1. TRGx is selected as trigger source, EXTEN = 10, CONT = 1
2. Channels selected = 1, 2, 3, 4; AUTDLY=0.

28.4.27 Data management

Data register, data alignment and offset (ADC_DR, ADC_JDRy, OFFSETy, OFFSETy_CH, OVSS, LSHIFT, RSHIFT, SSATE)

Data and alignment

At the end of each regular conversion channel (when EOC event occurs), the result of the converted data is stored into the ADC_DR data register which is 32 bits wide.

At the end of each injected conversion channel (when JEOC event occurs), the result of the converted data is stored into the corresponding ADC_JDRy data register which is 32 bits wide.

The OVSS[3:0] and LSHIFT[3:0] bitfields in the ADC_CFGR2 register selects the alignment of the data stored after conversion. Data can be right- or left-aligned as shown in *Figure 189*, *Figure 190*, *Figure 191* and *Figure 192*.

Note: The data can be re-aligned in normal and in oversampling mode.

Offset

An offset y (y=1, 2, 3, 4) can be applied to a channel by programming a value different from 0 in OFFSETy[25:0] bitfield into ADC_OFRy register. The channel to which the offset will be applied is programmed into the bits OFFSETy_CH[4:0] of ADC_OFRy register. In this case, the converted value is decreased by the user-defined offset written in the bits OFFSETy[25:0]. The result may be a negative value so the read data is signed and the SEXT bit represents the extended sign value.

The offset value should be lower than the max conversion value (ex. 16bit mode, offset value max is 0xFFFF).

The offset correction is also supported in oversampling mode. For the oversampling mode, offset is subtracted before OVSS right shift applied.

Table 229 describes how the comparison is performed for all the possible resolutions for analog watchdog 1, 2, 3.

Table 229. Offset computation versus data resolution

Resolution (bits RES[2:0])	Subtraction between raw converted data and offset:		Result	Comments
	Raw converted Data, left aligned	Offset		
16 bits	DATA[15:0]	OFFSET[25:0]	signed 27-bit data	-
14 bits	DATA[15:2],00	OFFSET[25:0]	signed 27-bit data	The user must configure OFFSET[1:0] to 00
12 bits	DATA[15:4],0000	OFFSET[25:0]	signed 27-bit data	The user must configure OFFSET[3:0] to 0000
10 bits	DATA[15:6],000000	OFFSET[25:0]	signed 27-bit data	The user must configure OFFSET[5:0] to 000000
8 bits	DATA[15:8],000000	OFFSET[25:0]	signed 27-bit data	The user must configure OFFSET[7:0] to 00000000

Figure 189, *Figure 190*, *Figure 191* and *Figure 192* show alignments for signed and unsigned data together with corresponding OVSS and LSHIFT values.

Figure 189. Right alignment (offset disabled, unsigned value)

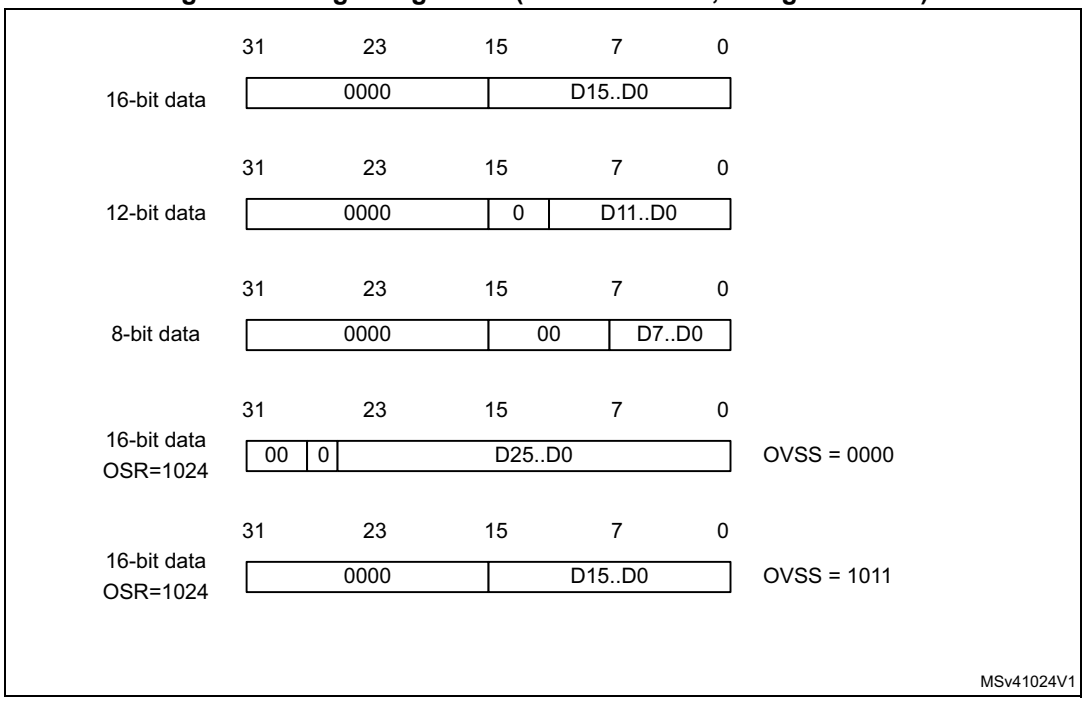


Figure 190. Right alignment (offset enabled, signed value)

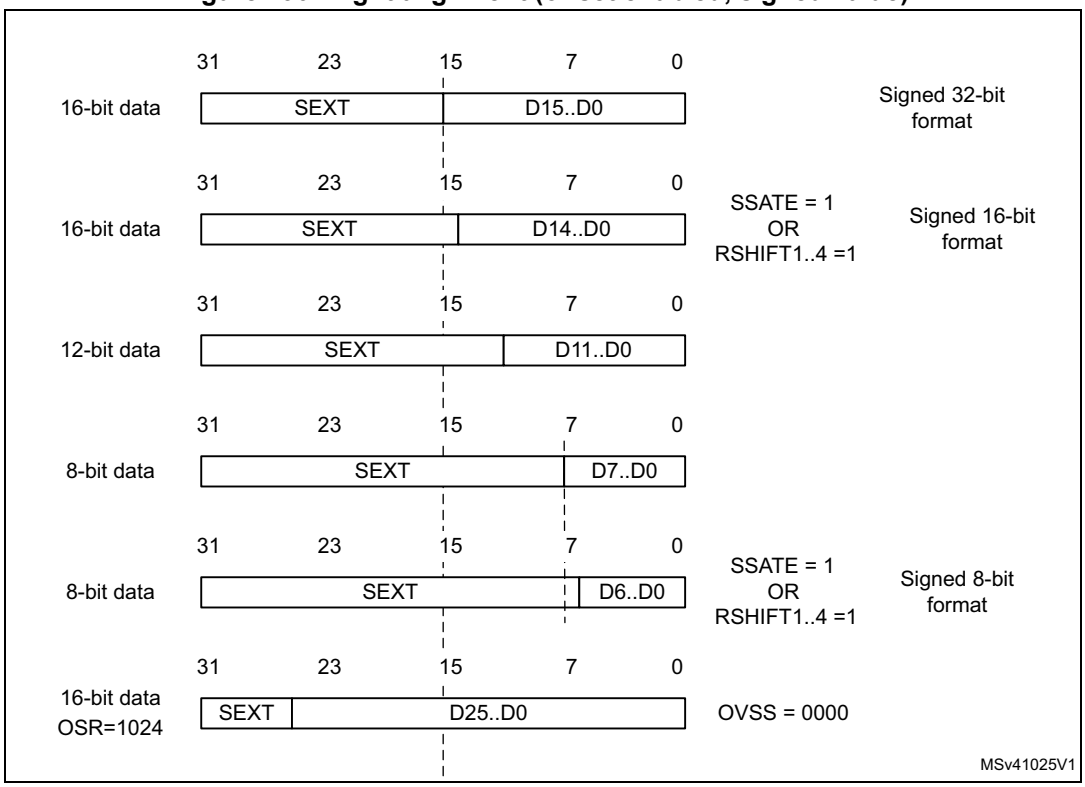


Figure 191. Left alignment (offset disabled, unsigned value)

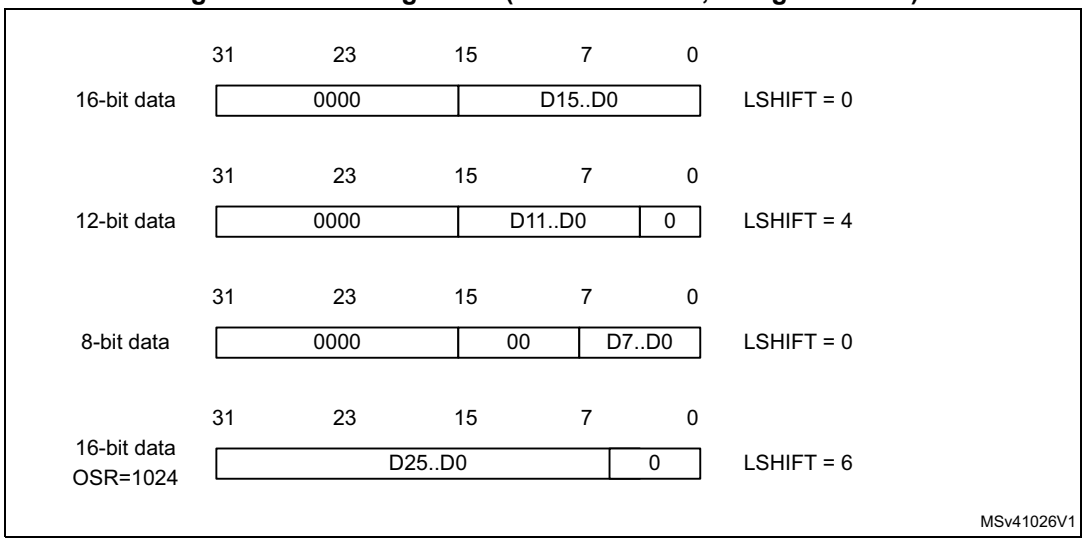
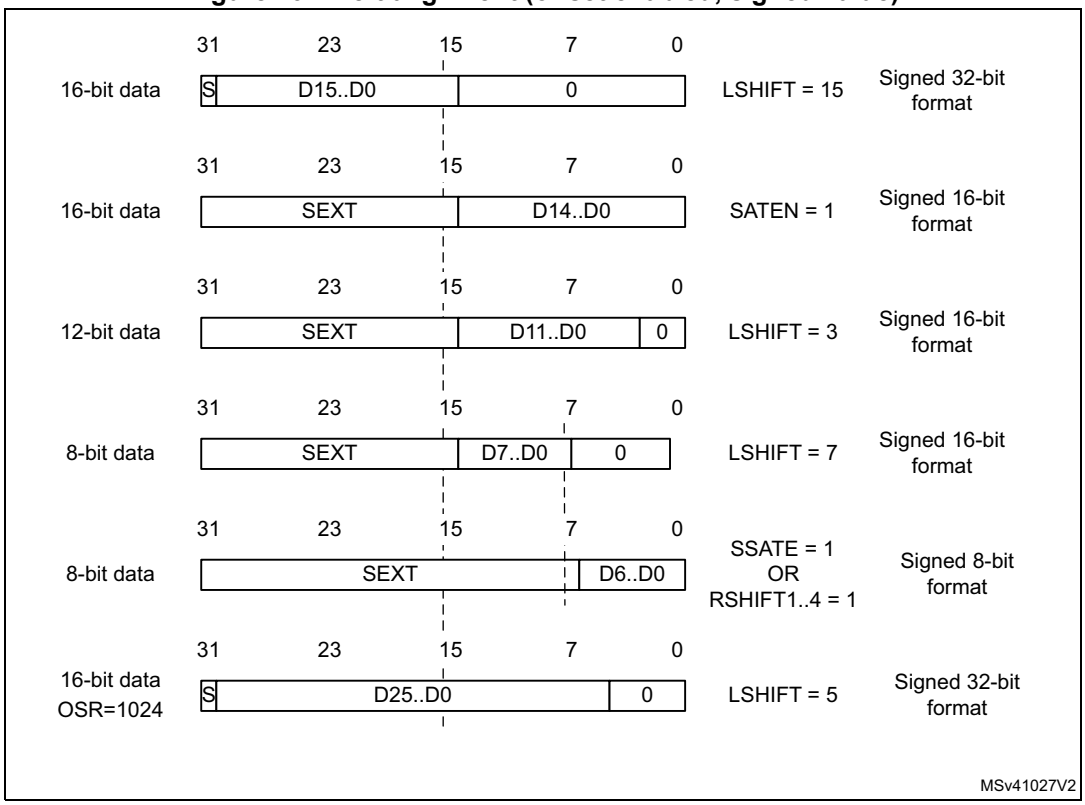


Figure 192. Left alignment (offset enabled, signed value)



16-bit and 8-bit signed format management: RSHIFTx,SSATE

The offset correction sign-extends the data format, resulting in an unsigned 16-bit conversion being extended to 17-bit signed format, for instance.

Three options are offered for formatting 8-bit and 16-bit conversion results.

For each offset correction channel 1 to 4, a RSHIFT1..4 bit in the ADC_CFGR2 register allows to have the result right-shifted 1-bit and have it fitting a standard 8 or 16-bit format.

Another option is to have the result saturated to the 16-bit and 8-bit signed formats, for the following cases only: RES[2:0] = 000 (16-bit format) and RES[2:0] = (8-bit format).

This mode is enabled with the SSATE bit in the ADC_OFRy register.

The table below summarizes the 3 available use case for 16-bit format.

Table 230. 16-bit data formats

SSATE	RSHIFTx	Format	Data range (offset = 0x8000)
0	0	Sign-extended 17-bit significant data SEXT[31:16] DATA[15:0]	0x00007FFF - 0x FFFF8000
0	1	Sign-extended right-shifted 16-bit significant data SEXT[31:15] DATA[14:0]	0x3FFF - 0xC000
1	0	Sign-extended saturated 16-bit significant data SEXT[31:15] DATA[14:0]	7FFF - 0x8000
1	1	Reserved	-

Numerical examples are given in *Table 231* with 3 different offset values.

Table 231. Numerical examples for 16-bit format (bold indicates saturation)

Raw conversion result	Offset value	Result SSATE = 0 RSHIFT = 0	Result SSATE = 0 RSHIFT = 1	Result SSATE = 1 RSHIFT = 0
0xFFFF	0x8000	0x0000 7FFF	3FFF	7FFF
0x8000		0x0000 0000	0	0
0x0000		0xFFFF 8000	C000	8000
0xFFFF	0x8020	0x0000 7FDF	3FEF	7FDF
0x8000		0xFFFF FFE0	FFF0	FFE0
0x0000		0xFFFF 7FE0	BFF0	8000
0xFFFF	0x7FF0	0x0000 800F	4007	7FFF
0x8000		0x0000 0010	8	0010
0x0000		0xFFFF 8010	C008	8010

When oversampling mode is active, the SSATE and RSHIFT1..4 bits are not supported.

ADC overrun (OVR, OVRMOD)

The overrun flag (OVR) notifies of a buffer overrun event when the regular converted data has not been read (by the CPU or the DMA) before ADC_DR FIFO (eight stages) is overflowed.

The OVR flag is set when a new conversion completes while ADC_CR register FIFO was full. An interrupt is generated if OVRIE bit is set to 1.

When an overrun condition occurs, the ADC is still operating and can continue to convert unless the software decides to stop and reset the sequence by setting ADSTP to 1.

OVR flag is cleared by software by writing 1 to it.

Data can be configured to be preserved or overwritten when an overrun event occurs by programming the OVRMOD control bit of the ADC_CFGR register:

- OVRMOD = 0

  The overrun event preserves the data register from being overwritten: the old data is maintained up to ADC_DR FIFO depth (8 data) and the new conversion is discarded and lost. If OVR remains at 1, any further conversion is be performed but the resulting data is also dicarded.
- OVRMOD = 1

  The data register is overwritten with the last conversion result and the previous unread data is lost. In this mode, ADC_DR FIFO is disabled. If OVR remains at 1, any further conversion is performed normally and the ADC_DR register always contains the latest converted data.

Figure 193. Example of overrun (OVRMOD = 0)

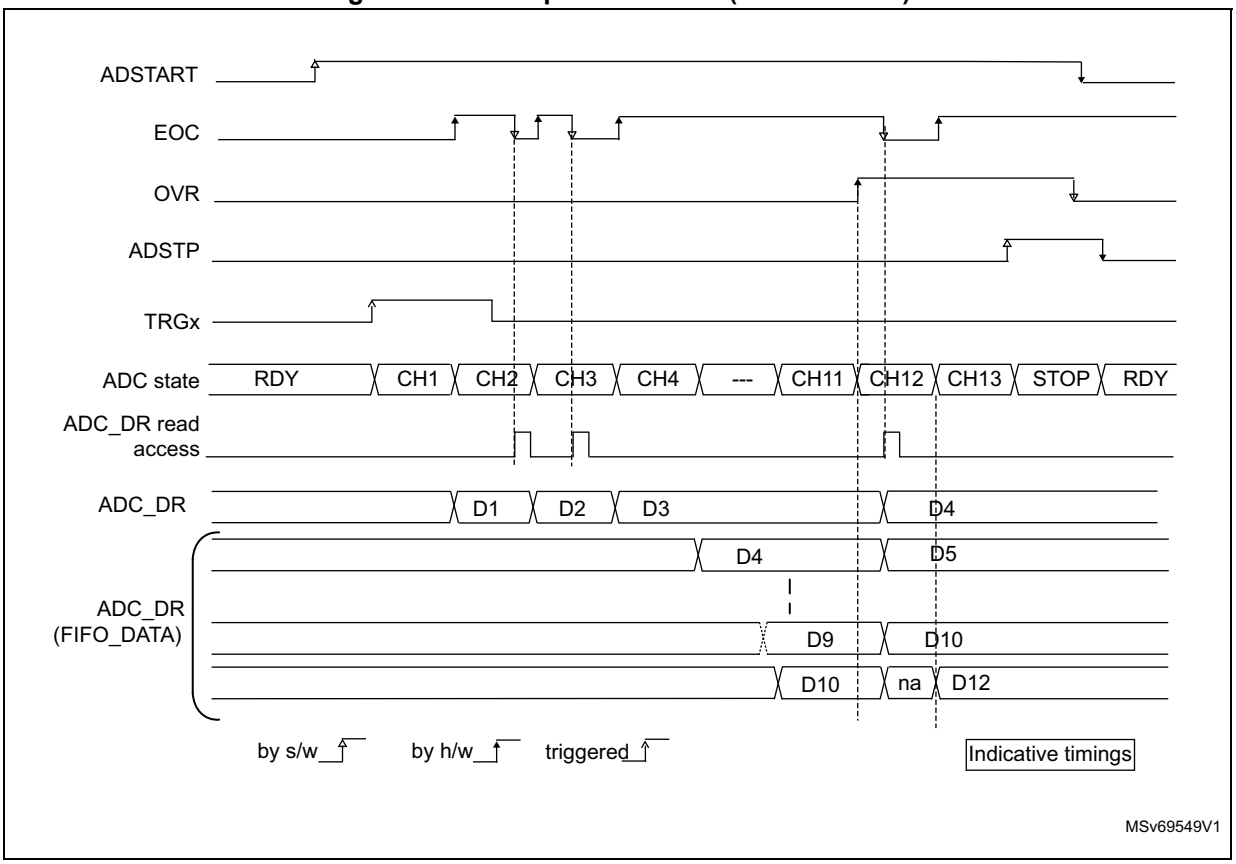
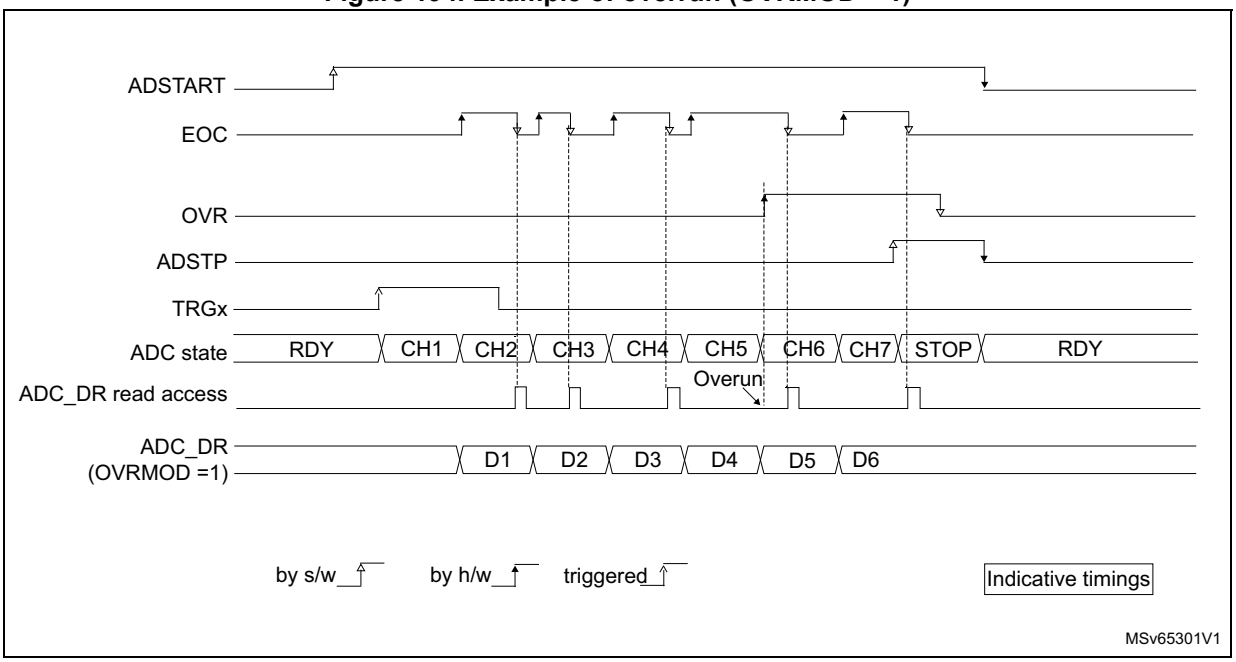


Figure 194. Example of overrun (OVRMOD = 1)



Note: There is no overrun detection on the injected channels since there is a dedicated data register for each of the four injected channels.

Managing a sequence of conversion without using the DMA

If the conversions are slow enough, the conversion sequence can be handled by the software. In this case the software must use the EOC flag and its associated interrupt to handle each data. Each time a conversion is complete, EOC is set and the ADC_DR register can be read. OVRMOD should be configured to 0 to manage overrun events or FIFO overflows as errors.

Managing conversions without using the DMA and without overrun

It may be useful to let the ADC convert one or more channels without reading the data each time (if there is an analog watchdog for instance). In this case, the OVRMOD bit must be configured to 1 and OVR flag should be ignored by the software. An overrun event will not prevent the ADC from continuing to convert and the ADC_DR register will always contain the latest conversion.

Managing conversions using the DMA

Since converted channel values are stored into a unique data register, it is useful to use DMA for conversion of more than one channel. This avoids the loss of the data already stored in the ADC_DR register.

When the DMA mode is enabled (DMNGT bit = 01 or 11 in the ADC_CFGR register in single ADC mode or MDMA different from 0b00 in dual ADC mode), a DMA request is generated after each conversion of a channel. This allows the transfer of the converted data from the ADC_DR register to the destination location selected by the software.

Despite this, if an overrun occurs (OVR=1) because the DMA could not serve the DMA transfer request in time, the ADC stops generating DMA requests and the data corresponding to the new conversion is not transferred by the DMA. Which means that all the data transferred to the RAM can be considered as valid.

Depending on the configuration of OVRMOD bit, the data is either preserved or overwritten (refer to *Section : ADC overrun (OVR, OVRMOD)*).

The DMA transfer requests are blocked until the software clears the OVR bit.

Two different DMA modes are proposed depending on the application use and are configured with bit DMNGT of the ADC_CFGR register in single ADC mode, or with bit DAMDF of the ADCx_CCR register in dual ADC mode:

- DMA one shot mode (DMNGT bit = 01).
  This mode is suitable when the DMA is programmed to transfer a fixed number of data.
- DMA circular mode (DMNGT bit = 11)
  This mode is suitable when programming the DMA in circular mode.

DMA one shot mode (DMNGT=01)

In this mode, the ADC generates a DMA transfer request each time a new conversion data is available and stops generating DMA requests once the DMA has reached the last DMA transfer (when DMA_EOT interrupt occurs - refer to DMA paragraph) even if a conversion has been started again.

When the DMA transfer is complete (all the transfers configured in the DMA controller have been done):

- The content of the ADC data register is frozen.
- Any ongoing conversion is aborted with partial result discarded.
- No new DMA request is issued to the DMA controller. This avoids generating an overrun error if there are still conversions which are started.
- Scan sequence is stopped and reset.
- The DMA is stopped.

DMA circular mode (DMNGT=11)

In this mode, the ADC generates a DMA transfer request each time a new conversion data is available in the data register, even if the DMA has reached the last DMA transfer. This allows configuring the DMA in circular mode to handle a continuous analog input data stream.

DMA with FIFO

The output data register has eight-stage FIFO. Two different DMA requests are generated parallel. When a data is available, “SREQ single request” generated, when 4 data are available, “BREQ burst request” generated. DMA2 can be programmed either single transfer mode or incremental burst mode(4 beats), according to this mode, correct request line is selected by the DMA2. Please refer to the DMA2 chapter for further information.

28.4.28 Managing conversions using the DFSDM

The ADC conversion results can be transferred directly to the Digital Filter for Sigma Delta Modulators (DFSDM).

In this case, the DMNGT[1:0] bits must be set to 10.

The ADC transfers 16 least significant bits of the regular data register data to the DFSDM, which in turns will reset the EOC flag once the transfer is effective.

The data format must be 16-bit signed:

ADC_DR[31:16] = don’t care

ADC_DR[15] = sign

ADC_DR[14:0] = data

Any value above 16-bit signed format will be truncated.

28.4.29 Dynamic low-power features

Auto-delayed conversion mode (AUTDLY)

The ADC implements an auto-delayed conversion mode controlled by the AUTDLY configuration bit. Auto-delayed conversions are useful to simplify the software as well as to optimize performance of an application clocked at low frequency where there would be risk of encountering an ADC overrun.

When AUTDLY=1, a new conversion can start only if all the previous data of the same group has been treated:

- For a regular conversion: once the ADC_DR register has been read or if the EOC bit has been cleared (see *Figure 195*).
- For an injected conversion: when the JEOS bit has been cleared (see *Figure 196*).

This is a way to automatically adapt the speed of the ADC to the speed of the system which will read the data.

The delay is inserted after each regular conversion (whatever DISCEN=0 or 1) and after each sequence of injected conversions (whatever JDISCEN=0 or 1).

Note: There is no delay inserted between each conversions of the injected sequence, except after the last one.

During a conversion, a hardware trigger event (for the same group of conversions) occurring during this delay is ignored.

Note: This is not true for software triggers where it remains possible during this delay to set the bits ADSTART or JADSTART to re-start a conversion: it is up to the software to read the data before launching a new conversion.

No delay is inserted between conversions of different groups (a regular conversion followed by an injected conversion or conversely):

- If an injected trigger occurs during the automatic delay of a regular conversion, the injected conversion starts immediately (see *Figure 196*).
- Once the injected sequence is complete, the ADC waits for the delay (if not ended) of the previous regular conversion before launching a new regular conversion (see *Figure 198*).

The behavior is slightly different in auto-injected mode (JAUTO=1) where a new regular conversion can start only when the automatic delay of the previous injected sequence of conversion has ended (when JEOS has been cleared). This is to ensure that the software can read all the data of a given sequence before starting a new sequence (see *Figure 199*).

To stop a conversion in continuous auto-injection mode combined with autodelay mode (JAUTO=1, CONT=1 and AUTDLY=1), follow the following procedure:

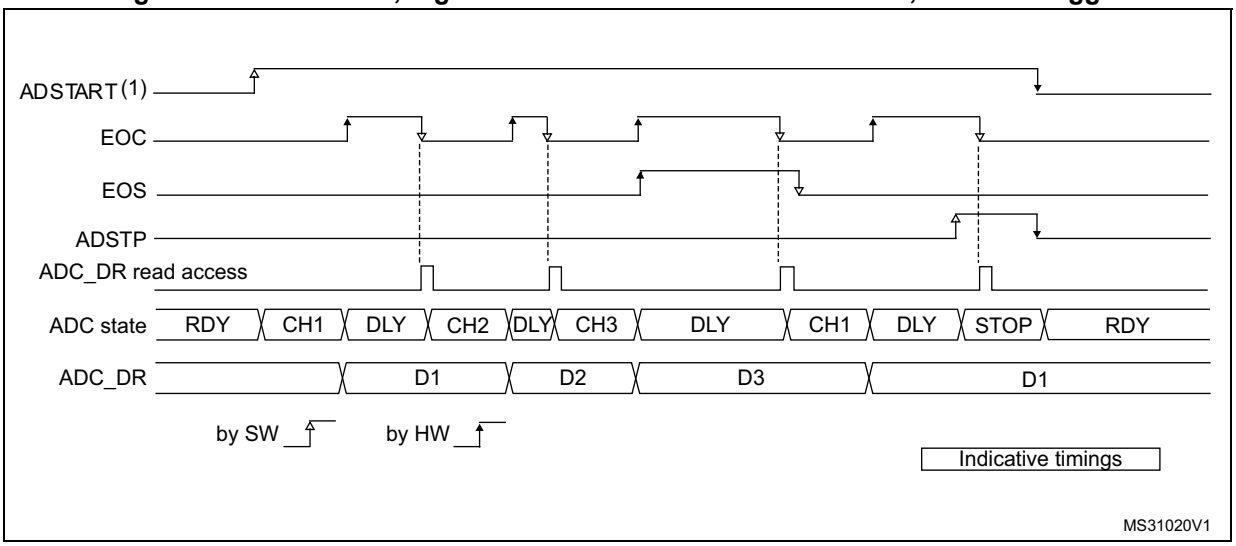
1. Wait until JEOS=1 (no more conversions are restarted)
2. Clear JEOS,
3. Set ADSTP=1
4. Read the regular data.

If this procedure is not respected, a new regular sequence can re-start if JEOS is cleared after ADSTP has been set.

In AUTDLY mode, a hardware regular trigger event is ignored if it occurs during an already ongoing regular sequence or during the delay that follows the last regular conversion of the sequence. It is however considered pending if it occurs after this delay, even if it occurs during an injected sequence of the delay that follows it. The conversion then starts at the end of the delay of the injected sequence.

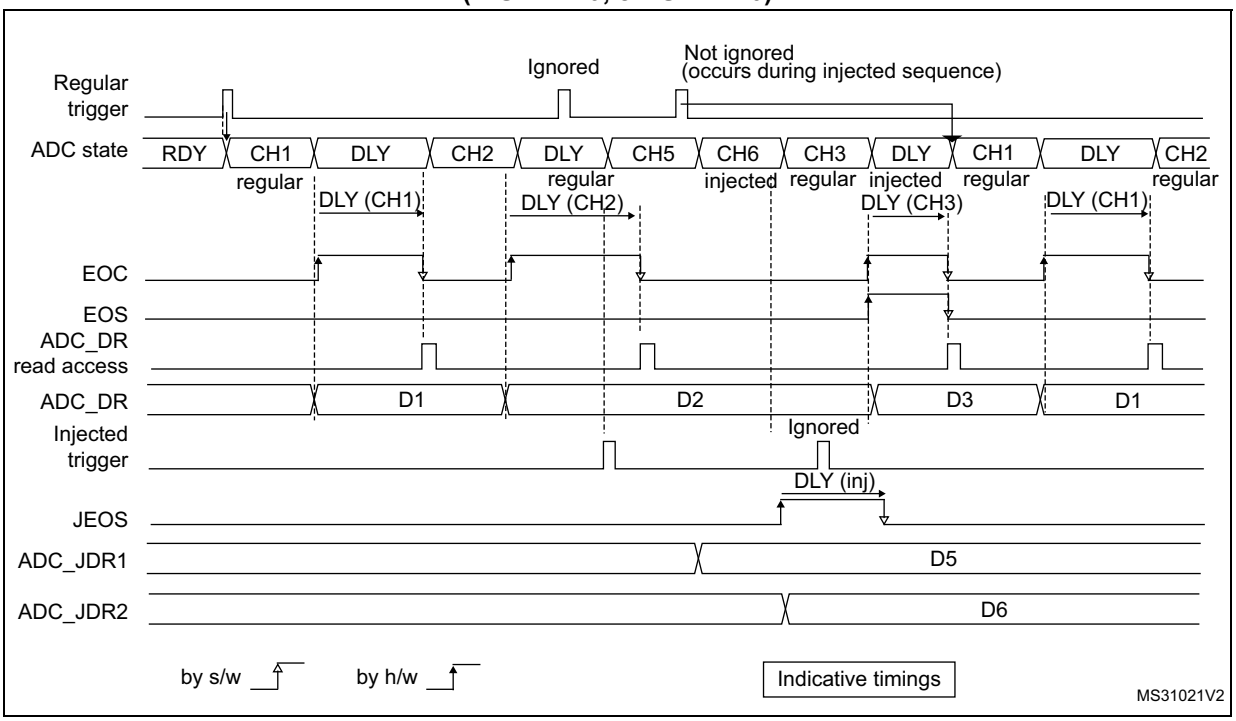
In AUTDLY mode, a hardware injected trigger event is ignored if it occurs during an already ongoing injected sequence or during the delay that follows the last injected conversion of the sequence.

Figure 195. AUTDLY=1, regular conversion in continuous mode, software trigger



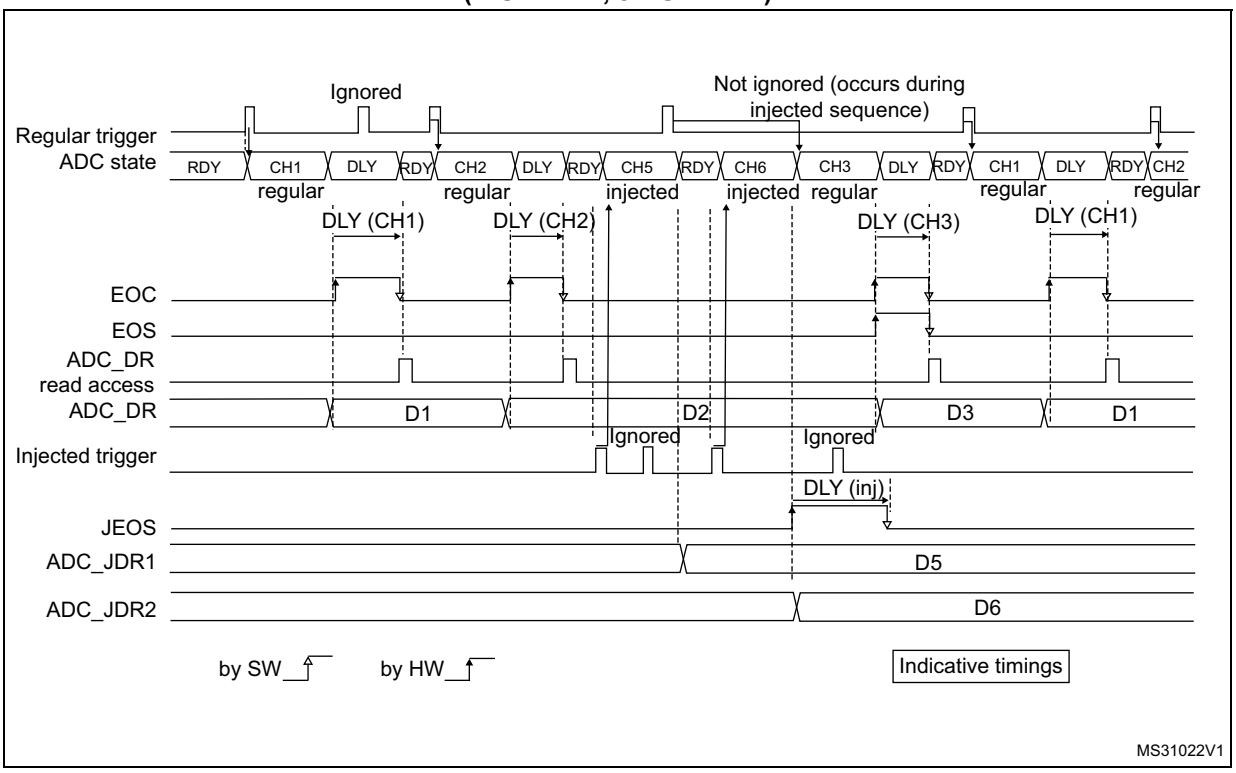
1. AUTDLY=1
2. Regular configuration: EXTEN=0x0 (SW trigger), CONT=1, CHANNELS = 1,2,3
3. Injected configuration DISABLED

Figure 196. AUTDLY=1, regular HW conversions interrupted by injected conversions (DISCEN=0; JDISCEN=0)



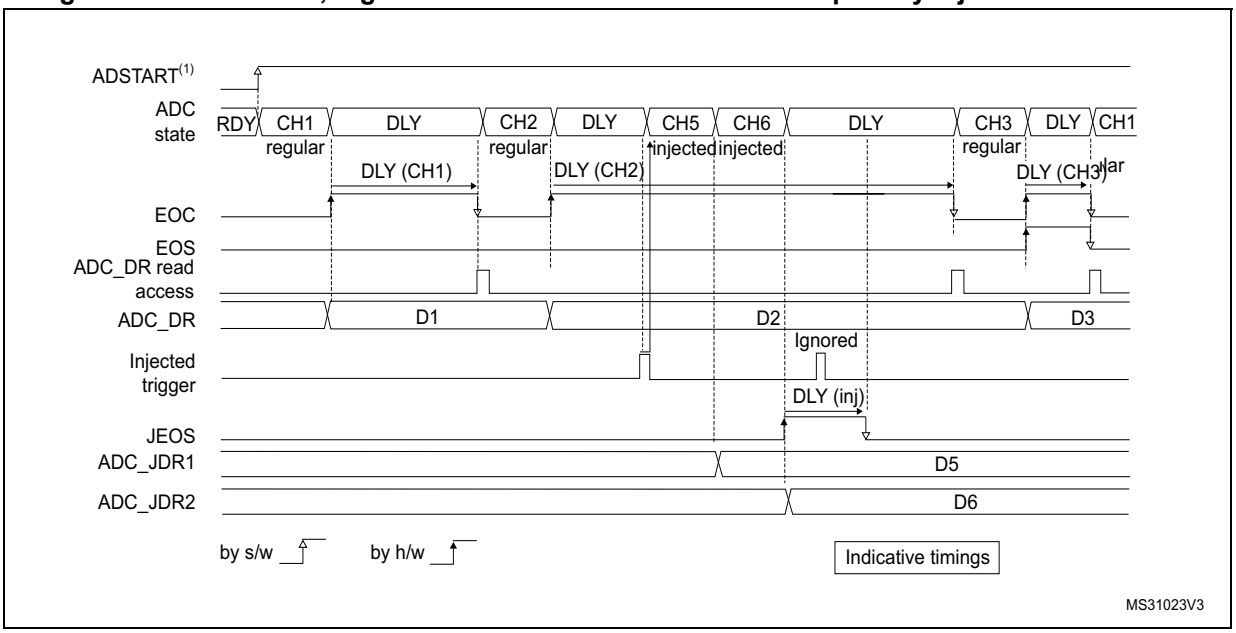
1. AUTDLY=1
2. Regular configuration: EXTEN=0x1 (HW trigger), CONT=0, DISCEN=0, CHANNELS = 1, 2, 3
3. Injected configuration: JEXTEN=0x1 (HW Trigger), JDISCEN=0, CHANNELS = 5,6

Figure 197. AUTDLY=1, regular HW conversions interrupted by injected conversions (DISCEN=1, JDISCEN=1)



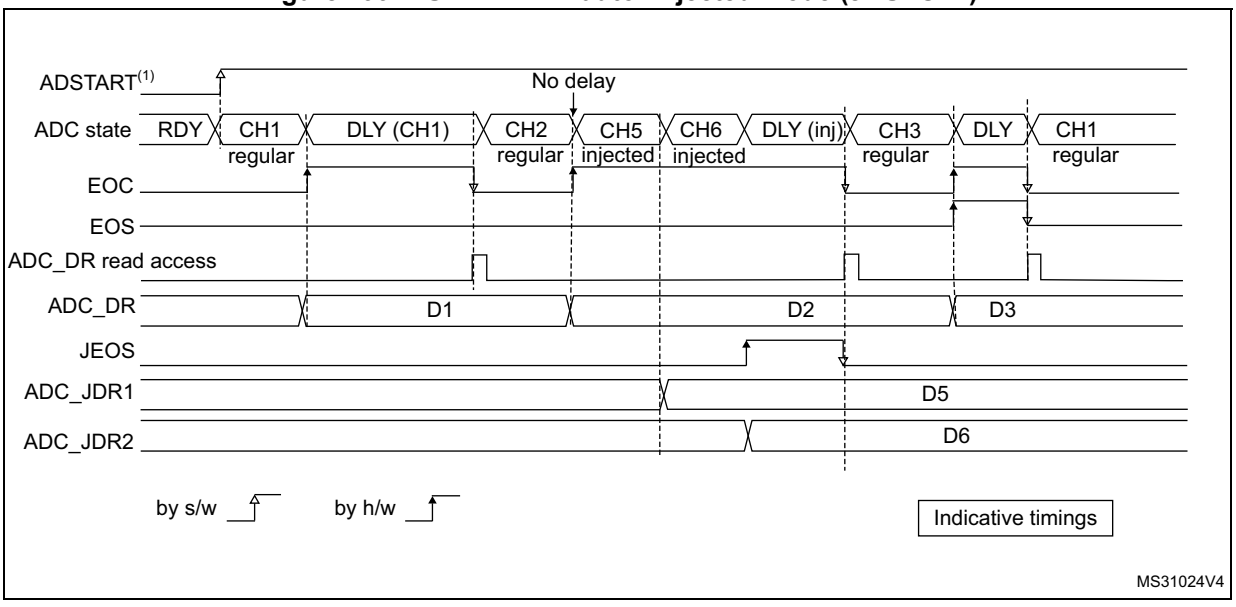
1. AUTDLY=1
2. Regular configuration: EXTEN=0x1 (HW trigger), CONT=0, DISCEN=1, DISCNUM=1, CHANNELS = 1, 2, 3.
3. Injected configuration: JEXTEN=0x1 (HW Trigger), JDISCEN=1, CHANNELS = 5,6

Figure 198. AUTDLY=1, regular continuous conversions interrupted by injected conversions



1. AUTDLY=1
2. Regular configuration: EXTEN=0x0 (SW trigger), CONT=1, DISCEN=0, CHANNELS = 1, 2, 3
3. Injected configuration: JEXTEN=0x1 (HW Trigger), JDISCEN=0, CHANNELS = 5,6

Figure 199. AUTDLY=1 in auto- injected mode (JAUTO=1)

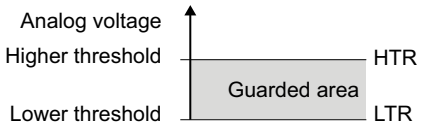


1. AUTDLY=1
2. Regular configuration: EXTEN=0x0 (SW trigger), CONT=1, DISCEN=0, CHANNELS = 1, 2
3. Injected configuration: JAUTO=1, CHANNELS = 5,6

28.4.30 Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTRy, AWD_LTRy, AWDy)

The three AWD analog watchdogs monitor whether some channels remain within a configured voltage range (window).

Figure 200. Analog watchdog guarded area



AWDx flag and interrupt

An interrupt can be enabled for each of the 3 analog watchdogs by setting AWDyIE in the ADC_IER register (x=1,2,3).

AWDy (y=1,2,3) flag is cleared by software by writing 1 to it.

The ADC conversion result is compared to the lower and higher thresholds before alignment.

Description of analog watchdog 1

The AWD analog watchdog 1 is enabled by setting the AWD1EN bit in the ADC_CFGR register. This watchdog monitors whether either one selected channel or all enabled channels(1) remain within a configured voltage range (window).

Table 232 shows how the ADC_CFGRy registers should be configured to enable the analog watchdog on one or more channels.

Table 232. Analog watchdog channel selection

Channels guarded by the analog watchdog	AWD1SGL bit	AWD1EN bit	JAWD1EN bit
None	x	0	0
All injected channels	0	0	1
All regular channels	0	1	0
All regular and injected channels	0	1	1
Single(1) injected channel	1	0	1
Single(1) regular channel	1	1	0
Single(1) regular or injected channel	1	1	1

1. Selected by the AWDyCH[4:0] bits. The channels must also be programmed to be converted in the appropriate regular or injected sequence.

The AWD1 analog watchdog status bit is set if the analog voltage converted by the ADC is below a lower threshold or above a higher threshold.

These thresholds are programmed in bits HTR1[25:0] of the ADC_HTR1 register and LTR1[25:0] of the ADC_LTR1 register for the analog watchdog 1.

The threshold can be up to 26-bits (16-bit resolution with oversampling, OSVR[9:0]=1024).

When converting data with a resolution of less than 16 bits (according to bits RES[2:0]), the LSBs of the programmed thresholds must be kept cleared, the internal comparison being performed on the full 16-bit converted data (left aligned to the half-word boundary).

Table 233 describes how the comparison is performed for all the possible resolutions for analog watchdog 1,2,3.

Table 233. Analog watchdog 1,2,3 comparison

Resolution (bit RES[2:0])	Analog watchdog comparison between:		Comments
	Raw converted data, left aligned(1)	Thresholds	
16 bits	DATA[15:0]	LTR1[25:0] and HTR1[25:0]	-
14 bits	DATA[15:2],00	LTR1[25:0] and HTR1[25:0]	User must configure LTR1[1:0] and HTR1[1:0] to 00
12 bits	DATA[15:4],0000	LTR1[25:0] and HTR1[25:0]	User must configure LTR1[3:0] and HTR1[3:0] to 0000
10 bits	DATA[15:6],000000	LTR1[25:0] and HTR1[25:0]	User must configure LTR1[5:0] and HTR1[5:0] to 000000
8 bits	DATA[15:8],00000000	LTR1[25:0] and HTR1[25:0]	User must configure LTR1[7:0] and HTR1[7:0] to 00000000

1. The watchdog comparison is performed on the raw converted data before any alignment calculation and before applying any offsets (the data which is compared is not signed).

Description of analog watchdog 2 and 3

The second and third analog watchdogs are more flexible and can guard several selected channels by programming the corresponding bits in AWDCHy[19:0] (y=2,3).

The corresponding watchdog is enabled when any bit of AWDCHy[19:0] (y=2,3) is set.

The threshold can be up to 26-bits (16-bit resolution with oversampling, OSVR[9:0]=1024) and are programmed with the ADC_HTR2, ADC_LTR2, ADC_LTR3, and ADC_HTR3 registers.

When converting data with a resolution of less than 16 bits (according to bits RES[2:0]), the LSBs of the programmed thresholds must be kept cleared, the internal comparison being performed on the full 16-bit converted data (left aligned to the half-word boundary).

ADCx_AWDy_OUT signal output generation

Each analog watchdog is associated to an internal hardware signal ADCx_AWDy_OUT (x=ADC number, y=watchdog number) which is directly connected to the ETR input (external trigger) of some on-chip timers. Refer to the on-chip timers section to understand how to select the ADCx_AWDy_OUT signal as ETR.

ADCx_AWDy_OUT is activated when the associated analog watchdog is enabled:

- ADCx_AWDy_OUT is set when a guarded conversion is outside the programmed thresholds.
- ADCx_AWDy_OUT is reset after the end of the next guarded conversion which is inside the programmed thresholds (It remains at 1 if the next guarded conversions are still outside the programmed thresholds).
- ADCx_AWDy_OUT is also reset when disabling the ADC (when setting ADDIS=1). Note that stopping regular or injected conversions (setting ADSTP=1 or JADSTP=1) has no influence on the generation of ADCy_AWDx_OUT.

Note: AWDx flag is set by hardware and reset by software: AWDy flag has no influence on the generation of ADCx_AWDy_OUT (ex: ADCy_AWDy_OUT can toggle while AWDx flag remains at 1 if the software did not clear the flag).

Figure 201. ADCy_AWDx_OUT signal generation (on all regular channels)

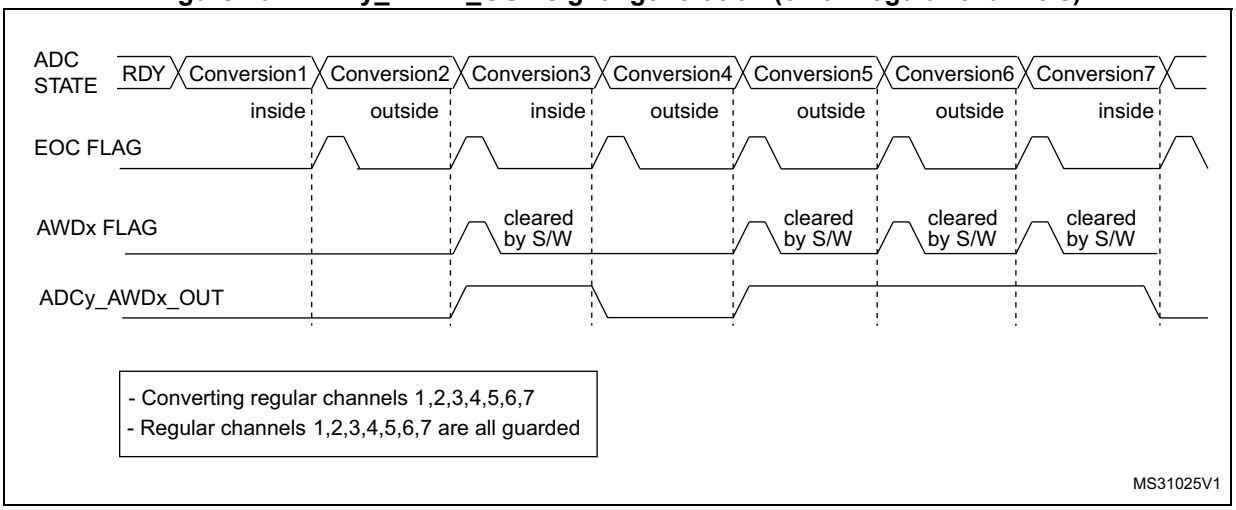


Figure 202. ADCy_AWDx_OUT signal generation (AWDx flag not cleared by SW)

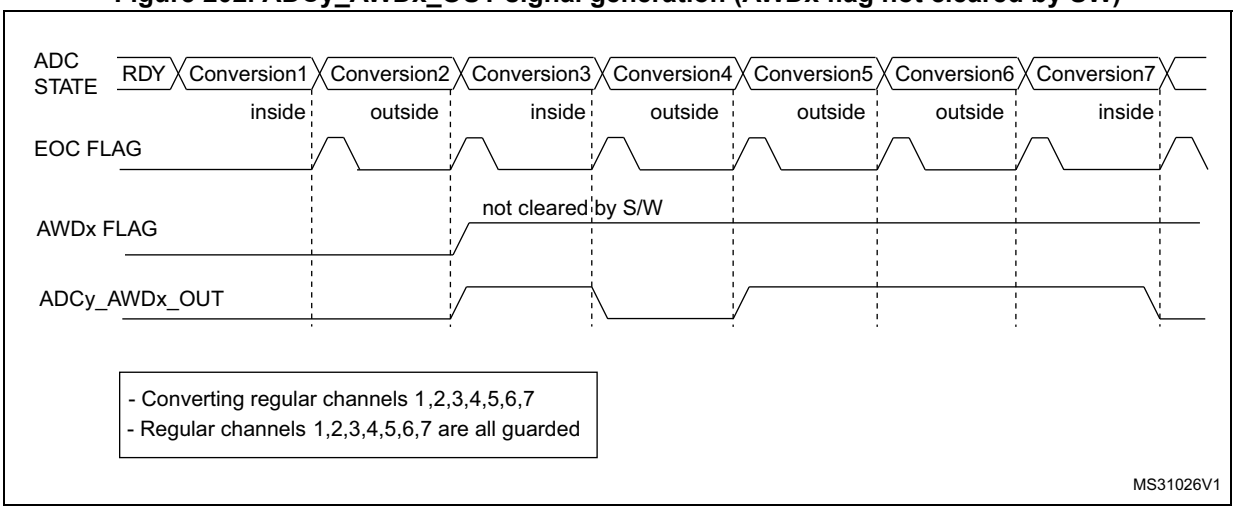


Figure 203. ADCy_AWDx_OUT signal generation (on a single regular channel)

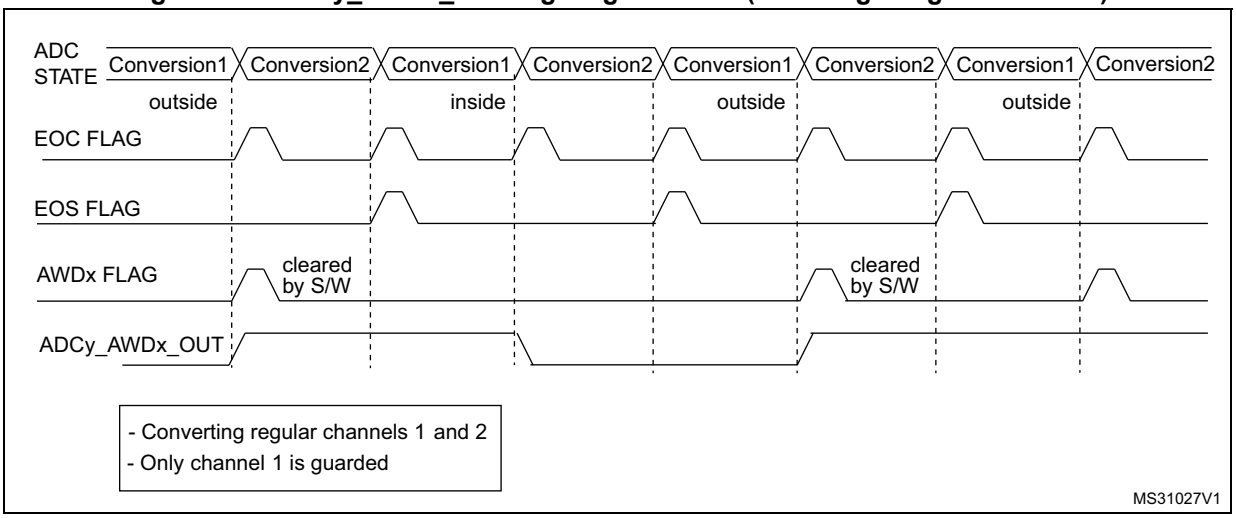
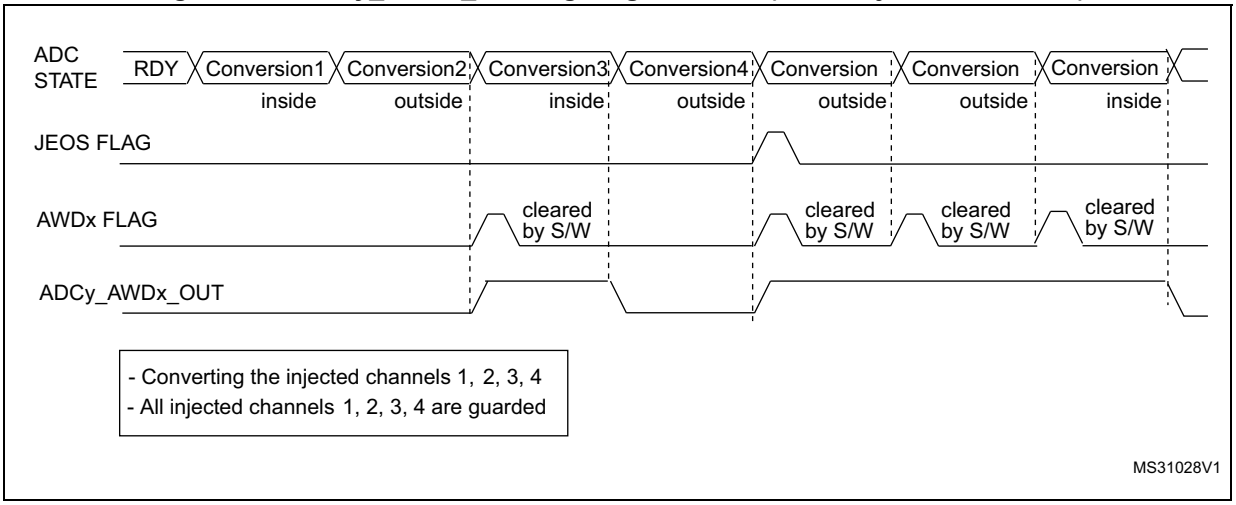


Figure 204. ADCy_AWDx_OUT signal generation (on all injected channels)



28.4.31 Oversampler

The oversampling unit performs data preprocessing to offload the CPU. It is able to handle multiple conversions and average them into a single data with increased data width, up to 26-bit (16-bit values and OSVR[9:0] = 1024).

It provides a result with the following form, where N and M can be adjusted:

$$\text{Result} = \frac{1}{M} \times \sum_{n=0}^{n=N-1} \text{Conversion}(t_n)$$

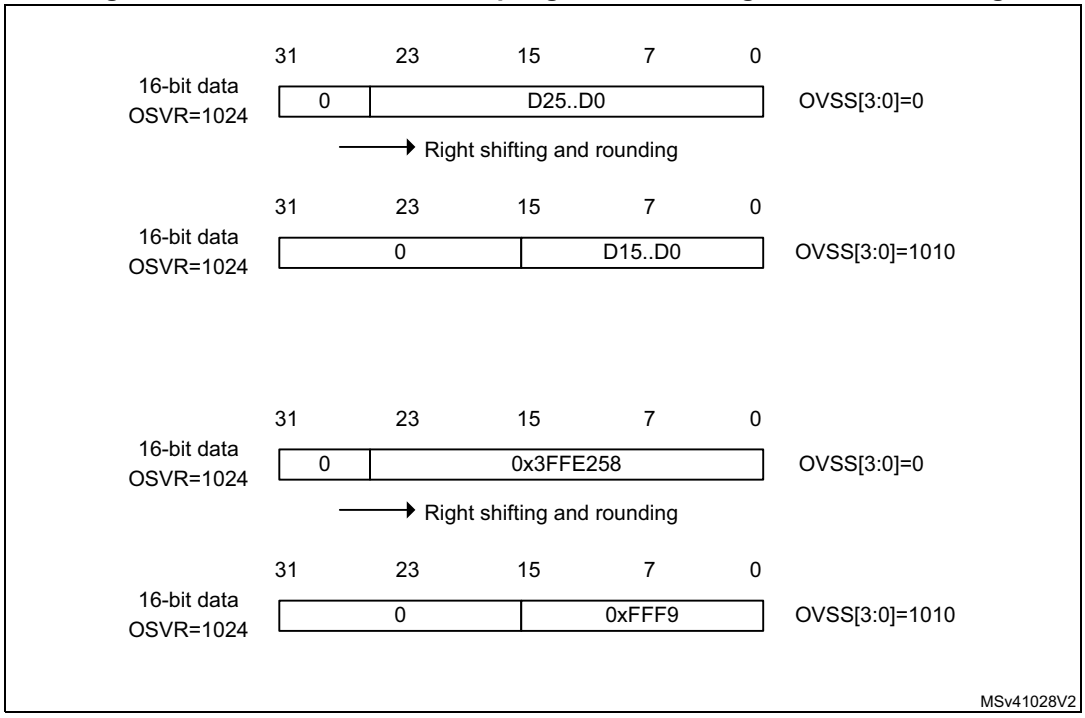
It allows to perform by hardware the following functions: averaging, data rate reduction, SNR improvement, basic filtering.

The oversampling ratio N is defined using the OSVR[9:0] bits in the ADC_CFGR2 register, and can range from 2x to 1024x. The division coefficient M consists of a right bit shift up to 10 bits, and is defined using the OVSS[3:0] bits in the ADC_CFGR2 register.

The summation unit can yield a result up to 26 bits (1024 x 16-bit results), which can be left or right shifted. When right shifting is selected, it is rounded to the nearest value using the least significant bits left apart by the shifting, before being transferred into the ADC_DR data register.

The *Table 205* gives a numerical example of the processing, from a raw 26-bit accumulated data to the final 16-bit result.

Figure 205. 16-bit result oversampling with 10-bits right shift and rouding



There are no changes for conversion timings in oversampled mode: the sample time is maintained equal during the whole oversampling sequence. A new data is provided every N conversions, with an equivalent delay equal to N x T_{CONV} = N x (t_{SMPL} + t_{SAR}). The flags are set as follow:

- the end of the sampling phase (EOSMP) is set after each sampling phase
- the end of conversion (EOC) occurs once every N conversions, when the oversampled result is available
- the end of sequence (EOS) occurs once the sequence of oversampled data is completed (i.e. after N x sequence length conversions total)

Single ADC operating modes support when oversampling

In oversampling mode, most of the ADC operating modes are maintained:

- Single or continuous mode conversions
- ADC conversions start either by software or with triggers
- ADC stop during a conversion (abort)
- Data read via CPU or DMA with overrun detection
- Low-power modes (AUTDLY)
- Programmable resolution: in this case, the reduced conversion values (as per RES[2:0] bits in ADC_CFGR register) are accumulated, truncated, rounded and shifted in the same way as 16-bit conversions are

Note: The alignment mode is not available when working with oversampled data. The data are always provided right-aligned.

Analog watchdog

The analog watchdog functionality is maintained (AWDSGL and AWDEN bits), with the following difference:

- the RES[2:0] bits are ignored, comparison is always done on using the full 26-bit values HTRx[25:0] and LTRx[25:0]
- *the comparison is performed on the oversampled accumulated value before shifting*

Note: Care must be taken when using high shifting values, this will reduce the comparison range. For instance, if the oversampled result is shifted by 4 bits, thus yielding a 12-bit data right-aligned, the effective analog watchdog comparison can only be performed on 8 bits. The comparison is done between ADC_DR[11:4] and HT[0:7] / LT[[0:7], and HT[11:8] / LT[11:8] must be kept reset.

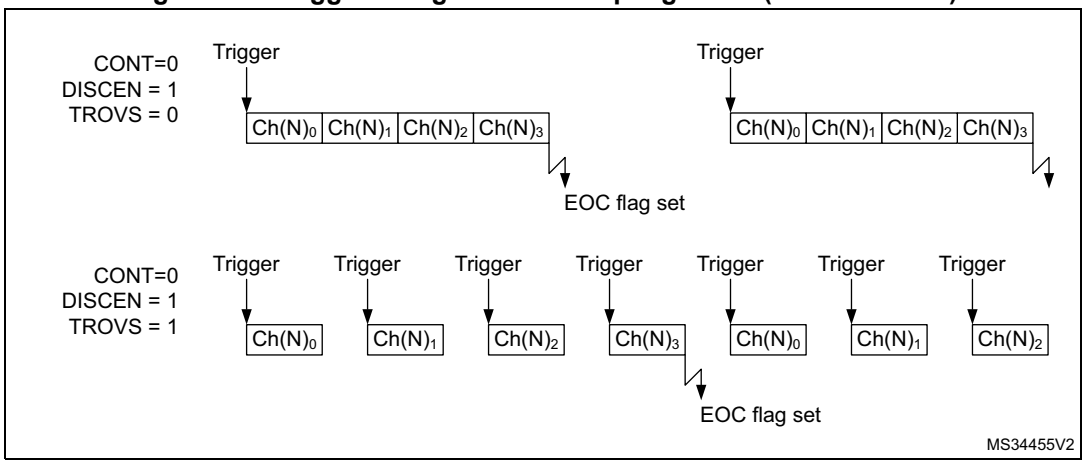
Triggered mode

The averager can also be used for basic filtering purpose. Although not a very powerful filter (slow roll-off and limited stop band attenuation), it can be used as a notch filter to reject constant parasitic frequencies (typically coming from the mains or from a switched mode power supply). For this purpose, a specific discontinuous mode can be enabled with TROVS bit in ADC_CFGR2, to be able to have an oversampling frequency defined by a user and independent from the conversion time itself.

The *Figure 206* below shows how conversions are started in response to triggers during discontinuous mode.

If the TROVS bit is set, the content of the DISCEN bit is ignored and considered as 1.

Figure 206. Triggered regular oversampling mode (TROVS bit = 1)



Injected and regular sequencer management when oversampling

In oversampling mode, it is possible to have differentiated behavior for injected and regular sequencers. The oversampling can be enabled for both sequencers with some limitations if they have to be used simultaneously (this is related to a unique accumulation unit).

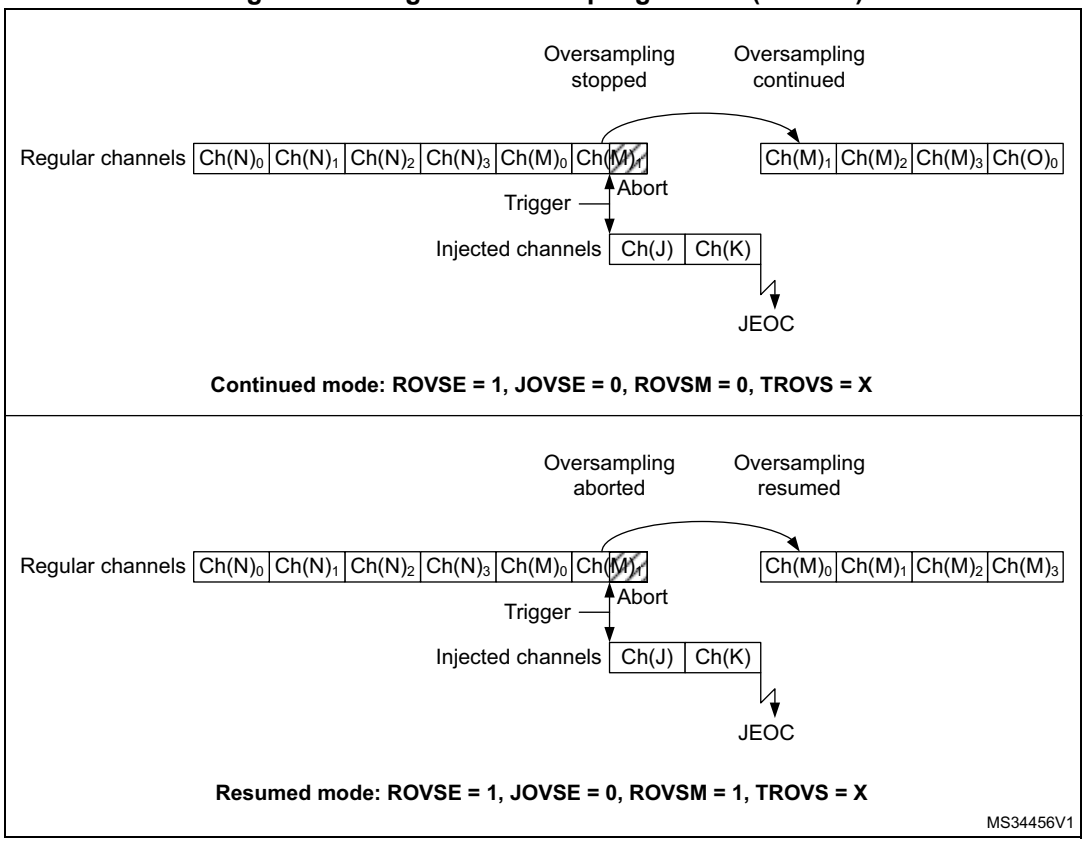
Oversampling regular channels only

The regular oversampling mode bit ROVSM defines how the regular oversampling sequence is resumed if it is interrupted by injected conversion:

- in continued mode, the accumulation re-starts from the last valid data (prior to the conversion abort request due to the injected trigger). This ensures that oversampling will be completed whatever the injection frequency (providing at least one regular conversion can be completed between triggers);
- in resumed mode, the accumulation re-starts from 0 (previous conversions results are ignored). This mode allows to guarantee that all data used for oversampling were converted back-to-back within a single timeslot. Care must be taken to have a injection trigger period above the oversampling period length. If this condition is not respected, the oversampling cannot be completed and the regular sequencer will be blocked.

The *Figure 207* gives examples for a 4x oversampling ratio.

Figure 207. Regular oversampling modes (4x ratio)



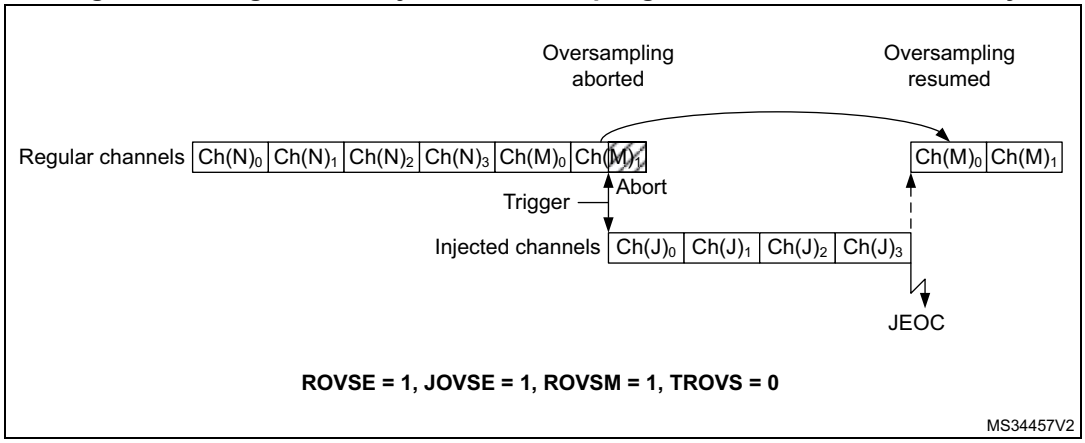
Oversampling Injected channels only

The Injected oversampling mode bit JOVSE enables oversampling solely for conversions in the injected sequencer.

Oversampling regular and Injected channels

It is possible to have both ROVSE and JOVSE bits set. In this case, the regular oversampling mode is forced to resumed mode (ROVSM bit ignored), as represented on *Figure 208* below.

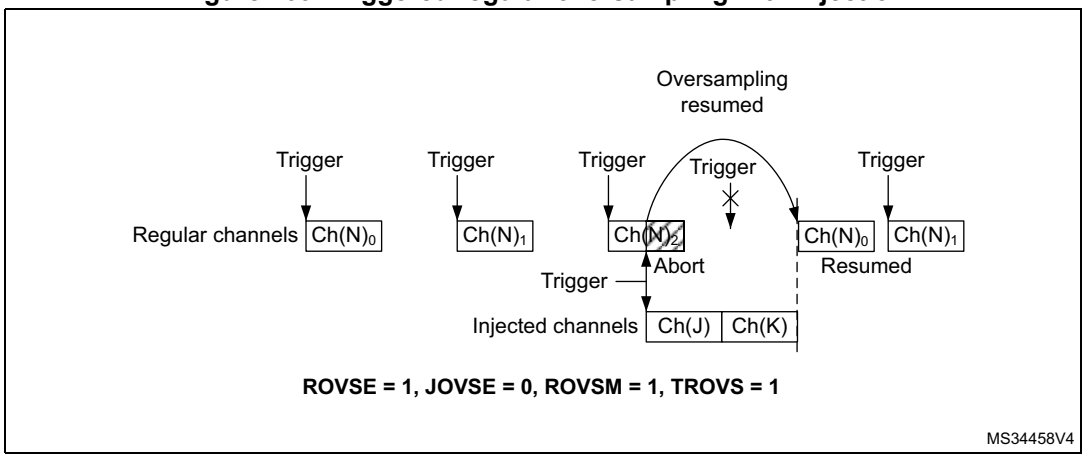
Figure 208. Regular and injected oversampling modes used simultaneously



Triggered regular oversampling with injected conversions

It is possible to have triggered regular mode with injected conversions. In this case, the injected mode oversampling mode must be disabled, and the ROVSM bit is ignored (resumed mode is forced). The JOVSE bit must be reset. The behavior is represented on *Figure 209* below.

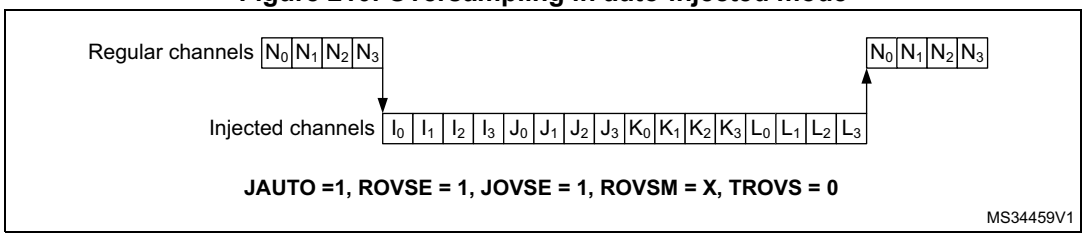
Figure 209. Triggered regular oversampling with injection



Auto-injected mode

It is possible to oversample auto-injected sequences and have all conversions results stored in registers to save a DMA resource. This mode is available only with both regular and injected oversampling active: JAUTO = 1, ROVSE = 1 and JOVSE = 1, other combinations are not supported. The ROVSM bit is ignored in auto-injected mode. The *Figure 210* below shows how the conversions are sequenced.

Figure 210. Oversampling in auto-injected mode



It is possible to have also the triggered mode enabled, using the TROVS bit. In this case, the ADC must be configured as following: JAUTO=1, DISCEN=0, JDISCEN=0, ROVSE=1, JOVSE=1 and TROVSE=1.

Dual ADC modes support when oversampling

It is possible to have oversampling enabled when working in dual ADC configuration, for the injected simultaneous mode and regular simultaneous mode. In this case, the two ADCs must be programmed with the very same settings (including oversampling).

All other dual ADC modes are not supported when either regular or injected oversampling is enabled (ROVSE = 1 or JOVSE = 1).

Combined modes summary

The *Table 234* below summarizes all combinations, including modes not supported.

Table 234. Oversampler operating modes summary

Regular Over-sampling ROVSE	Injected Over-sampling JOVSE	Oversampler mode ROVSM 0 = continued 1 = resumed	Triggered Regular mode TROVS	Comment
1	0	0	0	Regular continued mode
1	0	0	1	Not supported
1	0	1	0	Regular resumed mode
1	0	1	1	Triggered regular resumed mode
1	1	0	X	Not supported
1	1	1	0	Injected and regular resumed mode
1	1	1	1	Not supported
0	1	X	X	Injected oversampling

28.4.32 Dual ADC modes

In devices with two ADCs or more, dual ADC modes can be used (see *Figure 211*):

- ADC1 and ADC2 can be used together in dual mode (ADC1 is master)

In dual ADC mode the start of conversion is triggered alternately or simultaneously by the ADCx master to the ADC slave, depending on the mode selected by the bits DUAL[4:0] in the ADCx_CCR register.

Four possible modes are implemented:

- Injected simultaneous mode
- Regular simultaneous mode
- Interleaved mode
- Alternate trigger mode

It is also possible to use these modes combined in the following ways:

- Injected simultaneous mode + Regular simultaneous mode
- Regular simultaneous mode + Alternate trigger mode
- Injected simultaneous mode + Interleaved mode

In dual ADC mode (when bits DUAL[4:0] in ADCx_CCR register are not equal to zero), the bits CONT, AUTDLY, DISCEN, DISCNUM[2:0], JDISCEN, JQM, JAUTO of the ADC_CFGR register are shared between the master and slave ADC: the bits in the slave ADC are always equal to the corresponding bits of the master ADC.

To start a conversion in dual mode, the user must program the bits EXTEN, EXTSEL, JEXTEN, JEXTSEL of the master ADC only, to configure a software or hardware trigger,

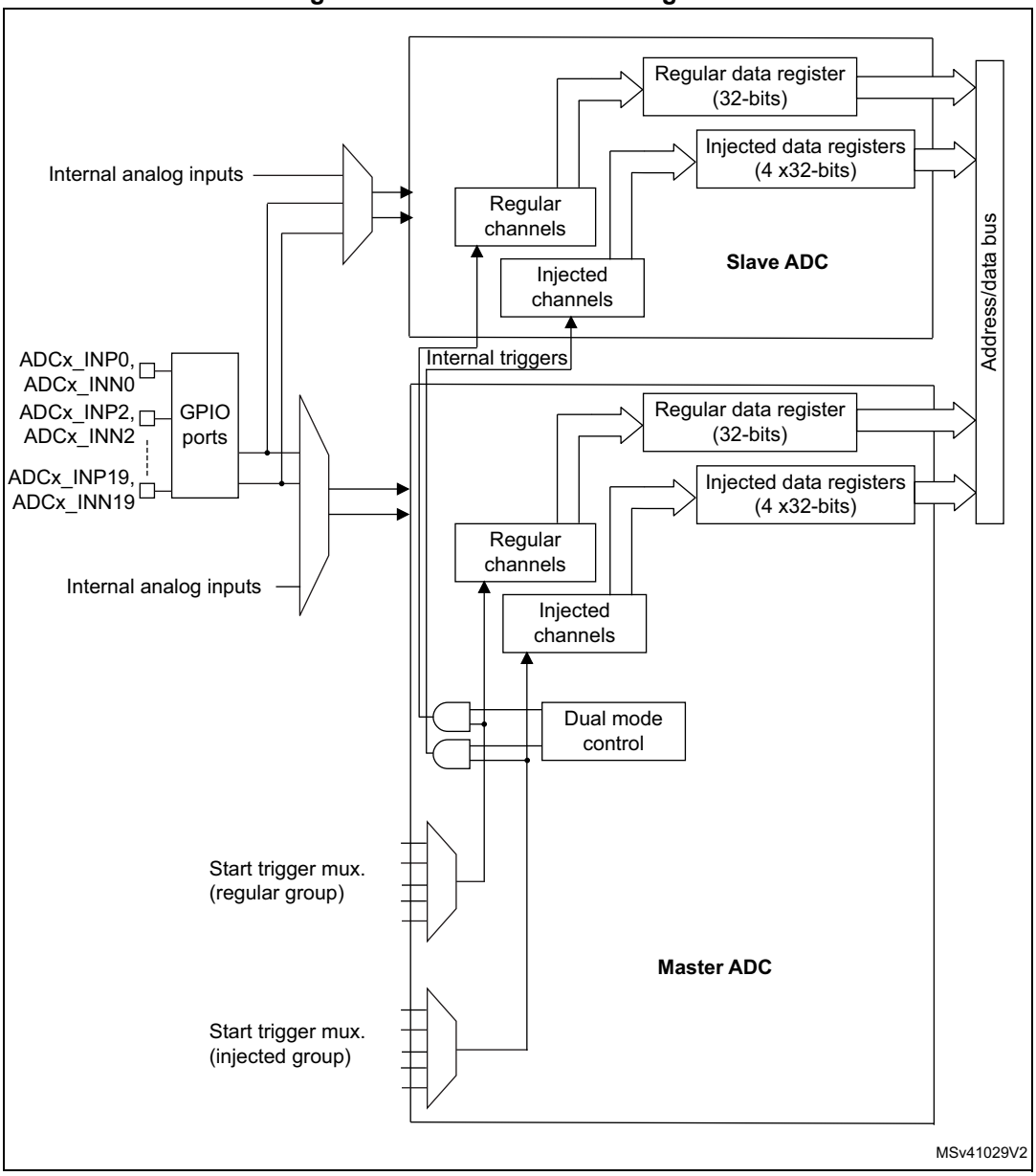
and a regular or injected trigger. (the bits EXTEN[1:0] and JEXTEN[1:0] of the slave ADC are don’t care).

In regular simultaneous or interleaved modes: once the user sets bit ADSTART or bit ADSTP of the master ADC, the corresponding bit of the slave ADC is also automatically set. However, bit ADSTART or bit ADSTP of the slave ADC is not necessary cleared at the same time as the master ADC bit.

In injected simultaneous or alternate trigger modes: once the user sets bit JADSTART or bit JADSTP of the master ADC, the corresponding bit of the slave ADC is also automatically set. However, bit JADSTART or bit JADSTP of the slave ADC is not necessary cleared at the same time as the master ADC bit.

In dual ADC mode, the converted data of the master and slave ADC can be read in parallel, by reading the ADC common data register (ADCx_CDR). The status bits can be also read in parallel by reading the dual-mode status register (ADCx_CSR).

Figure 211. Dual ADC block diagram(1)



1. External triggers also exist on slave ADC but are not shown for the purposes of this diagram.
2. The ADC common data register (ADCx_CDR) contains both the master and slave ADC regular converted data.

Injected simultaneous mode

This mode is selected by programming bits DUAL[4:0]=00101

This mode converts an injected group of channels. The external trigger source comes from the injected group multiplexer of the master ADC (selected by the JEXTSEL[4:0] bits in the ADC_JSQR register).

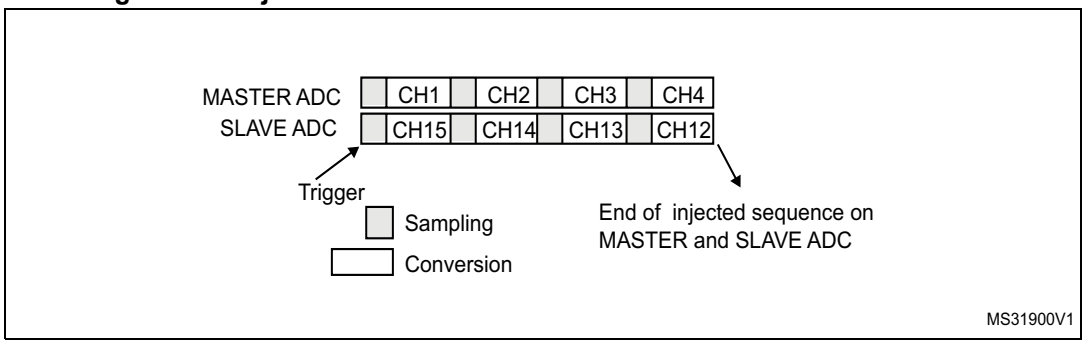
Note: Do not convert the same channel on the two ADCs (no overlapping sampling times for the two ADCs when converting the same channel).

In simultaneous mode, one must convert sequences with the same length and inside a sequence, the N-th conversion in master ans slave must be configured with the same sampling time.

Regular conversions can be performed on one or all ADCs. In that case, they are independent of each other and are interrupted when an injected event occurs. They are resumed at the end of the injected conversion group.

- At the end of injected sequence of conversion event (JEOS) on the master ADC, the converted data is stored into the master ADC_JDRy registers and a JEOS interrupt is generated (if enabled)
- At the end of injected sequence of conversion event (JEOS) on the slave ADC, the converted data is stored into the slave ADC_JDRy registers and a JEOS interrupt is generated (if enabled)
- If the duration of the master injected sequence is equal to the duration of the slave injected one (like in *Figure 212*), it is possible for the software to enable only one of the two JEOS interrupt (ex: master JEOS) and read both converted data (from master ADC_JDRy and slave ADC_JDRy registers).

Figure 212. Injected simultaneous mode on 4 channels: dual ADC mode



If JDISCEN=1, each simultaneous conversion of the injected sequence requires an injected trigger event to occur.

This mode can be combined with AUTDLY mode:

- Once a simultaneous injected sequence of conversions has ended, a new injected trigger event is accepted only if both JEOS bits of the master and the slave ADC have been cleared (delay phase). Any new injected trigger events occurring during the ongoing injected sequence and the associated delay phase are ignored.
- Once a regular sequence of conversions of the master ADC has ended, a new regular trigger event of the master ADC is accepted only if the master data register (ADC_DR) has been read. Any new regular trigger events occurring for the master ADC during the ongoing regular sequence and the associated delay phases are ignored.
  There is the same behavior for regular sequences occurring on the slave ADC.

Regular simultaneous mode with independent injected

This mode is selected by programming bits DUAL[4:0] = 00110.

This mode is performed on a regular group of channels. The external trigger source comes from the regular group multiplexer of the master ADC (selected by the EXTSEL[4:0] bits in the ADC_CFGR register). A simultaneous trigger is provided to the slave ADC.

In this mode, independent injected conversions are supported. An injection request (either on master or on the slave) will abort the current simultaneous conversions, which are re-started once the injected conversion is completed.

Note: Do not convert the same channel on the two ADCs (no overlapping sampling times for the two ADCs when converting the same channel).

In regular simultaneous mode, one must convert sequences with the same length and inside a sequence, the N-th conversion in master ans slave must be configured with the same sampling time.

Software is notified by interrupts when it can read the data:

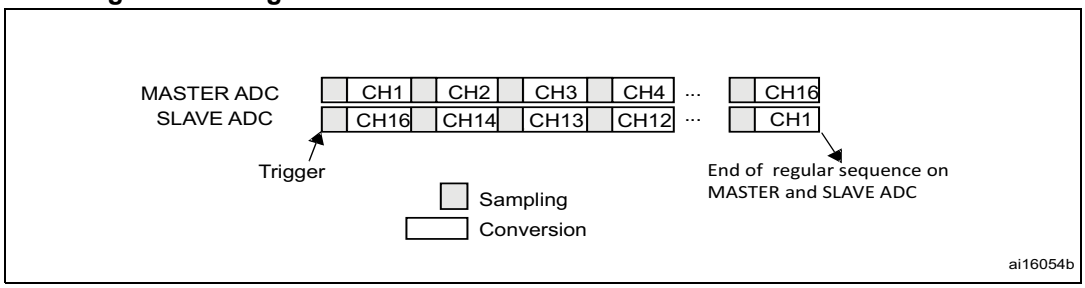
- At the end of each conversion event (EOC) on the master ADC, a master EOC interrupt is generated (if EOCIE is enabled) and software can read the ADC_DR of the master ADC.
- At the end of each conversion event (EOC) on the slave ADC, a slave EOC interrupt is generated (if EOCIE is enabled) and software can read the ADC_DR of the slave ADC.
- If the duration of the master regular sequence is equal to the duration of the slave one (like in *Figure 213*), it is possible for the software to enable only one of the two EOC interrupt (ex: master EOC) and read both converted data from the Common Data register (ADCx_CDR).

It is also possible to read the regular data using the DMA. Two methods are possible:

- Using two DMA channels (one for the master and one for the slave). In this case bits DAMDF[1:0] must be kept cleared.
  - Configure the DMA master ADC channel to read ADC_DR from the master. DMA requests are generated at each EOC event of the master ADC.
  - Configure the DMA slave ADC channel to read ADC_DR from the slave. DMA requests are generated at each EOC event of the slave ADC.
- Configuring Dual ADC mode data format DAMDF[1:0] bits, which leaves one DMA channel free for other uses:
  - Configure DAMDF[1:0]=0b10 or 0b11 (depending on resolution).
  - A single DMA channel is used (the one of the master). Configure the DMA master ADC channel to read the common ADC register (ADCx_CDR)
  - A single DMA request is generated each time both master and slave EOC events have occurred. At that time, the slave ADC converted data is available in the upper half-word of the ADCx_CDR 32-bit register and the master ADC converted data is available in the lower half-word of ADCx_CDR register.
  - both EOC flags are cleared when the DMA reads the ADCx_CDR register.

Note: When DAMDF[1:0]=0b10 or 0b11, the user must program the same number of conversions in the master's sequence as in the slave's sequence. Otherwise, the remaining conversions will not generate a DMA request.

Figure 213. Regular simultaneous mode on 16 channels: dual ADC mode



If DISCEN=1 then each “n” simultaneous conversions of the regular sequence require a regular trigger event to occur (“n” is defined by DISCNUM).

This mode can be combined with AUTDLY mode:

- Once a simultaneous conversion of the sequence has ended, the next conversion in the sequence is started only if the common data register, ADCx_CDR (or the regular data register of the master ADC) has been read (delay phase).
- Once a simultaneous regular sequence of conversions has ended, a new regular trigger event is accepted only if the common data register (ADCx_CDR) has been read (delay phase). Any new regular trigger events occurring during the ongoing regular sequence and the associated delay phases are ignored.

It is possible to use the DMA to handle data in regular simultaneous mode combined with AUTDLY mode, assuming that multi-DMA mode is used: bits DAMDF must be set to 0b10 or 0b11.

When regular simultaneous mode is combined with AUTDLY mode, it is mandatory for the user to ensure that:

- The number of conversions in the master’s sequence is equal to the number of conversions in the slave’s.
- For each simultaneous conversions of the sequence, the length of the conversion of the slave ADC is inferior to the length of the conversion of the master ADC. Note that the length of the sequence depends on the number of channels to convert and the sampling time and the resolution of each channels.

Note: This combination of regular simultaneous mode and AUTDLY mode is restricted to the use case when only regular channels are programmed: it is forbidden to program injected channels in this combined mode.

Interleaved mode with independent injected

This mode is selected by programming bits DUAL[4:0] = 00111.

This mode can be started only on a regular group (usually one channel). The external trigger source comes from the regular channel multiplexer of the master ADC.

After an external trigger occurs:

- The master ADC starts immediately.
- The slave ADC starts after a delay of several-ADC clock cycles after the sampling phase of the master ADC has complete.

The minimum delay which separates 2 conversions in interleaved mode is configured in the DELAY bits in the ADCx_CCR register. This delay starts to count after the end of the sampling phase of the master conversion. This way, an ADC cannot start a conversion if the

complementary ADC is still sampling its input (only one ADC can sample the input signal at a given time).

- The minimum possible DELAY is 1 to ensure that there is at least one cycle time between the opening of the analog switch of the master ADC sampling phase and the closing of the analog switch of the slave ADC sampling phase.
- The maximum DELAY is equal to the number of cycles corresponding to the selected resolution. However the user must properly calculate this delay to ensure that an ADC does not start a conversion while the other ADC is still sampling its input.

If the CONT bit is set on both master and slave ADCs, the selected regular channels of both ADCs are continuously converted.

The software is notified by interrupts when it can read the data at the end of each conversion event (EOC) on the slave ADC. A slave and master EOC interrupts are generated (if EOCIE is enabled) and the software can read the ADC_DR of the slave/master ADC.

Note: It is possible to enable only the EOC interrupt of the slave and read the common data register (ADCx_CDR). But in this case, the user must ensure that the duration of the conversions are compatible to ensure that inside the sequence, a master conversion is always followed by a slave conversion before a new master conversion restarts. It is recommended to use the MDMA mode.

It is also possible to have the regular data transferred by DMA. In this case, individual DMA requests on each ADC cannot be used and it is mandatory to use the MDMA mode, as following:

- Configure DAMDF[1:0]=0b10 or 0b11 (depending on resolution).
- A single DMA channel is used (the one of the master). Configure the DMA master ADC channel to read the common ADC register (ADCx_CDR).
- A single DMA request is generated each time both master and slave EOC events have occurred. At that time, the slave ADC converted data is available in the upper half-word of the ADCx_CDR 32-bit register and the master ADC converted data is available in the lower half-word of ADCx_CCR register.
- Both EOC flags are cleared when the DMA reads the ADCx_CCR register.

Figure 214. Interleaved mode on 1 channel in continuous conversion mode: dual ADC mode

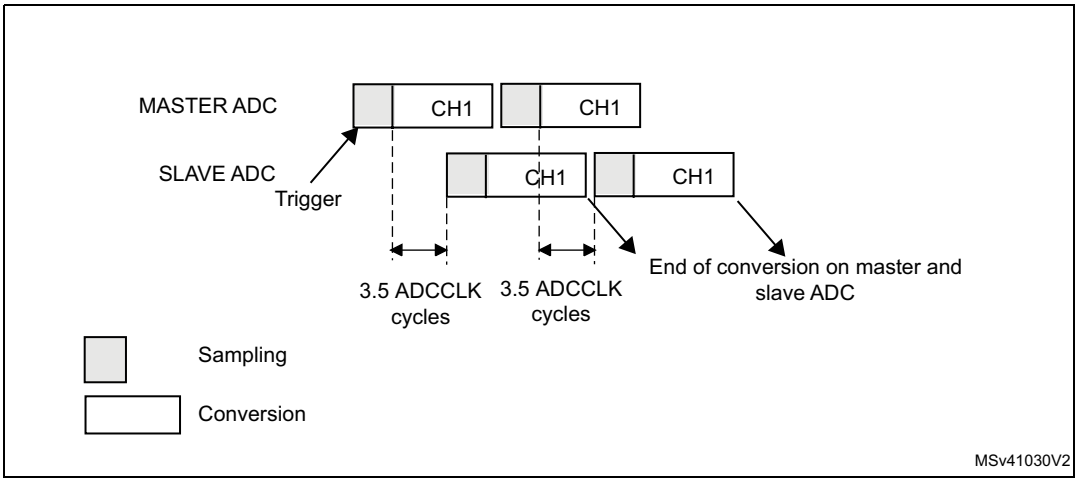
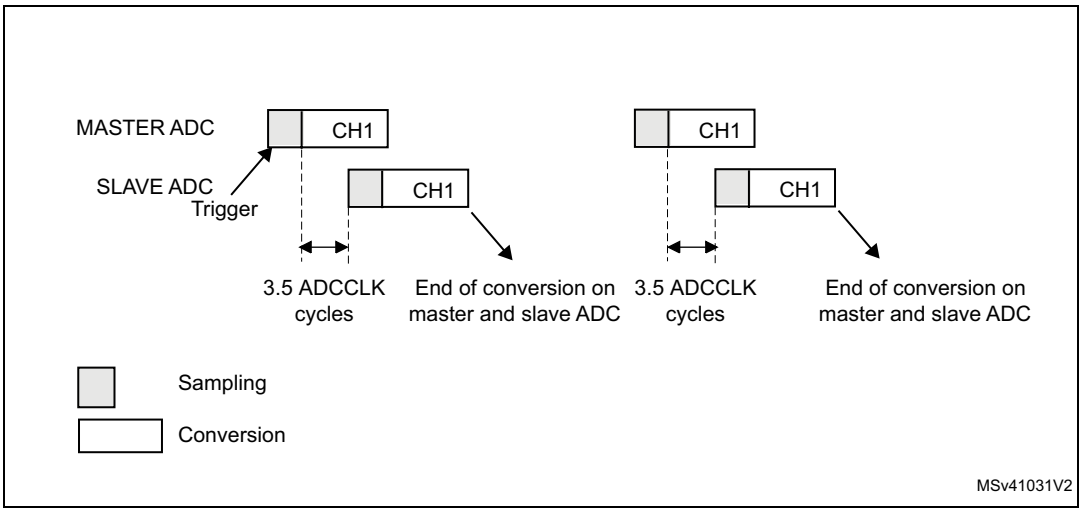


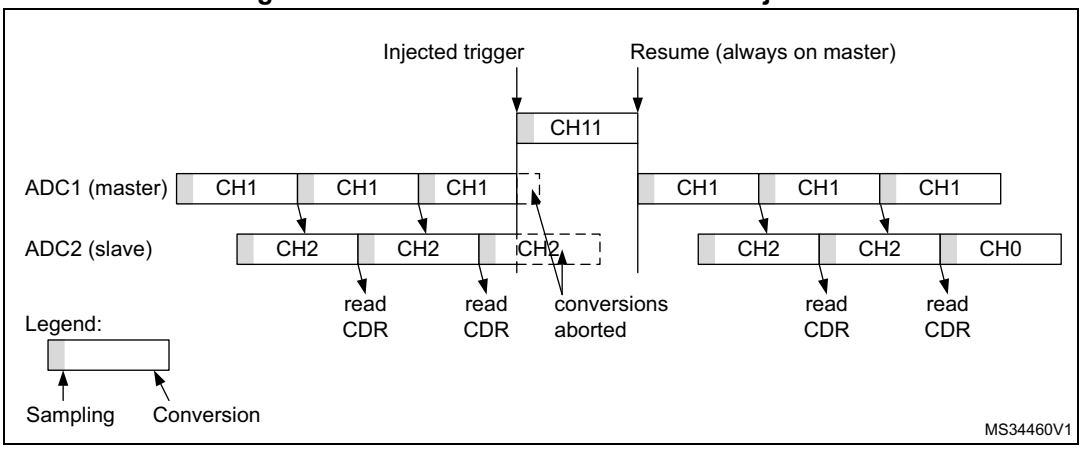
Figure 215. Interleaved mode on 1 channel in single conversion mode: dual ADC mode



If DISCEN=1, each “n” simultaneous conversions (“n” is defined by DISCNUM) of the regular sequence require a regular trigger event to occur.

In this mode, injected conversions are supported. When injection is done (either on master or on slave), both the master and the slave regular conversions are aborted and the sequence is re-started from the master (see *Figure 216* below).

Figure 216. Interleaved conversion with injection



Alternate trigger mode

This mode is selected by programming bits DUAL[4:0] = 01001.

This mode can be started only on an injected group. The source of external trigger comes from the injected group multiplexer of the master ADC.

This mode is only possible when selecting hardware triggers: JEXTEN must not be 0x0.

Injected discontinuous mode disabled (JDISCEN=0 for both ADC)

1. When the 1st trigger occurs, all injected master ADC channels in the group are converted.
2. When the 2nd trigger occurs, all injected slave ADC channels in the group are converted.
3. And so on.

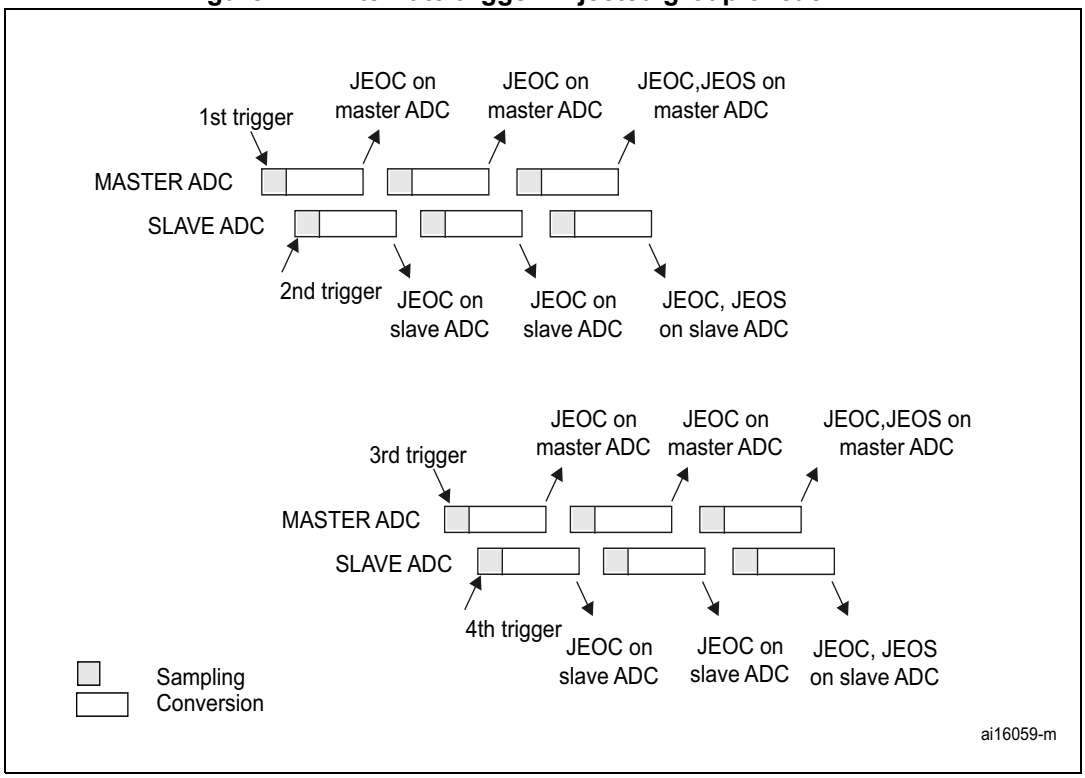
A JEOS interrupt, if enabled, is generated after all injected channels of the master ADC in the group have been converted.

A JEOS interrupt, if enabled, is generated after all injected channels of the slave ADC in the group have been converted.

JEOC interrupts, if enabled, can also be generated after each injected conversion.

If another external trigger occurs after all injected channels in the group have been converted then the alternate trigger process restarts by converting the injected channels of the master ADC in the group.

Figure 217. Alternate trigger: injected group of each ADC



Note: Regular conversions can be enabled on one or all ADCs. In this case the regular conversions are independent of each other. A regular conversion is interrupted when the ADC has to perform an injected conversion. It is resumed when the injected conversion is finished.

The time interval between 2 trigger events must be greater than or equal to 1 ADC clock period. The minimum time interval between 2 trigger events that start conversions on the same ADC is the same as in the single ADC mode.

Injected discontinuous mode enabled (JDISCEN=1 for both ADC)

If the injected discontinuous mode is enabled for both master and slave ADCs:

- When the 1st trigger occurs, the first injected channel of the master ADC is converted.
- When the 2nd trigger occurs, the first injected channel of the slave ADC is converted.
- And so on.

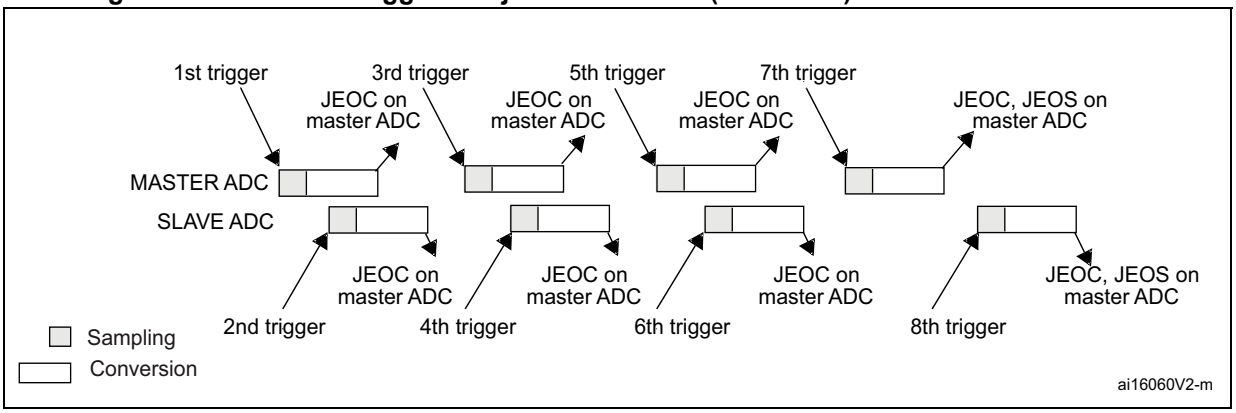
A JEOS interrupt, if enabled, is generated after all injected channels of the master ADC in the group have been converted.

A JEOS interrupt, if enabled, is generated after all injected channels of the slave ADC in the group have been converted.

JEOC interrupts, if enabled, can also be generated after each injected conversions.

If another external trigger occurs after all injected channels in the group have been converted then the alternate trigger process restarts.

Figure 218. Alternate trigger: 4 injected channels (each ADC) in discontinuous mode



Combined regular/injected simultaneous mode

This mode is selected by programming bits DUAL[4:0] = 00001.

It is possible to interrupt the simultaneous conversion of a regular group to start the simultaneous conversion of an injected group.

Note: The sequences must be converted with the same length, the N-th conversion in master and slave mode must be configured with the same sampling time inside a given sequence, or the interval between triggers has to be longer than the long conversion time of the 2 sequences. If the above conditions are not respected, the ADC with the shortest sequence may restart while the ADC with the longest sequence is completing the previous conversions.

Combined regular simultaneous + alternate trigger mode

This mode is selected by programming bits DUAL[4:0]=00010.

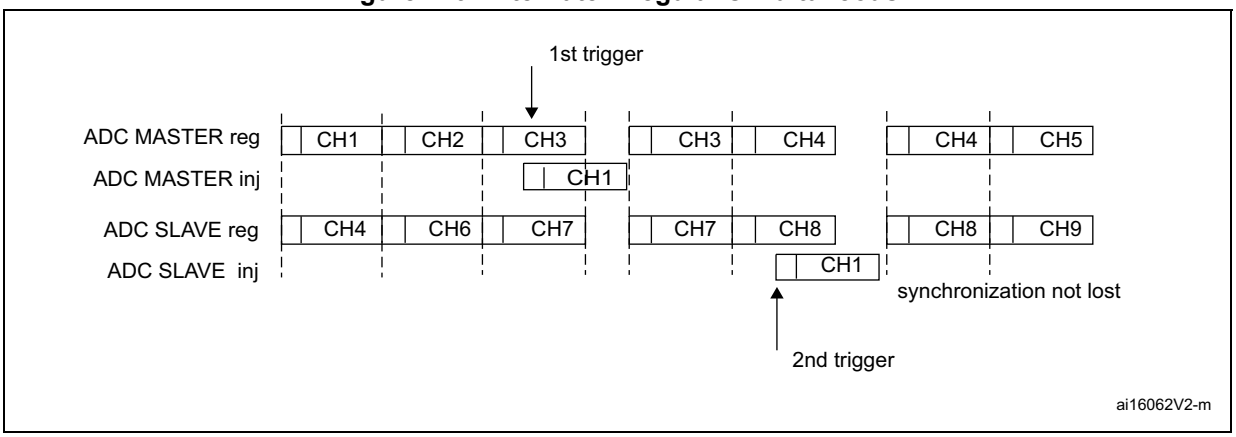
It is possible to interrupt the simultaneous conversion of a regular group to start the alternate trigger conversion of an injected group. *Figure 219* shows the behavior of an alternate trigger interrupting a simultaneous regular conversion.

The injected alternate conversion is immediately started after the injected event. If a regular conversion is already running, in order to ensure synchronization after the injected

conversion, the regular conversion of all (master/slave) ADCs is stopped and resumed synchronously at the end of the injected conversion.

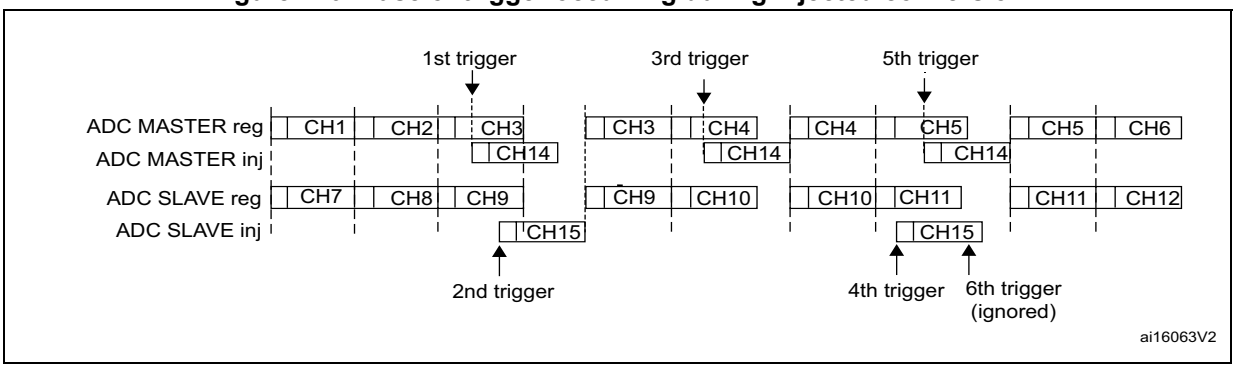
Note: The sequences must be converted with the same length, the N-th conversion in master and slave mode must be configured with the same sampling time inside a given sequence, or the interval between triggers has to be longer than the long conversion time of the 2 sequences. If the above conditions are not respected, the ADC with the shortest sequence may restart while the ADC with the longest sequence is completing the previous conversions.

Figure 219. Alternate + regular simultaneous



If a trigger occurs during an injected conversion that has interrupted a regular conversion, the alternate trigger is served. *Figure 220* shows the behavior in this case (note that the 6th trigger is ignored because the associated alternate conversion is not complete).

Figure 220. Case of trigger occurring during injected conversion



Combined injected simultaneous plus interleaved

This mode is selected by programming bits DUAL[4:0]=00011.

It is possible to interrupt an interleaved conversion with a simultaneous injected event.

In this case the interleaved conversion is interrupted immediately and the simultaneous injected conversion starts. At the end of the injected sequence the interleaved conversion is resumed. When the interleaved regular conversion resumes, the first regular conversion which is performed is alway the master's one. *Figure 221*, *Figure 222* and *Figure 223* show the behavior using an example.

Caution: In this mode, it is mandatory to use the Common Data Register to read the regular data with a single read access. On the contrary, master-slave data coherency is not guaranteed.

Figure 221. Interleaved single channel CH0 with injected sequence CH11, CH12

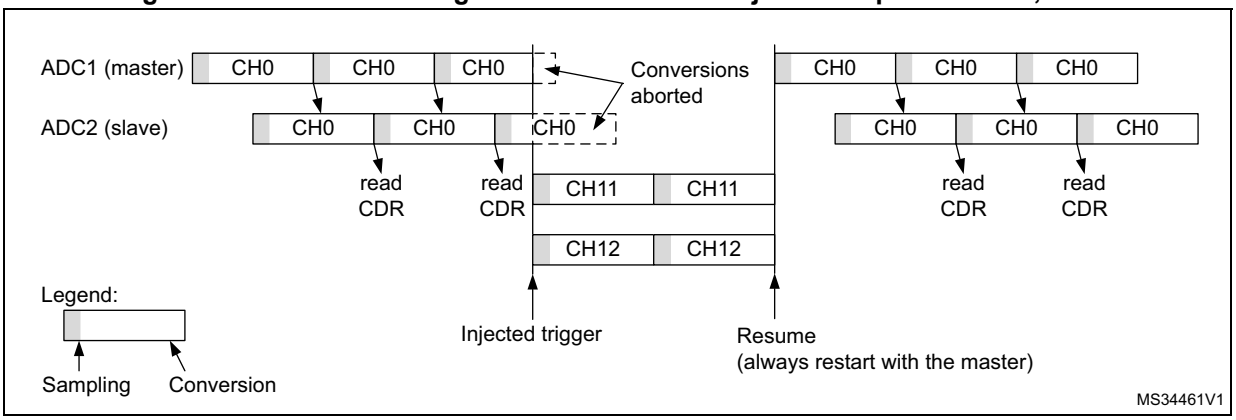


Figure 222. Two Interleaved channels (CH1, CH2) with injected sequence CH11, CH12 - case 1: Master interrupted first

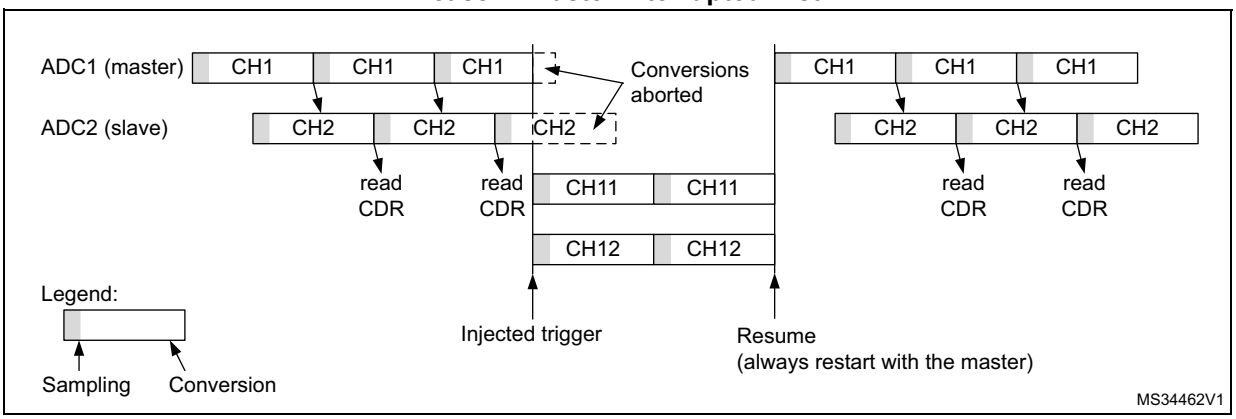
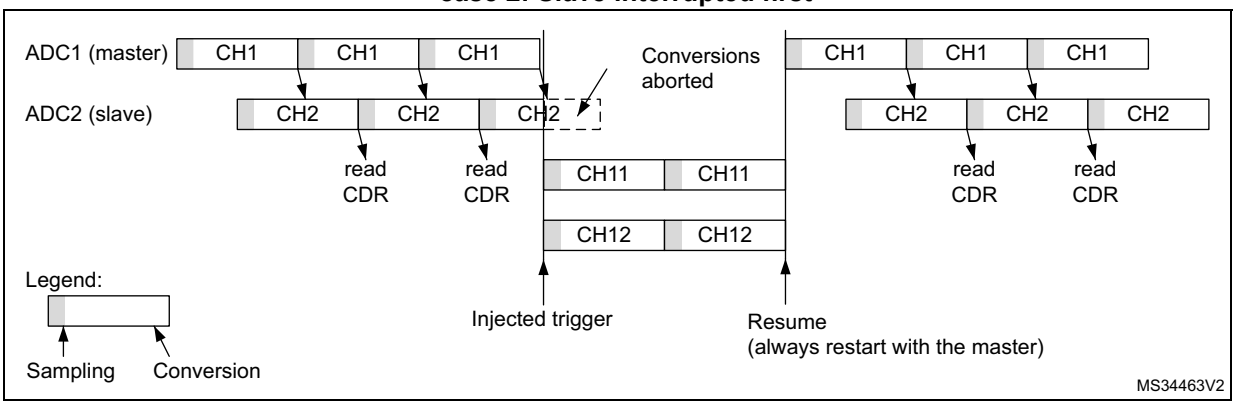


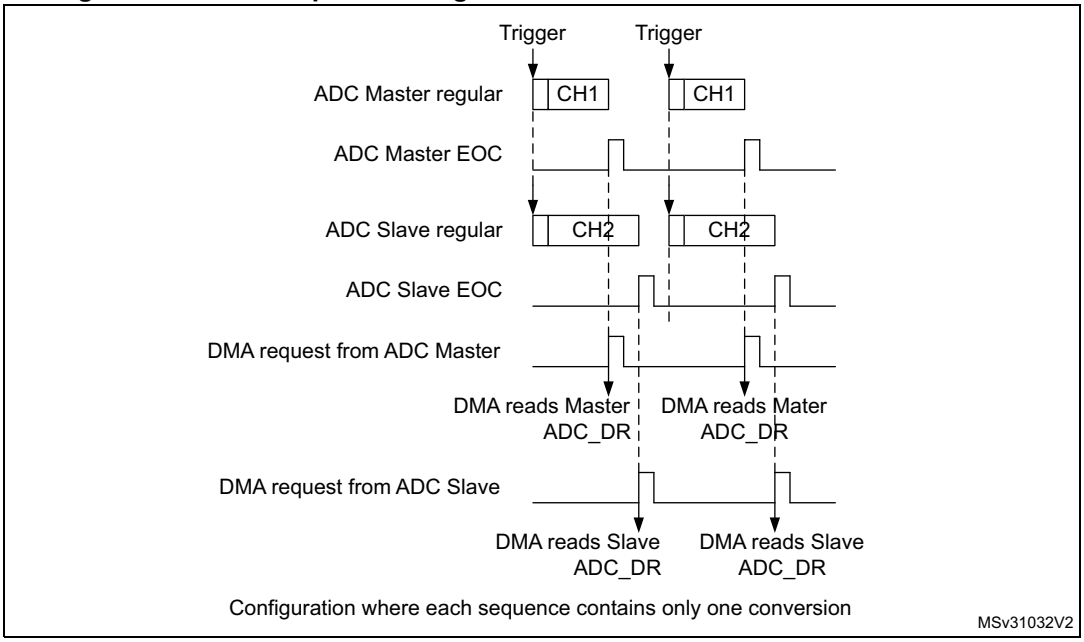
Figure 223. Two Interleaved channels (CH1, CH2) with injected sequence CH11, CH12 - case 2: Slave interrupted first



DMA requests in dual ADC mode

In all dual ADC modes, it is possible to use two DMA channels (one for the master, one for the slave) to transfer the data, like in single mode (refer to *Figure 224: DMA Requests in regular simultaneous mode when DAMDF=0b00*).

Figure 224. DMA Requests in regular simultaneous mode when DAMDF=0b00



In simultaneous regular and interleaved modes, it is also possible to save one DMA channel and transfer both data using a single DMA channel. For this DAMDF bits must be configured in the ADCx_CCR register:

- **DAMDF=0b10, 32-bit format**: A single DMA request is generated alternatively when either the master or slave EOC events have occurred. At that time, the data items are alternatively available in the ADCx_CDR2 32-bit register. This mode is used in interleaved mode and in regular simultaneous mode when resolution is above 16-bit.
  Example:

  Interleaved dual mode: a DMA request is generated each time a new 32-bit data is available:

  1st DMA request: ADCx_CDR2[31:0] = MST_ADC_DR[31:0]

  2nd DMA request: ADCx_CDR2[31:0] = SLV_ADC_DR[31:0]
- **DAMDF=0b10, 16-bit format**: A single DMA request is generated each time both master and slave EOC events have occurred. At that time, two data items are available and the 32-bit register ADCx_CDR contains the two half-words representing two ADC-

converted data items. The slave ADC data take the upper half-word and the master ADC data take the lower half-word.

This mode is used in interleaved mode and in regular simultaneous mode when resolution is ranging from 10 to 16-bit. Any value above 16-bit in the master or the slave converter will be truncated to the least 16 significant bits.

Example:

Interleaved dual mode: a DMA request is generated each time 2 data items are available:

1st DMA request: ADCx_CDR[31:0] = SLV_ADC_DR[15:0] | MST_ADC_DR[15:0]

2nd DMA request: ADCx_CDR[31:0] = SLV_ADC_DR[15:0] | MST_ADC_DR[15:0]

Figure 225. DMA requests in regular simultaneous mode when DAMDF=0b10

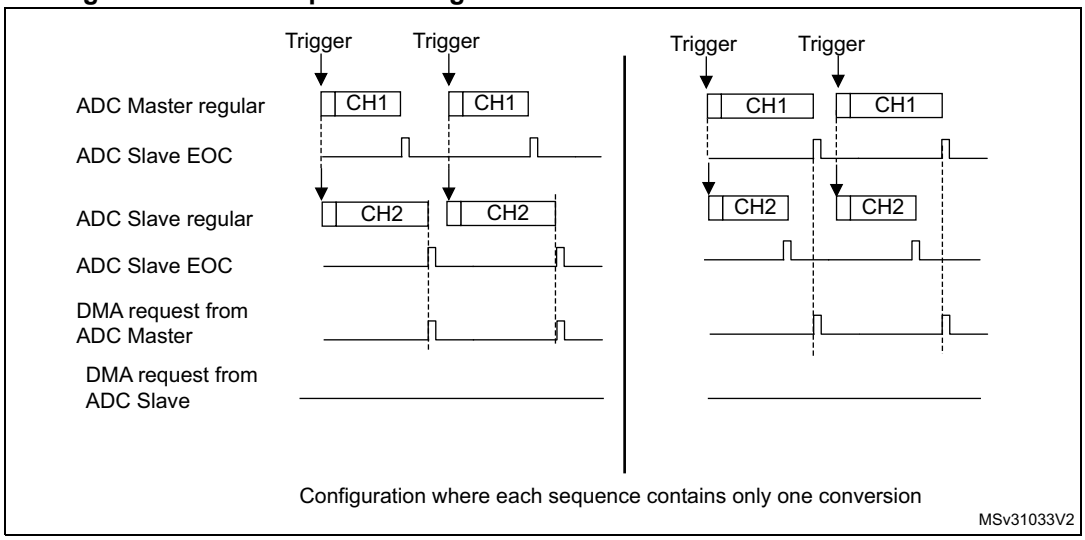
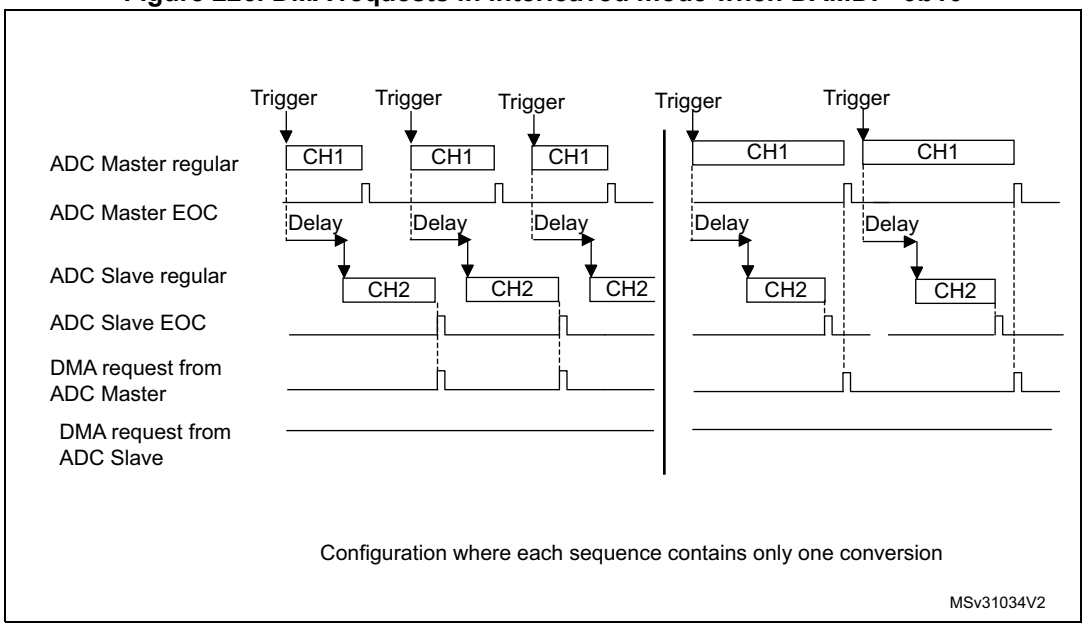


Figure 226. DMA requests in interleaved mode when DAMDF=0b10



Note: When using Multi ADC mode, the user must take care to configure properly the duration of the master and slave conversions so that a DMA request is generated and served for reading both data (master + slave) before a new conversion is available.

- **DAMDF=0b11**: This mode is similar to the DAMDF=0b10. The only differences are that on each DMA request (two data items are available), two bytes representing two ADC converted data items are transferred as a half-word.

  This mode is used in interleaved and regular simultaneous mode when the result is 8-bit. A new DMA request is issued when 4 new 8-bit values are available.

  Example:

  Interleaved dual mode: a DMA request is generated each time 4 data items are available (t0, t1,... are corresponding to the consecutive sampling instants)

  1st DMA request:

  ADCx_CDR[7:0] = MST_ADC_DR[7:0]$_{t0}$

  ADCx_CDR[15:8] = SLV_ADC_DR[7:0]$_{t0}$

  ADCx_CDR[23:16] = MST_ADC_DR[7:0]$_{t1}$

  ADCx_CDR[31:24] = SLV_ADC_DR[7:0]$_{t1}$

  2nd DMA request:

  ADCx_CDR[7:0] = MST_ADC_DR[7:0]$_{t2}$

  ADCx_CDR[15:8] = SLV_ADC_DR[7:0]$_{t2}$

  ADCx_CDR[23:16] = MST_ADC_DR[7:0]$_{t3}$

  ADCx_CDR[31:24] = SLV_ADC_DR[7:0]$_{t3}$

Overrun detection

In dual ADC mode (when DUAL[4:0] is not equal to b00000), if an overrun is detected on one of the ADCs, the DMA requests are no longer issued to ensure that all the data transferred to the RAM are valid (this behavior occurs whatever the DAMDF configuration). It may happen that the EOC bit corresponding to one ADC remains set because the data register of this ADC contains valid data.

DMA one shot mode/ DMA circular mode when Multi ADC mode is selected

When DAMDF mode is selected (0b10 or 0b11), bit DMNGT[1:0]=0b10 in the master ADC's ADCx_CCR register must also be configured to select between DMA one shot mode and circular mode, as explained in section *Section : Managing conversions using the DMA*.

Stopping the conversions in dual ADC modes

The user must set the control bits ADSTP/JADSTP of the master ADC to stop the conversions of both ADC in dual ADC mode. The other ADSTP control bit of the slave ADC has no effect in dual ADC mode.

Once both ADC are effectively stopped, the bits ADSTART/JADSTART of the master and slave ADCs are both cleared by hardware.

DFSDM mode in dual ADC mode interleaved mode

In dual ADC interleaved modes, the ADC conversion results can be transferred directly to the Digital Filter for Sigma Delta Modulators (DFSDM).

This mode is enabled by setting the bits DMNGT[1:0] = 0b10 in the master ADC's ADC_CFGR register.

The ADC transfers alternatively the 16 least significant bits of the regular data register from the master and the slave converter to a single channel of the DFSDM.

The data format must be 16-bit signed:

ADC_DR[31:16] = 0x0000

ADC_DR[15] = sign

ADC_DR[14:0] = data

Any value above 16-bit signed format in any converter will be truncated.

DFSDM mode in dual ADC simultaneous mode

The dual mode is not required to use DFSDM in dual ADC simultaneous mode since conversion data will be treated by each individual channel. Single mode with same trigger source results in simultaneous conversion with DFSDM interface.

28.4.33 V_{BAT} supply monitoring

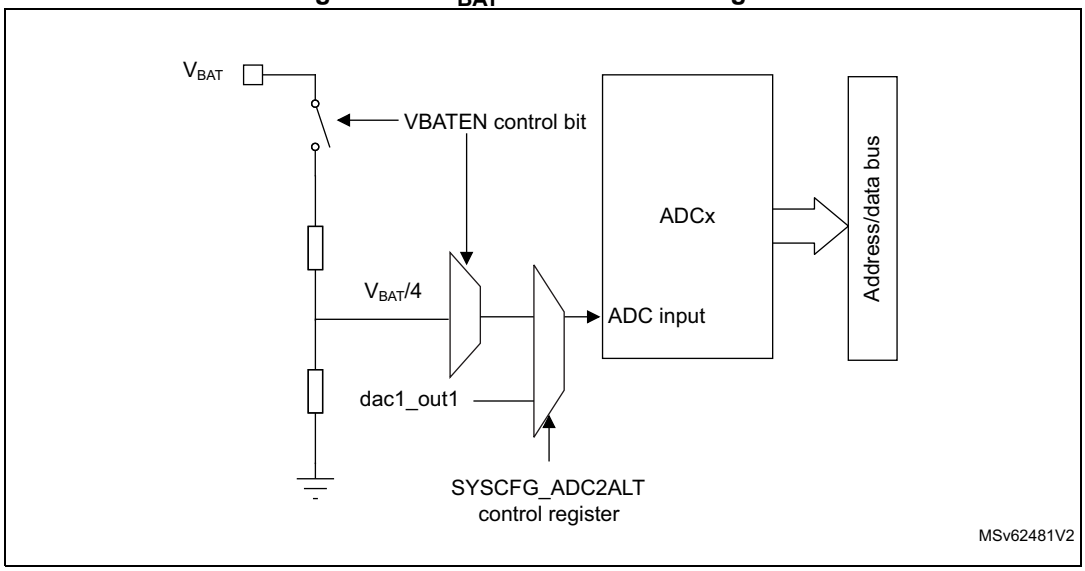
The VBATEN bit of the ADC3_CCR register is used to switch to the battery voltage. As the V_{BAT} voltage could be higher than V_{DDA}, to ensure the correct operation of the ADC, the V_{BAT} pin is internally connected to a bridge divider by 4. This bridge is automatically enabled when VBATEN is set, to connect $V_{BAT}/4$ to an ADC input channel (refer to *Table ADC interconnection* in *Section 28.4.2: ADC pins and internal signals*). Then the SYSCFG_ADC2ALT register must be configured to select between dac1_out1 output or $V_{BAT}/4$.

As a consequence, the converted digital value is one fourth of the V_{BAT} voltage. To prevent any unwanted consumption on the battery, it is recommended to enable the bridge divider only when needed, for ADC conversion.

Refer to the electrical characteristics of the device datasheet for the sampling time value to be applied when converting the $V_{BAT}/4$ voltage.

Figure 227 shows the block diagram of the V_{BAT} sensing feature.

Figure 227. V_{BAT} channel block diagram



Note: The VBATEN bit in ADC3_CCR as well as the SYSCFG_ADC2ALT register must be configured to enable the conversion of the corresponding ADC internal channel.

28.4.34 Monitoring the internal voltage reference

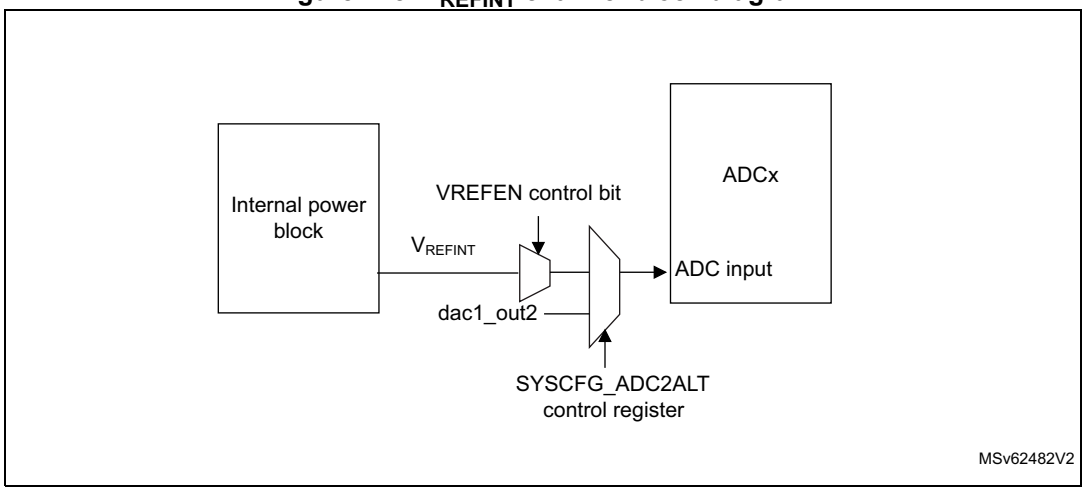
The internal voltage reference can be monitored to have a reference point for evaluating the ADC V_{REF+} voltage level.

The internal voltage reference is internally connected to an ADC input channel (refer to *Table ADC interconnection* in *Section 28.4.2: ADC pins and internal signals*).

The sampling time for this channel must be greater than the stabilization time specified in the product datasheet.

Figure 227 shows the block diagram of the V_{REFINT} sensing feature.

Figure 228. V_{REFINT} channel block diagram



Note: The VREFEN bit of the ADC3_CCR register as well as the SYSCFG_ADC2ALT control register *must be configured to enable the conversion of the corresponding ADC internal channel (V_{REFINT}).*

Calculating the actual V_{DDA} voltage using the internal reference voltage

The power supply voltage applied to the device may be subject to variations or not precisely known. When V_{DDA} is connected to V_{REF+}, it is possible to compute the actual V_{DDA} voltage using the embedded internal reference voltage (V_{REFINT}). V_{REFINT} and its calibration data acquired by the ADC during the manufacturing process at V_{DDA} = 3.3 V can be used to evaluate the actual V_{DDA} voltage level.

The following formula gives the actual V_{DDA} voltage supplying the device:

$$V_{REF+} = 3.3\ V \times VREFINT\_CAL / VREFINT\_DATA$$

Where:

- VREFINT_CAL is the VREFINT calibration value
- VREFINT_DATA is the actual VREFINT output value converted by ADC

Converting a supply-relative ADC measurement to an absolute voltage value

The ADC is designed to deliver a digital value corresponding to the ratio between V_{REF+} and the voltage applied on the converted channel.

For most applications V_{DDA} value is unknown and ADC converted values are right-aligned. In this case, it is necessary to convert this ratio into a voltage independent from V_{DDA}:

$$V_{CHANNELx} = \frac{V_{REF+}}{FULL\_SCALE} \times ADC\_DATA$$

By replacing V_{REF+} by the formula provided above, the absolute voltage value is given by the following formula

$$V_{CHANNELx} = \frac{3.3\ V \times VREFINT\_CAL \times ADC\_DATA}{VREFINT\_DATA \times FULL\_SCALE}$$

For applications where V_{DDA} is known and ADC converted values are right-aligned, the absolute voltage value can be obtained by using the following formula:

$$V_{CHANNELx} = \frac{V_{DDA}}{FULL\_SCALE} \times ADC\_DATA$$

Where:

- VREFINT_CAL is the VREFINT calibration value
- ADC_DATA is the value measured by the ADC on channel x (right-aligned)
- VREFINT_DATA is the actual VREFINT output value converted by the ADC
- FULL_SCALE is the maximum digital value of the ADC output. For example with 16-bit resolution, it will be 2^{16} - 1 = 65535 or with 8-bit resolution, 2^8 - 1 = 255.

Note: If ADC measurements are done using an output format other than 16-bit right-aligned, all the parameters must first be converted to a compatible format before the calculation is done.

28.4.35 Monitoring internal DAC output

The internal DAC voltage can be connected to the ADC input channel (refer to Table *ADC interconnection* in *Section 28.4.2: ADC pins and internal signals*) by configuring the SYSCFG_ADC2ALT control register.

28.5 ADC interrupts

For each ADC, an interrupt can be generated:

- After ADC power-up, when the ADC is ready (flag ADRDY)
- On the end of any conversion for regular groups (flag EOC)
- On the end of a sequence of conversion for regular groups (flag EOS)
- On the end of any conversion for injected groups (flag JEOC)
- On the end of a sequence of conversion for injected groups (flag JEOS)
- When an analog watchdog detection occurs (flag AWD1, AWD2 and AWD3)
- When the end of sampling phase occurs (flag EOSMP)
- When the data overrun occurs (OVR flag)
- When the injected sequence context queue overflows (flag JQOVF)

Separate interrupt enable bits are available for flexibility.

Table 235. ADC interrupts per each ADC

Interrupt event	Event flag	Enable control bit
ADC ready	ADRDY	ADRDYIE
End of conversion of a regular group	EOC	EOCIE
End of sequence of conversions of a regular group	EOS	EOSIE
End of conversion of a injected group	JEOC	JEOCIE
End of sequence of conversions of an injected group	JEOS	JEOSIE
Analog watchdog 1 status bit is set	AWD1	AWD1IE
Analog watchdog 2 status bit is set	AWD2	AWD2IE
Analog watchdog 3 status bit is set	AWD3	AWD3IE
End of sampling phase	EOSMP	EOSMPIE
Overrun	OVR	OVRIE
Injected context queue overflows	JQOVF	JQOVFIE

28.6 ADC registers (for each ADC)

Refer to *Section 1.2 on page 104* for a list of abbreviations used in register descriptions.

28.6.1 ADC interrupt and status register (ADC_ISR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	LDORDY	Res.	JQOVF	AWD3	AWD2	AWD1	JEOS	JEOC	OVR	EOS	EOC	EOSMP	ADRDY
			r		rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:13 Reserved, must be kept at reset value.

Bit 12 **LDORDY**: ADC LDO output voltage ready bit

This bit is set and cleared by hardware. It indicates that the ADC internal LDO output is ready and that the ADC can be enabled or calibrated.

0: ADC LDO voltage regulator disabled

1: ADC LDO voltage regulator enabled

Note: Refer to Section 28.3: ADC implementation for the availability of the LDO regulator.

Bit 11 Reserved, must be kept at reset value.

Bit 10 **JQOVF**: Injected context queue overflow

This bit is set by hardware when an Overflow of the Injected Queue of Context occurs. It is cleared by software writing 1 to it. Refer to *Section 28.4.22: Queue of context for injected conversions* for more information.

0: No injected context queue overflow occurred (or the flag event was already acknowledged and cleared by software)

1: Injected context queue overflow has occurred

Bit 9 **AWD3**: Analog watchdog 3 flag

This bit is set by hardware when the converted voltage crosses the values programmed in the fields LT3[7:0] and HT3[7:0] of ADC_TR3 register. It is cleared by software writing 1 to it.

0: No analog watchdog 3 event occurred (or the flag event was already acknowledged and cleared by software)

1: Analog watchdog 3 event occurred

Bit 8 **AWD2**: Analog watchdog 2 flag

This bit is set by hardware when the converted voltage crosses the values programmed in the fields LT2[7:0] and HT2[7:0] of ADC_TR2 register. It is cleared by software writing 1 to it.

0: No analog watchdog 2 event occurred (or the flag event was already acknowledged and cleared by software)

1: Analog watchdog 2 event occurred

Bit 7 **AWD1**: Analog watchdog 1 flag

This bit is set by hardware when the converted voltage crosses the values programmed in the fields LT1[11:0] and HT1[11:0] of ADC_TR1 register. It is cleared by software. writing 1 to it.

0: No analog watchdog 1 event occurred (or the flag event was already acknowledged and cleared by software)

1: Analog watchdog 1 event occurred

Bit 6 **JEOS:** Injected channel end of sequence flag

This bit is set by hardware at the end of the conversions of all injected channels in the group. It is cleared by software writing 1 to it.

0: Injected conversion sequence not complete (or the flag event was already acknowledged and cleared by software)

1: Injected conversions complete

Bit 5 **JEOC:** Injected channel end of conversion flag

This bit is set by hardware at the end of each injected conversion of a channel when a new data is available in the corresponding ADC_JDRy register. It is cleared by software writing 1 to it or by reading the corresponding ADC_JDRy register

0: Injected channel conversion not complete (or the flag event was already acknowledged and cleared by software)

1: Injected channel conversion complete

Bit 4 **OVR**: ADC overrun

This bit is set by hardware when an overrun occurs on a regular channel, meaning that a new conversion has completed while the EOC flag was already set. It is cleared by software writing 1 to it.

0: No overrun occurred (or the flag event was already acknowledged and cleared by software)

1: Overrun has occurred

Bit 3 **EOS**: End of regular sequence flag

This bit is set by hardware at the end of the conversions of a regular sequence of channels. It is cleared by software writing 1 to it.

0: Regular Conversions sequence not complete (or the flag event was already acknowledged and cleared by software)

1: Regular Conversions sequence complete

Bit 2 **EOC**: End of conversion flag

This bit is set by hardware at the end of each regular conversion of a channel when a new data is available in the ADC_DR register. It is cleared by software writing 1 to it or by reading the ADC_DR register

0: Regular channel conversion not complete (or the flag event was already acknowledged and cleared by software)

1: Regular channel conversion complete

Bit 1 **EOSMP**: End of sampling flag

This bit is set by hardware during the conversion of any channel (only for regular channels), at the end of the sampling phase.

0: not at the end of the sampling phase (or the flag event was already acknowledged and cleared by software)

1: End of sampling phase reached

Bit 0 **ADRDY**: ADC ready

This bit is set by hardware after the ADC has been enabled (bit ADEN=1) and when the ADC reaches a state where it is ready to accept conversion requests.

It is cleared by software writing 1 to it.

0: ADC not yet ready to start conversion (or the flag event was already acknowledged and cleared by software)

1: ADC is ready to start conversion

28.6.2 ADC interrupt enable register (ADC_IER)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	JQOVFIE	AWD3IE	AWD2IE	AWD1IE	JEOSIE	JEOCIE	OVRIE	EOSIE	EOCIE	EOSMPIE	ADRDYIE
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **JQOVFIE**: Injected context queue overflow interrupt enable

This bit is set and cleared by software to enable/disable the Injected Context Queue Overflow interrupt.

0: Injected Context Queue Overflow interrupt disabled

1: Injected Context Queue Overflow interrupt enabled. An interrupt is generated when the JQOVF bit is set.

Note: The software is allowed to write this bit only when JADSTART=0 (which ensures that no injected conversion is ongoing).

Bit 9 **AWD3IE**: Analog watchdog 3 interrupt enable

This bit is set and cleared by software to enable/disable the analog watchdog 2 interrupt.

0: Analog watchdog 3 interrupt disabled

1: Analog watchdog 3 interrupt enabled

Note: The software is allowed to write this bit only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

Bit 8 **AWD2IE**: Analog watchdog 2 interrupt enable

This bit is set and cleared by software to enable/disable the analog watchdog 2 interrupt.

0: Analog watchdog 2 interrupt disabled

1: Analog watchdog 2 interrupt enabled

Note: The software is allowed to write this bit only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

Bit 7 **AWD1IE**: Analog watchdog 1 interrupt enable

This bit is set and cleared by software to enable/disable the analog watchdog 1 interrupt.

0: Analog watchdog 1 interrupt disabled

1: Analog watchdog 1 interrupt enabled

Note: The software is allowed to write this bit only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

Bit 6 **JEOSIE**: End of injected sequence of conversions interrupt enable

This bit is set and cleared by software to enable/disable the end of injected sequence of conversions interrupt.

0: JEOS interrupt disabled

1: JEOS interrupt enabled. An interrupt is generated when the JEOS bit is set.

Note: The software is allowed to write this bit only when JADSTART=0 (which ensures that no injected conversion is ongoing).

Bit 5 **JEOCIE**: End of injected conversion interrupt enable

This bit is set and cleared by software to enable/disable the end of an injected conversion interrupt.

0: JEOC interrupt disabled.

1: JEOC interrupt enabled. An interrupt is generated when the JEOC bit is set.

Note: The software is allowed to write this bit only when JADSTART is cleared to 0 (no injected conversion is ongoing).

Bit 4 **OVRIE**: Overrun interrupt enable

This bit is set and cleared by software to enable/disable the Overrun interrupt of a regular conversion.

0: Overrun interrupt disabled

1: Overrun interrupt enabled. An interrupt is generated when the OVR bit is set.

Note: The software is allowed to write this bit only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 3 **EOSIE**: End of regular sequence of conversions interrupt enable

This bit is set and cleared by software to enable/disable the end of regular sequence of conversions interrupt.

0: EOS interrupt disabled

1: EOS interrupt enabled. An interrupt is generated when the EOS bit is set.

Note: The software is allowed to write this bit only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 2 **EOCIE**: End of regular conversion interrupt enable

This bit is set and cleared by software to enable/disable the end of a regular conversion interrupt.

0: EOC interrupt disabled.

1: EOC interrupt enabled. An interrupt is generated when the EOC bit is set.

Note: The software is allowed to write this bit only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 1 **EOSMPIE**: End of sampling flag interrupt enable for regular conversions

This bit is set and cleared by software to enable/disable the end of the sampling phase interrupt for regular conversions.

0: EOSMP interrupt disabled.

1: EOSMP interrupt enabled. An interrupt is generated when the EOSMP bit is set.

Note: The software is allowed to write this bit only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 0 **ADRDYIE**: ADC ready interrupt enable

This bit is set and cleared by software to enable/disable the ADC Ready interrupt.

0: ADRDY interrupt disabled

1: ADRDY interrupt enabled. An interrupt is generated when the ADRDY bit is set.

Note: The software is allowed to write this bit only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

28.6.3 ADC control register (ADC_CR)

Address offset: 0x08

Reset value: 0x2000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADCAL	ADCALDIF	DEEPPWD	ADVREGEN	LINCALRDYW6	LINCALRDYW5	LINCALRDYW4	LINCALRDYW3	LINCALRDYW2	LINCALRDYW1	Res.	Res.	Res.	Res.	Res.	ADCALLIN
rs	rw	rw	rw	rw	rw	rw	rw	rw	rw						rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	BOOST[1:0]		Res.	Res.	JADSTP	ADSTP	JADSTART	ADSTART	ADDIS	ADEN
						rw	rw			rs	rs	rs	rs	rs	rs

Bit 31 **ADCAL**: ADC calibration

This bit is set by software to start the calibration of the ADC. Program first the bit ADCALDIF to determine if this calibration applies for single-ended or differential inputs mode.

It is cleared by hardware after calibration is complete.

0: Calibration complete

1: Write 1 to calibrate the ADC. Read at 1 means that a calibration in progress.

Note: The software is allowed to launch a calibration by setting ADCAL only when ADEN=0.

The software is allowed to update the calibration factor by writing ADC_CALFACT only when ADEN=1 and ADSTART=0 and JADSTART=0 (ADC enabled and no conversion is ongoing)

Bit 30 **ADCALDIF**: Differential mode for calibration

This bit is set and cleared by software to configure the single-ended or differential inputs mode for the calibration.

0: Writing ADCAL will launch a calibration in Single-ended inputs Mode.

1: Writing ADCAL will launch a calibration in Differential inputs Mode.

Note: The software is allowed to write this bit only when the ADC is disabled and is not calibrating (ADCAL=0, JADSTART=0, JADSTP=0, ADSTART=0, ADSTP=0, ADDIS=0 and ADEN=0).

Bit 29 **DEEPPWD**: Deep-power-down enable

This bit is set and cleared by software to put the ADC in deep-power-down mode.

0: ADC not in deep-power down

1: ADC in deep-power-down (default reset state)

Note: The software is allowed to write this bit only when the ADC is disabled (ADCAL=0, JADSTART=0, JADSTP=0, ADSTART=0, ADSTP=0, ADDIS=0 and ADEN=0).

Bit 28 **ADVREGEN**: ADC voltage regulator enable

This bits is set by software to enable the ADC voltage regulator.

Before performing any operation such as launching a calibration or enabling the ADC, the ADC voltage regulator must first be enabled and the software must wait for the regulator start-up time.

0: ADC Voltage regulator disabled

1: ADC Voltage regulator enabled.

For more details about the ADC voltage regulator enable and disable sequences, refer to *Section 28.4.6: ADC deep-power-down mode (DEEPPWD) and ADC voltage regulator (ADVREGEN)*.

The software can program this bitfield only when the ADC is disabled (ADCAL=0, JADSTART=0, ADSTART=0, ADSTP=0, ADDIS=0 and ADEN=0).

Bit 27 **LINCALRDYW6**: Linearity calibration ready Word 6

This control / status bit allows to read/write the 6th linearity calibration factor.

When the linearity calibration is complete, this bit is set. A bit clear will launch the transfer of the linearity factor 6 into the LINCALFACT[29:0] of the ADC_CALFACT2 register. The bit will be reset by hardware when the ADC_CALFACT2 register can be read (software must poll the bit until it is cleared).

When the *LINCALRDYW6 bit is reset, a new linearity factor 6 value can be written into* the LINCALFACT[29:0] of the ADC_CALFACT2 register. A bit set will launch the linearity factor 6 update and the bit will be effectively set by hardware once the update will be done (software must poll the bit until it is set to indicate the write is effective).

Note: ADC_CALFACT2[29:10] *contains 0.* ADC_CALFACT2[9:0] *corresponds linearity correction factor bits[159:150].*

The software is allowed to toggle this bit only if the LINCALRDYW5, LINCALRDYW4, LINCALRDYW3, LINCALRDYW2 and LINCALRDYW1 bits are left unchanged, see chapter 28.4.8: Calibration (ADCAL, ADCALDIF, ADCALLIN, ADC_CALFACT) for details.

The software is allowed to update the linearity calibration factor by writing LINCALRDYWx only when ADEN=1 and ADSTART=0 and JADSTART=0 (ADC enabled and no conversion is ongoing)

Bit 26 **LINCALRDYW5**: Linearity calibration ready Word 5

Refer to LINCALRDYW6 description.

Note: ADC_CALFACT2[29:0] *corresponds linearity correction factor bits[149:120].*

The software is allowed to toggle this bit only if the LINCALRDYW6, LINCALRDYW5, LINCALRDYW3, LINCALRDYW2 and LINCALRDYW1 bits are left unchanged.

Bit 25 **LINCALRDYW4**: Linearity calibration ready Word 4

Refer to LINCALRDYW6 description.

Note: ADC_CALFACT2[29:0] *correspond linearity correction factor bits[119:90].*

The software is allowed to toggle this bit only if the LINCALRDYW6, LINCALRDYW5, LINCALRDYW3, LINCALRDYW2 and LINCALRDYW1 bits are left unchanged.

Bit 24 **LINCALRDYW3**: Linearity calibration ready Word 3

Refer to LINCALRDYW6 description.

Note: ADC_CALFACT2[29:0] *corresponds linearity correction factor bits[89:60].*

The software is allowed to toggle this bit only if the LINCALRDYW6, LINCALRDYW5, LINCALRDYW4, LINCALRDYW2 and LINCALRDYW1 bits are left unchanged.

Bit 23 **LINCALRDYW2**: Linearity calibration ready Word 2

Refer to LINCALRDYW6 description.

Note: ADC_CALFACT2[29:0] *corresponds linearity correction factor bits[59:30].*

The software is allowed to toggle this bit only if the LINCALRDYW6, LINCALRDYW5, LINCALRDYW4, LINCALRDYW3 and LINCALRDYW1 bits are left unchanged.

Bit 22 **LINCALRDYW1**: Linearity calibration ready Word 1

Refer to LINCALRDYW6 description.

Note: ADC_CALFACT2[29:0] corresponds linearity correction factor bits[29:0].

The software is allowed to toggle this bit only if the LINCALRDYW6, LINCALRDYW5, LINCALRDYW4, LINCALRDYW3 and LINCALRDYW2 bits are left unchanged.

Bits 21:17 Reserved, must be kept at reset value.

Bit 16 **ADCALLIN**: Linearity calibration

This bit is set and cleared by software to enable the Linearity calibration.

0: Writing ADCAL will launch a calibration without the Linearity calibration.

1: Writing ADCAL will launch a calibration with he Linearity calibration.

Note: The software is allowed to write this bit only when the ADC is disabled and is not calibrating (ADCAL=0, JADSTART=0, JADSTP=0, ADSTART=0, ADSTP=0, ADDIS=0 and ADEN=0).

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:8 **BOOST[1:0]**: Boost mode control

This bitfield is set and cleared by software to enable/disable the Boost mode.

00: used when ADC clock ≤ 6.25 MHz

01: used when 6.25 MHz < ADC clock frequency ≤ 12.5 MHz

10: used when 12.5 MHz < ADC clock ≤ 25.0 MHz

11: used when 25.0 MHz < ADC clock ≤ 50.0 MHz

Note: The software is allowed to write this bit only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

When dual mode is enabled (bits DAMDF of ADCx_CCR register are not equal to zero), the BOOST bitfield of the slave ADC is no more writable and its content must be equal to the master ADC BOOST bitfield.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **JADSTP**: ADC stop of injected conversion command

This bit is set by software to stop and discard an ongoing injected conversion (JADSTP Command). It is cleared by hardware when the conversion is effectively discarded and the ADC injected sequence and triggers can be re-configured. The ADC is then ready to accept a new start of injected conversions (JADSTART command).

0: No ADC stop injected conversion command ongoing

1: Write 1 to stop injected conversions ongoing. Read 1 means that an ADSTP command is in progress.

Note: The software is allowed to set JADSTP only when JADSTART=1 and ADDIS=0 (ADC is enabled and eventually converting an injected conversion and there is no pending request to disable the ADC).

In auto-injection mode (JAUTO=1), setting ADSTP bit aborts both regular and injected conversions (do not use JADSTP)

Bit 4 **ADSTP**: ADC stop of regular conversion command

This bit is set by software to stop and discard an ongoing regular conversion (ADSTP Command). It is cleared by hardware when the conversion is effectively discarded and the ADC regular sequence and triggers can be re-configured. The ADC is then ready to accept a new start of regular conversions (ADSTART command).

0: No ADC stop regular conversion command ongoing

1: Write 1 to stop regular conversions ongoing. Read 1 means that an ADSTP command is in progress.

Note: The software is allowed to set ADSTP only when ADSTART=1 and ADDIS=0 (ADC is enabled and eventually converting a regular conversion and there is no pending request to disable the ADC).

In auto-injection mode (JAUTO=1), setting ADSTP bit aborts both regular and injected conversions (do not use JADSTP).

In dual ADC regular simultaneous mode and interleaved mode, the bit ADSTP of the master ADC must be used to stop regular conversions. The other ADSTP bit is inactive.

Bit 3 **JADSTART**: ADC start of injected conversion

This bit is set by software to start ADC conversion of injected channels. Depending on the configuration bits JEXTEN, a conversion will start immediately (software trigger configuration) or once an injected hardware trigger event occurs (hardware trigger configuration).

It is cleared by hardware:

- in single conversion mode when software trigger is selected (JEXTSEL=0x0): at the assertion of the End of Injected Conversion Sequence (JEOS) flag.
- in all cases: after the execution of the JADSTP command, at the same time that JADSTP is cleared by hardware.

0: No ADC injected conversion is ongoing.

1: Write 1 to start injected conversions. Read 1 means that the ADC is operating and eventually converting an injected channel.

Note: The software is allowed to set JADSTART only when ADEN=1 and ADDIS=0 (ADC is enabled and there is no pending request to disable the ADC).

In auto-injection mode (JAUTO=1), regular and auto-injected conversions are started by setting bit ADSTART (JADSTART must be kept cleared)

Bit 2 **ADSTART**: ADC start of regular conversion

This bit is set by software to start ADC conversion of regular channels. Depending on the configuration bits EXTEN, a conversion will start immediately (software trigger configuration) or once a regular hardware trigger event occurs (hardware trigger configuration).

It is cleared by hardware:

- in single conversion mode (CONT=0, DISCEN=0) when software trigger is selected (EXTEN=0x0): at the assertion of the End of Regular Conversion Sequence (EOS) flag.
- In discontinuous conversion mode (CONT=0, DISCEN=1), when the software trigger is selected (EXTEN=0x0): at the end of conversion (EOC) flag.
- in all other cases: after the execution of the ADSTP command, at the same time that ADSTP is cleared by hardware.

0: No ADC regular conversion is ongoing.

1: Write 1 to start regular conversions. Read 1 means that the ADC is operating and eventually converting a regular channel.

Note: The software is allowed to set ADSTART only when ADEN=1 and ADDIS=0 (ADC is enabled and there is no pending request to disable the ADC)

In auto-injection mode (JAUTO=1), regular and auto-injected conversions are started by setting bit ADSTART (JADSTART must be kept cleared)

Bit 1 **ADDIS**: ADC disable command

This bit is set by software to disable the ADC (ADDIS command) and put it into power-down state (OFF state).

It is cleared by hardware once the ADC is effectively disabled (ADEN is also cleared by hardware at this time).

0: no ADDIS command ongoing

1: Write 1 to disable the ADC. Read 1 means that an ADDIS command is in progress.

Note: The software is allowed to set ADDIS only when ADEN=1 and both ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing)

Bit 0 **ADEN**: ADC enable control

This bit is set by software to enable the ADC. The ADC will be effectively ready to operate once the flag ADRDY has been set.

It is cleared by hardware when the ADC is disabled, after the execution of the ADDIS command.

0: ADC is disabled (OFF state)

1: Write 1 to enable the ADC.

Note: The software is allowed to set ADEN only when all bits of ADC_CR registers are 0 (ADCAL=0, JADSTART=0, ADSTART=0, ADSTP=0, ADDIS=0 and ADEN=0) except for bit ADVREGEN which must be 1 (and the software must have wait for the startup time of the voltage regulator)

28.6.4 ADC configuration register (ADC_CFGR)

Address offset: 0x0C

Reset value: 0x8000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
JQDIS	AWD1CH[4:0]					JAUTO	JAWD1EN	AWD1EN	AWD1SGL	JQM	JDISCEN	DISCNUM[2:0]			DISCEN
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	AUTDLY	CONT	OVRMOD	EXTEN[1:0]		EXTSEL[4:0]					RES[2:0]			DMNGT[1:0]	
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **JQDIS**: Injected Queue disable

These bits are set and cleared by software to disable the Injected Queue mechanism:

0: Injected Queue enabled

1: Injected Queue disabled

Note: The software is allowed to write this bit only when ADSTART=0 and JADSTART=0 (which ensures that no regular nor injected conversion is ongoing).

A set or reset of JQDIS bit causes the injected queue to be flushed and the JSQR register is cleared.

Bits 30:26 **AWD1CH[4:0]**: Analog watchdog 1 channel selection

These bits are set and cleared by software. They select the input channel to be guarded by the analog watchdog.

00000: ADC analog input channel-0 monitored by AWD1

00001: ADC analog input channel-1 monitored by AWD1

.....

10010: ADC analog input channel-19 monitored by AWD1

others: Reserved, must not be used

Note: The channel selected by AWD1CH must be also selected into the SQRi or JSQRi registers.

The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

Bit 25 **JAUTO:** Automatic injected group conversion

This bit is set and cleared by software to enable/disable automatic injected group conversion after regular group conversion.

0: Automatic injected group conversion disabled

1: Automatic injected group conversion enabled

Note: The software is allowed to write this bit only when ADSTART=0 and JADSTART=0 (which ensures that no regular nor injected conversion is ongoing).

When dual mode is enabled (DAMDF bits in ADCx_CCR register are not equal to zero), the bit JAUTO of the slave ADC is no more writable and its content is equal to the bit JAUTO of the master ADC.

Bit 24 **JAWD1EN**: Analog watchdog 1 enable on injected channels

This bit is set and cleared by software

0: Analog watchdog 1 disabled on injected channels

1: Analog watchdog 1 enabled on injected channels

Note: The software is allowed to write this bit only when JADSTART=0 (which ensures that no injected conversion is ongoing).

Bit 23 **AWD1EN**: Analog watchdog 1 enable on regular channels

This bit is set and cleared by software

0: Analog watchdog 1 disabled on regular channels

1: Analog watchdog 1 enabled on regular channels

Note: The software is allowed to write this bit only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 22 **AWD1SGL**: Enable the watchdog 1 on a single channel or on all channels

This bit is set and cleared by software to enable the analog watchdog on the channel identified by the AWD1CH[4:0] bits or on all the channels

0: Analog watchdog 1 enabled on all channels

1: Analog watchdog 1 enabled on a single channel

Note: The software is allowed to write this bit only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

Bit 21 **JQM**: JSQR queue mode

This bit is set and cleared by software.

It defines how an empty Queue is managed.

0: JSQR Mode 0: The Queue is never empty and maintains the last written configuration into JSQR.

1: JSQR Mode 1: The Queue can be empty and when this occurs, the software and hardware triggers of the injected sequence are both internally disabled just after the completion of the last valid injected sequence.

Refer to *Section 28.4.22: Queue of context for injected conversions* for more information.

Note: The software is allowed to write this bit only when JADSTART=0 (which ensures that no injected conversion is ongoing).

When dual mode is enabled (DAMDF bits in ADCx_CCR register are not equal to zero), the bit JQM of the slave ADC is no more writable and its content is equal to the bit JQM of the master ADC.

Bit 20 **JDISCEN:** Discontinuous mode on injected channels

This bit is set and cleared by software to enable/disable discontinuous mode on the injected channels of a group.

0: Discontinuous mode on injected channels disabled

1: Discontinuous mode on injected channels enabled

Note: The software is allowed to write this bit only when JADSTART=0 (which ensures that no injected conversion is ongoing).

It is not possible to use both auto-injected mode and discontinuous mode simultaneously: the bits DISCEN and JDISCEN must be kept cleared by software when JAUTO is set.

When dual mode is enabled (bits DAMDF of ADCx_CCR register are not equal to zero), the bit JDISCEN of the slave ADC is no more writable and its content is equal to the bit JDISCEN of the master ADC.

Bits 19:17 **DISCNUM[2:0]:** Discontinuous mode channel count

These bits are written by software to define the number of regular channels to be converted in discontinuous mode, after receiving an external trigger.

000: 1 channel

001: 2 channels

...

111: 8 channels

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

When dual mode is enabled (DAMDF bits in ADCx_CCR register are not equal to zero), the bits DISCNUM[2:0] of the slave ADC are no more writable and their content is equal to the bits DISCNUM[2:0] of the master ADC.

Bit 16 **DISCEN**: Discontinuous mode for regular channels

This bit is set and cleared by software to enable/disable Discontinuous mode for regular channels.

0: Discontinuous mode for regular channels disabled

1: Discontinuous mode for regular channels enabled

Note: It is not possible to have both discontinuous mode and continuous mode enabled: it is forbidden to set both DISCEN=1 and CONT=1.

It is not possible to use both auto-injected mode and discontinuous mode simultaneously: the bits DISCEN and JDISCEN must be kept cleared by software when JAUTO is set.

The software is allowed to write this bit only when ADSTART=0 (which ensures that no regular conversion is ongoing).

When dual mode is enabled (DAMDF bits in ADCx_CCR register are not equal to zero), the bit DISCEN of the slave ADC is no more writable and its content is equal to the bit DISCEN of the master ADC.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **AUTDLY**: Delayed conversion mode

This bit is set and cleared by software to enable/disable the Auto Delayed Conversion mode.

0: Auto-delayed conversion mode off

1: Auto-delayed conversion mode on

Note: The software is allowed to write this bit only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

When dual mode is enabled (DAMDF bits in ADCx_CCR register are not equal to zero), the bit AUTDLY of the slave ADC is no more writable and its content is equal to the bit AUTDLY of the master ADC.

Bit 13 **CONT**: Single / continuous conversion mode for regular conversions

This bit is set and cleared by software. If it is set, regular conversion takes place continuously until it is cleared.

0: Single conversion mode

1: Continuous conversion mode

Note: It is not possible to have both discontinuous mode and continuous mode enabled: it is forbidden to set both DISCEN=1 and CONT=1.

The software is allowed to write this bit only when ADSTART=0 (which ensures that no regular conversion is ongoing).

When dual mode is enabled (DAMDF bits in ADCx_CCR register are not equal to zero), the bit CONT of the slave ADC is no more writable and its content is equal to the bit CONT of the master ADC.

Bit 12 **OVRMOD**: Overrun Mode

This bit is set and cleared by software and configure the way data overrun is managed.

0: ADC_DR register is preserved with the old data when an overrun is detected.

1: ADC_DR register is overwritten with the last conversion result when an overrun is detected.

Note: The software is allowed to write this bit only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bits 11:10 **EXTEN[1:0]**: External trigger enable and polarity selection for regular channels

These bits are set and cleared by software to select the external trigger polarity and enable the trigger of a regular group.

00: Hardware trigger detection disabled (conversions can be launched by software)

01: Hardware trigger detection on the rising edge

10: Hardware trigger detection on the falling edge

11: Hardware trigger detection on both the rising and falling edges

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bits 9:5 **EXTSEL[4:0]**: External trigger selection for regular group

These bits select the external event used to trigger the start of conversion of a regular group:

00000: Event 0
00001: Event 1
00010: Event 2
00011: Event 3
00100: Event 4
00101: Event 5
00110: Event 6
00111: Event 7
...
11111: Event 31

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bits 4:2 **RES[2:0]**: Data resolution

These bits are written by software to select the resolution of the conversion.

000: 16 bits
001: 14 bits in legacy mode (not optimized power consumption)
010: 12 bits in legacy mode (not optimized power consumption)
101: 14 bits
110: 12 bits
011: 10 bits
111: 8 bits
Others: Reserved, must not be used.

Note: The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

Bits 1:0 **DMNGT[1:0]**: Data Management configuration

This bit is set and cleared by software to select how ADC interface output data are managed.

00: Regular conversion data stored in DR only
01: DMA One Shot Mode selected
10: DFSDM mode selected
11: DMA Circular Mode selected

Note: The software is allowed to write this bit only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

In dual-ADC modes, this bit is not relevant and replaced by control bit DAMDF of the ADCx_CCR register.

28.6.5 ADC configuration register 2 (ADC_CFGR2)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LSHIFT[3:0]				Res.	Res.	OSVR[9:0]									
rw	rw	rw	rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	RSHIFT4	RSHIFT3	RSHIFT2	RSHIFT1	ROVSM	TROVS	OVSS[3:0]				Res.	Res.	Res.	JOVSE	ROVSE
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				rw	rw

Bits 31:28 **LSHIFT[3:0]**: Left shift factor

This bitfield is set and cleared by software to define the left shifting applied to the final result with or without oversampling.

0000: No left shift
0001: Shift left 1-bit
0010: Shift left 2-bits
0011: Shift left 3-bits
0100: Shift left 4-bits
0101: Shift left 5-bits
0110: Shift left 6-bits
0111: Shift left 7-bits
1000: Shift left 8-bits
1001: Shift left 9-bits
1010: Shift left 10-bits
1011: Shift left 11-bits
1100: Shift left 12-bits
1101: Shift left 13-bits
1110: Shift left 14-bits
1111: Shift left 15-bits

Note: The software is allowed to write this bit only when ADSTART=0 (which ensures that no conversion is ongoing).

Bits 27:26 Reserved, must be kept at reset value.

Bits 25:16 **OSVR[9:0]**: Oversampling ratio

This bitfield is set and cleared by software to define the oversampling ratio.

0: 1x (no oversampling)
1: 2x
2: 3x
...
1023: 1024x

Note: The software is allowed to write this bit only when ADSTART=0 (which ensures that no conversion is ongoing).

Bit 15 Reserved, must be kept at reset value.

Bit 14 **RSHIFT4**: Right-shift data after Offset 4 correction

Refer to RSHIFT1 description.

Bit 13 **RSHIFT3**: Right-shift data after Offset 3 correction
Refer to RSHIFT1 description

Bit 12 **RSHIFT2**: Right-shift data after Offset 2 correction
Refer to RSHIFT1 description

Bit 11 **RSHIFT1**: Right-shift data after Offset 1 correction
This bitfield is set and cleared by software to right-shift 1-bit data after offset1 correction. This bit can only be used for 8-bit and 16-bit data format (see *Section : Data register, data alignment and offset (ADC_DR, ADC_JDRy, OFFSETy, OFFSETy_CH, OVSS, LSHIFT, RSHIFT, SSATE)* for details).
0: Right-shifting disabled
1: Data is right-shifted 1-bit.

Bit 10 **ROVSM**: Regular Oversampling mode
This bit is set and cleared by software to select the regular oversampling mode.
0: Continued mode: When injected conversions are triggered, the oversampling is temporary stopped and continued after the injection sequence (oversampling buffer is maintained during injected sequence)
1: Resumed mode: When injected conversions are triggered, the current oversampling is aborted and resumed from start after the injection sequence (oversampling buffer is zeroed by injected sequence start)
Note: The software is allowed to write this bit only when ADSTART=0 (which ensures that no conversion is ongoing).

Bit 9 **TROVS**: Triggered Regular Oversampling
This bit is set and cleared by software to enable triggered oversampling
0: All oversampled conversions for a channel are done consecutively following a trigger
1: Each oversampled conversion for a channel needs a new trigger
Note: The software is allowed to write this bit only when ADSTART=0 (which ensures that no conversion is ongoing).

Bits 8:5 **OVSS[3:0]**: Oversampling right shift
This bitfield is set and cleared by software to define the right shifting applied to the raw oversampling result.
0000: No right shift
0001: Shift right 1-bit
0010: Shift right 2-bits
0011: Shift right 3-bits
0100: Shift right 4-bits
0101: Shift right 5-bits
0110: Shift right 6-bits
0111: Shift right 7-bits
1000: Shift right 8-bits
1001: Shift right 9-bits
1010: Shift right 10-bits
1011: Shift right 11-bits
Others: Reserved, must not be used.
Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no conversion is ongoing).

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **JOVSE**: Injected Oversampling Enable

This bit is set and cleared by software to enable injected oversampling.

0: Injected Oversampling disabled

1: Injected Oversampling enabled

Note: The software is allowed to write this bit only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing)

Bit 0 **ROVSE**: Regular Oversampling Enable

This bit is set and cleared by software to enable regular oversampling.

0: Regular Oversampling disabled

1: Regular Oversampling enabled

Note: The software is allowed to write this bit only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing)

28.6.6 ADC sample time register 1 (ADC_SMPR1)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	SMP9[2:0]			SMP8[2:0]			SMP7[2:0]			SMP6[2:0]			SMP5[2:1]	
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SMP5[0]	SMP4[2:0]			SMP3[2:0]			SMP2[2:0]			SMP1[2:0]			SMP0[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:0 **SMP[9:0][2:0]:** Channel x sampling time selection (x = 0 to 9)

These bits are written by software to select the sampling time individually for each channel. During sample cycles, the channel selection bits must remain unchanged.

000: 1.5 ADC clock cycles

001: 2.5 ADC clock cycles

010: 8.5 ADC clock cycles

011: 16.5 ADC clock cycles

100: 32.5 ADC clock cycles

101: 64.5 ADC clock cycles

110: 387.5 ADC clock cycles

111: 810.5 ADC clock cycles

Note: The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

28.6.7 ADC sample time register 2 (ADC_SMPR2)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	SMP19[2:0]			SMP18[2:0]			SMP17[2:0]			SMP16[2:0]			SMP15[2:1]	
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SMP15[0]	SMP14[2:0]			SMP13[2:0]			SMP12[2:0]			SMP11[2:0]			SMP10[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:0 **SMP[19:10][2:0]:** Channel x sampling time selection (x = 10 to 19)

These bits are written by software to select the sampling time individually for each channel. During sampling cycles, the channel selection bits must remain unchanged.

000: 1.5 ADC clock cycles
001: 2.5 ADC clock cycles
010: 8.5 ADC clock cycles
011: 16.5 ADC clock cycles
100: 32.5 ADC clock cycles
101: 64.5 ADC clock cycles
110: 387.5 ADC clock cycles
111: 810.5 ADC clock cycles

Note: The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

28.6.8 ADC channel preselection register (ADC_PCSEL)

Address offset: 0x1C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCSEL19	PCSEL18	PCSEL17	PCSEL16
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PCSEL15	PCSEL14	PCSEL13	PCSEL12	PCSEL11	PCSEL10	PCSEL9	PCSEL8	PCSEL7	PCSEL6	PCSEL5	PCSEL4	PCSEL3	PCSEL2	PCSEL1	PCSEL0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 PCSEL[19:0] :Channel x ($V_{INP[i]}$) pre selection (x = 0 to 19)

These bits are written by software to pre select the input channel at IO instance to be converted.

0: Input Channel x (Vinp x) is not pre selected for conversion, the ADC conversion result with this channel shows wrong result.

1: Input Channel x (Vinp x) is pre selected for conversion

Note: The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

28.6.9 ADC watchdog threshold register 1 (ADC_LTR1)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	LTR1[25:16]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LTR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:0 **LTR1[25:0]**: Analog watchdog 1 lower threshold

These bits are written by software to define the lower threshold for the analog watchdog 1.

Refer to *Section 28.4.30: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTRy, AWD_LTRy, AWDy)*

Note: The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

28.6.10 ADC watchdog threshold register 1 (ADC_HTR1)

Address offset: 0x24

Reset value: 0x03FF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	HTR1[25:16]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HTR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:0 **HTR1[25:0]**: Analog watchdog 1 higher threshold

These bits are written by software to define the higher threshold for the analog watchdog 1.

Refer to *Section 28.4.30: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTRy, AWD_LTRy, AWDy)*

Note: The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

28.6.11 ADC regular sequence register 1 (ADC_SQR1)

Address offset: 0x30

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	SQ4[4:0]					Res.	SQ3[4:0]					Res.	SQ2[4]
			rw	rw	rw	rw	rw		rw	rw	rw	rw	rw		rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SQ2[3:0]				Res.	SQ1[4:0]					Res.	Res.	L[3:0]			
rw	rw	rw	rw		rw	rw	rw	rw	rw			rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:24 **SQ4[4:0]:** 4th conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 4th in the regular conversion sequence.

Bit 23 Reserved, must be kept at reset value.

Bits 22:18 **SQ3[4:0]:** 3rd conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 3rd in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 17 Reserved, must be kept at reset value.

Bits 16:12 **SQ2[4:0]:** 2nd conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 2nd in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 11 Reserved, must be kept at reset value.

Bits 10:6 **SQ1[4:0]:** 1st conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 1st in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bits 5:4 Reserved, must be kept at reset value.

Bits 3:0 **L[3:0]:** Regular channel sequence length

These bits are written by software to define the total number of conversions in the regular channel conversion sequence.

0000: 1 conversion

0001: 2 conversions

...

1111: 16 conversions

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

28.6.12 ADC regular sequence register 2 (ADC_SQR2)

Address offset: 0x34

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	SQ9[4:0]					Res.	SQ8[4:0]					Res.	SQ7[4]
			rw	rw	rw	rw	rw		rw	rw	rw	rw	rw		rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SQ7[3:0]				Res.	SQ6[4:0]					Res.	SQ5[4:0]				
rw	rw	rw	rw		rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:24 **SQ9[4:0]:** 9th conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 9th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 23 Reserved, must be kept at reset value.

Bits 22:18 **SQ8[4:0]:** 8th conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 8th in the regular conversion sequence

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 17 Reserved, must be kept at reset value.

Bits 16:12 **SQ7[4:0]:** 7th conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 7th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 11 Reserved, must be kept at reset value.

Bits 10:6 **SQ6[4:0]:** 6th conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 6th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **SQ5[4:0]:** 5th conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 5th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

28.6.13 ADC regular sequence register 3 (ADC_SQR3)

Address offset: 0x38

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	SQ14[4:0]					Res.	SQ13[4:0]					Res.	SQ12[4]
			rw	rw	rw	rw	rw		rw	rw	rw	rw	rw		rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SQ12[3:0]				Res.	SQ11[4:0]					Res.	SQ10[4:0]				
rw	rw	rw	rw		rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:24 **SQ14[4:0]:** 14th conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 14th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 23 Reserved, must be kept at reset value.

Bits 22:18 **SQ13[4:0]:** 13th conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 13th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 17 Reserved, must be kept at reset value.

Bits 16:12 **SQ12[4:0]:** 12th conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 12th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 11 Reserved, must be kept at reset value.

Bits 10:6 **SQ11[4:0]:** 11th conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 11th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **SQ10[4:0]:** 10th conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 10th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

28.6.14 ADC regular sequence register 4 (ADC_SQR4)

Address offset: 0x3C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	SQ16[4:0]					Res.	SQ15[4:0]				
					rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:6 **SQ16[4:0]:** 16th conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 16th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **SQ15[4:0]:** 15th conversion in regular sequence

These bits are written by software with the channel number (0..19) assigned as the 15th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

28.6.15 ADC regular Data Register (ADC_DR)

Address offset: 0x40

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RDATA[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RDATA[31:0]**: Regular Data converted

These bits are read-only. They contain the conversion result from the last converted regular channel. The data are left- or right-aligned as described in *Section 28.4.27: Data management*.

28.6.16 ADC injected sequence register (ADC_JSQR)

Address offset: 0x4C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
JSQ4[4:0]					Res.	JSQ3[4:0]					Res.	JSQ2[4:1]			
rw	rw	rw	rw	rw		rw	rw	rw	rw	rw		rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
JSQ2[0]	Res.	JSQ1[4:0]					JEXTEN[1:0]		JEXTSEL[4:0]					JL[1:0]	
rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 **JSQ4[4:0]:** 4th conversion in the injected sequence

These bits are written by software with the channel number (0..19) assigned as the 4th in the injected conversion sequence.

Note: The software is allowed to write these bits only when JADSTART is cleared to 0 (no injected conversion is ongoing) unless the context queue is enabled (JQDIS=0 in ADC_CFGR register).

Bit 26 Reserved, must be kept at reset value.

Bits 25:21 **JSQ3[4:0]:** 3rd conversion in the injected sequence

These bits are written by software with the channel number (0..19) assigned as the 3rd in the injected conversion sequence.

Note: The software is allowed to write these bits only when JADSTART is cleared to 0 (no injected conversion is ongoing) unless the context queue is enabled (JQDIS=0 in ADC_CFGR register).

Bit 20 Reserved, must be kept at reset value.

Bits 19:15 **JSQ2[4:0]:** 2nd conversion in the injected sequence

These bits are written by software with the channel number (0..19) assigned as the 2nd in the injected conversion sequence.

Note: The software is allowed to write these bits only when JADSTART is cleared to 0 (no injected conversion is ongoing) unless the context queue is enabled (JQDIS=0 in ADC_CFGR register).

Bit 14 Reserved, must be kept at reset value.

Bits 13:9 **JSQ1[4:0]:** 1st conversion in the injected sequence

These bits are written by software with the channel number (0..19) assigned as the 1st in the injected conversion sequence.

Note: The software is allowed to write these bits only when JADSTART is cleared to 0 (no injected conversion is ongoing) unless the context queue is enabled (JQDIS=0 in ADC_CFGR register).

Bits 8:7 **JEXTEN[1:0]**: External trigger enable and polarity selection for injected channels

These bits are set and cleared by software to select the external trigger polarity and enable the trigger of an injected group.

00: If JQDIS=0 (queue enabled), Hardware and software trigger detection disabled and If JQDIS=1 (queue disabled), Hardware trigger detection disabled (conversions can be launched by software

01: Hardware trigger detection on the rising edge

10: Hardware trigger detection on the falling edge

11: Hardware trigger detection on both the rising and falling edges

Note: The software is allowed to write these bits only when JADSTART is cleared to 0 (no injected conversion is ongoing).

If JQM=1 and if the Queue of Context becomes empty, the software and hardware triggers of the injected sequence are both internally disabled (refer to Section 28.4.22: Queue of context for injected conversions)

Bits 6:2 **JEXTSEL[4:0]**: External trigger selection for injected group

These bits select the external event used to trigger the start of conversion of an injected group:

00000: Event 0

00001: Event 1

00010: Event 2

00011: Event 3

00100: Event 4

00101: Event 5

00110: Event 6

00111: Event 7

...

11111: Event 31:

Note: The software is allowed to write these bits only when JADSTART is cleared to 0 (no injected conversion is ongoing).

Bits 1:0 **JL[1:0]:** Injected channel sequence length

These bits are written by software to define the total number of conversions in the injected channel conversion sequence.

00: 1 conversion

01: 2 conversions

10: 3 conversions

11: 4 conversions

Note: The software is allowed to write these bits only when JADSTART is cleared to 0 (no injected conversion is ongoing).

28.6.17 ADC injected channel y offset register (ADC_OFRy)

Address offset: 0x60 + 0x04 * (y-1), (y= 1 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SSATE	OFFSETy_CH[4:0]					OFFSETy[25:16]									
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OFFSETy[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **SSATE:** Signed saturation Enable

This bit is written by software to enable or disable the Signed saturation feature.

This bit can be enabled only for 8-bit and 16-bit data format (see *Section : Data register, data alignment and offset (ADC_DR, ADC_JDRy, OFFSETy, OFFSETy_CH, OVSS, LSHIFT, RSHIFT, SSATE)* for details).

0: Offset is subtracted maintaining data integrity and extending result size (9-bit and 17-bit signed format).

1: Offset is subtracted and result is saturated to maintain result size.

Note: The software is allowed to write this bit only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

Bits 30:26 **OFFSETy_CH[4:0]:** Channel selection for the Data offset y

These bits are written by software to define the channel to which the offset programmed into bits OFFSETy[25:0] will apply.

Note: The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

Bits 25:0 **OFFSETy[25:0]:** Data offset y for the channel programmed into bits OFFSETy_CH[4:0]

These bits are written by software to define the offset y to be subtracted from the raw converted data when converting a channel (can be regular or injected). The channel to which applies the data offset y must be programmed in the bits OFFSETy_CH[4:0]. The conversion result can be read from in the ADC_DR (regular conversion) or from in the ADC_JDRyi registers (injected conversion).

When OFFSETy[25:0] bitfield is reset, the offset compensation is disabled.

Note: The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

If several offset (OFFSETy) point to the same channel, only the offset with the lowest x value is considered for the subtraction.
Ex: if OFFSET1_CH[4:0]=4 and OFFSET2_CH[4:0]=4, this is OFFSET1[25:0] which is subtracted when converting channel 4.

28.6.18 ADC injected channel y data register (ADC_JDRy)

Address offset: 0x80 + 0x04 * (y-1), (y= 1 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
JDATA[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
JDATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **JDATA[31:0]:** Injected data

These bits are read-only. They contain the conversion result from injected channel y. The data are left -or right-aligned as described in *Section 28.4.27: Data management*.

28.6.19 ADC analog watchdog 2 configuration register (ADC_AWD2CR)

Address offset: 0xA0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWD2CH[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AWD2CH[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **AWD2CH[19:0]**: Analog watchdog 2 channel selection

These bits are set and cleared by software. They enable and select the input channels to be guarded by the analog watchdog 2.

AWD2CH[i] = 0: ADC analog input channel-i is not monitored by AWD2

AWD2CH[i] = 1: ADC analog input channel-i is monitored by AWD2

When AWD2CH[19:0] = 000..0, the analog Watchdog 2 is disabled

Note: The channels selected by AWD2CH must be also selected into the SQRi or JSQRi registers.

The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

28.6.20 ADC analog watchdog 3 configuration register (ADC_AWD3CR)

Address offset: 0xA4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWD3CH[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AWD3CH[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **AWD3CH[19:0]**: Analog watchdog 3 channel selection

These bits are set and cleared by software. They enable and select the input channels to be guarded by the analog watchdog 3.

AWD3CH[i] = 0: ADC analog input channel-i is not monitored by AWD3

AWD3CH[i] = 1: ADC analog input channel-i is monitored by AWD3

When AWD3CH[19:0] = 000..0, the analog Watchdog 3 is disabled

Note: The channels selected by AWD3CH must be also selected into the SQRi or JSQRi registers.

The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

28.6.21 ADC watchdog lower threshold register 2 (ADC_LTR2)

Address offset: 0xB0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	LTR2[25:16]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LTR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:0 **LTR2[25:0]**: Analog watchdog 2 lower threshold

These bits are written by software to define the lower threshold for the analog watchdog 2.

Refer to *Section 28.4.30: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTRy, AWD_LTRy, AWDy)*.

Note: The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

28.6.22 ADC watchdog higher threshold register 2 (ADC_HTR2)

Address offset: 0xB4

Reset value: 0x03FF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	HTR2[25:16]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HTR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:0 **HTR2[25:0]**: Analog watchdog 2 higher threshold

These bits are written by software to define the higher threshold for the analog watchdog 2.

Refer to *Section 28.4.30: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTRy, AWD_LTRy, AWDy)*.

Note: The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

28.6.23 ADC watchdog lower threshold register 3 (ADC_LTR3)

Address offset: 0xB8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	LTR3[25:16]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LTR3[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:0 **LTR3[25:0]**: Analog watchdog 3 lower threshold

These bits are written by software to define the lower threshold for the analog watchdog 3.

Refer to *Section 28.4.30: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTRy, AWD_LTRy, AWDy)*

Note: The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

28.6.24 ADC watchdog higher threshold register 3 (ADC_HTR3)

Address offset: 0xBC

Reset value: 0x03FF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	HTR3[25:16]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HTR3[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:0 **HTR3[25:0]**: Analog watchdog 3 higher threshold

These bits are written by software to define the higher threshold for the analog watchdog 3.

Refer to *Section 28.4.30: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTRy, AWD_LTRy, AWDy)*

Note: The software is allowed to write these bits only when ADSTART=0 and JADSTART=0 (which ensures that no conversion is ongoing).

28.6.25 ADC differential mode selection register (ADC_DIFSEL)

Address offset: 0xC0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIFSEL[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIFSEL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **DIFSEL[19:0]**: Differential mode for channels 19 to 0

These bits are set and cleared by software. They allow to select if a channel is configured as single ended or differential mode.

DIFSEL[i] = 0: ADC analog input channel-i is configured in single ended mode

DIFSEL[i] = 1: ADC analog input channel-i is configured in differential mode

Note: The software is allowed to write these bits only when the ADC is disabled (ADCAL=0, JADSTART=0, JADSTP=0, ADSTART=0, ADSTP=0, ADDIS=0 and ADEN=0).

28.6.26 ADC calibration factors register (ADC_CALFACT)

Address offset: 0xC4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	CALFACT_D[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	CALFACT_S[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bits 26:16 **CALFACT_D[10:0]**: Calibration Factors in differential mode

These bits are written by hardware or by software.

Once a differential inputs calibration is complete, they are updated by hardware with the calibration factors.

Software can write these bits with a new calibration factor. If the new calibration factor is different from the current one stored into the analog ADC, it will then be applied once a new differential conversion is launched.

Note: The software is allowed to write these bits only when ADEN=1, ADSTART=0 and JADSTART=0 (ADC is enabled and no calibration is ongoing and no conversion is ongoing).

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:0 **CALFACT_S[10:0]**: Calibration Factors In Single-Ended mode

These bits are written by hardware or by software.

Once a single-ended inputs calibration is complete, they are updated by hardware with the calibration factors.

Software can write these bits with a new calibration factor. If the new calibration factor is different from the current one stored into the analog ADC, it will then be applied once a new single-ended conversion is launched.

Note: The software is allowed to write these bits only when ADEN=1, ADSTART=0 and JADSTART=0 (ADC is enabled and no calibration is ongoing and no conversion is ongoing).

28.6.27 ADC calibration factor register 2 (ADC_CALFACT2)

Address offset: 0xC8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	LINCALFACT[29:16]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LINCALFACT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:0 **LINCALFACT[29:0]**: Linearity Calibration Factor

These bits are written by hardware or by software.

They hold 30-bit out of the 160-bit linearity calibration factor.

Once a single-ended inputs calibration is complete, they are updated by hardware with the calibration factors.

Software can write these bits with a new calibration factor. If the new calibration factor is different from the current one stored into the analog ADC, it will then be applied once a new single-ended calibration is launched.

Note: The software is allowed to write these bits only when ADEN=1, ADSTART=0 and JADSTART=0 (ADC is enabled and no calibration is ongoing and no conversion is ongoing).

28.7 ADC common registers

These registers define the control and status registers common to master and slave ADCs:

28.7.1 ADC common status register (ADCx_CSR) (x=1/2)

Address offset: 0x00

Reset value: 0x0000 0000

The address offset is relative to the master ADC base address + 0x300.

This register provides an image of the status bits of the different ADCs. Nevertheless it is read-only and does not allow to clear the different status bits. Instead each status bit must be cleared by writing 0 to it in the corresponding ADC_ISR register.

ADC1 and ADC2 are controlled by the same interface.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	JQOVF_SLV	AWD3_SLV	AWD2_SLV	AWD1_SLV	JEOS_SLV	JEOC_SLV	OVR_SLV	EOS_SLV	EOC_SLV	EOSMP_SLV	ADRDY_SLV
					r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	JQOVF_MST	AWD3_MST	AWD2_MST	AWD1_MST	JEOS_MST	JEOC_MST	OVR_MST	EOS_MST	EOC_MST	EOSMP_MST	ADRDY_MST
					r	r	r	r	r	r	r	r	r	r	r

Bits 31:27 Reserved, must be kept at reset value.

Bit 26 **JQOVF_SLV:** Injected Context Queue Overflow flag of the slave ADC
This bit is a copy of the JQOVF bit in the corresponding ADCx+1_ISR register.

Bit 25 **AWD3_SLV:** Analog watchdog 3 flag of the slave ADC
This bit is a copy of the AWD3 bit in the corresponding ADCx+1_ISR register.

Bit 24 **AWD2_SLV:** Analog watchdog 2 flag of the slave ADC
This bit is a copy of the AWD2 bit in the corresponding ADCx+1_ISR register.

Bit 23 **AWD1_SLV:** Analog watchdog 1 flag of the slave ADC
This bit is a copy of the AWD1 bit in the corresponding ADCx+1_ISR register.

Bit 22 **JEOS_SLV:** End of injected sequence flag of the slave ADC
This bit is a copy of the JEOS bit in the corresponding ADCx+1_ISR register.

Bit 21 **JEOC_SLV:** End of injected conversion flag of the slave ADC
This bit is a copy of the JEOC bit in the corresponding ADCx+1_ISR register.

Bit 20 **OVR_SLV:** Overrun flag of the slave ADC
This bit is a copy of the OVR bit in the corresponding ADCx+1_ISR register.

Bit 19 **EOS_SLV:** End of regular sequence flag of the slave ADC
This bit is a copy of the EOS bit in the corresponding ADCx+1_ISR register.

Bit 18 **EOC_SLV:** End of regular conversion of the slave ADC
This bit is a copy of the EOC bit in the corresponding ADCx+1_ISR register.

Bit 17 **EOSMP_SLV:** End of Sampling phase flag of the slave ADC
This bit is a copy of the EOSMP2 bit in the corresponding ADCx+1_ISR register.

Bit 16 **ADRDY_SLV:** Slave ADC ready
This bit is a copy of the ADRDY bit in the corresponding ADCx+1_ISR register.

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **JQOVF_MST:** Injected Context Queue Overflow flag of the master ADC
This bit is a copy of the JQOVF bit in the corresponding ADC_ISR register.

Bit 9 **AWD3_MST:** Analog watchdog 3 flag of the master ADC
This bit is a copy of the AWD3 bit in the corresponding ADC_ISR register.

Bit 8 **AWD2_MST:** Analog watchdog 2 flag of the master ADC
This bit is a copy of the AWD2 bit in the corresponding ADC_ISR register.

Bit 7 **AWD1_MST:** Analog watchdog 1 flag of the master ADC
This bit is a copy of the AWD1 bit in the corresponding ADC_ISR register.

Bit 6 **JEOS_MST:** End of injected sequence flag of the master ADC
This bit is a copy of the JEOS bit in the corresponding ADC_ISR register.

Bit 5 **JEOC_MST:** End of injected conversion flag of the master ADC
This bit is a copy of the JEOC bit in the corresponding ADC_ISR register.

Bit 4 **OVR_MST:** Overrun flag of the master ADC
This bit is a copy of the OVR bit in the corresponding ADC_ISR register.

Bit 3 **EOS_MST:** End of regular sequence flag of the master ADC
This bit is a copy of the EOS bit in the corresponding ADC_ISR register.

Bit 2 **EOC_MST:** End of regular conversion of the master ADC
This bit is a copy of the EOC bit in the corresponding ADC_ISR register.

Bit 1 **EOSMP_MST:** End of Sampling phase flag of the master ADC
This bit is a copy of the EOSMP bit in the corresponding ADC_ISR register.

Bit 0 **ADRDY_MST:** Master ADC ready
This bit is a copy of the ADRDY bit in the corresponding ADC_ISR register.

28.7.2 ADC common control register (ADCx_CCR) (x=1/2)

Address offset: 0x08

Reset value: 0x0000 0000

The address offset is relative to the master ADC base address + 0x300.

ADC1 and ADC2 are controlled by the same interface.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.		Res.		PRESC[3:0]				CKMODE[1:0]	
										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DAMDF[1:0]		Res.	Res.	DELAY[3:0]				Res.	Res.	Res.	DUAL[4:0]				
rw	rw			rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 Reserved, must be kept at reset value.

Bit 23 Reserved, must be kept at reset value.

Bit 22 Reserved, must be kept at reset value.

Bits 21:18 **PRESC[3:0]**: ADC prescaler

These bits are set and cleared by software to select the frequency of the clock to the ADC. The clock is common for all the ADCs.

0000: input ADC clock not divided
0001: input ADC clock divided by 2
0010: input ADC clock divided by 4
0011: input ADC clock divided by 6
0100: input ADC clock divided by 8
0101: input ADC clock divided by 10
0110: input ADC clock divided by 12
0111: input ADC clock divided by 16
1000: input ADC clock divided by 32
1001: input ADC clock divided by 64
1010: input ADC clock divided by 128
1011: input ADC clock divided by 256
Others: Reserved, must not be used

Note: The software is allowed to write these bits only when the ADC is disabled (ADCAL=0, JADSTART=0, ADSTART=0, ADSTP=0, ADDIS=0 and ADEN=0). The ADC prescaler value is applied only when CKMODE[1:0] = 0b00.

Bits 17:16 **CKMODE[1:0]:** ADC clock mode

These bits are set and cleared by software to define the ADC clock scheme (which is common to both master and slave ADCs):

00: CK_ADCx (x=1 to 23) (Asynchronous clock mode), generated at product level (refer to *Section Reset and Clock Control (RCC)*)

01: adc_sclk/1 (Synchronous clock mode).

10: adc_sclk/2 (Synchronous clock mode)

11: adc_sclk/4 (Synchronous clock mode)

Whatever CKMODE[1:0] settings, an additional divider factor of 2 is applied to the clock delivered to the analog ADC block.

In synchronous clock mode, when adc_ker_ck = 2 x adc_hclk, there is no jitter in the delay from a timer trigger to the start of a conversion.

Note: The software is allowed to write these bits only when the ADCs are disabled (ADCAL=0, JADSTART=0, ADSTART=0, ADSTP=0, ADDIS=0 and ADEN=0).

Bits 15:14 **DAMDF[1:0]:** Dual ADC Mode Data Format

This bit-field is set and cleared by software. It specifies the data format in the common data register ADCx_CDR.

00: Dual ADC mode without data packing (ADCx_CDR and ADCx_CDR2 registers not used).

01: Reserved.

10: Data formatting mode for 32 down to 10-bit resolution

11: Data formatting mode for 8-bit resolution

Note: The software is allowed to write these bits only when ADSTART=0 (which ensures that no regular conversion is ongoing).

Bits 13:12 Reserved, must be kept at reset value.

Bits 11:8 **DELAY[3:0]:** Delay between 2 sampling phases

These bits are set and cleared by software. These bits are used in dual interleaved modes. Refer to *Table 236* for the value of ADC resolution versus DELAY bits values.

Note: The software is allowed to write these bits only when the ADCs are disabled (ADCAL=0, JADSTART=0, ADSTART=0, ADSTP=0, ADDIS=0 and ADEN=0).

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **DUAL[4:0]:** Dual ADC mode selection

These bits are written by software to select the operating mode.

All the ADCs are independent:

00000: Independent mode

The configurations 00001 to 01001 correspond to the following operating modes: Dual mode, master and slave ADCs working together:

00001: Combined regular simultaneous + injected simultaneous mode

00010: Combined regular simultaneous + alternate trigger mode

00011: Combined Interleaved mode + injected simultaneous mode

00100: Reserved.

00101: Injected simultaneous mode only

00110: Regular simultaneous mode only

00111: Interleaved mode only

01001: Alternate trigger mode only

All other combinations are reserved and must not be programmed

Note: The software is allowed to write these bits only when the ADCs are disabled (ADCAL=0, JADSTART=0, ADSTART=0, ADSTP=0, ADDIS=0 and ADEN=0).

Table 236. DELAY bits versus ADC resolution

DELAY bits	16-bit resolution	14-bit resolution	12-bit resolution	10-bit resolution	8-bit resolution
0000	1.5 * $T_{adc\_ker\_ck}$	1.5 * $T_{adc\_ker\_ck}$	1.5 * $T_{adc\_ker\_ck}$	1.5 * $T_{adc\_ker\_ck}$	1.5 * $T_{adc\_ker\_ck}$
0001	2.5 * $T_{adc\_ker\_ck}$	2.5 * $T_{adc\_ker\_ck}$	2.5 * $T_{adc\_ker\_ck}$	2.5 * $T_{adc\_ker\_ck}$	2.5 * $T_{adc\_ker\_ck}$
0010	3.5 * $T_{adc\_ker\_ck}$	3.5 * $T_{adc\_ker\_ck}$	3.5 * $T_{adc\_ker\_ck}$	3.5 * $T_{adc\_ker\_ck}$	3.5 * $T_{adc\_ker\_ck}$
0011	4.5 * $T_{adc\_ker\_ck}$	4.5 * $T_{adc\_ker\_ck}$	4.5 * $T_{adc\_ker\_ck}$	4.5 * $T_{adc\_ker\_ck}$	4.5 * $T_{adc\_ker\_ck}$
0100	5.5 * $T_{adc\_ker\_ck}$	5.5 * $T_{adc\_ker\_ck}$	5.5 * $T_{adc\_ker\_ck}$	5.5 * $T_{adc\_ker\_ck}$	4.5 * $T_{adc\_ker\_ck}$
0101	6.5 * $T_{adc\_ker\_ck}$	6.5 * $T_{adc\_ker\_ck}$	6.5 * $T_{adc\_ker\_ck}$	5.5 * $T_{adc\_ker\_ck}$	4.5 * $T_{adc\_ker\_ck}$
0110	7.5 * $T_{adc\_ker\_ck}$	7.5 * $T_{adc\_ker\_ck}$	6.5 * $T_{adc\_ker\_c}$	5.5 * $T_{adc\_ker\_ck}$	4.5 * $T_{adc\_ker\_ck}$
0111	8.5 * $T_{adc\_ker\_ck}$	7.5 * $T_{adc\_ker\_ck}$	6.5 * $T_{adc\_ker\_ck}$	5.5 * $T_{adc\_ker\_ck}$	4.5 * $T_{adc\_ker\_ck}$
1000	8.5 * $T_{adc\_ker\_ck}$	7.5 * $T_{adc\_ker\_ck}$	6.5 * $T_{adc\_ker\_ck}$	5.5 * $T_{adc\_ker\_ck}$	4.5 * $T_{adc\_ker\_ck}$
others: reserved	-	-	-	-	-

28.7.3 ADC common regular data register for dual mode (ADCx_CDR) (x=1/2)

Address offset: 0x0C

Reset value: 0x0000 0000

The address offset is relative to the master ADC base address + 0x300.

ADC1 and ADC2 are controlled by the same interface.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RDATA_SLV[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDATA_MST[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **RDATA_SLV[15:0]:** Regular data of the slave ADC

In dual mode, these bits contain the regular data of the slave ADC. Refer to *Section 28.4.32: Dual ADC modes*.

The data alignment is applied as described in *Section : Data register, data alignment and offset (ADC_DR, ADC_JDRy, OFFSETy, OFFSETy_CH, OVSS, LSHIFT, RSHIFT, SSATE)*)

Bits 15:0 **RDATA_MST[15:0]**: Regular data of the master ADC.

In dual mode, these bits contain the regular data of the master ADC. Refer to *Section 28.4.32: Dual ADC modes*.

The data alignment is applied as described in *Section : Data register, data alignment and offset (ADC_DR, ADC_JDRy, OFFSETy, OFFSETy_CH, OVSS, LSHIFT, RSHIFT, SSATE)*)

In MDMA=0b11 mode, bits 15:8 contains SLV_ADC_DR[7:0], bits 7:0 contains MST_ADC_DR[7:0].

28.7.4 ADC common regular data register for 32-bit dual mode (ADCx_CDR2) (x=1/2)

Address offset: 0x10

Reset value: 0x0000 0000

The address offset is relative to the master ADC base address + 0x300.

ADC1 and ADC2 are controlled by the same interface.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RDATA_ALT[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDATA_ALT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RDATA_ALT[31:0]**: Regular data of the master/slave alternated ADCs

In dual mode, these bits alternatively contains the regular 32-bit data of the master and the slave ADC. Refer to *Section 28.4.32: Dual ADC modes*.

The data alignment is applied as described in *Section : Data register, data alignment and offset (ADC_DR, ADC_JDRy, OFFSETy, OFFSETy_CH, OVSS, LSHIFT, RSHIFT, SSATE)*.

28.8 ADC register map

The following table summarizes the ADC registers.

Table 237. ADC register map and reset values for each ADC (offset=0x000 for master ADC, 0x100 for slave ADC)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**ADC_ISR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LDORDY	Res.	JQOVF	AWD3	AWD2	AWD1	JEOS	JEOC	OVR	EOS	EOC	EOSMP	ADRDY
	Reset value																				0		0	0	0	0	0	0	0	0	0	0	0
0x04	**ADC_IER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JQOVFIE	AWD3IE	AWD2IE	AWD1IE	JEOSIE	JEOCIE	OVRIE	EOSIE	EOCIE	EOSMPIE	ADRDYIE
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x0C	**ADC_CFGR**	JQDIS	AWD1CH[4:0]					JAUTO	JAWD1EN	AWD1EN	AWD1SGL	JQM	JDISCEN	DISCNUM [2:0]			DISCEN	Res.	AUTDLY	CONT	OVRMOD	EXTEN[1:0]		EXTSEL [4:0]					RES [2:0]			DMN GT [1:0]	
	Reset value	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	**ADC_CFGR2**	Res.	Res.	Res.	Res.	Res.	Res.	OSVR[9:0]										Res.	RSHIFT4	RSHIFT3	RSHIFT2	RSHIFT1	ROVSM	TROVS	OVSS[3:0]				Res.	Res.	Res.	JOVSE	ROVSE
	Reset value							0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0				0	0
0x14	**ADC_SMPR1**	Res.	Res.	SMP9[2:0]			SMP8[2:0]			SMP7[2:0]			SMP6[2:0]			SMP5[2:0]			SMP4[2:0]			SMP3[2:0]			SMP2[2:0]			SMP1[2:0]			SMP0[2:0]	
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	**ADC_SMPR2**	Res.	Res.	SMP19 [2:0]			SMP18 [2:0]			SMP17 [2:0]			SMP16 [2:0]			SMP15 [2:0]			SMP14 [2:0]			SMP13 [2:0]			SMP12 [2:0]			SMP11 [2:0]			SMP10 [2:0]	
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	**ADC_PCSEL**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCSEL19	PCSEL18	PCSEL17	PCSEL16	PCSEL15	PCSEL14	PCSEL13	PCSEL12	PCSEL11	PCSEL10	PCSEL9	PCSEL8	PCSEL7	PCSEL6	PCSEL5	PCSEL4	PCSEL3	PCSEL2	PCSEL1	PCSEL0
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	**ADC_LTR1**	Res.	Res.	Res.	Res.	Res.	Res.	LTR1[25:0]																									
	Reset value							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x24	**ADC_HTR1**	Res.	Res.	Res.	Res.	Res.	Res.	HTR1[25:0]																									
	Reset value							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x28	Reserved	Res.																															
0x2C	Reserved	Res.																															
0x30	**ADC_SQR1**	Res.	Res.	Res.	SQ4[4:0]					Res.	SQ3[4:0]						Res.	SQ2[4:0]					Res.	SQ1[4:0]					Res.	Res.	Res.	L[3:0]		
	Reset value				0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0				0	0	0	0
0x34	**ADC_SQR2**	Res.	Res.	Res.	SQ9[4:0]					Res.	SQ8[4:0]						Res.	SQ7[4:0]					Res.	SQ6[4:0]					Res.	SQ5[4:0]			
	Reset value				0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0			0	0	0	0	0

Table 237. ADC register map and reset values for each ADC (offset=0x000 for master ADC, 0x100 for slave ADC) (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x38	**ADC_SQR3**	Res.	Res.	Res.	SQ14[4:0]					Res.	SQ13[4:0]					Res.	SQ12[4:0]					Res.	SQ11[4:0]					Res.	SQ10[4:0]				
	Reset value				0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0
0x3C	**ADC_SQR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SQ16[4:0]					Res.	SQ15[4:0]				
	Reset value																						0	0	0	0	0		0	0	0	0	0
0x40	**ADC_DR**	RDATA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x44-0x48	Reserved	Res.																															
0x4C	**ADC_JSQR**	JSQ4[4:0]					Res.	JSQ3[4:0]					Res.	JSQ2[4:0]				Res.	JSQ1[4:0]				JEXTEN[1:0]		JEXTSEL[4:0]				JL[1:0]				
	Reset value	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x50-0x5C	Reserved	Res.																															
0x60	**ADC_OFR1**	SSATE	OFFSET1_CH[4:0]																														
																							OFFSET1[25:0]										
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x64	**ADC_OFR2**	SSATE	OFFSET2_CH[4:0]																														
																							OFFSET2[25:0]										
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x68	**ADC_OFR3**	SSATE	OFFSET3_CH[4:0]																														
																							OFFSET3[25:0]										
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x6C	**ADC_OFR4**	SSATE	OFFSET4_CH[4:0]																														
																							OFFSET4[25:0]										
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x70-0x7C	Reserved	Res.																															
0x80	**ADC_JDR1**	JDATA1[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x84	**ADC_JDR2**	JDATA2[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x88	**ADC_JDR3**	JDATA3[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x8C	**ADC_JDR4**	JDATA4[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 237. ADC register map and reset values for each ADC (offset=0x000 for master ADC, 0x100 for slave ADC) (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x8C-0x9C	Reserved	Res.																															
0xA0	**ADC_AWD2CR**	Res.												AWD2CH[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xA4	**ADC_AWD3CR**	Res.												AWD3CH[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xA8-0xAC	Reserved	Res.																															
0xB0	**ADC_LTR2**	Res.						LTR2[25:0]																									
	Reset value							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xB4	**ADC_HTR2**	Res.						HTR2[25:0]																									
	Reset value							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0xB8	**ADC_LTR3**	Res.						LTR3[25:0]																									
	Reset value							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xBC	**ADC_HTR3**	Res.						HTR3[25:0]																									
	Reset value							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0xC0	**ADC_DIFSEL**	Res.												DIFSEL[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xC4	**ADC_CALFACT**	Res.					CALFACT_D[10:0]											Res.					CALFACT_S[10:0]										
	Reset value						0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0xC8	**ADC_ CALFACT2**	Res.		LINCALFACT[29:0]																													
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xCC - 0xD0	Reserved	Res.																															

Table 238. ADC register map and reset values (master and slave ADC common registers) offset =0x300)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**ADCx_CSR**	Res.					JQOVF_SLV	AWD3_SLV	AWD2_SLV	AWD1_SLV	JEOS_SLV	JEOC_SLV	OVR_SLV	EOS_SLV	EOC_SLV	EOSMP_SLV	ADRDY_SLV	Res.					JQOVF_MST	AWD3_MST	AWD2_MST	AWD1_MST	JEOS_MST	JEOC_MST	OVR_MST	EOS_MST	EOC_MST	EOSMP_MST	ADRDY_MST
							slave ADC2																master ADC1										
	Reset value						0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x04	Reserved	Res.																															
0x08	**ADCx_CCR**	Res.					Res.	Res.	Res.	Res.	Res.	PRESC[3:0]				CKMODE[1:0]		DAMDF[1:0]		Res.	Res.	DELAY[3:0]				Res.	Res.	Res.	DUAL[4:0]				
	Reset value											0	0	0	0	0	0	0	0			0	0	0	0				0	0	0	0	0
0x0C	**ADCx_CDR**	RDATA_SLV[15:0]																RDATA_MST[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	**ADCx_CDR2**	RDATA_ALT[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

29 Analog-to-digital converters (ADC3)

29.1 Introduction

The ADC consists of a 12-bit successive approximation analog-to-digital converter.

The ADC has up to 19 multiplexed channels. A/D conversion of the various channels can be performed in Single, Continuous, Scan or Discontinuous mode. The result of the ADC is stored in a left-aligned or right-aligned 16-bit data register.

The ADC is mapped on the AHB bus to allow fast data handling.

The analog watchdog features allow the application to detect if the input voltage goes outside the user-defined high or low thresholds.

A built-in hardware oversampler allows to improve analog performances while off-loading the related computational burden from the CPU.

An efficient low-power mode is implemented to allow very low consumption at low frequency.

29.2 ADC main features

- High-performance features
  - 16 external channels and to 3 internal channels
  - 12, 10, 8 or 6-bit configurable resolution
  - ADC conversion time independent from the AHB bus clock frequency
  - Faster conversion time by lowering resolution
  - Manage single-ended or differential inputs
  - AHB slave bus interface to allow fast data handling
  - Self-calibration
  - Channel-wise programmable sampling time
  - Flexible sampling time control
  - Up to 4 injected channels (analog inputs assignment to regular or injected channels is fully configurable)
  - Hardware assistant to prepare the context of the injected channels to allow fast context switching
  - Data alignment with in-built data coherency
  - Data can be managed by DMA for regular channel conversions
  - Data can be routed to DFSDM for post processing
  - Four dedicated data registers for the injected channels
- Low-power features
  - Speed adaptive low-power mode to reduce ADC consumption when operating at low frequency
  - Allows slow bus frequency application while keeping optimum ADC performance

  - Provides automatic control to avoid ADC overrun in low AHB bus clock frequency application (auto-delayed mode)
- Oversampler
  - 16-bit data register
  - Oversampling ratio adjustable from 2 to 256x
  - Programmable data shift up to 8 bits
- Data preconditioning
  - Offset compensation
- Analog input channels
  - External analog inputs:

    Up to 6 fast channels from GPIO pads

    Up to 10 slow channels from GPIO pads
  - 1 channel for the internal temperature sensor (V_{SENSE})
  - 1 channel for the internal reference voltage (V_{REFINT})
  - 1 channel for monitoring the external VBAT power supply pin
- Start-of-conversion can be initiated:
  - By software for both regular and injected conversions
  - By hardware triggers with configurable polarity (internal timers events or GPIO input events) for both regular and injected conversions
- Conversion modes
  - The ADC can convert a single channel or can scan a sequence of channels
  - Single mode converts selected inputs once per trigger
  - Continuous mode converts selected inputs continuously
  - Discontinuous mode
- Interrupt generation at ADC ready, the end of sampling, the end of conversion (regular or injected), end of sequence conversion (regular or injected), analog watchdog 1, 2 or 3 or overrun events
- 3 analog watchdogs
  - Watchdog can perform filtering to ignore out-of-range data
- ADC input range: $V_{SSA} \leq V_{IN} \leq V_{REF+}$

Figure 229 shows the block diagram of one ADC.

29.3 ADC implementation

Table 239. ADC features

ADC modes/features	ADC1, ADC2	ADC3
Resolution	16bit	12 bit
Maximum sampling speed	3.6 Msps (16-bit resolution)	5 Msps (12-bit resolution)
Dual mode operation	X	-
Hardware offset calibration	X	X

Table 239. ADC features (continued)

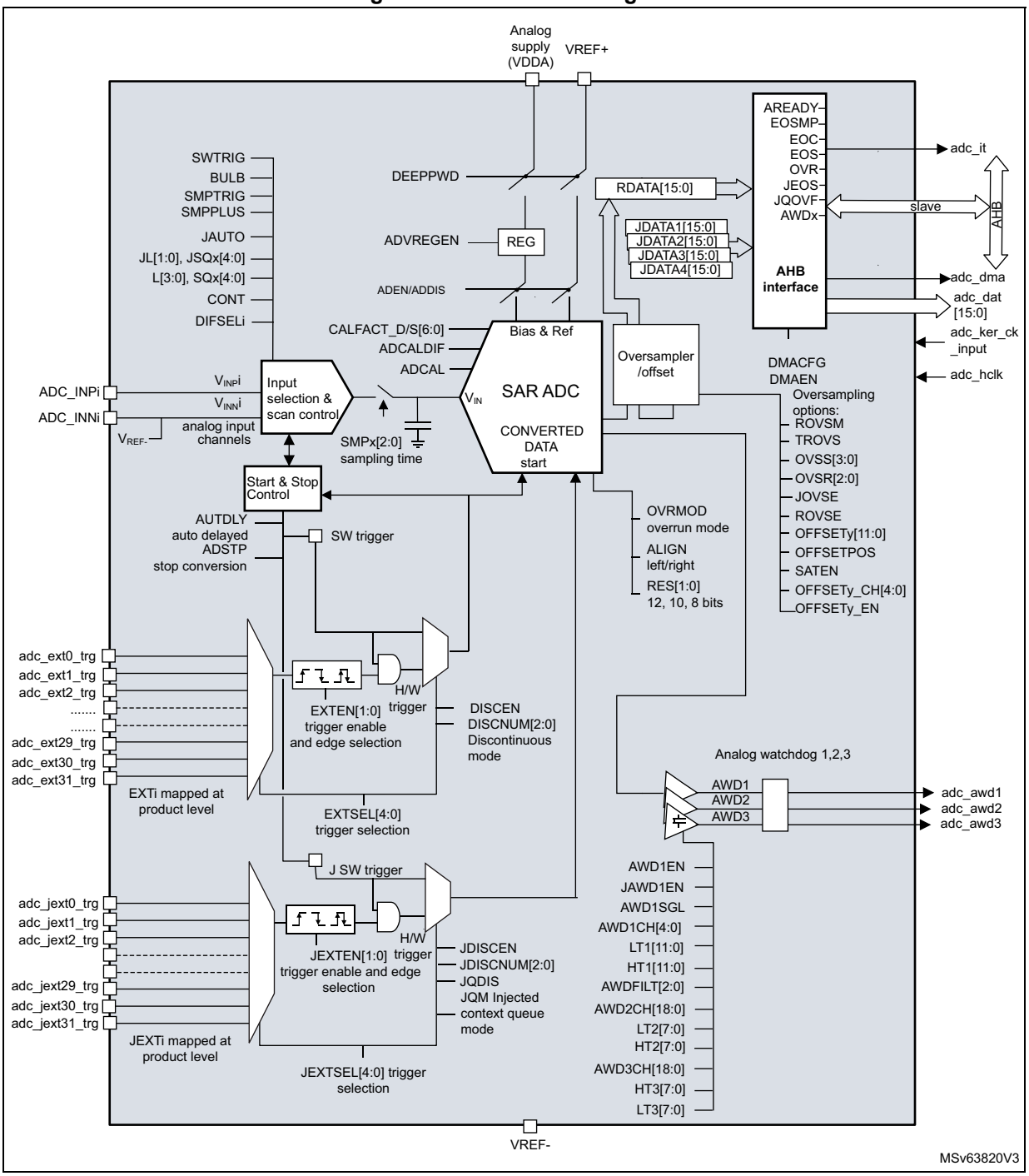
ADC modes/features	ADC1, ADC2	ADC3
Hardware linearity calibration	X	-
Single-end input	X	X
Differential input	X	X
Injected channel conversion	X	X
Oversampling	up to x1024	up to x256
Data register	32 bits	16 bits
Data register FIFO depth	3 stages	
DMA support	X	X
Parallel data output to DFSDM	X	X
Offset compensation	X	X
Gain compensation	-	-
Number of Analog watchdog	3	3
Option register	-	-

29.4 ADC functional description

29.4.1 ADC block diagram

Figure 229 shows the ADC block diagram and *Table 240* gives the ADC pin description.

Figure 229. ADC block diagram



29.4.2 ADC pins and internal signals

Table 240. ADC input/output pins

Pin name	Signal type	Description
VDDA	Input, analog supply	Analog power supply and positive reference voltage for the ADC
VSSA	Input, analog supply ground	Ground for analog power supply, equal to V_{SS}.
VREF+	Input, analog reference positive	The higher/positive reference voltage for the ADC.
VREF−	Input, analog reference negative	The lower/negative reference voltage for the ADC. V_{REF-} is internally connected to V_{SSA}
ADC3_INNi/INPi	Negative/positive external analog input signals	19 negative/positive external analog input channels (refer to *Section 29.4.4: ADC connectivity* for details)

Table 241. ADC internal input/output signals

Internal signal name	Signal type	Description
$V_{INP}i$	Positive analog input channels	Positive internal analog input channels connected either to ADC3_INP*i* external channels or to internal channels.
$V_{INN}i$	Negative analog input channels	Negative internal analog input channels connected either to ADC3_INN*i* external channels or to internal channels
adc_ext_trgi	Inputs	ADC external trigger inputs for regular conversions.
adc_jext_trgi	Inputs	ADC external trigger inputs for the injected conversions.
adc_awdx	Output	Internal analog watchdog output signal connected to on-chip timers. (x = Analog watchdog number 1,2,3)
adc_ker_ck_input	Output	ADC kernel clock
adc_hclk	Input	ADC peripheral clock
adc_it	Output	ADC interrupt
adc_dma	Output	ADC DMA request
adc_dat[15:0]	Output	ADC data outputs

Table 242. ADC interconnection

Signal name	Source/destination
ADC3 V_{INP}[17]	V_{SENSE} (internal temperature sensor output voltage).
ADC3 V_{INP}[18]	V_{REFINT} (output voltage from internal reference voltage).
ADC3 V_{INP}[16]	V_{BAT}/4 (VBAT pin input voltage divided by 4).
adc_dat[15:0]	dfsdm_adc3_dat[15:0]
adc_ext_trg0	tim1_oc1
adc_ext_trg1	tim1_oc2
adc_ext_trg2	tim1_oc3

Table 242. ADC interconnection (continued)

Signal name	Source/destination
adc_ext_trg3	tim2_oc2
adc_ext_trg4	tim3_trgo
adc_ext_trg5	tim4_oc4
adc_ext_trg6	exti11
adc_ext_trg7	tim8_trgo
adc_ext_trg8	tim8_trgo2
adc_ext_trg9	tim1_trgo
adc_ext_trg10	tim1_trgo2
adc_ext_trg11	tim2_trgo
adc_ext_trg12	tim4_trgo
adc_ext_trg13	tim6_trgo
adc_ext_trg14	tim15_trgo
adc_ext_trg15	tim3_oc4
adc_ext_trg16	reserved
adc_ext_trg17	reserved
adc_ext_trg18	lptim1_out
adc_ext_trg19	lptim2_out
adc_ext_trg20	lptim3_out
adc_ext_trg21	tim23_trgo
adc_ext_trg22	tim24_trgo
adc_ext_trg23	reserved
adc_ext_trg24	reserved
adc_ext_trg25	reserved
adc_ext_trg26	reserved
adc_ext_trg27	reserved
adc_ext_trg28	reserved
adc_ext_trg29	reserved
adc_ext_trg30	reserved
adc_ext_trg31	reserved
adc_jext_trg0	tim1_trgo
adc_jext_trg1	tim1_oc4
adc_jext_trg2	tim2_trgo
adc_jext_trg3	tim2_oc1
adc_jext_trg4	tim3_oc4
adc_jext_trg5	tim4_trgo

Table 242. ADC interconnection (continued)

Signal name	Source/destination
adc_jext_trg6	exti15
adc_jext_trg7	tim8_oc4
adc_jext_trg8	tim1_trgo2
adc_jext_trg9	tim8_trgo
adc_jext_trg10	tim8_trgo2
adc_jext_trg11	tim3_oc3
adc_jext_trg12	tim3_trgo
adc_jext_trg13	tim3_oc1
adc_jext_trg14	tim6_trgo
adc_jext_trg15	tim15_trgo
adc_jext_trg16	reserved
adc_jext_trg17	reserved
adc_jext_trg18	lptim1_out
adc_jext_trg19	lptim2_out
adc_jext_trg20	lptim3_out
adc_jext_trg21	tim23_trgo
adc_jext_trg22	tim24_trgo
adc_jext_trg23	reserved
adc_jext_trg24	reserved
adc_jext_trg25	reserved
adc_jext_trg26	reserved
adc_jext_trg27	reserved
adc_jext_trg28	reserved
adc_jext_trg29	reserved
adc_jext_trg30	reserved
adc_jext_trg31	reserved

29.4.3 ADC clocks

Dual clock domain architecture

The dual clock-domain architecture means that the ADC clock is independent from the AHB bus clock.

The ADC input clock can be selected between two different clock sources (see *Figure 230: ADC clock scheme*):

1. The ADC clock can be a specific clock source (adc_ker_ck_input), independent and asynchronous with the AHB clock.

   Refer to section *Reset and clock control (RCC)* for more information on how to generate the ADC dedicated clock. To select this scheme, CKMODE[1:0] bits of ADC_CCR register must be set to 00.

2. The ADC clock can be derived from the AHB clock interface divided by a programmable factor of 1, 2 or 4. To select this scheme, CKMODE[1:0] bits of ADC_CCR must be different from 00. The programmable divider factor can be configured through to CKMODE[1:0] bits of ADC_CCR.

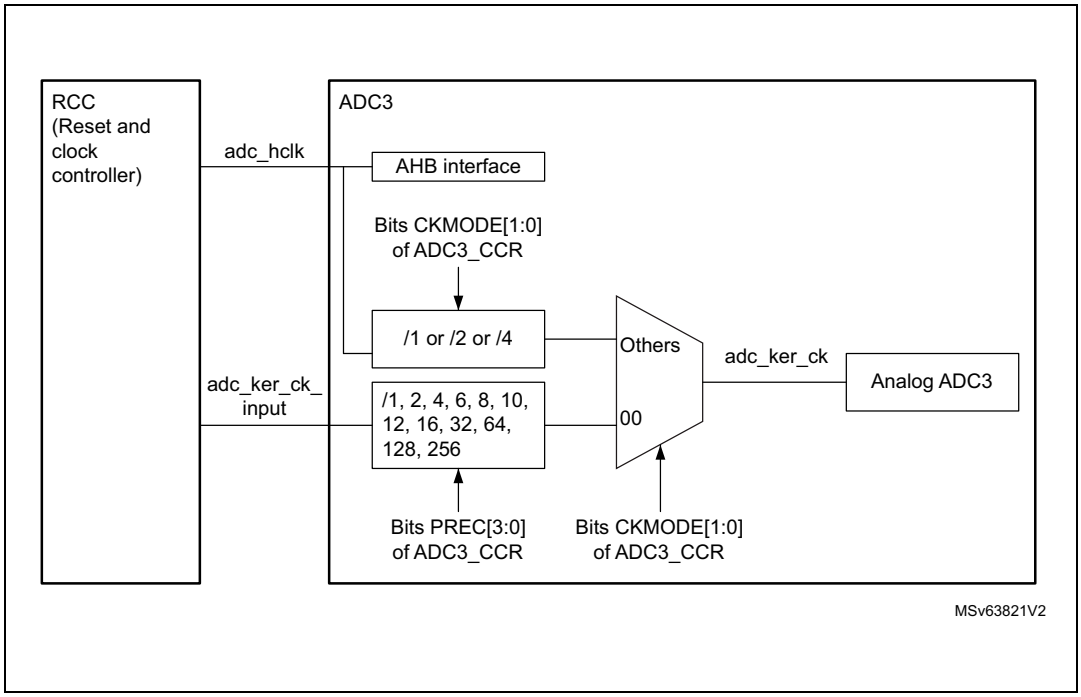
   The prescaling factor of 1 (CKMODE[1:0] = 01) can be used only if the AHB prescaler is set to 1 (HPRE[3:0] = 0xxx in the RCC_CFGR register).

Option **1** has the advantage of achieving the maximum ADC clock frequency whatever the AHB clock scheme selected. The ADC clock can eventually be divided by the following ratio: 1, 2, 4, 6, 8, 12, 16, 32, 64, 128, 256, using the prescaler configured with bits PRESC[3:0] in the ADC_CCR register.

Option **2** has the advantage of bypassing the clock domain resynchronizations. This can be useful when the ADC is triggered by a timer and if the application requires that the ADC is precisely triggered without any uncertainty (otherwise, an uncertainty of the trigger instant is added by the resynchronizations between the two clock domains).

The clock is configured through CKMODE[1:0] bits must be compliant with the operating frequency specified in the device datasheet.

Figure 230. ADC clock scheme



Clock ratio constraint between ADC clock and AHB clock

There are generally no constraints to be respected for the ratio between the ADC clock and the AHB clock except if some injected channels are programmed. In this case, it is mandatory to respect the following ratio:

- $F_{adc\_hclk} \geq F_{ADC} / 4$ if the resolution of all channels are 12-bit or 10-bit
- $F_{adc\_hclk} \geq F_{ADC} / 3$ if there are some channels with resolutions equal to 8-bit (and none with lower resolutions)
- $F_{adc\_hclk} \geq F_{ADC} / 2$ if there are some channels with resolutions equal to 6-bit

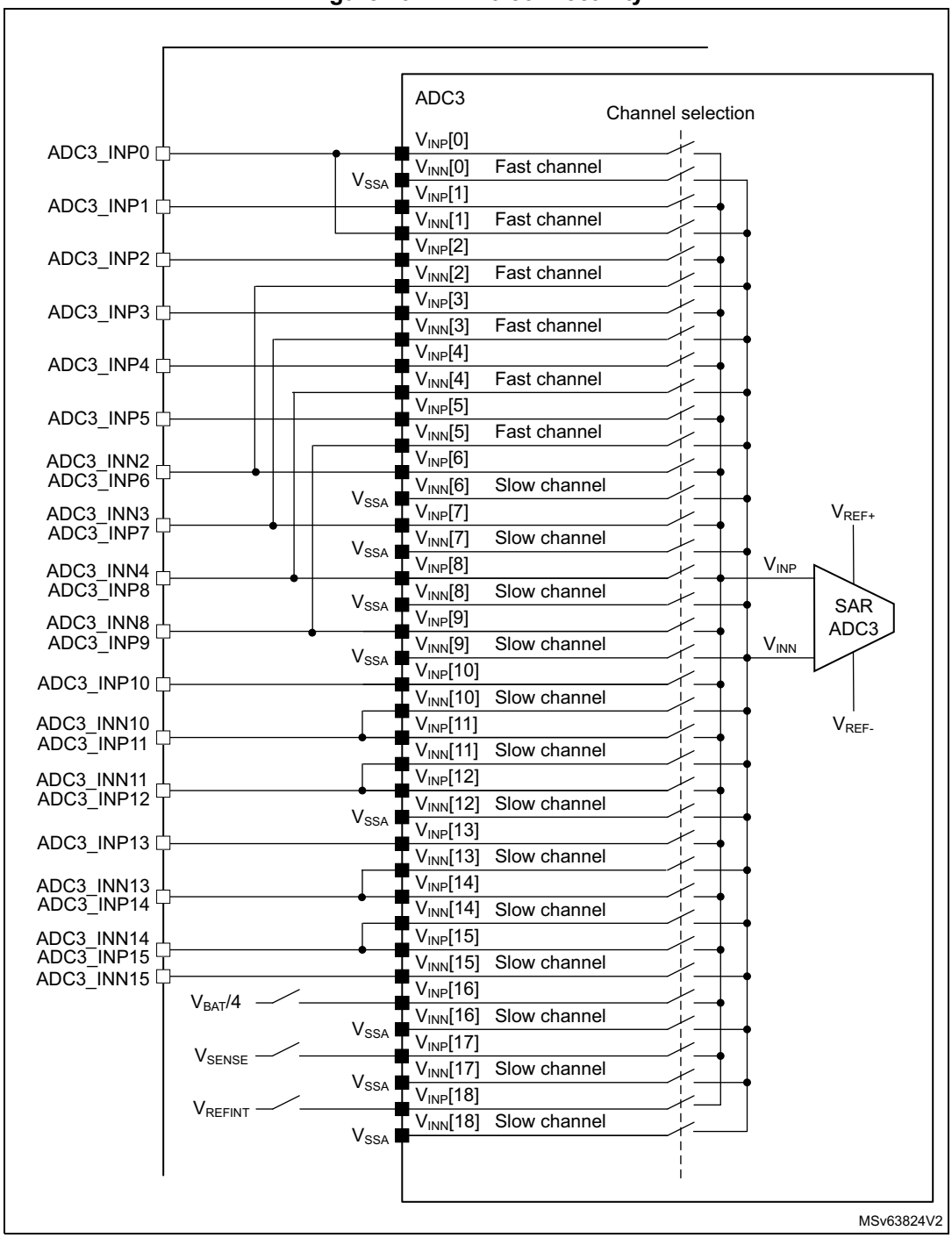
Constraints between ADC clocks

When several ADC interfaces are used simultaneously, it is mandatory to use the same clock source from the RCC block without prescaler ratio for all ADC interfaces.

29.4.4 ADC connectivity

ADC inputs are connected to the external channels as well as internal sources as described below.

Figure 231. ADC3 connectivity



29.4.5 Slave AHB interface

The ADC implements an AHB slave port for control/status register and data access. The features of the AHB interface are listed below:

- Word (32-bit) accesses
- Single cycle response
- Response to all read/write accesses to the registers with zero wait states.

The AHB slave interface does not support split/retry requests, and never generates AHB errors.

29.4.6 ADC Deep-power-down mode (DEEPPWD) and ADC voltage regulator (ADVREGEN)

By default, the ADC is in Deep-power-down mode where its supply is internally switched off to reduce the leakage currents (the reset state of bit DEEPPWD is 1 in the ADC_CR register).

To start ADC operations, it is first needed to exit Deep-power-down mode by setting bit DEEPPWD = 0.

Then, it is mandatory to enable the ADC internal voltage regulator by setting the bit ADVREGEN = 1 into ADC_CR register. The software must wait for the startup time of the ADC voltage regulator ($T_{ADCVREG\_STUP}$) before launching a calibration or enabling the ADC. This delay must be implemented by software.

For the startup time of the ADC voltage regulator, refer to device datasheet for $T_{ADCVREG\_STUP}$ parameter.

When ADC operations are complete, the ADC can be disabled (ADEN = 0). It is possible to save power by also disabling the ADC voltage regulator. This is done by writing bit ADVREGEN = 0.

Then, to save more power by reducing the leakage currents, it is also possible to re-enter in ADC Deep-power-down mode by setting bit DEEPPWD = 1 into ADC_CR register. This is particularly interesting before entering Stop mode.

Note: Writing DEEPPWD = 1 automatically disables the ADC voltage regulator and bit ADVREGEN is automatically cleared.

When the internal voltage regulator is disabled (ADVREGEN = 0), the internal analog calibration is kept.

In ADC Deep-power-down mode (DEEPPWD = 1), the internal analog calibration is lost and it is necessary to either relaunch a calibration or re-apply the calibration factor which was previously saved (refer to *Section 29.4.8: Calibration (ADCAL, ADCALDIF, ADC_CALFACT)*).

29.4.7 Single-ended and differential input channels

Channels can be configured to be either single-ended input or differential input by programming DIFSEL[i] bits in the ADC_DIFSEL register. This configuration must be written while the ADC is disabled (ADEN = 0). Note that the DIFSEL[i] bits corresponding to single-ended channels are always programmed at 0.

In single-ended input mode, the analog voltage to be converted for channel “i” is the difference between the external voltage $V_{INP[i]}$ (positive input) and V_{REF-} (negative input).

In differential input mode, the analog voltage to be converted for channel “i” is the difference between the external voltage $V_{INP[i]}$ (positive input) and $V_{INN[i]}$ (negative input).

The output data for the differential mode is an unsigned data. When $V_{INP[i]}$ equals V_{REF-}, $V_{INN[i]}$ equals V_{REF+} and the output data is 0x000 (12-bit resolution mode). When $V_{INP[i]}$ equals V_{REF+}, $V_{INN[i]}$ equals V_{REF-} and the output data is 0xFFF.

$$\text{Converted value} = \frac{\text{ADC\_Full\_Scale}}{2} \times \left[1 + \frac{V_{INP} - V_{INN}}{V_{REF+}}\right]$$

When ADC is configured as differential mode, both inputs should be biased at (V_{REF+}) /2 voltage.

The input signals are supposed to be differential (common mode voltage should be fixed).

Internal channels (such as V_{REFINT} and V_{SENSE}) are used in single-ended mode only.

For a complete description of how the input channels are connected, refer to *Section 29.4.4: ADC connectivity*.

Caution: When configuring the channel “i” in differential input mode, its negative input voltage $V_{INN[i]}$ is connected to another channel. As a consequence, this channel is no longer usable in Single-ended mode or in differential mode and must never be configured to be converted.

29.4.8 Calibration (ADCAL, ADCALDIF, ADC_CALFACT)

The ADC provides an automatic calibration procedure which drives all the calibration sequence including the power-on/off sequence of the ADC. During the procedure, the ADC calculates a calibration factor which is 7-bit wide and which is applied internally to the ADC until the next ADC power-off. During the calibration procedure, the application must not use the ADC and must wait until calibration is complete.

Calibration is preliminary to any ADC operation. It removes the offset error which may vary from chip to chip due to process or bandgap variation.

The calibration factor to be applied for single-ended input conversions is different from the factor to be applied for differential input conversions:

- Write ADCALDIF = 0 before launching a calibration which will be applied for single-ended input conversions.
- Write ADCALDIF = 1 before launching a calibration which will be applied for differential input conversions.

The calibration is then initiated by software by setting bit ADCAL = 1. Calibration can only be initiated when the ADC is disabled (when ADEN = 0). ADCAL bit stays at 1 during all the calibration sequence. It is then cleared by hardware as soon the calibration completes. At this time, the associated calibration factor is stored internally in the analog ADC and also in

the bits CALFACT_S[6:0] or CALFACT_D[6:0] of ADC_CALFACT register (depending on single-ended or differential input calibration)

The internal analog calibration is kept if the ADC is disabled (ADEN = 0). However, if the ADC is disabled for extended periods, then it is recommended that a new calibration cycle is run before re-enabling the ADC.

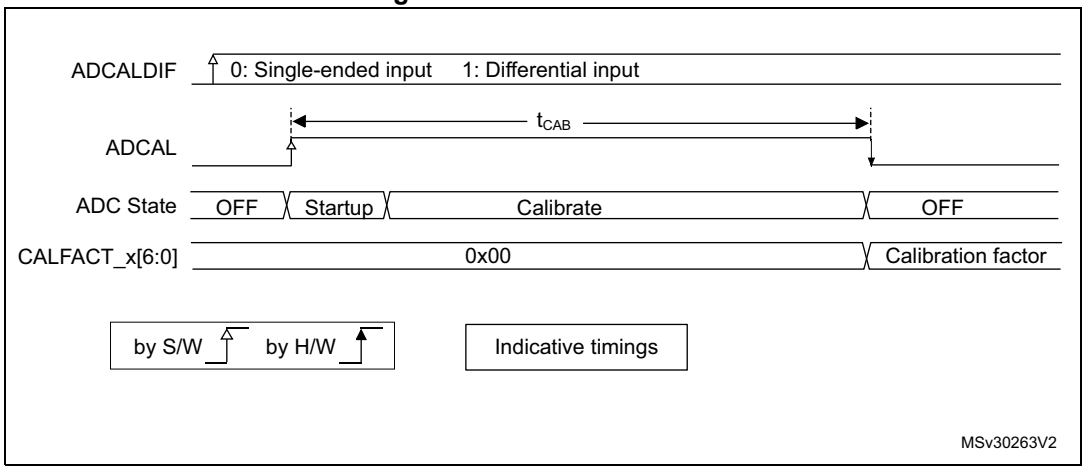
The internal analog calibration is lost each time the power of the ADC is removed (example, when the product enters in STANDBY or VBAT mode). In this case, to avoid spending time recalibrating the ADC, it is possible to re-write the calibration factor into the ADC_CALFACT register without recalibrating, supposing that the software has previously saved the calibration factor delivered during the previous calibration.

The calibration factor can be written if the ADC is enabled but not converting (ADEN = 1 and ADSTART = 0 and JADSTART = 0). Then, at the next start of conversion, the calibration factor is automatically injected into the analog ADC. This loading is transparent and does not add any cycle latency to the start of the conversion. It is recommended to recalibrate when V_{REF+} voltage changed more than 10%.

Software procedure to calibrate the ADC

1. Ensure DEEPPWD = 0, ADVREGEN = 1 and that ADC voltage regulator startup time has elapsed.
2. Ensure that ADEN = 0.
3. Select the input mode for this calibration by setting ADCALDIF = 0 (single-ended input) or ADCALDIF = 1 (differential input).
4. Set ADCAL = 1.
5. Wait until ADCAL = 0.
6. The calibration factor can be read from ADC_CALFACT register.

Figure 232. ADC calibration

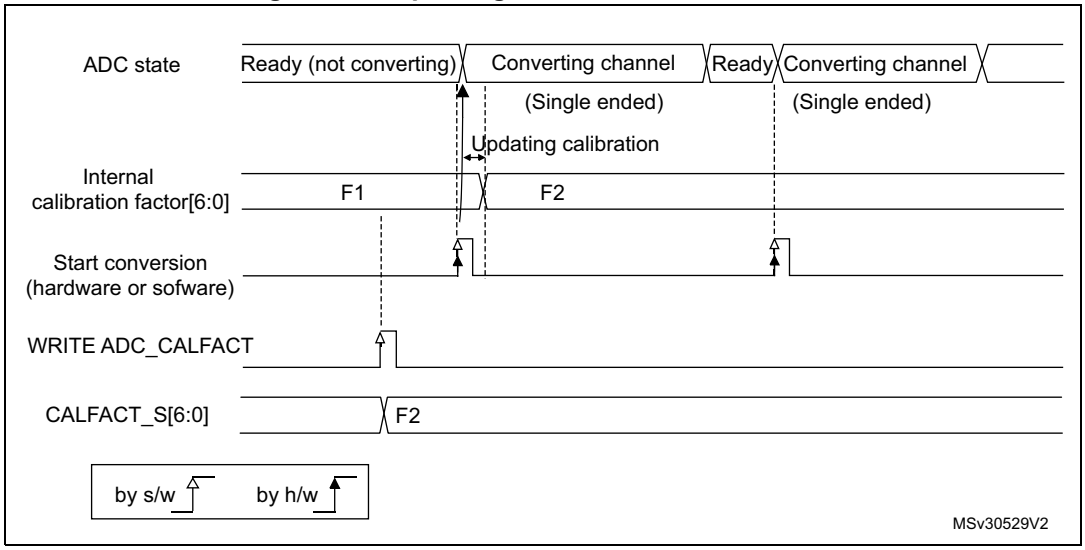


Software procedure to re-inject a calibration factor into the ADC

1. Ensure ADEN = 1 and ADSTART = 0 and JADSTART = 0 (ADC enabled and no conversion is ongoing).
2. Write CALFACT_S and CALFACT_D with the new calibration factors.
3. When a conversion is launched, the calibration factor is injected into the analog ADC only if the internal analog calibration factor differs from the one stored in bits

CALFACT_S for single-ended input channel or bits CALFACT_D for differential input channel.

Figure 233. Updating the ADC calibration factor

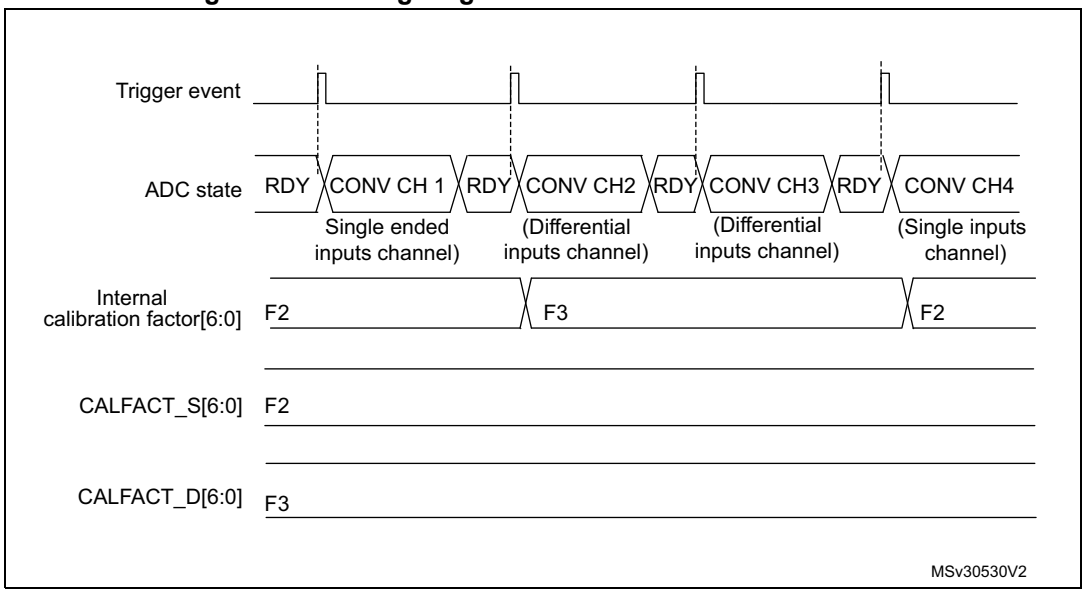


Converting single-ended and differential analog inputs with a single ADC

If the ADC is supposed to convert both differential and single-ended inputs, two calibrations must be performed, one with ADCALDIF = 0 and one with ADCALDIF = 1. The procedure is the following:

1. Disable the ADC.
2. Calibrate the ADC in single-ended input mode (with ADCALDIF = 0). This updates the register CALFACT_S[6:0].
3. Calibrate the ADC in differential input modes (with ADCALDIF = 1). This updates the register CALFACT_D[6:0].
4. Enable the ADC, configure the channels and launch the conversions. Each time there is a switch from a single-ended to a differential inputs channel (and vice-versa), the calibration is automatically injected into the analog ADC.

Figure 234. Mixing single-ended and differential channels



29.4.9 ADC on-off control (ADEN, ADDIS, ADRDY)

First of all, follow the procedure explained in *Section 29.4.6: ADC Deep-power-down mode (DEEPPWD) and ADC voltage regulator (ADVREGEN)*).

Once DEEPPWD = 0 and ADVREGEN = 1, the ADC can be enabled and the ADC needs a stabilization time of t_{STAB} before it starts converting accurately, as shown in *Figure 235*. Two control bits enable or disable the ADC:

- ADEN = 1 enables the ADC. The flag ADRDY is set once the ADC is ready for operation.
- ADDIS = 1 disables the ADC. ADEN and ADDIS are then automatically cleared by hardware as soon as the analog ADC is effectively disabled.

Regular conversion can then start either by setting ADSTART = 1 (refer to *Section 29.4.18: Conversion on external trigger and trigger polarity (EXTSEL, EXTEN,JEXTSEL, JEXTEN)*) or when an external trigger event occurs, if triggers are enabled.

Injected conversions start by setting JADSTART = 1 or when an external injected trigger event occurs, if injected triggers are enabled.

Software procedure to enable the ADC

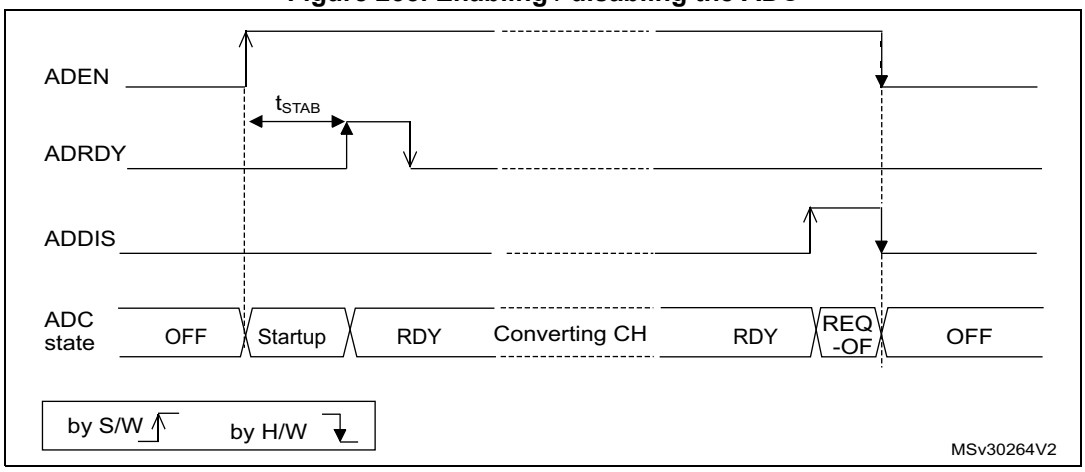
1. Clear the ADRDY bit in the ADC_ISR register by writing ‘1’.
2. Set ADEN = 1.
3. Wait until ADRDY = 1 (ADRDY is set after the ADC startup time). This can be done using the associated interrupt (setting ADRDYIE = 1).
4. Clear the ADRDY bit in the ADC_ISR register by writing ‘1’ (optional).

Caution: ADEN bit cannot be set when ADCAL is set and during four ADC clock cycles after the ADCAL bit is cleared by hardware (end of the calibration).

Software procedure to disable the ADC

1. Check that both ADSTART = 0 and JADSTART = 0 to ensure that no conversion is ongoing. If required, stop any regular and injected conversion ongoing by setting ADSTP = 1 and JADSTP = 1 and then wait until ADSTP = 0 and JADSTP = 0.
2. Set ADDIS = 1.
3. If required by the application, wait until ADEN = 0, until the analog ADC is effectively disabled (ADDIS is automatically reset once ADEN = 0).

Figure 235. Enabling / disabling the ADC



29.4.10 Constraints when writing the ADC control bits

The software is allowed to write the RCC control bits to configure and enable the ADC clock (refer to RCC Section), the DIFSEL[i] control bits in the ADC_DIFSEL register and the control bits ADCAL and ADEN in the ADC_CR register, only if the ADC is disabled (ADEN must be equal to 0).

The software is then allowed to write the control bits ADSTART, JADSTART and ADDIS of the ADC_CR register only if the ADC is enabled and there is no pending request to disable the ADC (ADEN must be equal to 1 and ADDIS to 0).

For all the other control bits of the ADC_CFGR, ADC_SMPRx, ADC_TRy, ADC_SQRy, ADC_JDRy, ADC_OFRy, ADC_OFCHRy and ADC_IER registers:

- For control bits related to configuration of regular conversions, the software is allowed to write them only if the ADC is enabled (ADEN = 1) and if there is no regular conversion ongoing (ADSTART must be equal to 0).
- For control bits related to configuration of injected conversions, the software is allowed to write them only if the ADC is enabled (ADEN = 1) and if there is no injected conversion ongoing (JADSTART must be equal to 0).
- ADC_TRy registers can be modified when an analog-to-digital conversion is ongoing (refer to *Section 29.4.29: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)*for details).

The software is allowed to write the ADSTP or JADSTP control bits of the ADC_CR register only if the ADC is enabled, possibly converting, and if there is no pending request to disable the ADC (ADSTART or JADSTART must be equal to 1 and ADDIS to 0).

The software can write the register ADC_JSQR at any time, when the ADC is enabled (ADEN = 1). Refer to *Section 29.6.16: ADC injected sequence register (ADC_JSQR)* for additional details.

Note: There is no hardware protection to prevent these forbidden write accesses and ADC behavior may become in an unknown state. To recover from this situation, the ADC must be disabled (clear ADEN = 0 as well as all the bits of ADC_CR register).

29.4.11 Channel selection (SQRx, JSQRx)

The ADC features up to 19 multiplexed channels, out of which:

- Up to 16 analog inputs coming from GPIO pads (ADC_INP/INN[i]) depending on the products, not all of them are available on GPIO pads.
- ADC is connected to 3 internal analog inputs:
  - the internal temperature sensor (V_{SENSE})
  - the internal reference voltage (V_{REFINT})
  - the V_{BAT} monitoring channel ($V_{BAT}/4$)

  To convert one of the internal analog channels, the corresponding analog sources must first be enabled by programming bits VREFEN, VBATEN or TSEN in the ADC_CCR registers.

Refer to *Table ADC interconnection* in *Section 29.4.2: ADC pins and internal signals* for the connection of the above internal analog inputs to external ADC pins or internal signals.

The conversions can be organized in two groups: regular and injected. A group consists of a sequence of conversions that can be done on any channel and in any order. For instance, it is possible to implement the conversion sequence in the following order: ADC3_INP/INN3, ADC3_INP/INN8, ADC3_INP/INN2, ADC3_INN/INP2, ADC3_INP/INN0, ADC3_INP/INN2, ADC3_INP/INN2, ADC3_INP/INN15.

- A **regular group** is composed of up to 16 conversions. The regular channels and their order in the conversion sequence must be selected in the ADC_SQRy registers. The total number of conversions in the regular group must be written in the L[3:0] bits in the ADC_SQR1 register.
- An **injected group** is composed of up to 4 conversions. The injected channels and their order in the conversion sequence must be selected in the ADC_JSQR register. The total number of conversions in the injected group must be written in the L[1:0] bits in the ADC_JSQR register.

ADC_SQRy registers must not be modified while regular conversions can occur. For this, the ADC regular conversions must be first stopped by writing ADSTP = 1 (refer to *Section 29.4.17: Stopping an ongoing conversion (ADSTP, JADSTP)*).

The software is allowed to modify on-the-fly the ADC_JSQR register when JADSTART is set to 1 (injected conversions ongoing) only when the context queue is enabled (JQDIS = 0 in ADC_CFGR register). Refer to *Section 29.4.21: Queue of context for injected conversions*

29.4.12 Channel-wise programmable sampling time (SMPR1, SMPR2)

Before starting a conversion, the ADC must establish a direct connection between the voltage source under measurement and the embedded sampling capacitor of the ADC. This sampling time must be enough for the input voltage source to charge the embedded capacitor to the input voltage level.

Each channel can be sampled with a different sampling time which is programmable using the SMP[2:0] bits in the ADC_SMPR1 and ADC registers. It is therefore possible to select among the following sampling time values:

- SMP = 000: 2.5 ADC clock cycles
- SMP = 001: 6.5 ADC clock cycles
- SMP = 010: 12.5 ADC clock cycles
- SMP = 011: 24.5 ADC clock cycles
- SMP = 100: 47.5 ADC clock cycles
- SMP = 101: 92.5 ADC clock cycles
- SMP = 110: 247.5 ADC clock cycles
- SMP = 111: 640.5 ADC clock cycles

The total conversion time is calculated as follows:

T_{CONV} = Sampling time + 12.5 ADC clock cycles

Example:

With $F_{adc\_ker\_ck}$ = 30 MHz and a sampling time of 2.5 ADC clock cycles:

T_{CONV} = (2.5 + 12.5) ADC clock cycles = 15 ADC clock cycles = 500 ns

The ADC notifies the end of the sampling phase by setting the status bit EOSMP (only for regular conversion).

Constraints on the sampling time

For each channel, SMP[2:0] bits must be programmed to respect a minimum sampling time as specified in the ADC characteristics section of the datasheets.

Bulb sampling mode

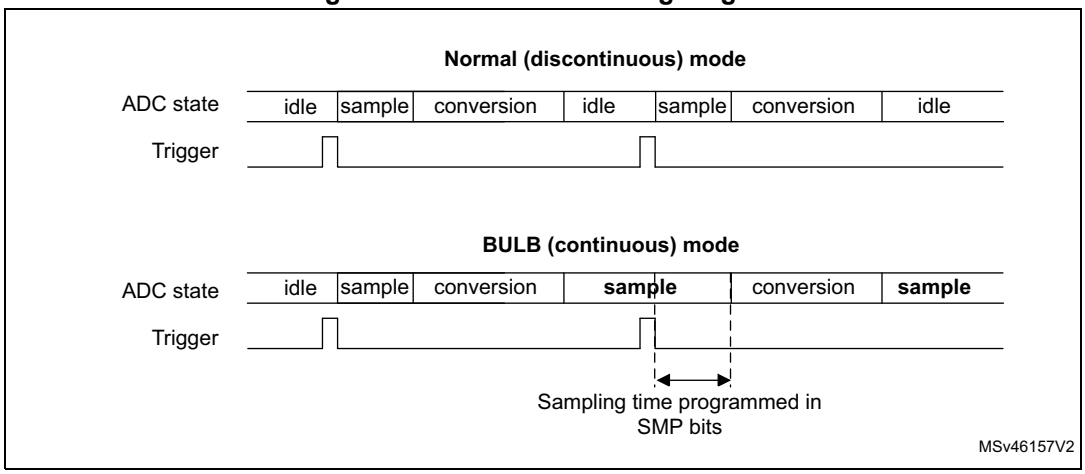
When the BULB bit is set in ADC register, the sampling period starts immediately after the last ADC conversion. A hardware or software trigger starts the conversion after the sampling time has been programmed in ADC_SMPR1 register. The very first ADC conversion, after the ADC is enabled, is performed with the sampling time programmed in SMP bits. The Bulb mode is effective starting from the second conversion.

The maximum sampling time is limited (refer to the ADC characteristics section of the datasheet).

The Bulb mode is neither compatible with the Continuous conversion mode nor with the injected channel conversion.

When the BULB bit is set, it is not allowed to set SMPTRIG bit in ADC_CFGR2.

Figure 236. Bulb mode timing diagram



Sampling time control trigger mode

When the SMPTRIG bit is set, the sampling time programmed though SMPx bits is not applicable. The sampling time is controlled by the trigger signal edge.

When a hardware trigger is selected, each rising edge of the trigger signal starts the sampling period. A falling edge ends the sampling period and starts the conversion.

When a software trigger is selected, the software trigger is not the ADSTART bit in ADC_CR but the SWTRIG bit. SWTRIG bit has to be set to start the sampling period, and the SWTRIG bit has to be cleared to end the sampling period and start the conversion.

The maximum sampling time is limited (refer to the ADC characteristics section of the datasheet).

This mode is neither compatible with the Continuous conversion mode, nor with the injected channel conversion.

When SMPTRIG bit is set, it is not allowed to set BULB bit.

I/O analog switches voltage booster

The I/O analog switches resistance increases when the V_{DDA} voltage is too low. This requires to have the sampling time adapted accordingly (cf datasheet for electrical characteristics). This resistance can be minimized at low V_{DDA} by enabling an internal voltage booster with BOOSTEN bit in the SYSCFG_CFGR1 register.

SMPPLUS control bit

The SMPPLUS bit can be used to change the sampling time from 2.5 ADC clock cycles to 3.5 ADC clock cycles.

29.4.13 Single conversion mode (CONT = 0)

In Single conversion mode, the ADC performs once all the conversions of the channels. This mode is started with the CONT bit at 0 by either:

- Setting the ADSTART bit in the ADC_CR register (for a regular channel)
- Setting the JADSTART bit in the ADC_CR register (for an injected channel)
- External hardware trigger event (for a regular or injected channel)

Inside the regular sequence, after each conversion is complete:

- The converted data are stored into the 16-bit ADC_DR register
- The EOC (end of regular conversion) flag is set
- An interrupt is generated if the EOCIE bit is set

Inside the injected sequence, after each conversion is complete:

- The converted data are stored into one of the four 16-bit ADC_JDRy registers
- The JEOC (end of injected conversion) flag is set
- An interrupt is generated if the JEOCIE bit is set

After the regular sequence is complete:

- The EOS (end of regular sequence) flag is set
- An interrupt is generated if the EOSIE bit is set

After the injected sequence is complete:

- The JEOS (end of injected sequence) flag is set
- An interrupt is generated if the JEOSIE bit is set

Then the ADC stops until a new external regular or injected trigger occurs or until bit ADSTART or JADSTART is set again.

Note: To convert a single channel, program a sequence with a length of 1.

29.4.14 Continuous conversion mode (CONT = 1)

This mode applies to regular channels only.

In Continuous conversion mode, when a software or hardware regular trigger event occurs, the ADC performs once all the regular conversions of the channels and then automatically restarts and continuously converts each conversions of the sequence. This mode is started with the CONT bit at 1 either by external trigger or by setting the ADSTART bit in the ADC_CR register.

Inside the regular sequence, after each conversion is complete:

- The converted data are stored into the 16-bit ADC_DR register
- The EOC (end of conversion) flag is set
- An interrupt is generated if the EOCIE bit is set

After the sequence of conversions is complete:

- The EOS (end of sequence) flag is set
- An interrupt is generated if the EOSIE bit is set

Then, a new sequence restarts immediately and the ADC continuously repeats the conversion sequence.

Note: To convert a single channel, program a sequence with a length of 1.

It is not possible to have both Discontinuous mode and Continuous mode enabled: it is forbidden to set both DISCEN = 1 and CONT = 1.

Injected channels cannot be converted continuously. The only exception is when an injected channel is configured to be converted automatically after regular channels in Continuous mode (using JAUTO bit), refer to Auto-injection mode section).

29.4.15 Starting conversions (ADSTART, JADSTART)

Software starts ADC regular conversions by setting ADSTART = 1.

When ADSTART is set, the conversion starts:

- Immediately: if EXTEN = 0x0 (software trigger)
- At the next active edge of the selected regular hardware trigger: if EXTEN is not equal to 0x0

Software starts ADC injected conversions by setting JADSTART = 1.

When JADSTART is set, the conversion starts:

- Immediately, if JEXTEN = 0x0 (software trigger)
- At the next active edge of the selected injected hardware trigger: if JEXTEN is not equal to 0x0

Note: In auto-injection mode (JAUTO = 1), use ADSTART bit to start the regular conversions followed by the auto-injected conversions (JADSTART must be kept cleared).

ADSTART and JADSTART also provide information on whether any ADC operation is currently ongoing. It is possible to re-configure the ADC while ADSTART = 0 and JADSTART = 0 are both true, indicating that the ADC is idle.

ADSTART is cleared by hardware:

- In Single mode with software regular trigger (CONT = 0, EXTSEL = 0x0)
  - At any end of regular conversion sequence (EOS assertion) or at any end of subgroup processing if DISCEN = 1
- In all cases (CONT = x, EXTSEL = x)
  - After execution of the ADSTP procedure asserted by the software.

Note: In Continuous mode (CONT = 1), ADSTART is not cleared by hardware with the assertion of EOS because the sequence is automatically relaunched.

When a hardware trigger is selected in Single mode (CONT = 0 and EXTSEL # 0x00), ADSTART is not cleared by hardware with the assertion of EOS to help the software which does not need to reset ADSTART again for the next hardware trigger event. This ensures that no further hardware triggers are missed.

JADSTART is cleared by hardware:

- In Single mode with software injected trigger (JEXTSEL = 0x0)
  - At any end of injected conversion sequence (JEOS assertion) or at any end of subgroup processing if JDISCEN = 1
- in all cases (JEXTSEL = x)
  - After execution of the JADSTP procedure asserted by the software.

Note: When the software trigger is selected, ADSTART bit should not be set if the EOC flag is still high.

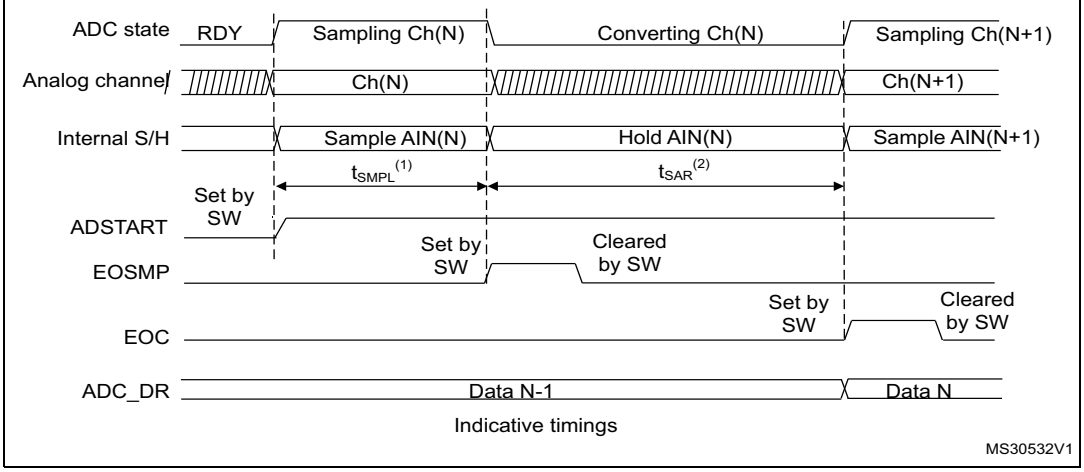
29.4.16 ADC timing

The elapsed time between the start of a conversion and the end of conversion is the sum of the configured sampling time plus the successive approximation time depending on data resolution:

$T_{CONV} = T_{SMPL} + T_{SAR} = [2.5\ _{|min} + 12.5\ _{|12bit}] \times T_{ADC\_CLK}$

$T_{CONV} = T_{SMPL} + T_{SAR} = 83.33\ ns\ _{|min} + 416.67\ ns\ _{|12bit} = 500.0\ ns$ (for $F_{ADC\_CLK} = 30$ MHz)

Figure 237. Analog to digital conversion time



1. T_{SMPL} depends on SMP[2:0].
2. T_{SAR} depends on RES[2:0].

29.4.17 Stopping an ongoing conversion (ADSTP, JADSTP)

The software can decide to stop regular conversions ongoing by setting ADSTP = 1 and injected conversions ongoing by setting JADSTP = 1.

Stopping conversions resets the ongoing ADC operation. Then the ADC can be reconfigured (ex: changing the channel selection or the trigger) ready for a new operation.

Note that it is possible to stop injected conversions while regular conversions are still operating and vice-versa. This allows, for instance, re-configuration of the injected conversion sequence and triggers while regular conversions are still operating (and vice-versa).

When the ADSTP bit is set by software, any ongoing regular conversion is aborted with partial result discarded (ADC_DR register is not updated with the current conversion).

When the JADSTP bit is set by software, any ongoing injected conversion is aborted with partial result discarded (ADC_JDRy register is not updated with the current conversion). The scan sequence is also aborted and reset (meaning that relaunching the ADC would restart a new sequence).

Once this procedure is complete, bits ADSTP/ADSTART (in case of regular conversion), or JADSTP/JADSTART (in case of injected conversion) are cleared by hardware and the software must poll ADSTART (or JADSTART) until the bit is reset before assuming the ADC is completely stopped.

Note: In auto-injection mode (JAUTO = 1), setting ADSTP bit aborts both regular and injected conversions (JADSTP must not be used).

Figure 238. Stopping ongoing regular conversions

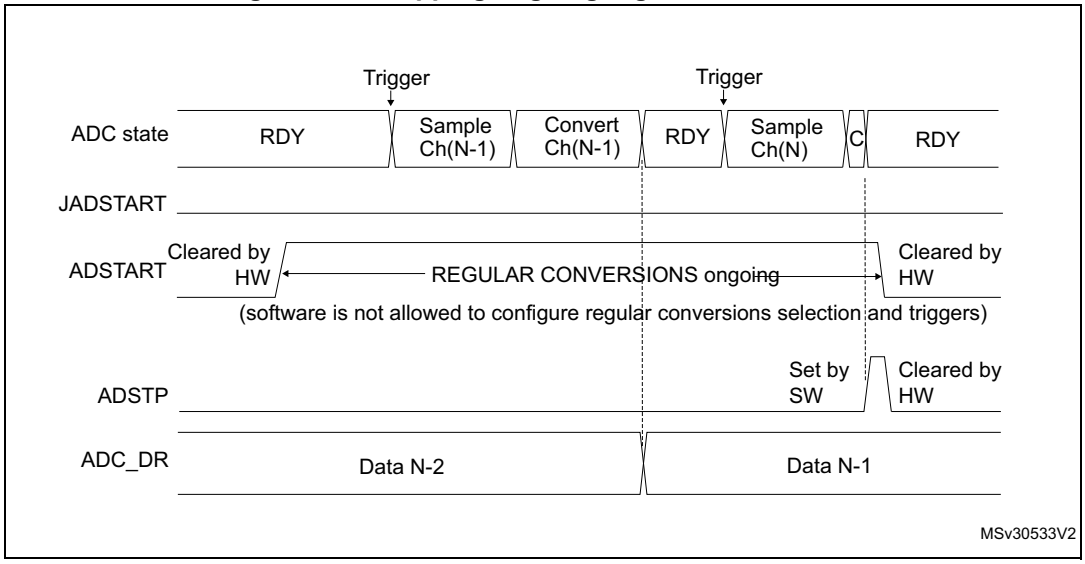
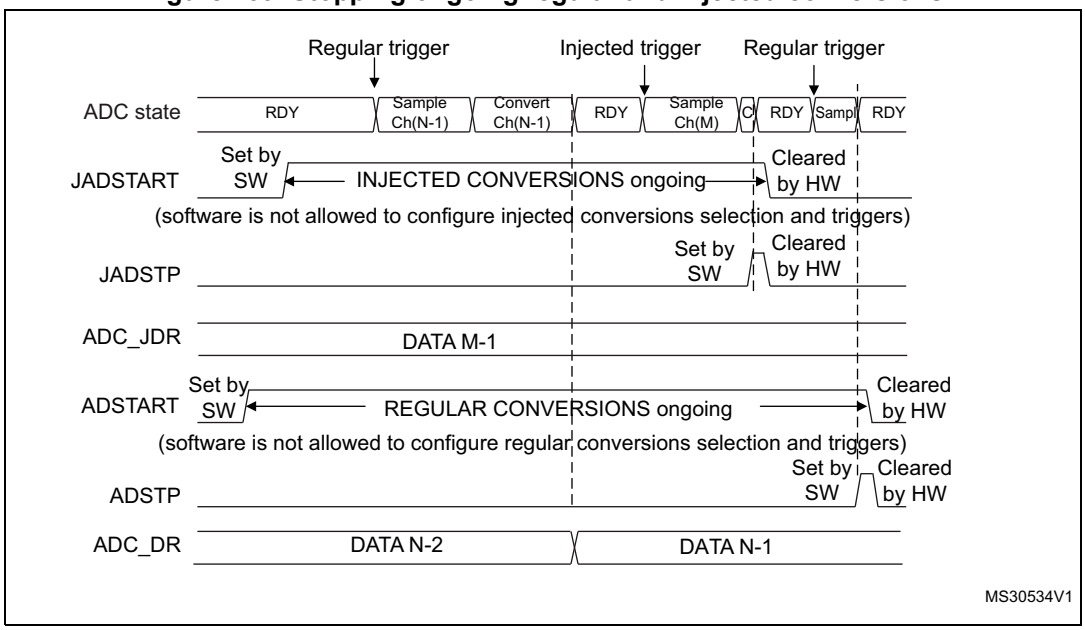


Figure 239. Stopping ongoing regular and injected conversions



29.4.18 Conversion on external trigger and trigger polarity (EXTSEL, EXTEN,JEXTSEL, JEXTEN)

A conversion or a sequence of conversions can be triggered either by software or by an external event (such as timer capture, input pins). If the EXTEN[1:0] control bits (for a regular conversion) or JEXTEN[1:0] bits (for an injected conversion) are different from 0b00, then external events are able to trigger a conversion with the selected polarity.

When the Injected Queue is enabled (bit JQDIS = 0), injected software triggers are not possible.

The regular trigger selection is effective once software has set bit ADSTART = 1 and the injected trigger selection is effective once software has set bit JADSTART = 1.

Any hardware triggers which occur while a conversion is ongoing are ignored.

- If bit ADSTART = 0, any regular hardware triggers which occur are ignored.
- If bit JADSTART = 0, any injected hardware triggers which occur are ignored.

Table 243 provides the correspondence between the EXTEN[1:0] and JEXTEN[1:0] values and the trigger polarity.

Table 243. Configuring the trigger polarity for regular external triggers

EXTEN[1:0]	Source
00	Hardware Trigger detection disabled, software trigger detection enabled
01	Hardware Trigger with detection on the rising edge
10	Hardware Trigger with detection on the falling edge
11	Hardware Trigger with detection on both the rising and falling edges

Note: The polarity of the regular trigger cannot be changed on-the-fly.

Table 244. Configuring the trigger polarity for injected external triggers

JEXTEN[1:0]	Source
00	– If JQDIS = 1 (Queue disabled): Hardware trigger detection disabled, software trigger detection enabled – If JQDIS = 0 (Queue enabled), Hardware and software trigger detection disabled
01	Hardware Trigger with detection on the rising edge
10	Hardware Trigger with detection on the falling edge
11	Hardware Trigger with detection on both the rising and falling edges

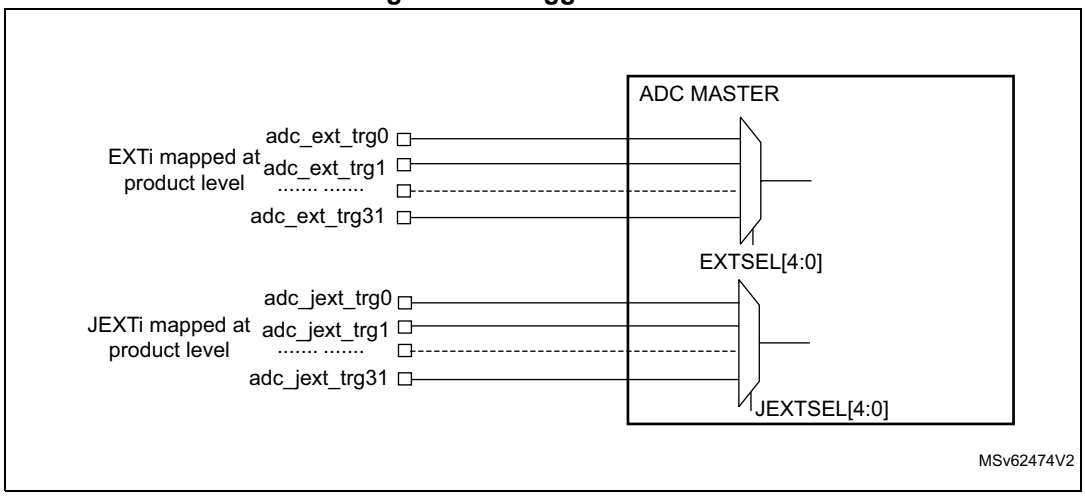
Note: The polarity of the injected trigger can be anticipated and changed on-the-fly when the queue is enabled (JQDIS = 0). Refer to Section 29.4.21: Queue of context for injected conversions.

The EXTSEL and JEXTSEL control bits select which out of 32 possible events can trigger conversion for the regular and injected groups.

A regular group conversion can be interrupted by an injected trigger.

Note: The regular trigger selection cannot be changed on-the-fly. The injected trigger selection can be anticipated and changed on-the-fly. Refer to Section 29.4.21: Queue of context for injected conversions on page 1127.

Figure 240. Trigger selection



Refer to Table ADC interconnection in *Section 29.4.2: ADC pins and internal signals* for the list of all the external triggers that can be used for regular conversion.

29.4.19 Injected channel management

Triggered injection mode

To use triggered injection, the JAUTO bit in the ADC_CFGR register must be cleared.

1. Start the conversion of a group of regular channels either by an external trigger or by setting the ADSTART bit in the ADC_CR register.
2. If an external injected trigger occurs, or if the JADSTART bit in the ADC_CR register is set during the conversion of a regular group of channels, the current conversion is reset and the injected channel sequence switches are launched (all the injected channels are converted once).
3. Then, the regular conversion of the regular group of channels is resumed from the last interrupted regular conversion.
4. If a regular event occurs during an injected conversion, the injected conversion is not interrupted but the regular sequence is executed at the end of the injected sequence. *Figure 241* shows the corresponding timing diagram.

Note: When using triggered injection, one must ensure that the interval between trigger events is longer than the injection sequence. For instance, if the sequence length is 30 ADC clock cycles (that is two conversions with a sampling time of 2.5 clock periods), the minimum interval between triggers must be 31 ADC clock cycles.

Auto-injection mode

If the JAUTO bit in the ADC_CFGR register is set, then the channels in the injected group are automatically converted after the regular group of channels. This can be used to convert a sequence of up to 20 conversions programmed in the ADC_SQRy and ADC_JSQR registers.

In this mode, the ADSTART bit in the ADC_CR register must be set to start regular conversions, followed by injected conversions (JADSTART must be kept cleared). Setting the ADSTP bit aborts both regular and injected conversions (JADSTP bit must not be used).

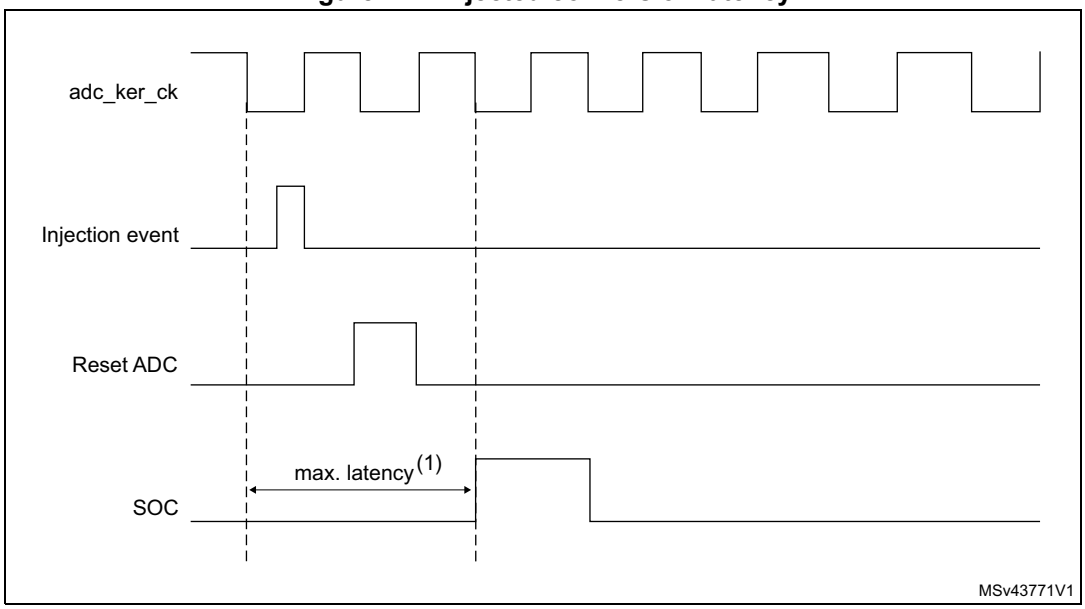
In this mode, external trigger on injected channels must be disabled.

If the CONT bit is also set in addition to the JAUTO bit, regular channels followed by injected channels are continuously converted.

Note: It is not possible to use both the auto-injected and Discontinuous modes simultaneously.

When the DMA is used for exporting regular sequencer's data in JAUTO mode, it is necessary to program it in circular mode (CIRC bit set in DMA_CCRx register). If the CIRC bit is reset (Single-shot mode), the JAUTO sequence is stopped upon DMA Transfer Complete event.

Figure 241. Injected conversion latency



1. The maximum latency value can be found in the electrical characteristics of the device datasheet.

29.4.20 Discontinuous mode (DISCEN, DISCNUM, JDISCEN)

Regular group mode

This mode is enabled by setting the DISCEN bit in the ADC_CFGR register.

It is used to convert a short sequence (subgroup) of n conversions (n ≤ 8) that is part of the sequence of conversions selected in the ADC_SQRy registers. The value of n is specified by writing to the DISCNUM[2:0] bits in the ADC_CFGR register.

When an external trigger occurs, it starts the next n conversions selected in the ADC_SQRy registers until all the conversions in the sequence are done. The total sequence length is defined by the L[3:0] bits in the ADC_SQR1 register.

Example:

- DISCEN = 1, n = 3, channels to be converted = 1, 2, 3, 6, 7, 8, 9, 10, 11
  - 1st trigger: channels converted are 1, 2, 3 (an EOC event is generated at each conversion).

  - 2nd trigger: channels converted are 6, 7, 8 (an EOC event is generated at each conversion).
  - 3rd trigger: channels converted are 9, 10, 11 (an EOC event is generated at each conversion) and an EOS event is generated after the conversion of channel 11.
  - 4th trigger: channels converted are 1, 2, 3 (an EOC event is generated at each conversion).
  - ...
- DISCEN = 0, channels to be converted = 1, 2, 3, 6, 7, 8, 9, 10,11
  - 1st trigger: the complete sequence is converted: channel 1, then 2, 3, 6, 7, 8, 9, 10 and 11. Each conversion generates an EOC event and the last one also generates an EOS event.
  - All the next trigger events relaunch the complete sequence.

Note: The channel numbers referred to in the above example might not be available on all microcontrollers.

When a regular group is converted in Discontinuous mode, no rollover occurs (the last subgroup of the sequence can have less than n conversions).

When all subgroups are converted, the next trigger starts the conversion of the first subgroup. In the example above, the 4th trigger reconverts the channels 1, 2 and 3 in the 1st subgroup.

It is not possible to have both Discontinuous mode and Continuous mode enabled. In this case (if DISCEN = 1, CONT = 1), the ADC behaves as if Continuous mode was disabled.

Injected group mode

This mode is enabled by setting the JDISCEN bit in the ADC_CFGR register. It converts the sequence selected in the ADC_JSQR register, channel by channel, after an external injected trigger event. This is equivalent to Discontinuous mode for regular channels where ‘n’ is fixed to 1.

When an external trigger occurs, it starts the next channel conversions selected in the ADC_JSQR registers until all the conversions in the sequence are done. The total sequence length is defined by the JL[1:0] bits in the ADC_JSQR register.

Example:

- JDISCEN = 1, channels to be converted = 1, 2, 3
  - 1st trigger: channel 1 converted (a JEOC event is generated)
  - 2nd trigger: channel 2 converted (a JEOC event is generated)
  - 3rd trigger: channel 3 converted and a JEOC event + a JEOS event are generated
  - ...

Note: The channel numbers referred to in the above example might not be available on all microcontrollers.

When all injected channels have been converted, the next trigger starts the conversion of the first injected channel. In the example above, the 4th trigger reconverts the 1st injected channel 1.

It is not possible to use both auto-injected mode and Discontinuous mode simultaneously: the bits DISCEN and JDISCEN must be kept cleared by software when JAUTO is set.

29.4.21 Queue of context for injected conversions

A queue of context is implemented to anticipate up to 2 contexts for the next injected sequence of conversions. JQDIS bit of ADC_CFGR register must be reset to enable this feature. Only hardware-triggered conversions are possible when the context queue is enabled.

This context consists of:

- Configuration of the injected triggers (bits JEXTEN[1:0] and JEXTSEL bits in ADC_JSQR register)
- Definition of the injected sequence (bits JSQx[4:0] and JL[1:0] in ADC_JSQR register)

All the parameters of the context are defined into a single register ADC_JSQR and this register implements a queue of 2 buffers, allowing the bufferization of up to 2 sets of parameters:

- The JSQR register can be written at any moment even when injected conversions are ongoing.
- Each data written into the JSQR register is stored into the Queue of context.
- At the beginning, the Queue is empty and the first write access into the JSQR register immediately changes the context and the ADC is ready to receive injected triggers.
- Once an injected sequence is complete, the Queue is consumed and the context changes according to the next JSQR parameters stored in the Queue. This new context is applied for the next injected sequence of conversions.
- A Queue overflow occurs when writing into register JSQR while the Queue is full. This overflow is signaled by the assertion of the flag JQOVF. When an overflow occurs, the write access of JSQR register which has created the overflow is ignored and the queue of context is unchanged. An interrupt can be generated if bit JQOVFIE is set.
- Two possible behaviors are possible when the Queue becomes empty, depending on the value of the control bit JQM of register ADC_CFGR:
  - If JQM = 0, the Queue is empty just after enabling the ADC, but then it can never be empty during run operations: the Queue always maintains the last active context and any further valid start of injected sequence is served according to the last active context.
  - If JQM = 1, the Queue can be empty after the end of an injected sequence or if the Queue is flushed. When this occurs, there is no more context in the queue and hardware triggers are disabled. Therefore, any further hardware injected triggers are ignored until the software re-writes a new injected context into JSQR register.
- Reading JSQR register returns the current JSQR context which is active at that moment. When the JSQR context is empty, JSQR is read as 0x0000.
- The Queue is flushed when stopping injected conversions by setting JADSTP = 1 or when disabling the ADC by setting ADDIS = 1:
  - If JQM = 0, the Queue is maintained with the last active context.
  - If JQM = 1, the Queue becomes empty and triggers are ignored.

Note: When configured in Discontinuous mode (bit JDISCEN = 1), only the last trigger of the injected sequence changes the context and consumes the Queue.The 1st trigger only

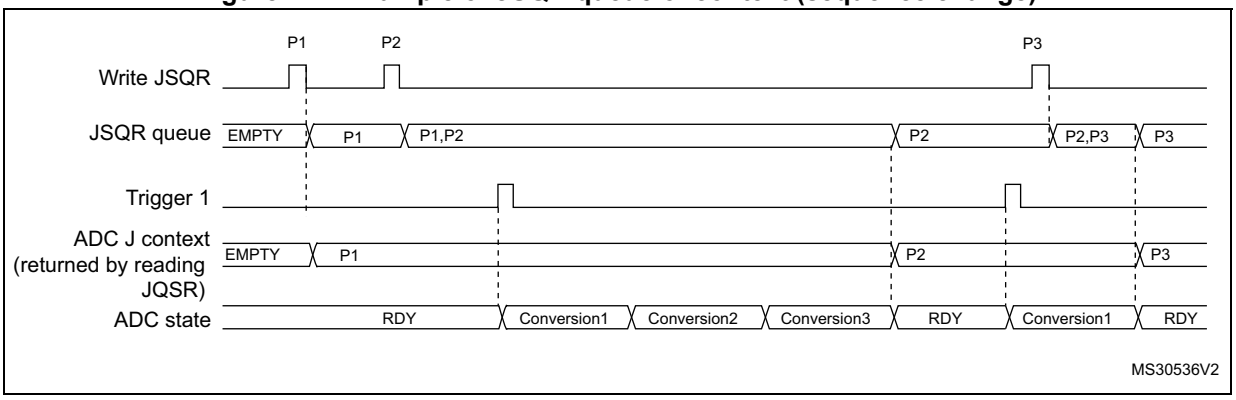
consumes the queue but others are still valid triggers as shown by the Discontinuous mode example below (length = 3 for both contexts):

- *1st trigger, Discontinuous. Sequence 1: context 1 consumed, 1st conversion carried out*
- *2nd trigger, disc. Sequence 1: 2nd conversion.*
- *3rd trigger, Discontinuous. Sequence 1: 3rd conversion.*
- *4th trigger, Discontinuous. Sequence 2: context 2 consumed, 1st conversion carried out.*
- *5th trigger, Discontinuous. Sequence 2: 2nd conversion.*
- *6th trigger, Discontinuous. Sequence 2: 3rd conversion.*

Behavior when changing the trigger or sequence context

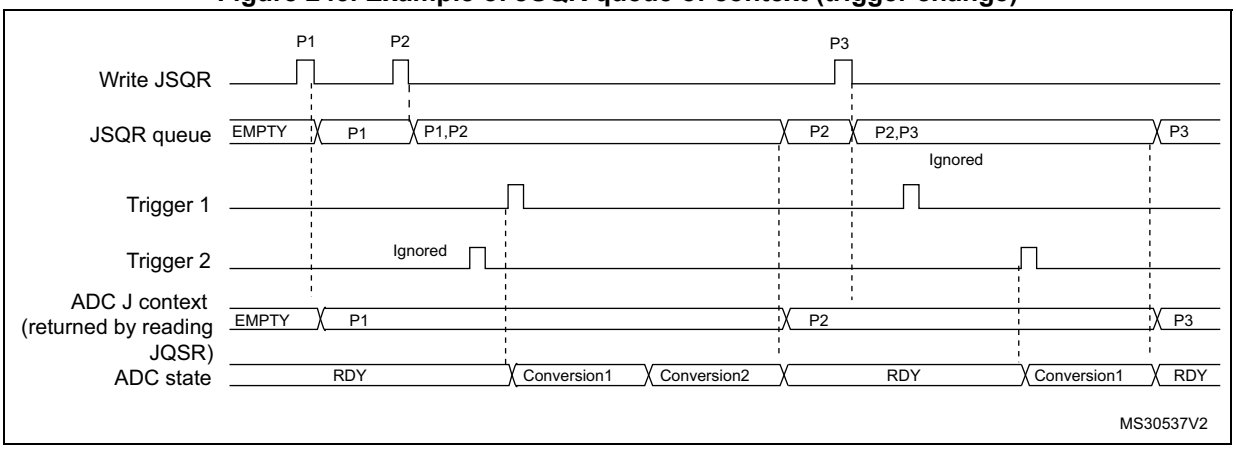
Figure 242 and *Figure 243* show the behavior of the context Queue when changing the sequence or the triggers.

Figure 242. Example of JSQR queue of context (sequence change)



1. Parameters:
   P1: sequence of 3 conversions, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 4 conversions, hardware trigger 1

Figure 243. Example of JSQR queue of context (trigger change)

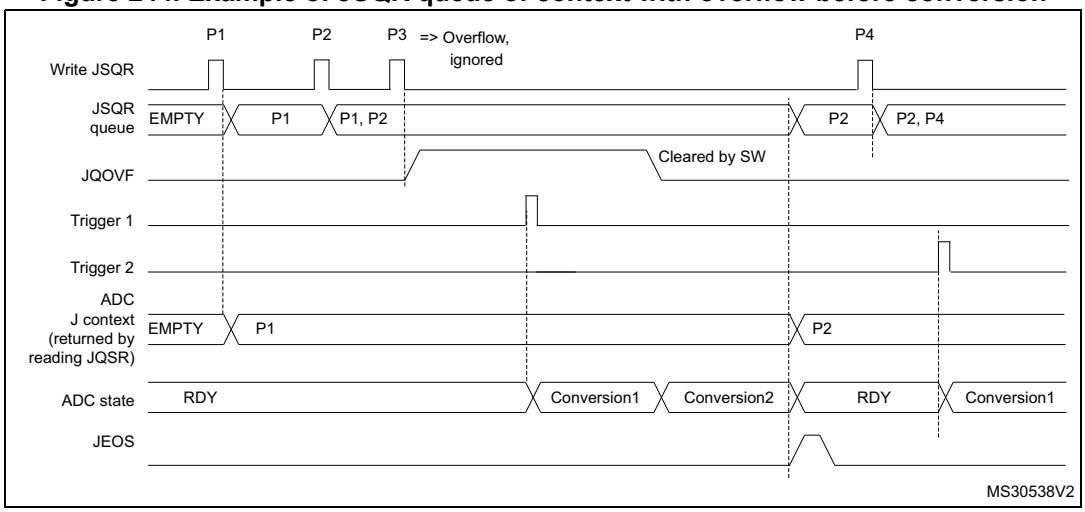


1. Parameters:
   P1: sequence of 2 conversions, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 2
   P3: sequence of 4 conversions, hardware trigger 1

Queue of context: Behavior when a queue overflow occurs

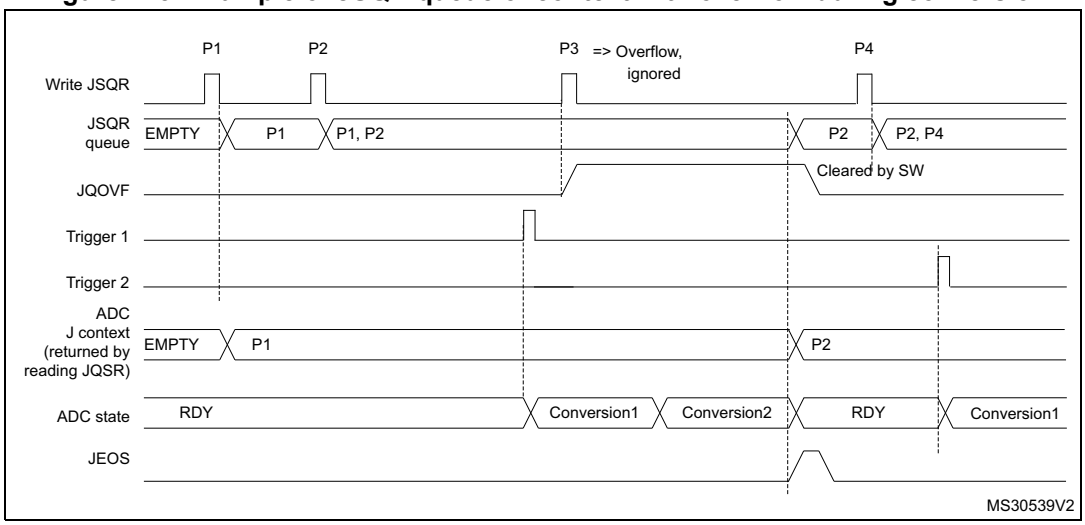
The *Figure 244* and *Figure 245* show the behavior of the context Queue if an overflow occurs before or during a conversion.

Figure 244. Example of JSQR queue of context with overflow before conversion



1. Parameters:
   P1: sequence of 2 conversions, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 2
   P3: sequence of 3 conversions, hardware trigger 1
   P4: sequence of 4 conversions, hardware trigger 1

Figure 245. Example of JSQR queue of context with overflow during conversion



1. Parameters:
   P1: sequence of 2 conversions, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 2
   P3: sequence of 3 conversions, hardware trigger 1
   P4: sequence of 4 conversions, hardware trigger 1

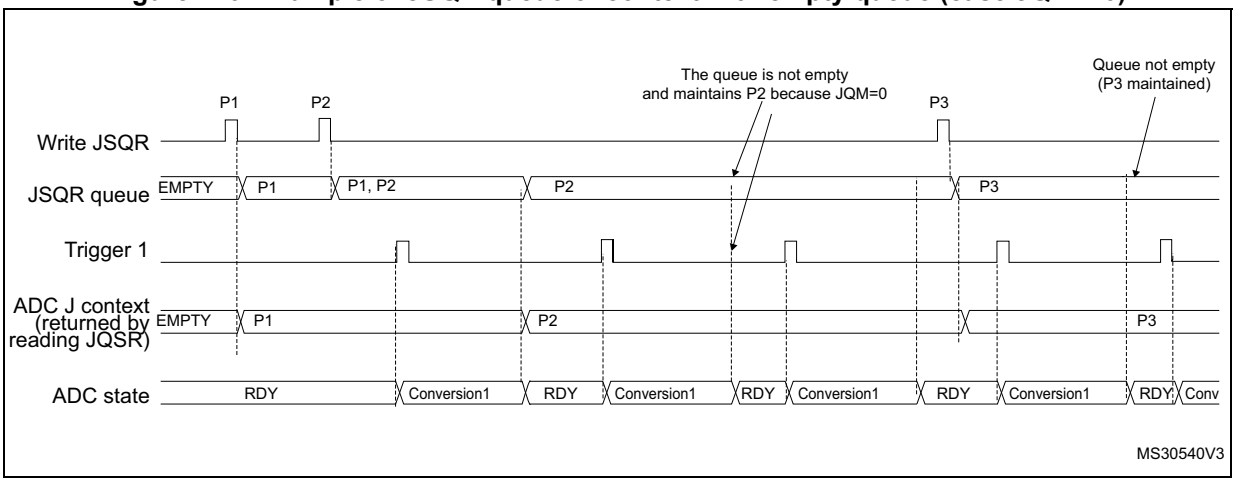
It is recommended to manage the queue overflows as described below:

- After each P context write into JSQR register, flag JQOVF shows if the write has been ignored or not (an interrupt can be generated).
- Avoid Queue overflows by writing the third context (P3) only once the flag JEOS of the previous context P2 has been set. This ensures that the previous context has been consumed and that the queue is not full.

Queue of context: Behavior when the queue becomes empty

Figure 246 and *Figure 247* show the behavior of the context Queue when the Queue becomes empty in both cases JQM = 0 or 1.

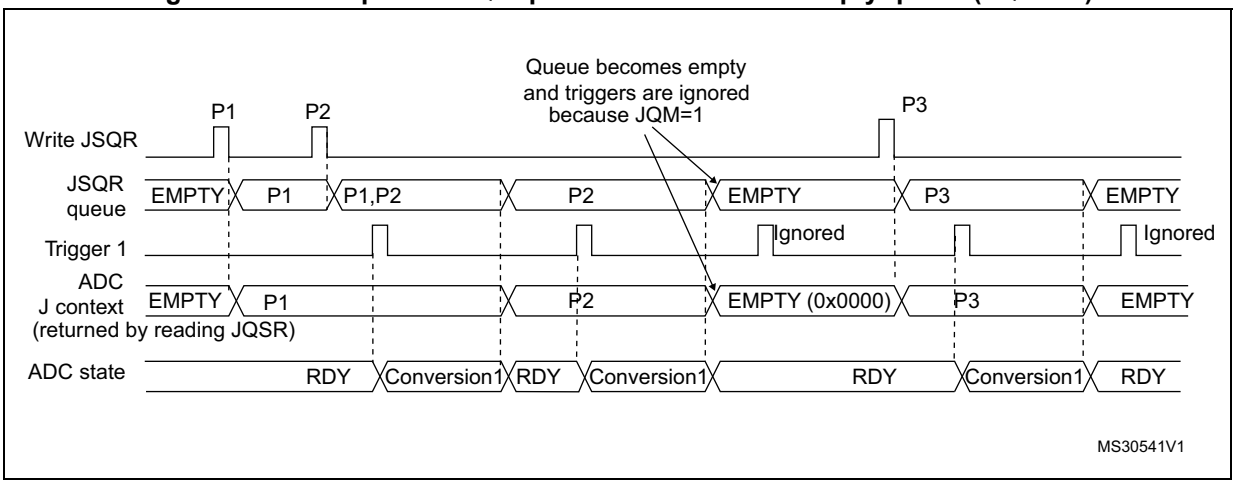
Figure 246. Example of JSQR queue of context with empty queue (case JQM = 0)



1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Note: When writing P3, the context changes immediately. However, because of internal resynchronization, there is a latency and if a trigger occurs just after or before writing P3, it can happen that the conversion is launched considering the context P2. To avoid this situation, the user must ensure that there is no ADC trigger happening when writing a new context that applies immediately.

Figure 247. Example of JSQR queue of context with empty queue (JQM = 1)

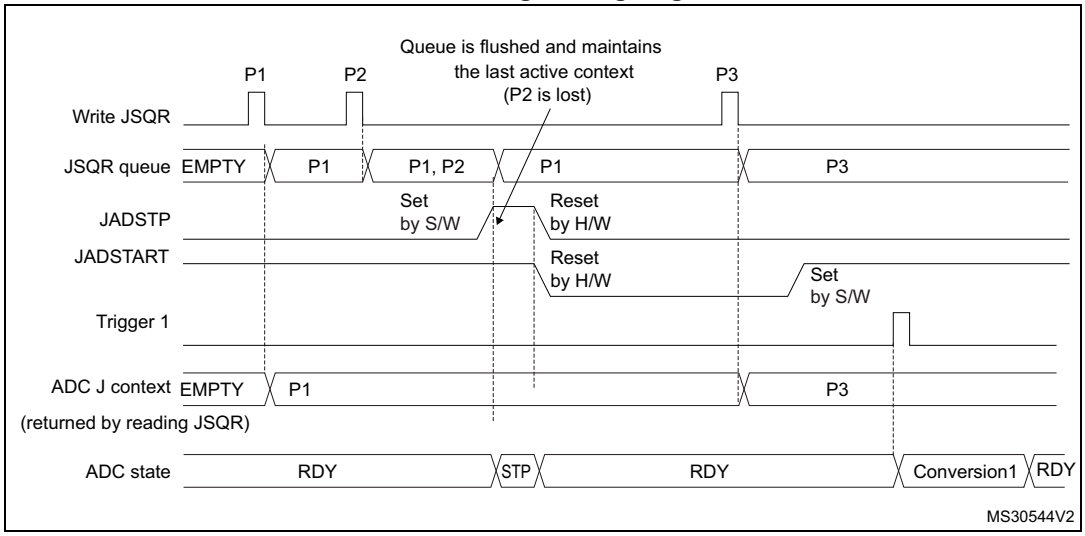


1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Flushing the queue of context

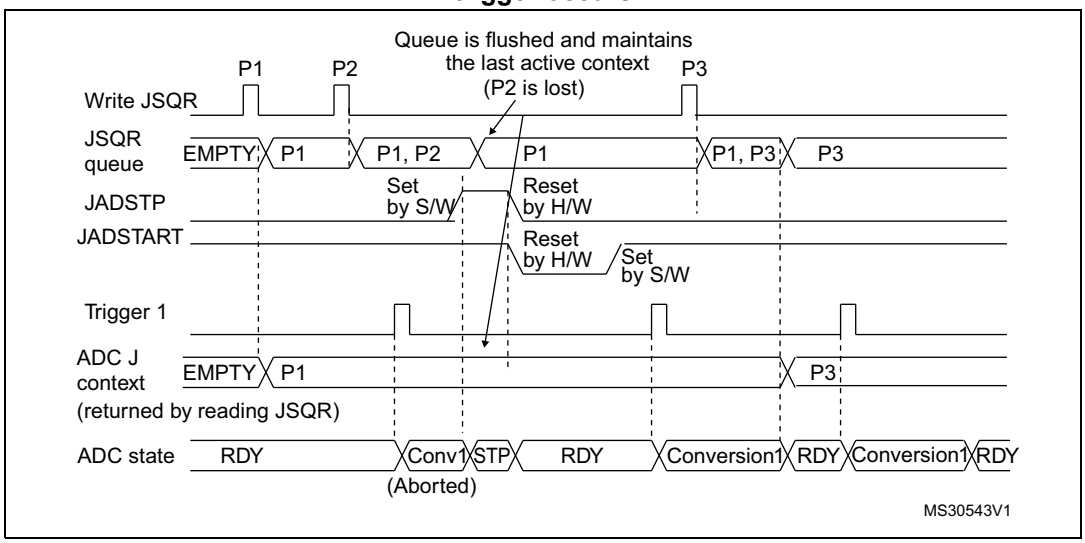
The figures below show the behavior of the context Queue in various situations when the queue is flushed.

Figure 248. Flushing JSQR queue of context by setting JADSTP = 1 (JQM = 0) - JADSTP occurs during an ongoing conversion.



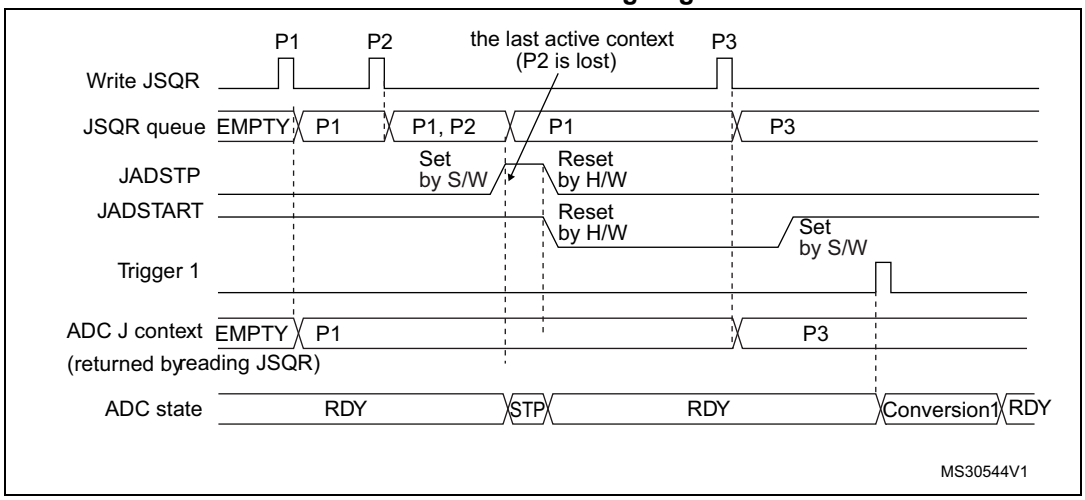
1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 249. Flushing JSQR queue of context by setting JADSTP = 1 (JQM = 0) - JADSTP occurs during an ongoing conversion and a new trigger occurs



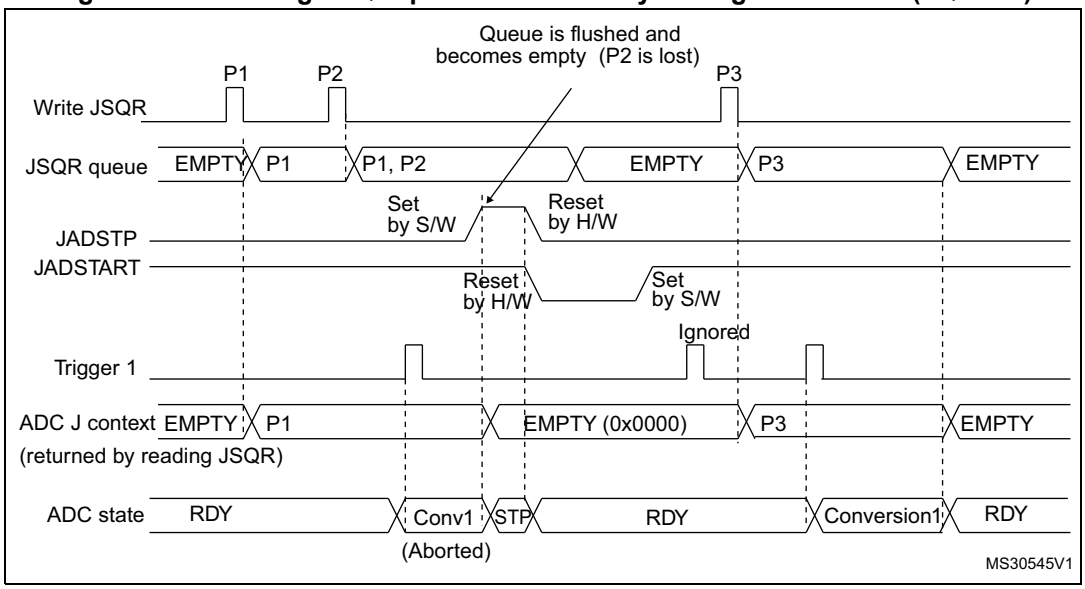
1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 250. Flushing JSQR queue of context by setting JADSTP = 1 (JQM = 0) - JADSTP occurs outside an ongoing conversion



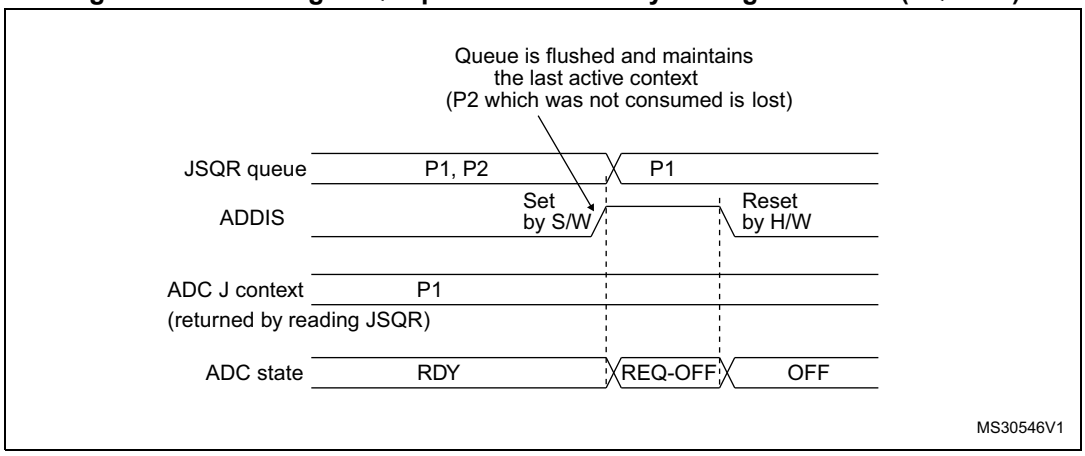
1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 251. Flushing JSQR queue of context by setting JADSTP = 1 (JQM = 1)



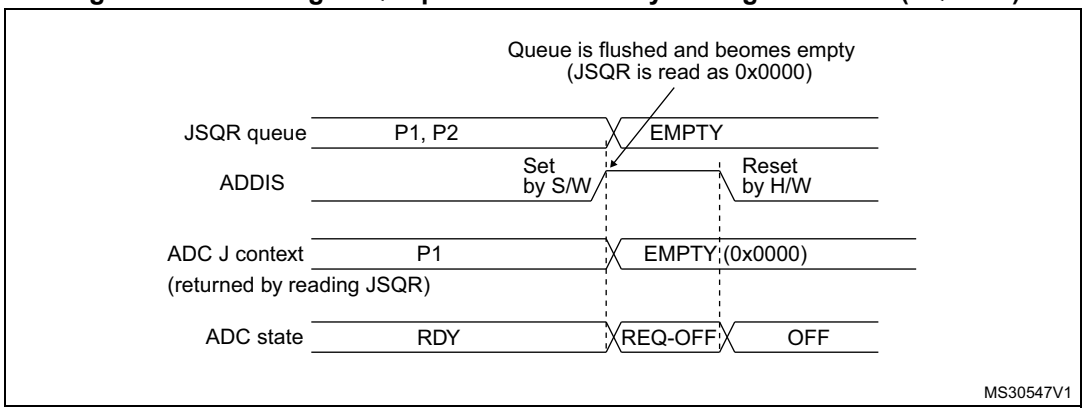
1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 252. Flushing JSQR queue of context by setting ADDIS = 1 (JQM = 0)



1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Figure 253. Flushing JSQR queue of context by setting ADDIS = 1 (JQM = 1)



1. Parameters:
   P1: sequence of 1 conversion, hardware trigger 1
   P2: sequence of 1 conversion, hardware trigger 1
   P3: sequence of 1 conversion, hardware trigger 1

Queue of context: Starting the ADC with an empty queue

The following procedure must be followed to start ADC operation with an empty queue, in case the first context is not known at the time the ADC is initialized. This procedure is only applicable when JQM bit is reset:

5. Write a dummy JSQR with JEXTEN not equal to 0 (otherwise triggering a software conversion)
6. Set JADSTART
7. Set JADSTP
8. Wait until JADSTART is reset
9. Set JADSTART.

Disabling the queue

It is possible to disable the queue by setting bit JQDIS = 1 into the ADC_CFGR register.

29.4.22 Programmable resolution (RES) - fast conversion mode

It is possible to perform faster conversion by reducing the ADC resolution.

The resolution can be configured to be either 12, 10, 8, or 6 bits by programming the control bits RES[1:0]. *Figure 258*, *Figure 259*, *Figure 260* and *Figure 261* show the conversion result format with respect to the resolution as well as to the data alignment.

Lower resolution allows faster conversion time for applications where high-data precision is not required. It reduces the conversion time spent by the successive approximation steps according to *Table 245*.

Table 245. T_{SAR} timings depending on resolution

RES (bits)	T_{SAR} (ADC clock cycles)	T_{SAR} (ns) at F_{ADC} = 30 MHz	T_{CONV} (ADC clock cycles) (with Sampling Time = 2.5 ADC clock cycles)	T_{CONV} (ns) at F_{ADC} = 30 MHz
12	12.5 ADC clock cycles	416.67 ns	15 ADC clock cycles	500.0 ns
10	10.5 ADC clock cycles	350.0 ns	13 ADC clock cycles	433.33 ns
8	8.5 ADC clock cycles	203.33 ns	11 ADC clock cycles	366.67 ns
6	6.5 ADC clock cycles	216.67 ns	9 ADC clock cycles	300.0 ns

29.4.23 End of conversion, end of sampling phase (EOC, JEOC, EOSMP)

The ADC notifies the application for each end of regular conversion (EOC) event and each injected conversion (JEOC) event.

The ADC sets the EOC flag as soon as a new regular conversion data is available in the ADC_DR register. An interrupt can be generated if bit EOCIE is set. EOC flag is cleared by the software either by writing 1 to it or by reading ADC_DR.

The ADC sets the JEOC flag as soon as a new injected conversion data is available in one of the ADC_JDRy register. An interrupt can be generated if bit JEOCIE is set. JEOC flag is cleared by the software either by writing 1 to it or by reading the corresponding ADC_JDRy register.

The ADC also notifies the end of Sampling phase by setting the status bit EOSMP (for regular conversions only). EOSMP flag is cleared by software by writing 1 to it. An interrupt can be generated if bit EOSMPIE is set.

29.4.24 End of conversion sequence (EOS, JEOS)

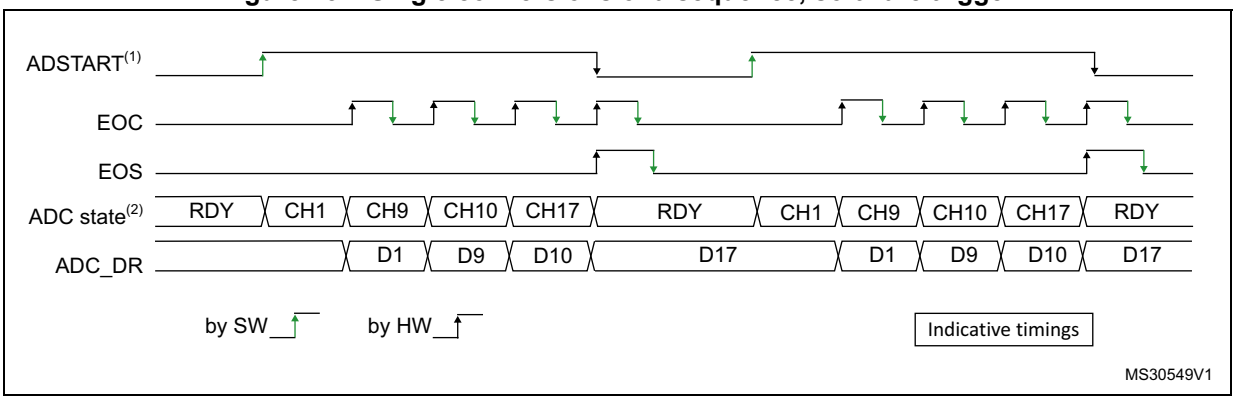
The ADC notifies the application for each end of regular sequence (EOS) and for each end of injected sequence (JEOS) event.

The ADC sets the EOS flag as soon as the last data of the regular conversion sequence is available in the ADC_DR register. An interrupt can be generated if bit EOSIE is set. EOS flag is cleared by the software either by writing 1 to it.

The ADC sets the JEOS flag as soon as the last data of the injected conversion sequence is complete. An interrupt can be generated if bit JEOSIE is set. JEOS flag is cleared by the software either by writing 1 to it.

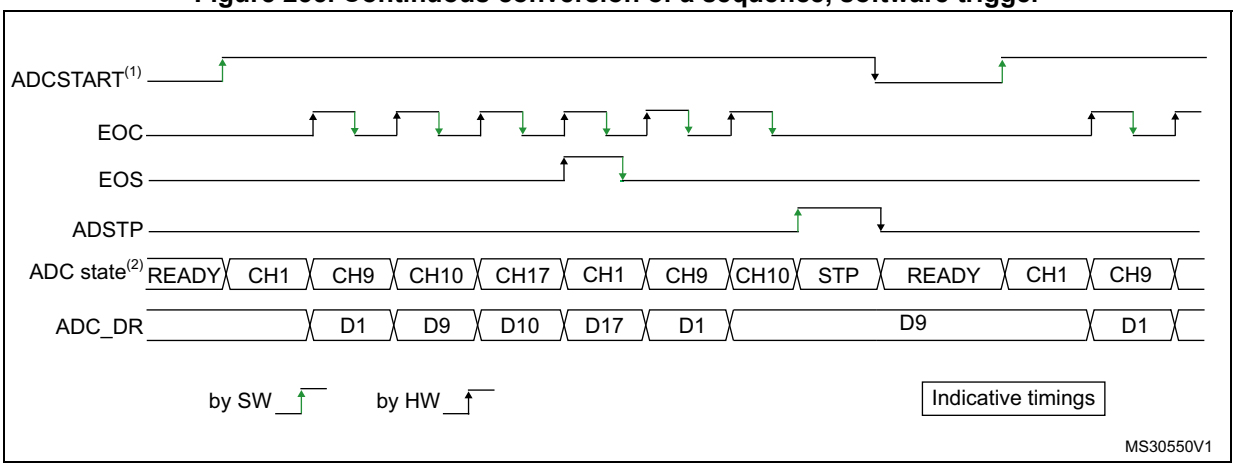
29.4.25 Timing diagrams example (Single/Continuous modes, hardware/software triggers)

Figure 254. Single conversions of a sequence, software trigger



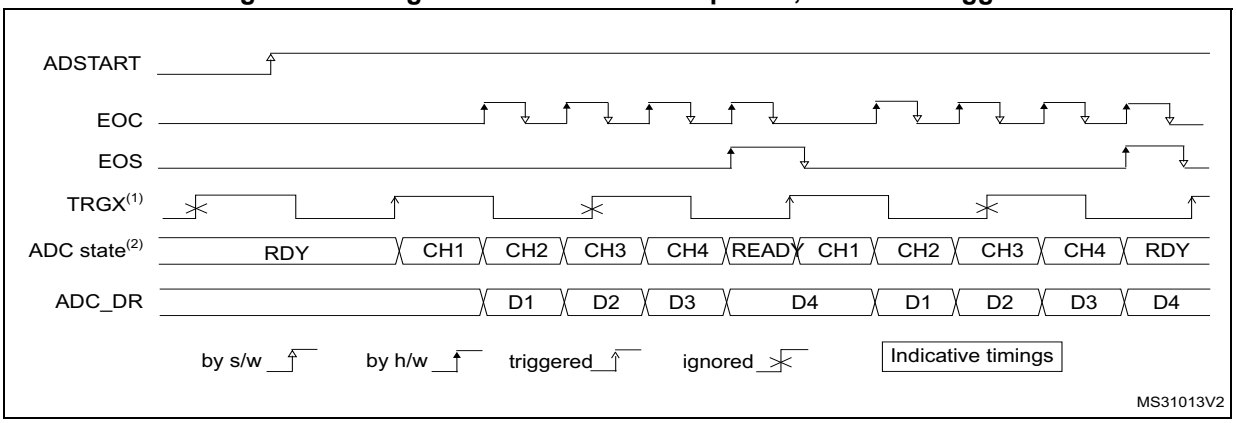
1. EXTEN = 0x0, CONT = 0
2. Channels selected = 1,9, 10, 17; AUTDLY = 0.

Figure 255. Continuous conversion of a sequence, software trigger



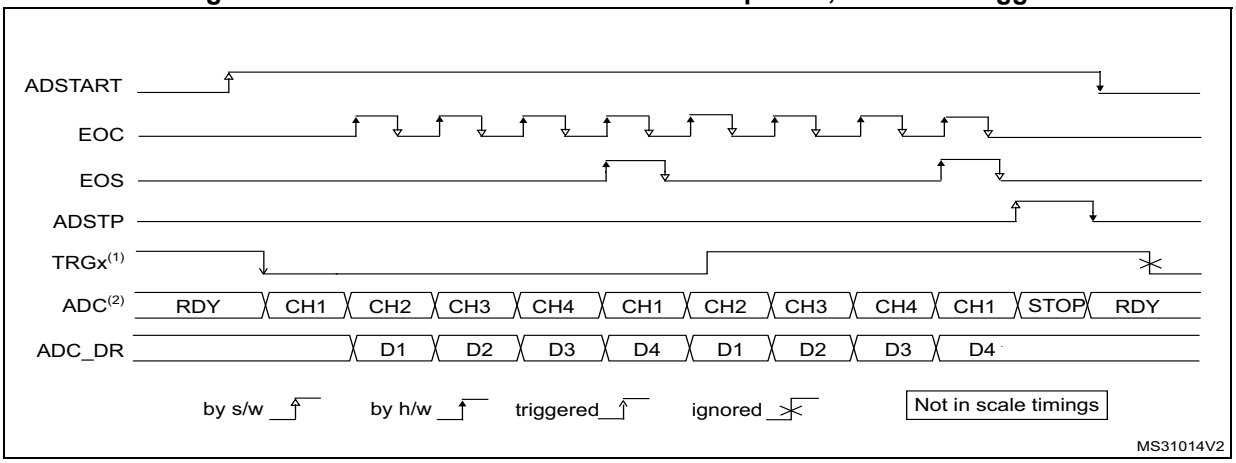
1. EXTEN = 0x0, CONT = 1
2. Channels selected = 1,9, 10, 17; AUTDLY = 0.

Figure 256. Single conversions of a sequence, hardware trigger



1. TRGx (over-frequency) is selected as trigger source, EXTEN = 01, CONT = 0
2. Channels selected = 1, 2, 3, 4; AUTDLY = 0.

Figure 257. Continuous conversions of a sequence, hardware trigger



1. TRGx is selected as trigger source, EXTEN = 10, CONT = 1
2. Channels selected = 1, 2, 3, 4; AUTDLY = 0.

29.4.26 Data management

Data register, data alignment and offset (ADC_DR, OFFSET, OFFSET_CH, ALIGN)

Data and alignment

At the end of each regular conversion channel (when EOC event occurs), the result of the converted data is stored into the ADC_DR data register which is 16 bits wide.

At the end of each injected conversion channel (when JEOC event occurs), the result of the converted data is stored into the corresponding ADC_JDRy data register which is 16 bits wide.

The ALIGN bit in the ADC_CFGR register selects the alignment of the data stored after conversion. Data can be right- or left-aligned as shown in *Figure 258*, *Figure 259*, *Figure 260* and *Figure 261*.

Special case: when left-aligned, the data are aligned on a half-word basis except when the resolution is set to 6-bit. In that case, the data are aligned on a byte basis as shown in *Figure 260* and *Figure 261*.

Note: Left-alignment is not supported in oversampling mode. When ROVSE and/or JOVSE bit is set, the ALIGN bit value is ignored and the ADC only provides right-aligned data.

Offset

An offset y (y = 1,2,3,4) can be applied to a channel by setting the bit OFFSET_EN = 1 into ADC_OFRy register. The channel to which the offset will be applied is programmed into the bits OFFSET_CH[4:0] of ADC_OFRy register. In this case, the converted value is decreased by the user-defined offset written in the bits OFFSET[11:0]. The result may be a negative value so the read data is signed and the SEXT bit represents the extended sign value.

Note: Offset correction is not supported in oversampling mode. When ROVSE and/or JOVSE bit is set, the value of the OFFSET_EN bit in ADC_OFRy register is ignored (considered as reset).

Table 248 describes how the comparison is performed for all the possible resolutions for analog watchdog 1.

Table 246. Offset computation versus data resolution

Resolution (bits RES[1:0])	Subtraction between raw converted data and offset		Result	Comments
	Raw converted Data, left aligned	Offset		
00: 12-bit	DATA[11:0]	OFFSET[11:0]	Signed 12-bit data	-
01: 10-bit	DATA[11:2],00	OFFSET[11:0]	Signed 10-bit data	The user must configure OFFSET[1:0] to “00”

Table 246. Offset computation versus data resolution (continued)

Resolution (bits RES[1:0])	Subtraction between raw converted data and offset		Result	Comments
	Raw converted Data, left aligned	Offset		
10: 8-bit	DATA[11:4],0000	OFFSET[11:0]	Signed 8-bit data	The user must configure OFFSET[3:0] to “0000”
11: 6-bit	DATA[11:6],000000	OFFSET[11:0]	Signed 6-bit data	The user must configure OFFSET[5:0] to “000000”

When reading data from ADC_DR (regular channel) or from ADC_JDRy (injected channel, y = 1,2,3,4) corresponding to the channel “i”:

- If one of the offsets is enabled (bit OFFSET_EN = 1) for the corresponding channel, the read data is signed.
- If none of the four offsets is enabled for this channel, the read data is not signed.

Figure 258, *Figure 259*, *Figure 260* and *Figure 261* show alignments for signed and unsigned data.

Figure 258. Right alignment (offset disabled, unsigned value)

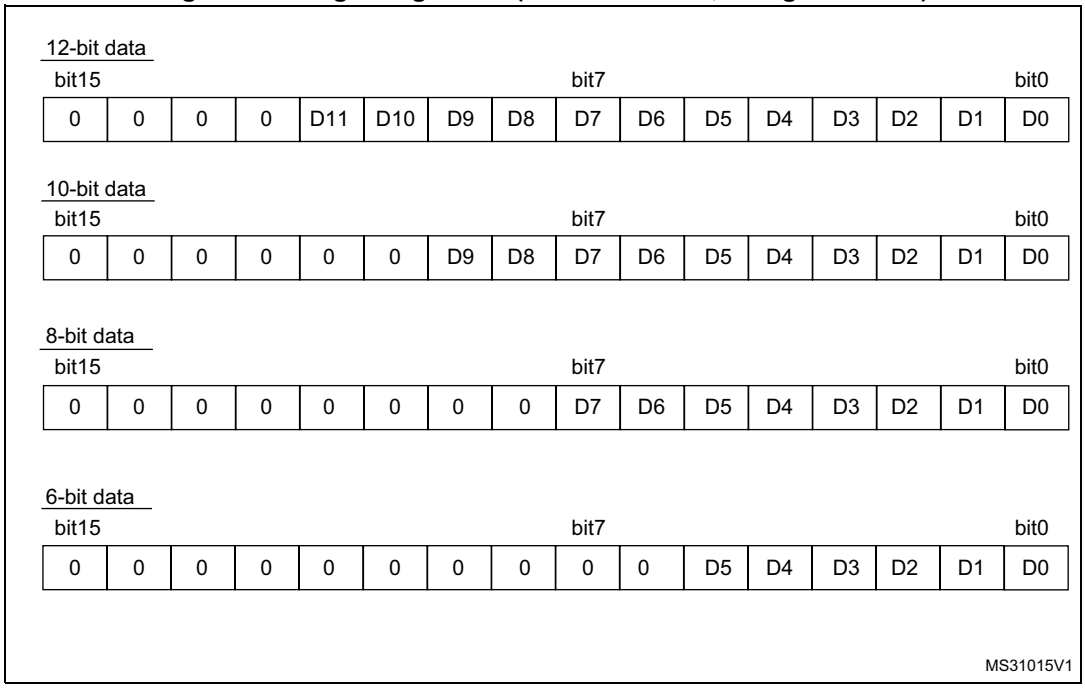


Figure 259. Right alignment (offset enabled, signed value)

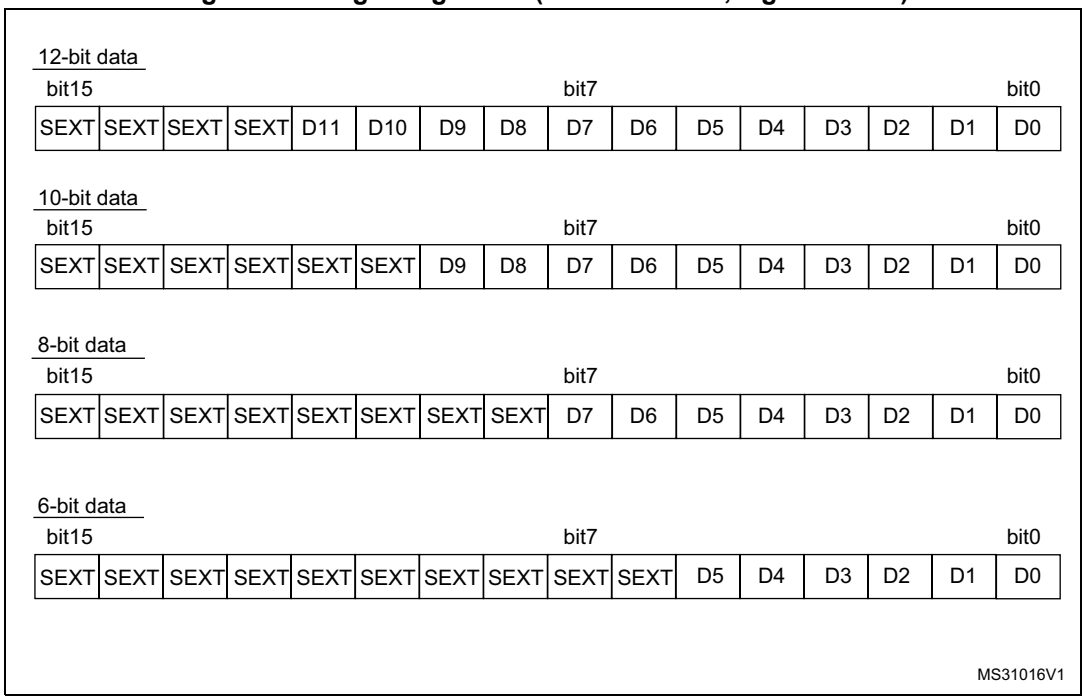


Figure 260. Left alignment (offset disabled, unsigned value)

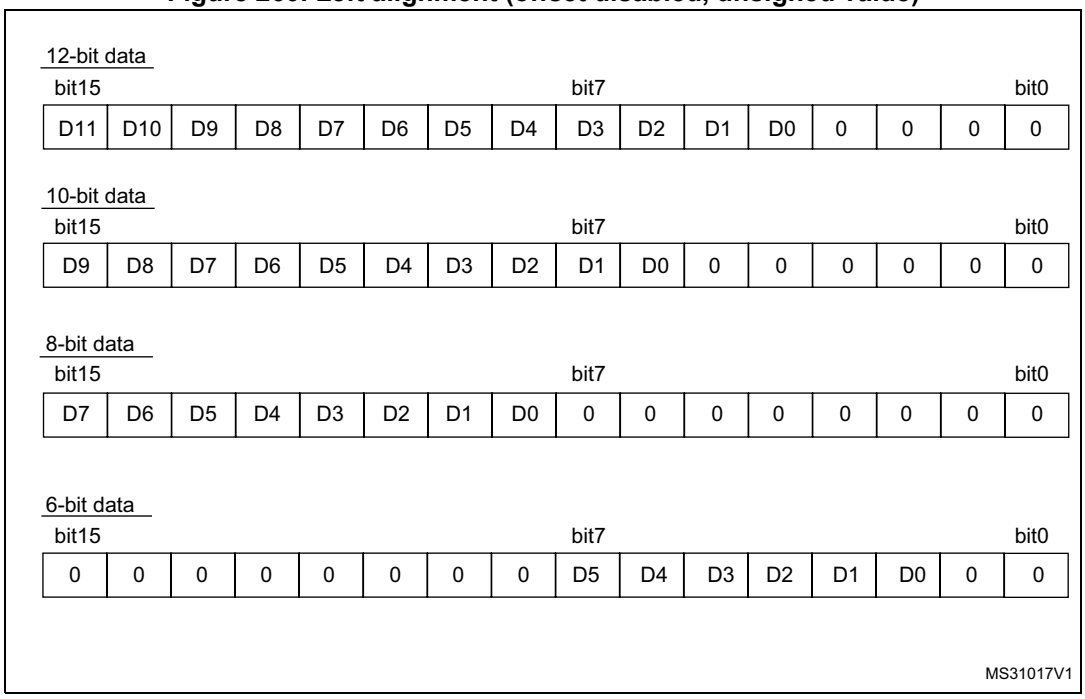
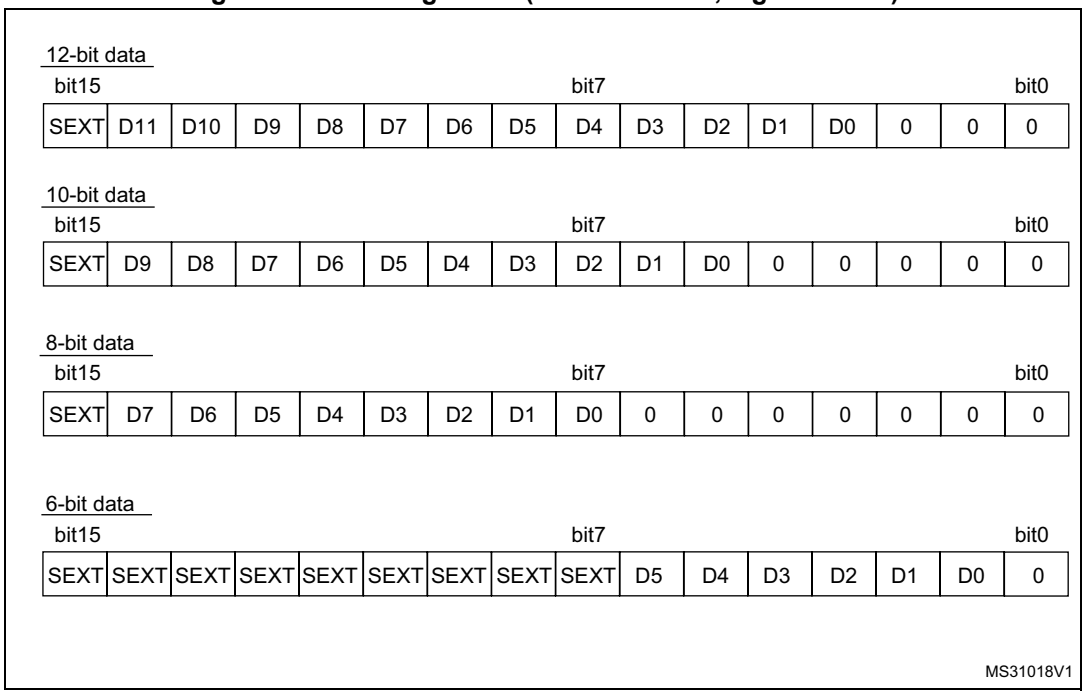


Figure 261. Left alignment (offset enabled, signed value)



Offset compensation

When SATEN bit is set in ADC_OFRy register during offset operation, data are unsigned. All the offset data saturate at 0x000 (in 12-bit mode). When OFFSETPOS bit is set, the offset direction is positive and the data saturate at 0xFFF (in 12-bit mode). In 8-bit mode, data saturate at 0x00 and 0xFF, respectively.

The analog watchdog comparison is performed before the offset compensation.

ADC overrun (OVR, OVRMOD)

The overrun flag (OVR) notifies when the regular converted data has not been read (by the CPU or the DMA) before ADC_DR FIFO (three stages) is overflowed.

The OVR flag is set when a new conversion completes while ADC_CR register FIFO was full. An interrupt is generated if OVRIE bit is set to 1.

When an overrun condition occurs, the ADC is still operating and can continue converting unless the software decides to stop and reset the sequence by setting ADSTP to 1. Since ADC_DR FIFO features three stages, up to three data are stored in the FIFO.

OVR flag is cleared by software by writing 1 to it.

It is possible to configure if data is preserved or overwritten when an overrun event occurs by programming the control bit OVRMOD:

- OVRMOD = 0: The overrun event preserves the data register from being overwritten: the old data is maintained up to ADC_DR FIFO depth (three stages) and the new conversion is discarded and lost. In this mode, ADC_DR FIFO is disabled. If the FIFO is full, any further conversion is performed but the resulting data is also discarded. EOC

is cleared by reading ADC_DR register. However, the FIFO can still contain previously converted data.

- OVRMOD = 1: The data register is overwritten with the last conversion result and the previous unread data is lost. In this mode, ADC_DR FIFO is disabled. If OVR remains at 1, any further conversions is performed normally and the ADC_DR register always contains the latest converted data.

Figure 262. Example of overrun (OVRMOD = 0)

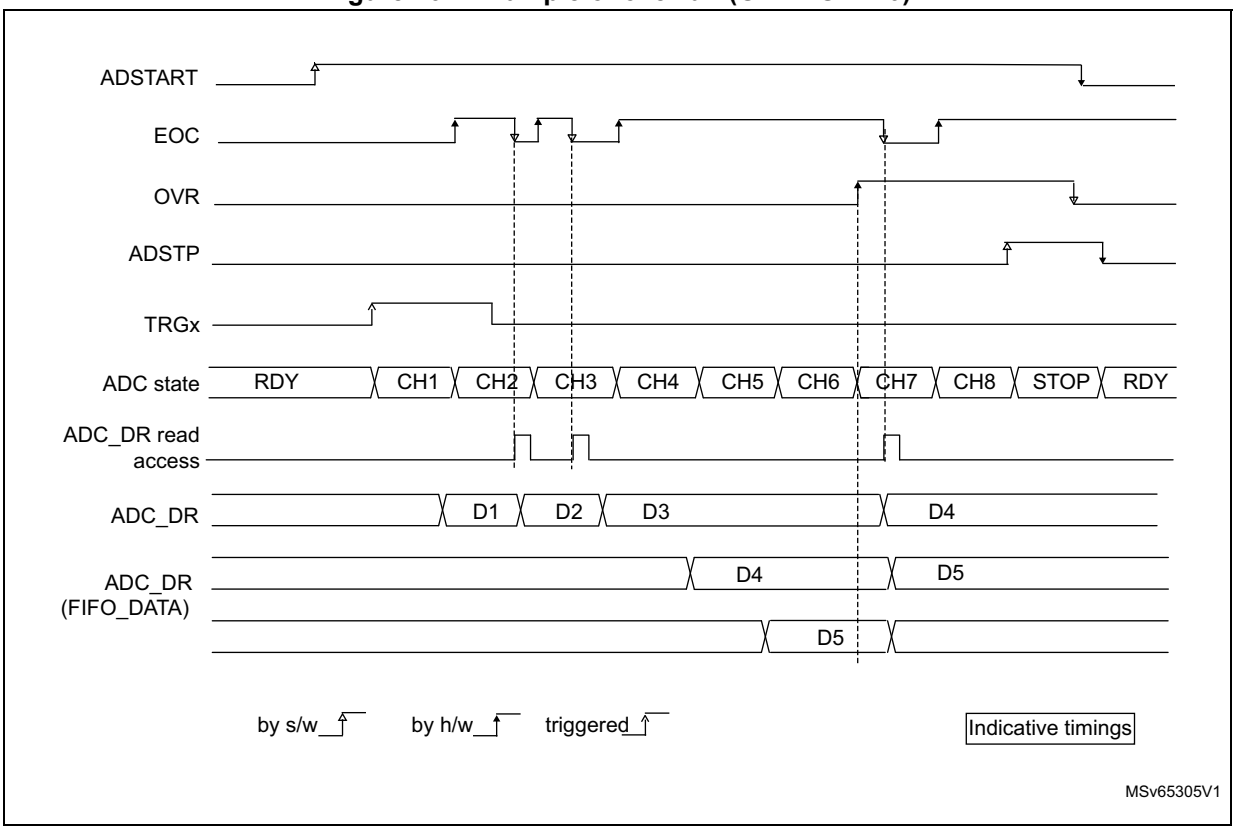
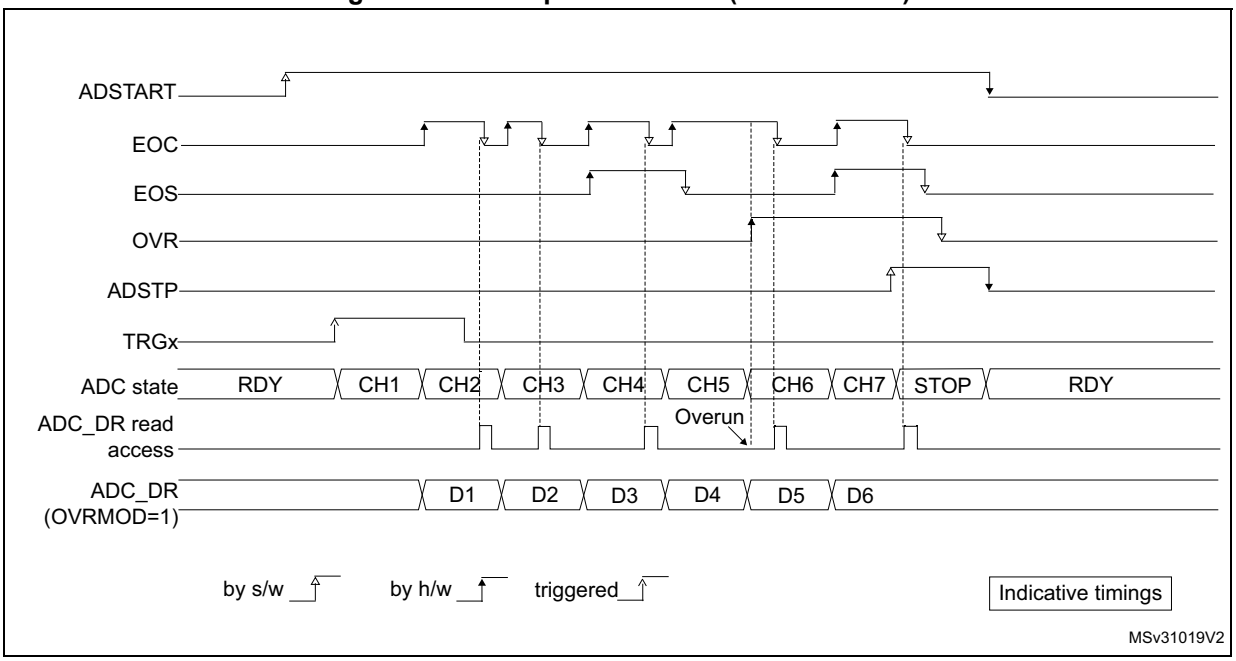


Figure 263. Example of overrun (OVRMOD = 1)



Note: There is no overrun detection on the injected channels since there is a dedicated data register for each of the four injected channels.

Managing a sequence of conversions without using the DMA

If the conversions are slow enough, the conversion sequence can be handled by the software. In this case the software must use the EOC flag and its associated interrupt to handle each data. Each time a conversion is complete, EOC is set and the ADC_DR register can be read. OVRMOD must be configured to 0 to manage overrun events or FIFO overflow as an error.

Managing conversions without using the DMA and without overrun

It may be useful to let the ADC convert one or more channels without reading the data each time (if there is an analog watchdog for instance). In this case, the OVRMOD bit must be configured to 1 and OVR flag should be ignored by the software. An overrun event does not prevent the ADC from continuing to convert and the ADC_DR register always contains the latest conversion.

Managing conversions using the DMA

Since converted channel values are stored into a unique data register, it is useful to use DMA for conversion of more than one channel. This avoids the loss of the data already stored in the ADC_DR register.

When the DMA mode is enabled (DMAEN bit set to 1 in the ADC_CFGR register, a DMA request is generated after each conversion of a channel. This allows the transfer of the converted data from the ADC_DR register to the destination location selected by the software.

Despite this, if an overrun occurs (OVR = 1) because the DMA could not serve the DMA transfer request in time, the ADC stops generating DMA requests and the data corresponding to the new conversion is not transferred by the DMA. Which means that all the data transferred to the RAM can be considered as valid.

Depending on the configuration of OVRMOD bit, the data is either preserved or overwritten (refer to *Section : ADC overrun (OVR, OVRMOD)*).

The DMA transfer requests are blocked until the software clears the OVR bit.

Two different DMA modes are proposed depending on the application use and are configured with bit DMACFG of the ADC_CFGR register:

- DMA one shot mode (DMACFG = 0).
  This mode is suitable when the DMA is programmed to transfer a fixed number of data.
- DMA circular mode (DMACFG = 1)
  This mode is suitable when programming the DMA in circular mode.

DMA one shot mode (DMACFG = 0)

In this mode, the ADC generates a DMA transfer request each time a new conversion data is available and stops generating DMA requests once the DMA has reached the last DMA transfer (when DMA_EOT interrupt occurs - refer to DMA paragraph) even if a conversion has been started again.

When the DMA transfer is complete (all the transfers configured in the DMA controller have been done):

- The content of the ADC data register is frozen.
- Any ongoing conversion is aborted with partial result discarded.
- No new DMA request is issued to the DMA controller. This avoids generating an overrun error if there are still conversions which are started.
- Scan sequence is stopped and reset.
- The DMA is stopped.

DMA circular mode (DMACFG = 1)

In this mode, the ADC generates a DMA transfer request each time a new conversion data is available in the data register, even if the DMA has reached the last DMA transfer. This allows configuring the DMA in circular mode to handle a continuous analog input data stream.

29.4.27 Managing conversions using the DFSDM

The ADC conversion results can be transferred directly to the digital filter for sigma delta modulators (DFSDM).

In this case, the DFSDMCFG bit must be set to 1 and DMAEN bit must be cleared to 0.

The ADC transfers all the 16 bits of the regular data register to the DFSDM and resets the EOC flag once the transfer is complete.

The data format must be 16-bit signed:

ADC_DR[15:12] = sign extended

ADC_DR[11] = sign

ADC_DR[11:0] = data

To obtain 16-bit signed format in 12-bit ADC mode, the software needs to configure the OFFSET[11:0] to 0x800 after having set OFFSET_EN to 1.

Only right aligned data format is available for the DFSDM interface (see *Figure 259: Right alignment (offset enabled, signed value)*).

29.4.28 Dynamic low-power features

Auto-delayed conversion mode (AUTDLY)

The ADC implements an auto-delayed conversion mode controlled by the AUTDLY configuration bit. Auto-delayed conversions are useful to simplify the software as well as to optimize performance of an application clocked at low frequency where there would be risk of encountering an ADC overrun.

When AUTDLY = 1, a new conversion can start only if all the previous data of the same group has been treated:

- For a regular conversion: once the ADC_DR register has been read or if the EOC bit has been cleared (see *Figure 264*).
- For an injected conversion: when the JEOS bit has been cleared (see *Figure 265*).

This is a way to automatically adapt the speed of the ADC to the speed of the system which reads the data.

The delay is inserted after each regular conversion (whatever DISCEN = 0 or 1) and after each sequence of injected conversions (whatever JDISCEN = 0 or 1).

Note: There is no delay inserted between each conversions of the injected sequence, except after the last one.

During a conversion, a hardware trigger event (for the same group of conversions) occurring during this delay is ignored.

Note: This is not true for software triggers where it remains possible during this delay to set the bits ADSTART or JADSTART to restart a conversion: it is up to the software to read the data before launching a new conversion.

No delay is inserted between conversions of different groups (a regular conversion followed by an injected conversion or conversely):

- If an injected trigger occurs during the automatic delay of a regular conversion, the injected conversion starts immediately (see *Figure 265*).
- Once the injected sequence is complete, the ADC waits for the delay (if not ended) of the previous regular conversion before launching a new regular conversion (see *Figure 267*).

The behavior is slightly different in auto-injected mode (JAUTO = 1) where a new regular conversion can start only when the automatic delay of the previous injected sequence of conversion has ended (when JEOS has been cleared). This is to ensure that the software can read all the data of a given sequence before starting a new sequence (see *Figure 268*).

To stop a conversion in Continuous auto-injection mode combined with autodelay mode (JAUTO = 1, CONT = 1 and AUTDLY = 1), follow the following procedure:

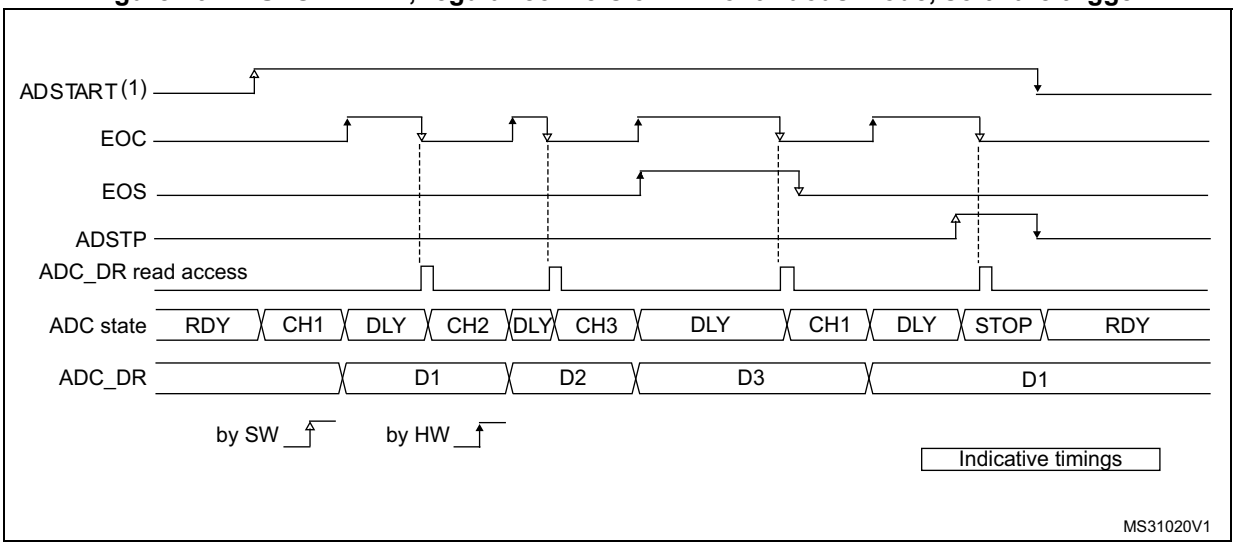
1. Wait until JEOS = 1 (no more conversions are restarted)
2. Clear JEOS,
3. Set ADSTP = 1
4. Read the regular data.

If this procedure is not respected, a new regular sequence can restart if JEOS is cleared after ADSTP has been set.

In AUTDLY mode, a hardware regular trigger event is ignored if it occurs during an already ongoing regular sequence or during the delay that follows the last regular conversion of the sequence. It is however considered pending if it occurs after this delay, even if it occurs during an injected sequence of the delay that follows it. The conversion then starts at the end of the delay of the injected sequence.

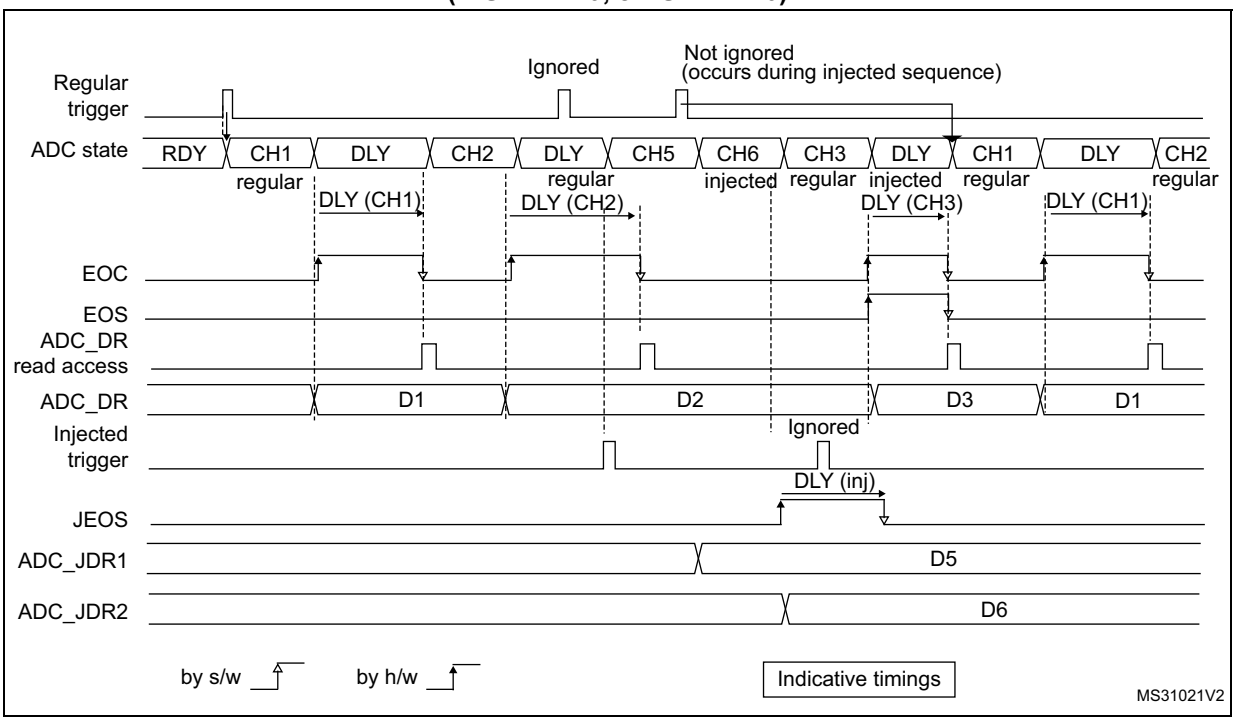
In AUTDLY mode, a hardware injected trigger event is ignored if it occurs during an already ongoing injected sequence or during the delay that follows the last injected conversion of the sequence.

Figure 264. AUTODLY = 1, regular conversion in Continuous mode, software trigger



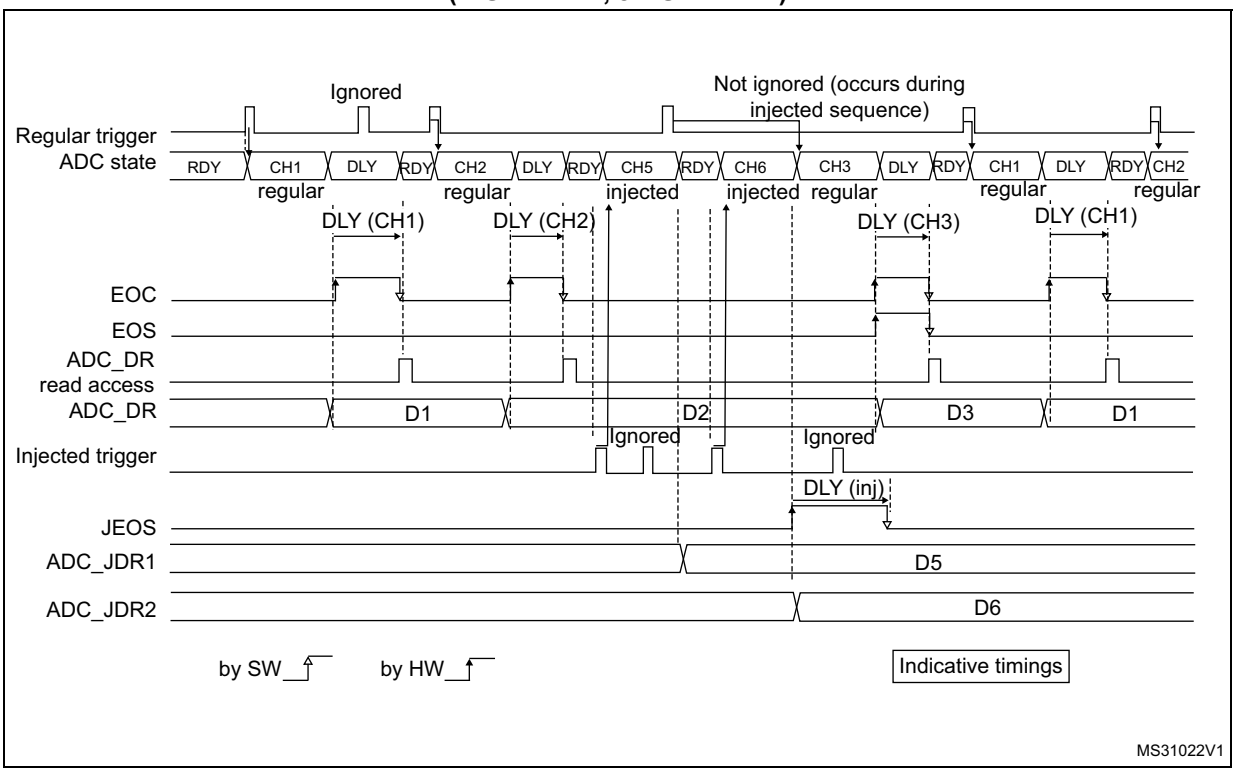
1. AUTDLY = 1
2. Regular configuration: EXTEN=0x0 (SW trigger), CONT = 1, CHANNELS = 1,2,3
3. Injected configuration DISABLED

Figure 265. AUTODLY = 1, regular HW conversions interrupted by injected conversions (DISCEN = 0; JDISCEN = 0)



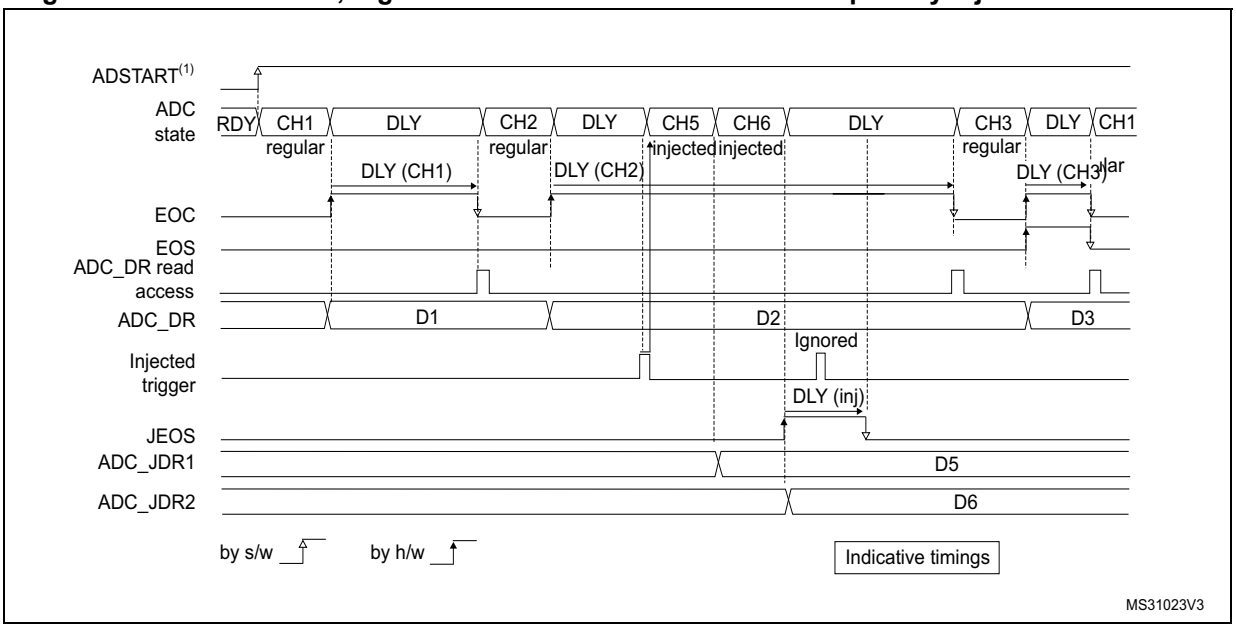
1. AUTDLY = 1
2. Regular configuration: EXTEN=0x1 (HW trigger), CONT = 0, DISCEN = 0, CHANNELS = 1, 2, 3
3. Injected configuration: JEXTEN = 0x1 (HW Trigger), JDISCEN = 0, CHANNELS = 5,6

Figure 266. AUTODLY = 1, regular HW conversions interrupted by injected conversions (DISCEN = 1, JDISCEN = 1)



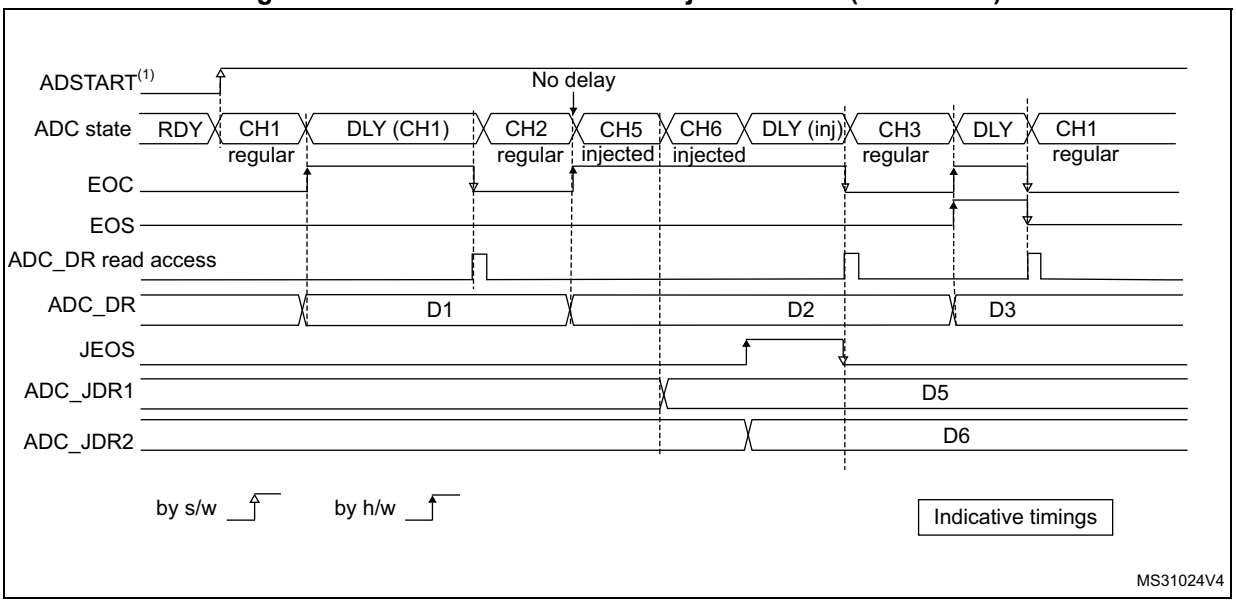
1. AUTDLY = 1
2. Regular configuration: EXTEN = 0x1 (HW trigger), CONT = 0, DISCEN = 1, DISCNUM = 1, CHANNELS = 1, 2, 3.
3. Injected configuration: JEXTEN = 0x1 (HW Trigger), JDISCEN = 1, CHANNELS = 5,6

Figure 267. AUTODLY = 1, regular continuous conversions interrupted by injected conversions



1. AUTDLY = 1
2. Regular configuration: EXTEN = 0x0 (SW trigger), CONT = 1, DISCEN = 0, CHANNELS = 1, 2, 3
3. Injected configuration: JEXTEN = 0x1 (HW Trigger), JDISCEN = 0, CHANNELS = 5,6

Figure 268. AUTODLY = 1 in auto- injected mode (JAUTO = 1)

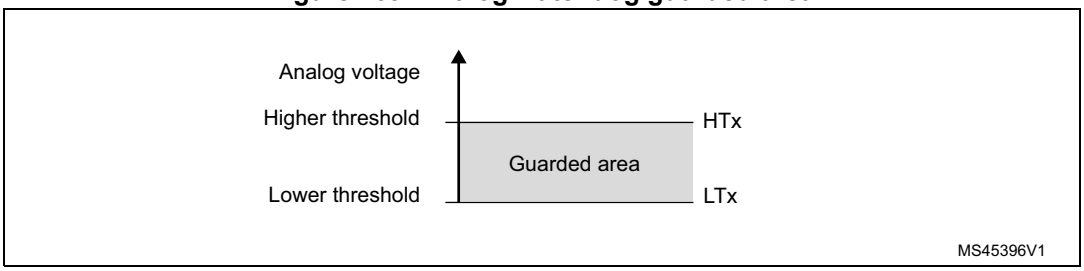


1. AUTDLY = 1
2. Regular configuration: EXTEN = 0x0 (SW trigger), CONT = 1, DISCEN = 0, CHANNELS = 1, 2
3. Injected configuration: JAUTO = 1, CHANNELS = 5,6

29.4.29 Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)

The three AWD analog watchdogs monitor whether some channels remain within a configured voltage range (window).

Figure 269. Analog watchdog guarded area



AWDx flag and interrupt

An interrupt can be enabled for each of the 3 analog watchdogs by setting AWDxIE in the ADC_IER register (x = 1,2,3).

AWDx (x = 1,2,3) flag is cleared by software by writing 1 to it.

The ADC conversion result is compared to the lower and higher thresholds before alignment.

Description of analog watchdog 1

The AWD analog watchdog 1 is enabled by setting the AWD1EN bit in the ADC_CFGR register. This watchdog monitors whether either one selected channel or all enabled channels(1) remain within a configured voltage range (window).

Table 247 shows how the ADC_CFGR registers should be configured to enable the analog watchdog on one or more channels.

Table 247. Analog watchdog channel selection

Channels guarded by the analog watchdog	AWD1SGL bit	AWD1EN bit	JAWD1EN bit
None	x	0	0
All injected channels	0	0	1
All regular channels	0	1	0
All regular and injected channels	0	1	1
Single(1) injected channel	1	0	1
Single(1) regular channel	1	1	0
Single(1) regular or injected channel	1	1	1

1. Selected by the AWD1CH[4:0] bits. The channels must also be programmed to be converted in the appropriate regular or injected sequence.

The AWD1 analog watchdog status bit is set if the analog voltage converted by the ADC is below a lower threshold or above a higher threshold.

These thresholds are programmed in bits HT1[11:0] and LT1[11:0] of the ADC_TR1 register for the analog watchdog 1. When converting data with a resolution of less than 12 bits (according to bits RES[1:0]), the LSB of the programmed thresholds must be kept cleared because the internal comparison is always performed on the full 12-bit raw converted data (left aligned) before the offset compensation stage.

Table 248 describes how the comparison is performed for all the possible resolutions for analog watchdog 1.

Table 248. Analog watchdog 1 comparison

Resolution(bit RES[1:0])	Analog watchdog comparison between:		Comments
	Raw converted data, left aligned	Thresholds	
00: 12-bit	DATA[11:0]	LT1[11:0] and HT1[11:0]	-
01: 10-bit	DATA[11:2],00	LT1[11:0] and HT1[11:0]	User must configure LT1[1:0] and HT1[1:0] to 00
10: 8-bit	DATA[11:4],0000	LT1[11:0] and HT1[11:0]	User must configure LT1[3:0] and HT1[3:0] to 0000
11: 6-bit	DATA[11:6],000000	LT1[11:0] and HT1[11:0]	User must configure LT1[5:0] and HT1[5:0] to 000000

Analog watchdog filter for watchdog 1

When an ADC is configured with only one input channel (selecting several channels in Scan mode not allowed), a valid ADC conversion data interval can be configured through the ADC_TR1 register:

- When converted data belong to the interval defined in ADC_TR1, a DMA request is generated.
- Otherwise, no DMA request is issued. RDATA register is updated at each conversion. If data are out-of-range a number of times higher than the value specified in AWDFILT bit of ADC_TR1, the AWDx flag is set an the corresponding interrupt is issued.

Description of analog watchdog 2 and 3

The second and third analog watchdogs are more flexible and can guard several selected channels by programming the corresponding bits in AWDxCH[18:0] (x = 2,3).

The corresponding watchdog is enabled when any bit of AWDxCH[18:0] (x = 2,3) is set.

They are limited to a resolution of 8 bits and only the 8 MSBs of the thresholds can be programmed into HTx[7:0] and LTx[7:0]. *Table 249* describes how the comparison is performed for all the possible resolutions.

Table 249. Analog watchdog 2 and 3 comparison

Resolution (bits RES[1:0])	Analog watchdog comparison between:		Comments
	Raw converted data, left aligned	Thresholds	
00: 12-bit	DATA[11:4]	LTx[7:0] and HTx[7:0]	DATA[3:0] are not relevant for the comparison
01: 10-bit	DATA[11:4]	LTx[7:0] and HTx[7:0]	DATA[3:2] are not relevant for the comparison
10: 8-bit	DATA[11:4]	LTx[7:0] and HTx[7:0]	-
11: 6-bit	DATA[11:6],00	LTx[7:0] and HTx[7:0]	User must configure LTx[1:0] and HTx[1:0] to 00

ADCy_AWDx_OUT signal output generation

Each analog watchdog is associated to an internal hardware signal ADCy_AWDx_OUT (y = ADC number, x = watchdog number) which is directly connected to the ETR input (external trigger) of some on-chip timers. Refer to the on-chip timers section to understand how to select the ADCy_AWDx_OUT signal as ETR.

ADCy_AWDx_OUT is activated when the associated analog watchdog is enabled:

- ADCy_AWDx_OUT is set when a guarded conversion is outside the programmed thresholds.
- ADCy_AWDx_OUT is reset after the end of the next guarded conversion which is inside the programmed thresholds (It remains at 1 if the next guarded conversions are still outside the programmed thresholds).
- ADCy_AWDx_OUT is also reset when disabling the ADC (when setting ADDIS = 1). Note that stopping regular or injected conversions (setting ADSTP = 1 or JADSTP = 1) has no influence on the generation of ADCy_AWDx_OUT.

Note: AWDx flag is set by hardware and reset by software: AWDx flag has no influence on the generation of ADCy_AWDx_OUT (ex: ADCy_AWDx_OUT can toggle while AWDx flag remains at 1 if the software did not clear the flag).

Figure 270. ADCy_AWDx_OUT signal generation (on all regular channels)

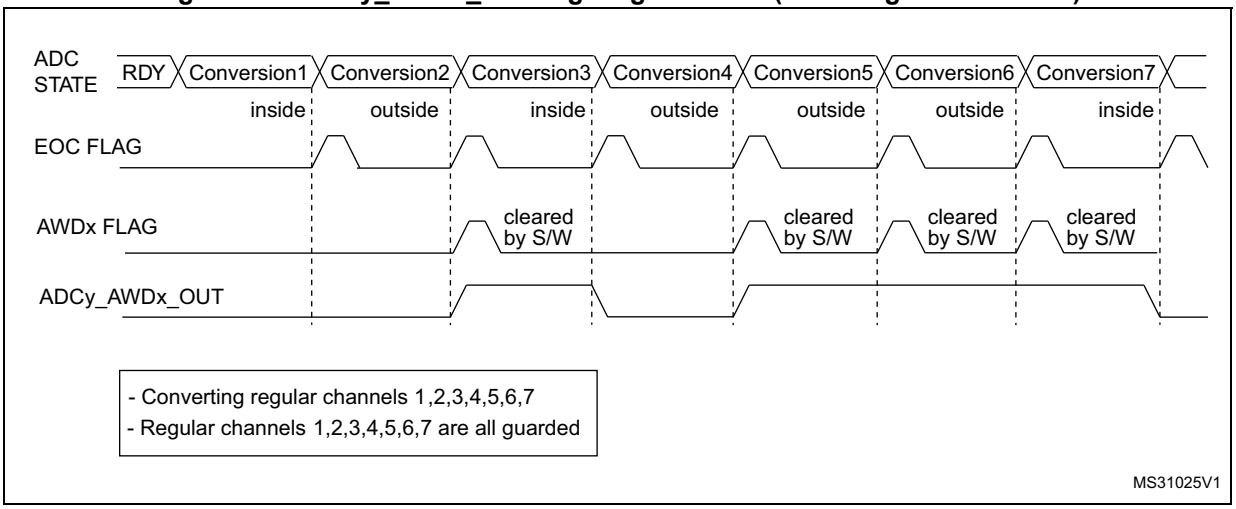


Figure 271. ADCy_AWDx_OUT signal generation (AWDx flag not cleared by software)

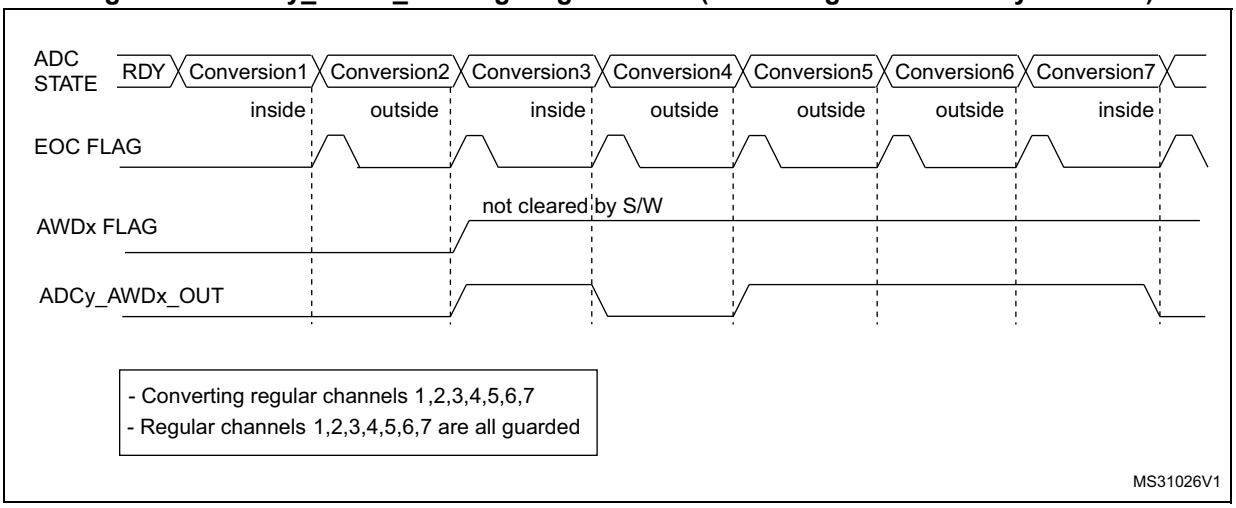


Figure 272. ADCy_AWDx_OUT signal generation (on a single regular channel)

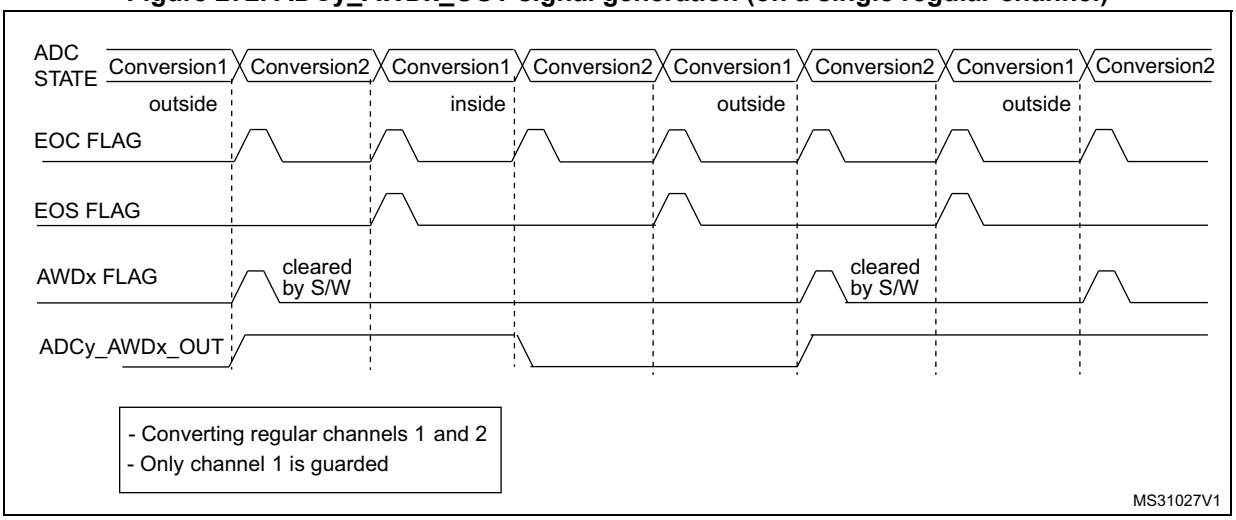
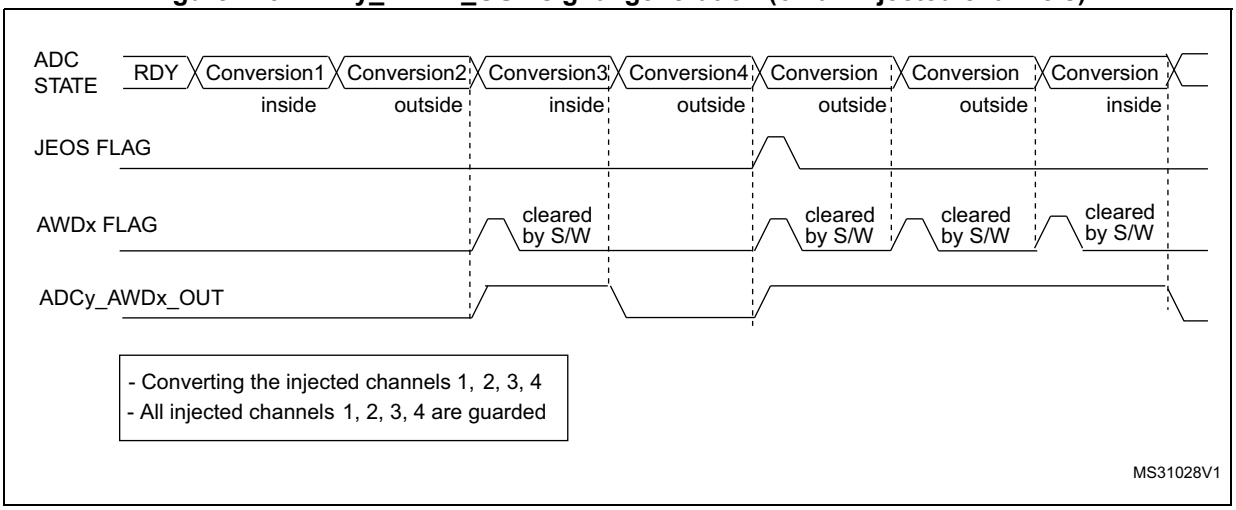


Figure 273. ADCy_AWDx_OUT signal generation (on all injected channels)



Analog watchdog threshold control

LTx[11:0] and HTx[11:0] can be changed when an analog-to-digital conversion is ongoing (that is between the start of conversion and the end of conversion of the ADC internal state). If LTx[11:0] and HTx[11:0] are updated during the ADC conversion of the ADC guarded channel, the watchdog function is masked for this conversion. This masking is removed at the next start of conversion, resulting in a analog watchdog thresholds to be applied from the next ADC conversion. The analog watchdog comparison is performed at each end of conversion. If the current ADC data is out of the new interval, no interrupt and AWDx_OUT signal are issued. The Interrupt and the AWD generation only happen at the end of the conversion which started after the threshold update. If AWD_xOUT is already asserted, programming the new thresholds does not deassert the AWDx_OUT signal.

Analog watchdog with offset compensation

When the offset compensation is enabled, the analog watchdog compares the threshold before the data compensation.

29.4.30 Oversampler

The oversampling unit performs data pre-processing to offload the CPU. It is able to handle multiple conversions and average them into a single data with increased data width, up to 16-bit.

It provides a result with the following form, where N and M can be adjusted:

$$\text{Result} = \frac{1}{M} \times \sum_{n=0}^{n=N-1} \text{Conversion}(t_n)$$

It allows to perform by hardware the following functions: averaging, data rate reduction, SNR improvement, basic filtering.

The oversampling ratio N is defined using the OVFS[2:0] bits in the ADC_CFGR2 register, and can range from 2x to 256x. The division coefficient M consists of a right bit shift up to 8 bits, and is defined using the OVSS[3:0] bits in the ADC_CFGR2 register.

The summation unit can yield a result up to 20 bits (256x 12-bit results), which is first shifted right. It is then truncated to the 16 least significant bits, rounded to the nearest value using the least significant bits left apart by the shifting, before being finally transferred into the ADC_DR data register.

Note: If the intermediary result after the shifting exceeds 16-bit, the result is truncated as is, without saturation.

Figure 274. 20-bit to 16-bit result truncation

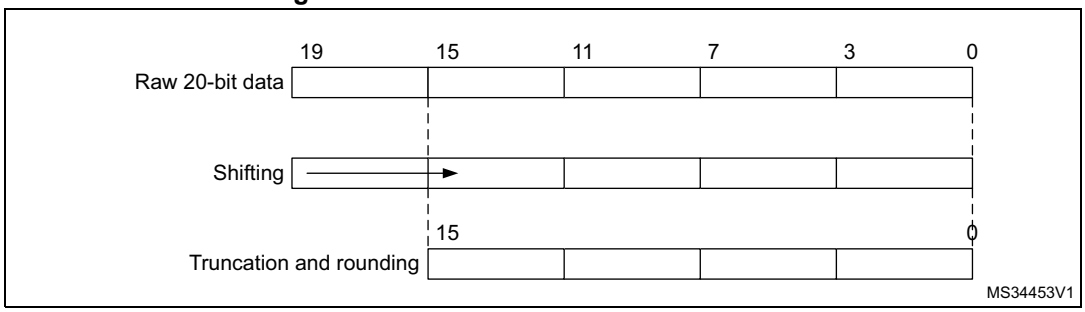


Figure 275 gives a numerical example of the processing, from a raw 20-bit accumulated data to the final 16-bit result.

Figure 275. Numerical example with 5-bit shift and rounding

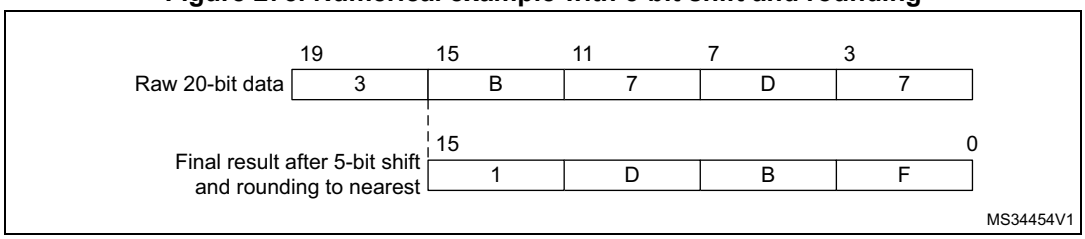


Table 250 gives the data format for the various N and M combinations, for a raw conversion data equal to 0xFFF.

Table 250. Maximum output results versus N and M (gray cells indicate truncation)

Over sampling ratio	Max Raw data	No-shift OVSS = 0000	1-bit shift OVSS = 0001	2-bit shift OVSS = 0010	3-bit shift OVSS = 0011	4-bit shift OVSS = 0100	5-bit shift OVSS = 0101	6-bit shift OVSS = 0110	7-bit shift OVSS = 0111	8-bit shift OVSS = 1000
2x	0x1FFE	0x1FFE	0x0FFF	0x0800	0x0400	0x0200	0x0100	0x0080	0x0040	0x020
4x	0x3FFC	0x3FFC	0x1FFE	0x0FFF	0x0800	0x0400	0x0200	0x0100	0x0080	0x0040
8x	0x7FF8	0x7FF8	0x3FFC	0x1FFE	0x0FFF	0x0800	0x0400	0x0200	0x0100	0x0080
16x	0xFFF0	0xFFF0	0x7FF8	0x3FFC	0x1FFE	0x0FFF	0x0800	0x0400	0x0200	0x0100
32x	0x1FFE0	0xFFE0	0xFFF0	0x7FF8	0x3FFC	0x1FFE	0x0FFF	0x0800	0x0400	0x0200
64x	0x3FFC0	0xFFC0	0xFFE0	0xFFF0	0x7FF8	0x3FFC	0x1FFE	0x0FFF	0x0800	0x0400
128x	0x7FF80	0xFF80	0xFFC0	0xFFE0	0xFFF0	0x7FF8	0x3FFC	0x1FFE	0x0FFF	0x0800
256x	0xFFF00	0xFF00	0xFF80	0xFFC0	0xFFE0	0xFFF0	0x7FF8	0x3FFC	0x1FFE	0x0FFF

There are no changes for conversion timings in oversampled mode: the sample time is maintained equal during the whole oversampling sequence. A new data is provided every N

conversions, with an equivalent delay equal to N x T_{CONV} = N x (t_{SMPL} + t_{SAR}). The flags are set as follow:

- The end of the sampling phase (EOSMP) is set after each sampling phase
- The end of conversion (EOC) occurs once every N conversions, when the oversampled result is available
- The end of sequence (EOS) occurs once the sequence of oversampled data is completed (that is after N x sequence length conversions total)

ADC operating modes supported when oversampling

In oversampling mode, most of the ADC operating modes are maintained:

- Single or Continuous conversion modes
- ADC conversions start either by software or with triggers
- ADC stop during a conversion (abort)
- Data read via CPU or DMA with overrun detection
- Low-power modes (AUTDLY)
- Programmable resolution: in this case, the reduced conversion values (as per RES[1:0] bits in ADC_CFGR1 register) are accumulated, truncated, rounded and shifted in the same way as 12-bit conversions are

Note: The alignment mode is not available when working with oversampled data. The ALIGN bit in ADC_CFGR1 is ignored and the data are always provided right-aligned.

Offset correction is not supported in oversampling mode. When ROVSE and/or JOVSE bit is set, the value of the OFFSET_EN bit in ADC_OFRy register is ignored (considered as reset).

Analog watchdog

The analog watchdog functionality is maintained (AWDSGL and AWDEN bits), with the following difference:

- The RES[1:0] bits are ignored, comparison is always done on using the full 12-bit values HT[11:0] and LT[11:0]
- the comparison is performed on the most significant 12-bit of the 16-bit oversampled results ADC_DR[15:4]

Note: Care must be taken when using high shifting values, this reduces the comparison range. For instance, if the oversampled result is shifted by 4 bits, thus yielding a 12-bit data right-aligned, the effective analog watchdog comparison can only be performed on 8 bits. The comparison is done between ADC_DR[11:4] and HT[0:7] / LT[[0:7], and HT[11:8] / LT[11:8] must be kept reset.

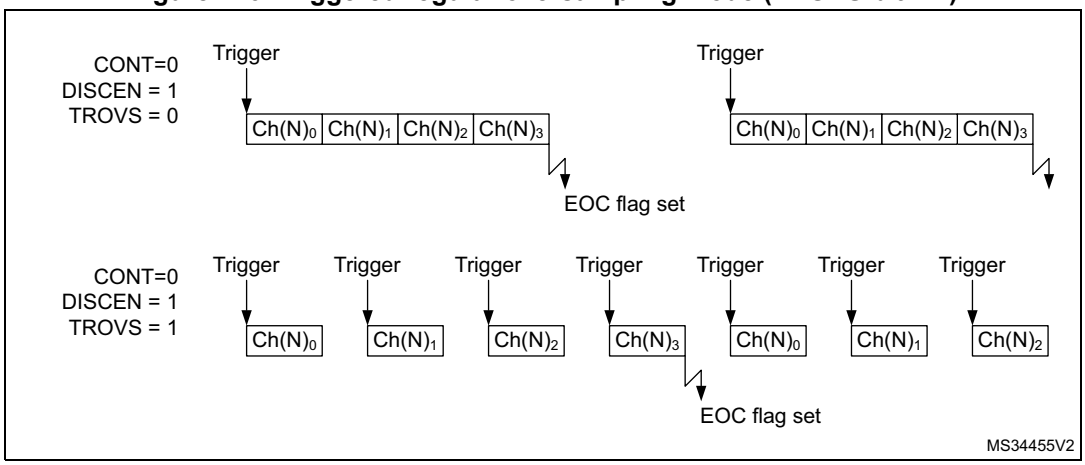
Triggered mode

The averager can also be used for basic filtering purpose. Although not a very powerful filter (slow roll-off and limited stop band attenuation), it can be used as a notch filter to reject constant parasitic frequencies (typically coming from the mains or from a switched mode power supply). For this purpose, a specific Discontinuous mode can be enabled with TROVS bit in ADC_CFGR2, to be able to have an oversampling frequency defined by a user and independent from the conversion time itself.

The *Figure 276* below shows how conversions are started in response to triggers during Discontinuous mode.

If the TROVS bit is set, the content of the DISCEN bit is ignored and considered as 1.

Figure 276. Triggered regular oversampling mode (TROVS bit = 1)



Injected and regular sequencer management when oversampling

In oversampling mode, it is possible to have differentiated behavior for injected and regular sequencers. The oversampling can be enabled for both sequencers with some limitations if they have to be used simultaneously (this is related to a unique accumulation unit).

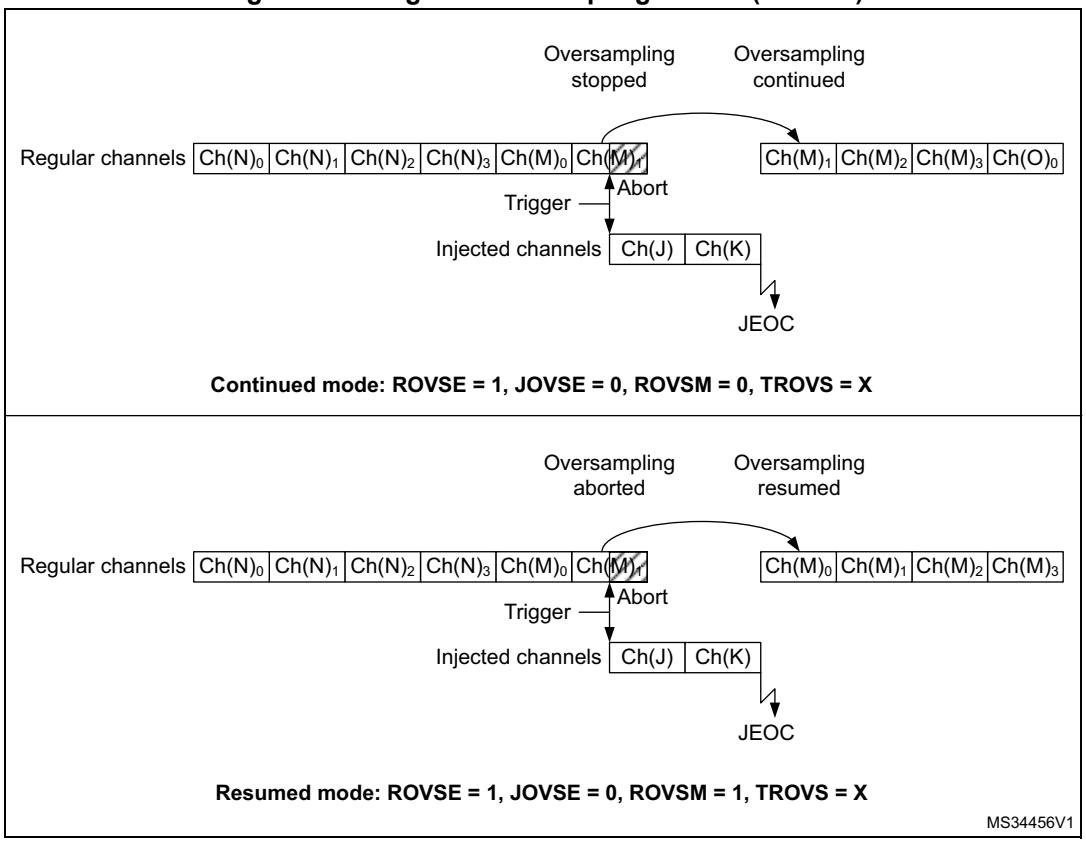
Oversampling regular channels only

The regular oversampling mode bit ROVSM defines how the regular oversampling sequence is resumed if it is interrupted by injected conversion:

- In continued mode, the accumulation restarts from the last valid data (prior to the conversion abort request due to the injected trigger). This ensures that oversampling is complete whatever the injection frequency (providing at least one regular conversion can be completed between triggers);
- In resumed mode, the accumulation restarts from 0 (previous conversions results are ignored). This mode allows to guarantee that all data used for oversampling were converted back-to-back within a single timeslot. Care must be taken to have a injection trigger period above the oversampling period length. If this condition is not respected, the oversampling cannot be completed and the regular sequencer is blocked.

The *Figure 277* gives examples for a 4x oversampling ratio.

Figure 277. Regular oversampling modes (4x ratio)



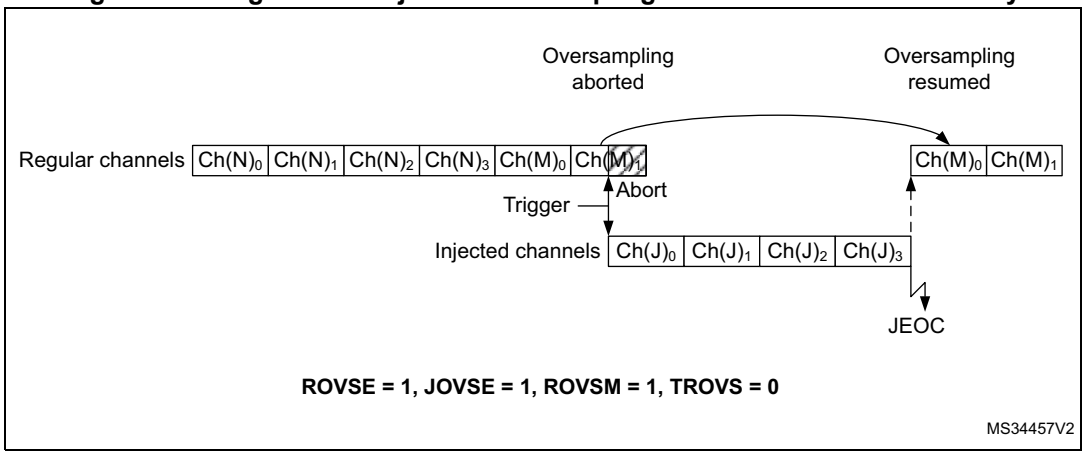
Oversampling Injected channels only

The Injected oversampling mode bit JOVSE enables oversampling solely for conversions in the injected sequencer.

Oversampling regular and Injected channels

It is possible to have both ROVSE and JOVSE bits set. In this case, the regular oversampling mode is forced to resumed mode (ROVSM bit ignored), as represented on *Figure 278* below.

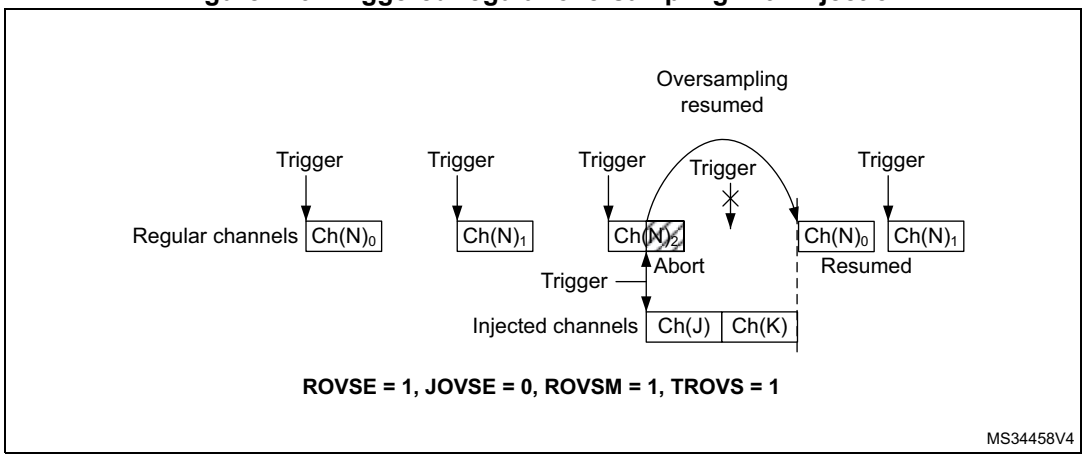
Figure 278. Regular and injected oversampling modes used simultaneously



Triggered regular oversampling with injected conversions

It is possible to have triggered regular mode with injected conversions. In this case, the injected mode oversampling mode must be disabled, and the ROVSM bit is ignored (resumed mode is forced). The JOVSE bit must be reset. The behavior is represented on *Figure 279* below.

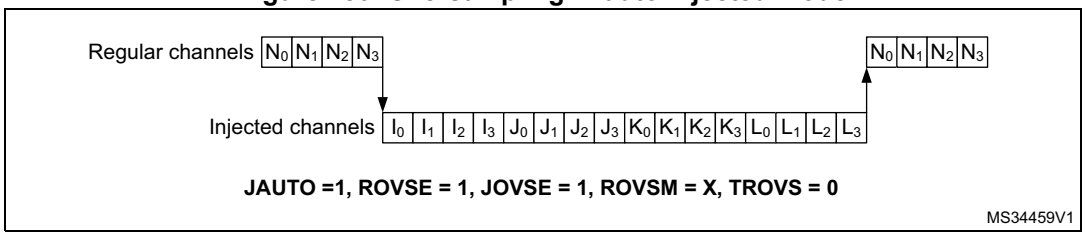
Figure 279. Triggered regular oversampling with injection



Auto-injected mode

It is possible to oversample auto-injected sequences and have all conversions results stored in registers to save a DMA resource. This mode is available only with both regular and injected oversampling active: JAUTO = 1, ROVSE = 1 and JOVSE = 1, other combinations are not supported. The ROVSM bit is ignored in auto-injected mode. The *Figure 280* below shows how the conversions are sequenced.

Figure 280. Oversampling in auto-injected mode



It is possible to have also the triggered mode enabled, using the TROVS bit. In this case, the ADC must be configured as following: JAUTO = 1, DISCEN = 0, JDISCEN = 0, ROVSE = 1, JOVSE = 1 and TROVSE = 1.

29.4.31 Temperature sensor

The temperature sensor can be used to measure the junction temperature (Tj) of the device.

The temperature sensor is internally connected to the ADC input channels which are used to convert the sensor output voltage to a digital value (see *Table: ADC interconnection* in *Section 29.4.2: ADC pins and internal signals* for more details). When not in use, the sensor can be put in power down mode. It support the temperature range –40 to 125 °C.

Figure 281 shows the block diagram of connections between the temperature sensor and the ADC.

The temperature sensor output voltage changes linearly with temperature. The offset of this line varies from chip to chip due to process variation (up to 45 °C from one chip to another).

The uncalibrated internal temperature sensor is more suited for applications that detect temperature variations instead of absolute temperatures. To improve the accuracy of the temperature sensor measurement, calibration values are stored in system memory for each device by ST during production.

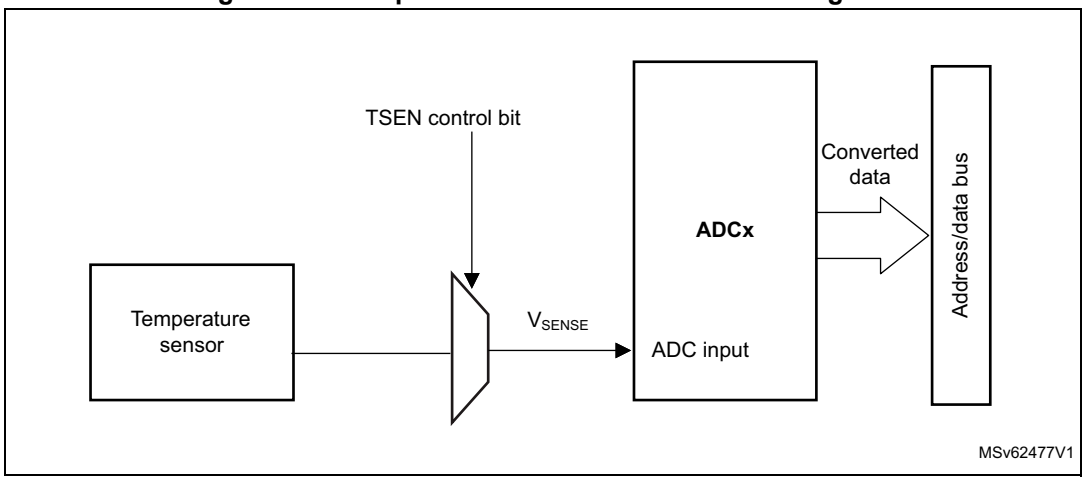
During the manufacturing process, the calibration data of the temperature sensor and the internal voltage reference are stored in the system memory area. The user application can then read them and use them to improve the accuracy of the temperature sensor or the internal reference (refer to the datasheet for additional information).

The temperature sensor is internally connected to the ADC input channel which is used to convert the sensor's output voltage to a digital value. Refer to the electrical characteristics section of the device datasheet for the sampling time value to be applied when converting the internal temperature sensor.

When not in use, the sensor can be put in power-down mode.

Figure 281 shows the block diagram of the temperature sensor.

Figure 281. Temperature sensor channel block diagram



Reading the temperature

To use the sensor:

1. Select the ADC input channels that is connected to V_{SENSE}.
2. Program with the appropriate sampling time (refer to electrical characteristics section of the device datasheet).
3. Set the bit in the ADC_CCR register to wake up the temperature sensor from power-down mode.
4. Start the ADC conversion.
5. Read the resulting V_{SENSE} data in the ADC data register.
6. Calculate the actual temperature using the following formula:

$$\text{Temperature (in °C)} = \frac{\text{TS\_CAL2\_TEMP} - \text{TS\_CAL1\_TEMP}}{\text{TS\_CAL2} - \text{TS\_CAL1}} \times (\text{TS\_DATA} - \text{TS\_CAL1}) + 30\ °\text{C}$$

where:

- TS_CAL2 is the temperature sensor calibration value acquired at TS_CAL2_TEMP.
- TS_CAL1 is the temperature sensor calibration value acquired at TS_CAL1_TEMP.
- TS_DATA is the actual temperature sensor output value converted by ADC.

  Refer to the device datasheet for more information about TS_CAL1 and TS_CAL2 calibration points.

Note: The sensor has a startup time after waking from power-down mode before it can output V_{SENSE} at the correct level. The ADC also has a startup time after power-on, so to minimize the delay, the ADEN and bits should be set at the same time.

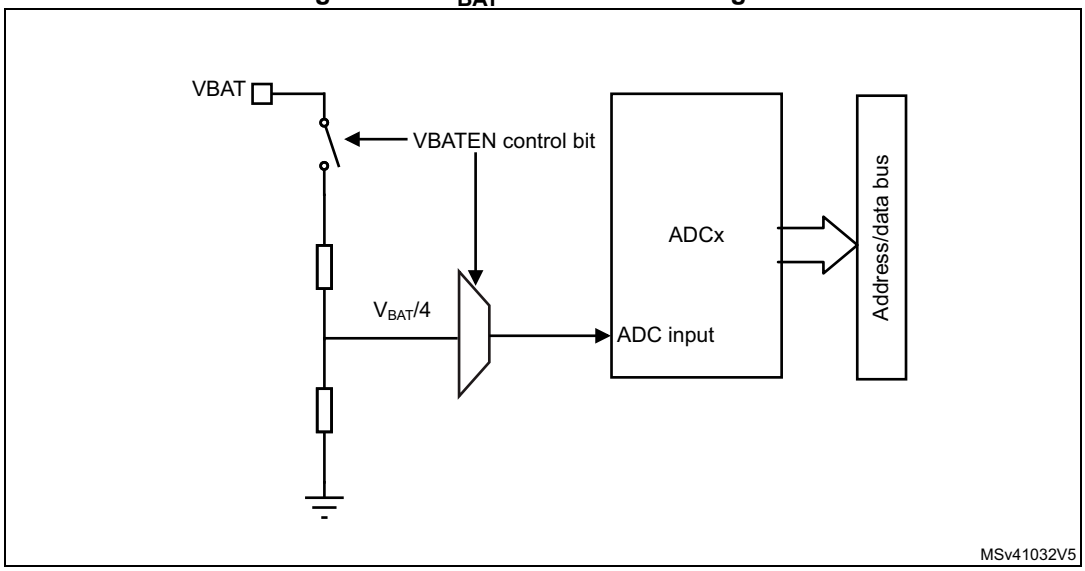
29.4.32 V_{BAT} supply monitoring

The VBATEN bit in the ADC_CCR register is used to switch to the battery voltage. As the V_{BAT} voltage could be higher than V_{DDA}, to ensure the correct operation of the ADC, the V_{BAT} pin is internally connected to a bridge divider by 4. This bridge is automatically enabled when VBATEN is set, to connect $V_{BAT}/4$ to the ADC input channels (see *Table: ADC interconnection* in *Section 29.4.2: ADC pins and internal signals* for more details). As a consequence, the converted digital value is one third of the V_{BAT} voltage. To prevent any unwanted consumption on the battery, it is recommended to enable the bridge divider only when needed, for ADC conversion.

Refer to the electrical characteristics of the device datasheet for the sampling time value to be applied when converting the $V_{BAT}/4$ voltage.

Figure 282 shows the block diagram of the V_{BAT} sensing feature.

Figure 282. V_{BAT} channel block diagram



1. The VBATEN bit must be set to enable the conversion of internal channel for $V_{BAT}/4$.

29.4.33 Monitoring the internal voltage reference

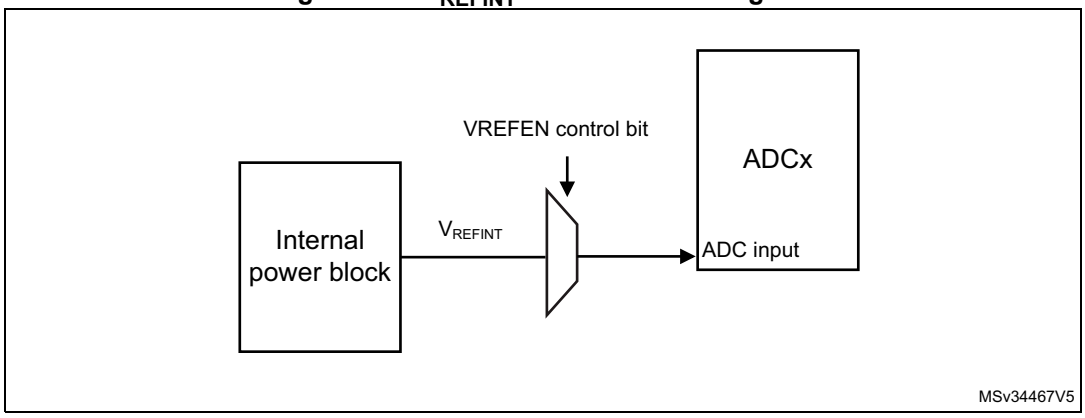
It is possible to monitor the internal voltage reference (V_{REFINT}) to have a reference point for evaluating the ADC V_{REF+} voltage level.

Refer to *Table: ADC interconnection* in *Section 29.4.2: ADC pins and internal signals* for details on the ADC input channels to which the internal voltage reference is internally connected.

Refer to the electrical characteristics section of the product datasheet for the sampling time value to be applied when converting the internal voltage reference voltage.

Figure 283 shows the block diagram of the V_{REFINT} sensing feature.

Figure 283. V_{REFINT} channel block diagram



1. The VREFEN bit into ADC_CCR register must be set to enable the conversion of internal channels (V_{REFINT}).

Calculating the actual V_{REF+} voltage using the internal reference voltage

V_{REF+} voltage may be subject to variations or not precisely known. The embedded internal reference voltage V_{REFINT} and its calibration data acquired by the ADC during the manufacturing process at V_{REF+_charac} can be used to evaluate the actual V_{REF+} voltage level.

The following formula gives the actual V_{REF+} voltage supplying the device:

$$V_{REF+} = V_{REF+\_Charac} \times VREFINT\_CAL / VREFINT\_DATA$$

Where:

- V_{REF+_Charac} is the value of V_{REF+} voltage characterized at V_{REFINT} during the manufacturing process. It is specified in the device datasheet.
- VREFINT_CAL is the VREFINVREFINT_CAL is the VREFINT calibration value
- VREFINT_DATA is the actual VREFINT output value converted by ADC

Converting a supply-relative ADC measurement to an absolute voltage value

The ADC is designed to deliver a digital value corresponding to the ratio between V_{REF+} and the voltage applied on the converted channel.

For applications where V_{REF+} value is unknown and ADC converted values are right-aligned. In this case, it is necessary to convert this ratio into a voltage independent from V_{REF+}:

$$V_{CHANNELx} = \frac{V_{REF+}}{FULL\_SCALE} \times ADC\_DATA$$

By replacing V_{REF+} by the formula provided above, the absolute voltage value is given by the following formula

$$V_{CHANNELx} = \frac{V_{REF+\_Charac} \times VREFINT\_CAL \times ADC\_DATA}{VREFINT\_DATA \times FULL\_SCALE}$$

Where:

- V_{REF+_Charac} is the value of V_{REF+} voltage characterized at V_{REFINT} during the manufacturing process.
- VREFINT_CAL is the VREFINT calibration value
- ADC_DATA is the value measured by the ADC on channel x (right-aligned)
- VREFINT_DATA is the actual VREFINT output value converted by the ADC
- FULL_SCALE is the maximum digital value of the ADC output. For example with 12-bit resolution, it is 2^{12} - 1 = 4095 or with 8-bit resolution, 2^8 - 1 = 255.

Note: If ADC measurements are done using an output format other than 12-bit right-aligned, all the parameters must first be converted to a compatible format before the calculation is done.

29.5 ADC interrupts

An interrupt can be generated:

- After ADC power-up, when the ADC is ready (flag ADRDY)
- On the end of any conversion for regular groups (flag EOC)
- On the end of a sequence of conversion for regular groups (flag EOS)
- On the end of any conversion for injected groups (flag JEOC)
- On the end of a sequence of conversion for injected groups (flag JEOS)
- When an analog watchdog detection occurs (flag AWD1, AWD2 and AWD3)
- When the end of sampling phase occurs (flag EOSMP)
- When the data overrun occurs (flag OVR)
- When the injected sequence context queue overflows (flag JQOVF)

Separate interrupt enable bits are available for flexibility.

Table 251. ADC interrupts

Interrupt vector	Interrupt event	Event flag	Enable Control bit	Interrupt clear method	Exit from Sleep mode	Exit from Stop, Standby mode
ADC	ADC ready	ADRDY	ADRDYIE	Set by hardware and cleared by software	Yes	No
	End of conversion of a regular group	EOC	EOCIE			
	End of conversion sequence of a regular group	EOS	EOSIE			
	End of conversion of an injected group	JEOC	JEOCIE			
	End of conversion sequence of an injected group	JEOS	JEOSIE			
	Analog watchdog 1 status bit is set	AWD1	AWD1IE			
	Analog watchdog 2 status bit is set	AWD2	AWD2IE			
	Analog watchdog 3 status bit is set	AWD3	AWD3IE			
	End of sampling phase	EOSMP	EOSMPIE			
	Overrun	OVR	OVRIE			
	Injected context queue overflows	JQOVF	JQOVFIE			

29.6 ADC registers

Refer to *Section 1.2 on page 104* for a list of abbreviations used in register descriptions.

29.6.1 ADC interrupt and status register (ADC_ISR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	JQOVF	AWD3	AWD2	AWD1	JEOS	JEOC	OVR	EOS	EOC	EOSMP	ADRDY
					rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **JQOVF**: Injected context queue overflow

This bit is set by hardware when an Overflow of the Injected Queue of Context occurs. It is cleared by software writing 1 to it. Refer to *Section 29.4.21: Queue of context for injected conversions* for more information.

0: No injected context queue overflow occurred (or the flag event was already acknowledged and cleared by software)

1: Injected context queue overflow has occurred

Bit 9 **AWD3**: Analog watchdog 3 flag

This bit is set by hardware when the converted voltage crosses the values programmed in the fields LT3[7:0] and HT3[7:0] of ADC_TR3 register. It is cleared by software writing 1 to it.

0: No analog watchdog 3 event occurred (or the flag event was already acknowledged and cleared by software)

1: Analog watchdog 3 event occurred

Bit 8 **AWD2**: Analog watchdog 2 flag

This bit is set by hardware when the converted voltage crosses the values programmed in the fields LT2[7:0] and HT2[7:0] of ADC_TR2 register. It is cleared by software writing 1 to it.

0: No analog watchdog 2 event occurred (or the flag event was already acknowledged and cleared by software)

1: Analog watchdog 2 event occurred

Bit 7 **AWD1**: Analog watchdog 1 flag

This bit is set by hardware when the converted voltage crosses the values programmed in the fields LT1[11:0] and HT1[11:0] of ADC_TR1 register. It is cleared by software. writing 1 to it.

0: No analog watchdog 1 event occurred (or the flag event was already acknowledged and cleared by software)

1: Analog watchdog 1 event occurred

Bit 6 **JEOS:** Injected channel end of sequence flag

This bit is set by hardware at the end of the conversions of all injected channels in the group. It is cleared by software writing 1 to it.

0: Injected conversion sequence not complete (or the flag event was already acknowledged and cleared by software)

1: Injected conversions complete

Bit 5 **JEOC:** Injected channel end of conversion flag

This bit is set by hardware at the end of each injected conversion of a channel when a new data is available in the corresponding ADC_JDRy register. It is cleared by software writing 1 to it or by reading the corresponding ADC_JDRy register

0: Injected channel conversion not complete (or the flag event was already acknowledged and cleared by software)

1: Injected channel conversion complete

Bit 4 **OVR**: ADC overrun

This bit is set by hardware when an overrun occurs on a regular channel, meaning that a new conversion has completed while the EOC flag was already set. It is cleared by software writing 1 to it.

0: No overrun occurred (or the flag event was already acknowledged and cleared by software)

1: Overrun has occurred

Bit 3 **EOS**: End of regular sequence flag

This bit is set by hardware at the end of the conversions of a regular sequence of channels. It is cleared by software writing 1 to it.

0: Regular Conversions sequence not complete (or the flag event was already acknowledged and cleared by software)

1: Regular Conversions sequence complete

Bit 2 **EOC**: End of conversion flag

This bit is set by hardware at the end of each regular conversion of a channel when a new data is available in the ADC_DR register. It is cleared by software writing 1 to it or by reading the ADC_DR register

0: Regular channel conversion not complete (or the flag event was already acknowledged and cleared by software)

1: Regular channel conversion complete

Bit 1 **EOSMP**: End of sampling flag

This bit is set by hardware during the conversion of any channel (only for regular channels), at the end of the sampling phase.

0: not at the end of the sampling phase (or the flag event was already acknowledged and cleared by software)

1: End of sampling phase reached

Bit 0 **ADRDY**: ADC ready

This bit is set by hardware after the ADC has been enabled (ADEN = 1) and when the ADC reaches a state where it is ready to accept conversion requests.

It is cleared by software writing 1 to it.

0: ADC not yet ready to start conversion (or the flag event was already acknowledged and cleared by software)

1: ADC is ready to start conversion

29.6.2 ADC interrupt enable register (ADC_IER)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	JQOVFIE	AWD3IE	AWD2IE	AWD1IE	JEOSIE	JEOCIE	OVRIE	EOSIE	EOCIE	EOSMPIE	ADRDYIE
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **JQOVFIE**: Injected context queue overflow interrupt enable

This bit is set and cleared by software to enable/disable the Injected Context Queue Overflow interrupt.

0: Injected Context Queue Overflow interrupt disabled

1: Injected Context Queue Overflow interrupt enabled. An interrupt is generated when the JQOVF bit is set.

Note: The software is allowed to write this bit only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 9 **AWD3IE**: Analog watchdog 3 interrupt enable

This bit is set and cleared by software to enable/disable the analog watchdog 2 interrupt.

0: Analog watchdog 3 interrupt disabled

1: Analog watchdog 3 interrupt enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 8 **AWD2IE**: Analog watchdog 2 interrupt enable

This bit is set and cleared by software to enable/disable the analog watchdog 2 interrupt.

0: Analog watchdog 2 interrupt disabled

1: Analog watchdog 2 interrupt enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 7 **AWD1IE**: Analog watchdog 1 interrupt enable

This bit is set and cleared by software to enable/disable the analog watchdog 1 interrupt.

0: Analog watchdog 1 interrupt disabled

1: Analog watchdog 1 interrupt enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 6 **JEOSIE**: End of injected sequence of conversions interrupt enable

This bit is set and cleared by software to enable/disable the end of injected sequence of conversions interrupt.

0: JEOS interrupt disabled

1: JEOS interrupt enabled. An interrupt is generated when the JEOS bit is set.

Note: The software is allowed to write this bit only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 5 **JEOCIE**: End of injected conversion interrupt enable

This bit is set and cleared by software to enable/disable the end of an injected conversion interrupt.

0: JEOC interrupt disabled.

1: JEOC interrupt enabled. An interrupt is generated when the JEOC bit is set.

Note: The software is allowed to write this bit only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 4 **OVRIE**: Overrun interrupt enable

This bit is set and cleared by software to enable/disable the Overrun interrupt of a regular conversion.

0: Overrun interrupt disabled

1: Overrun interrupt enabled. An interrupt is generated when the OVR bit is set.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 3 **EOSIE**: End of regular sequence of conversions interrupt enable

This bit is set and cleared by software to enable/disable the end of regular sequence of conversions interrupt.

0: EOS interrupt disabled

1: EOS interrupt enabled. An interrupt is generated when the EOS bit is set.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 2 **EOCIE**: End of regular conversion interrupt enable

This bit is set and cleared by software to enable/disable the end of a regular conversion interrupt.

0: EOC interrupt disabled.

1: EOC interrupt enabled. An interrupt is generated when the EOC bit is set.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 1 **EOSMPIE**: End of sampling flag interrupt enable for regular conversions

This bit is set and cleared by software to enable/disable the end of the sampling phase interrupt for regular conversions.

0: EOSMP interrupt disabled.

1: EOSMP interrupt enabled. An interrupt is generated when the EOSMP bit is set.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 0 **ADRDYIE**: ADC ready interrupt enable

This bit is set and cleared by software to enable/disable the ADC Ready interrupt.

0: ADRDY interrupt disabled

1: ADRDY interrupt enabled. An interrupt is generated when the ADRDY bit is set.

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

29.6.3 ADC control register (ADC_CR)

Address offset: 0x08

Reset value: 0x2000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADCAL	ADCALDIF	DEEPPWD	ADVREGEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rs	rw	rw	rw												
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JADSTP	ADSTP	JADSTART	ADSTART	ADDIS	ADEN
										rs	rs	rs	rs	rs	rs

Bit 31 **ADCAL**: ADC calibration

This bit is set by software to start the calibration of the ADC. Program first the bit ADCALDIF to determine if this calibration applies for Single-ended or Differential inputs mode.

It is cleared by hardware after calibration is complete.

0: Calibration complete

1: Write 1 to calibrate the ADC. Read at 1 means that a calibration in progress.

Note: The software is allowed to launch a calibration by setting ADCAL only when ADEN = 0.

The software is allowed to update the calibration factor by writing ADC_CALFACT only when ADEN = 1 and ADSTART = 0 and JADSTART = 0 (ADC enabled and no conversion is ongoing)

Bit 30 **ADCALDIF**: Differential mode for calibration

This bit is set and cleared by software to configure the Single-ended or Differential inputs mode for the calibration.

0: Writing ADCAL launches a calibration in Single-ended inputs mode.

1: Writing ADCAL launches a calibration in Differential inputs mode.

Note: The software is allowed to write this bit only when the ADC is disabled and is not calibrating (ADCAL = 0, JADSTART = 0, JADSTP = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0).

Bit 29 **DEEPPWD**: Deep-power-down enable

This bit is set and cleared by software to put the ADC in Deep-power-down mode.

0: ADC not in Deep-power down

1: ADC in Deep-power-down (default reset state)

Note: The software is allowed to write this bit only when the ADC is disabled (ADCAL = 0, JADSTART = 0, JADSTP = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0).

Bit 28 **ADVREGEN**: ADC voltage regulator enable

This bits is set by software to enable the ADC voltage regulator.

Before performing any operation such as launching a calibration or enabling the ADC, the ADC voltage regulator must first be enabled and the software must wait for the regulator start-up time.

0: ADC Voltage regulator disabled

1: ADC Voltage regulator enabled.

For more details about the ADC voltage regulator enable and disable sequences, refer to *Section 29.4.6: ADC Deep-power-down mode (DEEPPWD) and ADC voltage regulator (ADVREGEN)*.

The software can program this bit field only when the ADC is disabled (ADCAL = 0, JADSTART = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0).

Bits 27:6 Reserved, must be kept at reset value.

Bit 5 **JADSTP**: ADC stop of injected conversion command

This bit is set by software to stop and discard an ongoing injected conversion (JADSTP Command).

It is cleared by hardware when the conversion is effectively discarded and the ADC injected sequence and triggers can be re-configured. The ADC is then ready to accept a new start of injected conversions (JADSTART command).

0: No ADC stop injected conversion command ongoing

1: Write 1 to stop injected conversions ongoing. Read 1 means that an ADSTP command is in progress.

Note: The software is allowed to set JADSTP only when JADSTART = 1 and ADDIS = 0 (ADC is enabled and eventually converting an injected conversion and there is no pending request to disable the ADC)

In Auto-injection mode (JAUTO = 1), setting ADSTP bit aborts both regular and injected conversions (do not use JADSTP)

Bit 4 **ADSTP**: ADC stop of regular conversion command

This bit is set by software to stop and discard an ongoing regular conversion (ADSTP Command).

It is cleared by hardware when the conversion is effectively discarded and the ADC regular sequence and triggers can be re-configured. The ADC is then ready to accept a new start of regular conversions (ADSTART command).

0: No ADC stop regular conversion command ongoing

1: Write 1 to stop regular conversions ongoing. Read 1 means that an ADSTP command is in progress.

Note: The software is allowed to set ADSTP only when ADSTART = 1 and ADDIS = 0 (ADC is enabled and eventually converting a regular conversion and there is no pending request to disable the ADC).

In auto-injection mode (JAUTO = 1), setting ADSTP bit aborts both regular and injected conversions (do not use JADSTP).

Bit 3 **JADSTART**: ADC start of injected conversion

This bit is set by software to start ADC conversion of injected channels. Depending on the configuration bits JEXTEN, a conversion immediately starts (software trigger configuration) or once an injected hardware trigger event occurs (hardware trigger configuration).

It is cleared by hardware:

– in Single conversion mode when software trigger is selected (JEXTSEL = 0x0): at the assertion of the End of Injected Conversion Sequence (JEOS) flag.

– in all cases: after the execution of the JADSTP command, at the same time that JADSTP is cleared by hardware.

0: No ADC injected conversion is ongoing.

1: Write 1 to start injected conversions. Read 1 means that the ADC is operating and eventually converting an injected channel.

Note: The software is allowed to set JADSTART only when ADEN = 1 and ADDIS = 0 (ADC is enabled and there is no pending request to disable the ADC).

In auto-injection mode (JAUTO = 1), regular and auto-injected conversions are started by setting bit ADSTART (JADSTART must be kept cleared)

Bit 2 **ADSTART**: ADC start of regular conversion

This bit is set by software to start ADC conversion of regular channels. Depending on the configuration bits EXTEN, a conversion immediately starts (software trigger configuration) or once a regular hardware trigger event occurs (hardware trigger configuration).

It is cleared by hardware:

– in Single conversion mode when software trigger is selected (EXTSEL = 0x0): at the assertion of the End of Regular Conversion Sequence (EOS) flag.

– in all cases: after the execution of the ADSTP command, at the same time that ADSTP is cleared by hardware.

0: No ADC regular conversion is ongoing.

1: Write 1 to start regular conversions. Read 1 means that the ADC is operating and eventually converting a regular channel.

Note: The software is allowed to set ADSTART only when ADEN = 1 and ADDIS = 0 (ADC is enabled and there is no pending request to disable the ADC)

In auto-injection mode (JAUTO = 1), regular and auto-injected conversions are started by setting bit ADSTART (JADSTART must be kept cleared)

Bit 1 **ADDIS**: ADC disable command

This bit is set by software to disable the ADC (ADDIS command) and put it into power-down state (OFF state).

It is cleared by hardware once the ADC is effectively disabled (ADEN is also cleared by hardware at this time).

0: no ADDIS command ongoing

1: Write 1 to disable the ADC. Read 1 means that an ADDIS command is in progress.

Note: The software is allowed to set ADDIS only when ADEN = 1 and both ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing)

Bit 0 **ADEN**: ADC enable control

This bit is set by software to enable the ADC. The ADC is effectively ready to operate once the flag ADRDY has been set.

It is cleared by hardware when the ADC is disabled, after the execution of the ADDIS command.

0: ADC is disabled (OFF state)

1: Write 1 to enable the ADC.

Note: The software is allowed to set ADEN only when all bits of ADC_CR registers are 0 (ADCAL = 0, JADSTART = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0) except for bit ADVREGEN which must be 1 (and the software must have wait for the startup time of the voltage regulator)

29.6.4 ADC configuration register (ADC_CFGR)

Address offset: 0x0C

Reset value: 0x8000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
JQDIS	AWD1CH[4:0]					JAUTO	JAWD1EN	AWD1EN	AWD1SGL	JQM	JDISCEN	DISCNUM[2:0]			DISCEN
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ALIGN	AUTDLY	CONT	OVRMOD	EXTEN[1:0]		EXTSEL4	EXTSEL3	EXTSEL2	EXTSEL1	EXTSEL0	RES[1:0]		DFSDMCFG	DMACFG	DMAEN
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **JQDIS**: Injected Queue disable

These bits are set and cleared by software to disable the Injected Queue mechanism :

0: Injected Queue enabled

1: Injected Queue disabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no regular nor injected conversion is ongoing).

A set or reset of JQDIS bit causes the injected queue to be flushed and the JSQR register is cleared.

Bits 30:26 **AWD1CH[4:0]**: Analog watchdog 1 channel selection

These bits are set and cleared by software. They select the input channel to be guarded by the analog watchdog.

00000: ADC analog input channel 0 monitored by AWD1

00001: ADC analog input channel 1 monitored by AWD1

.....

10010: ADC analog input channel 18 monitored by AWD1

others: reserved, must not be used

Note: Some channels are not connected physically. Keep the corresponding AWD1CH[4:0] setting to the reset value.

The channel selected by AWD1CH must be also selected into the SQRi or JSQRi registers.

The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 25 **JAUTO:** Automatic injected group conversion

This bit is set and cleared by software to enable/disable automatic injected group conversion after regular group conversion.

0: Automatic injected group conversion disabled

1: Automatic injected group conversion enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no regular nor injected conversion is ongoing).

Bit 24 **JAWD1EN**: Analog watchdog 1 enable on injected channels
This bit is set and cleared by software
0: Analog watchdog 1 disabled on injected channels
1: Analog watchdog 1 enabled on injected channels
Note: The software is allowed to write this bit only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 23 **AWD1EN**: Analog watchdog 1 enable on regular channels
This bit is set and cleared by software
0: Analog watchdog 1 disabled on regular channels
1: Analog watchdog 1 enabled on regular channels
Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 22 **AWD1SGL**: Enable the watchdog 1 on a single channel or on all channels
This bit is set and cleared by software to enable the analog watchdog on the channel identified by the AWD1CH[4:0] bits or on all the channels
0: Analog watchdog 1 enabled on all channels
1: Analog watchdog 1 enabled on a single channel
Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 21 **JQM**: JSQR queue mode
This bit is set and cleared by software.
It defines how an empty Queue is managed.
0: JSQR mode 0: The Queue is never empty and maintains the last written configuration into JSQR.
1: JSQR mode 1: The Queue can be empty and when this occurs, the software and hardware triggers of the injected sequence are both internally disabled just after the completion of the last valid injected sequence.
Refer to *Section 29.4.21: Queue of context for injected conversions* for more information.
Note: The software is allowed to write this bit only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 20 **JDISCEN:** Discontinuous mode on injected channels
This bit is set and cleared by software to enable/disable Discontinuous mode on the injected channels of a group.
0: Discontinuous mode on injected channels disabled
1: Discontinuous mode on injected channels enabled
Note: The software is allowed to write this bit only when JADSTART = 0 (which ensures that no injected conversion is ongoing).
It is not possible to use both auto-injected mode and Discontinuous mode simultaneously: the bits DISCEN and JDISCEN must be kept cleared by software when JAUTO is set.

Bits 19:17 **DISCNUM[2:0]:** Discontinuous mode channel count
These bits are written by software to define the number of regular channels to be converted in Discontinuous mode, after receiving an external trigger.
000: 1 channel
001: 2 channels
...
111: 8 channels
Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 16 **DISCEN**: Discontinuous mode for regular channels

This bit is set and cleared by software to enable/disable Discontinuous mode for regular channels.

0: Discontinuous mode for regular channels disabled

1: Discontinuous mode for regular channels enabled

Note: It is not possible to have both Discontinuous mode and Continuous mode enabled: it is forbidden to set both DISCEN = 1 and CONT = 1.

It is not possible to use both auto-injected mode and Discontinuous mode simultaneously: the bits DISCEN and JDISCEN must be kept cleared by software when JAUTO is set.

The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 15 **ALIGN**: Data alignment

This bit is set and cleared by software to select right or left alignment. Refer to *Section : Data register, data alignment and offset (ADC_DR, OFFSET, OFFSET_CH, ALIGN)*.

0: Right alignment

1: Left alignment

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 14 **AUTDLY**: Delayed conversion mode

This bit is set and cleared by software to enable/disable the Auto Delayed Conversion mode.

0: Auto-delayed conversion mode off

1: Auto-delayed conversion mode on

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 13 **CONT**: Single / Continuous conversion mode for regular conversions

This bit is set and cleared by software. If it is set, regular conversion takes place continuously until it is cleared.

0: Single conversion mode

1: Continuous conversion mode

Note: It is not possible to have both Discontinuous mode and Continuous mode enabled: it is forbidden to set both DISCEN = 1 and CONT = 1.

The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 12 **OVRMOD**: Overrun mode

This bit is set and cleared by software and configure the way data overrun is managed.

0: ADC_DR register is preserved with the old data when an overrun is detected.

1: ADC_DR register is overwritten with the last conversion result when an overrun is detected.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bits 11:10 **EXTEN[1:0]**: External trigger enable and polarity selection for regular channels

These bits are set and cleared by software to select the external trigger polarity and enable the trigger of a regular group.

00: Hardware trigger detection disabled (conversions can be launched by software)
01: Hardware trigger detection on the rising edge
10: Hardware trigger detection on the falling edge
11: Hardware trigger detection on both the rising and falling edges

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bits 9:5 **EXTSEL[4:0]**: External trigger selection for regular group

These bits select the external event used to trigger the start of conversion of a regular group:

00000: adc_ext_trg0
00001: adc_ext_trg1
00010: adc_ext_trg2
00011: adc_ext_trg3
00100: adc_ext_trg4
00101: adc_ext_trg5
00110: adc_ext_trg6
00111: adc_ext_trg7
...
11111: adc_ext_trg31

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bits 4:3 **RES[1:0]**: Data resolution

These bits are written by software to select the resolution of the conversion.

00: 12-bit
01: 10-bit
10: 8-bit
11: 6-bit

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 2 **DFSDMCFG**: DFSDM mode configuration

This bit is set and cleared by software to enable the DFSDM mode. It is effective only when DMAEN = 0.

0: DFSDM mode disabled

1: DFSDM mode enabled

Note: To make sure no conversion is ongoing, the software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0.

Bit 1 **DMACFG**: Direct memory access configuration

This bit is set and cleared by software to select between two DMA modes of operation and is effective only when DMAEN = 1.

0: DMA One Shot mode selected

1: DMA Circular mode selected

For more details, refer to *Section : Managing conversions using the DMA*

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 0 **DMAEN**: Direct memory access enable

This bit is set and cleared by software to enable the generation of DMA requests. This allows to use the DMA to manage automatically the converted data. For more details, refer to *Section : Managing conversions using the DMA*.

0: DMA disabled

1: DMA enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

29.6.5 ADC configuration register 2 (ADC_CFGR2)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	SMPTRIG	BULB	SWTRIG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
				rw	rw	rw									

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	ROVSM	TROVS	OVSS[3:0]				OVSR[2:0]			JOVSE	ROVSE
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **SMPTRIG**: Sampling time control trigger mode

This bit is set and cleared by software to enable the sampling time control trigger mode.

0: Sampling time control trigger mode disabled

1: Sampling time control trigger mode enabled

The sampling time starts on the trigger rising edge, and the conversion on the trigger falling edge.

EXTEN bit should be set to 01. BULB bit must not be set when the SMPTRIG bit is set.

When EXTEN bit is set to 00, set SWTRIG to start the sampling and clear SWTRIG bit to start the conversion.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bit 26 **BULB**: Bulb sampling mode

This bit is set and cleared by software to enable the bulb sampling mode.

0: Bulb sampling mode disabled

1: Bulb sampling mode enabled. The sampling period starts just after the previous end of conversion.

SAMPTRIG bit must not be set when the BULB bit is set.

The very first ADC conversion is performed with the sampling time specified in SMPx bits.

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bit 25 **SWTRIG**: Software trigger bit for sampling time control trigger mode

This bit is set and cleared by software to enable the bulb sampling mode.

0: Software trigger starts the conversion for sampling time control trigger mode

1: Software trigger starts the sampling for sampling time control trigger mode

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bits 24:17 Reserved, must be kept at reset value.

Bits 16:11 Reserved, must be kept at reset value.

Bit 10 **ROVSM**: Regular Oversampling mode

This bit is set and cleared by software to select the regular oversampling mode.

0: Continued mode: When injected conversions are triggered, the oversampling is temporary stopped and continued after the injection sequence (oversampling buffer is maintained during injected sequence)

1: Resumed mode: When injected conversions are triggered, the current oversampling is aborted and resumed from start after the injection sequence (oversampling buffer is zeroed by injected sequence start)

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bit 9 **TROVS**: Triggered Regular Oversampling

This bit is set and cleared by software to enable triggered oversampling

0: All oversampled conversions for a channel are done consecutively following a trigger

1: Each oversampled conversion for a channel needs a new trigger

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bits 8:5 **OVSS[3:0]**: Oversampling shift

This bitfield is set and cleared by software to define the right shifting applied to the raw oversampling result.

0000: No shift
0001: Shift 1-bit
0010: Shift 2-bits
0011: Shift 3-bits
0100: Shift 4-bits
0101: Shift 5-bits
0110: Shift 6-bits
0111: Shift 7-bits
1000: Shift 8-bits
Other codes reserved

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bits 4:2 **OVSR[2:0]**: Oversampling ratio

This bitfield is set and cleared by software to define the oversampling ratio.

000: 2x
001: 4x
010: 8x
011: 16x
100: 32x
101: 64x
110: 128x
111: 256x

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bit 1 **JOVSE**: Injected Oversampling Enable

This bit is set and cleared by software to enable injected oversampling.

0: Injected Oversampling disabled
1: Injected Oversampling enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing)

Bit 0 **ROVSE**: Regular Oversampling Enable

This bit is set and cleared by software to enable regular oversampling.

0: Regular Oversampling disabled
1: Regular Oversampling enabled

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing)

29.6.6 ADC sample time register 1 (ADC_SMPR1)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SMPPLUS	Res.	SMP9[2:0]			SMP8[2:0]			SMP7[2:0]			SMP6[2:0]			SMP5[2:1]	
rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SMP5[0]	SMP4[2:0]			SMP3[2:0]			SMP2[2:0]			SMP1[2:0]			SMP0[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **SMPPLUS:** Addition of one clock cycle to the sampling time.

1: 2.5 ADC clock cycle sampling time becomes 3.5 ADC clock cycles for the ADC_SMPR1 and ADC_SMPR2 registers.

0: The sampling time remains set to 2.5 ADC clock cycles remains

To make sure no conversion is ongoing, the software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0.

Bit 30 Reserved, must be kept at reset value.

Bits 29:0 **SMP[9:0][2:0]:** Channel x sampling time selection

These bits are written by software to select the sampling time individually for each channel. During sample cycles, the channel selection bits must remain unchanged.

000: 2.5 ADC clock cycles

001: 6.5 ADC clock cycles

010: 12.5 ADC clock cycles

011: 24.5 ADC clock cycles

100: 47.5 ADC clock cycles

101: 92.5 ADC clock cycles

110: 247.5 ADC clock cycles

111: 640.5 ADC clock cycles

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Some channels are not connected physically. Keep the corresponding SMPx[2:0] setting to the reset value.

29.6.7 ADC sample time register 2 (ADC_SMPR2)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	SMP18[2:0]			SMP17[2:0]			SMP16[2:0]			SMP15[2:1]	
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SMP15[0]	SMP14[2:0]			SMP13[2:0]			SMP12[2:0]			SMP11[2:0]			SMP10[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bits 26:0 **SMP[18:10][2:0]:** Channel x sampling time selection

These bits are written by software to select the sampling time individually for each channel. During sampling cycles, the channel selection bits must remain unchanged.

000: 2.5 ADC clock cycles
001: 6.5 ADC clock cycles
010: 12.5 ADC clock cycles
011: 24.5 ADC clock cycles
100: 47.5 ADC clock cycles
101: 92.5 ADC clock cycles
110: 247.5 ADC clock cycles
111: 640.5 ADC clock cycles

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Some channels are not connected physically. Keep the corresponding SMPx[2:0] setting to the reset value.

29.6.8 ADC watchdog threshold register 1 (ADC_TR1)

Address offset: 0x20

Reset value: 0x0FFF 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	HT1[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	AWDFILT[2:0]			LT1[11:0]											
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **HT1[11:0]**: Analog watchdog 1 higher threshold

These bits are written by software to define the higher threshold for the analog watchdog 1.

Refer to *Section 29.4.29: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)*

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **AWDFILT[2:0]**: Analog watchdog filtering parameter

This bit is set and cleared by software.

000: No filtering

001: two consecutive detection generates an AWDx flag or an interrupt

...

111: Eight consecutive detection generates an AWDx flag or an interrupt

Note: The software is allowed to write this bit only when ADSTART = 0 (which ensures that no conversion is ongoing).

Bits 11:0 **LT1[11:0]**: Analog watchdog 1 lower threshold

These bits are written by software to define the lower threshold for the analog watchdog 1.

Refer to *Section 29.4.29: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)*

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

29.6.9 ADC watchdog threshold register 2 (ADC_TR2)

Address offset: 0x24

Reset value: 0x00FF 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HT2[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LT2[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **HT2[7:0]**: Analog watchdog 2 higher threshold

These bits are written by software to define the higher threshold for the analog watchdog 2.

Refer to *Section 29.4.29: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)*

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **LT2[7:0]**: Analog watchdog 2 lower threshold

These bits are written by software to define the lower threshold for the analog watchdog 2.

Refer to *Section 29.4.29: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)*

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

29.6.10 ADC watchdog threshold register 3 (ADC_TR3)

Address offset: 0x28

Reset value: 0x00FF 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HT3[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LT3[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **HT3[7:0]**: Analog watchdog 3 higher threshold

These bits are written by software to define the higher threshold for the analog watchdog 3.

Refer to *Section 29.4.29: Analog window watchdog (AWD1EN, JAWD1EN, AWD1SGL, AWD1CH, AWD2CH, AWD3CH, AWD_HTx, AWD_LTx, AWDx)*

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **LT3[7:0]**: Analog watchdog 3 lower threshold

These bits are written by software to define the lower threshold for the analog watchdog 3.

This watchdog compares the 8-bit of LT3 with the 8 MSB of the converted data.

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

29.6.11 ADC regular sequence register 1 (ADC_SQR1)

Address offset: 0x30

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	SQ4[4:0]					Res.	SQ3[4:0]					Res.	SQ2[4]
			rw	rw	rw	rw	rw		rw	rw	rw	rw	rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SQ2[3:0]				Res.	SQ1[4:0]					Res.	Res.	L[3:0]			
rw	rw	rw	rw		rw	rw	rw	rw	rw			rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:24 **SQ4[4:0]:** 4th conversion in regular sequence

These bits are written by software with the channel number (0 to 18) assigned as the 4th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 23 Reserved, must be kept at reset value.

Bits 22:18 **SQ3[4:0]:** 3rd conversion in regular sequence
These bits are written by software with the channel number (0 to 18) assigned as the 3rd in the regular conversion sequence.
Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 17 Reserved, must be kept at reset value.

Bits 16:12 **SQ2[4:0]:** 2nd conversion in regular sequence
These bits are written by software with the channel number (0 to 18) assigned as the 2nd in the regular conversion sequence.
Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 11 Reserved, must be kept at reset value.

Bits 10:6 **SQ1[4:0]:** 1st conversion in regular sequence
These bits are written by software with the channel number (0 to 18) assigned as the 1st in the regular conversion sequence.
Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bits 5:4 Reserved, must be kept at reset value.

Bits 3:0 **L[3:0]:** Regular channel sequence length
These bits are written by software to define the total number of conversions in the regular channel conversion sequence.
0000: 1 conversion
0001: 2 conversions
...
1111: 16 conversions
Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Note: Some channels are not connected physically and must not be selected for conversion.

29.6.12 ADC regular sequence register 2 (ADC_SQR2)

Address offset: 0x34

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	SQ9[4:0]					Res.	SQ8[4:0]					Res.	SQ7[4]
			rw	rw	rw	rw	rw		rw	rw	rw	rw	rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SQ7[3:0]				Res.	SQ6[4:0]					Res.	SQ5[4:0]				
rw	rw	rw	rw		rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:24 **SQ9[4:0]:** 9th conversion in regular sequence

These bits are written by software with the channel number (0 to 18) assigned as the 9th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 23 Reserved, must be kept at reset value.

Bits 22:18 **SQ8[4:0]:** 8th conversion in regular sequence

These bits are written by software with the channel number (0 to 18) assigned as the 8th in the regular conversion sequence

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 17 Reserved, must be kept at reset value.

Bits 16:12 **SQ7[4:0]:** 7th conversion in regular sequence

These bits are written by software with the channel number (0 to 18) assigned as the 7th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 11 Reserved, must be kept at reset value.

Bits 10:6 **SQ6[4:0]:** 6th conversion in regular sequence

These bits are written by software with the channel number (0 to 18) assigned as the 6th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **SQ5[4:0]:** 5th conversion in regular sequence

These bits are written by software with the channel number (0 to 18) assigned as the 5th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Note: Some channels are not connected physically and must not be selected for conversion.

29.6.13 ADC regular sequence register 3 (ADC_SQR3)

Address offset: 0x38

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	SQ14[4:0]					Res.	SQ13[4:0]					Res.	SQ12[4]
			rw	rw	rw	rw	rw		rw	rw	rw	rw	rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SQ12[3:0]				Res.	SQ11[4:0]					Res.	SQ10[4:0]				
rw	rw	rw	rw		rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:24 **SQ14[4:0]:** 14th conversion in regular sequence

These bits are written by software with the channel number (0 to 18) assigned as the 14th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 23 Reserved, must be kept at reset value.

Bits 22:18 **SQ13[4:0]:** 13th conversion in regular sequence

These bits are written by software with the channel number (0 to 18) assigned as the 13th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 17 Reserved, must be kept at reset value.

Bits 16:12 **SQ12[4:0]:** 12th conversion in regular sequence

These bits are written by software with the channel number (0 to 18) assigned as the 12th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 11 Reserved, must be kept at reset value.

Bits 10:6 **SQ11[4:0]:** 11th conversion in regular sequence

These bits are written by software with the channel number (0 to 18) assigned as the 11th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **SQ10[4:0]:** 10th conversion in regular sequence

These bits are written by software with the channel number (0 to 18) assigned as the 10th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Note: Some channels are not connected physically and must not be selected for conversion.

29.6.14 ADC regular sequence register 4 (ADC_SQR4)

Address offset: 0x3C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	SQ16[4:0]					Res.	SQ15[4:0]				
					rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:6 **SQ16[4:0]:** 16th conversion in regular sequence

These bits are written by software with the channel number (0 to 18) assigned as the 16th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **SQ15[4:0]:** 15th conversion in regular sequence

These bits are written by software with the channel number (0 to 18) assigned as the 15th in the regular conversion sequence.

Note: The software is allowed to write these bits only when ADSTART = 0 (which ensures that no regular conversion is ongoing).

Note: Some channels are not connected physically and must not be selected for conversion.

29.6.15 ADC regular data register (ADC_DR)

Address offset: 0x40

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **RDATA[15:0]**: Regular data converted

These bits are read-only. They contain the conversion result from the last converted regular channel. The data are left- or right-aligned as described in *Section 29.4.26: Data management*.

29.6.16 ADC injected sequence register (ADC_JSQR)

Address offset: 0x4C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
JSQ4[4:0]					Res.	JSQ3[4:0]					Res.	JSQ2[4:1]			
rw	rw	rw	rw	rw		rw	rw	rw	rw	rw		rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
JSQ2[0]	Res.	JSQ1[4:0]					JEXTEN[1:0]		JEXTSEL[4:0]					JL[1:0]	
rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 **JSQ4[4:0]:** 4th conversion in the injected sequence

These bits are written by software with the channel number (0 to 18) assigned as the 4th in the injected conversion sequence.

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 26 Reserved, must be kept at reset value.

Bits 25:21 **JSQ3[4:0]:** 3rd conversion in the injected sequence

These bits are written by software with the channel number (0 to 18) assigned as the 3rd in the injected conversion sequence.

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 20 Reserved, must be kept at reset value.

Bits 19:15 **JSQ2[4:0]:** 2nd conversion in the injected sequence

These bits are written by software with the channel number (0 to 18) assigned as the 2nd in the injected conversion sequence.

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bit 14 Reserved, must be kept at reset value.

Bits 13:9 **JSQ1[4:0]:** 1st conversion in the injected sequence

These bits are written by software with the channel number (0 to 18) assigned as the 1st in the injected conversion sequence.

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bits 8:7 **JEXTEN[1:0]**: External trigger enable and polarity selection for injected channels

These bits are set and cleared by software to select the external trigger polarity and enable the trigger of an injected group.

00: If JQDIS = 0 (queue enabled), hardware and software trigger detection disabled. Otherwise, the queue is disabled as well as hardware trigger detection (conversions can be launched by software)

01: Hardware trigger detection on the rising edge

10: Hardware trigger detection on the falling edge

11: Hardware trigger detection on both the rising and falling edges

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

If JQM = 1 and if the Queue of Context becomes empty, the software and hardware triggers of the injected sequence are both internally disabled (refer to Section 29.4.21: Queue of context for injected conversions)

Bits 6:2 **JEXTSEL[4:0]**: External Trigger Selection for injected group

These bits select the external event used to trigger the start of conversion of an injected group:

00000: adc_jext_trg0

00001: adc_jext_trg1

00010: adc_jext_trg2

00011: adc_jext_trg3

00100: adc_jext_trg4

00101: adc_jext_trg5

00110: adc_jext_trg6

00111: adc_jext_trg7

...

11111: adc_jext_trg31

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Bits 1:0 **JL[1:0]:** Injected channel sequence length

These bits are written by software to define the total number of conversions in the injected channel conversion sequence.

00: 1 conversion

01: 2 conversions

10: 3 conversions

11: 4 conversions

Note: The software is allowed to write these bits only when JADSTART = 0 (which ensures that no injected conversion is ongoing).

Note: Some channels are not connected physically and must not be selected for conversion.

29.6.17 ADC offset y register (ADC_OFRy)

Address offset: 0x60 + 0x04 * (y -1), (y = 1 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OFFSET_EN	OFFSET_CH[4:0]					SATEN	OFFSETPOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	OFFSET[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **OFFSET_EN:** Offset y enable

This bit is written by software to enable or disable the offset programmed into bits OFFSET[11:0].

Note: The software is allowed to write this bit only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bits 30:26 **OFFSET_CH[4:0]:** Channel selection for the data offset y

These bits are written by software to define the channel to which the offset programmed into bits OFFSET[11:0] applies.

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Some channels are not connected physically and must not be selected for the data offset y.

If OFFSET_EN is set, it is not allowed to select the same channel for different ADC_OFRy registers.

Bit 25 **SATEN**: Saturation enable

This bit is set and cleared by software to enable the saturation at 0x000 and 0xFFF for the offset function.

0: No saturation control, offset result can be signed

1: Saturation enabled, offset result unsigned and saturated at 0x000 and 0xFFF

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bit 24 **OFFSETPOS**: Positive offset

This bit is set and cleared by software to enable the positive offset.

0: Negative offset

1: Positive offset

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Bits 23:12 Reserved, must be kept at reset value.

Bits 11:0 **OFFSET[11:0]:** Data offset y for the channel programmed into bits OFFSET_CH[4:0]

These bits are written by software to define the offset to be subtracted from the raw converted data when converting a channel (can be regular or injected). The channel to which applies the data offset must be programmed in the bits OFFSET_CH[4:0]. The conversion result can be read from in the ADC_DR (regular conversion) or from in the ADC_JDRyi registers (injected conversion).

Note: The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

If several offset (OFFSET) point to the same channel, only the offset with the lowest x value is considered for the subtraction.
Ex: if OFFSET1_CH[4:0] = 4 and OFFSET2_CH[4:0] = 4, this is OFFSET1[11:0] which is subtracted when converting channel 4.

29.6.18 ADC injected channel y data register (ADC_JDRy)

Address offset: 0x80 + 0x04 * (y - 1), (y = 1 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
JDATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **JDATA[15:0]:** Injected data

These bits are read-only. They contain the conversion result from injected channel y. The data are left -or right-aligned as described in *Section 29.4.26: Data management*.

29.6.19 ADC Analog Watchdog 2 Configuration Register (ADC_AWD2CR)

Address offset: 0xA0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWD2CH[18:16]		
													rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AWD2CH[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:0 **AWD2CH[18:0]**: Analog watchdog 2 channel selection

These bits are set and cleared by software. They enable and select the input channels to be guarded by the analog watchdog 2.

AWD2CH[i] = 0: ADC analog input channel i is not monitored by AWD2

AWD2CH[i] = 1: ADC analog input channel i is monitored by AWD2

When AWD2CH[18:0] = 000..0, the analog Watchdog 2 is disabled

Note: The channels selected by AWD2CH must be also selected into the SQRi or JSQRi registers.

The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Some channels are not connected physically and must not be selected for the analog watchdog.

29.6.20 ADC Analog Watchdog 3 Configuration Register (ADC_AWD3CR)

Address offset: 0xA4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWD3CH[18:16]		
													rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AWD3CH[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:0 **AWD3CH[18:0]**: Analog watchdog 3 channel selection

These bits are set and cleared by software. They enable and select the input channels to be guarded by the analog watchdog 3.

AWD3CH[i] = 0: ADC analog input channel i is not monitored by AWD3

AWD3CH[i] = 1: ADC analog input channel i is monitored by AWD3

When AWD3CH[18:0] = 000..0, the analog Watchdog 3 is disabled

Note: The channels selected by AWD3CH must be also selected into the SQRi or JSQRi registers.

The software is allowed to write these bits only when ADSTART = 0 and JADSTART = 0 (which ensures that no conversion is ongoing).

Some channels are not connected physically and must not be selected for the analog watchdog.

29.6.21 ADC Differential mode Selection Register (ADC_DIFSEL)

Address offset: 0xB0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIFSEL[18:16]		
													rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIFSEL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:0 **DIFSEL[18:0]:** Differential mode for channels **18** to 0.

These bits are set and cleared by software. They allow to select if a channel is configured as Single-ended or Differential mode.

DIFSEL[i] = 0: ADC analog input channel is configured in Single-ended mode

DIFSEL[i] = 1: ADC analog input channel i is configured in Differential mode

Note: The DIFSEL bits corresponding to channels that are either connected to a single-ended I/O port or to an internal channel must be kept their reset value (Single-ended input mode).

The software is allowed to write these bits only when the ADC is disabled (ADCAL = 0, JADSTART = 0, JADSTP = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0).

29.6.22 ADC Calibration Factors (ADC_CALFACT)

Address offset: 0xB4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CALFACT_D[6:0]						
									rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CALFACT_S[6:0]						
									rw	rw	rw	rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:16 **CALFACT_D[6:0]**: Calibration Factors in differential mode

These bits are written by hardware or by software.

Once a differential inputs calibration is complete, they are updated by hardware with the calibration factors.

Software can write these bits with a new calibration factor. If the new calibration factor is different from the current one stored into the analog ADC, it is then applied once a new differential calibration is launched.

Note: The software is allowed to write these bits only when ADEN = 1, ADSTART = 0 and JADSTART = 0 (ADC is enabled and no calibration is ongoing and no conversion is ongoing).

Bits 15:7 Reserved, must be kept at reset value.

Bits 6:0 **CALFACT_S[6:0]**: Calibration Factors In Single-ended mode

These bits are written by hardware or by software.

Once a single-ended inputs calibration is complete, they are updated by hardware with the calibration factors.

Software can write these bits with a new calibration factor. If the new calibration factor is different from the current one stored into the analog ADC, it is then applied once a new single-ended calibration is launched.

Note: The software is allowed to write these bits only when ADEN = 1, ADSTART = 0 and JADSTART = 0 (ADC is enabled and no calibration is ongoing and no conversion is ongoing).

29.7 ADC common registers

29.7.1 ADC common control register (ADC_CCR)

Address offset: 0x308

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	VBATEN	TSEN	VREFEN	PRESC[3:0]				CKMODE[1:0]	
							rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **VBATEN**: VBAT enable

This bit is set and cleared by software to control.

0: V_{BAT} channel disabled

1: V_{BAT} channel enabled

Bit 23 **TSEN**: V_{SENSE} enable

This bit is set and cleared by software to control V_{SENSE}.

0: Temperature sensor channel disabled

1: Temperature sensor channel enabled

Bit 22 **VREFEN**: V_{REFINT} enable

This bit is set and cleared by software to enable/disable the V_{REFINT} channel.

0: V_{REFINT} channel disabled

1: V_{REFINT} channel enabled

Bits 21:18 **PRESC[3:0]**: ADC prescaler

These bits are set and cleared by software to select the frequency of the clock to the ADC. The clock is common for all the ADCs.

0000: input ADC clock not divided
0001: input ADC clock divided by 2
0010: input ADC clock divided by 4
0011: input ADC clock divided by 6
0100: input ADC clock divided by 8
0101: input ADC clock divided by 10
0110: input ADC clock divided by 12
0111: input ADC clock divided by 16
1000: input ADC clock divided by 32
1001: input ADC clock divided by 64
1010: input ADC clock divided by 128
1011: input ADC clock divided by 256
other: reserved

Note: The software is allowed to write these bits only when the ADC is disabled (ADCAL = 0, JADSTART = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0). The ADC prescaler value is applied only when CKMODE[1:0] = 0b00.

Bits 17:16 **CKMODE[1:0]:** ADC clock mode

These bits are set and cleared by software to define the ADC clock scheme (which is common to both master and slave ADCs):

00: adc_ker_ck (x = 3) (Asynchronous clock mode), generated at product level (refer to *Section 6: Reset and clock control (RCC)*)

01: adc_hclk/1 (Synchronous clock mode). This configuration must be enabled only if the AHB clock prescaler is set to 1 (HPRE[3:0] = 0XXX in RCC_CFGR register) and if the system clock has a 50% duty cycle.

10: adc_hclk/2 (Synchronous clock mode)

11: adc_hclk/4 (Synchronous clock mode)

In all synchronous clock modes, there is no jitter in the delay from a timer trigger to the start of a conversion.

Note: The software is allowed to write these bits only when the ADCs are disabled (ADCAL = 0, JADSTART = 0, ADSTART = 0, ADSTP = 0, ADDIS = 0 and ADEN = 0).

Bits 15:0 Reserved, must be kept at reset value.

29.8 ADC register map

Table 252. ADC global register map

Offset	Register
0x000 - 0x0B4	Master ADC3/2
0x0B8 - 0x2FC	Reserved
0x300 - 0x30C	Master and slave ADCs common registers

Table 253. ADC register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**ADC_ISR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JQOVF	AWD3	AWD2	AWD1	JEOS	JEOC	OVR	EOS	EOC	EOSMP	ADRDY
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x04	**ADC_IER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JQOVFIE	AWD3IE	AWD2IE	AWD1IE	JEOSIE	JEOCIE	OVRIE	EOSIE	EOCIE	EOSMPIE	ADRDYIE
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x08	**ADC_CR**	ADCAL	ADCALDIF	DEEPPWD	ADVREGEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JADSTP	ADSTP	JADSTART	ADSTART	ADDIS	ADEN
	Reset value	0	0	1	0																							0	0	0	0	0	0
0x0C	**ADC_CFGR**	JQDIS	AWD1CH[4:0]					JAUTO	JAWD1EN	AWD1EN	AWD1SGL	JQM	JDISCEN	DISCNUM[2:0]			DISCEN	ALIGN	AUTDLY	CONT	OVRMOD	EXTEN[1:0]		EXTSEL4	EXTSEL3	EXTSEL2	EXTSEL1	EXTSEL0	RES[1:0]		DFSDMCFG	DMACFG	DMAEN
	Reset value	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	**ADC_CFGR2**	Res.	Res.	Res.	Res.	SMPTRIG	BULB	SWTRIG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ROVSM	TROVS	OVSS[3:0]				OVSR[2:0]		JOVSE	ROVSE	
	Reset value					0	0	0															0	0	0	0	0	0	0	0	0	0	0
0x14	**ADC_SMPR1**	SMPPLUS	Res.	SMP9 [2:0]			SMP8 [2:0]			SMP7 [2:0]			SMP6 [2:0]			SMP5 [2:0]			SMP4 [2:0]			SMP3 [2:0]			SMP2 [2:0]			SMP1 [2:0]			SMP0 [2:0]		
	Reset value	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	**ADC_SMPR2**	Res.	Res.	Res.	Res.	Res.	SMP18 [2:0]			SMP17 [2:0]			SMP16 [2:0]			SMP15 [2:0]			SMP14 [2:0]			SMP13 [2:0]			SMP12 [2:0]			SMP11 [2:0]			SMP10 [2:0]		
	Reset value						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	Reserved	Res.																															
0x20	**ADC_TR1**	Res.	Res.	Res.	Res.	HT1[11:0]												Res.	AWDFILT [2:0]			LT1[11:0]												
	Reset value					1	1	1	1	1	1	1	1	1	1	1	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x24	**ADC_TR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HT2[[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LT2[7:0]							
	Reset value									1	1	1	1	1	1	1	1									0	0	0	0	0	0	0	0
0x28	**ADC_TR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HT3[[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LT3[7:0]							
	Reset value									1	1	1	1	1	1	1	1									0	0	0	0	0	0	0	0

Table 253. ADC register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x2C	Reserved	Res.																															
0x30	**ADC_SQR1**	Res.	Res.	Res.	SQ4[4:0]					Res.	SQ3[4:0]					Res.	SQ2[4:0]					Res.	SQ1[4:0]					Res.	Res.	L[3:0]			
	Reset value				0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0			0	0	0	0
0x34	**ADC_SQR2**	Res.	Res.	Res.	SQ9[4:0]					Res.	SQ8[4:0]					Res.	SQ7[4:0]					Res.	SQ6[4:0]					Res.	SQ5[4:0]				
	Reset value				0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0
0x38	**ADC_SQR3**	Res.	Res.	Res.	SQ14[4:0]					Res.	SQ13[4:0]					Res.	SQ12[4:0]					Res.	SQ11[4:0]					Res.	SQ10[4:0]				
	Reset value				0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0
0x3C	**ADC_SQR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SQ16[4:0]					Res.	SQ15[4:0]				
	Reset value																						0	0	0	0	0		0	0	0	0	0
0x40	**ADC_DR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	regular RDATA[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x44-0x48	Reserved	Res.																															
0x4C	**ADC_JSQR**	JSQ4[4:0]					Res.	JSQ3[4:0]					Res.	JSQ2[4:0]				Res.	JSQ1[4:0]				JEXTEN[1:0]		JEXTSEL [4:0]				JL[1:0]			
	Reset value	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x50-0x5C	Reserved	Res.																															
0x60	**ADC_OFR1**	OFFSET_EN	OFFSET_ CH[4:0]					SATEN	OFFSETPOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OFFSET[11:0]										
	Reset value	0	0	0	0	0	0	0	0														0	0	0	0	0	0	0	0	0	0	0
0x64	**ADC_OFR2**	OFFSET_EN	OFFSET_ CH[4:0]					SATEN	OFFSETPOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OFFSET[11:0]										
	Reset value	0	0	0	0	0	0	0	0														0	0	0	0	0	0	0	0	0	0	0
0x68	**ADC_OFR3**	OFFSET_EN	OFFSET_ CH[4:0]					SATEN	OFFSETPOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OFFSET[11:0]										
	Reset value	0	0	0	0	0	0	0	0														0	0	0	0	0	0	0	0	0	0	0
0x6C	**ADC_OFR4**	OFFSET_EN	OFFSET_ CH[4:0]					SATEN	OFFSETPOS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OFFSET[11:0]										
	Reset value	0	0	0	0	0	0	0	0														0	0	0	0	0	0	0	0	0	0	0
0x70-0x7C	Reserved	Res.																															
0x80	**ADC_JDR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JDATA1[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x84	**ADC_JDR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JDATA2[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 253. ADC register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x88	**ADC_JDR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JDATA3[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x8C	**ADC_JDR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JDATA4[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x90-0x9C	Reserved	Res.																															
0xA0	**ADC_AWD2CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWD2CH[18:0]																		
	Reset value														0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xA4	**ADC_AWD3CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWD3CH[18:0]																		
	Reset value														0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xA8-0xAC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0xB0	**ADC_DIFSEL**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIFSEL[18:0]																		
	Reset value														0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xB4	**ADC_CALFACT**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CALFACT_D[6:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CALFACT_S[6:0]							
	Reset value									0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0
0xB8-0xC4	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0xCC-0xFC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Table 254. ADC register map and reset values (master and slave ADC common registers)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x304	Reserved	Res.																															
0x308	**ADC_CCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VBATEN	TSEN	VREFEN	PRESC[3:0]				CKMODE[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value								0	0	0	0	0	0	0	0	0																
x30C-0x3EC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Refer to *Section 2.3 on page 131* for the register boundary addresses.

30 Digital temperature sensor (DTS)

30.1 Introduction

The device embeds a sensor that converts the temperature into a square wave which frequency is proportional to the temperature. The frequency is measured either with the PCLK or the LSE clock.

30.2 DTS main features

The temperature sensor block main features are the following:

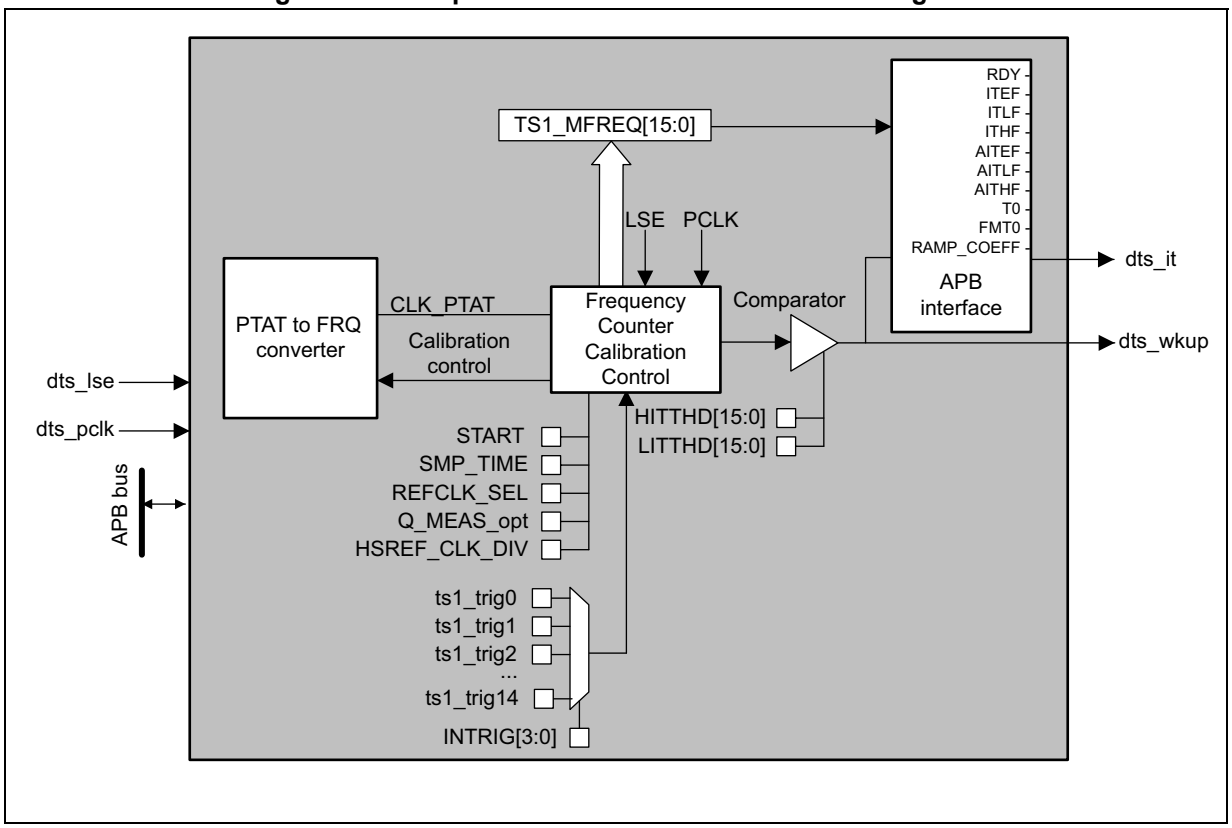
- Start of measurement triggered by software or 4 hardware sources
- Programmable sampling time to increase temperature measurement precision
- Counter synchronized on LSE or PCLK clock
- Temperature watchdog on low and high threshold
- Interrupt generation when the temperature is lower or higher than predefined thresholds and at the end of measurement.
- Asynchronous wakeup signal generation when the temperature is higher/lower than a predefined threshold (LSE mode only)
- Quick measurement using LSE clock

30.3 DTS functional description

30.3.1 DTS block diagram

The temperature sensor block diagram is shown in *Figure 284*.

Figure 284. Temperature sensor functional block diagram



30.3.2 DTS internal signals

Table 255. DTS internal input/output signals

Signal name	Signal type	Description
dts_lse	Digital input	LSE clock
dts_pclk	Digital input	APB clock
dts_it	Digital output	Temperature sensor interrupt
dts_wkup	Digital output	Temperature sensor wakeup

30.3.3 DTS block operation

The analog part of the temperature sensor outputs a frequency that is proportional to the absolute temperature (CLK_PTAT). The frequency measurement is based on the PCLK or the LSE clock.

Before each measurement, the temperature sensor performs a calibration of the frequency generation blocks.

30.3.4 Operating modes

Several operating modes can be selected by setting the REFCLK_SEL bit in *Temperature sensor configuration register 1 (DTS_CFGR1)*:

- PCLK only (REFCLK_SEL = 0)

  The temperature sensor registers can be accessed. The interface can consequently be reconfigured and the measurement sequence is performed using PCLK clock
- PCLK and LSE (REFCLK_SEL = 1)

  The temperature sensor registers can be accessed. The interface can consequently be reconfigured and the measurement sequence is performed using the LSE clock.
- LSE only (REFCLK_SEL = 1) and PCLK OFF

  The registers cannot be accessed. The measurement can be performed using the LSE clock. This mode is used to exit from Sleep mode by using hardware triggers and the asynchronous interrupt line.

30.3.5 Calibration

The temperature sensor must run the calibration prior to any frequency measurement. The calibration is performed automatically when the temperature measurement is triggered except for quick measurement mode (Q_MEAS_OPT set to 1 in DTS_CFGR1).

30.3.6 Prescaler

When a calibration is ongoing, the counter clock must be slower than 1 MHz. This is achieved by the PCLK clock prescaler embedded in the temperature sensor.

During the temperature measurement period, the prescaler is bypassed.

- When PCLK is used as reference clock (REFCLK_SEL set to 0 in DTS_CFGR1), a prescaler is used. Its division ratio must be configured up to 127 (refer to the HSREF_CLK_DIV[6:0] register definition for the divider setting).
- When LSE is used as reference clock (REFCLK_SEL set to 1 in DTS_CFGR1), the timebase is equal to 2 LSE periods. In this case, no prescaler is used.

30.3.7 Temperature measurement principles

The analog part of temperature sensor outputs a signal (CLK_PTAT) which FM(T) frequency is temperature-dependent (typically 641 kHz).

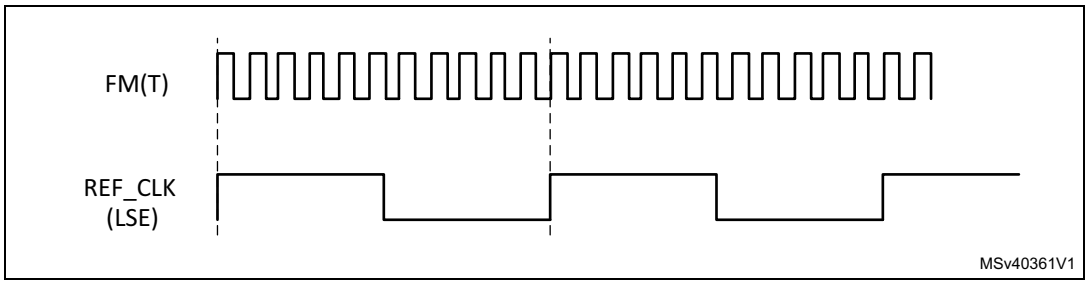
Either PCLK or LSE can be selected as reference clock (REF_CLK) through the REFCLK_SEL bit in DTS_CFGR1.

The counting method depends on the REF_CLK frequency. This is due to the fact that two counters are implemented in the temperature sensor block:

- For low REF_CLK frequencies, a counting of FM(T) cycles is performed during one or several REF_CLK cycles.
- For high REF_CLK frequencies, a counting of REF_CLK cycles is performed during one or several FM(T) cycles.

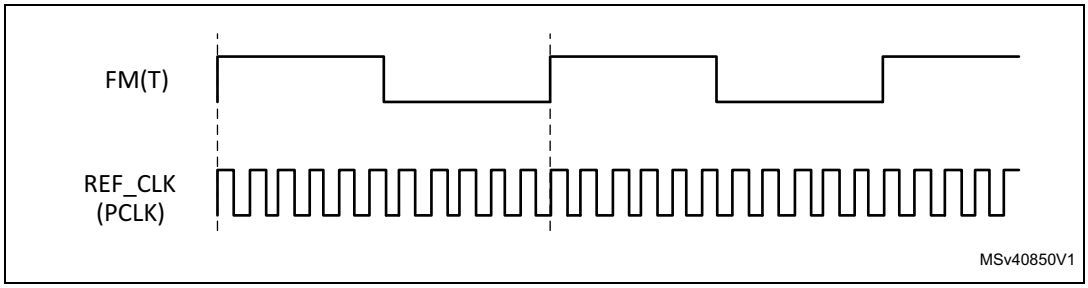
This counter behavior is shown in *Figure 285* and *Figure 286*.

Figure 285. Method for low REF_CLK frequencies



1. To increase the precision, FM(T) measurement can be done on several LSE periods.

Figure 286. Method for high REF_CLK frequencies



1. To increase the precision, PCLK measurement can be done on several FM(T) periods.

The counting result is stored in the DTS_DR register (see *Temperature sensor data register (DTS_DR)*.

Once the FM(T) frequency has been obtained, the corresponding temperature can be calculated by software using the following formula:

- When PCLK is used:

$$T = T_0 + ((F_{PCLK} / TS1\_MFREQ) \times TS1\_SMP\_TIME - 100 \times TS1\_FMT0) / TS1\_RAMP\_COEFF$$

where

T0 (factory calibration temperature) is equal to 30 °C.

TS1_FMT0 is measured and stored in the DTS_T0VALR1 register. It is expressed in hundreds of Hertz.

TS1_RAMP_COEFF is measured during tests in factory and stored in DTS_RAMPVALR register. This value is expressed in Hz/°C.

- When the LSE clock is used

$$T = T_0 + ((F_{LSE} \times TS1\_MFREQ / TS1\_SMP\_TIME) - (100 \times TS1\_FMT0)) / TS1\_RAMP\_COEFF$$

30.3.8 Sampling time

The sampling period can be increased to improve measurement accuracy. This is useful when the reference frequency (REF_CLK) is close to the FM(T) frequency. The default value is one REF_CLK cycle in LSE mode, and one FM(T) cycle in PCLK mode.

The sampling time is configured through TS1_SMP_TIME bits in DTS_CFGR1 register (see *Table 256*).

Table 256. Sampling time configuration

TS1_SMP_TIME[3:0]	LSE or FM(T) clock cycle(s)
0000	1
0001	1
0010	2
0011	3
0100	4
0101	5
0110	6
0111	7
1000	8
1001	9
1010	10
1011	11
1100	12
1101	13
1110	14
1111	15

30.3.9 Quick measurement mode

If a high precision is not required, the calibration step included in each measurement sequence can be skipped by setting Q_MEAS_OPT to 1 in the DTS_CFGR1 register. This method shall be used only when the LSE clock is selected as reference clock (LSREF_CLK set to 1). This mode can reduce the measurement time down to 162 µs.

30.3.10 Trigger input

The temperature measurement can be triggered either by software or by an external event. The trigger source can be selected through TS1_INTRIG[3:0] bits in DTS_CFGR1.

Table 257. Trigger configuration

Name	TS1_INTRIG[3:0]				Comment
N.A	0	0	0	0	No hardware trigger
ts1_trg0	0	0	0	1	lptim1_out
ts1_trg1	0	0	1	0	lptim2_out
ts1_trg2	0	0	1	1	lptim3_out
ts1_trg3	0	1	0	0	exti13
ts1_trg4	0	1	0	1	Reserved
ts1_trg5	0	1	1	0	
ts1_trg6	0	1	1	1	
ts1_trg7	1	0	0	0	
ts1_trg8	1	0	0	1	
ts1_trg9	1	0	1	0	
ts1_trg10	1	0	1	1	
ts1_trg11	1	1	0	0	
ts1_trg12	1	1	0	1	
ts1_trg13	1	1	1	0	
ts1_trg14	1	1	1	1	

Note: Hardware triggers are active only on the rising edge.

The temperature sensor can only capture a hardware trigger rising edge when TS1_RDY bit is set (see Section 30.3.11: On-off control and ready flag, otherwise the trigger is ignored.

If a trigger source changes on-the-fly, the new trigger source signal should be low. If the new source signal is high, the temperature sensor detects a rising edge and start the measurement sequence.

30.3.11 On-off control and ready flag

The DTS block can be enabled by setting TS1_EN bit in DTS_CFGR1 register. The TS1_RDY flag in the *Temperature sensor status register (DTS_SR)* indicate that the DTS block is ready for temperature measurement: when TS1_RDY bit is set to 1, the measurement can be started. Once a measurement has started, TS1_RDY bit is reset. New measurement requests will then be ignored. Once the measurement is finished, TS1_RDY bit is set again to indicate the sensor is ready to start a new measurement.

30.3.12 Temperature measurement sequence

Start of measurement can be triggered by software or hardware.

Software trigger

The software trigger is selected when TS1_INTRIG_SEL[3:0] is set to ‘0000’ in DTS_CFGR1.

If TS1_RDY is set to 1, writing TS1_START bit to 1 in DTS_CFGR1 starts the measurement.

If TS1_RDY equals 0, the software trigger does not start until TS1_RDY is set.

If TS1_START bit is kept at 1 once the measurement is finished, then the TS1_RDY flag become 1 and the measurement restarts.

Hardware trigger

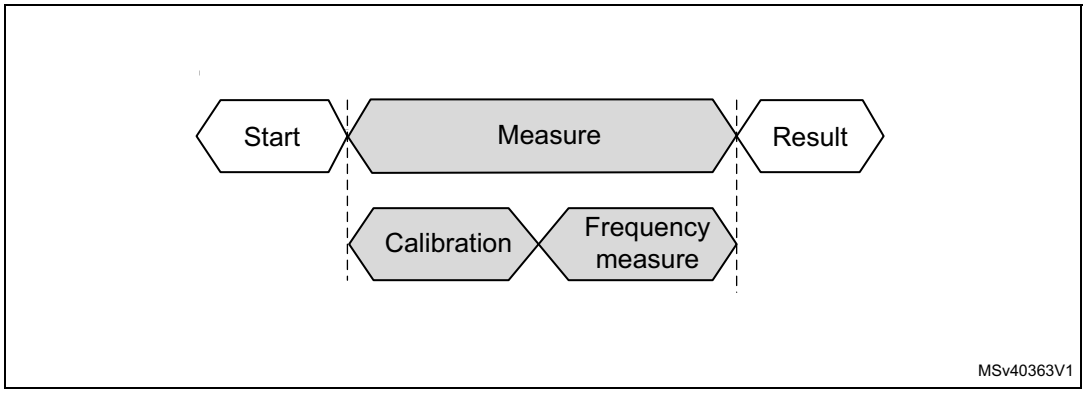
TS1_INTRIG_SEL[3:0] bits allow selecting one hardware trigger out of 4. If TS1_RDY is set to 1, a rising edge on the trigger signal starts the measurement. When TS1_RDY is 0, the rising edge is ignored.

Measurement sequence

One measurement contains two steps: the calibration of the analog blocks and the measurement. The calibration automatically starts when the measurement is triggered (see *Section 30.3.5: Calibration*). The measurement period depends on the following DTS_CFGR1 bits:

- the reference clock selected through REFCLK_SEL bit
- the divider ratio configured by HSREF_CLK_DIV bits
- the sampling time defined by TS1_SMP_TIME bits.

Figure 287. Temperature sensor sequence



30.4 DTS low-power modes

Table 258. Temperature sensor behavior in low-power modes

Mode	Description
Sleep	Only works in LSE mode. DTS interrupt causes the device to exit from Sleep mode.
Stop	Only works in LSE mode. DTS interrupt cause the device to exit from Stop mode.

30.5 DTS interrupts

There are two ways to use the DTS block as an interrupt source.The DTS interrupt line can be connected to the CPU NVIC (see *Section 30.5.2: Synchronous interrupt*) or to the EXTI controller (see *Section 30.5.3: Asynchronous wakeup*).

30.5.1 Temperature window comparator

The DTS_ITR1 register allows defining the high and low threshold that will be used for temperature comparison. If the temperature data is equal or higher than TS1_HITTHD, or equal or lower than TS1_LITTHD bit, an interrupt is generated and the corresponding flag, TS1_ ITLF, TS1_ITHF, TS1_AITLF and TS1_AITHF, is set in the DTS_SR register (see *Section 30.6.6*).

30.5.2 Synchronous interrupt

A global interrupt output line is available on the DTS block. The interrupt can be generated at the end of measurement and/or when the measurement result is equal/higher or equal/lower than a predefined threshold (see *Section 30.5.1: Temperature window comparator*).

Three interrupt events can be select via 3 bits in DTS_ITENR register (see *Section 30.6.7*). All combinations of interrupts are allowed.

The TS1_ITEF, TS1_ITLF and TS1_ITHF flags in the DTS_SR register reflect the interrupt event. They can be reset with the correspond bits of the DTS_ICIFR register (see *Section 30.6.8*).

30.5.3 Asynchronous wakeup

The DTS block also provides an asynchronous interrupt line. It is used only when the LSE is selected as reference clock (REFCLK_SEL=1).

This line can generate a signal that wakes up the system from Sleep mode at the end of measurement and/or when the measurement result is equal/higher or equal/lower than a predefined threshold (see *Section 30.5.1: Temperature window comparator*).

Three asynchronous wakeup events can be selected via 3 bits in DTS_ITENR register. All combination of interrupts are allowed.

The TS1_AITEF, TS1_AITLF and TS1_AITHF flags in the DTS_SR register reflect the interrupt status. They can be reset with the correspond bits of the DTS_ICIFR register.

The following table shows the interrupt bits an the their description.

Table 259. Interrupt control bits

Interrupt event	Interrupt flag	Enable control bit	Interrupt clear bit	Exit from Sleep mode	Synchronous/ Asynchronous
At the end of measurement	TS1_ITEF in DTS_SR	TS1_ITEEN in DTS_ITENR	TS1_CITEF in DTS_ICIFR	NO	Synchronous on PCLK
When the measure is equal or exceeds the low threshold	TS1_ITLF in DTS_SR	TS1_ITLEN in DTS_ITENR	TS1_CITLF in DTS_ICIFR	NO	
When the measure is equal or exceeds the high threshold	TS1_ITHF in DTS_SR	TS1_ITHEN in DTS_ITENR	TS1_CITHF in DTS_ICIFR	NO	
At the end of measurement	TS1_AITEF in DTS_SR	TS1_AITEEN in DTS_ITENR	TS1_CAITEF in DTS_ICIFR	YES	Asynchronous
When the measure is equal or exceeds the low threshold	TS1_AITLF in DTS_SR	TS1_AITLEN in DTS_ITENR	TS1_CAITLF in DTS_ICIFR	YES	
When the measure is equal or exceeds the high threshold	TS1_AITHF in DTS_SR	TS1_AITHEN in DTS_ITENR	TS1_CAITHF in DTS_ICIFR	YES	

30.6 DTS registers

The registers of this peripheral can only be accessed by-word (32-bit).

30.6.1 Temperature sensor configuration register 1 (DTS_CFGR1)

DTS_CFGR1 is the configuration register for temperature sensor 1.

Address offset: 0x00

System reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	HSREF_CLK_DIV[6:0]							Res.	Res.	Q_MEAS_OPT	REFCLK_SEL	TS1_SMP_TIME[3:0]			
	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TS1_INTRIG_SEL[3:0]				Res.	Res.	Res.	TS1_START	Res.	Res.	Res.	TS1_EN
				rw	rw	rw	rw				rw				rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:24 **HSREF_CLK_DIV[6:0]**: High speed clock division ratio

These bits are set and cleared by software. They can be used to define the division ratio for the main clock in order to obtain the internal frequency lower than 1 MHz required for the calibration. They are applicable only for calibration when PCLK is selected as reference clock (REFCLK_SEL=0).

0000000: No divider

0000001: No divider

0000010: 1/2 division ratio

...

1111111: 1/127 division ratio

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **Q_MEAS_OPT**: Quick measurement option bit

This bit is set and cleared by software. It is used to increase the measurement speed by suppressing the calibration step. It is effective only when the LSE clock is used as reference clock (REFCLK_SEL=1).

0: Measurement with calibration

1: Measurement without calibration

Bit 20 **REFCLK_SEL**: Reference clock selection bit

This bit is set and cleared by software. It indicates whether the reference clock is the high speed clock (PCLK) or the low speed clock (LSE).

0: High speed reference clock (PCLK)

1: Low speed reference clock (LSE)

Bits 19:16 **TS1_SMP_TIME[3:0]**: Sampling time for temperature sensor 1

These bits allow increasing the sampling time to improve measurement precision.

When the PCLK clock is selected as reference clock (REFCLK_SEL = 0), the measurement will be performed at TS1_SMP_TIME period of CLK_PTAT.

When the LSE is selected as reference clock (REFCLK_SEL =1), the measurement will be performed at TS1_SMP_TIME period of LSE.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TS1_INTRIG_SEL[3:0]**: Input trigger selection bit for temperature sensor 1
These bits are set and cleared by software. They select which input triggers a temperature measurement. Refer to *Section 30.3.10: Trigger input*.

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **TS1_START:** Start frequency measurement on temperature sensor 1
This bit is set and cleared by software.
0: No software trigger.
1: Software trigger for a frequency measurement. (only if TS1 is ready).

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **TS1_EN:** Temperature sensor 1 enable bit
This bit is set and cleared by software.
0: Temperature sensor 1 disabled
1: Temperature sensor 1 enabled

Note: Once enabled, the temperature sensor is active after a specific delay time. The TS1_RDY flag will be set when the sensor is ready.

30.6.2 Temperature sensor T0 value register 1 (DTS_T0VALR1)

DTS_T0VALR1 contains the value of the factory calibration temperature (T0) for temperature sensor 1. The system reset value is factory trimmed.

Address offset: 0x08

System reset value: 0x000X XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_T0[1:0]	
														r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TS1_FMT0[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:16 **TS1_T0[1:0]**: Engineering value of the T0 temperature for temperature sensor 1.
00: 30 °C
01: 130 °C
Others: Reserved, must not be used.

Bits 15:0 **TS1_FMT0[15:0]**: Engineering value of the frequency measured at T0 for temperature sensor 1
This value is expressed in 0.1 kHz.

30.6.3 Temperature sensor ramp value register (DTS_RAMPVALR)

The DTS_RAMPVALR is the ramp coefficient for the temperature sensor. The system reset value is factory trimmed.

Address offset: 0x10

System reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TS1_RAMP_COEFF[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **TS1_RAMP_COEFF[15:0]**: Engineering value of the ramp coefficient for the temperature sensor 1.

This value is expressed in Hz/°C.

30.6.4 Temperature sensor interrupt threshold register 1 (DTS_ITR1)

DTS_ITR1 contains the threshold values for sensor 1.

Address offset: 0x14

System reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TS1_HITTHD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TS1_LITTHD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **TS1_HITTHD[15:0]:** High interrupt threshold for temperature sensor 1

These bits are set and cleared by software. They indicate the highest value than can be reached before raising an interrupt signal.

Bits 15:0 **TS1_LITTHD[15:0]:** Low interrupt threshold for temperature sensor 1

These bits are set and cleared by software. They indicate the lowest value than can be reached before raising an interrupt signal.

30.6.5 Temperature sensor data register (DTS_DR)

The DTS_DR contains the number of REF_CLK cycles used to compute the FM(T) frequency.

Address offset: 0x1C

System reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TS1_MFREQ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **TS1_MFREQ[15:0]**: Value of the counter output value for temperature sensor 1

30.6.6 Temperature sensor status register (DTS_SR)

Address offset: 0x20

System reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TS1_RDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_AITHF	TS1_AITLF	TS1_AITEF	Res.	TS1_ITHF	TS1_ITLF	TS1_ITEF
r									r	r	r		r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **TS1_RDY:** Temperature sensor 1 ready flag
This bit is set and reset by hardware.
It indicates that a measurement is ongoing.
0: Temperature sensor 1 busy
1: Temperature sensor 1 ready

Bits 14:7 Reserved, must be kept at reset value.

Bit 6 **TS1_AITHF:** Asynchronous interrupt flag for high threshold on temperature sensor 1
This bit is set by hardware when the high threshold is reached.
It is cleared by software by writing 1 to the TS1_CAITHF bit in the DTS_ICIFR register.
0: High threshold not reached on temperature sensor 1
1: High threshold reached on temperature sensor 1
Note: This bit is active only when the TS1_AITHFEN bit is set

Bit 5 **TS1_AITLF:** Asynchronous interrupt flag for low threshold on temperature sensor 1
This bit is set by hardware when the low threshold is reached.
It is cleared by software by writing 1 to the TS1_CAITLF bit in the DTS_ICIFR register.
0: Low threshold not reached on temperature sensor 1
1: Low threshold reached on temperature sensor 1
Note: This bit is active only when the TS1_AITLFEN bit is set

Bit 4 **TS1_AITEF:** Asynchronous interrupt flag for end of measure on temperature sensor 1
This bit is set by hardware when a temperature measure is done.
It is cleared by software by writing 1 to the TS1_CAITEF bit in the DTS_ICIFR register.
0: End of measure not detected on temperature sensor 1
1: End of measure detected on temperature sensor 1
Note: This bit is active only when the TS1_AITEFEN bit is set

Bit 3 Reserved, must be kept at reset value.

Bit 2 **TS1_ITHF:** Interrupt flag for high threshold on temperature sensor 1, synchronized on PCLK
This bit is set by hardware when the high threshold is set and reached.
It is cleared by software by writing 1 to the TS1_CITHF bit in the DTS_ICIFR register.
0: High threshold not reached on temperature sensor 1
1: High threshold reached on temperature sensor 1
Note: This bit is active only when the TS1_ITHFEN bit is set

Bit 1 **TS1_ITLF:** Interrupt flag for low threshold on temperature sensor 1, synchronized on PCLK.
This bit is set by hardware when the low threshold is set and reached.
It is cleared by software by writing 1 to the TS1_CITLF bit in the DTS_ICIFR register.
0: Low threshold not reached on temperature sensor 1
1: Low threshold reached on temperature sensor 1
Note: This bit is active only when the TS1_ITLFEN bit is set

Bit 0 **TS1_ITEF:** Interrupt flag for end of measurement on temperature sensor 1, synchronized on PCLK.
This bit is set by hardware when a temperature measure is done.
It is cleared by software by writing 1 to the TS2_CITEF bit in the DTS_ICIFR register.
0: No end of measurement detected on temperature sensor 1
1: End of measure detected on temperature sensor 1
Note: This bit is active only when the TS1_ITEFEN bit is set

30.6.7 Temperature sensor interrupt enable register (DTS_ITENR)

Address offset: 0x24

System reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_ AITHEN	TS1_ AITLEN	TS1_ AITEEN	Res.	TS1_ ITHEN	TS1_ ITLEN	TS1_ ITEEN
									rw	rw	rw		rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **TS1_AITHEN:** Asynchronous interrupt enable flag on high threshold for temperature sensor 1.
This bit are set and cleared by software.
It enables the asynchronous interrupt when the temperature is above the high threshold (only when REFCLK_SEL= 1”)
0: Asynchronous interrupt on high threshold disabled for temperature sensor 1
1: Asynchronous interrupt on high threshold enabled for temperature sensor 1

Bit 5 **TS1_AITLEN:** Asynchronous interrupt enable flag for low threshold on temperature sensor 1.
This bit are set and cleared by software.
It enables the asynchronous interrupt when the temperature is below the low threshold (only when REFCLK_SEL= 1)
0: Asynchronous interrupt on low threshold disabled for temperature sensor 1
1: Asynchronous interrupt on low threshold enabled for temperature sensor 1

Bit 4 **TS1_AITEEN:** Asynchronous interrupt enable flag for end of measurement on temperature sensor 1

This bit are set and cleared by software.
It enables the asynchronous interrupt for end of measurement (only when REFCLK_SEL = 1).
0: Asynchronous interrupt for end of measurement disabled on temperature sensor 1
1: Asynchronous interrupt for end of measurement enabled on temperature sensor 1

Bit 3 Reserved, must be kept at reset value.

Bit 2 **TS1_ITHEN:** Interrupt enable flag for high threshold on temperature sensor 1, synchronized on PCLK.

This bit are set and cleared by software.
It enables the interrupt when the measure reaches or is above the high threshold.
0: Synchronous interrupt for high threshold disabled on temperature sensor 1
1: Synchronous interrupt for high threshold enabled on temperature sensor 1

Bit 1 **TS1_ITLEN:** Interrupt enable flag for low threshold on temperature sensor 1, synchronized on PCLK.

This bit are set and cleared by software.
It enables the synchronous interrupt when the measure reaches or is below the low threshold.
0: Synchronous interrupt for low threshold disabled on temperature sensor 1
1: Synchronous interrupt for low threshold enabled on temperature sensor 1

Bit 0 **TS1_ITEEN:** Interrupt enable flag for end of measurement on temperature sensor 1, synchronized on PCLK.

This bit are set and cleared by software.
It enables the synchronous interrupt for end of measurement.
0: Synchronous interrupt for end of measurement disabled on temperature sensor 1
1: Synchronous interrupt for end of measurement enabled on temperature sensor 1

30.6.8 Temperature sensor clear interrupt flag register (DTS_ICIFR)

DTS_ICIFR is the control register for the interrupt flags.

Address offset: 0x28

System reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_ CAITHF	TS1_ CAITLF	TS1_ CAITEF	Res.	TS1_ CITHF	TS1_ CITLF	TS1_ CITEF
									rc_w1	rc_w1	rc_w1		rc_w1	rc_w1	rc_w1

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **TS1_CAITHF:** Asynchronous interrupt clear flag for high threshold on temperature sensor 1
Writing 1 to this bit clears the TS1_AITHF flag in the DTS_SR register.

Bit 5 **TS1_CAITLF:** Asynchronous interrupt clear flag for low threshold on temperature sensor 1
Writing 1 to this bit clears the TS1_AITLF flag in the DTS_SR register.

Bit 4 **TS1_CAITEF:** Write once bit. Clear the asynchronous IT flag for End Of Measure for thermal sensor 1.
Writing 1 clears the TS1_AITEF flag of the DTS_SR register.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **TS1_CITHF:** Interrupt clear flag for high threshold on temperature sensor 1
Writing this bit to 1 clears the TS1_ITHF flag in the DTS_SR register.

Bit 1 **TS1_CITLF:** Interrupt clear flag for low threshold on temperature sensor 1
Writing 1 to this bit clears the TS1_ITLF flag in the DTS_SR register.

Bit 0 **TS1_CITEF:** Interrupt clear flag for end of measurement on temperature sensor 1
Writing 1 to this bit clears the TS1_ITEF flag in the DTS_SR register.

30.6.9 Temperature sensor option register (DTS_OR)

The DTS_OR contains general-purpose option bits.

Address offset: 0x2C

System reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TS_OP 31	TS_OP 30	TS_OP 29	TS_OP 28	TS_OP 27	TS_OP 26	TS_OP 25	TS_OP 24	TS_OP 23	TS_OP 22	TS_OP 21	TS_OP 20	TS_OP 19	TS_OP 18	TS_OP 17	TS_OP 16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TS_OP 15	TS_OP 14	TS_OP 13	TS_OP 12	TS_OP 11	TS_OP 10	TS_OP 9	TS_OP 8	TS_OP 7	TS_OP 6	TS_OP 5	TS_OP 4	TS_OP 3	TS_OP 2	TS_OP 1	TS_OP 0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TS_OP[31:0]:** general purpose option bits

30.6.10 DTS register map

The following table summarizes the temperature sensor registers.

Table 260. DTS register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**DTS_ CFGR1**	Res.	HSREF_CLK_DIV [6:0]							Res.	Res.	Q_MEAS_OPT	REFCLK_SEL	TS1_ SMP_TIME [3:0]				Res.	Res.	Res.	Res.	TS1_ INTRIG_SEL [3:0]				Res.	Res.	Res.	TS1_START	Res.	Res.	Res.	TS1_EN
	Reset value		0	0	0	0	0	0	0			0	0	0	0	0	0					0	0	0	0				0				0
0x08	**DTS_ T0VALR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_ T0[1:0]		TS1_FMT0[15:0]															
	Reset value															X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x0C	Reserved																																
0x10	**DTS_ RAMPVALR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_RAMP_ COEFF[15:0]															
	Reset value																	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0x14	**DTS_ITR1**	TS1_HITTHD[15:0]																TS1_LITTHD[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	Reserved																																
0x1C	**DTS_DR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_MFREQ[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	**DTS_SR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_RDY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_AITHF	TS1_AITLF	TS1_AITEF	Res.	TS1_ITHF	TS1_ITLF	TS1_ITEF
	Reset value																	0									0	0	0		0	0	0
0x24	**DTS_ITENR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_AITHEN	TS1_AITLEN	TS1_AITEEN	Res.	TS1_ITHEN	TS1_ITLEN	TS1_ITEEN
	Reset value																										0	0	0		0	0	0
0x28	**DTS_ICIFR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS1_CAITHF	TS1_CAITLF	TS1_CAITEF	Res.	TS1_CITHF	TS1_CITLF	TS1_CITEF
	Reset value																										0	0	0		0	0	0
0x2C	**DTS_ OR**	TS_OP31	TS_OP30	TS_OP29	TS_OP28	TS_OP27	TS_OP26	TS_OP25	TS_OP24	TS_OP23	TS_OP22	TS_OP21	TS_OP20	TS_OP19	TS_OP18	TS_OP17	TS_OP16	TS_OP15	TS_OP14	TS_OP13	TS_OP12	TS_OP11	TS_OP10	TS_OP9	TS_OP8	TS_OP7	TS_OP6	TS_OP5	TS_OP4	TS_OP3	TS_OP2	TS_OP1	TS_OP0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

31 Digital-to-analog converter (DAC)

31.1 Introduction

The DAC module is a 12-bit, voltage output digital-to-analog converter. The DAC can be configured in 8- or 12-bit mode and may be used in conjunction with the DMA controller. In 12-bit mode, the data could be left- or right-aligned. The DAC features two output channels, each with its own converter. In dual DAC channel mode, conversions could be done independently or simultaneously when both channels are grouped together for synchronous update operations. An input reference pin, V_{REF+} (shared with others analog peripherals) is available for better resolution. An internal reference can also be set on the same input. Refer to *voltage reference buffer (VREFBUF)* section.

The DACx_OUTy pin can be used as general purpose input/output (GPIO) when the DAC output is disconnected from output pad and connected to on chip peripheral. The DAC output buffer can be optionally enabled to obtain a high drive output current. An individual calibration can be applied on each DAC output channel. The DAC output channels support a low power mode, the Sample and hold mode.

31.2 DAC main features

The DAC main features are the following (see *Figure 288: Dual-channel DAC block diagram*)

- One DAC interface, maximum two output channels
- Left or right data alignment in 12-bit mode
- Synchronized update capability
- Noise-wave and Triangular-wave generation
- Dual DAC channel for independent or simultaneous conversions
- DMA capability for each channel including DMA underrun error detection
- External triggers for conversion
- DAC output channel buffered/unbuffered modes
- Buffer offset calibration
- Each DAC output can be disconnected from the DACx_OUTy output pin
- DAC output connection to on-chip peripherals
- Sample and hold mode for low power operation in Stop mode
- Input voltage reference from V_{REF+} pin or internal VREFBUF reference

Figure 288 shows the block diagram of a DAC channel and *Table 262* gives the pin description.

31.3 DAC implementation

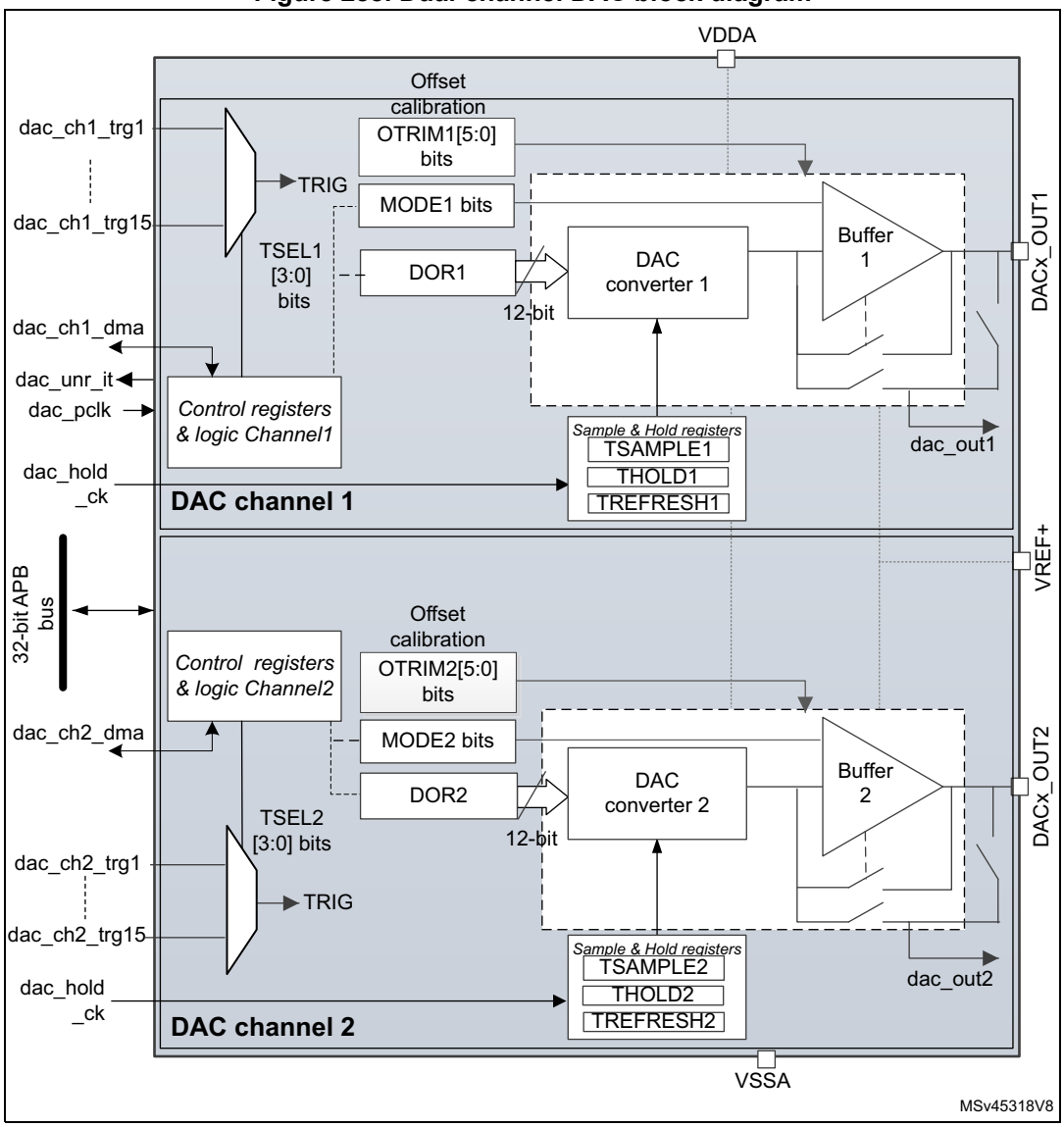
Table 261. DAC features

DAC features	DAC1
Dual channel	X
Output buffer	X
I/O connection	DAC1_OUT1 on PA4, DAC1_OUT2 on PA5
Maximum sampling time	1 MSPS
Autonomous mode	-
VREF+ pin	X

31.4 DAC functional description

31.4.1 DAC block diagram

Figure 288. Dual-channel DAC block diagram



1. MODEx bits in the DAC_MCR control the output mode and the switching between the Normal mode in buffer/unbuffered configuration and the Sample and hold mode.
2. Refer to *Section 31.3: DAC implementation* for channel2 availability.

31.4.2 DAC pins and internal signals

The DAC includes:

- Up to two output channels
- The DACx_OUTy can be disconnected from the output pin and used as an ordinary GPIO
- The dac_outx can use an internal pin connection to on-chip peripherals such as comparator, operational amplifier and ADC (if available).
- DAC output channel buffered or non buffered
- Sample and hold block and registers operational in Stop mode, using the LSI clock source (dac_hold_ck) for static conversion.

The DAC includes up to two separate output channels. Each output channel can be connected to on-chip peripherals such as comparator, operational amplifier and ADC (if available). In this case, the DAC output channel can be disconnected from the DACx_OUTy output pin and the corresponding GPIO can be used for another purpose.

The DAC output can be buffered or not. The Sample and hold block and its associated registers can run in Stop mode using the LSI clock source (dac_hold_ck).

Table 262. DAC input/output pins

Pin name	Signal type	Remarks
VREF+	Input, analog reference positive	The higher/positive reference voltage for the DAC, $V_{REF+} \leq V_{DDAmax}$ (refer to datasheet)
VDDA	Input, analog supply	Analog power supply
VSSA	Input, analog supply ground	Ground for analog power supply
DACx_OUTy	Analog output signal	DACx channely analog output

Table 263. DAC internal input/output signals

Internal signal name	Signal type	Description
dac_ch1_dma	Bidirectional	DAC channel1 DMA request/acknowledge
dac_ch2_dma	Bidirectional	DAC channel2 DMA request/acknowledge
dac_ch1_trgx (x = 1 to 15)	Inputs	DAC channel1 trigger inputs
dac_ch2_trgx (x = 1 to 15)	Inputs	DAC channel2 trigger inputs
dac_unr_it	Output	DAC underrun interrupt
dac_pclk	Input	DAC peripheral clock
dac_hold_ck	Input	DAC low-power clock used in Sample and hold mode
dac_out1	Analog output	DAC channel1 output for on-chip peripherals
dac_out2	Analog output	DAC channel2 output for on-chip peripherals

Table 264. DAC trigger selection

Signal name	Source	Source type
dac_hold_ck	dac_hold_ck	ck_lsi (selected in the RCC)
dac_chx_trg1 (x = 1, 2)	tim1_trgo	Internal signal from on-chip timers
dac_chx_trg2 (x = 1, 2)	tim2_trgo	Internal signal from on-chip timers
dac_chx_trg3 (x = 1, 2)	tim4_trgo	Internal signal from on-chip timers
dac_chx_trg4 (x = 1, 2)	tim5_trgo	Internal signal from on-chip timers
dac_chx_trg5 (x = 1, 2)	tim6_trgo	Internal signal from on-chip timers
dac_chx_trg6 (x = 1, 2)	tim7_trgo	Internal signal from on-chip timers
dac_chx_trg7 (x = 1, 2)	tim8_trgo	Internal signal from on-chip timers
dac_chx_trg8 (x = 1, 2)	tim15_trgo	Internal signal from on-chip timers
dac_chx_trg11 (x = 1, 2)	lptim1_out	Internal signal from on-chip timers
dac_chx_trg12 (x = 1, 2)	lptim2_out	Internal signal from on-chip timers
dac_chx_trg13 (x = 1, 2)	exti9	External pin
dac_chx_trg14 (x = 1, 2)	tim23_trgo	Internal signal from on-chip timers
dac_chx_trg15 (x = 1, 2)	tim24_trgo	Internal signal from on-chip timers

31.4.3 DAC channel enable

Each DAC channel can be powered on by setting its corresponding ENx bit in the DAC_CR register. The DAC channel is then enabled after a t_{WAKEUP} startup time.

Note: The ENx bit enables the analog DAC channelx only. The DAC channelx digital interface is enabled even if the ENx bit is reset.

31.4.4 DAC data format

Depending on the selected configuration mode, the data have to be written into the specified register as described below:

- Single DAC channel

  There are three possibilities:

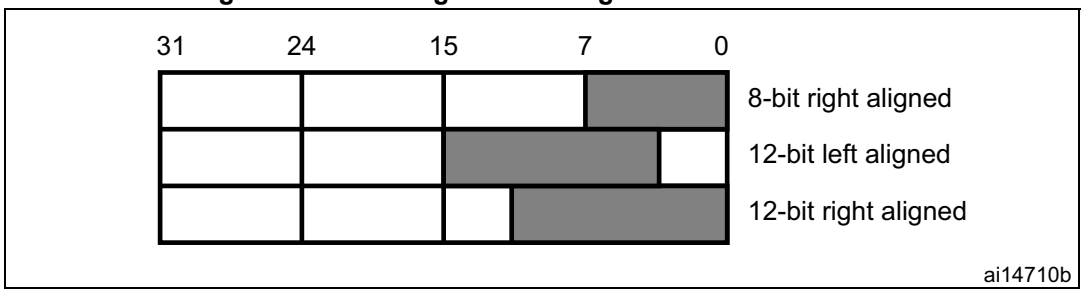
  – 8-bit right alignment: the software has to load data into the DAC_DHR8Rx[7:0] bits (stored into the DHRx[11:4] bits)

  – 12-bit left alignment: the software has to load data into the DAC_DHR12Lx [15:4] bits (stored into the DHRx[11:0] bits)

  – 12-bit right alignment: the software has to load data into the DAC_DHR12Rx [11:0] bits (stored into the DHRx[11:0] bits)

Depending on the loaded DAC_DHRyyyx register, the data written by the user is shifted and stored into the corresponding DHRx (data holding registerx, which are internal non-memory-mapped registers). The DHRx register is then loaded into the DORx register either automatically, by software trigger or by an external event trigger.

Figure 289. Data registers in single DAC channel mode



- Dual DAC channels (when available)

  There are three possibilities:

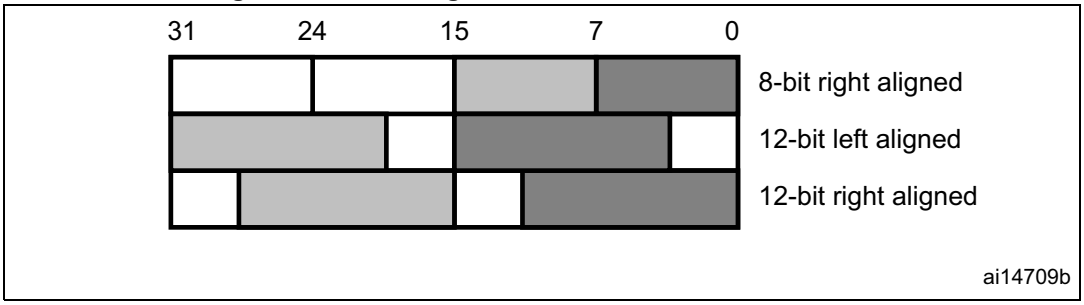
  – 8-bit right alignment: data for DAC channel1 to be loaded into the DAC_DHR8RD [7:0] bits (stored into the DHR1[11:4] bits) and data for DAC channel2 to be loaded into the DAC_DHR8RD [15:8] bits (stored into the DHR2[11:4] bits)

  – 12-bit left alignment: data for DAC channel1 to be loaded into the DAC_DHR12LD [15:4] bits (stored into the DHR1[11:0] bits) and data for DAC channel2 to be loaded into the DAC_DHR12LD [31:20] bits (stored into the DHR2[11:0] bits)

  – 12-bit right alignment: data for DAC channel1 to be loaded into the DAC_DHR12RD [11:0] bits (stored into the DHR1[11:0] bits) and data for DAC channel2 to be loaded into the DAC_DHR12RD [27:16] bits (stored into the DHR2[11:0] bits)

Depending on the loaded DAC_DHRyyyD register, the data written by the user is shifted and stored into DHR1 and DHR2 (data holding registers, which are internal non-memory-mapped registers). The DHR1 and DHR2 registers are then loaded into the DAC_DOR1 and DOR2 registers, respectively, either automatically, by software trigger or by an external event trigger.

Figure 290. Data registers in dual DAC channel mode



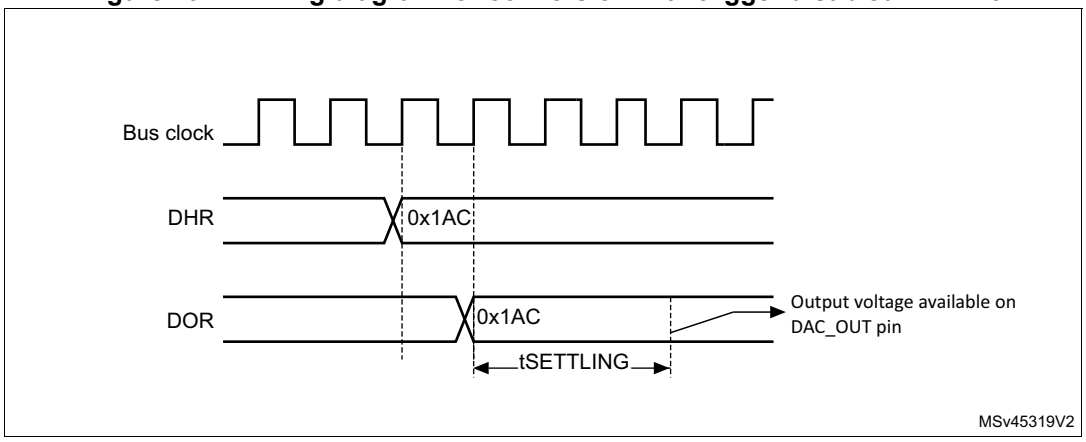
31.4.5 DAC conversion

The DAC_DORx cannot be written directly and any data transfer to the DAC channelx must be performed by loading the DAC_DHRx register (write operation to DAC_DHR8Rx, DAC_DHR12Lx, DAC_DHR12Rx, DAC_DHR8RD, DAC_DHR12RD or DAC_DHR12LD).

Data stored in the DAC_DHRx register are automatically transferred to the DAC_DORx register after one dac_pclk clock cycle, if no hardware trigger is selected (TENx bit in DAC_CR register is reset). However, when a hardware trigger is selected (TENx bit in DAC_CR register is set) and a trigger occurs, the transfer is performed three dac_pclk clock cycles after the trigger signal.

When DAC_DORx is loaded with the DAC_DHRx contents, the analog output voltage becomes available after a time $t_{SETTLING}$ that depends on the power supply voltage and the analog output load.

Figure 291. Timing diagram for conversion with trigger disabled TEN = 0



31.4.6 DAC output voltage

Digital inputs are converted to output voltages on a linear conversion between 0 and V_{REF+}.

The analog output voltages on each DAC channel pin are determined by the following equation:

$$\text{DACoutput} = V_{REF} \times \frac{DOR}{4096}$$

31.4.7 DAC trigger selection

If the TENx control bit is set, the conversion can then be triggered by an external event (timer counter, external interrupt line). The TSELx[3:0] control bits determine which out of 16 possible events triggers the conversion as shown in TSELx[3:0] bits of the DAC_CR register. These events can be either the software trigger or hardware triggers. Refer to the interconnection table in *Section 31.4.2: DAC pins and internal signals*.

Each time a DAC interface detects a rising edge on the selected trigger source (refer to the table below), the last data stored into the DAC_DHRx register are transferred into the DAC_DORx register. The DAC_DORx register is updated three dac_pclk cycles after the trigger occurs.

If the software trigger is selected, the conversion starts once the SWTRIG bit is set. SWTRIG is reset by hardware once the DAC_DORx register has been loaded with the DAC_DHRx register contents.

Note: TSELx[3:0] bit cannot be changed when the ENx bit is set.

When software trigger is selected, the transfer from the DAC_DHRx register to the DAC_DORx register takes only one dac_pclk clock cycle.

31.4.8 DMA requests

Each DAC channel has a DMA capability. Two DMA channels are used to service DAC channel DMA requests.

When an external trigger (but not a software trigger) occurs while the DMAENx bit is set, the value of the DAC_DHRx register is transferred into the DAC_DORx register when the transfer is complete, and a DMA request is generated.

In dual mode, if both DMAENx bits are set, two DMA requests are generated. If only one DMA request is needed, only the corresponding DMAENx bit must be set. In this way, the application can manage both DAC channels in dual mode by using one DMA request and a unique DMA channel.

As DAC_DHRx to DAC_DORx data transfer occurred before the DMA request, the very first data has to be written to the DAC_DHRx before the first trigger event occurs.

DMA underrun

The DAC DMA request is not queued so that if a second external trigger arrives before the acknowledgment for the first external trigger is received (first request), then no new request is issued and the DMA channelx underrun flag DMAUDRx in the DAC_SR register is set, reporting the error condition. The DAC channelx continues to convert old data.

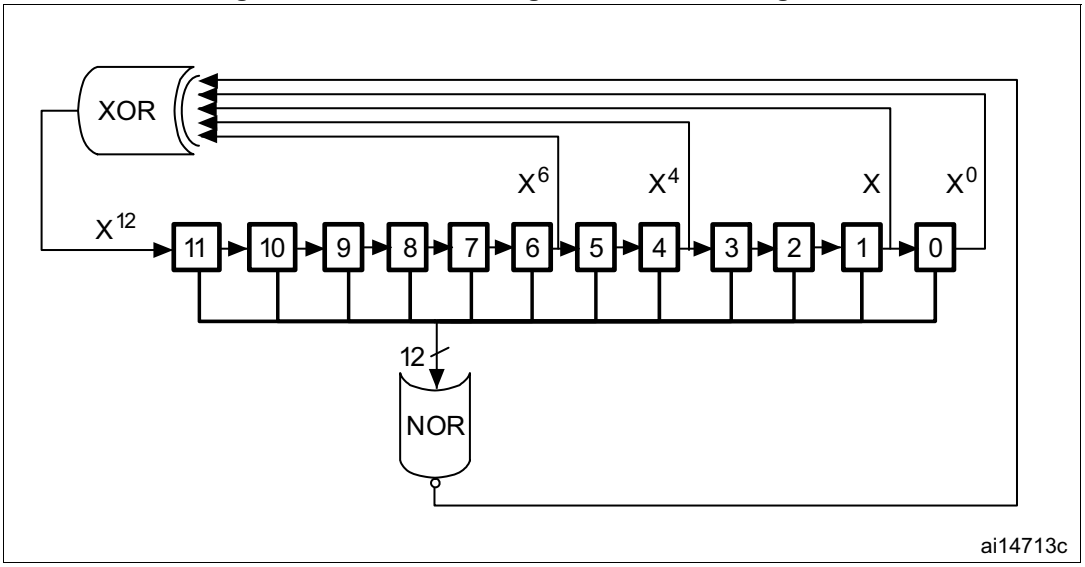
The software must clear the DMAUDRx flag by writing 1, clear the DMAEN bit of the used DMA stream and re-initialize both DMA and DAC channelx to restart the transfer correctly. The software must modify the DAC trigger conversion frequency or lighten the DMA workload to avoid a new DMA underrun. Finally, the DAC conversion could be resumed by enabling both DMA data transfer and conversion trigger.

For each DAC channelx, an interrupt is also generated if its corresponding DMAUDRIEx bit in the DAC_CR register is enabled.

31.4.9 Noise generation

In order to generate a variable-amplitude pseudonoise, an LFSR (linear feedback shift register) is available. DAC noise generation is selected by setting WAVEx[1:0] to 01. The preloaded value in LFSR is 0xAAA. This register is updated three dac_pclk clock cycles after each trigger event, following a specific calculation algorithm.

Figure 292. DAC LFSR register calculation algorithm

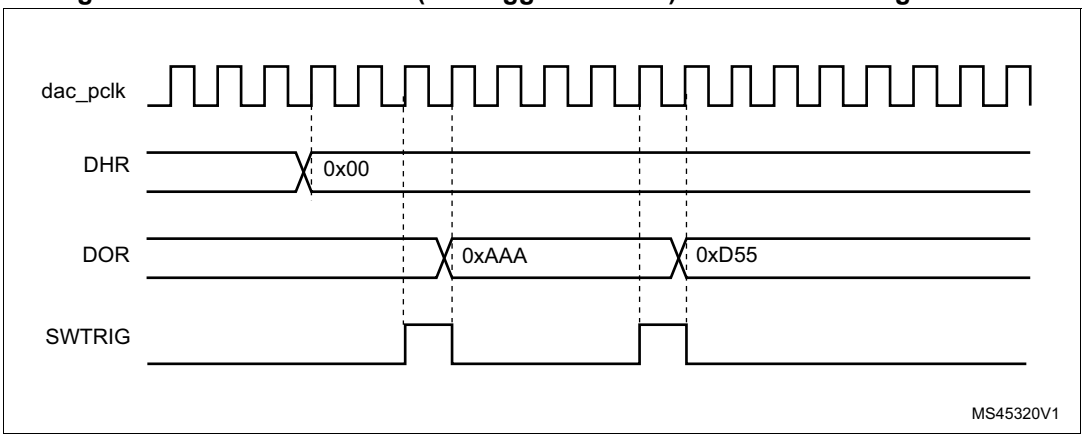


The LFSR value, that may be masked partially or totally by means of the MAMPx[3:0] bits in the DAC_CR register, is added up to the DAC_DHRx contents without overflow and this value is then transferred into the DAC_DORx register.

If LFSR is 0x0000, a ‘1 is injected into it (antilock-up mechanism).

It is possible to reset LFSR wave generation by resetting the WAVEx[1:0] bits.

Figure 293. DAC conversion (SW trigger enabled) with LFSR wave generation



Note: The DAC trigger must be enabled for noise generation by setting the TENx bit in the DAC_CR register.

31.4.10 Triangle-wave generation

It is possible to add a small-amplitude triangular waveform on a DC or slowly varying signal. DAC triangle-wave generation is selected by setting WAVEx[1:0] to 10”. The amplitude is configured through the MAMPx[3:0] bits in the DAC_CR register. An internal triangle counter is incremented three dac_pclk clock cycles after each trigger event. The value of this counter is then added to the DAC_DHRx register without overflow and the sum is transferred into the DAC_DORx register. The triangle counter is incremented as long as it is less than the maximum amplitude defined by the MAMPx[3:0] bits. Once the configured amplitude is reached, the counter is decremented down to 0, then incremented again and so on.

It is possible to reset triangle wave generation by resetting the WAVEx[1:0] bits.

Figure 294. DAC triangle wave generation

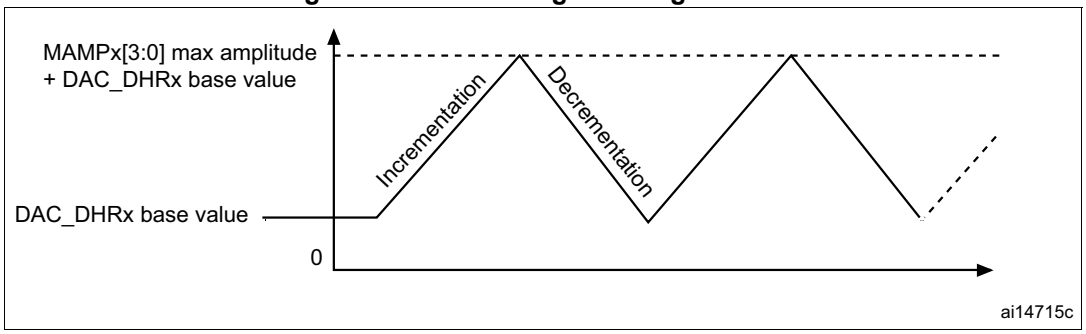
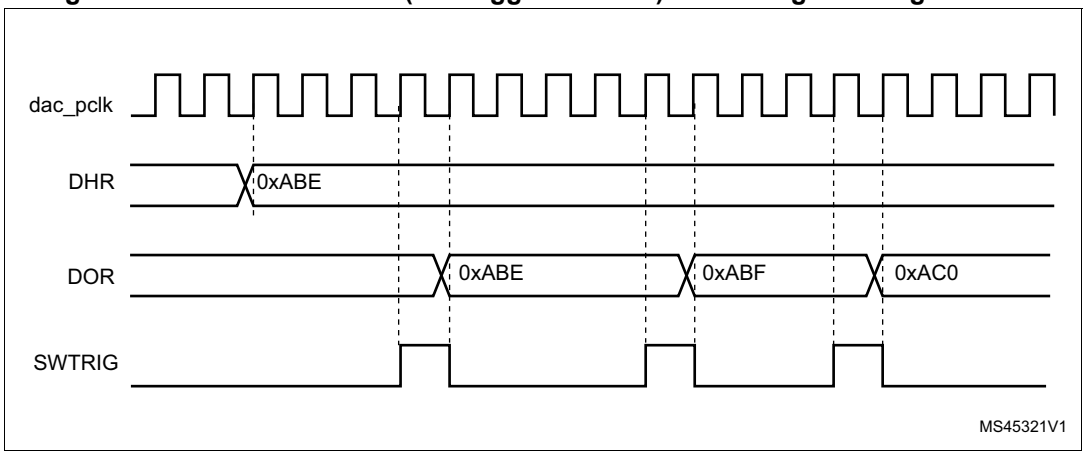


Figure 295. DAC conversion (SW trigger enabled) with triangle wave generation



Note: The DAC trigger must be enabled for triangle wave generation by setting the TENx bit in the DAC_CR register.

The MAMPx[3:0] bits must be configured before enabling the DAC, otherwise they cannot be changed.

31.4.11 DAC channel modes

Each DAC channel can be configured in Normal mode or Sample and hold mode. The output buffer can be enabled to obtain a high drive capability. Before enabling output buffer, the voltage offset needs to be calibrated. This calibration is performed at the factory (loaded after reset) and can be adjusted by software during application operation.

Normal mode

In Normal mode, there are four combinations, by changing the buffer state and by changing the DACx_OUTy pin interconnections.

To enable the output buffer, the MODEx[2:0] bits in DAC_MCR register must be:

- 000: DAC is connected to the external pin
- 001: DAC is connected to external pin and to on-chip peripherals

To disable the output buffer, the MODEx[2:0] bits in DAC_MCR register must be:

- 010: DAC is connected to the external pin
- 011: DAC is connected to on-chip peripherals

Sample and hold mode

In Sample and hold mode, the DAC core converts data on a triggered conversion, and then holds the converted voltage on a capacitor. When not converting, the DAC cores and buffer are completely turned off between samples and the DAC output is tri-stated, therefore reducing the overall power consumption. A stabilization period, which value depends on the buffer state, is required before each new conversion.

In this mode, the DAC core and all corresponding logic and registers are driven by the LSI low-speed clock (dac_hold_ck) in addition to the dac_pclk clock, allowing the DAC channels to be used in deep low power modes such as Stop mode.

The LSI low-speed clock (dac_hold_ck) must not be stopped when the Sample and hold mode is enabled.

The sample/hold mode operations can be divided into 3 phases:

1. Sample phase: the sample/hold element is charged to the desired voltage. The charging time depends on capacitor value (internal or external, selected by the user). The sampling time is configured with the TSAMPLEx[9:0] bits in DAC_SHSRx register. During the write of the TSAMPLEx[9:0] bits, the BWSTx bit in DAC_SR register is set to 1 to synchronize between both clocks domains (APB and low speed clock) and allowing the software to change the value of sample phase during the DAC channel operation
2. Hold phase: the DAC output channel is tri-stated, the DAC core and the buffer are turned off, to reduce the current consumption. The hold time is configured with the THOLDx[9:0] bits in DAC_SHHR register
3. Refresh phase: the refresh time is configured with the TREFRESHx[7:0] bits in DAC_SHRR register

The timings for the three phases above are in units of LSI clock periods. As an example, to configure a sample time of 350 µs, a hold time of 2 ms and a refresh time of 100 µs assuming LSI ~32 KHz is selected:

12 cycles are required for sample phase: TSAMPLEx[9:0] = 11,

62 cycles are required for hold phase: THOLDx[9:0] = 62,

and 4 cycles are required for refresh period: TREFRESHx[7:0] = 4.

In this example, the power consumption is reduced by almost a factor of 15 versus Normal modes.

The formulas to compute the right sample and refresh timings are described in the table below, the Hold time depends on the leakage current.

Table 265. Sample and refresh timings

Buffer State	t_{SAMP} (1)(2)	$t_{REFRESH}$ (2)(3)
Enable	7 µs + (10*R_{BON}*C_{SH})	7 µs + (R_{BON}*C_{SH})*ln(2*N_{LSB})
Disable	3 µs + (10*R_{BOFF}*C_{SH})	3 µs + (R_{BOFF}*C_{SH})*ln(2*N_{LSB})

1. In the above formula the settling to the desired code value with ½ LSB or accuracy requires 10 constant time for 12 bits resolution. For 8 bits resolution, the settling time is 7 constant time.
2. C_{SH} is the capacitor in Sample and hold mode.
3. The tolerated voltage drop during the hold phase “Vd” is represented by the number of LSBs after the capacitor discharging with the output leakage current. The settling back to the desired value with ½ LSB error accuracy requires ln(2*Nlsb) constant time of the DAC.

Example of the sample and refresh time calculation with output buffer on

The values used in the example below are provided as indication only. Please refer to the product datasheet for product data.

C_{SH} = 100 nF

V_{REF+} = 3.0 V

Sampling phase:

t_{SAMP} = 7 µs + (10 * 2000 * 100 * 10^{-9}) = 2.007 ms

(where R_{BON} = 2 kΩ)

Refresh phase:

$t_{REFRESH}$ = 7 µs + (2000 * 100 * 10^{-9}) * ln(2*10) = 606.1 µs

(where N_{LSB} = 10 (10 LSB drop during the hold phase)

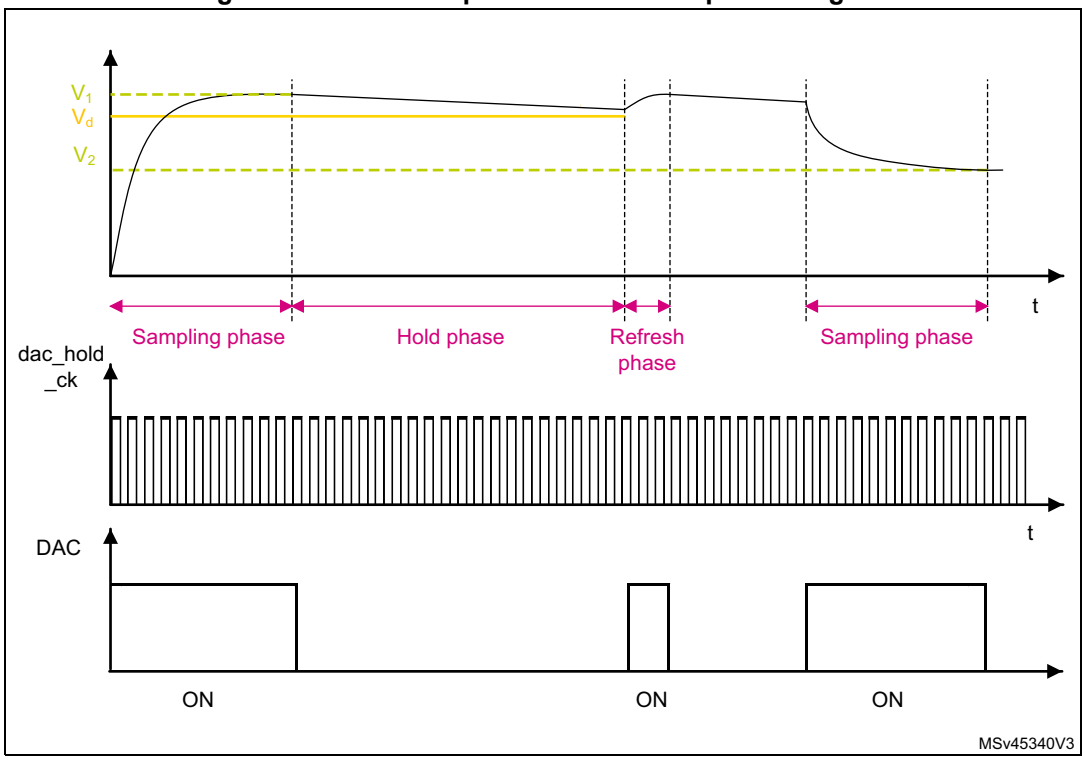
Hold phase:

D_v = i_{leak} * t_{hold} / C_{SH} = 0.0073 V (10 LSB of 12bit at 3 V)

i_{leak} = 150 nA (worst case on the IO leakage on all the temperature range)

t_{hold} = 0.0073 * 100 * 10^{-9} / (150 * 10^{-9}) = 4.867 ms

Figure 296. DAC Sample and hold mode phase diagram



Like in Normal mode, the Sample and hold mode has different configurations.

To enable the output buffer, MODEx[2:0] bits in DAC_MCR register must be set to:

- 100: DAC is connected to the external pin
- 101: DAC is connected to external pin and to on chip peripherals

To disabled the output buffer, MODEx[2:0] bits in DAC_MCR register must be set to:

- 110: DAC is connected to external pin and to on chip peripherals
- 111: DAC is connected to on chip peripherals

  When MODEx[2:0] bits are equal to 111, an internal capacitor, C_{Lint}, holds the voltage output of the DAC core and then drive it to on-chip peripherals.

All Sample and hold phases are interruptible, and any change in DAC_DHRx immediately triggers a new sample phase.

Table 266. Channel output modes summary

MODEx[2:0]			Mode	Buffer	Output connections
0	0	0	Normal mode	Enabled	Connected to external pin
0	0	1			Connected to external pin and to on chip-peripherals (such as comparators)
0	1	0		Disabled	Connected to external pin
0	1	1			Connected to on chip peripherals (such as comparators)

Table 266. Channel output modes summary (continued)

MODEx[2:0]			Mode	Buffer	Output connections
1	0	0	Sample and hold mode	Enabled	Connected to external pin
1	0	1			Connected to external pin and to on chip peripherals (such as comparators)
1	1	0		Disabled	Connected to external pin and to on chip peripherals (such as comparators)
1	1	1			Connected to on chip peripherals (such as comparators)

31.4.12 DAC channel buffer calibration

The transfer function for an N-bit digital-to-analog converter (DAC) is:

$$V_{out} = ((D/2^N) \times G \times V_{ref}) + V_{OS}$$

Where V_{OUT} is the analog output, D is the digital input, G is the gain, V_{ref} is the nominal full-scale voltage, and V_{os} is the offset voltage. For an ideal DAC channel, G = 1 and V_{os} = 0.

Due to output buffer characteristics, the voltage offset may differ from part-to-part and introduce an absolute offset error on the analog output. To compensate the V_{os}, a calibration is required by a trimming technique.

The calibration is only valid when the DAC channelx is operating with buffer enabled (MODEx[2:0] = 000b or 001b or 100b or 101b). if applied in other modes when the buffer is off, it has no effect. During the calibration:

- The buffer output is disconnected from the pin internal/external connections and put in tristate mode (HiZ).
- The buffer acts as a comparator to sense the middle-code value 0x800 and compare it to VREF+/2 signal through an internal bridge, then toggle its output signal to 0 or 1 depending on the comparison result (CAL_FLAGx bit).

Two calibration techniques are provided:

- Factory trimming (default setting)

  The DAC buffer offset is factory trimmed. The default value of OTRIMx[4:0] bits in DAC_CCR register is the factory trimming value and it is loaded once DAC digital interface is reset.
- User trimming

  The user trimming can be done when the operating conditions differs from nominal factory trimming conditions and in particular when V_{DDA} voltage, temperature, VREF+ values change and can be done at any point during application by software.

Note: Refer to the datasheet for more details of the Nominal factory trimming conditions

In addition, when V_{DD} is removed (example the device enters in STANDBY or VBAT modes) the calibration is required.

The steps to perform a user trimming calibration are as below:

1. If the DAC channel is active, write 0 to ENx bit in DAC_CR to disable the channel.
2. Select a mode where the buffer is enabled, by writing to DAC_MCR register, MODEx[2:0] = 000b or 001b or 100b or 101b.
3. Start the DAC channelx calibration, by setting the CENx bit in DAC_CR register to 1.
4. Apply a trimming algorithm:
   a) Write a code into OTRIMx[4:0] bits, starting by 00000b.
   b) Wait for t_{TRIM} delay.
   c) Check if CAL_FLAGx bit in DAC_SR is set to 1.
   d) If CAL_FLAGx is set to 1, the OTRIMx[4:0] trimming code is found and can be used during *device* operation to compensate the output value, else increment OTRIMx[4:0] and repeat sub-steps from (a) to (d) again.

The software algorithm may use either a successive approximation or dichotomy techniques to compute and set the content of OTRIMx[4:0] bits in a faster way.

The commutation/toggle of CAL_FLAGx bit indicates that the offset is correctly compensated and the corresponding trim code must be kept in the OTRIMx[4:0] bits in DAC_CCR register.

Note: A t_{TRIM} delay must be respected between the write to the OTRIMx[4:0] bits and the read of the CAL_FLAGx bit in DAC_SR register in order to get a correct value.This parameter is specified into datasheet electrical characteristics section.

If V_{DDA}, VREF+ and temperature conditions do not change during device operation while it enters more often in standby and VBAT mode, the software may store the OTRIMx[4:0] bits found in the first user calibration in the flash or in back-up registers. then to load/write them directly when the device power is back again thus avoiding to wait for a new calibration time.

When CENx bit is set, it is not allowed to set ENx bit.

31.4.13 Dual DAC channel conversion modes (if dual channels are available)

To efficiently use the bus bandwidth in applications that require the two DAC channels at the same time, three dual registers are implemented: DHR8RD, DHR12RD and DHR12LD. A unique register access is then required to drive both DAC channels at the same time. For the wave generation, no accesses to DHRxxxD registers are required. As a result, two output channels can be used either independently or simultaneously.

11 conversion modes are possible using the two DAC channels and these dual registers. All the conversion modes can nevertheless be obtained using separate DHRx registers if needed.

All modes are described in the paragraphs below.

Independent trigger without wave generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2.
2. Configure different trigger sources by setting different values in the TSEL1 and TSEL2 bitfields.
3. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a DAC channel1 trigger arrives, the DHR1 register is transferred into DAC_DOR1 (three dac_pclk clock cycles later).

When a DAC channel2 trigger arrives, the DHR2 register is transferred into DAC_DOR2 (three dac_pclk clock cycles later).

Independent trigger with single LFSR generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2.
2. Configure different trigger sources by setting different values in the TSEL1 and TSEL2 bitfields.
3. Configure the two DAC channel WAVEx[1:0] bits as 01 and the same LFSR mask value in the MAMPx[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a DAC channel1 trigger arrives, the LFSR1 counter, with the same mask, is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_pclk clock cycles later). Then the LFSR1 counter is updated.

When a DAC channel2 trigger arrives, the LFSR2 counter, with the same mask, is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_pclk clock cycles later). Then the LFSR2 counter is updated.

Independent trigger with different LFSR generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2.
2. Configure different trigger sources by setting different values in the TSEL1 and TSEL2 bitfields.
3. Configure the two DAC channel WAVEx[1:0] bits as 01 and set different LFSR masks values in the MAMP1[3:0] and MAMP2[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a DAC channel1 trigger arrives, the LFSR1 counter, with the mask configured by MAMP1[3:0], is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_pclk clock cycles later). Then the LFSR1 counter is updated.

When a DAC channel2 trigger arrives, the LFSR2 counter, with the mask configured by MAMP2[3:0], is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_pclk clock cycles later). Then the LFSR2 counter is updated.

Independent trigger with single triangle generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2.
2. Configure different trigger sources by setting different values in the TSEL1 and TSEL2 bitfields.
3. Configure the two DAC channel WAVEx[1:0] bits as 1x and the same maximum amplitude value in the MAMPx[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a DAC channel1 trigger arrives, the DAC channel1 triangle counter, with the same triangle amplitude, is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_pclk clock cycles later). The DAC channel1 triangle counter is then updated.

When a DAC channel2 trigger arrives, the DAC channel2 triangle counter, with the same triangle amplitude, is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_pclk clock cycles later). The DAC channel2 triangle counter is then updated.

Independent trigger with different triangle generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2.
2. Configure different trigger sources by setting different values in the TSEL1 and TSEL2 bits.
3. Configure the two DAC channel WAVEx[1:0] bits as 1x and set different maximum amplitude values in the MAMP1[3:0] and MAMP2[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a DAC channel1 trigger arrives, the DAC channel1 triangle counter, with a triangle amplitude configured by MAMP1[3:0], is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_pclk clock cycles later). The DAC channel1 triangle counter is then updated.

When a DAC channel2 trigger arrives, the DAC channel2 triangle counter, with a triangle amplitude configured by MAMP2[3:0], is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_pclk clock cycles later). The DAC channel2 triangle counter is then updated.

Simultaneous software start

To configure the DAC in this conversion mode, the following sequence is required:

- Load the dual DAC channel data to the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

In this configuration, one dac_pclk clock cycle later, the DHR1 and DHR2 registers are transferred into DAC_DOR1 and DAC_DOR2, respectively.

Simultaneous trigger without wave generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2.
2. Configure the same trigger source for both DAC channels by setting the same value in the TSEL1 and TSEL2 bitfields.
3. Load the dual DAC channel data to the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a trigger arrives, the DHR1 and DHR2 registers are transferred into DAC_DOR1 and DAC_DOR2, respectively (after three dac_pclk clock cycles).

Simultaneous trigger with single LFSR generation

1. To configure the DAC in this conversion mode, the following sequence is required:
2. Set the two DAC channel trigger enable bits TEN1 and TEN2.
3. Configure the same trigger source for both DAC channels by setting the same value in the TSEL1 and TSEL2 bitfields.
4. Configure the two DAC channel WAVEx[1:0] bits as 01 and the same LFSR mask value in the MAMPx[3:0] bits.
5. Load the dual DAC channel data to the desired DHR register (DHR12RD, DHR12LD or DHR8RD).

When a trigger arrives, the LFSR1 counter, with the same mask, is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_pclk clock cycles later). The LFSR1 counter is then updated. At the same time, the LFSR2 counter, with the same mask, is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_pclk clock cycles later). The LFSR2 counter is then updated.

Simultaneous trigger with different LFSR generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2
2. Configure the same trigger source for both DAC channels by setting the same value in the TSEL1 and TSEL2 bitfields.
3. Configure the two DAC channel WAVEx[1:0] bits as 01 and set different LFSR mask values using the MAMP1[3:0] and MAMP2[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a trigger arrives, the LFSR1 counter, with the mask configured by MAMP1[3:0], is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_pclk clock cycles later). The LFSR1 counter is then updated.
At the same time, the LFSR2 counter, with the mask configured by MAMP2[3:0], is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_pclk clock cycles later). The LFSR2 counter is then updated.

Simultaneous trigger with single triangle generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2
2. Configure the same trigger source for both DAC channels by setting the same value in the TSEL1 and TSEL2 bitfields.
3. Configure the two DAC channel WAVEx[1:0] bits as 1x and the same maximum amplitude value using the MAMPx[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a trigger arrives, the DAC channel1 triangle counter, with the same triangle amplitude, is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three dac_pclk clock cycles later). The DAC channel1 triangle counter is then updated.

At the same time, the DAC channel2 triangle counter, with the same triangle amplitude, is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_pclk clock cycles later). The DAC channel2 triangle counter is then updated.

Simultaneous trigger with different triangle generation

To configure the DAC in this conversion mode, the following sequence is required:

1. Set the two DAC channel trigger enable bits TEN1 and TEN2
2. Configure the same trigger source for both DAC channels by setting the same value in the TSEL1 and TSEL2 bitfields.
3. Configure the two DAC channel WAVEx[1:0] bits as 1x and set different maximum amplitude values in the MAMP1[3:0] and MAMP2[3:0] bits.
4. Load the dual DAC channel data into the desired DHR register (DAC_DHR12RD, DAC_DHR12LD or DAC_DHR8RD).

When a trigger arrives, the DAC channel1 triangle counter, with a triangle amplitude configured by MAMP1[3:0], is added to the DHR1 register and the sum is transferred into DAC_DOR1 (three APB clock cycles later). Then the DAC channel1 triangle counter is updated.

At the same time, the DAC channel2 triangle counter, with a triangle amplitude configured by MAMP2[3:0], is added to the DHR2 register and the sum is transferred into DAC_DOR2 (three dac_pclk clock cycles later). Then the DAC channel2 triangle counter is updated.

31.5 DAC in low-power modes

Table 267. Effect of low-power modes on DAC

Mode	Description
Sleep	No effect, DAC can be used with DMA
Stop	The DAC remains active with a static output value. The Sample and hold mode is not available.
Standby	The DAC peripheral is powered down and must be reinitialized after exiting Standby mode.

31.6 DAC interrupts

Table 268. DAC interrupts

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit Sleep mode	Exit Stop mode	Exit Standby mode
DAC	DMA underrun	DMAUDRx	DMAUDRIEx	Write DMAUDRx = 1	Yes	No	No

31.7 DAC registers

Refer to *Section 1 on page 104* for a list of abbreviations used in register descriptions.

The peripheral registers have to be accessed by words (32-bit).

31.7.1 DAC control register (DAC_CR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	CEN2	DMAUDRIE2	DMAEN2	MAMP2[3:0]				WAVE2[1:0]		TSEL2[3]	TSEL2[2]	TSEL2[1]	TSEL2[0]	TEN2	EN2
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	CEN1	DMAUDRIE1	DMAEN1	MAMP1[3:0]				WAVE1[1:0]		TSEL1[3]	TSEL1[2]	TSEL1[1]	TSEL1[0]	TEN1	EN1
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **CEN2**: DAC channel2 calibration enable

This bit is set and cleared by software to enable/disable DAC channel2 calibration, it can be written only if EN2 bit is set to 0 into DAC_CR (the calibration mode can be entered/exit only when the DAC channel is disabled) Otherwise, the write operation is ignored.

0: DAC channel2 in Normal operating mode

1: DAC channel2 in calibration mode

Note: This bit is available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bit 29 **DMAUDRIE2**: DAC channel2 DMA underrun interrupt enable

This bit is set and cleared by software.

0: DAC channel2 DMA underrun interrupt disabled

1: DAC channel2 DMA underrun interrupt enabled

Note: This bit is available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bit 28 **DMAEN2**: DAC channel2 DMA enable

This bit is set and cleared by software.

0: DAC channel2 DMA mode disabled

1: DAC channel2 DMA mode enabled

Note: This bit is available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bits 27:24 **MAMP2[3:0]**: DAC channel2 mask/amplitude selector

These bits are written by software to select mask in wave generation mode or amplitude in triangle generation mode.

0000: Unmask bit0 of LFSR/ triangle amplitude equal to 1

0001: Unmask bits[1:0] of LFSR/ triangle amplitude equal to 3

0010: Unmask bits[2:0] of LFSR/ triangle amplitude equal to 7

0011: Unmask bits[3:0] of LFSR/ triangle amplitude equal to 15

0100: Unmask bits[4:0] of LFSR/ triangle amplitude equal to 31

0101: Unmask bits[5:0] of LFSR/ triangle amplitude equal to 63

0110: Unmask bits[6:0] of LFSR/ triangle amplitude equal to 127

0111: Unmask bits[7:0] of LFSR/ triangle amplitude equal to 255

1000: Unmask bits[8:0] of LFSR/ triangle amplitude equal to 511

1001: Unmask bits[9:0] of LFSR/ triangle amplitude equal to 1023

1010: Unmask bits[10:0] of LFSR/ triangle amplitude equal to 2047

≥ 1011: Unmask bits[11:0] of LFSR/ triangle amplitude equal to 4095

Note: These bits are available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bits 23:22 **WAVE2[1:0]**: DAC channel2 noise/triangle wave generation enable

These bits are set/reset by software.

00: wave generation disabled

01: Noise wave generation enabled

1x: Triangle wave generation enabled

Note: Only used if bit TEN2 = 1 (DAC channel2 trigger enabled)

These bits are available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bits 21:18 **TSEL2[3:0]**: DAC channel2 trigger selection

These bits select the external event used to trigger DAC channel2

0000: SWTRIG2

0001: dac_ch2_trg1

0010: dac_ch2_trg2

...

1111: dac_ch2_trg15

Refer to the trigger selection tables in *Section 31.4.2: DAC pins and internal signals* for details on trigger configuration and mapping.

Note: Only used if bit TEN2 = 1 (DAC channel2 trigger enabled).

These bits are available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bit 17 **TEN2**: DAC channel2 trigger enable

This bit is set and cleared by software to enable/disable DAC channel2 trigger

0: DAC channel2 trigger disabled and data written into the DAC_DHR2 register are transferred one dac_pclk clock cycle later to the DAC_DOR2 register

1: DAC channel2 trigger enabled and data from the DAC_DHR2 register are transferred three dac_pclk clock cycles later to the DAC_DOR2 register

Note: When software trigger is selected, the transfer from the DAC_DHR2 register to the DAC_DOR2 register takes only one dac_pclk clock cycle.

These bits are available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bit 16 **EN2**: DAC channel2 enable

This bit is set and cleared by software to enable/disable DAC channel2.

0: DAC channel2 disabled

1: DAC channel2 enabled

Note: These bits are available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **CEN1**: DAC channel1 calibration enable

This bit is set and cleared by software to enable/disable DAC channel1 calibration, it can be written only if bit EN1 = 0 into DAC_CR (the calibration mode can be entered/exit only when the DAC channel is disabled) Otherwise, the write operation is ignored.

0: DAC channel1 in Normal operating mode

1: DAC channel1 in calibration mode

Bit 13 **DMAUDRIE1**: DAC channel1 DMA Underrun Interrupt enable

This bit is set and cleared by software.

0: DAC channel1 DMA Underrun Interrupt disabled

1: DAC channel1 DMA Underrun Interrupt enabled

Bit 12 **DMAEN1**: DAC channel1 DMA enable

This bit is set and cleared by software.

0: DAC channel1 DMA mode disabled

1: DAC channel1 DMA mode enabled

Bits 11:8 **MAMP1[3:0]**: DAC channel1 mask/amplitude selector

These bits are written by software to select mask in wave generation mode or amplitude in triangle generation mode.

0000: Unmask bit0 of LFSR/ triangle amplitude equal to 1

0001: Unmask bits[1:0] of LFSR/ triangle amplitude equal to 3

0010: Unmask bits[2:0] of LFSR/ triangle amplitude equal to 7

0011: Unmask bits[3:0] of LFSR/ triangle amplitude equal to 15

0100: Unmask bits[4:0] of LFSR/ triangle amplitude equal to 31

0101: Unmask bits[5:0] of LFSR/ triangle amplitude equal to 63

0110: Unmask bits[6:0] of LFSR/ triangle amplitude equal to 127

0111: Unmask bits[7:0] of LFSR/ triangle amplitude equal to 255

1000: Unmask bits[8:0] of LFSR/ triangle amplitude equal to 511

1001: Unmask bits[9:0] of LFSR/ triangle amplitude equal to 1023

1010: Unmask bits[10:0] of LFSR/ triangle amplitude equal to 2047

≥ 1011: Unmask bits[11:0] of LFSR/ triangle amplitude equal to 4095

Bits 7:6 **WAVE1[1:0]**: DAC channel1 noise/triangle wave generation enable

These bits are set and cleared by software.

00: wave generation disabled

01: Noise wave generation enabled

1x: Triangle wave generation enabled

Only used if bit TEN1 = 1 (DAC channel1 trigger enabled).

Bits 5:2 **TSEL1[3:0]**: DAC channel1 trigger selection
These bits select the external event used to trigger DAC channel1
0000: SWTRIG1
0001: dac_ch1_trg1
0010: dac_ch1_trg2
...
1111: dac_ch1_trg15
Refer to the trigger selection tables in *Section 31.4.2: DAC pins and internal signals* for details on trigger configuration and mapping.
Note: Only used if bit TEN1 = 1 (DAC channel1 trigger enabled).

Bit 1 **TEN1**: DAC channel1 trigger enable
This bit is set and cleared by software to enable/disable DAC channel1 trigger.
0: DAC channel1 trigger disabled and data written into the DAC_DHR1 register are transferred one dac_pclk clock cycle later to the DAC_DOR1 register
1: DAC channel1 trigger enabled and data from the DAC_DHR1 register are transferred three dac_pclk clock cycles later to the DAC_DOR1 register
Note: When software trigger is selected, the transfer from the DAC_DHR1 *register to the DAC_DOR1 register takes only one dac_pclk clock cycle.*

Bit 0 **EN1**: DAC channel1 enable
This bit is set and cleared by software to enable/disable DAC channel1.
0: DAC channel1 disabled
1: DAC channel1 enabled

31.7.2 DAC software trigger register (DAC_SWTRGR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWTRIG2	SWTRIG1
														w	w

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **SWTRIG2**: DAC channel2 software trigger

This bit is set by software to trigger the DAC in software trigger mode.

0: No trigger

1: Trigger

Note: This bit is cleared by hardware (one dac_pclk clock cycle later) once the DAC_DHR2 register value has been loaded into the DAC_DOR2 register.

This bit is available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bit 0 **SWTRIG1**: DAC channel1 software trigger

This bit is set by software to trigger the DAC in software trigger mode.

0: No trigger

1: Trigger

Note: This bit is cleared by hardware (one dac_pclk clock cycle later) once the DAC_DHR1 register value has been loaded into the DAC_DOR1 register.

31.7.3 DAC channel1 12-bit right-aligned data holding register (DAC_DHR12R1)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DACC1DHR[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **DACC1DHR[11:0]**: DAC channel1 12-bit right-aligned data

These bits are written by software. They specify 12-bit data for DAC channel1.

31.7.4 DAC channel1 12-bit left aligned data holding register (DAC_DHR12L1)

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DACC1DHR[11:0]												Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:4 **DACC1DHR[11:0]**: DAC channel1 12-bit left-aligned data
These bits are written by software.
They specify 12-bit data for DAC channel1.

Bits 3:0 Reserved, must be kept at reset value.

31.7.5 DAC channel1 8-bit right aligned data holding register (DAC_DHR8R1)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC1DHR[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **DACC1DHR[7:0]**: DAC channel1 8-bit right-aligned data
These bits are written by software. They specify 8-bit data for DAC channel1.

31.7.6 DAC channel2 12-bit right aligned data holding register (DAC_DHR12R2)

This register is available only on dual-channel DACs. Refer to *Section 31.3: DAC implementation*.

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DACC2DHR[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **DACC2DHR[11:0]**: DAC channel2 12-bit right-aligned data
These bits are written by software. They specify 12-bit data for DAC channel2.

31.7.7 DAC channel2 12-bit left aligned data holding register (DAC_DHR12L2)

This register is available only on dual-channel DACs. Refer to *Section 31.3: DAC implementation*.

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DACC2DHR[11:0]												Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:4 **DACC2DHR[11:0]**: DAC channel2 12-bit left-aligned data
These bits are written by software which specify 12-bit data for DAC channel2.

Bits 3:0 Reserved, must be kept at reset value.

31.7.8 DAC channel2 8-bit right-aligned data holding register (DAC_DHR8R2)

This register is available only on dual-channel DACs. Refer to *Section 31.3: DAC implementation*.

Address offset: 0x1C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC2DHR[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **DACC2DHR[7:0]**: DAC channel2 8-bit right-aligned data
These bits are written by software which specifies 8-bit data for DAC channel2.

31.7.9 Dual DAC 12-bit right-aligned data holding register (DAC_DHR12RD)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	DACC2DHR[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DACC1DHR[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **DACC2DHR[11:0]**: DAC channel2 12-bit right-aligned data
These bits are written by software which specifies 12-bit data for DAC channel2.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **DACC1DHR[11:0]**: DAC channel1 12-bit right-aligned data
These bits are written by software which specifies 12-bit data for DAC channel1.

31.7.10 Dual DAC 12-bit left aligned data holding register (DAC_DHR12LD)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DACC2DHR[11:0]												Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DACC1DHR[11:0]												Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				

Bits 31:20 **DACC2DHR[11:0]**: DAC channel2 12-bit left-aligned data
These bits are written by software which specifies 12-bit data for DAC channel2.

Bits 19:16 Reserved, must be kept at reset value.

Bits 15:4 **DACC1DHR[11:0]**: DAC channel1 12-bit left-aligned data
These bits are written by software which specifies 12-bit data for DAC channel1.

Bits 3:0 Reserved, must be kept at reset value.

31.7.11 Dual DAC 8-bit right aligned data holding register (DAC_DHR8RD)

Address offset: 0x28

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DACC2DHR[7:0]								DACC1DHR[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **DACC2DHR[7:0]**: DAC channel2 8-bit right-aligned data
These bits are written by software which specifies 8-bit data for DAC channel2.

Bits 7:0 **DACC1DHR[7:0]**: DAC channel1 8-bit right-aligned data
These bits are written by software which specifies 8-bit data for DAC channel1.

31.7.12 DAC channel1 data output register (DAC_DOR1)

Address offset: 0x2C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DACC1DOR[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **DACC1DOR[11:0]**: DAC channel1 data output
These bits are read-only, they contain data output for DAC channel1.

31.7.13 DAC channel2 data output register (DAC_DOR2)

This register is available only on dual-channel DACs. Refer to *Section 31.3: DAC implementation*.

Address offset: 0x30

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DACC2DOR[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **DACC2DOR[11:0]**: DAC channel2 data output

These bits are read-only, they contain data output for DAC channel2.

31.7.14 DAC status register (DAC_SR)

Address offset: 0x34

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BWST2	CAL_ FLAG2	DMAU DR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	rc_w1													
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BWST1	CAL_ FLAG1	DMAU DR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	rc_w1													

Bit 31 **BWST2**: DAC channel2 busy writing sample time flag

This bit is systematically set just after Sample and hold mode enable. It is set each time the software writes the register DAC_SHSR2, It is cleared by hardware when the write operation of DAC_SHSR2 is complete. (It takes about 3 LSI periods of synchronization).

0:There is no write operation of DAC_SHSR2 ongoing: DAC_SHSR2 can be written

1:There is a write operation of DAC_SHSR2 ongoing: DAC_SHSR2 cannot be written

Note: This bit is available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bit 30 **CAL_FLAG2**: DAC channel2 calibration offset status

This bit is set and cleared by hardware

0: calibration trimming value is lower than the offset correction value

1: calibration trimming value is equal or greater than the offset correction value

Note: This bit is available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bit 29 **DMAUDR2**: DAC channel2 DMA underrun flag

This bit is set by hardware and cleared by software (by writing it to 1).

0: No DMA underrun error condition occurred for DAC channel2

1: DMA underrun error condition occurred for DAC channel2 (the currently selected trigger is driving DAC channel2 conversion at a frequency higher than the DMA service capability rate).

Note: This bit is available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bit 28 Reserved, must be kept at reset value.

Bit 27 Reserved, must be kept at reset value.

Bits 26:16 Reserved, must be kept at reset value.

Bit 15 **BWST1**: DAC channel1 busy writing sample time flag

This bit is systematically set just after Sample and hold mode enable and is set each time the software writes the register DAC_SHSR1, It is cleared by hardware when the write operation of DAC_SHSR1 is complete. (It takes about 3 LSI periods of synchronization).

0:There is no write operation of DAC_SHSR1 ongoing: DAC_SHSR1 can be written

1:There is a write operation of DAC_SHSR1 ongoing: DAC_SHSR1 cannot be written

Bit 14 **CAL_FLAG1**: DAC channel1 calibration offset status

This bit is set and cleared by hardware

0: calibration trimming value is lower than the offset correction value

1: calibration trimming value is equal or greater than the offset correction value

Bit 13 **DMAUDR1**: DAC channel1 DMA underrun flag

This bit is set by hardware and cleared by software (by writing it to 1).

0: No DMA underrun error condition occurred for DAC channel1

1: DMA underrun error condition occurred for DAC channel1 (the currently selected trigger is driving DAC channel1 conversion at a frequency higher than the DMA service capability rate)

Bit 12 Reserved, must be kept at reset value.

Bit 11 Reserved, must be kept at reset value.

Bits 10:0 Reserved, must be kept at reset value.

31.7.15 DAC calibration control register (DAC_CCR)

Address offset: 0x38

Reset value: 0x00XX 00XX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OTRIM2[4:0]				
											rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OTRIM1[4:0]				
											rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:16 **OTRIM2[4:0]**: DAC channel2 offset trimming value
These bits are available only on dual-channel DACs. Refer to *Section 31.3: DAC implementation*.

Bits 15:5 Reserved, must be kept at reset value.

Bits 4:0 **OTRIM1[4:0]**: DAC channel1 offset trimming value

31.7.16 DAC mode control register (DAC_MCR)

Address offset: 0x3C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE2[2:0]		
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE1[2:0]		
													rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 Reserved, must be kept at reset value.

Bit 24 Reserved, must be kept at reset value.

Bits 23:19 Reserved, must be kept at reset value.

Bits 18:16 **MODE2[2:0]:** DAC channel2 mode

These bits can be written only when the DAC is disabled and not in the calibration mode (when bit EN2 = 0 and bit CEN2 = 0 in the DAC_CR register). If EN2 = 1 or CEN2 = 1 the write operation is ignored.

They can be set and cleared by software to select the DAC channel2 mode:

– DAC channel2 in Normal mode

000: DAC channel2 is connected to external pin with Buffer enabled

001: DAC channel2 is connected to external pin and to on chip peripherals with buffer enabled

010: DAC channel2 is connected to external pin with buffer disabled

011: DAC channel2 is connected to on chip peripherals with Buffer disabled

– DAC channel2 in Sample and hold mode

100: DAC channel2 is connected to external pin with Buffer enabled

101: DAC channel2 is connected to external pin and to on chip peripherals with Buffer enabled

110: DAC channel2 is connected to external pin and to on chip peripherals with Buffer disabled

111: DAC channel2 is connected to on chip peripherals with Buffer disabled

Note: This register can be modified only when EN2 = 0.

Refer to Section 31.3: DAC implementation for the availability of DAC channel2.

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:10 Reserved, must be kept at reset value.

Bit 9 Reserved, must be kept at reset value.

Bit 8 Reserved, must be kept at reset value.

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **MODE1[2:0]:** DAC channel1 mode

These bits can be written only when the DAC is disabled and not in the calibration mode (when bit EN1 = 0 and bit CEN1 = 0 in the DAC_CR register). If EN1 = 1 or CEN1 = 1 the write operation is ignored.

They can be set and cleared by software to select the DAC channel1 mode:

– DAC channel1 in Normal mode

000: DAC channel1 is connected to external pin with Buffer enabled

001: DAC channel1 is connected to external pin and to on chip peripherals with Buffer enabled

010: DAC channel1 is connected to external pin with Buffer disabled

011: DAC channel1 is connected to on chip peripherals with Buffer disabled

– DAC channel1 in sample & hold mode

100: DAC channel1 is connected to external pin with Buffer enabled

101: DAC channel1 is connected to external pin and to on chip peripherals with Buffer enabled

110: DAC channel1 is connected to external pin and to on chip peripherals with Buffer disabled

111: DAC channel1 is connected to on chip peripherals with Buffer disabled

Note: This register can be modified only when EN1 = 0.

31.7.17 DAC channel1 sample and hold sample time register (DAC_SHSR1)

Address offset: 0x40

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	TSAMPLE1[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:0 **TSAMPLE1[9:0]:** DAC channel1 sample time (only valid in Sample and hold mode)

These bits can be written when the DAC channel1 is disabled or also during normal operation. in the latter case, the write can be done only when BWST1 of DAC_SR register is low, If BWST1 = 1, the write operation is ignored.

*Note: It represents the number of LSI clocks to perform a sample phase. Sampling time = (*TSAMPLE1[9:0] + 1) x *LSI clock period.*

31.7.18 DAC channel2 sample and hold sample time register (DAC_SHSR2)

This register is available only on dual-channel DACs. Refer to *Section 31.3: DAC implementation*.

Address offset: 0x44

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	TSAMPLE2[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:0 **TSAMPLE2[9:0]:** DAC channel2 sample time (only valid in Sample and hold mode)
These bits can be written when the DAC channel2 is disabled or also during normal operation. in the latter case, the write can be done only when BWST2 of DAC_SR register is low, if BWST2 = 1, the write operation is ignored.

*Note: It represents the number of LSI clocks to perform a sample phase. Sampling time = (*TSAMPLE1[9:0] + 1) x *LSI clock period.*

31.7.19 DAC sample and hold time register (DAC_SHHR)

Address offset: 0x48

Reset value: 0x0001 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	THOLD2[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	THOLD1[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:16 **THOLD2[9:0]:** DAC channel2 hold time (only valid in Sample and hold mode).
Hold time = (THOLD[9:0]) x LSI clock period

Note: This register can be modified only when EN2 = 0.

These bits are available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:0 **THOLD1[9:0]:** DAC channel1 hold time (only valid in Sample and hold mode)
Hold time = (THOLD[9:0]) x LSI clock period

Note: This register can be modified only when EN1 = 0.

Note: These bits can be written only when the DAC channel is disabled and in Normal operating mode (when bit ENx = 0 and bit CENx = 0 in the DAC_CR register). If ENx = 1 or CENx = 1 the write operation is ignored.

31.7.20 DAC sample and hold refresh time register (DAC_SHRR)

Address offset: 0x4C

Reset value: 0x0001 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TREFRESH2[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TREFRESH1[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **TREFRESH2[7:0]:** DAC channel2 refresh time (only valid in Sample and hold mode)
Refresh time = (TREFRESH[7:0]) x LSI clock period

Note: This register can be modified only when EN2 = 0.
These bits are available only on dual-channel DACs. Refer to Section 31.3: DAC implementation.

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **TREFRESH1[7:0]:** DAC channel1 refresh time (only valid in Sample and hold mode)
Refresh time = (TREFRESH[7:0]) x LSI clock period

Note: This register can be modified only when EN1 = 0.

Note: These bits can be written only when the DAC channel is disabled and in Normal operating mode (when bit ENx = 0 and bit CENx = 0 in the DAC_CR register). If ENx = 1 or CENx = 1 the write operation is ignored.

31.7.21 DAC register map

Table 269 summarizes the DAC registers.

Table 269. DAC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	DAC_CR	Res.	CEN2	DMAUDRIE2	DMAEN2	MAMP2[3:0]				WAVE2[2:0]		TSEL23	TSEL22	TSEL21	TSEL20	TEN2	EN2	Res.	CEN1	DMAUDRIE1	DMAEN1	MAMP1[3:0]				WAVE1[1:0]		TSEL13	TSEL12	TSEL11	TSEL10	TEN1	EN1
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	DAC_SWTRGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWTRIG2	SWTRIG1
	Reset value																															0	0
0x08	DAC_DHR12R1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC1DHR[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x0C	DAC_DHR12L1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC1DHR[11:0]												Res.	Res.	Res.	Res.
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0				
0x10	DAC_DHR8R1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC1DHR[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x14	DAC_DHR12R2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC2DHR[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x18	DAC_DHR12L2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC2DHR[11:0]												Res.	Res.	Res.	Res.
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0				
0x1C	DAC_DHR8R2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC2DHR[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x20	DAC_DHR12RD	Res.	Res.	Res.	Res.	DACC2DHR[11:0]												Res.	Res.	Res.	Res.	DACC1DHR[11:0]											
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
0x24	DAC_DHR12LD	DACC2DHR[11:0]												Res.	Res.	Res.	Res.	DACC1DHR[11:0]												Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0				
0x28	DAC_DHR8RD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC2DHR[7:0]				DACC1DHR[7:0]											
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	DAC_DOR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC1DOR[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x30	DAC_DOR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DACC2DOR[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x34	DAC_SR	BWST2	CAL_FLAG2	DMAUDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BWST1	CAL_FLAG1	DMAUDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0														0	0	0													

Table 269. DAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x38	**DAC_CCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OTRIM2[4:0]					Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OTRIM1[4:0]				
	Reset value												X	X	X	X	X												X	X	X	X	X
0x3C	**DAC_MCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE2 [2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE1 [2:0]		
	Reset value														0	0	0														0	0	0
0x40	**DAC_ SHSR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSAMPLE1[9:0]									
	Reset value																							0	0	0	0	0	0	0	0	0	0
0x44	**DAC_ SHSR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSAMPLE2[9:0]									
	Reset value																							0	0	0	0	0	0	0	0	0	0
0x48	**DAC_ SHHR**	Res.	Res.	Res.	Res.	Res.	Res.	THOLD2[9:0]										Res.	Res.	Res.	Res.	Res.	Res.	THOLD1[9:0]									
	Reset value							0	0	0	0	0	0	0	0	0	1							0	0	0	0	0	0	0	0	0	1
0x4C	**DAC_ SHRR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TREFRESH2[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TREFRESH1[7:0]							
	Reset value									0	0	0	0	0	0	0	1									0	0	0	0	0	0	0	1

Refer to *Section 2.3 on page 131* for the register boundary addresses.

32 Voltage reference buffer (VREFBUF)

32.1 Introduction

The devices embed a voltage reference buffer which can be used as voltage reference for ADCs, DACs and also as voltage reference for external components through the VREF+ pin.

32.2 VREFBUF functional description

The internal voltage reference buffer supports four voltages[a], which are configured with VRS bits in the VREFBUF_CSR register:

- VRS = 000: around 2.5 V.
- VRS = 001: around 2.048 V.
- VRS = 010: around 1.8 V.
- VRS = 011: around 1.5 V (ADC and DAC peripherals are not compatible with this reference voltage setting).

The internal voltage reference can be configured in four different modes depending on ENVR and HIZ bits configuration. These modes are provided in the table below:

Table 270. VREF buffer modes

ENVR	HIZ	VREF buffer configuration
0	0	VREFBUF buffer off mode: – V_{REF+} pin pulled-down to V_{SSA}
0	1	External voltage reference mode (default value): – VREFBUF buffer off – V_{REF+} pin input mode
1	0	Internal voltage reference mode: – VREFBUF buffer on – V_{REF+} pin connected to VREFBUF buffer output
1	1	Hold mode: – VREF is enable without output buffer, VREF+ pin voltage is hold with the external capacitor – VRR detection disabled and VRR bit keeps last state

After enabling the VREFBUF by setting ENVR bit and clearing HIZ bit in the VREFBUF_CSR register, the user must wait until VRR bit is set, meaning that the voltage reference output has reached its expected value.

a. The minimum V_{DDA} voltage depends on VRS setting, refer to the product datasheet.

32.3 VREFBUF registers

32.3.1 VREFBUF control and status register (VREFBUF_CSR)

Address offset: 0x00

Reset value: 0x0000 0002

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VRS[2:0]			VRR	Res.	HIZ	ENVR
									rw	rw	rw	r		rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bits 6:4 **VRS[2:0]**: Voltage reference scale

These bits select the value generated by the voltage reference buffer.

000: Voltage reference set to 2.5 V

001: Voltage reference set to 2.048 V

010: Voltage reference set to 1.8 V

011: Voltage reference set to 1.5 V

Others: Reserved

Note: The software can program this bitfield only when the VREFBUF is disabled (ENVR=0).

Bit 3 **VRR:** Voltage reference buffer ready

0: the voltage reference buffer output is not ready.

1: the voltage reference buffer output reached the requested level.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **HIZ:** High impedance mode

This bit controls the analog switch to connect or not the V_{REF+} pin.

0: V_{REF+} pin is internally connected to the voltage reference buffer output.

1: V_{REF+} pin is high impedance.

Refer to *Table 270: VREF buffer modes* for the mode descriptions depending on ENVR bit configuration.

Bit 0 **ENVR:** Voltage reference buffer mode enable

This bit is used to enable the voltage reference buffer mode.

0: Internal voltage reference mode disable (external voltage reference mode).

1: Internal voltage reference mode (reference buffer enable or hold mode) enable.

32.3.2 VREFBUF calibration control register (VREFBUF_CCR)

Address offset: 0x04

Reset value: 0x0000 00XX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIM[5:0]					
										rw	rw	rw	rw	rw	rw

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:0 **TRIM[5:0]**: Trimming code

These bits are automatically initialized after reset with the trimming value stored in the Flash memory during the production test. Writing into these bits allows the tuning of the internal reference buffer voltage.

Note: If the user application performs the trimming, the trimming code must start from 000000 to 111111 in ascending order.

32.3.3 VREFBUF register map

The following table gives the VREFBUF register map and the reset values.

Table 271. VREFBUF register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**VREFBUF_CSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VRS[2:0]			VRR	Res.	HIZ	ENVR
	Reset value																										0	0	0	0		1	0
0x04	**VREFBUF_CCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIM[5:0]					
	Reset value																											x	x	x	x	x	x

Refer to *Section 2.3 on page 131* for the register boundary addresses.

33 Comparator (COMP)

33.1 Introduction

The device embeds two ultra-low-power comparator channels (COMP1 and COMP2). They can be used for a variety of functions including:

- wake up from low-power mode triggered by an analog signal
- analog signal conditioning
- cycle-by-cycle current control loop when combined with a PWM output from a timer

33.2 COMP main features

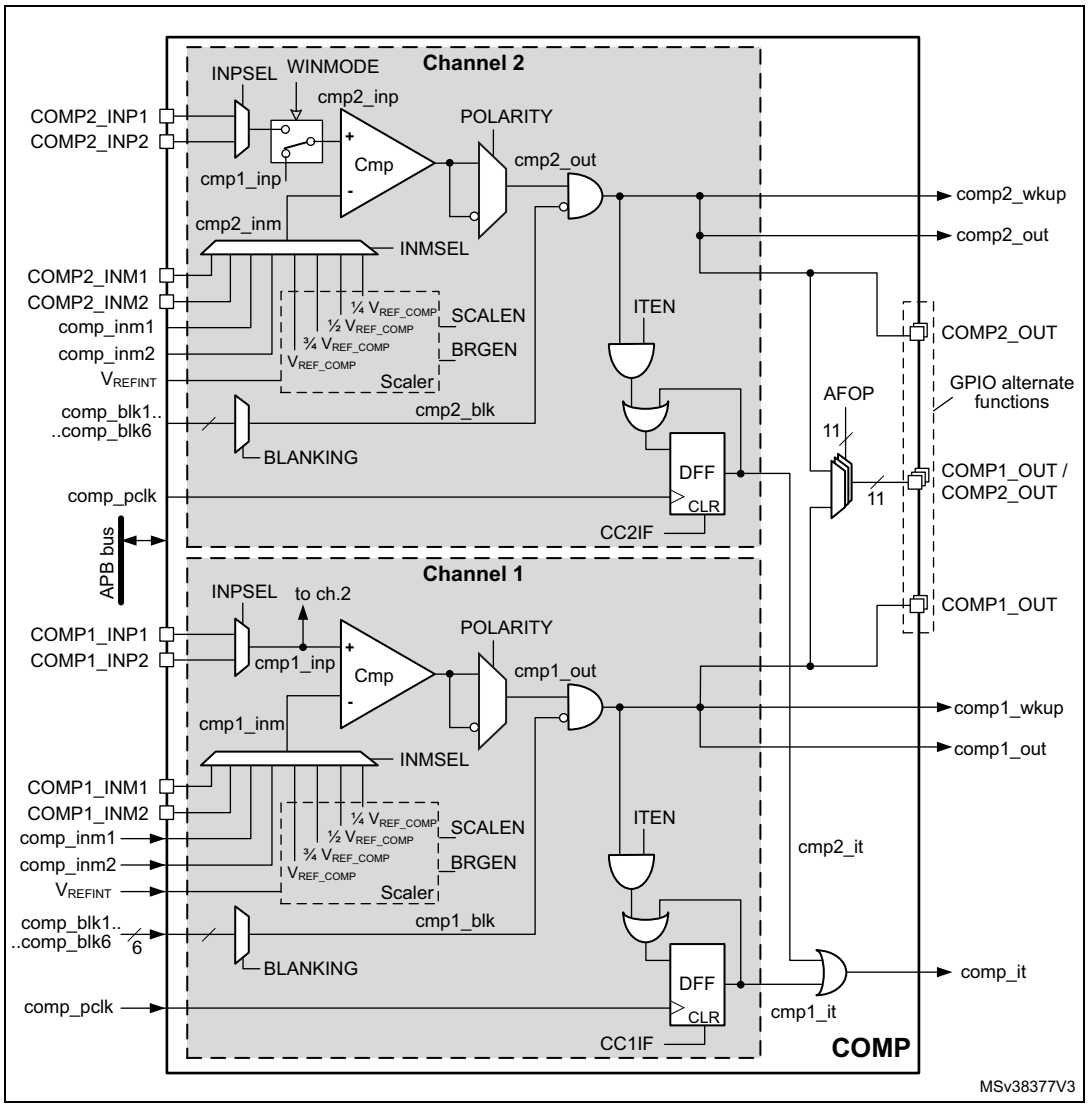
- Selectable inverting analog inputs:
  - I/O pins (different for either channel)
  - DAC Channel1 and Channel2 outputs
  - internal reference voltage and three sub multiple values (1/4, 1/2, 3/4) provided by scaler (buffered voltage divider)
- Two I/O pins per channel selectable as non-inverting analog inputs
- Programmable hysteresis
- Programmable speed / consumption
- Mapping of outputs to I/Os
- Redirection of outputs to timer inputs for triggering:
  - capture events
  - OCREF_CLR events (for cycle-by-cycle current control)
  - break events for fast PWM shutdowns
- Blanking of comparator outputs
- Window comparator
- Interrupt generation capability with wake up from Sleep and Stop modes (through the EXTI controller)
- Direct interrupt output to the CPU

33.3 COMP functional description

33.3.1 COMP block diagram

The block diagram of the comparators is shown in *Figure 297: Comparator functional block diagram*.

Figure 297. Comparator functional block diagram



33.3.2 COMP pins and internal signals

The I/Os used as comparator inputs must be configured in analog mode in the GPIO registers.

The comparator outputs can be connected to the I/Os through their alternate functions. Refer to the product datasheet.

The outputs can also be internally redirected to a variety of timer inputs for the following purposes:

- emergency shut-down of PWM signals, using BKIN and BKIN2 inputs
- cycle-by-cycle current control, using ETR inputs of timers
- input capture for timing measurements

The comparator output can be routed simultaneously internally and to the I/O pins.

Table 272. COMP input/output internal signals

Signal name	Signal type	Description
comp_inm1	Analog input	Inverting input source for both COMP channels: DAC ch.1
comp_inm2	Analog input	Inverting input source for both COMP channels: DAC ch.2
comp_blk1	Digital input	Blanking input source for both COMP channels: TIM1 OC5
comp_blk2	Digital input	Blanking input source for both COMP channels: TIM2 OC3
comp_blk3	Digital input	Blanking input source for both COMP channels: TIM3 OC3
comp_blk4	Digital input	Blanking input source for both COMP channels: TIM3 OC4
comp_blk5	Digital input	Blanking input source for both COMP channels: TIM8 OC5
comp_blk6	Digital input	Blanking input source for both COMP channels: TIM15 OC1
comp_pclk	Digital input	APB clock for both COMP channels
comp1_wkup	Digital output	COMP channel 1 wakeup out
comp1_out	Digital output	COMP channel 1 out
comp2_wkup	Digital output	COMP channel 2 wakeup out
comp2_out	Digital output	COMP channel 2 out
comp_it	Digital output	COMP interrupt out

Table 273. COMP input/output pins

Signal name	Signal type	Description
COMP1_INM1	Analog input	COMP channel 1 inverting input source 1 (PB1)
COMP1_INM2	Analog input	COMP channel 1 inverting input source 2 (PC4)
COMP1_INP1	Analog input	COMP channel 1 non-inverting input source 1 (PB0)
COMP1_INP2	Analog input	COMP channel 1 non-inverting input source 2 (PB2)
COMP2_INM1	Analog input	COMP channel 2 inverting input source 1 (PE10)
COMP2_INM2	Analog input	COMP channel 2 inverting input source 2 (PE7)
COMP2_INP1	Analog input	COMP channel 2 non-inverting input source 1 (PE9)
COMP2_INP2	Analog input	COMP channel 2 non-inverting input source 2 (PE11)
COMP1_OUT	Digital output	COMP channel 1 output: see *Section 33.3.8: Comparator output on GPIOs*.
COMP2_OUT	Digital output	COMP channel 2 output: see *Section 33.3.8: Comparator output on GPIOs*.

33.3.3 COMP reset and clocks

The clock comp_pclk provided by the clock controller is synchronous with the APB clock.

Note: ***Important:*** *The polarity selection logic and the output redirection to the port works independently from the APB clock. This allows the comparator to work even in Stop mode. The interrupt line, connected to the NVIC of CPU, requires the APB clock (comp_pclk) to work. In absence of the APB clock, the interrupt signal comp_it cannot be generated.*

33.3.4 Comparator LOCK mechanism

The comparators can be used for safety purposes, such as over-current or thermal protection. For applications with specific functional safety requirements, the comparator configuration can be protected against undesired alteration that could happen, for example, at program counter corruption.

For this purpose, the comparator configuration registers can be write-protected (read-only).

Upon configuring a comparator channel, its LOCK bit is set to 1. This causes the whole register set of the comparator channel, as well as the common COMP_OR register, to become read-only, the LOCK bit inclusive.

The write protection can only be removed through the MCU reset.

The COMP_OR register is locked by the LOCK bit of COMP_CFGR1 OR COMP_CFGR2.

33.3.5 Window comparator

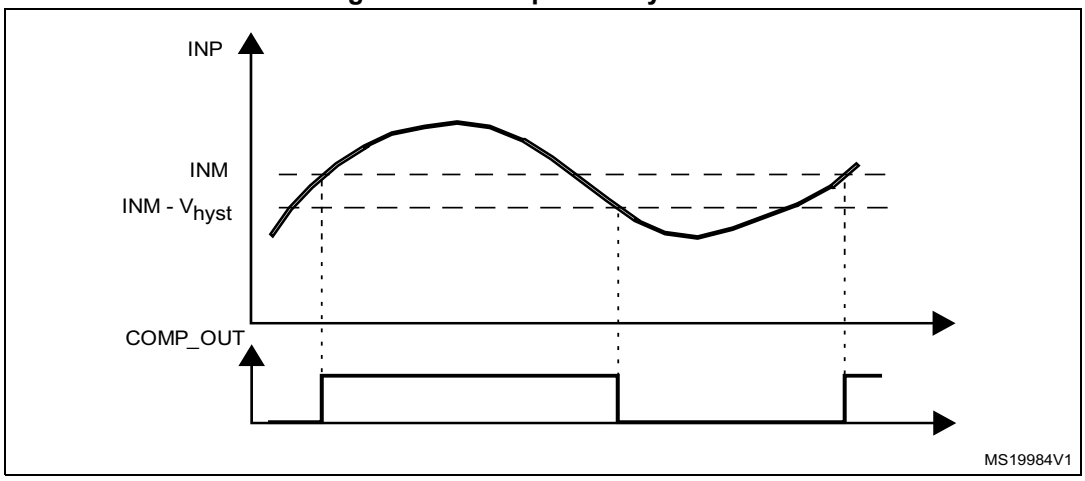
The purpose of the window comparator is to monitor the analog voltage and check that it is comprised within the specified voltage range defined by lower and upper thresholds.

The window comparator requires both COMP channels. The monitored analog voltage is connected to their non-inverting (plus) inputs and the upper and lower threshold voltages are connected to the inverting (minus) input of either comparator, respectively. The non-inverting input of the COMP channel 2 can be connected internally with the non-inverting input of the COMP channel 1 by enabling WINMODE bit. This can save the input pins of COMP channel 2 for other purposes. See *Figure 297: Comparator functional block diagram*.

33.3.6 Hysteresis

The comparator includes a programmable hysteresis to avoid spurious output transitions in case of noisy signals. The hysteresis can be disabled if it is not needed (for instance when exiting from low-power mode) to be able to force the hysteresis value using external components.

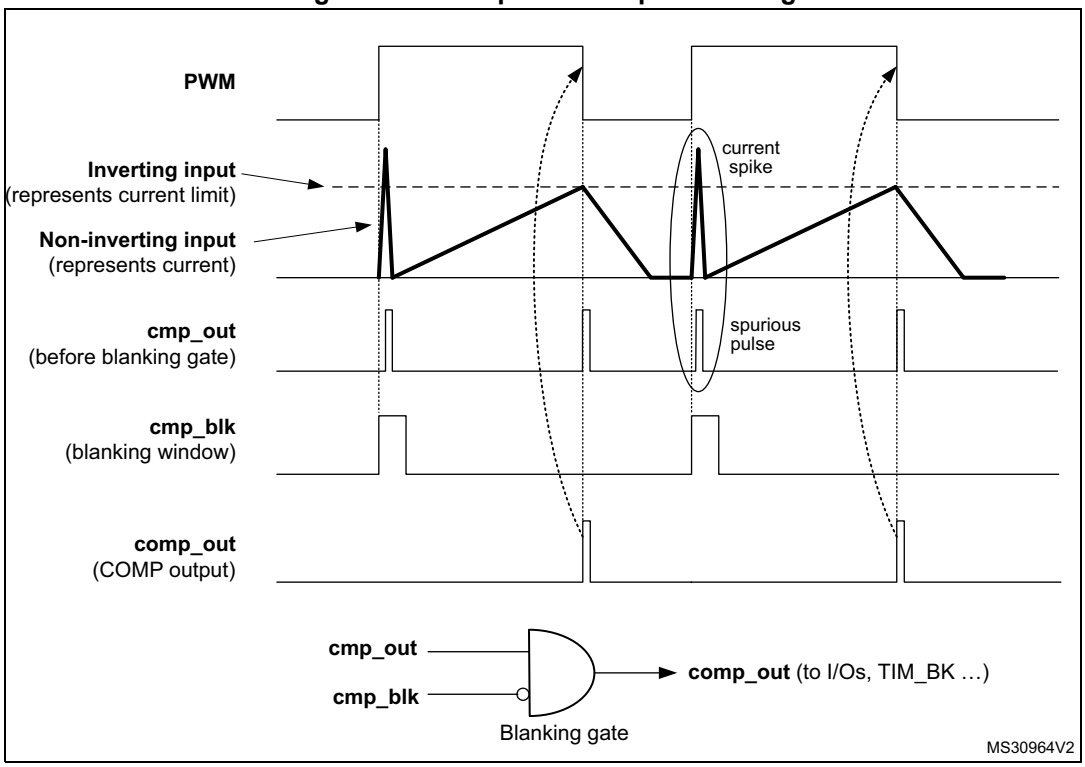
Figure 298. Comparator hysteresis



33.3.7 Comparator output blanking function

The purpose of the blanking function is to prevent the current regulation to trip upon short current spikes at the beginning of the PWM period (typically the recovery current in power switches anti parallel diodes). It uses a blanking window defined with a timer output compare signal. Refer to the register description for selectable blanking signals. The blanking signal gates the internal comparator output such as to clean the comp_out from spurious pulses due to current spikes, as depicted in *Figure 299* (the COMP channel number is not represented).

Figure 299. Comparator output blanking



33.3.8 Comparator output on GPIOs

The COMP1_OUT and COMP2_OUT outputs of the comparator channels are mapped to GPIOs through the AFOP field of the COMP_OR register, bits [10:0], and through the GPIO alternate function.

Table 274. COMP1_OUT assignment to GPIOs

COMP1_OUT	Alternate Function
PC5	AF13
PE12	AF13
PA6	AF10, AF12 (can be used as timer break in)
PA8	AF12 (can be used as timer break in)
PB12	AF13 (can be used as timer break in)
PE6	AF11 (can be used as timer break in)
PE15	AF13 (can be used as timer break in)
PG2	AF11 (can be used as timer break in)
PG3	AF11 (can be used as timer break in)
PG4	AF11 (can be used as timer break in)
PI1	AF11 (can be used as timer break in)
PI4	AF11 (can be used as timer break in)
PK2	AF10, AF11 (can be used as timer break in)

Table 275. COMP2_OUT assignment to GPIOs

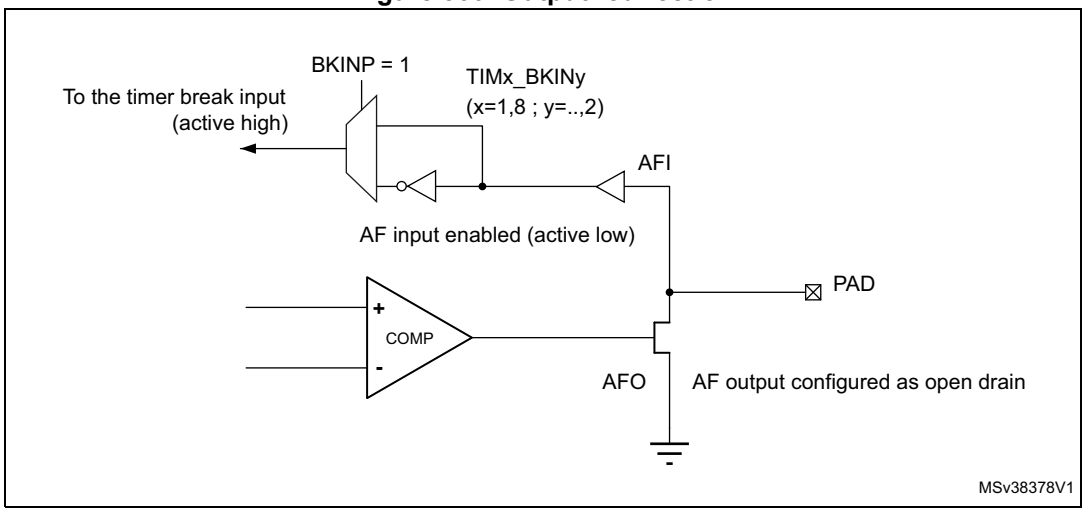
COMP2_OUT	Alternate Function
PE8	AF13
PE13	AF13
PA6	AF10, AF12 (can be used as timer break in)
PA8	AF12 (can be used as timer break in)
PB12	AF13 (can be used as timer break in)
PE6	AF11 (can be used as timer break in)
PE15	AF13 (can be used as timer break in)
PG2	AF11 (can be used as timer break in)
PG3	AF11 (can be used as timer break in)
PG4	AF11 (can be used as timer break in)
PI1	AF11 (can be used as timer break in)
PI4	AF11 (can be used as timer break in)
PK2	AF10, AF11 (can be used as timer break in)

The assignment to GPIOs for both comparator channel outputs must be done before locking registers of any channel, because the common COMP_OR register is locked when locking the registers of either comparator channel.

33.3.9 Comparator output redirection

The outputs of either COMP channel can be redirected to timer break inputs (TIMx_BKIN or TIMx_BKIN2), as shown in *Figure 300*. For that end, the COMP channel output is connected to one of GPIOs programmable in alternate function as timer break input. See *Table 274* and *Table 275*. The selected GPIO(s) must be set in open drain mode. The COMP output passes through the GPIO to the timer break input. With a pull-up resistor, the selected GPIO can be used as timer break input logic OR-ed with the comparator output.

Figure 300. Output redirection



33.3.10 COMP power and speed modes

The power consumption of the COMP channels versus propagation delay can be adjusted to have the optimum trade-off for a given application.

The bits PWRMODE[1:0] in COMP_CFGRx registers can be programmed as follows:

00: High speed / full power

01: Medium speed / medium power

10: Medium speed / medium power

11: Very-low speed / ultra-low-power

33.4 COMP low-power modes

Table 276. Comparator behavior in the low-power modes

Mode	Description
Sleep	No effect on the comparators. Comparator interrupts cause the device to exit the Sleep mode.
Stop	No effect on the comparators. Comparator interrupts cause the device to exit the Stop mode.

Note: The comparators cannot be used to exit the device from Sleep or Stop mode when the internal reference voltage is switched off.

33.5 COMP interrupts

There are two ways to use the comparator as interrupt source.

The comparator outputs are internally connected to the Extended interrupt and event controller. Each comparator has its own EXTI line and can generate either interrupts or events to make the device exit low-power modes.

The comparators also provide an interrupt line to the NVIC of CPU. This functionality is used when the CPU is active to handle low latency interrupt. It requires APB clock running.

33.5.1 Interrupt through EXTI block

Refer to Interrupt and events section for more details.

Sequence to enable the COMPx interrupt through EXTI block:

1. Configure the EXTI line, receiving the comp_wkup signal, in interrupt mode, select the rising, falling or either-edge sensitivity and enable the EXTI line.
2. Configure and enable the NVIC IRQ channel mapped to the corresponding EXTI lines.
3. Enable the COMPx.

Table 277. Interrupt control bits

Interrupt event	Event flag	Enable control bit	Exit from Sleep mode	Exit from Stop modes	Exit from Standby mode
comp1_wkup	through EXTI	through EXTI	yes	yes	N/A
comp2_whup	through EXTI	through EXTI	yes	yes	N/A

33.5.2 Interrupt through NVIC of the CPU

Sequence to enable the COMPx interrupt through NVIC of the CPU:

1. Configure and enable the NVIC IRQ channel mapped to the comp_it line.
2. Configure and enable the ITEN in COMP_CFGRx.
3. Enable the COMPx.

Table 278. Interrupt control bits

Interrupt event	Interrupt flag	Enable control bit	Interrupt clear bit	Exit from Sleep mode	Exit from Stop modes
comp_it	C1IF in	ITEN in COMP_CFGR1	CC1IF	yes (With APB clock)	no
comp_it	C2IF in	ITEN in COMP_CFGR2	CC2IF	yes (With APB clock)	no

Note: It is mandatory to enable APB clock to use this interrupt. If clock is not enabled, interrupt is not generated.

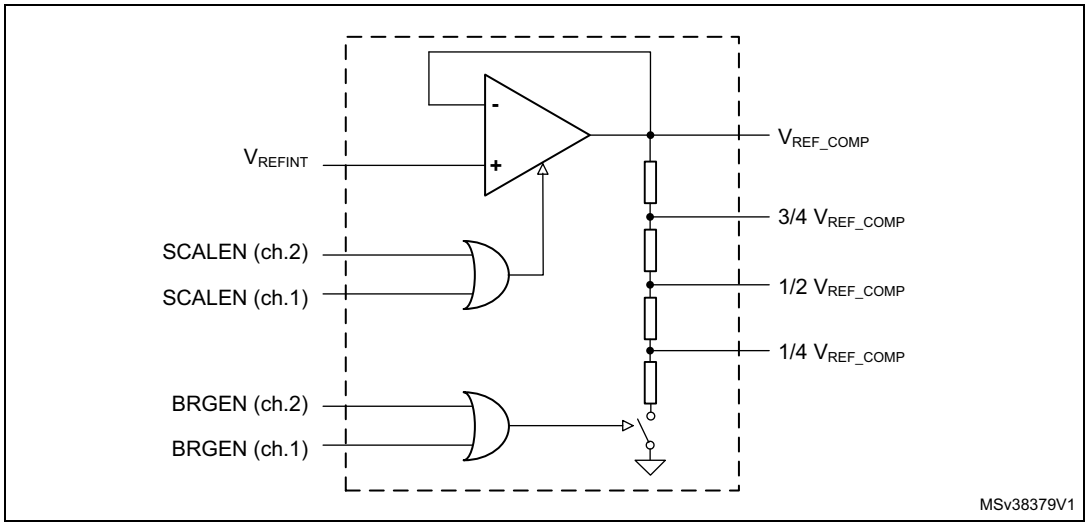
33.6 SCALER function

The scaler block is available to provide the different voltage reference levels to the comparator inputs. It is based on an amplifier driving a resistor bridge. The amplifier input is connected to the internal voltage reference.

The amplifier and the resistor bridge can be enabled separately. The amplifier is enabled by the SCALEN bits of the COMP_CFGRx registers. The resistor bridge is enabled by the BRGEN bits of the COMP_CFGRx registers.

When the resistor divided voltage is not used, the resistor bridge can be disconnected in order to reduce the consumption. When it is disconnected, the 1/4 V_{REF_COMP}, 1/2 V_{REF_COMP} and 3/4 V_{REF_COMP} levels are equal to V_{REF_COMP}.

Figure 301. Scaler block diagram



33.7 COMP registers

33.7.1 Comparator status register (COMP_SR)

The COMP_SR is the comparator status register.

Address offset: 0x00

System reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	C2IF	C1IF
														r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	C2VAL	C1VAL
														r	r

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **C2IF**: COMP channel 2 Interrupt Flag
This bit is set by hardware when the COMP channel 2 output is set
This bit is cleared by software writing 1 the CC2IF bit in the COMP_ICFR register.

Bit 16 **C1IF**: COMP channel 1 Interrupt Flag
This bit is set by hardware when the COMP channel 1 output is set
This bit is cleared by software writing 1 the CC1IF bit in the COMP_ICFR register.

Bits 15:2 Reserved, must be kept at reset value.

Bit 1 **C2VAL:** COMP channel 2 output status bit
This bit is read-only. It reflects the current COMP channel 2 output taking into account POLARITY and BLANKING bits effect.

Bit 0 **C1VAL:** COMP channel 1 output status bit
This bit is read-only. It reflects the current COMP channel 1 output taking into account POLARITY and BLANKING bits effect.

33.7.2 Comparator interrupt clear flag register (COMP_ICFR)

The COMP_ICFR is the Comparator interrupt clear flag register.

Address offset: 0x00

System reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2IF	CC1IF
														w1o	w1o
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **CC2IF**: Clear COMP channel 2 Interrupt Flag
Writing 1 clears the C2IF flag in the COMP_SR register.

Bit 16 **CC1IF**: Clear COMP channel 1 Interrupt Flag
Writing 1 clears the C1IF flag in the COMP_SR register.

Bits 15:0 Reserved, must be kept at reset value.

33.7.3 Comparator option register (COMP_OR)

The COMP_OR is the Comparator option register.

Address offset: 0x08

System reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	AFOP										
					rw										

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:0 **AFOP[10:0]:** Selection of source for alternate function of output ports
Bits of this field are set end cleared by software (only if LOCK not set).
Output port (GPIO) correspondence:

bit 10	bit 9	bit 8	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
PK2	PI4	PI1	PG4	PG3	PG2	PE15	PE6	PB12	PA8	PA6

For each bit:
0: COMP1_OUT is selected for the alternate function of the corresponding GPIO
1: COMP2_OUT is selected for the alternate function of the corresponding GPIO

33.7.4 Comparator configuration register 1 (COMP_CFGR1)

The COMP_CFGR1 is the COMP channel 1 configuration register.

Address offset: 0x0C

System reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LOCK	Res.	Res.	Res.	BLANKING[3:0]				Res.	Res.	Res.	INPSEL	Res.	INMSEL[2:0]		
rw				rw							rw		rw		

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	PWRMODE[1:0]		Res.	Res.	HYST[1:0]		Res.	ITEN	Res.	Res.	POLARITY	SCALEN	BRGEN	EN
		rw				rw			rw			rw	rw	rw	rw

Bit 31 **LOCK:** Lock bit
This bit is set by software and cleared by a hardware system reset. It locks the whole content of the COMP channel 1 configuration register COMP_CFGR1[31:0], and COMP_OR register
0: COMP_CFGR1[31:0] register is read/write
1: COMP_CFGR1[31:0] and COMP_OR registers are read-only

Bits 30:28 Reserved, must be kept at reset value.

Bits 27:24 **BLANKING[3:0]:** COMP channel 1 blanking source selection bits
Bits of this field are set and cleared by software (only if LOCK not set).
The field selects the input source for COMP channel 1 output blanking:
0000: No blanking
0001: comp_blk1
0010: comp_blk2
0011: comp_blk3
0100: comp_blk4
0101: comp_blk5
0110: comp_blk6
All other values: reserved

Bits 23:21 Reserved, must be kept at reset value.

Bit 20 **INPSEL**: COMP channel 1 non-inverting input selection bit
This bit is set and cleared by software (only if LOCK not set).
0: COMP1_INP1 (PB0)
1: COMP1_INP2 (PB2)

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **INMSEL[2:0]**: COMP channel 1 inverting input selection field
These bits are set and cleared by software (only if LOCK not set). They select which input is connected to the input minus of COMP channel 1.
000 = 1/4 V_{REF_COMP}
001 = 1/2 V_{REF_COMP}
010 = 3/4 V_{REF_COMP}
011 = V_{REF_COMP}
100 = comp_inm1 (DAC channel 1 output)
101 = comp_inm2 (DAC channel 2 output)
110 = COMP1_INM1 (PB1)
111 = COMP1_INM2 (PC4)

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:12 **PWRMODE[1:0]:** Power Mode of the COMP channel 1
These bits are set and cleared by software (only if LOCK not set). They control the power/speed of the COMP channel 1.
00: High speed / full power
01: Medium speed / medium power
10: Medium speed / medium power
11: Ultra low power / ultra-low-power

Bits 11:10 Reserved, must be kept at reset value.

Bits 9:8 **HYST[1:0]:** COMP channel 1 hysteresis selection bits
These bits are set and cleared by software (only if LOCK not set). They select the Hysteresis voltage of the COMP channel 1.
00: No hysteresis
01: Low hysteresis
10: Medium hysteresis
11: High hysteresis

Bit 7 Reserved, must be kept at reset value.

Bit 6 **ITEN:** COMP channel 1 interrupt enable
This bit is set and cleared by software (only if LOCK not set). This bit enable the interrupt generation of the COMP channel 1.
0: Interrupt generation disabled for COMP channel 1
1: Interrupt generation enabled for COMP channel 1

Bits 5:4 Reserved, must be kept at reset value.

Bit 3 **POLARITY:** COMP channel 1 polarity selection bit
This bit is set and cleared by software (only if LOCK not set). It inverts COMP channel 1 polarity.
0: COMP channel 1 output is not inverted
1: COMP channel 1output is inverted

Bit 2 **SCALEN**: Voltage scaler enable bit
This bit is set and cleared by software (only if LOCK not set). This bit enables the V_{REFINT} scaler for the COMP channels.
0: V_{REFINT} scaler disabled (if SCALEN bit of COMP_CFGR2 register is also low)
1: V_{REFINT} scaler enabled

Bit 1 **BRGEN:** Scaler bridge enable
This bit is set and cleared by software (only if LOCK not set). This bit enables the bridge of the scaler.
0: Scaler resistor bridge disabled (if BRGEN bit of COMP_CFGR2 register is also low)
1: Scaler resistor bridge enabled
If SCALEN is set and BRGEN is reset, all four scaler outputs provide the same level V_{REF_COMP} (similar to V_{REFINT}).
If SCALEN and BRGEN are set, the four scaler outputs provide V_{REF_COMP}, 3/4 V_{REF_COMP}, 1/2 V_{REF_COMP} and 1/4 V_{REF_COMP} levels, respectively.

Bit 0 **EN:** COMP channel 1 enable bit
This bit is set and cleared by software (only if LOCK not set). It enables the COMP channel 1.
0: Disable
1: Enable

33.7.5 Comparator configuration register 2 (COMP_CFGR2)

The COMP_CFGR2 is the COMP channel 2 configuration register.

Address offset: 0x10

System reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LOCK	Res.	Res.	Res.	BLANKING[3:0]				Res.	Res.	Res.	INPSEL	Res.	INMSEL[2:0]		
rw				rw							rw		rw		

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	PWRMODE[1:0]		Res.	Res.	HYST[1:0]		Res.	ITEN	Res.	WINMODE	POLARITY	SCALEN	BRGEN	EN
		rw				rw			rw		rw	rw	rw	rw	rw

Bit 31 **LOCK:** Lock bit
This bit is set by software and cleared by a hardware system reset. It locks the whole content of the COMP channel 2 configuration register COMP_CFGR2[31:0], and COMP_OR register
0: COMP_CFGR2[31:0] register is read/write
1: COMP_CFGR2[31:0] and COMP_OR registers are read-only

Bits 30:28 Reserved, must be kept at reset value.

Bits 27:24 **BLANKING[3:0]:** COMP channel 2 blanking source selection bits
These bits are set and cleared by software (only if LOCK not set). These bits select which timer output controls the COMP channel 2 output blanking.
0000: No blanking
0001: TIM1 OC5 selected as blanking source
0010: TIM2 OC3 selected as blanking source
0011: TIM3 OC3 selected as blanking source
0100: TIM3 OC4 selected as blanking source
0101: TIM8 OC5 selected as blanking source
0110: TIM15 OC1 selected as blanking source
All other values: reserved

Bits 23:21 Reserved, must be kept at reset value.

Bit 20 **INPSEL**: COMP channel 2 non-inverting input selection bit
This bit is set and cleared by software (only if LOCK not set).
0: COMP2_INP1 (PE9)
1: COMP2_INP2 (PE11)

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **INMSEL[2:0]**: COMP channel 2 inverting input selection field
These bits are set and cleared by software (only if LOCK not set). They select which input is connected to the input minus of COMP channel 2.
000 = 1/4 V_{REF_COMP}
001 = 1/2 V_{REF_COMP}
010 = 3/4 V_{REF_COMP}
011 = V_{REF_COMP}
100 = comp_inm1 (DAC channel 1 output)
101 = comp_inm2 (DAC channel 2 output)
110 = COMP2_INM1 (PE10)
111 = COMP2_INM2 (PE7)

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:12 **PWRMODE[1:0]:** Power Mode of the COMP channel 2
These bits are set and cleared by software (only if LOCK not set). They control the power/speed of the COMP channel 2.
00: High speed / full power
01: Medium speed / medium power
10: Medium speed / medium power
11: Ultra low power / ultra-low-power

Bits 11:10 Reserved, must be kept at reset value.

Bits 9:8 **HYST[1:0]:** COMP channel 2 hysteresis selection bits
These bits are set and cleared by software (only if LOCK not set). They select the Hysteresis voltage of the COMP channel 2.
00: No hysteresis
01: Low hysteresis
10: Medium hysteresis
11: High hysteresis

Bit 7 Reserved, must be kept at reset value.

Bit 6 **ITEN:** COMP channel 2 interrupt enable
This bit is set and cleared by software (only if LOCK not set). This bit enable the interrupt generation of the COMP channel 2.
0: Interrupt generation disabled for COMP channel 2
1: Interrupt generation enabled for COMP channel 2

Bit 5 Reserved, must be kept at reset value.

Bit 4 **WINMODE**: Window comparator mode selection bit
This bit is set and cleared by software (only if LOCK not set). This bit selects the window mode of the comparators. If set, the non-inverting input of COMP channel 2 is connected to the non-inverting input of the COMP channel 1.
Depending on the bit value, the non-inverting input of COMP channel 2 is connected to:
0: COMP2_INP input selector
1: Non-inverting input comp1_inp of COMP channel 1

Bit 3 **POLARITY:** COMP channel 2 polarity selection bit
This bit is set and cleared by software (only if LOCK not set). It inverts COMP channel 2 polarity.
0: COMP channel 2 output is not inverted
1: COMP channel 2 output is inverted

Bit 2 **SCALEN**: Voltage scaler enable bit
This bit is set and cleared by software (only if LOCK not set). This bit enables the V_{REFINT} scaler for the COMP channels.
0: V_{REFINT} scaler disabled (if SCALEN bit of COMP_CFGR1 register is also low)
1: V_{REFINT} scaler enabled

Bit 1 **BRGEN:** Scaler bridge enable
This bit is set and cleared by software (only if LOCK not set). This bit enables the bridge of the scaler.
0: Scaler resistor bridge disabled (if BRGEN bit of COMP_CFGR1 register is also low)
1: Scaler resistor bridge enabled
If SCALEN is set and BRGEN is reset, all four scaler outputs provide the same level V_{REF_COMP} (similar to V_{REFINT}).
If SCALEN and BRGEN are set, the four scaler outputs provide V_{REF_COMP}, 3/4 V_{REF_COMP}, 1/2 V_{REF_COMP} and 1/4 V_{REF_COMP} levels, respectively.

Bit 0 **EN:** COMP channel 2 enable bit
This bit is set and cleared by software (only if LOCK not set). It enables the COMP channel 2.
0: Disable
1: Enable

33.7.6 COMP register map

The following table summarizes the comparator registers.

Table 279. COMP register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**COMP_SR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	C2IF	C1IF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	C2VAL	C1VAL
	Reset value															0	0															0	0
0x04	**COMP_ICFR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2IF	CC1IF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value															0	0																
0x08	**COMP_OR (OR_CFG=0)**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OR15	OR14	OR13	OR12	OR11	AFOP										
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	**COMP_OR (OR_CFG=1)**	OR31	OR30	OR29	OR28	OR27	OR26	OR25	OR24	OR23	OR22	OR21	OR20	OR19	OR18	OR17	OR16	OR15	OR14	OR13	OR12	OR11	AFOP										
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	**COMP_CFG R1**	LOCK	Res.	Res.	Res.	BLANKING				Res.	Res.	Res.	INPSEL	Res.	INMSEL			Res.	Res.	PWRMODE		Res.	Res.	HYST		Res.	ITEN	Res.	Res.	POLARITY	SCALEN	BRGEN	EN
	Reset value	0				0	0	0	0				0		0	0	0			0	0			0	0		0			0	0	0	0
0x10	**COMP_CFG R2**	LOCK	Res.	Res.	Res.	BLANKING				Res.	Res.	Res.	INPSEL	Res.	INMSEL			Res.	Res.	PWRMODE		Res.	Res.	HYST		Res.	ITEN	Res.	WINMODE	POLARITY	SCALEN	BRGEN	EN
	Reset value	0				0	0	0	0				0		0	0	0			0	0			0	0		0		0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

34 Operational amplifiers (OPAMP)

34.1 Introduction

The devices embed two operational amplifiers with two inputs and one output each. The three I/Os can be connected to the external pins, thus enabling any type of external interconnections. The operational amplifiers can be configured internally as a follower, as an amplifier with a non-inverting gain ranging from 2 to 16 or with inverting gain ranging from -1 to -15.

Refer to *Section 34.3.3: Signal routing* for detailed information on OPAMP input and output connection to internal peripherals.

34.2 OPAMP main features

- Rail-to-rail input and output voltage range
- Low input bias current (down to 1 nA)
- Low input offset voltage (1.5 mV after calibration, 10 mV with factory calibration)
- 7 MHz gain bandwidth
- High-speed mode to achieve a better slew rate

Note: Refer to the product datasheet for detailed OPAMP characteristics.

34.3 OPAMP functional description

The OPAMP has several modes.

Each OPAMP can be individually enabled, when disabled the output is high-impedance.

When enabled, it can be in calibration mode, all input and output of the OPAMP are then disconnected, or in functional mode.

There are two functional modes, the high-speed mode and the normal mode. In functional mode the inputs and output of the OPAMP are connected as described in *Section 34.3.3: Signal routing*.

34.3.1 OPAMP reset and clocks

The operational amplifier clock is necessary for accessing the registers. When the application does not need to have read or write access to those registers, the clock can be switched off using the peripheral clock enable register (see OPAMPEN bit in *Section 8.7.43: RCC APB1 clock register (RCC_APB1LENR)*).

The bit OPAEN enables and disables the OPAMP operation. The OPAMP registers configurations should be changed before enabling the OPAEN bit in order to avoid spurious effects on the output.

When the output of the operational amplifier is no more needed the operational amplifier can be disabled to save power. All the configurations previously set (including the calibration) are maintained while OPAMP is disabled.

34.3.2 Initial configuration

The default configuration of the operational amplifier is a functional mode where the three input/outputs are connected to external pins. In the default mode the operational amplifier uses the factory trimming values for its offset calibration. See electrical characteristics section of the datasheet for factory trimming conditions, usually the temperature is 30 °C and the voltage is 3 V. The trimming values can be adjusted, see *Section 34.3.5: Calibration* for changing the trimming values. The default configuration uses the normal mode, which provides the standard performance. The bit OPAHSM can be set in order to switch the operational amplifier to high-speed mode for a better slew rate. Both normal and high-speed mode characteristics are defined in *Section: Electrical characteristics* of the datasheet.

As soon as the OPAEN bit in OPAMPx_CSR register is set, the operational amplifier is functional. The two input pins and the output pin are connected as defined in *Section 34.3.3: Signal routing* and the default connection settings can be changed.

Note: The inputs and output pins must be configured in analog mode (default state) in the corresponding GPIOx_MODER register.

34.3.3 Signal routing

The routing for the operational amplifier pins is determined by OPAMPx_CSR register.

The connections of the two operational amplifiers (OPAMP1 and OPAMP2) are described in the table below.

Table 280. Operational amplifier possible connections

Signal	Pin	Internal	comment
OPAMP1_VINM	PC5(INM0) PA7(INM1)	ADC1_INP7 ADC1_INN3 ADC1_INP8 ADC1_INN4 ADC2_INP7 ADC2_INN3 ADC2_INP8 ADC2_INN4 COMP1_OUT OPAMP1_VOUT or PGA	This pin is controlled by bits PGA_GAIN and VM_SEL.
OPAMP1_VINP	PB0	dac1_out1 ADC1_INN5 ADC1_INP9 ADC2_INN5 ADC2_INP9 COMP1_INP1	This pin is controlled by bit VP_SEL.
OPAMP1_VOUT(1)	PC4	ADC1_INP4 ADC2_INP4 COMP1_INN7	The pin is connected when the OPAMP is enabled. The ADC input is controlled by ADC.

Table 280. Operational amplifier possible connections (continued)

Signal	Pin	Internal	comment
OPAMP2_VINM	PE8(INM0) PG1(INM1)	COMP2_OUT OPAMP2_VOUT or PGA	This pin is controlled by bits PGA_GAIN and VM_SEL.
OPAMP2_VINP	PE9	dac1_out2 COMP2_INP	controlled by bit VP_SEL
OPAMP2_VOUT(1)	PE7	COMP2_INN7	-

1. Both OPAMP1_VOUT and OPAMP2_VOUT are not available on all packages. The unconnected OPAMP must not be activated (see *Section 34.6.1: OPAMP1 control/status register (OPAMP1_CSR)*).

34.3.4 OPAMP modes

The operational amplifier inputs and outputs are all accessible on terminals. The amplifiers can be used in multiple configuration environments:

- Standalone mode (external gain setting mode)
- Follower configuration mode
- PGA modes

Note: The amplifier output pin is directly connected to the output pad to minimize the output impedance. When the amplifier is enabled, it cannot be used as a general purpose I/O, even if the amplifier is configured as a PGA and only connected to the internal channel.

The impedance of the signal must be maintained below a level which avoids the input leakage to create significant artifacts (due to a resistive drop in the source). Please refer to the electrical characteristics section in the datasheet for further details.

Standalone mode (external gain setting mode)

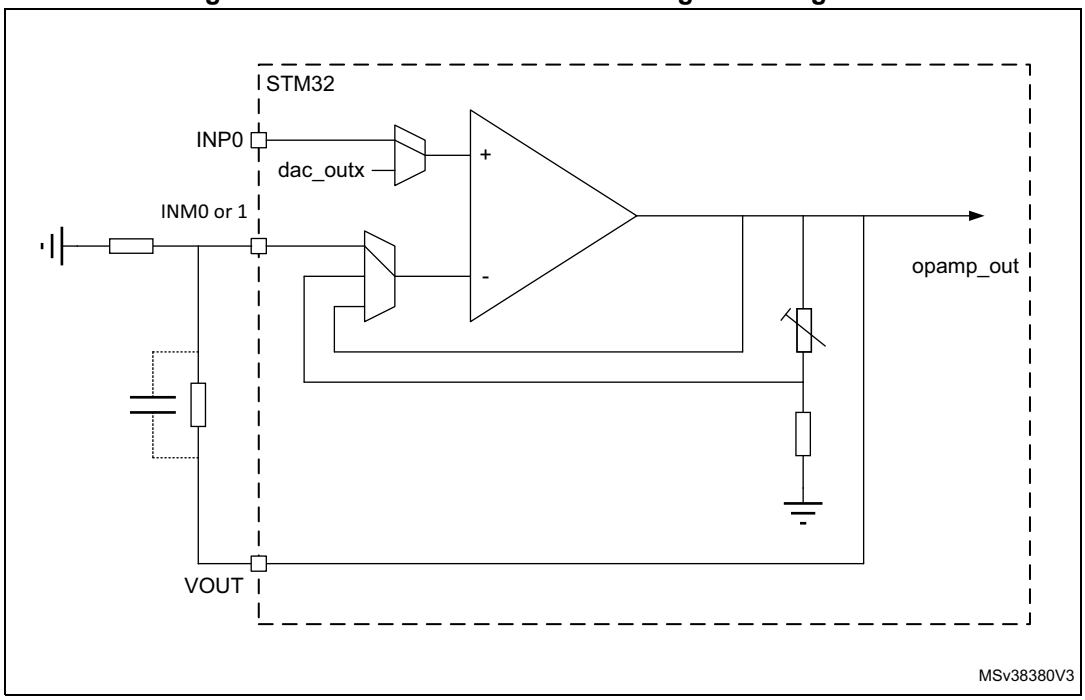
The procedure to use the OPAMP in standalone mode is presented hereafter.

Starting from the default value of OPAMPx_CSR, and the default state of GPIOx_MODER, as soon as the OPAEN bit is set, the two input pins and the output pin are connected to the operational amplifier.

This default configuration uses the factory trimming values and operates in normal mode (highest performance). The behavior of the OPAMP can be changed as follows:

- OPAHSM can be set to “operational amplifier high-speed” mode in order to have high slew rate.
- USERTRIM can be set to modify the trimming values for input offsets.

Figure 302. Standalone mode: external gain setting mode



Follower configuration mode

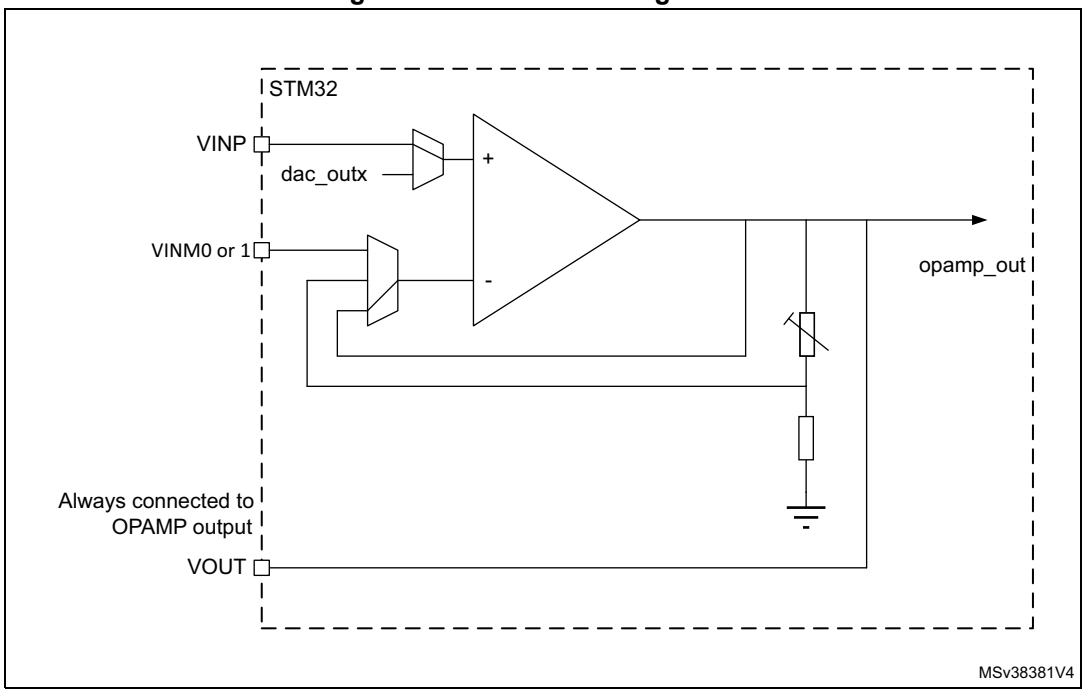
The procedure to use the OPAMP in follower mode is presented hereafter.

- configure VM_SEL bits as “opamp_out connected to OPAMPx_VINM input”, 11
- configure VP_SEL bits as “GPIO connected to OPAMPx_VINP”, 00
- As soon as the OPAEN bit is set, the voltage on pin OPAMPx_VINP is buffered to pin OPAMPx_VOUT.

Note: The pin corresponding to OPAMPx_VINM is free for another usage.

The signal on the OPAMP1 output is also seen as an ADC input. As a consequence, the OPAMP configured in follower mode can be used to perform impedance adaptation on input signals before feeding them to the ADC input, assuming the input signal frequency is compatible with the operational amplifier gain bandwidth specification.

Figure 303. Follower configuration



Programmable gain amplifier mode

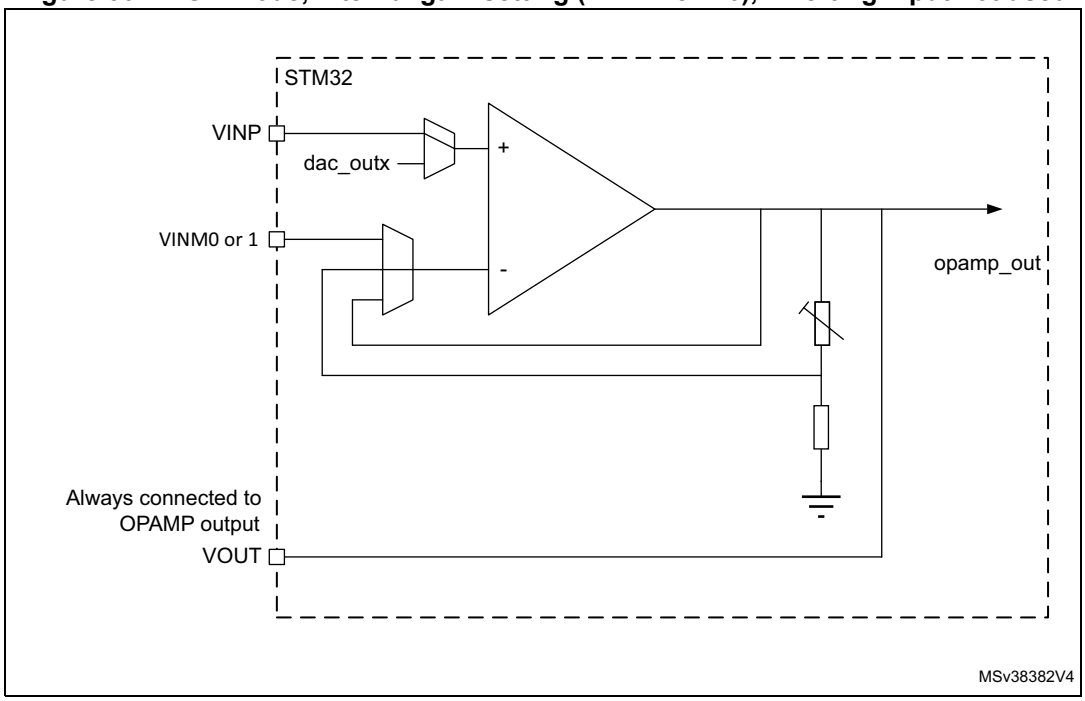
The procedure to use the OPAMP as programmable gain amplifier is presented hereafter.

- configure VM_SEL bits as “Feedback resistor is connected to OPAMPx_VINM input”, 10
- configure PGA_GAIN bits as “internal Gain 2, 4, 8 or 16”, 0000 to 0011
- configure VP_SEL bits as “GPIO connected to OPAMPx_VINP”, 00

  As soon as the OPAEN bit is set, the voltage on pin OPAMPx_VINP is amplified by the selected gain and visible on pin OPAMPx_VOUT.

Note: To avoid saturation, the input voltage should stay below V_{DDA} divided by the selected gain.

Figure 304. PGA mode, internal gain setting (x2/x4/x8/x16), inverting input not used



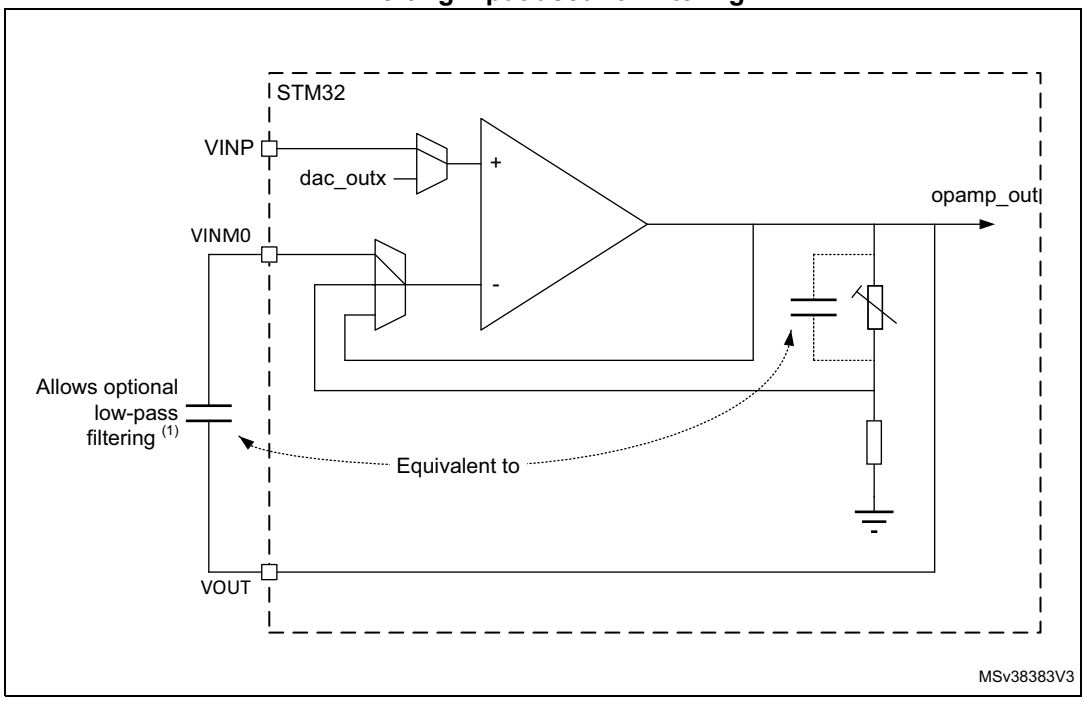
Programmable gain amplifier mode with external filtering

The procedure to use the OPAMP to amplify the amplitude of an input signal, with an external filtering, is presented hereafter.

- configure VM_SEL bits as “Feedback resistor is connected to OPAMPx_VINM input”, 10
- configure PGA_GAIN bits as “internal Gain 2, 4, 8 or 16 with filtering on INM0”, 0100 to 0111
- configure VP_SEL bits as “GPIO connected to OPAMPx_VINP”.

  Any external connection on INM can be used in parallel with the internal PGA, for example a capacitor can be connected between opamp_out and INM for filtering purpose (see datasheet for the value of resistors used in the PGA resistor network).

Figure 305. PGA mode, internal gain setting (x2/x4/x8/x16), inverting input used for filtering



1. The gain depends on the cut-off frequency.

Programmable gain amplifier, non-inverting with external bias or inverting mode

The procedure to use the OPAMP to amplify the amplitude of an input signal with bias voltage for non-inverting mode or inverting mode.

- configure VM_SEL bits as “Feedback resistor is connected to OPAMPx_VINM input”, 10
- configure PGA_GAIN bits as “Inverting gain=-1,-3,-7,-15/ Non-inverting gain =2,4,8,16 with INM0”, 1000 to 1011
- configure VP_SEL bits as “GPIO connected to OPAMPx_VINP”.

Figure 306. PGA mode, non-inverting gain setting (x2/x4/x8/x16) or inverting gain setting (x-1/x-3/x-7/x-15)

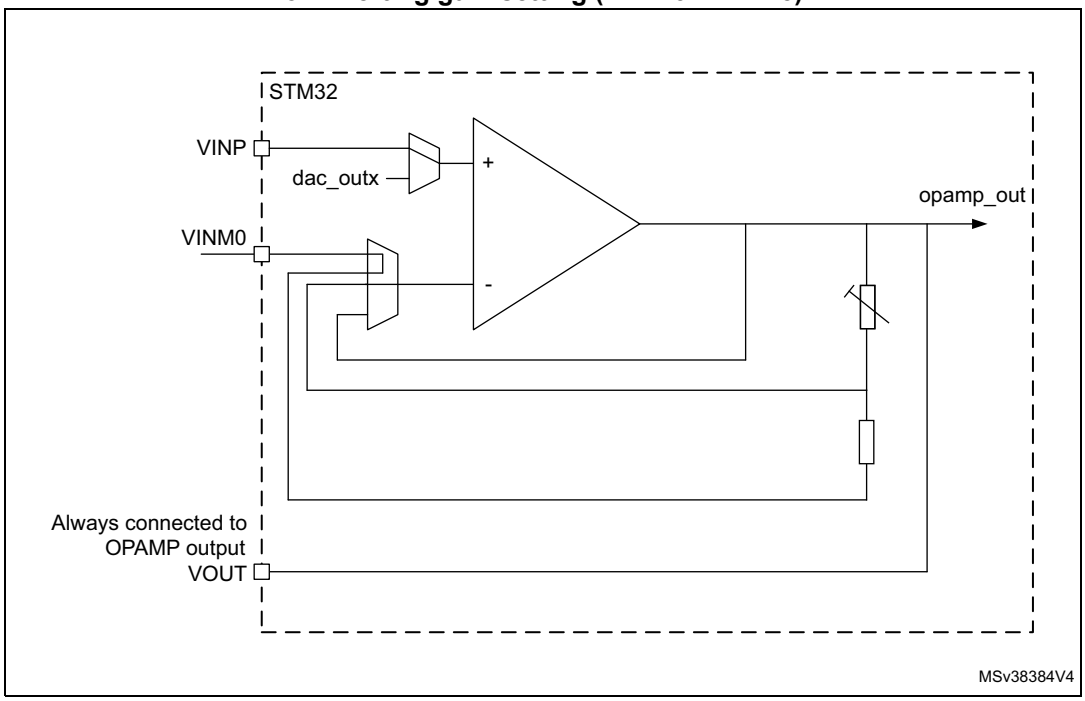
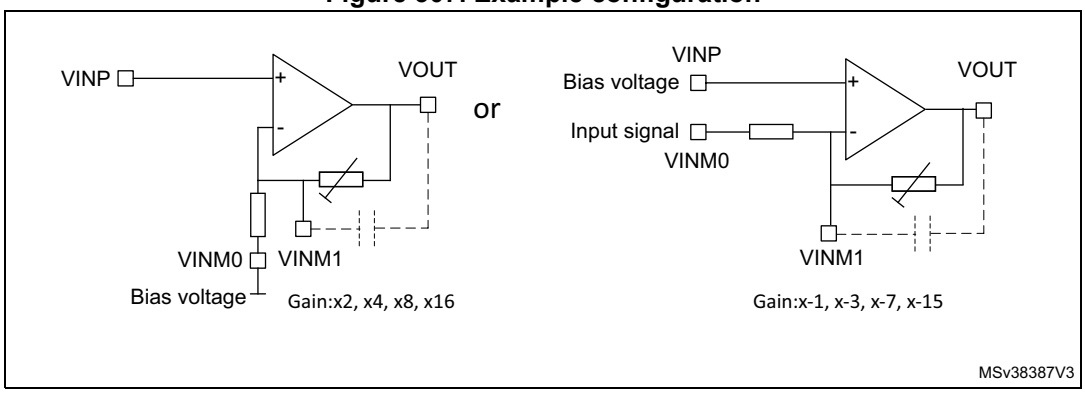


Figure 307. Example configuration



Programmable gain amplifier, non-inverting with external bias or inverting mode with filtering

The procedure to use the OPAMP to amplify the amplitude of an input signal with bias voltage for non-inverting mode or inverting mode with filtering

- configure VM_SEL bits as “Feedback resistor is connected to OPAMPx_VINM input”, 10
- configure PGA_GAIN bits as “Inverting gain=-1,-3,-7,-15/ Non-inverting gain =2,4,8,16 with INM0, INM1 node for filtering”, 1100 to 1111
- configure VP_SEL bits as “GPIO connected to OPAMPx_VINP”.

  Any external connection on VM1 can be used in parallel with the internal PGA, for example a capacitor can be connected between opamp_out and VM1 for filtering purpose (see datasheet for the value of resistors used in the PGA resistor network).

Figure 308. PGA mode, non-inverting gain setting (x2/x4/x8/x16) or inverting gain setting (x-1/x-3/x-7/x-15) with filtering

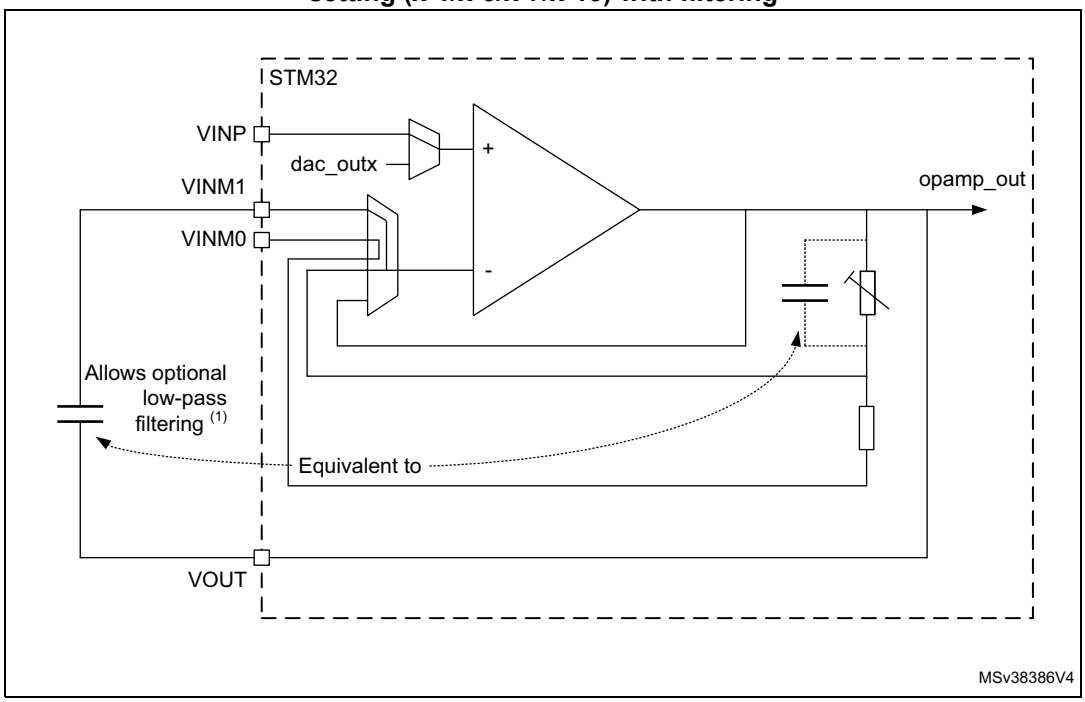
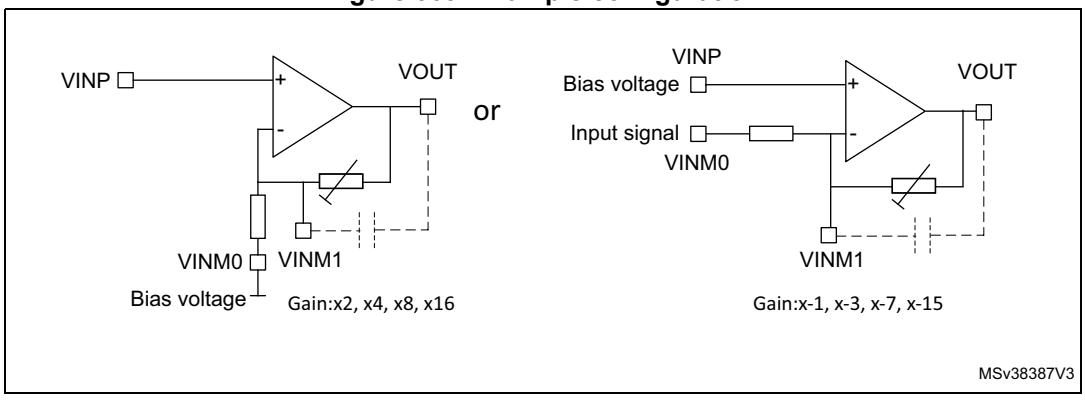


Figure 309. Example configuration



34.3.5 Calibration

The OPAMP interface continuously sends trimmed offset values to the operational amplifiers. At startup, the trimming values are initialized with the preset ‘factory’ trimming value.

Each operational amplifier can be trimmed by the user. Specific registers allow to have different trimming values for normal mode and for high-speed mode.

The aim of the calibration is to cancel as much as possible the OPAMP inputs offset voltage. The calibration circuitry allows to reduce the input offset voltage to less than +/-1.5 mV within stable voltage and temperature conditions.

For each operational amplifier and each mode two trimming value needs to be trimmed, one for N differential pair and one for P differential pair.

There are two registers for trimming the offsets for each operational amplifiers, one for normal mode (OPAMPx_OTR) and one high-speed mode (OPAMPx_HSOTR). Each register is composed of five bits for P differential pair trimming and five bits for N differential pair trimming. These are the ‘user’ values.

The user is able to switch from ‘factory’ values to ‘user’ trimmed values using the USERTRIM bit in the OPAMPx_CSR register. This bit is reset at startup and so the ‘factory’ value are applied by default to the OPAMP option registers.

User is liable to change the trimming values in calibration or in functional mode.

The offset trimming registers are typically configured after the calibration operation is initialized by setting bit CALON to 1. When CALON = 1 the inputs of the operational amplifier are disconnected from the functional environment.

- Setting CALSEL to 01 initializes the offset calibration for the P differential pair (low voltage reference used).
- Resetting CALSEL to 11 initializes the offset calibration for the N differential pair (high voltage reference used).

When CALON = 1, the bit CALOUT will reflect the influence of the trimming value selected by CALSEL and OPAHSM. The software should increment the TRIMOFFSETN bits in the OPAMP control register from 0x00 to the first value that causes the CALOUT bit to change from 1 to 0 in the OPAMP register. If the CALOUT bit is reset, the offset is calibrated correctly and the corresponding trimming value must be stored. The CALOUT flag needs up to 1 ms after the trimming value is changed to become steady (see $t_{OFFTRIM}$max delay specification in the electrical characteristics section of the datasheet).

Note: The closer the trimming value is to the optimum trimming value, the longer it takes to stabilize (with a maximum stabilization time remaining below 1 ms in any case).

Table 281. Operating modes and calibration

Mode	Control bits				Output	
	OPAEN	OPAHSM	CALON	CALSEL	V_{OUT}	CALOUT flag
Normal operating mode	1	0	0	X	analog	0
High-speed mode	1	1	0	X	analog	0
Power down	0	X	X	X	Z	0

Table 281. Operating modes and calibration (continued)

Mode	Control bits				Output	
	OPAEN	OPAHSM	CALON	CALSEL	V_{OUT}	CALOUT flag
Offset calibration N difference for normal mode	1	0	1	11	analog	X
Offset calibration P difference for normal mode	1	0	1	01	analog	X
Offset calibration N difference for high-speed mode	1	1	1	11	analog	X
Offset calibration P difference for high-speed mode	1	1	1	01	analog	X

Calibration procedure

Here are the steps to perform a full calibration of either one of the operational amplifiers:

1. Set the OPAEN bit in OPAMPx_CSR to 1 to enable the operational amplifier.
2. Set the USERTRIM bit in the OPAMPx_CSR register to 1.
3. Choose a calibration mode (refer to *Table 281: Operating modes and calibration*). The steps 3 to 4 will have to be repeated 4 times. For the first iteration select
   – Normal mode and N differential pair

   The above calibration mode correspond to OPAHSM=0 and CALSEL=11 in the OPAMPx_CSR register.
4. Increment TRIMOFFSETN[4:0] in OPAMPx_OTR starting from 00000b until CALOUT changes to 0 in OPAMPx_CSR.

Note: Between the write to the OPAMPx_OTR register and the read of the CALOUT value, make sure to wait for the $t_{OFFTRIM}$max delay specified in the electrical characteristics section of the datasheet, to get the correct CALOUT value.

The commutation means that the is correctly compensated and that the corresponding trim code must be saved in the OPAMPx_OTR register.

Repeat steps 3 to 4 for:

- Normal_mode and P differential pair, CALSEL=01
- High-speed mode and N differential pair
- High-speed mode and P differential pair

If a mode is not used, it is not necessary to perform the corresponding calibration.

All operational amplifier can be calibrated at the same time.

Note: During the whole calibration phase the external connection of the operational amplifier output must not pull up or down currents higher than 500 µA.

34.4 OPAMP low-power modes

Table 282. Effect of low-power modes on the OPAMP

Mode	Description
Sleep	No effect.
D2 Stop	No effect, OPAMP registers content is kept.
Standby	The OPAMP registers are powered down and must be re-initialized after exiting Standby.

34.5 OPAMP PGA gain

When OPAMP is configured as PGA mode, it can select the gain of x2,x4,x8,x16 for non-inverting mode and x-1, x-3, x-7, x-15 for inverting mode.

When OPAMP is configured as non-inverting mode, the Gain error can be refer to the product datasheet. When it is configured as inverting mode, Gain factor is defined not only the on chip feedback resistor but also the signal source output impedance. If signal source output impedance is not negligible compare to the input feedback resistance of PGA, it will create the gain error. Please refer to the PGA resistance value in the product datasheet.

34.6 OPAMP registers

The registers of this peripheral can only be accessed by-word (32-bit).

34.6.1 OPAMP1 control/status register (OPAMP1_CSR)

Address: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	CAL OUT	TST REF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	USER TRIM	PGA_GAIN	
	r	rw											rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PGA_GAIN		CALSEL		CALON	Res.	Res.	OPA HSM	Res.	VM_SEL		Res.	VP_SEL		FORCE _VP	OPAEN
rw	rw	rw	rw	rw			rw		rw	rw		rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **CALOUT:** Operational amplifier calibration output
OPAMP output status flag. During the calibration mode, OPAMP is used as comparator.
0: Non-inverting < inverting
1: Non-inverting > inverting

Bit 29 **TSTREF:** OPAMP calibration reference voltage output control (reserved for test)
0: INTVREF of OPAMP is not output
1: INTVREF of OPAMP is output

Bits 28:19 Reserved, must be kept at reset value.

Bit 18 **USERTRIM:** User trimming enable

This bit allows to switch from ‘factory’ AOP offset trimmed values to ‘user’ AOP offset trimmed values

This bit is active for both mode normal and high-power.

0: ‘factory’ trim code used

1: ‘user’ trim code used

Bits 17:14 **PGA_GAIN:** Operational amplifier Programmable amplifier gain value

0000: Non-inverting internal Gain 2, VREF- referenced

0001: Non-inverting internal Gain 4, VREF- referenced

0010: Non-inverting internal Gain 8, VREF- referenced

0011: Non-inverting internal Gain 16, VREF- referenced

0100: Non-inverting internal Gain 2 with filtering on INM0, VREF- referenced

0101: Non-inverting internal Gain 4 with filtering on INM0, VREF- referenced

0110: Non-inverting internal Gain 8 with filtering on INM0, VREF- referenced

0111: Non-inverting internal Gain 16 with filtering on INM0, VREF- referenced

1000: Inverting gain=-1/ Non-inverting gain =2 with INM0 node for input or bias

1001: Inverting gain=-3/ Non-inverting gain =4 with INM0 node for input or bias

1010: Inverting gain=-7/ Non-inverting gain =8 with INM0 node for input or bias

1011: Inverting gain=-15/ Non-inverting gain =16 with INM0 node for input or bias

1100: Inverting gain=-1/ Non-inverting gain =2 with INM0 node for input or bias, INM1 node for filtering

1101: Inverting gain=-3/ Non-inverting gain =4 with INM0 node for input or bias, INM1 node for filtering

1110: Inverting gain=-7/ Non-inverting gain =8 with INM0 node for input or bias, INM1 node for filtering

1111: Inverting gain=-15/ Non-inverting gain =16 with INM0 node for input or bias, INM1 node for filtering

Bits 13:12 **CALSEL:** Calibration selection

It is used to select the offset calibration bus used to generate the internal reference voltage when CALON = 1 or FORCE_VP= 1.

00: 0.033*VDDA applied on OPAMP inputs

01: 0.1*VDDA applied on OPAMP inputs (for PMOS calibration)

10: 0.5*VDDA applied on OPAMP inputs

11: 0.9*VDDA applied on OPAMP inputs (for NMOS calibration)

Bit 11 **CALON:** Calibration mode enabled

0: Normal mode

1: Calibration mode (all switches opened by HW)

Bits 10:9 Reserved, must be kept at reset value.

Bit 8 **OPAHSM:** Operational amplifier high-speed mode

The operational amplifier must be disable to change this configuration.

0: operational amplifier in normal mode

1: operational amplifier in high-speed mode

Bit 7 Reserved, must be kept at reset value.

Bits 6:5 **VM_SEL:** Inverting input selection
- 00: INM0 connected to OPAMP INM input
- 01: INM1 connected to OPAMP NM input
- 10: Feedback resistor is connected to OPAMP INM input (PGA mode), Inverting input selection is depends on the PGA_GAIN setting
- 11: opamp_out connected to OPAMP INM input (Follower mode)

Bit 4 Reserved, must be kept at reset value.

Bits 3:2 **VP_SEL:** Non inverted input selection
- 00: GPIO connected to OPAMPx_VINP
- 01: dac_outx connected to OPAMPx_VINP
- 10: Reserved
- 11: Reserved

Bit 1 **FORCE_VP:** Force internal reference on VP (reserved for test)
- 0: Normal operating mode. Non-inverting input connected to inputs.
- 1: Calibration verification mode: Non-inverting input connected to calibration reference voltage.

Bit 0 **OPAEN:** Operational amplifier Enable
- 0: operational amplifier disabled
- 1: operational amplifier enabled

Note: If OPAMP1 is unconnected in a specific package, it must remain disabled (keep OPAMP1_CSR register default value).

34.6.2 OPAMP1 trimming register in normal mode (OPAMP1_OTR)

Address: 0x04

Reset value: 0x0000 XXXX (factory trimmed values)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	TRIMOFFSETP					Res.	Res.	Res.	TRIMOFFSETN				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:8 **TRIMOFFSETP[4:0]:** Trim for PMOS differential pairs

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **TRIMOFFSETN[4:0]:** Trim for NMOS differential pairs

34.6.3 OPAMP1 trimming register in high-speed mode (OPAMP1_HSOTR)

Address: 0x08

Reset value: 0x0000 XXXX (factory trimmed values)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	TRIMHSOFFSETP					Res.	Res.	Res.	TRIMHSOFFSETN				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:8 **TRIMHSOFFSETP[4:0]:** High-speed mode trim for PMOS differential pairs

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **TRIMHSOFFSETN[4:0]:** High-speed mode trim for NMOS differential pairs

34.6.4 OPAMP option register (OPAMP_OR)

Address: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:0 Reserved, must be kept at reset value.

34.6.5 OPAMP2 control/status register (OPAMP2_CSR)

Address: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	CAL OUT	TST REF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	USER TRIM	PGA_GAIN	
	r	rw											rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PGA_GAIN		CALSEL		CALON	Res.	Res.	OPA HSM	Res.	VM_SEL		Res.	VP_SEL		FORCE _VP	OPAEN
rw	rw	rw	rw	rw			rw		rw	rw		rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **CALOUT:** Operational amplifier calibration output

OPAMP output status flag. During the calibration mode, OPAMP is used as comparator.

0: Non-inverting < inverting

1: Non-inverting > inverting

Bit 29 **TSTREF:** OPAMP calibration reference voltage output control (reserved for test)

0: INTVREF of OPAMP is not output

1: INTVREF of OPAMP is output

Bits 28:19 Reserved, must be kept at reset value.

Bit 18 **USERTRIM:** User trimming enable

This bit allows to switch from ‘factory’ AOP offset trimmed values to ‘user’ AOP offset trimmed values

This bit is active for both mode normal and high-power.

0: ‘factory’ trim code used

1: ‘user’ trim code used

Bits 17:14 **PGA_GAIN:** Operational amplifier Programmable amplifier gain value

0000: Non-inverting internal Gain 2, VREF- referenced

0001: Non-inverting internal Gain 4, VREF- referenced

0010: Non-inverting internal Gain 8, VREF- referenced

0011: Non-inverting internal Gain 16, VREF- referenced

0100: Non-inverting internal Gain 2 with filtering on INM0, VREF- referenced

0101: Non-inverting internal Gain 4 with filtering on INM0, VREF- referenced

0110: Non-inverting internal Gain 8 with filtering on INMINM0, VREF- referenced

0111: Non-inverting internal Gain 16 with filtering on INM0, VREF- referenced

1000: Inverting gain=-1/ Non-inverting gain =2 with INM0 node for input or bias

1001: Inverting gain=-3/ Non-inverting gain =4 with INM0 node for input or bias

1010: Inverting gain=-7/ Non-inverting gain =8 with INM0 node for input or bias

1011: Inverting gain=-15/ Non-inverting gain =16 with INM0 node for input or bias

1100: Inverting gain=-1/ Non-inverting gain =2 with INM0 node for input or bias, INM1 node for filtering

1101: Inverting gain=-3/ Non-inverting gain =4 with INM0 node for input or bias, INM1 node for filtering

1110: Inverting gain=-7/ Non-inverting gain =8 with INM0 node for input or bias, INM1 node for filtering

1111: Inverting gain=-15/ Non-inverting gain =16 with INM0 node for input or bias, INM1 node for filtering

Bits 13:12 **CALSEL:** Calibration selection

It is used to select the offset calibration bus used to generate the internal reference voltage when CALON = 1 or FORCE_VP= 1.

00: 0.033*VDDA applied on OPAMP inputs

01: 0.1*VDDA applied on OPAMP inputs (for PMOS calibration)

10: 0.5*VDDA applied on OPAMP inputs

11: 0.9*VDDA applied on OPAMP inputs (for NMOS calibration)

Bit 11 **CALON:** Calibration mode enabled

0: Normal mode

1: Calibration mode (all switches opened by HW)

Bits 10:9 Reserved, must be kept at reset value.

Bit 8 **OPAHSM:** Operational amplifier high-speed mode
The operational amplifier must be disable to change this configuration.
0: operational amplifier in normal mode
1: operational amplifier in high-speed mode

Bit 7 Reserved, must be kept at reset value.

Bits 6:5 **VM_SEL:** Inverting input selection
00: INM0 connected to OPAMP INM input
01: INM1 connected to OPAMP INM input
10: Feedback resistor is connected to OPAMP INM input (PGA mode), Inverting input selection is depends on the PGA_GAIN setting
11: opamp_out connected to OPAMP INM input (Follower mode)

Bit 4 Reserved, must be kept at reset value.

Bits 3:2 **VP_SEL:** Non inverted input selection
00: GPIO connected to OPAMPx_VINP
01: DAC connected to OPAMPx_VINP
10: Reserved
11: Reserved

Bit 1 **FORCE_VP:** Force internal reference on VP (reserved for test)
0: Normal operating mode. Non-inverting input connected to inputs.
1: Calibration verification mode: Non-inverting input connected to calibration reference voltage.

Bit 0 **OPAEN:** Operational amplifier Enable
0: operational amplifier disabled
1: operational amplifier enabled
Note: If OPAMP2 is unconnected in a specific package, it must remain disabled (keep OPAMP2_CSR register default value).

34.6.6 OPAMP2 trimming register in normal mode (OPAMP2_OTR)

Address: 0x14

Reset value: 0x0000 XXXX (factory trimmed values)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	TRIMOFFSETP					Res.	Res.	Res.	TRIMOFFSETN				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:8 **TRIMOFFSETP[4:0]:** Trim for PMOS differential pairs

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **TRIMOFFSETN[4:0]:** Trim for NMOS differential pairs

34.6.7 OPAMP2 trimming register in high-speed mode (OPAMP2_HSOTR)

Address: 0x18

Reset value: 0x0000 XXXX (factory trimmed values)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	TRIMHSOFFSETP					Res.	Res.	Res.	TRIMHSOFFSETN				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:8 **TRIMHSOFFSETP[4:0]:** High-speed mode trim for PMOS differential pairs

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **TRIMHSOFFSETN[4:0]:** High-speed mode trim for NMOS differential pairs

34.6.8 OPAMP register map

Table 283. OPAMP register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**OPAMP1_CSR**	Res.	CALOUT	TSTREF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	USERTRIM	PGA_GAIN				CALSEL		CALON	Res.	Res.	OPAHSM	Res.	VM_SEL		Res.	VP_SEL		FORCE_VP	OPAEN
	Reset value		0	0											0	0	0	0	0	0	0	0			0		0	0		0	0	0	0
0x04	**OPAMP1_OTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIM OFFSETP[4:0]					Res.	Res.	Res.	TRIM OFFSETN[4:0]				
	Reset value																				(1)								(1)				
0x08	**OPAMP1_ HSOTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIMHS OFFSETP[4:0]					Res.	Res.	Res.	TRIMHS OFFSETN[4:0]				
	Reset value																				(1)								(1)				
0x0C	**OPAMP_OR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																																
0x10	**OPAMP2_CSR**	Res.	CALOUT	TSTREF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	USERTRIM	PGA_GAIN				CALSEL		CALON	Res.	Res.	OPAHSM	Res.	VM_SEL		Res.	VP_SEL		FORCE_VP	OPAEN
	Reset value		0	0											0	0	0	0	0	0	0	0			0		0	0		0	0	0	0
0x14	**OPAMP2_OTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIM OFFSETP[4:0]					Res.	Res.	Res.	TRIM OFFSETN[4:0]				
	Reset value																				(1)								(1)				
0x18	**OPAMP2_ HSOTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIMHS OFFSETP[4:0]					Res.	Res.	Res.	TRIMHS OFFSETN[4:0]				
	Reset value																				(1)								(1)				

1. Factory trimmed values.

Refer to *Section 2.3 on page 131* for the register boundary addresses.

35 Digital filter for sigma delta modulators (DFSDM)

35.1 Introduction

Digital filter for sigma delta modulators (DFSDM) is a high-performance module dedicated to interface external ΣΔ modulators. It is featuring up to 8 external digital serial interfaces (channels) and up to 4 digital filters with flexible Sigma Delta stream digital processing options to offer up to 24-bit final ADC resolution. DFSDM also features optional parallel data stream input from internal ADC peripherals or from device memory.

An external ΣΔ modulator provides digital data stream of converted analog values from the external ΣΔ modulator analog input. This digital data stream is sent into a DFSDM input channel through a serial interface. DFSDM supports several standards to connect various ΣΔ modulator outputs: SPI interface and Manchester coded 1-wire interface (both with adjustable parameters). DFSDM module supports the connection of up to 8 multiplexed input digital serial channels which are shared with up to 4 DFSDM modules. DFSDM module also supports alternative parallel data inputs from up to 8 internal 16-bit data channels (from internal ADCs or from device memory).

DFSDM is converting an input data stream into a final digital data word which represents an analog input value on a ΣΔ modulator analog input. The conversion is based on a configurable digital process: the digital filtering and decimation of the input serial data stream.

The conversion speed and resolution are adjustable according to configurable parameters for digital processing: filter type, filter order, length of filter, integrator length. The maximum output data resolution is up to 24 bits. There are two conversion modes: single conversion mode and continuous mode. The data can be automatically stored in a system RAM buffer through DMA, thus reducing the software overhead.

A flexible timer triggering system can be used to control the start of conversion of DFSDM. This timing control is capable of triggering simultaneous conversions or inserting a programmable delay between conversions.

DFSDM features an analog watchdog function. Analog watchdog can be assigned to any of the input channel data stream or to final output data. Analog watchdog has its own digital filtering of input data stream to reach the required speed and resolution of watched data.

To detect short-circuit in control applications, there is a short-circuit detector. This block watches each input channel data stream for occurrence of stable data for a defined time duration (several 0’s or 1’s in an input data stream).

An extremes detector block watches final output data and stores maximum and minimum values from the output data values. The extremes values stored can be restarted by software.

Two power modes are supported: normal mode and stop mode.

35.2 DFSDM main features

- Up to 8 multiplexed input digital serial channels:
  - configurable SPI interface to connect various ΣΔ modulators
  - configurable Manchester coded 1 wire interface support
  - clock output for ΣΔ modulator(s)
- Alternative inputs from up to 8 internal digital parallel channels:
  - inputs with up to 16 bit resolution
  - internal sources: ADCs data or memory (CPU/DMA write) data streams
- Adjustable digital signal processing:
  - $Sinc^x$ filter: filter order/type (1..5), oversampling ratio (up to 1..1024)
  - integrator: oversampling ratio (1..256)
- Up to 24-bit output data resolution:
  - right bit-shifter on final data (0..31 bits)
- Signed output data format
- Automatic data offset correction (offset stored in register by user)
- Continuous or single conversion
- Start-of-conversion synchronization with:
  - software trigger
  - internal timers
  - external events
  - start-of-conversion synchronously with first DFSDM filter (DFSDM_FLT0)
- Analog watchdog feature:
  - low value and high value data threshold registers
  - own configurable $Sinc^x$ digital filter (order = 1..3, oversampling ratio = 1..32)
  - input from output data register or from one or more input digital serial channels
  - continuous monitoring independently from standard conversion
- Short-circuit detector to detect saturated analog input values (bottom and top ranges):
  - up to 8-bit counter to detect 1..256 consecutive 0's or 1's on input data stream
  - monitoring continuously each channel (8 serial channel transceiver outputs)
- Break generation on analog watchdog event or short-circuit detector event
- Extremes detector:
  - store minimum and maximum values of output data values
  - refreshed by software
- Pulse skipper feature to support beamforming applications (delay line like behavior)
- DMA may be used to read the conversion data
- Interrupts: end of conversion, overrun, analog watchdog, short-circuit, channel clock absence
- "regular" or "injected" conversions:
  - "regular" conversions can be requested at any time or even in continuous mode without having any impact on the timing of "injected" conversions
  - "injected" conversions for precise timing and with high conversion priority

35.3 DFSDM implementation

This section describes the configuration implemented in DFSDMx.

Table 284. DFSDM1 implementation

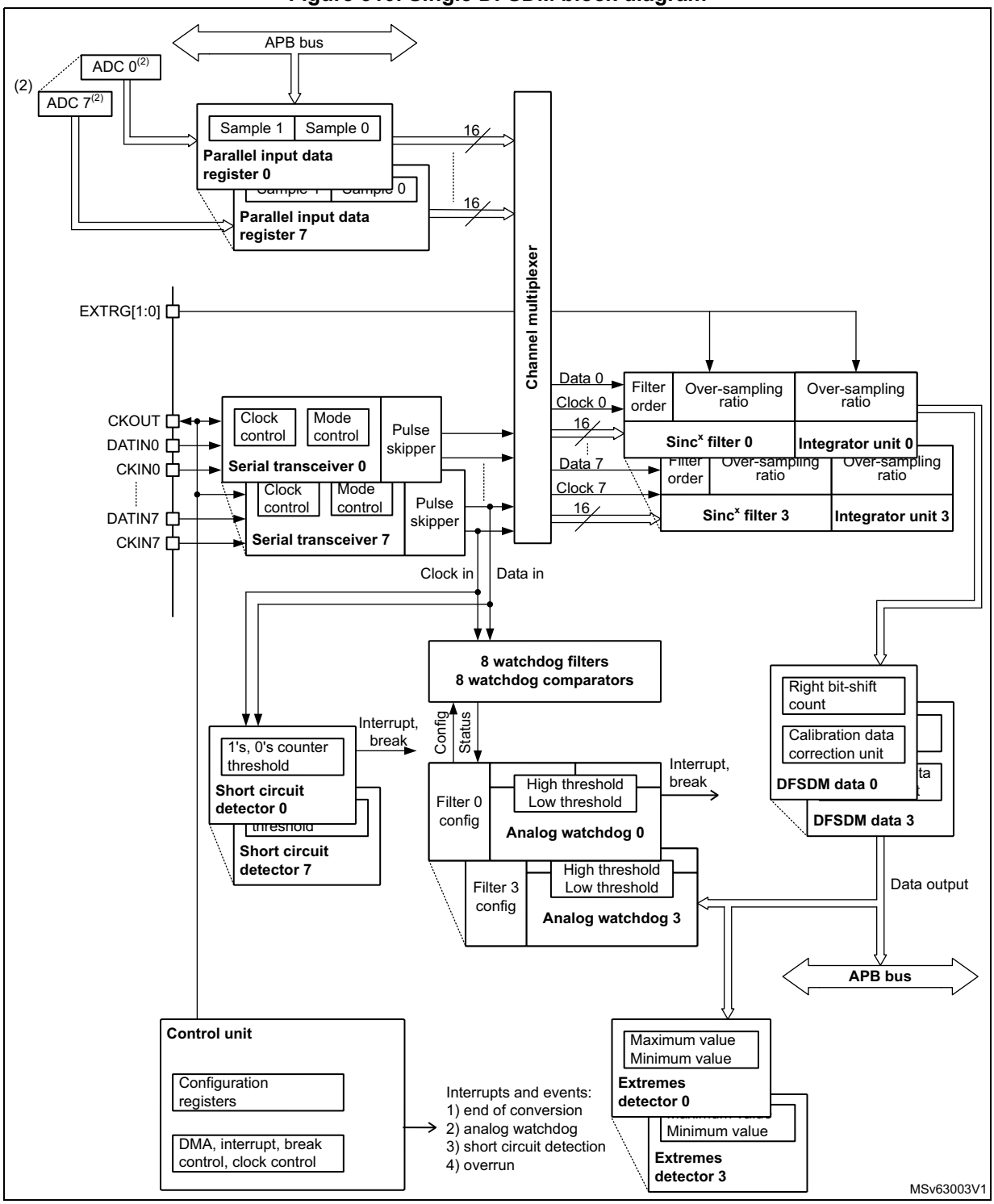
DFSDM features	DFSDM1
Number of channels	8
Number of filters	4
Input from internal ADC	X
Supported trigger sources	32(1)
Pulses skipper	X

1. Refer to *Table 287: DFSDM triggers connection* for available trigger sources.

35.4 DFSDM functional description

35.4.1 DFSDM block diagram

Figure 310. Single DFSDM block diagram



1. This example shows 4 DFSDM filters and 8 input channels (max. configuration).

35.4.2 DFSDM pins and internal signals

Table 285. DFSDM external pins

Name	Signal Type	Remarks
VDD	Power supply	Digital power supply.
VSS	Power supply	Digital ground power supply.
CKIN[7:0]	Clock input	Clock signal provided from external ΣΔ modulator. FT input.
DATIN[7:0]	Data input	Data signal provided from external ΣΔ modulator. FT input.
CKOUT	Clock output	Clock output to provide clock signal into external ΣΔ modulator.
EXTRG[1:0]	External trigger signal	Input trigger from two EXTI signals to start analog conversion (from GPIOs: EXTI11, EXTI15).

Table 286. DFSDM internal signals

Name	Signal Type	Remarks
dfsdm_jtrg[31:0]	Internal/ external trigger signal	Input trigger from internal/external trigger sources in order to start analog conversion (from internal sources: synchronous input, from external sources: asynchronous input with synchronization). See *Table 287* for details.
dfsdm_break[3:0]	break signal output	Break signals event generation from Analog watchdog or short-circuit detector
dfsdm_dma[3:0]	DMA request signal	DMA request signal from each DFSDM_FLTx (x=0..3): end of injected conversion event.
dfsdm_it[3:0]	Interrupt request signal	Interrupt signal for each DFSDM_FLTx (x=0..3)
dfsdm_dat_adc[15:0]	ADC input data	Up to 4 internal ADC data buses as parallel inputs.

Table 287. DFSDM triggers connection

Trigger name	Trigger source
dfsdm_jtrg0	TIM1_TRGO
dfsdm_jtrg1	TIM1_TRGO2
dfsdm_jtrg2	TIM8_TRGO
dfsdm_jtrg3	TIM8_TRGO2
dfsdm_jtrg4	TIM3_TRGO
dfsdm_jtrg5	TIM4_TRGO
dfsdm_jtrg6	TIM16_OC1
dfsdm_jtrg7	TIM6_TRGO
dfsdm_jtrg8	TIM7_TRGO

Table 287. DFSDM triggers connection (continued)

Trigger name	Trigger source
dfsdm_jtrg[10:9]	Reserved
dfsdm_jtrg11	TIM23_TRGO
dfsdm_jtrg12	TIM24_TRGO
dfsdm_jtrg[23:13]	Reserved
dfsdm_jtrg24	EXTI11
dfsdm_jtrg25	EXTI15
dfsdm_jtrg26	LPTIMER1
dfsdm_jtrg27	LPTIMER2
dfsdm_jtrg28	LPTIMER3
dfsdm_jtrg[31:29]	Reserved

Table 288. DFSDM break connection

Break name	Break destination
dfsdm_break[0]	TIM1 break / TIM15 break
dfsdm_break[1]	TIM1 break2 / TIM16 break
dfsdm_break[2]	TIM8 break / TIM17 break
dfsdm_break[3]	TIM8 break2

35.4.3 DFSDM reset and clocks

DFSDM on-off control

The DFSDM interface is globally enabled by setting DFSDMEN=1 in the DFSDM_CH0CFGR1 register. Once DFSDM is globally enabled, all input channels (y=0..7) and digital filters DFSDM_FLTx (x=0..3) start to work if their enable bits are set (channel enable bit CHEN in DFSDM_CHyCFGR1 and DFSDM_FLTx enable bit DFEN in DFSDM_FLTxCR1).

Digital filter x DFSDM_FLTx (x=0..3) is enabled by setting DFEN=1 in the DFSDM_FLTxCR1 register. Once DFSDM_FLTx is enabled (DFEN=1), both $Sinc^x$ digital filter unit and integrator unit are reinitialized.

By clearing DFEN, any conversion which may be in progress is immediately stopped and DFSDM_FLTx is put into stop mode. All register settings remain unchanged except DFSDM_FLTxAWSR and DFSDM_FLTxISR (which are reset).

Channel y (y=0..7) is enabled by setting CHEN=1 in the DFSDM_CHyCFGR1 register. Once the channel is enabled, it receives serial data from the external ΣΔ modulator or parallel internal data sources (ADCs or CPU/DMA wire from memory).

DFSDM must be globally disabled (by DFSDMEN=0 in DFSDM_CH0CFGR1) before stopping the system clock to enter in the STOP mode of the device.

DFSDM clocks

The internal DFSDM clock $f_{DFSDMCLK}$, which is used to drive the channel transceivers, digital processing blocks (digital filter, integrator) and next additional blocks (analog watchdog, short-circuit detector, extremes detector, control block) is generated by the RCC block and is derived from the system clock SYSCLK or peripheral clock PCLK2 (see *Section 8.7.19: RCC domain 2 kernel clock configuration register (RCC_D2CCIP1R)*). The DFSDM clock is automatically stopped in stop mode (if DFEN = 0 for all DFSDM_FLTx, x=0..3).

The DFSDM serial channel transceivers can receive an external serial clock to sample an external serial data stream. The internal DFSDM clock must be at least 4 times faster than the external serial clock if standard SPI coding is used, and 6 times faster than the external serial clock if Manchester coding is used.

DFSDM can provide one external output clock signal to drive external ΣΔ modulator(s) clock input(s). It is provided on CKOUT pin. This output clock signal must be in the range specified in given device datasheet and is derived from DFSDM clock or from audio clock (see CKOUTSRC bit in DFSDM_CH0CFGR1 register) by programmable divider in the range 2 - 256 (CKOUTDIV in DFSDM_CH0CFGR1 register). Audio clock source is SAI1 clock selected by SAI1SEL[1:0] field in RCC configuration (see *Section 8.7.19: RCC domain 2 kernel clock configuration register (RCC_D2CCIP1R)*).

35.4.4 Serial channel transceivers

There are 8 multiplexed serial data channels which can be selected for conversion by each filter or Analog watchdog or Short-circuit detector. Those serial transceivers receive data stream from external ΣΔ modulator. Data stream can be sent in SPI format or Manchester coded format (see SITP[1:0] bits in DFSDM_CHyCFGR1 register).
The channel is enabled for operation by setting CHEN=1 in DFSDM_CHyCFGR1 register.

Channel inputs selection

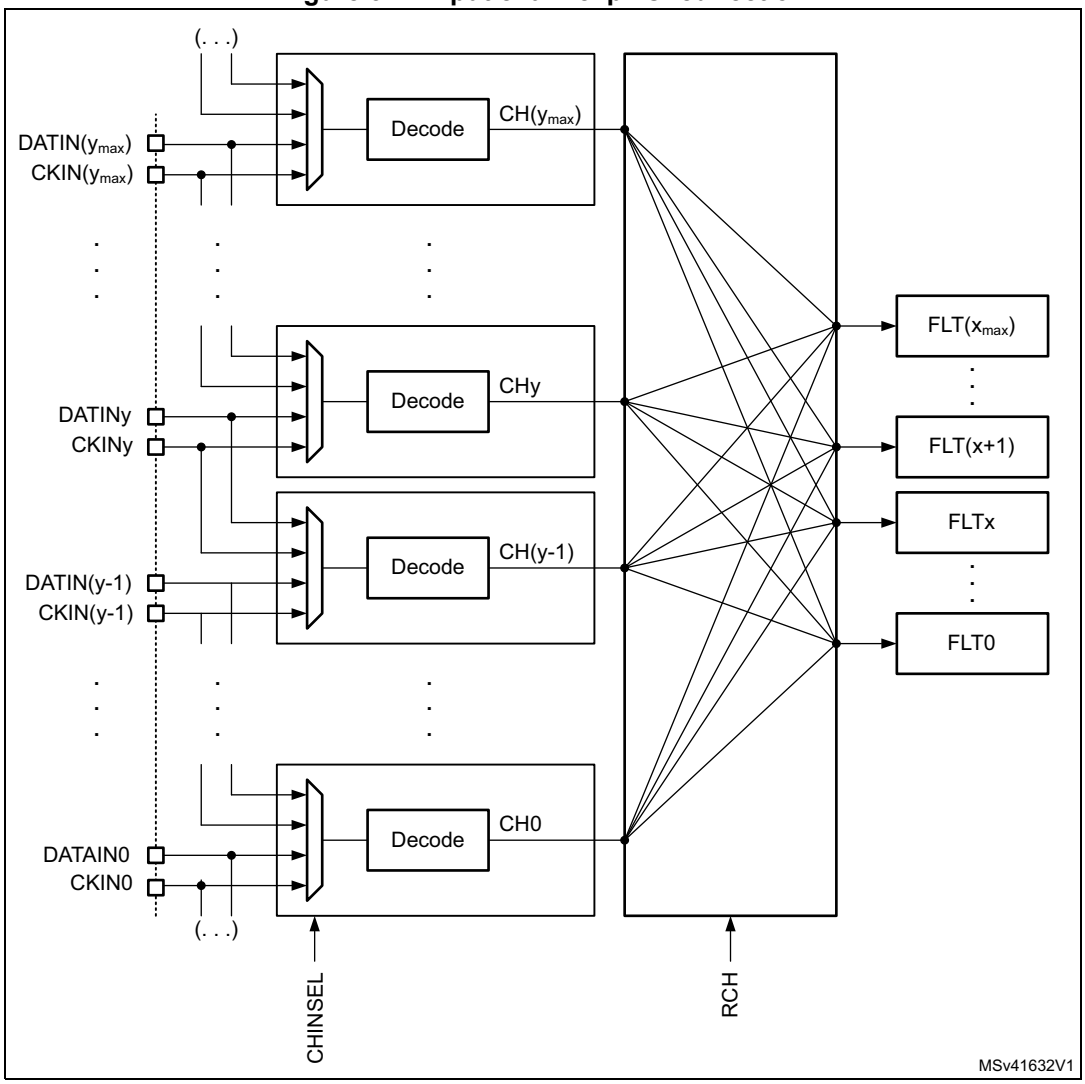
Serial inputs (data and clock signals) from DATINy and CKINy pins can be redirected from the following channel pins. This serial input channel redirection is set by CHINSEL bit in DFSDM_CHyCFGR1 register.

Channel redirection can be used to collect audio data from PDM (pulse density modulation) stereo microphone type. PDM stereo microphone has one data and one clock signal. Data signal provides information for both left and right audio channel (rising clock edge samples for left channel and falling clock edge samples for right channel).

Configuration of serial channels for PDM microphone input:

- PDM microphone signals (data, clock) will be connected to DFSDM input serial channel y (DATINy, CKOUT) pins.
- Channel y will be configured: CHINSEL = 0 (input from given channel pins: DATINy, CKINy).
- Channel (y-1) (modulo 8) will be configured: CHINSEL = 1 (input from the following channel ((y-1)+1) pins: DATINy, CKINy).
- Channel y: SITP[1:0] = 0 (rising edge to strobe data) => left audio channel on channel y.
- Channel (y-1): SITP[1:0] = 1 (falling edge to strobe data) => right audio channel on channel y-1.
- Two DFSDM filters will be assigned to channel y and channel (y-1) (to filter left and right channels from PDM microphone).

Figure 311. Input channel pins redirection



Output clock generation

A clock signal can be provided on CKOUT pin to drive external ΣΔ modulator clock inputs. The frequency of this CKOUT signal is derived from DFSDM clock or from audio clock (see CKOUTSRC bit in DFSDM_CH0CFGR1 register) divided by a predivider (see CKOUTDIV bits in DFSDM_CH0CFGR1 register). If the output clock is stopped, then CKOUT signal is set to low state (output clock can be stopped by CKOUTDIV=0 in DFSDM_CHyCFGR1 register or by DFSDMEN=0 in DFSDM_CH0CFGR1 register). The output clock stopping is performed:

- 4 system clocks after DFSDMEN is cleared (if CKOUTSRC=0)
- 1 system clock and 3 audio clocks after DFSDMEN is cleared (if CKOUTSRC=1)

Before changing CKOUTSRC the software has to wait for CKOUT being stopped to avoid glitch on CKOUT pin. The output clock signal frequency must be in the range 0 - 20 MHz.

SPI data input format operation

In SPI format, the data stream is sent in serial format through data and clock signals. Data signal is always provided from DATINy pin. A clock signal can be provided externally from CKINy pin or internally from a signal derived from the CKOUT signal source.

In case of external clock source selection (SPICKSEL[1:0]=0) data signal (on DATINy pin) is sampled on rising or falling clock edge (of CKINy pin) according SITP[1:0] bits setting (in DFSDM_CHyCFGR1 register).

Internal clock sources - see SPICKSEL[1:0] in DFSDM_CHyCFGR1 register:

- CKOUT signal:
  - For connection to external ΣΔ modulator which uses directly its clock input (from CKOUT) to generate its output serial communication clock.
  - Sampling point: on rising/falling edge according SITP[1:0] setting.
- CKOUT/2 signal (generated on CKOUT rising edge):
  - For connection to external ΣΔ modulator which divides its clock input (from CKOUT) by 2 to generate its output serial communication clock (and this output clock change is active on each clock input rising edge).
  - Sampling point: on each second CKOUT falling edge.
- CKOUT/2 signal (generated on CKOUT falling edge):
  - For connection to external ΣΔ modulator which divides its clock input (from CKOUT) by 2 to generate its output serial communication clock (and this output clock change is active on each clock input falling edge).
  - Sampling point: on each second CKOUT rising edge.

Note: An internal clock source can only be used when the external ΣΔ modulator uses CKOUT signal as a clock input (to have synchronous clock and data operation).

Internal clock source usage can save CKINy pin connection (CKINy pins can be used for other purpose).

The clock source signal frequency must be in the range 0 - 20 MHz for SPI coding and less than $f_{DFSDMCLK}/4$.

Manchester coded data input format operation

In Manchester coded format, the data stream is sent in serial format through DATINy pin only. Decoded data and clock signal are recovered from serial stream after Manchester

decoding. There are two possible settings of Manchester codings (see SITP[1:0] bits in DFSDM_CHyCFGR1 register):

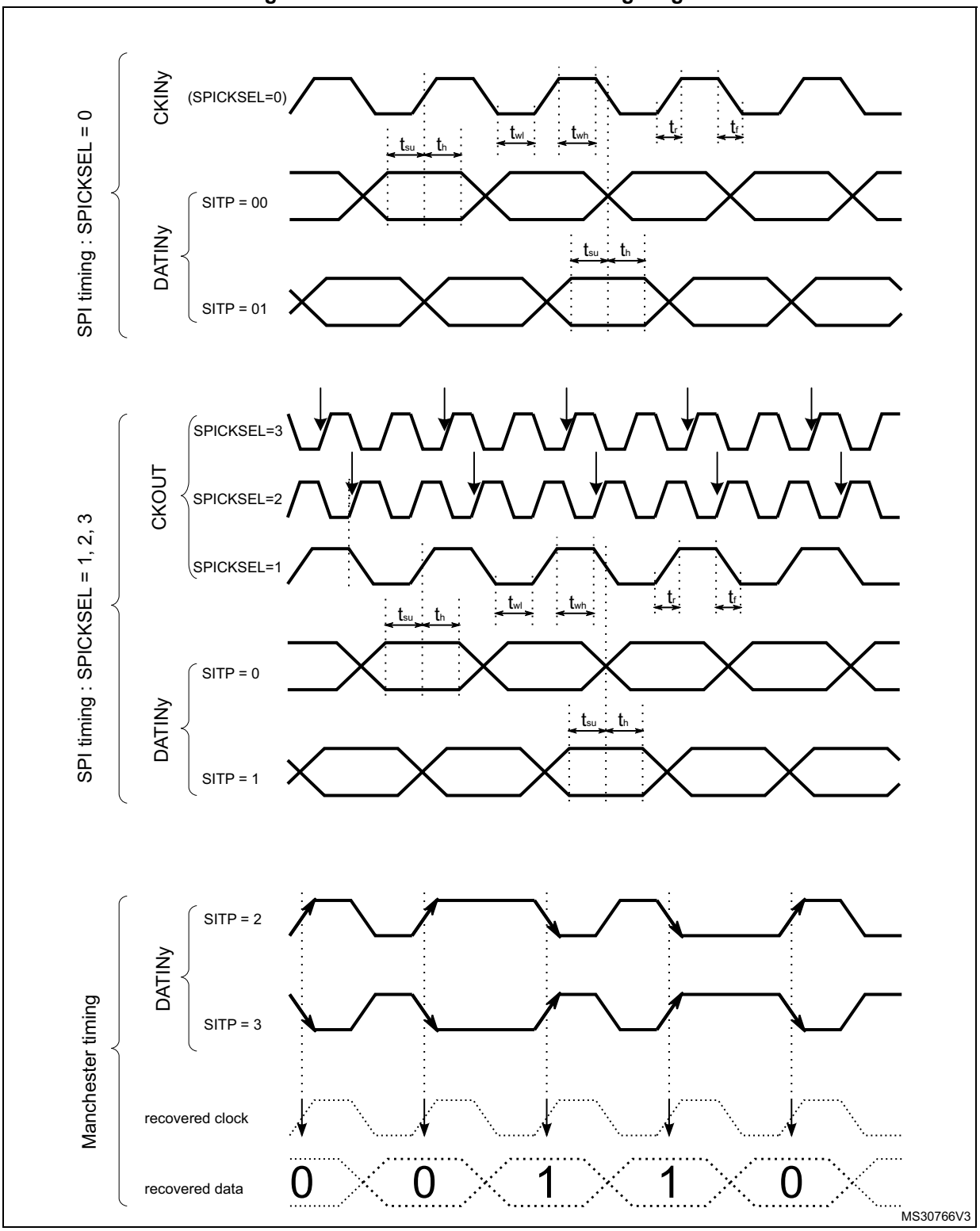
- signal rising edge = log 0; signal falling edge = log 1
- signal rising edge = log 1; signal falling edge = log 0

The recovered clock signal frequency for Manchester coding must be in the range 0 - 10 MHz and less than $f_{DFSDMCLK}/6$.

To correctly receive Manchester coded data, the CKOUTDIV divider (in DFSDM_CH0CFGR1 register) must be set with respect to expected Manchester data rate according formula:

$$((CKOUTDIV + 1) \times T_{SYSCLK}) < T_{Manchester\ clock} < (2 \times CKOUTDIV \times T_{SYSCLK})$$

Figure 312. Channel transceiver timing diagrams



Clock absence detection

Channels serial clock inputs can be checked for clock absence/presence to ensure the correct operation of conversion and error reporting. Clock absence detection can be enabled or disabled on each input channel y by bit CKABEN in DFSDM_CHyCFGR1 register. If enabled, then this clock absence detection is performed continuously on a given channel. A clock absence flag is set (CKABF[y] = 1) and an interrupt can be invoked (if CKABIE=1) in case of an input clock error (see CKABF[7:0] in DFSDM_FLT0ISR register and CKABEN in DFSDM_CHyCFGR1). After a clock absence flag clearing (by CLRCKABF in DFSDM_FLT0ICR register), the clock absence flag is refreshed. Clock absence status bit CKABF[y] is set also by hardware when corresponding channel y is disabled (if CHEN[y] = 0 then CKABF[y] is held in set state).

When a clock absence event has occurred, the data conversion (and/or analog watchdog and short-circuit detector) provides incorrect data. The user should manage this event and discard given data while a clock absence is reported.

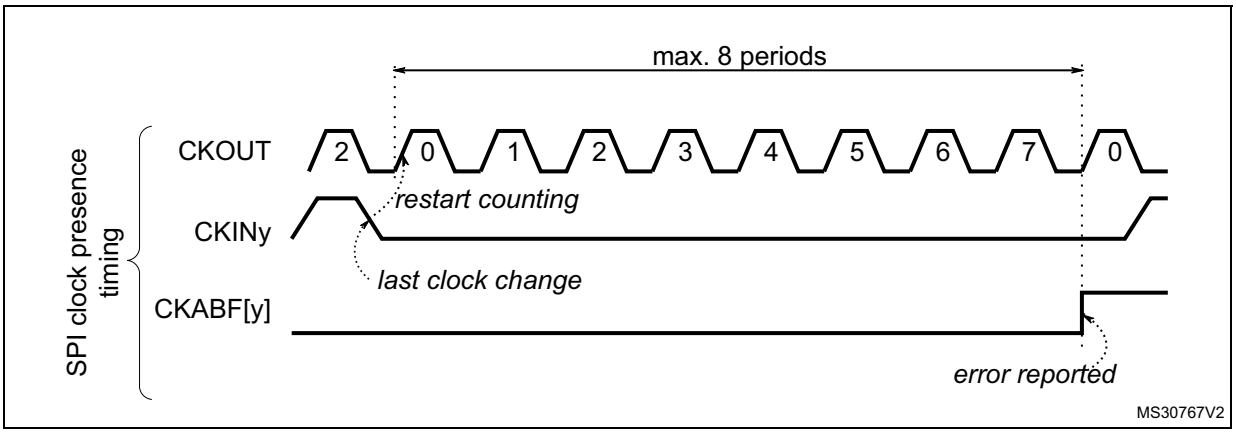
The clock absence feature is available only when the system clock is used for the CKOUT signal (CKOUTSRC=0 in DFSDM_CH0CFGR1 register).

When the transceiver is not yet synchronized, the clock absence flag is set and cannot be cleared by CLRCKABF[y] bit (in DFSDM_FLT0ICR register). The software sequence concerning clock absence detection feature should be:

- Enable given channel by CHEN = 1
- Try to clear the clock absence flag (by CLRCKABF = 1) until the clock absence flag is really cleared (CKABF = 0). At this time, the transceiver is synchronized (signal clock is valid) and is able to receive data.
- Enable the clock absence feature CKABEN = 1 and the associated interrupt CKABIE = 1 to detect if the SPI clock is lost or Manchester data edges are missing.

If SPI data format is used, then the clock absence detection is based on the comparison of an external input clock with an output clock generation (CKOUT signal). The external input clock signal into the input channel must be changed at least once per 8 signal periods of CKOUT signal (which is controlled by CKOUTDIV field in DFSDM_CH0CFGR1 register).

Figure 313. Clock absence timing diagram for SPI



If Manchester data format is used, then the clock absence means that the clock recovery is unable to perform from Manchester coded signal. For a correct clock recovery, it is first necessary to receive data with 1 to 0 or 0 to 1 transition (see *Figure 315* for Manchester synchronization).

The detection of a clock absence in Manchester coding (after a first successful synchronization) is based on changes comparison of coded serial data input signal with output clock generation (CKOUT signal). There must be a voltage level change on DATINy pin during 2 periods of CKOUT signal (which is controlled by CKOUTDIV bits in DFSDM_CH0CFGR1 register). This condition also defines the minimum data rate to be able to correctly recover the Manchester coded data and clock signals.

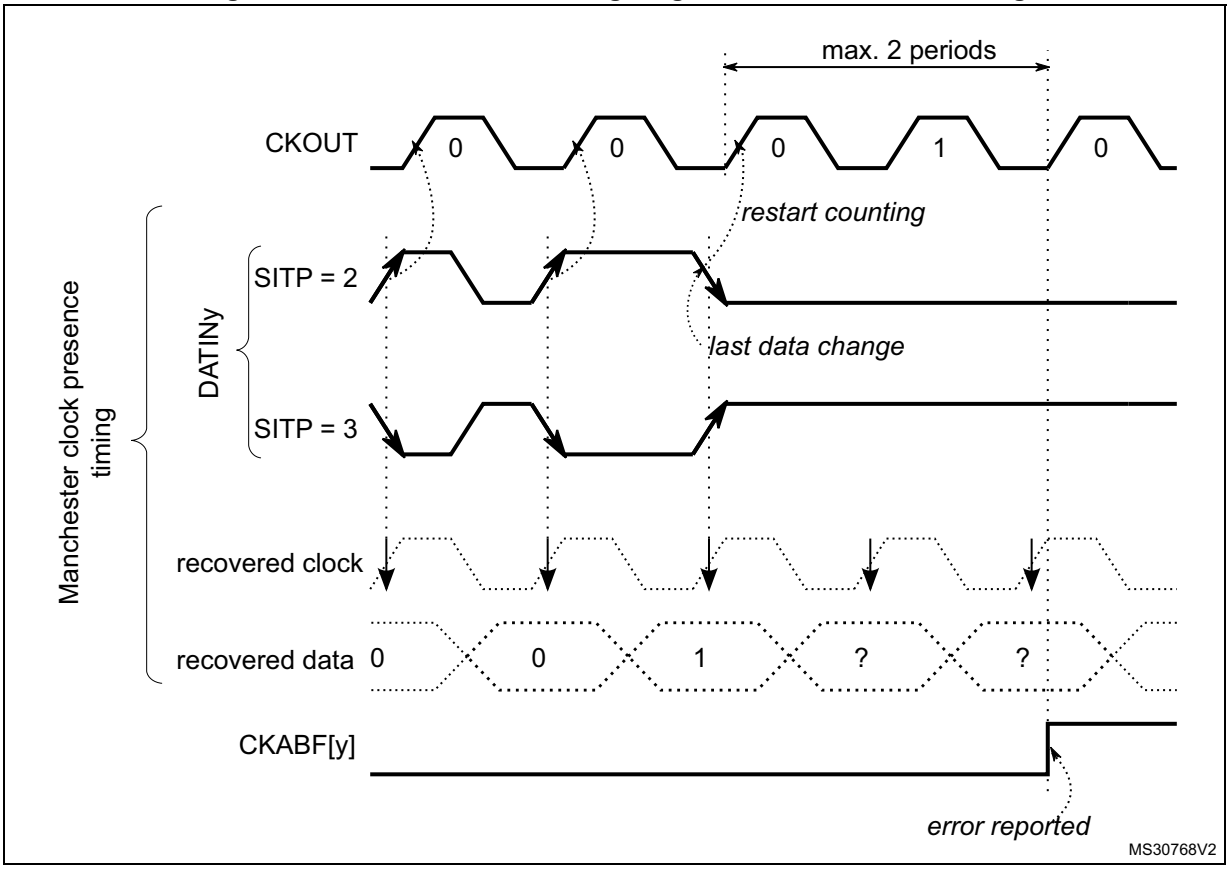
The maximum data rate of Manchester coded data must be less than the CKOUT signal.

So to correctly receive Manchester coded data, the CKOUTDIV divider must be set according the formula:

$$((CKOUTDIV + 1) \times T_{SYSCLK}) < T_{Manchester\ clock} < (2 \times CKOUTDIV \times T_{SYSCLK})$$

A clock absence flag is set (CKABF[y] = 1) and an interrupt can be invoked (if CKABIE=1) in case of an input clock recovery error (see CKABF[7:0] in DFSDM_FLT0ISR register and CKABEN in DFSDM_CHyCFGR1). After a clock absence flag clearing (by CLRCKABF in DFSDM_FLT0ICR register), the clock absence flag is refreshed.

Figure 314. Clock absence timing diagram for Manchester coding



Manchester/SPI code synchronization

The Manchester coded stream must be synchronized the first time after enabling the channel (CHEN=1 in DFSDM_CHyCFGR1 register). The synchronization ends when a data transition from 0 to 1 or from 1 to 0 (to be able to detect valid data edge) is received. The end of the synchronization can be checked by polling CKABF[y]=0 for a given channel after it has been cleared by CLRCKABF[y] in DFSDM_FLT0ICR, following the software sequence detailed hereafter:

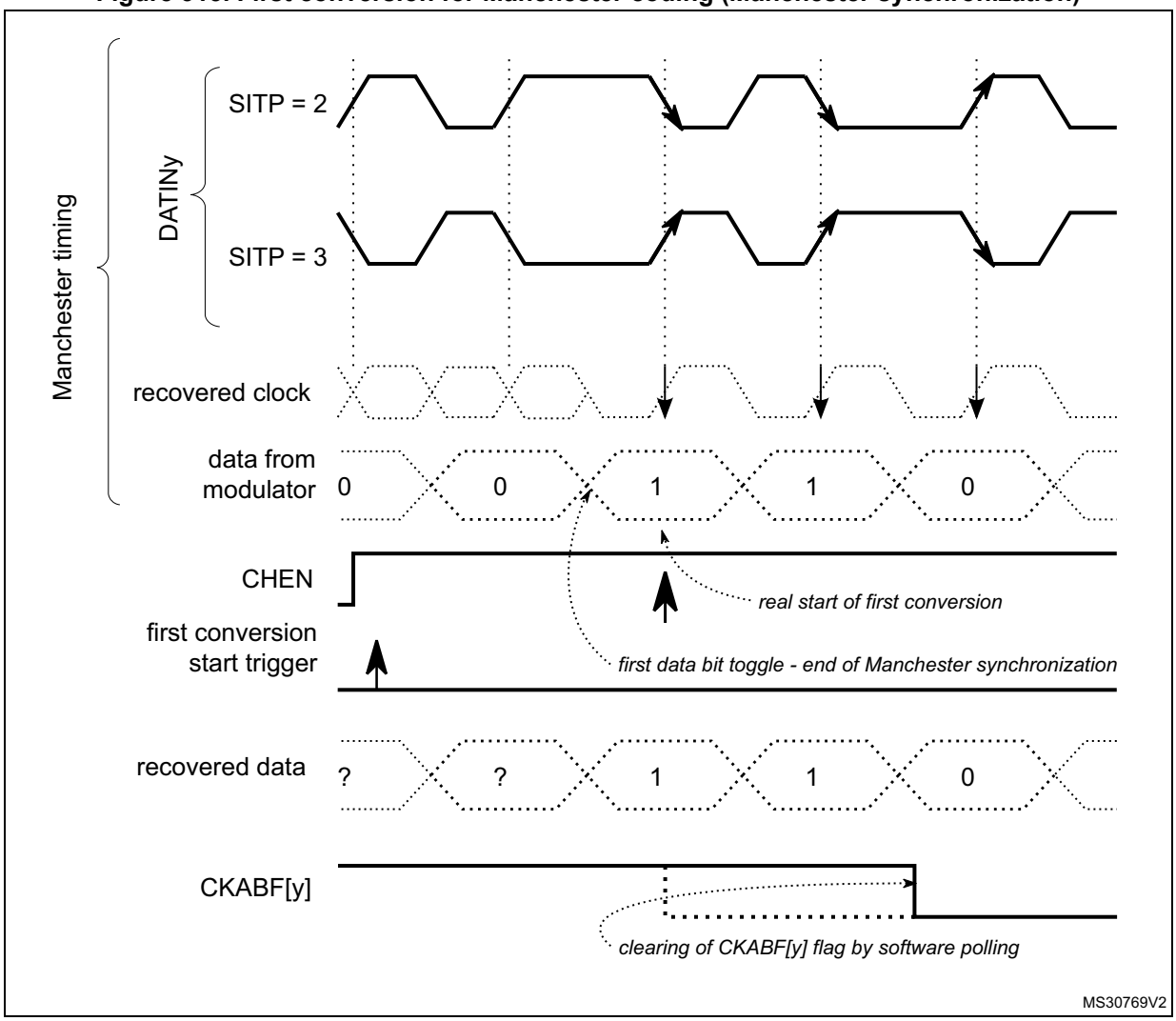
CKABF[y] flag is cleared by setting CLRCKABF[y] bit. If channel y is not yet synchronized the hardware immediately set the CKABF[y] flag. Software is then reading back the CKABF[y] flag and if it is set then perform again clearing of this flag by setting CLRCKABF[y] bit. This software sequence (polling of CKABF[y] flag) continues until CKABF[y] flag is set (signalizing that Manchester stream is synchronized). To be able to synchronize/receive Manchester coded data the CKOUTDIV divider (in DFSDM_CH0CFGR1 register) must be set with respect to expected Manchester data rate according the formula below.

$$((CKOUTDIV + 1) \times T_{SYSCLK}) < T_{Manchester\ clock} < (2 \times CKOUTDIV \times T_{SYSCLK})$$

SPI coded stream is synchronized after first detection of clock input signal (valid rising/falling edge).

Note: When the transceiver is not yet synchronized, the clock absence flag is set and cannot be cleared by CLRCKABF[y] bit (in DFSDM_FLT0ICR register).

Figure 315. First conversion for Manchester coding (Manchester synchronization)



External serial clock frequency measurement

The measuring of a channel serial clock input frequency provides a real data rate from an external ΣΔ modulator, which is important for application purposes.

An external serial clock input frequency can be measured by a timer counting DFSDM clocks ($f_{DFSDMCLK}$) during one conversion duration. The counting starts at the first input data clock after a conversion trigger (regular or injected) and finishes by last input data clock before conversion ends (end of conversion flag is set). Each conversion duration (time between first serial sample and last serial sample) is updated in counter CNVCNT[27:0] in register DFSDM_FLTxCNVTIMR when the conversion finishes (JEOCF=1 or REOCF=1). The user can then compute the data rate according to the digital filter settings (FORD, FOSR, IOSR, FAST). The external serial frequency measurement is stopped only if the filter is bypassed (FOSR=0, only integrator is active, CNVCNT[27:0]=0 in DFSDM_FLTxCNVTIMR register).

In case of parallel data input (*Section 35.4.6: Parallel data inputs*) the measured frequency is the average input data rate during one conversion.

Note: When conversion is interrupted (e.g. by disabling/enabling the selected channel) the interruption time is also counted in CNVCNT[27:0]. Therefore it is recommended to not interrupt the conversion for correct conversion duration result.

Conversion times:

injected conversion or regular conversion with FAST = 0 (or first conversion if FAST=1):

for $Sinc^x$ filters (x=1..5):

$t = CNVCNT/f_{DFSDMCLK} = [F_{OSR} * (I_{OSR}-1 + F_{ORD}) + F_{ORD}] / f_{CKIN}$

for FastSinc filter:

$t = CNVCNT/f_{DFSDMCLK} = [F_{OSR} * (I_{OSR}-1 + 4) + 2] / f_{CKIN}$

regular conversion with FAST = 1 (except first conversion):

for $Sinc^x$ and FastSinc filters:

$t = CNVCNT/f_{DFSDMCLK} = [F_{OSR} * I_{OSR}] / f_{CKIN}$

in case if F_{OSR} = FOSR[9:0]+1 = 1 (filter bypassed, active only integrator):

$t = I_{OSR} / f_{CKIN}$ (... but CNVCNT=0)

where:

- f_{CKIN} is the channel input clock frequency (on given channel CKINy pin) or input data rate (in case of parallel data input)
- F_{OSR} is the filter oversampling ratio: F_{OSR} = FOSR[9:0]+1 (see DFSDM_FLTxFCR register)
- I_{OSR} is the integrator oversampling ratio: I_{OSR} = IOSR[7:0]+1 (see DFSDM_FLTxFCR register)
- F_{ORD} is the filter order: F_{ORD} = FORD[2:0] (see DFSDM_FLTxFCR register)

Channel offset setting

Each channel has its own offset setting (in register) which is finally subtracted from each conversion result (injected or regular) from a given channel. Offset correction is performed after the data right bit shift. The offset is stored as a 24-bit signed value in OFFSET[23:0] field in DFSDM_CHyCFGR2 register.

Data right bit shift

To have the result aligned to a 24-bit value, each channel defines a number of right bit shifts which will be applied on each conversion result (injected or regular) from a given channel. The data bit shift number is stored in DTRBS[4:0] bits in DFSDM_CHyCFGR2 register.

The right bit-shift is rounding the result to nearest integer value. The sign of shifted result is maintained, in order to have valid 24-bit signed format of result data.

Pulses skipper

Purpose of the pulses skipper is to implement delay line like behavior for given input channel(s). Given number of samples from input serial data stream (serial stream only) can be discarded before they enter into the filter. This data discarding is performed by skipping given number of sampling input clock pulses (given serial data samples are then not sampled by filter). The sampling clock is gated by pulses skipper function for given number of clock pulses. When given clock pulses are skipped then the filtering continues for following input data. With comparison to non skipped data stream this operation causes that

the final output sample (and next samples) from filter will be calculated from later input data. This final sample then looks a bit in forward - because it is calculated from newer input samples than the “non-skipped” sample. The final “skipped sample” is converted later because the skipped input data samples must be replaced by followed input data samples. The final data buffers behavior (skipped and non-skipped output data buffers comparison) looks like the non-skipped data stream is a bit delayed - both data buffers will be phase shifted.

Number of clock pulses to be skipped should be written into PLSSKP[5:0] field in DFSDM_CHyDLYR register. Once PLSSKP[5:0] field is written the execution of pulses skipping is started on given channel. PLSSKP[5:0] field can be read in order to check the progress of pulses skipper. When PLSSKP[5:0]=0 means that pulses skipping has been executed.

Up to 63 clock pulses can be skip with a single write operation into PLSSKP[5:0]. If more pulses need to be skipped, then user has to write several times into the PLSSKP[5:0] field. The application software should handle cumulative skipped clock number per each filter.

35.4.5 Configuring the input serial interface

The following parameters must be configured for the input serial interface:

- **Output clock predivider**. There is a programmable predivider to generate the output clock from DFSDM clock (2 - 256). It is defined by CKOUTDIV[7:0] bits in DFSDM_CH0CFGR1 register.
- **Serial interface type and input clock phase.** Selection of SPI or Manchester coding and sampling edge of input clock. It is defined by SITP [1:0] bits in DFSDM_CHyCFGR1 register.
- **Input clock source.** External source from CKINy pin or internal from CKOUT pin. It is defined by SPICKSEL[1:0] field in DFSDM_CHyCFGR1 register.
- **Final data right bit-shift.** Defines the final data right bit shift to have the result aligned to a 24-bit value. It is defined by DTRBS[4:0] in DFSDM_CHyCFGR2 register.
- **Channel offset per channel.** Defines the analog offset of a given serial channel (offset of connected external ΣΔ modulator). It is defined by OFFSET[23:0] bits in DFSDM_CHyCFGR2 register.
- **short-circuit detector and clock absence per channel enable.** To enable or disable the short-circuit detector (by SCDEN bit) and the clock absence monitoring (by CKABEN bit) on a given serial channel in register DFSDM_CHyCFGR1.
- **Analog watchdog filter and short-circuit detector threshold settings.** To configure channel analog watchdog filter parameters and channel short-circuit detector parameters. Configurations are defined in DFSDM_CHyAWSCDR register.

35.4.6 Parallel data inputs

Each input channel provides a register for 16-bit parallel data input (besides serial data input). Each 16-bit parallel input can be sourced from internal data sources only:

- internal ADC results
- direct CPU/DMA writing.

The selection for using serial or parallel data input for a given channel is done by field DATMPX[1:0] of DFSDM_CHyCFGR1 register. In DATMPX[1:0] is also defined the parallel data source: internal ADC or direct write by CPU/DMA.

Each channel contains a 32-bit data input register DFSDM_CHyDATINR in which it can be written a 16-bit data. Data are in 16-bit signed format. Those data can be used as input to the digital filter which is accepting 16-bit parallel data.

If serial data input is selected (DATMPX[1:0] = 0), the DFSDM_CHyDATINR register is write protected.

Input from internal ADC

In case of ADC data parallel input (DATMPX[1:0]=1) the ADC[y+1] result is assigned to channel y input (ADC1 is filling DFSDM_CHDATIN0R register, ADC2 is filling DFSDM_CHDATIN1R register, ... , ADC8 is filling DFSDM_CHDATIN7R register). End of conversion event from ADC[y+1] causes update of channel y data (parallel data from ADC[y+1] are put as next sample to digital filter). Data from ADC[y+1] is written into DFSDM_CHyDATINR register (field INDAT0[15:0]) when end of conversion event occurred.

The setting of data packing mode (DATPACK[1:0] in the DFSDM_CHyCFGR1 register) has no effect in case of ADC data input.

Note: Extension of ADC specification: in case the internal ADC is configured in interleaved mode (e.g. ADC1 together with ADC2 - see ADC specification) then each result from ADC1 or from ADC2 will come to the same 16-bit bus - to the bus of ADC1 - which is coming into DFSDM channel 0 (fixed connection). So there will be double input data rate into DFSDM channel 0 (even samples come from ADC1 and odd samples from ADC2). Channel 1 associated with ADC2 will be free.

Input from memory (direct CPU/DMA write)

The direct data write into DFSDM_CHyDATINR register by CPU or DMA (DATMPX[1:0]=2) can be used as data input in order to process digital data streams from memory or peripherals.

Data can be written by CPU or DMA into DFSDM_CHyDATINR register:

1. **CPU data write:**

   Input data are written directly by CPU into DFSDM_CHyDATINR register.

2. **DMA data write:**

   The DMA should be configured in memory-to-memory transfer mode to transfer data from memory buffer into DFSDM_CHyDATINR register. The destination memory address is the address of DFSDM_CHyDATINR register. Data are transferred at DMA transfer speed from memory to DFSDM parallel input.

   This DMA transfer is different from DMA used to read DFSDM conversion results. Both DMA can be used at the same time - first DMA (configured as memory-to-memory transfer) for input data writings and second DMA (configured as peripheral-to-memory transfer) for data results reading.

The accesses to DFSDM_CHyDATINR can be either 16-bit or 32-bit wide, allowing to load respectively one or two samples in one write operation. 32-bit input data register (DFSDM_CHyDATINR) can be filled with one or two 16-bit data samples, depending on the data packing operation mode defined in field DATPACK[1:0] of DFSDM_CHyCFGR1 register:

1. **Standard mode (DATPACK[1:0]=0):**

   Only one sample is stored in field INDAT0[15:0] of DFSDM_CHyDATINR register which is used as input data for channel y. The upper 16 bits (INDAT1[15:0]) are ignored and write protected. The digital filter must perform one input sampling (from INDAT0[15:0])

to empty data register after it has been filled by CPU/DMA. This mode is used together with 16-bit CPU/DMA access to DFSDM_CHyDATINR register to load one sample per write operation.

2. **Interleaved mode (DATPACK[1:0]=1):**

   DFSDM_CHyDATINR register is used as a two sample buffer. The first sample is stored in INDAT0[15:0] and the second sample is stored in INDAT1[15:0]. The digital filter must perform two input samplings from channel y to empty DFSDM_CHyDATINR register. This mode is used together with 32-bit CPU/DMA access to DFSDM_CHyDATINR register to load two samples per write operation.

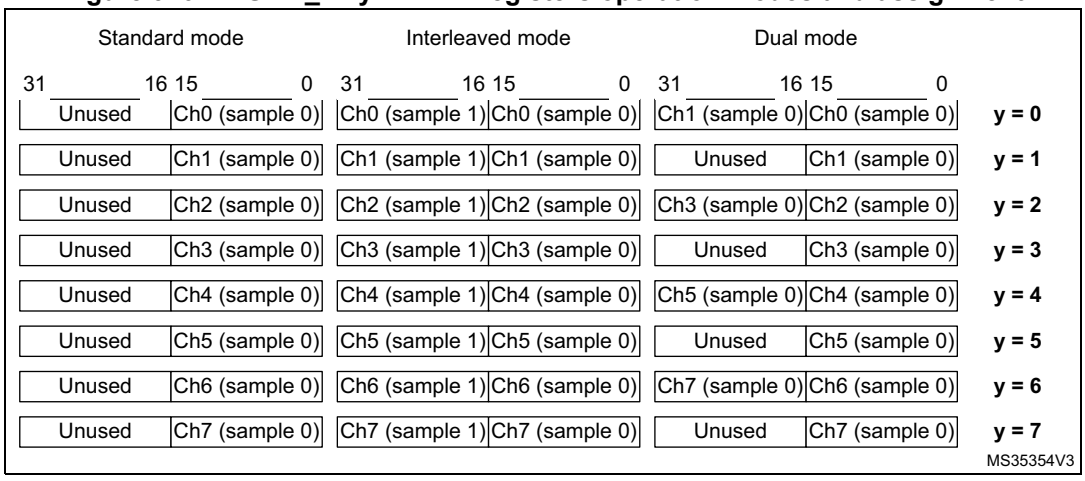
3. **Dual mode (DATPACK[1:0]=2):**

   Two samples are written into DFSDM_CHyDATINR register. The data INDAT0[15:0] is for channel y, the data in INDAT1[15:0] is for channel y+1. The data in INDAT1[15:0] is automatically copied INDAT0[15:0] of the following (y+1) channel data register DFSDM_CH[y+1]DATINR). The digital filters must perform two samplings - one from channel y and one from channel (y+1) - in order to empty DFSDM_CHyDATINR registers.

   Dual mode setting (DATPACK[1:0]=2) is available only on even channel numbers (y = 0, 2, 4, 6). If odd channel (y = 1, 3, 5, 7) is set to Dual mode then both INDAT0[15:0] and INDAT1[15:0] parts are write protected for this channel. If even channel is set to Dual mode then the following odd channel must be set into Standard mode (DATPACK[1:0]=0) for correct cooperation with even channels.

See *Figure 316* for DFSDM_CHyDATINR registers data modes and assignments of data samples to channels.

Figure 316. DFSDM_CHyDATINR registers operation modes and assignment



The write into DFSDM_CHyDATINR register to load one or two samples must be performed after the selected input channel (channel y) is enabled for data collection (starting conversion for channel y). Otherwise written data are lost for next processing.

For example: for single conversion and interleaved mode, do not start writing pair of data samples into DFSDM_CHyDATINR before the single conversion is started (any data present in the DFSDM_CHyDATINR before starting a conversion is discarded).

35.4.7 Channel selection

There are 8 multiplexed channels which can be selected for conversion using the injected channel group and/or using the regular channel.

The **injected channel group** is a selection of any or all of the 8 channels. JCHG[7:0] in the DFSDM_FLTxJCHGR register selects the channels of the injected group, where JCHG[y]=1 means that channel y is selected.

Injected conversions can operate in scan mode (JSCAN=1) or single mode (JSCAN=0). In scan mode, each of the selected channels is converted, one after another. The lowest channel (channel 0, if selected) is converted first, followed immediately by the next higher channel until all the channels selected by JCHG[7:0] have been converted. In single mode (JSCAN=0), only one channel from the selected channels is converted, and the channel selection is moved to the next channel. Writing to JCHG[7:0] if JSCAN=0 resets the channel selection to the lowest selected channel.

Injected conversions can be launched by software or by a trigger. They are never interrupted by regular conversions.

The **regular channel** is a selection of just one of the 8 channels. RCH[2:0] in the DFSDM_FLTxCR1 register indicates the selected channel.

Regular conversions can be launched only by software (not by a trigger). A sequence of continuous regular conversions is temporarily interrupted when an injected conversion is requested.

Performing a conversion on a disabled channel (CHEN=0 in DFSDM_CHyCFGR1 register) causes that the conversion will never end - because no input data is provided (with no clock signal). In this case, it is necessary to enable a given channel (CHEN=1 in DFSDM_CHyCFGR1 register) or to stop the conversion by DFEN=0 in DFSDM_FLTxCR1 register.

35.4.8 Digital filter configuration

DFSDM contains a $Sinc^x$ type digital filter implementation. This $Sinc^x$ filter performs an input digital data stream filtering, which results in decreasing the output data rate (decimation) and increasing the output data resolution. The $Sinc^x$ digital filter is configurable in order to reach the required output data rates and required output data resolution. The configurable parameters are:

- Filter order/type: (see FORD[2:0] bits in DFSDM_FLTxFCR register):
  - FastSinc
  - $Sinc^1$
  - $Sinc^2$
  - $Sinc^3$
  - $Sinc^4$
  - $Sinc^5$
- Filter oversampling/decimation ratio (see FOSR[9:0] bits in DFSDM_FLTxFCR register):
  - FOSR = 1-1024 - for FastSinc filter and $Sinc^x$ filter x = F_{ORD} = 1..3
  - FOSR = 1-215 - for $Sinc^x$ filter x = F_{ORD} = 4
  - FOSR = 1-73 - for $Sinc^x$ filter x = F_{ORD} = 5

The filter has the following transfer function (impulse response in H domain):

- Sinc^x filter type: $$H(z) = \left(\frac{1 - z^{-FOSR}}{1 - z^{-1}} \right)^x$$

- FastSinc filter type: $$H(z) = \left(\frac{1 - z^{-FOSR}}{1 - z^{-1}} \right)^2 \cdot (1 + z^{-(2 \cdot FOSR)})$$

Figure 317. Example: Sinc^3 filter response

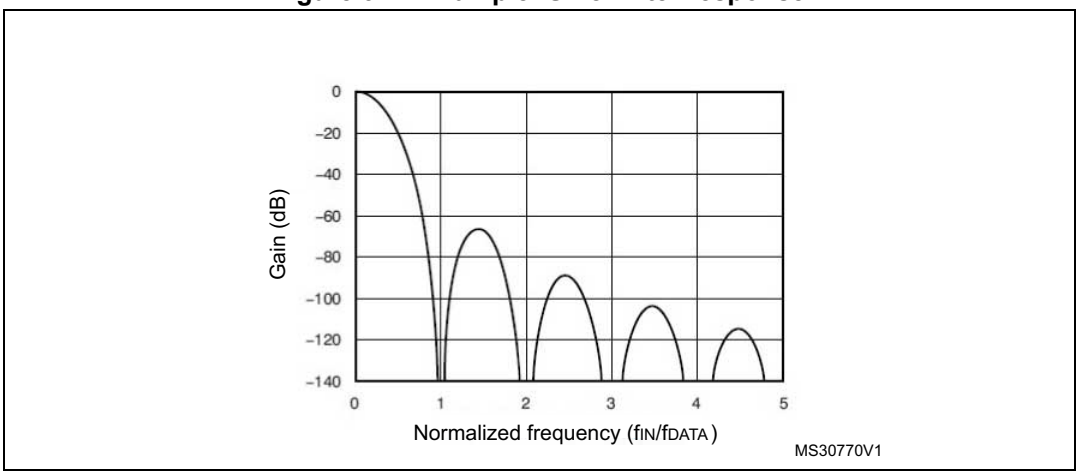


Table 289. Filter maximum output resolution (peak data values from filter output) for some FOSR values

FOSR	Sinc^1	Sinc^2	FastSinc	Sinc^3	Sinc^4	Sinc^5
x	+/- x	+/- x^2	+/- 2x^2	+/- x^3	+/- x^4	+/- x^5
4	+/- 4	+/- 16	+/- 32	+/- 64	+/- 256	+/- 1024
8	+/- 8	+/- 64	+/- 128	+/- 512	+/- 4096	-
32	+/- 32	+/- 1024	+/- 2048	+/- 32768	+/- 1048576	+/- 33554432
64	+/- 64	+/- 4096	+/- 8192	+/- 262144	+/- 16777216	+/- 1073741824
128	+/- 128	+/- 16384	+/- 32768	+/- 2097152	+/- 268435456	Result can overflow on full scale input (> 32-bit signed integer)
256	+/- 256	+/- 65536	+/- 131072	+/- 16777216		
1024	+/- 1024	+/- 1048576	+/- 2097152	+/- 1073741824		

For more information about Sinc filter type properties and usage, it is recommended to study the theory about digital filters (more resources can be downloaded from internet).

35.4.9 Integrator unit

The integrator performs additional decimation and a resolution increase of data coming from the digital filter. The integrator simply performs the sum of data from a digital filter for a given number of data samples from a filter.

The integrator oversampling ratio parameter defines how many data counts will be summed to one data output from the integrator. IOSR can be set in the range 1-256 (see IOSR[7:0] bits description in DFSDM_FLTxFCR register).

Table 290. Integrator maximum output resolution (peak data values from integrator output) for some IOSR values and FOSR = 256 and $Sinc^3$ filter type (largest data)

IOSR	$Sinc^1$	$Sinc^2$	FastSinc	$Sinc^3$	$Sinc^4$	$Sinc^5$
x	+/- FOSR. x	+/- $FOSR^2$. x	+/- 2.$FOSR^2$. x	+/- $FOSR^3$. x	+/- $FOSR^4$. x	+/- $FOSR^5$. x
4	-	-	-	+/- 67 108 864	-	-
32	-	-	-	+/- 536 870 912	-	-
128	-	-	-	+/- 2 147 483 648	-	-
256	-	-	-	+/- 2^{32}	-	-

35.4.10 Analog watchdog

The analog watchdog purpose is to trigger an external signal (break or interrupt) when an analog signal reaches or crosses given maximum and minimum threshold values. An interrupt/event/break generation can then be invoked.

Each analog watchdog will supervise serial data receiver outputs (after the analog watchdog filter on each channel) or data output register (current injected or regular conversion result) according to AWFSEL bit setting (in DFSDM_FLTxCR1 register). The input channels to be monitored or not by the analog watchdog x will be selected by AWDCH[7:0] in DFSDM_FLTxCR2 register.

Analog watchdog conversions on input channels are independent from standard conversions. In this case, the analog watchdog uses its own filters and signal processing on each input channel independently from the main injected or regular conversions. Analog watchdog conversions are performed in a continuous mode on the selected input channels in order to watch channels also when main injected or regular conversions are paused (RCIP = 0, JCIP = 0).

There are high and low threshold registers which are compared with given data values (set by AWHT[23:0] bits in DFSDM_FLTxAWHTR register and by AWLT[23:0] bits in DFSDM_FLTxAWLTR register).

There are 2 options for comparing the threshold registers with the data values

- Option1: in this case, the input data are taken from final output data register (AWFSEL=0). This option is characterized by:
  - high input data resolution (up to 24-bits)
  - slow response time - inappropriate for fast response applications like overcurrent detection
  - for the comparison the final data are taken after bit shifting and offset data correction
  - final data are available only after main regular or injected conversions are performed
  - can be used in case of parallel input data source (DATMPX[1:0] ≠ 0 in DFSDM_CHyCFGR1 register)
- Option2: in this case, the input data are taken from any serial data receivers output (AWFSEL=1). This option is characterized by:
  - input serial data are processed by dedicated analog watchdog $Sinc^x$ channel filters with configurable oversampling ratio (1..32) and filter order (1..3) (see AWFOSR[4:0] and AWFORD[1:0] bits setting in DFSDM_CHyAWSCDR register)
  - lower resolution (up to 16-bit)
  - fast response time - appropriate for applications which require a fast response like overcurrent/overvoltage detection)
  - data are available in continuous mode independently from main regular or injected conversions activity

In case of input channels monitoring (AWFSEL=1), the data for comparison to threshold is taken from channels selected by AWDCH[7:0] field (DFSDM_FLTxCR2 register). Each of the selected channels filter result is compared to one threshold value pair (AWHT[23:0] / AWLT[23:0]). In this case, only higher 16 bits (AWHT[23:8] / AWLT[23:8]) define the 16-bit threshold compared with the analog watchdog filter output because data coming from the analog watchdog filter is up to a 16-bit resolution. Bits AWHT[7:0] / AWLT[7:0] are not taken into comparison in this case (AWFSEL=1).

Parameters of the analog watchdog filter configuration for each input channel are set in DFSDM_CHyAWSCDR register (filter order AWFORD[1:0] and filter oversampling ratio AWFOSR[4:0]).

Each input channel has its own comparator which compares the analog watchdog data (from analog watchdog filter) with analog watchdog threshold values (AWHT/AWLT). When several channels are selected (field AWDCH[7:0] field of DFSDM_FLTxCR2 register), several comparison requests may be received simultaneously. In this case, the channel request with the lowest number is managed first and then continuing to higher selected channels. For each channel, the result can be recorded in a separate flag (fields AWHTF[7:0], AWLTF[7:0] of DFSDM_FLTxAWSR register). Each channel request is executed in 8 DFSDM clock cycles. So, the bandwidth from each channel is limited to 8 DFSDM clock cycles (if AWDCH[7:0] = 0xFF). Because the maximum input channel sampling clock frequency is the DFSDM clock frequency divided by 4, the configuration AWFOSR = 0 (analog watchdog filter is bypassed) cannot be used for analog watchdog feature at this input clock speed. Therefore user must properly configure the number of watched channels and analog watchdog filter parameters with respect to input sampling clock speed and DFSDM frequency.

Analog watchdog filter data for given channel y is available for reading by firmware on field WDATA[15:0] in DFSDM_CHyWDATR register. That analog watchdog filter data is converted continuously (if CHEN=1 in DFSDM_CHyCFGR1 register) with the data rate given by the analog watchdog filter setting and the channel input clock frequency.

The analog watchdog filter conversion works like a regular Fast Continuous Conversion without the intergator. The number of serial samples needed for one result from analog watchdog filter output (at channel input clock frequency f_{CKIN}):

first conversion:

for $Sinc^x$ filters (x=1..5): number of samples = [F_{OSR} * F_{ORD} + F_{ORD} + 1]

for FastSinc filter: number of samples = [F_{OSR} * 4 + 2 + 1]

next conversions:

for $Sinc^x$ and FastSinc filters: number of samples = [FOSR * IOSR]

where:

F_{OSR} ..... filter oversampling ratio: F_{OSR} = AWFOSR[4:0]+1 (see DFSDM_CHyAWSCDR register)

F_{ORD} ..... the filter order: F_{ORD} = AWFORD[1:0] (see DFSDM_CHyAWSCDR register)

In case of output data register monitoring (AWFSEL=0), the comparison is done after a right bit shift and an offset correction of final data (see OFFSET[23:0] and DTRBS[4:0] fields in DFSDM_CHyCFGR2 register). A comparison is performed after each injected or regular end of conversion for the channels selected by AWDCH[7:0] field (in DFSDM_FLTxCR2 register).

The status of an analog watchdog event is signalized in DFSDM_FLTxAWSR register where a given event is latched. AWHTF[y]=1 flag signalizes crossing AWHT[23:0] value on channel y. AWLTF[y]=1 flag signalizes crossing AWLT[23:0] value on channel y. Latched events in DFSDM_FLTxAWSR register are cleared by writing ‘1’ into the corresponding clearing bit CLRAWHTF[y] or CLRAWLTF[y] in DFSDM_FLTxAWCFR register.

The global status of an analog watchdog is signalized by the AWDF flag bit in DFSDM_FLTxISR register (it is used for the fast detection of an interrupt source). AWDF=1 signalizes that at least one watchdog occurred (AWHTF[y]=1 or AWLTF[y]=1 for at least one channel). AWDF bit is cleared when all AWHTF[7:0] and AWLTF[7:0] are cleared.

An analog watchdog event can be assigned to break output signal. There are four break outputs to be assigned to a high or low threshold crossing event (dfsdm_break[3:0]). The break signal assignment to a given analog watchdog event is done by BKAWH[3:0] and BKAWL[3:0] fields in DFSDM_FLTxAWHTR and DFSDM_FLTxAWLTR register.

35.4.11 Short-circuit detector

The purpose of a short-circuit detector is to signalize with a very fast response time if an analog signal reached saturated values (out of full scale ranges) and remained on this value given time. This behavior can detect short-circuit or open circuit errors (e.g. overcurrent or overvoltage). An interrupt/event/break generation can be invoked.

Input data into a short-circuit detector is taken from channel transceiver outputs.

There is an upcounting counter on each input channel which is counting consecutive 0’s or 1’s on serial data receiver outputs. A counter is restarted if there is a change in the data stream received - 1 to 0 or 0 to 1 change of data signal. If this counter reaches a short-circuit threshold register value (SCDT[7:0] bits in DFSDM_CHyAWSCDR register), then a short-

circuit event is invoked. Each input channel has its short-circuit detector. Any channel can be selected to be continuously monitored by setting the SCDEN bit (in DFSDM_CHyCFGR1 register) and it has its own short-circuit detector settings (threshold value in SCDT[7:0] bits, status bit SCDF[7:0], status clearing bits CLRSCDF[7:0]). Status flag SCDF[y] is cleared also by hardware when corresponding channel y is disabled (CHEN[y] = 0).

On each channel, a short-circuit detector event can be assigned to break output signal dfsdm_break[3:0]. There are four break outputs to be assigned to a short-circuit detector event. The break signal assignment to a given channel short-circuit detector event is done by BKSCD[3:0] field in DFSDM_CHyAWSCDR register.

Short circuit detector cannot be used in case of parallel input data channel selection (DATMPX[1:0] ≠ 0 in DFSDM_CHyCFGR1 register).

Four break outputs are totally available (shared with the analog watchdog function).

35.4.12 Extreme detector

The purpose of an extremes detector is to collect the minimum and maximum values of final output data words (peak to peak values).

If the output data word is higher than the value stored in the extremes detector maximum register (EXMAX[23:0] bits in DFSDM_FLTxEXMAX register), then this register is updated with the current output data word value and the channel from which the data is stored is in EXMAXCH[2:0] bits (in DFSDM_FLTxEXMAX register) .

If the output data word is lower than the value stored in the extremes detector minimum register (EXMIN[23:0] bits in DFSDM_FLTxEXMIN register), then this register is updated with the current output data word value and the channel from which the data is stored is in EXMINCH[2:0] bits (in DFSDM_FLTxEXMIN register).

The minimum and maximum register values can be refreshed by software (by reading given DFSDM_FLTxEXMAX or DFSDM_FLTxEXMIN register). After refresh, the extremes detector minimum data register DFSDM_FLTxEXMIN is filled with 0x7FFFFF (maximum positive value) and the extremes detector maximum register DFSDM_FLTxEXMAX is filled with 0x800000 (minimum negative value).

The extremes detector performs a comparison after a right bit shift and an offset data correction. For each extremes detector, the input channels to be considered into computing the extremes value are selected in EXCH[7:0] bits (in DFSDM_FLTxCR2 register).

35.4.13 Data unit block

The data unit block is the last block of the whole processing path: External ΣΔ modulators - Serial transceivers - Sinc filter - Integrator - Data unit block.

The output data rate depends on the serial data stream rate, and filter and integrator settings. The maximum output data rate is:

$$Datarate[samples/s] = \frac{f_{CKIN}}{F_{OSR} \cdot (I_{OSR} - 1 + F_{ORD}) + (F_{ORD} + 1)} \quad \text{...FAST = 0, Sincx filter}$$

$$Datarate[samples/s] = \frac{f_{CKIN}}{F_{OSR} \cdot (I_{OSR} - 1 + 4) + (2 + 1)} \quad \text{...FAST = 0, FastSinc filter}$$

or

$$Datarate[samples/s] = \frac{f_{CKIN}}{F_{OSR} \cdot I_{OSR}} \quad \text{...FAST = 1}$$

Maximum output data rate in case of parallel data input:

$$Datarate[samples/s] = \frac{f_{DATAIN\_RATE}}{F_{OSR} \cdot (I_{OSR} - 1 + F_{ORD}) + (F_{ORD} + 1)} \quad \text{...FAST = 0, Sincx filter}$$

or

$$Datarate[samples/s] = \frac{f_{DATAIN\_RATE}}{F_{OSR} \cdot (I_{OSR} - 1 + 4) + (2 + 1)} \quad \text{...FAST = 0, FastSinc filter}$$

or

$$Datarate[samples/s] = \frac{f_{DATAIN\_RATE}}{F_{OSR} \cdot I_{OSR}} \quad \text{...FAST=1 or any filter bypass case } (F_{OSR} = 1)$$

where: f_{DATAIN_RATE}...input data rate from ADC or from CPU/DMA

The right bit-shift of final data is performed in this module because the final data width is 24-bit and data coming from the processing path can be up to 32 bits. This right bit-shift is configurable in the range 0-31 bits for each selected input channel (see DTRBS[4:0] bits in DFSDM_CHyCFGR2 register). The right bit-shift is rounding the result to nearest integer value. The sign of shifted result is maintained - to have valid 24-bit signed format of result data.

In the next step, an offset correction of the result is performed. The offset correction value (OFFSET[23:0] stored in register DFSDM_CHyCFGR2) is subtracted from the output data for a given channel. Data in the OFFSET[23:0] field is set by software by the appropriate calibration routine.

Due to the fact that all operations in digital processing are performed on 32-bit signed registers, the following conditions must be fulfilled not to overflow the result:

$FOSR^{FORD} \cdot IOSR <= 2^{31}$ ... for $Sinc^x$ filters, x = 1..5)
$2 \cdot FOSR^{2} \cdot IOSR <= 2^{31}$ ... for FastSinc filter)

Note: In case of filter and integrator bypass (IOSR[7:0]=0, FOSR[9:0]=0), the input data rate (f_{DATAIN_RATE}) must be limited to be able to read all output data:
$f_{DATAIN\_RATE} \leq f_{APB}$
where f_{APB} is the bus frequency to which the DFSDM peripheral is connected.

35.4.14 Signed data format

Each DFSDM input serial channel can be connected to one external ΣΔ modulator. An external ΣΔ modulator can have 2 differential inputs (positive and negative) which can be used for a differential or single-ended signal measurement.

A ΣΔ modulator output is always assumed in a signed format (a data stream of zeros and ones from a ΣΔ modulator represents values -1 and +1).

Signed data format in registers: Data is in a signed format in registers for final output data, analog watchdog, extremes detector, offset correction. The msb of output data word represents the sign of value (two's complement format).

35.4.15 Launching conversions

Injected conversions can be launched using the following methods:

- Software: writing '1' to JSWSTART in the DFSDM_FLTxCR1 register.
- Trigger: JEXTSEL[4:0] selects the trigger signal while JEXTEN activates the trigger and selects the active edge at the same time (see the DFSDM_FLTxCR1 register).
- Synchronous with DFSDM_FLT0 if JSYNC=1: for DFSDM_FLTx (x>0), an injected conversion is automatically launched when in DFSDM_FLT0; the injected conversion is started by software (JSWSTART=1 in DFSDM_FLT0CR2 register). Each injected conversion in DFSDM_FLTx (x>0) is always executed according to its local configuration settings (JSCAN, JCHG, etc.).

If the scan conversion is enabled (bit JSCAN=1) then, each time an injected conversion is triggered, all of the selected channels in the injected group (JCHG[7:0] bits in DFSDM_FLTxJCHGR register) are converted sequentially, starting with the lowest channel (channel 0, if selected).

If the scan conversion is disabled (bit JSCAN=0) then, each time an injected conversion is triggered, only one of the selected channels in the injected group (JCHG[7:0] bits in DFSDM_FLTxJCHGR register) is converted and the channel selection is then moved to the next selected channel. Writing to the JCHG[7:0] bits when JSCAN=0 sets the channel selection to the lowest selected injected channel.

Only one injected conversion can be ongoing at a given time. Thus, any request to launch an injected conversion is ignored if another request for an injected conversion has already been issued but not yet completed.

Regular conversions can be launched using the following methods:

- Software: by writing '1' to RSWSTART in the DFSDM_FLTxCR1 register.
- Synchronous with DFSDM_FLT0 if RSYNC=1: for DFSDM_FLTx (x>0), a regular conversion is automatically launched when in DFSDM_FLT0; a regular conversion is started by software (RSWSTART=1 in DFSDM_FLT0CR2 register). Each regular conversion in DFSDM_FLTx (x>0) is always executed according to its local configuration settings (RCONT, RCH, etc.).

Only one regular conversion can be pending or ongoing at a given time. Thus, any request to launch a regular conversion is ignored if another request for a regular conversion has already been issued but not yet completed. A regular conversion can be pending if it was interrupted by an injected conversion or if it was started while an injected conversion was in progress. This pending regular conversion is then delayed and is performed when all injected conversion are finished. Any delayed regular conversion is signalized by RPEND bit in DFSDM_FLTxRDATAR register.

35.4.16 Continuous and fast continuous modes

Setting RCONT in the DFSDM_FLTxCR1 register causes regular conversions to execute in continuous mode. RCONT=1 means that the channel selected by RCH[2:0] is converted repeatedly after '1' is written to RSWSTART.

The regular conversions executing in continuous mode can be stopped by writing ‘0’ to RCONT. After clearing RCONT, the on-going conversion is stopped immediately.

In continuous mode, the data rate can be increased by setting the FAST bit in the DFSDM_FLTxCR1 register. In this case, the filter does not need to be refilled by new fresh data if converting continuously from one channel because data inside the filter is valid from previously sampled continuous data. The speed increase depends on the chosen filter order. The first conversion in fast mode (FAST=1) after starting a continuous conversion by RSWSTART=1 takes still full time (as when FAST=0), then each subsequent conversion is finished in shorter intervals.

Conversion time in continuous mode:

if FAST = 0 (or first conversion if FAST=1):

for $Sinc^x$ filters:

$t = CNVCNT/f_{DFSDMCLK} = [F_{OSR} * (I_{OSR}-1 + F_{ORD}) + F_{ORD}] / f_{CKIN}$

for FastSinc filter:

$t = CNVCNT/f_{DFSDMCLK} = [F_{OSR} * (I_{OSR}-1 + 4) + 2] / f_{CKIN}$

if FAST = 1 (except first conversion):

for $Sinc^x$ and FastSinc filters:

$t = CNVCNT/f_{DFSDMCLK} = [F_{OSR} * I_{OSR}] / f_{CKIN}$

in case F_{OSR} = FOSR[9:0]+1 = 1 (filter bypassed, only integrator active):

$t = I_{OSR} / f_{CKIN}$ (... but CNVCNT=0)

Continuous mode is not available for injected conversions. Injected conversions can be started by timer trigger to emulate the continuous mode with precise timing.

If a regular continuous conversion is in progress (RCONT=1) and if a write access to DFSDM_FLTxCR1 register requesting regular continuous conversion (RCONT=1) is performed, then regular continuous conversion is restarted from the next conversion cycle (like new regular continuous conversion is applied for new channel selection - even if there is no change in DFSDM_FLTxCR1 register).

35.4.17 Request precedence

An injected conversion has a higher precedence than a regular conversion. A regular conversion which is already in progress is immediately interrupted by the request of an injected conversion; this regular conversion is restarted after the injected conversion finishes.

An injected conversion cannot be launched if another injected conversion is pending or already in progress: any request to launch an injected conversion (either by JSWSTART or by a trigger) is ignored as long as bit JCIP is ‘1’ (in the DFSDM_FLTxISR register).

Similarly, a regular conversion cannot be launched if another regular conversion is pending or already in progress: any request to launch a regular conversion (using RSWSTART) is ignored as long as bit RCIP is ‘1’ (in the DFSDM_FLTxISR register).

However, if an injected conversion is requested while a regular conversion is already in progress, the regular conversion is immediately stopped and an injected conversion is launched. The regular conversion is then restarted and this delayed restart is signalized in bit RPEND.

Injected conversions have precedence over regular conversions in that a injected conversion can temporarily interrupt a sequence of continuous regular conversions. When

the sequence of injected conversions finishes, the continuous regular conversions start again if RCONT is still set (and RPEND bit will signalize the delayed start on the first regular conversion result).

Precedence also matters when actions are initiated by the same write to DFSDM, or if multiple actions are pending at the end of another action. For example, suppose that, while an injected conversion is in process (JCIP=1), a single write operation to DFSDM_FLTxCR1 writes ‘1’ to RSWSTART, requesting a regular conversion. When the injected sequence finishes, the precedence dictates that the regular conversion is performed next and its delayed start is signalized in RPEND bit.

35.4.18 Power optimization in run mode

In order to reduce the consumption, the DFSDM filter and integrator are automatically put into idle when not used by conversions (RCIP=0, JCIP=0).

35.5 DFSDM interrupts

In order to increase the CPU performance, a set of interrupts related to the CPU event occurrence has been implemented:

- End of injected conversion interrupt:
  - enabled by JEOCIE bit in DFSDM_FLTxCR2 register
  - indicated in JEOCF bit in DFSDM_FLTxISR register
  - cleared by reading DFSDM_FLTxJDATAR register (injected data)
  - indication of which channel end of conversion occurred, reported in JDATACH[2:0] bits in DFSDM_FLTxJDATAR register
- End of regular conversion interrupt:
  - enabled by REOCIE bit in DFSDM_FLTxCR2 register
  - indicated in REOCF bit in DFSDM_FLTxISR register
  - cleared by reading DFSDM_FLTxRDATAR register (regular data)
  - indication of which channel end of conversion occurred, reported in RDATACH[2:0] bits in DFSDM_FLTxRDATAR register
- Data overrun interrupt for injected conversions:
  - occurred when injected converted data were not read from DFSDM_FLTxJDATAR register (by CPU or DMA) and were overwritten by a new injected conversion
  - enabled by JOVRIE bit in DFSDM_FLTxCR2 register
  - indicated in JOVRF bit in DFSDM_FLTxISR register
  - cleared by writing ‘1’ into CLRJOVRF bit in DFSDM_FLTxICR register
- Data overrun interrupt for regular conversions:
  - occurred when regular converted data were not read from DFSDM_FLTxRDATAR register (by CPU or DMA) and were overwritten by a new regular conversion
  - enabled by ROVRIE bit in DFSDM_FLTxCR2 register
  - indicated in ROVRF bit in DFSDM_FLTxISR register
  - cleared by writing ‘1’ into CLRROVRF bit in DFSDM_FLTxICR register
- Analog watchdog interrupt:

  - occurred when converted data (output data or data from analog watchdog filter - according to AWFSEL bit setting in DFSDM_FLTxCR1 register) crosses over/under high/low thresholds in DFSDM_FLTxAWHTR / DFSDM_FLTxAWLTR registers
  - enabled by AWDIE bit in DFSDM_FLTxCR2 register (on selected channels AWDCH[7:0])
  - indicated in AWDF bit in DFSDM_FLTxISR register
  - separate indication of high or low analog watchdog threshold error by AWHTF[7:0] and AWLTF[7:0] fields in DFSDM_FLTxAWSR register
  - cleared by writing ‘1’ into corresponding CLRAWHTF[7:0] or CLRAWLTF[7:0] bits in DFSDM_FLTxAWCFR register
- Short-circuit detector interrupt:
  - occurred when the number of stable data crosses over thresholds in DFSDM_CHyAWSCDR register
  - enabled by SCDIE bit in DFSDM_FLTxCR2 register (on channel selected by SCDEN bi tin DFSDM_CHyCFGR1 register)
  - indicated in SCDF[7:0] bits in DFSDM_FLTxISR register (which also reports the channel on which the short-circuit detector event occurred)
  - cleared by writing ‘1’ into the corresponding CLRSCDF[7:0] bit in DFSDM_FLTxICR register
- Channel clock absence interrupt:
  - occurred when there is clock absence on CKINy pin (see *Clock absence detection* in *Section 35.4.4: Serial channel transceivers*)
  - enabled by CKABIE bit in DFSDM_FLTxCR2 register (on channels selected by CKABEN bit in DFSDM_CHyCFGR1 register)
  - indicated in CKABF[y] bit in DFSDM_FLTxISR register
  - cleared by writing ‘1’ into CLRCKABF[y] bit in DFSDM_FLTxICR register

Table 291. DFSDM interrupt requests

Interrupt event	Event flag	Event/Interrupt clearing method	Interrupt enable control bit
End of injected conversion	JEOCF	reading DFSDM_FLTxJDATAR	JEOCIE
End of regular conversion	REOCF	reading DFSDM_FLTxRDATAR	REOCIE
Injected data overrun	JOVRF	writing CLRJOVRF = 1	JOVRIE
Regular data overrun	ROVRF	writing CLRROVRF = 1	ROVRIE
Analog watchdog	AWDF, AWHTF[7:0], AWLTF[7:0]	writing CLRAWHTF[7:0] = 1 writing CLRAWLTF[7:0] = 1	AWDIE, (AWDCH[7:0])
short-circuit detector	SCDF[7:0]	writing CLRSCDF[7:0] = 1	SCDIE, (SCDEN)
Channel clock absence	CKABF[7:0]	writing CLRCKABF[7:0] = 1	CKABIE, (CKABEN)

35.6 DFSDM DMA transfer

To decrease the CPU intervention, conversions can be transferred into memory using a DMA transfer. A DMA transfer for injected conversions is enabled by setting bit JDMAEN=1 in DFSDM_FLTxCR1 register. A DMA transfer for regular conversions is enabled by setting bit RDMAEN=1 in DFSDM_FLTxCR1 register.

Note: With a DMA transfer, the interrupt flag is automatically cleared at the end of the injected or regular conversion (JEOCF or REOCF bit in DFSDM_FLTxISR register) because DMA is reading DFSDM_FLTxJDATAR or DFSDM_FLTxRDATAR register.

35.7 DFSDM channel y registers (y=0..7)

Word access (32-bit) must be used for registers write access except DFSDM_CHyDATINR register. Write access to DFSDM_CHyDATINR register can be either word access (32-bit) or half-word access (16-bit).

35.7.1 DFSDM channel y configuration register (DFSDM_CHyCFGR1)

This register specifies the parameters used by channel y.

Address offset: 0x00 + 0x20 * y, (y = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DFSDMEN	CKOUTSRC	Res.	Res.	Res.	Res.	Res.	Res.	CKOUTDIV[7:0]							
rw	rw							rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATPACK[1:0]		DATMPX[1:0]		Res.	Res.	Res.	CHINSEL	CHEN	CKABEN	SCDEN	Res.	SPICKSEL[1:0]		SITP[1:0]	
rw	rw	rw	rw				rw	rw	rw	rw		rw	rw	rw	rw

Bit 31 **DFSDMEN**: Global enable for DFSDM interface

0: DFSDM interface disabled

1: DFSDM interface enabled

If DFSDM interface is enabled, then it is started to operate according to enabled y channels and enabled x filters settings (CHEN bit in DFSDM_CHyCFGR1 and DFEN bit in DFSDM_FLTxCR1). Data cleared by setting DFSDMEN=0:

–all registers DFSDM_FLTxISR are set to reset state (x = 0..3)

–all registers DFSDM_FLTxAWSR are set to reset state (x = 0..3)

Note: DFSDMEN is present only in DFSDM_CH0CFGR1 register (channel y=0)

Bit 30 **CKOUTSRC**: Output serial clock source selection

0: Source for output clock is from system clock

1: Source for output clock is from audio clock

This value can be modified only when DFSDMEN=0 (in DFSDM_CH0CFGR1 register).

Note: CKOUTSRC is present only in DFSDM_CH0CFGR1 register (channel y=0)

Bits 29:24 Reserved, must be kept at reset value.

Bits 23:16 **CKOUTDIV[7:0]**: Output serial clock divider

0: Output clock generation is disabled (CKOUT signal is set to low state)

1- 255: Defines the division of system clock for the serial clock output for CKOUT signal in range 2 - 256 (Divider = CKOUTDIV+1).

CKOUTDIV also defines the threshold for a clock absence detection.

This value can only be modified when DFSDMEN=0 (in DFSDM_CH0CFGR1 register).

If DFSDMEN=0 (in DFSDM_CH0CFGR1 register) then CKOUT signal is set to low state (setting is performed one DFSDM clock cycle after DFSDMEN=0).

Note: CKOUTDIV is present only in DFSDM_CH0CFGR1 register (channel y=0)

Bits 15:14 **DATPACK[1:0]**: Data packing mode in DFSDM_CHyDATINR register.

0: Standard: input data in DFSDM_CHyDATINR register are stored only in INDAT0[15:0]. To empty DFSDM_CHyDATINR register one sample must be read by the DFSDM filter from channel y.

1: Interleaved: input data in DFSDM_CHyDATINR register are stored as two samples:

–first sample in INDAT0[15:0] (assigned to channel y)

–second sample INDAT1[15:0] (assigned to channel y)

To empty DFSDM_CHyDATINR register, two samples must be read by the digital filter from channel y (INDAT0[15:0] part is read as first sample and then INDAT1[15:0] part is read as next sample).

2: Dual: input data in DFSDM_CHyDATINR register are stored as two samples:

–first sample INDAT0[15:0] (assigned to channel y)

–second sample INDAT1[15:0] (assigned to channel y+1)

To empty DFSDM_CHyDATINR register first sample must be read by the digital filter from channel y and second sample must be read by another digital filter from channel y+1. Dual mode is available only on even channel numbers (y = 0, 2, 4, 6), for odd channel numbers (y = 1, 3, 5, 7) DFSDM_CHyDATINR is write protected. If an even channel is set to dual mode then the following odd channel must be set into standard mode (DATPACK[1:0]=0) for correct cooperation with even channel.

3: Reserved

This value can be modified only when CHEN=0 (in DFSDM_CHyCFGR1 register).

Bits 13:12 **DATMPX[1:0]**: Input data multiplexer for channel y

0: Data to channel y are taken from external serial inputs as 1-bit values. DFSDM_CHyDATINR register is write protected.

1: Data to channel y are taken from internal analog to digital converter ADC_{y+1} output register update as 16-bit values (if ADC_{y+1} is available). Data from ADCs are written into INDAT0[15:0] part of DFSDM_CHyDATINR register.

2: Data to channel y are taken from internal DFSDM_CHyDATINR register by direct CPU/DMA write. There can be written one or two 16-bit data samples according DATPACK[1:0] bit field setting.

3: Reserved

This value can be modified only when CHEN=0 (in DFSDM_CHyCFGR1 register).

Bits 11:9 Reserved, must be kept at reset value.

Bit 8 **CHINSEL**: Channel inputs selection

0: Channel inputs are taken from pins of the same channel y.

1: Channel inputs are taken from pins of the following channel (channel (y+1) modulo 8).

This value can be modified only when CHEN=0 (in DFSDM_CHyCFGR1 register).

Bit 7 **CHEN**: Channel y enable

0: Channel y disabled

1: Channel y enabled

If channel y is enabled, then serial data receiving is started according to the given channel setting.

Bit 6 **CKABEN**: Clock absence detector enable on channel y
- 0: Clock absence detector disabled on channel y
- 1: Clock absence detector enabled on channel y

Bit 5 **SCDEN**: Short-circuit detector enable on channel y
- 0: Input channel y will not be guarded by the short-circuit detector
- 1: Input channel y will be continuously guarded by the short-circuit detector

Bit 4 Reserved, must be kept at reset value.

Bits 3:2 **SPICKSEL[1:0]**: SPI clock select for channel y
- 0: clock coming from external CKINy input - sampling point according SITP[1:0]
- 1: clock coming from internal CKOUT output - sampling point according SITP[1:0]
- 2: clock coming from internal CKOUT - sampling point on each second CKOUT falling edge. For connection to external ΣΔ modulator which divides its clock input (from CKOUT) by 2 to generate its output serial communication clock (and this output clock change is active on each clock input rising edge).
- 3: clock coming from internal CKOUT output - sampling point on each second CKOUT rising edge. For connection to external ΣΔ modulator which divides its clock input (from CKOUT) by 2 to generate its output serial communication clock (and this output clock change is active on each clock input falling edge).

This value can be modified only when CHEN=0 (in DFSDM_CHyCFGR1 register).

Bits 1:0 **SITP[1:0]**: Serial interface type for channel y
- 00: SPI with rising edge to strobe data
- 01: SPI with falling edge to strobe data
- 10: Manchester coded input on DATINy pin: rising edge = logic 0, falling edge = logic 1
- 11: Manchester coded input on DATINy pin: rising edge = logic 1, falling edge = logic 0

This value can only be modified when CHEN=0 (in DFSDM_CHyCFGR1 register).

35.7.2 DFSDM channel y configuration register (DFSDM_CHyCFGR2)

This register specifies the parameters used by channel y.

Address offset: 0x04 + 0x20 * y, (y = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OFFSET[23:8]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OFFSET[7:0]								DTRBS[4:0]					Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw			

Bits 31:8 **OFFSET[23:0]**: 24-bit calibration offset for channel y
For channel y, OFFSET is applied to the results of each conversion from this channel.
This value is set by software.

Bits 7:3 **DTRBS[4:0]**: Data right bit-shift for channel y
0-31: Defines the shift of the data result coming from the integrator - how many bit shifts to the right will be performed to have final results. Bit-shift is performed before offset correction. The data shift is rounding the result to nearest integer value. The sign of shifted result is maintained (to have valid 24-bit signed format of result data).
This value can be modified only when CHEN=0 (in DFSDM_CHyCFGR1 register).

Bits 2:0 Reserved, must be kept at reset value.

35.7.3 DFSDM channel y analog watchdog and short-circuit detector register (DFSDM_CHyAWSCDR)

Short-circuit detector and analog watchdog settings for channel y.

Address offset: 0x08 + 0x20 * y, (y = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWFORD[1:0]		Res.	AWFOSR[4:0]				
								rw	rw		rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BKSCD[3:0]				Res.	Res.	Res.	Res.	SCDT[7:0]							
rw	rw	rw	rw					rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:22 **AWFORD[1:0]**: Analog watchdog Sinc filter order on channel y
0: FastSinc filter type
1: $Sinc^1$ filter type
2: $Sinc^2$ filter type
3: $Sinc^3$ filter type
$Sinc^x$ filter type transfer function:

$$H(z) = \left(\frac{1 - z^{-FOSR}}{1 - z^{-1}}\right)^x$$

FastSinc filter type transfer function:

$$H(z) = \left(\frac{1 - z^{-FOSR}}{1 - z^{-1}}\right)^2 \cdot (1 + z^{-(2 \cdot FOSR)})$$

This bit can be modified only when CHEN=0 (in DFSDM_CHyCFGR1 register).

Bit 21 Reserved, must be kept at reset value.

Bits 20:16 **AWFOSR[4:0]**: Analog watchdog filter oversampling ratio (decimation rate) on channel y
0 - 31: Defines the length of the Sinc type filter in the range 1 - 32 (AWFOSR + 1). This number is also the decimation ratio of the analog data rate.
This bit can be modified only when CHEN=0 (in DFSDM_CHyCFGR1 register).
Note: If AWFOSR = 0 then the filter has no effect (filter bypass).

Bits 15:12 **BKSCD[3:0]**: Break signal assignment for short-circuit detector on channel y
BKSCD[i] = 0: Break i signal not assigned to short-circuit detector on channel y
BKSCD[i] = 1: Break i signal assigned to short-circuit detector on channel y

Bits 11:8 Reserved, must be kept at reset value.

Bits 7:0 **SCDT[7:0]**: short-circuit detector threshold for channel y
These bits are written by software to define the threshold counter for the short-circuit detector. If this value is reached, then a short-circuit detector event occurs on a given channel.

35.7.4 DFSDM channel y watchdog filter data register (DFSDM_CHyWDATR)

This register contains the data resulting from the analog watchdog filter associated to the input channel y.

Address offset: 0x0C + 0x20 * y, (y = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WDATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **WDATA[15:0]**: Input channel y watchdog data
Data converted by the analog watchdog filter for input channel y. This data is continuously converted (no trigger) for this channel, with a limited resolution (OSR=1..32/sinc order = 1..3).

35.7.5 DFSDM channel y data input register (DFSDM_CHyDATINR)

This register contains 16-bit input data to be processed by DFSDM filter module. Write access can be either word access (32-bit) or half-word access (16-bit).

Address offset: 0x10 + 0x20 * y, (y = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
INDAT1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INDAT0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **INDAT1[15:0]**: Input data for channel y or channel y+1

Input parallel channel data to be processed by the digital filter if DATMPX[1:0]=1 or DATMPX[1:0]=2. Data can be written by CPU/DMA (if DATMPX[1:0]=2) or directly by internal ADC (if DATMPX[1:0]=1).

If DATPACK[1:0]=0 (standard mode)

INDAT0[15:0] is write protected (not used for input sample).

If DATPACK[1:0]=1 (interleaved mode)

Second channel y data sample is stored into INDAT1[15:0]. First channel y data sample is stored into INDAT0[15:0]. Both samples are read sequentially by DFSDM_FLTx filter as two channel y data samples.

If DATPACK[1:0]=2 (dual mode).

For even y channels: sample in INDAT1[15:0] is automatically copied into INDAT0[15:0] of channel (y+1).

For odd y channels: INDAT1[15:0] is write protected.

See *Section 35.4.6: Parallel data inputs* for more details.

INDAT0[15:1] is in the16-bit signed format.

Bits 15:0 **INDAT0[15:0]**: Input data for channel y

Input parallel channel data to be processed by the digital filter if DATMPX[1:0]=1 or DATMPX[1:0]=2. Data can be written by CPU/DMA (if DATMPX[1:0]=2) or directly by internal ADC (if DATMPX[1:0]=1).

If DATPACK[1:0]=0 (standard mode)

Channel y data sample is stored into INDAT0[15:0].

If DATPACK[1:0]=1 (interleaved mode)

First channel y data sample is stored into INDAT0[15:0]. Second channel y data sample is stored into INDAT1[15:0]. Both samples are read sequentially by DFSDM_FLTx filter as two channel y data samples.

If DATPACK[1:0]=2 (dual mode).

For even y channels: Channel y data sample is stored into INDAT0[15:0].

For odd y channels: INDAT0[15:0] is write protected.

See *Section 35.4.6: Parallel data inputs* for more details.

INDAT0[15:0] is in the16-bit signed format.

35.7.6 DFSDM channel y delay register (DFSDM_CHyDLYR)

Address offset: 0x14 + 0x20 * y, (y = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLSSKP[5:0]					
										rw	rw	rw	rw	rw	rw

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:0 **PLSSKP[5:0]**: Pulses to skip for input data skipping function

0-63: Defines the number of serial input samples that will be skipped. Skipping is applied immediately after writing to this field. Reading of PLSSKP[5:0] returns current value of pulses which will be skipped. If PLSSKP[5:0]=0 then all required data samples were already skipped.

Note: User can update PLSSKP[5:0] also when PLSSKP[5:0] is not zero.

35.8 DFSDM filter x module registers (x=0..3)

Word access (32-bit) must be used for registers write access except DFSDM_CHyDATINR register.

35.8.1 DFSDM filter x control register 1 (DFSDM_FLTxCR1)

Address offset: 0x100 + 0x80 * x, (x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	AWFSEL	FAST	Res.	Res.	RCH[2:0]			Res.	Res.	RDMAEN	Res.	RSYNC	RCONT	RSWSTART	Res.
	rw	rw			rw	rw	rw			rw		rw	rw	rt_w1	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	JEXTEN[1:0]		JEXTSEL[4:0]					Res.	Res.	JDMAEN	JSCAN	JSYNC	Res.	JSWSTART	DFEN
	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw		rt_w1	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **AWFSEL**: Analog watchdog fast mode select

0: Analog watchdog on data output value (after the digital filter). The comparison is done after offset correction and shift

1: Analog watchdog on channel transceivers value (after watchdog filter)

Bit 29 **FAST**: Fast conversion mode selection for regular conversions

0: Fast conversion mode disabled

1: Fast conversion mode enabled

When converting a regular conversion in continuous mode, having enabled the fast mode causes each conversion (except the first) to execute faster than in standard mode. This bit has no effect on conversions which are not continuous.

This bit can be modified only when DFEN=0 (DFSDM_FLTxCR1).

if FAST=0 (or first conversion in continuous mode if FAST=1):

$t = [F_{OSR} * (I_{OSR}\text{-}1 + F_{ORD}) + F_{ORD}] / f_{CKIN}$..... for $Sinc^x$ filters

$t = [F_{OSR} * (I_{OSR}\text{-}1 + 4) + 2] / f_{CKIN}$..... for FastSinc filter

if FAST=1 in continuous mode (except first conversion):

$t = [F_{OSR} * I_{OSR}] / f_{CKIN}$

in case if $F_{OSR} = F_{OSR}[9:0]+1 = 1$ (filter bypassed, active only integrator):

$t = I_{OSR} / f_{CKIN}$ (... but CNVCNT=0)

where: f_{CKIN} is the channel input clock frequency (on given channel CKINy pin) or input data rate in case of parallel data input.

Bits 28:27 Reserved, must be kept at reset value.

Bits 26:24 **RCH[2:0]**: Regular channel selection
0: Channel 0 is selected as the regular channel
1: Channel 1 is selected as the regular channel
...
7: Channel 7 is selected as the regular channel
Writing these bits when RCIP=1 takes effect when the next regular conversion begins. This is especially useful in continuous mode (when RCONT=1). It also affects regular conversions which are pending (due to ongoing injected conversion).

Bits 23:22 Reserved, must be kept at reset value.

Bit 21 **RDMAEN**: DMA channel enabled to read data for the regular conversion
0: The DMA channel is not enabled to read regular data
1: The DMA channel is enabled to read regular data
This bit can be modified only when DFEN=0 (DFSDM_FLTxCR1).

Bit 20 Reserved, must be kept at reset value.

Bit 19 **RSYNC**: Launch regular conversion synchronously with DFSDM_FLT0
0: Do not launch a regular conversion synchronously with DFSDM_FLT0
1: Launch a regular conversion in this DFSDM_FLTx at the very moment when a regular conversion is launched in DFSDM_FLT0
This bit can be modified only when DFEN=0 (DFSDM_FLTxCR1).

Bit 18 **RCONT**: Continuous mode selection for regular conversions
0: The regular channel is converted just once for each conversion request
1: The regular channel is converted repeatedly after each conversion request
Writing ‘0’ to this bit while a continuous regular conversion is already in progress stops the continuous mode immediately.

Bit 17 **RSWSTART**: Software start of a conversion on the regular channel
0: Writing ‘0’ has no effect
1: Writing ‘1’ makes a request to start a conversion on the regular channel and causes RCIP to become ‘1’. If RCIP=1 already, writing to RSWSTART has no effect. Writing ‘1’ has no effect if RSYNC=1.
This bit is always read as ‘0’.

Bits 16:15 Reserved, must be kept at reset value.

Bits 14:13 **JEXTEN[1:0]**: Trigger enable and trigger edge selection for injected conversions
00: Trigger detection is disabled
01: Each rising edge on the selected trigger makes a request to launch an injected conversion
10: Each falling edge on the selected trigger makes a request to launch an injected conversion
11: Both rising edges and falling edges on the selected trigger make requests to launch injected conversions
This bit can be modified only when DFEN=0 (DFSDM_FLTxCR1).

Bits 12:8 **JEXTSEL[4:0]**: Trigger signal selection for launching injected conversions

0x0-0x1F: Trigger inputs selected by the following table (internal or external trigger).

This bit can be modified only when DFEN=0 (DFSDM_FLTxCR1).

Note: synchronous trigger has latency up to one $f_{DFSDMCLK}$ clock cycle (with deterministic jitter), asynchronous trigger has latency 2-3 $f_{DFSDMCLK}$ clock cycles (with jitter up to 1 cycle).

	DFSDM_FLTx
0x00	dfsdm_jtrg0
0x01	dfsdm_jtrg1
...	
0x1E	dfsdm_jtrg30
0x1F	dfsdm_jtrg31

Refer to *Table 287: DFSDM triggers connection*.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **JDMAEN**: DMA channel enabled to read data for the injected channel group

0: The DMA channel is not enabled to read injected data

1: The DMA channel is enabled to read injected data

This bit can be modified only when DFEN=0 (DFSDM_FLTxCR1).

Bit 4 **JSCAN**: Scanning conversion mode for injected conversions

0: One channel conversion is performed from the injected channel group and next the selected channel from this group is selected.

1: The series of conversions for the injected group channels is executed, starting over with the lowest selected channel.

This bit can be modified only when DFEN=0 (DFSDM_FLTxCR1).

Writing JCHG if JSCAN=0 resets the channel selection to the lowest selected channel.

Bit 3 **JSYNC**: Launch an injected conversion synchronously with the DFSDM_FLT0 JSWSTART trigger

0: Do not launch an injected conversion synchronously with DFSDM_FLT0

1: Launch an injected conversion in this DFSDM_FLTx at the very moment when an injected conversion is launched in DFSDM_FLT0 by its JSWSTART trigger

This bit can be modified only when DFEN=0 (DFSDM_FLTxCR1).

Bit 2 Reserved, must be kept at reset value.

Bit 1 **JSWSTART**: Start a conversion of the injected group of channels

0: Writing ‘0’ has no effect.

1: Writing ‘1’ makes a request to convert the channels in the injected conversion group, causing JCIP to become ‘1’ at the same time. If JCIP=1 already, then writing to JSWSTART has no effect. Writing ‘1’ has no effect if JSYNC=1.

This bit is always read as ‘0’.

Bit 0 **DFEN**: DFSDM_FLTx enable

0: DFSDM_FLTx is disabled. All conversions of given DFSDM_FLTx are stopped immediately and all DFSDM_FLTx functions are stopped.

1: DFSDM_FLTx is enabled. If DFSDM_FLTx is enabled, then DFSDM_FLTx starts operating according to its setting.

Data which are cleared by setting DFEN=0:

–register DFSDM_FLTxISR is set to the reset state

–register DFSDM_FLTxAWSR is set to the reset state

35.8.2 DFSDM filter x control register 2 (DFSDM_FLTxCR2)

Address offset: 0x104 + 0x80 * x, (x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWDCH[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXCH[7:0]								Res.	CKABIE	SCDIE	AWDIE	ROVRIE	JOVRIE	REOCIE	JEOCIE
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **AWDCH[7:0]**: Analog watchdog channel selection
These bits select the input channel to be guarded continuously by the analog watchdog.
AWDCH[y] = 0: Analog watchdog is disabled on channel y
AWDCH[y] = 1: Analog watchdog is enabled on channel y

Bits 15:8 **EXCH[7:0]**: Extremes detector channel selection
These bits select the input channels to be taken by the Extremes detector.
EXCH[y] = 0: Extremes detector does not accept data from channel y
EXCH[y] = 1: Extremes detector accepts data from channel y

Bit 7 Reserved, must be kept at reset value.

Bit 6 **CKABIE**: Clock absence interrupt enable
0: Detection of channel input clock absence interrupt is disabled
1: Detection of channel input clock absence interrupt is enabled
Please see the explanation of CKABF[7:0] in DFSDM_FLTxISR.
Note: CKABIE is present only in DFSDM_FLT0CR2 register (filter x=0)

Bit 5 **SCDIE**: Short-circuit detector interrupt enable
0: short-circuit detector interrupt is disabled
1: short-circuit detector interrupt is enabled
Please see the explanation of SCDF[7:0] in DFSDM_FLTxISR.
Note: SCDIE is present only in DFSDM_FLT0CR2 register (filter x=0)

Bit 4 **AWDIE**: Analog watchdog interrupt enable
0: Analog watchdog interrupt is disabled
1: Analog watchdog interrupt is enabled
Please see the explanation of AWDF in DFSDM_FLTxISR.

Bit 3 **ROVRIE**: Regular data overrun interrupt enable
0: Regular data overrun interrupt is disabled
1: Regular data overrun interrupt is enabled
Please see the explanation of ROVRF in DFSDM_FLTxISR.

Bit 2 **JOVRIE**: Injected data overrun interrupt enable
0: Injected data overrun interrupt is disabled
1: Injected data overrun interrupt is enabled
Please see the explanation of JOVRF in DFSDM_FLTxISR.

Bit 1 **REOCIE**: Regular end of conversion interrupt enable
0: Regular end of conversion interrupt is disabled
1: Regular end of conversion interrupt is enabled
Please see the explanation of REOCF in DFSDM_FLTxISR.

Bit 0 **JEOCIE**: Injected end of conversion interrupt enable
0: Injected end of conversion interrupt is disabled
1: Injected end of conversion interrupt is enabled
Please see the explanation of JEOCF in DFSDM_FLTxISR.

35.8.3 DFSDM filter x interrupt and status register (DFSDM_FLTxISR)

Address offset: 0x108 + 0x80 * x, (x = 0 to 3)

Reset value: 0x00FF 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SCDF[7:0]								CKABF[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	RCIP	JCIP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWDF	ROVRF	JOVRF	REOCF	JEOCF
	r	r									r	r	r	r	r

Bits 31:24 **SCDF[7:0]**: short-circuit detector flag
SDCF[y]=0: No short-circuit detector event occurred on channel y
SDCF[y]=1: The short-circuit detector counter reaches, on channel y, the value programmed in the DFSDM_CHyAWSCDR registers
This bit is set by hardware. It can be cleared by software using the corresponding CLRSCDF[y] bit in the DFSDM_FLTxICR register. SCDF[y] is cleared also by hardware when CHEN[y] = 0 (given channel is disabled).
Note: SCDF[7:0] is present only in DFSDM_FLT0ISR register (filter x=0)

Bits 23:16 **CKABF[7:0]**: Clock absence flag
CKABF[y]=0: Clock signal on channel y is present.
CKABF[y]=1: Clock signal on channel y is not present.
Given y bit is set by hardware when clock absence is detected on channel y. It is held at CKABF[y]=1 state by hardware when CHEN=0 (see DFSDM_CHyCFGR1 register). It is held at CKABF[y]=1 state by hardware when the transceiver is not yet synchronized.It can be cleared by software using the corresponding CLRCKABF[y] bit in the DFSDM_FLTxICR register.
Note: CKABF[7:0] is present only in DFSDM_FLT0ISR register (filter x=0)

Bit 15 Reserved, must be kept at reset value.

Bit 14 **RCIP**: Regular conversion in progress status
0: No request to convert the regular channel has been issued
1: The conversion of the regular channel is in progress or a request for a regular conversion is pending
A request to start a regular conversion is ignored when RCIP=1.

Bit 13 **JCIP**: Injected conversion in progress status

0: No request to convert the injected channel group (neither by software nor by trigger) has been issued

1: The conversion of the injected channel group is in progress or a request for a injected conversion is pending, due either to ‘1’ being written to JSWSTART or to a trigger detection

A request to start an injected conversion is ignored when JCIP=1.

Bits 12:5 Reserved, must be kept at reset value.

Bit 4 **AWDF**: Analog watchdog

0: No Analog watchdog event occurred

1: The analog watchdog block detected voltage which crosses the value programmed in the DFSDM_FLTxAWLTR or DFSDM_FLTxAWHTR registers.

This bit is set by hardware. It is cleared by software by clearing all source flag bits AWHTF[7:0] and AWLTF[7:0] in DFSDM_FLTxAWSR register (by writing ‘1’ into the clear bits in DFSDM_FLTxAWCFR register).

Bit 3 **ROVRF**: Regular conversion overrun flag

0: No regular conversion overrun has occurred

1: A regular conversion overrun has occurred, which means that a regular conversion finished while REOCF was already ‘1’. RDATAR is not affected by overruns

This bit is set by hardware. It can be cleared by software using the CLRROVRF bit in the DFSDM_FLTxICR register.

Bit 2 **JOVRF**: Injected conversion overrun flag

0: No injected conversion overrun has occurred

1: An injected conversion overrun has occurred, which means that an injected conversion finished while JEOCF was already ‘1’. JDATAR is not affected by overruns

This bit is set by hardware. It can be cleared by software using the CLRJOVRF bit in the DFSDM_FLTxICR register.

Bit 1 **REOCF**: End of regular conversion flag

0: No regular conversion has completed

1: A regular conversion has completed and its data may be read

This bit is set by hardware. It is cleared when the software or DMA reads DFSDM_FLTxRDATAR.

Bit 0 **JEOCF**: End of injected conversion flag

0: No injected conversion has completed

1: An injected conversion has completed and its data may be read

This bit is set by hardware. It is cleared when the software or DMA reads DFSDM_FLTxJDATAR.

Note: For each of the flag bits, an interrupt can be enabled by setting the corresponding bit in DFSDM_FLTxCR2. If an interrupt is called, the flag must be cleared before exiting the interrupt service routine.

All the bits of DFSDM_FLTxISR are automatically reset when DFEN=0.

35.8.4 DFSDM filter x interrupt flag clear register (DFSDM_FLTxICR)

Address offset: 0x10C + 0x80 * x, (x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CLRSCDF[7:0]								CLRCKABF[7:0]							
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLRROVRF	CLRJOVRF	Res.	Res.
												rc_w1	rc_w1		

Bits 31:24 **CLRSCDF[7:0]**: Clear the short-circuit detector flag

CLRSCDF[y]=0: Writing ‘0’ has no effect

CLRSCDF[y]=1: Writing ‘1’ to position y clears the corresponding SCDF[y] bit in the DFSDM_FLTxISR register

Note: CLRSCDF[7:0] is present only in DFSDM_FLT0ICR register (filter x=0)

Bits 23:16 **CLRCKABF[7:0]**: Clear the clock absence flag

CLRCKABF[y]=0: Writing ‘0’ has no effect

CLRCKABF[y]=1: Writing ‘1’ to position y clears the corresponding CKABF[y] bit in the DFSDM_FLTxISR register. When the transceiver is not yet synchronized, the clock absence flag is set and cannot be cleared by CLRCKABF[y].

Note: CLRCKABF[7:0] is present only in DFSDM_FLT0ICR register (filter x=0)

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **CLRROVRF**: Clear the regular conversion overrun flag

0: Writing ‘0’ has no effect

1: Writing ‘1’ clears the ROVRF bit in the DFSDM_FLTxISR register

Bit 2 **CLRJOVRF**: Clear the injected conversion overrun flag

0: Writing ‘0’ has no effect

1: Writing ‘1’ clears the JOVRF bit in the DFSDM_FLTxISR register

Bits 1:0 Reserved, must be kept at reset value.

Note: The bits of DFSDM_FLTxICR are always read as ‘0’.

35.8.5 DFSDM filter x injected channel group selection register (DFSDM_FLTxJCHGR)

Address offset: 0x110 + 0x80 * x, (x = 0 to 3)

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JCHG[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **JCHG[7:0]**: Injected channel group selection

JCHG[y]=0: channel y is not part of the injected group

JCHG[y]=1: channel y is part of the injected group

If JSCAN=1, each of the selected channels is converted, one after another. The lowest channel (channel 0, if selected) is converted first and the sequence ends at the highest selected channel.

If JSCAN=0, then only one channel is converted from the selected channels, and the channel selection is moved to the next channel. Writing JCHG, if JSCAN=0, resets the channel selection to the lowest selected channel.

At least one channel must always be selected for the injected group. Writes causing all JCHG bits to be zero are ignored.

35.8.6 DFSDM filter x control register (DFSDM_FLTxFCR)

Address offset: 0x114 + 0x80 * x, (x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FORD[2:0]			Res.	Res.	Res.	FOSR[9:0]									
rw	rw	rw				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IOSR[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 **FORD[2:0]**: Sinc filter order

0: FastSinc filter type
1: $Sinc^1$ filter type
2: $Sinc^2$ filter type
3: $Sinc^3$ filter type
4: $Sinc^4$ filter type
5: $Sinc^5$ filter type
6-7: Reserved

$Sinc^x$ filter type transfer function: $$H(z) = \left(\frac{1 - z^{-FOSR}}{1 - z^{-1}}\right)^x$$

FastSinc filter type transfer function: $$H(z) = \left(\frac{1 - z^{-FOSR}}{1 - z^{-1}}\right)^2 \cdot (1 + z^{-(2 \cdot FOSR)})$$

This bit can only be modified when DFEN=0 (DFSDM_FLTxCR1).

Bits 28:26 Reserved, must be kept at reset value.

Bits 25:16 **FOSR[9:0]**: Sinc filter oversampling ratio (decimation rate)

0 - 1023: Defines the length of the Sinc type filter in the range 1 - 1024 (F_{OSR} = FOSR[9:0] +1). This number is also the decimation ratio of the output data rate from filter.
This bit can only be modified when DFEN=0 (DFSDM_FLTxCR1)

Note: If FOSR = 0, then the filter has no effect (filter bypass).

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **IOSR[7:0]**: Integrator oversampling ratio (averaging length)

0- 255: The length of the Integrator in the range 1 - 256 (IOSR + 1). Defines how many samples from Sinc filter will be summed into one output data sample from the integrator. The output data rate from the integrator will be decreased by this number (additional data decimation ratio).
This bit can only be modified when DFEN=0 (DFSDM_FLTxCR1)

Note: If IOSR = 0, then the Integrator has no effect (Integrator bypass).

35.8.7 DFSDM filter x data register for injected group (DFSDM_FLTxJDATAR)

Address offset: 0x118 + 0x80 * x, (x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
JDATA[23:8]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
JDATA[7:0]								Res.	Res.	Res.	Res.	Res.	JDATACH[2:0]		
r	r	r	r	r	r	r	r						r	r	r

Bits 31:8 **JDATA[23:0]**: Injected group conversion data
When each conversion of a channel in the injected group finishes, its resulting data is stored in this field. The data is valid when JEOCF=1. Reading this register clears the corresponding JEOCF.

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **JDATACH[2:0]**: Injected channel most recently converted
When each conversion of a channel in the injected group finishes, JDATACH[2:0] is updated to indicate which channel was converted. Thus, JDATA[23:0] holds the data that corresponds to the channel indicated by JDATACH[2:0].

Note: DMA may be used to read the data from this register. Half-word accesses may be used to read only the MSBs of conversion data.

Reading this register also clears JEOCF in DFSDM_FLTxISR. Thus, the firmware must not read this register if DMA is activated to read data from this register.

35.8.8 DFSDM filter x data register for the regular channel (DFSDM_FLTxRDATAR)

Address offset: 0x11C + 0x80 * x, (x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RDATA[23:8]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDATA[7:0]								Res.	Res.	Res.	RPEND	Res.	RDATACH[2:0]		
r	r	r	r	r	r	r	r				r		r	r	r

Bits 31:8 **RDATA[23:0]**: Regular channel conversion data
When each regular conversion finishes, its data is stored in this register. The data is valid when REOCF=1. Reading this register clears the corresponding REOCF.

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **RPEND**: Regular channel pending data
Regular data in RDATA[23:0] was delayed due to an injected channel trigger during the conversion

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **RDATACH[2:0]**: Regular channel most recently converted
When each regular conversion finishes, RDATACH[2:0] is updated to indicate which channel was converted (because regular channel selection RCH[2:0] in DFSDM_FLTxCR1 register can be updated during regular conversion). Thus RDATA[23:0] holds the data that corresponds to the channel indicated by RDATACH[2:0].

Note: Half-word accesses may be used to read only the MSBs of conversion data.

Reading this register also clears REOCF in DFSDM_FLTxISR.

35.8.9 DFSDM filter x analog watchdog high threshold register (DFSDM_FLTxAWHTR)

Address offset: 0x120 + 0x80 * x, (x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AWHT[23:8]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AWHT[7:0]								Res.	Res.	Res.	Res.	BKAWH[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:8 **AWHT[23:0]**: Analog watchdog high threshold

These bits are written by software to define the high threshold for the analog watchdog.

Note: In case channel transceivers monitor (AWFSEL=1), the higher 16 bits (AWHT[23:8]) define the 16-bit threshold as compared with the analog watchdog filter output (because data coming from the analog watchdog filter are up to a 16-bit resolution). Bits AWHT[7:0] are not taken into comparison in this case.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **BKAWH[3:0]**: Break signal assignment to analog watchdog high threshold event

BKAWH[i] = 0: Break i signal is not assigned to an analog watchdog high threshold event

BKAWH[i] = 1: Break i signal is assigned to an analog watchdog high threshold event

35.8.10 DFSDM filter x analog watchdog low threshold register (DFSDM_FLTxAWLTR)

Address offset: 0x124 + 0x80 * x, (x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AWLT[23:8]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AWLT[7:0]								Res.	Res.	Res.	Res.	BKAWL[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:8 **AWLT[23:0]**: Analog watchdog low threshold

These bits are written by software to define the low threshold for the analog watchdog.

Note: In case channel transceivers monitor (AWFSEL=1), only the higher 16 bits (AWLT[23:8]) define the 16-bit threshold as compared with the analog watchdog filter output (because data coming from the analog watchdog filter are up to a 16-bit resolution). Bits AWLT[7:0] are not taken into comparison in this case.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **BKAWL[3:0]**: Break signal assignment to analog watchdog low threshold event

BKAWL[i] = 0: Break i signal is not assigned to an analog watchdog low threshold event

BKAWL[i] = 1: Break i signal is assigned to an analog watchdog low threshold event

35.8.11 DFSDM filter x analog watchdog status register (DFSDM_FLTxAWSR)

Address offset: 0x128 + 0x80 * x, (x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AWHTF[7:0]								AWLTF[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **AWHTF[7:0]**: Analog watchdog high threshold flag

AWHTF[y]=1 indicates a high threshold error on channel y. It is set by hardware. It can be cleared by software using the corresponding CLRAWHTF[y] bit in the DFSDM_FLTxAWCFR register.

Bits 7:0 **AWLTF[7:0]**: Analog watchdog low threshold flag

AWLTF[y]=1 indicates a low threshold error on channel y. It is set by hardware. It can be cleared by software using the corresponding CLRAWLTF[y] bit in the DFSDM_FLTxAWCFR register.

Note: All the bits of DFSDM_FLTxAWSR are automatically reset when DFEN=0.

35.8.12 DFSDM filter x analog watchdog clear flag register (DFSDM_FLTxAWCFR)

Address offset: 0x12C + 0x80 * x, (x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CLRAWHTF[7:0]								CLRAWLTF[7:0]							
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **CLRAWHTF[7:0]**: Clear the analog watchdog high threshold flag

CLRAWHTF[y]=0: Writing ‘0’ has no effect

CLRAWHTF[y]=1: Writing ‘1’ to position y clears the corresponding AWHTF[y] bit in the DFSDM_FLTxAWSR register

Bits 7:0 **CLRAWLTF[7:0]**: Clear the analog watchdog low threshold flag

CLRAWLTF[y]=0: Writing ‘0’ has no effect

CLRAWLTF[y]=1: Writing ‘1’ to position y clears the corresponding AWLTF[y] bit in the DFSDM_FLTxAWSR register

35.8.13 DFSDM filter x extremes detector maximum register (DFSDM_FLTxEXMAX)

Address offset: 0x130 + 0x80 * x, (x = 0 to 3)

Reset value: 0x8000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EXMAX[23:8]															
rs_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXMAX[7:0]								Res.	Res.	Res.	Res.	Res.	EXMAXCH[2:0]		
rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r						r	r	r

Bits 31:8 **EXMAX[23:0]**: Extremes detector maximum value

These bits are set by hardware and indicate the highest value converted by DFSDM_FLTx. EXMAX[23:0] bits are reset to value (0x800000) by reading of this register.

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **EXMAXCH[2:0]**: Extremes detector maximum data channel.

These bits contains information about the channel on which the data is stored into EXMAX[23:0]. Bits are cleared by reading of this register.

35.8.14 DFSDM filter x extremes detector minimum register (DFSDM_FLTxEXMIN)

Address offset: 0x134 + 0x80 * x, (x = 0 to 3)

Reset value: 0x7FFF FF00

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EXMIN[23:8]															
rc_r	rs_r	rs_r	rs_r	rs_r	rs_r	rs_r	rs_r	rs_r	rs_r	rs_r	rs_r	rs_r	rs_r	rs_r	rs_r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXMIN[7:0]								Res.	Res.	Res.	Res.	Res.	EXMINCH[2:0]		
rs_r	rs_r	rs_r	rs_r	rs_r	rs_r	rs_r	rs_r						r	r	r

Bits 31:8 **EXMIN[23:0]**: Extremes detector minimum value

These bits are set by hardware and indicate the lowest value converted by DFSDM_FLTx. EXMIN[23:0] bits are reset to value (0x7FFFFF) by reading of this register.

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **EXMINCH[2:0]**: Extremes detector minimum data channel

These bits contain information about the channel on which the data is stored into EXMIN[23:0]. Bits are cleared by reading of this register.

35.8.15 DFSDM filter x conversion timer register (DFSDM_FLTxCNVTIMR)

Address offset: 0x138 + 0x80 * x, (x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CNVCNT[27:12]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNVCNT[11:0]												Res.	Res.	Res.	Res.
r	r	r	r	r	r	r	r	r	r	r	r				

Bits 31:4 **CNVCNT[27:0]**: 28-bit timer counting conversion time t = CNVCNT[27:0] / $f_{DFSDMCLK}$

The timer has an input clock from DFSDM clock (system clock $f_{DFSDMCLK}$). Conversion time measurement is started on each conversion start and stopped when conversion finishes (interval between first and last serial sample). Only in case of filter bypass (FOSR[9:0] = 0) is the conversion time measurement stopped and CNVCNT[27:0] = 0. The counted time is:

if FAST=0 (or first conversion in continuous mode if FAST=1):

$t = [F_{OSR} * (I_{OSR}-1 + F_{ORD}) + F_{ORD}] / f_{CKIN}$..... for $Sinc^x$ filters

$t = [F_{OSR} * (I_{OSR}-1 + 4) + 2] / f_{CKIN}$..... for FastSinc filter

if FAST=1 in continuous mode (except first conversion):

$t = [F_{OSR} * I_{OSR}] / f_{CKIN}$

in case if F_{OSR} = FOSR[9:0]+1 = 1 (filter bypassed, active only integrator):

CNVCNT = 0 (counting is stopped, conversion time: $t = I_{OSR} / f_{CKIN}$)

where: f_{CKIN} is the channel input clock frequency (on given channel CKINy pin) or input data rate in case of parallel data input (from internal ADC or from CPU/DMA write)

Note: When conversion is interrupted (e.g. by disable/enable selected channel) the timer counts also this interruption time.

Bits 3:0 Reserved, must be kept at reset value.

35.8.16 DFSDM register map

The following table summarizes the DFSDM registers.

Table 292. DFSDM register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**DFSDM_CH0CFGR1**	DFSDMEN	CKOUTSRC	Res.	Res.	Res.	Res.	Res.	Res.	CKOUTDIV[7:0]								DATPACK[1:0]		DATMPX[1:0]		Res.	Res.	Res.	CHINSEL	CHEN	CKABEN	SCDEN	Res.	SPICKSEL[1:0]		SITP[1:0]	
	reset value	0	0							0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0		0	0	0	0
0x04	**DFSDM_CH0CFGR2**	OFFSET[23:0]																								DTRBS[4:0]					Res.	Res.	Res.
	reset value	0																								0							
0x08	**DFSDM_CH0AWSCDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWFORD[1:0]	Res.	AWFOSR[4:0]						BKSCD[3:0]				Res.	Res.	Res.	Res.	SCDT[7:0]							
	reset value									0	0		0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0
0x0C	**DFSDM_CH0WDATR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDATA[15:0]															
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	**DFSDM_CH0DATINR**	INDAT1[15:0]																INDAT0[15:0]															
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	**DFSDM_CH0DLYR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLSSKP[5:0]					
	reset value																											0	0	0	0	0	0
0x18 - 0x1C	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Table 292. DFSDM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x20	**DFSDM_CH1CFGR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATPACK[1:0]		DATMPX[1:0]		Res.	Res.	Res.	CHINSEL	CHEN	CKABEN	SCDEN	Res.	SPICKSEL[1:0]		SITP[1:0]	
	reset value																	0	0	0	0				0	0	0	0		0	0	0	0
0x24	**DFSDM_CH1CFGR2**	OFFSET[23:0]																								DTRBS[4:0]					Res.	Res.	Res.
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x28	**DFSDM_CH1AWSCDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWFORD[1:0]		Res.	AWFOSR[4:0]					BKSCD[3:0]				Res.	Res.	Res.	Res.	SCDT[7:0]							
	reset value									0	0		0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0
0x2C	**DFSDM_CH1WDATR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	WDATA[15:0]															
	reset value																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x30	**DFSDM_CH1DATINR**	INDAT1[15:0]																INDAT0[15:0]															
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x34	**DFSDM_CH1DLYR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	PLSSKP[5:0]					
	reset value																											0	0	0	0	0	0
0x38 - 0x3C	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x40	**DFSDM_CH2CFGR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATPACK[1:0]		DATMPX[1:0]		Res.	Res.	Res.	CHINSEL	CHEN	CKABEN	SCDEN	Res.	SPICKSEL[1:0]		SITP[1:0]	
	reset value																	0	0	0	0				0	0	0	0		0	0	0	0
0x44	**DFSDM_CH2CFGR2**	OFFSET[23:0]																								DTRBS[4:0]					Res.	Res.	Res.
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x48	**DFSDM_CH2AWSCDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWFORD[1:0]		Res.	AWFOSR[4:0]					BKSCD[3:0]				Res.	Res.	Res.	Res.	SCDT[7:0]							
	reset value									0	0		0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0
0x4C	**DFSDM_CH2WDATR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	WDATA[15:0]															
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x50	**DFSDM_CH2DATINR**	INDAT1[15:0]																INDAT0[15:0]															
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x54	**DFSDM_CH2DLYR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	PLSSKP[5:0]					
	reset value																											0	0	0	0	0	0
0x58 - 0x5C	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Table 292. DFSDM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x60	**DFSDM_ CH3CFGR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATPACK[1:0]		DATMPX[1:0]		Res.	Res.	Res.	CHINSEL	CHEN	CKABEN	SCDEN	Res.	SPICKSEL[1:0]		SITP[1:0]	
	reset value																	0	0	0	0				0	0	0	0		0	0	0	0
0x64	**DFSDM_ CH3CFGR2**	OFFSET[23:0]																								DTRBS[4:0]					Res.	Res.	Res.
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x68	**DFSDM_ CH3AWSCDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWFORD[1:0]		Res.	AWFOSR[4:0]					BKSCD[3:0]				Res.	Res.	Res.	Res.	SCDT[7:0]							
	reset value									0	0		0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0
0x6C	**DFSDM_ CH3WDATR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDATA[15:0]															
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x70	**DFSDM_ CH3DATINR**	INDAT1[15:0]																INDAT0[15:0]															
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x74	**DFSDM_ CH3DLYR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLSSKP[5:0]					
	reset value																											0	0	0	0	0	0
0x78 - 0x	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x80	**DFSDM_ CH4CFGR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATPACK[1:0]		DATMPX[1:0]		Res.	Res.	Res.	CHINSEL	CHEN	CKABEN	SCDEN	Res.	SPICKSEL[1:0]		SITP[1:0]	
	reset value																	0	0	0	0				0	0	0	0		0	0	0	0
0x84	**DFSDM_ CH4CFGR2**	OFFSET[23:0]																								DTRBS[4:0]					Res.	Res.	Res.
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x88	**DFSDM_ CH4AWSCDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWFORD[1:0]		Res.	AWFOSR[4:0]					BKSCD[3:0]				Res.	Res.	Res.	Res.	SCDT[7:0]							
	reset value									0	0		0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0
0x8C	**DFSDM_ CH4WDATR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDATA[15:0]															
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x90	**DFSDM_ CH4DATINR**	INDAT1[15:0]																INDAT0[15:0]															
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x94	**DFSDM_ CH4DLYR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLSSKP[5:0]					
	reset value																											0	0	0	0	0	0
0x98 - 0x9C	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Table 292. DFSDM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xA0	**DFSDM_ CH5CFGR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATPACK[1:0]		DATMPX[1:0]		Res.	Res.	Res.	CHINSEL	CHEN	CKABEN	SCDEN	Res.	SPICKSEL[1:0]		SITP[1:0]	
	reset value																	0	0	0	0				0	0	0	0		0	0	0	0
0xA4	**DFSDM_ CH5CFGR2**	OFFSET[23:0]																								DTRBS[4:0]					Res.	Res.	Res.
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0xA8	**DFSDM_ CH5AWSCDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWFORD[1:0]		Res.	AWFOSR[4:0]					BKSCD[3:0]				Res.	Res.	Res.	Res.	SCDT[7:0]							
	reset value									0	0		0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0
0xAC	**DFSDM_ CH5WDATR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.			Res.	Res.	Res.	Res.	Res.	Res.	WDATA[15:0]															
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xB0	**DFSDM_ CH5DATINR**	INDAT1[15:0]																INDAT0[15:0]															
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xB4	**DFSDM_ CH5DLYR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLSSKP[5:0]					
	reset value																											0	0	0	0	0	0
0xB8 - 0xBC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0xC0	**DFSDM_ CH6CFGR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATPACK[1:0]		DATMPX[1:0]		Res.	Res.	Res.	CHINSEL	CHEN	CKABEN	SCDEN	Res.	SPICKSEL[1:0]		SITP[1:0]	
	reset value																	0	0	0	0				0	0	0	0		0	0	0	0
0xC4	**DFSDM_ CH6CFGR2**	OFFSET[23:0]																								DTRBS[4:0]					Res	Res	Res
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0xC8	**DFSDM_ CH6AWSCDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWFORD[1:0]		Res.	AWFOSR[4:0]					BKSCD[3:0]				Res.	Res.	Res.	Res.	SCDT[7:0]							
	reset value									0	0		0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0
0xCC	**DFSDM_ CH6WDATR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDATA[15:0]															
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xD0	**DFSDM_ CH6DATINR**	INDAT1[15:0]																INDAT0[15:0]															
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xD4	**DFSDM_ CH6DLYR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLSSKP[5:0]					
	reset value																											0	0	0	0	0	0
0xD8 - 0xDC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Table 292. DFSDM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xE0	**DFSDM_ CH7CFGR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATPACK[1:0]		DATMPX[1:0]		Res.	Res.	Res.	CHINSEL	CHEN	CKABEN	SCDEN	Res.	SPICKSEL[1:0]		SITP[1:0]	
	reset value																	0	0	0	0				0	0	0	0		0	0	0	0
0xE4	**DFSDM_ CH7CFGR2**	OFFSET[23:0]																								DTRBS[4:0]					Res.	Res.	Res.
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0xE8	**DFSDM_ CH7AWSCDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWFORD[1:0]		Res.	AWFOSR[4:0]					BKSCD[3:0]				Res.	Res.	Res.	Res.	SCDT[7:0]							
	reset value									0	0		0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0
0xEC	**DFSDM_ CH7WDATR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDATA[15:0]															
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xF0	**DFSDM_ CH7DATINR**	INDAT1[15:0]																INDAT0[15:0]															
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xF4	**DFSDM_ CH7DLYR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PLSSKP[5:0]					
	reset value																											0	0	0	0	0	0
0xF8 - 0xFC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x100	**DFSDM_ FLT0CR1**	Res.	AWFSEL	FAST	Res.	Res.	RCH[2:0]			Res.	Res.	RDMAEN	Res.	RSYNC	RCONT	RSW START	Res.	Res.	JEXTEN[1:0]		JEXTSEL[4:0]					Res.	Res.	JDMAEN	JSCAN	JSYNC	Res.	JSW START	DFEN
	reset value		0	0			0	0	0			0		0	0	0			0	0	0	0	0	0	0			0	0	0		0	0
0x104	**DFSDM_ FLT0CR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWDCH[7:0]								EXCH[7:0]								Res.	CKABIE	SCDIE	AWDIE	ROVRIE	JOVRIE	REOCIE	JEOCIE
	reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
0x108	**DFSDM_ FLT0ISR**	SCDF[7:0]								CKABF[7:0]								Res.	RCIP	JCIP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWDF	ROVRF	JOVRF	REOCF	JEOCF
	reset value	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1		0	0									0	0	0	0	0
0x10C	**DFSDM_ FLT0ICR**	CLRSCDF[7:0]								CLRCKABF[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLR ROVRF	CLR JOVRF	Res.	Res.
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0													0	0		
0x110	**DFSDM_ FLT0JCHGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JCHG[7:0]							
	reset value																									0	0	0	0	0	0	0	1
0x114	**DFSDM_ FLT0FCR**	FORD[2:0]			Res.	Res.	Res.	FOSR[9:0]										Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IOSR[7:0]							
	reset value	0	0	0				0	0	0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0

Table 292. DFSDM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x118	**DFSDM_FLT0JDATAR**	JDATA[23:0]																								Res.	Res.	Res.	Res.	Res.	JDATACH [2:0]		
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						0	0	0
0x11C	**DFSDM_FLT0RDATAR**	RDATA[23:0]																								Res.	Res.	Res.	RPEND	Res.	RDATACH[2:0]		
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0		0	0	0
0x120	**DFSDM_FLT0AWHTR**	AWHT[23:0]																								Res.	Res.	Res.	Res.	BKAWH[3:0]			
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0
0x124	**DFSDM_FLT0AWLTR**	AWLT[23:0]																								Res.	Res.	Res.	Res.	BKAWL[3:0]			
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0
0x128	**DFSDM_FLT0AWSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWHTF[7:0]								AWLTF[7:0]							
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x12C	**DFSDM_FLT0AWCFR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLRAWHTF[7:0]								CLRAWLTF[7:0]							
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x130	**DFSDM_FLT0EXMAX**	EXMAX[23:0]																								Res.	Res.	Res.	Res.	Res.	EXMAXCH[2:0]		
	reset value	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						0	0	0
0x134	**DFSDM_FLT0EXMIN**	EXMIN[23:0]																								Res.	Res.	Res.	Res.	Res.	EXMINCH[2:0]		
	reset value	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						0	0	0
0x138	**DFSDM_FLT0CNVTIMR**	CNVCNT[27:0]																												Res.	Res.	Res.	Res.
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x13C - 0x17C	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x180	**DFSDM_FLT1CR1**	Res.	AWFSEL	FAST	Res.	Res.	RCH[2:0]			Res.	Res.	RDMAEN	Res.	RSYNC	RCONT	RSW START	Res.	Res.	JEXTEN[1:0]		JEXTSEL[4:0]					Res.	Res.	JDMAEN	JSCAN	JSYNC	Res.	JSW START	DFEN
	reset value		0	0			0	0	0			0		0	0	0			0	0	0	0	0	0	0			0	0	0		0	0
0x184	**DFSDM_FLT1CR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWDCH[7:0]								EXCH[7:0]								Res.	Res.	Res.	AWDIE	ROVRIE	JOVRIE	REOCIE	JEOCIE
	reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0
0x188	**DFSDM_FLT1ISR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RCIP	JCIP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWDF	ROVRF	JOVRF	REOCF	JEOCF
	reset value																		0	0									0	0	0	0	0

Table 292. DFSDM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x18C	**DFSDM_FLT1ICR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLR ROVRF	CLR JOVRF	Res.	Res.
	reset value																													0	0		
0x190	**DFSDM_FLT1JCHGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JCHG[7:0]							
	reset value																									0	0	0	0	0	0	0	1
0x194	**DFSDM_FLT1FCR**	FORD[2:0]			Res.	Res.	Res.	FOSR[9:0]										Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IOSR[7:0]							
	reset value	0	0	0				0	0	0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0
0x198	**DFSDM_FLT1JDATAR**	JDATA[23:0]																								Res.	Res.	Res.	Res.	Res.	JDATACH[2:0]		
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						0	0	0
0x19C	**DFSDM_FLT1RDATAR**	RDATA[23:0]																								Res.	Res.	Res.	RPEND	Res.	RDATACH[2:0]		
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0		0	0	0
0x1A0	**DFSDM_FLT1AWHTR**	AWHT[23:0]																								Res.	Res.	Res.	Res.	BKAWH[3:0]			
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0
0x1A4	**DFSDM_FLT1AWLTR**	AWLT[23:0]																								Res.	Res.	Res.	Res.	BKAWL[3:0]			
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0
0x1A8	**DFSDM_FLT1AWSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWHTF[7:0]								AWLTF[7:0]							
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1AC	**DFSDM_FLT1AWCFR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLRAWHTF[7:0]								CLRAWLTF[7:0]							
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1B0	**DFSDM_FLT1EXMAX**	EXMAX[23:0]																								Res.	Res.	Res.	Res.	Res.	EXMAXCH[2:0]		
	reset value	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						0	0	0
0x1B4	**DFSDM_FLT1EXMIN**	EXMIN[23:0]																								Res.	Res.	Res.	Res.	Res.	EXMINCH[2:0]		
	reset value	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						0	0	0
0x1B8	**DFSDM_FLT1CNVTIMR**	CNVCNT[27:0]																												Res.	Res.	Res.	Res.
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x1BC - 0x1FC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Table 292. DFSDM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x200	**DFSDM_FLT2CR1**	Res.	AWFSEL	FAST	Res.	Res.	RCH[2:0]			Res.	Res.	RDMAEN	Res.	RSYNC	RCONT	RSW START	Res.	Res.	JEXTEN[1:0]		JEXTSEL[4:0]					Res.	Res.	JDMAEN	JSCAN	JSYNC	Res.	JSW START	DFEN
	reset value		0	0			0	0	0			0		0	0	0			0	0	0	0	0	0	0			0	0	0		0	0
0x204	**DFSDM_FLT2CR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWDCH[7:0]								EXCH[7:0]								Res.	Res.	Res.	AWDIE	ROVRIE	JOVRIE	REOCIE	JEOCIE
	reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0
0x208	**DFSDM_FLT2ISR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RCIP	JCIP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWDF	ROVRF	JOVRF	REOCF	JEOCF
	reset value																		0	0									0	0	0	0	0
0x20C	**DFSDM_FLT2ICR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLR ROVRF	CLR JOVRF	Res.	Res.
	reset value																													0	0		
0x210	**DFSDM_FLT2JCHGR**	Res	Res.	Res.	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	JCHG[7:0]							
	reset value																									0	0	0	0	0	0	0	1
0x214	**DFSDM_FLT2FCR**	FORD[2:0]			Res.	Res.	Res.	FOSR[9:0]										Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IOSR[7:0]							
	reset value	0	0	0				0	0	0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0
0x218	**DFSDM_FLT2JDATAR**	JDATA[23:0]																								Res.	Res.	Res.	Res.	Res.	JDATACH[2:0]		
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						0	0	0
0x21C	**DFSDM_FLT2RDATAR**	RDATA[23:0]																								Res.	Res.	Res.	RPEND	Res.	RDATACH[2:0]		
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0		0	0	0
0x220	**DFSDM_FLT2AWHTR**	AWHT[23:0]																								Res.	Res.	Res.	Res.	BKAWH[3:0]			
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0
0x224	**DFSDM_FLT2AWLTR**	AWLT[23:0]																								Res.	Res.	Res.	Res.	BKAWL[3:0]			
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0
0x228	**DFSDM_FLT2AWSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWHTF[7:0]								AWLTF[7:0]							
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x22C	**DFSDM_FLT2AWCFR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLRAWHTF[7:0]								CLRAWLTF[7:0]							
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 292. DFSDM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x230	**DFSDM_FLT2EXMAX**	EXMAX[23:0]																								Res.	Res.	Res.	Res.	Res.	EXMAXCH[2:0]		
	reset value	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						0	0	0
0x234	**DFSDM_FLT2EXMIN**	EXMIN[23:0]																								Res.	Res.	Res.	Res.	Res.	EXMINCH[2:0]		
	reset value	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						0	0	0
0x238	**DFSDM_FLT2CNVTIMR**	CNVCNT[27:0]																												Res.	Res.	Res.	Res.
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x23C - 0x27C	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x280	**DFSDM_FLT3CR1**	Res.	AWFSEL	FAST	Res.	Res.	RCH[2:0]			Res.	Res.	RDMAEN	Res.	RSYNC	RCONT	RSW START	Res.	Res.	JEXTEN[1:0]		JEXTSEL[4:0]					Res.	Res.	JDMAEN	JSCAN	JSYNC	Res.	JSW START	DFEN
	reset value		0	0			0	0	0			0		0	0	0			0	0	0	0	0	0	0			0	0	0		0	0
0x284	**DFSDM_FLT3CR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWDCH[7:0]								EXCH[7:0]								Res.	Res.	Res.	AWDIE	ROVRIE	JOVRIE	REOCIE	JEOCIE
	reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0
0x288	**DFSDM_FLT3ISR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RCIP	JCIP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWDF	ROVRF	JOVRF	REOCF	JEOCF
	reset value																		0	0									0	0	0	0	0
0x28C	**DFSDM_FLT3ICR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLR ROVRF	CLR JOVRF	Res.	Res.
	reset value																													0	0		
0x290	**DFSDM_FLT3JCHGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JCHG[7:0]							
	reset value																									0	0	0	0	0	0	0	1
0x294	**DFSDM_FLT3FCR**	FORD[2:0]			Res.	Res.	Res.	FOSR[9:0]											Res.	Res.	Res.	Res.	Res.	Res.	Res.	IOSR[7:0]							
	reset value	0	0	0				0	0	0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0
0x298	**DFSDM_FLT3JDATAR**	JDATA[23:0]																								Res.	Res.	Res.	Res.	Res.	JDATACH[2:0]		
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						0	0	0

Table 292. DFSDM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x29C	**DFSDM_ FLT3RDATAR**	RDATA[23:0]																								Res.	Res.	Res.	RPEND	Res.	RDATA CH[2:0]		
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0		0	0	0
0x2A0	**DFSDM_ FLT3AWHTR**	AWHT[23:0]																								Res.	Res.	Res.	Res.	BKAWH[3:0]			
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0
0x2A4	**DFSDM_ FLT3AWLTR**	AWLT[23:0]																								Res.	Res.	Res.	Res.	BKAWL[3:0]			
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0
0x2A8	**DFSDM_ FLT3AWSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	AWHTF[7:0]								AWLTF[7:0]							
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2AC	**DFSDM_ FLT3AWCFR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLRAWHTF[7:0]								CLRAWLTF[7:0]							
	reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2B0	**DFSDM_ FLT3EXMAX**	EXMAX[23:0]																								Res.	Res.	Res.	Res.	Res.	EXMAXCH[2:0]		
	reset value	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						0	0	0
0x2B4	**DFSDM_ FLT3EXMIN**	EXMIN[23:0]																								Res.	Res.	Res.	Res.	Res.	EXMINCH[2:0]		
	reset value	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						0	0	0
0x2B8	**DFSDM_ FLT3CNVTIMR**	CNVCNT[27:0]																												Res.	Res.	Res.	Res.
	reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
0x2BC - 0x3FC	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Refer to *Section 2.3 on page 131* for the register boundary addresses.

36 Digital camera interface (DCMI)

36.1 Introduction

The digital camera is a synchronous parallel interface able to receive a high-speed data flow from an external 8-, 10-, 12- or 14-bit CMOS camera module. It supports different data formats: YCbCr4:2:2/RGB565 progressive video and compressed data (JPEG).

36.2 DCMI main features

- 8-, 10-, 12- or 14-bit parallel interface
- Embedded/external line and frame synchronization
- Continuous or snapshot mode
- Crop feature
- Supports the following data formats:
  - 8/10/12/14-bit progressive video: either monochrome or raw Bayer
  - YCbCr 4:2:2 progressive video
  - RGB 565 progressive video
  - Compressed data: JPEG

36.3 DCMI functional description

The digital camera interface is a synchronous parallel interface that can receive high-speed data flows. It consists of up to 14 data lines (DCMI_D[13:0]) and a pixel clock line (DCMI_PIXCLK). The pixel clock has a programmable polarity, so that data can be captured on either the rising or the falling edge of the pixel clock.

The data are packed into a 32-bit data register (DCMI_DR) and then transferred through a general-purpose DMA channel. The image buffer is managed by the DMA, not by the camera interface.

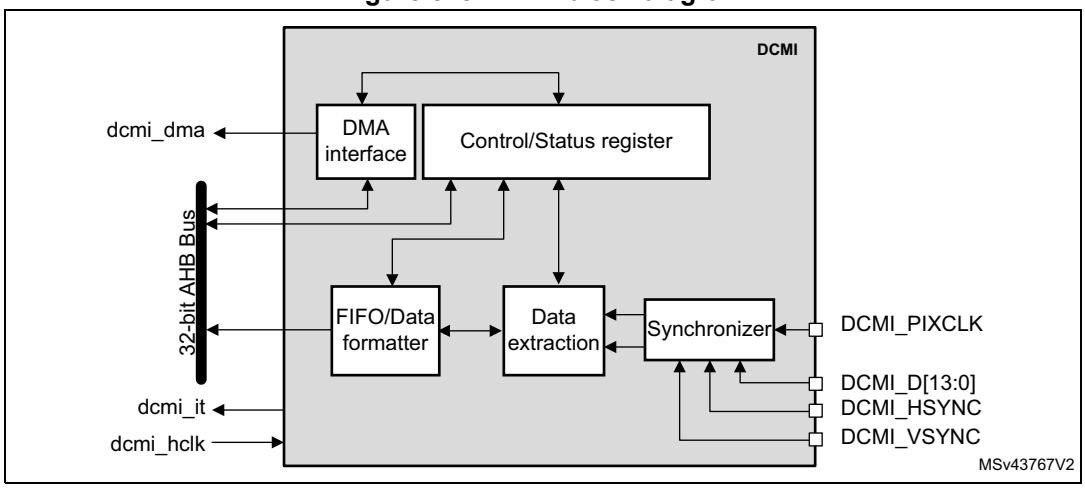
The data received from the camera can be organized in lines/frames (raw YUB/RGB/Bayer modes) or can be a sequence of JPEG images. To enable JPEG image reception, the JPEG bit (bit 3 of DCMI_CR register) must be set.

The data flow is synchronized either by hardware using the optional DCMI_HSYNC (horizontal synchronization) and DCMI_VSYNC (vertical synchronization) signals or by synchronization codes embedded in the data flow.

36.3.1 DCMI block diagram

Figure 318 shows the DCMI block diagram.

Figure 318. DCMI block diagram



36.3.2 DCMI pins and internal signals

The following table shows DCMI pins.

Table 293. DCMI input/output pins

Mode	Pin name	Signal type	Description
8 bits 10 bits 12 bits 14 bits	DCMI_D[7:0] DCMI_D[9:0] DCMI_D[11:0] DCMI_D[13:0]	Inputs	DCMI data
DCMI_PIXCLK		Input	Pixel clock
DCMI_HSYNC		Input	Horizontal synchronization / Data valid
DCMI_VSYNC		Input	Vertical synchronization

The following table shows DCMI internal signals.

Table 294. DCMI internal input/output signals

Internal signal name	Signal type	Description
dcmi_dma	Output	DCMI DMA request
dcmi_it	Output	DCMI interrupt request
dcmi_hclk	Input	DCMI interface clock

36.3.3 DCMI clocks

The digital camera interface uses two clock domains, DCMI_PIXCLK and HCLK. The signals generated with DCMI_PIXCLK are sampled on the rising edge of HCLK once they are stable. An enable signal is generated in the HCLK domain, to indicate that data coming from the camera are stable and can be sampled. The maximum DCMI_PIXCLK period must be higher than 2.5 HCLK periods.

36.3.4 DCMI DMA interface

The DMA interface is active when the CAPTURE bit of the DCMI_CR register is set. A DMA request is generated each time the camera interface receives a complete 32-bit data block in its register.

36.3.5 DCMI physical interface

The interface is composed of 11/13/15/17 inputs. Only the Slave mode is supported.

The camera interface can capture 8-bit, 10-bit, 12-bit or 14-bit data depending on the EDM[1:0] bits of the DCMI_CR register. If less than 14 bits are used, the unused input pins must be connected to ground.

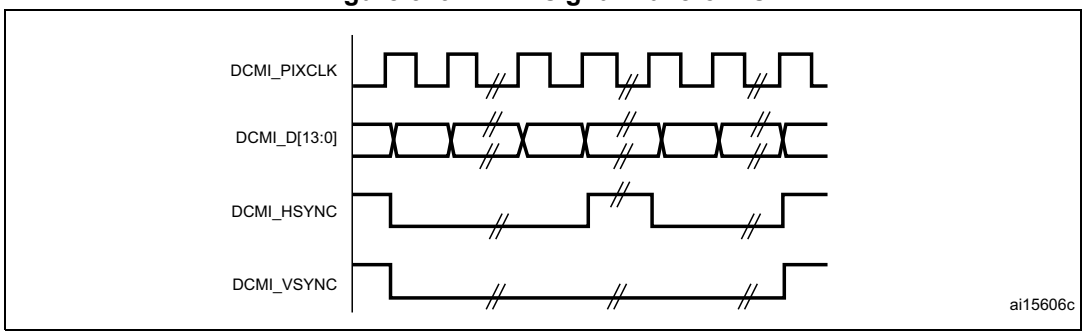
DCMI pins are shown in *Table 293*.

The data are synchronous with DCMI_PIXCLK and change on the rising/falling edge of the pixel clock depending on the polarity.

The DCMI_HSYNC signal indicates the start/end of a line.

The DCMI_VSYNC signal indicates the start/end of a frame

Figure 319. DCMI signal waveforms



1. The capture edge of DCMI_PIXCLK is the falling edge, the active state of DCMI_HSYNC and DCMI_VSYNC is 1.
2. DCMI_HSYNC and DCMI_VSYNC can change states at the same time.

8-bit data

When EDM[1:0] = 00 in DCMI_CR the interface captures 8 LSBs at its input (DCMI_D[7:0]) and stores them as 8-bit data. The DCMI_D[13:8] inputs are ignored. In this case, to capture a 32-bit word, the camera interface takes four pixel clock cycles.

The first captured data byte is placed in the LSB position in the 32-bit word and the 4th captured data byte is placed in the MSB position in the 32-bit word. The table below gives an example of the positioning of captured data bytes in two 32-bit words.

Table 295. Positioning of captured data bytes in 32-bit words (8-bit width)

Byte address	31:24	23:16	15:8	7:0
0	D_{n+3}[7:0]	D_{n+2}[7:0]	D_{n+1}[7:0]	D_n[7:0]
4	D_{n+7}[7:0]	D_{n+6}[7:0]	D_{n+5}[7:0]	D_{n+4}[7:0]

10-bit data

When EDM[1:0] = 01 in DCMI_CR, the camera interface captures 10-bit data at its input DCMI_D[9:0] and stores them as the 10 least significant bits of a 16-bit word. The remaining most significant bits of the DCMI_DR register (bits 11 to 15) are cleared to zero. So, in this case, a 32-bit data word is made up every two pixel clock cycles.

The first captured data are placed in the LSB position in the 32-bit word and the 2nd captured data are placed in the MSB position in the 32-bit word as shown in the table below.

Table 296. Positioning of captured data bytes in 32-bit words (10-bit width)

Byte address	31:26	25:16	15:10	9:0
0	0	D_{n+1}[9:0]	0	D_n[9:0]
4	0	D_{n+3}[9:0]	0	D_{n+2}[9:0]

12-bit data

When EDM[1:0] = 10 in DCMI_CR, the camera interface captures the 12-bit data at its input DCMI_D[11:0] and stores them as the 12 least significant bits of a 16-bit word. The remaining most significant bits are cleared to zero. So, in this case a 32-bit data word is made up every two pixel clock cycles.

The first captured data are placed in the LSB position in the 32-bit word and the 2nd captured data are placed in the MSB position in the 32-bit word as shown in the table below.

Table 297. Positioning of captured data bytes in 32-bit words (12-bit width)

Byte address	31:28	27:16	15:12	11:0
0	0	D_{n+1}[11:0]	0	D_n[11:0]
4	0	D_{n+3}[11:0]	0	D_{n+2}[11:0]

14-bit data

When EDM[1:0] = 11 in DCMI_CR, the camera interface captures the 14-bit data at its input DCMI_D[13:0] and stores them as the 14 least significant bits of a 16-bit word. The remaining most significant bits are cleared to zero. So, in this case a 32-bit data word is made up every two pixel clock cycles.

The first captured data are placed in the LSB position in the 32-bit word and the 2nd captured data are placed in the MSB position in the 32-bit word as shown in the table below.

Table 298. Positioning of captured data bytes in 32-bit words (14-bit width)

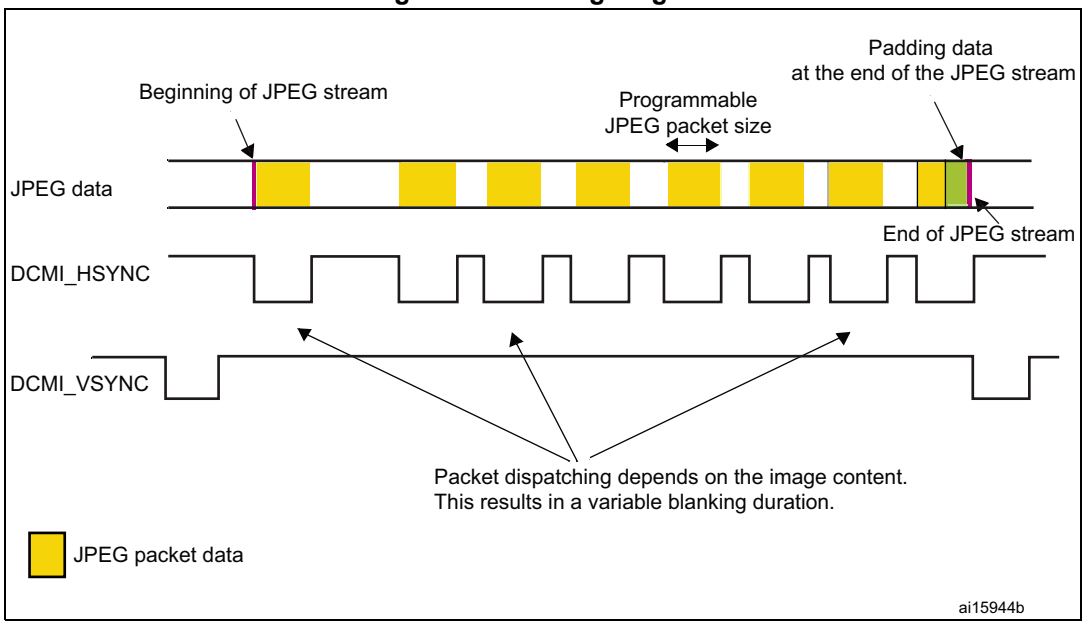
Byte address	31:30	29:16	15:14	13:0
0	0	D_{n+1}[13:0]	0	D_n[13:0]
4	0	D_{n+3}[13:0]	0	D_{n+2}[13:0]

36.3.6 DCMI synchronization

The digital camera interface supports embedded or hardware (DCMI_HSYNC and DCMI_VSYNC) synchronization. When embedded synchronization is used, it is up to the digital camera module to make sure that the 0x00 and 0xFF values are used ONLY for synchronization (not in data). Embedded synchronization codes are supported only for the 8-bit parallel data interface width (that is, in the DCMI_CR register, the EDM[1:0] bits must be cleared).

For compressed data, the DCMI supports only the hardware synchronization mode. In this case, DCMI_VSYNC is used as a start/end of the image, and DCMI_HSYNC is used as a Data Valid signal. *Figure 320* shows the corresponding timing diagram.

Figure 320. Timing diagram



Hardware synchronization mode

In hardware synchronization mode, the two synchronization signals (DCMI_HSYNC/DCMI_VSYNC) are used.

Depending on the camera module/mode, data may be transmitted during horizontal/vertical synchronization periods. The DCMI_HSYNC/DCMI_VSYNC signals act like blanking signals since all the data received during DCMI_HSYNC/DCMI_VSYNC active periods are ignored.

In order to correctly transfer images into the DMA/RAM buffer, data transfer is synchronized with the DCMI_VSYNC signal. When the hardware synchronization mode is selected, and

capture is enabled (CAPTURE bit set in DCMI_CR), data transfer is synchronized with the deactivation of the DCMI_VSYNC signal (next start of frame).

Transfer can then be continuous, with successive frames transferred by DMA to successive buffers or the same/circular buffer. To allow the DMA management of successive frames, a VSIF (Vertical synchronization interrupt flag) is activated at the end of each frame.

Embedded data synchronization mode

In this synchronization mode, the data flow is synchronized using 32-bit codes embedded in the data flow. These codes use the 0x00/0xFF values that are *not* used in data anymore. There are 4 types of codes, all with a 0xFF0000XY format. The embedded synchronization codes are supported only in 8-bit parallel data width capture (in the DCMI_CR register, the EDM[1:0] bits must be cleared). For other data widths, this mode generates unpredictable results and must not be used.

Note: Camera modules can have 8 such codes (in interleaved mode). For this reason, the interleaved mode is not supported by the camera interface (otherwise, every other half-frame would be discarded).

- Mode 2

  Four embedded codes signal the following events
  - Frame start (FS)
  - Frame end (FE)
  - Line start (LS)
  - Line end (LE)

  The XY values in the 0xFF0000XY format of the four codes are programmable (see *Section 36.5.7: DCMI embedded synchronization code register (DCMI_ESCR)*).

  A 0xFF value programmed as a “frame end” means that all the unused codes are interpreted as valid frame end codes.

  In this mode, once the camera interface has been enabled, the frame capture starts after the first occurrence of the frame end (FE) code followed by a frame start (FS) code.
- Mode 1

  An alternative coding is the camera mode 1. This mode is ITU656 compatible.

  The codes signal another set of events:
  - SAV (active line) - line start
  - EAV (active line) - line end
  - SAV (blanking) - end of line during interframe blanking period
  - EAV (blanking) - end of line during interframe blanking period

This mode can be supported by programming the following codes:

- FS $\leq$ 0xFF
- FE ≤ 0xFF
- LS ≤ SAV (active)
- LE ≤ EAV (active)

An embedded unmask code is also implemented for frame/line start and frame/line end codes. Using it, it is possible to compare only the selected unmasked bits with the programmed code. A bit can therefore be selected to compare in the embedded code and

detect a frame/line start or frame/line end. This means that there can be different codes for the frame/line start and frame/line end with the unmasked bit position remaining the same.

Example

FS = 0xA5

Unmask code for FS = 0x10

In this case the frame start code is embedded in the bit 4 of the frame start code.

36.3.7 DCMI capture modes

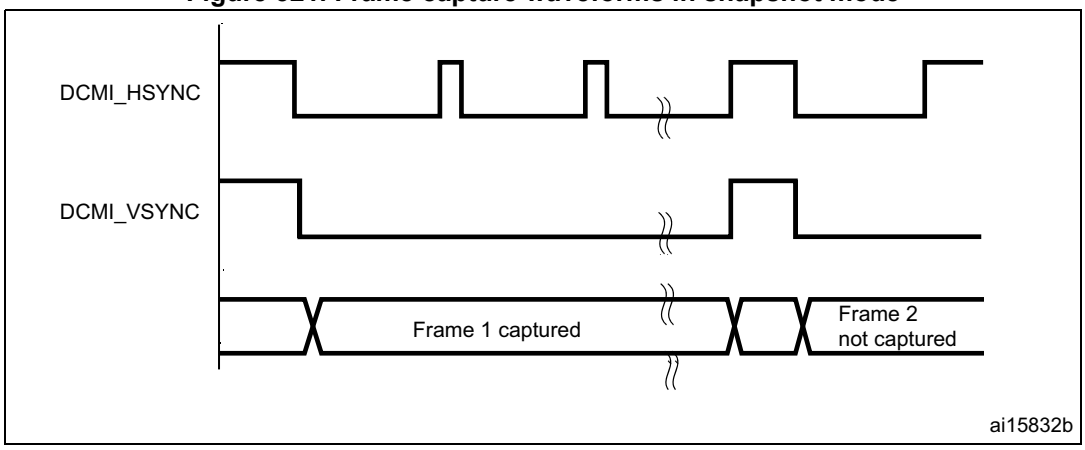
This interface supports two types of capture: snapshot (single frame) and continuous grab.

Snapshot mode (single frame)

In this mode, a single frame is captured (CM = 1 of the DCMI_CR register). After the CAPTURE bit is set in DCMI_CR, the interface waits for the detection of a start of frame before sampling the data. The camera interface is automatically disabled (CAPTURE bit cleared in DCMI_CR) after receiving the first complete frame. An interrupt is generated (IT_FRAME) if it is enabled.

In case of an overrun, the frame is lost and the CAPTURE bit is cleared.

Figure 321. Frame capture waveforms in snapshot mode

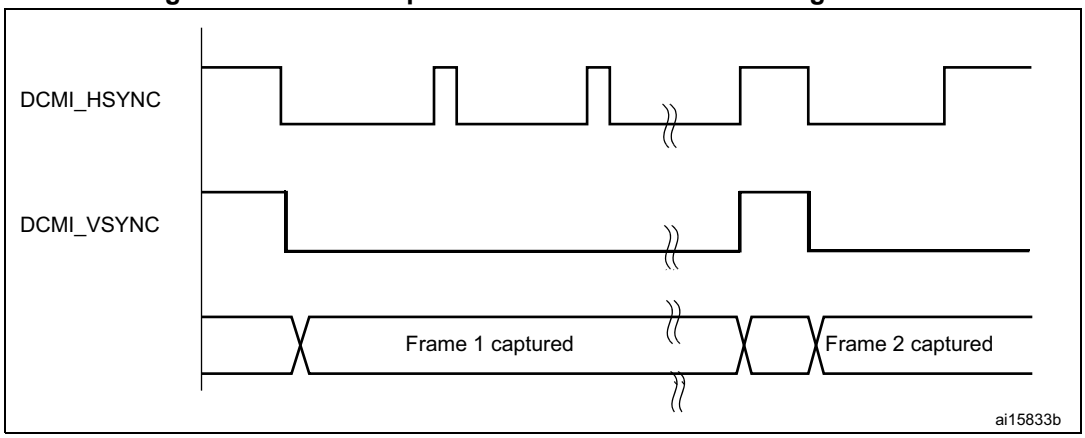


1. Here, the active state of DCMI_HSYNC and DCMI_VSYNC is 1.
2. DCMI_HSYNC and DCMI_VSYNC can change states at the same time.

Continuous grab mode

In this mode (CM bit = 0 in DCMI_CR), once the CAPTURE bit has been set in DCMI_CR, the grabbing process starts on the next DCMI_VSYNC or embedded frame start depending on the mode. The process continues until the CAPTURE bit is cleared in DCMI_CR. Once the CAPTURE bit has been cleared, the grabbing process continues until the end of the current frame.

Figure 322. Frame capture waveforms in continuous grab mode



1. Here, the active state of DCMI_HSYNC and DCMI_VSYNC is 1.
2. DCMI_HSYNC and DCMI_VSYNC can change states at the same time.

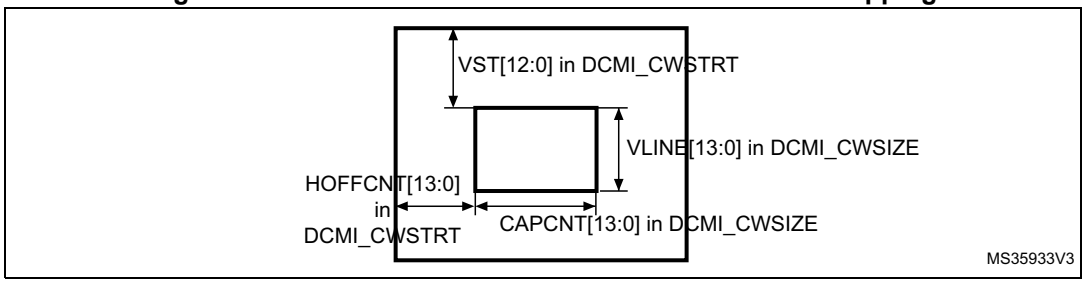
In continuous grab mode, the FCRC[1:0] bits in DCMI_CR can be configured to grab all pictures, every second picture or one out of four pictures to decrease the frame capture rate.

Note: In the hardware synchronization mode (ESS = 0 in DCMI_CR), the IT_VSYNC interrupt is generated (if enabled) even when CAPTURE = 0 in DCMI_CR so, to reduce the frame capture rate even further, the IT_VSYNC interrupt can be used to count the number of frames between 2 captures in conjunction with the Snapshot mode. This is not allowed by embedded data synchronization mode.

36.3.8 DCMI crop feature

With the crop feature, the camera interface can select a rectangular window from the received image. The start (upper left corner) coordinates and size (horizontal dimension in number of pixel clocks and vertical dimension in number of lines) are specified using two 32-bit registers (DCMI_CWSTRT and DCMI_CWSIZE). The size of the window is specified in number of pixel clocks (horizontal dimension) and in number of lines (vertical dimension).

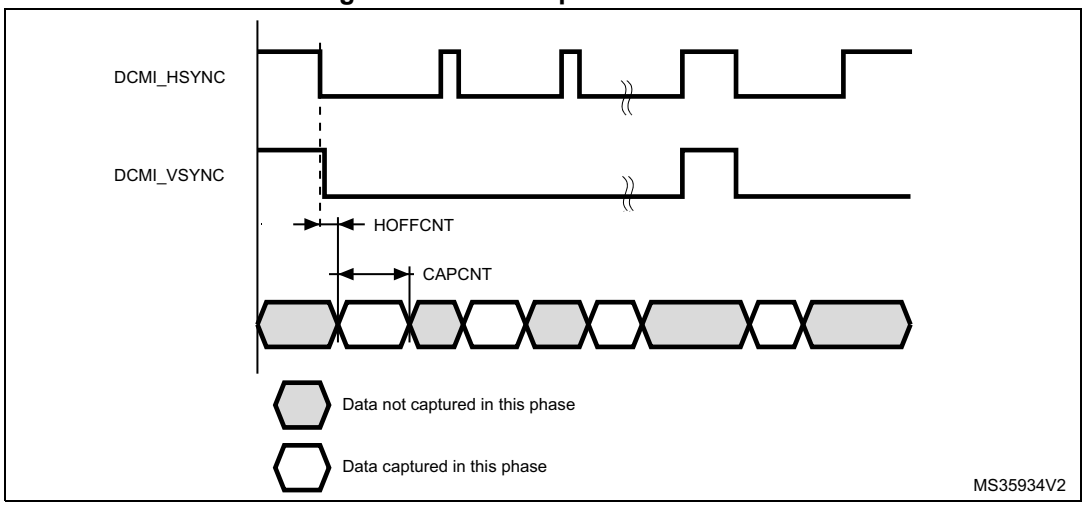
Figure 323. Coordinates and size of the window after cropping



These registers specify the coordinates of the starting point of the capture window as a line number (in the frame, starting from 0) and a number of pixel clocks (on the line, starting from 0), and the size of the window as a line number and a number of pixel clocks. The CAPCNT value can only be a multiple of 4 (two least significant bits are forced to 0) to allow the correct transfer of data through the DMA.

If the DCMI_VSYNC signal goes active before the number of lines is specified in the DCMI_CWSIZE register, then the capture stops and an IT_FRAME interrupt is generated when enabled.

Figure 324. Data capture waveforms



1. Here, the active state of DCMI_HSYNC and DCMI_VSYNC is 1.
2. DCMI_HSYNC and DCMI_VSYNC can change states at the same time.

36.3.9 DCMI JPEG format

To allow JPEG image reception, it is necessary to set the JPEG bit of the DCMI_CR register. JPEG images are not stored as lines and frames, so the DCMI_VSYNC signal is used to start the capture while DCMI_HSYNC serves as a data enable signal. The number of bytes in a line may not be a multiple of 4. This case must be carefully handled since a DMA request is generated each time a complete 32-bit word has been constructed from the captured data. When an end of frame is detected and the 32-bit word to be transferred has not been completely received, the remaining data are padded with zeros and a DMA request is generated.

The crop feature and embedded synchronization codes cannot be used in JPEG format.

36.3.10 DCMI FIFO

A 8-word FIFO is implemented to manage data rate transfers on the AHB. The DCMI features a simple FIFO controller with a read pointer incremented each time the camera interface reads from the AHB, and a write pointer incremented each time the camera interface writes to the FIFO. There is no overrun protection to prevent the data from being overwritten if the AHB interface does not sustain the data transfer rate.

In case of overrun or errors in the synchronization signals, the FIFO is reset and the DCMI interface waits for a new start of frame.

36.3.11 DCMI data format description

Data formats

Three types of data are supported:

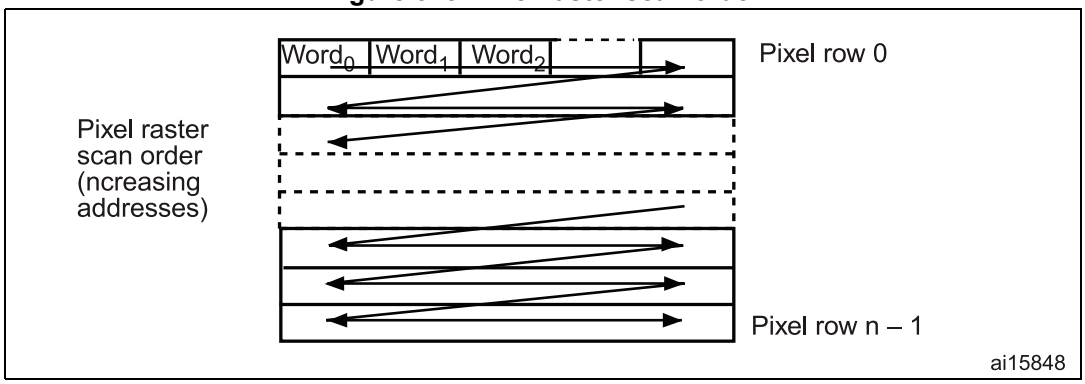
- 8/10/12/14-bit progressive video: either monochrome or raw Bayer format
- YCbCr 4:2:2 progressive video
- RGB565 progressive video. A pixel coded in 16 bits (5 bits for blue, 5 bits for red, 6 bits for green) takes two clock cycles to be transferred.

Compressed data: JPEG

For B&W (black and white), YCbCr or RGB data, the maximum input size is 2048 × 2048 pixels. No limit in JPEG compressed mode.

For monochrome, RGB and YCbCr, the frame buffer is stored in raster mode. 32-bit words are used. Only the little-endian format is supported.

Figure 325. Pixel raster scan order



Monochrome format

Characteristics:

- Raster format
- 8 bits per pixel

The table below shows how the data are stored.

Table 299. Data storage in monochrome progressive video format

Byte address	31:24	23:16	15:8	7:0
0	n + 3	n + 2	n + 1	n
4	n + 7	n + 6	n + 5	n + 4

RGB format

Characteristics:

- Raster format
- RGB
- Interleaved: one buffer: R, G and B interleaved (such as BRGBRGBRG)
- Optimized for display output

The RGB planar format is compatible with standard OS frame buffer display formats.

Only 16 BPP (bits per pixel): RGB565 (2 pixels per 32-bit word) is supported.

The 24 BPP (palletized format) and gray-scale formats are not supported. Pixels are stored in a raster scan order, that is from top to bottom for pixel rows, and from left to right within a pixel row. Pixel components are R (red), G (green) and B (blue). All components have the same spatial resolution (4:4:4 format). A frame is stored in a single part, with the components interleaved on a pixel basis.

The table below shows how the data are stored.

Table 300. Data storage in RGB progressive video format

Byte address	31:27	26:21	20:16	15:11	10:5	4:0
0	Red n + 1	Green n + 1	Blue n + 1	Red n	Green n	Blue n
4	Red n + 4	Green n + 3	Blue n + 3	Red n + 2	Green n + 2	Blue n + 2

YCbCr format

Characteristics:

- Raster format
- YCbCr 4:2:2
- Interleaved: one buffer: Y, Cb and Cr interleaved (such as CbYCrYCbYCr)

Pixel components are Y (luminance or “luma”), Cb and Cr (chrominance or “chroma” blue and red). Each component is encoded in 8 bits. Luma and chroma are stored together (interleaved) as shown in the table below.

Table 301. Data storage in YCbCr progressive video format

Byte address	31:24	23:16	15:8	7:0
0	Y n + 1	Cr n	Y n	Cb n
4	Y n + 3	Cr n + 2	Y n + 2	Cb n + 2

YCbCr format - Y only

Characteristics:

- Raster format
- YCbCr 4:2:2
- The buffer only contains Y information - monochrome image

Pixel components are Y (luminance or “luma”), Cb and Cr (chrominance or “chroma” blue and red). In this mode, the chroma information is dropped. Only the luma component of each pixel, encoded in 8 bits, is stored as shown in *Table 302*.

The result is a monochrome image having the same resolution as the original YCbCr data.

Table 302. Data storage in YCbCr progressive video format - Y extraction mode

Byte address	31:24	23:16	15:8	7:0
0	Y n + 3	Y n + 2	Y n + 1	Y n
4	Y n + 7	Y n + 6	Y n + 5	Y n + 4

Half resolution image extraction

This is a modification of the previous reception modes, being applicable to monochrome, RGB or Y extraction modes.

This mode is used to only store a half resolution image. It is selected through OELS and LSM control bits.

36.4 DCMI interrupts

Five interrupts are generated. All interrupts are maskable by software. The global interrupt (dcmi_it) is the OR of all the individual interrupts. The table below gives the list of all interrupts.

Table 303. DCMI interrupts

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exits Sleep mode	Exists Stop and Standby modes
dcmi_it	End of line	LINE_RIS	LINE_IE	Set LINE_ISC	Yes	No
	End of frame capture	FRAME_RIS	FRAME_IE	Set FRAME_ISC	Yes	No
	Overrun of data reception	OVR_RIS	OVR_IE	Set OVR_ISC	Yes	No
	Synchronization frame	VSYNC_RIS	VSYNC_IE	Set VSYNC_ISC	Yes	No
	Detection of an error in the embedded synchronization frame detection	ERR_RIS	ERR_IE	Set ERR_ISC	Yes	No

36.5 DCMI registers

Refer to *Section 1.2 on page 104* for list of abbreviations used in register descriptions. All DCMI registers must be accessed as 32-bit words, otherwise a bus error occurs.

36.5.1 DCMI control register (DCMI_CR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OELS	LSM	OEBS	BSM[1:0]	
											rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	ENABLE	Res.	Res.	EDM[1:0]		FCRC[1:0]		VSPOL	HSPOL	PCKPOL	ESS	JPEG	CROP	CM	CAPTURE
	rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **OELS:** Odd/Even Line Select (Line Select Start)
This bit works in conjunction with the LSM field (LSM = 1).
0: Interface captures first line after the frame start, second one being dropped.
1: Interface captures second line from the frame start, first one being dropped.

Bit 19 **LSM:** Line Select mode
0: Interface captures all received lines.
1: Interface captures one line out of two.

Bit 18 **OEBS:** Odd/Even Byte Select (Byte Select Start)
This bit works in conjunction with BSM field (BSM $\neq$ 00).
0: Interface captures first data (byte or double byte) from the frame/line start, second one being dropped.
1: Interface captures second data (byte or double byte) from the frame/line start, first one being dropped.

Bits 17:16 **BSM[1:0]:** Byte Select mode
00: Interface captures all received data.
01: Interface captures every other byte from the received data.
10: Interface captures one byte out of four.
11: Interface captures two bytes out of four.
Note: This mode only works for EDM[1:0] = 00. For all other EDM values, this field must be programmed to the reset value.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **ENABLE:** DCMI enable
0: DCMI disabled
1: DCMI enabled
Note: The DCMI configuration registers must be programmed correctly before enabling this bit.

Bits 13:12 Reserved, must be kept at reset value.

Bits 11:10 **EDM[1:0]:** Extended data mode
00: Interface captures 8-bit data on every pixel clock.
01: Interface captures 10-bit data on every pixel clock.
10: Interface captures 12-bit data on every pixel clock.
11: Interface captures 14-bit data on every pixel clock.

Bits 9:8 **FCRC[1:0]:** Frame capture rate control
These bits define the frequency of frame capture. They are meaningful only in Continuous grab mode. They are ignored in snapshot mode.
00: All frames are captured.
01: Every alternate frame captured (50% bandwidth reduction)
10: One frame out of four captured (75% bandwidth reduction)
11: reserved

Bit 7 **VSPOL:** Vertical synchronization polarity
This bit indicates the level on the DCMI_VSYNC pin when the data are not valid on the parallel interface.
0: DCMI_VSYNC active low
1: DCMI_VSYNC active high

Bit 6 **HSPOL:** Horizontal synchronization polarity
This bit indicates the level on the DCMI_HSYNC pin when the data are not valid on the parallel interface.
0: DCMI_HSYNC active low
1: DCMI_HSYNC active high

Bit 5 **PCKPOL:** Pixel clock polarity
This bit configures the capture edge of the pixel clock.
0: Falling edge active
1: Rising edge active

Bit 4 **ESS:** Embedded synchronization select
0: Hardware synchronization data capture (frame/line start/stop) is synchronized with the DCMI_HSYNC/DCMI_VSYNC signals.
1: Embedded synchronization data capture is synchronized with synchronization codes embedded in the data flow.
Note: Valid only for 8-bit parallel data. HSPOL/VSPOL are ignored when the ESS bit is set.
This bit is disabled in JPEG mode.

Bit 3 **JPEG:** JPEG format
0: Uncompressed video format
1: This bit is used for JPEG data transfers. The DCMI_HSYNC signal is used as data enable. The crop and embedded synchronization features (ESS bit) cannot be used in this mode.

Bit 2 **CROP:** Crop feature
0: The full image is captured. In this case the total number of bytes in an image frame must be a multiple of four.
1: Only the data inside the window specified by the crop register is captured. If the size of the crop window exceeds the picture size, then only the picture size is captured.

Bit 1 **CM:** Capture mode
0: Continuous grab mode - The received data are transferred into the destination memory through the DMA. The buffer location and mode (linear or circular buffer) is controlled through the system DMA.
1: Snapshot mode (single frame) - Once activated, the interface waits for the start of frame and then transfers a single frame through the DMA. At the end of the frame, the CAPTURE bit is automatically reset.

Bit 0 **CAPTURE:** Capture enable

0: Capture disabled

1: Capture enabled

The camera interface waits for the first start of frame, then a DMA request is generated to transfer the received data into the destination memory.

In snapshot mode, the CAPTURE bit is automatically cleared at the end of the first frame received.

In continuous grab mode, if the software clears this bit while a capture is ongoing, the bit is effectively cleared after the frame end.

Note: The DMA controller and all DCMI configuration registers must be programmed correctly before enabling this bit.

36.5.2 DCMI status register (DCMI_SR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FNE	VSYNC	HSYNC
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **FNE**: FIFO not empty

This bit gives the status of the FIFO.

1: FIFO contains valid data.

0: FIFO empty

Bit 1 **VSYNC**: Vertical synchronization

This bit gives the state of the DCMI_VSYNC pin with the correct programmed polarity. When embedded synchronization codes are used, the meaning of this bit is the following:

0: active frame

1: synchronization between frames

In case of embedded synchronization, this bit is meaningful only if the CAPTURE bit in DCMI_CR is set.

Bit 0 **HSYNC**: Horizontal synchronization

This bit gives the state of the DCMI_HSYNC pin with the correct programmed polarity. When embedded synchronization codes are used, the meaning of this bit is the following:

0: active line

1: synchronization between lines

In case of embedded synchronization, this bit is meaningful only if the CAPTURE bit in DCMI_CR is set.

36.5.3 DCMI raw interrupt status register (DCMI_RIS)

DCMI_RIS gives the raw interrupt status and is accessible in read only. When read, this register returns the status of the corresponding interrupt before masking with the DCMI_IER register value.

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_RIS	VSYNC_RIS	ERR_RIS	OVR_RIS	FRAME_RIS
											r	r	r	r	r

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **LINE_RIS**: Line raw interrupt status

This bit gets set when the DCMI_HSYNC signal changes from the inactive state to the active state. It goes high even if the line is not valid.

In the case of embedded synchronization, this bit is set only if the CAPTURE bit in DCMI_CR is set.

It is cleared by setting the LINE_ISC bit of the DCMI_ICR register.

Bit 3 **VSYNC_RIS**: DCMI_VSYNC raw interrupt status

This bit is set when the DCMI_VSYNC signal changes from the inactive state to the active state.

In the case of embedded synchronization, this bit is set only if the CAPTURE bit is set in DCMI_CR.

It is cleared by setting the VSYNC_ISC bit of the DCMI_ICR register.

Bit 2 **ERR_RIS**: Synchronization error raw interrupt status

0: No synchronization error detected

1: Embedded synchronization characters are not received in the correct order.

This bit is valid only in the embedded synchronization mode. It is cleared by setting the ERR_ISC bit of the DCMI_ICR register.

Note: This bit is available only in embedded synchronization mode.

Bit 1 **OVR_RIS**: Overrun raw interrupt status

0: No data buffer overrun occurred

1: A data buffer overrun occurred and the data FIFO is corrupted.

The bit is cleared by setting the OVR_ISC bit of the DCMI_ICR register.

Bit 0 **FRAME_RIS**: Capture complete raw interrupt status

0: No new capture

1: A frame has been captured.

This bit is set when a frame or window has been captured.

In case of a cropped window, this bit is set at the end of line of the last line in the crop. It is set even if the captured frame is empty (e.g. window cropped outside the frame).

The bit is cleared by setting the FRAME_ISC bit of the DCMI_ICR register.

36.5.4 DCMI interrupt enable register (DCMI_IER)

The DCMI_IER register is used to enable interrupts. When one of the DCMI_IER bits is set, the corresponding interrupt is enabled. This register is accessible in both read and write.

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_IE	VSYNC_IE	ERR_IE	OVR_IE	FRAME_IE
											rw	rw	rw	rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **LINE_IE**: Line interrupt enable
0: No interrupt generation when the line is received
1: An Interrupt is generated when a line has been completely received.

Bit 3 **VSYNC_IE**: DCMI_VSYNC interrupt enable
0: No interrupt generation
1: An interrupt is generated on each DCMI_VSYNC transition from the inactive to the active state.
The active state of the DCMI_VSYNC signal is defined by the VSPOL bit.

Bit 2 **ERR_IE**: Synchronization error interrupt enable
0: No interrupt generation
1: An interrupt is generated if the embedded synchronization codes are not received in the correct order.
Note: This bit is available only in embedded synchronization mode.

Bit 1 **OVR_IE**: Overrun interrupt enable
0: No interrupt generation
1: An interrupt is generated if the DMA was not able to transfer the last data before new data (32-bit) are received.

Bit 0 **FRAME_IE**: Capture complete interrupt enable
0: No interrupt generation
1: An interrupt is generated at the end of each received frame/crop window (in crop mode).

36.5.5 DCMI masked interrupt status register (DCMI_MIS)

This DCMI_MIS register is a read-only register. When read, it returns the current masked status value (depending on the value in DCMI_IER) of the corresponding interrupt. A bit in this register is set if the corresponding enable bit in DCMI_IER is set and the corresponding bit in DCMI_RIS is set.

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_MIS	VSYNC_MIS	ERR_MIS	OVR_MIS	FRAME_MIS
											r	r	r	r	r

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **LINE_MIS**: Line masked interrupt status
This bit gives the status of the masked line interrupt.
0: No interrupt generation when the line is received
1: An Interrupt is generated when a line has been completely received and the LINE_IE bit is set in DCMI_IER.

Bit 3 **VSYNC_MIS**: VSYNC masked interrupt status
This bit gives the status of the masked VSYNC interrupt.
0: No interrupt is generated on DCMI_VSYNC transitions.
1: An interrupt is generated on each DCMI_VSYNC transition from the inactive to the active state and the VSYNC_IE bit is set in DCMI_IER.
The active state of the DCMI_VSYNC signal is defined by the VSPOL bit.

Bit 2 **ERR_MIS**: Synchronization error masked interrupt status
This bit gives the status of the masked synchronization error interrupt.
0: No interrupt is generated on a synchronization error.
1: An interrupt is generated if the embedded synchronization codes are not received in the correct order and the ERR_IE bit in DCMI_IER is set.
Note: This bit is available only in embedded synchronization mode.

Bit 1 **OVR_MIS**: Overrun masked interrupt status
This bit gives the status of the masked overflow interrupt.
0: No interrupt is generated on overrun.
1: An interrupt is generated if the DMA was not able to transfer the last data before new data (32-bit) are received and the OVR_IE bit is set in DCMI_IER.

Bit 0 **FRAME_MIS**: Capture complete masked interrupt status
This bit gives the status of the masked capture complete interrupt
0: No interrupt is generated after a complete capture.
1: An interrupt is generated at the end of each received frame/crop window (in crop mode) and the FRAME_IE bit is set in DCMI_IER.

36.5.6 DCMI interrupt clear register (DCMI_ICR)

The DCMI_ICR register is write-only. Setting a bit of this register clears the corresponding flag in the DCMI_RIS and DCMI_MIS registers. Writing 0 has no effect.

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_ISC	VSYNC_ISC	ERR_ISC	OVR_ISC	FRAME_ISC
											w	w	w	w	w

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **LINE_ISC**: line interrupt status clear
Setting this bit clears the LINE_RIS flag in the DCMI_RIS register.

Bit 3 **VSYNC_ISC**: Vertical Synchronization interrupt status clear
Setting this bit clears the VSYNC_RIS flag in the DCMI_RIS register.

Bit 2 **ERR_ISC**: Synchronization error interrupt status clear
Setting this bit clears the ERR_RIS flag in the DCMI_RIS register.
Note: This bit is available only in embedded synchronization mode.

Bit 1 **OVR_ISC**: Overrun interrupt status clear
Setting this bit clears the OVR_RIS flag in the DCMI_RIS register.

Bit 0 **FRAME_ISC**: Capture complete interrupt status clear
Setting this bit clears the FRAME_RIS flag in the DCMI_RIS register.

36.5.7 DCMI embedded synchronization code register (DCMI_ESCR)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FEC[7:0]								LEC[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LSC[7:0]								FSC[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **FEC[7:0]**: Frame end delimiter code

This byte specifies the code of the frame end delimiter. The code consists of 4 bytes in the form of 0xFF, 0x00, 0x00, FEC.

If FEC is programmed to 0xFF, all the unused codes (0xFF0000XY) are interpreted as frame end delimiters.

Bits 23:16 **LEC[7:0]**: Line end delimiter code

This byte specifies the code of the line end delimiter. The code consists of 4 bytes in the form of 0xFF, 0x00, 0x00, LEC.

Bits 15:8 **LSC[7:0]**: Line start delimiter code

This byte specifies the code of the line start delimiter. The code consists of 4 bytes in the form of 0xFF, 0x00, 0x00, LSC.

Bits 7:0 **FSC[7:0]**: Frame start delimiter code

This byte specifies the code of the frame start delimiter. The code consists of 4 bytes in the form of 0xFF, 0x00, 0x00, FSC.

If FSC is programmed to 0xFF, no frame start delimiter is detected. But, the first occurrence of LSC after an FEC code is interpreted as a start of frame delimiter.

36.5.8 DCMI embedded synchronization unmask register (DCMI_ESUR)

Address offset: 0x1C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FEU[7:0]								LEU[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LSU[7:0]								FSU[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **FEU[7:0]**: Frame end delimiter unmask

This byte specifies the mask to be applied to the code of the frame end delimiter.

0: The corresponding bit in the FEC byte in DCMI_ESCR is masked while comparing the frame end delimiter with the received data.

1: The corresponding bit in the FEC byte in DCMI_ESCR is compared while comparing the frame end delimiter with the received data.

Bits 23:16 **LEU[7:0]**: Line end delimiter unmask

This byte specifies the mask to be applied to the code of the line end delimiter.

0: The corresponding bit in the LEC byte in DCMI_ESCR is masked while comparing the line end delimiter with the received data.

1: The corresponding bit in the LEC byte in DCMI_ESCR is compared while comparing the line end delimiter with the received data.

Bits 15:8 **LSU[7:0]**: Line start delimiter unmask

This byte specifies the mask to be applied to the code of the line start delimiter.

0: The corresponding bit in the LSC byte in DCMI_ESCR is masked while comparing the line start delimiter with the received data.

1: The corresponding bit in the LSC byte in DCMI_ESCR is compared while comparing the line start delimiter with the received data.

Bits 7:0 **FSU[7:0]**: Frame start delimiter unmask

This byte specifies the mask to be applied to the code of the frame start delimiter.
0: The corresponding bit in the FSC byte in DCMI_ESCR is masked while comparing the frame start delimiter with the received data.
1: The corresponding bit in the FSC byte in DCMI_ESCR is compared while comparing the frame start delimiter with the received data.

36.5.9 DCMI crop window start (DCMI_CWSTRT)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	VST[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	HOFFCNT[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:16 **VST[12:0]**: Vertical start line count

The image capture starts with this line number. Previous line data are ignored.
0x0000: line 1
0x0001: line 2
0x0002: line 3
....

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:0 **HOFFCNT[13:0]**: Horizontal offset count

This value gives the number of pixel clocks to count before starting a capture.

36.5.10 DCMI crop window size (DCMI_CWSIZE)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	VLINE[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	CAPCNT[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:16 **VLINE[13:0]**: Vertical line count
This value gives the number of lines to be captured from the starting point.
0x0000: 1 line
0x0001: 2 lines
0x0002: 3 lines
....

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:0 **CAPCNT[13:0]**: Capture count
This value gives the number of pixel clocks to be captured from the starting point on the same line. It value must corresponds to word-aligned data for different widths of parallel interfaces.
0x0000 => 1 pixel
0x0001 => 2 pixels
0x0002 => 3 pixels
....

36.5.11 DCMI data register (DCMI_DR)

Address offset: 0x28

Reset value: 0x0000 0000

The digital camera Interface packages all the received data in 32-bit format before requesting a DMA transfer. A 8-word deep FIFO is available to leave enough time for DMA transfers and avoid DMA overrun conditions.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BYTE3[7:0]								BYTE2[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BYTE1[7:0]								BYTE0[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 **BYTE3[7:0]**: Data byte 3

Bits 23:16 **BYTE2[7:0]**: Data byte 2

Bits 15:8 **BYTE1[7:0]**: Data byte 1

Bits 7:0 **BYTE0[7:0]**: Data byte 0

36.5.12 DCMI register map

Table 304. DCMI register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	DCMI_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OELS	LSM	OEBS	BSM[1:0]		Res.	ENABLE	Res.	Res.	EDM[1:0]		FCRC[1:0]		VSPOL	HSPOL	PCKPOL	ESS	JPEG	CROP	CM	CAPTURE
	Reset value												0	0	0	0	0		0			0	0	0	0	0	0	0	0	0	0	0	0

Table 304. DCMI register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x04	DCMI_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FNE	VSYNC	HSYNC
	Reset value																														0	0	0
0x08	DCMI_RIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_RIS	VSYNC_RIS	ERR_RIS	OVR_RIS	FRAME_RIS
	Reset value																												0	0	0	0	0
0x0C	DCMI_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_IE	VSYNC_IE	ERR_IE	OVR_IE	FRAME_IE
	Reset value																												0	0	0	0	0
0x10	DCMI_MIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_MIS	VSYNC_MIS	ERR_MIS	OVR_MIS	FRAME_MIS
	Reset value																												0	0	0	0	0
0x14	DCMI_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LINE_ISC	VSYNC_ISC	ERR_ISC	OVR_ISC	FRAME_ISC
	Reset value																												0	0	0	0	0
0x18	DCMI_ESCR	FEC[7:0]								LEC[7:0]								LSC[7:0]								FSC[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	DCMI_ESUR	FEU[7:0]								LEU[7:0]								LSU[7:0]								FSU[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	DCMI_CWSTRT	Res.	Res.	Res.	VST[12:0]													Res.	Res.	HOFFCNT[13:0]													
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x24	DCMI_CWSIZE	Res.	Res.	VLINE[13:0]														Res.	Res.	CAPCNT[13:0]													
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	DCMI_DR	BYTE3[7:0]								BYTE2[7:0]								BYTE1[7:0]								BYTE0[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3* for the register boundary addresses.

37 Parallel synchronous slave interface (PSSI)

The PSSI peripheral and the DCMI (digital camera interface) use the same circuitry. As a result, these two peripherals cannot be used at the same time: when using the PSSI, the DCMI registers cannot be accessed, and vice-versa.

In addition, the PSSI and the DCMI share the same alternate functions and interrupt vector (see *Section 37.3.2: PSSI pins and internal signals*).

37.1 Introduction

The PSSI is a generic synchronous 8/16-bit parallel data input/output slave interface. It enables the transmitter to send a data valid signal that indicates when the data is valid, and the receiver to output a flow control signal that indicates when it is ready to sample the data.

37.2 PSSI main features

The PSSI peripheral main features are the following:

- Slave mode operation
- 8-bit or 16-bit parallel data input or output
- 8-word (32-byte) FIFO
- Data enable (PSSI_DE) alternate function input and Ready (PSSI_RDY) alternate function output

  When selected, these signals can either enable the transmitter to indicate when the data is valid, allow the receiver to indicate when it is ready to sample the data, or both.

37.3 PSSI functional description

The PSSI is a synchronous parallel slave interface that can send or receive high-speed data flows. It consists of up to 16 data lines (PSSI_D[15:0]) plus a clock line (PSSI_PDCK). The clock polarity can be configured so that data can be captured or transmitted on either the clock rising or falling edge.

Usually, a general-purpose DMA channel is used to pass 32-bit packed data via the data register (PSSI_DR).

The data flow can either be continuous or synchronized by hardware using the optional PSSI_DE (Data enable), and PSSI_RDY (Ready) signals.

Figure 326 shows the PSSI block diagram.

37.3.1 PSSI block diagram

Figure 326. PSSI block diagram

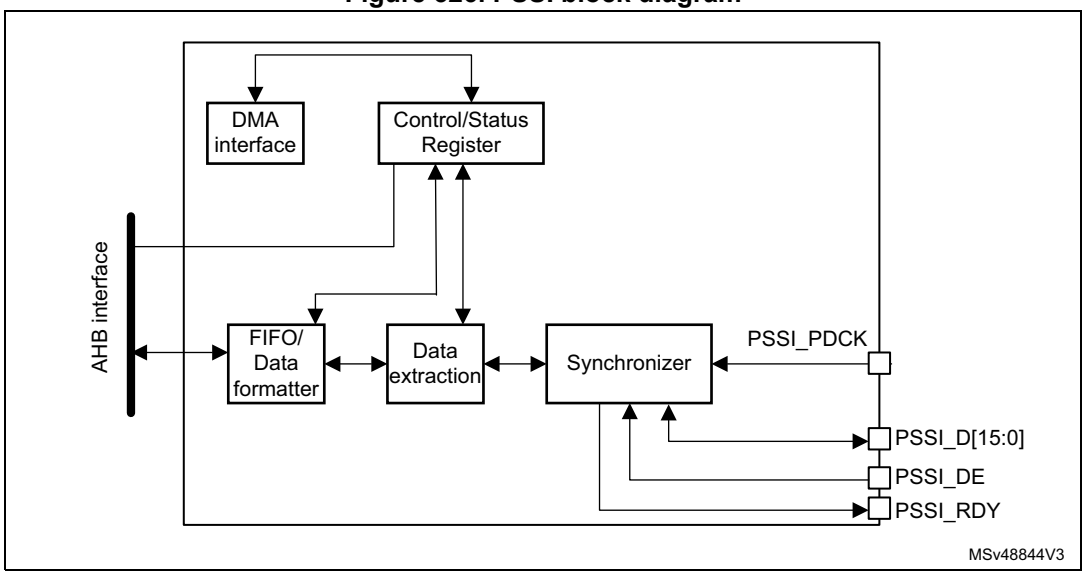
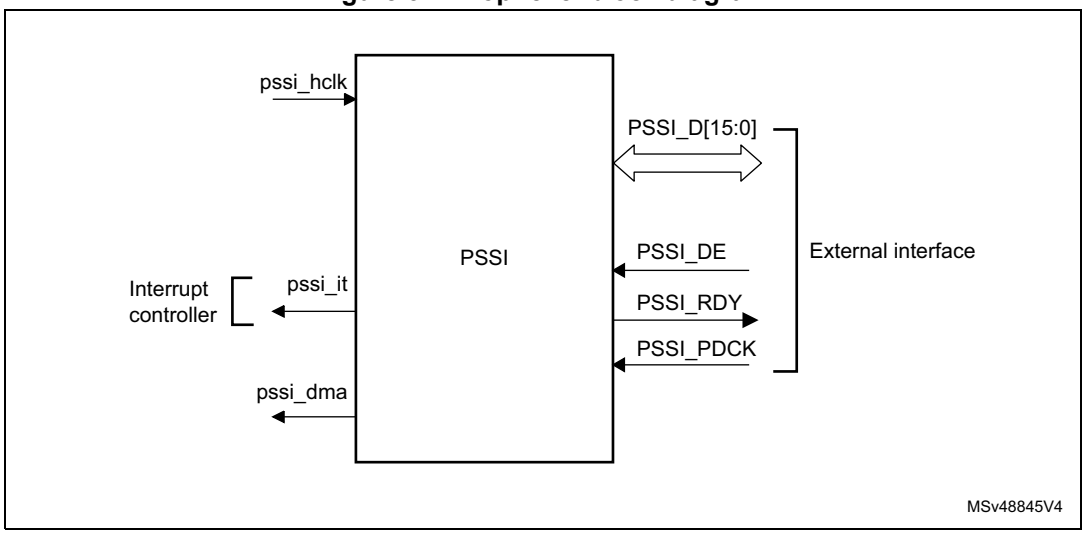


Figure 327. Top-level block diagram



37.3.2 PSSI pins and internal signals

The PSSI interface is composed of 19 pins, though nine signals are enough to transfer parallel data. *Table 305* shows the PSSI pins.

When the PSSI ENABLE bit (bit 14 of PSSI_CR) is set to 1, the alternate functions and the interrupt vector are associated with the PSSI. Otherwise, they are associated with the DCMI. The DCMI ENABLE bit (bit 15 of DCMI_CR) and the PSSI ENABLE bit (bit 14 of PSSI_CR) must not be set to 1 at the same time. As an example, if a GPIO is configured to use the alternate function PSSI_PDCK/DCMI_PIXCK, it is the PSSI_PDCK function which becomes active if PSSI_CR/ENABLE is set to 1.

Table 305. PSSI input/output pins

PSSI signal name	DCMI signal it is shared with	Signal type	Description
PSSI_PDCK	DCMI_PIXCK	Input	Parallel data clock input
PSSI_D[15:0]	DCMI_D[13:0]	Input/output	Data output when transmitting, data input when receiving
PSSI_DE	DCMI_HSYNC	Input	Data enable signal: data valid signal when receiving or flow control signal when transmitting
PSSI_RDY	DCMI_VSYNC	Output	Ready signal: flow control signal when receiving or data valid signal when transmitting

Table 306 shows the PSSI internal input/output signals.

Table 306. PSSI internal input/output signals

Internal signal name	Signal type	Description
pssi_it	Output	Interrupt
pssi_dma	Output	DMA request
pssi_hclk	Input	AHB clock

37.3.3 PSSI clock

The AHB clock frequency must be at least 2.5 times higher than the PSSI_PDCK frequency. At frequency ratios lower than 2.5, data might be corrupted or lost during transfers.

Data transfers are synchronous with PSSI_PDCK. The PSSI_PDCK polarity can be configured as follows, through CKPOL bit (bit 5 of PSSI_CR):

- When CKPOL = 0
  - Input pins are sampled on PSSI_PDCK falling edge
  - Output pins are driven on PSSI_PDCK rising edge
- When CKPOL = 1
  - Input pins are sampled on PSSI_PDCK rising edge
  - Output pins are driven on PSSI_PDCK falling edge

37.3.4 PSSI data management

Data direction

The direction of data transfers is configured through the OUTEN control bit (bit 31 of PSSI_CR):

- When OUTEN is cleared to 0 (default setting), the PSSI operates in receive mode and the data is input on the data pins.
- When OUTEN is set to 1, the peripheral operates in transmit mode and the data is output on the data pins.

OUTEN can be modified only when the ENABLE bit is cleared to 0.

Data register and DMA

Data are transferred from/to the FIFO using the PSSI_DR data register:

- In receive mode, data must be read from the FIFO by reading PSSI_DR.
- In transmit mode, data must be written to the FIFO by writing into PSSI_DR.

Word (32-bit) accesses to PSSI_DR and half-word (16-bit) accesses to PSSI_DR[15:0] are permitted in all modes. Byte (8-bit) accesses to PSSI_DR[7:0] are permitted only when the PSSI is configured to transfer 8 bits at a time (EDM=00 in the PSSI_CR register).

To reduce the load on the CPU, it is recommended to use the DMA to transfer data from/to the PSSI FIFO. When it is used, the DMA must be configured to transfer data via the PSSI_DR register. Using 32-bit transfers optimizes bandwidth and reduces the bus load. However, 8-bit and 16-bit transfers are also permitted.

To use the DMA, set the PSSI DMA enable bit (DMAEN in PSSI_CR) to 1 (default setting). When DMAEN is set to 1, a DMA transfer is initiated when the FIFO is ready for a 32-bit transfer (four valid bytes in receive mode or four empty bytes in transmit mode). As a result, in receive mode, no DMA transfers are initiated if there are three bytes or fewer in the FIFO, even if the DMA is configured to perform 8-bit transfers.

The RTT4B and RTT1B status bits (PSSI_SR) are useful when the CPU directly perform transfers to and from the FIFO. RTT4B set to 1 indicates that the FIFO is ready to transfer four bytes: at least four valid bytes in the FIFO in receive mode or at least four free bytes in transmit mode. RTT1B set to 1 indicates that the FIFO is ready to transfer one byte: at least one valid byte in the FIFO in receive mode or at least one free byte in transmit mode.

8-bit data

The PSSI parallel interface can transfer either 8-bit (using D[7:0]) or 16-bit data (using D[15:0]) depending on the EDM[1:0] control bits (bits 11:10 of PSSI_CR). If the 8-bit configuration is selected (EDM[1:0] set to 00), the unused D[15:0] pins can be used for GPIO or other functions.

When EDM[1:0] in PSSI_CR are programmed to 00, the interface transfers 8 bits using the D[7:0] pins. In this case, D[15:8] are not used and four PSSI_PDCK cycles are required to transfer a 32-bit word.

The least-significant byte (bits 7:0) correspond to the first byte transferred, and the most-significant byte (bits 31:28) corresponds to the forth byte transferred. *Table 307* illustrates the positioning of the data bytes in two 32-bit words.

Table 307. Positioning of captured data bytes in 32-bit words (8-bit width)

Byte address	31:24	23:16	15:8	7:0
0	D_{n+3}[7:0]	D_{n+2}[7:0]	D_{n+1}[7:0]	D_n[7:0]
4	D_{n+7}[7:0]	D_{n+6}[7:0]	D_{n+5}[7:0]	D_{n+4}[7:0]

16-bit data

When EDM[1:0] in PSSI_CR are programmed to 11, the interface transfers 16 bits using the D[15:0] pins. In this case, two PSSI_PDCK cycles are required to transfer a 32-bit word.

The least-significant half word (bits 15:0) correspond to the first half word transferred, and the most-significant half-word (bits 31:16) corresponds to the second half word transferred. *Table 308* illustrates the positioning of the data in two 32-bit words.

Table 308. Positioning of captured data bytes in 32-bit words (16-bit width)

Byte address	31:16	15:0
0	D_{n+1}[15:0]	D_n[15:0]
4	D_{n+3}[15:0]	D_{n+2}[15:0]

FIFO data buffer and error conditions

An eight-word FIFO helps improving performance and avoids overruns and underruns.

If the ready signal (PSSI_RDY) is disabled in receive mode, an overrun error is generated when a clock active edge occurs when the FIFO is full. In this case, the input data is lost.

If the data enable signal (PSSI_DE) is disabled in transmit mode, an underrun error is generated when a clock active edge occurs when the FIFO is empty. In this case, unpredictable data are output.

The OVR_RIS status bit indicates that either an overrun or an underrun occurred. An interrupt can be generated when these events occur.

37.3.5 PSSI optional control signals

Data Enable (PSSI_DE) alternate function input

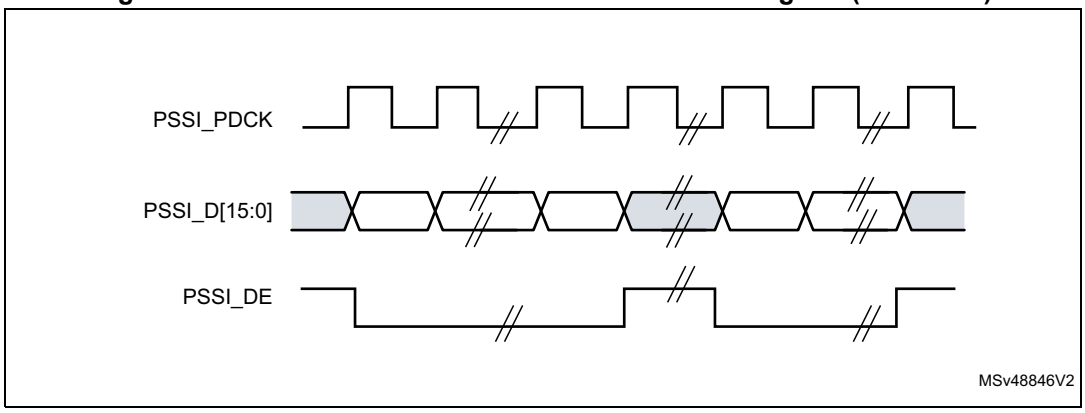
The data enable signal, PSSI_DE, is an optional signal. It is driven by the data source/transmitter in order to indicate that the data is valid to be transferred during the current cycle. When PSSI_DE is inactive, it means that the data must not be sampled by the receiver at the next clock edge.

This alternate function signal can be enabled using the DERDYCFG (bits 20:18 of PSSI_CR) control bits. PSSI_DE polarity is configured through DEPOL control bit (bit 6 of PSSI_CR). PSSI_DE is active low when DEPOL is cleared to 0, and high when DEPOL is et to 1.

The direction of the PSSI_DE signal is defined by the OUTEN value. It is the same as the data direction.

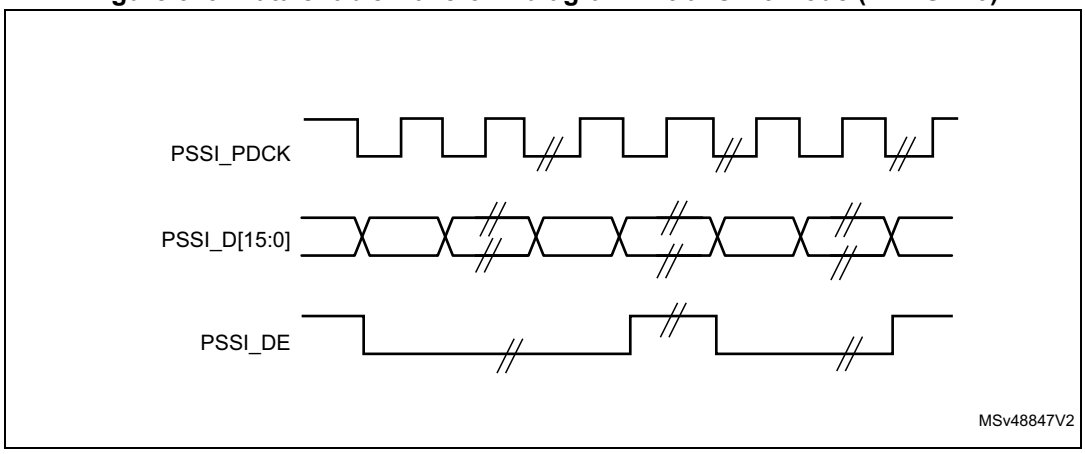
If the PSSI_DE alternate function input is enabled (through DERDYCFG) in receive mode (OUTEN cleared to 0), the PSSI samples PSSI_DE on the same PSSI_PDCK edge as the one used for sampling the data (D[15:0]). If PSSI_DE is active, the sampled data is saved in the FIFO. Otherwise, the sampled data is considered invalid and discarded. The transmitting device can use PSSI_DE as a data valid signal, driving it inactive when the data in the current cycle is not valid. This flow control function allows avoiding underrun errors.

Figure 328. Data enable in receive mode waveform diagram (CKPOL=0)



If the PSSI_DE alternate output function is enabled (through DERDYCFG) in transmit mode (OUTEN=1), the PSSI drives PSSI_DE on the same PSSI_PDCK edge that the one used to drive the data (D[15:0]). If a new 8 or 16-bit data (as programmed in the EDM[1:0] control bits in PSSI_CR) is available for transmission in the internal FIFO, this data is output on the data outputs (D[15:0]) and the PSSI_DE output becomes active on the current PSSI_PDCK edge. Otherwise (if the TX FIFO is empty), the D[15:0] outputs remains unchanged on the next clock edge and the PSSI_DE output becomes inactive.

Figure 329. Data enable waveform diagram in transmit mode (CKPOL=0)



Ready (PSSI_RDY) alternate function output

The ready signal, PSSI_RDY, is an optional signal. It is driven by the receiving device and indicates whether data is being accepted in the current cycle. When PSSI_RDY is inactive, it means that the data must not be sampled by the receiver at the next clock edge.

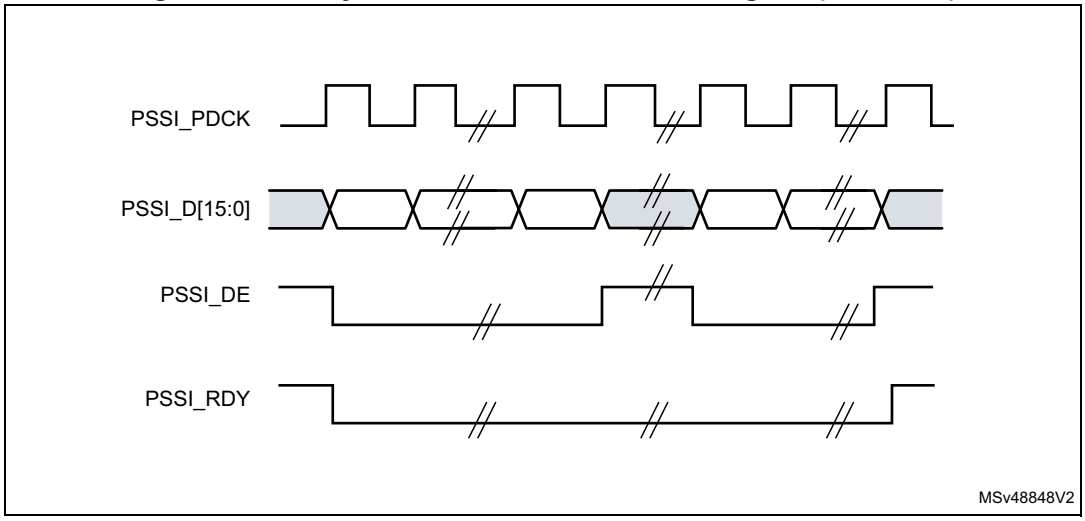
This alternate function signal can be enabled using the DERDYCFG control bits (bits 20:18 of PSSI_CR). PSSI_RDY polarity is configured through the RDYPOL control bit (bit 6 of PSSI_CR). PSSI_RDY is active low when RDYPOL is cleared to 0, and high when RDYPOL set to 1.

The direction of the PSSI_RDY signal is defined by the OUTEN (bit 31 of PSSI_CR). It is set in the opposite direction compared to the PSSI_DE and data signals.

If the PSSI_RDY alternate output function is enabled (through DERDYCFG) in receive mode (OUTEN=0), the PSSI drives PSSI_RDY one PSSI_PDCK half cycle after it samples

the data (D[15:0]). If the FIFO has enough free space to receive more data, the PSSI drives the PSSI_RDY signal active. Otherwise, if the FIFO is full and cannot accept more data, the PSSI drives the PSSI_RDY signal inactive. The transmitting device must repeat the current data in the next cycle when it detects that PSSI_RDY is inactive. This flow control function allows the PSSI to avoid overrun errors when the system (via the DMA) is unable to keep up with the data flow.

Figure 330. Ready in receive mode waveform diagram (CKPOL=0)



If the PSSI_RDY alternate input function is enabled (through DERDYCFG) in transmit mode (OUTEN=1), the PSSI samples the PSSI_RDY signal on the opposite PSSI_PDCK edge to the one at which D[15:0] are driven. If the PSSI_RDY signal is inactive, the PSSI keeps the same data (D[15:0]) and PSSI_DE signals that valid data are available during the next PSSI_PDCK clock cycle. Otherwise, if PSSI_RDY signal is sampled as active, the next data from the TX FIFO (if available) is output on the data outputs (D[15:0]). If no new data are available in the TX FIFO, the PSSI keeps the data output values and outputs the PSSI_DE signal as inactive (if enabled).

The receiving device uses the PSSI_RDY to control the data flow and avoid overrun errors when the system (via the DMA) is unable to keep up with the data flow.

Bidirectional PSSI_DE/PSSI_RDY signal

A single pin can be used for both data enable (PSSI_DE) and ready (PSSI_RDY) functions if DEPOL and RDYPOL are both set to 1 and DERDYCFG is set to 111 or 100 in the PSSI_CR register. In this case, the GPIO corresponding to selected alternate function (PSSI_DE when DERDYCFG=111 or PSSI_RDY when DERDYCFG=100) must be configured as open-drain. The other device must also be configured to drive the line as open-drain, and a weak pull-up must be applied to the line.

The signal thus becomes bidirectional. If either the sender drives the line low (to indicate that the data is not valid) or the receiver drives the line low (to indicate that it is not sampling the current data), then both devices know that the data is not being transferred in the current cycle.

Figure 331. Bidirectional PSSI_DE/PSSI_RDY waveform

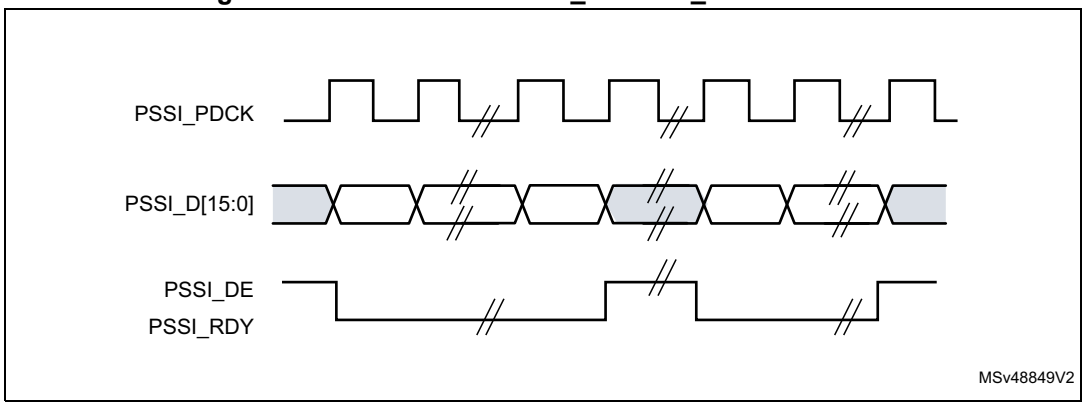
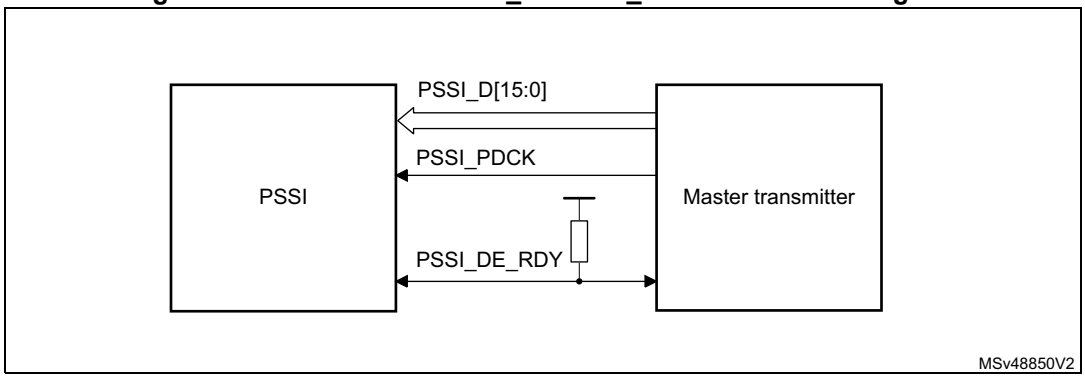


Figure 332. Bidirectional PSSI_DE/PSSI_RDY connection diagram



37.4 PSSI interrupts

The PSSI generates only one interrupt (IT_OVR). It is consequently equivalent to the global interrupt (pssi_it). Refer to *Table 309* for the list of interrupts.

The PSSI and the DCMI share the same interrupt vector. When the PSSI ENABLE bit (bit 14 of PSSI_CR) is set to 1, these interrupts are triggered by the PSSI. Otherwise, they are controlled by the DCMI.

The DCMI ENABLE bit (bit 14 of DCMI_CR) and PSSI ENABLE bit must not be set to 1 at the same time.

Table 309. PSSI interrupt requests

Interrupt acronym	Shared with DCMI	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit from low-power mode
IT_OVR	IT_OVR	indicates overrun in receive mode or underrun in transmit mode	OVR_RIS	OVR_IE	OVR_ISC	NA

37.5 PSSI registers

An 8-bit write or a 16-bit write operation to any PSSI register besides PSSI_DR, results in a bus error. 32-bit read and write operations are permitted.

37.5.1 PSSI control register (PSSI_CR)

Address offset: 0x00

Reset value: 0x4000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OUTEN	DMAEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DERDYCFG[2:0]			Res.	Res.
rw	rw										rw	rw	rw		

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	ENABLE	Res.	Res.	EDM[1:0]		Res.	RDYPOL	Res.	DEPOL	CKPOL	Res.	Res.	Res.	Res.	Res.
	rw			rw	rw		rw		rw	rw					

Bit 31 **OUTEN:** Data direction selection bit

0: Receive mode: data is input synchronously with PSSI_PDCK

1: Transmit mode: data is output synchronously with PSSI_PDCK

Bit 30 **DMAEN:** DMA enable bit

0: DMA transfers are disabled. The user application can directly access the PSSI_DR register when DMA transfers are disabled.

1: DMA transfers are enabled (default configuration). A DMA channel in the general-purpose DMA controller must be configured to perform transfers from/to PSSI_DR.

Bits 29:21 Reserved, must be kept at reset value.

Bits 20:18 **DERDYCFG[2:0]:** Data enable and ready configuration

000: PSSI_DE and PSSI_RDY both disabled

001: Only PSSI_RDY enabled

010: Only PSSI_DE enabled

011: Both PSSI_RDY and PSSI_DE alternate functions enabled

100: Both PSSI_RDY and PSSI_DE features enabled - bidirectional on PSSI_RDY pin (see *Bidirectional PSSI_DE/PSSI_RDY signal on page 1382*)

101: Only PSSI_RDY function enabled, but mapped to PSSI_DE pin

110: Only PSSI_DE function enabled, but mapped to PSSI_RDY pin

111: Both PSSI_RDY and PSSI_DE features enabled - bidirectional on PSSI_DE pin (see *Bidirectional PSSI_DE/PSSI_RDY signal on page 1382*)

When the PSSI_RDY function is mapped to the PSSI_DE pin (settings 101 or 111), it is still the RDYPOL bit which determines its polarity. Similarly, when the PSSI_DE function is mapped to the PSSI_RDY pin (settings 110 or 111), it is still the DEPOL bit which determines its polarity.

Bits 17:15 Reserved, must be kept at reset value.

Bit 14 **ENABLE:** PSSI enable

0: PSSI disabled

1: PSSI enabled

The contents of the FIFO are flushed when ENABLE is cleared to 0.

Note: When ENABLE=1, the content of PSSI_CR must not be changed, except for the ENABLE bit itself. All configuration bits can change as soon as ENABLE changes from 0 to 1.

The DMA controller and all PSSI configuration registers must be programmed correctly before setting the ENABLE bit to 1.

The ENABLE bit and the DCMI ENABLE bit (bit 15 of DCMI_CR) must not be set to 1 at the same time.

Bits 13:12 Reserved, must be kept at reset value.

Bits 11:10 **EDM[1:0]:** Extended data mode

00: Interface captures 8-bit data on every parallel data clock

01: Reserved, must not be selected

10: Reserved, must not be selected

11: The interface captures 16-bit data on every parallel data clock

Bit 9 Reserved, must be kept at reset value.

Bit 8 **RDYPOL:** Ready (PSSI_RDY) polarity

This bit indicates the level on the PSSI_RDY pin when the data are not valid on the parallel interface.

0: PSSI_RDY active low (0 indicates that the receiver is ready to receive)

1: PSSI_RDY active high (1 indicates that the receiver is ready to receive)

Bit 7 Reserved, must be kept at reset value.

Bit 6 **DEPOL:** Data enable (PSSI_DE) polarity

This bit indicates the level on the PSSI_DE pin when the data are not valid on the parallel interface.

0: PSSI_DE active low (0 indicates that data is valid)

1: PSSI_DE active high (1 indicates that data is valid)

Bit 5 **CKPOL:** Parallel data clock polarity

This bit configures the capture edge of the parallel clock or the edge used for driving outputs, depending on OUTEN.

0: Falling edge active for inputs or rising edge active for outputs

1: Rising edge active for inputs or falling edge active for outputs.

Bits 4:0 Reserved, must be kept at reset value.

37.5.2 PSSI status register (PSSI_SR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RTT1B	RTT4B	Res.	Res.
												r	r		

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **RTT1B:** FIFO is ready to transfer one byte

1: FIFO is ready for a one byte (32-bit) transfer. In receive mode, this means that at least one valid data byte is in the FIFO. In transmit mode, this means that there is at least one byte free in the FIFO.

0: FIFO is not ready for a 1-byte transfer

Bit 2 **RTT4B:** FIFO is ready to transfer four bytes

1: FIFO is ready for a four-byte (32-bit) transfer. In receive mode, this means that at least four valid data bytes are in the FIFO. In transmit mode, this means that there are at least four bytes free in the FIFO.

0: FIFO is not ready for a four-byte transfer

Bits 1:0 Reserved, must be kept at reset value.

37.5.3 PSSI raw interrupt status register (PSSI_RIS)

Address offset: 0x08

Reset value: 0x0000 0000

PSSI_RIS gives the raw interrupt status. This register is read-only. When read, it returns the status of the corresponding interrupt before masking with the PSSI_IER register value.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_RIS	Res.
														r	

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **OVR_RIS:** Data buffer overrun/underrun raw interrupt status
0: No overrun/underrun occurred
1: An overrun/underrun occurred: overrun in receive mode, underrun in transmit mode.
This bit is cleared by writing a 1 to the OVR_ISC bit in PSSI_ICR.

Bit 0 Reserved, must be kept at reset value.

37.5.4 PSSI interrupt enable register (PSSI_IER)

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_IE	Res.
														rw	

The PSSI_IER register is used to enable interrupts. When one of the PSSI_IER bits is set, the corresponding interrupt is enabled. This register is accessible both in read and write modes.

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **OVR_IE:** Data buffer overrun/underrun interrupt enable
0: No interrupt generation
1: An interrupt is generated if either an overrun or an underrun error occurred.

Bit 0 Reserved, must be kept at reset value.

37.5.5 PSSI masked interrupt status register (PSSI_MIS)

This PSSI_MIS register is read-only. When read, it returns the current masked status value of the corresponding interrupt (depending on the value in PSSI_IER). A bit in this register is

set if the corresponding enable bit in PSSI_IER is set and the corresponding bit in PSSI_RIS is set.

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_MIS	Res.
														r	

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **OVR_MIS:** Data buffer overrun/underrun masked interrupt status
This bit is set to 1 only when PSSI_IER/OVR_IE and PSSI_RIS/OVR_RIS are both set to 1.
0: No interrupt is generated when an overrun/underrun error occurs
1: An interrupt is generated if there is either an overrun or an underrun error and the OVR_IE bit is set in PSSI_IER.

Bit 0 Reserved, must be kept at reset value.

37.5.6 PSSI interrupt clear register (PSSI_ICR)

Address offset: 0x14

Reset value: 0x0000 0000

The PSSI_ICR register is write-only. Writing a 1 into a bit of this register clears the corresponding bit in the PSSI_RIS and PSSI_MIS registers. Writing a 0 has no effect. Reading this register always gives zeros.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_ISC	Res.
														w	

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **OVR_ISC:** Data buffer overrun/underrun interrupt status clear
Writing this bit to 1 clears the OVR_RIS bit in PSSI_RIS.

Bit 0 Reserved, must be kept at reset value.

37.5.7 PSSI data register (PSSI_DR)

Address offset: 0x28

Reset value: 0x0000 0000

In receive mode (OUTEN=0), the DMA controller must read the received data from this register. Write operations to PSSI_DR result in an error response. When more bytes than the number of valid bytes are read in the FIFO, the invalid bytes return zeros.

In transmit mode (OUTEN=1), the DMA controller must write the data to be transmitted into this register. Read operations to PSSI_DR result in an error response.

32-bit, 16-bit, and 8-bit accesses are all supported for PSSI_DR. For instance, 16-bit read/write operations remove/add two bytes from/to the FIFO. However, 8-bit accesses are permitted only when the PSSI is configured to transfer 8 data bits at a time (EDM=00 in PSSI_CR). 8-bit accesses to PSSI_DR when EDM is not set to 0 result in an error response.

All accesses must include byte 0: 8-bit accesses must be performed to bits 7 to 0 and 16-bit accesses from bits 15 to 0. Accesses that do not include byte 0 results in an error response.

Accessing PSSI_DR when ENABLE bit in PSSI_CR is set to 0 results in an error response.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BYTE3[7:0]								BYTE2[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BYTE1[7:0]								BYTE0[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **BYTE3[7:0]**: Data byte 3

Bits 23:16 **BYTE2[7:0]**: Data byte 2

Bits 15:8 **BYTE1[7:0]**: Data byte 1

Bits 7:0 **BYTE0[7:0]**: Data byte 0

37.5.8 PSSI register map

Table 310. PSSI register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	PSSI_CR	OUTEN	DMAEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DERDYCFG			Res.	Res.	Res.	ENABLE[2:0]			EDM		Res.	RDYPOL	Res.	DEPOL	CKPOL	Res.	Res.	Res.	Res.	Res.
	Reset value	0	1										0	0	0				0			0	0		0		0	0					
0x04	PSSI_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RTT1B	RTT4B	Res.	Res.
	Reset value																													0	0		

Table 310. PSSI register map and reset values (continued)

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x08	PSSI_RIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_RIS	Res.
	Reset value																															0	
0x0C	PSSI_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.am	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_IE	Res.
	Reset value																															0	
0x10	PSSI_MIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_MIS	Res.
	Reset value																															0	
0x14	PSSI_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OVR_ISC	Res.
	Reset value																															0	
0x18 to 0x24	Reserved	Res.																															
0x28	PSSI_DR	BYTE3[7:0]								BYTE2[7:0]								BYTE1[7:0]								BYTE0[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

38 LCD-TFT display controller (LTDC)

38.1 Introduction

The LCD-TFT (liquid crystal display - thin film transistor) display controller provides a parallel digital RGB (red, green, blue) and signals for horizontal, vertical synchronization, pixel clock and data enable as output to interface directly to a variety of LCD and TFT panels.

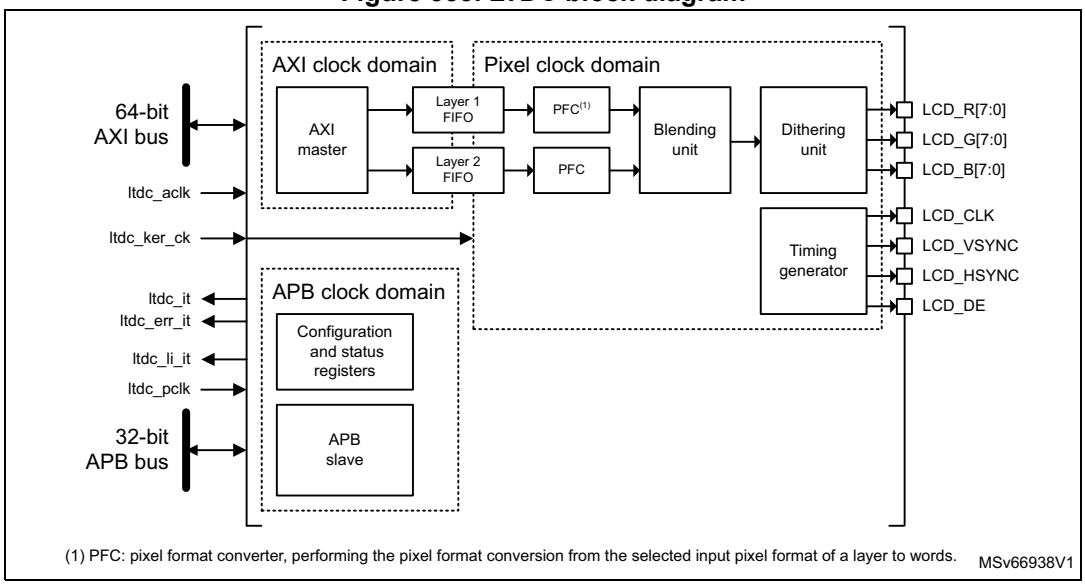
38.2 LTDC main features

- 24-bit RGB parallel pixel output; 8 bits-per-pixel (RGB888)
- 2 display layers with dedicated FIFO (64x64-bit)
- Color look-up table (CLUT) up to 256 color (256x24-bit) per layer
- Programmable timings for different display panels
- Programmable background color
- Programmable polarity for HSYNC, VSYNC and data enable
- Up to 8 input color formats selectable per layer:
  - ARGB8888
  - RGB888
  - RGB565
  - ARGB1555
  - ARGB4444
  - L8 (8-bit luminance or CLUT)
  - AL44 (4-bit alpha + 4-bit luminance)
  - AL88 (8-bit alpha + 8-bit luminance)
- Pseudo-random dithering output for low bits per channel
  - Dither width 2 bits for red, green, blue
- Flexible blending between two layers using alpha value (per pixel or constant)
- Color keying (transparency color)
- Programmable window position and size
- Supports thin film transistor (TFT) color displays
- AXI master interface with burst of 16 double-words
- Up to 4 programmable interrupt events

38.3 LTDC functional description

38.3.1 LTDC block diagram

Figure 333. LTDC block diagram



38.3.2 LTDC pins and internal signals

The table below summarizes the LTDC signal interface.

Table 311. LTDC external pins

LCD-TFT signals	Signal type	Description
LCD_CLK	Output	Clock output
LCD_HSYNC	Output	Horizontal synchronization
LCD_VSYNC	Output	Vertical synchronization
LCD_DE	Output	Not data enable
LCD_R[7:0]	Output	8-bit Red data
LCD_G[7:0]	Output	8-bit Green data
LCD_B[7:0]	Output	8-bit Blue data

The LTDC pins must be configured by the user application. The unused pins can be used for other purposes.

For LTDC outputs up to 24 bits (RGB888), if less than 8 bpp are used to output for example RGB565 or RGB666 to interface on 16- or 18-bit displays, the RGB display data lines must be connected to the MSB of the LTDC RGB data lines.

As an example, in the case of an LTDC interfacing with a RGB565 16-bit display, the LTDC display R[4:0], G[5:0] and B[4:0] data lines pins must be connected to the LCD_R[7:3], LCD_G[7:2] and LCD_B[7:3] pins.

The internal signals of the LTDC are given in the table below.

Table 312. LTDC internal signals

Names	Signal type	Description
ltdc_aclk	Input	LTDC AXI clock
ltdc_pclk	Input	LTDC APB clock for register access
ltdc_ker_ck	Input	LTDC kernel clock used for LCD_CLK (pixel clock) generation
ltdc_li_it	Output	LTDC line interrupt trigger for MDMA
ltdc_it	Output	LTDC global interrupt request
ltdc_err_it	Output	LTDC global error interrupt request

38.3.3 LTDC reset and clocks

The LTDC controller peripheral uses the following clock domains:

- AXI clock domain (ltdc_aclk)

  This domain contains the LTDC AXI master interface for data transfer from the memories to the layer FIFO and the frame-buffer configuration register.
- APB clock domain (ltdc_pclk)

  This domain contains the global configuration registers and the interrupt register.
- Pixel clock domain (LCD_CLK)

  This domain contains the pixel data generation, the layer configuration register as well as the LTDC interface signal generator. The LCD_CLK output must be configured following the panel requirements. The LCD_CLK is generated from a specific PLL output (refer to the reset and clock control section).

The table below summarizes the clock domain for each register.

Table 313. Clock domain for each register

LTDC register	Clock domain
LTDC_LxCR	ltdc_aclk
LTDC_LxCFBAR	
LTDC_LxCFBLR	
LTDC_LxCFBLNR	
LTDC_SRCR	ltdc_pclk
LTDC_IER	
LTDC_ISR	
LTDC_ICR	

Table 313. Clock domain for each register (continued)

LTDC register	Clock domain
LTDC_SSCR	Pixel clock (LCD_CLK)
LTDC_BPCR	
LTDC_AWCR	
LTDC_TWCR	
LTDC_GCR	
LTDC_BCCR	
LTDC_LIPCR	
LTDC_CPSR	
LTDC_CDSR	
LTDC_LxWHPCR	
LTDC_LxWVPCR	
LTDC_LxCKCR	
LTDC_LxPFCR	
LTDC_LxCACR	
LTDC_LxDCCR	
LTDC_LxBFCR	
LTDC_LxCLUTWR	

Care must be taken while accessing the LTDC registers, the APB bus is stalled during the access for a given time period (see the table below).

Table 314. LTDC register access and update durations

	Register clock domain		
	AXI domain	**APB domain**	**Pixel clock domain**
Register read access duration	7 x ltdc_pclk + 5 x ltdc_aclk	7 x ltdc_pclk	7 x ltdc_pclk + 5 x ltdc_ker_clk
Register write access duration	6 x ltdc_pclk + 5 x ltdc_aclk	6 x ltdc_pclk	6 x ltdc_pclk + 5 x ltdc_ker_clk

The LTDC controller can be reset by setting the corresponding bit in the RCC. It resets the three clock domains.

38.4 LTDC programmable parameters

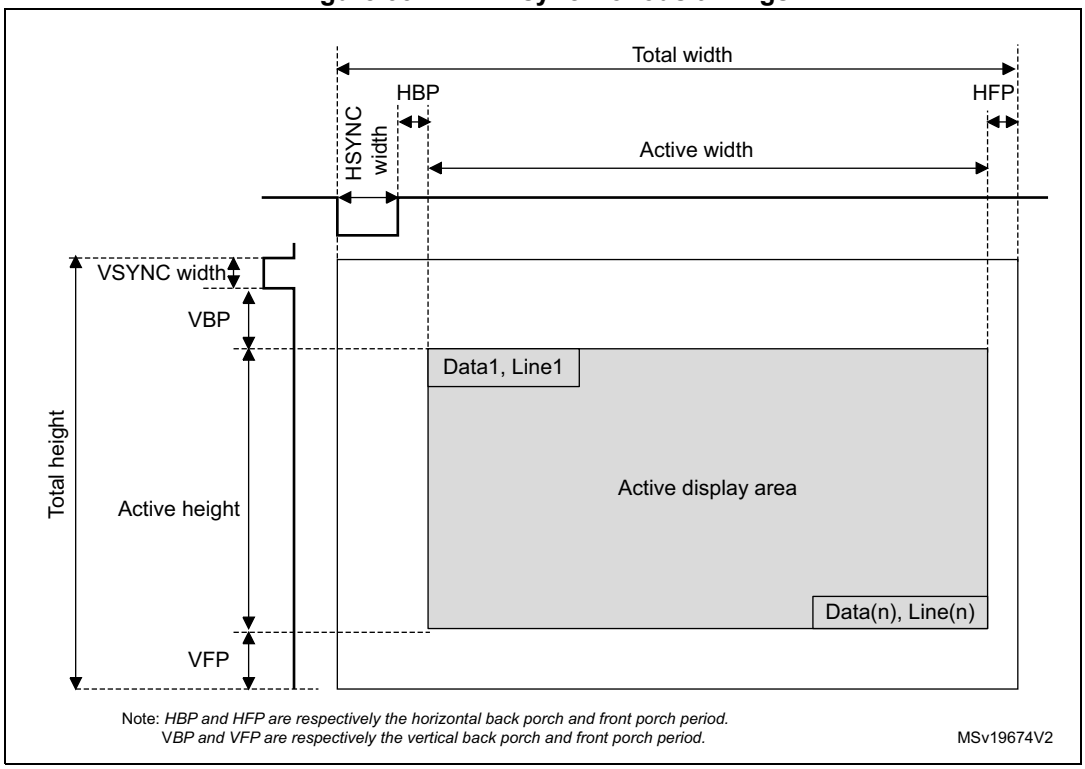
The LTDC controller provides flexible configurable parameters. It can be enabled or disabled through the LTDC_GCR register.

38.4.1 LTDC global configuration parameters

Synchronous timings

The figure below presents the configurable timing parameters generated by the synchronous timings generator block presented in the block diagram *Figure 333*. It generates the horizontal and vertical synchronization timings panel signals, the pixel clock and the data enable signals.

Figure 334. LTDC synchronous timings



The LTDC programmable synchronous timings are the following:

- HSYNC and VSYNC width: horizontal and vertical synchronization width, configured by programming a value of HSYNC width - 1 and VSYNC width - 1 in the LTDC_SSCR register
- HBP and VBP: horizontal and vertical synchronization back porch width, configured by programming the accumulated value HSYNC width + HBP - 1 and the accumulated value VSYNC width + VBP - 1 in the LTDC_BPCR register.
- Active width and active height: the active width and active height are configured by programming the accumulated value HSYNC width + HBP + active width - 1 and the

accumulated value VSYNC width + VBP + active height - 1 in the LTDC_AWCR register.

- Total width: the total width is configured by programming the accumulated value HSYNC width + HBP + active width + HFP - 1 in the LTDC_TWCR register. The HFP is the horizontal front porch period.
- Total height: the total height is configured by programming the accumulated value VSYNC height + VBP + active height + VFP - 1 in the LTDC_TWCR register. The VFP is the vertical front porch period.

Note: When the LTDC is enabled, the timings generated start with X/Y = 0/0 position as the first horizontal synchronization pixel in the vertical synchronization area and following the back porch, active data display area and the front porch.
When the LTDC is disabled, the timing generator block is reset to X = total width - 1, Y = total height - 1 and held the last pixel before the vertical synchronization phase and the FIFO are flushed. Therefore only blanking data is output continuously.

Example of synchronous timings configuration

LTDC timings (must be extracted from panel datasheet):

- horizontal and vertical synchronization width: 0xA pixels and 0x2 lines
- horizontal and vertical back porch: 0x14 pixels and 0x2 lines
- active width and active height: 0x140 pixels, 0xF0 lines (320x240)
- horizontal front porch: 0xA pixels
- vertical front porch: 0x4 lines

The programmed values in the LTDC timings registers are:

- LTDC_SSCR register to be programmed to 0x00090001
(HSW[11:0] is 0x9 and VSH[10:0] is 0x1)
- LTDC_BPCR register to be programmed to 0x001D0003
(AHBP[11:0] is 0x1D (0xA+ 0x13) and AVBP[10:0]A is 0x3 (0x2 + 0x1))
- LTDC_AWCR register to be programmed to 0x015D00F3
(AAW[11:0] is 0x15D (0xA +0x14 +0x13F) and AAH[10:0] is 0xF3 (0x2 + 0x2 + 0xEF))
- LTDC_TWCR register to be programmed to 0x00000167
(TOTALW[11:0] is 0x167 (0xA +0x14 +0x140 + 0x9))
- LTDC_THCR register to be programmed to 0x000000F7
(TOTALH[10:0]is 0xF7 (0x2 +0x2 + 0xF0 + 3))

Programmable polarity

The horizontal and vertical synchronization, data enable and pixel clock output signals polarity can be programmed to active high or active low through the LTDC_GCR register.

Background color

A constant background color (RGB888) can programmed through the LTDC_BCCR register. It is used for blending with the bottom layer.

Dithering

The dithering pseudo-random technique using an LFSR is used to add a small random value (threshold) to each pixel color channel (R, G or B) value, thus rounding up the MSB in

some cases when displaying a 24-bit data on 18-bit display. Thus the dithering technique is used to round data which is different from one frame to the other.

The dithering pseudo-random technique is the same as comparing LSBs against a threshold value and adding a 1 to the MSB part only, if the LSB part is ≥ the threshold. The LSBs are typically dropped once dithering was applied.

The width of the added pseudo-random value is two bits for each color channel: two bits for red, two bits for green and two bits for blue.

Once the LTDC is enabled, the LFSR starts running with the first active pixel and it is kept running even during blanking periods and when dithering is switched off. If the LTDC is disabled, the LFSR is reset.

The dithering can be switched on and off on the fly through the LTDC_GCR register.

Reload shadow registers

Some configuration registers are shadowed. The shadow registers values can be reloaded immediately to the active registers when writing to these registers or at the beginning of the vertical blanking period following the configuration in the LTDC_SRCR register. If the immediate reload configuration is selected, the reload must be activated only when all new registers have been written.

The shadow registers must not be modified again before the reload is done. Reading from the shadow registers returns the actual active value. The new written value can only be read after the reload has taken place.

A register reload interrupt can be generated if enabled in the LTDC_IER register.

The shadowed registers are all Layer1 and Layer2 registers except LTDC_LxCLUTWR.

Interrupt generation event

Refer to *Section 38.5: LTDC interrupts* for the interrupt configuration.

38.4.2 Layer programmable parameters

Up to two layers can be enabled, disabled and configured separately. The layer display order is fixed and it is bottom up. If two layers are enabled, the layer2 is the top displayed window.

Windowing

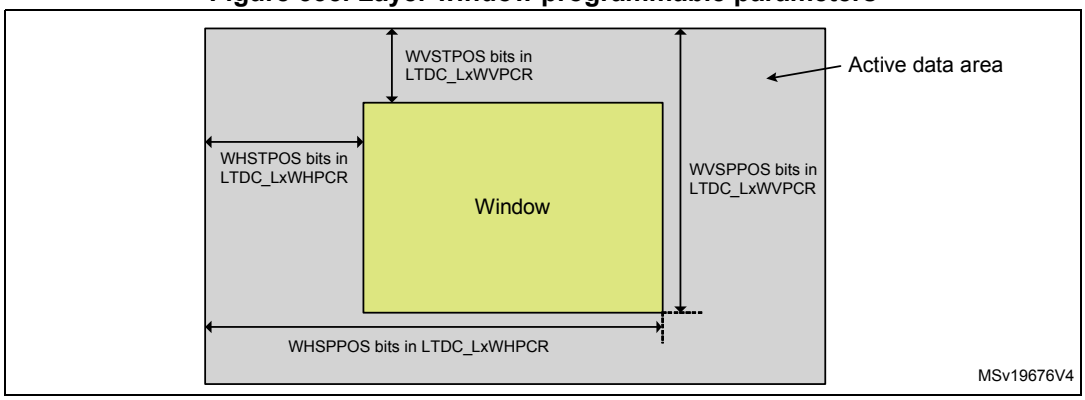
Every layer can be positioned and resized and it must be inside the active display area.

The window position and size are configured through the top-left and bottom-right X/Y positions and the internal timing generator that includes the synchronous, back porch size and the active data area. Refer to LTDC_LxWHPCR and LTDC_WVPCR registers.

The programmable layer position and size defines the first/last visible pixel of a line and the first/last visible line in the window. It allows to display either the full image frame or only a part of the image frame (see the figure below):

- The first and the last visible pixel in the layer are set by configuring the WHSTPOS[11:0] and WHSPPOS[11:0] in the LTDC_LxWHPCR register.
- The first and the last visible lines in the layer are set by configuring the WVSTPOS[10:0] and WVSPPOS[10:0] in the LTDC_LxWVPCR register.

Figure 335. Layer window programmable parameters



Pixel input format

The programmable pixel format is used for the data stored in the frame buffer of a layer.

Up to eight input pixel formats can be configured for every layer through the LTDC_LxPFCR register

The pixel data is read from the frame buffer and then transformed to the internal 8888 (ARGB) format as follows: components having a width of less than 8 bits get expanded to 8 bits by bit replication. The selected bit range is concatenated multiple times until it is longer than 8 bits. Of the resulting vector, the 8 MSB bits are chosen. Example: 5 bits of an RGB565 red channel become (bit positions) 43210432 (the three LSBs are filled with the three MSBs of the five bits)

The table below describes the pixel data mapping depending on the selected format.

Table 315. Pixel data mapping versus color format

ARGB8888			
@+3 A_x[7:0]	@+2 R_x[7:0]	@+1 G_x[7:0]	@ B_x[7:0]
@+7 A_{x+1}[7:0]	@+6 R_{x+1}[7:0]	@+5 G_{x+1}[7:0]	@+4 B_{x+1}[7:0]
RGB888			
@+3 B_{x+1}[7:0]	@+2 R_x[7:0]	@+1 G_x[7:0]	@ B_x[7:0]
@+7 G_{x+2}[7:0]	@+6 B_{x+2}[7:0]	@+5 R_{x+1}[7:0]	@+4 G_{x+1}[7:0]
RGB565			

Table 315. Pixel data mapping versus color format (continued)

@+3 $R_{x+1}[4:0]$ $G_{x+1}[5:3]$	@+2 $G_{x+1}[2:0]$ $B_{x+1}[4:0]$	@+1 $R_x[4:0]$ $G_x[5:3]$	@ $G_x[2:0]$ $B_x[4:0]$
@+7 $R_{x+3}[4:0]$ $G_{x+3}[5:3]$	@+6 $G_{x+3}[2:0]$ $B_{x+3}[4:0]$	@+5 $R_{x+2}[4:0]$ $G_{x+2}[5:3]$	@+4 $G_{x+2}[2:0]$ $B_{x+2}[4:0]$
ARGB1555			
@+3 $A_{x+1}[0]R_{x+1}[4:0]$ $G_{x+1}[4:3]$	@+2 $G_{x+1}[2:0]$ $B_{x+1}[4:0]$	@+1 $A_x[0]$ $R_x[4:0]$ $G_x[4:3]$	@ $G_x[2:0]$ $B_x[4:0]$
@+7 $A_{x+3}[0]R_{x+3}[4:0]$ $G_{x+3}[4:3]$	@+6 $G_{x+3}[2:0]$ $B_{x+3}[4:0]$	@+5 $A_{x+2}[0]R_{x+2}[4:0]G_{x+2}[4:3]$	@+4 $G_{x+2}[2:0]$ $B_{x+2}[4:0]$
ARGB4444			
@+3 $A_{x+1}[3:0]R_{x+1}[3:0]$	@+2 $G_{x+1}[3:0]$ $B_{x+1}[3:0]$	@+1 $A_x[3:0]$ $R_x[3:0]$	@ $G_x[3:0]$ $B_x[3:0]$
@+7 $A_{x+3}[3:0]R_{x+3}[3:0]$	@+6 $G_{x+3}[3:0]$ $B_{x+3}[3:0]$	@+5 $A_{x+2}[3:0]R_{x+2}[3:0]$	@+4 $G_{x+2}[3:0]$ $B_{x+2}[3:0]$
L8			
@+3 $L_{x+3}[7:0]$	@+2 $L_{x+2}[7:0]$	@+1 $L_{x+1}[7:0]$	@ $L_x[7:0]$
@+7 $L_{x+7}[7:0]$	@+6 $L_{x+6}[7:0]$	@+5 $L_{x+5}[7:0]$	@+4 $L_{x+4}[7:0]$
AL44			
@+3 $A_{x+3}[3:0]$ $L_{x+3}[3:0]$	@+2 $A_{x+2}[3:0]$ $L_{x+2}[3:0]$	@+1 $A_{x+1}[3:0]$ $L_{x+1}[3:0]$	@ $A_x[3:0]$ $L_x[3:0]$
@+7 $A_{x+7}[3:0]$ $L_{x+7}[3:0]$	@+6 $A_{x+6}[3:0]$ $L_{x+6}[3:0]$	@+5 $A_{x+5}[3:0]$ $L_{x+5}[3:0]$	@+4 $A_{x+4}[3:0]$ $L_{x+4}[3:0]$
AL88			
@+3 $A_{x+1}[7:0]$	@+2 $L_{x+1}[7:0]$	@+1 $A_x[7:0]$	@ $L_x[7:0]$
@+7 $A_{x+3}[7:0]$	@+6 $L_{x+3}[7:0]$	@+5 $A_{x+2}[7:0]$	@+4 $L_{x+2}[7:0]$

Color look-up table (CLUT)

The CLUT can be enabled at run-time for every layer through the LTDC_LxCR register and it is only useful in case of indexed color when using the L8, AL44 and AL88 input pixel format.

First, the CLUT must be loaded with the R, G and B values that replace the original R, G, B values of that pixel (indexed color). Each color (RGB value) has its own address that is the position within the CLUT.

The R, G and B values and their own respective address are programmed through the LTDC_LxCLUTWR register:

- In case of L8 and AL88 input pixel format, the CLUT must be loaded by 256 colors. The address of each color is configured in the CLUTADD bits in the LTDC_LxCLUTWR register.
- In case of AL44 input pixel format, the CLUT must be loaded by only16 colors. The address of each color must be filled by replicating the 4-bit L channel to 8-bit as follows:
  - L0 (indexed color 0), at address 0x00
  - L1, at address 0x11
  - L2, at address 0x22
  - .....
  - L15, at address 0xFF

Color frame buffer address

Every layer has a start address for the color frame buffer configured through the LTDC_LxCFBAR register.

When a layer is enabled, the data is fetched from the color frame buffer.

Color frame buffer length

Every layer has a total line length setting for the color frame buffer in bytes and a number of lines in the frame buffer configurable in the LTDC_LxCFBLR and LTDC_LxCFBLNR register respectively.

The line length and the number of lines settings are used to stop the prefetching of data to the layer FIFO at the end of the frame buffer:

- If it is set to less bytes than required, a FIFO underrun interrupt is generated if it has been previously enabled.
- If it is set to more bytes than actually required, the useless data read from the FIFO is discarded. The useless data is not displayed.

Color frame buffer pitch

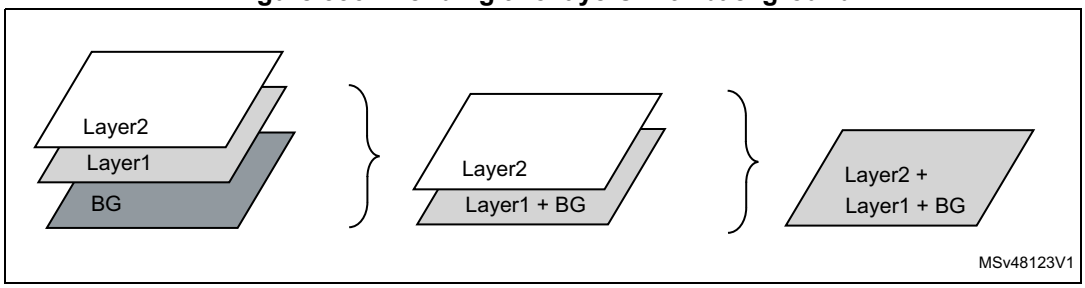
Every layer has a configurable pitch for the color frame buffer, that is the distance between the start of one line and the beginning of the next line in bytes. It is configured through the LTDC_LxCFBLR register.

Layer blending

The blending is always active and the two layers can be blended following the blending factors configured through the LTDC_LxBFCR register.

The blending order is fixed and it is bottom up. If two layers are enabled, first the Layer1 is blended with the Background color, then the layer2 is blended with the result of blended color of layer1 and the background. Refer to the figure below.

Figure 336. Blending two layers with background



Default color

Every layer can have a default color in the format ARGB which is used outside the defined layer window or when a layer is disabled.

The default color is configured through the LTDC_LxDCCR register.

The blending is always performed between the two layers even when a layer is disabled. To avoid displaying the default color when a layer is disabled, keep the blending factors of this layer in the LTDC_LxBFCR register to their reset value.

Color keying

A color key (RGB) can be configured to be representative for a transparent pixel.

If the color keying is enabled, the current pixels (after format conversion and before CLUT respectively blending) are compared to the color key. If they match for the programmed RGB value, all channels (ARGB) of that pixel are set to 0.

The color key value can be configured and used at run-time to replace the pixel RGB value.

The color keying is enabled through the LTDC_LxCKCR register.

The color keying is configured through the LTDC_LxCKCR register. The programmed value depends on the pixel format as it is compared to current pixel after pixel format conversion to ARGB888.

Example: if the a mid-yellow color (50 % red + 50 % green) is used as the transparent color key:

- In RGB565, the mid-yellow color is 0x8400. Set the LTDC_LxCKCR to 0x848200.
- In ARGB8888, the mid-yellow color is 0x808000. Set LTDC_LxCKCR to 0x808000.
- In all CLUT-based color modes (L8, AL88, AL44), set one of the palette entry to the mid-yellow color 0x808000 and set the LTDC_LxCKCR to 0x808000.

38.5 LTDC interrupts

The LTDC provides four maskable interrupts logically ORed to two interrupt vectors.

The interrupt sources can be enabled or disabled separately through the LTDC_IER register. Setting the appropriate mask bit to 1 enables the corresponding interrupt.

The two interrupts are generated on the following events:

- Line interrupt: generated when a programmed line is reached. The line interrupt position is programmed in the LTDC_LIPCR register
- Register reload interrupt: generated when the shadow registers reload is performed during the vertical blanking period
- FIFO underrun interrupt: generated when a pixel is requested from an empty layer FIFO
- Transfer error interrupt: generated when an AXI bus error occurs during data transfer

Those interrupts events are connected to the NVIC controller as described in the figure below.

Figure 337. Interrupt events

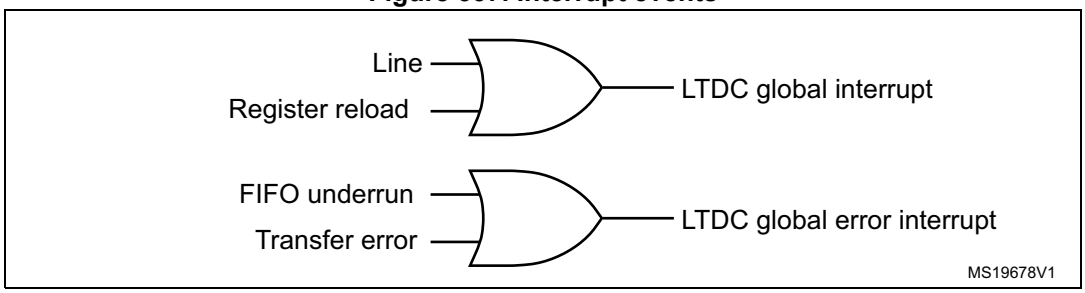


Table 316. LTDC interrupt requests

Interrupt event	Event flag	Enable control bit
Line	LIF	LIE
Register reload	RRIF	RRIEN
FIFO underrun	FUDERRIF	FUDERRIE
Transfer error	TERRIF	TERRIE

38.6 LTDC programming procedure

The steps listed below are needed to program the LTDC:

1. Enable the LTDC clock in the RCC register.
2. Configure the required pixel clock following the panel datasheet.
3. Configure the synchronous timings: VSYNC, HSYNC, vertical and horizontal back porch, active data area and the front porch timings following the panel datasheet as described in the *Section 38.4.1*.
4. Configure the synchronous signals and clock polarity in the LTDC_GCR register.
5. If needed, configure the background color in the LTDC_BCCR register.
6. Configure the needed interrupts in the LTDC_IER and LTDC_LIPCR register.
7. Configure the layer1/2 parameters by:
   - programming the layer window horizontal and vertical position in the LTDC_LxWHPCR and LTDC_WVPCR registers. The layer window must be in the active data area.
   - programming the pixel input format in the LTDC_LxPFCR register
   - programming the color frame buffer start address in the LTDC_LxCFBAR register
   - programming the line length and pitch of the color frame buffer in the LTDC_LxCFBLR register
   - programming the number of lines of the color frame buffer in the LTDC_LxCFBLNR register
   - if needed, loading the CLUT with the RGB values and its address in the LTDC_LxCLUTWR register
   - If needed, configuring the default color and the blending factors respectively in the LTDC_LxDCCR and LTDC_LxBFCR registers
8. Enable layer1/2 and if needed the CLUT in the LTDC_LxCR register.
9. If needed, enable dithering and color keying respectively in the LTDC_GCR and LTDC_LxCKCR registers. They can be also enabled on the fly.
10. Reload the shadow registers to active register through the LTDC_SRCR register.
11. Enable the LTDC controller in the LTDC_GCR register.
12. All layer parameters can be modified on the fly except the CLUT. The new configuration must be either reloaded immediately or during vertical blanking period by configuring the LTDC_SRCR register.

Note: All layer's registers are shadowed. Once a register is written, it must not be modified again before the reload has been done. Thus, a new write to the same register overrides the previous configuration if not yet reloaded.

38.7 LTDC registers

38.7.1 LTDC synchronization size configuration register (LTDC_SSCR)

Address offset: 0x008

Reset value: 0x0000 0000

This register defines the number of horizontal synchronization pixels minus 1 and the number of vertical synchronization lines minus 1. Refer to *Figure 334* and *Section 38.4* for an example of configuration.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	HSW[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	VSH[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **HSW[11:0]**: horizontal synchronization width (in units of pixel clock period)
These bits define the number of Horizontal Synchronization pixel minus 1.

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:0 **VSH[10:0]**: vertical synchronization height (in units of horizontal scan line)
These bits define the vertical Synchronization height minus 1. It represents the number of horizontal synchronization lines.

38.7.2 LTDC back porch configuration register (LTDC_BPCR)

Address offset: 0x00C

Reset value: 0x0000 0000

This register defines the accumulated number of horizontal synchronization and back porch pixels minus 1 (HSYNC width + HBP - 1) and the accumulated number of vertical synchronization and back porch lines minus 1 (VSYNC height + VBP - 1). Refer to *Figure 334* and *Section 38.4* for an example of configuration.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	AHBP[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	AVBP[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **AHBP[11:0]**: accumulated horizontal back porch (in units of pixel clock period)

These bits define the accumulated horizontal back porch width that includes the horizontal synchronization and horizontal back porch pixels minus 1.

The horizontal back porch is the period between horizontal synchronization going inactive and the start of the active display part of the next scan line.

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:0 **AVBP[10:0]:** accumulated Vertical back porch (in units of horizontal scan line)

These bits define the accumulated vertical back porch width that includes the vertical synchronization and vertical back porch lines minus 1.

The vertical back porch is the number of horizontal scan lines at a start of frame to the start of the first active scan line of the next frame.

38.7.3 LTDC active width configuration register (LTDC_AWCR)

Address offset: 0x010

Reset value: 0x0000 0000

This register defines the accumulated number of horizontal synchronization, back porch and active pixels minus 1 (HSYNC width + HBP + active width - 1) and the accumulated number of vertical synchronization, back porch lines and active lines minus 1 (VSYNC height + VBP + active height - 1). Refer to *Figure 334* and *Section 38.4* for an example of configuration.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	AAW[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	AAH[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **AAW[11:0]**: accumulated active width (in units of pixel clock period)

These bits define the accumulated active width which includes the horizontal synchronization, horizontal back porch and active pixels minus 1.

The active width is the number of pixels in active display area of the panel scan line.

Refer to device datasheet for maximum active width supported following maximum pixel clock.

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:0 **AAH[10:0]**: accumulated active height (in units of horizontal scan line)

These bits define the accumulated height which includes the vertical synchronization, vertical back porch and the active height lines minus 1. The active height is the number of active lines in the panel.

Refer to device datasheet for maximum active height supported following maximum pixel clock.

38.7.4 LTDC total width configuration register (LTDC_TWCR)

Address offset: 0x014

Reset value: 0x0000 0000

This register defines the accumulated number of horizontal synchronization, back porch, active and front porch pixels minus 1 (HSYNC width + HBP + active width + HFP - 1) and the accumulated number of vertical synchronization, back porch lines, active and front lines minus 1 (VSYNC height + VBP + active height + VFP - 1). Refer to *Figure 334* and *Section 38.4* for an example of configuration.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TOTALW[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	TOTALH[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **TOTALW[11:0]**: total width (in units of pixel clock period)

These bits defines the accumulated total width which includes the horizontal synchronization, horizontal back porch, active width and horizontal front porch pixels minus 1.

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:0 **TOTALH[10:0]**: total height (in units of horizontal scan line)

These bits defines the accumulated height which includes the vertical synchronization, vertical back porch, the active height and vertical front porch height lines minus 1.

38.7.5 LTDC global control register (LTDC_GCR)

Address offset: 0x018

Reset value: 0x0000 2220

This register defines the global configuration of the LCD-TFT controller.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HSPOL	VSPOL	DEPOL	PCPOL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEN
rw	rw	rw	rw												rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	DRW[2:0]			Res.	DGW[2:0]			Res.	DBW[2:0]			Res.	Res.	Res.	LTDCEN
	r	r	r		r	r	r		r	r	r				rw

Bit 31 **HSPOL**: horizontal synchronization polarity

This bit is set and cleared by software.

0: horizontal synchronization polarity is active low.

1: horizontal synchronization polarity is active high.

Bit 30 **VSPOL**: vertical synchronization polarity
This bit is set and cleared by software.
0: vertical synchronization is active low.
1: vertical synchronization is active high.

Bit 29 **DEPOL**: not data enable polarity
This bit is set and cleared by software.
0: not data enable polarity is active low.
1: not data enable polarity is active high.

Bit 28 **PCPOL**: pixel clock polarity
This bit is set and cleared by software.
0: pixel clock polarity is active low.
1: pixel clock is active high.

Bits 27:17 Reserved, must be kept at reset value.

Bit 16 **DEN**: dither enable
This bit is set and cleared by software.
0: dither disabled
1: dither enabled

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **DRW[2:0]**: dither red width
These bits return the Dither Red Bits.

Bit 11 Reserved, must be kept at reset value.

Bits 10:8 **DGW[2:0]**: dither green width
These bits return the dither green bits.

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **DBW[2:0]**: dither blue width
These bits return the dither blue bits.

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **LTDCEN**: LCD-TFT controller enable
This bit is set and cleared by software.
0: LTDC disabled
1: LTDC enabled

38.7.6 LTDC shadow reload configuration register (LTDC_SRCR)

Address offset: 0x024

Reset value: 0x0000 0000

This register allows to reload either immediately or during the vertical blanking period, the shadow registers values to the active registers. The shadow registers are all Layer1 and Layer2 registers except the LTDC_L1CLUTWR and the LTDC_L2CLUTWR.

The shadow registers read back the active values. Until the reload has been done, the 'old' value is read.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VBR	IMR
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **VBR**: vertical blanking reload

This bit is set by software and cleared only by hardware after reload (it cannot be cleared through register write once it is set).

0: no effect

1: The shadow registers are reloaded during the vertical blanking period (at the beginning of the first line after the active display area).

Bit 0 **IMR**: immediate reload

This bit is set by software and cleared only by hardware after reload.

0: no effect

1: The shadow registers are reloaded immediately.

38.7.7 LTDC background color configuration register (LTDC_BCCR)

Address offset: 0x02C

Reset value: 0x0000 0000

This register defines the background color (RGB888).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BCRED[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BCGREEN[7:0]								BCBLUE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **BCRED[7:0]**: background color red value
These bits configure the background red value.

Bits 15:8 **BCGREEN[7:0]**: background color green value
These bits configure the background green value.

Bits 7:0 **BCBLUE[7:0]**: background color blue value
These bits configure the background blue value.

38.7.8 LTDC interrupt enable register (LTDC_IER)

Address offset: 0x034

Reset value: 0x0000 0000

This register determines which status flags generate an interrupt request by setting the corresponding bit to 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RRIE	TERRIE	FUIE	LIE
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **RRIE**: register reload interrupt enable
This bit is set and cleared by software.
0: register reload interrupt disable
1: register reload interrupt enable

Bit 2 **TERRIE**: transfer error interrupt enable
This bit is set and cleared by software.
0: transfer error interrupt disable
1: transfer error interrupt enable

Bit 1 **FUIE**: FIFO underrun interrupt enable
This bit is set and cleared by software.
0: FIFO underrun interrupt disable
1: FIFO underrun Interrupt enable

Bit 0 **LIE**: line interrupt enable
This bit is set and cleared by software.
0: line interrupt disable
1: line interrupt enable

38.7.9 LTDC interrupt status register (LTDC_ISR)

Address offset: 0x038

Reset value: 0x0000 0000

This register returns the interrupt status flag.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RRIF	TERRIF	FUIF	LIF
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **RRIF**: register reload interrupt flag
0: no register reload interrupt generated
1: register reload interrupt generated when a vertical blanking reload occurs (and the first line after the active area is reached)

Bit 2 **TERRIF**: transfer error interrupt flag
0: no transfer error interrupt generated
1: transfer error interrupt generated when a bus error occurs

Bit 1 **FUIF**: FIFO underrun interrupt flag
0: no FIFO underrun interrupt generated.
1: FIFO underrun interrupt generated, if one of the layer FIFOs is empty and pixel data is read from the FIFO

Bit 0 **LIF**: line interrupt flag
0: no line interrupt generated
1: line interrupt generated when a programmed line is reached

38.7.10 LTDC interrupt clear register (LTDC_ICR)

Address offset: 0x03C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CRRIF	CTERRIF	CFUIF	CLIF
												w	w	w	w

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **CRRIF**: clears register reload interrupt flag
0: no effect
1: clears the RRIF flag in the LTDC_ISR register

Bit 2 **CTERRIF**: clears the transfer error interrupt flag
0: no effect
1: clears the TERRIF flag in the LTDC_ISR register.

Bit 1 **CFUIF**: clears the FIFO underrun interrupt flag
0: no effect
1: clears the FUDERRIF flag in the LTDC_ISR register.

Bit 0 **CLIF**: clears the line interrupt flag
0: no effect
1: clears the LIF flag in the LTDC_ISR register.

38.7.11 LTDC line interrupt position configuration register (LTDC_LIPCR)

Address offset: 0x040

Reset value: 0x0000 0000

This register defines the position of the line interrupt. The line value to be programmed depends on the timings parameters. Refer to *Figure 334*.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	LIPOS[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:0 **LIPOS[10:0]**: line interrupt position
These bits configure the line interrupt position.

38.7.12 LTDC current position status register (LTDC_CPSR)

Address offset: 0x044

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CXPOS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CYPOS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **CXPOS[15:0]**: current X position
These bits return the current X position.

Bits 15:0 **CYPOS[15:0]**: current Y position
These bits return the current Y position.

38.7.13 LTDC current display status register (LTDC_CDSR)

Address offset: 0x048

Reset value: 0x0000 000F

This register returns the status of the current display phase which is controlled by the HSYNC, VSYNC, and horizontal/vertical DE signals.

Example: if the current display phase is the vertical synchronization, the VSYNCS bit is set (active high). If the current display phase is the horizontal synchronization, the HSYNCS bit is active high.

The returned status does not depend on the configured polarity in the LTDC_GCR register, instead it returns the current active display phase.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSYNCS	VSYNCS	HDES	VDES
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **HSYNCS**: horizontal synchronization display status
0: active low
1: active high

Bit 2 **VSYNCS**: vertical synchronization display status
0: active low
1: active high

Bit 1 **HDES**: horizontal data enable display status
0: active low
1: active high

Bit 0 **VDES**: vertical data enable display status
0: active low
1: active high

38.7.14 LTDC layer x control register (LTDC_LxCR)

Address offset: 0x084 + 0x080 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLUTEN	Res.	Res.	COLKEN	LEN
											rw			rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **CLUTEN**: color look-up table enable
This bit is set and cleared by software.
0: color look-up table disable
1: color look-up table enable
The CLUT is only meaningful for L8, AL44 and AL88 pixel format. Refer to *Color look-up table (CLUT)*

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **COLKEN**: color keying enable
This bit is set and cleared by software.
0: color keying disable
1: color keying enable

Bit 0 **LEN**: layer enable
This bit is set and cleared by software.
0: layer disable
1: layer enable

38.7.15 LTDC layer x window horizontal position configuration register (LTDC_LxWHPCR)

Address offset: 0x088 + 0x080 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the horizontal position (first and last pixel) of the layer 1 or 2 window.

The first visible pixel of a line is the programmed value of AHBP[11:0] bits + 1 in the LTDC_BPCR register.

The last visible pixel of a line is the programmed value of AAW[11:0] bits in the LTDC_AWCR register.

Example: The LTDC_BPCR register is configured to 0x000E0005 (AHBP[11:0] is 0xE) and the LTDC_AWCR register is configured to 0x028E01E5 (AAW[11:0] is 0x28E). To configure

the horizontal position of a window size of 630x460, with horizontal start offset of 5 pixels in the active data area:

- layer window first pixel, WHSTPOS[11:0], must be programmed to 0x14 (0xE+1+0x5).
- layer window last pixel, WHSPPOS[11:0], must be programmed to 0x28A.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	WHSPPOS[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	WHSTPOS[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **WHSPPOS[11:0]**: window horizontal stop position
These bits configure the last visible pixel of a line of the layer window.
WHSPPOS[11:0] must be ≥ AHBP[11:0] bits + 1 (programmed in LTDC_BPCR register).

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **WHSTPOS[11:0]**: window horizontal start position
These bits configure the first visible pixel of a line of the layer window.
WHSTPOS[11:0] must be ≤ AAW[11:0] bits (programmed in LTDC_AWCR register).

38.7.16 LTDC layer x window vertical position configuration register (LTDC_LxWVPCR)

Address offset: 0x08C + 0x080 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the vertical position (first and last line) of the layer1 or 2 window.

The first visible line of a frame is the programmed value of AVBP[10:0] bits + 1 in the register LTDC_BPCR register.

The last visible line of a frame is the programmed value of AAH[10:0] bits in the LTDC_AWCR register.

Example:

The LTDC_BPCR register is configured to 0x000E0005 (AVBP[10:0] is 0x5) and the LTDC_AWCR register is configured to 0x028E01E5 (AAH[10:0] is 0x1E5).

To configure the vertical position of a window size of 630x460, with vertical start offset of eight lines in the active data area:

- layer window first line, WVSTPOS[10:0], must be programmed to 0xE (0x5 + 1 + 0x8).
- layer window last line, WVSPPOS[10:0] must be programmed to 0x1DA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	WVSPPOS[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	WVSTPOS[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bits 26:16 **WVSPPOS[10:0]**: window vertical stop position
These bits configure the last visible line of the layer window.
WVSPPOS[10:0] must be ≥ AVBP[10:0] bits + 1 (programmed in LTDC_BPCR register).

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:0 **WVSTPOS[10:0]**: window vertical start position
These bits configure the first visible line of the layer window.
WVSTPOS[10:0] must be ≤ AAH[10:0] bits (programmed in LTDC_AWCR register).

38.7.17 LTDC layer x color keying configuration register (LTDC_LxCKCR)

Address offset: 0x090 + 0x080 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the color key value (RGB), that is used by the color keying.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CKRED[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CKGREEN[7:0]								CKBLUE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **CKRED[7:0]**: color key red value

Bits 15:8 **CKGREEN[7:0]**: color key green value

Bits 7:0 **CKBLUE[7:0]**: color key blue value

38.7.18 LTDC layer x pixel format configuration register (LTDC_LxPFCR)

Address offset: 0x094 + 0x080 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the pixel format that is used for the stored data in the frame buffer of a layer. The pixel data is read from the frame buffer and then transformed to the internal format 8888 (ARGB).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PF[2:0]		
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **PF[2:0]**: pixel format

These bits configure the pixel format
000: ARGB8888
001: RGB888
010: RGB565
011: ARGB1555
100: ARGB4444
101: L8 (8-bit luminance)
110: AL44 (4-bit alpha, 4-bit luminance)
111: AL88 (8-bit alpha, 8-bit luminance)

38.7.19 LTDC layer x constant alpha configuration register (LTDC_LxCACR)

Address offset: 0x098 + 0x080 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 00FF

This register defines the constant alpha value (divided by 255 by hardware), that is used in the alpha blending. Refer to LTDC_LxBFCR register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CONSTA[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **CONSTA[7:0]**: constant alpha

These bits configure the constant alpha used for blending. The constant alpha is divided by 255 by hardware.
Example: if the programmed constant alpha is 0xFF, the constant alpha value is 255 / 255 = 1.

38.7.20 LTDC layer x default color configuration register (LTDC_LxDCCR)

Address offset: 0x09C + 0x080 * (x - 1), (*x* = 1 to 2)

Reset value: 0x0000 0000

This register defines the default color of a layer in the format ARGB. The default color is used outside the defined layer window or when a layer is disabled. The reset value of 0x00000000 defines a transparent black color.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DCALPHA[7:0]								DCRED[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DCGREEN[7:0]								DCBLUE[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **DCALPHA[7:0]**: default color alpha
These bits configure the default alpha value.

Bits 23:16 **DCRED[7:0]**: default color red
These bits configure the default red value.

Bits 15:8 **DCGREEN[7:0]**: default color green
These bits configure the default green value.

Bits 7:0 **DCBLUE[7:0]**: default color blue
These bits configure the default blue value.

38.7.21 LTDC layer x blending factors configuration register (LTDC_LxBFCR)

Address offset: 0x0A0 + 0x080 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0607

This register defines the blending factors F1 and F2.

The general blending formula is: BC = BF1 x C + BF2 x Cs

- BC = blended color
- BF1 = blend factor 1
- C = current layer color
- BF2 = blend factor 2
- Cs = subjacent layers blended color

The constant alpha value, is the programmed value in LTDC_LxCACR divided by 255 by hardware.

Example: Only layer1 is enabled, BF1 configured to constant alpha. BF2 configured to 1 - *constant alpha. The constant alpha programmed in LTDC_LxCACR is 240 (0xF0). Thus, the constant alpha value is 240 / 255 = 0.94. C: current layer color is 128.*

Cs: background color is 48. Layer1 is blended with the background color.
BC = constant alpha x C + *(1 - Constant Alpha*) x Cs = *0.94 x 128 + (1- 0.94) x 48 = 123.*

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	BF1[2:0]			Res.	Res.	Res.	Res.	Res.	BF2[2:0]		
					rw	rw	rw						rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:8 **BF1[2:0]**: blending factor 1
These bits select the blending factor F1.
000: reserved
001: reserved
010: reserved
011: reserved
100: constant alpha
101: reserved
110: pixel alpha x constant alpha
111: reserved

Bits 7:3 Reserved, must be kept at reset value.

Bits 2:0 **BF2[2:0]**: blending factor 2
These bits select the blending factor F2
000: reserved
001: reserved
010: reserved
011: reserved
100: reserved
101: 1 - constant alpha
110: reserved
111: 1 - (pixel alpha x constant alpha)

38.7.22 LTDC layer x color frame buffer address register (LTDC_LxCFBAR)

Address offset: 0x0AC + 0x080 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the color frame buffer start address which has to point to the address where the pixel data of the top left pixel of a layer is stored in the frame buffer.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CFBADD[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CFBADD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CFBADD[31:0]**: color frame buffer start address
These bits define the color frame buffer start address.

38.7.23 LTDC layer x color frame buffer length register (LTDC_LxCFBLR)

Address offset: 0x0B0 + 0x080 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the color frame buffer line length and pitch.

Example:

- A frame buffer having the format RGB565 (2 bytes per pixel) and a width of 256 pixels (total number of bytes per line is 256 * 2 = 512), where pitch = line length requires a value of 0x02000207 to be written into this register.
- A frame buffer having the format RGB888 (3 bytes per pixel) and a width of 320 pixels (total number of bytes per line is 320 * 3 = 960), where pitch = line length requires a value of 0x03C003C7 to be written into this register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	CFBP[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	CFBLL[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:16 **CFBP[12:0]**: color frame buffer pitch in bytes
These bits define the pitch that is the increment from the start of one line of pixels to the start of the next line in bytes.

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:0 **CFBLL[12:0]**: color frame buffer line length
These bits define the length of one line of pixels in bytes + 7.
The line length is computed as follows:
active high width * number of bytes per pixel + 7.

38.7.24 LTDC layer x color frame buffer line number register (LTDC_LxCFBLNR)

Address offset: 0x0B4 + 0x080 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the number of lines in the color frame buffer.

The number of lines and line length settings define how much data is fetched per frame for every layer. If it is configured to less bytes than required, a FIFO underrun interrupt is generated if enabled.

The start address and pitch settings on the other hand define the correct start of every line in memory.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	CFBLNBR[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:0 **CFBLNBR[10:0]**: frame buffer line number
These bits define the number of lines in the frame buffer that corresponds to the active high width.

38.7.25 LTDC layer x CLUT write register (LTDC_LxCLUTWR)

Address offset: 0x0C4 + 0x080 * (x - 1), (x = 1 to 2)

Reset value: 0x0000 0000

This register defines the CLUT address and the RGB value.

The CLUT write register must be configured only during blanking period or if the layer is disabled. The CLUT can be enabled or disabled in the LTDC_LxCR register.

The CLUT is only meaningful for L8, AL44 and AL88 pixel format.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CLUTADD[7:0]								RED[7:0]							
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GREEN[7:0]								BLUE[7:0]							
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:24 **CLUTADD[7:0]**: CLUT address
These bits configure the CLUT address (color position within the CLUT) of each RGB value.

Bits 23:16 **RED[7:0]**: red value
These bits configure the red value.

Bits 15:8 **GREEN[7:0]**: green value
These bits configure the green value.

Bits 7:0 **BLUE[7:0]**: blue value
These bits configure the blue value.

38.7.26 LTDC register map

Table 317. LTDC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x008	**LTDC_SSCR**	Res.	Res.	Res.	Res.	HSW[11:0]												Res.	Res.	Res.	Res.	Res.	VSH[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x00C	**LTDC_BPCR**	Res.	Res.	Res.	Res.	AHBP[11:0]												Res.	Res.	Res.	Res.	Res.	AVBP[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x010	**LTDC_AWCR**	Res.	Res.	Res.	Res.	AAW[11:0]												Res.	Res.	Res.	Res.	Res.	AAH[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x014	**LTDC_TWCR**	Res.	Res.	Res.	Res.	TOTALW[11:0]												Res.	Res.	Res.	Res.	Res.	TOTALH[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x018	**LTDC_GCR**	HSPOL	VSPOL	DEPOL	PCPOL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEN	Res.	DRW[2:0]			Res.	DGW[2:0]			Res.	DBW[2:0]			Res.	Res.	Res.	LTDCEN
	Reset value	0	0	0	0												0		0	1	0		0	1	0		0	1	0				0
0x024	**LTDC_SRCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VBR	IMR
	Reset value																															0	0
0x02C	**LTDC_BCCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BCRED[7:0]								BCGREEN[7:0]								BCBLUE[7:0]							
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x030	Reserved	Reserved																															
0x034	**LTDC_IER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RRIE	TERRIE	FUIE	LIE
	Reset value																													0	0	0	0
0x038	**LTDC_ISR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RRIF	TERRIF	FUIF	LIF
	Reset value																													0	0	0	0

Table 317. LTDC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x03C	**LTDC_ICR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CRRIF	CTERRIF	CFUIF	CLIF
	Reset value																													0	0	0	0
0x040	**LTDC_LIPCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LIPOS10:0]										
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x044	**LTDC_CPSR**	CXPOS[15:0]																CYPOS[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x048	**LTDC_CDSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HSYNCS	VSYNCS	HDES	VDES
	Reset value																													1	1	1	1
0x04C-0x080	Reserved	Reserved																															
0x084	**LTDC_L1CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLUTEN			COLKEN	LEN
	Reset value																												0			0	0
0x088	**LTDC_L1WHPCR**	Res.	Res.	Res.	Res.	WHSPPOS[11:0]												Res.	Res.	Res.	Res.	WHSTPOS[11:0]											
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
0x08C	**LTDC_L1WVPCR**	Res.	Res.	Res.	Res.	Res.	WVSPPOS[10:0]											Res.	Res.	Res.	Res.	Res.	WVSTPOS[10:0]										
	Reset value						0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x090	**LTDC_L1CKCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CKRED[7:0]								CKGREEN[7:0]								CKBLUE[7:0]							
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x094	**LTDC_L1PFCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PF[2:0]		
	Reset value																														0	0	0
0x098	**LTDC_L1CACR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CONSTA[7:0]							
	Reset value																									1	1	1	1	1	1	1	1
0x09C	**LTDC_L1DCCR**	DCALPHA[7:0]								DCRED[7:0]								DCGREEN[7:0]								DCBLUE[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0A0	**LTDC_L1BFCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BF1[2:0]			Res.	Res.	Res.	Res.	Res.	BF2[2:0]		
	Reset value																						1	1	0						1	1	1
0x0A4-0x0A8	Reserved	Reserved																															
0x0AC	**LTDC_L1CFBAR**	CFBADD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B0	**LTDC_L1CFBLR**	Res.	Res.	Res.	CFBP[12:0]													Res.	Res.	Res.	CFBLL[12:0]												
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B4	**LTDC_L1CFBLNR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CFBLNBR[10:0]										
	Reset value																						0	0	0	0	0	0	0	0	0	0	0

Table 317. LTDC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0B8-0x0C0	Reserved	Reserved																															
0x0C4	**LTDC_L1CLUTWR**	CLUTADD[7:0]								RED[7:0]								GREEN[7:0]								BLUE[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C8-0x100	Reserved	Reserved																															
0x104	**LTDC_L2CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLUTEN	Res.	Res.	COLKEN	LEN
	Reset value																												0			0	0
0x108	**LTDC_L2WHPCR**	Res.	Res.	Res.	Res.	WHSPPOS[11:0]												Res.	Res.	Res.	Res.	WHSTPOS[11:0]											
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
0x10C	**LTDC_L2WVPCR**	Res.	Res.	Res.	Res.	Res.	WVSPPOS[10:0]											Res.	Res.	Res.	Res.	Res.	WVSTPOS[10:0]										
	Reset value						0	0	0	0	0	0	0	0	0	0	0						0	0	0	0	0	0	0	0	0	0	0
0x110	**LTDC_L2CKCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CKRED[7:0]								CKGREEN[7:0]								CKBLUE[7:0]							
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x114	**LTDC_L2PFCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PF[2:0]		
	Reset value																														0	0	0
0x118	**LTDC_L2CACR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CONSTA[7:0]							
	Reset value																									1	1	1	1	1	1	1	1
0x11C	**LTDC_L2DCCR**	DCALPHA[7:0]								DCRED[7:0]								DCGREEN[7:0]								DCBLUE[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x120	**LTDC_L2BFCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BF1[2:0]			Res.	Res.	Res.	Res.	Res.	BF2[2:0]		
	Reset value																						1	1	0						1	1	1
0x124-0x128	Reserved	Reserved																															
0x12C	**LTDC_L2CFBAR**	CFBADD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x130	**LTDC_L2CFBLR**	Res.	Res.	Res.	CFBP[12:0]													Res.	Res.	Res.	CFBLL[12:0]												
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0	0
0x134	**LTDC_L2CFBLNR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CFBLNBR[10:0]										
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x138-0x140	Reserved	Reserved																															
0x144	**LTDC_L2CLUTWR**	CLUTADD[7:0]								RED[7:0]								GREEN[7:0]								BLUE[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3* for the register boundary addresses.

39 True random number generator (RNG)

39.1 Introduction

The RNG is a true random number generator that provides full entropy outputs to the application as 32-bit samples. It is composed of a live entropy source (analog) and an internal conditioning component.

The RNG is a NIST SP 800-90B compliant entropy source that can be used to construct a non-deterministic random bit generator (NDRBG).

The RNG true random number generator has been pre-certified NIST SP800-90B. It has also been tested using German BSI statistical tests of AIS-31 (T0 to T8).

39.2 RNG main features

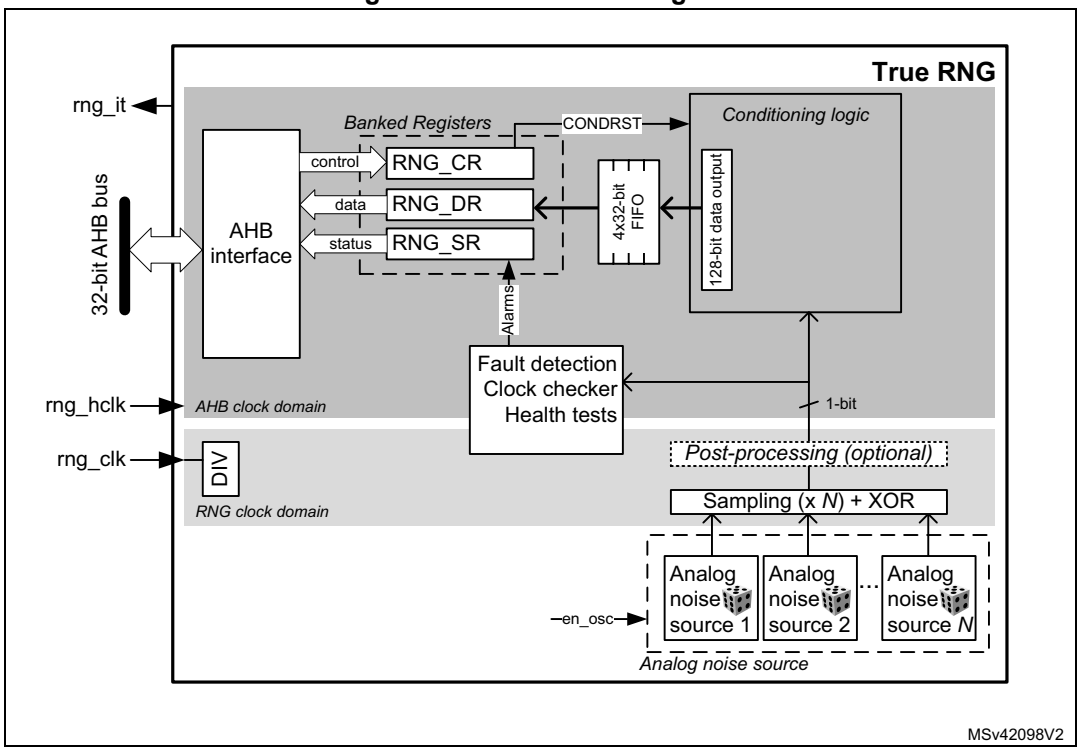
- The RNG delivers 32-bit true random numbers, produced by an analog entropy source conditioned by a NIST SP800-90B approved conditioning stage.
- It can be used as entropy source to construct a non-deterministic random bit generator (NDRBG).
- It produces four 32-bit random samples every 412 AHB clock cycles if f_{AHB} < 77 MHz (256 RNG clock cycles otherwise).
- It embeds start-up and NIST SP800-90B approved continuous health tests (repetition count and adaptive proportion tests), associated with specific error management
- It can be disabled to reduce power consumption, or enabled with an automatic low power mode (default configuration).
- It has an AMBA AHB slave peripheral, accessible through 32-bit word single accesses only (else an AHB bus error is generated, and the write accesses are ignored).

39.3 RNG functional description

39.3.1 RNG block diagram

Figure 338 shows the RNG block diagram.

Figure 338. RNG block diagram



39.3.2 RNG internal signals

Table 318 describes a list of useful-to-know internal signals available at the RNG level, not at the STM32 product level (on pads).

Table 318. RNG internal input/output signals

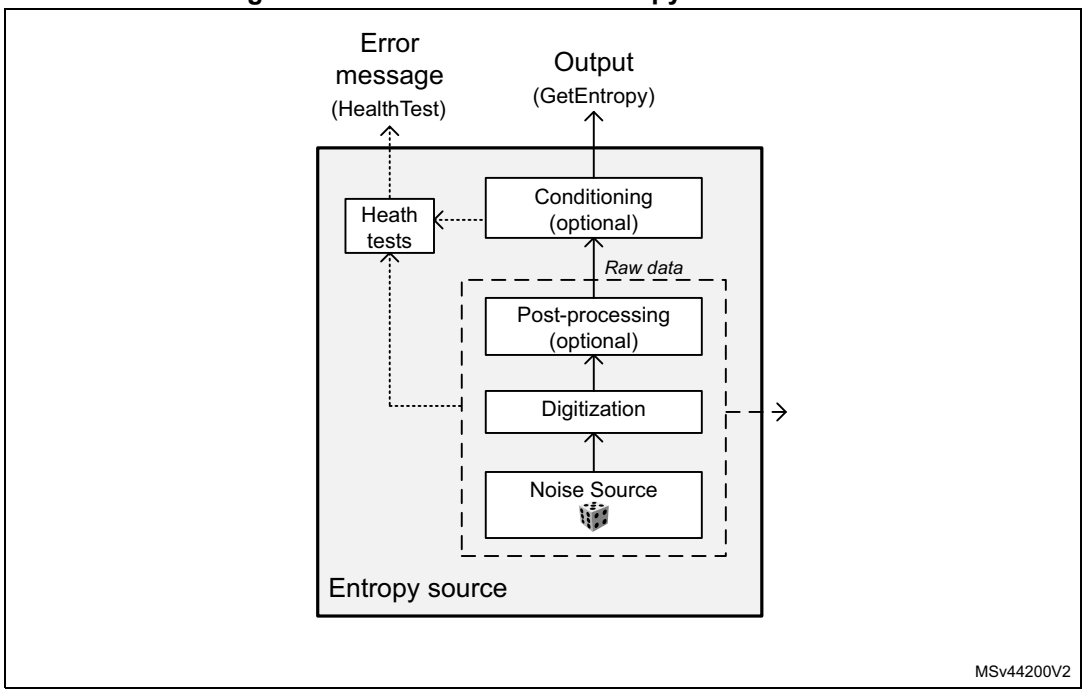
Signal name	Signal type	Description
rng_it	Digital output	RNG global interrupt request
rng_hclk	Digital input	AHB clock
rng_clk	Digital input	RNG dedicated clock, asynchronous to rng_hclk

39.3.3 Random number generation

The true random number generator (RNG) delivers truly random data through its AHB interface at deterministic intervals.

Within its boundary RNG integrates all the required NIST components depicted on *Figure 339*. Those components are an analog noise source, a digitization stage, a conditioning algorithm, a health monitoring block and two interfaces that are used to interact with the entropy source: GetEntropy and HealthTest.

Figure 339. NIST SP800-90B entropy source model



The components pictured above are detailed hereafter:

Noise source

The noise source is the component that contains the non-deterministic, entropy-providing activity that is ultimately responsible for the uncertainty associated with the bitstring output by the entropy source. This noise source provides 1-bit samples. It is composed of:

- Multiple analog noise sources (x6), each based on three XORed free-running ring oscillator outputs. It is possible to disable those analog oscillators to save power, as described in *Section 39.3.8: RNG low-power usage*.
- The XORing of the six noise sources into a single analog output.
- A sampling stage of this output clocked by a dedicated clock input (**rng_clk** with integrated divider), delivering a 1-bit raw data output.

This noise source sampling is independent to the AHB interface clock frequency (**rng_hclk**), with a possibility for the software to decrease the sampling frequency by using the integrated divider.

Note: In Section 39.6: RNG entropy source validation recommended RNG clock frequencies and associated divider value are given.

Post processing

In NIST configuration no post-processing is applied to sampled noise source. In non-NIST configuration B (as defined in *Section 39.6.2*) a normalization debiasing is applied, i.e. half of the bits are taken from the sampled noise source, half of the bits are taken from inverted sampled noise source.

Conditioning

The conditioning component in the RNG is a deterministic function that increases the entropy rate of the resulting fixed-length bitstrings output (128-bit). The NIST SP800-90B target is full entropy on the output (128-bit).

The times required between two random number generations, and between the RNG initialization and availability of first sample are described in *Section 39.5: RNG processing time*.

Output buffer

A data output buffer can store up to four 32-bit words that have been output from the conditioning component. When four words have been read from the output FIFO through the RNG_DR register, the content of the 128-bit conditioning output register is pushed into the output FIFO, and a new conditioning round is automatically started. Four new words are added to the conditioning output register after a number of clock cycles specified in *Section 39.5: RNG processing time*.

Whenever a random number is available through the RNG_DR register the DRDY flag transitions from 0 to 1. This flag remains high until output buffer becomes empty after reading four words from the RNG_DR register.

Note: When interrupts are enabled an interrupt is generated when this data ready flag transitions from 0 to 1. Interrupt is then cleared automatically by the RNG as explained above.

Health checks

This component ensures that the entire entropy source (with its noise source) starts then operates as expected, obtaining assurance that failures are caught quickly and with a high probability and reliability.

The RNG implements the following health check features in accordance with NIST SP800-90B. The described thresholds correspond to the value recommended for register RNG_HTCR (in *Section 39.6.2*).

1. Start-up health tests, performed after reset and before the first use of the RNG as entropy source
   - Adaptive proportion test running on one 1024 bit windows: the RNG verifies that the first bit on the outputs of the noise source is not repeated more than 628 times.
   - Known-answer tests, to verify the conditioning stage.
   - Repetition count test, flagging an error when the noise source has provided more than 40 consecutive bits at a constant value (0 or 1)
2. Continuous health tests, running indefinitely on the outputs of the noise source
   - Repetition count test, similar to the one running in start-up tests
   - Adaptive proportion test running on 1024 consecutive samples, like during start-up health tests.
3. Vendor specific continuous tests
   - Transition count test, flagging an error when the noise source has delivered more than 42 consecutive occurrences of 2-bit patterns (01 or 10).
   - Real-time “too slow” sampling clock detector, flagging an error when one RNG clock cycle (before divider) is smaller than AHB clock cycle divided by 32.
4. On-demand test of digitized noise source (raw data)
   - Supported by restarting the entropy source and re-running the startup tests (see software reset sequence in *Section 39.3.4: RNG initialization*). Other kinds of on-demand testing (software based) are *not supported*.

The CECS and SECS status bits in the RNG_SR register indicate when an error condition is detected, as detailed in *Section 39.3.7: Error management*.

Note: An interrupt can be generated when an error is detected.

Above health test thresholds are modified by changing value in RNG_HTCR register. See Section 39.6: RNG entropy source validation for details.

39.3.4 RNG initialization

The RNG simplified state machine is pictured on *Figure 340*.

After enabling the RNG (RNGEN = 1 in RNG_CR) the following chain of events occurs:

1. The analog noise source is enabled, and by default the RNG waits 16 cycles of RNG clock cycles (before divider) before starting to sample analog output and filling 128-bit conditioning shift register.
2. The conditioning hardware initializes, automatically triggering start-up behavior test on the raw data samples and known-answer tests.
3. When start-up health tests are completed. During this time three 128-bit noise source samples are used.
4. The conditioning stage internal input data buffer is filled again with 128-bit and a number of conditioning rounds defined by the RNG configuration (NIST or non-NIST) is performed. The output buffer is then filled with the post processing result.
5. The output buffer is refilled automatically according to the RNG usage.

The associated initialization time can be found in *Section 39.5: RNG processing time*.

Figure 340. RNG initialization overview

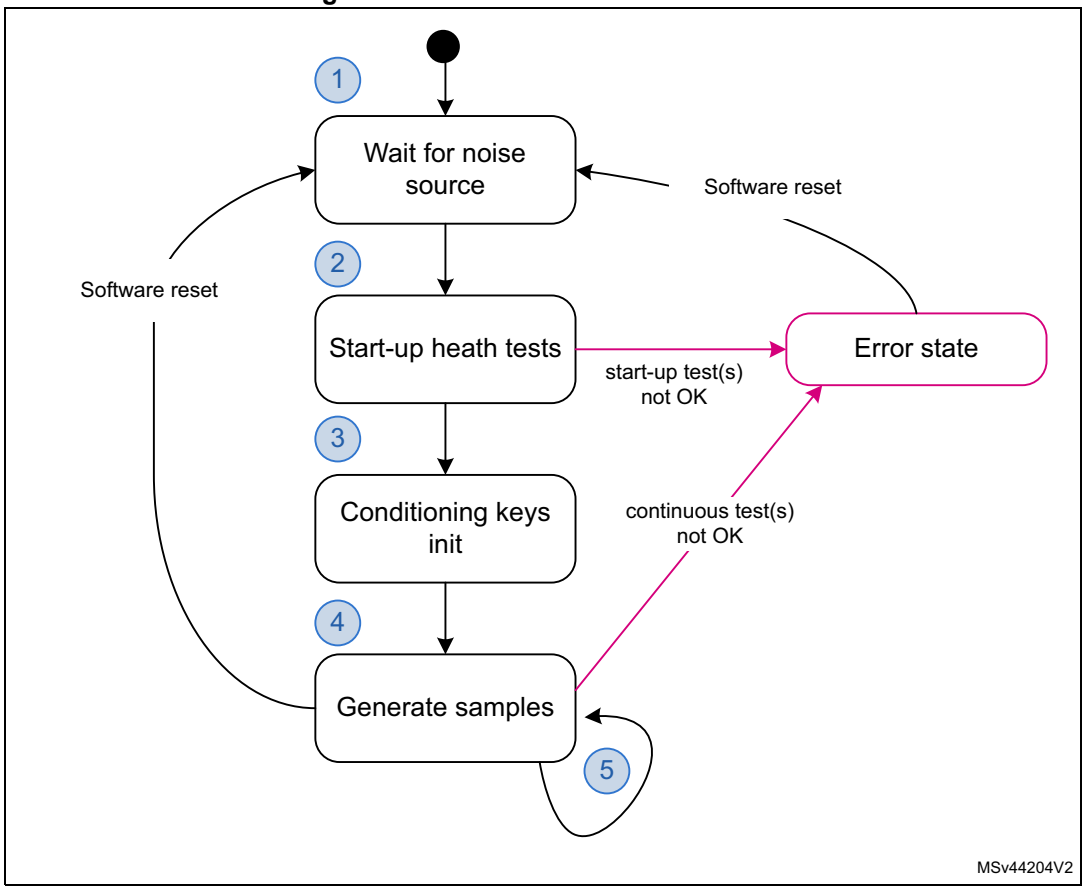


Figure 340 also highlights a possible software reset sequence, implemented by:

1. Writing bits RNGEN = 0 and CONDRST = 1 in the RNG_CR register with the same RNG configuration and a new CLKDIV if needed.
2. Then writing RNGEN = 1 and CONDRST = 0 in the RNG_CR register.
3. Wait for random number to be ready, after initialization completes

Note: When RNG peripheral is reset through RCC (hardware reset), the RNG configuration for optimal randomness is lost in RNG registers. Software reset with CONFIGLOCK set preserves the RNG configuration.

39.3.5 RNG operation

Normal operations

To run the RNG using interrupts, the following steps are recommended:

1. Consult *Section 39.6: RNG entropy source validation* and verify if a specific RNG configuration is required for the application.
   - If it is the case, write in the RNG_CR register the bit CONDRST = 1 together with the correct RNG configuration. Then perform a second write to the RNG_CR register with the bit CONDRST = 0, the interrupt enable bit IE = 1 and the RNG enable bit RNGEN = 1.
   - If it is not the case perform a write to the RNG_CR register with the interrupt enable bit IE = 1 and the RNG enable bit RNGEN = 1.
2. An interrupt is now generated when a random number is ready or when an error occurs. Therefore at each interrupt, check that:
   - No error occurred. The SEIS and CEIS bits must be set to 0 in the RNG_SR register.
   - A random number is ready. The DRDY bit must be set to 1 in the RNG_SR register.
   - If above two conditions are true the content of the RNG_DR register can be read up to four consecutive times. If valid data is available in the conditioning output buffer, four additional words can be read by the application (in this case the DRDY bit is still high). If one or both of above conditions are false, the RNG_DR register must not be read. If an error occurred error recovery sequence described in *Section 39.3.7* must be used.

To run the RNG in polling mode following steps are recommended:

1. Consult *Section 39.6: RNG entropy source validation* and verify if a specific RNG configuration is required for the application.
   - If it is the case write in the RNG_CR register the bit CONDRST = 1 together with the correction RNG configuration. Then perform a second write to the RNG_CR register with the bit CONDRST = 0 and the RNG enable bit RNGEN = 1.
   - If it is not the case only enable the RNG by setting the RNGEN bit to 1 in the RNG_CR register.
2. Read the RNG_SR register and check that:
   - No error occurred (the SEIS and CEIS bits must be set to 0)
   - A random number is ready (the DRDY bit must be set to 1)
3. If above conditions are true read the content of the RNG_DR register up to four consecutive times. If valid data is available in the conditioning output buffer four

additional words can be read by the application (in this case the DRDY bit is still high). If one or both of above conditions are false, the RNG_DR register must not be read. If an error occurred error recovery sequence described in *Section 39.3.7* must be used.

Note: When data is not ready (DRDY = 0) RNG_DR returns zero.
It is recommended to always verify that RNG_DR is different from zero. Because when it is the case a seed error occurred between RNG_SR polling and RND_DR output reading (rare event).

If the random number generation period is a concern to the application and if NIST compliance is not required it is possible to select a faster RNG configuration by using the RNG configuration “B”, described in *Section 39.6: RNG entropy source validation*. The gain in random number generation speed is summarized in *Section 39.5: RNG processing time*.

Low-power operations

If the power consumption is a concern to the application, low-power strategies can be used, as described in *Section 39.3.8: RNG low-power usage*.

Software post-processing

No specific software post-processing/conditioning is expected to meet the AIS-31 or NIST SP800-90B approvals.

Built-in health check functions are described in *Section 39.3.3: Random number generation*.

39.3.6 RNG clocking

The RNG runs on two different clocks: the AHB bus clock and a dedicated RNG clock.

The AHB clock is used to clock the AHB banked registers and conditioning component. The RNG clock, coupled with a programmable divider (see CLKDIV bitfield in the RNG_CR register) is used for noise source sampling. Recommended clock configurations are detailed in *Section 39.6: RNG entropy source validation*.

*Note: When the CED bit in the RNG_CR register is set to 0, the RNG clock frequency before internal divider **must be higher** than AHB clock frequency divided by 32, otherwise the clock checker always flags a clock error (CECS = 1 in the RNG_SR register).*

See *Section 39.3.1: RNG block diagram* for details (AHB and RNG clock domains).

39.3.7 Error management

In parallel to random number generation an health check block verifies the correct noise source behavior and the frequency of the RNG source clock as detailed in this section. Associated error state is also described.

Clock error detection

When the clock error detection is enabled (CED = 0) and if the RNG clock frequency is too low, the RNG sets to 1 both the **CEIS** and **CECS** bits to indicate that a clock error occurred. In this case, the application should check that the RNG clock is configured correctly (see *Section 39.3.6: RNG clocking*) and then it must clear the CEIS bit interrupt flag. The CECS bit is automatically cleared when clocking condition is normal.

Note: The clock error has no impact on generated random numbers, i.e. application can still read RNG_DR register.

CEIS is set only when CECS is set to 1 by RNG.

Noise source error detection

When a noise source (or seed) error occurs, the RNG stops generating random numbers and sets to 1 both **SEIS** and **SECS** bits to indicate that a seed error occurred. If a value is available in the RNG_DR register, it must not be used as it may not have enough entropy.

The following sequence must be used to fully recover from a seed error:

1. Software reset by writing CONDRST at 1 and at 0 (see bitfield description for details).
2. wait for CONDRST to be cleared in the RNG_CR register, then confirm that SEIS is cleared in the RNG_SR register.
3. wait for SECS to be cleared by RNG. The random number generation is now back to normal.

39.3.8 RNG low-power usage

If power consumption is a concern, the RNG can be disabled as soon as the DRDY bit is set to 1 by setting the RNGEN bit to 0 in the RNG_CR register. As the post-processing logic and the output buffer remain operational while RNGEN = 0 following features are available to software:

- If there are valid words in the output buffer four random numbers can still be read from the RNG_DR register.
- If there are valid bits in the conditioning output internal register four additional random numbers can be still be read from the RNG_DR register. If it is not the case RNG must be re-enabled by the application until the expected new noise source bits threshold is reached (128-bit in NIST mode) and a complete conditioning round is done.
  Four new random words are then available only if the expected number of conditioning round is reached (two if NISTC = 0). The overall time can be found in *Section 39.5: RNG processing time on page 1435*.

When disabling the RNG the user deactivates all the analog seed generators, whose power consumption is given in the datasheet electrical characteristics section. The user also gates all the logic clocked by the RNG clock. Note that this strategy is adding latency before a random sample is available on the RNG_DR register, because of the RNG initialization time.

If the RNG block is disabled during initialization (i.e. well before the DRDY bit rises for the first time), the initialization sequence resumes from where it was stopped when RNGEN bit is set to 1, unless the application resets the conditioning logic using CONDRST bit in the RNG_CR register.

39.4 RNG interrupts

In the RNG an interrupt can be produced on the following events:

- Data ready flag
- Seed error, see *Section 39.3.7: Error management*
- Clock error, see *Section 39.3.7: Error management*

Dedicated interrupt enable control bits are available as shown in *Table 319*.

Table 319. RNG interrupt requests

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method
RNG	Data ready flag	DRDY	IE	None (automatic)
	Seed error flag	SEIS	IE	Write 0 to SEIS or write CONDRST to 1 then to 0
	Clock error flag	CEIS	IE	Write 0 to CEIS

The user can enable or disable the above interrupt sources individually by changing the mask bits or the general interrupt control bit IE in the RNG_CR register. The status of the individual interrupt sources can be read from the RNG_SR register.

Note: Interrupts are generated only when RNG is enabled.

39.5 RNG processing time

In recommended configurations described in *Table 320*, the time between two sets of four 32-bit data is either:

- 412 AHB cycles if $f_{AHB} < f_{threshold}$ (conditioning stage is limiting), or
- 256 RNG cycles $f_{AHB} \geq f_{threshold}$ (noise source stage is limiting).

With $f_{threshold} = 1.6 \times f_{RNG}$, e.g. 77 MHz if f_{RNG}= 48 MHz.

Note: When CLKDIV is different from zero, f_{RNG} must take into account the internal divider ratio.

39.6 RNG entropy source validation

39.6.1 Introduction

In order to assess the amount of entropy available from the RNG, STMicroelectronics has tested the peripheral using German BSI AIS-31 statistical tests (T0 to T8), and NIST SP800-90B test suite. The results can be provided on demand or the customer can reproduce the tests.

39.6.2 Validation conditions

STMicroelectronics has tested the RNG true random number generator in the following conditions:

- RNG clock rng_clk= 48 MHz
- RNG configurations described in *Table 320*. Note that only configuration A can be certified NIST SP800-90B.

Table 320. RNG configurations

RNG Config	RNG_CR bits						Nb loop (N)	RNG_HTCR register(1)
	NISTC bit	RNG_CONFIG1 [5:0]	CLKDIV [3:0]	RNG_CONFIG2 [2:0]	RNG_CONFIG3 [3:0]	CED bit		
A	0	0x0F	0x0	0x0	0xD	0	2	0x0000 AA74
B	1	0x18	0x0	0x0	0x0	0	2	0x0000 AA74

1. When writing this register magic number 0x17590ABC must be written immediately before the indicated value

39.6.3 Data collection

In order to run statistical tests it is required to collect samples from the entropy source at raw data level as well as at the output of the entropy source. For details on data collection and the running of statistical test suites refer to “STM32 microcontrollers random number generation validation using NIST statistical test suite” application note (AN4230) available from *www.st.com*.

Contact STMicroelectronics if above samples need to be retrieved for the product.

39.7 RNG registers

The RNG is associated with a control register, a data register and a status register.

39.7.1 RNG control register (RNG_CR)

Address offset: 0x000

Reset value: 0x0080 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CONFIGLOCK	CONDRST	Res.	Res.	Res.	Res.	RNG_CONFIG1[5:0]						CLKDIV[3:0]			
rs	rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RNG_CONFIG2[2:0]			NISTC	RNG_CONFIG3[3:0]				Res.	Res.	CED	Res.	IE	RNGEN	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw			rw		rw	rw		

Bit 31 **CONFIGLOCK**: RNG Config lock

0: Writes to the RNG_CR configuration bits [29:4] are allowed.

1: Writes to the RNG_CR configuration bits [29:4] are ignored until the next RNG reset.

This bitfield is set once: if this bit is set it can only be reset to 0 if RNG is reset.

Bit 30 **CONDRST**: Conditioning soft reset

Write 1 and then write 0 to reset the conditioning logic, clear all the FIFOs and start a new RNG initialization process, with RNG_SR cleared. Registers RNG_CR and RNG_NSCR are not changed by CONDRST.

This bit must be set to 1 in the same access that set any configuration bits [29:4]. In other words, when CONDRST bit is set to 1 correct configuration in bits [29:4] must also be written.

When CONDRST is set to 0 by software its value goes to 0 when the reset process is done. It takes about 2 AHB clock cycles + 2 RNG clock cycles.

Bits 29:26 Reserved, must be kept at reset value.

Bits 25:20 **RNG_CONFIG1[5:0]:** RNG configuration 1

Reserved to the RNG configuration (bitfield 1). Must be initialized using the recommended value documented in *Section 39.6: RNG entropy source validation*.

Writing any bit of RNG_CONFIG1 is taken into account only if CONDRST bit is set to 1 in the same access, while CONFIGLOCK remains at 0. Writing to this bit is ignored if CONFIGLOCK = 1.

Bits 19:16 **CLKDIV[3:0]**: Clock divider factor

This value used to configure an internal programmable divider (from 1 to 16) acting on the incoming RNG clock. These bits can be written only when the core is disabled (RNGEN = 0).

0x0: internal RNG clock after divider is similar to incoming RNG clock.

0x1: two RNG clock cycles per internal RNG clock.

0x2: 2^2 (= 4) RNG clock cycles per internal RNG clock.

...

0xF: 2^{15} RNG clock cycles per internal clock (for example. an incoming 48 MHz RNG clock becomes a 1.5 kHz internal RNG clock)

Writing these bits is taken into account only if CONDRST bit is set to 1 in the same access, while CONFIGLOCK remains at 0. Writing to this bit is ignored if CONFIGLOCK = 1.

Bits 15:13 **RNG_CONFIG2[2:0]:** RNG configuration 2

Reserved to the RNG configuration (bitfield 2). Refer to RNG_CONFIG1 bitfield for details.

Bit 12 **NISTC**: Non NIST compliant

0: Hardware default values for NIST compliant RNG. In this configuration per 128-bit output two conditioning loops are performed and 256 bits of noise source are used.

1: Custom values for NIST compliant RNG. See *Section 39.6: RNG entropy source validation* for proposed configuration.

Writing this bit is taken into account only if CONDRST bit is set to 1 in the same access, while CONFIGLOCK remains at 0. Writing to this bit is ignored if CONFIGLOCK = 1.

Bits 11:8 **RNG_CONFIG3[3:0]:** RNG configuration 3

Reserved to the RNG configuration (bitfield 3). Refer to RNG_CONFIG1 bitfield for details.

If NISTC bit is cleared in this register RNG_CONFIG3 bitfield values are ignored by RNG.

Bit 7 Reserved, must be kept at reset value.

Bit 6 Reserved, must be kept at reset value.

Bit 5 **CED:** Clock error detection

0: Clock error detection is enable

1: Clock error detection is disable

The clock error detection cannot be enabled nor disabled on-the-fly when the RNG is enabled, i.e. to enable or disable CED the RNG must be disabled.

Writing this bit is taken into account only if CONDRST bit is set to 1 in the same access, while CONFIGLOCK remains at 0. Writing to this bit is ignored if CONFIGLOCK = 1.

Bit 4 Reserved, must be kept at reset value.

Bit 3 **IE:** Interrupt Enable

0: RNG Interrupt is disabled

1: RNG Interrupt is enabled. An interrupt is pending as soon as DRDY = 1, SEIS = 1 or CEIS = 1 in the RNG_SR register.

Bit 2 **RNGEN:** True random number generator enable

0: True random number generator is disabled. Analog noise sources are powered off and logic clocked by the RNG clock is gated.

1: True random number generator is enabled.

Bits 1:0 Reserved, must be kept at reset value.

39.7.2 RNG status register (RNG_SR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEIS	CEIS	Res.	Res.	SECS	CECS	DRDY
									rc_w0	rc_w0			r	r	r

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **SEIS:** Seed error interrupt status

This bit is set at the same time as SECS. It is cleared by writing 0 (unless CONDRST is used). Writing 1 has no effect.

0: No faulty sequence detected

1: At least one faulty sequence is detected. See **SECS** bit description for details.

An interrupt is pending if IE = 1 in the RNG_CR register.

Bit 5 **CEIS:** Clock error interrupt status

This bit is set at the same time as CECS. It is cleared by writing 0. Writing 1 has no effect.

0: The RNG clock is correct (fRNGCLK> fHCLK/32)

1: The RNG clock before internal divider is detected too slow (fRNGCLK< fHCLK/32)

An interrupt is pending if IE = 1 in the RNG_CR register.

Bits 4:3 Reserved, must be kept at reset value.

Bit 2 **SECS:** Seed error current status

0: No faulty sequence has currently been detected. If the SEIS bit is set, this means that a faulty sequence was detected and the situation has been recovered.

1: At least one of the following faulty sequence has been detected:

- Run-time repetition count test failed (noise source has provided more than 24 consecutive bits at a constant value 0 or 1, or more than 32 consecutive occurrence of two bits patterns 01 or 10)
- Start-up or continuous adaptive proportion test on noise source failed.
- Start-up post-processing/conditioning sanity check failed.

Bit 1 **CECS:** Clock error current status

0: The RNG clock is correct (fRNGCLK> fHCLK/32). If the CEIS bit is set, this means that a slow clock was detected and the situation has been recovered.

1: The RNG clock is too slow (fRNGCLK< fHCLK/32).

Note: CECS bit is valid only if the CED bit in the RNG_CR register is set to 0.

Bit 0 **DRDY:** Data Ready

0: The RNG_DR register is not yet valid, no random data is available.

1: The RNG_DR register contains valid random data.

Once the output buffer becomes empty (after reading the RNG_DR register), this bit returns to 0 until a new random value is generated.

Note: The DRDY bit can rise when the peripheral is disabled (RNGEN = 0 in the RNG_CR register).

If IE=1 in the RNG_CR register, an interrupt is generated when DRDY = 1.

39.7.3 RNG data register (RNG_DR)

Address offset: 0x008

Reset value: 0x0000 0000

The RNG_DR register is a read-only register that delivers a 32-bit random value when read. The content of this register is valid when DRDY = 1 and value is not 0x0, even if RNGEN = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RNDATA[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RNDATA[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RNDATA[31:0]:** Random data

32-bit random data which are valid when DRDY = 1. When DRDY = 0 RNDATA value is zero.

It is recommended to always verify that RNG_DR is different from zero. Because when it is the case a seed error occurred between RNG_SR polling and RND_DR output reading (rare event).

39.7.4 RNG health test control register (RNG_HTCR)

Address offset: 0x010

Reset value: 0x0000 5A4E

Writing in RNG_HTCR is taken into account only if CONDRST bit is set, and CONFIGLOCK bit is cleared in RNG_CR. Writing to this register is ignored if CONFIGLOCK=1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HTCFG[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HTCFG[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **HTCFG[31:0]:** health test configuration

This configuration is used by RNG to configure the health tests. See *Section 39.6: RNG entropy source validation* for the recommended value.

Note: The RNG behavior, including the read to this register, is not guaranteed if a different value from the recommended value is written.

When reading or writing this register magic number; 0x17590ABC must be written immediately before to RNG_HTCR register.

39.7.5 RNG register map

Table 321. RNG register map and reset map

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	RNG_CR	CONFIGLOCK	CONDRST	Res.	Res.	Res.	Res.	RNG_CONFIG1[5:0]						CLKDIV[3:0]				RNG_CONFIG2[2:0]			NISTC	RNG_CONFIG3[3:0]				Res.	Res.	CED	Res.	IE	RNGEN	Res.	Res.
	Reset value	0	0					0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0		0	0		
0x004	RNG_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEIS	CEIS	Res.	Res.	SECS	CECS	DRDY
	Reset value																										0	0			0	0	0
0x008	RNG_DR	RNDATA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x010	RNG_HTCR	HTCFG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	1	1	0	1	0	0	1	0	0	1	1	1	0

Refer to *Section 2.3* for the register boundary addresses.

40 Cryptographic processor (CRYP)

40.1 Introduction

The cryptographic processor (CRYP) can be used both to encrypt and decrypt data using the DES, Triple-DES or AES algorithms. It is a fully compliant implementation of the following standards:

- The data encryption standard (DES) and Triple-DES (TDES) as defined by Federal Information Processing Standards Publication (FIPS PUB 46-3, Oct 1999), and the American National Standards Institute (ANSI X9.52)
- The advanced encryption standard (AES) as defined by Federal Information Processing Standards Publication (FIPS PUB 197, Nov 2001)

Multiple key sizes and chaining modes are supported:

- DES/TDES chaining modes ECB and CBC, supporting standard 56-bit keys with 8-bit parity per key
- AES chaining modes ECB, CBC, CTR, GCM, GMAC, CCM for key sizes of 128, 192 or 256 bits

The CRYP processor is a 32-bit AHB peripheral. It supports DMA transfers for incoming and outgoing data (two DMA channels are required). The peripheral also includes input and output FIFOs (each 8 words deep) for better performance.

40.2 CRYP main features

- Compliant implementation of the following standards:
  - NIST *FIPS publication 46-3, Data Encryption Standard (DES)*
  - ANSI *X9.52, Triple Data Encryption Algorithm Modes of Operation*
  - NIST *FIPS publication 197, Advanced Encryption Standard (AES)*
- AES symmetric block cipher implementation
  - 128-bit data block processing
  - Support for 128-, 192- and 256-bit cipher key lengths
  - Encryption and decryption with multiple chaining modes: Electronic Code Book (ECB), Cipher Block Chaining (CBC), Counter mode (CTR), Galois Counter Mode (GCM), Galois Message Authentication Code mode (GMAC) and Counter with CBC-MAC (CCM)
  - 14 (respectively 18) clock cycles for processing one 128-bit block of data with a 128-bit (respectively 256-bit) key in AES-ECB mode
  - Integrated key scheduler with its key derivation stage (ECB or CBC decryption only)
- DES/TDES encryption/decryption implementation
  - 64-bit data block processing
  - Support for 64-, 128- and 192-bit cipher key lengths (including parity)
  - Encryption and decryption with support of ECB and CBC chaining modes
  - Direct implementation of simple DES algorithms (a single key K1 is used)

  - 16 (respectively 48) clock cycles for processing one 64-bit block of data in DES (respectively TDES) ECB mode
  - Software implementation of ciphertext stealing
- Features common to DES/TDES and AES
  - AMBA AHB slave peripheral, accessible through 32-bit word single accesses only (otherwise an AHB bus error is generated, and write accesses are ignored)
  - 256-bit register for storing the cryptographic key (8x 32-bit registers)
  - 128-bit registers for storing initialization vectors (4× 32-bit)
  - 1x32-bit INPUT buffer associated with an internal IN FIFO of eight 32- bit words, corresponding to four incoming DES blocks or two AES blocks
  - 1x32-bit OUTPUT buffer associated with an internal OUT FIFO of eight 32-bit words, corresponding to four processed DES blocks or two AES blocks
  - Automatic data flow control supporting direct memory access (DMA) using two channels (one for incoming data, one for processed data). The OUT FIFO supports both single and burst transfers, while the IN FIFO supports only burst transfers.
  - Data swapping logic to support 1-, 8-, 16- or 32-bit data
  - Possibility for software to suspend a message if the cryptographic processor needs to process another message with higher priority (suspend/resume operation)

40.3 CRYP implementation

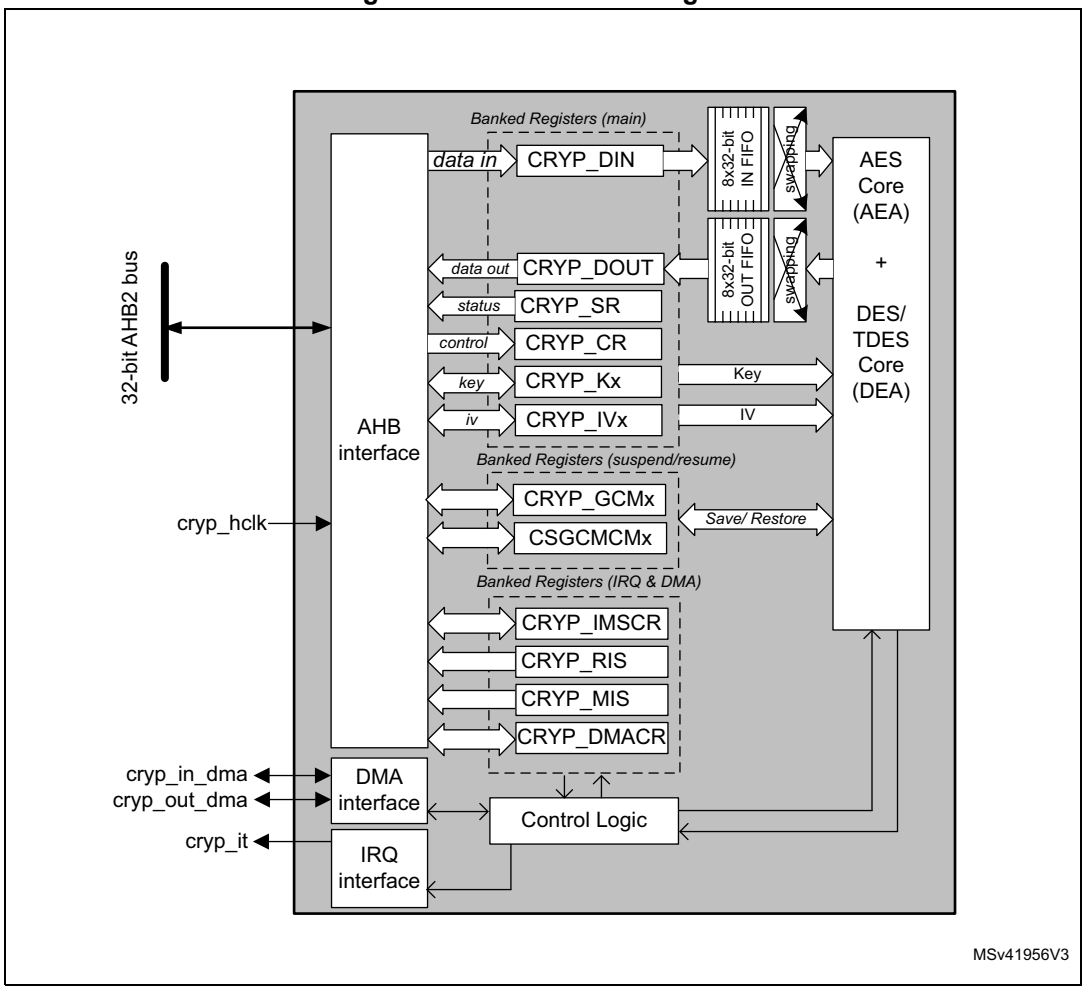
This device has one CRYP instance.

40.4 CRYP functional description

40.4.1 CRYP block diagram

The figure below shows the block diagram of the cryptographic processor.

Figure 341. CRYP block diagram



40.4.2 CRYP internal signals

Table 322 provides a list of useful-to-know internal signals available at cryptographic processor level and not at STM32 product level (on pads).

Table 322. CRYP internal input/output signals

Signal name	Signal type	Description
cryp_hclk	Digital input	AHB bus clock
cryp_it	Digital output	Cryptographic processor global interrupt request
cryp_in_dma	Digital input/output	IN FIFO DMA burst request/ acknowledge
cryp_out_dma	Digital input/output	OUT FIFO DMA burst request/ acknowledge (with single request for DES/TDES)

40.4.3 CRYP DES/TDES cryptographic core

Overview

The DES/Triple-DES cryptographic core consists of three components:

- The DES Algorithm (DEA core)
- Multiple keys (one for the DES algorithm, one to three for the TDES algorithm)
- The initialization vector, which is used only in CBC mode

The DES/Triple-DES cryptographic core provides two operating modes:

- **ALGODIR = 0**: Plaintext encryption using the key stored in the CRYP_Kx registers.
- **ALGODIR = 1**: Ciphertext decryption using the key stored in the CRYP_Kx registers.

The operating mode is selected by programming the ALGODIR bit in the CRYP_CR register.

Typical data processing

Typical usage of the cryptographic processor in DES modes can be found in *Section 40.4.10: CRYP DES/TDES basic chaining modes (ECB, CBC)*.

Note: The outputs of the intermediate DEA stages are never revealed outside the cryptographic boundary, with the exclusion of the IV registers in CBC mode.

DES/TDES keying and chaining modes

The DES/TDES allows three different keying options:

- *Three independent keys*

  The first option specifies that all the keys are independent, that is, K1, K2 and K3 are independent. FIPS PUB 46-3 – 1999 (and ANSI X9.52 – 1998) refers to this option as the Keying Option 1 and, to the TDES as 3-key TDES.

- *Two independent keys*

  The second option specifies that K1 and K2 are independent and K3 is equal to K1, that is, K1 and K2 are independent, K3 = K1. FIPS PUB 46-3 – 1999 (and ANSI X9.52

– 1998) refers to this second option as the Keying Option 2 and, to the TDES as 2-key TDES.

- *Three equal keys*

  The third option specifies that K1, K2 and K3 are equal, that is:

  K1 = K2 = K3

  FIPS PUB 46-3 – 1999 (and ANSI X9.52 – 1998) refers to the third option as the Keying Option 3. This “1-key” TDES is equivalent to single DES.

The following chaining algorithms are supported by the DES hardware and can be selected through the ALGOMODE bits in the CRYP_CR register:

- Electronic Code Book (ECB)
- Cipher Block Chaining (CBC)

These modes are described in details in *Section 40.4.10: CRYP DES/TDES basic chaining modes (ECB, CBC)*.

40.4.4 CRYP AES cryptographic core

Overview

The AES cryptographic core consists of the following components:

- The AES algorithm (AEA core)
- The Multiplier over a binary Galois field (GF2mul)
- The key information
- The initialization vector (IV) or Nonce information
- Chaining algorithms logic (XOR, feedback/counter, mask)

The AES core works on 128-bit data blocks of (four words) with 128-, 192- or 256-bit key lengths. Depending on the chaining mode, the peripheral requires zero or one 128-bit initialization vector (IV).

The cryptographic peripheral features two operating modes:

- **ALGODIR = 0**: Plaintext encryption using the key stored in the CRYP_Kx registers.
- **ALGODIR = 1**: Ciphertext decryption using the key stored in the CRYP_Kx registers. When ECB and CBC chaining modes are selected, an initial key derivation process is automatically performed by the cryptographic peripheral.

The operating mode is selected by programming the ALGODIR bit in the CRYP_CR register.

Typical data processing

A description of cryptographic processor typical usage in AES mode can be found in *Section 40.4.11: CRYP AES basic chaining modes (ECB, CBC)*.

Note: The outputs of the intermediate AEA stages is never revealed outside the cryptographic boundary, with the exclusion of the IV registers.

AES chaining modes

The following chaining algorithms are supported by the cryptographic processor and can be selected through the ALGOMODE bits in the CRYP_CR register:

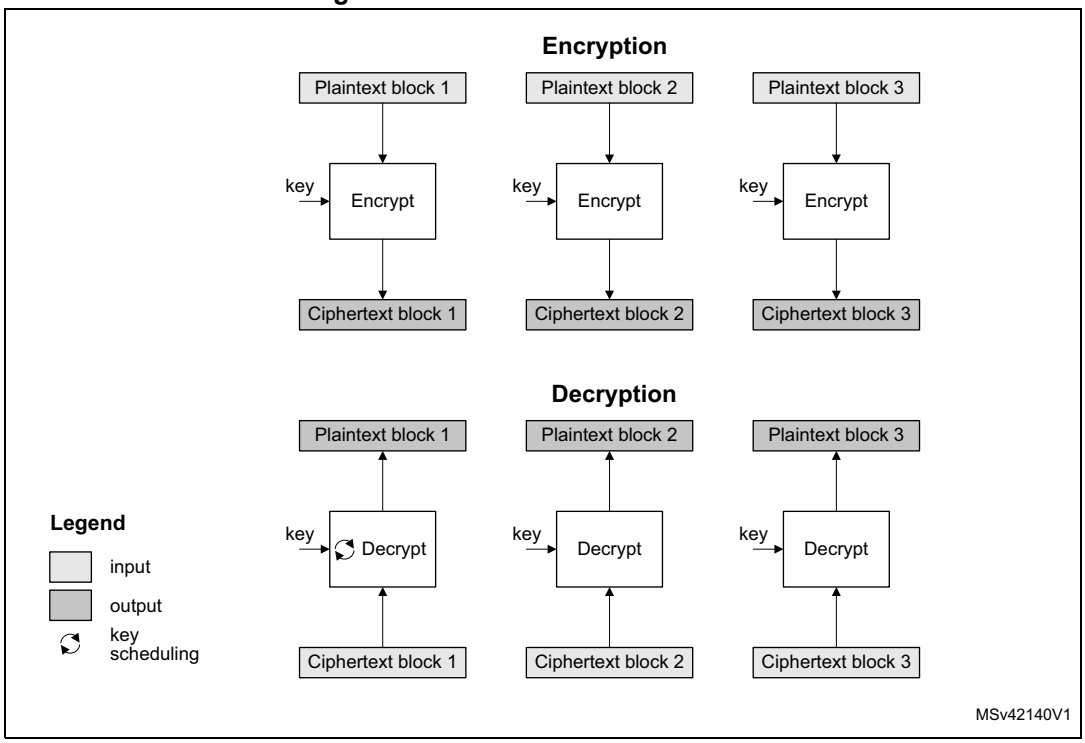
- Electronic Code Book (ECB)
- Cipher Block Chaining (CBC)
- Counter Mode (CTR)
- Galois/Counter Mode (GCM)
- Galois Message Authentication Code mode (GMAC)
- Counter with CBC-MAC (CCM)

A quick introduction on these chaining modes can be found in the following subsections.

For detailed instructions, refer to *Section 40.4.11: CRYP AES basic chaining modes (ECB, CBC)* and onward.

AES Electronic CodeBook (ECB)

Figure 342. AES-ECB mode overview

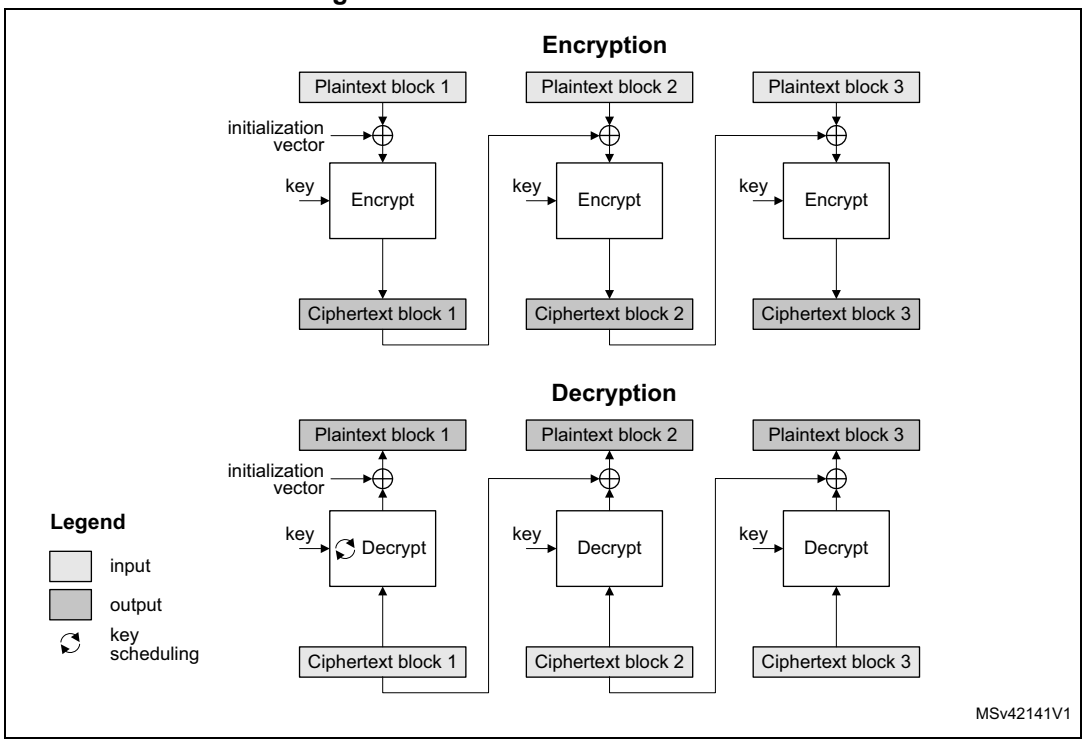


ECB is the simplest operating mode. There are no chaining operations, and no special initialization stage. The message is divided into blocks and each block is encrypted or decrypted separately.

Note: For decryption, a special key scheduling is required before processing the first block.

AES Cipher block chaining (CBC)

Figure 343. AES-CBC mode overview

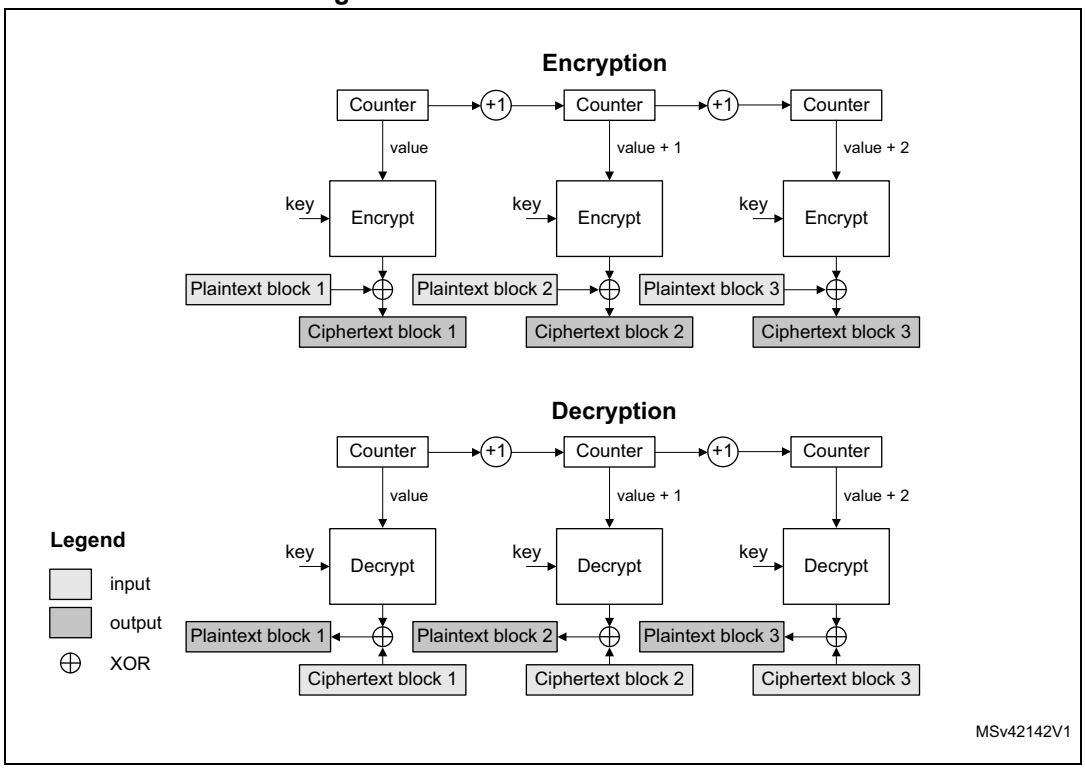


CBC operating mode chains the output of each block with the input of the following block. To make each message unique, an initialization vector is used during the first block processing.

Note: For decryption, a special key scheduling is required before processing the first block.

AES Counter mode (CTR)

Figure 344. AES-CTR mode overview

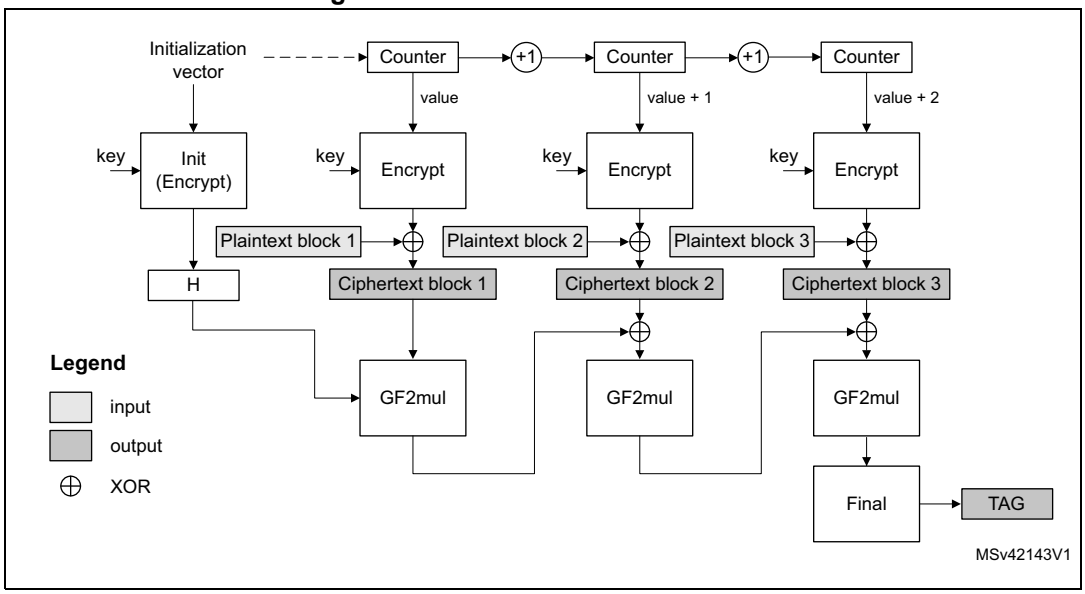


The CTR mode uses the AES core to generate a key stream; these keys are then XORed with the plaintext to obtain the ciphertext as specified in NIST *Special Publication 800-38A, Recommendation for Block Cipher Modes of Operation*.

Note: Unlike ECB and CBC modes, no key scheduling is required for the CTR decryption, since in this chaining scheme the AES core is always used in encryption mode for producing the counter blocks.

AES Galois/Counter mode (GCM)

Figure 345. AES-GCM mode overview

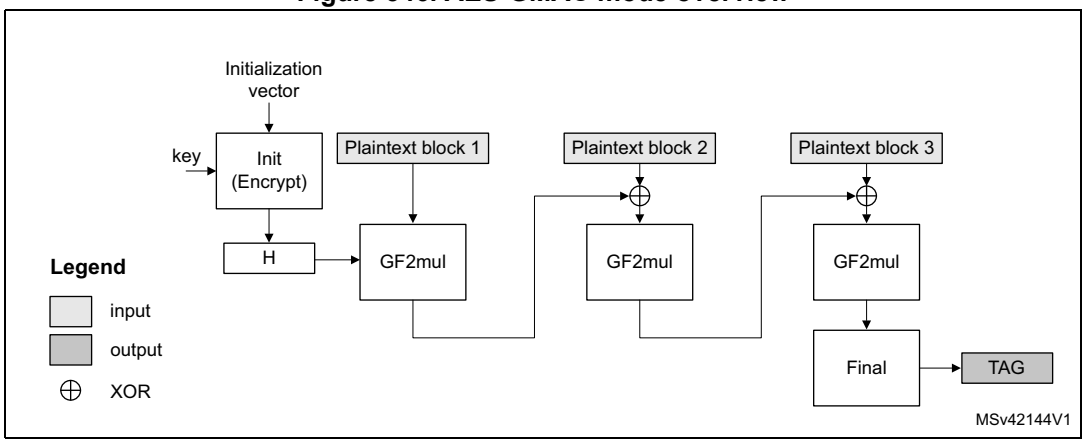


In Galois/Counter mode (GCM), the plaintext message is encrypted, while a message authentication code (MAC) is computed in parallel, thus generating the corresponding ciphertext and its MAC (also known as authentication tag). It is defined in NIST *Special Publication 800-38D, Recommendation for Block Cipher Modes of Operation - Galois/Counter Mode (GCM) and GMAC.*

GCM mode is based on AES in counter mode for confidentiality. It uses a multiplier over a fixed finite field for computing the message authentication code. It requires an initial value and a particular 128-bit block at the end of the message.

AES Galois Message Authentication Code (GMAC)

Figure 346. AES-GMAC mode overview

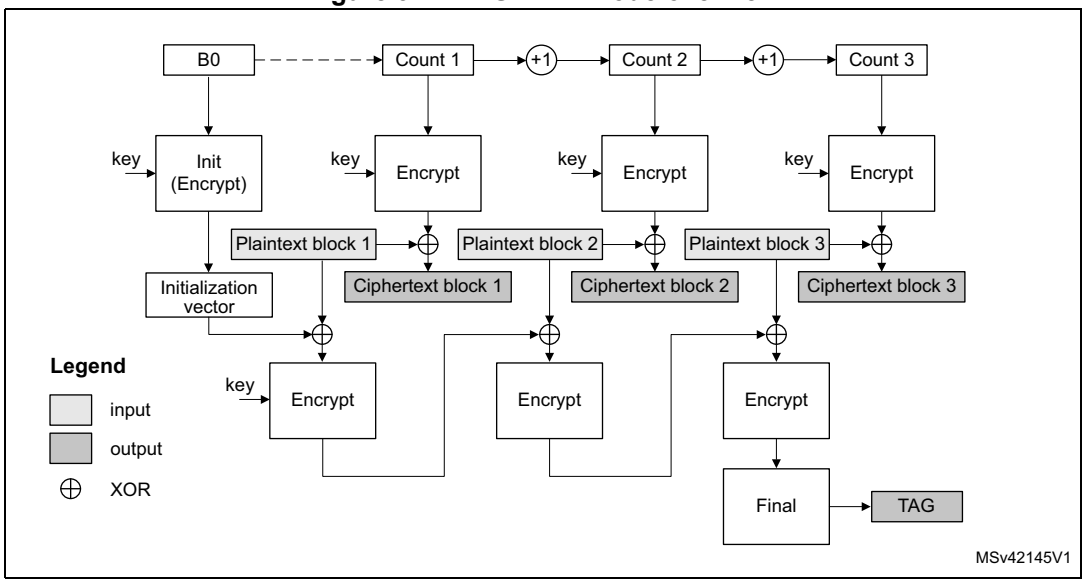


Galois Message Authentication Code (GMAC) allows authenticating a message and generating the corresponding message authentication code (MAC). It is defined in NIST *Special Publication 800-38D, Recommendation for Block Cipher Modes of Operation - Galois/Counter Mode (GCM) and GMAC*.

GMAC is similar to Galois/Counter mode (GCM), except that it is applied on a message composed only by clear-text authenticated data (i.e. only header, no payload).

AES Counter with CBC-MAC (CCM)

Figure 347. AES-CCM mode overview



In Counter with Cipher Block Chaining-Message Authentication Code (CCM), the plaintext message is encrypted while a message authentication code (MAC) is computed in parallel, thus generating the corresponding ciphertext and the corresponding MAC (also known as tag). It is described by NIST in *Special Publication 800-38C, Recommendation for Block Cipher Modes of Operation - The CCM Mode for Authentication and Confidentiality*.

CCM mode is based on AES in counter mode for confidentiality and it uses CBC for computing the message authentication code. It requires an initial value.

Like GCM CCM chaining mode, AES-CCM mode can be applied on a message composed only by cleartext authenticated data (i.e. only header, no payload). Note that this way of using CCM is not called CMAC (it is not similar to GCM/GMAC), and its usage is not recommended by NIST.

40.4.5 CRYP procedure to perform a cipher operation

Introduction

To understand how the cryptographic peripheral operates, a typical cipher operation is described below. For the detailed peripheral usage according to the cipher mode, refer to the specific section, for example *Section 40.4.11: CRYP AES basic chaining modes (ECB, CBC)*.

CRYP initialization

To initialize the cryptographic processor, first disable it by clearing the CRYPEN bit in the CRYP_CR register. Then execute the following steps:

1. Configure the algorithm and the chaining mode through the ALGOMODE and ALGODIR bits in the CRYP_CR register. Configure also the key size with the KEYSIZE bits.
   – When ALGODIR is set to 1 (decryption) and the selected algorithm/chaining mode is AES-ECB or AES-CBC, an initial key derivation of the encryption key must be performed as described in *Section 40.4.7: Preparing the CRYP AES key for decryption*.
2. When the previous step is complete, and when applicable, write the symmetric key into the CRYP_KxL/R registers. The way to write key registers is defined in *Section 40.4.17: CRYP key registers*
3. Configure the data type (1, 8, 16 or 32 bits) through the DATATYPE bits of the CRYP_CR register.
4. When it is required (for example for CBC or CTR chaining modes), write the initialization vectors into the CRYP_IVxL/R register.
5. Flush the IN and OUT FIFOs by writing the FFLUSH bit to 1 in the CRYP_CR register.

Preliminary warning for all cases

If the ECB or CBC mode is selected and data are not a multiple of 64 bits (for DES) or 128 bits (for AES), the second and the last block management is more complex than the sequences below. Refer to *Section 40.4.8: CRYP stealing and data padding* for more details.

Appending data using the CPU in Polling mode

1. Enable the cryptographic processor by setting to 1 the CRYPEN bit in the CRYP_CR register.
2. Write data in the IN FIFO (one block or until the FIFO is full).
3. Repeat the following sequence until the second last block of data has been processed:
   a) Wait until the not-empty-flag OFNE is set to 1, then read the OUT FIFO (one block or until the FIFO is empty).
   b) Wait until the not-full-flag IFNF is set to 1, then write the IN FIFO (one block or until the FIFO is full) except if it is the last block.
4. The BUSY bit is set automatically by the cryptographic processor. At the end of the processing, the BUSY bit returns to 0 and both FIFOs are empty (IN FIFO empty flag IFEM = 1 and OUT FIFO not empty flag OFNE = 0).
5. If the next processing block is the last block, the CPU must pad (when applicable) the data with zeroes to obtain a complete block and specify the number of non-valid bytes using NPBLB bits in CRYP_CR register in case of AES GCM payload encryption or AES CCM payload decryption (otherwise the tag computation will be wrong). This operation must be performed after checking that the BUSY bit in the CRYP_CR register is set to 0.

Note: NPBLB bits are not used in the header phase of AES GCM, GMAC and CCM modes.

6. When the operation is complete, the cryptographic processor can be disabled by clearing the CRYPEN bit in CRYP_CR register.

Appending data using the CPU in Interrupt mode

1. Enable the interrupts by setting the INIM and OUTIM bits in the CRYP_IMSCR register.
2. Enable the cryptographic processor by setting to 1 the CRYPEN bit in the CRYP_CR register.
3. In the interrupt service routine that manages the input data:
   a) If the last block is being loaded, the CPU must pad (when applicable) the data with zeroes to have a complete block and specify the number of non-valid bytes using NPBLB bits in CRYP_CR register in case of AES GCM payload encryption or AES CCM payload decryption (otherwise the tag computation will be wrong). This operation must be performed after checking that the BUSY bit in the CRYP_CR register is set to 0. Then load the block into the IN FIFO.

Note: NPBLB bits are not used in the header phase of AES GCM, GMAC and CCM.

   b) If it is not the last block, load the data into the IN FIFO. You can load only one block (2 words for DES, 4 words for AES), or load data until the FIFO is full.
   c) In all cases, after the last word of data has been written, disable the interrupt by clearing the INIM interrupt mask.
4. In the interrupt service routine that manages the input data:
   a) Read the output data from the OUT FIFO. You can read only one block (2 words for DES, 4 words for AES), or read data until the FIFO is empty.
   b) When the last word has been read, INIM and BUSY bits are set to 0 and both FIFOs are empty (IFEM = 1 and OFNE = 0). You can disable the interrupt by clearing the OUTIM bit, and disable the peripheral by clearing the CRYPEN bit.
   c) If you read the last block of cleartext data (i.e. decryption), optionally discard the data that is not part of message/payload.

Appending data using the DMA

1. Prepare the last block of data by optionally padding it with zeroes to have a complete block.
2. Configure the DMA controller to transfer the input data from the memory and transfer the output data from the peripheral to the memory, as described in *Section 40.4.19: CRYP DMA interface*. The DMA should be configured to set an interrupt on transfer completion to indicate that the processing is complete. In case of AES GCM payload encryption or AES CCM payload decryption, DMA transfers must not include the last block. The sequence using the CPU described above must be used instead for this last block, because NPBLB bits needs to be setup before processing the block (otherwise the tag computation will be wrong).

Note: NPBLB bits are not used in the header phase of AES GCM, GMAC and CCM.

3. Enable the cryptographic processor by setting to 1 the CRYPEN bit in CRYP_CR register, then enable the DMA IN and OUT requests by setting to 1 the DIEN and DOEN bits in the CRYP_DMACR register.
4. All the transfers and processing are managed by the DMA and the cryptographic processor. The DMA interrupt indicates that the processing is complete. Both FIFOs are normally empty and BUSY flag is set 0.

Caution: It is important that DMA controller empties the cryptographic processor output FIFO before filling up the cryptographic processor input FIFO. To achieve this, the DMA controller should be configured so that the transfer from the cryptographic peripheral to the memory has a higher priority than the transfer from the memory to the cryptographic peripheral.

40.4.6 CRYP busy state

The cryptographic processor is busy and processing data (BUSY set to 1 in CRYP_SR register) when all the conditions below are met:

- CRYPEN = 1 in CRYP_CR register.
- There are enough data in the input FIFO (at least two words for the DES or TDES algorithm mode, four words for the AES algorithm mode).
- There is enough free-space in the output FIFO (at least two word locations for DES, four for AES).

Write operations to the CRYP_Kx(L/R)R key registers, to the CRYP_IVx(L/R)R initialization registers, or to bits [9:2] of the CRYP_CR register, are ignored when cryptographic processor is busy (i.e. the registers are not modified). It is thus not possible to modify the configuration of the cryptographic processor while it is processing a data block.

It is possible to clear the CRYPEN bit while BUSY bit is set to 1. In this case the ongoing DES/TDES or AES processing first completes (i.e. the word results are written to the output FIFO) before the BUSY bit is cleared by hardware.

Note: If the application needs to suspend a message to process another one with a higher priority, refer to Section 40.4.9: CRYP suspend/resume operations

When a block is being processed in DES or TDES mode, if the output FIFO becomes full and the input FIFO contains at least one new block, then the new block is popped off the input FIFO and the BUSY bit remains high until there is enough space to store this new block into the output FIFO.

40.4.7 Preparing the CRYP AES key for decryption

When performing an AES **ECB or CBC decryption**, the AES key has to be prepared. Indeed, in AES encryption the round 0 key is the one stored in the key registers, and AES decryption must start using the last round key. Hence, as the encryption key is stored in memory, a special key scheduling must be performed to obtain the decryption key. This preparation is not required in any other AES modes than ECB or CBC decryption.

When the cryptographic processor is disabled (CRYPEN = 0), the CRYP key preparation process is performed as follows:

1. Program ALGOMODE bits to 0x7 in CRYP_CR. In addition, configure the key length with the KEYSIZE bits.
2. Write the symmetric key to the CRYP_KxL/R registers, as described in *Section 40.4.17: CRYP key registers*.
3. Enable the cryptographic processor by setting the CRYPEN bit in the CRYP_CR register. It immediately starts an AES round for key preparation (BUSY = 1).
4. Wait until the BUSY bit is cleared in the CRYP_SR register. Then update ALGOMODE bits in the CRYP_CR register to select the correct chaining mode, that is 0x4 for ECB or 0x5 for CBC.
5. The AES key is available in the CRYP key registers, ready to use for decryption.

Note: As the CRYPEN bitfield is reset by hardware at the end of the key preparation, the application software must set it again for the next operation.

The latency of the key preparation operation is 14, 16 or 18 clock cycles depending on the key size (128, 192 or 256 bits).

40.4.8 CRYP stealing and data padding

When using DES or AES algorithm in **ECB** or **CBC** modes to manage messages that are not multiple of the block size (64 bits for DES, 128 bits for AES), use ciphertext stealing techniques such as those described in NIST *Special Publication 800-38A, Recommendation for Block Cipher Modes of Operation: Three Variants of Ciphertext Stealing for CBC Mode*. Since the cryptographic processor does not implement such techniques, **the last two blocks** must be handled in a special way by the application.

Note: Ciphertext stealing techniques are not documented in this reference manual.

Similarly, when the AES algorithm is used in other modes than ECB or CBC, incomplete input data blocks (i.e. block shorter than 128 bits) have to be padded with zeroes by the application prior to encryption (i.e. extra bits should be appended to the trailing end of the data string). After decryption, the extra bits have to be discarded. The cryptographic processor does not implement automatic data padding operation to **the last block**, so the application should follow the recommendation given in *Section 40.4.5: CRYP procedure to perform a cipher operation* to manage messages that are not multiple of 128 bits.

Note: Padding data are swapped in a similar way as normal data, according to the DATATYPE field in CRYP_CR register (see Section 40.4.16: CRYP data registers and data swapping for details).

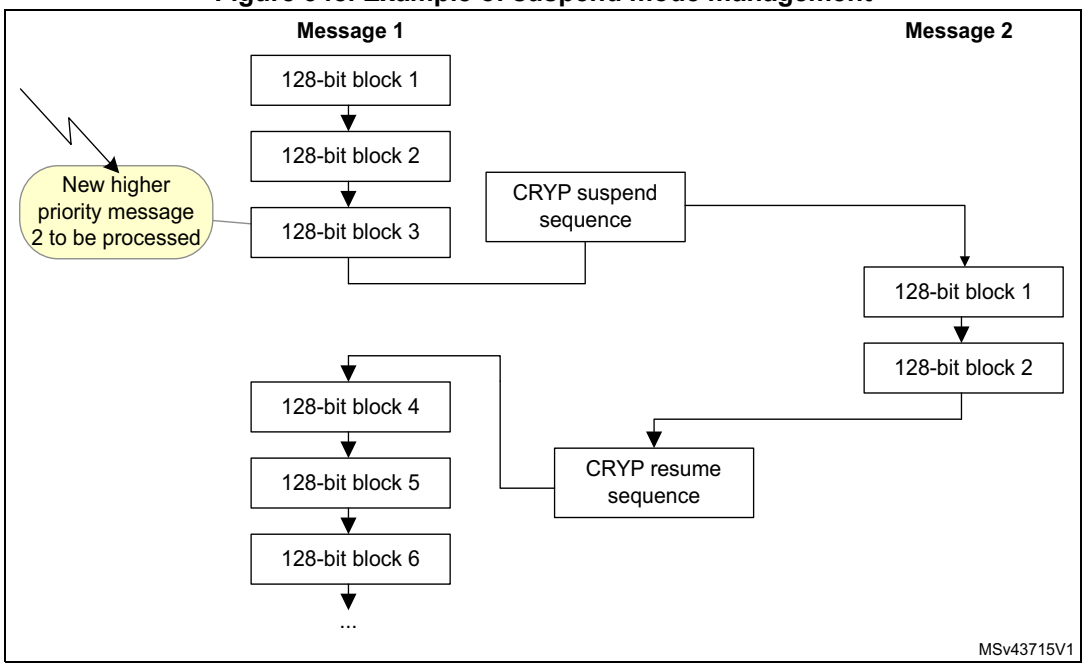
40.4.9 CRYP suspend/resume operations

A message can be suspended if another message with a higher priority has to be processed. When this highest priority message has been sent, the suspended message can be resumed in both encryption or decryption mode.

Suspend/resume operations do not break the chaining operation and the message processing can be resumed as soon as cryptographic processor is enabled again to receive the next data block.

Figure 348 gives an example of suspend.resume operation: message 1 is suspended in order to send a higher priority message (message 2), which is shorter than message 1 (AES algorithm).

Figure 348. Example of suspend mode management



A detailed description of suspend/resume operations can be found in each AES mode section.

40.4.10 CRYP DES/TDES basic chaining modes (ECB, CBC)

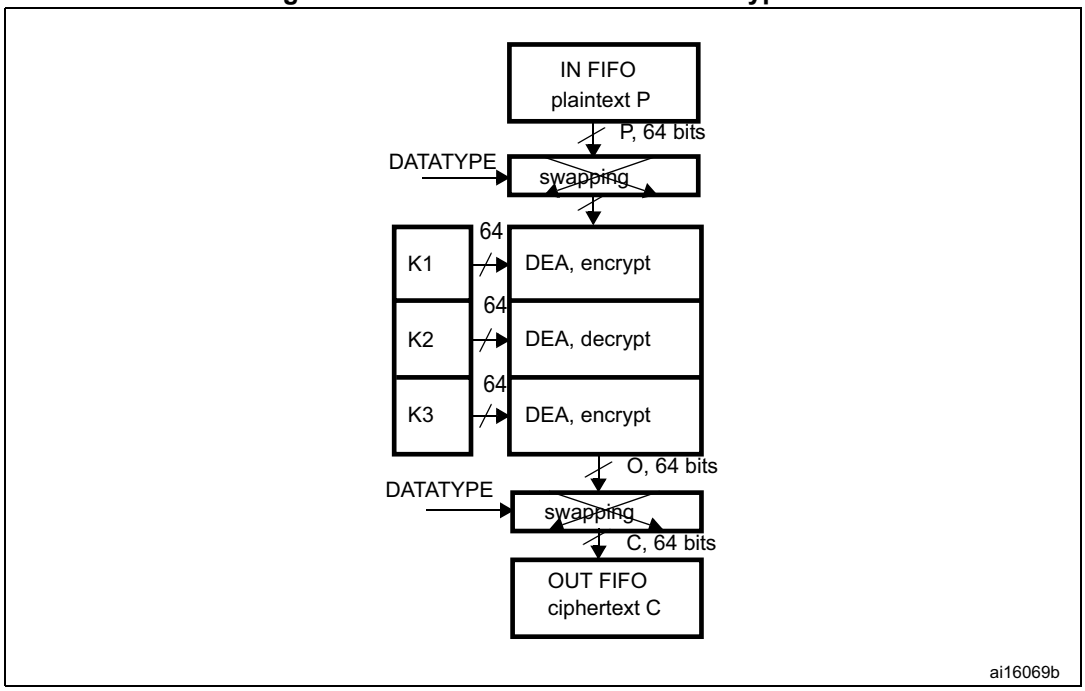
Overview

FIPS PUB 46-3 – 1999 (and ANSI X9.52-1998) provides a thorough explanation of the processing involved in the four operation modes supplied by the DES computing core: TDES-ECB encryption, TDES-ECB decryption, TDES-CBC encryption and TDES-CBC decryption. This section only gives a brief explanation of each mode.

DES/TDES-ECB encryption

Figure 349 illustrates the encryption in DES and TDES Electronic CodeBook (DES/TDES-ECB) mode. This mode is selected by programming ALGOMODE 0x0 and ALGODIR to 0 in CRYP_CR.

Figure 349. DES/TDES-ECB mode encryption



1. K: key; C: cipher text; I: input block; O: output block; P: plain text.

A 64-bit plaintext data block (P) is used after bit/byte/half-word as the input block (I). The input block is processed through the DEA in the encrypt state using K1. The output of this process is fed back directly to the input of the DEA where the DES is performed in the decrypt state using K2. The output of this process is fed back directly to the input of the DEA where the DES is performed in the encrypt state using K3. The resultant 64-bit output block (O) is used, after bit/byte/half-word swapping, as ciphertext (C) and it is pushed into the OUT FIFO.

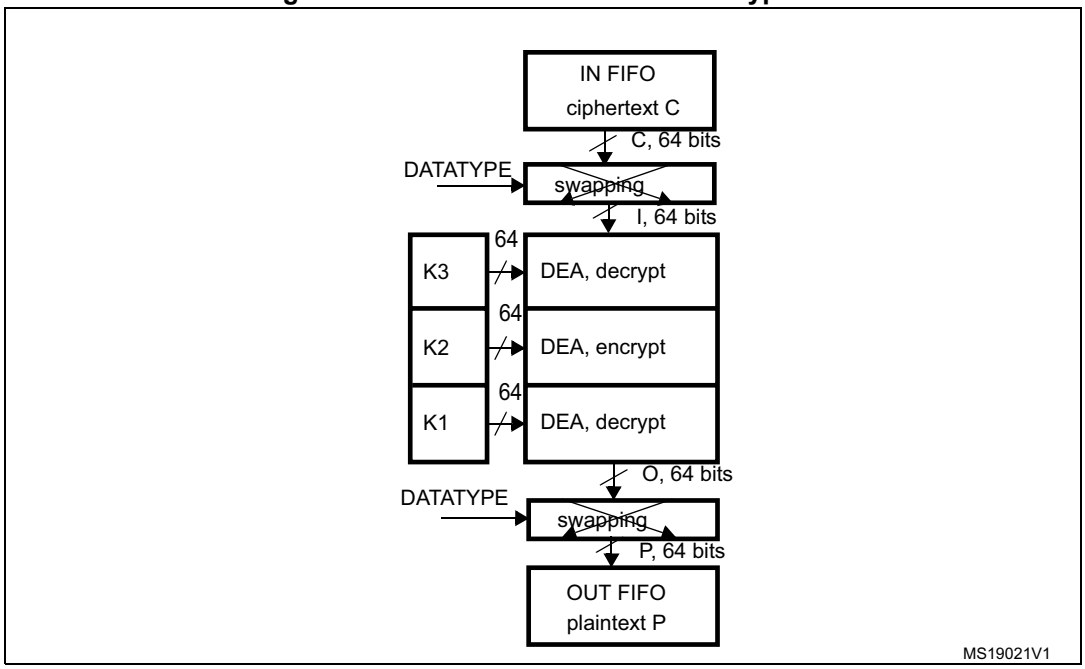
Note: For more information on data swapping, refer to Section 40.4.16: CRYP data registers and data swapping.

Detailed DES/TDES encryption sequence can be found in Section 40.4.5: CRYP procedure to perform a cipher operation.

DES/TDES-ECB mode decryption

Figure 350 illustrates the decryption in DES and TDES Electronic CodeBook (DES/TDES-ECB) mode. This mode is selected by programming ALGOMODE to 0x0 and ALGODIR to 1 in CRYP_CR.

Figure 350. DES/TDES-ECB mode decryption



1. K: key; C: cipher text; I: input block; O: output block; P: plain text.

A 64-bit ciphertext block (C) is used, after bit/byte/half-word swapping, as the input block (I). The keying sequence is reversed compared to that used in the encryption process. The input block is processed through the DEA in the decrypt state using K3. The output of this process is fed back directly to the input of the DEA where the DES is performed in the encrypt state using K2. The new result is directly fed to the input of the DEA where the DES is performed in the decrypt state using K1. The resultant 64-bit output block (O), after bit/byte/half-word swapping, produces the plaintext (P).

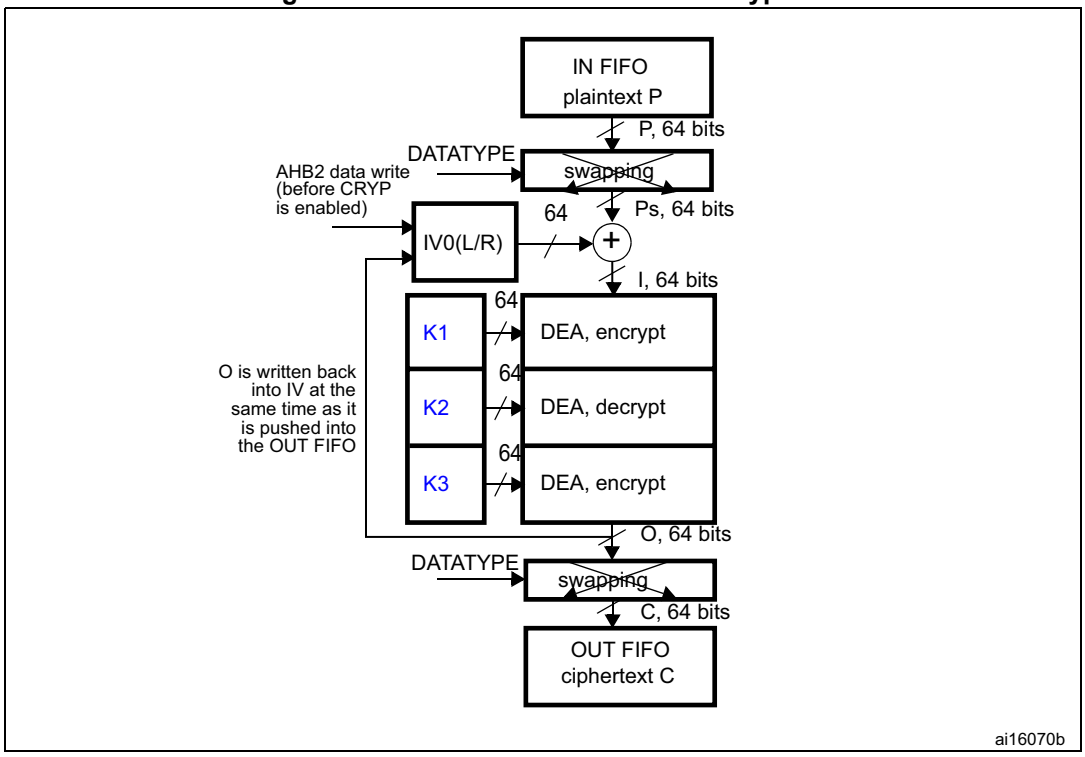
Note: For more information on data swapping refer to Section 40.4.16: CRYP data registers and data swapping.

Detailed DES/TDES encryption sequence can be found in Section 40.4.5: CRYP procedure to perform a cipher operation.

DES/TDES-CBC encryption

Figure 351 illustrates the encryption in DES and TDES Cipher Block Chaining (DES/TDES-ECB) mode. This mode is selected by programming ALGOMODE to 0x1 and ALGODIR to 0 in CRYP_CR.

Figure 351. DES/TDES-CBC mode encryption



K: key; C: cipher text; I: input block; O: output block; Ps: plain text before swapping (when decoding) or after swapping (when encoding); P: plain text; IV: initialization vectors.

This mode begins by dividing a plaintext message into 64-bit data blocks. In TCBC encryption, the first input block (I_1), obtained after bit/byte/half-word swapping, is formed by exclusive-ORing the first plaintext data block (P_1) with a 64-bit initialization vector IV ($I_1 = IV \oplus P_1$). The input block is processed through the DEA in the encrypt state using K1. The output of this process is fed back directly to the input of the DEA, which performs the DES in the decrypt state using K2. The output of this process is fed directly to the input of the DEA, which performs the DES in the encrypt state using K3. The resultant 64-bit output block (O_1) is used directly as the ciphertext (C_1), that is, $C_1 = O_1$.

This first ciphertext block is then exclusive-ORed with the second plaintext data block to produce the second input block, (I_2) = ($C_1 \oplus P_2$). Note that I_2 and P_2 now refer to the second block. The second input block is processed through the TDEA to produce the second ciphertext block.

This encryption process continues to “chain” successive cipher and plaintext blocks together until the last plaintext block in the message is encrypted.

If the message does not consist of an integral number of data blocks, then the final partial data block should be encrypted in a manner specified for the application.

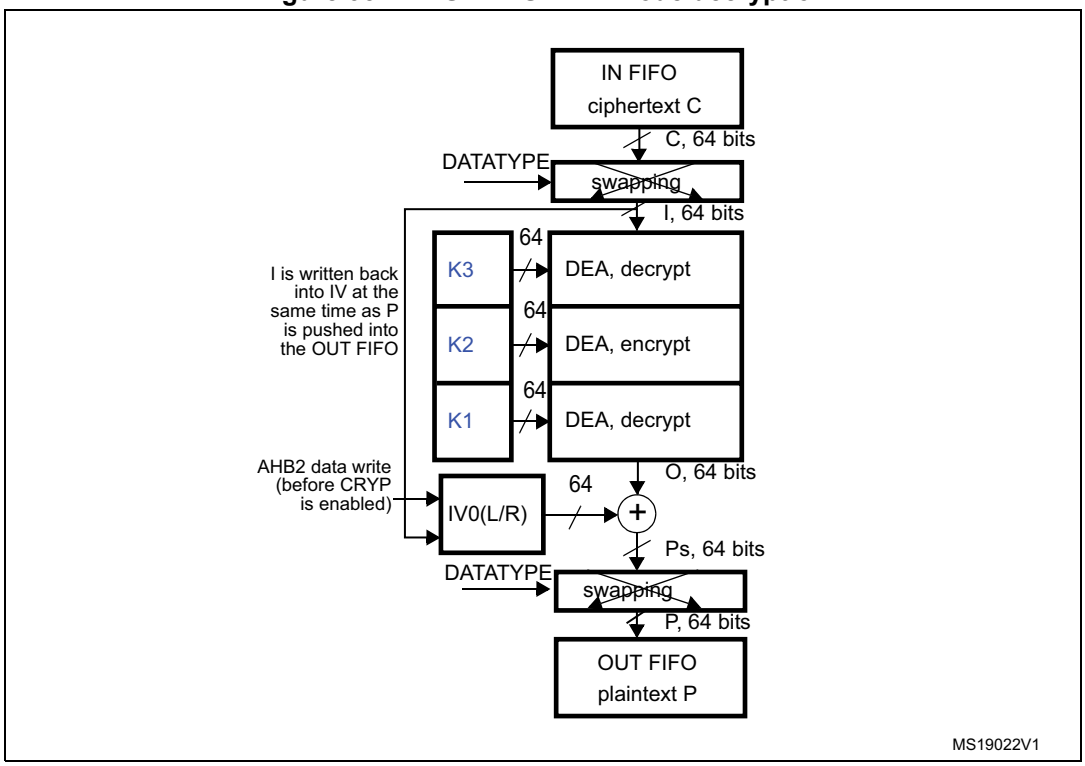
Note: For more information on data swapping refer to Section 40.4.16: CRYP data registers and data swapping.

Detailed DES/TDES encryption sequence can be found in Section 40.4.5: CRYP procedure to perform a cipher operation.

DES/TDES-CBC decryption

Figure 351 illustrates the decryption in DES and TDES Cipher Block Chaining (DES/TDES-ECB) mode. This mode is selected by writing ALGOMODE to 0x1 and ALGODIR to 1 in CRYP_CR.

Figure 352. DES/TDES-CBC mode decryption



1. K: key; C: cipher text; I: input block; O: output block; Ps: plain text before swapping (when decoding) or after swapping (when encoding); P: plain text; IV: initialization vectors.

In this mode the first ciphertext block (C_1) is used directly as the input block (I_1). The keying sequence is reversed compared to that used for the encrypt process. The input block is processed through the DEA in the decrypt state using K3. The output of this process is fed directly to the input of the DEA where the DES is processed in the encrypt state using K2. This resulting value is directly fed to the input of the DEA where the DES is processed in the decrypt state using K1. The resulting output block is exclusive-ORed with the IV (which must be the same as that used during encryption) to produce the first plaintext block ($P_1 = O_1 \oplus IV$).

The second ciphertext block is then used as the next input block and is processed through the TDEA. The resulting output block is exclusive-ORed with the first ciphertext block to produce the second plaintext data block ($P_2 = O_2 \oplus C_1$). Note that P_2 and O_2 refer to the second block of data.

The DES/TDES-CBC decryption process continues in this manner until the last complete ciphertext block has been decrypted.

Ciphertext representing a partial data block must be decrypted in a manner specified for the application.

Note: For more information on data swapping refer to Section 40.4.16: CRYP data registers and data swapping.

Detailed DES/TDES encryption sequence can be found in Section 40.4.5: CRYP procedure to perform a cipher operation.

DES/TDES suspend/resume operations in ECB/CBC modes

Before interrupting the current message, the user application must respect the following steps:

1. If DMA is used, stop the DMA transfers to the IN FIFO by clearing to 0 the DIEN bit in the CRYP_DMACR register.
2. Wait until both the IN and the OUT FIFOs are empty (IFEM = 1 and OFNE = 0 in the CRYP_SR) and the BUSY bit is cleared. Alternatively, as the input FIFO can contain up to four unprocessed DES blocks, the application could decide for real-time reason to interrupt the cryptographic processing without waiting for the IN FIFO to be empty. In this case, the alternative is:
   a) Wait until OUT FIFO is empty (OFNE = 0).
   b) Read back the data loaded in the IN FIFO that have not been processed and save them in the memory until the IN FIFO is empty.
3. If DMA is used stop the DMA transfers from the OUT FIFO by clearing to 0 the DOEN bit in the CRYP_DMACR register.
4. Disable the cryptographic processor by setting the CRYPEN bit to 0 in CRYP_CR, then save the current configuration (bits [9:2] in the CRYP_CR register). If CBC mode is selected, save the initialization vector registers, since CRYP_IVx registers have changed from initial values during the data processing.

Note: Key registers do not need to be saved as the original key value is known by the application.

5. If DMA is used, save the DMA controller status (such as the pointers to IN and OUT data transfers, number of remaining bytes).

To resume message processing, the user application must respect the following sequence:

1. If DMA is used, reconfigure the DMA controller to complete the rest of the FIFO IN and FIFO OUT transfers.
2. Make sure the cryptographic processor is disabled by reading the CRYPEN bit in CRYP_CR (it must be 0).
3. Configure again the cryptographic processor with the initial setting in CRYP_CR, as well as the key registers using the saved configuration.
4. If the CBC mode is selected, restore CRYP_IVx registers using the saved configuration.
5. Optionally, write the data that were saved during context saving into the IN FIFO.
6. Enable the cryptographic processor by setting the CRYPEN bit to 1.
7. If DMA is used, enable again DMA requests for the cryptographic processor, by setting to 1 the DIEN and DOEN bits in the CRYP_DMACR register.

40.4.11 CRYP AES basic chaining modes (ECB, CBC)

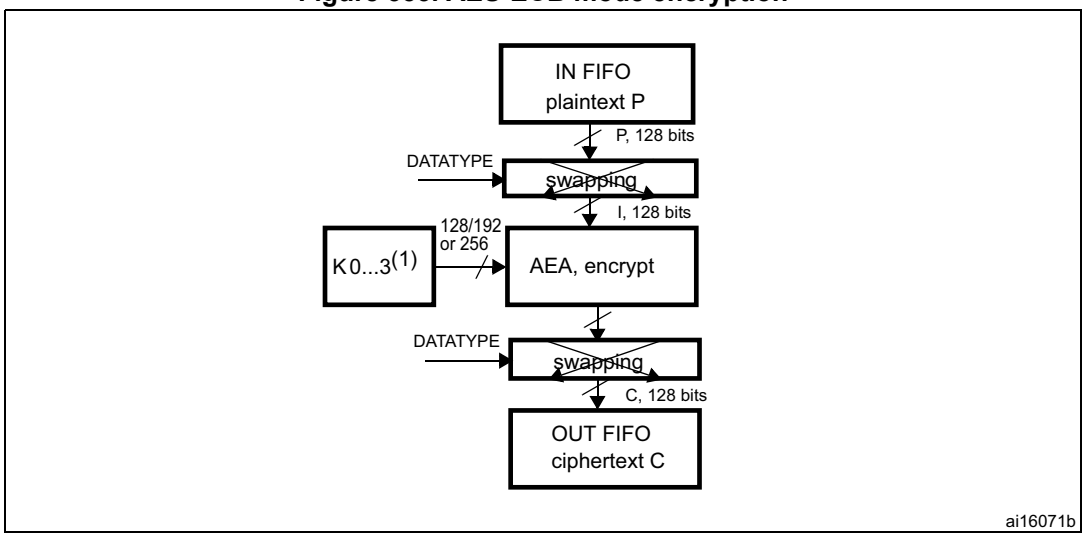
Overview

FIPS PUB 197 (November 26, 2001) provides a thorough explanation of the processing involved in the four basic operation modes supplied by the AES computing core: AES-ECB encryption, AES-ECB decryption, AES-CBC encryption and AES-CBC decryption. This section only gives a brief explanation of each mode.

AES ECB encryption

Figure 353 illustrates the AES Electronic codebook (AES-ECB) mode encryption. This mode is selected by writing ALGOMODE to 0x4 and ALGODIR to 0 in CRYP_CR.

Figure 353. AES-ECB mode encryption



1. K: key; C: cipher text; I: input block; O: output block; P: plain text.
2. If Key size = 128: Key = [K3 K2].
   If Key size = 192: Key = [K3 K2 K1]
   If Key size = 256: Key = [K3 K2 K1 K0].

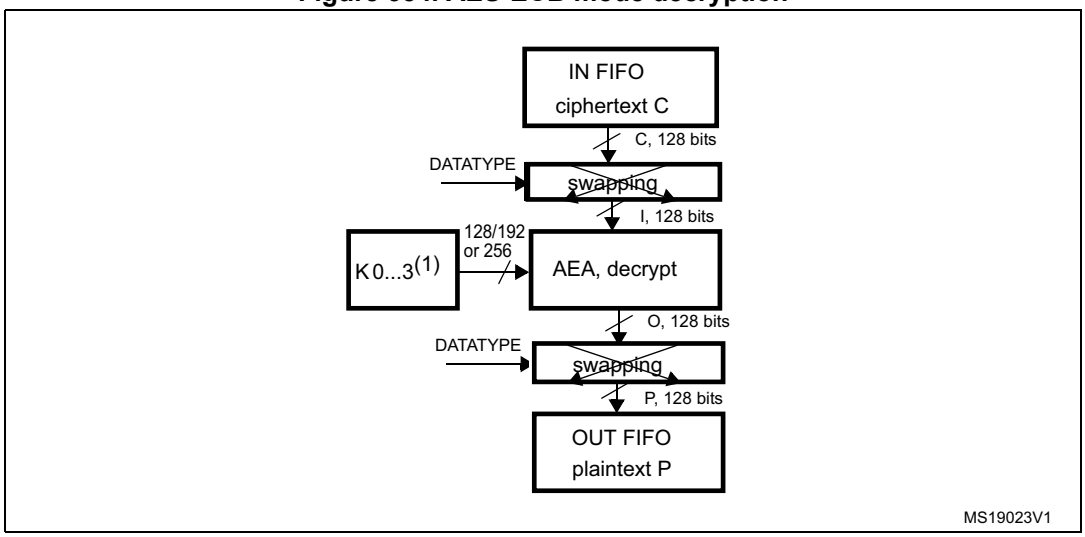
In this mode a 128- bit plaintext data block (P) is used after bit/byte/half-word swapping as the input block (I). The input block is processed through the AEA in the encrypt state using the 128, 192 or 256-bit key. The resultant 128-bit output block (O) is used after bit/byte/half-word swapping as ciphertext (C). It is then pushed into the OUT FIFO.

For more information on data swapping refer to *Section 40.4.16: CRYP data registers and data swapping*.

AES ECB decryption

Figure 354 illustrates the AES Electronic codebook (AES-ECB) mode decryption. This mode is selected by programming ALGOMODE to 0x4 and ALGODIR to 1 in CRYP_CR.

Figure 354. AES-ECB mode decryption



1. K: key; C: cipher text; I: input block; O: output block; P: plain text.
2. If Key size = 128 => Key = [K3 K2].
   If Key size = 192 => Key = [K3 K2 K1]
   If Key size = 256 => Key = [K3 K2 K1 K0].

To perform an AES decryption in ECB mode, the secret key has to be prepared (it is necessary to execute the complete key schedule for encryption) by collecting the last round key, and using it as the first round key for the decryption of the ciphertext. This preparation phase is computed by the AES core. Refer to *Section 40.4.7: Preparing the CRYP AES key for decryption* for more details on how to prepare the key.

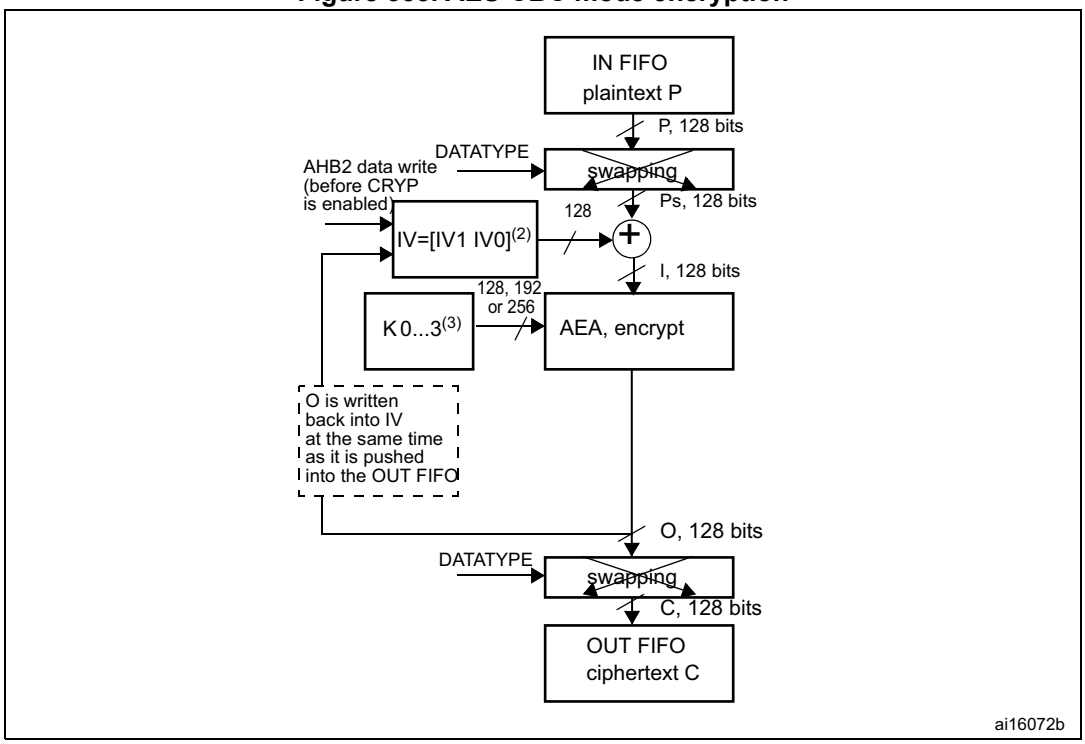
When the key preparation is complete, the decryption proceed as follows: a 128-bit ciphertext block (C) is used after bit/byte/half-word swapping as the input block (I). The keying sequence is reversed compared to that of the encryption process. The resultant 128-bit output block (O), after bit/byte or half-word swapping, produces the plaintext (P). The AES-CBC decryption process continues in this manner until the last complete ciphertext block has been decrypted.

For more information on data swapping refer to *Section 40.4.16: CRYP data registers and data swapping*.

AES CBC encryption

Figure 355 illustrates the AES Cipher block chaining (AES-CBC) mode encryption. This mode is selected by writing ALGOMODE to 0x5 and ALGODIR to 0 in CRYP_CR.

Figure 355. AES-CBC mode encryption



1. K: key; C: cipher text; I: input block; O: output block; Ps: plain text before swapping (when decoding) or after swapping (when encoding); P: plain text; IV: Initialization vectors.
2. IVx = [IVxR IVxL], R = right, L = left.
3. If Key size = 128 => Key = [K3 K2].
   If Key size = 192 => Key = [K3 K2 K1]
   If Key size = 256 => Key = [K3 K2 K1 K0].

In this mode the first input block (I_1) obtained after bit/byte/half-word swapping is formed by exclusive-ORing the first plaintext data block (P_1) with a 128-bit initialization vector IV ($I_1 = IV \oplus P_1$). The input block is processed through the AEA in the encrypt state using the 128-, 192- or 256-bit key (K0...K3). The resultant 128-bit output block (O_1) is used directly as ciphertext (C_1), that is, $C_1 = O_1$. This first ciphertext block is then exclusive-ORed with the second plaintext data block to produce the second input block, (I_2) = ($C_1 \oplus P_2$). Note that I_2 and P_2 now refer to the second block. The second input block is processed through the AEA to produce the second ciphertext block. This encryption process continues to “chain” successive cipher and plaintext blocks together until the last plaintext block in the message is encrypted.

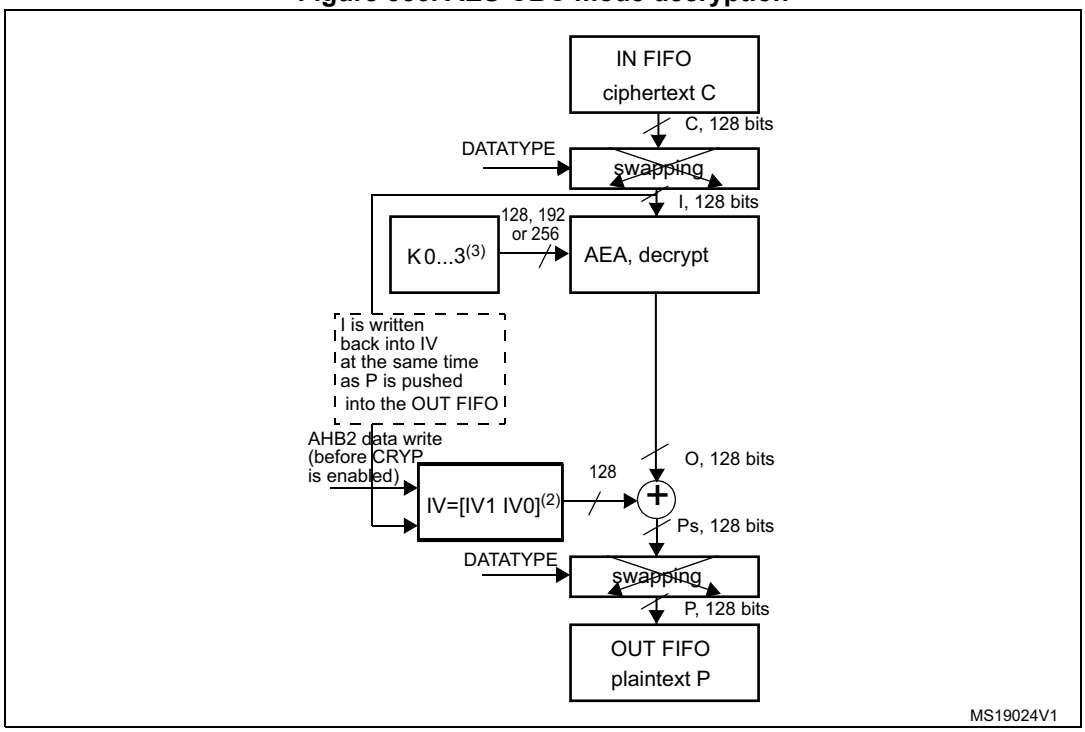
If the message does not consist of an integral number of data blocks, then the final partial data block should be encrypted in a manner specified for the application, as explained in *Section 40.4.8: CRYP stealing and data padding*.

For more information on data swapping, refer to *Section 40.4.16: CRYP data registers and data swapping*.

AES CBC decryption

Figure 356 illustrates the AES Cipher block chaining (AES-CBC) mode decryption. This mode is selected by writing ALGOMODE to 0x5 and ALGODIR to 1 in CRYP_CR.

Figure 356. AES-CBC mode decryption



1. K: key; C: cipher text; I: input block; O: output block; Ps: plain text before swapping (when decoding) or after swapping (when encoding); P: plain text; IV: Initialization vectors.
2. IVx = [IVxR IVxL], R = right, L = left.
3. If Key size = 128 => Key = [K3 K2].
   If Key size = 192 => Key = [K3 K2 K1]
   If Key size = 256 => Key = [K3 K2 K1 K0].

In CBC mode, like in ECB mode, the secret key must be prepared to perform an AES decryption. Refer to *Section 40.4.7: Preparing the CRYP AES key for decryption* for more details on how to prepare the key.

When the key preparation process is complete, the decryption proceeds as follows: the first 128-bit ciphertext block (C_1) is used directly as the input block (I_1). The input block is processed through the AEA in the decrypt state using the 128-, 192- or 256-bit key. The resulting output block is exclusive-ORed with the 128-bit initialization vector IV (which must be the same as that used during encryption) to produce the first plaintext block ($P_1 = O_1 \oplus$ IV).

The second ciphertext block is then used as the next input block and is processed through the AEA. The resulting output block is exclusive-ORed with the first ciphertext block to produce the second plaintext data block ($P_2 = O_2 \oplus C_1$). Note that P_2 and O_2 refer to the second block of data. The AES-CBC decryption process continues in this manner until the last complete ciphertext block has been decrypted.

Ciphertext representing a partial data block must be decrypted in a manner specified for the application, as explained in *Section 40.4.8: CRYP stealing and data padding*.

For more information on data swapping, refer to *Section 40.4.16: CRYP data registers and data swapping*.

AES suspend/resume operations in ECB/CBC modes

Before interrupting the current message, the user application must respect the following sequence:

1. If DMA is used, stop the DMA transfers to the IN FIFO by clearing to 0 the DIEN bit in the CRYP_DMACR register.
2. Wait until both the IN and the OUT FIFOs are empty (IFEM = 1 and OFNE = 0 in the CRYP_SR) and the BUSY bit is cleared.
3. If DMA is used, stop the DMA transfers from the OUT FIFO by clearing to 0 the DOEN bit in the CRYP_DMACR register.
4. Disable the CRYP by setting the CRYPEN bit to 0 in CRYP_CR, then save the current configuration (bits [9:2] in the CRYP_CR register). If ECB mode is not selected, save the initialization vector registers, because CRYP_IVx registers have changed from initial values during the data processing.

Note: Key registers do not need to be saved as the original key value is known by the application.

5. If DMA is used, save the DMA controller status (such as pointers to IN and OUT data transfers, number of remaining bytes).

To resume message processing, the user application must respect the following sequence:

1. If DMA is used, reconfigure the DMA controller to complete the rest of the FIFO IN and FIFO OUT transfers.
2. Make sure the cryptographic processor is disabled by reading the CRYPEN bit in CRYP_CR (it must be set to 0).
3. Configure the cryptographic processor again with the initial setting in CRYP_CR, as well as the key registers using the saved configuration.
4. For AES-ECB or AES-CBC decryption, the key must be prepared again, as described in *Section 40.4.7: Preparing the CRYP AES key for decryption*.
5. If ECB mode is not selected, restore CRYP_IVx registers using the saved configuration.
6. Enable the cryptographic processor by setting the CRYPEN bit to 1.
7. If DMA is used, enable again the DMA requests from the cryptographic processor, by setting DIEN and DOEN bits to 1 in the CRYP_DMACR register.

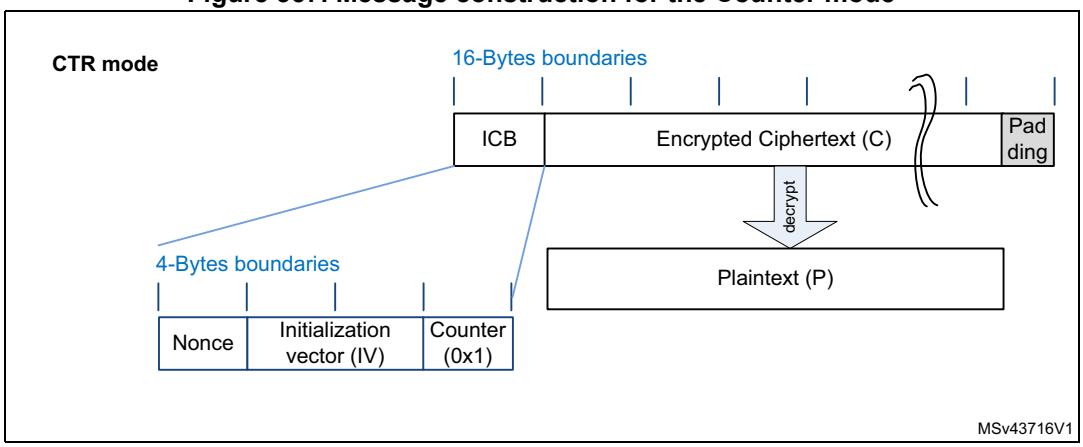
40.4.12 CRYP AES counter mode (AES-CTR)

Overview

The AES counter mode (CTR) uses the AES block as a key stream generator. The generated keys are then XORed with the plaintext to obtain the ciphertext.

CTR chaining is defined in NIST *Special Publication 800-38A, Recommendation for Block Cipher Modes of Operation.* A typical message construction in CTR mode is given in *Figure 357*.

Figure 357. Message construction for the Counter mode



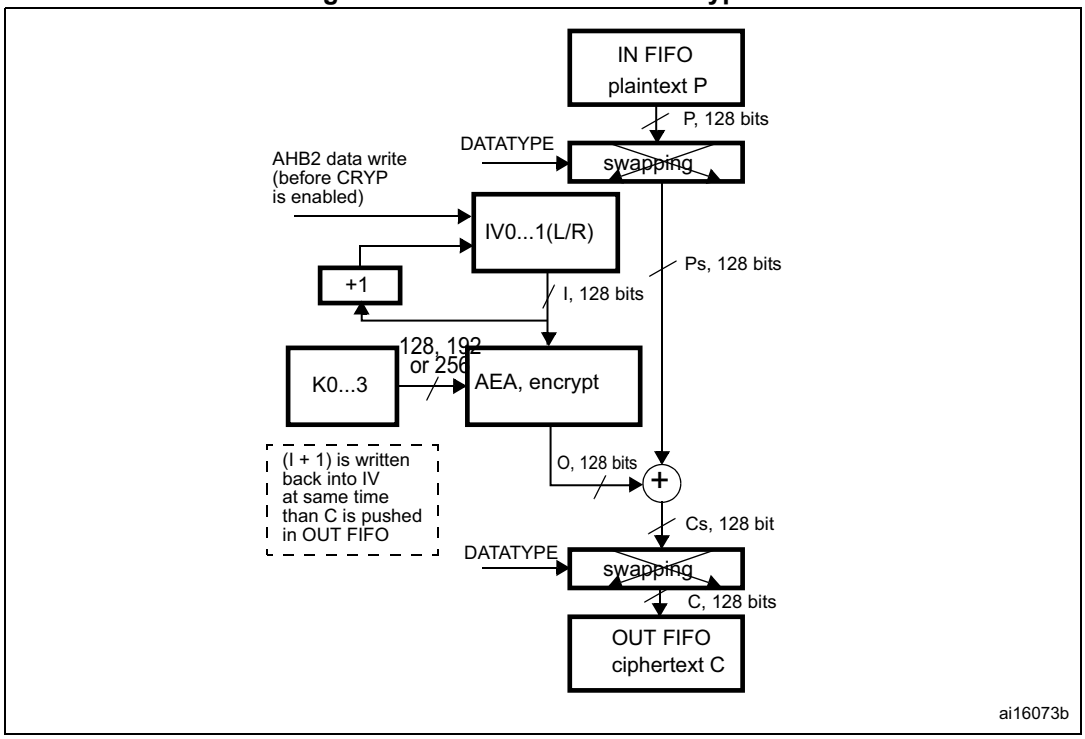
The structure of this message is as below:

- A 16-byte Initial Counter Block (ICB), composed of three distinct fields:
  - A *nonce:* a 32-bit, single-use value (i.e. a new nonce should be assigned to each new communication).
  - The *initialization vector* (IV): a 64-bit value that must be unique for each execution of the mode under a given key.
  - The *counter:* a 32-bit big-endian integer that is incremented each time a block has been processed. The initial value of the counter should be set to 1.
- The plaintext (P) is both authenticated and encrypted as ciphertext C, with a known length. This length can be non-multiple of 16 bytes, in which case a plaintext padding is required.

AES CTR processing

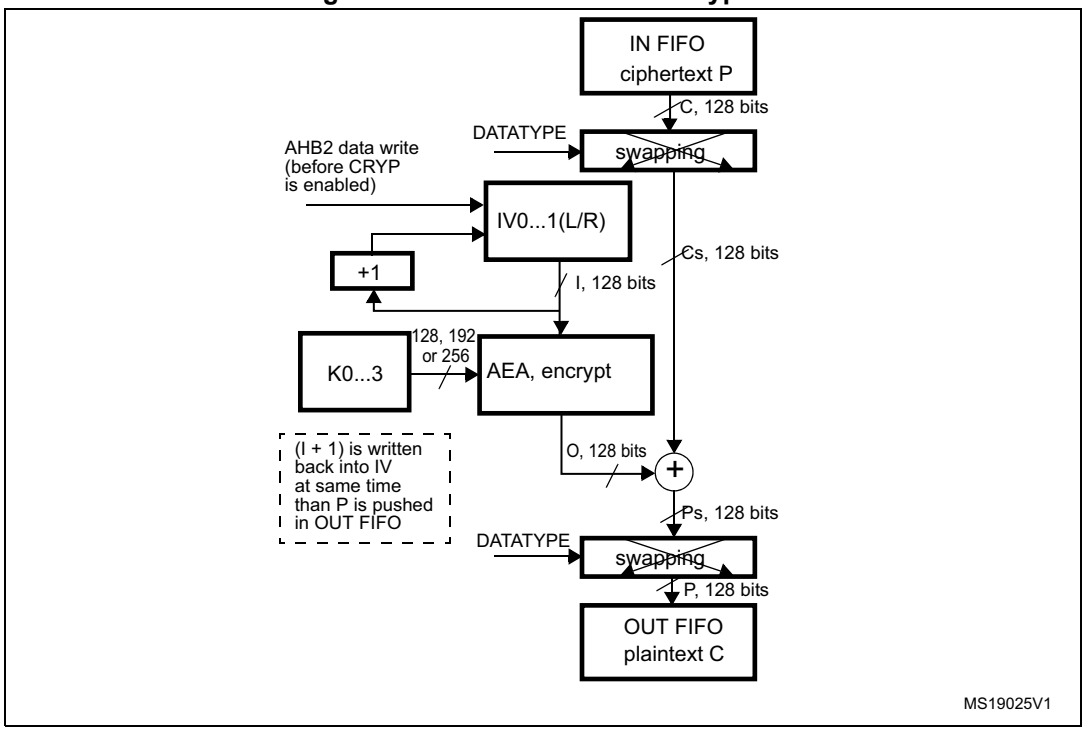
Figure 358 (respectively *Figure 359*) describes the AES-CTR encryption (respectively decryption) process implemented within this peripheral. This mode is selected by programming ALGOMODE bitfield to 0x6 in CRYP_CR.

Figure 358. AES-CTR mode encryption



1. K: key; C: cipher text; I: input Block; o: output block; Ps: plain text before swapping (when decoding) or after swapping (when encoding); Cs: cipher text after swapping (when decoding) or before swapping (when encoding); P: plain text; IV: Initialization vectors.

Figure 359. AES-CTR mode decryption



1. K: key; C: cipher text; I: input Block; o: output block; Ps: plain text before swapping (when decoding) or after swapping (when encoding); Cs: cipher text after swapping (when decoding) or before swapping (when encoding); P: plain text; IV: Initialization vectors.

In CTR mode, the output block is XORed with the subsequent input block before it is input to the algorithm. Initialization vectors in the peripheral must be initialized as shown on *Table 323*.

Table 323. Counter mode initialization vector

CRYP_IV1R[31:0]	CRYP_IV1L[31:0]	CRYP_IV0R[31:0]	CRYP_IV0L[31:0]
IV[127:96]	IV[95:64]	IV[63:32]	IV[31:0] 32-bit counter = 0x1

Unlike in CBC mode, which uses the CRYP_IVx registers only once when processing the first data block, in CTR mode IV registers are used for processing each data block, and the peripheral increments the least significant 32 bits (leaving the other most significant 96 bits unchanged).

CTR decryption does not differ from CTR encryption, since the core always encrypts the current counter block to produce the key stream that will be XORed with the plaintext or cipher as input. Thus when ALGOMODE is set to 0x6, ALGODIR is don't care.

Note: In this mode the key must NOT be prepared for decryption.

The following sequence must be used to perform an encryption or a decryption in CTR chaining mode:

1. Make sure the cryptographic processor is disabled by clearing the CRYPEN bit in the CRYP_CR register.
2. Configure CRYP_CR as follows:
   a) Program ALGOMODE bits to 0x6 to select CTR mode. ALGODIR can be set to any value.
   b) Configure the data type (1, 8, 16 or 32 bits) through the DATATYPE bits.
   c) Define the key length using KEYSIZE bits.
3. Initialize the key registers (128,192 or 256 bits) in CRYP_KEYRx as well as the initialization vector (IV) as described in *Table 323*.
4. Flush the IN and OUT FIFOs by writing the FFLUSH bit to 1 in the CRYP_CR register.
5. If it is the last block, optionally pad the data with zeros to have a complete block.
6. Append data in the cryptographic processor and read the result. The three possible scenarios are described in *Section 40.4.5: CRYP procedure to perform a cipher operation*.
7. Repeat the previous step until the second last block is processed. For the last block, execute the two previous steps. For this last block, the driver must discard the data that is not part of the data when the last block size is less than 16 bytes.

Suspend/resume operations in CTR mode

Like for the CBC mode, it is possible to interrupt a message to send a higher priority message, and resume the message which was interrupted. Detailed CBC sequence can be found in *Section 40.4.11: CRYP AES basic chaining modes (ECB, CBC)*.

Note: Like for CBC mode, IV registers must be reloaded during the resume operation.

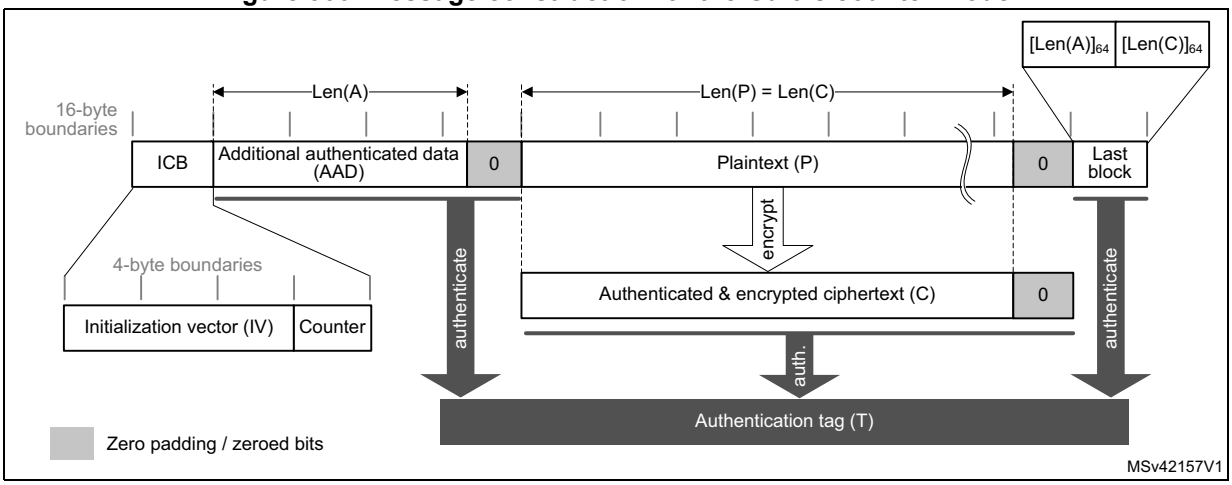
40.4.13 CRYP AES Galois/counter mode (GCM)

Overview

The AES Galois/counter mode (GCM) allows encrypting and authenticating the plaintext, and generating the correspondent ciphertext and tag (also known as message authentication code). To ensure confidentiality, GCM algorithm is based on AES counter mode. It uses a multiplier over a fixed finite field to generate the tag.

GCM chaining is defined in NIST *Special Publication 800-38D, Recommendation for Block Cipher Modes of Operation - Galois/Counter Mode (GCM) and GMAC.* A typical message construction in GCM mode is given in *Figure 360*.

Figure 360. Message construction for the Galois/counter mode



The structure of this message is defined as below:

- A 16-byte Initial Counter Block (ICB), composed of two distinct fields:
  - The *initialization vector* (IV): a 96-bit value that must be unique for each execution of the mode under a given key. Note that the GCM standard supports IV that are shorter than 96-bit, but in this case strict rules apply.
  - The *counter:* a 32-bit big-endian integer that is incremented each time a block has been processed. According to NIST specification, the counter value is 0x2 when processing the first block of payload.
- The authenticated header A (also knows as Additional Authentication Data) has a known length *Len(A)* that can be non-multiple of 16 bytes and cannot exceed 2^{64}-1 bits. This part of the message is only authenticated, not encrypted.
- The plaintext message (P) is both authenticated and encrypted as ciphertext C, with a known length *Len(P)* that can be non-multiple of 16 bytes, and cannot exceed 2^{32} -2 blocks of 128-bits.

Note: GCM standard specifies that ciphertext C has same bit length as the plaintext P.

- When a part of the message (AAD or P) has a length which is non-multiple of 16 bytes, a special padding scheme is required.
- The last block is composed of the length of A (on 64 bits) and the length of ciphertext C (on 64 bits) as shown in *Table 324*.

Table 324. GCM last block definition

Endianness	Bit[0]	Bit[32]	Bit[64]	Bit[96]
Input data	0x0	Header length[31:0]	0x0	Payload length[31:0]

AES GCM processing

This mode is selected by writing ALGOMODE bitfield to 0x6 in CRYP_CR.

The mechanism for the confidentiality of the plaintext in GCM mode is a variation of the Counter mode, with a particular 32-bit incrementing function that generates the necessary sequence of counter blocks.

CRYP_IV registers are used for processing each data block. The cryptographic processor automatically increments the 32 least signification bits of the counter block. The first counter block (CB1) written by the application is equal to the Initial Counter Block incremented by one (see *Table 325*).

Table 325. GCM mode IV registers initialization

Register	CRYP_IV0LR[31:0]	CRYP_IV0RR[31:0]	CRYP_IV1LR[31:0]	CRYP_IV1RR[31:0]
Input data	ICB[127:96]	ICB[95:64]	ICB[63:32]	ICB[31:0] 32-bit counter = 0x2

Note: In this mode the key must NOT be prepared for decryption.

The authentication mechanism in GCM mode is based on a hash function, called *GF2mul*, that performs multiplication by a fixed parameter, called the hash subkey (H), within a binary Galois field.

To process a GCM message, the driver must go through four phases, which are described in the following subsections.

- The Init phase: the peripheral prepares the GCM hash subkey (H) and performs the IV processing
- The Header phase: the peripheral processes the Additional Authenticated Data (AAD), with hash computation only.
- The Payload phase: the peripheral processes the plaintext (P) with hash computation, keystream encryption and data XORing. It operates in a similar way for ciphertext (C).
- The Final phase: the peripheral generates the authenticated tag (T) using the data last block.

1. **GCM initialization phase**

   During this first step, the GCM hash subkey (H) is calculated and saved internally to be used for processing all the blocks. It is recommended to follow the sequence below:

   a) Make sure the cryptographic processor is disabled by clearing the CRYPEN bit in the CRYP_CR register.

   b) Select the GCM chaining mode by programming ALGOMODE bits to 0x8 in CRYP_CR. In the same register define the key length using KEYSIZE bits and the data type using DATATYPE bits.

   c) Configure GCM_CCMPH bits to 0b00 in CRYP_CR to indicate that the initialization phase is ongoing.

   d) Initialize the key registers (128, 192 or 256 bits) in CRYP_KEYRx as well as the initialization vector (IV) as defined in *Table 325*.

   e) Set CRYPEN bit to 1 to start the calculation of the hash key.

   f) Wait for the CRYPEN bit to be cleared to 0 by the cryptographic processor, before moving on to the next phase.

2. **GCM header phase**

   The below sequence shall be performed after the GCM initialization phase. It must be complete before jumping to the payload phase. The sequence is identical for encryption and decryption.

   g) Set the GCM_CCMPH bits to 0b01 in CRYP_CR to indicate that the header phase is ongoing.

   h) Set the CRYPEN bit to 1 to start accepting data.

   i) If it is the last block of additional authenticated data, optionally pad the data with zeros to have a complete block.

   j) Append additional authenticated data in the cryptographic processor. The three possible scenarios are described in *Section 40.4.5: CRYP procedure to perform a cipher operation*.

   k) Repeat the previous step until the second last additional authenticated data block is processed. For the last block, execute the two previous steps. Once all the additional authenticated data have been supplied, wait until the BUSY flag is cleared before moving on to the next phase.

Note: This phase can be skipped if there is no additional authenticated data, i.e. Len(A) = 0.

In header and payload phases, CRYPEN bit is not automatically cleared by the cryptographic processor.

3. **GCM payload phase (encryption or decryption)**

When the payload size is not null, this sequence must be executed after the GCM header phase. During this phase, the encrypted/decrypted payload is stored in the CRYP_DOUT register.

l) Set the CRYPEN bit to 0.

m) Configure GCM_CCMPH to 0b10 in the CRYP_CR register to indicate that the payload phase is ongoing.

n) Select the algorithm direction (0 for encryption, 1 for decryption) through the ALGODIR bit in CRYP_CR.

o) Set the CRYPEN bit to 1 to start accepting data.

p) If it is the last block of cleartext or plaintext, optionally pad the data with zeros to have a complete block. For encryption, refer to *Section 40.4.8: CRYP stealing and data padding* for more details.

q) Append payload data in the cryptographic processor, and read the result. The three possible scenarios are described in *Section 40.4.5: CRYP procedure to perform a cipher operation*.

r) Repeat the previous step until the second last plaintext block is encrypted or until the last block of ciphertext is decrypted. For the last block of plaintext (encryption only), execute the two previous steps. For the last block, the driver must discard the bits that are not part of the cleartext or the ciphertext when the last block size is less than 16 bytes. Once all payload data have been supplied, wait until the BUSY flag is cleared.

Note: This phase can be skipped if there is no payload data, i.e. Len(C) = 0 (see GMAC mode).

4. **GCM final phase**

In this last step, the cryptographic processor generates the GCM authentication tag and stores it in CRYP_DOUT register.

s) Configure GCM_CCMPH[1:0] to 0b11 in CRYP_CR to indicate that the Final phase is ongoing. Set the ALGODIR bit to 0 in the same register.

t) Write the input to the CRYP_DIN register four times. The input must be composed of the length in bits of the additional authenticated data (coded on 64 bits) concatenated with the length in bits of the payload (coded of 64 bits), as show in *Table 324*.

Note: In this final phase, data have to be inserted normally (no swapping).

u) Wait until the OFNE flag (FIFO output not empty) is set to 1 in the CRYP_SR register.

v) Read the CRYP_DOUT register four times: the output corresponds to the authentication tag.

w) Disable the cryptographic processor (CRYPEN bit = 0 in CRYP_CR)

x) If an authenticated decryption is being performed, compare the generated tag with the expected tag passed with the message.

Suspend/resume operations in GCM mode

Before interrupting the current message in header or payload phase, the user application must respect the following sequence:

1. If DMA is used, stop DMA transfers to the IN FIFO by clearing to 0 the DIEN bit in the CRYP_DMACR register.
2. Wait until both the IN and the OUT FIFOs are empty (IFEM = 1 and OFNE = 0 in the CRYP_SR register) and the BUSY bit is cleared.
3. If DMA is used, stop DMA transfers from the OUT FIFO by clearing to 0 the DOEN bit in the CRYP_DMACR register.
4. Disable the cryptographic processor by setting the CRYPEN bit to 0 in CRYP_CR, then save the current configuration (bits [9:2], bits [17:16] and bits 19 of the CRYP_CR register). In addition, save the initialization vector registers, since CRYP_IVx registers have changed from their initial values during data processing.

Note: Key registers do not need to be saved as original their key value is known by the application.

5. Save context swap registers: CRYP_CSGCMCCM0..7R and CRYP_CSGCM0..7R
6. If DMA is used, save the DMA controller status (pointers to IN and OUT data transfers, number of remaining bytes, etc.).

To resume message processing, the user must respect the following sequence:

1. If DMA is used, reconfigure the DMA controller to complete the rest of the FIFO IN and FIFO OUT transfers.
2. Make sure the cryptographic processor is disabled by reading the CRYPEN bit in CRYP_CR (it must be 0).
3. Configure again the cryptographic processor with the initial setting in CRYP_CR, as well as the key registers using the saved configuration.
4. Restore context swap registers: CRYP_CSGCMCCM0..7R and CRYP_CSGCM0..7R
5. Restore CRYP_IVx registers using the saved configuration.
6. Enable the cryptographic processor by setting the CRYPEN bit to 1.
7. If DMA is used, enable again cryptographic processor DMA requests by setting to 1 the DIEN and DOEN bits in the CRYP_DMACR register.

Note: In Header phase, DMA OUT FIFO transfer is not used.

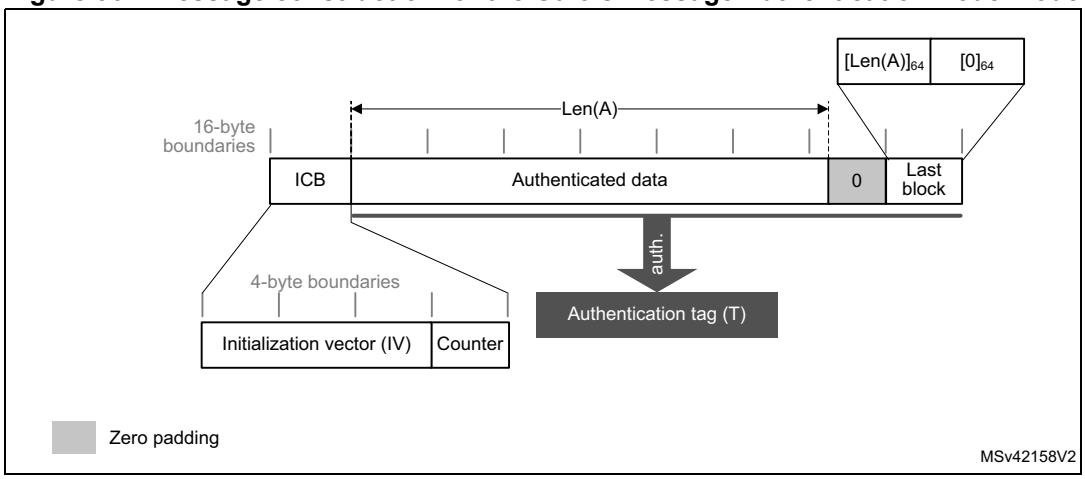
40.4.14 CRYP AES Galois message authentication code (GMAC)

Overview

The Galois message authentication code (GMAC) allows authenticating a plaintext and generating the corresponding tag information (also known as message authentication code). It is based on GCM algorithm, as defined in NIST *Special Publication 800-38D, Recommendation for Block Cipher Modes of Operation - Galois/Counter Mode (GCM) and GMAC.*

A typical message construction in GMAC mode is given in *Figure 361*.

Figure 361. Message construction for the Galois Message Authentication Code mode



AES GMAC processing

This mode is selected by writing ALGOMODE bitfield to 0x6 in CRYP_CR.

GMAC algorithm corresponds to the GCM algorithm applied on a message composed only of an header. As a consequence, all steps and settings are the same as in GCM mode, except that the payload phase (3) is not used.

Suspend/resume operations in GMAC

GMAC is exactly the same as GCM algorithm except that only header phase (2) can be interrupted.

40.4.15 CRYP AES Counter with CBC-MAC (CCM)

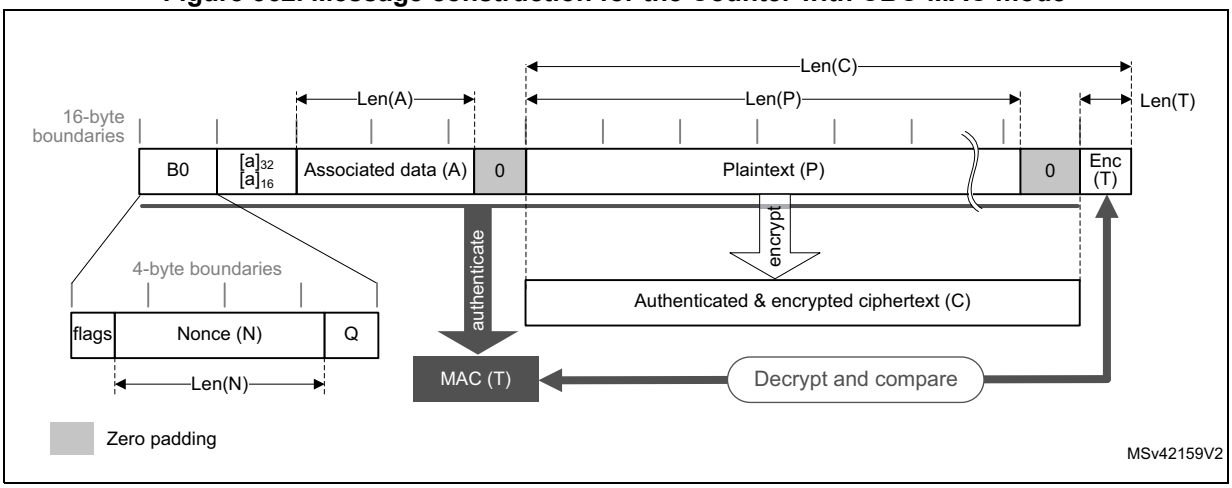
Overview

The AES Counter with Cipher Block Chaining-Message Authentication Code (CCM) algorithm allows encrypting and authenticating the plaintext, and generating the correspondent ciphertext and tag (also known as message authentication code). To ensure confidentiality, CCM algorithm is based on AES counter mode. It uses Cipher Block Chaining technique to generate the message authentication code. This is commonly called CBC-MAC

Note: NIST does not approve this CBC-MAC as an authentication mode outside of the context of the CCM specification.

CCM chaining is specified in NIST *Special Publication 800-38C, Recommendation for Block Cipher Modes of Operation - The CCM Mode for Authentication and Confidentiality*. A typical message construction in CCM mode is given in *Figure 362*

Figure 362. Message construction for the Counter with CBC-MAC mode



The structure of this message is as below:

- One 16-byte first authentication block (called B0 by the standard), composed of three distinct fields:
  - *Q*: a bit string representation of the byte length of P (Plen)
  - A *nonce* (N)*:* single-use value (i.e. a new nonce should be assigned to each new communication). Size of nonce *Nlen* + size of *Plen* shall be equal to 15 bytes.
  - *Flags*: most significant byte containing four flags for control information, as specified by the standard. It contains two 3-bit strings to encode the values t (MAC length expressed in bytes) and *q* (plaintext length such as Plen<2^{8q} bytes). Note that the counter blocks range associated to q is equal to 2^{8q-4}, i.e. if q maximum value is 8, the counter blocks used in cipher shall be on 60 bits.

- 16-bytes blocks (B) associated to the Associated Data (A).

  This part of the message is only authenticated, not encrypted. This section has a known length, *ALen,* that can be a non-multiple of 16 bytes (see *Figure 362*). The standard also states that, on the MSB bits of the first message block (B1), the associated data length expressed in bytes (*a*) must be encoded as defined below:
  - If $0 < a < 2^{16}-2^8$, then it is encoded as $[a]_{16}$, i.e. two bytes.
  - If $2^{16}-2^8 < a < 2^{32}$, then it is encoded as 0xff || 0xfe || $[a]_{32}$, i.e. six bytes.
  - If $2^{32} < a < 2^{64}$, then it is encoded as 0xff || 0xff || $[a]_{64}$, i.e. ten bytes.
- 16-byte blocks (B) associated to the plaintext message (P), which is both authenticated and encrypted as ciphertext C, with a known length of *Plen*. This length can be a non-multiple of 16 bytes (see *Figure 362*).
- The encrypted MAC (T) of length *Tlen* appended to the ciphertext C of overall length *Clen*.
- When a part of the message (A or P) has a length which is a non-multiple of 16 bytes, a special padding scheme is required.

Note: CCM chaining mode can also be used with associated data only (i.e. no payload).

As an example, the C.1 section in *NIST Special Publication 800-38C* gives the following:

N: **10111213 141516** (Nlen = 56 bits or 0x7 bytes)

A: ***00010203 04050607*** (Alen = 64 bits or 0x8 bytes)

P: *20212223* (Plen = 32 bits i.e. Q = 0x*4* bytes)

T: 6084341b (Tlen = 32 bits or t = 4)

B0: 4f**101112 13141516** 00000000 00000004
B1: 0008***0001 02030405 0607***0000 00000000
B2: *20212223* 00000000 00000000 00000000

CTR0: 07**10111213 141516** 00000000 00000000

CTR1: 07**10111213 141516** 00000000 00000001

The usage of control blocks CTRx is explained in the following section. The generation of CTR0 from the first block (B0) must be managed by software.

AES CCM processing

This mode is selected by writing ALGOMODE bitfield to 0x9 in CRYP_CR.

The data input to the generation-encryption process are a valid nonce, a valid payload string, and a valid associated data string, all properly formatted. The CBC chaining mechanism is applied to the formatted data to generate a MAC, whose length is known. Counter mode encryption, which requires a sufficiently long sequence of counter blocks as input, is applied to the payload string and separately to the MAC. The resulting data, called the ciphertext C, is the output of the generation-encryption process on plaintext P.

CRYP_IV registers are used for processing each data block. The cryptographic processor automatically increments the CTR counter with a bit length defined by the first block (B0). The first counter written by application, CTR1, is equal to B0 with the first 5 bits zeroed and the most significant bits containing P byte length also zeroed, then incremented by one (see *Table 326*).

Table 326. CCM mode IV registers initialization

Register	CRYP_IV0LR[31:0]	CRYP_IV0RR[31:0]	CRYP_IV1LR[31:0]	CRYP_IV1RR[31:0]
Input data	B0[127:96], where the 5 most significant bits are set to 0 (flag bits)	B0[95:64]	B0[63:32]	B0[31:0], where Q length bits are set to 0, except for bit 0 that is set to 1

Note: In this mode, the key must NOT be prepared for decryption.

To process a CCM message, the driver must go through four phases, which are described below.

- The **Initialization phase**: the peripheral processes the first block and prepares the first counter block.
- The **Header phase**: the peripheral processes the Associated data (A), with hash computation only.
- The **Payload phase**: the peripheral processes the plaintext (P), with hash computation, counter block encryption and data XORing. It operates in a similar way for ciphertext (C).
- The **Final phase**: the peripheral generates the message authentication code (MAC).

1. **CCM initialization phase**

   In this first step, the first block (B0) of the CCM message is programmed into the CRYP_DIN register. During this phase, the CRYP_DOUT register does not contain any output data. It is recommended to follow the sequence below:

   a) Make sure that the cryptographic processor is disabled by clearing the CRYPEN bit in the CRYP_CR register.

   b) Select the CCM chaining mode by programming the ALGOMODE bits to 0x9 in the CRYP_CR register. In the same register define the key length using KEYSIZE bits and the data type using DATATYPE bits.

   c) Configure the GCM_CCMPH bits to 0b00 in CRYP_CR to indicate that we are in the initialization phase.

   d) Initialize the key registers (128, 192 or 256 bits) in CRYP_KEYRx as well as the initialization vector (IV) with CTR1 information, as defined in *Table 326*.

   e) Set the CRYPEN bit to 1 in CRYP_CR to start accepting data.

   f) Write the B0 packet into CRYP_DIN register, then wait for the CRYPEN bit to be cleared to 0 by the cryptographic processor before moving on to the next phase.

Note: In this initialization phase, data have to be inserted normally (no swapping).

2. **CCM header phase**

   The below sequence shall be performed after the CCM initialization phase. It must be complete before jumping to the payload phase. The sequence is identical for encryption and decryption. During this phase, the CRYP_DOUT register does not contain any output data.

   g) Set the GCM_CCMPH bit to 0b01 in CRYP_CR to indicate that the header phase is ongoing.

   h) Set the CRYPEN bit to 1 to start accepting data.

   i) If it is the last block of associated data, optionally pad the data with zeros to have a complete block.

   j) Append the associated data in the cryptographic processor. The three possible scenarios are described in *Section 40.4.5: CRYP procedure to perform a cipher operation*.

   k) Repeat the previous step until the second last associated data block is processed. For the last block, execute the two previous steps. Once all the additional authenticated data have been supplied, wait until the BUSY flag is cleared.

Note: This phase can be skipped if there is no associated data (Alen = 0).

The first block of the associated data B1 must be formatted with the associated data length. This task must be managed by the driver.

3. CCM payload phase (encryption or decryption)

When the payload size is not null, this sequence must be performed after the CCM header phase. During this phase, the encrypted/decrypted payload is stored in the CRYP_DOUT register.

l) Set the CRYPEN bit to 0.

m) Configure GCM_CCMPH bits to 0b10 in CRYP_CR to indicate that the payload phase is ongoing.

n) Select the algorithm direction (0 for encryption, 1 for decryption) through the ALGODIR bit in CRYP_CR.

o) Set the CRYPEN bit to 1 to start accepting data.

p) If it is the last block of cleartext, optionally pad the data with zeros to have a complete block (encryption only). For decryption, refer to *Section 40.4.8: CRYP stealing and data padding* for more details.

q) Append payload data in the cryptographic processor, and read the result. The three possible scenarios are described in *Section 40.4.5: CRYP procedure to perform a cipher operation*.

r) Repeat the previous step until the second last plaintext block is encrypted or until the last block of ciphertext is decrypted. For the last block of plaintext (encryption only), execute the two previous steps. For the last block of ciphertext (decryption only), the driver must discard the data that is not part of the cleartext when the last block size is less than 16 bytes. Once all payload data have been supplied, wait until the BUSY flag is cleared

Note: This phase can be skipped if there is no payload data, i.e. Plen = 0 or Clen = Tlen

Note: Do not forget to remove $LSB_{Tlen}(C)$ encrypted tag information when decrypting ciphertext C.

4. CCM final phase

In this last step, the cryptographic processor generates the CCM authentication tag and stores it in the CRYP_DOUT register.

s) Configure GCM_CCMPH[1:0] bits to 0b11 in CRYP_CR to indicate that the final phase is ongoing and set the ALGODIR bit to 0 in the same register.

t) Load in CRYP_DIN, the CTR0 information which is described in *Table 326* with bit[0] set to 0.

Note: In this final phase, data have to be inserted normally (no swapping).

u) Wait until the OFNE flag (FIFO output not empty) is set to 1 in the CRYP_SR register.

v) Read the CRYP_DOUT register four times: the output corresponds to the encrypted CCM tag.

w) Disable the cryptographic processor (CRYPEN bit set to 0 in CRYP_CR)

x) If an authenticated decryption is being performed, compare the generated encrypted tag with the encrypted tag padded in the ciphertext, i.e. $LSB_{Tlen}(C) = MSB_{Tlen}$(CRYP_DOUT data).

Suspend/resume operations in CCM mode

Before interrupting the current message in payload phase, the user application must respect the following sequence:

1. If DMA is used, stop the DMA transfers to the IN FIFO by clearing to 0 the DIEN bit in the CRYP_DMACR register.
2. Wait until both the IN and the OUT FIFOs are empty (IFEM = 1 and OFNE = 0 in the CRYP_SR register) and the BUSY bit is cleared.
3. If DMA is used, stop the DMA transfers from the OUT FIFO by clearing to 0 the DOEN bit in the CRYP_DMACR register.
4. Disable the cryptographic processor by setting the CRYPEN bit to 0 in CRYP_CR, then save the current configuration (bits [9:2], bits [17:16] and bits 19 in the CRYP_CR register). In addition, save the initialization vector registers, since CRYP_IVx registers have changed from their initial values during the data processing.

Note: Key registers do not need to be saved as their original key value is known by the application.

5. Save context swap registers: CRYP_CSGCMCCM0..7R
6. If DMA is used, save the DMA controller status (pointers for IN and OUT data transfers, number of remaining bytes, etc.).

To resume message processing, the user application must respect the following sequence:

1. If DMA is used, reconfigure the DMA controller to complete the rest of the FIFO IN and FIFO OUT transfers.
2. Make sure the cryptographic processor is disabled by reading the CRYPEN bit in CRYP_CR (must be 0).
3. Configure the cryptographic processor again with the initial setting in CRYP_CR and key registers using the saved configuration.
4. Restore context swap registers: CRYP_CSGCMCCM0..7R
5. Restore CRYP_IVx registers using the saved configuration.
6. Enable the cryptographic processor by setting the CRYPEN bit to 1.
7. If DMA is used, enable again cryptographic processor DMA requests by setting to 1 the DIEN and DOEN bits in the CRYP_DMACR register.

Note: In Header phase DMA OUT FIFO transfer is not used.

40.4.16 CRYP data registers and data swapping

The CRYP_DIN register is the 32-bit wide data input register of the peripheral. It is used to enter into the input FIFO up to four 64-bit blocks (TDES) or two 128-bit blocks (AES) of plaintext (when encrypting) or ciphertext (when decrypting), one 32-bit word at a time.

The four adjacent (respectively two) words of the AES (respectively DES/TDES) data block are organized in big-endian order, with the most significant byte of a word on the lowest address.

The cryptographic accelerator can be configured to perform a bit, byte, half-word, or no swapping on the input data word in the CRYP_DINR register, before loading it to the CRYP processing core, and on the data output from the CRYP processing core, before sending it

to the CRYP_DOUTR register. The choice depends on the type of data. For example, a byte swapping is used for an ASCII text stream.

The data swap type is selected through the DATATYPE[1:0] bitfield of the AES_CR register. The selection applies both to the input and the output of the CRYP processing core.

Note: The CRYP Key registers (CRYP_Kx(L/R)) and initialization registers (CRYP_IVx(L/R)) are not sensitive to the swap mode selected.

More information on data input and data swapping can be found in the next subsections.

DES/TDES data input and output

A 64-bit data block is entered into the cryptographic processor with two successive 32-bit word write operations to the CRYP_DINR register (DIN[31:0] bitfield), the most significant word (bits [64:33]) first, the least significant word (bits [32:1]) last.

A 64-bit data block is retrieved from the cryptographic processor with two successive 32-bit word read operations from the CRYP_DOUTR register (DOUT[31:0] bitfield), the most significant word (bits [64:33]) first, the least significant word (bits [32:1]) last.

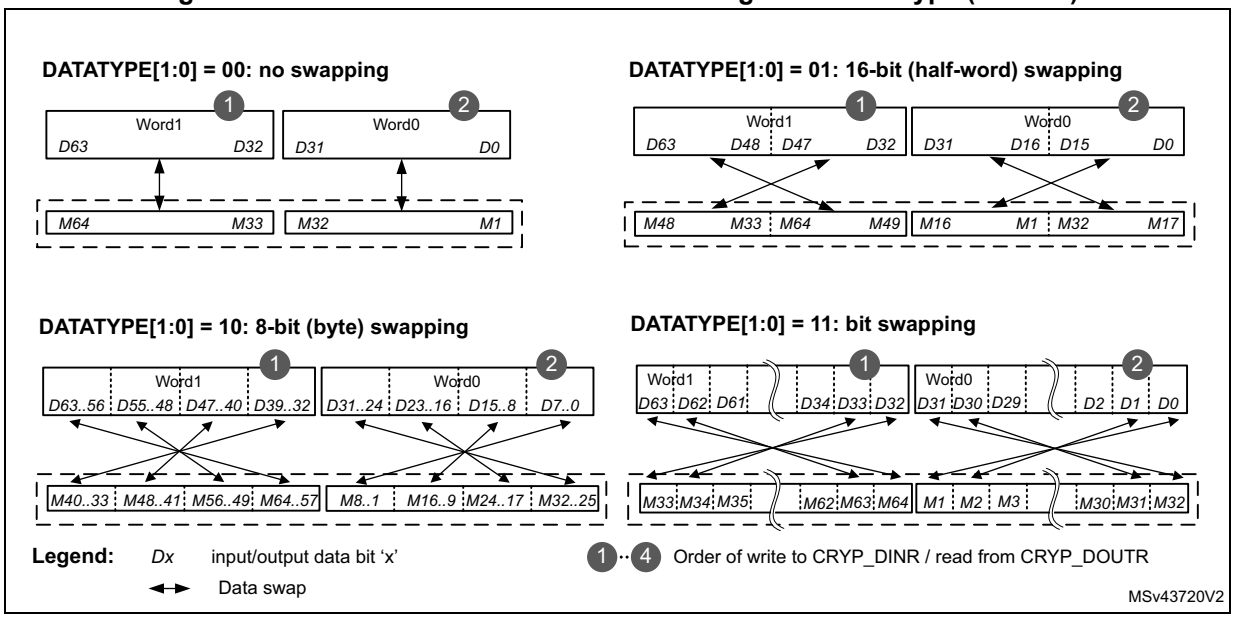
DES/TDES data swapping feature

The cryptographic processor data swapping feature for DES/TDES is summarized in *Table 327* and *Figure 363*.

Table 327. DES/TDES data swapping example

DATATYPE in CRYP_CR	Swapping performed	Data block representation (64-bit)
		System memory data (big-endian)
00	No swapping	Block[64..1]: 0xABCD7720 6973FE01
		Address @, word[63..32]: 0xABCD 7720 Address @+4, word[31..0]: 0x6973 FE01
01	Half-word (16-bit) swapping	Block[64..1]: 0x**ABCD** 7720 **6973** FE01
		Address @, word[63..32]: 0x7720 **ABCD** Address @+4, word[31..0]: 0xFE01 **6973**
10	Byte (8-bit) swapping	Block[64..1]: 0x**AB** CD **77** 20 **69** 73 **FE** 01
		Address @, word[63..32]: 0x20**77** CD**AB** Address @+4, word[31..0]: 0x01**FE** 73**69**
11	Bit swapping in 32-bit word	Block[64..33]: 0xABCD7720 1010 1011 1100 1101 0111 0111 0010 0000 Block[32..1]: 0x6973FE01 0110 1001 0111 0011 1111 1110 0000 0001
		Address @, word[63..32]: 0x04EEB3D5 0000 0100 1110 1110 1011 0011 1101 0101 Address @+4, word[31..0]: 0x807FCE96 1000 0000 0111 1111 1100 1110 1001 0110

Figure 363. 64-bit block construction according to the data type (IN FIFO)



AES data input and output

A 128-bit data block is entered into the cryptographic processor with four successive 32-bit word writes into the CRYP_DINR register (bitfield DIN[31:0]), the most significant word (bits [127:96]) first, the least significant word (bits [31:0]) last.

A 128-bit data block is retrieved from the cryptographic processor with four successive 32-bit word reads from the CRYP_DOUTR register (bitfield DOUT[31:0]), the most significant word (bits [127:96]) first, the least significant word (bits [31:0]) last.

AES data swapping feature

The cryptographic processor data swapping feature for AES is summarized in *Table 328* and *Figure 364*.

Note: Data swapping does not apply to GCM and CCM final phases. Data can be inserted normally by the application.

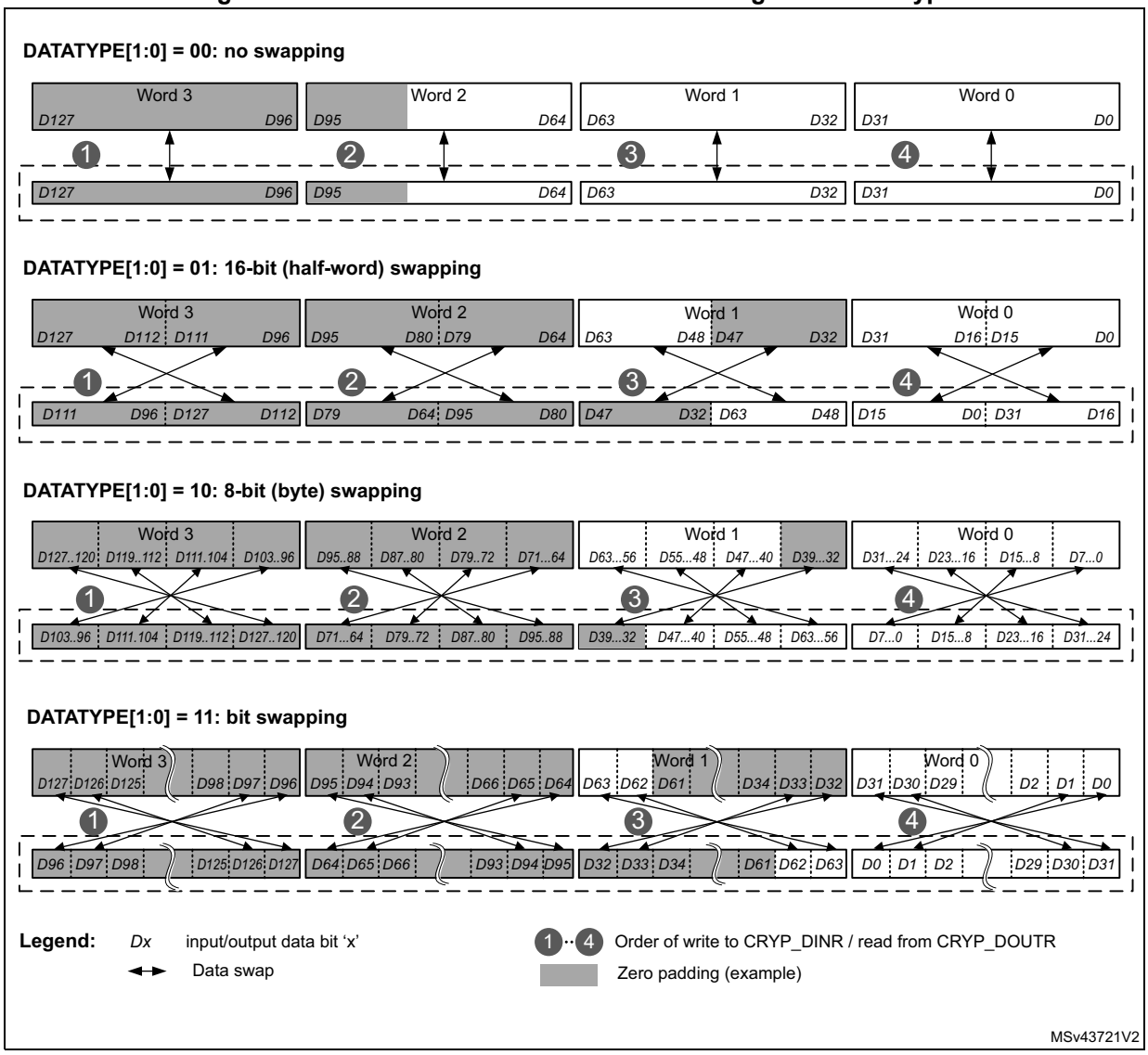
Table 328. AES data swapping example

DATATYPE in CRYP_CR	Swapping performed	First half data block (64-bit)
		System memory data (big-endian)
00	No swapping	Block[63..0]: 0x4E6F7720 69732074
		Address @, word[63..32]: 0x4E6F7720 Address @+4, word[31..0]: 0x69732074
01	Half-word (16-bit) swapping	Block[63..0]: 0x**4E6F** 7720 **6973** 2074
		Address @, word[63..32]: 0x7720 **4E6F** Address @+4, word[31..0]: 0x2074 **6973**

Table 328. AES data swapping example (continued)

DATATYPE in CRYP_CR	Swapping performed	First half data block (64-bit)
		System memory data (big-endian)
10	Byte (8-bit) swapping	Block[63..0]: 0x**4E** 6F **77** 20 **69** 73 **20** 74
		Address @, word[63..32]: 0x20**77** 6F**4E** Address @+4, word[31..0]: 0x74**20** 73**69**
11	Bit swapping	Block[63..32]: 0x4E6F7720 0100 1110 0110 1111 0111 0111 0010 0000 Block[31..0]: 0x69732074 0110 1001 0111 0011 0010 0000 0111 0100
		Address @, word[63..32]: 0x04EE F672 0000 0100 1110 1110 1111 0110 0111 0010 Address @+4, word[31..0]: 0x2E04 CE96 0010 1110 0000 0100 1100 1110 1001 0110

Figure 364. 128-bit block construction according to the data type



40.4.17 CRYP key registers

The CRYP_Kx registers are write-only registers used to store the encryption or decryption keys. They are organized as four 64-bit registers, as shown in *Table 329* and *Table 330*.

Note: In memory and in CRYP key registers, AES and DES/TDES keys are stored in big-endian format, with most significant byte on the lowest address.

Table 329. Key endianness in CRYP_KxR/LR registers (AES 128/192/256-bit keys)

K0LR[31:0]	K0RR[31:0]	K1LR[31:0]	K1RR[31:0]	K2LR[31:0]	K2RR[31:0]	K3LR[31:0]	K3RR[31:0]
-	-	-	-	k[127:96]	k[95:64]	k[63:32]	k[31:0]
K0LR[31:0]	**K0RR[31:0]**	**K1LR[31:0]**	**K1RR[31:0]**	**K2LR[31:0]**	**K2RR[31:0]**	**K3LR[31:0]**	**K3RR[31:0]**
-	-	k[191:160]	k[159:128]	k[127:96]	k[95:64]	k[63:32]	k[31:0]

Table 329. Key endianness in CRYP_KxR/LR registers (AES 128/192/256-bit keys) (continued)

K0LR[31:0]	K0RR[31:0]	K1LR[31:0]	K1RR[31:0]	K2LR[31:0]	K2RR[31:0]	K3LR[31:0]	K3RR[31:0]
k[255:224]	k[223:192]	k[191:160]	k[159:128]	k[127:96]	k[95:64]	k[63:32]	k[31:0]

Table 330. Key endianness in CRYP_KxR/LR registers (DES K1 and TDES K1/2/3)

K0LR[31:0]	K0RR[31:0]	K1LR[31:0]	K1RR[31:0]	K2LR[31:0]	K2RR[31:0]	K3LR[31:0]	K3RR[31:0]
-	-	K1[64:33]	K1[32:1]	-	-	-	-
-	-	K1[64:33]	K1[32:1]	K2[64:33]	K2[32:1]	K3[64:33]	K3[32:1]

As shown on *Table 330*, when TDES is selected (ALGOMODE[2:0] = 000 or 001) a 3-key vector (K1, K2, and K3) is used. When DES is selected (ALGOMODE[2:0] = 010 or 011) only 1-key vector (K1) is used.

Note: DES/TDES keys include 8-bit parity information that are not used by the cryptographic processor. In other words, bits 8, 16, 24, 32, 40, 48, 56 and 64 of each 64-bit key value Kx[1:64] are not used.

Write operations to the CRYP_Kx(L/R) registers when the BUSY bit is set to 1 in the CRYP_SR register are ignored (which means that the register content is not modified). The application must thus check that the BUSY bit is cleared to 0 before modifying key registers.

Key registers are not affected by the data swapping controlled by DATATYPE value in CRYP_CR register.

Refer to *Section 40.7: CRYP registers* for a detailed description of CRYP_Kx(L/R) registers.

40.4.18 CRYP initialization vector registers

The CRYP_IVxL/IVxR registers are used to store the initialization vector or the nonce, depending on the chaining mode selected. When used, these registers are updated by the core after each computation round of the TDES or AES core.

They are organized as four 64-bit registers, as shown in shown in *Table 331* and *Table 332*. In DES/TDES mode only CRYP_IV0x are used.

Note: In memory and in CRYP IV registers, AES and DES/TDES initialization vectors *are stored in big-endian format, with most significant byte on the lowest address.*

Table 331. Initialization vector endianness in CRYP_IVxR registers (AES)

CRYP_IV0L[31:0]	CRYP_IV0R[31:0]	CRYP_IV1L[31:0]	CRYP_IV1R[31:0]
IV[127:96]	IV[95:64]	IV[63:32]	IV[31:0]

Table 332. Initialization vector endianness in CRYP_IVxR registers (DES/TDES)

CRYP_IV0L[31:0]	CRYP_IV0R[31:0]	CRYP_IV1L[31:0]	CRYP_IV1R[31:0]
IV[64:32]	IV[31:0]	-	-

Any write operation to the CRYP_IV0...1(L/R) registers when the BUSY bit is set to 1 in the CRYP_SR register is disregarded (which means that register content not modified). The

software must thus check that the BUSY bit is cleared to 0 in the CRYP_SR register before modifying initialization vectors.

Reading the CRYP_IV0...1(L/R) register returns the latest counter value (useful for managing suspend mode) except for CCM/GCM.

The initialization vector registers are not affected by the data swapping feature controlled by DATATYPE value in CRYP_CR register.

Refer to *Section 40.7: CRYP registers* for a detailed description of CRYP_IVxL/IVxR registers.

40.4.19 CRYP DMA interface

The cryptographic processor provides an interface to connect to the DMA (Direct Memory Access) controller. The DMA operation is controlled through the CRYP DMA control register (CRYP_DMACR).

Data input using DMA

DMA can be enabled for writing data into the cryptographic peripheral by setting the DIEN bit in the CRYP_DMACR register. When this bit is set, the cryptographic processor initiates a DMA request during the INPUT phase each time it requires a word to be written to the CRYP_DIN register.

Table 333 shows the recommended configuration to transfer data from memory to cryptographic processor through the DMA controller.

Table 333. Cryptographic processor configuration for memory-to-peripheral DMA transfers

DMA channel control register field	Programming recommendation
Transfer size	Message length, multiple of four 32-bit words. This 128-bit granularity corresponds to two blocks for DES/TDES, one block for AES. According to the algorithm and the mode selected, special padding/ ciphertext stealing might be required. As an example, in case of AES GCM encryption or AES CCM decryption, DMA transfers must not include the last block. Refer to *Section 40.4.5: CRYP procedure to perform a cipher operation* for details.
Source burst size (memory)	CRYP FIFO_size /2 /transfer_width = **4**
Destination burst size (peripheral)	CRYP FIFO_size /2 /transfer_width = **4** (FIFO_size = 8x32-bit, transfer_width = 32-bit)
DMA FIFO size	CRYP FIFO_size /2 = 16 bytes
Source transfer width (memory)	32-bit words
Destination transfer width (peripheral)	32-bit words

Table 333. Cryptographic processor configuration for memory-to-peripheral DMA transfers (continued)

DMA channel control register field	Programming recommendation
Source address increment (memory)	Yes, after each 32-bit transfer.
Destination address increment (peripheral)	Fixed address of CRYP_DIN shall be used (no increment).

Data output using DMA

To enable the DMA for reading data from CRYP processor, set the DOEN bit in the CRYP_DMACR register. When this bit is set, the cryptographic processor initiates a DMA request during the OUTPUT phase each time it requires a word to be read from the CRYP_DOUT register.

Table 334 shows the recommended configuration to transfer data from cryptographic processor to memory through the DMA controller.

Table 334. Cryptographic processor configuration for peripheral-to-memory DMA transfers

DMA channel control register field	Programming recommendation
Transfer size	Message length, multiple of four 32-bit words. This 128-bit granularity corresponds to two blocks for DES/TDES, one block for AES. Depending on the chaining mode selected, extra bits have to be discarded.
Source burst size (peripheral)	When *DES* is used: Single transfer (burst size = **1**) When *AES* is used: CRYP FIFO_size /2 /transfer_width = **4** (FIFO_size = 8x32-bit, transfer_width = 32-bit)
Destination burst size (memory)	CRYP FIFO_size /2 /transfer_width = **4**
DMA FIFO size	CRYP FIFO_size /2 = 16 bytes
Source transfer width (peripheral)	32-bit words
memory transfer width (memory)	32-bit words
Source address increment (peripheral)	Fixed address of CRYP_DOUT shall be used (no increment).
Destination address increment (memory)	Yes, after each 32-bit transfer.

DMA mode

When AES is used, the cryptographic processor manages two DMA transfer requests through `cryp_in_dma` and `cryp_out_dma` internal input/output signals, which are asserted:

- for IN FIFO: every time a block has been read from FIFO by CRYP,
- for OUT FIFO: every time a block has been written into the FIFO by the cryptographic processor.

When DES/TDES is used, the cryptographic processor manages two DMA transfer requests through `cryp_in_dma` and `cryp_out_dma` internal input/output signals, which are asserted:

- for IN FIFO: every time two blocks have been read from FIFO by the cryptographic processor

for OUT FIFO: every time a word has been written into the FIFO by the cryptographic processor (single transfer). Note that a burst transfer is also triggered when two blocks have been written into the FIFO.

All request signals are deasserted if the cryptographic peripheral is disabled or the DMA enable bit is cleared (DIEN bit for the IN FIFO and DOEN bit for the OUT FIFO in the CRYP_DMACR register).

Caution: It is important that DMA controller empties the cryptographic peripheral output FIFO before filling up the CRYP input FIFO. To achieve it, the DMA controller should be configured so that the transfer from the peripheral to the memory has a higher priority than the transfer from the memory to the peripheral.

For more detailed information on DMA operations, refer to *Section 40.4.5: CRYP procedure to perform a cipher operation*.

40.4.20 CRYP error management

No error flags are generated by the cryptographic processor.

40.5 CRYP interrupts

Overview

There are two individual maskable interrupt sources generated by the cryptographic processor to signal the following events:

- Input FIFO empty or not full
- Output FIFO full or not empty

These two sources are combined into a single interrupt signal which is the only interrupt signal from the CRYP processor that drives the Cortex® CPU interrupt controller. You can enable or disable CRYP interrupt sources individually by changing the mask bits in the CRYP_IMSCR register. Setting the appropriate mask bit to 1 enables the interrupt.

The status of the individual maskable interrupt sources can be read either from the CRYP_RISR register, for raw interrupt status, or from the CRYP_MISR register for masked

interrupt status. The status of the individual source of event flags can be read from the CRYP_SR register.

Table 335 gives a summary of the available features.

Table 335. CRYP interrupt requests

Interrupt acronym	Interrupt event	Event flag		Enable bit	Interrupt clear method
		in CRYP_xISR(1)	in CRYP_SR		
CRYP	Output FIFO full	OUTRIS (not masked) OUTMIS (masked)	OFFU	OUTIM(2) and CRYPEN	Read one data from output FIFO
	Output FIFO not empty		OFNE		Read all data from output FIFO
	Input FIFO not full	INRIS (not masked) INMIS (masked)	IFNF	INIM(2) and CRYPEN	Write data until input FIFO is full
	Input FIFO empty		IFEM		Write at least one word in input FIFO

1. The flags belong to CRYP_RISR registers (unmasked or raw) or CRYP_MISR registers (masked).
2. The flags belong to CRYP_IMSCR register.

Output FIFO service interrupt - OUTMIS

The output FIFO service interrupt is asserted when there is one or more (32-bit word) data items in the output FIFO. This interrupt is cleared by reading data from the output FIFO until there is no valid (32-bit) word left (that is when the interrupt follows the state of the output FIFO not empty flag OFNE).

The output FIFO service interrupt OUTMIS is NOT enabled with the CRYP processor enable bit. Consequently, disabling the CRYP processor does not force the OUTMIS signal low if the output FIFO is not empty.

Input FIFO service interrupt - INMIS

The input FIFO service interrupt is asserted when there are less than four words in the input FIFO. It is cleared by performing write operations to the input FIFO until it holds four or more words.

The input FIFO service interrupt INMIS is enabled with the CRYP enable bit. Consequently, when CRYP is disabled, the INMIS signal is low even if the input FIFO is empty.

40.6 CRYP processing time

The time required to process a block for each mode of operation is summarized below. The block size is 128 bits for AES and 64 bits for DES/TDES.

Table 336. Processing latency for ECB, CBC and CTR

Key size	Operating modes	Chaining algorithm	Clock cycles
64 bits	DES encryption or decryption	ECD, CBC	16
3x64 bits	TDES encryption or decryption		48
128 bits	AES encryption or decryption(1)	ECD, CBC, CTR	14
	AES key preparation	-	12
192 bits	AES encryption or decryption(1)	ECD, CBC, CTR	16
	AES key preparation	-	14
256 bits	AES encryption or decryption(1)	ECD, CBC, CTR	18
	AES key preparation	-	16

1. Excluding key preparation time (ECB and CBC only).

Table 337. Processing time (in clock cycle) for GCM and CCM per 128-bit block

Key size	Operating modes	Chaining algorithm	Initialization phase	Header phase	Payload phase	Tag phase
128 bits	AES encryption or decryption	GCM	24	10	14	14
		CCM	12	14	25	14
192 bits		GCM	28	10	16	16
		CCM	14	16	29	16
256 bits		GCM	32	10	18	18
		CCM	16	18	33	18

40.7 CRYP registers

The cryptographic core is associated with several control and status registers, eight key registers and four initialization vectors registers.

40.7.1 CRYP control register (CRYP_CR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NPBLB[3:0]				ALGOMODE3	Res.	GCM_CCMPH[1:0]	
								rw	rw	rw	rw	rw		rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CRYPEN	FFLUSH	Res.	Res.	Res.	Res.	KEYSIZE[1:0]		DATATYPE[1:0]		ALGOMODE[2:0]			ALGODIR	Res.	Res.
rw	rw					rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:20 **NPBLB[3:0]:** Number of Padding Bytes in Last Block of payload.

This padding information must be filled by software before processing the last block of GCM payload encryption or CCM payload decryption, otherwise authentication tag computation is incorrect.

0000: All bytes are valid (no padding)

0001: Padding for the last LSB byte

...

1111: Padding for the 15 LSB bytes of last block.

Writing NPBLB bits while BUSY = 1 has no effect.

Bit 18 Reserved, must be kept at reset value.

Bits 17:16 **GCM_CCMPH[1:0]**: GCM or CCM Phase selection

This bitfield has no effect if GCM, GMAC or CCM algorithm is not selected in ALGOMODE field.

00: Initialization phase

01: Header phase

10: Payload phase

11: Final phase

Writing to GCM_CCMPH bits while BUSY = 1 has no effect.

Bit 15 **CRYPEN:** CRYP processor Enable

0: Cryptographic processor peripheral is disabled

1: Cryptographic processor peripheral is enabled

This bit is automatically cleared by hardware when the key preparation process ends (ALGOMODE = 0111) or after GCM/GMAC or CCM Initialization phase.

Bit 14 **FFLUSH:** CRYP FIFO Flush

0: No FIFO flush

1: FIFO flush enabled

When CRYPEN = 0, writing this bit to 1 flushes the IN and OUT FIFOs (that is read and write pointers of the FIFOs are reset). Writing this bit to 0 has no effect.

When CRYPEN = 1, writing this bit to 0 or 1 has no effect.

Reading this bit always returns 0.

FFLUSH bit has to be set only when BUSY = 0. If not, the FIFO is flushed, but the block being processed may be pushed into the output FIFO just after the flush operation, resulting in a non-empty FIFO condition.

Bits 13:10 Reserved, must be kept at reset value.

Bits 9:8 **KEYSIZE[1:0]**: Key size selection (AES mode only)

This bitfield defines the bit-length of the key used for the AES cryptographic core. This bitfield is ‘don’t care’ in the DES or TDES modes.

00: 128-bit key length

01: 192-bit key length

10: 256-bit key length

11: Reserved, do not use this value

Writing KEYSIZE bits while BUSY = 1 has no effect.

Bits 7:6 **DATATYPE[1:0]**: Data Type selection

This bitfield defines the format of data written in CRYP_DIN or read from CRYP_DOUT registers. For more details refer to *Section 40.4.16: CRYP data registers and data swapping*).

00: 32-bit data. No swapping for each word. First word pushed into the IN FIFO (or popped off the OUT FIFO) forms bits 1...32 of the data block, the second word forms bits 33...64 etc.

01: 16-bit data, or half-word. Each word pushed into the IN FIFO (or popped off the OUT FIFO) is considered as 2 half-words, which are swapped with each other.

10: 8-bit data, or bytes. Each word pushed into the IN FIFO (or popped off the OUT FIFO) is considered as 4 bytes, which are swapped with each other.

11: bit data, or bit-string. Each word pushed into the IN FIFO (or popped off the OUT FIFO) is considered as 32 bits (1st bit of the string at position 0), which are swapped with each other.

Writing DATATYPE bits while BUSY = 1 has no effect.

Bits 19, 5:3 **ALGOMODE[3:0]:** Algorithm mode
Below definition includes the bit 19:
0000: TDES-ECB (triple-DES Electronic Codebook).
0001: TDES-CBC (triple-DES Cipher Block Chaining).
0010: DES-ECB (simple DES Electronic Codebook).
0011: DES-CBC (simple DES Cipher Block Chaining).
0100: AES-ECB (AES Electronic Codebook).
0101: AES-CBC (AES Cipher Block Chaining).
0110: AES-CTR (AES Counter mode).
0111: AES key preparation for ECB or CBC decryption.
1000: AES-GCM (Galois Counter mode) and AES-GMAC (Galois Message Authentication Code mode).
1001: AES-CCM (Counter with CBC-MAC).
Writing ALGOMODE bits while BUSY = 1 has no effect.
Others: Reserved, must no be used

Bit 2 **ALGODIR:** Algorithm Direction
0: Encrypt
1: Decrypt

Writing ALGODIR bit while BUSY = 1 has no effect.

Bits 1:0 Reserved, must be kept at reset value.

40.7.2 CRYP status register (CRYP_SR)

Address offset: 0x04

Reset value: 0x0000 0003

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSY	OFFU	OFNE	IFNF	IFEM
											r	r	r	r	r

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **BUSY:** Busy bit
0: The CRYP core is not processing any data. The reason is:
– either that the CRYP core is disabled (CRYPEN = 0 in the CRYP_CR register) and the last processing has completed,
– or the CRYP core is waiting for enough data in the input FIFO or enough free space in the output FIFO (that is in each case at least 2 words in the DES, 4 words in the AES).
1: The CRYP core is currently processing a block of data or a key preparation is ongoing (AES ECB or CBC decryption only).

Bit 3 **OFFU:** Output FIFO full flag
0: Output FIFO is not full
1: Output FIFO is full

Bit 2 **OFNE:** Output FIFO not empty flag
0: Output FIFO is empty
1: Output FIFO is not empty

Bit 1 **IFNF:** Input FIFO not full flag
0: Input FIFO is full
1: Input FIFO is not full

Bit 0 **IFEM:** Input FIFO empty flag
0: Input FIFO is not empty
1: Input FIFO is empty

40.7.3 CRYP data input register (CRYP_DIN)

Address offset: 0x08

Reset value: 0x0000 0000

The CRYP_DIN register is the data input register. It is 32-bit wide. It is used to enter into the input FIFO up to four 64-bit blocks (TDES) or two 128-bit blocks (AES) of plaintext (when encrypting) or ciphertext (when decrypting), one 32-bit word at a time.

To fit different data sizes, the data can be swapped after processing by configuring the DATATYPE bits in the CRYP_CR register. Refer to *Section 40.4.16: CRYP data registers and data swapping* for more details.

When CRYP_DIN register is written to the data are pushed into the input FIFO.

- If CRYPEN = 1, when at least four 32-bit words in the AES mode have been pushed into the input FIFO (two words in the DES/TDES mode), and when at least four words are free in the output FIFO (two words in the DES/DTES mode), the CRYP engine starts an encrypting or decrypting process.

When CRYP_DIN register is read:

- If CRYPEN = 0, the FIFO is popped, and then the data present in the Input FIFO are returned, from the oldest one (first reading) to the newest one (last reading). The IFEM flag must be checked before each read operation to make sure that the FIFO is not empty.
- if CRYPEN = 1, an undefined value is returned.

Note: After the CRYP_DIN register has been read once or several times, the FIFO must be flushed by setting the FFLUSH bit prior to processing new data.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATAIN[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATAIN[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DATAIN[31:0]:** Data Input

On read FIFO is popped (last written value is returned), and its value is returned if CRYPEN = 0. If CRYPEN = 1 DATAIN register returns an undefined value.
On write current register content is pushed inside the FIFO.

40.7.4 CRYP data output register (CRYP_DOUT)

Address offset: 0x0C

Reset value: 0x0000 0000

The CRYP_DOUT register is the data output register. It is read-only and 32-bit wide. It is used to retrieve from the output FIFO up to four 64-bit blocks (TDES) or two 128-bit blocks (AES) of plaintext (when encrypting) or ciphertext (when decrypting), one 32-bit word at a time.

To fit different data sizes, the data can be swapped after processing by configuring the DATATYPE bits in the CRYP_CR register. Refer to *Section 40.4.16: CRYP data registers and data swapping* for more details.

When CRYP_DOUT register is read, the last data entered into the output FIFO (pointed to by the read pointer) is returned.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATAOUT[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATAOUT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **DATAOUT[31:0]:** Data Output

On read returns output FIFO content (pointed to by read pointer), else returns an undefined value.
On write, no effect.

40.7.5 CRYP DMA control register (CRYP_DMACR)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DOEN	DIEN
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **DOEN:** DMA Output Enable
When this bit is set, DMA requests are automatically generated by the peripheral during the output data phase.
0: DMA for outgoing data transfer is disabled
1: DMA for outgoing data transfer is enabled

Bit 0 **DIEN:** DMA Input Enable
When this bit is set, DMA requests are automatically generated by the peripheral during the input data phase.
0: DMA for incoming data transfer is disabled
1: DMA for incoming data transfer is enabled

40.7.6 CRYP interrupt mask set/clear register (CRYP_IMSCR)

Address offset: 0x14

Reset value: 0x0000 0000

The CRYP_IMSCR register is the interrupt mask set or clear register. It is a read/write register. When a read operation is performed, this register gives the current value of the mask applied to the relevant interrupt. Writing 1 to the particular bit sets the mask, thus enabling the interrupt to be read. Writing 0 to this bit clears the corresponding mask. All the bits are cleared to 0 when the peripheral is reset.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OUTIM	INIM
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **OUTIM:** Output FIFO service interrupt mask
0: Output FIFO service interrupt is masked
1: Output FIFO service interrupt is not masked

Bit 0 **INIM:** Input FIFO service interrupt mask
0: Input FIFO service interrupt is masked
1: Input FIFO service interrupt is not masked

40.7.7 CRYP raw interrupt status register (CRYP_RISR)

Address offset: 0x18

Reset value: 0x0000 0001

The CRYP_RISR register is the raw interrupt status register. It is a read-only register. When a read operation is performed, this register gives the current raw status of the corresponding

interrupt, i.e. the interrupt information without taking CRYP_IMSCR mask into account. Write operations have no effect.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OUTRIS	INRIS
														r	r

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **OUTRIS:** Output FIFO service raw interrupt status

This bit gives the output FIFO interrupt information without taking CRYP_IMSCR corresponding mask into account.

0: Raw interrupt not pending

1: Raw interrupt pending

Bit 0 **INRIS:** Input FIFO service raw interrupt status

This bit gives the input FIFO interrupt information without taking CRYP_IMSCR corresponding mask into account.

0: Raw interrupt not pending

1: Raw interrupt pending

40.7.8 CRYP masked interrupt status register (CRYP_MISR)

Address offset: 0x1C

Reset value: 0x0000 0000

The CRYP_MISR register is the masked interrupt status register. It is a read-only register. When a read operation is performed, this register gives the current masked status of the corresponding interrupt, i.e. the interrupt information taking CRYP_IMSCR mask into account. Write operations have no effect.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OUTMIS	INMIS
														r	r

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **OUTMIS:** Output FIFO service masked interrupt status

This bit gives the output FIFO interrupt information without taking into account the corresponding CRYP_IMSCR mask.

0: Interrupt not pending

1: Interrupt pending

Bit 0 **INMIS:** Input FIFO service masked interrupt status
This bit gives the input FIFO interrupt information without taking into account the corresponding CRYP_IMSCR mask.
0: Interrupt not pending
1: Interrupt pending when CRYPEN = 1

40.7.9 CRYP key register 0L (CRYP_K0LR)

Address offset: 0x20

Reset value: 0x0000 0000

CRYP key registers contain the cryptographic keys.

For more information refer to *Section 40.4.17: CRYP key registers*.

Note: Write accesses to these registers are disregarded when the cryptographic processor is busy (bit BUSY = 1 in the CRYP_SR register) .

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
K[255:240]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
K[239:224]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **K[255:224]**: Key bit x (x = 255 to 224)
This write-only bitfield contains the bits [255:224] of the AES encryption or decryption key, depending on the operating mode. This register is not used in DES/TDES mode.

40.7.10 CRYP key register 0R (CRYP_K0RR)

Address offset: 0x24

Reset value: 0x0000 0000

Refer to *Section 40.7.9: CRYP key register 0L (CRYP_K0LR)* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
K[223:208]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
K[207:192]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **K[223:192]**: Key bit x (x = 223 to 192)
This write-only bitfield contains the bits [223:192] of the AES encryption or decryption key, depending on the operating mode. This register is not used in DES/TDES mode.

40.7.11 CRYP key register 1L (CRYP_K1LR)

Address offset: 0x28

Reset value: 0x0000 0000

Refer to *Section 40.7.9: CRYP key register 0L (CRYP_K0LR)* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
K[191:176]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
K[175:160]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **K[191:160]**: Key bit x (x = 191 to 160)

This write-only bitfield contains the bits [191:160] of the AES encryption or decryption key, depending on the operating mode. In DES/TDES mode this bitfield contains the bits [64:33] of the key K1, with parity bits unused.

40.7.12 CRYP key register 1R (CRYP_K1RR)

Address offset: 0x2C

Reset value: 0x0000 0000

Refer to *Section 40.7.9: CRYP key register 0L (CRYP_K0LR)* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
K[159:144]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
K[143:128]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **K[159:128]**: Key bit x (x = 159 to 128)

This write-only bitfield contains the bits [159:128] of the AES encryption or decryption key, depending on the operating mode. In DES/TDES mode this bitfield contains the bits [32:1] of the key K1, with parity bits unused.

40.7.13 CRYP key register 2L (CRYP_K2LR)

Address offset: 0x30

Reset value: 0x0000 0000

Refer to *Section 40.7.9: CRYP key register 0L (CRYP_K0LR)* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
K[127:112]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
K[111:96]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **K[127:96]**: Key bit x (x = 127 to 96)

This write-only bitfield contains the bits [127:96] of the AES encryption or decryption key, depending on the operating mode. In DES/TDES mode this bitfield contains the bits [64:33] of the key K2, with parity bits unused.

40.7.14 CRYP key register 2R (CRYP_K2RR)

Address offset: 0x34

Reset value: 0x0000 0000

Refer to *Section 40.7.9: CRYP key register 0L (CRYP_K0LR)* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
K[95:80]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
K[79:64]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **K[95:64]**: Key bit x (x = 95 to 64)

This write-only bitfield contains the bits [95:64] of the AES encryption or decryption key, depending on the operating mode. In DES/TDES mode this bitfield contains the bits [32:1] of the key K2, with parity bits unused.

40.7.15 CRYP key register 3L (CRYP_K3LR)

Address offset: 0x38

Reset value: 0x0000 0000

Refer to *Section 40.7.9: CRYP key register 0L (CRYP_K0LR)* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
K[63:48]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
K[47:32]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **K[63:32]**: Key bit x (x = 63 to 32)

This write-only bitfield contains the bits [63:32] of the AES encryption or decryption key, depending on the operating mode. In DES/TDES mode this bitfield contains the bits [64:33] of the key K3, with parity bits unused.

40.7.16 CRYP key register 3R (CRYP_K3RR)

Address offset: 0x3C

Reset value: 0x0000 0000

Refer to *Section 40.7.9: CRYP key register 0L (CRYP_K0LR)* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
K[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
K[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **K[31:0]**: Key bit x (x = 31 to 0)

This write-only bitfield contains the bits [31:0] of the AES encryption or decryption key, depending on the operating mode. In DES/TDES mode this bitfield contains the bits [32:1] of the key K3, with parity bits unused.

40.7.17 CRYP initialization vector register 0L (CRYP_IV0LR)

Address offset: 0x40

Reset value: 0x0000 0000

The CRYP_IV registers store the initialization vector or the nonce, depending on the chaining mode selected. The size of the IV data is 64 bits for DES/TDES and 128 bits for AES. For more information refer to *Section 40.4.18: CRYP initialization vector registers*.

Note: Write accesses to these registers are disregarded when the cryptographic processor is busy (BUSY = 1 in the CRYP_SR register).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IV[127:112]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IV[111:96]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IV[127:96]**: Initialization vector bit x (x = 127 to 96)

This bitfield stores the initialization vector bits [127:96] for AES chaining modes other than ECB. In DES/TDES mode it corresponds to IV bits [63:32].

IV registers are updated by the core after each computation round of the DES/TDES or AES core.

40.7.18 CRYP initialization vector register 0R (CRYP_IV0RR)

Address offset: 0x44

Reset value: 0x0000 0000

Refer to *Section 40.7.17: CRYP initialization vector register 0L (CRYP_IV0LR)* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IV[95:80]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IV[79:64]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IV[95:64]**: Initialization vector bit x (x = 95 to 64)

This bitfield stores the initialization vector bits [95:64] for AES chaining modes other than ECB. In DES/TDES mode it corresponds to IV bits [31:0].

IV registers are updated by the core after each computation round of the DES/TDES or AES core.

40.7.19 CRYP initialization vector register 1L (CRYP_IV1LR)

Address offset: 0x48

Reset value: 0x0000 0000

Refer to *Section 40.7.17: CRYP initialization vector register 0L (CRYP_IV0LR)* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IV[63:48]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IV[47:32]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IV[63:32]**: Initialization vector bit x (x = 63 to 32)

This bitfield stores the initialization vector bits [63:32] for AES chaining modes other than ECB. *This register is not used in DES mode*.

IV registers are updated by the core after each computation round of the AES core.

40.7.20 CRYP initialization vector register 1R (CRYP_IV1RR)

Address offset: 0x4C

Reset value: 0x0000 0000

Refer to *Section 40.7.17: CRYP initialization vector register 0L (CRYP_IV0LR)* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IV[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IV[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **IV[31:16]**: Initialization vector bit x (x = 31 to 16)

This bitfield stores the initialization vector bits [31:0] for AES chaining modes other than ECB. *This register is not used in DES mode*.

IV registers are updated by the core after each computation round of the AES core.

40.7.21 CRYP context swap GCM-CCM registers (CRYP_CSGCMCCMxR)

Address offset: 0x050 + x* 0x4 (x = 0 to 7)

Reset value: 0x0000 0000

These registers contain the complete internal register states of the CRYP processor when the GCM/GMAC or CCM algorithm is selected. They are useful when a context swap has to be performed because a high-priority task needs the cryptographic processor while it is already in use by another task.

When such an event occurs, the CRYP_CSGCMCCM0..7R and CRYP_CSGCM0..7R (in GCM/GMAC mode) or CRYP_CSGCMCCM0..7R (in CCM mode) registers have to be read and the values retrieved have to be saved in the system memory space. The cryptographic processor can then be used by the preemptive task. Then when the cryptographic computation is complete, the saved context can be read from memory and written back into the corresponding context swap registers.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CSGCMCCMx[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CSGCMCCMx[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CSGCMCCMx[31:0]**: CRYP processor internal register states for GCM, GMAC and CCM modes.

Note: This register is not used in DES/TDES or other AES modes than the ones indicated

40.7.22 CRYP context swap GCM registers (CRYP_CSGCMxR)

Address offset: 0x070 + x* 0x4 (x = 0 to 7)

Reset value: 0x0000 0000

Refer to *Section 40.7.21: CRYP context swap GCM-CCM registers (CRYP_CSGCMCCMxR)* for details.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CSGCMx[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CSGCMx[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CSGCMx[31:0]**: CRYP processor internal register states for GCM and GMAC modes.

Note: This register is not used in DES/TDES or other AES modes than the ones indicated

40.7.23 CRYP register map

Table 338. CRYP register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	CRYP_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.		NPBLB				ALGOMODE[3]	Res.	GCM_CCMPH		CRYPEN	FFLUSH	Res.	Res.	Res.	Res.	KEYSIZE		DATATYPE		ALGOMODE[2:0]			ALGODIR	Res.	Res.
	Reset value									0	0	0	0	0		0	0	0	0					0	0	0	0	0	0	0	0		
0x04	CRYP_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSY	OFFU	OFNE	IFNF	IFEM
	Reset value																												0	0	0	1	1
0x08	CRYP_DIN	DATAIN																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	CRYP_DOUT	DATAOUT																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	CRYP_DMACR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DOEN	DIEN
	Reset value																															0	0
0x14	CRYP_IMSCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OUTIM	INIM
	Reset value																															0	0
0x18	CRYP_RISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OUTRIS	INRIS
	Reset value																															0	1
0x1C	CRYP_MISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OUTMIS	INMIS
	Reset value																															0	0
0x20	CRYP_K0LR	K[255:224]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x24	CRYP_K0RR	K[223:192]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
...																																	
0x38	CRYP_K3LR	K[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x3C	CRYP_K3RR	K[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x40	CRYP_IV0LR	IV0	IV1	IV2	IV3	IV4	IV5	IV6	IV7	IV8	IV9	IV10	IV11	IV12	IV13	IV14	IV15	IV16	IV17	IV18	IV19	IV20	IV21	IV22	IV23	IV24	IV25	IV26	IV27	IV28	IV29	IV30	IV31
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 338. CRYP register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x44	CRYP_IV0RR	IV32	IV33	IV34	IV35	IV36	IV37	IV38	IV39	IV40	IV41	IV42	IV43	IV44	IV45	IV46	IV47	IV48	IV49	IV50	IV51	IV52	IV53	IV54	IV55	IV56	IV57	IV58	IV59	IV60	IV61	IV62	IV63
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x48	CRYP_IV1LR	IV62	IV63	IV64	IV65	IV66	IV67	IV68	IV69	IV70	IV71	IV72	IV73	IV74	IV75	IV76	IV77	IV78	IV79	IV80	IV81	IV82	IV83	IV84	IV85	IV86	IV87	IV88	IV89	IV90	IV91	I962	IV93
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x4C	CRYP_IV1RR	IV96	IV97	IV98	IV99	IV100	IV101	IV102	IV103	IV104	IV105	IV106	IV107	IV108	IV109	IV110	IV111	IV112	IV113	IV114	IV115	IV116	IV117	IV118	IV119	IV120	IV121	IV122	IV123	IV124	IV125	IV126	IV127
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x50	CRYP_CSGCMCCM0R	CSGCMCCM0																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x54	CRYP_CSGCMCCM1R	CSGCMCCM1																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x58	CRYP_CSGCMCCM2R	CSGCMCCM2																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x5C	CRYP_CSGCMCCM3R	CSGCMCCM3																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x60	CRYP_CSGCMCCM4R	CSGCMCCM4																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x64	CRYP_CSGCMCCM5R	CSGCMCCM5																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x68	CRYP_CSGCMCCM6R	CSGCMCCM6																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x6C	CRYP_CSGCMCCM7R	CSGCMCCM7																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x70	CRYP_CSGCM0R	CSGCM0																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x74	CRYP_CSGCM1R	CSGCM1																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x78	CRYP_CSGCM2R	CSGCM2																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x7C	CRYP_CSGCM3R	CSGCM3																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x80	CRYP_CSGCM4R	CSGCM4																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 338. CRYP register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x84	CRYP_CSGCM5R	CSGCM5																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x88	CRYP_CSGCM6R	CSGCM6																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x8C	CRYP_CSGCM7R	CSGCM7																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

41 Hash processor (HASH)

41.1 Introduction

The hash processor is a fully compliant implementation of the secure hash algorithm (SHA-1, SHA-224, SHA-256), the MD5 (message-digest algorithm 5) hash algorithm and the HMAC (keyed-hash message authentication code) algorithm. HMAC is suitable for applications requiring message authentication.

The hash processor computes FIPS (Federal Information Processing Standards) approved digests of length of 160, 224, 256 bits, for messages of up to (2^{64} – 1) bits. It also computes 128-bit digests for the MD5 algorithm.

41.2 HASH main features

- Suitable for data authentication applications, compliant with:
  - Federal Information Processing Standards Publication FIPS PUB 180-4, *Secure Hash Standard* (SHA-1 and SHA-2 family)
  - Federal Information Processing Standards Publication FIPS PUB 186-4, *Digital Signature Standard (DSS)*
  - Internet Engineering Task Force (IETF) Request For Comments RFC 1321, *MD5 Message-Digest Algorithm*
  - Internet Engineering Task Force (IETF) Request For Comments RFC 2104, *HMAC: Keyed-Hashing for Message Authentication* and Federal Information Processing Standards Publication FIPS PUB 198-1, *The Keyed-Hash Message Authentication Code (HMAC)*
- Fast computation of SHA-1, SHA-224, SHA-256, and MD5
  - 82 (respectively 66) clock cycles for processing one 512-bit block of data using SHA-1 (respectively SHA-256) algorithm
  - 66 clock cycles for processing one 512-bit block of data using MD5 algorithm
- Corresponding 32-bit words of the digest from consecutive message blocks are added to each other to form the digest of the whole message
  - Automatic 32-bit words swapping to comply with the internal little-endian representation of the input bit-string
  - Word swapping supported: bits, bytes, half-words and 32-bit words
- Automatic padding to complete the input bit string to fit digest minimum block size of 512 bits (16 × 32 bits)
- Single 32-bit input register associated to an internal input FIFO, corresponding to one block size
- AHB slave peripheral, accessible through 32-bit word accesses only (else an AHB error is generated)
- 8 × 32-bit words (H0 to H7) for output message digest
- Automatic data flow control with support of direct memory access (DMA) using one channel.
- Single or fixed DMA burst transfers of four words

- Interruptible message digest computation, on a per-block basis
  - Re-loadable digest registers
  - Hashing computation suspend/resume mechanism, including DMA

41.3 HASH implementation

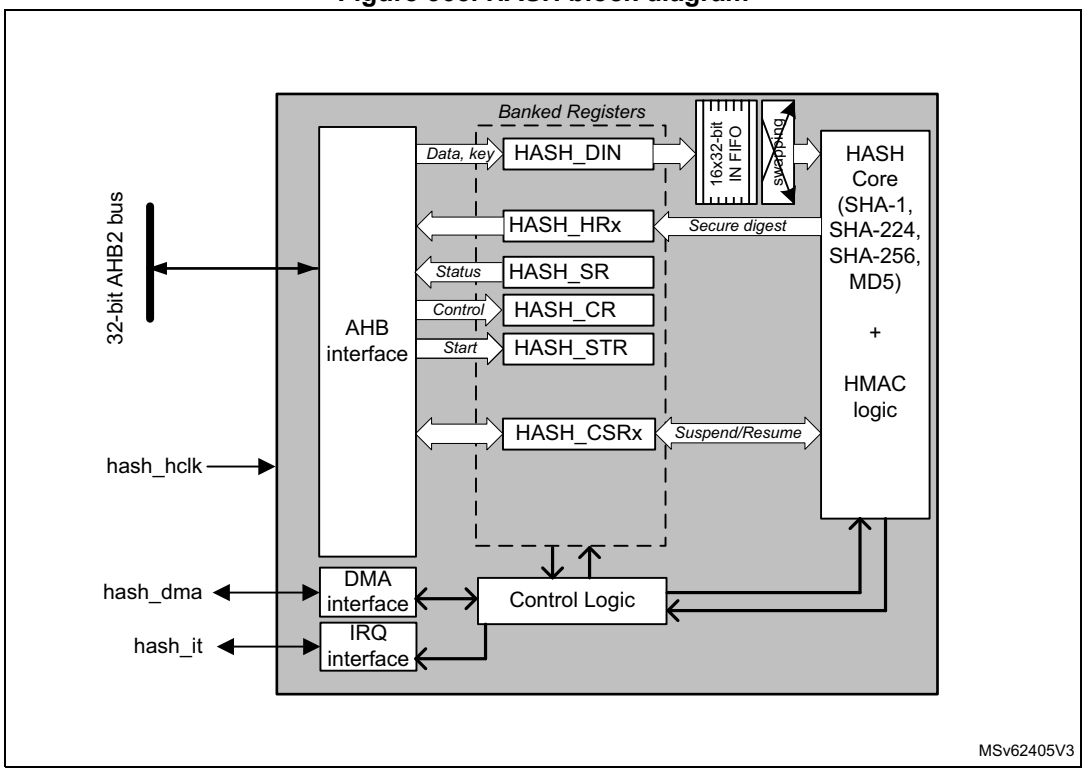
The devices have a single instance of HASH peripheral.

41.4 HASH functional description

41.4.1 HASH block diagram

Figure 365 shows the block diagram of the hash processor.

Figure 365. HASH block diagram



41.4.2 HASH internal signals

Table 339 describes a list of useful to know internal signals available at HASH level, not at product level (on pads).

Table 339. HASH internal input/output signals

Signal name	Signal type	Description
hash_hclk	digital input	AHB bus clock
hash_it	digital output	Hash processor global interrupt request
hash_dma	digital input/output	DMA transfer request/ acknowledge

41.4.3 About secure hash algorithms

The hash processor is a fully compliant implementation of the secure hash algorithm defined by FIPS PUB 180-4 standard and the IETF RFC1321 publication (MD5).

With each algorithm, the HASH computes a condensed representation of a message or data file. More specifically, when a message of any length below 2^{64} bits is provided on input, the HASH processing core produces respectively a fixed-length output string called a message digest, defined as follows:

- For MD5 digest size is 128-bit
- For SHA-1 digest size is 160-bit
- For SHA-224 and SHA-256, the digest size is 224 bits and 256 bits, respectively

The message digest can then be processed with a digital signature algorithm in order to generate or verify the signature for the message.

Signing the message digest rather than the message often improves the efficiency of the process because the message digest is usually much smaller in size than the message. The verifier of a digital signature has to use the same hash algorithm as the one used by the creator of the digital signature.

The SHA-2 functions supported by the hash processor are qualified as “secure” by NIST because it is computationally infeasible to find a message that corresponds to a given message digest, or to find two different messages that produce the same message digest (SHA-1 does not qualify as secure since February 2017). Any change to a message in transit, with very high probability, results in a different message digest, and the signature fails to verify.

41.4.4 Message data feeding

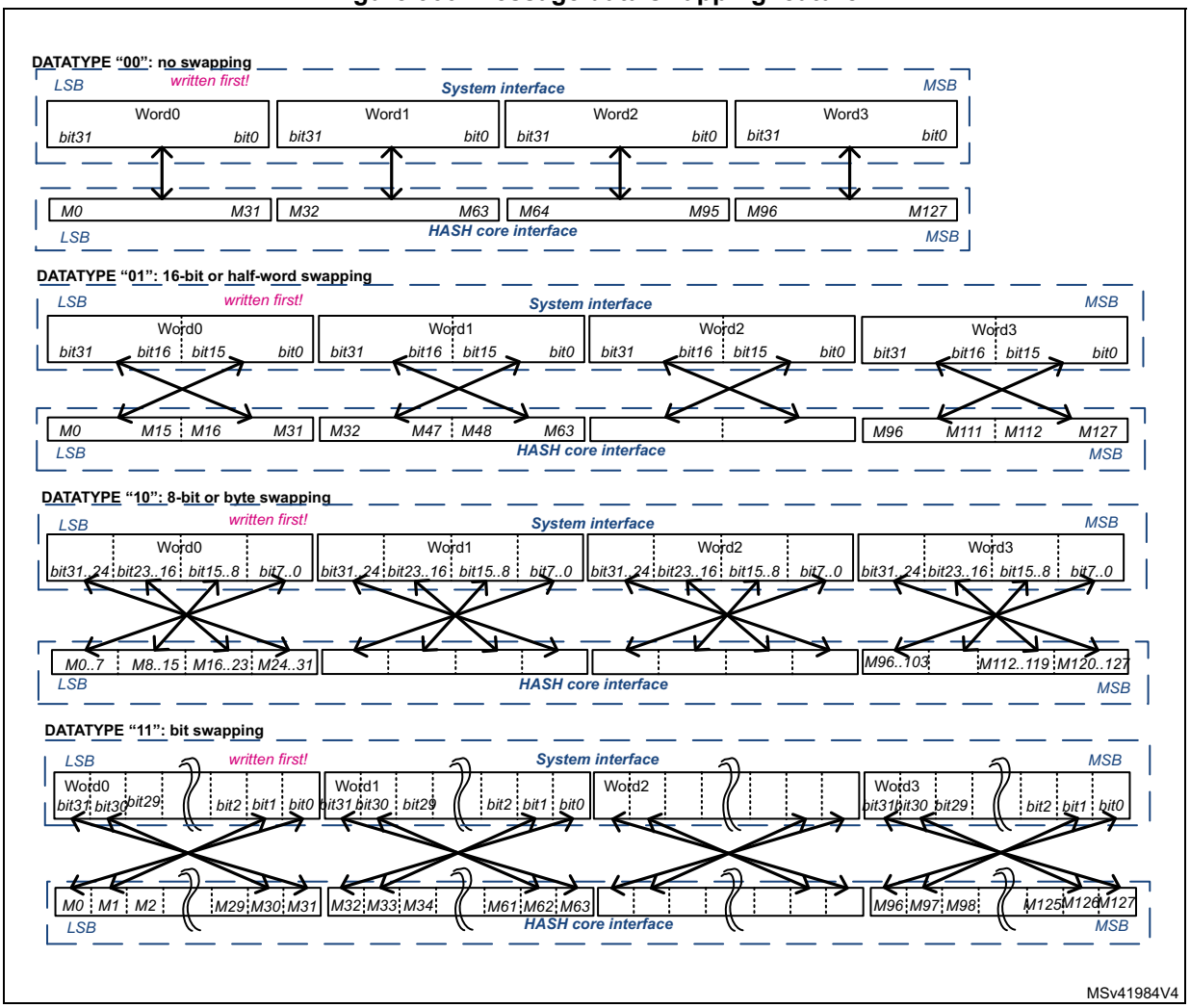
The message (or data file) to be processed by the HASH should be considered as a bit string. Per FIPS PUB 180-4 standard this message bit string grows from left to right, with hexadecimal words expressed in “big-endian” convention, so that within each word, the most significant bit is stored in the left-most bit position. For example message string “abc” with a bit string representation of “**01100001 01100010 01100011**” is represented by a 32-bit word **0x00636261**, and 8-bit words **0x61626300**.

Data are entered into the HASH one 32-bit word at a time, by writing them into the HASH_DIN register. The current contents of the HASH_DIN register are transferred to the 16 words input FIFO each time the register is written with new data. Hence HASH_DIN and the FIFO form a seventeen 32-bit words length FIFO (named the IN buffer).

In accordance to the kind of data to be processed (e.g. byte swapping when data are ASCII text stream) there must be a bit, byte, half-word or no swapping operation to be performed on data from the input FIFO before entering the little-endian hash processing core. *Figure 366* shows how the hash processing core 32-bit data block M0...31 is constructed from one 32-bit words popped into input FIFO by the driver, according to the DATATYPE bitfield in the HASH control register (HASH_CR).

HASH_DIN data endianness when bit swapping is disabled (DATATYPE = 00) can be described as following: the least significant bit of the message has to be at MSB position in the first word entered into the hash processor, the 32nd bit of the bit string has to be at MSB position in the second word entered into the hash processor and so on.

Figure 366. Message data swapping feature



41.4.5 Message digest computing

The hash processor sequentially processes several blocks when computing the message digest. For MD5, SHA1 and SHA2, the block size is 512 bits.

Each time the DMA or the CPU writes a block to the hash processor, the HASH automatically starts computing the message digest. This operation is known as partial digest computation.

As described in *Section 41.4.4: Message data feeding*, the message to be processed is entered into the HASH 32-bit word at a time, writing to the HASH_DIN register to fill the input FIFO.

In order to perform the hash computation on this data below sequence must be used by the application:

1. Initialize the hash processor using the HASH_CR register:
   a) Select the right algorithm using the ALGO bitfield. If needed program the correct swapping operation on the message input words using DATATYPE bitfield in HASH_CR.
   b) When the HMAC mode is required, set the MODE bit, as well as the LKEY bit if the HMAC key size is greater than the known block size of the algorithm (else keep LKEY cleared). Refer to *Section 41.4.7: HMAC operation* for details.
   c) Set MODE = 1 and select the key length using LKEY if HMAC mode has been selected.
   d) Update NBLW[4:0] to define the number of valid bits in last word of the message if it is different from 32 bits. NBLW[4:0] information are used to correctly perform the automatic message padding before the final message digest computation.
2. Complete the initialization by setting to 1 the INIT bit in HASH_CR. Also set the bit DMAE to 1 if data are transferred via DMA.

Caution: When programming step 2, it is important to set up before or at the same time the correct configuration values (ALGO, DATATYPE, HMAC mode, key length, NBLW[4:0]).

3. Start filling data by writing to HASH_DIN register, unless data are automatically: transferred via DMA. Note that the processing of a block can start only once the last value of the block has entered the input FIFO. The way the partial or final digest computation is managed depends on the way data are fed into the processor:
   a) When data are filled by software:
   – Partial digest computation are triggered each time the application writes the first word of the next block. Once the processor is ready again (DINIS = 1 in HASH_SR), the software can write new data to HASH_DIN. This mechanism avoids the introduction of wait states by the HASH.
   – The final digest computation is triggered when the last block is entered and the software writes the DCAL bit to 1. If the message length is not an exact multiple of the block size, the NBLW[4:0] bitfield in HASH_STR register must be written prior to writing DCAL bit (see *Section 41.4.6* for details).
   b) When data are filled by DMA as a single DMA transfer (MDMAT bit = 0):
   – Partial digest computations are triggered automatically each time the FIFO is full.
   The final digest computation is triggered automatically when the last block has been transferred to the HASH_DIN register (DCAL bit is set to 1 by hardware). If the message length is not an exact multiple of the block size, the NBLW[4:0] field

in HASH_STR register must be written prior to enabling the DMA (see *Section 41.4.6* for details).

c) When data are filled using multiple DMA transfers (MDMAT bit = 1):

– Partial digest computations are triggered as for single DMA transfers. However the final digest computation is not triggered automatically when the last block has been transferred to the HASH_DIN register (DCAL bit is not set to 1 by hardware). It allows the hash processor to receive a new DMA transfer as part of this digest computation. To launch the final digest computation, the software must set MDMAT bit to 0 before the last DMA transfer in order to trigger the final digest computation as it is done for single DMA transfers (see description before).

4. Once the digest computation is complete (DCIS = 1), the resulting digest can be read from the output registers as described in *Table 340*.

Table 340. Hash processor outputs

Algorithm	Valid output registers	Most significant bit	Digest size (in bits)
MD5	HASH_H0 to HASH_H3	HASH_H0[31]	128
SHA-1	HASH_H0 to HASH_H4	HASH_H0[31]	160
SHA-224	HASH_H0 to HASH_H6	HASH_H0[31]	224
SHA-256	HASH_H0 to HASH_H7		256

For more information about HMAC detailed instructions, refer to *Section 41.4.7: HMAC operation*.

41.4.6 Message padding

Overview

When computing a condensed representation of a message, the process of feeding data into the hash processor (with automatic partial digest computation every block transfer) loops until the last bits of the original message are written to the HASH_DIN register.

As the length (number of bits) of a message can be any integer value, the last word written to the hash processor may have a valid number of bits between 1 and 32. This number of valid bits in the last word, NBLW[4:0], has to be written to the HASH_STR register, so that message padding is correctly performed before the final message digest computation.

Padding processing

Detailed padding sequences with DMA enabled or disabled are described in *Section 41.4.5: Message digest computing*.

Padding example

As specified by Federal Information Processing Standards PUB 180-4, the message padding consists in appending a “1” followed by k “0”s, itself followed by a 64-bit integer that is equal to the length L in bits of the message. These three padding operations generate a padded message of length $L + 1 + k + 64$, which by construction is a multiple of 512 bits.

For the hash processor, the “1” is added to the last word written to the HASH_DIN register at the bit position defined by the NBLW[4:0] bitfield, and the remaining upper bits are cleared (“0”s).

Example from FIPS PUB180-4

Let us assume that the original message is the ASCII binary-coded form of “abc”, of length L = 24:

```
byte 0    byte 1   byte 2   byte 3
01100001 01100010 01100011 UUUUUUUU
<-- 1st word written to HASH_DIN -->
```

NBLW[4:0] has to be loaded with the value 24: a **“1”** is appended at bit location 24 in the bit string (starting counting from left to right in the above bit string), which corresponds to bit 31 in the HASH_DIN register (little-endian convention):

```
01100001 01100010 01100011 1UUUUUUU
```

Since L = 24, the number of bits in the above bit string is 25, and 423 “0” bits are appended, making now 448 bits.

This gives in hexadecimal (byte words in big-endian format):

```
61626380 00000000 00000000 00000000
00000000 00000000 00000000 00000000
00000000 00000000 00000000 00000000
00000000 00000000 00000000 00000018
```

The message length value, L, in two-word format (that is 00000000 00000018) is appended. Hence the final padded message in hexadecimal (byte words in big-endian format):

```
61626380 00000000 00000000 00000000
00000000 00000000 00000000 00000000
00000000 00000000 00000000 00000000
00000000 00000000 00000000 00000018
```

If the hash processor is programmed to swap byte within HASH_DIN input register (DATATYPE = 10 in HASH_CR), the above message has to be entered by following the below sequence:

1. **0xUU636261** is written to the HASH_DIN register (where ‘U’ means don’t care).
2. **0x18** is written to the HASH_STR register (the number of valid bits in the last word written to the HASH_DIN register is 24, as the original message length is 24 bits).
3. **0x10** is written to the HASH_STR register to start the message padding (described above) and then perform the digest computation.
4. The hash computing is complete with the message digest available in the HASH_HRx registers (x = 0...4) for the SHA-1 algorithm. For this FIPS example, the expected value is as follows:

```
HASH_HR0 = 0xA9993E36
HASH_HR1 = 0x4706816A
HASH_HR2 = 0xBA3E2571
HASH_HR3 = 0x7850C26C
HASH_HR4 = 0x9CD0D89D
```

41.4.7 HMAC operation

Overview

As specified by Internet Engineering Task Force RFC2104 and NIST FIPS PUB 198-1, the HMAC algorithm is used for message authentication by irreversibly binding the message being processed to a key chosen by the user. The algorithm consists of two nested hash operations:

```
HMAC(message)= Hash((Key | pad) XOR opad |
                    Hash((Key | pad) XOR ipad | message))
```

where:

- **opad** = $[0x5C]_n$ (outer pad) and **ipad** = $[0x36]_n$ (inner pad)
- $[X]_n$ represents a repetition of X *n* times, where *n* equal to the size of the underlying hash function data block (n = 64 for 512-bit blocks).
- **pad** is a sequence of zeroes needed to extend the key to the length *n* defined above. If the key length is greater than *n,* the application must first hash the key using Hash() function and then use the resultant byte string as the actual key to HMAC.
- | represents the concatenation operator.

HMAC processing

Four different steps are required to compute the HMAC:

1. The software writes the INIT bit to 1 with the MODE bit at 1 and the ALGO bits set to the value corresponding to the desired algorithm. The LKEY bit must also be set to 1 if the key being used is longer than 64 bytes. In this case, as required by HMAC specifications, the hash processor uses the hash of the key instead of the real key.
2. The software provides the key to be used for the inner hash function, using the same mechanism as the message string loading, that is writing the key data into HASH_DIN register then completing the transfer by writing DCAL bit to 1 and the correct NBLW[4:0] to HASH_STR register.

Note: Endianness details can be found in Section 41.4.4: Message data feeding.

3. Once the processor is ready again (DINIS = 1 in HASH_SR), the software can write the message string to HASH_DIN. When the last word of the last block is entered and the software writes DCAL bit to 1 in HASH_STR register, the NBLW[4:0] bitfield must be written at the same time to a value different from zero if the message length is not an exact multiple of the block size. Note that the DMA can also be used to feed the message string, as described in *Section 41.4.4: Message data feeding*.
4. Once the processor is ready again (DINIS = 1 in HASH_SR), the software provides the key to be used for the outer hash function, writing the key data into HASH_DIN register then completing the transfer by writing DCAL bit to 1 and the correct NBLW[4:0] to HASH_STR register. The HMAC result can be found in the valid output registers (HASH_HR7) as soon as DCIS bit is set to 1.

Note: The computation latency of the HMAC primitive depends on the lengths of the keys and message, as described in Section 41.6: HASH processing time.

HMAC example

Below is an example of HMAC SHA-1 algorithm (ALGO = 00 and MODE = 1 in HASH_CR) as specified by NIST.

Let us assume that the original message is the ASCII binary-coded form of "**Sample message for keylen = blocklen**", of length L = 34 bytes. If the HASH is programmed in no swapping mode (DATATYPE = 00 in HASH_CR), the following data must be loaded sequentially into HASH_DIN register:

1. **Inner hash key** input (length = 64, that is no padding), specified by NIST. As key length = 64, LKEY bit is set to 0 in HASH_CR register

   00010203 04050607 08090A0B 0C0D0E0F 10111213 14151617

   18191A1B 1C1D1E1F 20212223 24252627 28292A2B 2C2D2E2F

   30313233 34353637 38393A3B 3C3D3E3F

2. **Message** input (length = 34, that is padding required). HASH_STR must be set to **0x20** to start message padding and inner hash computation (see 'U' as don't care)

   53616D70 6C65206D 65737361 67652066 6F72206B 65796C65

   6E3D626C 6F636B6C 656EUUUU

3. **Outer hash key** input (length = 64, that is no padding). A key identical to the inner hash key is entered here.

4. **Final outer hash computing** is then performed by the HASH. The HMAC-SHA1 digest result is available in the HASH_HRx registers (x = 0 to 4), as shown below:

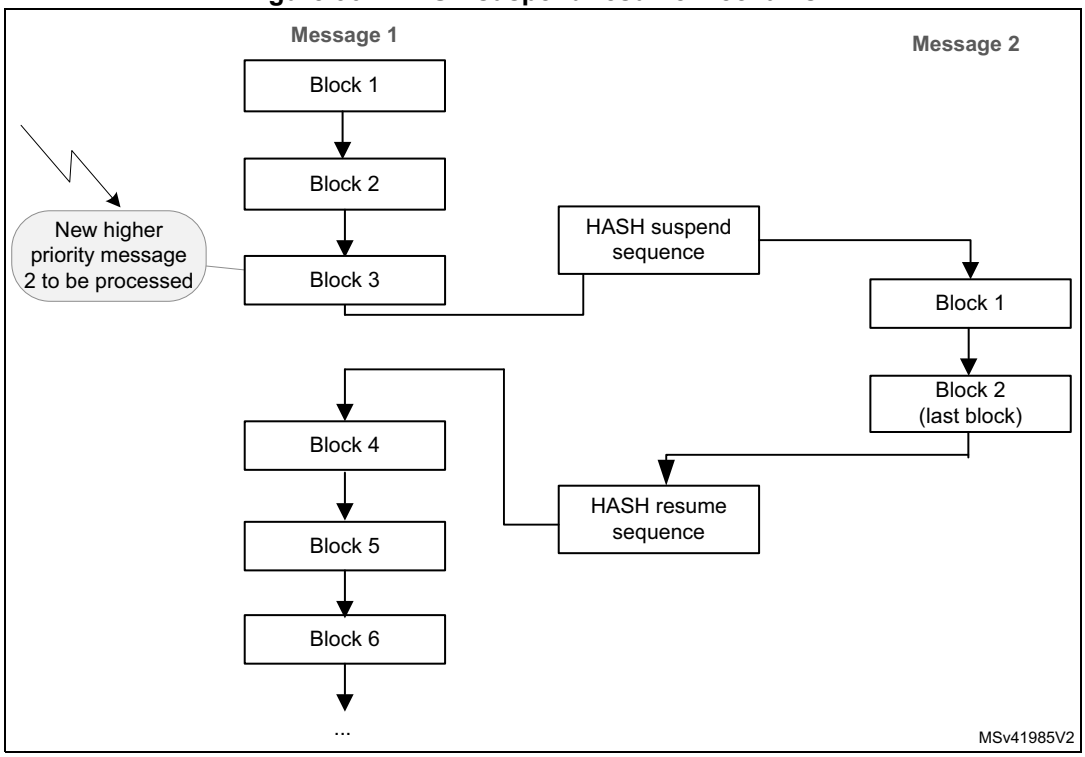
   HASH_HR0 = 0x5FD596EE
   HASH_HR1 = 0x78D5553C
   HASH_HR2 = 0x8FF4E72D
   HASH_HR3 = 0x266DFD19
   HASH_HR4 = 0x2366DA29

41.4.8 HASH suspend/resume operations

Overview

It is possible to interrupt a hash/HMAC operation to perform another processing with a higher priority. The interrupted process completes later when the higher-priority task has been processed, as shown in *Figure 367*.

Figure 367. HASH suspend/resume mechanism



To do so, the context of the interrupted task must be saved from the HASH registers to memory, and then be restored from memory to the HASH registers.

The procedures where the data flow is controlled by software or by DMA are described below.

Data loaded by software

When the DMA is not used to load the message into the hash processor, the context can be saved only when no block processing is ongoing.

To suspend the processing of a message, proceed as follows after writing 16 words 32-bit (plus one if it is the first block):

1. In Polling mode, wait for BUSY = 0, then poll if the DINIS status bit is set to 1.

   In Interrupt mode, implement the next step in DINIS interrupt handler (recommended).
2. Store the contents of the following registers into memory:
   - HASH_IMR
   - HASH_STR
   - HASH_CR
   - HASH_CSR0 to HASH_CSR37. HASH_CSR38 to HASH_CSR53 registers must also be saved if an HMAC operation was ongoing.

To resume the processing of a message, proceed as follows:

1. Write the following registers with the values saved in memory: HASH_IMR, HASH_STR and HASH_CR.
2. Initialize the hash processor by setting the INIT bit in the HASH_CR register.
3. Write the HASH_CSRx registers with the values saved in memory.
4. Restart the processing from the point where it has been interrupted.

Note: To optimize the resume process when NBW[3:0] = 0x0, HASH_CSR22 to HASH_CSR37 registers do not need to be saved then restored as the FIFO is empty.

Data loaded by DMA

When the DMA is used to load the message into the hash processor, it is recommended to suspend and then restore a secure digest computing is described below.

To suspend the processing of a message using DMA, proceed as follows:

1. In Polling mode, wait for BUSY = 0. If DCIS is set in HASH_SR, the hash result is available and the context swapping is useless. Else go to step 2.
2. In Polling mode, wait for BUSY = 1.
3. Disable the DMA channel. Then clear DMAE bit in HASH_CR register.
4. In Polling mode, wait for BUSY = 0. If DCIS is set in HASH_SR, the hash result is available and the context swapping is useless. Else go to step 5.
5. Save HASH_IMR, HASH_STR, HASH_CR, and HASH_CSR0 to HASH_CSR37 registers. HASH_CSR38 to HASH_CSR53 registers must also be saved if an HMAC operation was ongoing.

To resume the processing of a message using DMA, proceed as follows:

1. Reconfigure the DMA controller so that it proceeds with the transfer of the message up to the end if it is not interrupted again. Do not forget to take into account the words that have been already pushed into the FIFO if NBW[3:0] is higher than 0x0.
2. Program the values saved in memory to HASH_IMR, HASH_STR and HASH_CR registers.
3. Initialize the hash processor by setting the INIT bit in the HASH_CR register.
4. Program the values saved in memory to the HASH_CSRx registers.
5. Restart the processing from the point where it was interrupted by setting the DMAE bit.

Note: To optimize the resume process when NBW[3:0] = 0x0, HASH_CSR22 to HASH_CSR37 registers do not need to be saved then restored as the FIFO is empty.

41.4.9 HASH DMA interface

The HASH supports both single and fixed DMA burst transfers of four words.

The hash processor provides an interface to connect to the DMA controller. This DMA can be used to write data to the HASH by setting the DMAE bit in the HASH_CR register. When this bit is set, the HASH initiates a DMA request each time a block has to be written to the HASH_DIN register.

Once four 32-bit words have been received, the HASH automatically triggers a new request to the DMA. For more information refer to *Section 41.4.5: Message digest computing*.

Before starting the DMA transfer, the software must program the number of valid bits in the last word that is copied into HASH_DIN register. This is done by writing in HASH_STR register the following value:

`NBLW[4:0] = Len(Message)% 32` where "**`x%32`**" gives the remainder of x divided by 32.

The DMAS bit of the HASH_SR register provides information on the DMA interface activity. This bit is set with DMAE and cleared when DMAE is cleared and no DMA transfer is ongoing.

Note: No interrupt is associated to DMAS bit.

When MDMAT is set, the size of the transfer must be a multiple of four words.

41.4.10 HASH error management

No error flags are generated by the hash processor.

41.5 HASH interrupts

Two individual maskable interrupt sources are generated by the hash processor to signal the following events:

- Digest calculation completion (DCIS)
- Data input buffer ready (DINIS)

Both interrupt sources are connected to the same global interrupt request signal (hash_it), which is in turn connected to the NVIC (nested vectored interrupt controller). Each interrupt source can individually be enabled or disabled by changing the mask bits in the HASH_IMR register. Setting the appropriate mask bit to 1 enables the interrupt.

The status of each maskable interrupt source can be read from the HASH_SR register. *Table 341* gives a summary of the available features.

Table 341. HASH interrupt requests

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method
HASH	Digest computation completed	DCIS	DCIE	Clear DCIS or set INIT
	Data input buffer ready to get a new block	DINIS	DINIE	Clear DINIS or write to HASH_DIN

41.6 HASH processing time

Table 342 summarizes the time required to process an intermediate block for each mode of operation.

Table 342. Processing time (in clock cycle)

Mode of operation	FIFO load(1)	Computation phase	Total
MD5	16	50	**66**
SHA-1	16	66	**82**
SHA-224	16	50	**66**
SHA-256			

1. Add the time required to load the block into the processor.

The time required to process the last block of a message (or of a key in HMAC) can be longer. This time depends on the length of the last block and the size of the key (in HMAC mode).

Compared to the processing of an intermediate block, it can be increased by the factor below:

- **1 to 2.5** for a hash message
- **~2.5** for an HMAC input-key
- **1 to 2.5** for an HMAC message
- **~2.5** for an HMAC output key in case of a short key
- **3.5 to 5** for an HMAC output key in case of a long key

41.7 HASH registers

The HASH core is associated with several control and status registers and several message digest registers. All these registers are accessible through 32-bit word accesses only, else an AHB error is generated.

41.7.1 HASH control register (HASH_CR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALGO1	Res.	LKEY
													rw		rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	MDMAT	DINNE	NBW[3:0]				ALGO0	MODE	DATATYPE[1:0]		DMAE	INIT	Res.	Res.
		rw	r	r	r	r	r	rw	rw	rw	rw	rw	rw		

Bits 31:19 Reserved, must be kept at reset value.

Bit 17 Reserved, must be kept at reset value.

Bit 16 **LKEY:** Long key selection

This bit selects between short key (≤ 64 bytes) or long key (> 64 bytes) in HMAC mode.

0: the HMAC key is shorter or equal to 64 bytes. The actual key value written to HASH_DIN is used during the HMAC computation.

1: the HMAC key is longer than 64 bytes. The hash of the key is used instead of the real key during the HMAC computation.

This selection is only taken into account when the INIT bit is set and MODE = 1. Changing this bit during a computation has no effect.

Bit 15 Reserved, must be kept at reset value.

Bit 14 Reserved, must be kept at reset value.

Bit 13 **MDMAT:** Multiple DMA transfers

This bit is set when hashing large files when multiple DMA transfers are needed.

0: DCAL is automatically set at the end of a DMA transfer.

1: DCAL is not automatically set at the end of a DMA transfer.

Bit 12 **DINNE:** DIN not empty

This bit is set when the HASH_DIN register holds valid data (that is after being written at least once). It is cleared when either the INIT bit (initialization) or the DCAL bit (completion of the previous message processing) is written to 1.

0: No data are present in the data input buffer

1: The input buffer contains at least one word of data

This bit is read-only.

Bits 11:8 **NBW[3:0]:** Number of words already pushed

This bitfield reflects the number of words in the message that have already been pushed into the IN FIFO. NBW is incremented by one when a write access to the HASH_DIN register is performed (except if DINNE = 0 and the DMA is not used, see below description). NBW goes to zero when the INIT bit is written to 1.

This bitfield is read-only.

If the DMA is not used

0000: if DINNE = 0, no word has been pushed into the DIN buffer (both HASH_DIN register and IN FIFO are empty), otherwise one word has been pushed into the DIN buffer (HASH_DIN register contains one word and IN FIFO is empty)

0001: two words have been pushed into the DIN buffer (that is HASH_DIN register and the IN FIFO contain one word each)

...

1111: 16 words have been pushed into the DIN buffer.

If the DMA is used

NBW contains the exact number of words that have been pushed into the IN FIFO by the DMA.

Bits 18, 7 **ALGO[1:0]**: Algorithm selection

These bits select the hash algorithm.

00: SHA-1

01: MD5

10: SHA-224

11: SHA-256

This selection is only taken into account when the INIT bit is set. Changing this bitfield during a computation has no effect.

Bit 6 **MODE:** Mode selection

This bit selects the HASH or HMAC mode for the selected algorithm:

0: Hash mode selected

1: HMAC mode selected. LKEY must be set if the key being used is longer than 64 bytes.

This selection is only taken into account when the INIT bit is set. Changing this bit during a computation has no effect.

Bits 5:4 **DATATYPE[1:0]:** Data type selection

Defines the format of the data entered into the HASH_DIN register:

00: 32-bit data. The data written into HASH_DIN are directly used by the HASH processing, without reordering.

01: 16-bit data, or half-word. The data written into HASH_DIN are considered as two half-words, and are swapped before being used by the HASH processing.

10: 8-bit data, or bytes. The data written into HASH_DIN are considered as four bytes, and are swapped before being used by the HASH processing.

11: bit data, or bit-string. The data written into HASH_DIN are considered as 32 bits (1st bit of the string at position 0), and are swapped before being used by the HASH processing (1st bit of the string at position 31).

Bit 3 **DMAE:** DMA enable

0: DMA transfers disabled

1: DMA transfers enabled. A DMA request is sent as soon as the HASH core is ready to receive data.

After this bit is set it is cleared by hardware while the last data of the message is written into the hash processor.

Setting this bit to 0 while a DMA transfer is ongoing is not aborting this current transfer. Instead, the DMA interface of the IP remains internally enabled until the transfer is completed or INIT is written to 1.

Setting INIT bit to 1 does not clear DMAE bit.

Bit 2 **INIT:** Initialize message digest calculation

Writing this bit to 1 resets the hash processor core, so that the HASH is ready to compute the message digest of a new message.

Writing this bit to 0 has no effect. Reading this bit always return 0.

Bits 1:0 Reserved, must be kept at reset value.

41.7.2 HASH data input register (HASH_DIN)

Address offset: 0x04

Reset value: 0x0000 0000

HASH_DIN is the data input register. It is 32-bit wide. This register is used to enter the message by blocks. When the HASH_DIN register is programmed, the value presented on the AHB databus is ‘pushed’ into the hash core and the register takes the new value presented on the AHB databus. To get a correct message format, the DATATYPE bits must have been previously configured in the HASH_CR register.

When a complete block has been written to the HASH_DIN register, an intermediate digest calculation is launched:

- by writing new data into the HASH_DIN register (the first word of the next block) if the DMA is not used (intermediate digest calculation),
- automatically if the DMA is used.

When the last block has been written to the HASH_DIN register, the final digest calculation (including padding) is launched by writing the DCAL bit to 1 in the HASH_STR register (final digest calculation). This operation is automatic if the DMA is used and MDMAT bit is set to 0.

Reading the HASH_DIN register returns the last word written to this location (zero after reset).

Note: When the HASH is busy, a write access to the HASH_DIN register might stall the AHB bus if the digest calculation (intermediate or final) is not complete.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATAIN[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATAIN[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DATAIN[31:0]:** Data input

Writing this register pushes the current register content into the IN FIFO, and the register takes the new value presented on the AHB databus.
Reading this register returns the current register content.

41.7.3 HASH start register (HASH_STR)

Address offset: 0x08

Reset value: 0x0000 0000

The HASH_STR register has two functions:

- It is used to define the number of valid bits in the last word of the message entered in the hash processor (that is the number of valid least significant bits in the last data written to the HASH_DIN register)
- It is used to start the processing of the last block in the message by writing the DCAL bit to 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCAL	Res.	Res.	Res.	NBLW[4:0]				
							rw				rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **DCAL:** Digest calculation

Writing this bit to 1 starts the message padding, using the previously written value of NBLW[4:0], and starts the calculation of the final message digest with all data words written to the input FIFO since the INIT bit was last written to 1.
Reading this bit returns 0.

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **NBLW[4:0]:** Number of valid bits in the last word

When the last word of the message bit string is written in HASH_DIN register, the hash processor takes only the valid bits specified as below, after internal data swapping:
0x00: All 32 bits of the last data written are valid message bits that is M[31:0]
0x01: Only one bit of the last data written (after swapping) is valid that is M[0]
0x02: Only two bits of the last data written (after swapping) are valid that is M[1:0]
0x03: Only three bits of the last data written (after swapping) are valid that is M[2:0]
...
0x1F: Only 31 bits of the last data written (after swapping) are valid that is M[30:0]
The above mechanism is valid only if DCAL = 0. If NBLW[4:0] bitfield is written while DCAL is set to 1, the NBLW[4:0] bitfield remains unchanged. In other words it is not possible to configure NBLW[4:0] and set DCAL at the same time.
Reading NBLW[4:0] bitfield returns the last value written to NBLW[4:0].

41.7.4 HASH digest registers

These registers contain the message digest result named as follows:

- HASH_HR0, HASH_HR1, HASH_HR2, HASH_HR3 and HASH_HR4 registers return the SHA-1 digest result
- HASH_HR0, HASH_HR1, HASH_HR2 and HASH_HR3 registers return A, B, C and D (respectively), as defined by MD5.
- HASH_HR0 to HASH_HR6 registers return the SHA-224 digest result.
- HASH_HR0 to HASH_HR7 registers return the SHA-256 digest result.

In all cases, the digest most significant bit is stored in HASH_H0[31] and unused HASH_HRx registers are read as zeros.

If a read access to one of these registers is performed while the hash core is calculating an intermediate digest or a final message digest (DCIS bit equals 0), then the read operation is stalled until the hash calculation has completed.

Note: When starting a digest computation for a new message (by writing the INIT bit to 1), HASH_HRx registers are forced to their reset values.

HASH_HR0 to HASH_HR4 registers can be accessed through two different addresses.

HASH aliased digest register x (HASH_HRAx)

Address offset: 0x0C + 0x04 * x, (x = 0 to 4)

Reset value: 0x0000 0000

The content of the HASH_HRAx registers is identical to the one of the HASH_HRx registers located at address offset 0x310.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Hx[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Hx[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **Hx[31:0]**: Hash data x

Refer to *Section 41.7.4: HASH digest registers* introduction.

HASH digest register x (HASH_HRx)

Address offset: 0x310 + 0x04 * x, (x = 0 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Hx[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Hx[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **Hx[31:0]**: Hash data x
Refer to *Section 41.7.4: HASH digest registers* introduction.

HASH supplementary digest register x (HASH_HRx)

Address offset: 0x310 + 0x04 * x, (x = 5 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Hx[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Hx[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **Hx[31:0]**: Hash data x
Refer to *Section 41.7.4: HASH digest registers* introduction.

41.7.5 HASH interrupt enable register (HASH_IMR)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCIE	DINIE
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **DCIE:** Digest calculation completion interrupt enable
0: Digest calculation completion interrupt disabled
1: Digest calculation completion interrupt enabled.

Bit 0 **DINIE:** Data input interrupt enable
0: Data input interrupt disabled
1: Data input interrupt enabled

41.7.6 HASH status register (HASH_SR)

Address offset: 0x24

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSY	DMAS	DCIS	DINIS
												r	r	rc_w0	rc_w0

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **BUSY:** Busy bit

0: No block is currently being processed
1: The hash core is processing a block of data

Bit 2 **DMAS:** DMA Status

This bit provides information on the DMA interface activity. It is set with DMAE and cleared when DMAE = 0 and no DMA transfer is ongoing. No interrupt is associated with this bit.
0: DMA interface is disabled (DMAE = 0) and no transfer is ongoing
1: DMA interface is enabled (DMAE = 1) or a transfer is ongoing

Bit 1 **DCIS:** Digest calculation completion interrupt status

This bit is set by hardware when a digest becomes ready (the whole message has been processed). It is cleared by writing it to 0 or by writing the INIT bit to 1 in the HASH_CR register.
0: No digest available in the HASH_HRx registers (zeros are returned)
1: Digest calculation complete, a digest is available in the HASH_HRx registers. An interrupt is generated if the DCIE bit is set in the HASH_IMR register.

Bit 0 **DINIS:** Data input interrupt status

This bit is set by hardware when the FIFO is ready to get a new block (16 locations are free). It is cleared by writing it to 0 or by writing the HASH_DIN register.
0: Less than 16 locations are free in the input buffer
1: A new block can be entered into the input buffer. An interrupt is generated if the DINIE bit is set in the HASH_IMR register.
When DINIS=0, HASH_CSRx registers reads as zero.

41.7.7 HASH context swap registers

These registers contain the complete internal register states of the hash processor. They are useful when a suspend/resume operation has to be performed because a high-priority task needs to use the hash processor while it is already used by another task.

When such an event occurs, the HASH_CSRx registers have to be read and the read values have to be saved in the system memory space. Then the hash processor can be used by the preemptive task, and when the hash computation is complete, the saved context can be read from memory and written back into the HASH_CSRx registers.

HASH_CSRx registers can be read only when DINIS equals to 1, otherwise zeros are returned.

HASH context swap register x (HASH_CSRx)

Address offset: 0x0F8 + x * 0x4, (x = 0 to 53)

Reset value: 0x0000 0002 (HASH_CSR0)

Reset value: 0x0000 0000 (HASH_CSR1 to 53)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CSx[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CSx[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CSx[31:0]**: Context swap x

Refer to *Section 41.7.7: HASH context swap registers* introduction.

41.7.8 HASH register map

Table 343 gives the summary HASH register map and reset values.

Table 343. HASH register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	HASH_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALGO[1]	Res.	LKEY	Res.	Res.	MDMAT	DINNE	NBW[3:0]				ALGO[0]	MODE	DATATYPE		DMAE	INIT	Res.	Res.
	Reset value														0		0			0	0	0	0	0	0	0	0	0	0	0	0		
0x04	HASH_DIN	DATAIN[31:16]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	HASH_STR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCAL	Res.	Res.	Res.	NBLW[4:0]				
	Reset value																								0				0	0	0	0	0
0x0C	HASH_HRA0	H0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	HASH_HRA1	H1[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	HASH_HRA2	H2[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	HASH_HRA3	H3[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	HASH_HRA4	H4[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	HASH_IMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DCIE	DINIE	
	Reset value																														0	0	
0x24	HASH_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSY	DMAS	DCIS	DINIS
	Reset value																													0	0	0	1
0x28 to 0xF4	Reserved	Res.																															
0x0F8	HASH_CSR0	CS0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Table 343. HASH register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0F8 + 0x4 * x, (x = 1 to 53) Last address: 0x1CC	HASH_CSRx	CSx[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
...																																	
0x1D0 to 0x30C	Reserved	Res.																															
0x310	HASH_HR0	H0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x314	HASH_HR1	H1[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x318	HASH_HR2	H2[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x31C	HASH_HR3	H3[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x320	HASH_HR4	H4[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x324	HASH_HR5	H5[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x328	HASH_HR6	H6[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x32C	HASH_HR7	H7[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

42 On-The-Fly decryption engine - AXI (OTFDEC)

42.1 Introduction

On-the-fly decryption engine OTFDEC allows to decrypt on-the-fly AXI traffic based on the read request address information. Four independent and non-overlapping encrypted regions can be defined in OTFDEC, with optional execute-only or execute-never enforcement per region.

OTFDEC is using AES-128 in counter mode to achieve the lowest possible latency. As a consequence, each time the content of one encrypted region is changed the entire region must be re-encrypted with a different cryptographic context (key or initialization vector). This constraint makes OTFDEC suitable to decrypt read-only data or code, stored for example in external NOR Flash memory.

Note: When OTFDEC is used in conjunction with OCTOSPI it is mandatory to access the external read-only memory using the memory map mode of the Flash memory controller.

CPU memories and OTFDEC follow little endian notation whereas AES hardware accelerator follows big endian notation. See AN5281 “How to use OTFDEC for encryption/decryption in trusted environment on STM32 MCUs“ for more details.

42.2 OTFDEC main features

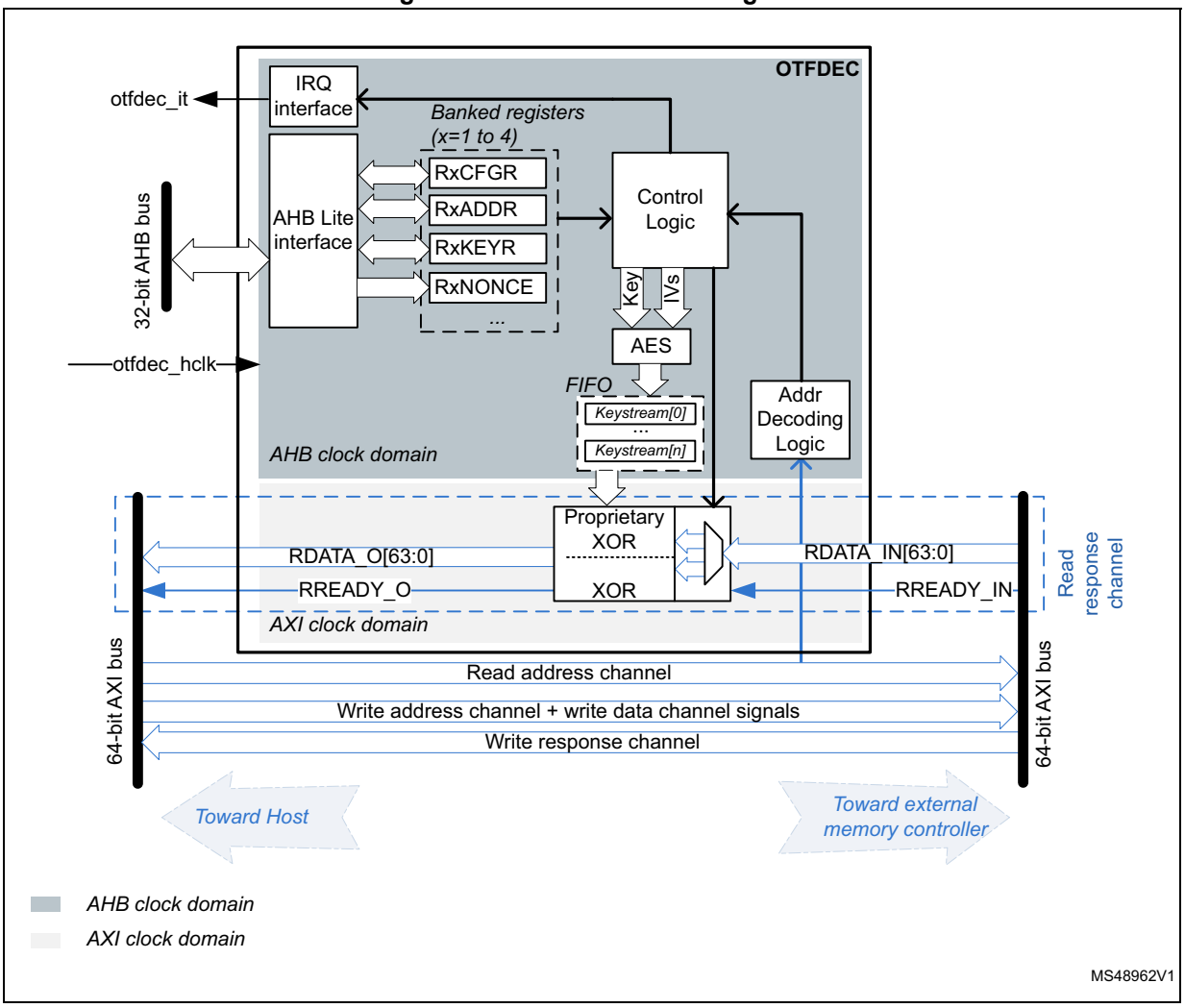
- On-the-fly 128-bit decryption during STM32 OCTOSPI memory-mapped read operations (single or multiple).
  - Use of AES in counter (CTR) mode, with keystream FIFO (depth=4)
  - Support for any read size
  - Physical address of the reads is used for the encryption/decryption
- Up to four independent encrypted regions
  - Granularity of the region definition: 4096 bytes
  - Region configuration write locking mechanism
  - Two optional decryption modes: execute-only and execute-never.
  - Each region has its own 128-bit key, two bytes firmware version, and eight bytes application-defined nonce. At least one of those must be changed each time an encryption is performed by the application.
- Encryption keys confidentiality and integrity protection
  - Write-only registers, with software locking mechanism
  - Availability of 8-bit CRC as public key information
- Support for STM32 Octo-SPI pre-fetching mechanism.
- In execute-only mode, possibility to select an enhanced encryption mode to add a proprietary layer of protection on top of AES stream cipher.
- AMBA AHB slave peripheral, accessible through 32-bit word single accesses only (otherwise an AHB bus error is generated, and write accesses are ignored).
- Encryption mode

42.3 OTFDEC functional description

42.3.1 OTFDEC block diagram

Figure 368 shows the block diagram of the OTFDEC.

Figure 368. OTFDEC block diagram



42.3.2 OTFDEC internal signals

Table 344 describes a list of useful to know internal signals available at OTFDEC level, not at the product level (on pads).

Table 344. OTFDEC internal input/output signals

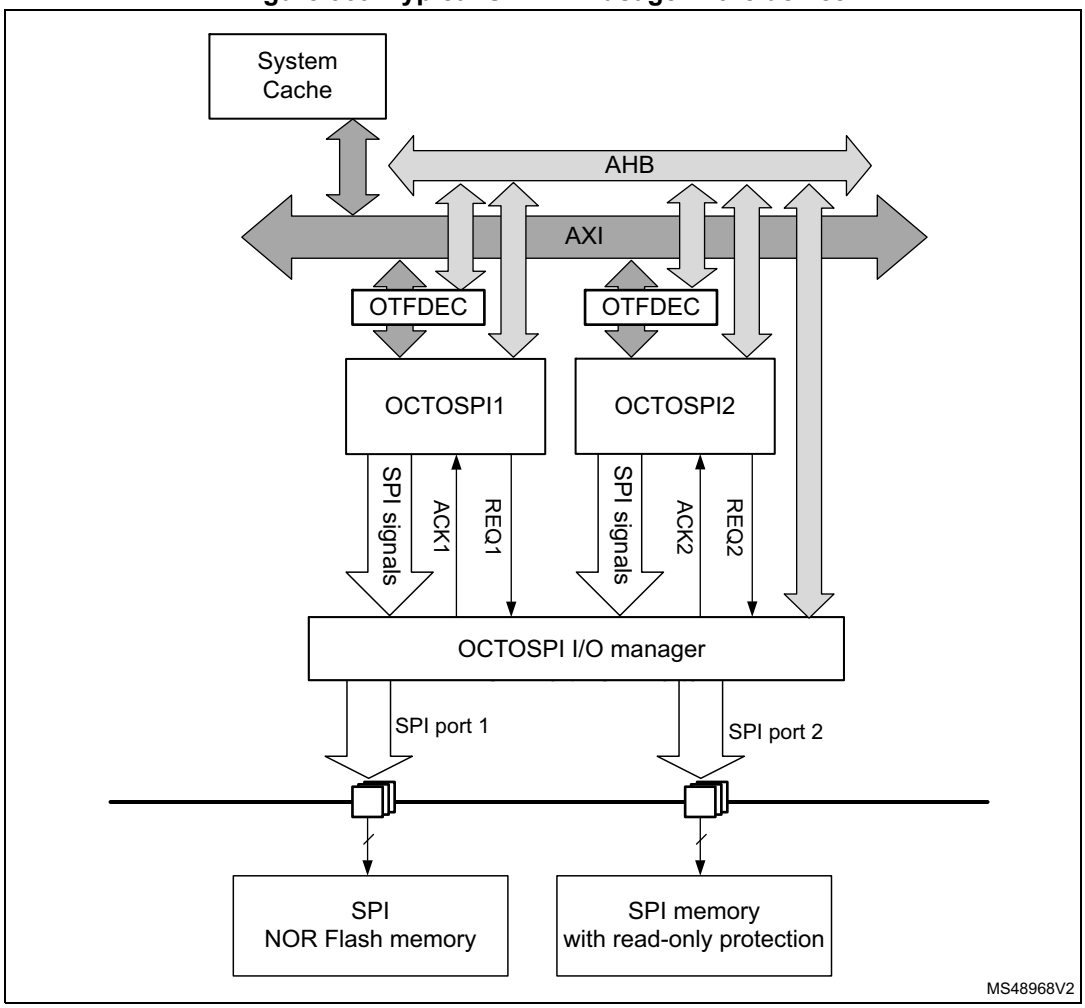
Signal name	Signal type	Description
otfdec_hclk	digital input	AHB bus clock
otfdec_it	digital output	OTFDEC global interrupt request

42.3.3 OTFDEC on-the-fly decryption

Introduction

Typical usage for OTFDEC is shown on *Figure 369*.

Figure 369. Typical OTFDEC usage in the device



Original purpose of OTFDEC is to protect the confidentiality of execute-only firmware libraries, executed from external SPI NOR Flash memory devices. This scheme is part of

STM32 family of proprietary code read-out protection, leveraging on the capability to securely load secrets during microcontroller start up. OTFDEC protection also applies to read-only “code + data libraries”, and to execute-never, read-only data stored in external memory.

Note: OTFDEC provides optional execute-only and execute-never enforcement on any of the four encrypted regions.

A special locking scheme is available in OTFDEC in order to protect the integrity of the decryption keys and also to protect the other configurations against software denial of services attacks.

When OTFDEC is used in conjunction with OCTOSPI it is mandatory to access the external read-only memory using the memory map mode of the Flash memory controller.

OTFDEC architecture

OTFDEC principle is to analyze all read address channel transactions on the AXI interconnect between the host and a target, like the OCTOSPI controller shown on *Figure 369*.

If the read request is within one of the four regions programmed in OTFDEC the control logic will trigger a keystream computation based on AES algorithm in counter mode. This keystream is then used to decrypt on-the-fly the data present in the read response channel, tying low the RREADY signal while the keystream information is being computed (this takes up to 11 cycles). Any accesses outside the enabled OTFDEC regions belong to a non-encrypted region.

Each OTFDEC regions are programmed through registers RxCFGR, RxSTARTADDR, RxENDADDR, RxNONCER and RxKEYR, where x=1 to 4. In register RxCFGR the MODE bits define whether the region is code (execute-only), data (execute-never), or both.

Granularity for the region determination is 4096 bytes.

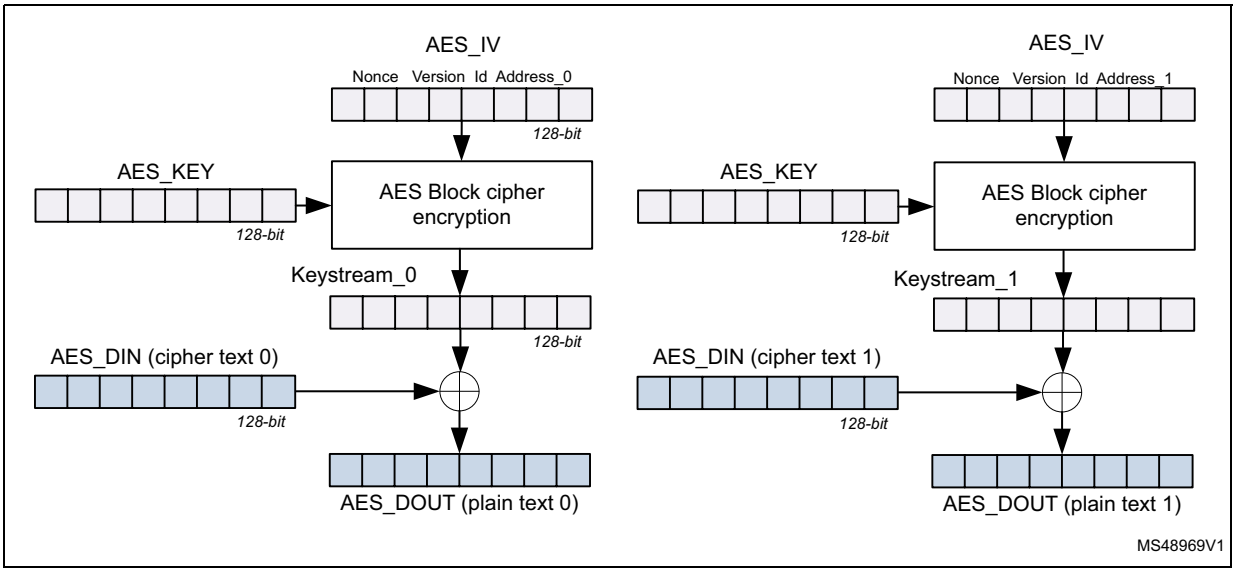
Note: Although OTFDEC does not prevent region overlapping it is not a valid programming and it should be avoided by application software.

OTFDEC can decrypt incremental or wrap bursts only if they do not cross the 4096-byte aligned address boundaries.

42.3.4 AES in counter mode decryption

Figure 370 shows how OTFDEC uses industry standard Advanced Encryption Standard (AES) algorithm in counter chaining mode. This mode is specified by NIST in *Special Publication 800-38A, Recommendation for Block Cipher Modes of Operation*.

Figure 370. AES CTR decryption flow



Every 128-bit data block a special keystream information is computed using AES block cipher, as defined below:

- The initialization vector AES_IV[127:0]= R*x*NONCER[63:0] || 0b0000 0000 0000 0000 || R*x*CFGR[31:16] || 0b00 || (*x*-1) || ReadAddress[31:4] (address modulo 128-bit)
- The key material AES_KEY[127:0]= R*x*KEYR3[31:0] || R*x*KEYR2[31:0] || R*x*KEYR1[31:0] || R*x*KEYR0[31:0]

Note: Above x is the RegionID of the selected encrypted region (x=1 to 4).

Resulting 128-bit keystream is XORed with 128-bit cipher text data to produce the 128-bit clear text data.

- AES_DIN and AES_DOUT data blocks are constructed following the rule below: AES_Dx[127:0]= AXI_word(@+0x8)[63:0] || AXI_word(@)[63:0], where @ is the hexadecimal address used to compute the keystream.

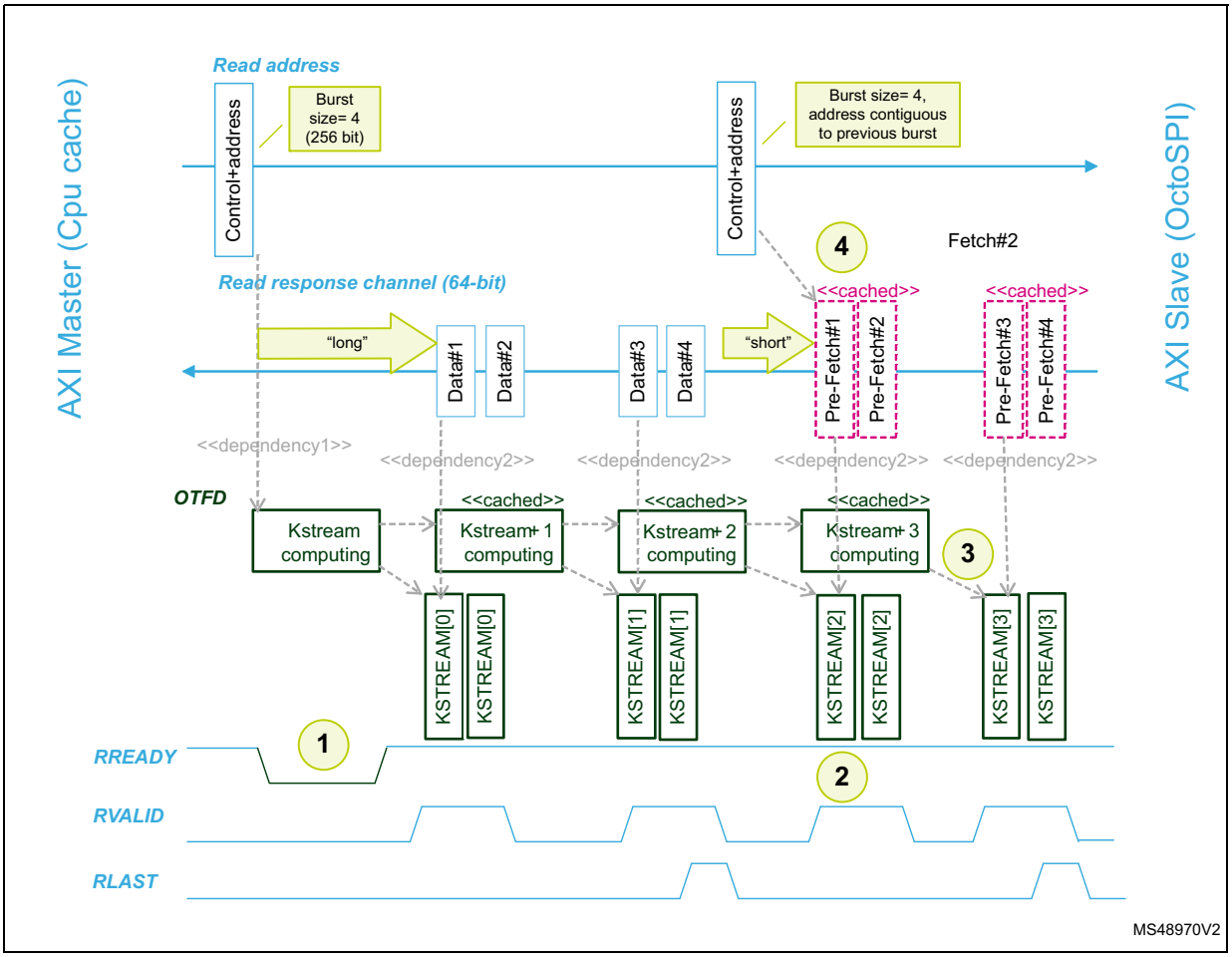
When the read request is not within an encrypted region, or the decryption is not enabled in this region the 128-bit AXI data is not changed.

Note: When application sets the MODE bitfield to 11 in OTFDEC_RxCFGR an additional layer of protection is added on top of the AES stream cipher. This enhanced encryption mode is valid only in execute-only.

42.3.5 Flow control management

Figure 371 shows how OTFDEC manages two back-to-back AXI requests for a burst read of 4 words (256-bit). All 128-bit data blocks have contiguous address values.

Figure 371. OTFDEC flow control overview (dual burst read request)

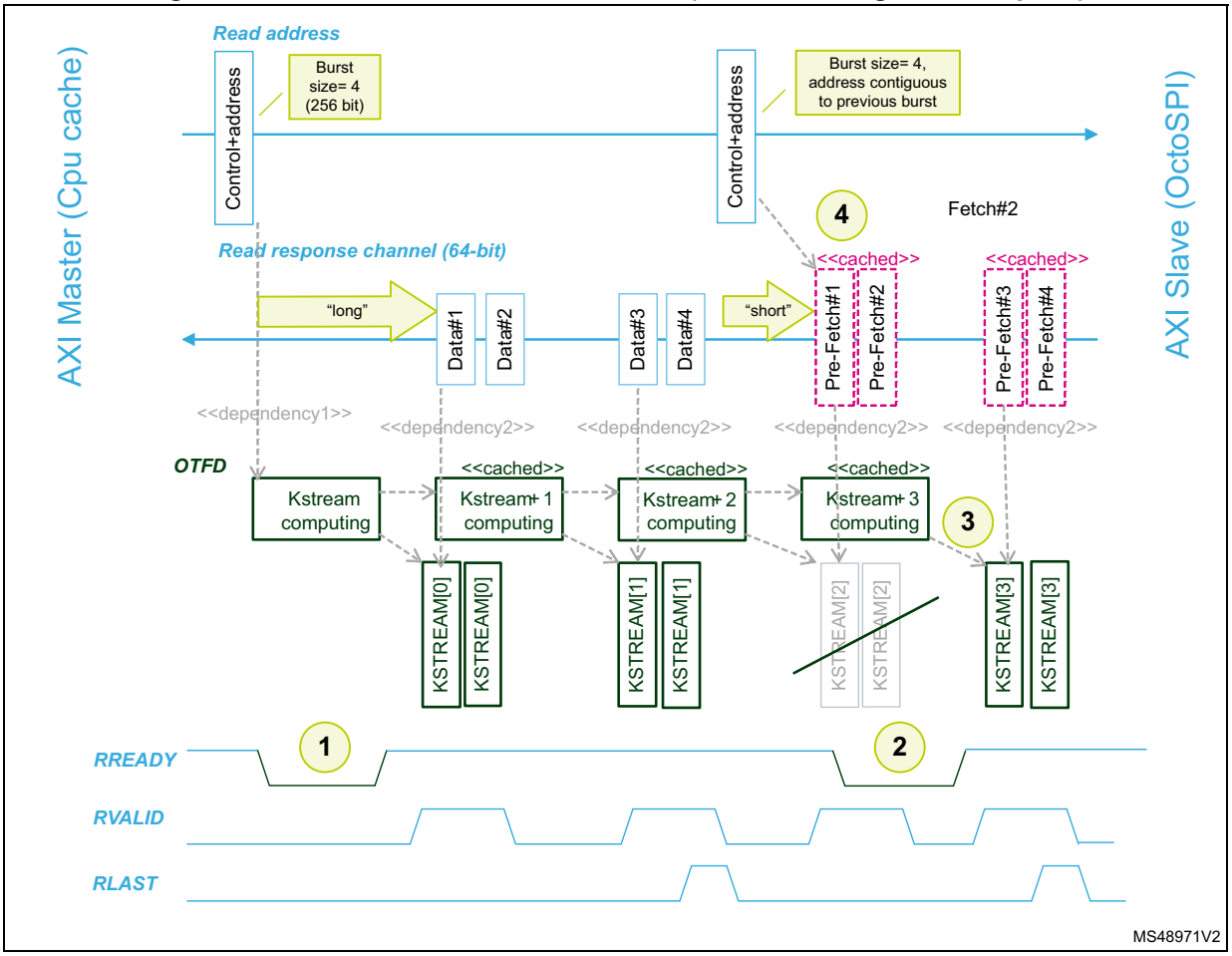


Few notes on this diagram:

1. OTFDEC enforces RREADY low as it is not ready to decrypt data (keystream computation).
2. OTFDEC does not enforce RREADY low as a valid mask is ready to XOR the incoming data. The decryption is done with zero latency, as expected.
3. The keystream FIFO is full. Next time a keystream is needed 11 clock cycles will be needed.
4. STM32 OctoSPI controller has a pre-fetching mechanism that greatly speed up any read request to an address that is consecutive to the last one. OTFDEC is able to manage this shorter latency thanks to the mask FIFO mechanism.

Figure 372 shows how OTFDEC manages an AXI request for a burst read of 4 words (256-bit), followed by a single read on an address that is not contiguous to the previous one.

Figure 372. OTFDEC flow control overview (burst then single read request)



Few notes on this diagram:

1. OTFDEC enforces RREADY low as it is not ready to decrypt data.
2. OTFDEC enforces RREADY low as pre-computed mask cannot be used for this request (the encrypted region address is not contiguous).

42.3.6 OTFDEC error management

OTFDEC automatically manages errors defined as below:

- Illegal read to OTFDEC_RxKEYR registers
- Illegal write to OTFDEC_RxKEYR registers while CONFIGLOCK or KEYLOCK=”1” in OTFDEC_RxCFGR.
- Illegal write to OTFDEC_RxCFGR, OTFDEC_RxSTARTADDR, OTFDEC_RxENDADDR or OTFDEC_RxNONCER registers while CONFIGLOCK=”1” in OTFDEC_RxCFGR (x=1 to 4).
- Illegal read to an execute-only region (MODE[1:0]=00 or 11), and illegal execution request to an execute-never region (MODE[1:0]=01). Such illegal requests return 0x0, without bus error.
- Key error: read requests to a encrypted region after the key registers have been cleared by an abort event (tamper detection, unauthorized debug connection, untrusted boot, RDP level regression). Such read requests return 0x0, without bus error.

An interrupt can be generated by one or more of above errors if the bit SEIE, XONEIE or KEIE is set in OTFDEC_IER register, as explained in next *Section 42.4*.

Note: After a key error OTFDEC keys must be initialized again, and a reset of OTFDEC might be needed if registers are locked.

42.4 OTFDEC interrupts

There are three independent maskable interrupt sources generated by the OTFDEC, signaling following security events:

- Illegal read or write access to keys (SEIF flag), see *Section 42.3.6*
- Illegal write to a region’s configuration while CONFIGLOCK=1 (SEIF flag), see *Section 42.3.6*
- Read access to an execute-only region (MODE[1:0]=00 or 11), execute access to a execute-never data region (MODE[1:0]=01). Both are triggering the XONEIF flag.
- Key error (encrypted regions read as zero), triggering the KEIF flag. See *Section 42.3.6*.

Interrupt sources are connected to the same global interrupt request signal.

You can enable or disable OTFDEC interrupt sources by setting corresponding SEIE, XONEIE or KEIE bits in OTFDEC_IER register, as described in *Table 345*. Status of the interrupt event is found in OTFDEC_ISR register, and this event can be cleared using OTFDEC_ICR register.

Table 345. OTFDEC interrupt requests

Interrupt event	Event flag	Enable control bit
Security Error	SEIF	SEIE
Execute-only, Execute-Never Error	XONEIF	XONEIE
Key Error	KEIF	KEIE

42.5 OTFDEC application information

42.5.1 OTFDEC initialization process

Introduction

One key aspect of OTFDEC is the trusted initialization of its registers, as it involves secret keys and critical options like MODE bits.

Two trusted initialization schemes are recommended here below.

Note: Those sequence are for production code, as during firmware development it is not always recommended to lock the key or the region configuration.

Writes to configuration registers are effective when the configuration locks allow it, even if the region is enabled.

One key for all regions initialization scheme

In this scheme one entity owns the secret key used to decrypt the four protected regions. The recommended OTFDEC configuration sequence is described below:

3. For *x*=1 to 4 write the correct MODE[1:0] value in RxCFGR register.
4. For *x*=1 to 4 program RxKEYR registers using the sequence described in KEYCRC (to have a valid CRC). Warning key registers are write only!
5. For *x*=1 to 4 check the key CRC. If OK set KEYLOCK bit in RxCFGR register. This bit cannot be cleared, i.e. the key registers in this region *x* are no more writable.
6. Do while you have a region *x* to decrypt. This task does not necessarily have to be performed by the entity that owns the decryption keys.
   a) Verify if the key CRC corresponds to the encrypted binary stored in the region.
   b) Fill the detailed information corresponding to this binary (nonce, start address, end address, version number).
   c) Enable decryption of this region using REG_EN.
   d) Set CONFIGLOCK bit in RxCFGR. This bit cannot be cleared, i.e. the region configuration is no more writable.

Caution: For a given region, when MODE bits are changed the key registers and associated CRC are cleared by hardware. As a consequence step 1 above must be done before step 2, and MODE bits must not be modified after step 2.

One key per region initialization scheme

In this scheme one entity can own the secret used to decrypt one (or more) protected region. The recommended OTFDEC configuration sequence is described below:

Do while you have a region *x* to decrypt. This task must be performed by the entity that owns the corresponding key.

a) Write the correct MODE[1:0] value in RxCFGR register.

b) Program RxKEYR registers using the sequence described in KEYCRC (to have a valid key CRC). Warning key registers are write only!

c) Check the key CRC. If OK set KEYLOCK bit in RxCFGR register. This bit cannot be cleared, i.e. the key registers are no more writable.

d) Fill the detailed information corresponding to the protected firmware (nonce, start address, end address, version number).

e) Enable decryption of this region using REG_EN.

f) Set CONFIGLOCK bit in RxCFGR. This bit cannot be cleared, i.e. the region configuration is no more writable.

Caution: For a given region, when MODE bits are changed the key registers and associated CRC are cleared by hardware. As a consequence step a) above must be done before step b), and MODE bits must not be modified after step b).

42.5.2 OTFDEC and power management

Each time OTFDEC is reset the correct key loading sequence described in *Section 42.5.1* must be performed (in this case KEYCRC equals to zero in OTFDEC_RxCFGR registers).

It is recommended for application software to verify this point each time OTFDEC is reset by hardware.

42.5.3 Encrypting for OTFDEC

When MODE equals 00, 01 and 10

OTFDEC uses a standard AES in counter (CTR) mode to encrypt binary stored in a region with this MODE value. CTR chaining is defined in NIST *Special Publication 800-38A, Recommendation for Block Cipher Modes of Operation*.

When this mode is selected, any AES compatible hardware accelerator or library can be used to encrypt those protected libraries. Definition and endianness of the AES inputs and outputs are defined in *Section 42.3.4: AES in counter mode decryption*.

For more details, refer to AN5281 application note available on *www.st.com*.

When MODE equals to 11

OTFDEC uses a proprietary layer of protection on top of standard AES in counter mode when processing a code stored in a protected region with MODE[1:0] = 11.

Enhanced encryption mode can be used to increase the robustness against tampering.

When it is selected, two encryption scenarios are proposed:

a) Use any device in RDP0 and a debugger to encrypt the code using a RSS service. Refer to AN5281 application note for more details.

b) During a firmware install or update, use the OTFDEC in the device to encrypt the target code. For more details, refer to AN4992 application note (install) and UM2262 user manual (update) available on *www.st.com*.

42.5.4 OTFDEC Key CRC source code

Below is the CRC source code that can be used to compare with the result of the computation provided by OTFDEC in KEYCRC bitfield after loading the keys in OTFDEC_RxKEYR registers.

```
uint8_t getCRC(uint32_t * keyin)
{
  const uint8_t CRC7_POLY = 0x7;
  const uint32_t key_strobe[4] = {0xAA55AA55, 0x3, 0x18, 0xC0};
  uint8_t  i, j, k, crc = 0x0;
  uint32_t  keyval;

  for (j = 0; j < 4; j++)
  {
    keyval = *(keyin+j);
    if (j == 0)
    {
      keyval ^= key_strobe[0];
    }
    else
    {
      keyval ^= (key_strobe[j] << 24) | (crc << 16) | (key_strobe[j] << 8)
| crc;
    }

    for (i = 0, crc = 0; i < 32; i++)
    {
      k = (((crc >> 7) ^ (keyval >> (31-i))&0xF)) & 1;
      crc <<= 1;
      if (k)
      {
        crc ^= CRC7_POLY;
       }
    }
    crc^=0x55;
  }
  return crc;
}
```

42.6 OTFDEC registers

42.6.1 OTFDEC region x configuration register (OTFDEC_RxCFGR)

Address offset: 0x20 + 0x30 * (x -1) (x = 1 to 4)

Reset value: 0x0000 0000

Writes are ignored if CONFIGLOCK bit is set to 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REGx_VERSION[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEYCRC[7:0]								Res.	Res.	MODE[1:0]		Res.	KEYLOCK	CONFIGLOCK	REG_EN
r	r	r	r	r	r	r	r			rw	rw		rs	rs	rw

Bits 31:16 **REGx_VERSION[15:0]**: region firmware version

This 16-bit bitfield must be correctly initialized before the region corresponding REG_EN bit is set in the RxCFGR register.

Bits 15:8 **KEYCRC[7:0]**: region key 8-bit CRC

When KEYLOCK=0, KEYCRC bitfield is automatically computed by hardware while loading the key of this region in this exact sequence: KEYR0 then KEYR1 then KEYR2 then finally KEYR3 (all written once). A new computation starts as soon as a new valid sequence is initiated, and KEYCRC is read as zero until a valid sequence is completed.

When KEYLOCK=1, KEYCRC remains unchanged until the next reset.

CRC computation is an 8-bit checksum using the standard CRC-8-CCITT algorithm $X^8 + X^2 + X + 1$ (according the convention). Source code is available in this manual.

This field is read only.

Note: CRC information is updated only after the last bit of the key has been written.

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **MODE[1:0]**: operating mode

This bitfield selects the OTFDEC operating mode for this region:

00: Only instruction accesses are decrypted.
01: Only data accesses are decrypted.
10: All read accesses are decrypted (instruction or data).
11: Only instruction accesses are decrypted, and enhanced encryption mode is activated.

When MODE is not equal to 11 the standard AES encryption mode is activated.

When either of the MODE bits are changed the region's key and associated CRC are zeroed.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **KEYLOCK**: region key lock

0: Writes to this region KEYRx registers are allowed.

1: Writes to this region KEYRx registers are ignored until next OTFDEC reset. KEYCRC bitfield is locked.

This bitfield is set once, i.e. if this bit is set it can only be reset to “0” if the OTFDEC is reset.

Bit 1 **CONFIGLOCK**: region config lock

0: Writes to this region CFGR1, STARTADDR, ENDADDR and NONCERx registers are allowed.

1: Writes to this region CFGR1, STARTADDR, ENDADDR and NONCERx registers are ignored until next OTFDEC reset.

This bit-field is set once, i.e. if this bit is set it can only be reset to “0” if OTFDEC is reset.

Setting this bit forces KEYLOCK bit to “1”.

Bit 0 **REG_EN**: region on-the-fly decryption enable

0: On-the-fly decryption is disabled for this region.

1: On-the-fly decryption is enabled for this region. Data are XORed with the corresponding keystream.

Note: When this bit is set region context (version, key, nonce) must be valid or garbage will be decrypted.

42.6.2 OTFDEC region x start address register (OTFDEC2_RxSTARTADDR)

Address offset: 0x24 + 0x30 * (x -1) (x = 1 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REGx_START_ADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REGx_START_ADDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **REGx_START_ADDR[31:0]**: Region AXI start address

This register must be written before the region corresponding REG_EN bit in the RxCFGR register is set.

Writing this register while the region CONFIGLOCK bit in the RxCFGR register is set will be discarded.

Note: When determining the region the first 12 bits (LSB) and the last 4 bits (MSB) are ignored.

When this register is accessed in read the 4 MSB bits and the 12 LSB bits return zero.

42.6.3 OTFDEC region x end address register (OTFDEC_RxENDADDR)

Address offset: 0x28 + 0x30 * (x -1) (x= 1 to 4)

Reset value: 0x0000 0FFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REGx_END_ADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REGx_END_ADDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **REGx_END_ADDR[31:0]**: Region AXI end address

This register must be written before the region corresponding REG_EN bit in the RxCFGR register is set, and RxENDADDR must be strictly greater than RxSTARTADDR to be valid.

Writing this register while the region CONFIGLOCK bit in the RxCFGR register is set will be discarded.

Note: When determining the region the first 12 bits (LSB) and the last 4 bits (MSB) are ignored.

When this register is accessed in read the 4 MSB bits returns zeros and the 12 LSB bits return ones.

42.6.4 OTFDEC region x nonce register 0 (OTFDEC_RxNONCER0)

Address offset: 0x2C + 0x30 * (x -1) (x = 1 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REGx_NONCE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REGx_NONCE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **REGx_NONCE[31:0]**: Region nonce, bits [31:0]

This register must be written before the region corresponding REG_EN bit in the RxCFGR register is set.

Writing this register while the region CONFIGLOCK bit in the RxCFGR register is set will be discarded.

42.6.5 OTFDEC region x nonce register 1 (OTFDEC_RxNONCER1)

Address offset: 0x30 + 0x30 * (x -1) (x = 1 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REGx_NONCE[63:48]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REGx_NONCE[47:32]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **REGx_NONCE[63:32]**: Region nonce, bits [63:32]

Refer to the OTFDEC_RxNONCER0 register for description of the NONCE[63:0] bitfield.

42.6.6 OTFDEC region x key register 0 (OTFDEC_RxKEYR0)

Address offset: 0x34 + 0x30 * (x -1) (x = 1 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REGx_KEY[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REGx_KEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **REGx_KEY[31:0]**: Region key, bits [31:0]

This register must be written before the region corresponding REG_EN bit in the RxCFGR register is set.

Reading this register returns a zero value. Writing this register while the region CONFIGLOCK or KEYLOCK bit is set in the RxCFGR register will be discarded.

Note: When application successfully changes MODE bits in RxCFGR register RxKEYR registers and associated KEYCRC are erased.

42.6.7 OTFDEC region x key register 1 (OTFDEC_RxKEYR1)

Address offset: 0x38 + 0x30 * (x -1) (x = 1 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REGx_KEY[63:48]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REGx_KEY[47:32]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **REGx_KEY[63:32]**: Region key, bits [63:32]

Refer to the OTFDEC_RxKEYR0 register for description of the KEY[127:0] bitfield.

42.6.8 OTFDEC region x key register 2 (OTFDEC_RxKEYR2)

Address offset: 0x3C + 0x30 * (x -1) (x = 1 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REGx_KEY[95:80]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REGx_KEY[79:64]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **REGx_KEY[95:64]**: Region key, bits [95:64]
Refer to the OTFDEC_RxKEYR0 register for description of the KEY[127:0] bitfield.

42.6.9 OTFDEC region x key register 3 (OTFDEC_RxKEYR3)

Address offset: 0x40 + 0x30 * (x -1) (x = 1 to 4)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REGx_KEY[127:112]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REGx_KEY[111:96]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **REGx_KEY[127:96]**: Region key, bits [127:96]
Refer to the OTFDEC_RxKEYR0 register for description of the KEY[127:0] bitfield.

42.6.10 OTFDEC interrupt status register (OTFDEC_ISR)

Address offset: 0x300

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIF	XONEIF	SEIF
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **KEIF:** Key Error Interrupt Flag status

This bit is set by hardware and read only by application. Bit is set when a read access occurs on any encrypted region following the reset of the key registers by an abort event (tamper detection, unauthorized debugger connection, untrusted boot, RDP level regression).

Bit is cleared when application sets in OTFDEC_ICR the corresponding bit to “1”.

0: OTFDEC is operating properly.

1: Read access detected on an enabled encrypted region following an abort event. OTFDEC returns a zeroed value for the read, and an optional interrupt is generated if bit KEIE is set to “1” in OTFDEC_IER register.

After KEIF is set any subsequent read to any enabled encrypted region returns a zeroed value. This state remains until OTFDEC keys are initialized again.

Bit 1 **XONEIF:** Execute-only execute-Never Error Interrupt Flag status

This bit is set by hardware and read only by application. Bit is set when a read access and not an instruction fetch is detected on any encrypted region with MODE bits set to 00 or 11. It is also set when an instruction fetch and not a read access is detected on any encrypted region with MODE bits set to 01.

Bit is cleared when application sets in OTFDEC_ICR the corresponding bit to “1”.

0: No execute-only error status. No interrupt pending.

1: Read access detected on one region with MODE bits set to 00 or 11, or execute access detected on one region with MODE bits set to 01. OTFDEC returns a zeroed value for the illegal access, and an optional interrupt is generated if bit XONEIE is set to “1” in OTFDEC_IER register.

Bit 0 **SEIF:** Security Error Interrupt Flag status

This bit is set by hardware and read only by application. Bit is set when at least one security error has been detected (illegal access to keys, illegal write on locked configuration).

Bit is cleared when application sets in OTFDEC_ICR the corresponding bit to “1”.

0: No security error status. No interrupt pending.

1: Security error flag status, with interrupt pending. Actual interrupt generation is dependent on OTFDEC_IER corresponding bit SEIE.

42.6.11 OTFDEC interrupt clear register (OTFDEC_ICR)

Address offset: 0x304

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIF	XONEIF	SEIF
													w	w	w

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **KEIF:** Key Error Interrupt Flag clear

This bit is written by application, and always reads as 0.

0: KEIF flag status is not affected
1: KEIF flag status is cleared in OTFDEC_ISR register

Note: Clearing KEIF does not solve the source of the problem (bad key registers). To be able to read or execute again any encrypted region, OTFDEC key registers must properly initialized, again.

Bit 1 **XONEIF:** Execute-only execute-Never Error Interrupt Flag clear

This bit is written by application, and always reads as 0.

0: XONEIF flag status is not affected
1: XONEIF flag status is cleared in OTFDEC_ISR register

Bit 0 **SEIF:** Security Error Interrupt Flag clear

This bit is written by application, and always reads as 0.

0: SEIF flag status is not affected
1: SEIF flag status is cleared in OTFDEC_ISR register

42.6.12 OTFDEC interrupt enable register (OTFDEC_IER)

Address offset: 0x308

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIE	XONEIE	SEIE
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **KEIE:** Key Error Interrupt Enable

This bit is read and written by application. It controls the OTFDEC interrupt generation when KEIF flag status is set.

0: Interrupt generation on key error flag KEIF is disabled (masked)
1: Interrupt generation on key error flag KEIF is enabled (not masked)

Bit 1 **XONEIE:** Execute-only execute-Never Error Interrupt Enable

This bit is read and written by application. It controls the OTFDEC interrupt generation when XONEIF flag status is set.

0: Interrupt generation on execute-only error XONEIF is disabled (masked)
1: Interrupt generation on execute-only error XONEIF is enabled (not masked)

Bit 0 **SEIE:** Security Error Interrupt Enable

This bit is read and written by application. It controls the OTFDEC interrupt generation when SEIF flag status is set.

0: Interrupt generation on security error SEIF is disabled (masked)
1: Interrupt generation on security error SEIF is enabled (not masked)

42.6.13 OTFDEC register map

Table 346 gives the summary OTFDEC register map and reset values.

Table 346. OTFDEC register map and reset values

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00 - 0x1C	**Reserved**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x20	**OTFDEC_ R1CFGR**	REG1_VERSION[15:0]																KEYCRC[7:0]								Res.	Res.	MODE[1:0]		Res.	KEYLOCK.	CONFIGLOCK.	REG_EN
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x24	**OTFDEC_ R1STARTADDR**	REG1_START_ADD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	**OTFDEC_ R1ENDADDR**	REG1_END_ADD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
0x2C	**OTFDEC_ R1NONCER0**	REG1_NONCE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x30	**OTFDEC_ R1NONCER1**	REG1_NONCE[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x34	**OTFDEC_ R1KEYR0**	REG1_KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x38	**OTFDEC_ R1KEYR1**	REG1_KEY[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x3C	**OTFDEC_ R1KEYR2**	REG1_KEY[95:64]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x40	**OTFDEC_REG1_ KEYR3**	REG1_KEY[127:96]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x44 - 0x4C	**Reserved**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																																
0x50	**OTFDEC_R2CFGR**	REG2_VERSION[15:0]																KEYCRC[7:0]								Res.	Res.	MODE[1:0]		Res.	KEYLOCK.	CONFIGLOCK.	REG_EN
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 346. OTFDEC register map and reset values (continued)

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x054	**OTFDEC_ R2STARTADDR**	REG2_START_ADD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x058	**OTFDEC_ R2ENDADDR**	REG2_END_ADD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
0x05C	**OTFDEC_ R2NONCER0**	REG2_NONCE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x60	**OTFDEC_ R2NONCER1**	REG2_NONCE[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x64	**OTFDEC_ R2KEYR0**	REG2_KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x68	**OTFDEC_ R2KEYR1**	REG2_KEY[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x6C	**OTFDEC_ R2KEYR2**	REG2_KEY[95:64]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x70	**OTFDEC_ R2KEYR3**	REG2_KEY[127:96]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x74 - 0x7C	**Reserved**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																																
0x80	**OTFDEC_R3CFGR**	REG3_VERSION[15:0]																KEYCRC[7:0]								Res.	Res.	MODE[1:0]		Res.	KEYLOCK.	CONFIGLOCK.	REG_EN
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x84	**OTFDEC_ R3STARTADDR**	REG3_START_ADD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x88	**OTFDEC_ R3ENDADDR**	REG3_END_ADD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
0x8C	**OTFDEC_ R3NONCER0**	REG3_NONCE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x90	**OTFDEC_ R3NONCER1**	REG3_NONCE[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 346. OTFDEC register map and reset values (continued)

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x94	**OTFDEC_ R3KEYR0**	REG3_KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x98	**OTFDEC_ R3KEYR1**	REG3_KEY[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x9C	**OTFDEC_ R3KEYR2**	REG3_KEY[95:64]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xA0	**OTFDEC_REG3_ KEYR3**	REG3_KEY[127:96]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xA4 - 0xAC	**Reserved**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																																
0xB0	**OTFDEC_R4CFGR**	REG4_VERSION[15:0]																KEYCRC[7:0]								Res.	Res.	MODE[1:0]		Res.	KEYLOCK.	CONFIGLOCK.	REG_EN
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xB4	**OTFDEC_R4STAR TADDR**	REG4_START_ADD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xB8	**OTFDEC_R4ENDA DDR**	REG4_END_ADD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
0xBC	**OTFDEC_R4NON CER0**	REG4_NONCE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xC0	**OTFDEC_ R4NONCER1**	REG4_NONCE[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xC4	**OTFDEC_ R4KEYR0**	REG4_KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xC8	**OTFDEC_ R4KEYR1**	REG4_KEY[63:32]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xCC	**OTFDEC_ R4KEYR2**	REG4_KEY[95:64]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xD0	**OTFDEC_ R4KEYR3**	REG4_KEY[127:96]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 346. OTFDEC register map and reset values (continued)

Offset	Register name reset value	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0D4 - 0x2FC	**Reserved**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																																
0x300	**OTFDEC_ISR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIF	XONEIF	SEIF
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x304	**OTFDEC_ICR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIF	XONEIF	SEIF
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x308	**OTFDEC_IER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEIE	XONEIE	SEIE
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x30C - 0x3E8	**Reserved**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																																

Refer to *Section 2.3* for the register boundary addresses.

43 Advanced-control timers (TIM1/TIM8)

43.1 TIM1/TIM8 introduction

The advanced-control timers (TIM1/TIM8) consist of a 16-bit auto-reload counter driven by a programmable prescaler.

It may be used for a variety of purposes, including measuring the pulse lengths of input signals (input capture) or generating output waveforms (output compare, PWM, complementary PWM with dead-time insertion).

Pulse lengths and waveform periods can be modulated from a few microseconds to several milliseconds using the timer prescaler and the RCC clock controller prescalers.

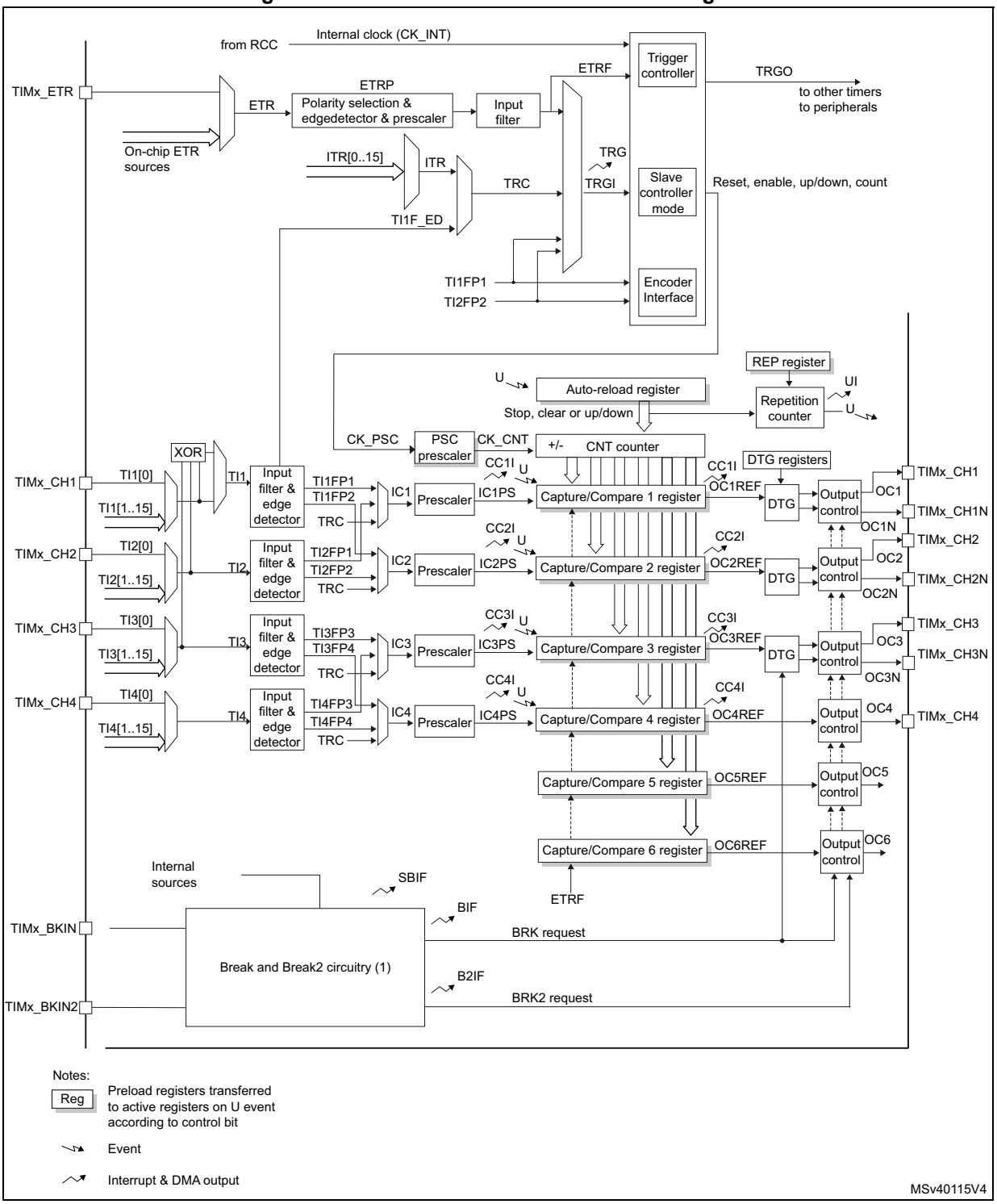
The advanced-control (TIM1/TIM8) and general-purpose (TIMy) timers are completely independent, and do not share any resources. They can be synchronized together as described in *Section 43.3.26: Timer synchronization*.

43.2 TIM1/TIM8 main features

TIM1/TIM8 timer features include:

- 16-bit up, down, up/down auto-reload counter.
- 16-bit programmable prescaler allowing dividing (also “on the fly”) the counter clock frequency either by any factor between 1 and 65536.
- Up to 6 independent channels for:
  - Input Capture (but channels 5 and 6)
  - Output Compare
  - PWM generation (Edge and Center-aligned Mode)
  - One-pulse mode output
- Complementary outputs with programmable dead-time
- Synchronization circuit to control the timer with external signals and to interconnect several timers together.
- Repetition counter to update the timer registers only after a given number of cycles of the counter.
- 2 break inputs to put the timer’s output signals in a safe user selectable configuration.
- Interrupt/DMA generation on the following events:
  - Update: counter overflow/underflow, counter initialization (by software or internal/external trigger)
  - Trigger event (counter start, stop, initialization or count by internal/external trigger)
  - Input capture
  - Output compare
- Supports incremental (quadrature) encoder and Hall-sensor circuitry for positioning purposes
- Trigger input for external clock or cycle-by-cycle current management

Figure 373. Advanced-control timer block diagram



1. See *Figure 416: Break and Break2 circuitry overview* for details

43.3 TIM1/TIM8 functional description

43.3.1 Time-base unit

The main block of the programmable advanced-control timer is a 16-bit counter with its related auto-reload register. The counter can count up, down or both up and down. The counter clock can be divided by a prescaler.

The counter, the auto-reload register and the prescaler register can be written or read by software. This is true even when the counter is running.

The time-base unit includes:

- Counter register (TIMx_CNT)
- Prescaler register (TIMx_PSC)
- Auto-reload register (TIMx_ARR)
- Repetition counter register (TIMx_RCR)

The auto-reload register is preloaded. Writing to or reading from the auto-reload register accesses the preload register. The content of the preload register are transferred into the shadow register permanently or at each update event (UEV), depending on the auto-reload preload enable bit (ARPE) in TIMx_CR1 register. The update event is sent when the counter reaches the overflow (or underflow when downcounting) and if the UDIS bit equals 0 in the TIMx_CR1 register. It can also be generated by software. The generation of the update event is described in detailed for each configuration.

The counter is clocked by the prescaler output CK_CNT, which is enabled only when the counter enable bit (CEN) in TIMx_CR1 register is set (refer also to the slave mode controller description to get more details on counter enabling).

Note that the counter starts counting 1 clock cycle after setting the CEN bit in the TIMx_CR1 register.

Prescaler description

The prescaler can divide the counter clock frequency by any factor between 1 and 65536. It is based on a 16-bit counter controlled through a 16-bit register (in the TIMx_PSC register). It can be changed on the fly as this control register is buffered. The new prescaler ratio is taken into account at the next update event.

Figure 374 and *Figure 375* give some examples of the counter behavior when the prescaler ratio is changed on the fly:

Figure 374. Counter timing diagram with prescaler division change from 1 to 2

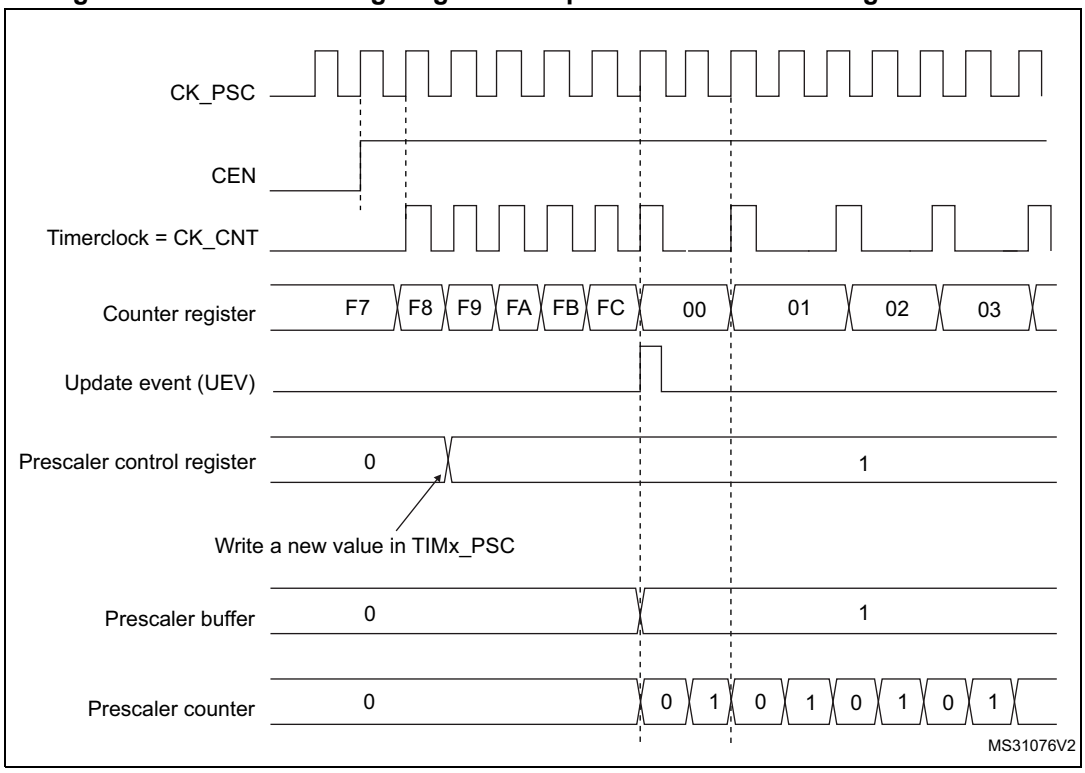
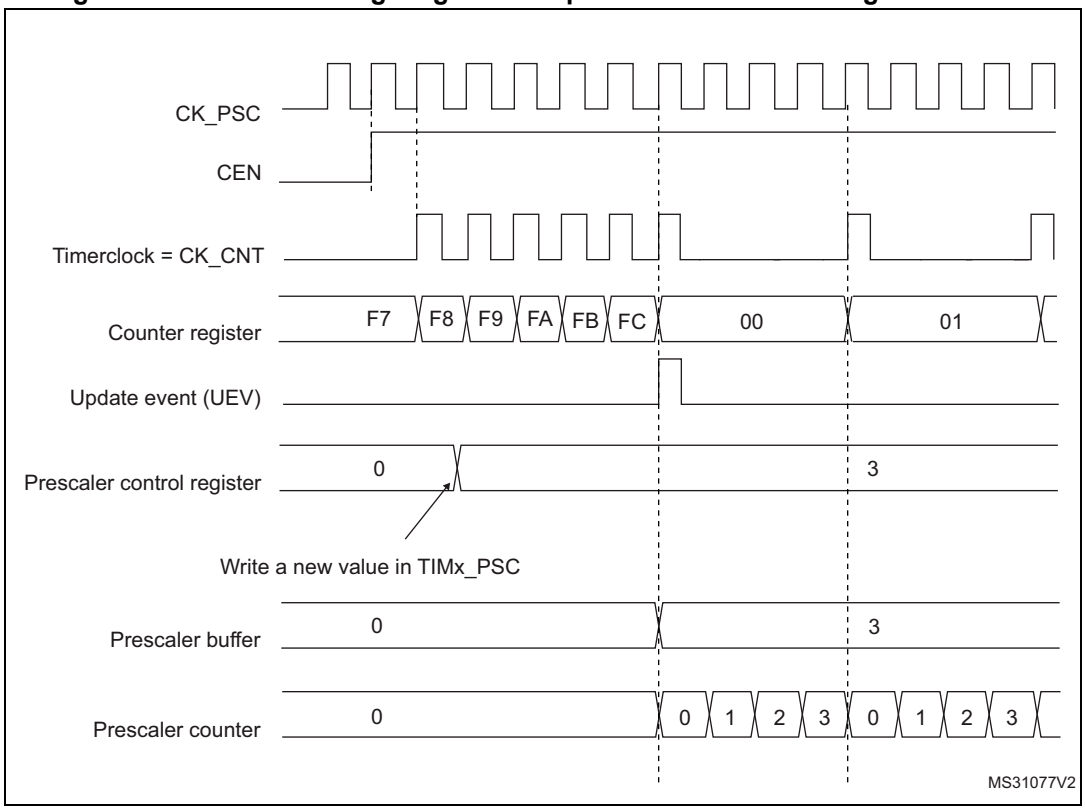


Figure 375. Counter timing diagram with prescaler division change from 1 to 4



43.3.2 Counter modes

Upcounting mode

In upcounting mode, the counter counts from 0 to the auto-reload value (content of the TIMx_ARR register), then restarts from 0 and generates a counter overflow event.

If the repetition counter is used, the update event (UEV) is generated after upcounting is repeated for the number of times programmed in the repetition counter register (TIMx_RCR) + 1. Else the update event is generated at each counter overflow.

Setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller) also generates an update event.

The UEV event can be disabled by software by setting the UDIS bit in the TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter restarts from 0, as well as the counter of the prescaler (but the prescale rate does not change). In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The repetition counter is reloaded with the content of TIMx_RCR register,
- The auto-reload shadow register is updated with the preload value (TIMx_ARR),
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register).

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR=0x36.

Figure 376. Counter timing diagram, internal clock divided by 1

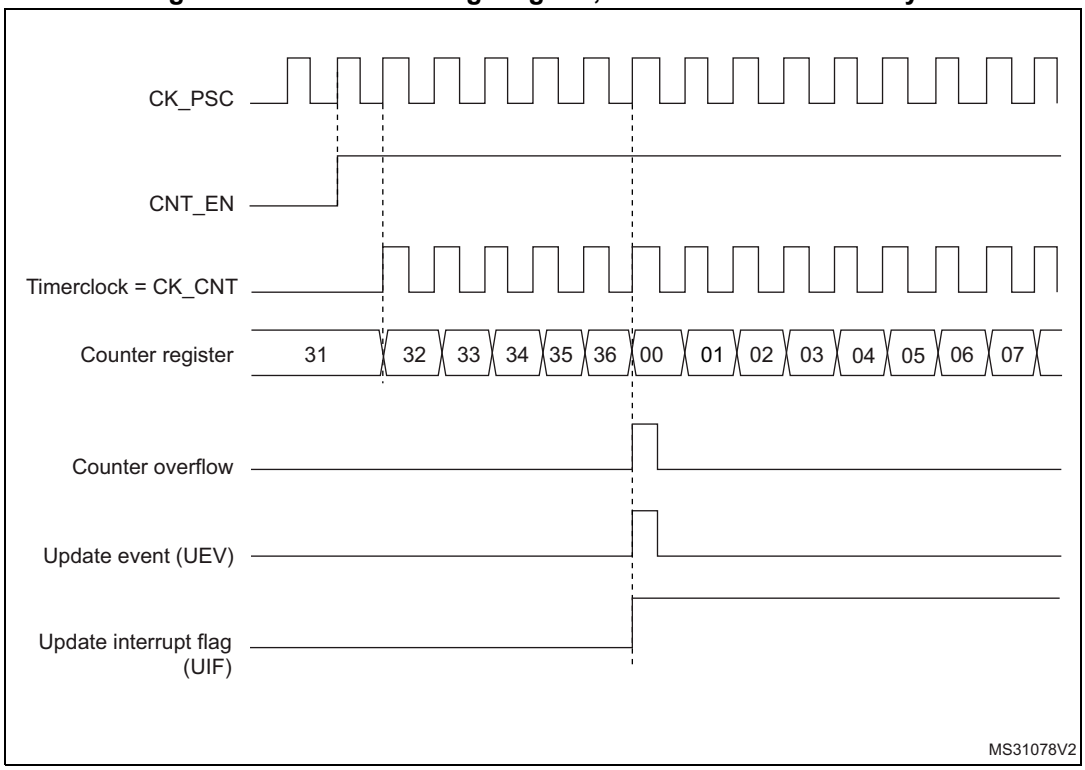


Figure 377. Counter timing diagram, internal clock divided by 2

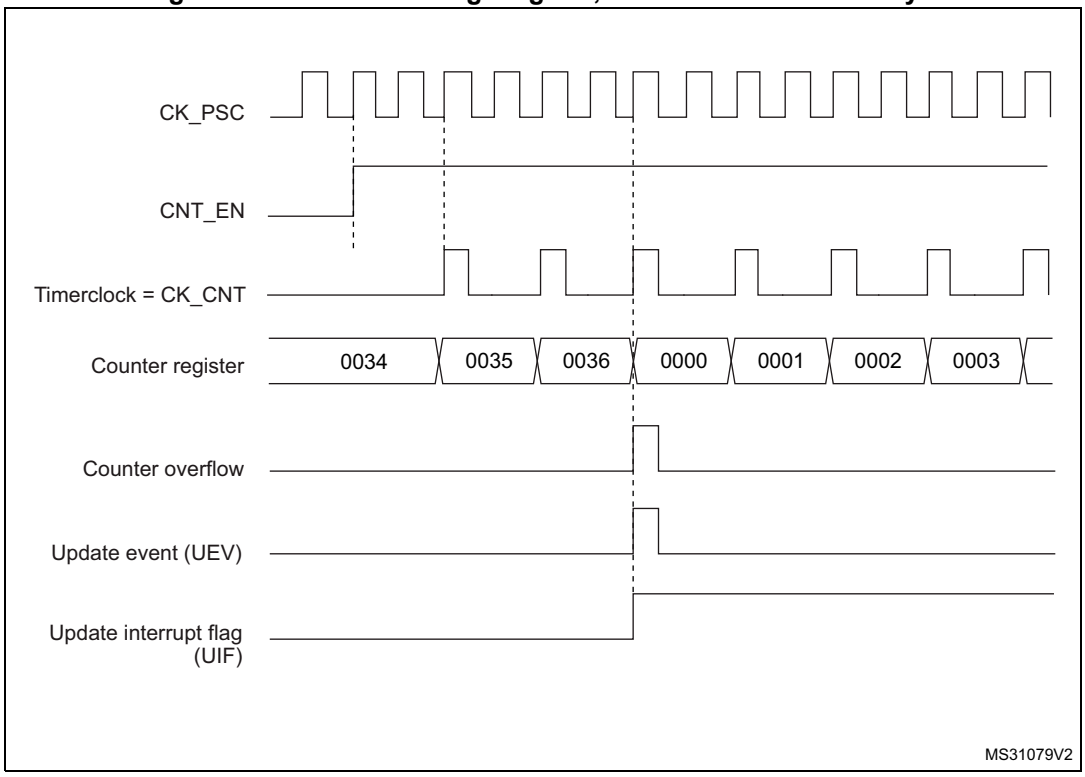


Figure 378. Counter timing diagram, internal clock divided by 4

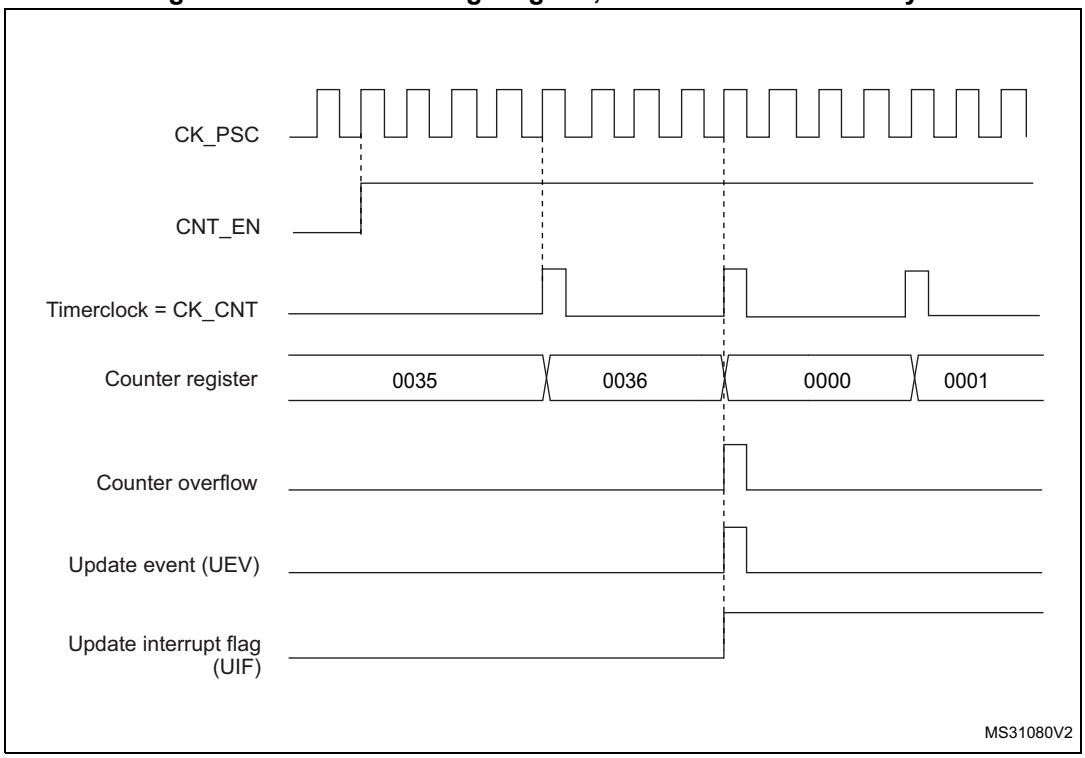


Figure 379. Counter timing diagram, internal clock divided by N

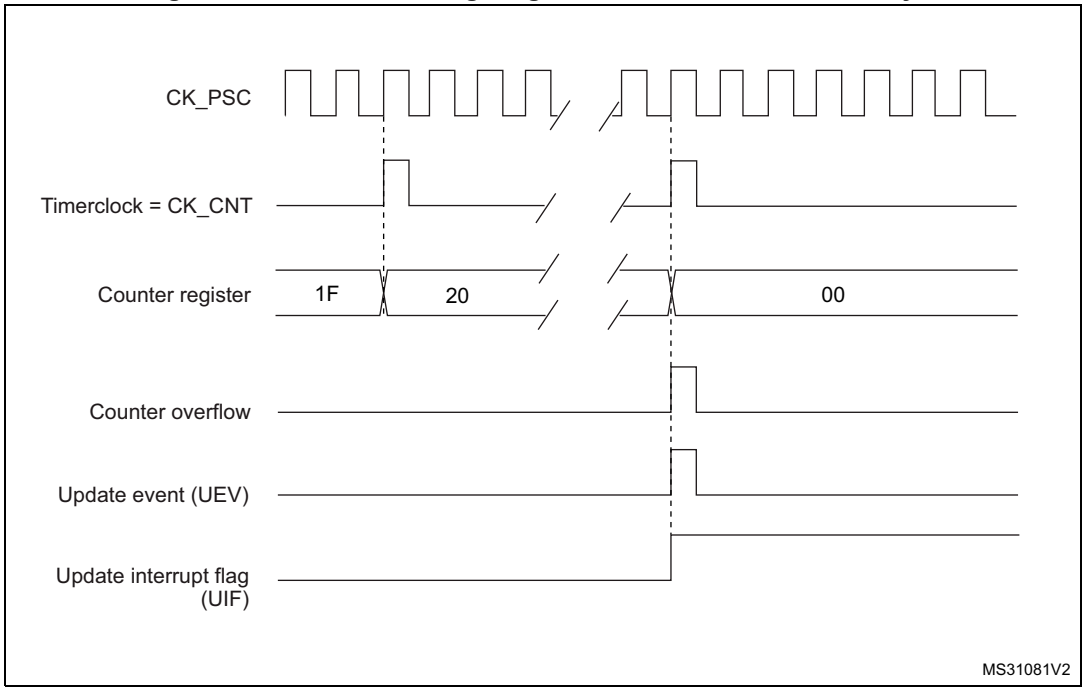


Figure 380. Counter timing diagram, update event when ARPE=0 (TIMx_ARR not preloaded)

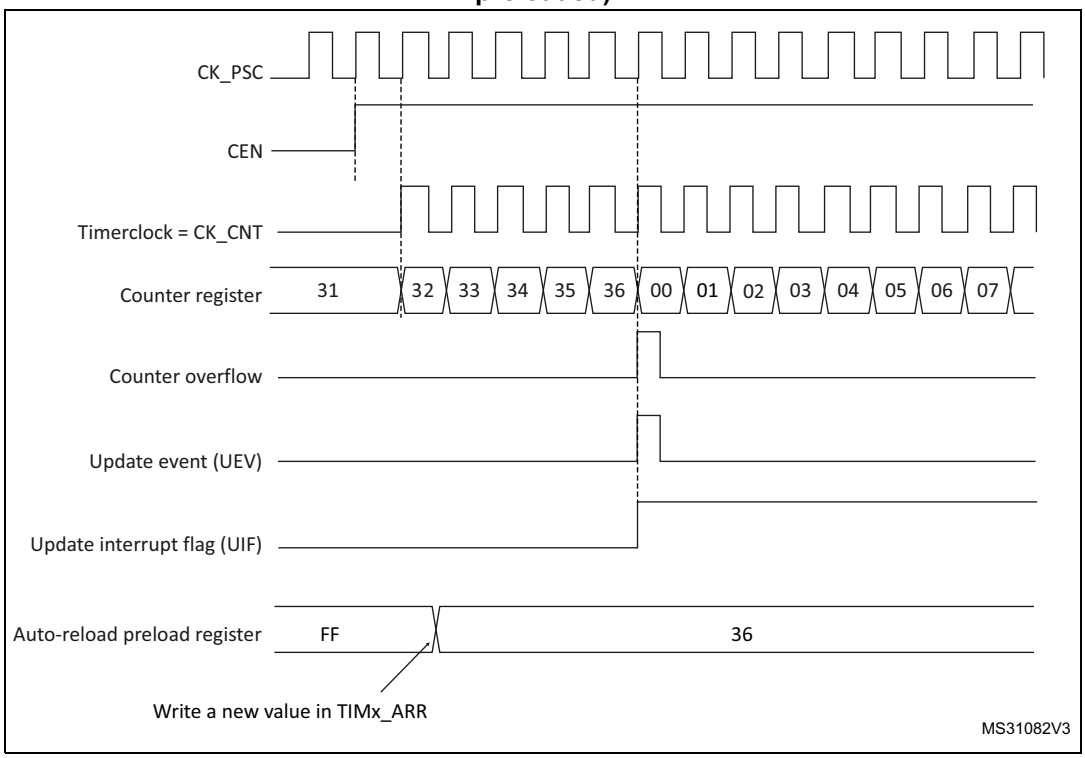
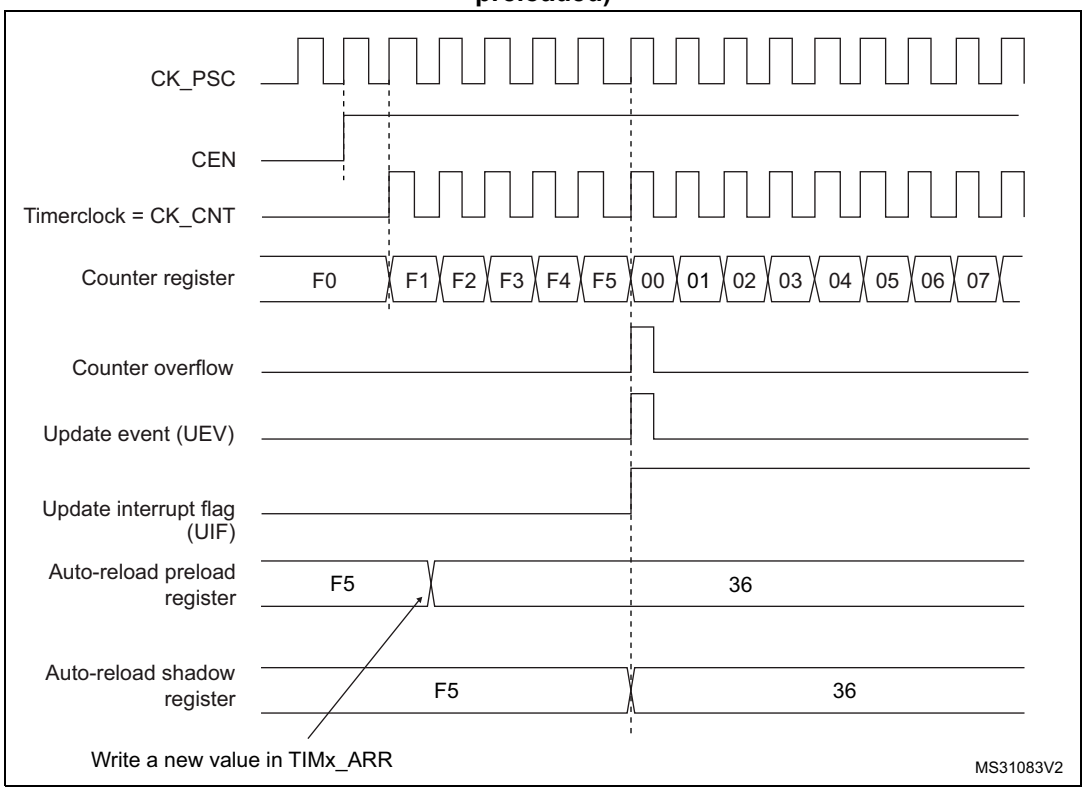


Figure 381. Counter timing diagram, update event when ARPE=1 (TIMx_ARR preloaded)



Downcounting mode

In downcounting mode, the counter counts from the auto-reload value (content of the TIMx_ARR register) down to 0, then restarts from the auto-reload value and generates a counter underflow event.

If the repetition counter is used, the update event (UEV) is generated after downcounting is repeated for the number of times programmed in the repetition counter register (TIMx_RCR) + 1. Else the update event is generated at each counter underflow.

Setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller) also generates an update event.

The UEV update event can be disabled by software by setting the UDIS bit in TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until UDIS bit has been written to 0. However, the counter restarts from the current auto-reload value, whereas the counter of the prescaler restarts from 0 (but the prescale rate doesn't change).

In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The repetition counter is reloaded with the content of TIMx_RCR register.
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register).
- The auto-reload active register is updated with the preload value (content of the TIMx_ARR register). Note that the auto-reload is updated before the counter is reloaded, so that the next period is the expected one.

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR=0x36.

Figure 382. Counter timing diagram, internal clock divided by 1

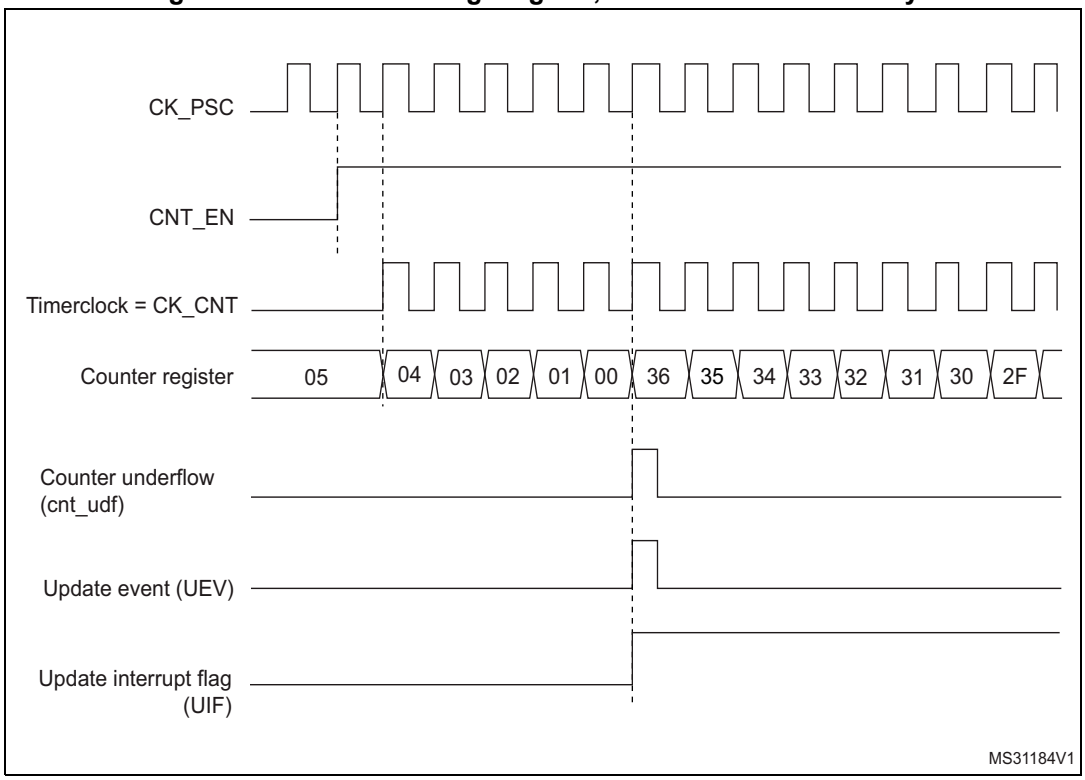


Figure 383. Counter timing diagram, internal clock divided by 2

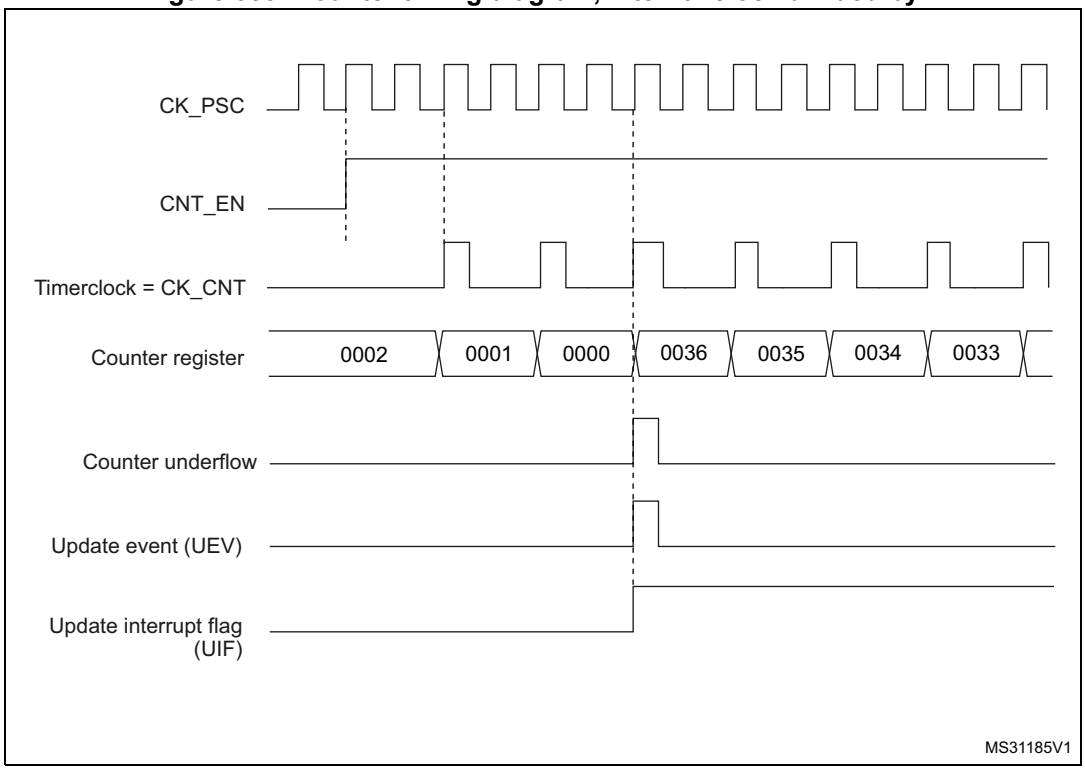


Figure 384. Counter timing diagram, internal clock divided by 4

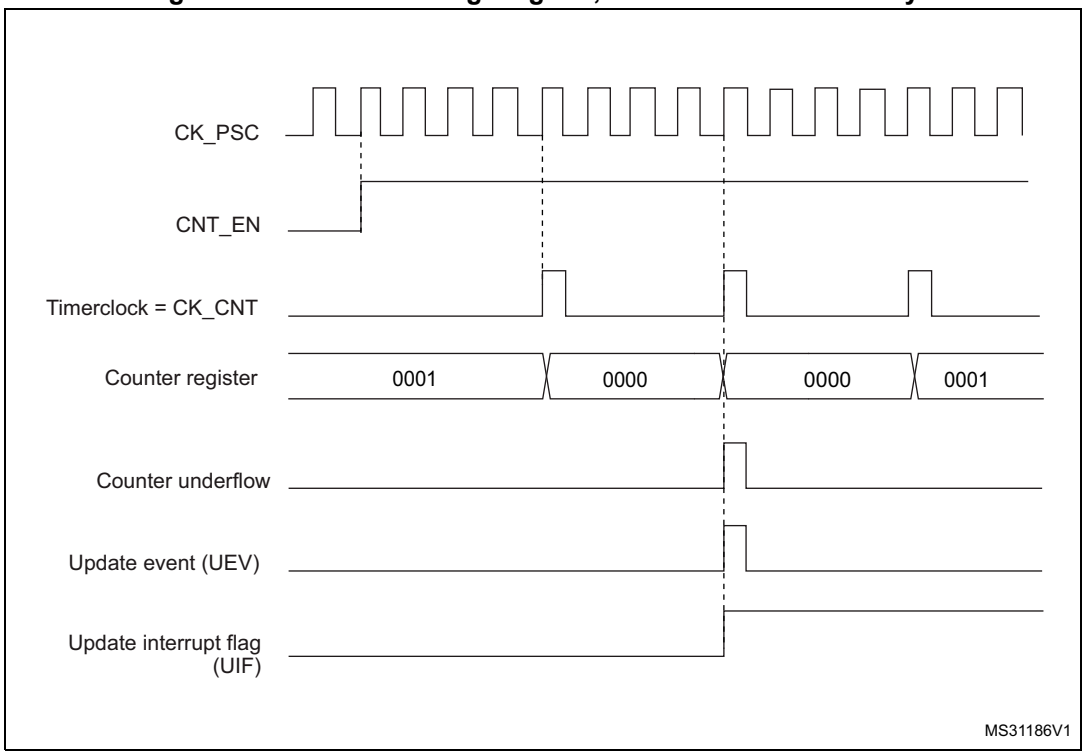


Figure 385. Counter timing diagram, internal clock divided by N

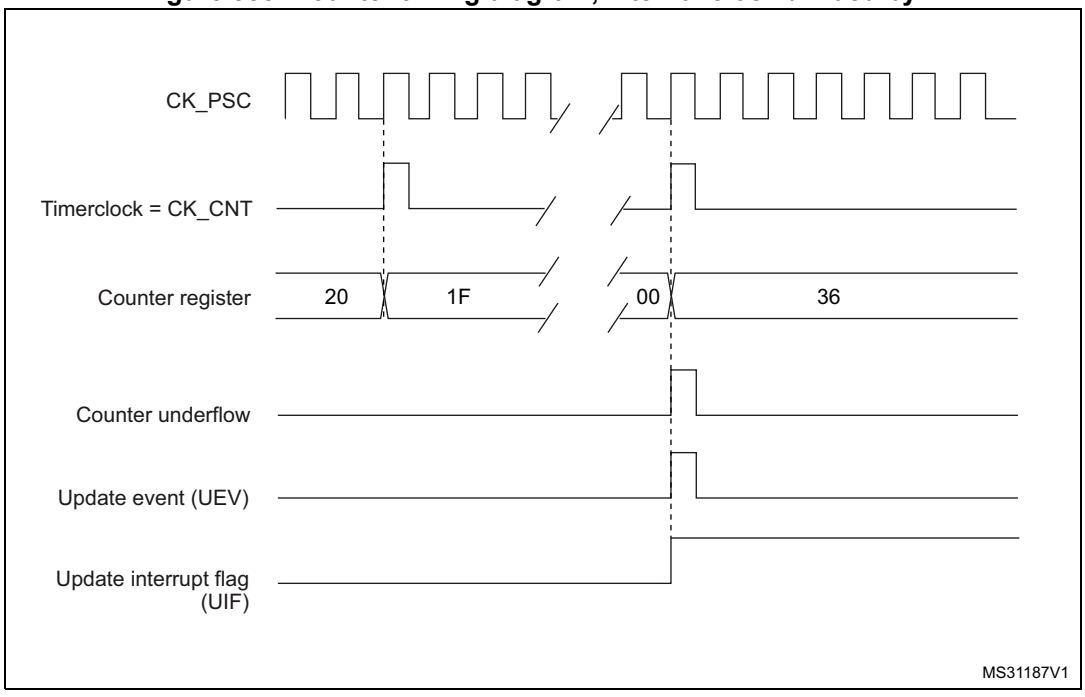
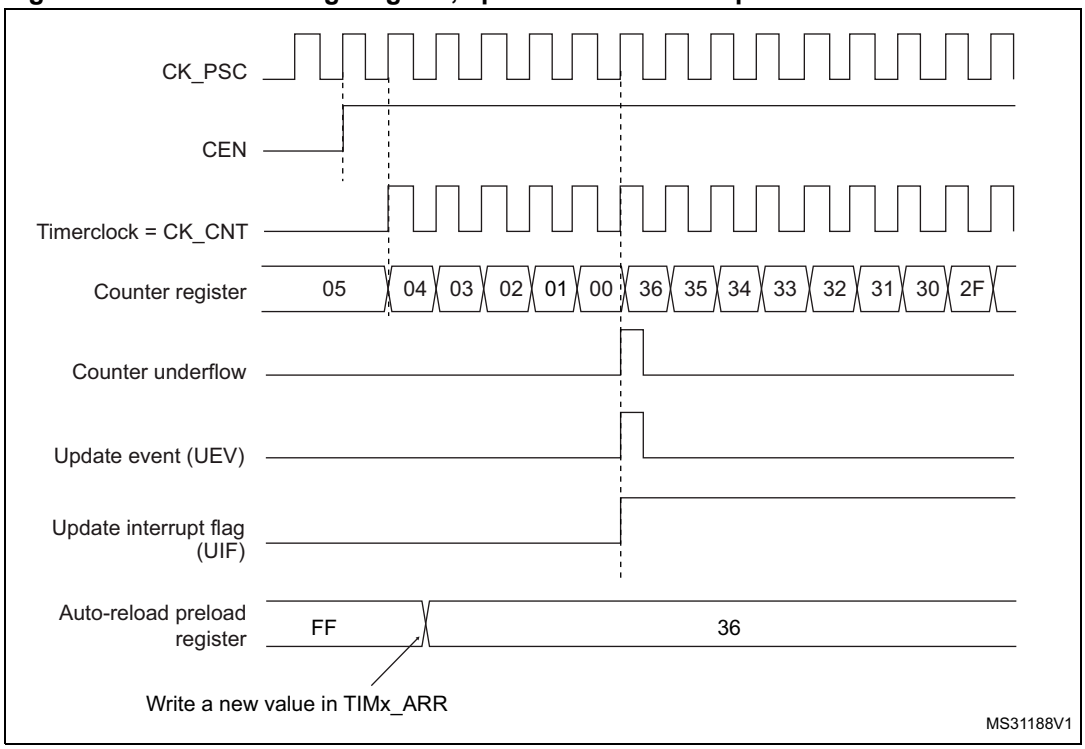


Figure 386. Counter timing diagram, update event when repetition counter is not used



Center-aligned mode (up/down counting)

In center-aligned mode, the counter counts from 0 to the auto-reload value (content of the TIMx_ARR register) – 1, generates a counter overflow event, then counts from the auto-reload value down to 1 and generates a counter underflow event. Then it restarts counting from 0.

Center-aligned mode is active when the CMS bits in TIMx_CR1 register are not equal to '00'. The Output compare interrupt flag of channels configured in output is set when: the counter counts down (Center aligned mode 1, CMS = "01"), the counter counts up (Center aligned mode 2, CMS = "10") the counter counts up and down (Center aligned mode 3, CMS = "11").

In this mode, the DIR direction bit in the TIMx_CR1 register cannot be written. It is updated by hardware and gives the current direction of the counter.

The update event can be generated at each counter overflow and at each counter underflow or by setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller) also generates an update event. In this case, the counter restarts counting from 0, as well as the counter of the prescaler.

The UEV update event can be disabled by software by setting the UDIS bit in the TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until UDIS bit has been written to 0. However, the counter continues counting up and down, based on the current auto-reload value.

In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an UEV update event but without setting the UIF flag (thus no interrupt or

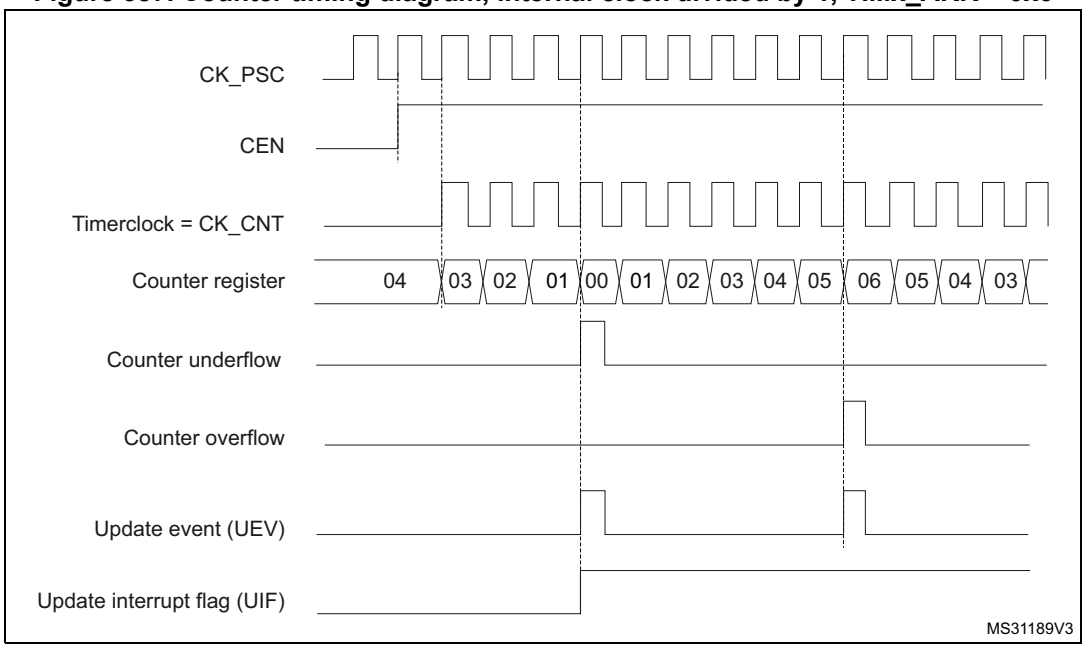
DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The repetition counter is reloaded with the content of TIMx_RCR register
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register)
- The auto-reload active register is updated with the preload value (content of the TIMx_ARR register). Note that if the update source is a counter overflow, the auto-reload is updated before the counter is reloaded, so that the next period is the expected one (the counter is loaded with the new value).

The following figures show some examples of the counter behavior for different clock frequencies.

Figure 387. Counter timing diagram, internal clock divided by 1, TIMx_ARR = 0x6



1. Here, center-aligned mode 1 is used (for more details refer to *Section 43.4: TIM1/TIM8 registers*).

Figure 388. Counter timing diagram, internal clock divided by 2

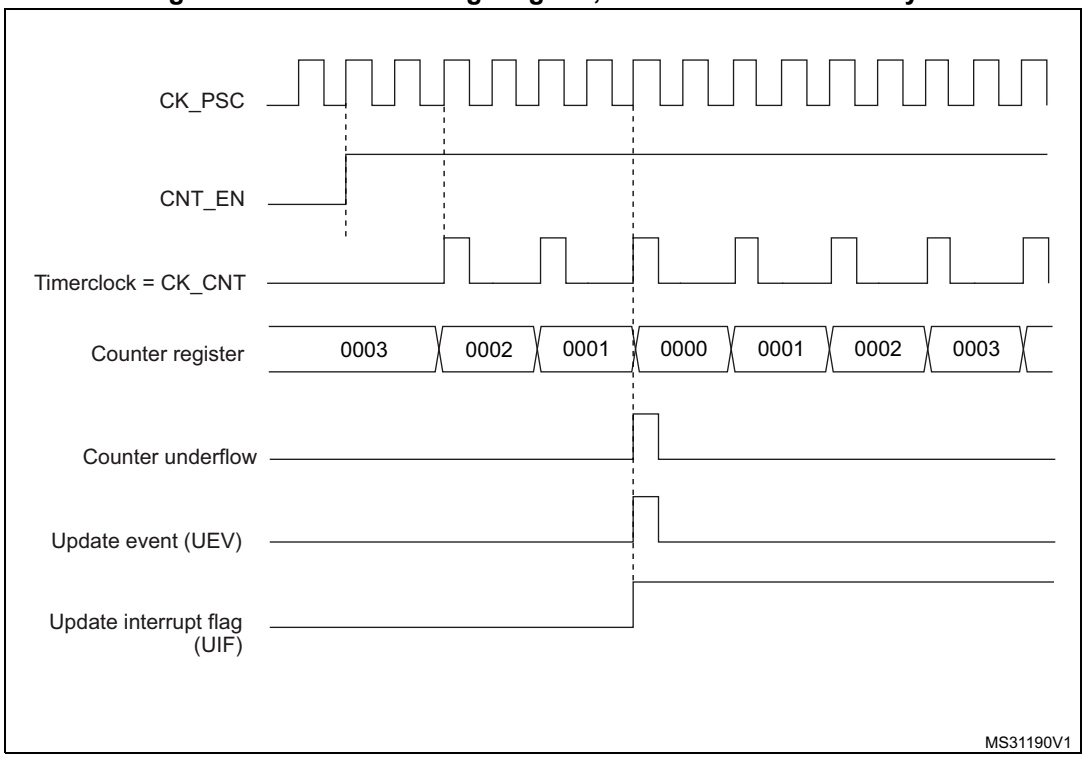


Figure 389. Counter timing diagram, internal clock divided by 4, TIMx_ARR=0x36

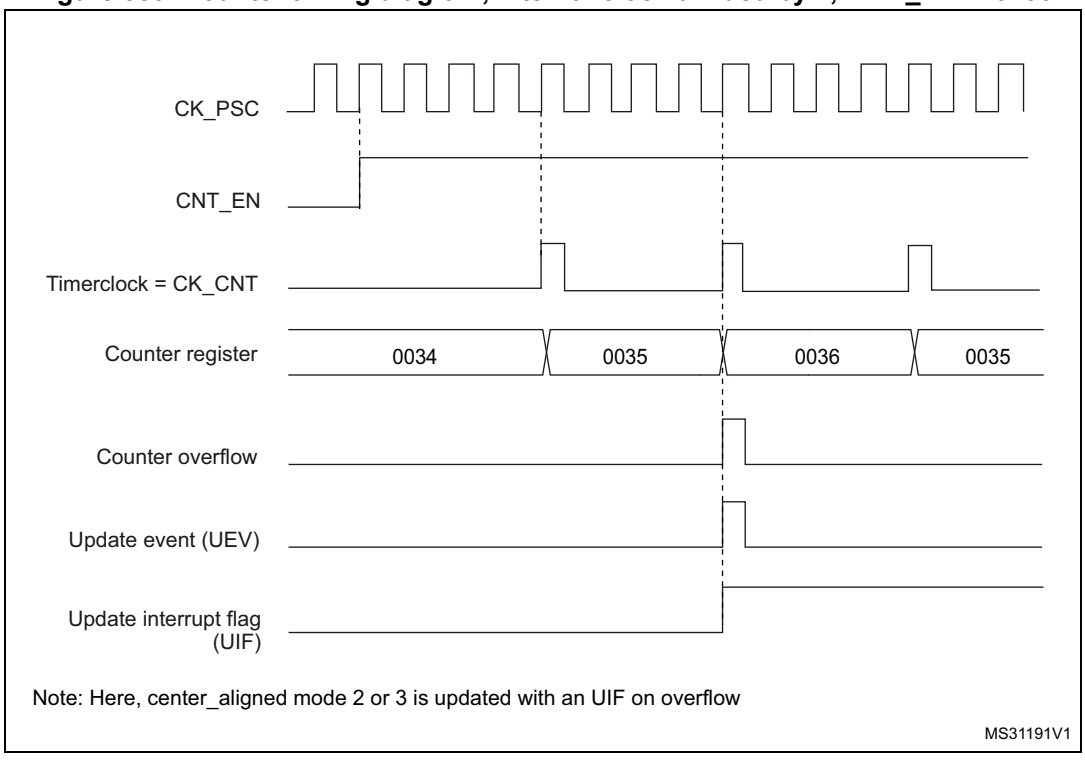


Figure 390. Counter timing diagram, internal clock divided by N

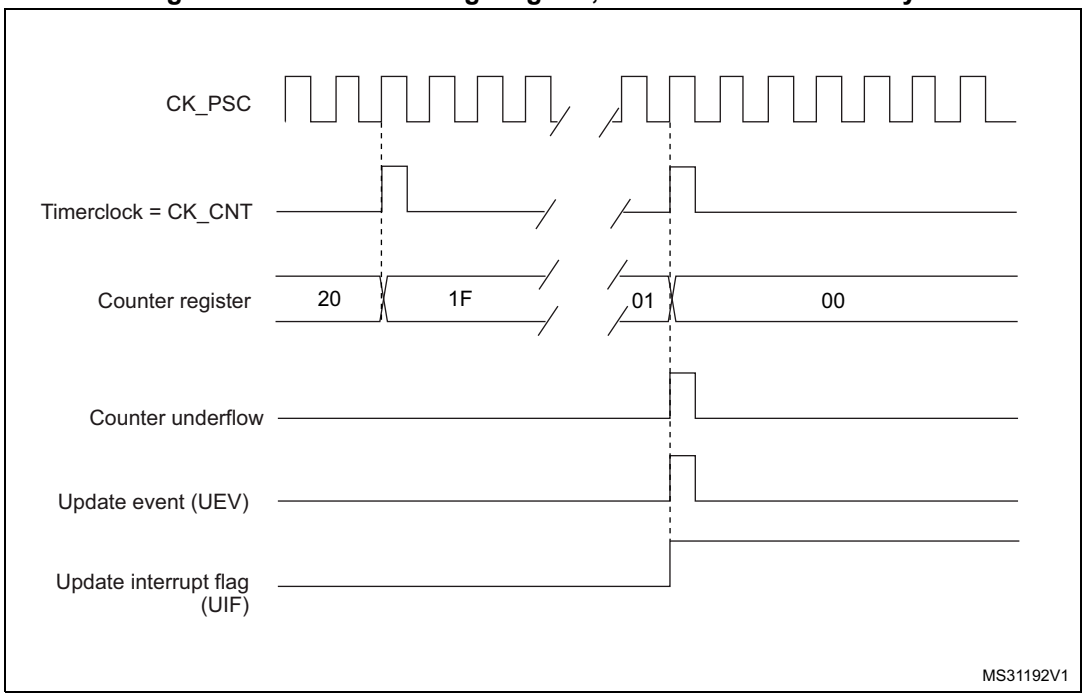


Figure 391. Counter timing diagram, update event with ARPE=1 (counter underflow)

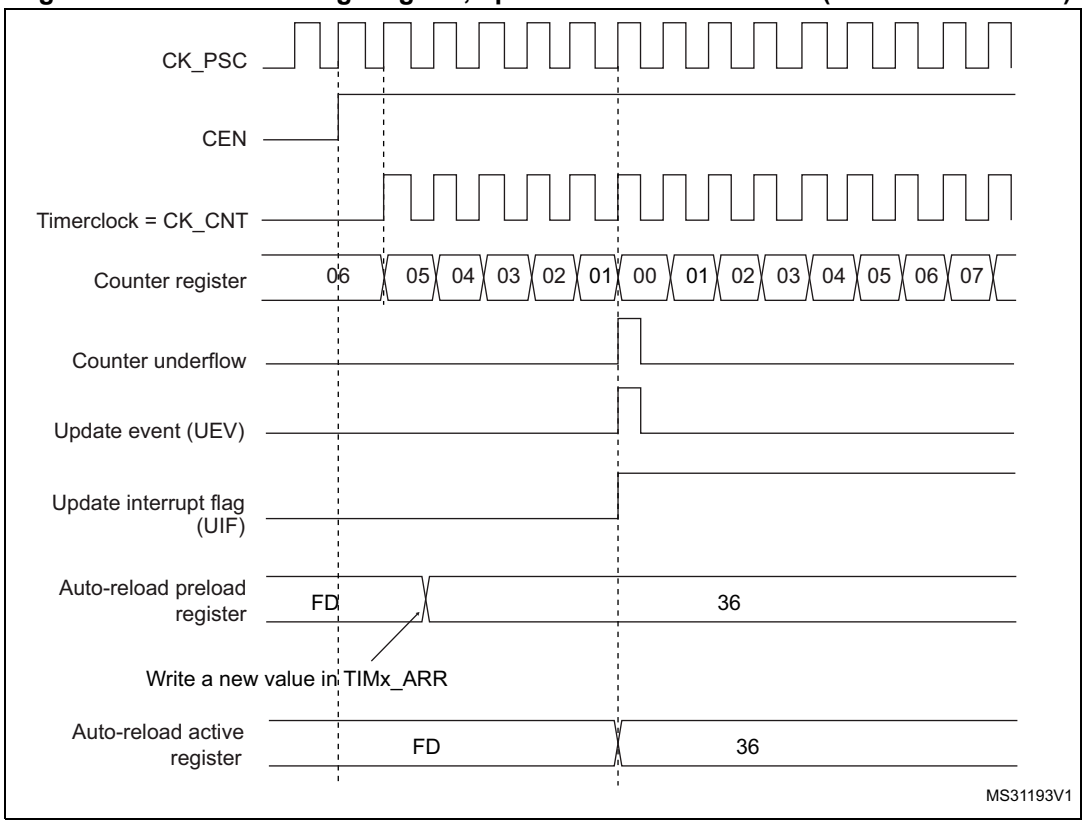
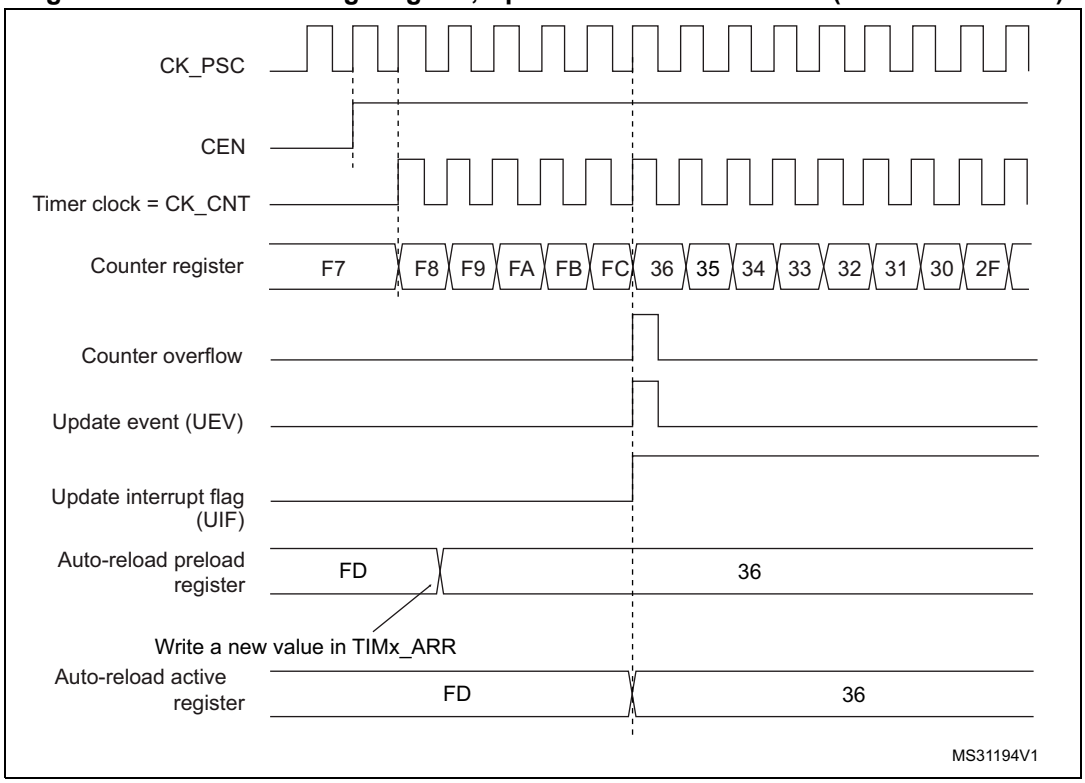


Figure 392. Counter timing diagram, Update event with ARPE=1 (counter overflow)



43.3.3 Repetition counter

Section 43.3.1: Time-base unit describes how the update event (UEV) is generated with respect to the counter overflows/underflows. It is actually generated only when the repetition counter has reached zero. This can be useful when generating PWM signals.

This means that data are transferred from the preload registers to the shadow registers (TIMx_ARR auto-reload register, TIMx_PSC prescaler register, but also TIMx_CCRx capture/compare registers in compare mode) every N+1 counter overflows or underflows, where N is the value in the TIMx_RCR repetition counter register.

The repetition counter is decremented:

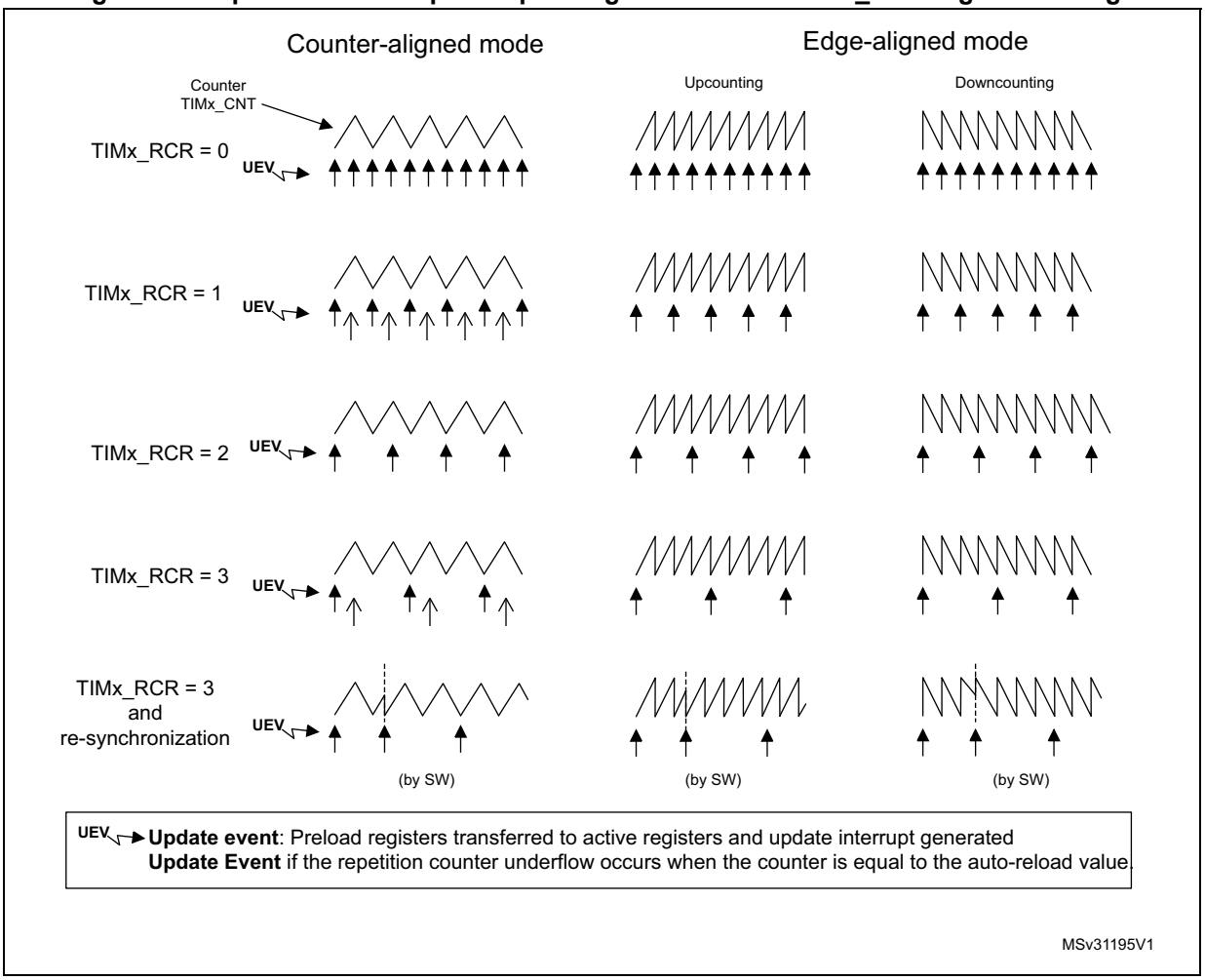
- At each counter overflow in upcounting mode,
- At each counter underflow in downcounting mode,
- At each counter overflow and at each counter underflow in center-aligned mode. Although this limits the maximum number of repetition to 32768 PWM cycles, it makes it possible to update the duty cycle twice per PWM period. When refreshing compare registers only once per PWM period in center-aligned mode, maximum resolution is $2xT_{ck}$, due to the symmetry of the pattern.

The repetition counter is an auto-reload type; the repetition rate is maintained as defined by the TIMx_RCR register value (refer to *Figure 393*). When the update event is generated by software (by setting the UG bit in TIMx_EGR register) or by hardware through the slave mode controller, it occurs immediately whatever the value of the repetition counter is and the repetition counter is reloaded with the content of the TIMx_RCR register.

In Center aligned mode, for odd values of RCR, the update event occurs either on the overflow or on the underflow depending on when the RCR register was written and when the counter was launched: if the RCR was written before launching the counter, the UEV occurs on the underflow. If the RCR was written after launching the counter, the UEV occurs on the overflow.

For example, for RCR = 3, the UEV is generated each 4th overflow or underflow event depending on when the RCR was written.

Figure 393. Update rate examples depending on mode and TIMx_RCR register settings



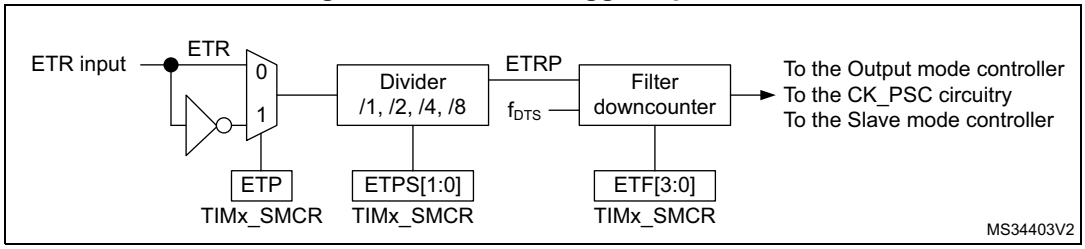
43.3.4 External trigger input

The timer features an external trigger input ETR. It can be used as:

- external clock (external clock mode 2, see *Section 43.3.5*)
- trigger for the slave mode (see *Section 43.3.26*)
- PWM reset input for cycle-by-cycle current regulation (see *Section 43.3.7*)

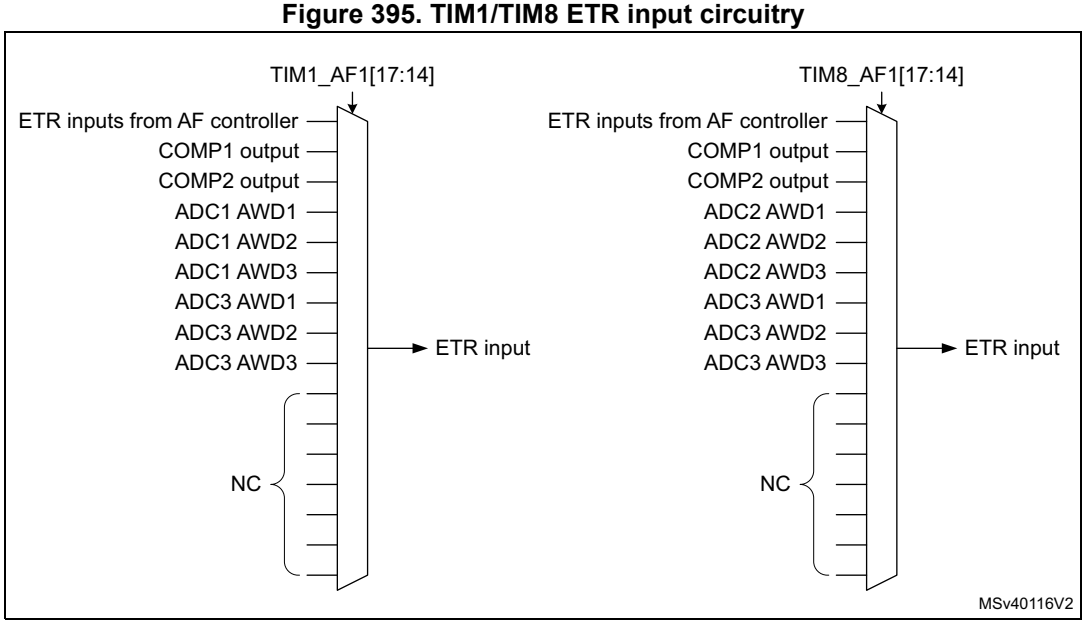
Figure 394 below describes the ETR input conditioning. The input polarity is defined with the ETP bit in TIMxSMCR register. The trigger can be prescaled with the divider programmed by the ETPS[1:0] bitfield and digitally filtered with the ETF[3:0] bitfield.

Figure 394. External trigger input block



The ETR input comes from multiple sources: input pins (default configuration), comparator outputs and analog watchdogs. The selection is done with the ETRSEL[3:0] bitfield.

Figure 395. TIM1/TIM8 ETR input circuitry



43.3.5 Clock selection

The counter clock can be provided by the following clock sources:

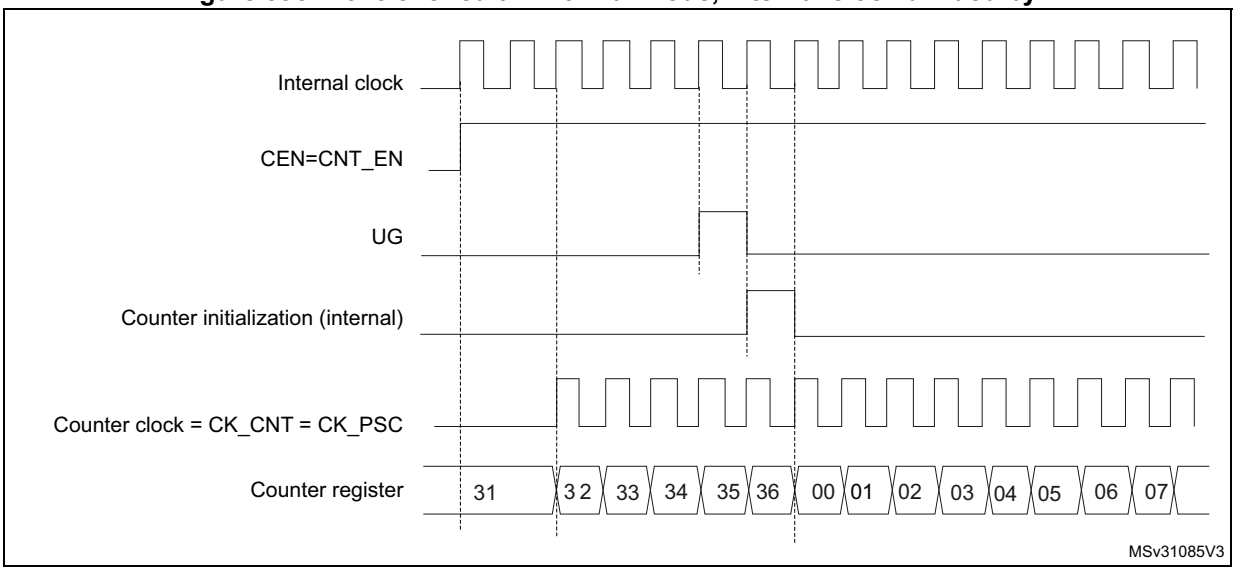
- Internal clock (CK_INT)
- External clock mode1: external input pin
- External clock mode2: external trigger input ETR
- Encoder mode

Internal clock source (CK_INT)

If the slave mode controller is disabled (SMS=000), then the CEN, DIR (in the TIMx_CR1 register) and UG bits (in the TIMx_EGR register) are actual control bits and can be changed only by software (except UG which remains cleared automatically). As soon as the CEN bit is written to 1, the prescaler is clocked by the internal clock CK_INT.

Figure 396 shows the behavior of the control circuit and the upcounter in normal mode, without prescaler.

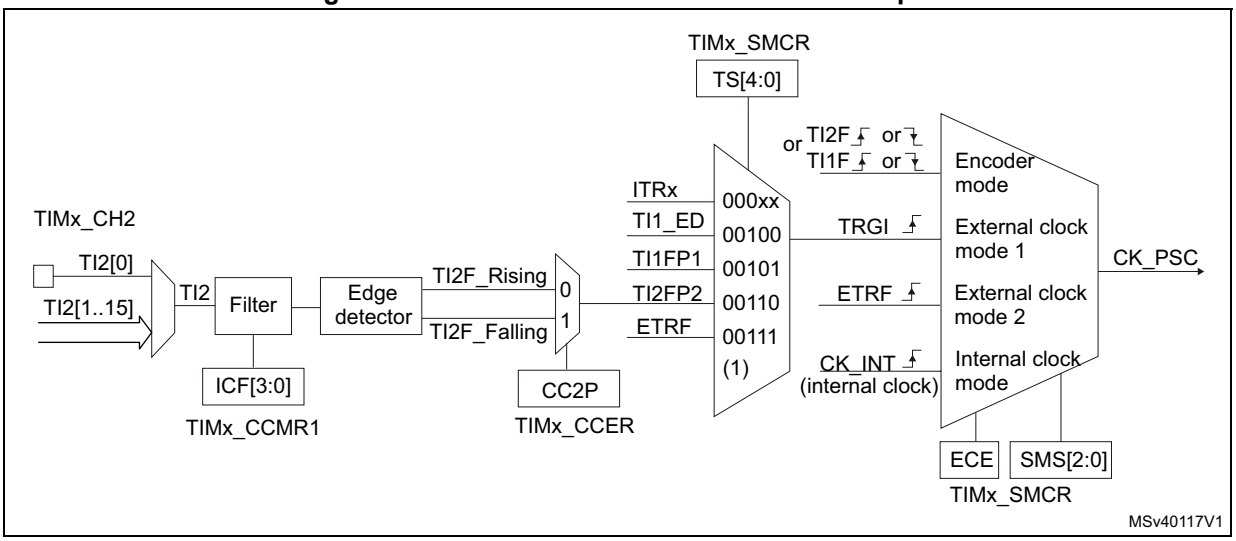
Figure 396. Control circuit in normal mode, internal clock divided by 1



External clock source mode 1

This mode is selected when SMS=111 in the TIMx_SMCR register. The counter can count at each rising or falling edge on a selected input.

Figure 397. TI2 external clock connection example



1. Codes ranging from 01000 to 11111 are reserved

For example, to configure the upcounter to count in response to a rising edge on the TI2 input, use the following procedure:

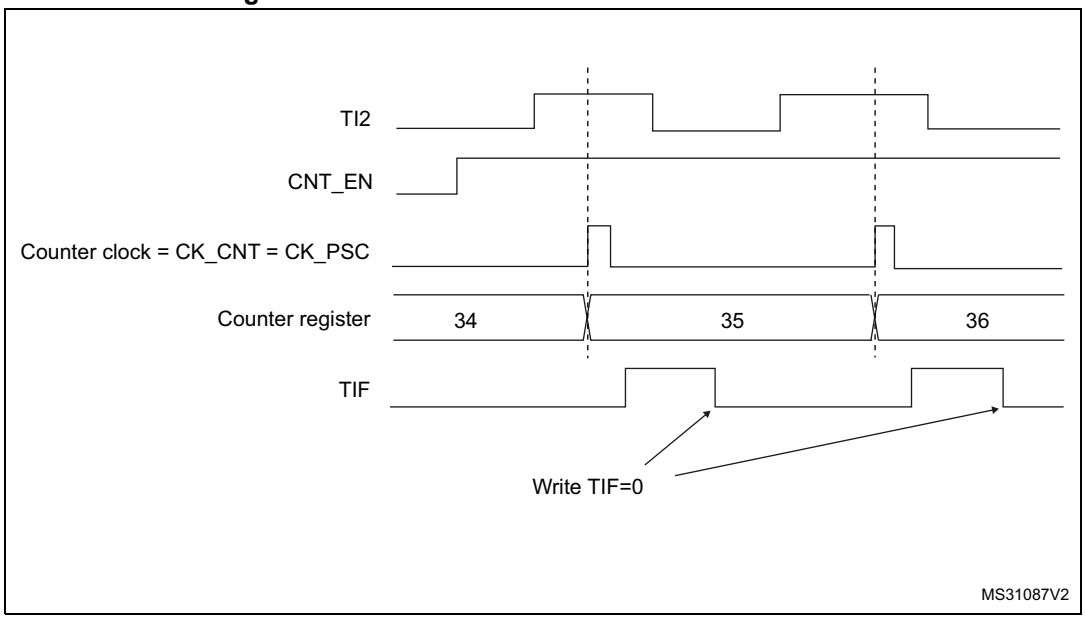
1. Select the proper TI2x source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Configure channel 2 to detect rising edges on the TI2 input by writing CC2S = ‘01’ in the TIMx_CCMR1 register.
3. Configure the input filter duration by writing the IC2F[3:0] bits in the TIMx_CCMR1 register (if no filter is needed, keep IC2F=0000).
4. Select rising edge polarity by writing CC2P=0 and CC2NP=0 in the TIMx_CCER register.
5. Configure the timer in external clock mode 1 by writing SMS=111 in the TIMx_SMCR register.
6. Select TI2 as the trigger input source by writing TS=00110 in the TIMx_SMCR register.
7. Enable the counter by writing CEN=1 in the TIMx_CR1 register.

Note: The capture prescaler is not used for triggering, so the user does not need to configure it.

When a rising edge occurs on TI2, the counter counts once and the TIF flag is set.

The delay between the rising edge on TI2 and the actual clock of the counter is due to the resynchronization circuit on TI2 input.

Figure 398. Control circuit in external clock mode 1



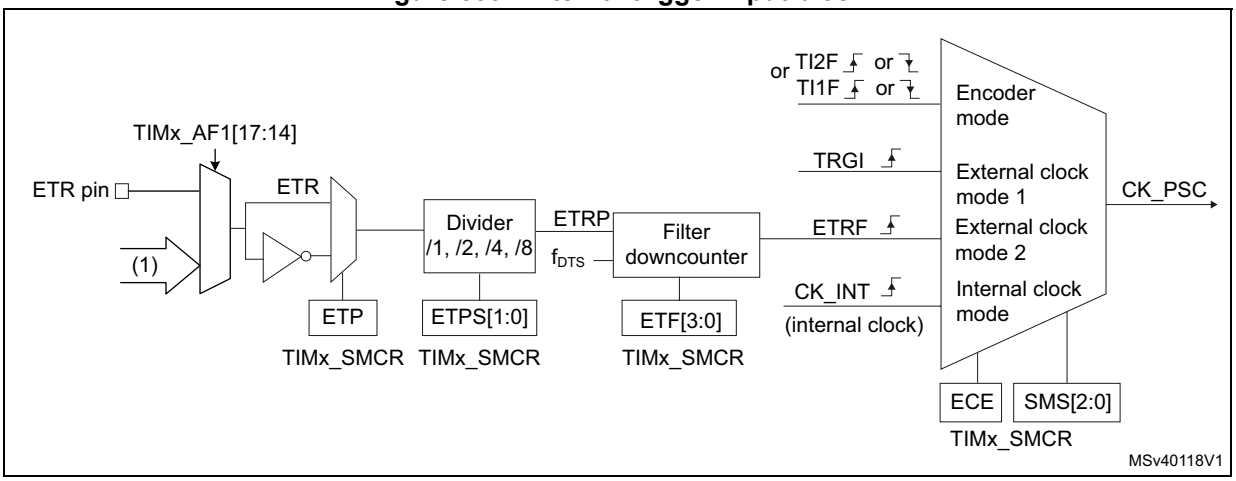
External clock source mode 2

This mode is selected by writing ECE=1 in the TIMx_SMCR register.

The counter can count at each rising or falling edge on the external trigger input ETR.

The *Figure 399* gives an overview of the external trigger input block.

Figure 399. External trigger input block



1. Refer to *Figure 395: TIM1/TIM8 ETR input circuitry*.

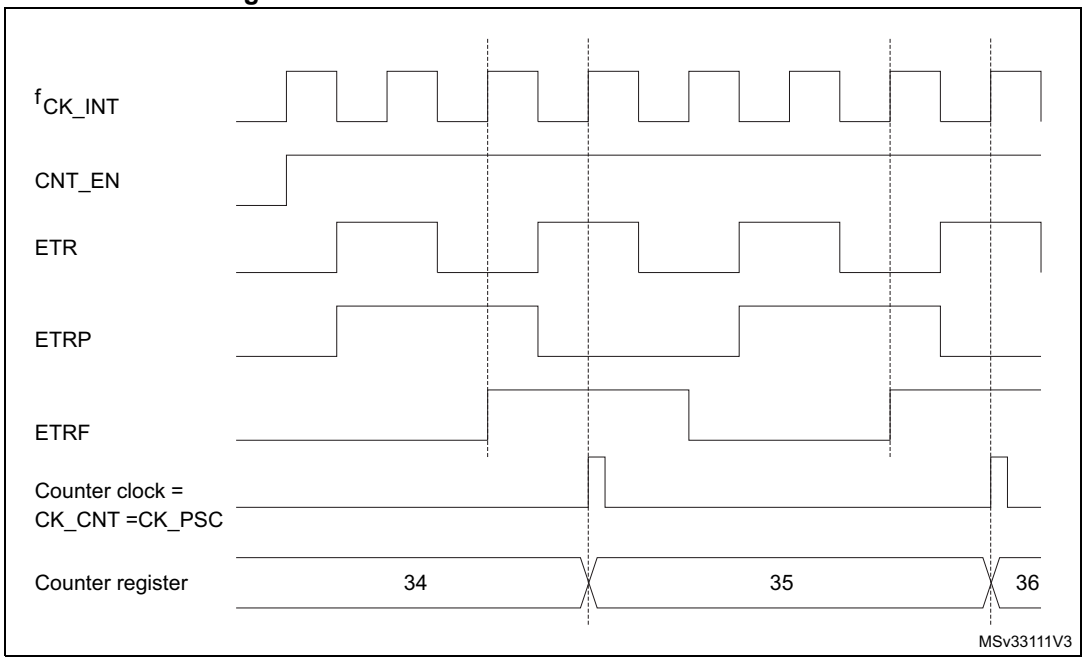
For example, to configure the upcounter to count each 2 rising edges on ETR, use the following procedure:

1. As no filter is needed in this example, write ETF[3:0]=0000 in the TIMx_SMCR register.
2. Set the prescaler by writing ETPS[1:0]=01 in the TIMx_SMCR register
3. Select rising edge detection on the ETR pin by writing ETP=0 in the TIMx_SMCR register
4. Enable external clock mode 2 by writing ECE=1 in the TIMx_SMCR register.
5. Enable the counter by writing CEN=1 in the TIMx_CR1 register.

The counter counts once each 2 ETR rising edges.

The delay between the rising edge on ETR and the actual clock of the counter is due to the resynchronization circuit on the ETRP signal. As a consequence, the maximum frequency which can be correctly captured by the counter is at most ¼ of TIMxCLK frequency. When the ETRP signal is faster, the user should apply a division of the external signal by proper ETPS prescaler setting.

Figure 400. Control circuit in external clock mode 2



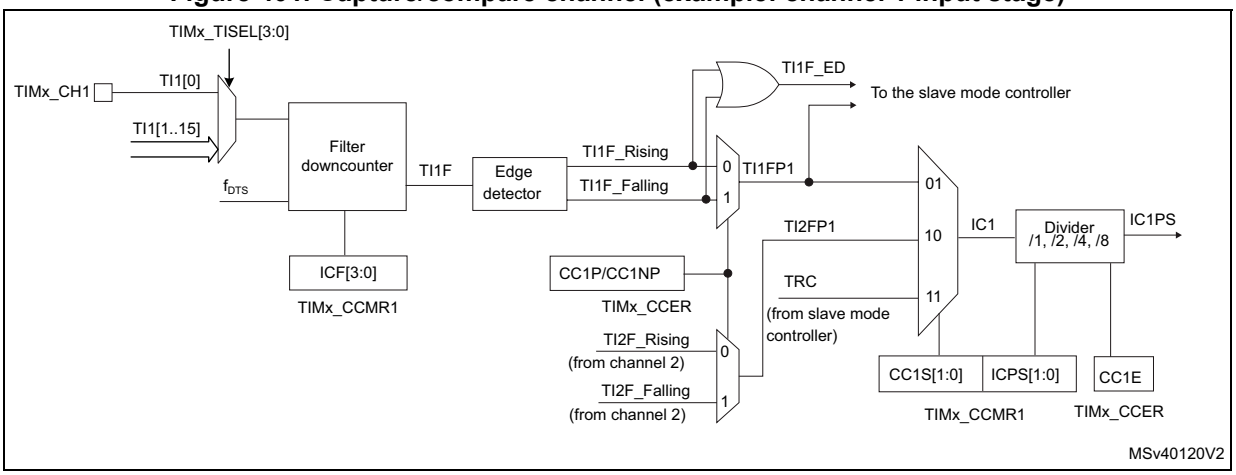
43.3.6 Capture/compare channels

Each Capture/Compare channel is built around a capture/compare register (including a shadow register), an input stage for capture (with digital filter, multiplexing, and prescaler, except for channels 5 and 6) and an output stage (with comparator and output control).

Figure 401 to *Figure 404* give an overview of one Capture/Compare channel.

The input stage samples the corresponding TIx input to generate a filtered signal TIxF. Then, an edge detector with polarity selection generates a signal (TIxFPx) which can be used as trigger input by the slave mode controller or as the capture command. It is prescaled before the capture register (ICxPS).

Figure 401. Capture/compare channel (example: channel 1 input stage)



The output stage generates an intermediate waveform which is then used for reference: OCxRef (active high). The polarity acts at the end of the chain.

Figure 402. Capture/compare channel 1 main circuit

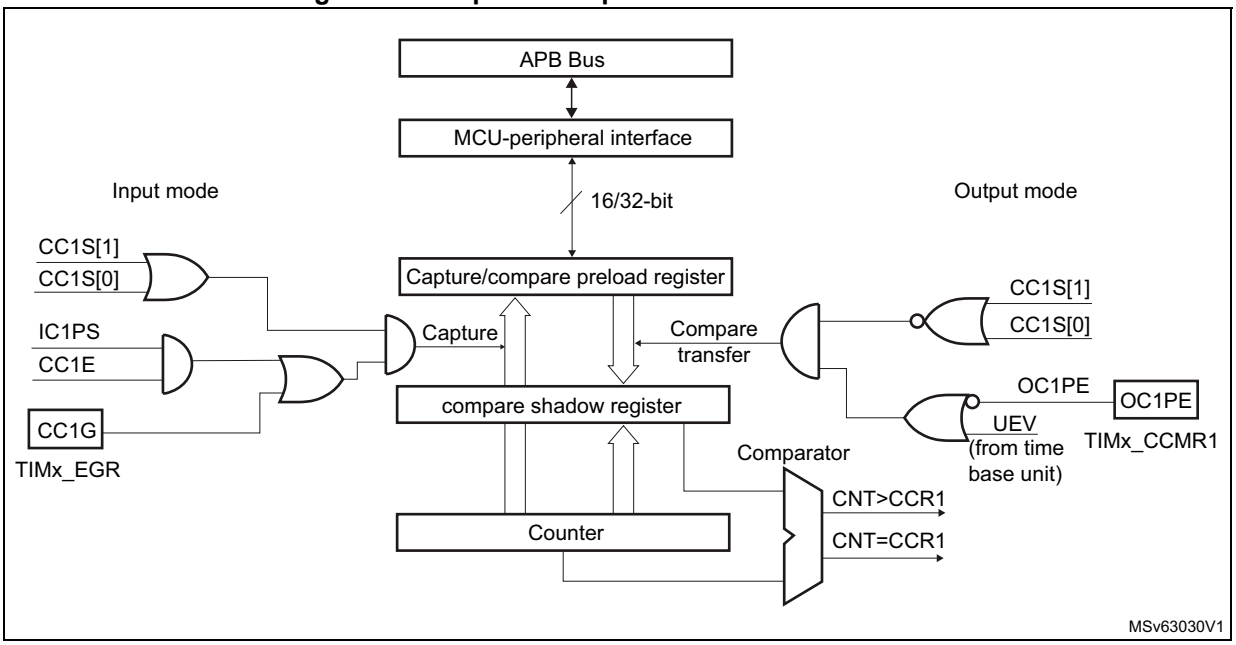
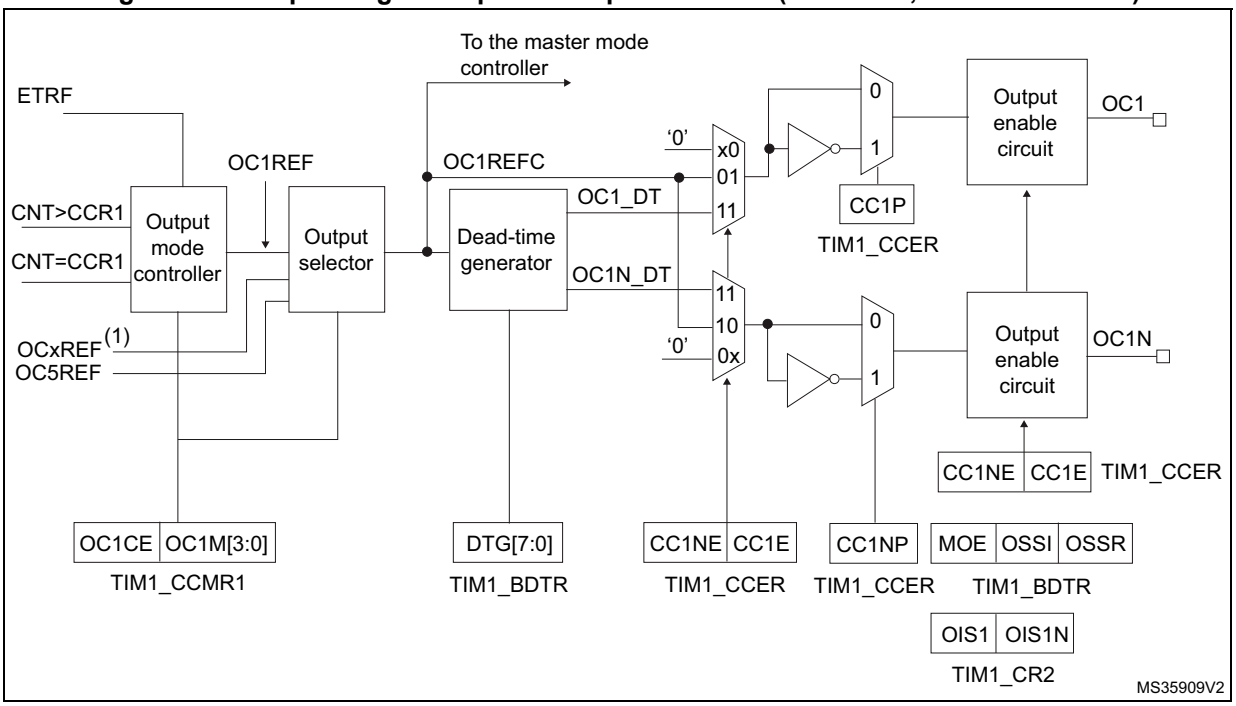


Figure 403. Output stage of capture/compare channel (channel 1, idem ch. 2 and 3)



1. OCxREF, where x is the rank of the complementary channel

Figure 404. Output stage of capture/compare channel (channel 4)

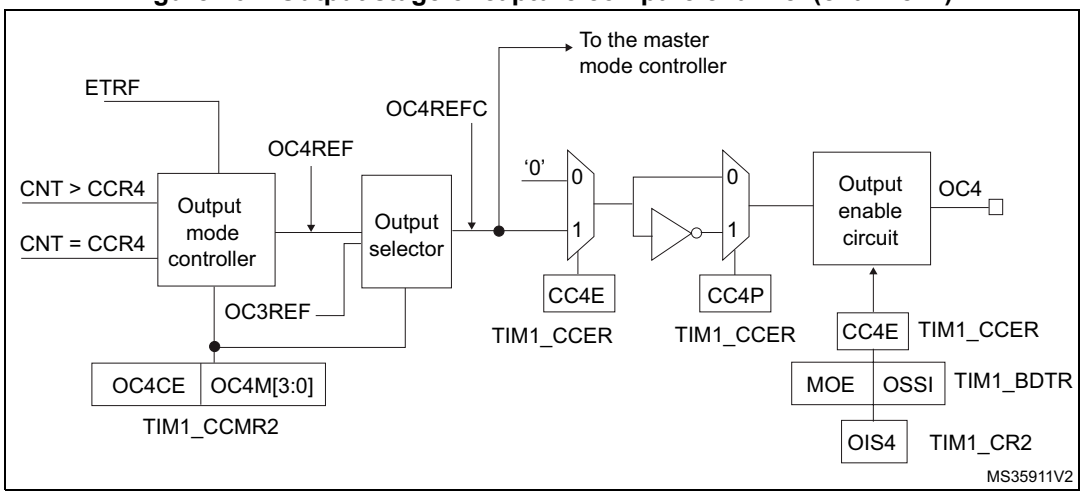
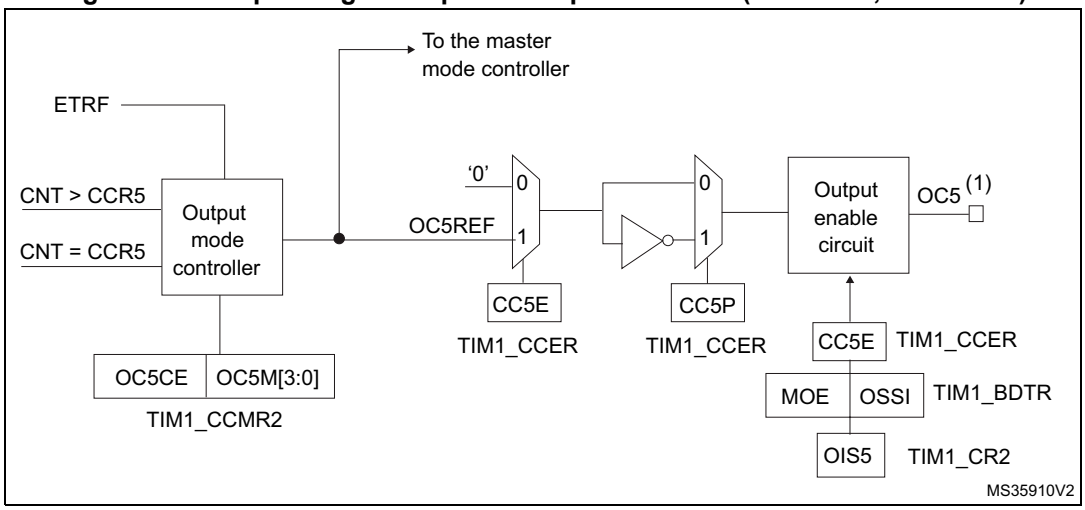


Figure 405. Output stage of capture/compare channel (channel 5, idem ch. 6)



1. Not available externally.

The capture/compare block is made of one preload register and one shadow register. Write and read always access the preload register.

In capture mode, captures are actually done in the shadow register, which is copied into the preload register.

In compare mode, the content of the preload register is copied into the shadow register which is compared to the counter.

43.3.7 Input capture mode

In Input capture mode, the Capture/Compare Registers (TIMx_CCRx) are used to latch the value of the counter after a transition detected by the corresponding ICx signal. When a capture occurs, the corresponding CCXIF flag (TIMx_SR register) is set and an interrupt or a DMA request can be sent if they are enabled. If a capture occurs while the CCxIF flag was already high, then the over-capture flag CCxOF (TIMx_SR register) is set. CCxIF can be cleared by software by writing it to '0' or by reading the captured data stored in the TIMx_CCRx register. CCxOF is cleared when written with '0'.

The following example shows how to capture the counter value in TIMx_CCR1 when TI1 input rises. To do this, use the following procedure:

1. Select the proper TI1x source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input: TIMx_CCR1 must be linked to the TI1 input, so write the CC1S bits to 01 in the TIMx_CCMR1 register. As soon as CC1S becomes different from 00, the channel is configured in input and the TIMx_CCR1 register becomes read-only.
3. Program the appropriate input filter duration in relation with the signal connected to the timer (when the input is one of the TIx (ICxF bits in the TIMx_CCMRx register). Let's imagine that, when toggling, the input signal is not stable during at must 5 internal clock cycles. We must program a filter duration longer than these 5 clock cycles. We can validate a transition on TI1 when 8 consecutive samples with the new level have been

detected (sampled at f_{DTS} frequency). Then write IC1F bits to 0011 in the TIMx_CCMR1 register.

4. Select the edge of the active transition on the TI1 channel by writing CC1P and CC1NP bits to 0 in the TIMx_CCER register (rising edge in this case).
5. Program the input prescaler. In our example, we wish the capture to be performed at each valid transition, so the prescaler is disabled (write IC1PS bits to '00' in the TIMx_CCMR1 register).
6. Enable capture from the counter into the capture register by setting the CC1E bit in the TIMx_CCER register.
7. If needed, enable the related interrupt request by setting the CC1IE bit in the TIMx_DIER register, and/or the DMA request by setting the CC1DE bit in the TIMx_DIER register.

When an input capture occurs:

- The TIMx_CCR1 register gets the value of the counter on the active transition.
- CC1IF flag is set (interrupt flag). CC1OF is also set if at least two consecutive captures occurred whereas the flag was not cleared.
- An interrupt is generated depending on the CC1IE bit.
- A DMA request is generated depending on the CC1DE bit.

In order to handle the overcapture, it is recommended to read the data before the overcapture flag. This is to avoid missing an overcapture which could happen after reading the flag and before reading the data.

Note: IC interrupt and/or DMA requests can be generated by software by setting the corresponding CCxG bit in the TIMx_EGR register.

43.3.8 PWM input mode

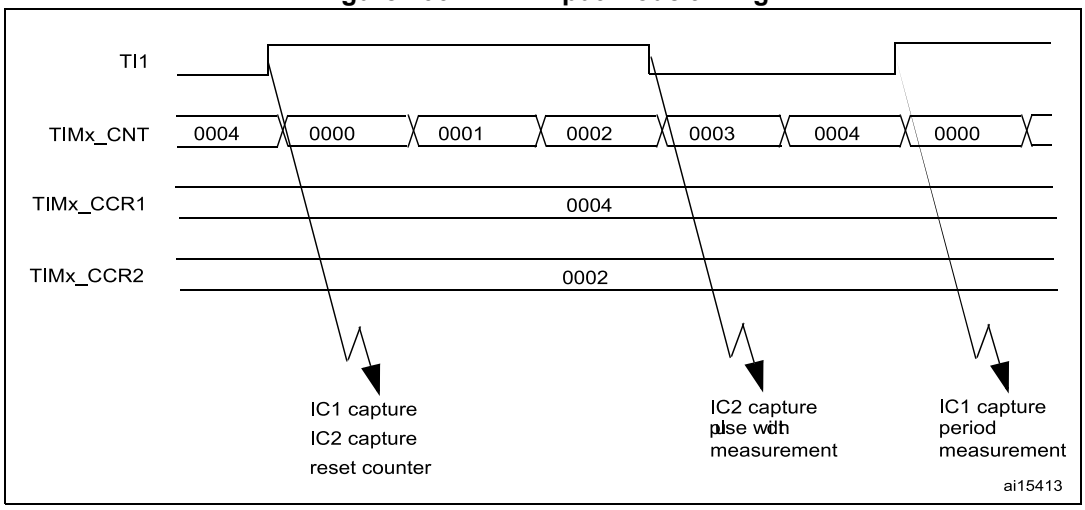
This mode is a particular case of input capture mode. The procedure is the same except:

- Two ICx signals are mapped on the same TIx input.
- These 2 ICx signals are active on edges with opposite polarity.
- One of the two TIxFP signals is selected as trigger input and the slave mode controller is configured in reset mode.

For example, the user can measure the period (in TIMx_CCR1 register) and the duty cycle (in TIMx_CCR2 register) of the PWM applied on TI1 using the following procedure (depending on CK_INT frequency and prescaler value):

1. Select the proper TI1x source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input for TIMx_CCR1: write the CC1S bits to 01 in the TIMx_CCMR1 register (TI1 selected).
3. Select the active polarity for TI1FP1 (used both for capture in TIMx_CCR1 and counter clear): write the CC1P and CC1NP bits to '0' (active on rising edge).
4. Select the active input for TIMx_CCR2: write the CC2S bits to 10 in the TIMx_CCMR1 register (TI1 selected).
5. Select the active polarity for TI1FP2 (used for capture in TIMx_CCR2): write the CC2P and CC2NP bits to CC2P/CC2NP='10' (active on falling edge).
6. Select the valid trigger input: write the TS bits to 00101 in the TIMx_SMCR register (TI1FP1 selected).
7. Configure the slave mode controller in reset mode: write the SMS bits to 0100 in the TIMx_SMCR register.
8. Enable the captures: write the CC1E and CC2E bits to '1' in the TIMx_CCER register.

Figure 406. PWM input mode timing



43.3.9 Forced output mode

In output mode (CCxS bits = 00 in the TIMx_CCMRx register), each output compare signal (OCxREF and then OCx/OCxN) can be forced to active or inactive level directly by software, independently of any comparison between the output compare register and the counter.

To force an output compare signal (OCXREF/OCx) to its active level, user just needs to write 0101 in the OCxM bits in the corresponding TIMx_CCMRx register. Thus OCXREF is forced high (OCxREF is always active high) and OCx get opposite value to CCxP polarity bit.

For example: CCxP=0 (OCx active high) => OCx is forced to high level.

The OCxREF signal can be forced low by writing the OCxM bits to 0100 in the TIMx_CCMRx register.

Anyway, the comparison between the TIMx_CCRx shadow register and the counter is still performed and allows the flag to be set. Interrupt and DMA requests can be sent accordingly. This is described in the output compare mode section below.

43.3.10 Output compare mode

This function is used to control an output waveform or indicate when a period of time has elapsed. Channels 1 to 4 can be output, while Channel 5 and 6 are only available inside the device (for instance, for compound waveform generation or for ADC triggering).

When a match is found between the capture/compare register and the counter, the output compare function:

- Assigns the corresponding output pin to a programmable value defined by the output compare mode (OCxM bits in the TIMx_CCMRx register) and the output polarity (CCxP bit in the TIMx_CCER register). The output pin can keep its level (OCXM=0000), be set active (OCxM=0001), be set inactive (OCxM=0010) or can toggle (OCxM=0011) on match.
- Sets a flag in the interrupt status register (CCxIF bit in the TIMx_SR register).
- Generates an interrupt if the corresponding interrupt mask is set (CCXIE bit in the TIMx_DIER register).
- Sends a DMA request if the corresponding enable bit is set (CCxDE bit in the TIMx_DIER register, CCDS bit in the TIMx_CR2 register for the DMA request selection).

The TIMx_CCRx registers can be programmed with or without preload registers using the OCxPE bit in the TIMx_CCMRx register.

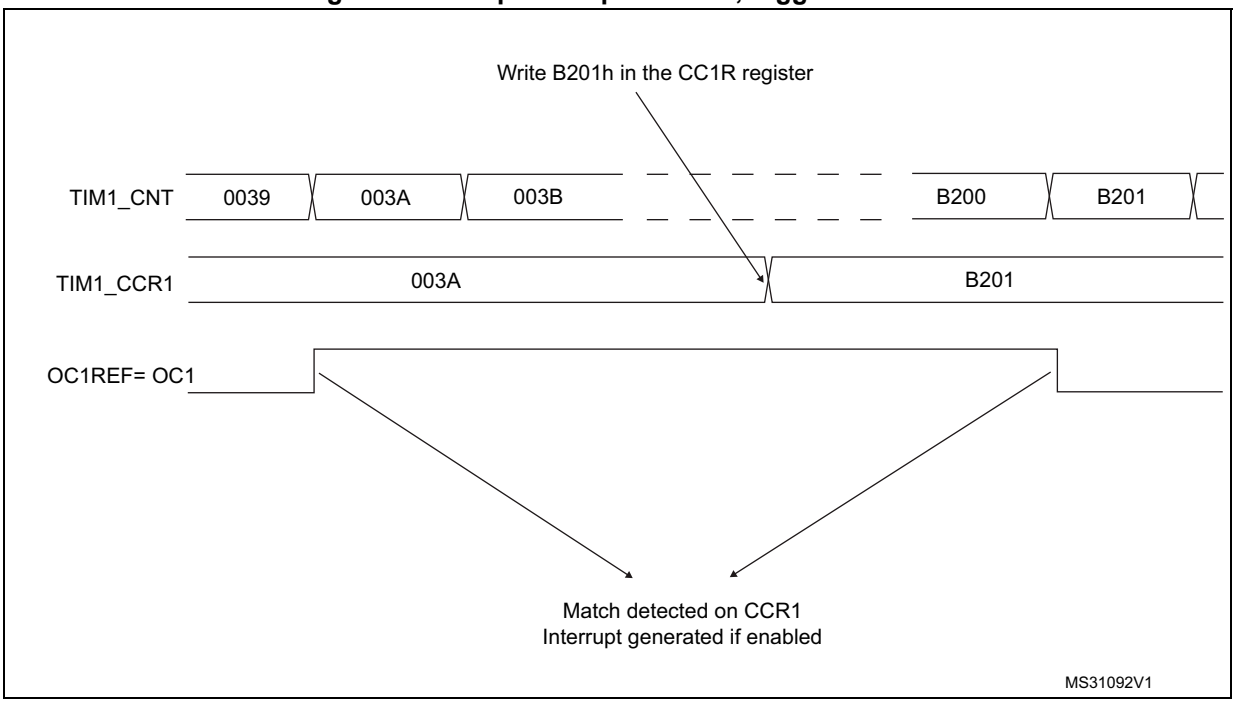
In output compare mode, the update event UEV has no effect on OCxREF and OCx output. The timing resolution is one count of the counter. Output compare mode can also be used to output a single pulse (in One Pulse mode).

Procedure

1. Select the counter clock (internal, external, prescaler).
2. Write the desired data in the TIMx_ARR and TIMx_CCRx registers.
3. Set the CCxIE bit if an interrupt request is to be generated.
4. Select the output mode. For example:
   - Write OCxM = 0011 to toggle OCx output pin when CNT matches CCRx
   - Write OCxPE = 0 to disable preload register
   - Write CCxP = 0 to select active high polarity
   - Write CCxE = 1 to enable the output
5. Enable the counter by setting the CEN bit in the TIMx_CR1 register.

The TIMx_CCRx register can be updated at any time by software to control the output waveform, provided that the preload register is not enabled (OCxPE='0', else TIMx_CCRx shadow register is updated only at the next update event UEV). An example is given in *Figure 407*.

Figure 407. Output compare mode, toggle on OC1



43.3.11 PWM mode

Pulse Width Modulation mode allows a signal to be generated with a frequency determined by the value of the TIMx_ARR register and a duty cycle determined by the value of the TIMx_CCRx register.

The PWM mode can be selected independently on each channel (one PWM per OCx output) by writing ‘0110’ (PWM mode 1) or ‘0111’ (PWM mode 2) in the OCxM bits in the TIMx_CCMRx register. The corresponding preload register must be enabled by setting the OCxPE bit in the TIMx_CCMRx register, and eventually the auto-reload preload register (in upcounting or center-aligned modes) by setting the ARPE bit in the TIMx_CR1 register.

As the preload registers are transferred to the shadow registers only when an update event occurs, before starting the counter, all registers must be initialized by setting the UG bit in the TIMx_EGR register.

OCx polarity is software programmable using the CCxP bit in the TIMx_CCER register. It can be programmed as active high or active low. OCx output is enabled by a combination of the CCxE, CCxNE, MOE, OSSI and OSSR bits (TIMx_CCER and TIMx_BDTR registers). Refer to the TIMx_CCER register description for more details.

In PWM mode (1 or 2), TIMx_CNT and TIMx_CCRx are always compared to determine whether TIMx_CCRx ≤ TIMx_CNT or TIMx_CNT ≤ TIMx_CCRx (depending on the direction of the counter).

The timer is able to generate PWM in edge-aligned mode or center-aligned mode depending on the CMS bits in the TIMx_CR1 register.

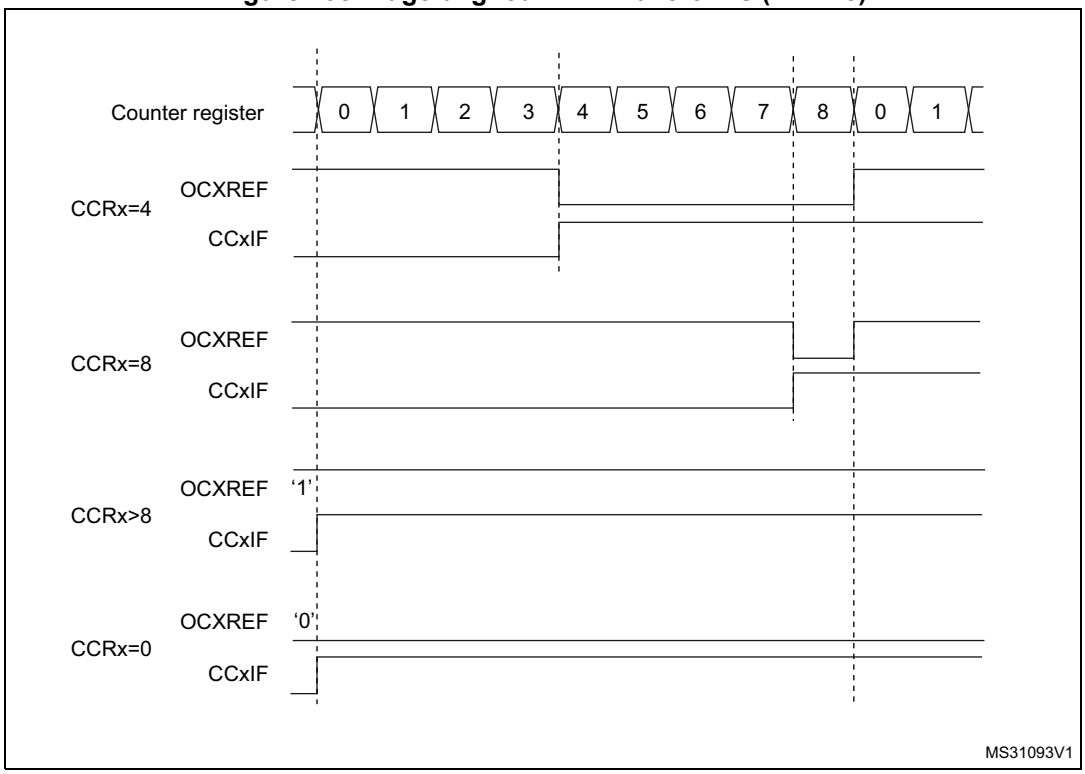
PWM edge-aligned mode

- Upcounting configuration

  Upcounting is active when the DIR bit in the TIMx_CR1 register is low. Refer to the *Upcounting mode on page 1559*.

  In the following example, we consider PWM mode 1. The reference PWM signal OCxREF is high as long as TIMx_CNT < TIMx_CCRx else it becomes low. If the compare value in TIMx_CCRx is greater than the auto-reload value (in TIMx_ARR) then OCxREF is held at ‘1’. If the compare value is 0 then OCxRef is held at ‘0’. *Figure 408* shows some edge-aligned PWM waveforms in an example where TIMx_ARR=8.

Figure 408. Edge-aligned PWM waveforms (ARR=8)



- Downcounting configuration

  Downcounting is active when DIR bit in TIMx_CR1 register is high. Refer to the *Downcounting mode on page 1563*

  In PWM mode 1, the reference signal OCxRef is low as long as TIMx_CNT > TIMx_CCRx else it becomes high. If the compare value in TIMx_CCRx is greater than the auto-reload value in TIMx_ARR, then OCxREF is held at ‘1’. 0% PWM is not possible in this mode.

PWM center-aligned mode

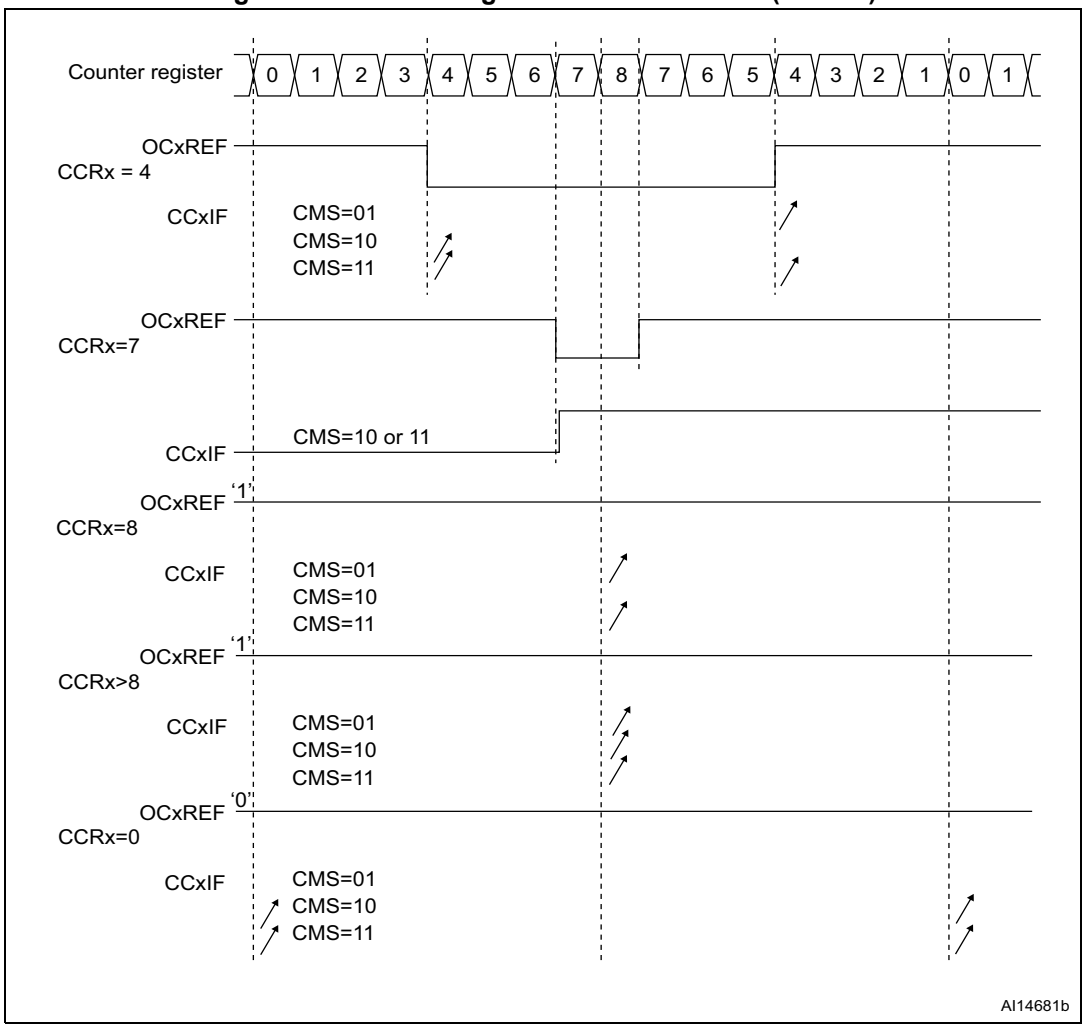
Center-aligned mode is active when the CMS bits in TIMx_CR1 register are different from ‘00’ (all the remaining configurations having the same effect on the OCxRef/OCx signals). The compare flag is set when the counter counts up, when it counts down or both when it counts up and down depending on the CMS bits configuration. The direction bit (DIR) in the

TIMx_CR1 register is updated by hardware and must not be changed by software. Refer to the *Center-aligned mode (up/down counting) on page 1566*.

Figure 409 shows some center-aligned PWM waveforms in an example where:

- TIMx_ARR=8,
- PWM mode is the PWM mode 1,
- The flag is set when the counter counts down corresponding to the center-aligned mode 1 selected for CMS=01 in TIMx_CR1 register.

Figure 409. Center-aligned PWM waveforms (ARR=8)



Hints on using center-aligned mode

- When starting in center-aligned mode, the current up-down configuration is used. It means that the counter counts up or down depending on the value written in the DIR bit

in the TIMx_CR1 register. Moreover, the DIR and CMS bits must not be changed at the same time by the software.

- Writing to the counter while running in center-aligned mode is not recommended as it can lead to unexpected results. In particular:
  - The direction is not updated if a value greater than the auto-reload value is written in the counter (TIMx_CNT>TIMx_ARR). For example, if the counter was counting up, it continues to count up.
  - The direction is updated if 0 or the TIMx_ARR value is written in the counter but no Update Event UEV is generated.
- The safest way to use center-aligned mode is to generate an update by software (setting the UG bit in the TIMx_EGR register) just before starting the counter and not to write the counter while it is running.

43.3.12 Asymmetric PWM mode

Asymmetric mode allows two center-aligned PWM signals to be generated with a programmable phase shift. While the frequency is determined by the value of the TIMx_ARR register, the duty cycle and the phase-shift are determined by a pair of TIMx_CCRx register. One register controls the PWM during up-counting, the second during down counting, so that PWM is adjusted every half PWM cycle:

- OC1REFC (or OC2REFC) is controlled by TIMx_CCR1 and TIMx_CCR2
- OC3REFC (or OC4REFC) is controlled by TIMx_CCR3 and TIMx_CCR4

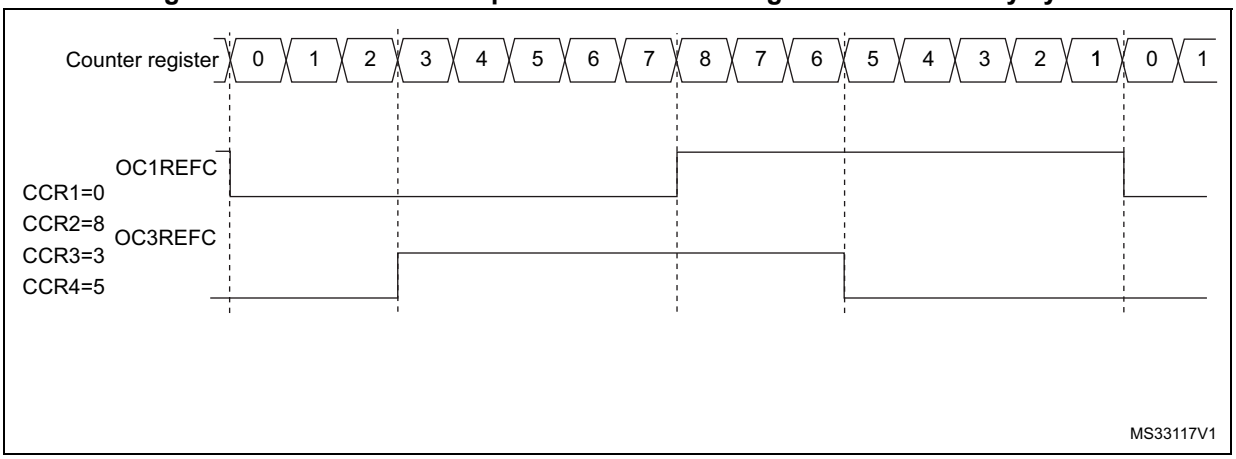
Asymmetric PWM mode can be selected independently on two channel (one OCx output per pair of CCR registers) by writing ‘1110’ (Asymmetric PWM mode 1) or ‘1111’ (Asymmetric PWM mode 2) in the OCxM bits in the TIMx_CCMRx register.

Note: The OCxM[3:0] bit field is split into two parts for compatibility reasons, the most significant bit is not contiguous with the 3 least significant ones.

When a given channel is used as asymmetric PWM channel, its complementary channel can also be used. For instance, if an OC1REFC signal is generated on channel 1 (Asymmetric PWM mode 1), it is possible to output either the OC2REF signal on channel 2, or an OC2REFC signal resulting from asymmetric PWM mode 1.

Figure 410 represents an example of signals that can be generated using Asymmetric PWM mode (channels 1 to 4 are configured in Asymmetric PWM mode 1). Together with the deadtime generator, this allows a full-bridge phase-shifted DC to DC converter to be controlled.

Figure 410. Generation of 2 phase-shifted PWM signals with 50% duty cycle



43.3.13 Combined PWM mode

Combined PWM mode allows two edge or center-aligned PWM signals to be generated with programmable delay and phase shift between respective pulses. While the frequency is determined by the value of the TIMx_ARR register, the duty cycle and delay are determined by the two TIMx_CCRx registers. The resulting signals, OCxREFC, are made of an OR or AND logical combination of two reference PWMs:

- OC1REFC (or OC2REFC) is controlled by TIMx_CCR1 and TIMx_CCR2
- OC3REFC (or OC4REFC) is controlled by TIMx_CCR3 and TIMx_CCR4

Combined PWM mode can be selected independently on two channels (one OCx output per pair of CCR registers) by writing ‘1100’ (Combined PWM mode 1) or ‘1101’ (Combined PWM mode 2) in the OCxM bits in the TIMx_CCMRx register.

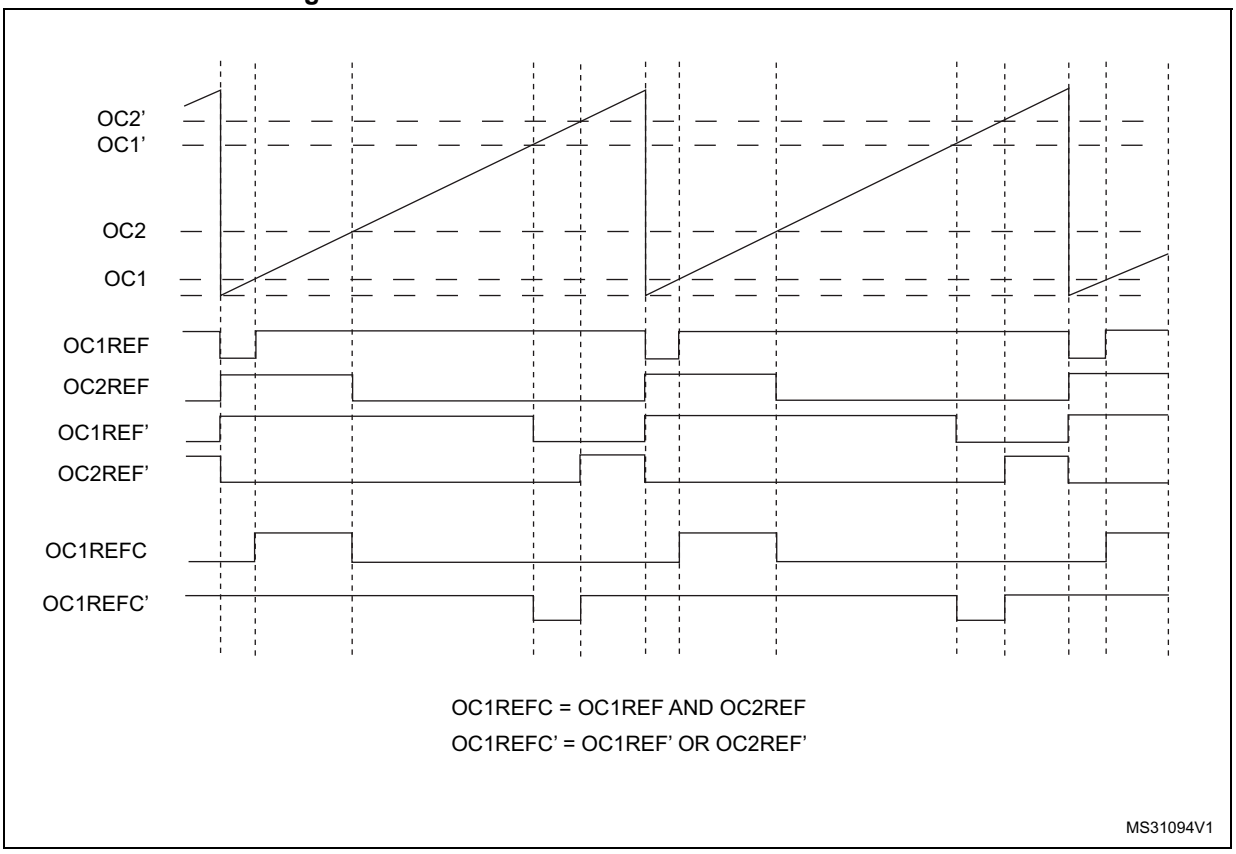
When a given channel is used as combined PWM channel, its complementary channel must be configured in the opposite PWM mode (for instance, one in Combined PWM mode 1 and the other in Combined PWM mode 2).

Note: The OCxM[3:0] bit field is split into two parts for compatibility reasons, the most significant bit is not contiguous with the 3 least significant ones.

Figure 411 represents an example of signals that can be generated using Asymmetric PWM mode, obtained with the following configuration:

- Channel 1 is configured in Combined PWM mode 2,
- Channel 2 is configured in PWM mode 1,
- Channel 3 is configured in Combined PWM mode 2,
- Channel 4 is configured in PWM mode 1.

Figure 411. Combined PWM mode on channel 1 and 3



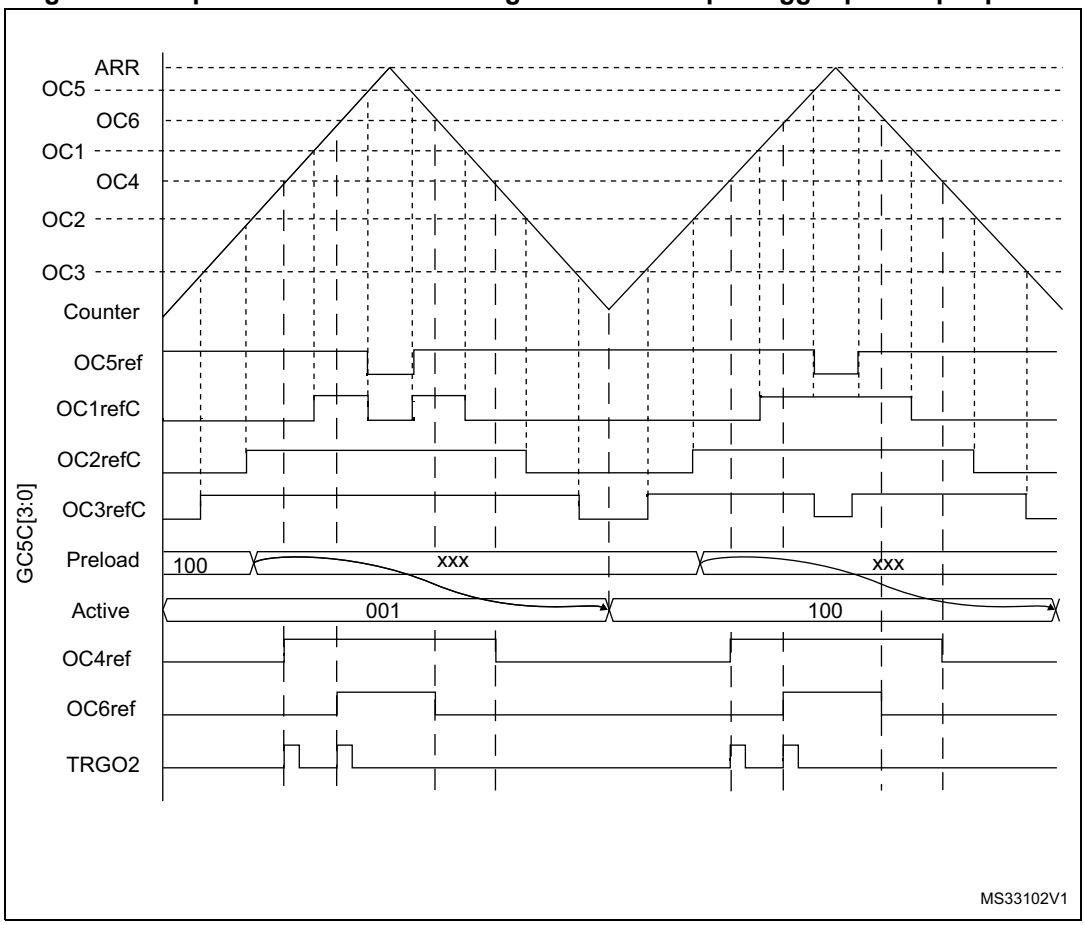
43.3.14 Combined 3-phase PWM mode

Combined 3-phase PWM mode allows one to three center-aligned PWM signals to be generated with a single programmable signal ANDed in the middle of the pulses. The OC5REF signal is used to define the resulting combined signal. The 3-bits GC5C[3:1] in the TIMx_CCR5 allow selection on which reference signal the OC5REF is combined. The resulting signals, OCxREFC, are made of an AND logical combination of two reference PWMs:

- If GC5C1 is set, OC1REFC is controlled by TIMx_CCR1 and TIMx_CCR5
- If GC5C2 is set, OC2REFC is controlled by TIMx_CCR2 and TIMx_CCR5
- If GC5C3 is set, OC3REFC is controlled by TIMx_CCR3 and TIMx_CCR5

Combined 3-phase PWM mode can be selected independently on channels 1 to 3 by setting at least one of the 3-bits GC5C[3:1].

Figure 412. 3-phase combined PWM signals with multiple trigger pulses per period



The TRGO2 waveform shows how the ADC can be synchronized on given 3-phase PWM signals. Refer to *Section 43.3.27: ADC synchronization* for more details.

43.3.15 Complementary outputs and dead-time insertion

The advanced-control timers (TIM1/TIM8) can output two complementary signals and manage the switching-off and the switching-on instants of the outputs.

This time is generally known as dead-time and it has to be adjusted depending on the devices that are connected to the outputs and their characteristics (intrinsic delays of level-shifters, delays due to power switches...)

The polarity of the outputs (main output OCx or complementary OCxN) can be selected independently for each output. This is done by writing to the CCxP and CCxNP bits in the TIMx_CCER register.

The complementary signals OCx and OCxN are activated by a combination of several control bits: the CCxE and CCxNE bits in the TIMx_CCER register and the MOE, OISx, OISxN, OSSI and OSSR bits in the TIMx_BDTR and TIMx_CR2 registers. Refer to *Table 351: Output control bits for complementary OCx and OCxN channels with break feature on page 1635* for more details. In particular, the dead-time is activated when switching to the idle state (MOE falling down to 0).

Dead-time insertion is enabled by setting both CCxE and CCxNE bits, and the MOE bit if the break circuit is present. There is one 10-bit dead-time generator for each channel. From a reference waveform OCxREF, it generates 2 outputs OCx and OCxN. If OCx and OCxN are active high:

- The OCx output signal is the same as the reference signal except for the rising edge, which is delayed relative to the reference rising edge.
- The OCxN output signal is the opposite of the reference signal except for the rising edge, which is delayed relative to the reference falling edge.

If the delay is greater than the width of the active output (OCx or OCxN) then the corresponding pulse is not generated.

The following figures show the relationships between the output signals of the dead-time generator and the reference signal OCxREF. (we suppose CCxP=0, CCxNP=0, MOE=1, CCxE=1 and CCxNE=1 in these examples)

Figure 413. Complementary output with dead-time insertion

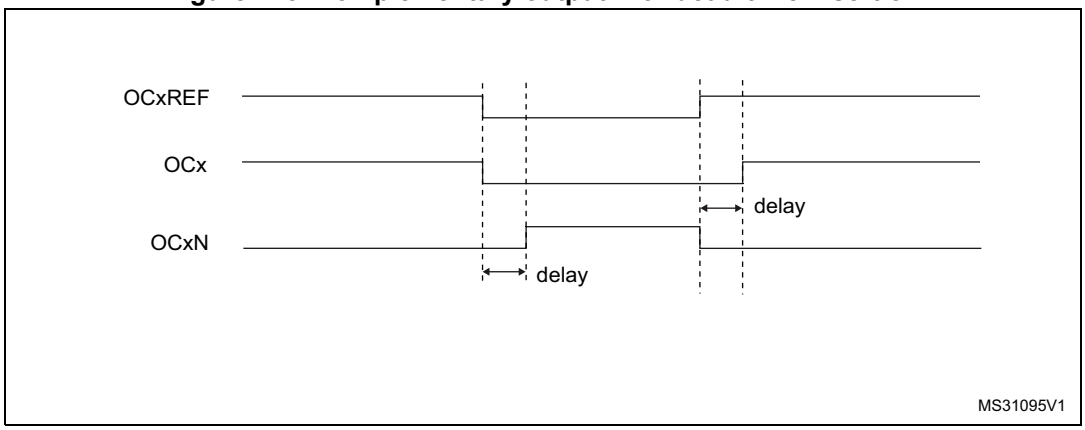


Figure 414. Dead-time waveforms with delay greater than the negative pulse

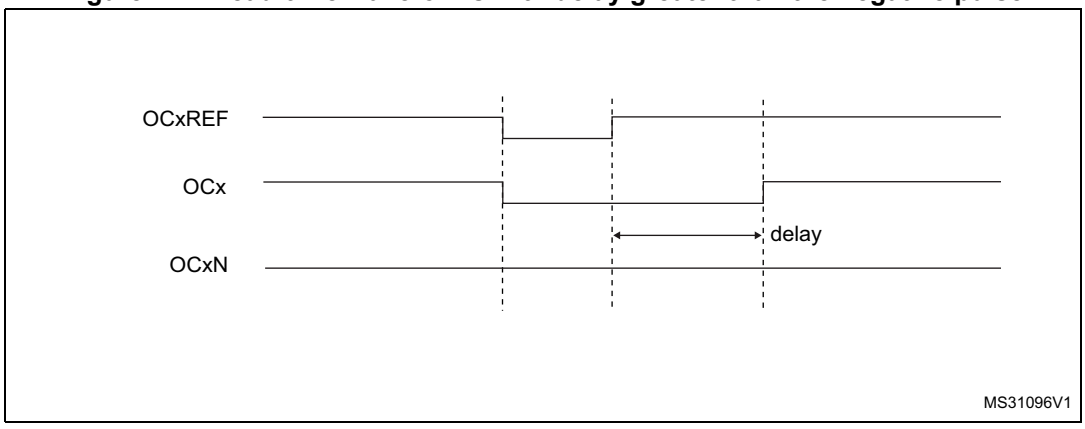
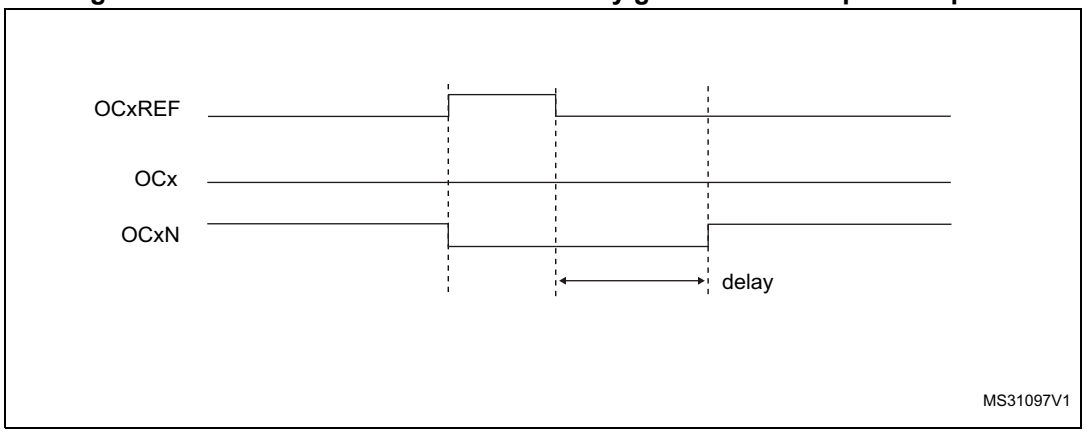


Figure 415. Dead-time waveforms with delay greater than the positive pulse



The dead-time delay is the same for each of the channels and is programmable with the DTG bits in the TIMx_BDTR register. Refer to *Section 43.4.20: TIMx break and dead-time register (TIMx_BDTR)(x = 1, 8)* for delay calculation.

Re-directing OCxREF to OCx or OCxN

In output mode (forced, output compare or PWM), OCxREF can be re-directed to the OCx output or to OCxN output by configuring the CCxE and CCxNE bits in the TIMx_CCER register.

This allows a specific waveform to be sent (such as PWM or static active level) on one output while the complementary remains at its inactive level. Other alternative possibilities are to have both outputs at inactive level or both outputs active and complementary with dead-time.

Note: When only OCxN is enabled (CCxE=0, CCxNE=1), it is not complemented and becomes active as soon as OCxREF is high. For example, if CCxNP=0 then OCxN=OCxRef. On the other hand, when both OCx and OCxN are enabled (CCxE=CCxNE=1) OCx becomes active when OCxREF is high whereas OCxN is complemented and becomes active when OCxREF is low.

43.3.16 Using the break function

The purpose of the break function is to protect power switches driven by PWM signals generated with the TIM1 and TIM8 timers. The two break inputs are usually connected to fault outputs of power stages and 3-phase inverters. When activated, the break circuitry shuts down the PWM outputs and forces them to a predefined safe state. A number of internal MCU events can also be selected to trigger an output shut-down.

The break features two channels. A break channel which gathers both system-level fault (clock failure, parity error,...) and application fault (from input pins and built-in comparator), and can force the outputs to a predefined level (either active or inactive) after a deadtime duration. A break2 channel which only includes application faults and is able to force the outputs to an inactive state.

The output enable signal and output levels during break are depending on several control bits:

- the MOE bit in TIMx_BDTR register allows the outputs to be enabled/disabled by software and is reset in case of break or break2 event.
- the OSSI bit in the TIMx_BDTR register defines whether the timer controls the output in inactive state or releases the control to the GPIO controller (typically to have it in Hi-Z mode)
- the OISx and OISxN bits in the TIMx_CR2 register which are setting the output shut-down level, either active or inactive. The OCx and OCxN outputs cannot be set both to active level at a given time, whatever the OISx and OISxN values. Refer to *Table 351: Output control bits for complementary OCx and OCxN channels with break feature on page 1635* for more details.

When exiting from reset, the break circuit is disabled and the MOE bit is low. The break functions can be enabled by setting the BKE and BK2E bits in the TIMx_BDTR register. The break input polarities can be selected by configuring the BKP and BK2P bits in the same register. BKE/BK2E and BKP/BK2P can be modified at the same time. When the BKE/BK2E and BKP/BK2P bits are written, a delay of 1 APB clock cycle is applied before the writing is effective. Consequently, it is necessary to wait 1 APB clock period to correctly read back the bit after the write operation.

Because MOE falling edge can be asynchronous, a resynchronization circuit has been inserted between the actual signal (acting on the outputs) and the synchronous control bit (accessed in the TIMx_BDTR register). It results in some delays between the asynchronous and the synchronous signals. In particular, if MOE is set to 1 whereas it was low, a delay must be inserted (dummy instruction) before reading it correctly. This is because the write acts on the asynchronous signal whereas the read reflects the synchronous signal.

The sources for break (BRK) channel are:

- An external source connected to one of the BKIN pin (as per selection done in the GPIO alternate function registers), with polarity selection and optional digital filtering
- An internal source:
  - the output from a comparator, with polarity selection and optional digital filtering
  - the analog watchdog output of the DFSDM1 peripheral
  - A system break:

    - the Cortex®-M7 LOCKUP output

    - the PVD output

    - all SRAM and TCM ECC dual error detections (AXI-SRAM, ITCM, DTCM, SRAM1, SRAM2, SRAM3, SRAM4, BKRAM, refer to SYSCFG_CFGR register for details)

    - a Flash memory ECC dual error detection

    - a clock failure event generated by the CSS detector

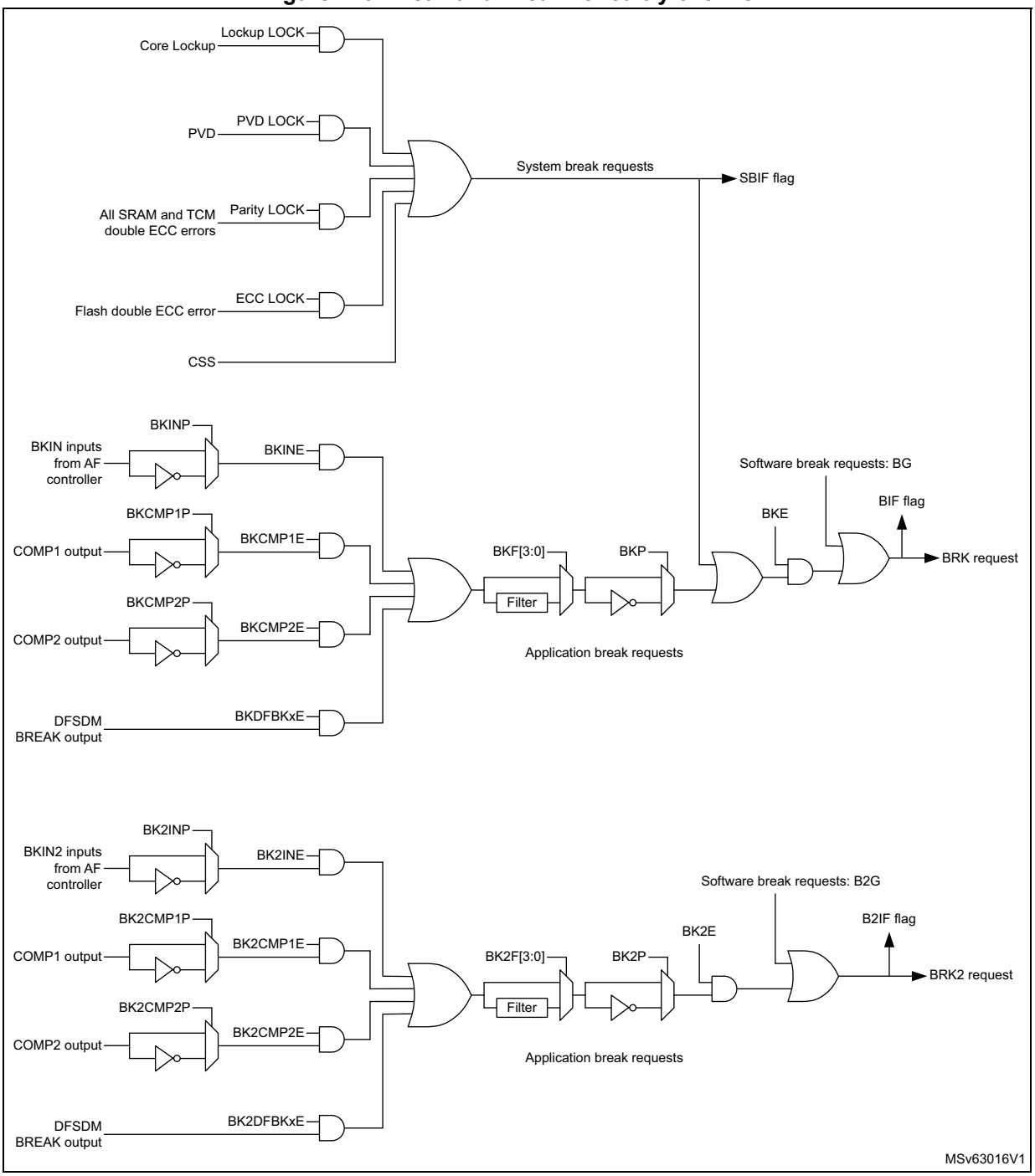
The sources for break2 (BRK2) are:

- An external source connected to one of the BKIN pin (as per selection done in the GPIO alternate function registers), with polarity selection and optional digital filtering
- An internal source coming from a comparator output.
- The analog watchdog output of the DFSDM1 peripheral

Break events can also be generated by software using BG and B2G bits in the TIMx_EGR register. The software break generation using BG and B2G is active whatever the BKE and BK2E enable bits values.

All sources are ORed before entering the timer BRK or BRK2 inputs, as per *Figure 416* below.

Figure 416. Break and Break2 circuitry overview



Note: An asynchronous (clockless) operation is only guaranteed when the programmable filter is disabled. If it is enabled, a fail safe clock mode (for example by using the internal PLL and/or the CSS) must be used to guarantee that break events are handled.

When one of the breaks occurs (selected level on one of the break inputs):

- The MOE bit is cleared asynchronously, putting the outputs in inactive state, idle state or even releasing the control to the GPIO controller (selected by the OSSI bit). This feature is enabled even if the MCU oscillator is off.
- Each output channel is driven with the level programmed in the OISx bit in the TIMx_CR2 register as soon as MOE=0. If OSSI=0, the timer releases the output control (taken over by the GPIO controller), otherwise the enable output remains high.
- When complementary outputs are used:
  - The outputs are first put in inactive state (depending on the polarity). This is done asynchronously so that it works even if no clock is provided to the timer.
  - If the timer clock is still present, then the dead-time generator is reactivated in order to drive the outputs with the level programmed in the OISx and OISxN bits after a dead-time. Even in this case, OCx and OCxN cannot be driven to their active level together. Note that because of the resynchronization on MOE, the dead-time duration is slightly longer than usual (around 2 ck_tim clock cycles).
  - If OSSI=0, the timer releases the output control (taken over by the GPIO controller which forces a Hi-Z state), otherwise the enable outputs remain or become high as soon as one of the CCxE or CCxNE bits is high.
- The break status flag (SBIF, BIF and B2IF bits in the TIMx_SR register) is set. An interrupt is generated if the BIE bit in the TIMx_DIER register is set.
- If the AOE bit in the TIMx_BDTR register is set, the MOE bit is automatically set again at the next update event (UEV). As an example, this can be used to perform a regulation. Otherwise, MOE remains low until the application sets it to '1' again. In this case, it can be used for security and the break input can be connected to an alarm from power drivers, thermal sensors or any security components.

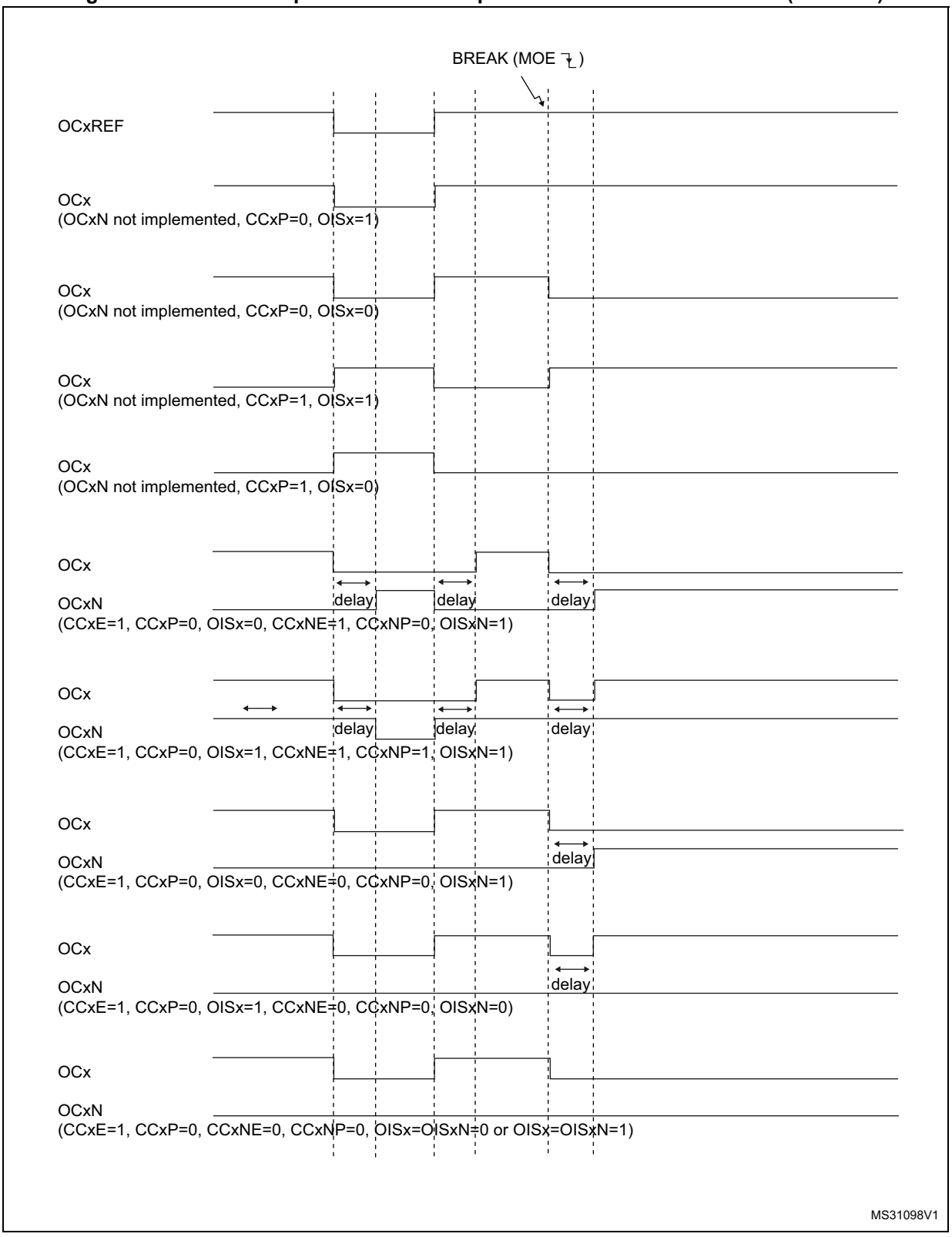
Note: If the MOE is reset by the CPU while the AOE bit is set, the outputs will be in idle state and forced to inactive level or Hi-Z depending on OSSI value.
If both the MOE and AOE bits are reset by the CPU, the outputs will be in disabled state and driven with the level programmed in the OISx bit in the TIMx_CR2 register.

Note: The break inputs are active on level. Thus, the MOE cannot be set while the break input is active (neither automatically nor by software). In the meantime, the status flag BIF and B2IF cannot be cleared.

In addition to the break input and the output management, a write protection has been implemented inside the break circuit to safeguard the application. It allows the configuration of several parameters to be freezed (dead-time duration, OCx/OCxN polarities and state when disabled, OCxM configurations, break enable and polarity). The application can choose from 3 levels of protection selected by the LOCK bits in the TIMx_BDTR register. Refer to *Section 43.4.20: TIMx break and dead-time register (TIMx_BDTR)(x = 1, 8)*. The LOCK bits can be written only once after an MCU reset.

Figure 417 shows an example of behavior of the outputs in response to a break.

Figure 417. Various output behavior in response to a break event on BRK (OSSI = 1)



The two break inputs have different behaviors on timer outputs:

- The BRK input can either disable (inactive state) or force the PWM outputs to a predefined safe state.
- BRK2 can only disable (inactive state) the PWM outputs.

The BRK has a higher priority than BRK2 input, as described in *Table 347*.

Note: BRK2 must only be used with OSSR = OSSI = 1.

Table 347. Behavior of timer outputs versus BRK/BRK2 inputs

BRK	BRK2	Timer outputs state	Typical use case	
			OCxN output (low side switches)	OCx output (high side switches)
Active	X	– Inactive then forced output state (after a deadtime) – Outputs disabled if OSSI = 0 (control taken over by GPIO logic)	ON after deadtime insertion	OFF
Inactive	Active	Inactive	OFF	OFF

Figure 418 gives an example of OCx and OCxN output behavior in case of active signals on BRK and BRK2 inputs. In this case, both outputs have active high polarities (CCxP = CCxNP = 0 in TIMx_CCER register).

Figure 418. PWM output state following BRK and BRK2 pins assertion (OSSI=1)

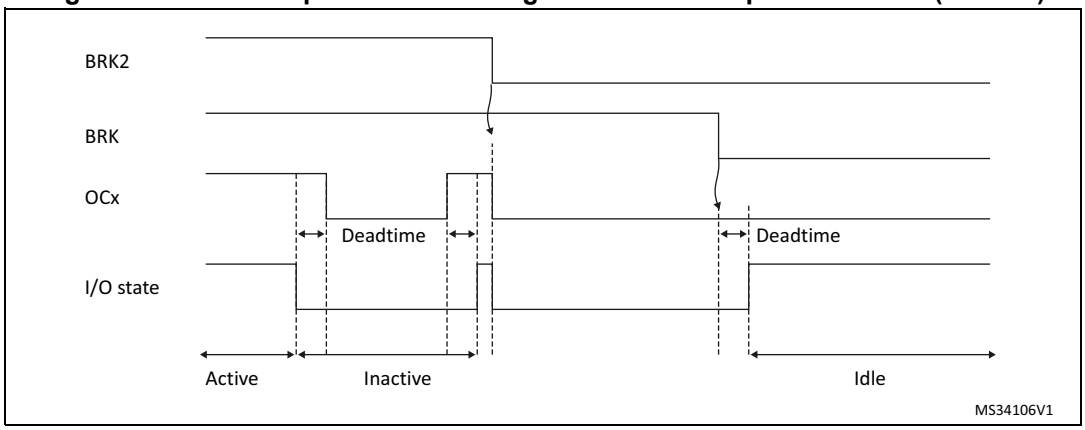
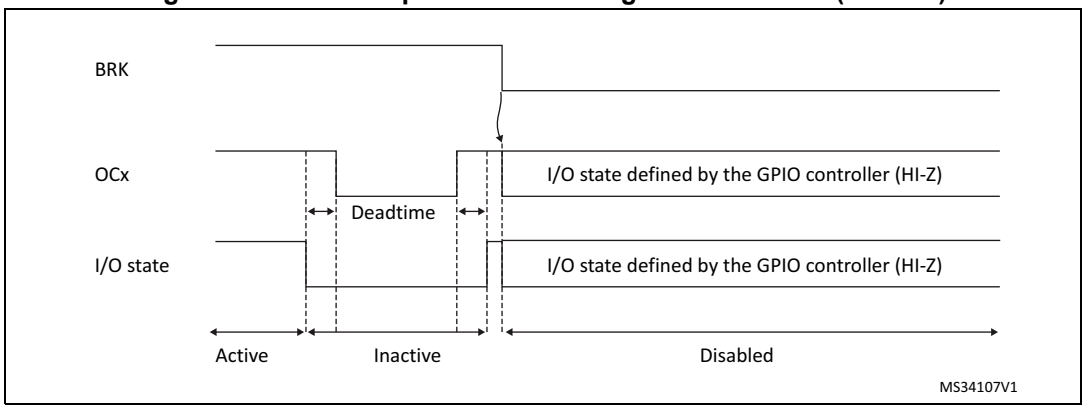


Figure 419. PWM output state following BRK assertion (OSSI=0)



43.3.17 Bidirectional break inputs

The TIM1/TIM8 are featuring bidirectional break I/Os, as represented on *Figure 420*.

They allow the following:

- A board-level global break signal available for signaling faults to external MCUs or gate drivers, with a unique pin being both an input and an output status pin
- Internal break sources and multiple external open drain comparator outputs ORed together to trigger a unique break event, when multiple internal and external break sources must be merged

The break and break2 inputs are configured in bidirectional mode using the BKBID and BK2BID bits in the TIMxBDTR register. The BKBID programming bits can be locked in read-only mode using the LOCK bits in the TIMxBDTR register (in LOCK level 1 or above).

The bidirectional mode is available for both the break and break2 inputs, and require the I/O to be configured in open-drain mode with active low polarity (using BKINP, BKP, BK2INP and BK2P bits). Any break request coming either from system (e.g. CSS), from on-chip peripherals or from break inputs forces a low level on the break input to signal the fault event. The bidirectional mode is inhibited if the polarity bits are not correctly set (active high polarity), for safety purposes.

The break software events (BG and B2G) also cause the break I/O to be forced to '0' to indicate to the external components that the timer has entered in break state. However, this is valid only if the break is enabled (BK(2)E = 1). When a software break event is generated with BK(2)E = 0, the outputs are put in safe state and the break flag is set, but there is no effect on the break(2) I/O.

A safe disarming mechanism prevents the system to be definitively locked-up (a low level on the break input triggers a break which enforces a low level on the same input).

When the BKDSRM (BK2DSRM) bit is set to 1, this releases the break output to clear a fault signal and to give the possibility to re-arm the system.

At no point the break protection circuitry can be disabled:

- The break input path is always active: a break event is active even if the BKDSRM (BK2DSRM) bit is set and the open drain control is released. This prevents the PWM output to be re-started as long as the break condition is present.
- The BK(2)DSRM bit cannot disarm the break protection as long as the outputs are enabled (MOE bit is set) (see *Table 348*)

Table 348. Break protection disarming conditions

MOE	BKDIR (BK2DIR)	BKDSRM (BK2DSRM)	Break protection state
0	0	X	Armed
0	1	0	Armed
0	1	1	Disarmed
1	X	X	Armed

Arming and re-arming break circuitry

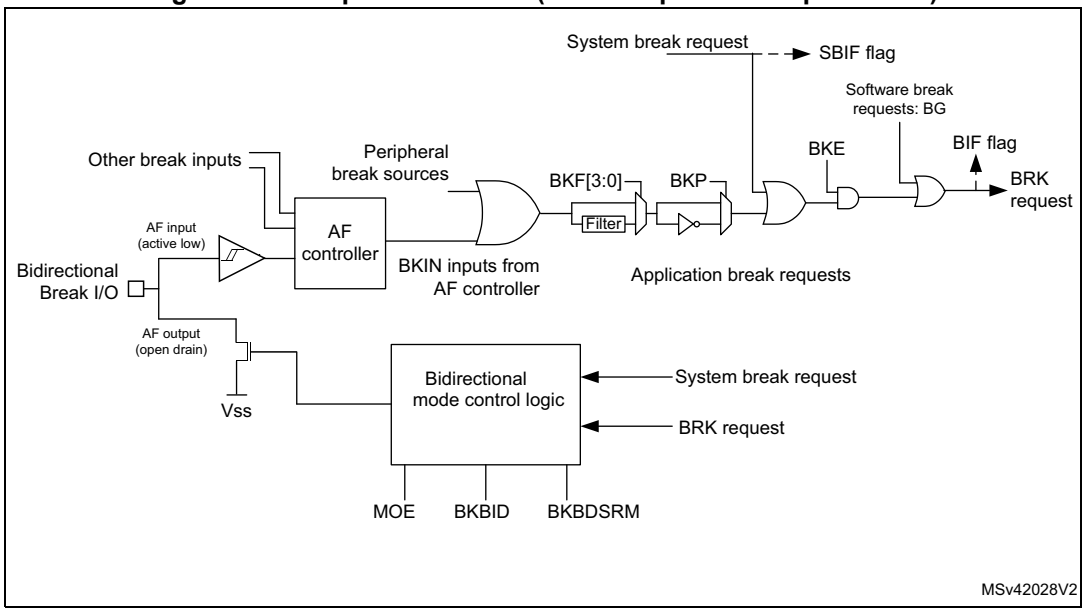
The break circuitry (in input or bidirectional mode) is armed by default (peripheral reset configuration).

The following procedure must be followed to re-arm the protection after a break (break2) event:

- The BKDSRM (BK2DSRM) bit must be set to release the output control
- The software must wait until the system break condition disappears (if any) and clear the SBIF status flag (or clear it systematically before re-arming)
- The software must poll the BKDSRM (BK2DSRM) bit until it is cleared by hardware (when the application break condition disappears)

From this point, the break circuitry is armed and active, and the MOE bit can be set to re-enable the PWM outputs.

Figure 420. Output redirection (BRK2 request not represented)



43.3.18 Clearing the OCxREF signal on an external event

The OCxREF signal of a given channel can be cleared when a high level is applied on the ocref_clr_int input (OCxCE enable bit in the corresponding TIMx_CCMRx register set to 1). OCxREF remains low until the next update event (UEV) occurs. This function can only be

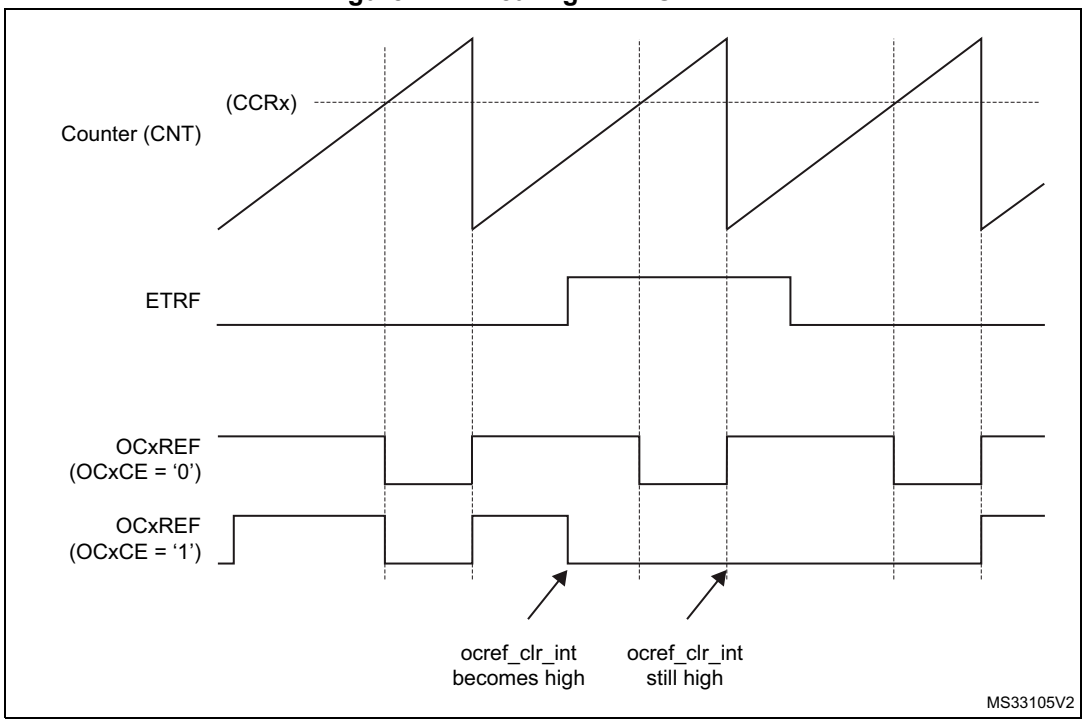
used in Output compare and PWM modes. It does not work in Forced mode. The ocref_clr_int is connected to the ETRF signal (ETR after filtering).

When ETRF is chosen, ETR must be configured as follows:

1. The External Trigger Prescaler should be kept off: bits ETPS[1:0] of the TIMx_SMCR register set to ‘00’.
2. The external clock mode 2 must be disabled: bit ECE of the TIMx_SMCR register set to ‘0’.
3. The External Trigger Polarity (ETP) and the External Trigger Filter (ETF) can be configured according to the user needs.

Figure 421 shows the behavior of the OCxREF signal when the ETRF Input becomes High, for both values of the enable bit OCxCE. In this example, the timer TIMx is programmed in PWM mode.

Figure 421. Clearing TIMx OCxREF



Note: In case of a PWM with a 100% duty cycle (if CCRx>ARR), then OCxREF is enabled again at the next counter overflow.

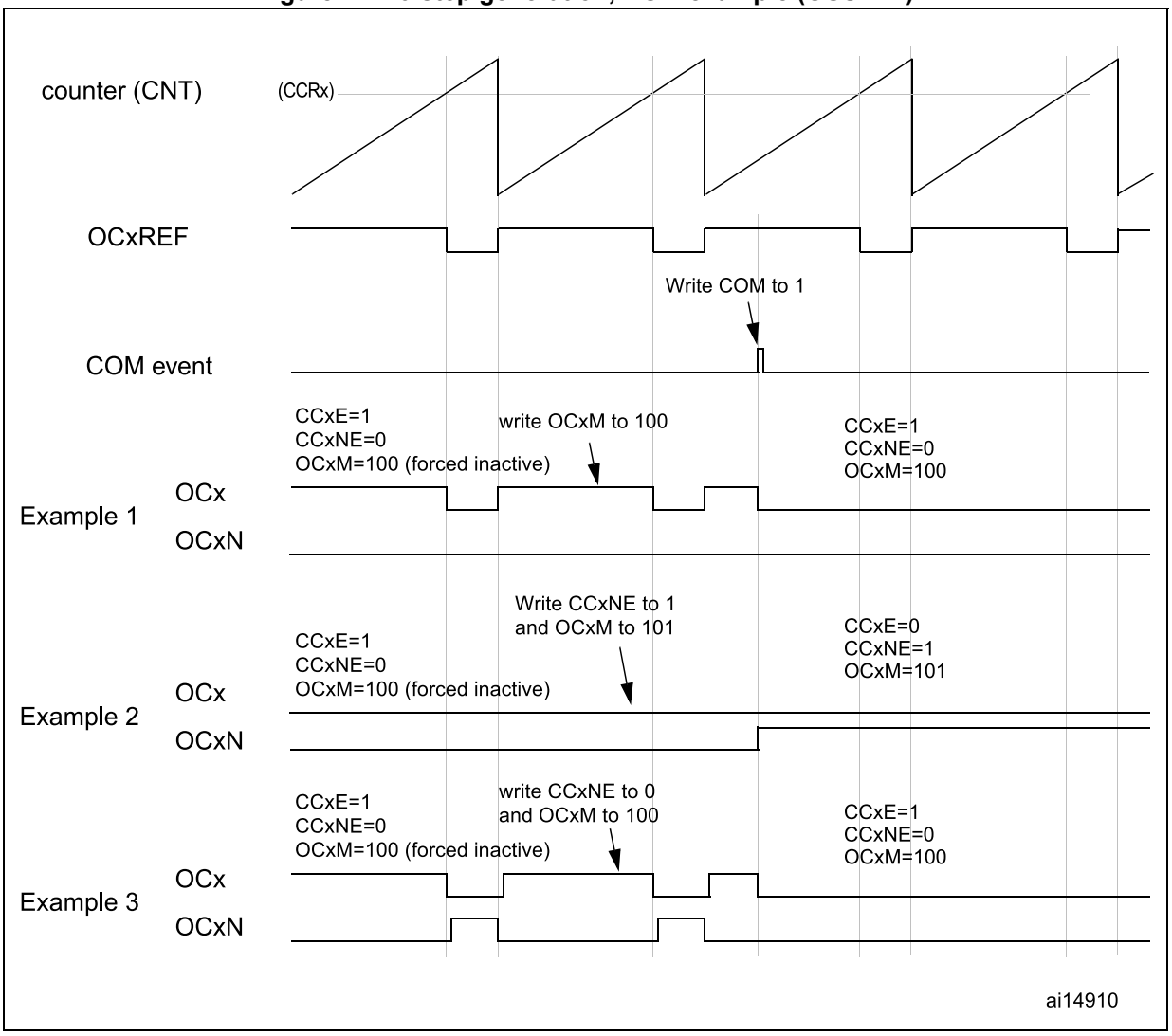
43.3.19 6-step PWM generation

When complementary outputs are used on a channel, preload bits are available on the OCxM, CCxE and CCxNE bits. The preload bits are transferred to the shadow bits at the COM commutation event. Thus one can program in advance the configuration for the next step and change the configuration of all the channels at the same time. COM can be generated by software by setting the COM bit in the TIMx_EGR register or by hardware (on TRGI rising edge).

A flag is set when the COM event occurs (COMIF bit in the TIMx_SR register), which can generate an interrupt (if the COMIE bit is set in the TIMx_DIER register) or a DMA request (if the COMDE bit is set in the TIMx_DIER register).

The *Figure 422* describes the behavior of the OCx and OCxN outputs when a COM event occurs, in 3 different examples of programmed configurations.

Figure 422. 6-step generation, COM example (OSSR=1)



43.3.20 One-pulse mode

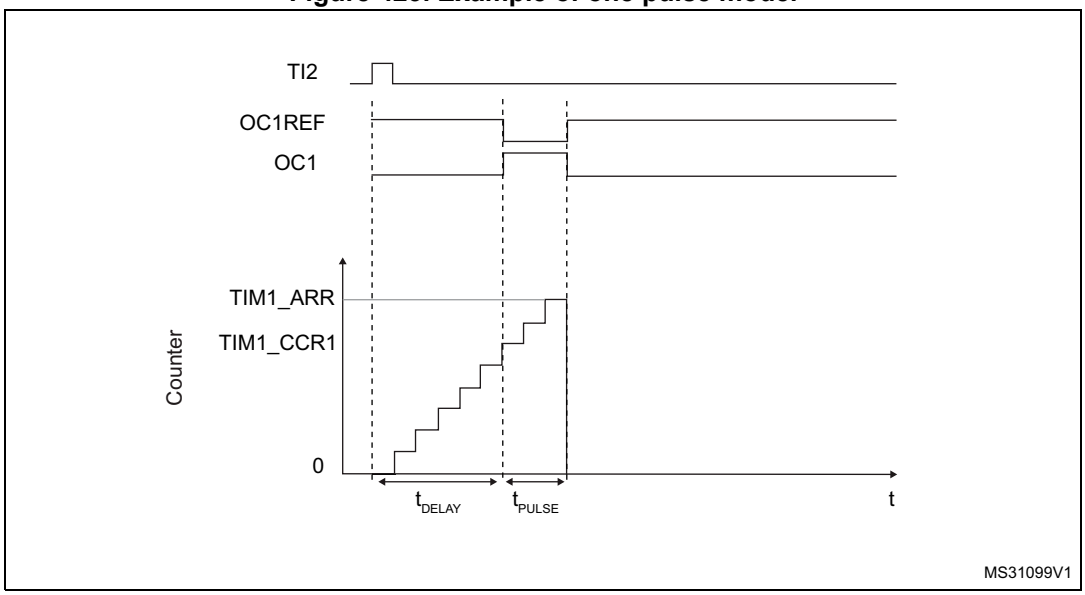
One-pulse mode (OPM) is a particular case of the previous modes. It allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length after a programmable delay.

Starting the counter can be controlled through the slave mode controller. Generating the waveform can be done in output compare mode or PWM mode. One-pulse mode is selected by setting the OPM bit in the TIMx_CR1 register. This makes the counter stop automatically at the next update event UEV.

A pulse can be correctly generated only if the compare value is different from the counter initial value. Before starting (when the timer is waiting for the trigger), the configuration must be:

- In upcounting: CNT < CCRx ≤ ARR (in particular, 0 < CCRx)
- In downcounting: CNT > CCRx

Figure 423. Example of one pulse mode.



For example one may want to generate a positive pulse on OC1 with a length of t_{PULSE} and after a delay of t_{DELAY} as soon as a positive edge is detected on the TI2 input pin.

Let's use TI2FP2 as trigger 1:

1. Select the proper TI2x source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Map TI2FP2 to TI2 by writing CC2S='01' in the TIMx_CCMR1 register.
3. TI2FP2 must detect a rising edge, write CC2P='0' and CC2NP='0' in the TIMx_CCER register.
4. Configure TI2FP2 as trigger for the slave mode controller (TRGI) by writing TS=00110 in the TIMx_SMCR register.
5. TI2FP2 is used to start the counter by writing SMS to '110' in the TIMx_SMCR register (trigger mode).

The OPM waveform is defined by writing the compare registers (taking into account the clock frequency and the counter prescaler).

- The t_{DELAY} is defined by the value written in the TIMx_CCR1 register.
- The t_{PULSE} is defined by the difference between the auto-reload value and the compare value (TIMx_ARR - TIMx_CCR1).
- Let's say one want to build a waveform with a transition from '0' to '1' when a compare match occurs and a transition from '1' to '0' when the counter reaches the auto-reload value. To do this PWM mode 2 must be enabled by writing OC1M=111 in the TIMx_CCMR1 register. Optionally the preload registers can be enabled by writing OC1PE='1' in the TIMx_CCMR1 register and ARPE in the TIMx_CR1 register. In this case one has to write the compare value in the TIMx_CCR1 register, the auto-reload value in the TIMx_ARR register, generate an update by setting the UG bit and wait for external trigger event on TI2. CC1P is written to '0' in this example.

In our example, the DIR and CMS bits in the TIMx_CR1 register should be low.

Since only 1 pulse (Single mode) is needed, a 1 must be written in the OPM bit in the TIMx_CR1 register to stop the counter at the next update event (when the counter rolls over from the auto-reload value back to 0). When OPM bit in the TIMx_CR1 register is set to '0', so the Repetitive Mode is selected.

Particular case: OCx fast enable:

In One-pulse mode, the edge detection on TIx input set the CEN bit which enables the counter. Then the comparison between the counter and the compare value makes the output toggle. But several clock cycles are needed for these operations and it limits the minimum delay t_{DELAY} min we can get.

If one wants to output a waveform with the minimum delay, the OCxFE bit can be set in the TIMx_CCMRx register. Then OCxRef (and OCx) are forced in response to the stimulus, without taking in account the comparison. Its new level is the same as if a compare match had occurred. OCxFE acts only if the channel is configured in PWM1 or PWM2 mode.

43.3.21 Retriggerable one pulse mode

This mode allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length, but with the following differences with Non-retriggerable one pulse mode described in *Section 43.3.20*:

- The pulse starts as soon as the trigger occurs (no programmable delay)
- The pulse is extended if a new trigger occurs before the previous one is completed

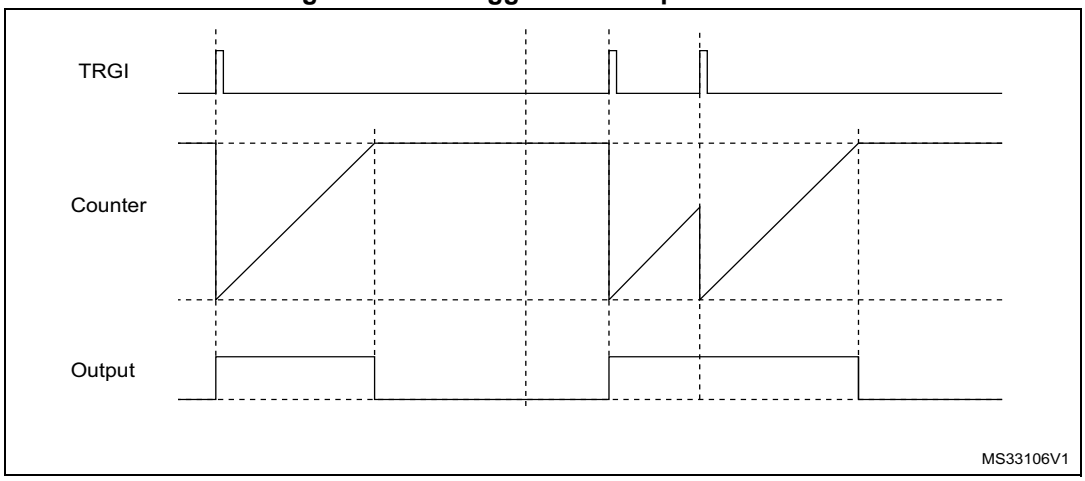
The timer must be in Slave mode, with the bits SMS[3:0] = '1000' (Combined Reset + trigger mode) in the TIMx_SMCR register, and the OCxM[3:0] bits set to '1000' or '1001' for Retrigerrable OPM mode 1 or 2.

If the timer is configured in Up-counting mode, the corresponding CCRx must be set to 0 (the ARR register sets the pulse length). If the timer is configured in Down-counting mode, CCRx must be above or equal to ARR.

Note: The OCxM[3:0] and SMS[3:0] bit fields are split into two parts for compatibility reasons, the most significant bit are not contiguous with the 3 least significant ones.

This mode must not be used with center-aligned PWM modes. It is mandatory to have CMS[1:0] = 00 in TIMx_CR1.

Figure 424. Retriggerable one pulse mode



43.3.22 Encoder interface mode

To select Encoder Interface mode write SMS='001' in the TIMx_SMCR register if the counter is counting on TI2 edges only, SMS='010' if it is counting on TI1 edges only and SMS='011' if it is counting on both TI1 and TI2 edges.

Select the TI1 and TI2 polarity by programming the CC1P and CC2P bits in the TIMx_CCER register. When needed, the input filter can be programmed as well. CC1NP and CC2NP must be kept low.

The two inputs TI1 and TI2 are used to interface to a quadrature encoder. Refer to *Table 349*. The counter is clocked by each valid transition on TI1FP1 or TI2FP2 (TI1 and TI2 after input filter and polarity selection, TI1FP1=TI1 if not filtered and not inverted, TI2FP2=TI2 if not filtered and not inverted) assuming that it is enabled (CEN bit in TIMx_CR1 register written to '1'). The sequence of transitions of the two inputs is evaluated and generates count pulses as well as the direction signal. Depending on the sequence the counter counts up or down, the DIR bit in the TIMx_CR1 register is modified by hardware accordingly. The DIR bit is calculated at each transition on any input (TI1 or TI2), whatever the counter is counting on TI1 only, TI2 only or both TI1 and TI2.

Encoder interface mode acts simply as an external clock with direction selection. This means that the counter just counts continuously between 0 and the auto-reload value in the TIMx_ARR register (0 to ARR or ARR down to 0 depending on the direction). So the TIMx_ARR must be configured before starting. In the same way, the capture, compare, repetition counter, trigger output features continue to work as normal. Encoder mode and External clock mode 2 are not compatible and must not be selected together.

Note: The prescaler must be set to zero when encoder mode is enabled

In this mode, the counter is modified automatically following the speed and the direction of the quadrature encoder and its content, therefore, always represents the encoder's position. The count direction correspond to the rotation direction of the connected sensor. The table summarizes the possible combinations, assuming TI1 and TI2 do not switch at the same time.

Table 349. Counting direction versus encoder signals

Active edge	Level on opposite signal (TI1FP1 for TI2, TI2FP2 for TI1)	TI1FP1 signal		TI2FP2 signal	
		Rising	Falling	Rising	Falling
Counting on TI1 only	High	Down	Up	No Count	No Count
	Low	Up	Down	No Count	No Count
Counting on TI2 only	High	No Count	No Count	Up	Down
	Low	No Count	No Count	Down	Up
Counting on TI1 and TI2	High	Down	Up	Up	Down
	Low	Up	Down	Down	Up

A quadrature encoder can be connected directly to the MCU without external interface logic. However, comparators are normally be used to convert the encoder's differential outputs to digital signals. This greatly increases noise immunity. The third encoder output which indicate the mechanical zero position, may be connected to an external interrupt input and trigger a counter reset.

The *Figure 425* gives an example of counter operation, showing count signal generation and direction control. It also shows how input jitter is compensated where both edges are selected. This might occur if the sensor is positioned near to one of the switching points. For this example we assume that the configuration is the following:

- CC1S='01' (TIMx_CCMR1 register, TI1FP1 mapped on TI1).
- CC2S='01' (TIMx_CCMR2 register, TI1FP2 mapped on TI2).
- CC1P='0' and CC1NP='0' (TIMx_CCER register, TI1FP1 non-inverted, TI1FP1=TI1).
- CC2P='0' and CC2NP='0' (TIMx_CCER register, TI1FP2 non-inverted, TI1FP2= TI2).
- SMS='011' (TIMx_SMCR register, both inputs are active on both rising and falling edges).
- CEN='1' (TIMx_CR1 register, Counter enabled).

Figure 425. Example of counter operation in encoder interface mode.

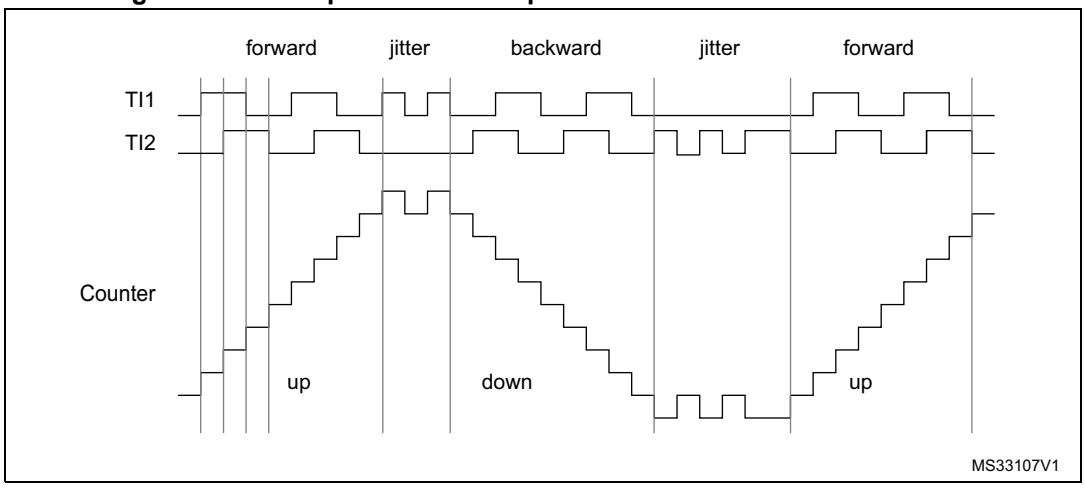
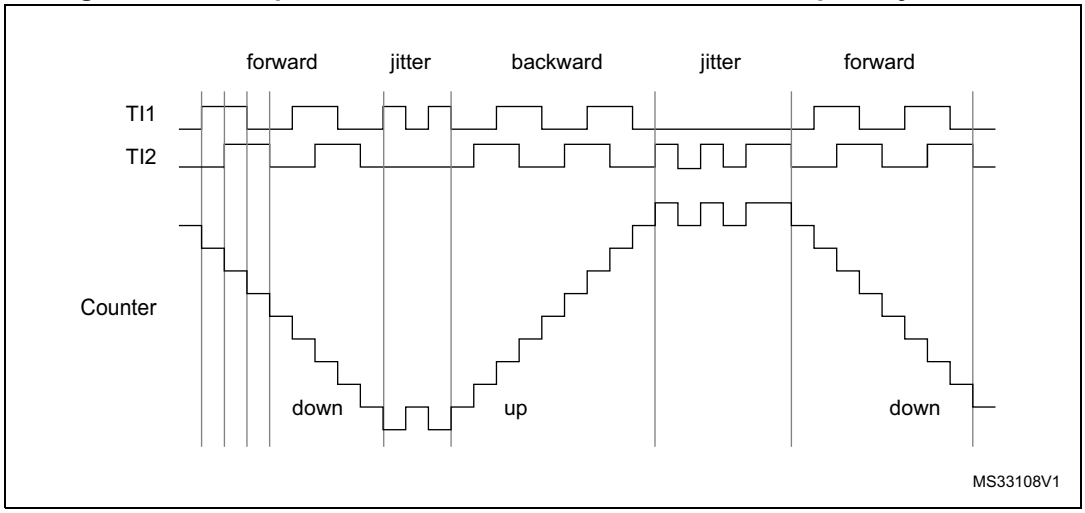


Figure 426 gives an example of counter behavior when TI1FP1 polarity is inverted (same configuration as above except CC1P='1').

Figure 426. Example of encoder interface mode with TI1FP1 polarity inverted.



The timer, when configured in Encoder Interface mode provides information on the sensor's current position. Dynamic information can be obtained (speed, acceleration, deceleration) by measuring the period between two encoder events using a second timer configured in capture mode. The output of the encoder which indicates the mechanical zero can be used for this purpose. Depending on the time between two events, the counter can also be read at regular times. This can be done by latching the counter value into a third input capture register if available (then the capture signal must be periodic and can be generated by another timer). when available, it is also possible to read its value through a DMA request.

The IUFREMAP bit in the TIMx_CR1 register forces a continuous copy of the update interrupt flag (UIF) into the timer counter register's bit 31 (TIMxCNT[31]). This allows both the counter value and a potential roll-over condition signaled by the UIFCPY flag to be read in an atomic way. It eases the calculation of angular speed by avoiding race conditions caused, for instance, by a processing shared between a background task (counter reading) and an interrupt (update interrupt).

There is no latency between the UIF and UIFCPY flag assertions.

In 32-bit timer implementations, when the IUFREMAP bit is set, bit 31 of the counter is overwritten by the UIFCPY flag upon read access (the counter's most significant bit is only accessible in write mode).

43.3.23 UIF bit remapping

The IUFREMAP bit in the TIMx_CR1 register forces a continuous copy of the Update Interrupt Flag UIF into the timer counter register's bit 31 (TIMxCNT[31]). This allows both the counter value and a potential roll-over condition signaled by the UIFCPY flag to be read in an atomic way. In particular cases, it can ease the calculations by avoiding race conditions, caused for instance by a processing shared between a background task (counter reading) and an interrupt (Update Interrupt).

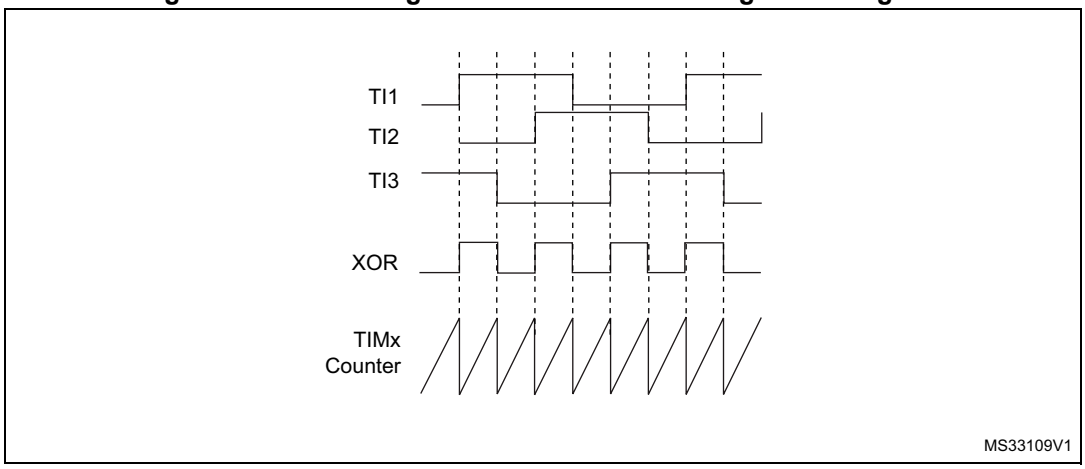
There is no latency between the UIF and UIFCPY flags assertion.

43.3.24 Timer input XOR function

The TI1S bit in the TIMx_CR2 register, allows the input filter of channel 1 to be connected to the output of an XOR gate, combining the three input pins TIMx_CH1, TIMx_CH2 and TIMx_CH3.

The XOR output can be used with all the timer input functions such as trigger or input capture. It is convenient to measure the interval between edges on two input signals, as per *Figure 427* below.

Figure 427. Measuring time interval between edges on 3 signals



43.3.25 Interfacing with Hall sensors

This is done using the advanced-control timers (TIM1 or TIM8) to generate PWM signals to drive the motor and another timer TIMx (TIM2, TIM3, TIM4) referred to as “interfacing timer” in *Figure 428*. The “interfacing timer” captures the 3 timer input pins (CC1, CC2, CC3) connected through a XOR to the TI1 input channel (selected by setting the TI1S bit in the TIMx_CR2 register).

The slave mode controller is configured in reset mode; the slave input is TI1F_ED. Thus, each time one of the 3 inputs toggles, the counter restarts counting from 0. This creates a time base triggered by any change on the Hall inputs.

On the “interfacing timer”, capture/compare channel 1 is configured in capture mode, capture signal is TRC (See *Figure 401: Capture/compare channel (example: channel 1 input stage) on page 1577*). The captured value, which corresponds to the time elapsed between 2 changes on the inputs, gives information about motor speed.

The “interfacing timer” can be used in output mode to generate a pulse which changes the configuration of the channels of the advanced-control timer (TIM1 or TIM8) (by triggering a COM event). The TIM1 timer is used to generate PWM signals to drive the motor. To do this, the interfacing timer channel must be programmed so that a positive pulse is generated after a programmed delay (in output compare or PWM mode). This pulse is sent to the advanced-control timer (TIM1 or TIM8) through the TRGO output.

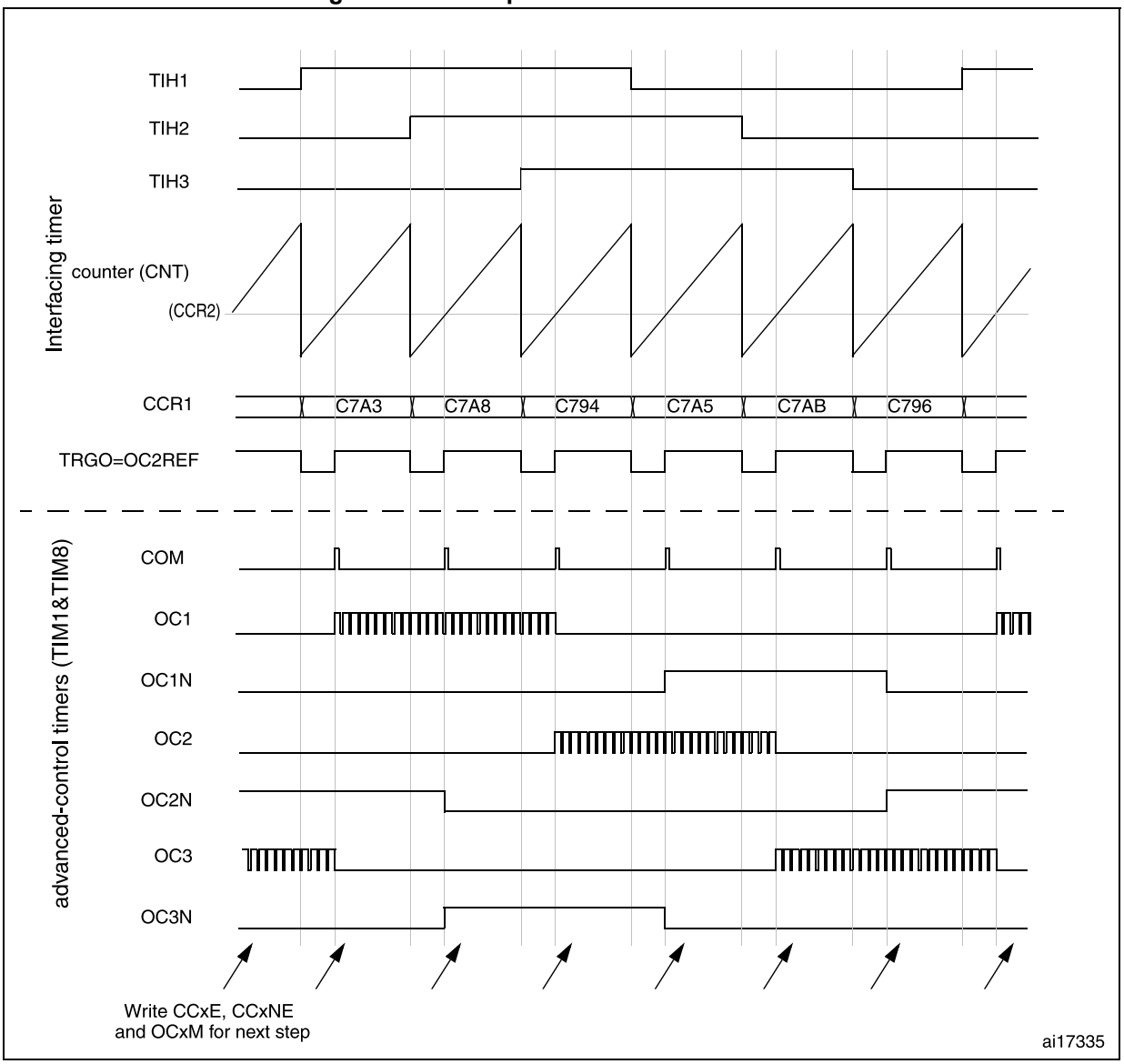
Example: one wants to change the PWM configuration of the advanced-control timer TIM1 after a programmed delay each time a change occurs on the Hall inputs connected to one of the TIMx timers.

- Configure 3 timer inputs ORed to the TI1 input channel by writing the TI1S bit in the TIMx_CR2 register to '1',
- Program the time base: write the TIMx_ARR to the max value (the counter must be cleared by the TI1 change. Set the prescaler to get a maximum counter period longer than the time between 2 changes on the sensors,
- Program the channel 1 in capture mode (TRC selected): write the CC1S bits in the TIMx_CCMR1 register to '01'. The digital filter can also be programmed if needed,
- Program the channel 2 in PWM 2 mode with the desired delay: write the OC2M bits to '111' and the CC2S bits to '00' in the TIMx_CCMR1 register,
- Select OC2REF as trigger output on TRGO: write the MMS bits in the TIMx_CR2 register to '101',

In the advanced-control timer TIM1, the right ITR input must be selected as trigger input, the timer is programmed to generate PWM signals, the capture/compare control signals are preloaded (CCPC=1 in the TIMx_CR2 register) and the COM event is controlled by the trigger input (CCUS=1 in the TIMx_CR2 register). The PWM control bits (CCxE, OCxM) are written after a COM event for the next step (this can be done in an interrupt subroutine generated by the rising edge of OC2REF).

The *Figure 428* describes this example.

Figure 428. Example of Hall sensor interface



43.3.26 Timer synchronization

The TIMx timers are linked together internally for timer synchronization or chaining. Refer to *Section 44.3.19: Timer synchronization* for details. They can be synchronized in several modes: Reset mode, Gated mode, and Trigger mode.

Slave mode: Reset mode

The counter and its prescaler can be reinitialized in response to an event on a trigger input. Moreover, if the URS bit from the TIMx_CR1 register is low, an update event UEV is generated. Then all the preloaded registers (TIMx_ARR, TIMx_CCRx) are updated.

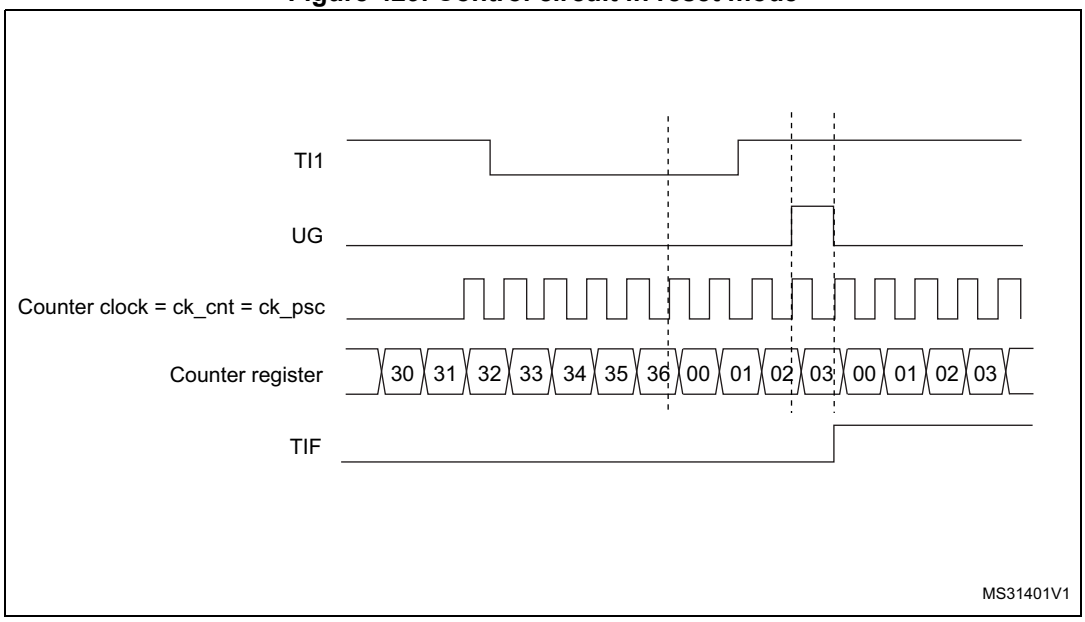
In the following example, the upcounter is cleared in response to a rising edge on TI1 input:

- Configure the channel 1 to detect rising edges on TI1. Configure the input filter duration (in this example, we do not need any filter, so we keep IC1F=0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S = 01 in the TIMx_CCMR1 register. Write CC1P=0 and CC1NP='0' in TIMx_CCER register to validate the polarity (and detect rising edges only).
- Configure the timer in reset mode by writing SMS=100 in TIMx_SMCR register. Select TI1 as the input source by writing TS=00101 in TIMx_SMCR register.
- Start the counter by writing CEN=1 in the TIMx_CR1 register.

The counter starts counting on the internal clock, then behaves normally until TI1 rising edge. When TI1 rises, the counter is cleared and restarts from 0. In the meantime, the trigger flag is set (TIF bit in the TIMx_SR register) and an interrupt request, or a DMA request can be sent if enabled (depending on the TIE and TDE bits in TIMx_DIER register).

The following figure shows this behavior when the auto-reload register TIMx_ARR=0x36. The delay between the rising edge on TI1 and the actual reset of the counter is due to the resynchronization circuit on TI1 input.

Figure 429. Control circuit in reset mode



Slave mode: Gated mode

The counter can be enabled depending on the level of a selected input.

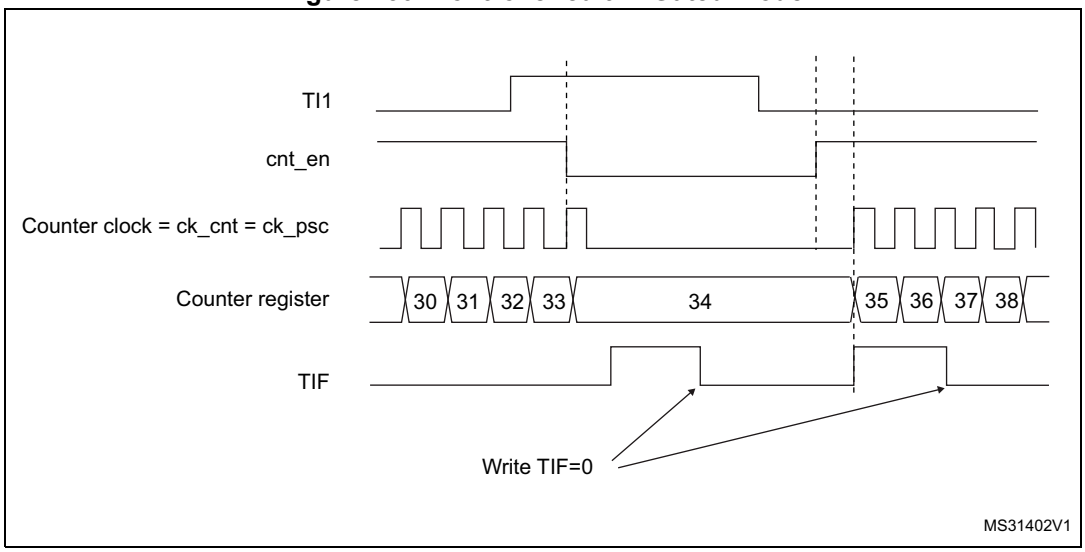
In the following example, the upcounter counts only when TI1 input is low:

- Configure the channel 1 to detect low levels on TI1. Configure the input filter duration (in this example, we do not need any filter, so we keep IC1F=0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S=01 in TIMx_CCMR1 register. Write CC1P=1 and CC1NP='0' in TIMx_CCER register to validate the polarity (and detect low level only).
- Configure the timer in gated mode by writing SMS=101 in TIMx_SMCR register. Select TI1 as the input source by writing TS=00101 in TIMx_SMCR register.
- Enable the counter by writing CEN=1 in the TIMx_CR1 register (in gated mode, the counter doesn't start if CEN=0, whatever is the trigger input level).

The counter starts counting on the internal clock as long as TI1 is low and stops as soon as TI1 becomes high. The TIF flag in the TIMx_SR register is set both when the counter starts or stops.

The delay between the rising edge on TI1 and the actual stop of the counter is due to the resynchronization circuit on TI1 input.

Figure 430. Control circuit in Gated mode



Slave mode: Trigger mode

The counter can start in response to an event on a selected input.

In the following example, the upcounter starts in response to a rising edge on TI2 input:

- Configure the channel 2 to detect rising edges on TI2. Configure the input filter duration (in this example, we do not need any filter, so we keep IC2F=0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC2S bits are configured to select the input capture source only, CC2S=01 in TIMx_CCMR1

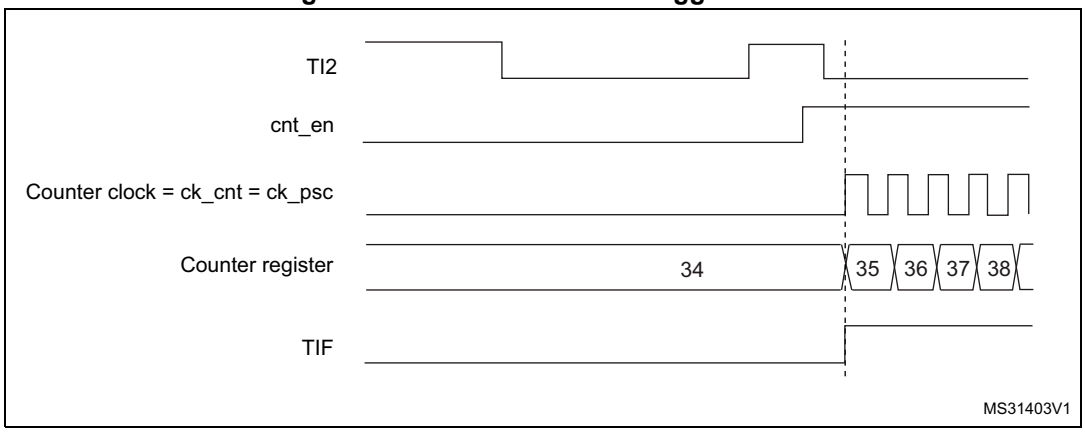
register. Write CC2P=1 and CC2NP=0 in TIMx_CCER register to validate the polarity (and detect low level only).

- Configure the timer in trigger mode by writing SMS=110 in TIMx_SMCR register. Select TI2 as the input source by writing TS=00110 in TIMx_SMCR register.

When a rising edge occurs on TI2, the counter starts counting on the internal clock and the TIF flag is set.

The delay between the rising edge on TI2 and the actual start of the counter is due to the resynchronization circuit on TI2 input.

Figure 431. Control circuit in trigger mode



Slave mode: Combined reset + trigger mode

In this case, a rising edge of the selected trigger input (TRGI) reinitializes the counter, generates an update of the registers, and starts the counter.

This mode is used for one-pulse mode.

Slave mode: external clock mode 2 + trigger mode

The external clock mode 2 can be used in addition to another slave mode (except external clock mode 1 and encoder mode). In this case, the ETR signal is used as external clock input, and another input can be selected as trigger input (in reset mode, gated mode or trigger mode). It is recommended not to select ETR as TRGI through the TS bits of TIMx_SMCR register.

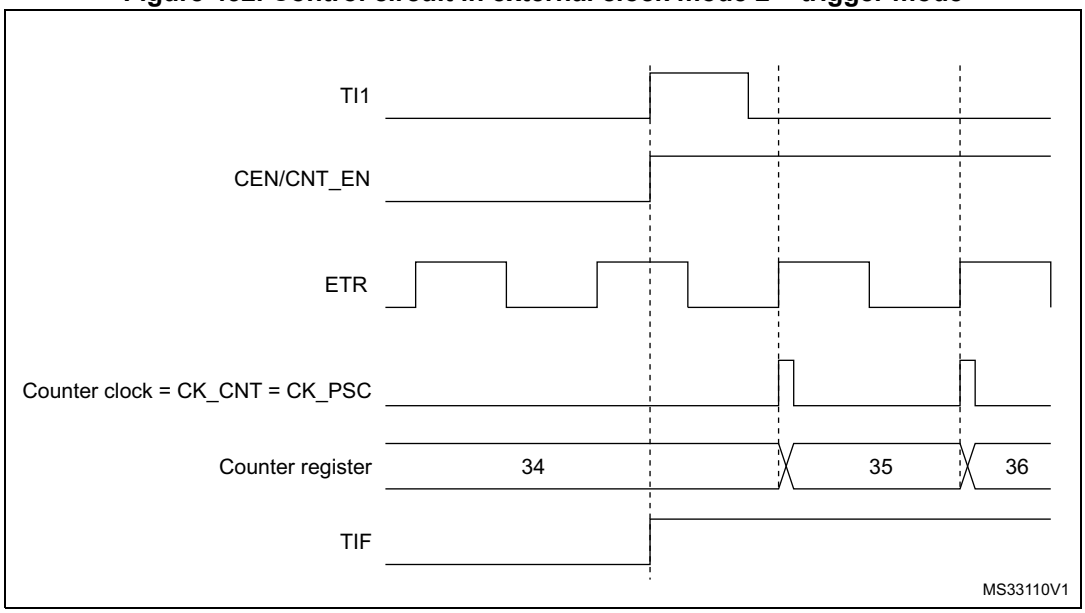
In the following example, the upcounter is incremented at each rising edge of the ETR signal as soon as a rising edge of TI1 occurs:

1. Configure the external trigger input circuit by programming the TIMx_SMCR register as follows:
   - ETF = 0000: no filter
   - ETPS = 00: prescaler disabled
   - ETP = 0: detection of rising edges on ETR and ECE=1 to enable the external clock mode 2.
2. Configure the channel 1 as follows, to detect rising edges on TI:
   - IC1F = 0000: no filter.
   - The capture prescaler is not used for triggering and does not need to be configured.
   - CC1S = 01in TIMx_CCMR1 register to select only the input capture source
   - CC1P = 0 and CC1NP = 0 in TIMx_CCER register to validate the polarity (and detect rising edge only).
3. Configure the timer in trigger mode by writing SMS=110 in TIMx_SMCR register. Select TI1 as the input source by writing TS=00101 in TIMx_SMCR register.

A rising edge on TI1 enables the counter and sets the TIF flag. The counter then counts on ETR rising edges.

The delay between the rising edge of the ETR signal and the actual reset of the counter is due to the resynchronization circuit on ETRP input.

Figure 432. Control circuit in external clock mode 2 + trigger mode



Note: The clock of the slave peripherals (timer, ADC, ...) receiving the TRGO or the TRGO2 signals must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

43.3.27 ADC synchronization

The timer can generate an ADC triggering event with various internal signals, such as reset, enable or compare events. It is also possible to generate a pulse issued by internal edge detectors, such as:

- Rising and falling edges of OC4ref
- Rising edge on OC5ref or falling edge on OC6ref

The triggers are issued on the TRGO2 internal line which is redirected to the ADC. There is a total of 16 possible events, which can be selected using the MMS2[3:0] bits in the TIMx_CR2 register.

An example of an application for 3-phase motor drives is given in *Figure 412 on page 1589*.

Note: The clock of the slave peripherals (timer, ADC, ...) receiving the TRGO or the TRGO2 signals must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

Note: The clock of the ADC must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the timer.

43.3.28 DMA burst mode

The TIMx timers have the capability to generate multiple DMA requests upon a single event. The main purpose is to be able to re-program part of the timer multiple times without software overhead, but it can also be used to read several registers in a row, at regular intervals.

The DMA controller destination is unique and must point to the virtual register TIMx_DMAR. On a given timer event, the timer launches a sequence of DMA requests (burst). Each write into the TIMx_DMAR register is actually redirected to one of the timer registers.

The DBL[4:0] bits in the TIMx_DCR register set the DMA burst length. The timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address), i.e. the number of transfers (either in half-words or in bytes).

The DBA[4:0] bits in the TIMx_DCR registers define the DMA base address for DMA transfers (when read/write access are done through the TIMx_DMAR address). DBA is defined as an offset starting from the address of the TIMx_CR1 register:

Example:

00000: TIMx_CR1

00001: TIMx_CR2

00010: TIMx_SMCR

As an example, the timer DMA burst feature is used to update the contents of the CCRx registers (x = 2, 3, 4) upon an update event, with the DMA transferring half words into the CCRx registers.

This is done in the following steps:

1. Configure the corresponding DMA channel as follows:
   – DMA channel peripheral address is the DMAR register address
   – DMA channel memory address is the address of the buffer in the RAM containing the data to be transferred by DMA into CCRx registers.
   – Number of data to transfer = 3 (See note below).
   – Circular mode disabled.
2. Configure the DCR register by configuring the DBA and DBL bit fields as follows: DBL = 3 transfers, DBA = 0xE.
3. Enable the TIMx update DMA request (set the UDE bit in the DIER register).
4. Enable TIMx
5. Enable the DMA channel

This example is for the case where every CCRx register to be updated once. If every CCRx register is to be updated twice for example, the number of data to transfer should be 6. Let's take the example of a buffer in the RAM containing data1, data2, data3, data4, data5 and data6. The data is transferred to the CCRx registers as follows: on the first update DMA request, data1 is transferred to CCR2, data2 is transferred to CCR3, data3 is transferred to CCR4 and on the second update DMA request, data4 is transferred to CCR2, data5 is transferred to CCR3 and data6 is transferred to CCR4.

Note: A null value can be written to the reserved registers.

43.3.29 Debug mode

When the microcontroller enters debug mode (Cortex®-M7 core halted), the TIMx counter either continues to work normally or stops, depending on DBG_TIMx_STOP configuration bit in DBG module.

For safety purposes, when the counter is stopped, the outputs are disabled (as if the MOE bit was reset). The outputs can either be forced to an inactive state (OSSI bit = 1), or have their control taken over by the GPIO controller (OSSI bit = 0), typically to force a Hi-Z.

For more details, refer to section Debug support (DBG).

43.4 TIM1/TIM8 registers

Refer to for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by half-words (16-bit) or words (32-bit).

43.4.1 TIMx control register 1 (TIMx_CR1)(x = 1, 8)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	UIFREMAP	Res.	CKD[1:0]		ARPE	CMS[1:0]		DIR	OPM	URS	UDIS	CEN
				rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **UIFREMAP**: UIF status bit remapping

0: No remapping. UIF status bit is not copied to TIMx_CNT register bit 31.
1: Remapping enabled. UIF status bit is copied to TIMx_CNT register bit 31.

Bit 10 Reserved, must be kept at reset value.

Bits 9:8 **CKD[1:0]**: Clock division

This bit-field indicates the division ratio between the timer clock (CK_INT) frequency and the dead-time and sampling clock (t_{DTS})used by the dead-time generators and the digital filters (ETR, TIx):

00: $t_{DTS}=t_{CK\_INT}$
01: $t_{DTS}=2*t_{CK\_INT}$
10: $t_{DTS}=4*t_{CK\_INT}$
11: Reserved, do not program this value

Note: $t_{DTS} = 1/f_{DTS}$, $t_{CK\_INT} = 1/f_{CK\_INT}$.

Bit 7 **ARPE**: Auto-reload preload enable

0: TIMx_ARR register is not buffered
1: TIMx_ARR register is buffered

Bits 6:5 **CMS[1:0]**: Center-aligned mode selection

00: Edge-aligned mode. The counter counts up or down depending on the direction bit (DIR).
01: Center-aligned mode 1. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS=00 in TIMx_CCMRx register) are set only when the counter is counting down.
10: Center-aligned mode 2. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS=00 in TIMx_CCMRx register) are set only when the counter is counting up.
11: Center-aligned mode 3. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS=00 in TIMx_CCMRx register) are set both when the counter is counting up or down.

Note: Switch from edge-aligned mode to center-aligned mode as long as the counter is enabled (CEN=1) is not allowed

Bit 4 **DIR**: Direction
0: Counter used as upcounter
1: Counter used as downcounter
Note: This bit is read only when the timer is configured in Center-aligned mode or Encoder mode.

Bit 3 **OPM**: One pulse mode
0: Counter is not stopped at update event
1: Counter stops counting at the next update event (clearing the bit CEN)

Bit 2 **URS**: Update request source
This bit is set and cleared by software to select the UEV event sources.
0: Any of the following events generate an update interrupt or DMA request if enabled. These events can be:
– Counter overflow/underflow
– Setting the UG bit
– Update generation through the slave mode controller
1: Only counter overflow/underflow generates an update interrupt or DMA request if enabled.

Bit 1 **UDIS**: Update disable
This bit is set and cleared by software to enable/disable UEV event generation.
0: UEV enabled. The Update (UEV) event is generated by one of the following events:
– Counter overflow/underflow
– Setting the UG bit
– Update generation through the slave mode controller
Buffered registers are then loaded with their preload values.
1: UEV disabled. The Update event is not generated, shadow registers keep their value (ARR, PSC, CCRx). However the counter and the prescaler are reinitialized if the UG bit is set or if a hardware reset is received from the slave mode controller.

Bit 0 **CEN**: Counter enable
0: Counter disabled
1: Counter enabled
Note: External clock, gated mode and encoder mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.

43.4.2 TIMx control register 2 (TIMx_CR2)(x = 1, 8)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MMS2[3:0]				Res.	OIS6	Res.	OIS5
								rw	rw	rw	rw		rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	OIS4	OIS3N	OIS3	OIS2N	OIS2	OIS1N	OIS1	TI1S	MMS[2:0]			CCDS	CCUS	Res.	CCPC
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:20 **MMS2[3:0]**: Master mode selection 2

These bits allow the information to be sent to ADC for synchronization (TRGO2) to be selected. The combination is as follows:

0000: **Reset** - the UG bit from the TIMx_EGR register is used as trigger output (TRGO2). If the reset is generated by the trigger input (slave mode controller configured in reset mode), the signal on TRGO2 is delayed compared to the actual reset.

0001: **Enable** - the Counter Enable signal CNT_EN is used as trigger output (TRGO2). It is useful to start several timers at the same time or to control a window in which a slave timer is enabled. The Counter Enable signal is generated by a logic AND between the CEN control bit and the trigger input when configured in Gated mode. When the Counter Enable signal is controlled by the trigger input, there is a delay on TRGO2, except if the Master/Slave mode is selected (see the MSM bit description in TIMx_SMCR register).

0010: **Update** - the update event is selected as trigger output (TRGO2). For instance, a master timer can then be used as a prescaler for a slave timer.

0011: **Compare pulse** - the trigger output sends a positive pulse when the CC1IF flag is to be set (even if it was already high), as soon as a capture or compare match occurs (TRGO2).

0100: **Compare** - OC1REFC signal is used as trigger output (TRGO2)

0101: **Compare** - OC2REFC signal is used as trigger output (TRGO2)

0110: **Compare** - OC3REFC signal is used as trigger output (TRGO2)

0111: **Compare** - OC4REFC signal is used as trigger output (TRGO2)

1000: **Compare** - OC5REFC signal is used as trigger output (TRGO2)

1001: **Compare** - OC6REFC signal is used as trigger output (TRGO2)

1010: **Compare Pulse** - OC4REFC rising or falling edges generate pulses on TRGO2

1011: **Compare Pulse** - OC6REFC rising or falling edges generate pulses on TRGO2

1100: **Compare Pulse** - OC4REFC or OC6REFC rising edges generate pulses on TRGO2

1101: **Compare Pulse** - OC4REFC rising or OC6REFC falling edges generate pulses on TRGO2

1110: **Compare Pulse** - OC5REFC or OC6REFC rising edges generate pulses on TRGO2

1111: **Compare Pulse** - OC5REFC rising or OC6REFC falling edges generate pulses on TRGO2

Note: The clock of the slave timer or ADC must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the master timer.

Bit 19 Reserved, must be kept at reset value.

Bit 18 **OIS6**: Output Idle state 6 (OC6 output)
Refer to OIS1 bit

Bit 17 Reserved, must be kept at reset value.

Bit 16 **OIS5**: Output Idle state 5 (OC5 output)
Refer to OIS1 bit

Bit 15 Reserved, must be kept at reset value.

Bit 14 **OIS4**: Output Idle state 4 (OC4 output)
Refer to OIS1 bit

Bit 13 **OIS3N**: Output Idle state 3 (OC3N output)
Refer to OIS1N bit

Bit 12 **OIS3**: Output Idle state 3 (OC3 output)
Refer to OIS1 bit

Bit 11 **OIS2N**: Output Idle state 2 (OC2N output)
Refer to OIS1N bit

Bit 10 **OIS2**: Output Idle state 2 (OC2 output)
Refer to OIS1 bit

Bit 9 **OIS1N**: Output Idle state 1 (OC1N output)
0: OC1N=0 after a dead-time when MOE=0
1: OC1N=1 after a dead-time when MOE=0
Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 8 **OIS1**: Output Idle state 1 (OC1 output)
0: OC1=0 (after a dead-time if OC1N is implemented) when MOE=0
1: OC1=1 (after a dead-time if OC1N is implemented) when MOE=0
Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 7 **TI1S**: TI1 selection
0: The TIMx_CH1 pin is connected to TI1 input
1: The TIMx_CH1, CH2 and CH3 pins are connected to the TI1 input (XOR combination)

Bits 6:4 **MMS[2:0]**: Master mode selection
These bits allow selected information to be sent in master mode to slave timers for synchronization (TRGO). The combination is as follows:
000: **Reset** - the UG bit from the TIMx_EGR register is used as trigger output (TRGO). If the reset is generated by the trigger input (slave mode controller configured in reset mode) then the signal on TRGO is delayed compared to the actual reset.
001: **Enable** - the Counter Enable signal CNT_EN is used as trigger output (TRGO). It is useful to start several timers at the same time or to control a window in which a slave timer is enable. The Counter Enable signal is generated by a logic AND between CEN control bit and the trigger input when configured in gated mode. When the Counter Enable signal is controlled by the trigger input, there is a delay on TRGO, except if the master/slave mode is selected (see the MSM bit description in TIMx_SMCR register).
010: **Update** - The update event is selected as trigger output (TRGO). For instance a master timer can then be used as a prescaler for a slave timer.
011: **Compare Pulse** - The trigger output send a positive pulse when the CC1IF flag is to be set (even if it was already high), as soon as a capture or a compare match occurred. (TRGO).
100: **Compare** - OC1REFC signal is used as trigger output (TRGO)
101: **Compare** - OC2REFC signal is used as trigger output (TRGO)
110: **Compare** - OC3REFC signal is used as trigger output (TRGO)
111: **Compare** - OC4REFC signal is used as trigger output (TRGO)
Note: The clock of the slave timer or ADC must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the master timer.

Bit 3 **CCDS**: Capture/compare DMA selection
0: CCx DMA request sent when CCx event occurs
1: CCx DMA requests sent when update event occurs

Bit 2 **CCUS**: Capture/compare control update selection
0: When capture/compare control bits are preloaded (CCPC=1), they are updated by setting the COMG bit only
1: When capture/compare control bits are preloaded (CCPC=1), they are updated by setting the COMG bit or when an rising edge occurs on TRGI
Note: This bit acts only on channels that have a complementary output.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **CCPC**: Capture/compare preloaded control
0: CCxE, CCxNE and OCxM bits are not preloaded
1: CCxE, CCxNE and OCxM bits are preloaded, after having been written, they are updated only when a commutation event (COM) occurs (COMG bit set or rising edge detected on TRGI, depending on the CCUS bit).
Note: This bit acts only on channels that have a complementary output.

43.4.3 TIMx slave mode control register (TIMx_SMCR)(x = 1, 8)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS[4:3]		Res.	Res.	Res.	SMS[3]
										rw	rw				rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETP	ECE	ETPS[1:0]		ETF[3:0]				MSM	TS[2:0]			Res.	SMS[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 19:17 Reserved, must be kept at reset value.

Bit 15 **ETP**: External trigger polarity
This bit selects whether ETR or $\overline{ETR}$ is used for trigger operations
0: ETR is non-inverted, active at high level or rising edge.
1: ETR is inverted, active at low level or falling edge.

Bit 14 **ECE**: External clock enable
This bit enables External clock mode 2.
0: External clock mode 2 disabled
1: External clock mode 2 enabled. The counter is clocked by any active edge on the ETRF signal.
Note: Setting the ECE bit has the same effect as selecting external clock mode 1 with TRGI connected to ETRF (SMS=111 and TS=00111).
It is possible to simultaneously use external clock mode 2 with the following slave modes: reset mode, gated mode and trigger mode. Nevertheless, TRGI must not be connected to ETRF in this case (TS bits must not be 00111).
If external clock mode 1 and external clock mode 2 are enabled at the same time, the external clock input is ETRF.

Bits 13:12 **ETPS[1:0]**: External trigger prescaler

External trigger signal ETRP frequency must be at most 1/4 of f_{CK_INT} frequency. A prescaler can be enabled to reduce ETRP frequency. It is useful when inputting fast external clocks.

00: Prescaler OFF
01: ETRP frequency divided by 2
10: ETRP frequency divided by 4
11: ETRP frequency divided by 8

Bits 11:8 **ETF[3:0]**: External trigger filter

This bit-field then defines the frequency used to sample ETRP signal and the length of the digital filter applied to ETRP. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}
0001: $f_{SAMPLING}=f_{CK\_INT}$, N=2
0010: $f_{SAMPLING}=f_{CK\_INT}$, N=4
0011: $f_{SAMPLING}=f_{CK\_INT}$, N=8
0100: $f_{SAMPLING}=f_{DTS}/2$, N=6
0101: $f_{SAMPLING}=f_{DTS}/2$, N=8
0110: $f_{SAMPLING}=f_{DTS}/4$, N=6
0111: $f_{SAMPLING}=f_{DTS}/4$, N=8
1000: $f_{SAMPLING}=f_{DTS}/8$, N=6
1001: $f_{SAMPLING}=f_{DTS}/8$, N=8
1010: $f_{SAMPLING}=f_{DTS}/16$, N=5
1011: $f_{SAMPLING}=f_{DTS}/16$, N=6
1100: $f_{SAMPLING}=f_{DTS}/16$, N=8
1101: $f_{SAMPLING}=f_{DTS}/32$, N=5
1110: $f_{SAMPLING}=f_{DTS}/32$, N=6
1111: $f_{SAMPLING}=f_{DTS}/32$, N=8

Bit 7 **MSM:** Master/slave mode

0: No action
1: The effect of an event on the trigger input (TRGI) is delayed to allow a perfect synchronization between the current timer and its slaves (through TRGO). It is useful if we want to synchronize several timers on a single external event.

Bits 21, 20, 6, 5, 4 **TS[4:0]:** Trigger selection

This bit-field selects the trigger input to be used to synchronize the counter.

00000: Internal Trigger 0 (ITR0)
00001: Internal Trigger 1 (ITR1)
00010: Internal Trigger 2 (ITR2)
00011: Internal Trigger 3 (ITR3)
00100: TI1 Edge Detector (TI1F_ED)
00101: Filtered Timer Input 1 (TI1FP1)
00110: Filtered Timer Input 2 (TI2FP2)
00111: External Trigger input (ETRF)
01000 to 01111: Reserved
10000: Internal trigger 12 (ITR12)
10001: Internal trigger 13 (ITR13)
Others: Reserved

See *Table 350: TIMx internal trigger connection on page 1621* for more details on ITRx meaning for each Timer.

Note: These bits must be changed only when they are not used (e.g. when SMS=000) to avoid wrong edge detections at the transition.

Bit 3 Reserved, must be kept at reset value.

Bits 16, 2, 1, 0 **SMS[3:0]:** Slave mode selection

When external signals are selected the active edge of the trigger signal (TRGI) is linked to the polarity selected on the external input (see Input Control register and Control Register description.

0000: Slave mode disabled - if CEN = ‘1’ then the prescaler is clocked directly by the internal clock.

0001: Encoder mode 1 - Counter counts up/down on TI1FP1 edge depending on TI2FP2 level.

0010: Encoder mode 2 - Counter counts up/down on TI2FP2 edge depending on TI1FP1 level.

0011: Encoder mode 3 - Counter counts up/down on both TI1FP1 and TI2FP2 edges depending on the level of the other input.

0100: Reset Mode - Rising edge of the selected trigger input (TRGI) reinitializes the counter and generates an update of the registers.

0101: Gated Mode - The counter clock is enabled when the trigger input (TRGI) is high. The counter stops (but is not reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

0110: Trigger Mode - The counter starts at a rising edge of the trigger TRGI (but it is not reset). Only the start of the counter is controlled.

0111: External Clock Mode 1 - Rising edges of the selected trigger (TRGI) clock the counter.

1000: Combined reset + trigger mode - Rising edge of the selected trigger input (TRGI) reinitializes the counter, generates an update of the registers and starts the counter.

Codes above 1000: Reserved.

Note: The gated mode must not be used if TI1F_ED is selected as the trigger input (TS=00100). Indeed, TI1F_ED outputs 1 pulse for each transition on TI1F, whereas the gated mode checks the level of the trigger signal.

Note: The clock of the slave peripherals (timer, ADC, ...) receiving the TRGO or the TRGO2 signals must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

Table 350. TIMx internal trigger connection

Slave TIM	ITR0 (TS = 00000)	ITR1 (TS = 00001)	ITR2 (TS = 00010)	ITR3 (TS = 00011)	ITR4..ITR11 (TS = 01000 ..01111)	ITR12 (TS = 10000)	ITR13 (TS = 10001)
TIM1	TIM15	TIM2	TIM3	TIM4	Reserved	TIM23	TIM24
TIM8	TIM1	TIM2	TIM4	TIM5	Reserved	TIM23	TIM24

43.4.4 TIMx DMA/interrupt enable register (TIMx_DIER)(x = 1, 8)

Address offset: 0x0C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TDE	COMDE	CC4DE	CC3DE	CC2DE	CC1DE	UDE	BIE	TIE	COMIE	CC4IE	CC3IE	CC2IE	CC1IE	UIE
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 15 Reserved, must be kept at reset value.

Bit 14 **TDE**: Trigger DMA request enable
0: Trigger DMA request disabled
1: Trigger DMA request enabled

Bit 13 **COMDE**: COM DMA request enable
0: COM DMA request disabled
1: COM DMA request enabled

Bit 12 **CC4DE**: Capture/Compare 4 DMA request enable
0: CC4 DMA request disabled
1: CC4 DMA request enabled

Bit 11 **CC3DE**: Capture/Compare 3 DMA request enable
0: CC3 DMA request disabled
1: CC3 DMA request enabled

Bit 10 **CC2DE**: Capture/Compare 2 DMA request enable
0: CC2 DMA request disabled
1: CC2 DMA request enabled

Bit 9 **CC1DE**: Capture/Compare 1 DMA request enable
0: CC1 DMA request disabled
1: CC1 DMA request enabled

Bit 8 **UDE**: Update DMA request enable
0: Update DMA request disabled
1: Update DMA request enabled

Bit 7 **BIE**: Break interrupt enable
0: Break interrupt disabled
1: Break interrupt enabled

Bit 6 **TIE**: Trigger interrupt enable
0: Trigger interrupt disabled
1: Trigger interrupt enabled

Bit 5 **COMIE**: COM interrupt enable
0: COM interrupt disabled
1: COM interrupt enabled

Bit 4 **CC4IE**: Capture/Compare 4 interrupt enable
0: CC4 interrupt disabled
1: CC4 interrupt enabled

Bit 3 **CC3IE**: Capture/Compare 3 interrupt enable
0: CC3 interrupt disabled
1: CC3 interrupt enabled

Bit 2 **CC2IE**: Capture/Compare 2 interrupt enable
0: CC2 interrupt disabled
1: CC2 interrupt enabled

Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable
0: CC1 interrupt disabled
1: CC1 interrupt enabled

Bit 0 **UIE**: Update interrupt enable
0: Update interrupt disabled
1: Update interrupt enabled

43.4.5 TIMx status register (TIMx_SR)(x = 1, 8)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC6IF	CC5IF
														rc_w0	rc_w0

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	SBIF	CC4OF	CC3OF	CC2OF	CC1OF	B2IF	BIF	TIF	COMIF	CC4IF	CC3IF	CC2IF	CC1IF	UIF
		rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **CC6IF**: Compare 6 interrupt flag
Refer to CC1IF description (Note: Channel 6 can only be configured as output)

Bit 16 **CC5IF**: Compare 5 interrupt flag
Refer to CC1IF description (Note: Channel 5 can only be configured as output)

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **SBIF**: System Break interrupt flag
This flag is set by hardware as soon as the system break input goes active. It can be cleared by software if the system break input is not active.
This flag must be reset to re-start PWM operation.
0: No break event occurred.
1: An active level has been detected on the system break input. An interrupt is generated if BIE=1 in the TIMx_DIER register.

Bit 12 **CC4OF**: Capture/Compare 4 overcapture flag
Refer to CC1OF description

Bit 11 **CC3OF**: Capture/Compare 3 overcapture flag
Refer to CC1OF description

Bit 10 **CC2OF**: Capture/Compare 2 overcapture flag
Refer to CC1OF description

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag

This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to ‘0’.

0: No overcapture has been detected.

1: The counter value has been captured in TIMx_CCR1 register while CC1IF flag was already set

Bit 8 **B2IF**: Break 2 interrupt flag

This flag is set by hardware as soon as the break 2 input goes active. It can be cleared by software if the break 2 input is not active.

0: No break event occurred.

1: An active level has been detected on the break 2 input. An interrupt is generated if BIE=1 in the TIMx_DIER register.

Bit 7 **BIF**: Break interrupt flag

This flag is set by hardware as soon as the break input goes active. It can be cleared by software if the break input is not active.

0: No break event occurred.

1: An active level has been detected on the break input. An interrupt is generated if BIE=1 in the TIMx_DIER register.

Bit 6 **TIF**: Trigger interrupt flag

This flag is set by hardware on the TRG trigger event (active edge detected on TRGI input when the slave mode controller is enabled in all modes but gated mode. It is set when the counter starts or stops when gated mode is selected. It is cleared by software.

0: No trigger event occurred.

1: Trigger interrupt pending.

Bit 5 **COMIF**: COM interrupt flag

This flag is set by hardware on COM event (when Capture/compare Control bits - CCxE, CCxNE, OCxM - have been updated). It is cleared by software.

0: No COM event occurred.

1: COM interrupt pending.

Bit 4 **CC4IF**: Capture/Compare 4 interrupt flag

Refer to CC1IF description

Bit 3 **CC3IF**: Capture/Compare 3 interrupt flag

Refer to CC1IF description

Bit 2 **CC2IF**: Capture/Compare 2 interrupt flag

Refer to CC1IF description

Bit 1 **CC1IF**: Capture/Compare 1 interrupt flag

This flag is set by hardware. It is cleared by software (input capture or output compare mode) or by reading the TIMx_CCR1 register (input capture mode only).

0: No compare match / No input capture occurred

1: A compare match or an input capture occurred.

If channel CC1 is configured as output: this flag is set when he content of the counter TIMx_CNT matches the content of the TIMx_CCR1 register. When the content of TIMx_CCR1 is greater than the content of TIMx_ARR, the CC1IF bit goes high on the counter overflow (in up-counting and up/down-counting modes) or underflow (in down-counting mode). There are 3 possible options for flag setting in center-aligned mode, refer to the CMS bits in the TIMx_CR1 register for the full description.

If channel CC1 is configured as input: this bit is set when counter value has been captured in TIMx_CCR1 register (an edge has been detected on IC1, as per the edge sensitivity defined with the CC1P and CC1NP bits setting, in TIMx_CCER).

Bit 0 **UIF**: Update interrupt flag

This bit is set by hardware on an update event. It is cleared by software.

0: No update occurred.

1: Update interrupt pending. This bit is set by hardware when the registers are updated:

– At overflow or underflow regarding the repetition counter value (update if repetition counter = 0) and if the UDIS=0 in the TIMx_CR1 register.

– When CNT is reinitialized by software using the UG bit in TIMx_EGR register, if URS=0 and UDIS=0 in the TIMx_CR1 register.

– When CNT is reinitialized by a trigger event (refer to *Section 43.4.3: TIMx slave mode control register (TIMx_SMCR)(x = 1, 8)*), if URS=0 and UDIS=0 in the TIMx_CR1 register.

43.4.6 TIMx event generation register (TIMx_EGR)(x = 1, 8)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	B2G	BG	TG	COMG	CC4G	CC3G	CC2G	CC1G	UG
							w	w	w	w	w	w	w	w	w

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **B2G**: Break 2 generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: A break 2 event is generated. MOE bit is cleared and B2IF flag is set. Related interrupt can occur if enabled.

Bit 7 **BG**: Break generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: A break event is generated. MOE bit is cleared and BIF flag is set. Related interrupt or DMA transfer can occur if enabled.

Bit 6 **TG**: Trigger generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: The TIF flag is set in TIMx_SR register. Related interrupt or DMA transfer can occur if enabled.

Bit 5 **COMG**: Capture/Compare control update generation

This bit can be set by software, it is automatically cleared by hardware

0: No action

1: When CCPC bit is set, it allows CCxE, CCxNE and OCxM bits to be updated.

Note: This bit acts only on channels having a complementary output.

Bit 4 **CC4G**: Capture/Compare 4 generation

Refer to CC1G description

Bit 3 **CC3G**: Capture/Compare 3 generation

Refer to CC1G description

Bit 2 **CC2G**: Capture/Compare 2 generation
Refer to CC1G description

Bit 1 **CC1G**: Capture/Compare 1 generation
This bit is set by software in order to generate an event, it is automatically cleared by hardware.
0: No action
1: A capture/compare event is generated on channel 1:
If channel CC1 is configured as output:
CC1IF flag is set, Corresponding interrupt or DMA request is sent if enabled.
If channel CC1 is configured as input:
The current value of the counter is captured in TIMx_CCR1 register. The CC1IF flag is set, the corresponding interrupt or DMA request is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation
This bit can be set by software, it is automatically cleared by hardware.
0: No action
1: Reinitialize the counter and generates an update of the registers. The prescaler internal counter is also cleared (the prescaler ratio is not affected). The counter is cleared if the center-aligned mode is selected or if DIR=0 (upcounting), else it takes the auto-reload value (TIMx_ARR) if DIR=1 (downcounting).

43.4.7 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 1, 8)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (e.g. channel 1 in input capture mode and channel 2 in output compare mode).

Input capture mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IC2F[3:0]				IC2PSC[1:0]		CC2S[1:0]		IC1F[3:0]				IC1PSC[1:0]		CC1S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **IC2F[3:0]**: Input capture 2 filter
Refer to IC1F[3:0] description.

Bits 11:10 **IC2PSC[1:0]**: Input capture 2 prescaler
Refer to IC1PSC[1:0] description.

Bits 9:8 **CC2S[1:0]**: Capture/Compare 2 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC2 channel is configured as output

01: CC2 channel is configured as input, IC2 is mapped on TI2

10: CC2 channel is configured as input, IC2 is mapped on TI1

11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC2S bits are writable only when the channel is OFF (CC2E = '0' in TIMx_CCER).

Bits 7:4 **IC1F[3:0]**: Input capture 1 filter

This bit-field defines the frequency used to sample TI1 input and the length of the digital filter applied to TI1. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}

0001: $f_{SAMPLING}=f_{CK\_INT}$, N=2

0010: $f_{SAMPLING}=f_{CK\_INT}$, N=4

0011: $f_{SAMPLING}=f_{CK\_INT}$, N=8

0100: $f_{SAMPLING}=f_{DTS}/2$, N=6

0101: $f_{SAMPLING}=f_{DTS}/2$, N=8

0110: $f_{SAMPLING}=f_{DTS}/4$, N=6

0111: $f_{SAMPLING}=f_{DTS}/4$, N=8

1000: $f_{SAMPLING}=f_{DTS}/8$, N=6

1001: $f_{SAMPLING}=f_{DTS}/8$, N=8

1010: $f_{SAMPLING}=f_{DTS}/16$, N=5

1011: $f_{SAMPLING}=f_{DTS}/16$, N=6

1100: $f_{SAMPLING}=f_{DTS}/16$, N=8

1101: $f_{SAMPLING}=f_{DTS}/32$, N=5

1110: $f_{SAMPLING}=f_{DTS}/32$, N=6

1111: $f_{SAMPLING}=f_{DTS}/32$, N=8

Bits 3:2 **IC1PSC[1:0]**: Input capture 1 prescaler

This bit-field defines the ratio of the prescaler acting on CC1 input (IC1). The prescaler is reset as soon as CC1E='0' (TIMx_CCER register).

00: no prescaler, capture is done each time an edge is detected on the capture input

01: capture is done once every 2 events

10: capture is done once every 4 events

11: capture is done once every 8 events

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 Selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output

01: CC1 channel is configured as input, IC1 is mapped on TI1

10: CC1 channel is configured as input, IC1 is mapped on TI2

11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC1S bits are writable only when the channel is OFF (CC1E = '0' in TIMx_CCER).

43.4.8 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 1, 8)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the

corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (e.g. channel 1 in input capture mode and channel 2 in output compare mode).

Output compare mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]
							rw								rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC2 CE	OC2M[2:0]			OC2 PE	OC2 FE	CC2S[1:0]		OC1 CE	OC1M[2:0]			OC1 PE	OC1 FE	CC1S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 **OC2CE:** Output Compare 2 clear enable
Refer to OC1CE description.

Bits 24, 14:12 **OC2M[3:0]**: Output Compare 2 mode
Refer to OC1M[3:0] description.

Bit 11 **OC2PE**: Output Compare 2 preload enable
Refer to OC1PE description.

Bit 10 **OC2FE**: Output Compare 2 fast enable
Refer to OC1FE description.

Bits 9:8 **CC2S[1:0]**: Capture/Compare 2 selection
This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC2 channel is configured as output
01: CC2 channel is configured as input, IC2 is mapped on TI2
10: CC2 channel is configured as input, IC2 is mapped on TI1
11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode is working only if an internal trigger input is selected through the TS bit (TIMx_SMCR register)

Note: CC2S bits are writable only when the channel is OFF (CC2E = '0' in TIMx_CCER).

Bit 7 **OC1CE:** Output Compare 1 clear enable
0: OC1Ref is not affected by the ETRF input
1: OC1Ref is cleared as soon as a High level is detected on ETRF input

Bits 16, 6:4 **OC1M[3:0]**: Output Compare 1 mode

These bits define the behavior of the output reference signal OC1REF from which OC1 and OC1N are derived. OC1REF is active high whereas OC1 and OC1N active level depends on CC1P and CC1NP bits.

0000: Frozen - The comparison between the output compare register TIMx_CCR1 and the counter TIMx_CNT has no effect on the outputs.(this mode is used to generate a timing base).

0001: Set channel 1 to active level on match. OC1REF signal is forced high when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0010: Set channel 1 to inactive level on match. OC1REF signal is forced low when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0011: Toggle - OC1REF toggles when TIMx_CNT=TIMx_CCR1.

0100: Force inactive level - OC1REF is forced low.

0101: Force active level - OC1REF is forced high.

0110: PWM mode 1 - In upcounting, channel 1 is active as long as TIMx_CNT<TIMx_CCR1 else inactive. In downcounting, channel 1 is inactive (OC1REF=‘0’) as long as TIMx_CNT>TIMx_CCR1 else active (OC1REF=’1’).

0111: PWM mode 2 - In upcounting, channel 1 is inactive as long as TIMx_CNT<TIMx_CCR1 else active. In downcounting, channel 1 is active as long as TIMx_CNT>TIMx_CCR1 else inactive.

1000: Retrigerrable OPM mode 1 - In up-counting mode, the channel is active until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update. In down-counting mode, the channel is inactive until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes inactive again at the next update.

1001: Retrigerrable OPM mode 2 - In up-counting mode, the channel is inactive until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 2 and the channels becomes inactive again at the next update. In down-counting mode, the channel is active until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update.

1010: Reserved,

1011: Reserved,

1100: Combined PWM mode 1 - OC1REF has the same behavior as in PWM mode 1. OC1REFC is the logical OR between OC1REF and OC2REF.

1101: Combined PWM mode 2 - OC1REF has the same behavior as in PWM mode 2. OC1REFC is the logical AND between OC1REF and OC2REF.

1110: Asymmetric PWM mode 1 - OC1REF has the same behavior as in PWM mode 1. OC1REFC outputs OC1REF when the counter is counting up, OC2REF when it is counting down.

1111: Asymmetric PWM mode 2 - OC1REF has the same behavior as in PWM mode 2. OC1REFC outputs OC1REF when the counter is counting up, OC2REF when it is counting down.

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S=’00’ (the channel is configured in output).

Note: In PWM mode, the OCREF level changes only when the result of the comparison changes or when the output compare mode switches from “frozen” mode to “PWM” mode.

Note: On channels having a complementary output, this bit field is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the OC1M active bits take the new value from the preloaded bits only when a COM event is generated.

Note: The OC1M[3] bit is not contiguous, located in bit 16.

Bit 3 **OC1PE**: Output Compare 1 preload enable

0: Preload register on TIMx_CCR1 disabled. TIMx_CCR1 can be written at anytime, the new value is taken in account immediately.

1: Preload register on TIMx_CCR1 enabled. Read/Write operations access the preload register. TIMx_CCR1 preload value is loaded in the active register at each update event.

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S='00' (the channel is configured in output).

Bit 2 **OC1FE**: Output Compare 1 fast enable

This bit decreases the latency between a trigger event and a transition on the timer output. It must be used in one-pulse mode (OPM bit set in TIMx_CR1 register), to have the output pulse starting as soon as possible after the starting trigger.

0: CC1 behaves normally depending on counter and CCR1 values even when the trigger is ON. The minimum delay to activate CC1 output when an edge occurs on the trigger input is 5 clock cycles.

1: An active edge on the trigger input acts like a compare match on CC1 output. Then, OC is set to the compare level independently from the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OCFE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output

01: CC1 channel is configured as input, IC1 is mapped on TI1

10: CC1 channel is configured as input, IC1 is mapped on TI2

11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC1S bits are writable only when the channel is OFF (CC1E = '0' in TIMx_CCER).

43.4.9 TIMx capture/compare mode register 2 [alternate] (TIMx_CCMR2)(x = 1, 8)

Address offset: 0x1C

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (e.g. channel 1 in input capture mode and channel 2 in output compare mode).

Input capture mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IC4F[3:0]				IC4PSC[1:0]		CC4S[1:0]		IC3F[3:0]				IC3PSC[1:0]		CC3S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **IC4F[3:0]**: Input capture 4 filter
Refer to IC1F[3:0] description.

Bits 11:10 **IC4PSC[1:0]**: Input capture 4 prescaler
Refer to IC1PSC[1:0] description.

Bits 9:8 **CC4S[1:0]**: Capture/Compare 4 selection
This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC4 channel is configured as output
01: CC4 channel is configured as input, IC4 is mapped on TI4
10: CC4 channel is configured as input, IC4 is mapped on TI3
11: CC4 channel is configured as input, IC4 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)
Note: CC4S bits are writable only when the channel is OFF (CC4E = '0' in TIMx_CCER).

Bits 7:4 **IC3F[3:0]**: Input capture 3 filter
Refer to IC1F[3:0] description.

Bits 3:2 **IC3PSC[1:0]**: Input capture 3 prescaler
Refer to IC1PSC[1:0] description.

Bits 1:0 **CC3S[1:0]**: Capture/compare 3 selection
This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC3 channel is configured as output
01: CC3 channel is configured as input, IC3 is mapped on TI3
10: CC3 channel is configured as input, IC3 is mapped on TI4
11: CC3 channel is configured as input, IC3 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)
Note: CC3S bits are writable only when the channel is OFF (CC3E = '0' in TIMx_CCER).

43.4.10 TIMx capture/compare mode register 2 [alternate] (TIMx_CCMR2)(x = 1, 8)

Address offset: 0x1C

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function for input capture and for output compare modes. It is possible to combine both modes independently (e.g. channel 1 in input capture mode and channel 2 in output compare mode).

Output compare mode

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC4M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC3M[3]
							rw								rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC4 CE	OC4M[2:0]			OC4 PE	OC4 FE	CC4S[1:0]		OC3 CE	OC3M[2:0]			OC3 PE	OC3 FE	CC3S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 **OC4CE**: Output compare 4 clear enable
Refer to OC1CE description.

Bits 24, 14:12 **OC4M[3:0]**: Output compare 4 mode
Refer to OC3M[3:0] description.

Bit 11 **OC4PE**: Output compare 4 preload enable
Refer to OC1PE description.

Bit 10 **OC4FE**: Output compare 4 fast enable
Refer to OC1FE description.

Bits 9:8 **CC4S[1:0]**: Capture/Compare 4 selection
This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC4 channel is configured as output
01: CC4 channel is configured as input, IC4 is mapped on TI4
10: CC4 channel is configured as input, IC4 is mapped on TI3
11: CC4 channel is configured as input, IC4 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)
Note: CC4S bits are writable only when the channel is OFF (CC4E = '0' in TIMx_CCER).

Bit 7 **OC3CE:** Output compare 3 clear enable
Refer to OC1CE description.

Bits 16, 6:4 **OC3M[3:0]**: Output compare 3 mode
Refer to OC1M[3:0] description.

Bit 3 **OC3PE**: Output compare 3 preload enable
Refer to OC1PE description.

Bit 2 **OC3FE**: Output compare 3 fast enable
Refer to OC1FE description.

Bits 1:0 **CC3S[1:0]**: Capture/Compare 3 selection
This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC3 channel is configured as output
01: CC3 channel is configured as input, IC3 is mapped on TI3
10: CC3 channel is configured as input, IC3 is mapped on TI4
11: CC3 channel is configured as input, IC3 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)
Note: CC3S bits are writable only when the channel is OFF (CC3E = '0' in TIMx_CCER).

43.4.11 TIMx capture/compare enable register (TIMx_CCER)(x = 1, 8)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC6P	CC6E	Res.	Res.	CC5P	CC5E
										rw	rw			rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CC4NP	Res.	CC4P	CC4E	CC3NP	CC3NE	CC3P	CC3E	CC2NP	CC2NE	CC2P	CC2E	CC1NP	CC1NE	CC1P	CC1E
rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **CC6P**: Capture/Compare 6 output polarity
Refer to CC1P description

Bit 20 **CC6E**: Capture/Compare 6 output enable
Refer to CC1E description

Bits 19:18 Reserved, must be kept at reset value.

Bit 17 **CC5P**: Capture/Compare 5 output polarity
Refer to CC1P description

Bit 16 **CC5E**: Capture/Compare 5 output enable
Refer to CC1E description

Bit 15 **CC4NP**: Capture/Compare 4 complementary output polarity
Refer to CC1NP description

Bit 14 Reserved, must be kept at reset value.

Bit 13 **CC4P**: Capture/Compare 4 output polarity
Refer to CC1P description

Bit 12 **CC4E**: Capture/Compare 4 output enable
Refer to CC1E description

Bit 11 **CC3NP**: Capture/Compare 3 complementary output polarity
Refer to CC1NP description

Bit 10 **CC3NE**: Capture/Compare 3 complementary output enable
Refer to CC1NE description

Bit 9 **CC3P**: Capture/Compare 3 output polarity
Refer to CC1P description

Bit 8 **CC3E**: Capture/Compare 3 output enable
Refer to CC1E description

Bit 7 **CC2NP**: Capture/Compare 2 complementary output polarity
Refer to CC1NP description

Bit 6 **CC2NE**: Capture/Compare 2 complementary output enable
Refer to CC1NE description

Bit 5 **CC2P**: Capture/Compare 2 output polarity
Refer to CC1P description

Bit 4 **CC2E**: Capture/Compare 2 output enable
Refer to CC1E description

Bit 3 **CC1NP**: Capture/Compare 1 complementary output polarity
CC1 channel configured as output:
0: OC1N active high.
1: OC1N active low.
CC1 channel configured as input:
This bit is used in conjunction with CC1P to define the polarity of TI1FP1 and TI2FP1. Refer to CC1P description.

Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S="00" (channel configured as output).

On channels having a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1NP active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Bit 2 **CC1NE**: Capture/Compare 1 complementary output enable
0: Off - OC1N is not active. OC1N level is then function of MOE, OSSI, OSSR, OIS1, OIS1N and CC1E bits.
1: On - OC1N signal is output on the corresponding output pin depending on MOE, OSSI, OSSR, OIS1, OIS1N and CC1E bits.

On channels having a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1NE active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Bit 1 **CC1P**: Capture/Compare 1 output polarity
0: OC1 active high (output mode) / Edge sensitivity selection (input mode, see below)
1: OC1 active low (output mode) / Edge sensitivity selection (input mode, see below)
When CC1 channel is configured as input, both CC1NP/CC1P bits select the active polarity of TI1FP1 and TI2FP1 for trigger or capture operations.
CC1NP=0, CC1P=0: non-inverted/rising edge. The circuit is sensitive to TIxFP1 rising edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger operation in gated mode or encoder mode).
CC1NP=0, CC1P=1: inverted/falling edge. The circuit is sensitive to TIxFP1 falling edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is inverted (trigger operation in gated mode or encoder mode).
CC1NP=1, CC1P=1: non-inverted/both edges/ The circuit is sensitive to both TIxFP1 rising and falling edges (capture or trigger operations in reset, external clock or trigger mode), TIxFP1is not inverted (trigger operation in gated mode). This configuration must not be used in encoder mode.
CC1NP=1, CC1P=0: The configuration is reserved, it must not be used.

Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

On channels having a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1P active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Bit 0 **CC1E**: Capture/Compare 1 output enable

0: Capture mode disabled / OC1 is not active (see below)

1: Capture mode enabled / OC1 signal is output on the corresponding output pin

When CC1 channel is configured as output, the OC1 level depends on MOE, OSSI, OSSR, OIS1, OIS1N and CC1NE bits, regardless of the CC1E bits state. Refer to *Table 351* for details.

Note: On channels having a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1E active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Table 351. Output control bits for complementary OCx and OCxN channels with break feature

Control bits					Output states(1)	
MOE bit	OSSI bit	OSSR bit	CCxE bit	CCxNE bit	OCx output state	OCxN output state
1	X	X	0	0	Output disabled (not driven by the timer: Hi-Z) OCx=0, OCxN=0	
		0	0	1	Output disabled (not driven by the timer: Hi-Z) OCx=0	OCxREF + Polarity OCxN = OCxREF xor CCxNP
		0	1	0	OCxREF + Polarity OCx=OCxREF xor CCxP	Output Disabled (not driven by the timer: Hi-Z) OCxN=0
		X	1	1	OCREF + Polarity + dead-time	Complementary to OCREF (not OCREF) + Polarity + dead-time
		1	0	1	Off-State (output enabled with inactive state) OCx=CCxP	OCxREF + Polarity OCxN = OCxREF x or CCxNP
		1	1	0	OCxREF + Polarity OCx=OCxREF xor CCxP	Off-State (output enabled with inactive state) OCxN=CCxNP
0	0	X	X	X	Output disabled (not driven by the timer: Hi-Z).	
	1		0	0		
			0	1	Off-State (output enabled with inactive state) Asynchronously: OCx=CCxP, OCxN=CCxNP (if BRK or BRK2 is triggered). Then (this is valid only if BRK is triggered), if the clock is present: OCx=OISx and OCxN=OISxN after a dead-time, assuming that OISx and OISxN do not correspond to OCX and OCxN both in active state (may cause a short circuit when driving switches in half-bridge configuration). **Note**: BRK2 can only be used if OSSI = OSSR = 1.	
			1	0		
			1	1		

1. When both outputs of a channel are not used (control taken over by GPIO), the OISx, OISxN, CCxP and CCxNP bits must be kept cleared.

Note: The state of the external I/O pins connected to the complementary OCx and OCxN channels depends on the OCx and OCxN channel state and the GPIO registers.

43.4.12 TIMx counter (TIMx_CNT)(x = 1, 8)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIF CPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: UIF copy

This bit is a read-only copy of the UIF bit of the TIMx_ISR register. If the UIFREMAP bit in the TIMxCR1 is reset, bit 31 is reserved and read at 0.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]**: Counter value

43.4.13 TIMx prescaler (TIMx_PSC)(x = 1, 8)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency (CK_CNT) is equal to f_{CK_PSC} / (PSC[15:0] + 1).
PSC contains the value to be loaded in the active prescaler register at each update event (including when the counter is cleared through UG bit of TIMx_EGR register or through trigger controller when configured in “reset mode”).

43.4.14 TIMx auto-reload register (TIMx_ARR)(x = 1, 8)

Address offset: 0x2C

Reset value: 0xFFFF

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **ARR[15:0]**: Auto-reload value

ARR is the value to be loaded in the actual auto-reload register.
Refer to the *Section 43.3.1: Time-base unit on page 1557* for more details about ARR update and behavior.
The counter is blocked while the auto-reload value is null.

43.4.15 TIMx repetition counter register (TIMx_RCR)(x = 1, 8)

Address offset: 0x30

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **REP[15:0]**: Repetition counter value

These bits allow the user to set-up the update rate of the compare registers (i.e. periodic transfers from preload to active registers) when preload registers are enable, as well as the update interrupt generation rate, if this interrupt is enable.

Each time the REP_CNT related downcounter reaches zero, an update event is generated and it restarts counting from REP value. As REP_CNT is reloaded with REP value only at the repetition update event U_RC, any write to the TIMx_RCR register is not taken in account until the next repetition update event.

It means in PWM mode (REP+1) corresponds to:

the number of PWM periods in edge-aligned mode

the number of half PWM period in center-aligned mode.

43.4.16 TIMx capture/compare register 1 (TIMx_CCR1)(x = 1, 8)

Address offset: 0x34

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR1[15:0]**: Capture/Compare 1 value

If channel CC1 is configured as output: CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on OC1 output.

If channel CC1 is configured as input: CR1 is the counter value transferred by the last input capture 1 event (IC1). The TIMx_CCR1 register is read-only and cannot be programmed.

43.4.17 TIMx capture/compare register 2 (TIMx_CCR2)(x = 1, 8)

Address offset: 0x38

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR2[15:0]**: Capture/Compare 2 value

If channel CC2 is configured as output: CCR2 is the value to be loaded in the actual capture/compare 2 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC2PE). Else the preload value is copied in the active capture/compare 2 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on OC2 output.

If channel CC2 is configured as input: CCR2 is the counter value transferred by the last input capture 2 event (IC2). The TIMx_CCR2 register is read-only and cannot be programmed.

43.4.18 TIMx capture/compare register 3 (TIMx_CCR3)(x = 1, 8)

Address offset: 0x3C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR3[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR3[15:0]**: Capture/Compare value

If channel CC3 is configured as output: CCR3 is the value to be loaded in the actual capture/compare 3 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR2 register (bit OC3PE). Else the preload value is copied in the active capture/compare 3 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signalled on OC3 output.

If channel CC3 is configured as input: CCR3 is the counter value transferred by the last input capture 3 event (IC3). The TIMx_CCR3 register is read-only and cannot be programmed.

43.4.19 TIMx capture/compare register 4 (TIMx_CCR4)(x = 1, 8)

Address offset: 0x40

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR4[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR4[15:0]**: Capture/Compare value

If channel CC4 is configured as output: CCR4 is the value to be loaded in the actual capture/compare 4 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR2 register (bit OC4PE). Else the preload value is copied in the active capture/compare 4 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signalled on OC4 output.

If channel CC4 is configured as input: CCR4 is the counter value transferred by the last input capture 4 event (IC4). The TIMx_CCR4 register is read-only and cannot be programmed.

43.4.20 TIMx break and dead-time register (TIMx_BDTR)(x = 1, 8)

Address offset: 0x44

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	BK2BID	BKBID	BK2 DSRM	BK DSRM	BK2P	BK2E	BK2F[3:0]				BKF[3:0]			
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK[1:0]		DTG[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Note: As the bits BK2BID, BKBID, BK2DSRM, BKDSRM, BK2P, BK2E, BK2F[3:0], BKF[3:0], AOE, BKP, BKE, OSSI, OSSR and DTG[7:0] can be write-locked depending on the LOCK configuration, it can be necessary to configure all of them during the first write access to the TIMx_BDTR register.

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **BK2BID**: Break2 bidirectional

Refer to BKBID description

Bit 28 **BKBID**: Break Bidirectional

0: Break input BRK in input mode
1: Break input BRK in bidirectional mode
In the bidirectional mode (BKBID bit set to 1), the break input is configured both in input mode and in open drain output mode. Any active break event asserts a low logic level on the Break input to indicate an internal break event to external devices.

Note: This bit cannot be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 27 **BK2DSRM**: Break2 Disarm

Refer to BKDSRM description

Bit 26 **BKDSRM**: Break Disarm

0: Break input BRK is armed
1: Break input BRK is disarmed
This bit is cleared by hardware when no break source is active.
The BKDSRM bit must be set by software to release the bidirectional output control (open-drain output in Hi-Z state) and then be polled it until it is reset by hardware, indicating that the fault condition has disappeared.

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 25 **BK2P**: Break 2 polarity

0: Break input BRK2 is active low
1: Break input BRK2 is active high

Note: This bit cannot be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 24 **BK2E**: Break 2 enable

This bit enables the complete break 2 protection (including all sources connected to bk_acth and BKIN sources, as per *Figure 416: Break and Break2 circuitry overview*).
0: Break2 function disabled
1: Break2 function enabled

Note: The BKIN2 must only be used with OSSR = OSSI = 1.

Note: This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bits 23:20 **BK2F[3:0]**: Break 2 filter

This bit-field defines the frequency used to sample BRK2 input and the length of the digital filter applied to BRK2. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, BRK2 acts asynchronously
0001: $f_{SAMPLING}=f_{CK\_INT}$, N=2
0010: $f_{SAMPLING}=f_{CK\_INT}$, N=4
0011: $f_{SAMPLING}=f_{CK\_INT}$, N=8
0100: $f_{SAMPLING}=f_{DTS}/2$, N=6
0101: $f_{SAMPLING}=f_{DTS}/2$, N=8
0110: $f_{SAMPLING}=f_{DTS}/4$, N=6
0111: $f_{SAMPLING}=f_{DTS}/4$, N=8
1000: $f_{SAMPLING}=f_{DTS}/8$, N=6
1001: $f_{SAMPLING}=f_{DTS}/8$, N=8
1010: $f_{SAMPLING}=f_{DTS}/16$, N=5
1011: $f_{SAMPLING}=f_{DTS}/16$, N=6
1100: $f_{SAMPLING}=f_{DTS}/16$, N=8
1101: $f_{SAMPLING}=f_{DTS}/32$, N=5
1110: $f_{SAMPLING}=f_{DTS}/32$, N=6
1111: $f_{SAMPLING}=f_{DTS}/32$, N=8

Note: This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 19:16 **BKF[3:0]**: Break filter

This bit-field defines the frequency used to sample BRK input and the length of the digital filter applied to BRK. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, BRK acts asynchronously
0001: $f_{SAMPLING}=f_{CK\_INT}$, N=2
0010: $f_{SAMPLING}=f_{CK\_INT}$, N=4
0011: $f_{SAMPLING}=f_{CK\_INT}$, N=8
0100: $f_{SAMPLING}=f_{DTS}/2$, N=6
0101: $f_{SAMPLING}=f_{DTS}/2$, N=8
0110: $f_{SAMPLING}=f_{DTS}/4$, N=6
0111: $f_{SAMPLING}=f_{DTS}/4$, N=8
1000: $f_{SAMPLING}=f_{DTS}/8$, N=6
1001: $f_{SAMPLING}=f_{DTS}/8$, N=8
1010: $f_{SAMPLING}=f_{DTS}/16$, N=5
1011: $f_{SAMPLING}=f_{DTS}/16$, N=6
1100: $f_{SAMPLING}=f_{DTS}/16$, N=8
1101: $f_{SAMPLING}=f_{DTS}/32$, N=5
1110: $f_{SAMPLING}=f_{DTS}/32$, N=6
1111: $f_{SAMPLING}=f_{DTS}/32$, N=8

Note: This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 15 **MOE**: Main output enable

This bit is cleared asynchronously by hardware as soon as one of the break inputs is active (BRK or BRK2). It is set by software or automatically depending on the AOE bit. It is acting only on the channels which are configured in output.

0: In response to a break 2 event. OC and OCN outputs are disabled
In response to a break event or if MOE is written to 0: OC and OCN outputs are disabled or forced to idle state depending on the OSSI bit.

1: OC and OCN outputs are enabled if their respective enable bits are set (CCxE, CCxNE in TIMx_CCER register).

See OC/OCN enable description for more details (*Section 43.4.11: TIMx capture/compare enable register (TIMx_CCER)(x = 1, 8)*).

Bit 14 **AOE**: Automatic output enable

0: MOE can be set only by software

1: MOE can be set by software or automatically at the next update event (if none of the break inputs BRK and BRK2 is active)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 13 **BKP**: Break polarity

0: Break input BRK is active low

1: Break input BRK is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 12 **BKE**: Break enable

This bit enables the complete break protection (including all sources connected to bk_acth and BKIN sources, as per *Figure 416: Break and Break2 circuitry overview*).

0: Break function disabled

1: Break function enabled

Note: This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 11 **OSSR**: Off-state selection for Run mode

This bit is used when MOE=1 on channels having a complementary output which are configured as outputs. OSSR is not implemented if no complementary output is implemented in the timer.

See OC/OCN enable description for more details (*Section 43.4.11: TIMx capture/compare enable register (TIMx_CCER)(x = 1, 8)*).

0: When inactive, OC/OCN outputs are disabled (the timer releases the output control which is taken over by the GPIO logic, which forces a Hi-Z state).

1: When inactive, OC/OCN outputs are enabled with their inactive level as soon as CCxE=1 or CCxNE=1 (the output is still controlled by the timer).

Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **OSSI**: Off-state selection for Idle mode

This bit is used when MOE=0 due to a break event or by a software write, on channels configured as outputs.
See OC/OCN enable description for more details (*Section 43.4.11: TIMx capture/compare enable register (TIMx_CCER)(x = 1, 8)*).

0: When inactive, OC/OCN outputs are disabled (the timer releases the output control which is taken over by the GPIO logic and which imposes a Hi-Z state).

1: When inactive, OC/OCN outputs are first forced with their inactive level then forced to their idle level after the deadtime. The timer maintains its control over the output.

Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 9:8 **LOCK[1:0]**: Lock configuration

These bits offer a write protection against software errors.

00: LOCK OFF - No bit is write protected.

01: LOCK Level 1 = DTG bits in TIMx_BDTR register, OISx and OISxN bits in TIMx_CR2 register and B*K2BID, BKBID, BK2DSRM, BKDSRM, BK2P, BK2E, BK2F[3:0], BKF[3:0], AOE, BKP, BKE, OSSI, OSSR and DTG[7:0]* bits in TIMx_BDTR register can no longer be written.

10: LOCK Level 2 = LOCK Level 1 + CC Polarity bits (CCxP/CCxNP bits in TIMx_CCER register, as long as the related channel is configured in output through the CCxS bits) as well as OSSR and OSSI bits can no longer be written.

11: LOCK Level 3 = LOCK Level 2 + CC Control bits (OCxM and OCxPE bits in TIMx_CCMRx registers, as long as the related channel is configured in output through the CCxS bits) can no longer be written.

Note: The LOCK bits can be written only once after the reset. Once the TIMx_BDTR register has been written, their content is frozen until the next reset.

Bits 7:0 **DTG[7:0]**: Dead-time generator setup

This bit-field defines the duration of the dead-time inserted between the complementary outputs. DT correspond to this duration.
DTG[7:5] = 0xx => DT = DTG[7:0] x t_{DTG} with $t_{DTG} = t_{DTS}$.
DTG[7:5] = 10x => DT = (64 + DTG[5:0]) x t_{DTG} with $t_{DTG} = 2 \times t_{DTS}$.
DTG[7:5] = 110 => DT = (32 + DTG[4:0]) x t_{DTG} with $t_{DTG} = 8 \times t_{DTS}$.
DTG[7:5] = 111 => DT = (32 + DTG[4:0]) x t_{DTG} with $t_{DTG} = 16 \times t_{DTS}$.
Example if t_{DTS} = 125 ns (8 MHz), dead-time possible values are:
0 to 15875 ns by 125 ns steps,
16 µs to 31750 ns by 250 ns steps,
32 µs to 63 µs by 1 µs steps,
64 µs to 126 µs by 2 µs steps

Note: This bit-field can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

43.4.21 TIMx DMA control register (TIMx_DCR)(x = 1, 8)

Address offset: 0x48

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **DBL[4:0]**: DMA burst length

This 5-bit vector defines the length of DMA transfers (the timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address), i.e. the number of transfers. Transfers can be in half-words or in bytes (see example below).

00000: 1 transfer
00001: 2 transfers
00010: 3 transfers
...
10001: 18 transfers

Example: Let us consider the following transfer: DBL = 7 bytes & DBA = TIMx_CR1.

– If DBL = 7 bytes and DBA = TIMx_CR1 represents the address of the byte to be transferred, the address of the transfer should be given by the following equation:

(TIMx_CR1 address) + DBA + (DMA index), where DMA index = DBL

In this example, 7 bytes are added to (TIMx_CR1 address) + DBA, which gives us the address from/to which the data is copied. In this case, the transfer is done to 7 registers starting from the following address: (TIMx_CR1 address) + DBA

According to the configuration of the DMA Data Size, several cases may occur:

– If the DMA Data Size is configured in half-words, 16-bit data is transferred to each of the 7 registers.

– If the DMA Data Size is configured in bytes, the data is also transferred to 7 registers: the first register contains the first MSB byte, the second register, the first LSB byte and so on. So with the transfer Timer, one also has to specify the size of data transferred by DMA.

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **DBA[4:0]**: DMA base address

This 5-bits vector defines the base-address for DMA transfers (when read/write access are done through the TIMx_DMAR address). DBA is defined as an offset starting from the address of the TIMx_CR1 register.

Example:
00000: TIMx_CR1,
00001: TIMx_CR2,
00010: TIMx_SMCR,
...

43.4.22 TIMx DMA address for full transfer (TIMx_DMAR)(x = 1, 8)

Address offset: 0x4C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMAB[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAB[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DMAB[31:0]**: DMA register for burst accesses

A read or write operation to the DMAR register accesses the register located at the address (TIMx_CR1 address) + (DBA + DMA index) x 4
where TIMx_CR1 address is the address of the control register 1, DBA is the DMA base address configured in TIMx_DCR register, DMA index is automatically controlled by the DMA transfer, and ranges from 0 to DBL (DBL configured in TIMx_DCR).

43.4.23 TIMx capture/compare mode register 3 (TIMx_CCMR3)(x = 1, 8)

Address offset: 0x54

Reset value: 0x0000 0000

The channels 5 and 6 can only be configured in output.

Output compare mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC6M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC5M[3]
							rw								rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC6 CE	OC6M[2:0]			OC6 PE	OC6FE	Res.	Res.	OC5 CE	OC5M[2:0]			OC5PE	OC5FE	Res.	Res.
rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw		

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 **OC6CE**: Output compare 6 clear enable
Refer to OC1CE description.

Bits 24, 14, 13, 12 **OC6M[3:0]**: Output compare 6 mode
Refer to OC1M description.

Bit 11 **OC6PE**: Output compare 6 preload enable
Refer to OC1PE description.

Bit 10 **OC6FE**: Output compare 6 fast enable
Refer to OC1FE description.

Bits 9:8 Reserved, must be kept at reset value.

Bit 7 **OC5CE:** Output compare 5 clear enable
Refer to OC1CE description.

Bits 16, 6, 5, 4 **OC5M[3:0]**: Output compare 5 mode
Refer to OC1M description.

Bit 3 **OC5PE**: Output compare 5 preload enable
Refer to OC1PE description.

Bit 2 **OC5FE**: Output compare 5 fast enable
Refer to OC1FE description.

Bits 1:0 Reserved, must be kept at reset value.

43.4.24 TIMx capture/compare register 5 (TIMx_CCR5)(x = 1, 8)

Address offset: 0x58

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GC5C3	GC5C2	GC5C1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw													
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR5[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **GC5C3**: Group Channel 5 and Channel 3

Distortion on Channel 3 output:

0: No effect of OC5REF on OC3REFC

1: OC3REFC is the logical AND of OC3REFC and OC5REF

This bit can either have immediate effect or be preloaded and taken into account after an update event (if preload feature is selected in TIMxCCMR2).

Note: it is also possible to apply this distortion on combined PWM signals.

Bit 30 **GC5C2**: Group Channel 5 and Channel 2

Distortion on Channel 2 output:

0: No effect of OC5REF on OC2REFC

1: OC2REFC is the logical AND of OC2REFC and OC5REF

This bit can either have immediate effect or be preloaded and taken into account after an update event (if preload feature is selected in TIMxCCMR1).

Note: it is also possible to apply this distortion on combined PWM signals.

Bit 29 **GC5C1**: Group Channel 5 and Channel 1

Distortion on Channel 1 output:

0: No effect of OC5REF on OC1REFC5

1: OC1REFC is the logical AND of OC1REFC and OC5REF

This bit can either have immediate effect or be preloaded and taken into account after an update event (if preload feature is selected in TIMxCCMR1).

Note: it is also possible to apply this distortion on combined PWM signals.

Bits 28:16 Reserved, must be kept at reset value.

Bits 15:0 **CCR5[15:0]**: Capture/Compare 5 value

CCR5 is the value to be loaded in the actual capture/compare 5 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR3 register (bit OC5PE). Else the preload value is copied in the active capture/compare 5 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on OC5 output.

43.4.25 TIMx capture/compare register 6 (TIMx_CCR6)(x = 1, 8)

Address offset: 0x5C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR6[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR6[15:0]**: Capture/Compare 6 value

CCR6 is the value to be loaded in the actual capture/compare 6 register (preload value).
It is loaded permanently if the preload feature is not selected in the TIMx_CCMR3 register (bit OC6PE). Else the preload value is copied in the active capture/compare 6 register when an update event occurs.
The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on OC6 output.

43.4.26 TIM1 alternate function option register 1 (TIM1_AF1)

Address offset: 0x60

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL[3:2]	
														rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETRSEL[1:0]		Res.	Res.	BK CMP2P	BK CMP1P	BKINP	BKDF1 BK0E	Res.	Res.	Res.	Res.	Res.	BK CMP2E	BK CMP1E	BKINE
rw	rw			rw	rw	rw	rw						rw	rw	rw

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:14 **ETRSEL[3:0]**: ETR source selection

These bits select the ETR input source.
0000: ETR input is connected to I/O
0001: COMP1 output
0010: COMP2 output
0011: ADC1 AWD1
0100: ADC1 AWD2
0101: ADC1 AWD3
0110: ADC3 AWD1
0111: ADC3 AWD2
1000: ADC3 AWD3
Others: Reserved

Note: These bits can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 13:12 Reserved, must be kept at reset value.

Bit 11 **BKCMP2P**: BRK COMP2 input polarity

This bit selects the COMP2 input sensitivity. It must be programmed together with the BKP polarity bit.

0: COMP2 input polarity is not inverted (active low if BKP=0, active high if BKP=1)

1: COMP2 input polarity is inverted (active high if BKP=0, active low if BKP=1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **BKCMP1P**: BRK COMP1 input polarity

This bit selects the COMP1 input sensitivity. It must be programmed together with the BKP polarity bit.

0: COMP1 input polarity is not inverted (active low if BKP=0, active high if BKP=1)

1: COMP1 input polarity is inverted (active high if BKP=0, active low if BKP=1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 9 **BKINP**: BRK BKIN input polarity

This bit selects the BKIN alternate function input sensitivity. It must be programmed together with the BKP polarity bit.

0: BKIN input polarity is not inverted (active low if BKP=0, active high if BKP=1)

1: BKIN input polarity is inverted (active high if BKP=0, active low if BKP=1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 8 **BKDF1BK0E**: BRK dfsdm1_break[0] enable

This bit enables the dfsdm1_break[0] for the timer's BRK input. dfsdm1_break[0] output is 'ORed' with the other BRK sources.

0: dfsdm1_break[0] input disabled

1: dfsdm1_break[0] input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 7:3 Reserved, must be kept at reset value.

Bit 2 **BKCMP2E**: BRK COMP2 enable

This bit enables the COMP2 for the timer's BRK input. COMP2 output is 'ORed' with the other BRK sources.

0: COMP2 input disabled

1: COMP2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 1 **BKCMP1E**: BRK COMP1 enable

This bit enables the COMP1 for the timer's BRK input. COMP1 output is 'ORed' with the other BRK sources.

0: COMP1 input disabled

1: COMP1 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 0 **BKINE**: BRK BKIN input enable

This bit enables the BKIN alternate function input for the timer's BRK input. BKIN input is 'ORed' with the other BRK sources.

0: BKIN input disabled

1: BKIN input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Refer to Figure 395: TIM1/TIM8 ETR input circuitry and to Figure 416: Break and Break2 circuitry overview.

43.4.27 TIM1 Alternate function register 2 (TIM1_AF2)

Address offset: 0x64

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	BK2 CMP2 P	BK2 CMP1 P	BK2 INP	BK2DF1 BK1E	Res.	Res.	Res.	Res.	Res.	BK2 CMP2E	BK2 CMP1E	BK2INE
				rw	rw	rw	rw						rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **BK2CMP2P**: BRK2 COMP2 input polarity

This bit selects the COMP2 input sensitivity. It must be programmed together with the BK2P polarity bit.

0: COMP2 input polarity is not inverted (active low if BK2P=0, active high if BK2P=1)

1: COMP2 input polarity is inverted (active high if BK2P=0, active low if BK2P=1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **BK2CMP1P**: BRK2 COMP1 input polarity

This bit selects the COMP1 input sensitivity. It must be programmed together with the BK2P polarity bit.

0: COMP1 input polarity is not inverted (active low if BK2P=0, active high if BK2P=1)

1: COMP1 input polarity is inverted (active high if BK2P=0, active low if BK2P=1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 9 **BK2INP**: BRK2 BKIN2 input polarity

This bit selects the BKIN2 alternate function input sensitivity. It must be programmed together with the BK2P polarity bit.

0: BKIN2 input polarity is not inverted (active low if BK2P=0, active high if BK2P=1)

1: BKIN2 input polarity is inverted (active high if BK2P=0, active low if BK2P=1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 8 **BK2DF1BK1E**: BRK2 dfsdm1_break[1] enable

This bit enables the dfsdm1_break[1] for the timer's BRK2 input. dfsdm1_break[1] output is 'ORed' with the other BRK2 sources.

0: dfsdm1_break[1] input disabled

1: dfsdm1_break[1] input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 7:3 Reserved, must be kept at reset value.

Bit 2 **BK2CMP2E**: BRK2 COMP2 enable

This bit enables the COMP2 for the timer's BRK2 input. COMP2 output is 'ORed' with the other BRK2 sources.

0: COMP2 input disabled

1: COMP2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 1 **BK2CMP1E**: BRK2 COMP1 enable

This bit enables the COMP1 for the timer's BRK2 input. COMP1 output is 'ORed' with the other BRK2 sources.

0: COMP1 input disabled

1: COMP1 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 0 **BK2INE**: BRK2 BKIN input enable

This bit enables the BKIN2 alternate function input for the timer's BRK2 input. BKIN2 input is 'ORed' with the other BRK2 sources.

0: BKIN2 input disabled

1: BKIN2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Refer to Figure 416: Break and Break2 circuitry overview.

43.4.28 TIM8 Alternate function option register 1 (TIM8_AF1)

Address offset: 0x60

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL[3:2]	
														rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETRSEL[1:0]		Res.	Res.	BK CMP2 P	BK CMP1 P	BKINP	BKDF1 BK2E	Res.	Res.	Res.	Res.	Res.	BK CMP2E	BK CMP1E	BKINE
rw	rw			rw	rw	rw	rw						rw	rw	rw

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:14 **ETRSEL[3:0]**: ETR source selection
These bits select the ETR input source.
0000: ETR input is connected to I/O
0001: COMP1 output
0010: COMP2 output
0011: ADC2 AWD1
0100: ADC2 AWD2
0101: ADC2 AWD3
0110: ADC3 AWD1
0111: ADC3 AWD2
1000: ADC3 AWD3
Others: Reserved
Note: These bits can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 13:12 Reserved, must be kept at reset value.

Bit 11 **BKCMP2P**: BRK COMP2 input polarity
This bit selects the COMP2 input sensitivity. It must be programmed together with the BKP polarity bit.
0: COMP2 input polarity is not inverted (active low if BKP=0, active high if BKP=1)
1: COMP2 input polarity is inverted (active high if BKP=0, active low if BKP=1)
Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **BKCMP1P**: BRK COMP1 input polarity
This bit selects the COMP1 input sensitivity. It must be programmed together with the BKP polarity bit.
0: COMP1 input polarity is not inverted (active low if BKP=0, active high if BKP=1)
1: COMP1 input polarity is inverted (active high if BKP=0, active low if BKP=1)
Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 9 **BKINP**: BRK BKIN input polarity
This bit selects the BKIN alternate function input sensitivity. It must be programmed together with the BKP polarity bit.
0: BKIN input polarity is not inverted (active low if BKP=0, active high if BKP=1)
1: BKIN input polarity is inverted (active high if BKP=0, active low if BKP=1)
Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 8 **BKDF1BK2E**: BRK dfsdm1_break[2] enable
This bit enables the dfsdm1_break[2] for the timer's BRK input. dfsdm1_break[2] output is 'ORed' with the other BRK sources.
0: dfsdm1_break[2] input disabled
1: dfsdm1_break[2] input enabled
Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 7:3 Reserved, must be kept at reset value.

Bit 2 **BKCMP2E**: BRK COMP2 enable

This bit enables the COMP2 for the timer's BRK input. COMP2 output is 'ORed' with the other BRK sources.

0: COMP2 input disabled

1: COMP2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 1 **BKCMP1E**: BRK COMP1 enable

This bit enables the COMP1 for the timer's BRK input. COMP1 output is 'ORed' with the other BRK sources.

0: COMP1 input disabled

1: COMP1 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 0 **BKINE**: BRK BKIN input enable

This bit enables the BKIN alternate function input for the timer's BRK input. BKIN input is 'ORed' with the other BRK sources.

0: BKIN input disabled

1: BKIN input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Refer to Figure 395: TIM1/TIM8 ETR input circuitry and to Figure 416: Break and Break2 circuitry overview.

43.4.29 TIM8 Alternate function option register 2 (TIM8_AF2)

Address offset: 0x64

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	BK2 CMP2 P	BK2 CMP1 P	BK2 INP	BK2DF1 BK3E	Res.	Res.	Res.	Res.	Res.	BK2 CMP2E	BK2 CMP1E	BK2INE
				rw	rw	rw	rw						rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **BK2CMP2P**: BRK2 COMP2 input polarity

This bit selects the COMP2 input sensitivity. It must be programmed together with the BK2P polarity bit.

0: COMP2 input polarity is not inverted (active low if BK2P=0, active high if BK2P=1)

1: COMP2 input polarity is inverted (active high if BK2P=0, active low if BK2P=1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **BK2CMP1P**: BRK2 COMP1 input polarity

This bit selects the COMP1 input sensitivity. It must be programmed together with the BK2P polarity bit.

0: COMP1 input polarity is not inverted (active low if BK2P=0, active high if BK2P=1)

1: COMP1 input polarity is inverted (active high if BK2P=0, active low if BK2P=1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 9 **BK2INP**: BRK2 BKIN2 input polarity

This bit selects the BKIN2 alternate function input sensitivity. It must be programmed together with the BK2P polarity bit.

0: BKIN2 input polarity is not inverted (active low if BK2P=0, active high if BK2P=1)

1: BKIN2 input polarity is inverted (active high if BK2P=0, active low if BK2P=1)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 8 **BK2DF1BK3E**: BRK2 dfsdm1_break[3] enable

This bit enables the dfsdm1_break[3] for the timer's BRK2 input. dfsdm1_break[3] output is 'ORed' with the other BRK2 sources.

0: dfsdm1_break[3] input disabled

1: dfsdm1_break[3] input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 7:3 Reserved, must be kept at reset value.

Bit 2 **BK2CMP2E**: BRK2 COMP2 enable

This bit enables the COMP2 for the timer's BRK2 input. COMP2 output is 'ORed' with the other BRK2 sources.

0: COMP2 input disabled

1: COMP2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 1 **BK2CMP1E**: BRK2 COMP1 enable

This bit enables the COMP1 for the timer's BRK2 input. COMP1 output is 'ORed' with the other BRK2 sources.

0: COMP1 input disabled

1: COMP1 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 0 **BK2INE**: BRK2 BKIN input enable

This bit enables the BKIN2 alternate function input for the timer's BRK2 input. BKIN2 input is 'ORed' with the other BRK2 sources.

0: BKIN2 input disabled

1: BKIN2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Refer to Figure 416: Break and Break2 circuitry overview.

43.4.30 TIM1 timer input selection register (TIM1_TISEL)

Address offset: 0x68

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw						rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **TI4SEL[3:0]**: selects TI4[0] to TI4[15] input
0000: TIM1_CH4 input
Others: Reserved

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **TI3SEL[3:0]**: selects TI3[0] to TI3[15] input
0000: TIM1_CH3 input
Others: Reserved

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: selects TI2[0] to TI2[15] input
0000: TIM1_CH2 input
Others: Reserved

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: selects TI1[0] to TI1[15] input
0000: TIM1_CH1 input
0001: COMP1 output
Others: Reserved

43.4.31 TIM8 timer input selection register (TIM8_TISEL)

Address offset: 0x68

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw						rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **TI4SEL[3:0]**: selects TI4[0] to TI4[15] input
0000: TIM8_CH4 input
Others: Reserved

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **TI3SEL[3:0]**: selects TI3[0] to TI3[15] input
0000: TIM8_CH3 input
Others: Reserved

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: selects TI2[0] to TI2[15] input
0000: TIM8_CH2 input
Others: Reserved

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: selects TI1[0] to TI1[15] input
0000: TIM8_CH1 input
0001: COMP2 output
Others: Reserved

43.4.32 TIM1 register map

TIM1 registers are mapped as 16-bit addressable registers as described in the table below:

Table 352. TIM1 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**TIM1_CR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIFREMAP	Res.	CKD [1:0]		ARPE	CMS [1:0]		DIR	OPM	URS	UDIS	CEN
	Reset value																					0		0	0	0	0	0	0	0	0	0	0
0x04	**TIM1_CR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MMS2[3:0]				Res.	OIS6	Res.	OIS5	Res.	OIS4	OIS3N	OIS3	OIS2N	OIS2	OIS1N	OIS1	TI1S	MMS [2:0]			CCDS	CCUS	Res.	CCPC
	Reset value									0	0	0	0		0		0		0	0	0	0	0	0	0	0	0	0	0	0	0		0
0x08	**TIM1_SMCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS [4:3]		Res.	Res.	Res.	SMS[3]	ETP	ECE	ETPS [1:0]		ETF[3:0]				MSM	TS[2:0]			Res.	SMS[2:0]		
	Reset value											0	0				0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
0x0C	**TIM1_DIER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDE	COMDE	CC4DE	CC3DE	CC2DE	CC1DE	UDE	BIE	TIE	COMIE	CC4IE	CC3IE	CC2IE	CC1IE	UIE
	Reset value																		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	**TIM1_SR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC6IF	CC5IF	Res.	Res.	SBIF	CC4OF	CC3OF	CC2OF	CC1OF	B2IF	BIF	TIF	COMIF	CC4IF	CC3IF	CC2IF	CC1IF	UIF
	Reset value															0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	**TIM1_EGR**	Res.	Res.	Res	Res	Res.	Res.	Res.	Res	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	B2G	BG	TG	COMG	CC4G	CC3G	CC2G	CC1G	UG
	Reset value																								0	0	0	0	0	0	0	0	0
0x18	**TIM1_CCMR1** Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]	OC2CE	OC2M [2:0]			OC2PE	OC2FE	CC2S [1:0]		OC1CE	OC1M [2:0]			OC1PE	OC1FE	CC1S [1:0]	
	Reset value								0								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TIM1_CCMR1 Input Capture mode	Res.	Res.	Res	Res	Res.	Res.	Res.	Res	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC2F[3:0]				IC2PSC [1:0]		CC2S [1:0]		IC1F[3:0]				IC1PSC [1:0]		CC1S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	**TIM1_CCMR2** Output Compare mode	Res.	Res.	Res	Res	Res.	Res.	Res.	OC4M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC3M[3]	OC4CE	OC4M [2:0]			OC4PE	OC4FE	CC4S [1:0]		OC3CE	OC3M [2:0]			OC3PE	OC3FE	CC3S [1:0]	
	Reset value								0								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TIM1_CCMR2 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC4F[3:0]				IC4PSC [1:0]		CC4S [1:0]		IC3F[3:0]				IC3PSC [1:0]		CC3S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	**TIM1_CCER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC6P	CC6E	Res.	Res.	CC5P	CC5E	CC4NP	Res.	CC4P	CC4E	CC3NP	CC3NE	CC3P	CC3E	CC2NP	CC2NE	CC2P	CC2E	CC1NP	CC1NE	CC1P	CC1E
	Reset value											0	0			0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 352. TIM1 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x24	**TIM1_CNT**	UIFCP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value	0																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	**TIM1_PSC**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	**TIM1_ARR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[15:0]															
	Reset value																	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x30	**TIM1_RCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REP[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x34	**TIM1_CCR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x38	**TIM1_CCR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR2[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x3C	**TIM1_CCR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR3[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x40	**TIM1_CCR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR4[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x44	**TIM1_BDTR**	Res.	Res.	BK2BID	BKBID	BK2DSRM	BKDSRM	BK2P	BK2E	BK2F[3:0]				BKF[3:0]				MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK [1:0]		DT[7:0]							
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x48	**TIM1_DCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
	Reset value																				0	0	0	0	0				0	0	0	0	0
0x4C	**TIM1_DMAR**	DMAB[31:0]																															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x54	**TIM1_CCMR3** Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC6M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC5M[3]	OC6CE	OC6M [2:0]			OC6PE	OC6FE	Res.	Res.	OC5CE	OC5M [2:0]			OC5PE	OC5FE	Res.	Res.
	Reset value								0								0	0	0	0	0	0	0			0	0	0	0	0	0		
0x58	**TIM1_CCR5**	GC5C3	GC5C2	GC5C1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR5[15:0]															
	Reset value	0	0	0														0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 352. TIM1 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x5C	**TIM1_CCR6**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR6[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x60	**TIM1_AF1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res ETRSEL [3:0]				Res.	Res.	BKCMP2P	BKCMP1P	BKINP	BKDF1BK0E	Res.	Res.	Res.	Res.	Res.	BKCMP2E	BKCMP1E	BKINE
	Reset value															0	0	0	0			0	0	0	0						0	0	1
0x64	**TIM1_AF2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BK2CMP2P	BK2CMP1P	BK2INP	BK2DF1BK1E	Res.	Res.	Res.	Res.	Res.	BK2CMP2E	BK2CMP1E	BK2INE
	Reset value																					0	0	0	0						0	0	1
0x68	**TIM1_TISEL**	Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]				Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value					0	0	0	0					0	0	0	0					0	0	0	0					0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

43.4.33 TIM8 register map

TIM8 registers are mapped as 16-bit addressable registers as described in the table below:

Table 353. TIM8 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**TIM8_CR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIFREMA	Res.	CKD [1:0]		ARPE	CMS [1:0]		DIR	OPM	URS	UDIS	CEN
	Reset value																					0		0	0	0	0	0	0	0	0	0	0
0x04	**TIM8_CR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MMS2[3:0]				Res.	OIS6	Res.	OIS5	Res.	OIS4	OIS3N	OIS3	OIS2N	OIS2	OIS1N	OIS1	TI1S	MMS [2:0]			CCDS	CCUS	Res.	CCPC
	Reset value									0	0	0	0		0		0		0	0	0	0	0	0	0	0	0	0	0	0	0		0
0x08	**TIM8_SMCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS [4:3]		Res.	Res.	Res.	SMS[3]	ETP	ECE	ETP S [1:0]		ETF[3:0]				MSM	TS[2:0]			Res.	SMS[2:0]		
	Reset value											0	0				0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
0x0C	**TIM8_DIER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDE	COMDE	CC4DE	CC3DE	CC2DE	CC1DE	UDE	BIE	TIE	COMIE	CC4IE	CC3IE	CC2IE	CC1IE	UIE
	Reset value																		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	**TIM8_SR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC6IF	CC5IF	Res.	Res.	SBIF	CC4OF	CC3OF	CC2OF	CC1OF	B2IF	BIF	TIF	COMIF	CC4IF	CC3IF	CC2IF	CC1IF	UIF
	Reset value															0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 353. TIM8 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x14	**TIM8_EGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	B2G	BG	TG	COMG	CC4G	CC3G	CC2G	CC1G	UG
	Reset value																								0	0	0	0	0	0	0	0	0
0x18	**TIM8_CCMR1** Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]	OC2CE	OC2M [2:0]			OC2PE	OC2FE	CC2S [1:0]		OC1CE	OC1M [2:0]			OC1PE	OC1FE	CC1S [1:0]	
	Reset value								0								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TIM8_CCMR1 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC2F[3:0]				IC2PSC [1:0]		CC2S [1:0]		IC1F[3:0]				IC1PSC [1:0]		CC1S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	**TIM8_CCMR2** Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC4M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC3M[3]	OC4CE	OC4M [2:0]			OC4PE	OC4FE	CC4S [1:0]		OC3CE	OC3M [2:0]			OC3PE	OC3FE	CC3S [1:0]	
	Reset value								0								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TIM8_CCMR2 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC4F[3:0]				IC4PSC [1:0]		CC4S [1:0]		IC3F[3:0]				IC3PSC [1:0]		CC3S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	**TIM8_CCER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC6P	CC6E	Res.	Res.	CC5P	CC5E	CC4NP	Res.	CC4P	CC4E	CC3NP	CC3NE	CC3P	CC3E	CC2NP	CC2NE	CC2P	CC2E	CC1NP	CC1NE	CC1P	CC1E
	Reset value											0	0			0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x24	**TIM8_CNT**	UIFCPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value	0																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	**TIM8_PSC**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	**TIM8_ARR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[15:0]															
	Reset value																	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x30	**TIM8_RCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REP[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x34	**TIMx_CCR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x38	**TIM8_CCR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR2[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x3C	**TIM8_CCR3**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR3[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x40	**TIM8_CCR4**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR4[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 353. TIM8 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x44	**TIM8_BDTR**	Res.	Res.	BK2BID	BKBID	BK2DSRM	BKDSRM	BK2P	BK2E	BK2F[3:0]				BKF[3:0]				MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK [1:0]		DT[7:0]							
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x48	**TIM8_DCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
	Reset value																				0	0	0	0	0				0	0	0	0	0
0x4C	**TIM8_DMAR**	DMAB[31:0]																															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x54	**TIM8_CCMR3** Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC6M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC5M[3]	OC6CE	OC6M [2:0]			OC6PE	OC6FE	Res.	Res.	OC5CE	OC5M [2:0]			OC5PE	OC5FE	Res.	Res.
	Reset value								0								0	0	0	0	0	0	0			0	0	0	0	0	0		
0x58	**TIM8_CCR5**	GC5C3	GC5C2	GC5C1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR5[15:0]															
	Reset value	0	0	0														0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x5C	**TIM8_CCR6**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR6[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x60	**TIM8_AF1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res ETRSEL [3:0]				Res.	Res.	BKCMP2P	BKCMP1P	BKINP	BKDF1BK2E	Res.	Res.	Res.	Res.	Res.	BKCMP2E	BKCMP1E	BKINE
	Reset value															0	0	0	0			0	0	0	0						0	0	1
0x64	**TIM8_AF2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BK2CMP2P	BK2CMP1P	BK2INP	BK2DF1BK3E	Res.	Res.	Res.	Res.	Res.	BK2CMP2E	BK2CMP1E	BK2INE
	Reset value																					0	0	0	0						0	0	1
0x68	**TIM8_TISEL**	Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]				Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value					0	0	0	0					0	0	0	0					0	0	0	0					0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

44 General-purpose timers (TIM2/TIM3/TIM4/TIM5/TIM23/TIM24)

44.1 TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 introduction

The general-purpose timers consist of a 16-bit/32-bit auto-reload counter driven by a programmable prescaler.

They may be used for a variety of purposes, including measuring the pulse lengths of input signals (*input capture*) or generating output waveforms (*output compare and PWM*).

Pulse lengths and waveform periods can be modulated from a few microseconds to several milliseconds using the timer prescaler and the RCC clock controller prescalers.

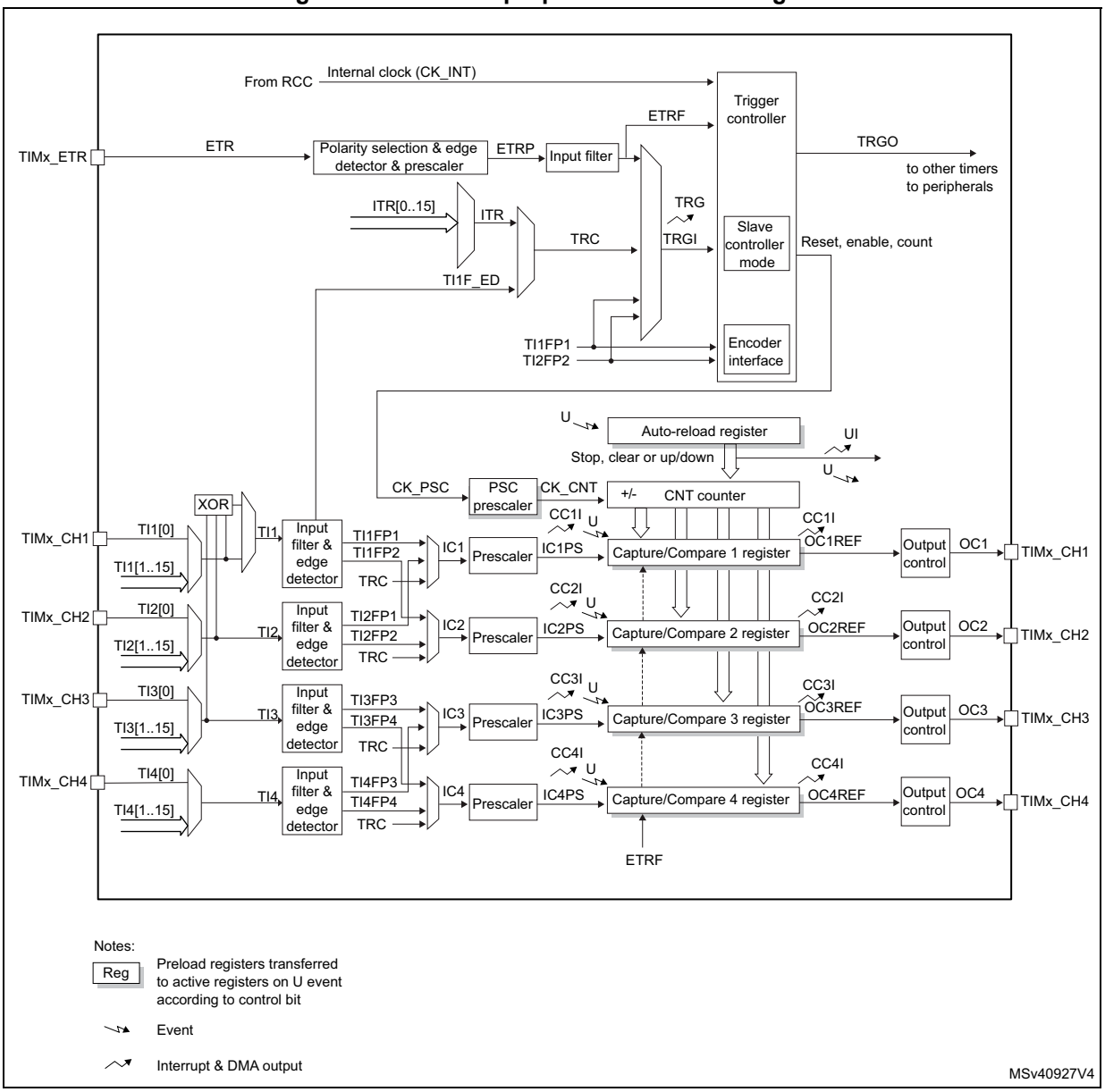
The timers are completely independent, and do not share any resources. They can be synchronized together as described in *Section 44.3.19: Timer synchronization*.

44.2 TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 main features

General-purpose TIMx timer features include:

- 16-bit (TIM3, TIM4) or 32-bit (TIM2, TIM5, TIM23 and TIM24) up, down, up/down auto-reload counter.
- 16-bit programmable prescaler used to divide (also “on the fly”) the counter clock frequency by any factor between 1 and 65535.
- Up to 4 independent channels for:
  - Input capture
  - Output compare
  - PWM generation (Edge- and Center-aligned modes)
  - One-pulse mode output
- Synchronization circuit to control the timer with external signals and to interconnect several timers.
- Interrupt/DMA generation on the following events:
  - Update: counter overflow/underflow, counter initialization (by software or internal/external trigger)
  - Trigger event (counter start, stop, initialization or count by internal/external trigger)
  - Input capture
  - Output compare
- Supports incremental (quadrature) encoder and hall-sensor circuitry for positioning purposes
- Trigger input for external clock or cycle-by-cycle current management

Figure 433. General-purpose timer block diagram



44.3 TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 functional description

44.3.1 Time-base unit

The main block of the programmable timer is a 16-bit/32-bit counter with its related auto-reload register. The counter can count up, down or both up and down but also down or both up and down. The counter clock can be divided by a prescaler.

The counter, the auto-reload register and the prescaler register can be written or read by software. This is true even when the counter is running.

The time-base unit includes:

- Counter Register (TIMx_CNT)
- Prescaler Register (TIMx_PSC)
- Auto-Reload Register (TIMx_ARR)

The auto-reload register is preloaded. Writing to or reading from the auto-reload register accesses the preload register. The content of the preload register are transferred into the shadow register permanently or at each update event (UEV), depending on the auto-reload preload enable bit (ARPE) in TIMx_CR1 register. The update event is sent when the counter reaches the overflow (or underflow when downcounting) and if the UDIS bit equals 0 in the TIMx_CR1 register. It can also be generated by software. The generation of the update event is described in detail for each configuration.

The counter is clocked by the prescaler output CK_CNT, which is enabled only when the counter enable bit (CEN) in TIMx_CR1 register is set (refer also to the slave mode controller description to get more details on counter enabling).

Note that the actual counter enable signal CNT_EN is set 1 clock cycle after CEN.

Prescaler description

The prescaler can divide the counter clock frequency by any factor between 1 and 65536. It is based on a 16-bit counter controlled through a 16-bit/32-bit register (in the TIMx_PSC register). It can be changed on the fly as this control register is buffered. The new prescaler ratio is taken into account at the next update event.

Figure 434 and *Figure 435* give some examples of the counter behavior when the prescaler ratio is changed on the fly:

Figure 434. Counter timing diagram with prescaler division change from 1 to 2

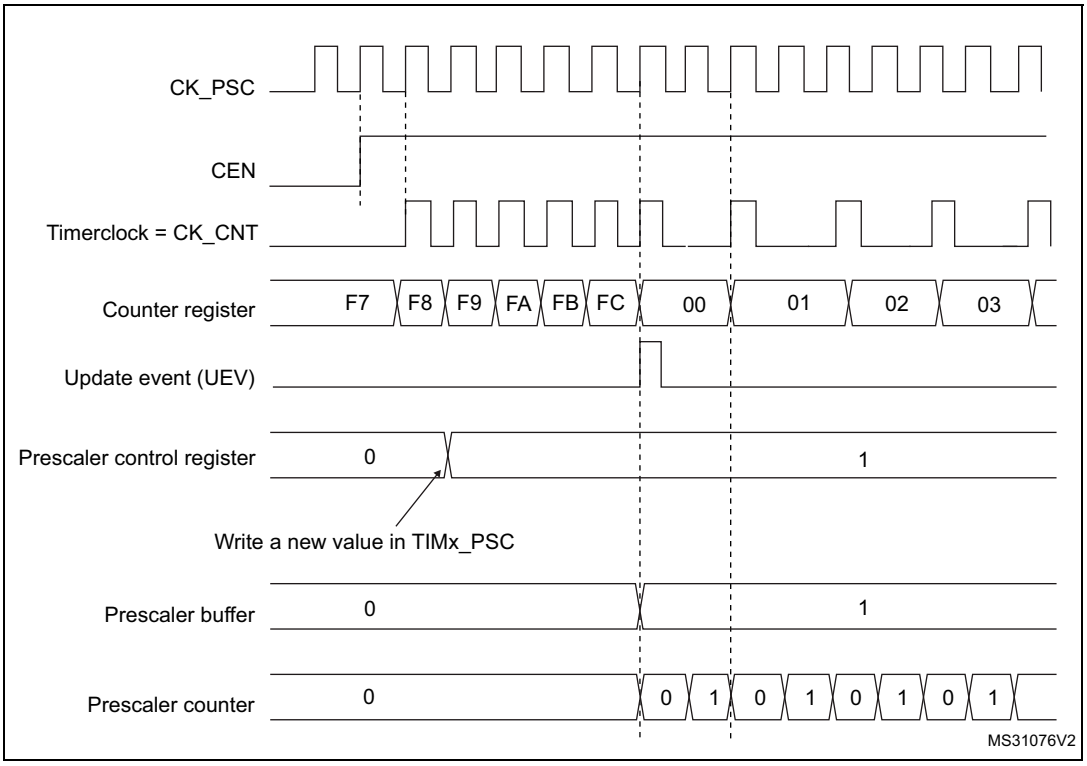
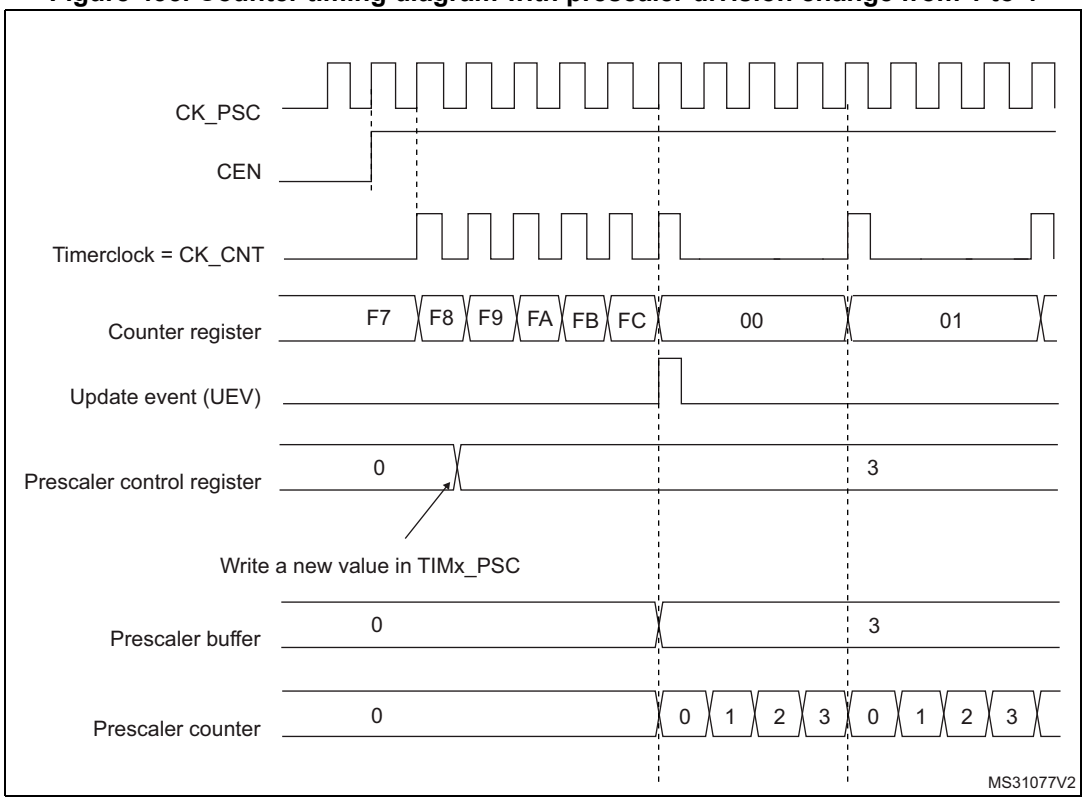


Figure 435. Counter timing diagram with prescaler division change from 1 to 4



44.3.2 Counter modes

Upcounting mode

In upcounting mode, the counter counts from 0 to the auto-reload value (content of the TIMx_ARR register), then restarts from 0 and generates a counter overflow event.

An Update event can be generated at each counter overflow or by setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller).

The UEV event can be disabled by software by setting the UDIS bit in TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter restarts from 0, as well as the counter of the prescaler (but the prescale rate does not change). In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register)
- The auto-reload shadow register is updated with the preload value (TIMx_ARR)

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR=0x36.

Figure 436. Counter timing diagram, internal clock divided by 1

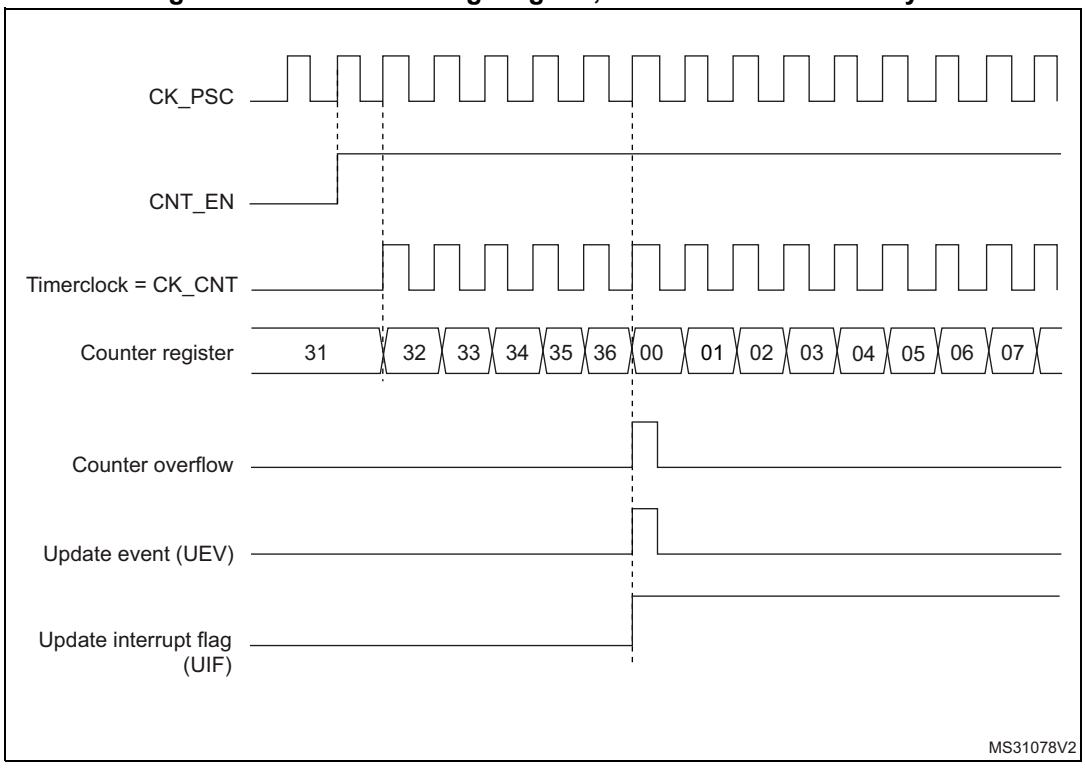


Figure 437. Counter timing diagram, internal clock divided by 2

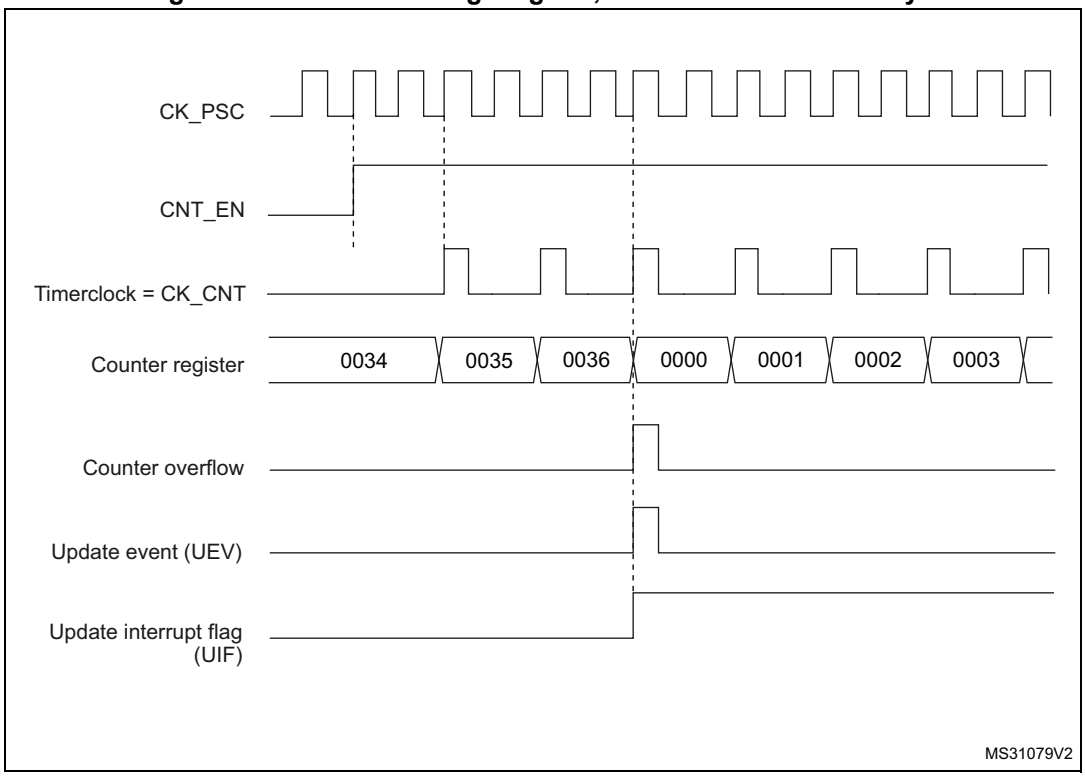


Figure 438. Counter timing diagram, internal clock divided by 4

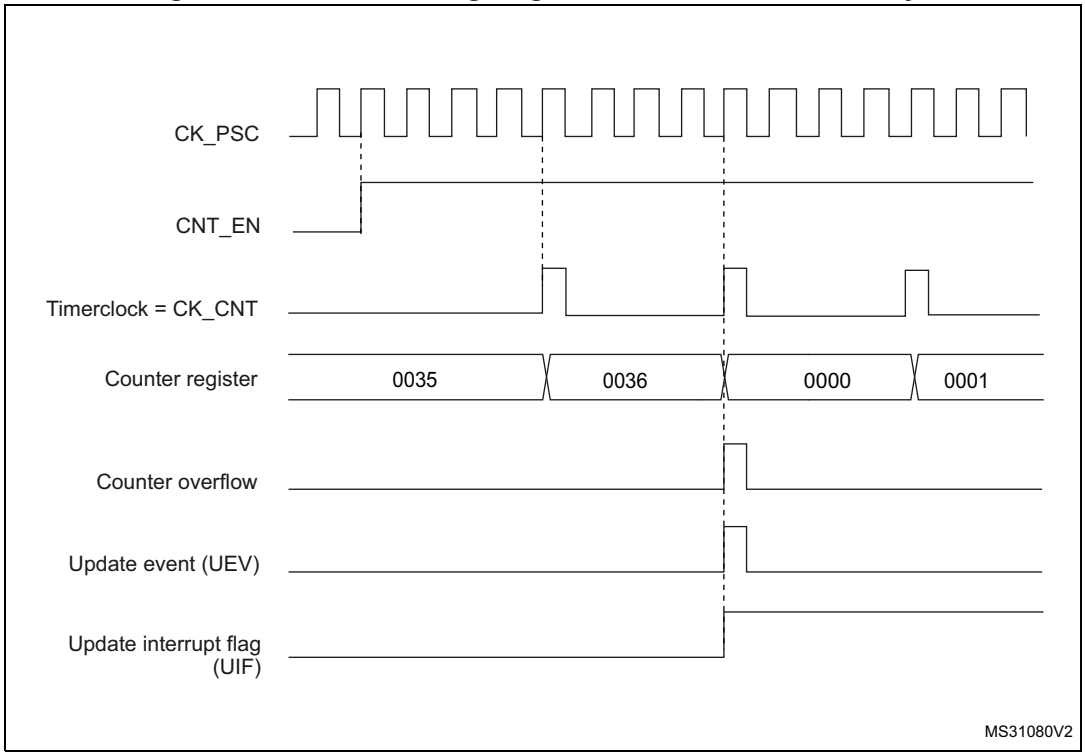


Figure 439. Counter timing diagram, internal clock divided by N

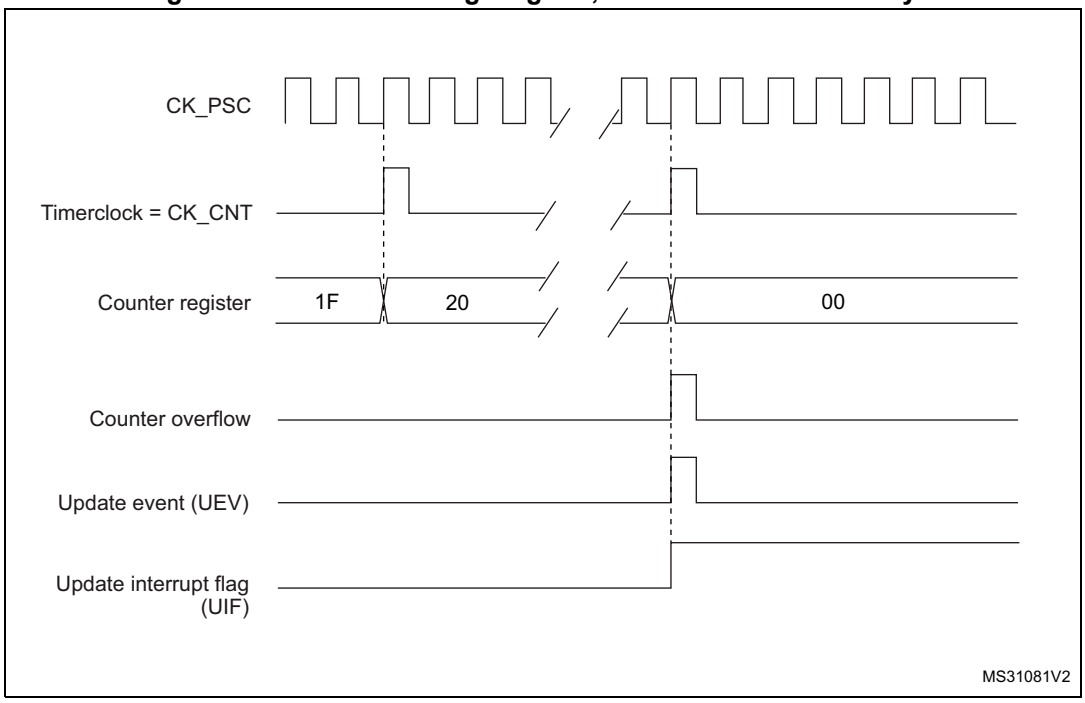


Figure 440. Counter timing diagram, Update event when ARPE=0 (TIMx_ARR not preloaded)

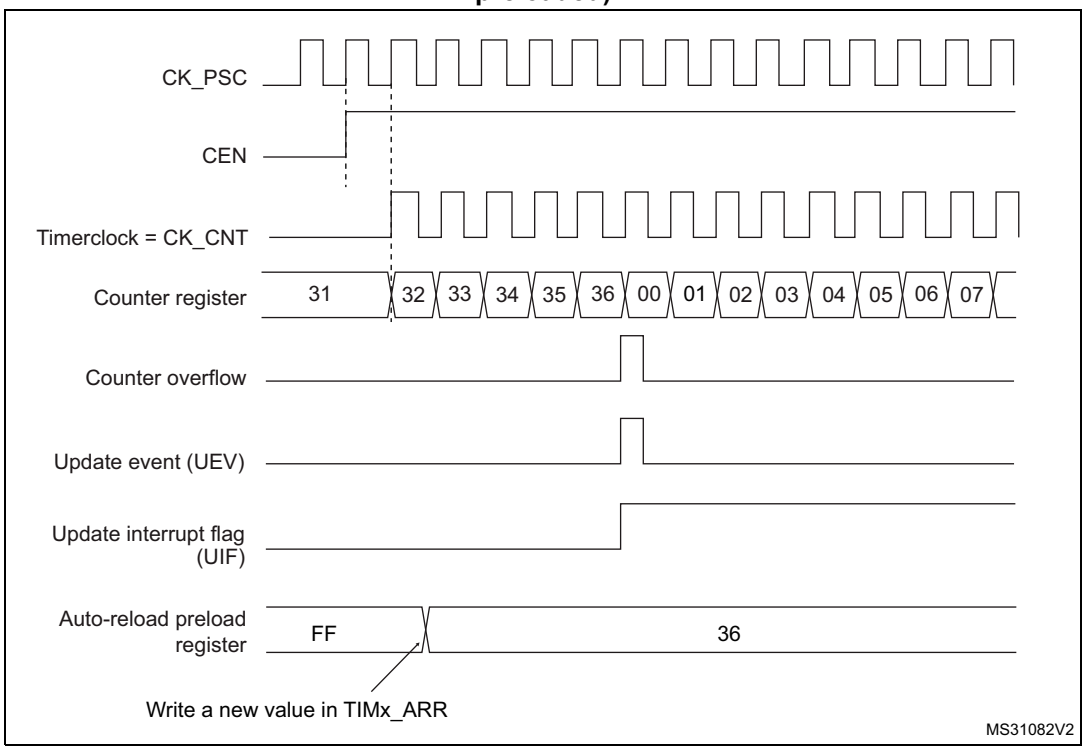
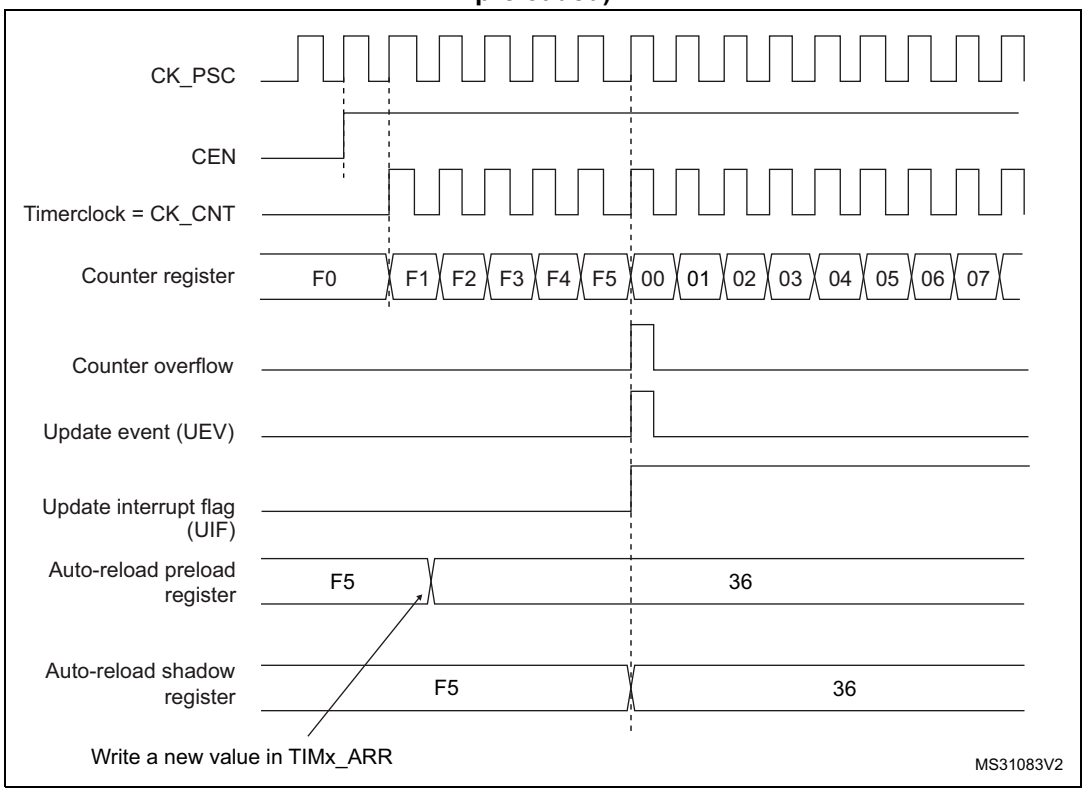


Figure 441. Counter timing diagram, Update event when ARPE=1 (TIMx_ARR preloaded)



Downcounting mode

In downcounting mode, the counter counts from the auto-reload value (content of the TIMx_ARR register) down to 0, then restarts from the auto-reload value and generates a counter underflow event.

An Update event can be generate at each counter underflow or by setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller)

The UEV update event can be disabled by software by setting the UDIS bit in TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until UDIS bit has been written to 0. However, the counter restarts from the current auto-reload value, whereas the counter of the prescaler restarts from 0 (but the prescale rate doesn't change).

In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register).
- The auto-reload active register is updated with the preload value (content of the TIMx_ARR register). Note that the auto-reload is updated before the counter is reloaded, so that the next period is the expected one.

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR=0x36.

Figure 442. Counter timing diagram, internal clock divided by 1

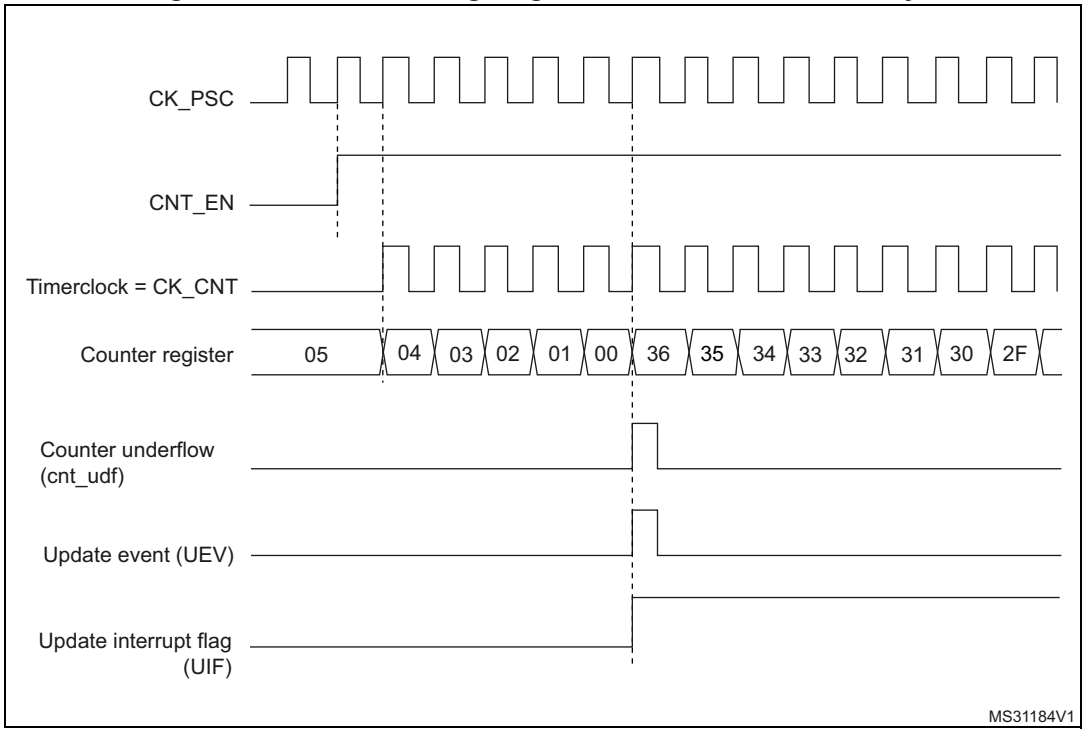


Figure 443. Counter timing diagram, internal clock divided by 2

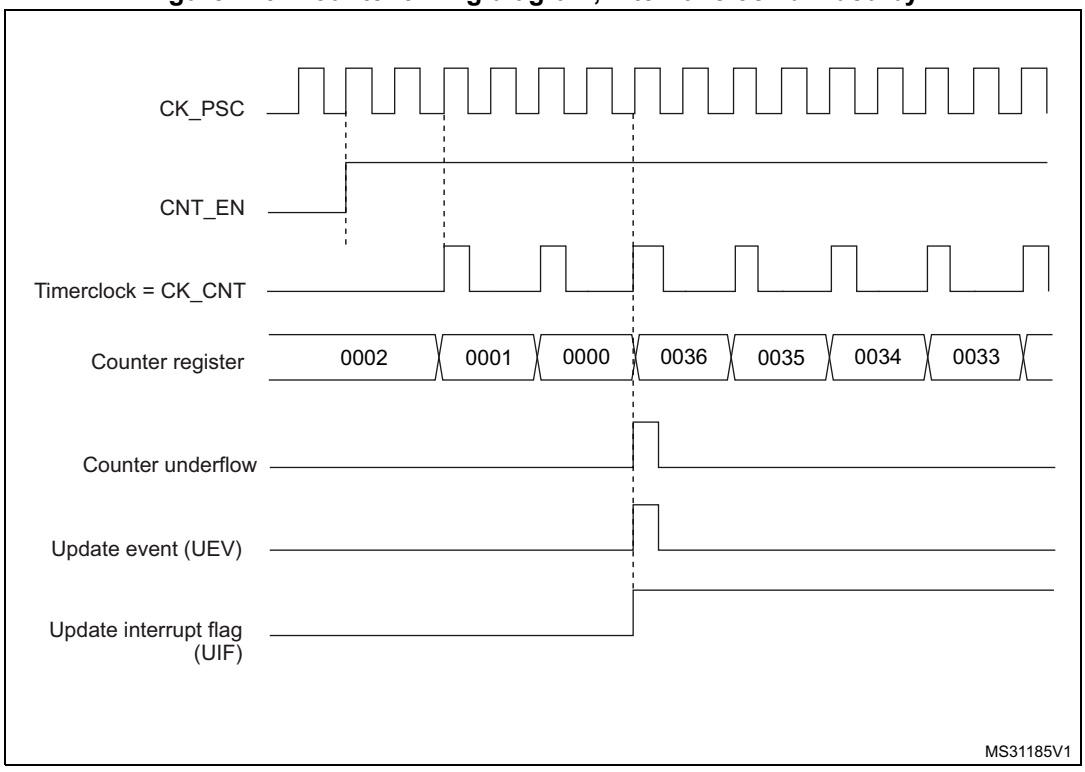


Figure 444. Counter timing diagram, internal clock divided by 4

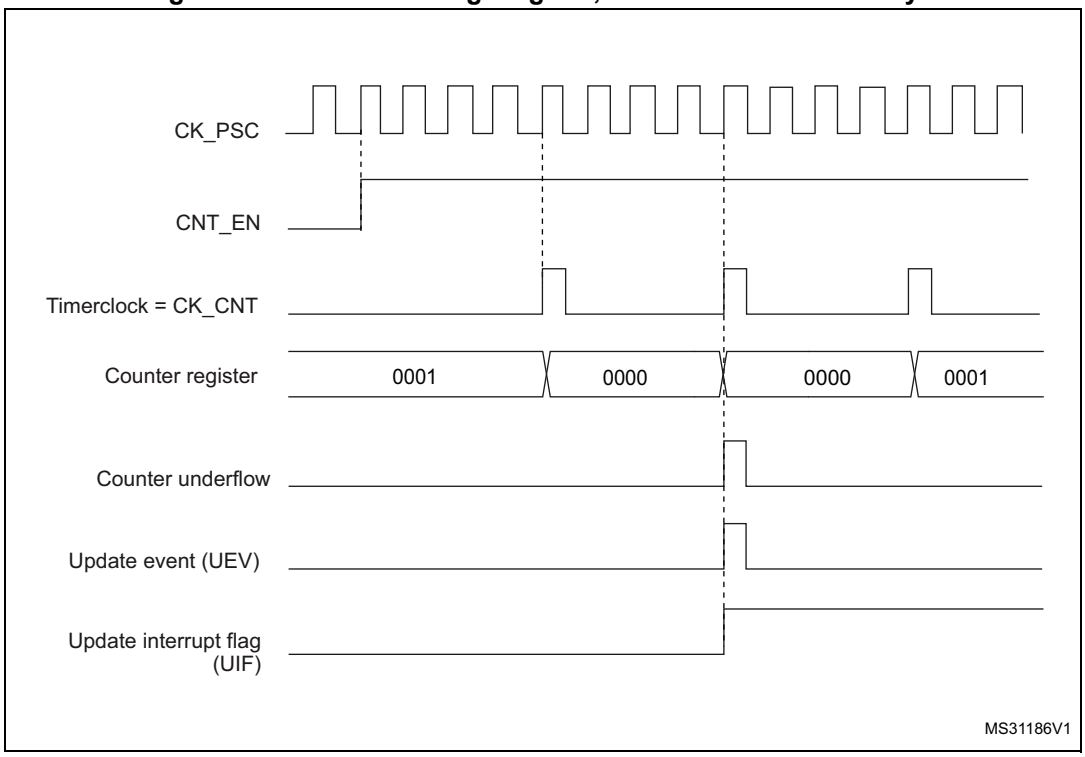


Figure 445. Counter timing diagram, internal clock divided by N

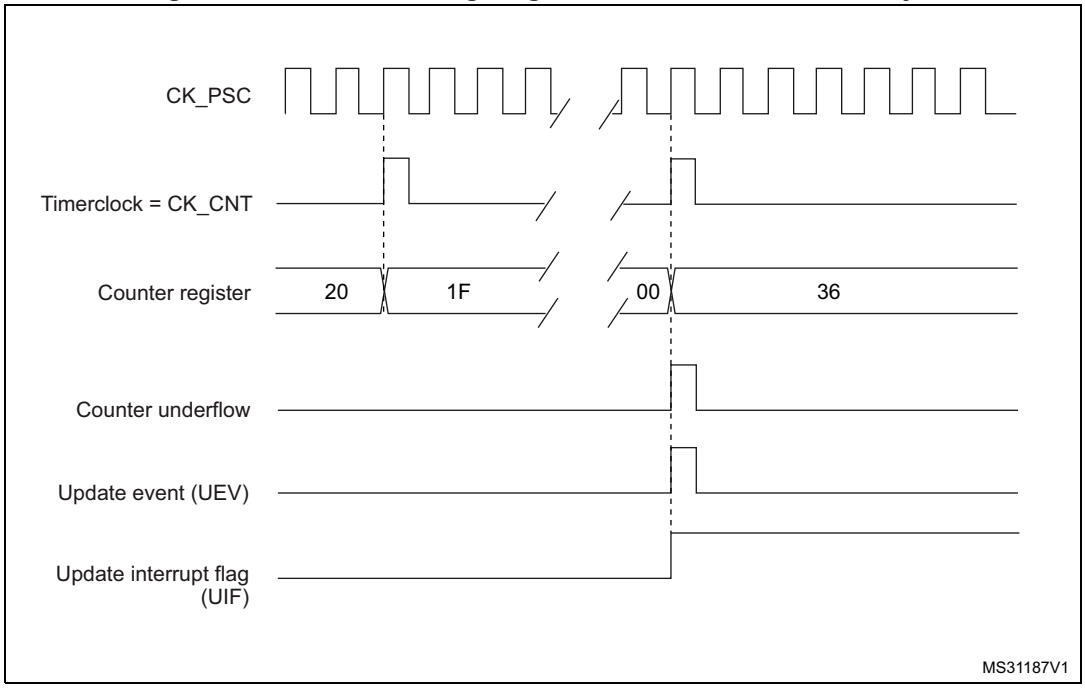
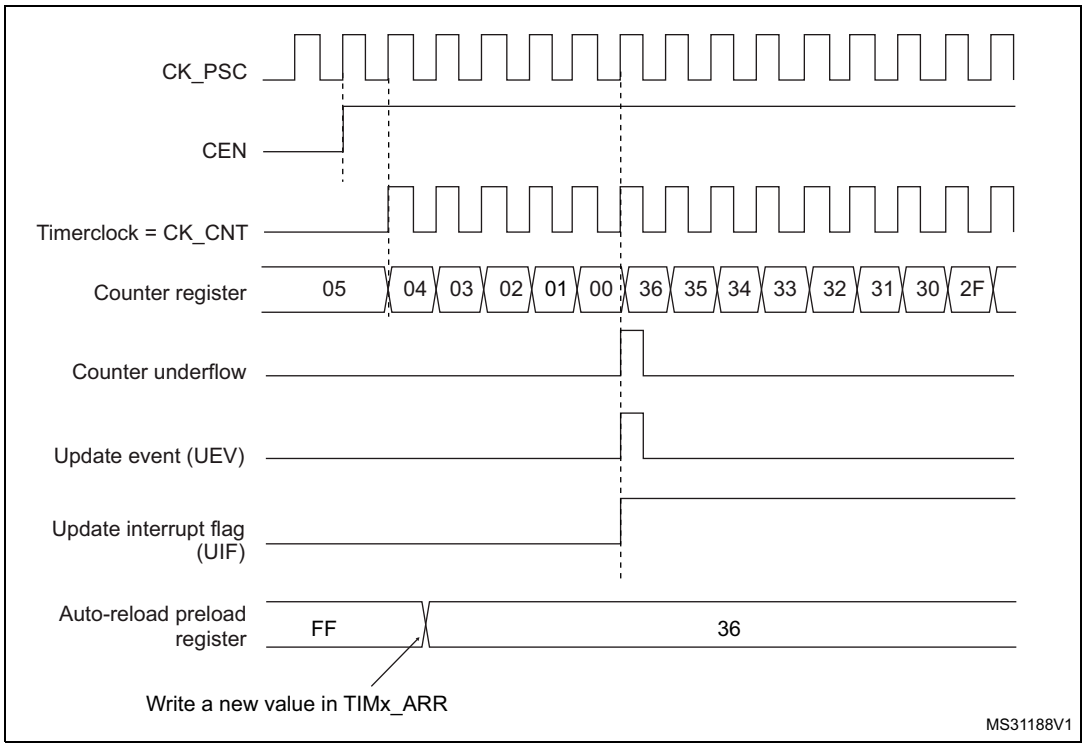


Figure 446. Counter timing diagram, Update event when repetition counter is not used



Center-aligned mode (up/down counting)

In center-aligned mode, the counter counts from 0 to the auto-reload value (content of the TIMx_ARR register) – 1, generates a counter overflow event, then counts from the auto-reload value down to 1 and generates a counter underflow event. Then it restarts counting from 0.

Center-aligned mode is active when the CMS bits in TIMx_CR1 register are not equal to '00'. The Output compare interrupt flag of channels configured in output is set when: the counter counts down (Center aligned mode 1, CMS = "01"), the counter counts up (Center aligned mode 2, CMS = "10") the counter counts up and down (Center aligned mode 3, CMS = "11").

In this mode, the direction bit (DIR from TIMx_CR1 register) cannot be written. It is updated by hardware and gives the current direction of the counter.

The update event can be generated at each counter overflow and at each counter underflow or by setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller) also generates an update event. In this case, the counter restarts counting from 0, as well as the counter of the prescaler.

The UEV update event can be disabled by software by setting the UDIS bit in TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter continues counting up and down, based on the current auto-reload value.

In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or

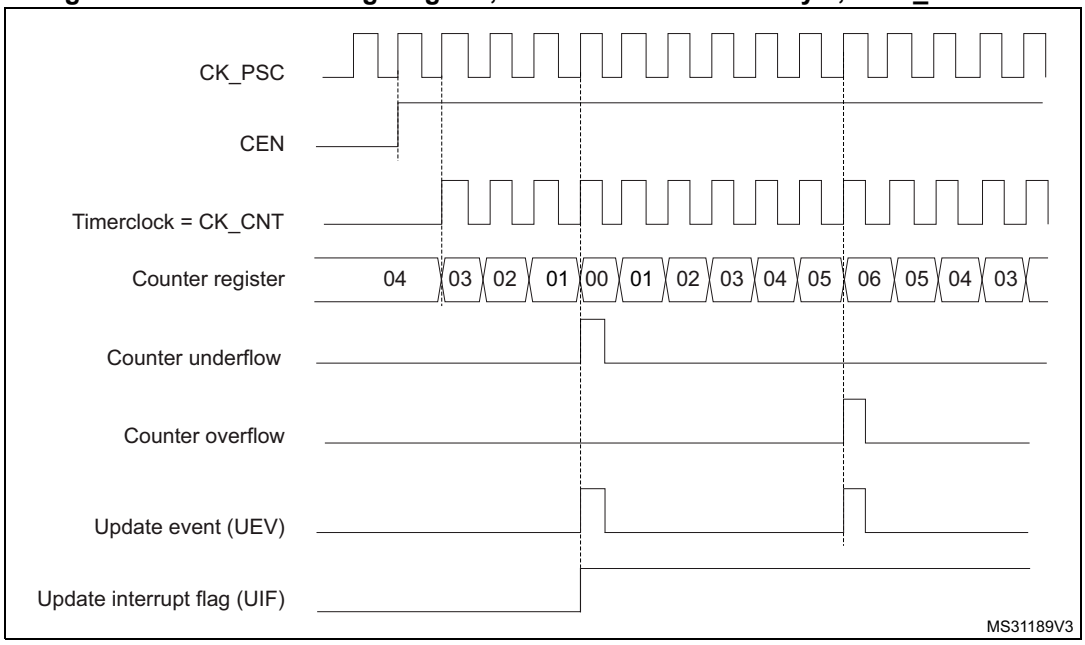
DMA request is sent). This is to avoid generating both update and capture interrupt when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register).
- The auto-reload active register is updated with the preload value (content of the TIMx_ARR register). Note that if the update source is a counter overflow, the auto-reload is updated before the counter is reloaded, so that the next period is the expected one (the counter is loaded with the new value).

The following figures show some examples of the counter behavior for different clock frequencies.

Figure 447. Counter timing diagram, internal clock divided by 1, TIMx_ARR=0x6



1. Here, center-aligned mode 1 is used (for more details refer to *Section 44.4.1: TIMx control register 1 (TIMx_CR1)(x = 2 to 5, 23, 24) on page 1706*).

Figure 448. Counter timing diagram, internal clock divided by 2

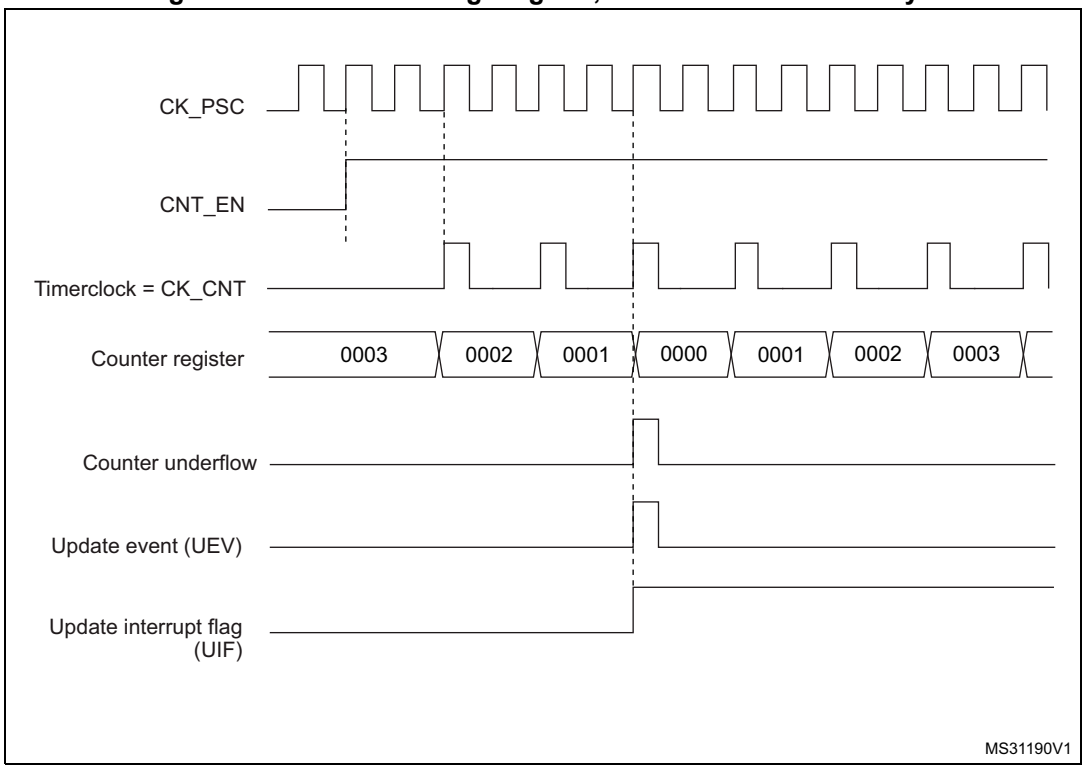
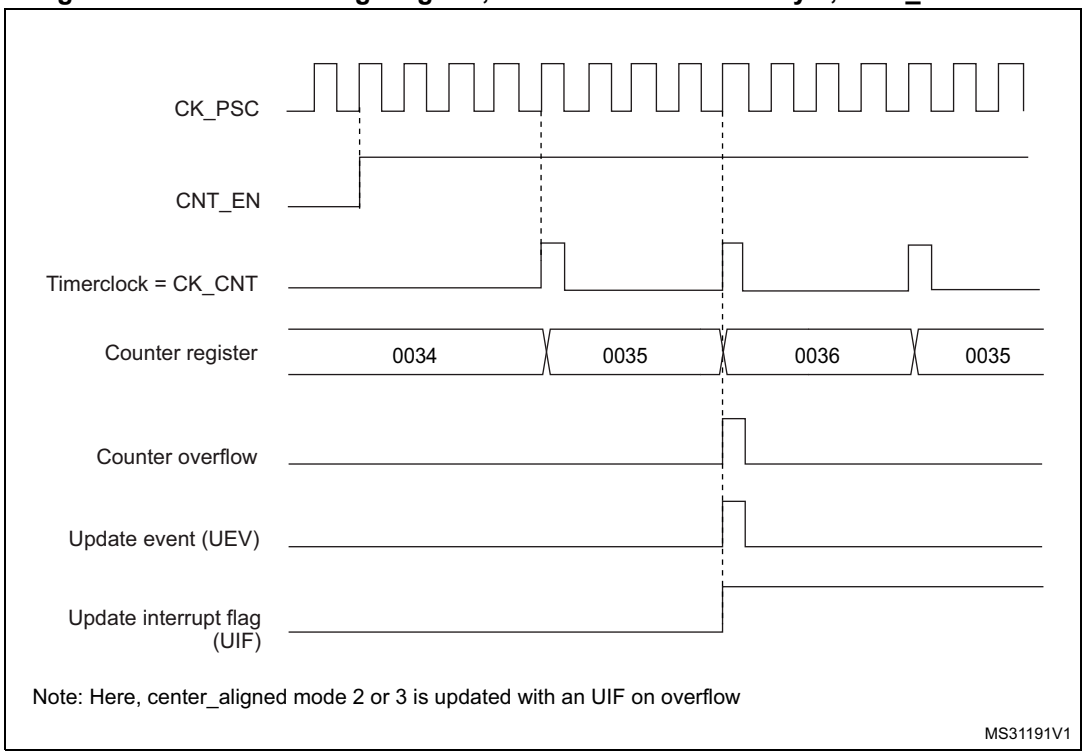


Figure 449. Counter timing diagram, internal clock divided by 4, TIMx_ARR=0x36



1. Center-aligned mode 2 or 3 is used with an UIF on overflow.

Figure 450. Counter timing diagram, internal clock divided by N

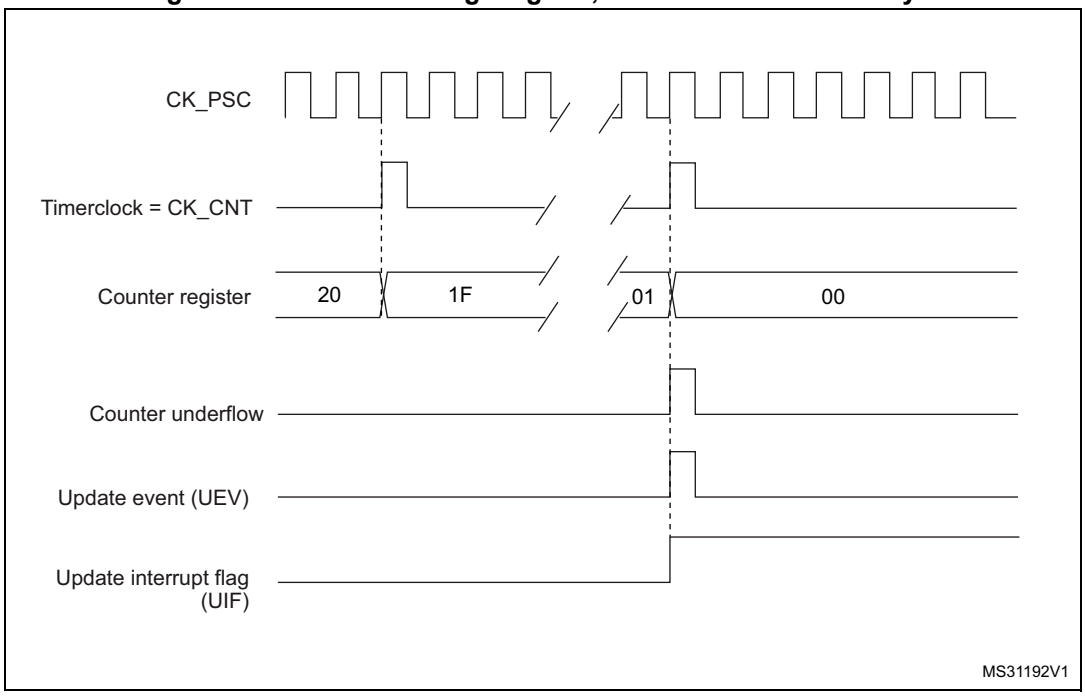


Figure 451. Counter timing diagram, Update event with ARPE=1 (counter underflow)

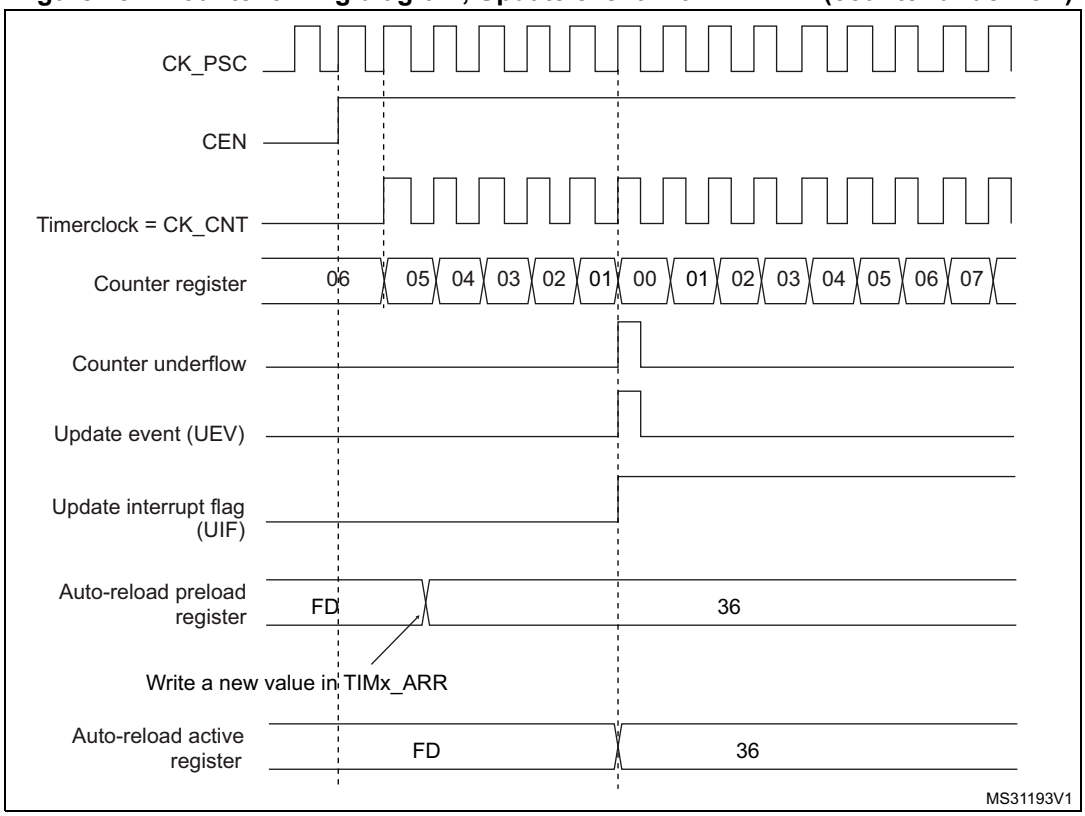
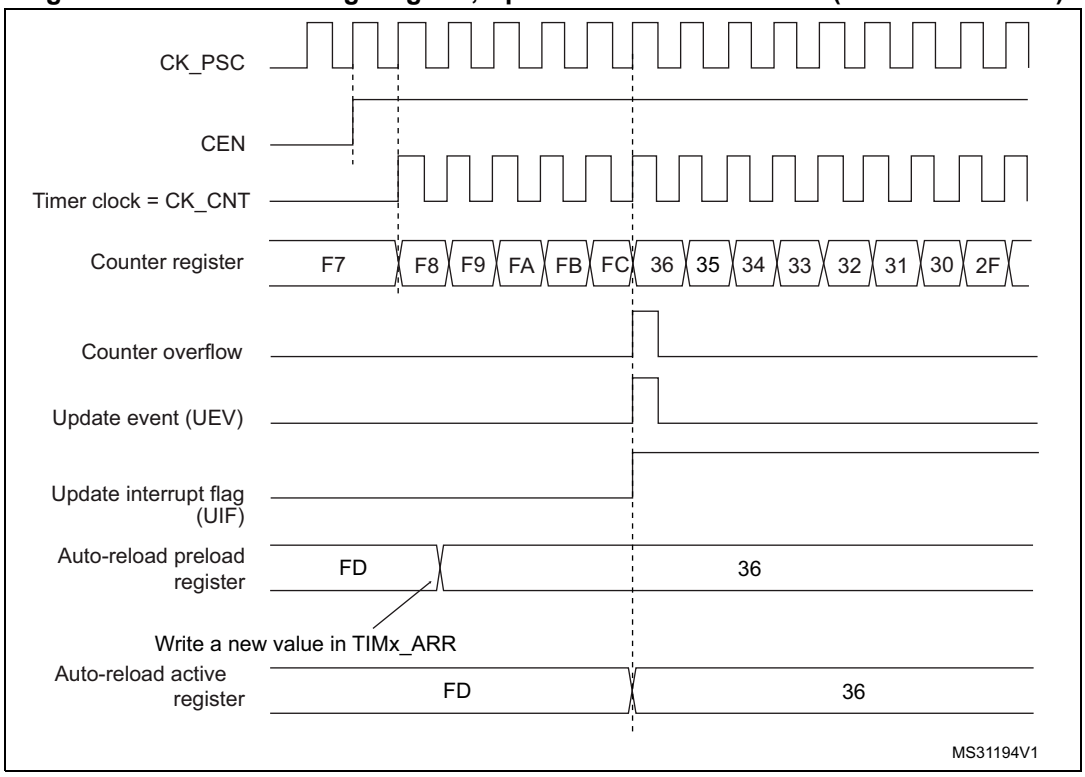


Figure 452. Counter timing diagram, Update event with ARPE=1 (counter overflow)



44.3.3 Clock selection

The counter clock can be provided by the following clock sources:

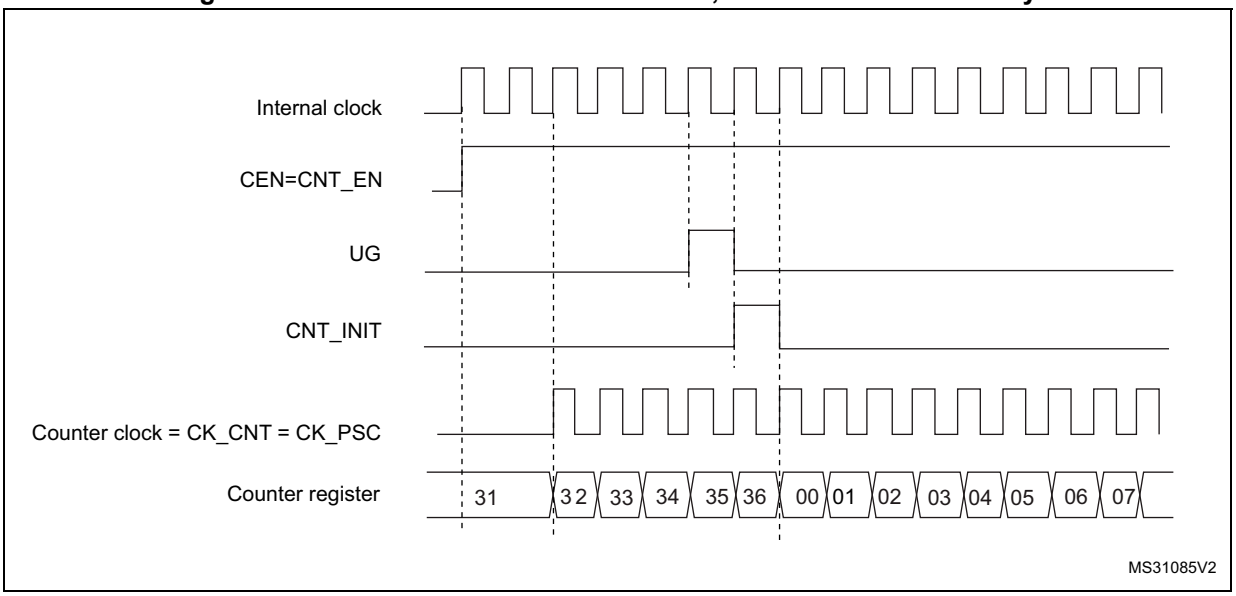
- Internal clock (CK_INT)
- External clock mode1: external input pin (TIx)
- External clock mode2: external trigger input (ETR)
- Internal trigger inputs (ITRx): using one timer as prescaler for another timer, for example, Timer X can be configured to act as a prescaler for Timer Y. Refer to *: Using one timer as prescaler for another timer on page 1700* for more details.

Internal clock source (CK_INT)

If the slave mode controller is disabled (SMS=000 in the TIMx_SMCR register), then the CEN, DIR (in the TIMx_CR1 register) and UG bits (in the TIMx_EGR register) are actual control bits and can be changed only by software (except UG which remains cleared automatically). As soon as the CEN bit is written to 1, the prescaler is clocked by the internal clock CK_INT.

Figure 453 shows the behavior of the control circuit and the upcounter in normal mode, without prescaler.

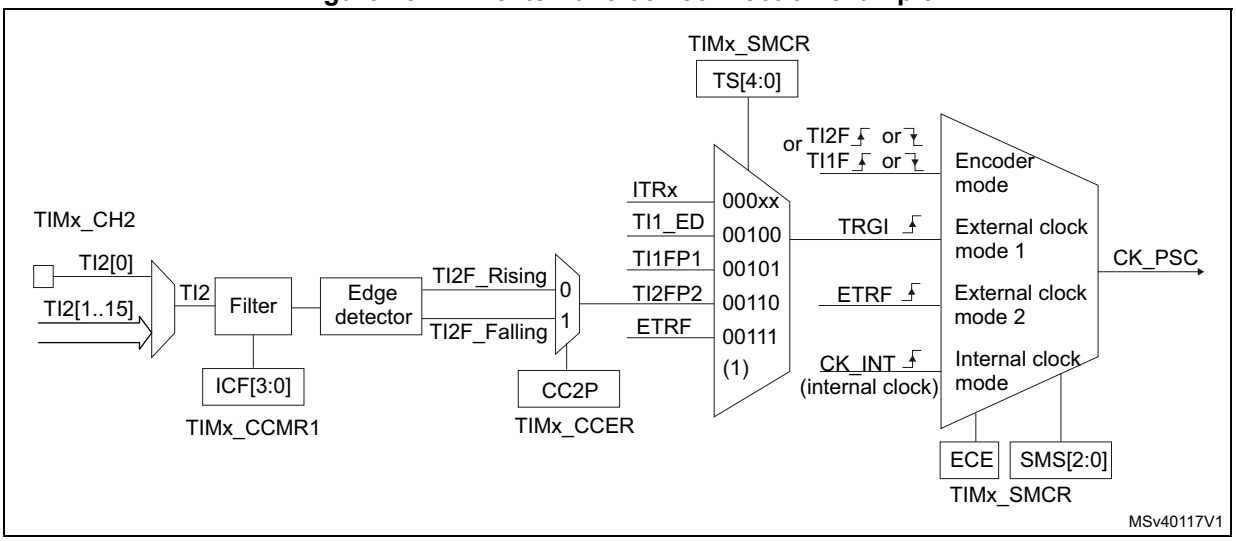
Figure 453. Control circuit in normal mode, internal clock divided by 1



External clock source mode 1

This mode is selected when SMS=111 in the TIMx_SMCR register. The counter can count at each rising or falling edge on a selected input.

Figure 454. TI2 external clock connection example



1. Codes ranging from 01000 to 11111: ITRy.

For example, to configure the upcounter to count in response to a rising edge on the TI2 input, use the following procedure:

1. Select the proper TI2x source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Configure channel 2 to detect rising edges on the TI2 input by writing CC2S= ‘01 in the TIMx_CCMR1 register.
3. Configure the input filter duration by writing the IC2F[3:0] bits in the TIMx_CCMR1 register (if no filter is needed, keep IC2F=0000).

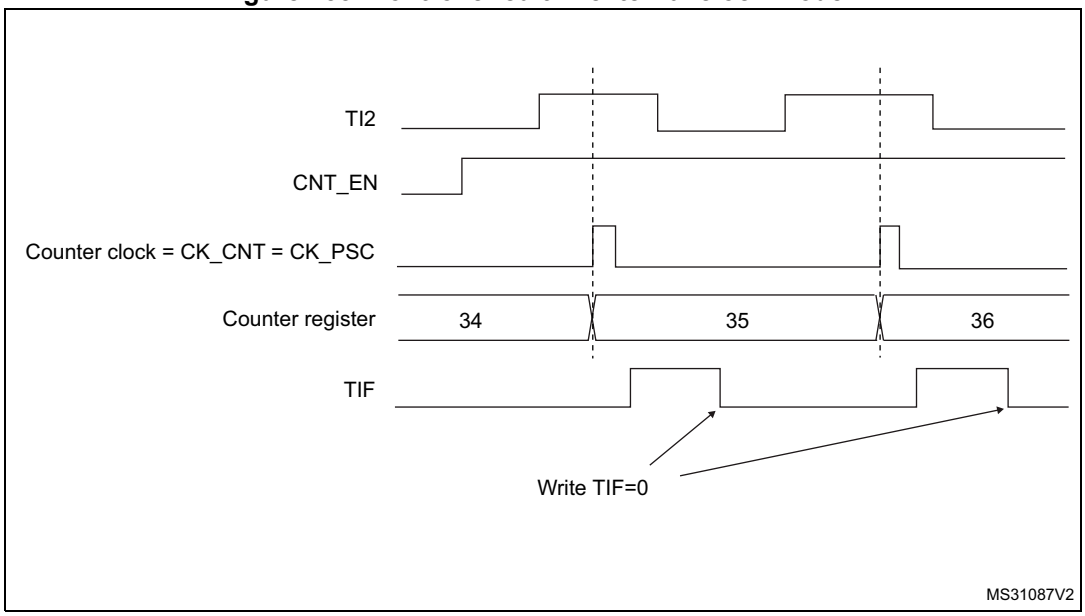
Note: The capture prescaler is not used for triggering, so it does not need to be configured.

4. Select rising edge polarity by writing CC2P=0 and CC2NP=0 and CC2NP=0 in the TIMx_CCER register.
5. Configure the timer in external clock mode 1 by writing SMS=111 in the TIMx_SMCR register.
6. Select TI2 as the input source by writing TS=00110 in the TIMx_SMCR register.
7. Enable the counter by writing CEN=1 in the TIMx_CR1 register.

When a rising edge occurs on TI2, the counter counts once and the TIF flag is set.

The delay between the rising edge on TI2 and the actual clock of the counter is due to the resynchronization circuit on TI2 input.

Figure 455. Control circuit in external clock mode 1



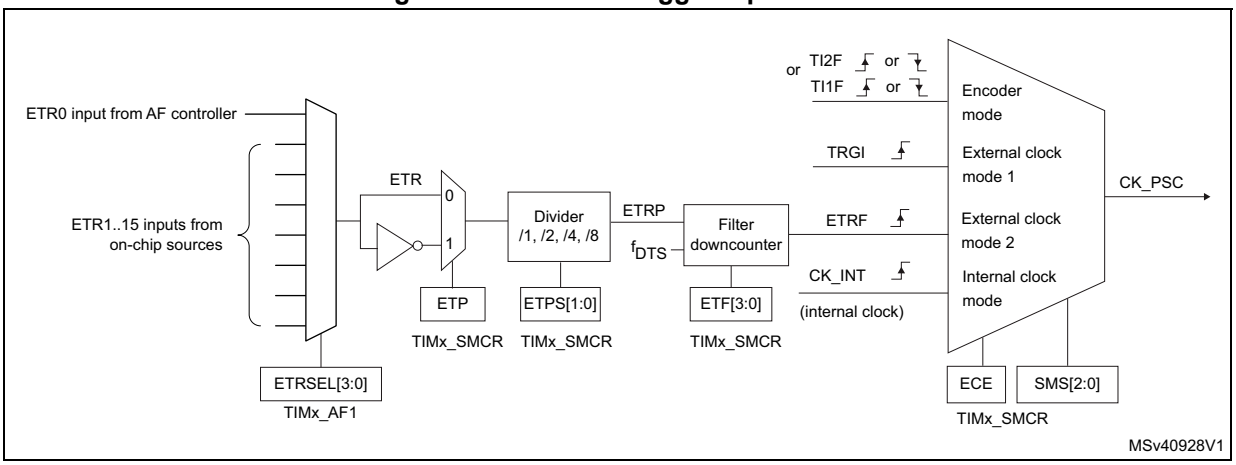
External clock source mode 2

This mode is selected by writing ECE=1 in the TIMx_SMCR register.

The counter can count at each rising or falling edge on the external trigger input ETR.

Figure 456 gives an overview of the external trigger input block.

Figure 456. External trigger input block



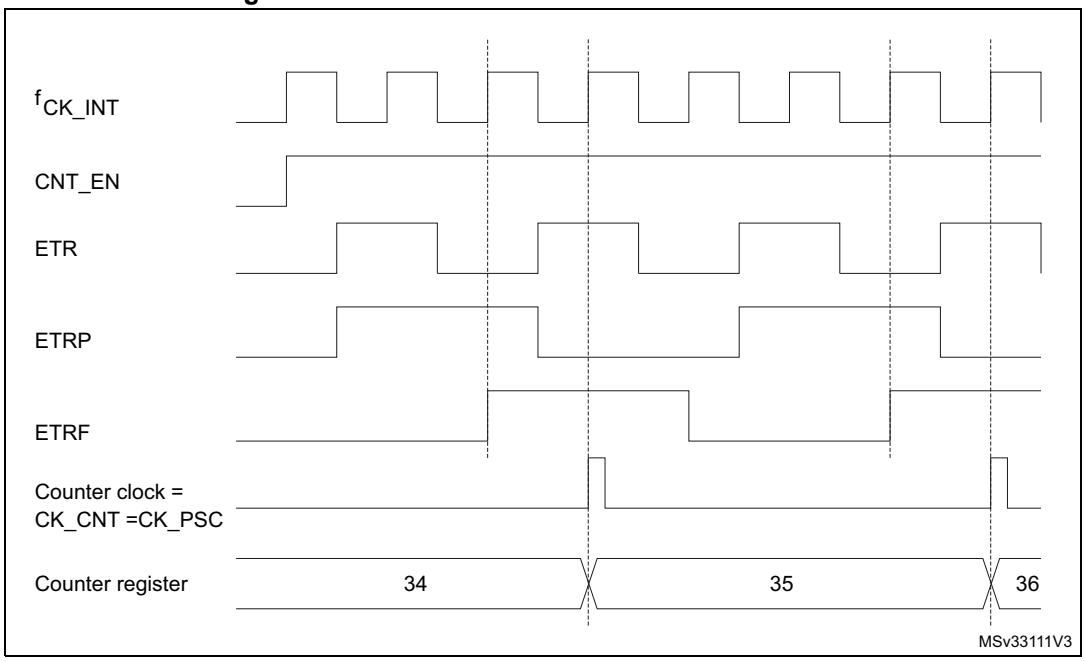
For example, to configure the upcounter to count each 2 rising edges on ETR, use the following procedure:

1. Select the proper ETR source (internal or external) with the ETRSEL[3:0] bits in the TIMx_AF1 register.
2. As no filter is needed in this example, write ETF[3:0]=0000 in the TIMx_SMCR register.
3. Set the prescaler by writing ETPS[1:0]=01 in the TIMx_SMCR register
4. Select rising edge detection on the ETR pin by writing ETP=0 in the TIMx_SMCR register
5. Enable external clock mode 2 by writing ECE=1 in the TIMx_SMCR register.
6. Enable the counter by writing CEN=1 in the TIMx_CR1 register.

The counter counts once each 2 ETR rising edges.

The delay between the rising edge on ETR and the actual clock of the counter is due to the resynchronization circuit on the ETRP signal. As a consequence, the maximum frequency which can be correctly captured by the counter is at most ¼ of TIMxCLK frequency. When the ETRP signal is faster, the user should apply a division of the external signal by a proper ETPS prescaler setting.

Figure 457. Control circuit in external clock mode 2



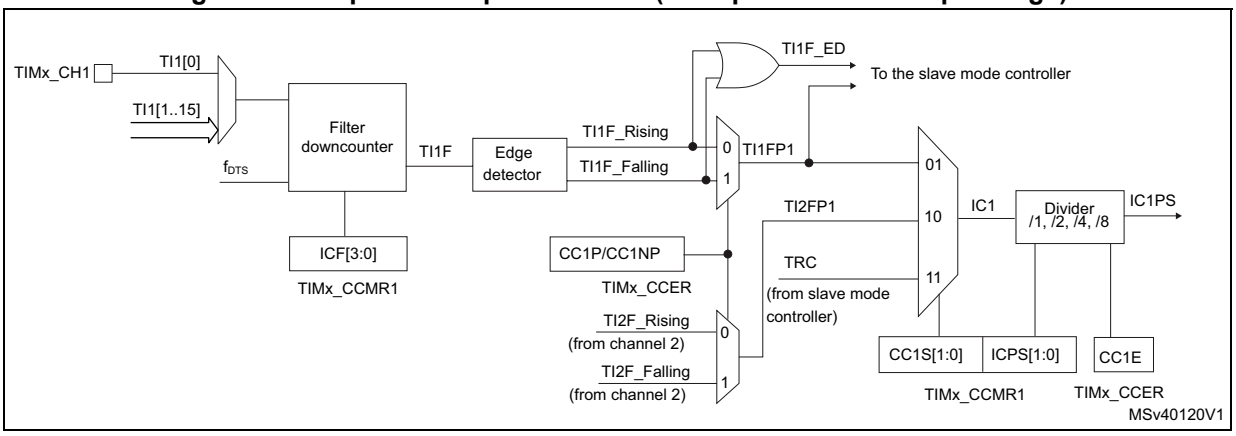
44.3.4 Capture/Compare channels

Each Capture/Compare channel is built around a capture/compare register (including a shadow register), a input stage for capture (with digital filter, multiplexing and prescaler) and an output stage (with comparator and output control).

The following figure gives an overview of one Capture/Compare channel.

The input stage samples the corresponding TIx input to generate a filtered signal TIxF. Then, an edge detector with polarity selection generates a signal (TIxFPx) which can be used as trigger input by the slave mode controller or as the capture command. It is prescaled before the capture register (ICxPS).

Figure 458. Capture/Compare channel (example: channel 1 input stage)



The output stage generates an intermediate waveform which is then used for reference: OCxRef (active high). The polarity acts at the end of the chain.

Figure 459. Capture/Compare channel 1 main circuit

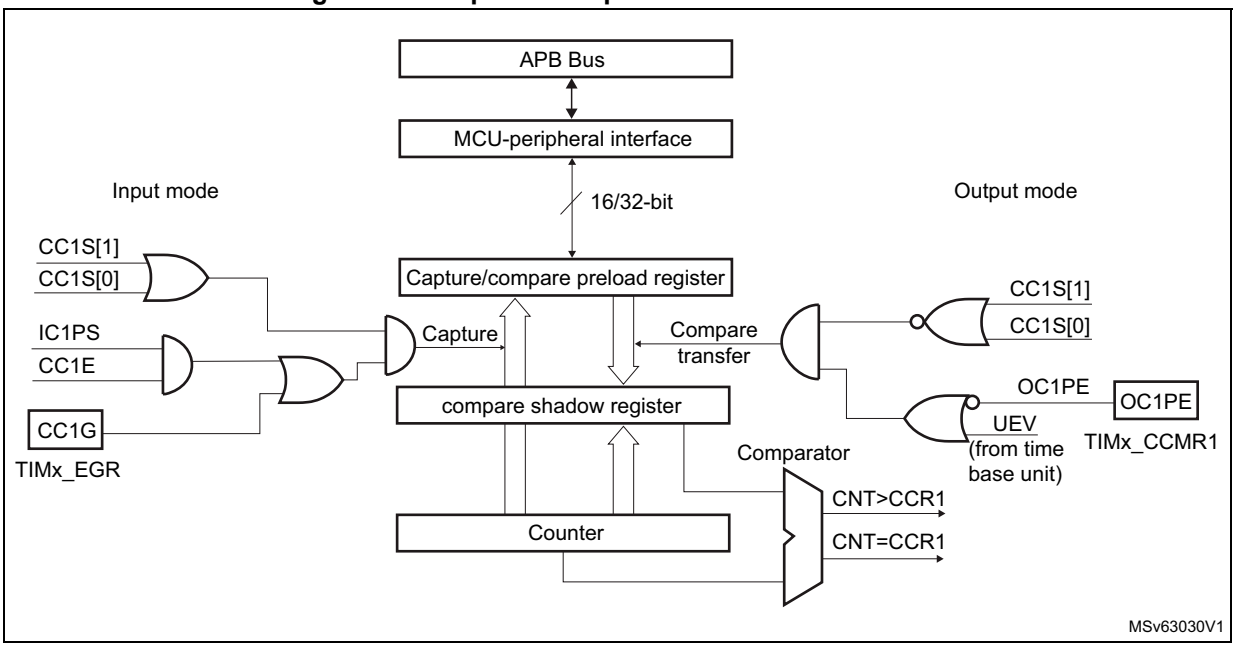
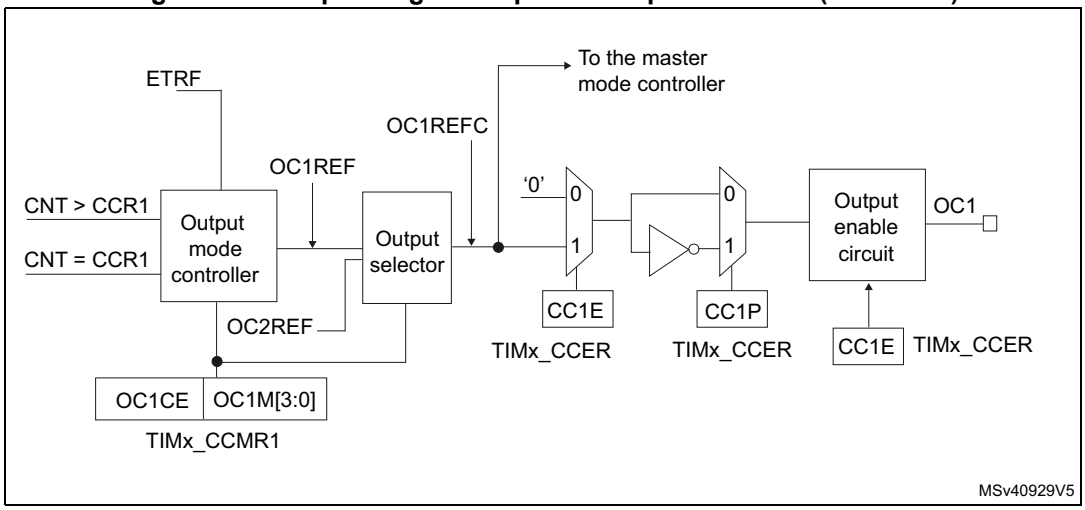


Figure 460. Output stage of Capture/Compare channel (channel 1)



The capture/compare block is made of one preload register and one shadow register. Write and read always access the preload register.

In capture mode, captures are actually done in the shadow register, which is copied into the preload register.

In compare mode, the content of the preload register is copied into the shadow register which is compared to the counter.

44.3.5 Input capture mode

In Input capture mode, the Capture/Compare Registers (TIMx_CCRx) are used to latch the value of the counter after a transition detected by the corresponding ICx signal. When a capture occurs, the corresponding CCXIF flag (TIMx_SR register) is set and an interrupt or

a DMA request can be sent if they are enabled. If a capture occurs while the CCxIF flag was already high, then the over-capture flag CCxOF (TIMx_SR register) is set. CCxIF can be cleared by software by writing it to 0 or by reading the captured data stored in the TIMx_CCRx register. CCxOF is cleared when it is written with 0.

The following example shows how to capture the counter value in TIMx_CCR1 when TI1 input rises. To do this, use the following procedure:

1. Select the proper TI1x source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input: TIMx_CCR1 must be linked to the TI1 input, so write the CC1S bits to 01 in the TIMx_CCMR1 register. As soon as CC1S becomes different from 00, the channel is configured in input and the TIMx_CCR1 register becomes read-only.
3. Program the appropriate input filter duration in relation with the signal connected to the timer (when the input is one of the TIx (ICxF bits in the TIMx_CCMRx register). Let's imagine that, when toggling, the input signal is not stable during at must 5 internal clock cycles. We must program a filter duration longer than these 5 clock cycles. We can validate a transition on TI1 when 8 consecutive samples with the new level have been detected (sampled at f_{DTS} frequency). Then write IC1F bits to 0011 in the TIMx_CCMR1 register.
4. Select the edge of the active transition on the TI1 channel by writing the CC1P and CC1NP and CC1NP bits to 000 in the TIMx_CCER register (rising edge in this case).
5. Program the input prescaler. In our example, we wish the capture to be performed at each valid transition, so the prescaler is disabled (write IC1PS bits to 00 in the TIMx_CCMR1 register).
6. Enable capture from the counter into the capture register by setting the CC1E bit in the TIMx_CCER register.
7. If needed, enable the related interrupt request by setting the CC1IE bit in the TIMx_DIER register, and/or the DMA request by setting the CC1DE bit in the TIMx_DIER register.

When an input capture occurs:

- The TIMx_CCR1 register gets the value of the counter on the active transition.
- CC1IF flag is set (interrupt flag). CC1OF is also set if at least two consecutive captures occurred whereas the flag was not cleared.
- An interrupt is generated depending on the CC1IE bit.
- A DMA request is generated depending on the CC1DE bit.

In order to handle the overcapture, it is recommended to read the data before the overcapture flag. This is to avoid missing an overcapture which could happen after reading the flag and before reading the data.

Note: IC interrupt and/or DMA requests can be generated by software by setting the corresponding CCxG bit in the TIMx_EGR register.

44.3.6 PWM input mode

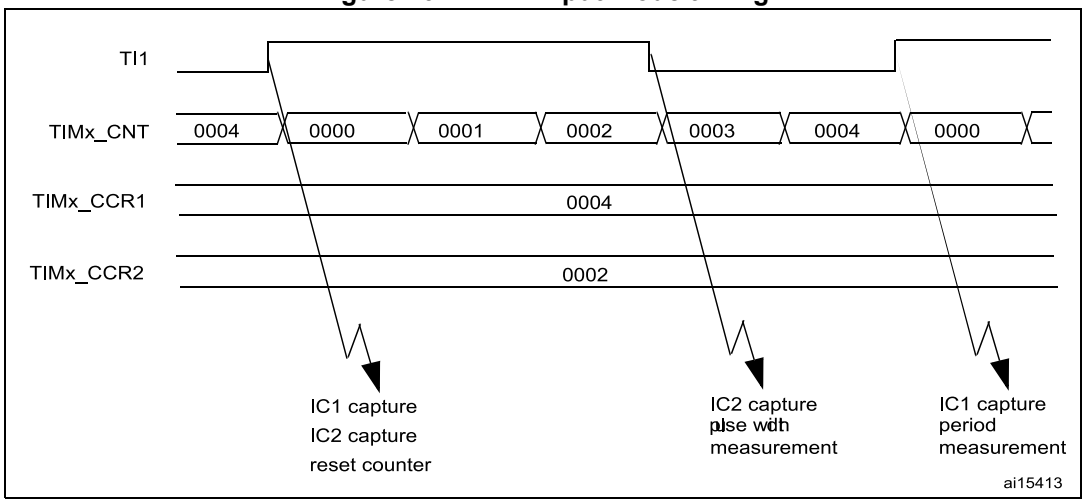
This mode is a particular case of input capture mode. The procedure is the same except:

- Two ICx signals are mapped on the same TIx input.
- These 2 ICx signals are active on edges with opposite polarity.
- One of the two TIxFP signals is selected as trigger input and the slave mode controller is configured in reset mode.

For example, one can measure the period (in TIMx_CCR1 register) and the duty cycle (in TIMx_CCR2 register) of the PWM applied on TI1 using the following procedure (depending on CK_INT frequency and prescaler value):

1. Select the proper TI1x source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input for TIMx_CCR1: write the CC1S bits to 01 in the TIMx_CCMR1 register (TI1 selected).
3. Select the active polarity for TI1FP1 (used both for capture in TIMx_CCR1 and counter clear): write the CC1P to ‘0’ and the CC1NP bit to ‘0’ (active on rising edge).
4. Select the active input for TIMx_CCR2: write the CC2S bits to 10 in the TIMx_CCMR1 register (TI1 selected).
5. Select the active polarity for TI1FP2 (used for capture in TIMx_CCR2): write the CC2P bit to ‘1’ and the CC2NP bit to ’0’ (active on falling edge).
6. Select the valid trigger input: write the TS bits to 00101 in the TIMx_SMCR register (TI1FP1 selected).
7. Configure the slave mode controller in reset mode: write the SMS bits to 100 in the TIMx_SMCR register.
8. Enable the captures: write the CC1E and CC2E bits to ‘1 in the TIMx_CCER register.

Figure 461. PWM input mode timing



1. The PWM input mode can be used only with the TIMx_CH1/TIMx_CH2 signals due to the fact that only TI1FP1 and TI2FP2 are connected to the slave mode controller.

44.3.7 Forced output mode

In output mode (CCxS bits = 00 in the TIMx_CCMRx register), each output compare signal (OCxREF and then OCx) can be forced to active or inactive level directly by software, independently of any comparison between the output compare register and the counter.

To force an output compare signal (ocxref/OCx) to its active level, one just needs to write 101 in the OCxM bits in the corresponding TIMx_CCMRx register. Thus ocxref is forced high (OCxREF is always active high) and OCx get opposite value to CCxP polarity bit.

e.g.: CCxP=0 (OCx active high) => OCx is forced to high level.

ocxref signal can be forced low by writing the OCxM bits to 100 in the TIMx_CCMRx register.

Anyway, the comparison between the TIMx_CCRx shadow register and the counter is still performed and allows the flag to be set. Interrupt and DMA requests can be sent accordingly. This is described in the Output Compare Mode section.

44.3.8 Output compare mode

This function is used to control an output waveform or indicating when a period of time has elapsed.

When a match is found between the capture/compare register and the counter, the output compare function:

- Assigns the corresponding output pin to a programmable value defined by the output compare mode (OCxM bits in the TIMx_CCMRx register) and the output polarity (CCxP bit in the TIMx_CCER register). The output pin can keep its level (OCXM=000), be set active (OCxM=001), be set inactive (OCxM=010) or can toggle (OCxM=011) on match.
- Sets a flag in the interrupt status register (CCxIF bit in the TIMx_SR register).
- Generates an interrupt if the corresponding interrupt mask is set (CCXIE bit in the TIMx_DIER register).
- Sends a DMA request if the corresponding enable bit is set (CCxDE bit in the TIMx_DIER register, CCDS bit in the TIMx_CR2 register for the DMA request selection).

The TIMx_CCRx registers can be programmed with or without preload registers using the OCxPE bit in the TIMx_CCMRx register.

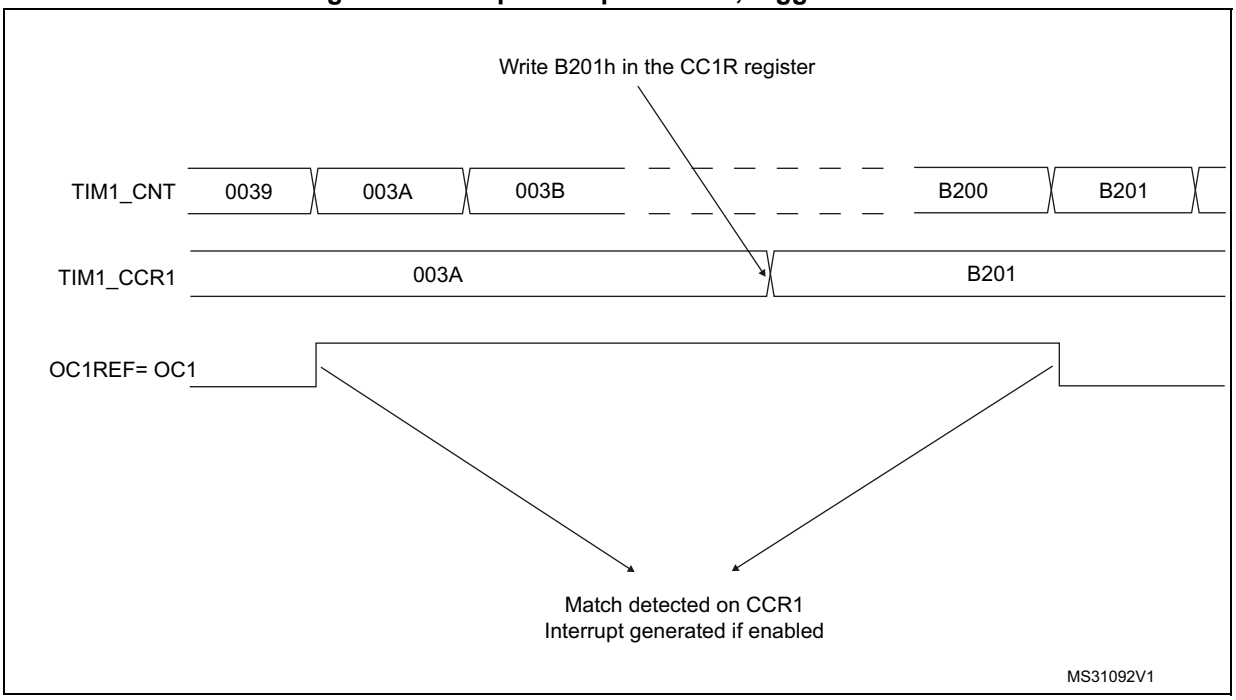
In output compare mode, the update event UEV has no effect on ocxref and OCx output. The timing resolution is one count of the counter. Output compare mode can also be used to output a single pulse (in One-pulse mode).

Procedure

1. Select the counter clock (internal, external, prescaler).
2. Write the desired data in the TIMx_ARR and TIMx_CCRx registers.
3. Set the CCxIE and/or CCxDE bits if an interrupt and/or a DMA request is to be generated.
4. Select the output mode. For example, one must write OCxM=011, OCxPE=0, CCxP=0 and CCxE=1 to toggle OCx output pin when CNT matches CCRx, CCRx preload is not used, OCx is enabled and active high.
5. Enable the counter by setting the CEN bit in the TIMx_CR1 register.

The TIMx_CCRx register can be updated at any time by software to control the output waveform, provided that the preload register is not enabled (OCxPE=0, else TIMx_CCRx shadow register is updated only at the next update event UEV). An example is given in *Figure 462*.

Figure 462. Output compare mode, toggle on OC1



44.3.9 PWM mode

Pulse width modulation mode permits to generate a signal with a frequency determined by the value of the TIMx_ARR register and a duty cycle determined by the value of the TIMx_CCRx register.

The PWM mode can be selected independently on each channel (one PWM per OCx output) by writing 110 (PWM mode 1) or ‘111 (PWM mode 2) in the OCxM bits in the TIMx_CCMRx register. The corresponding preload register must be enabled by setting the OCxPE bit in the TIMx_CCMRx register, and eventually the auto-reload preload register (in upcounting or center-aligned modes) by setting the ARPE bit in the TIMx_CR1 register.

As the preload registers are transferred to the shadow registers only when an update event occurs, before starting the counter, all registers must be initialized by setting the UG bit in the TIMx_EGR register.

OCx polarity is software programmable using the CCxP bit in the TIMx_CCER register. It can be programmed as active high or active low. OCx output is enabled by the CCxE bit in the TIMx_CCER register. Refer to the TIMx_CCERx register description for more details.

In PWM mode (1 or 2), TIMx_CNT and TIMx_CCRx are always compared to determine whether TIMx_CCRx ≤ TIMx_CNT or TIMx_CNT ≤ TIMx_CCRx (depending on the direction of the counter). However, to comply with the OCREF_CLR functionality (OCREF can be cleared by an external event through the ETR signal until the next PWM period), the OCREF signal is asserted only:

- When the result of the comparison or
- When the output compare mode (OCxM bits in TIMx_CCMRx register) switches from the “frozen” configuration (no comparison, OCxM=‘000) to one of the PWM modes (OCxM=‘110 or ‘111).

This forces the PWM by software while the timer is running.

The timer is able to generate PWM in edge-aligned mode or center-aligned mode depending on the CMS bits in the TIMx_CR1 register.

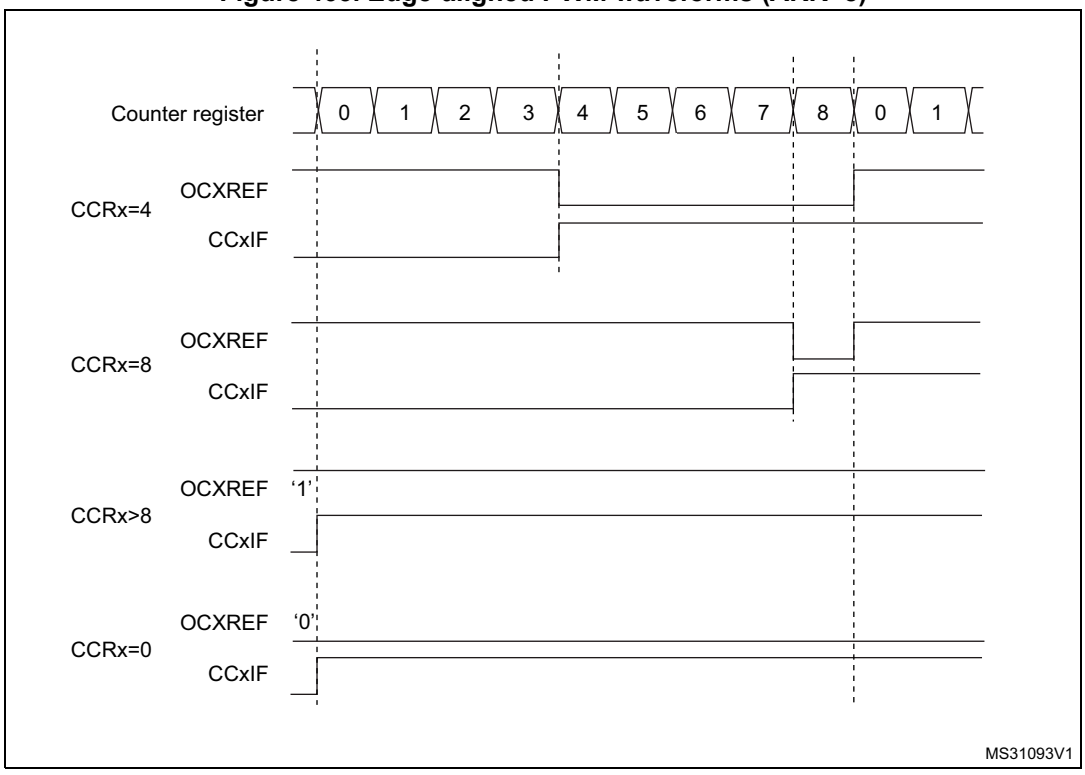
PWM edge-aligned mode

Upcounting configuration

Upcounting is active when the DIR bit in the TIMx_CR1 register is low. Refer to *Upcounting mode on page 1665*.

In the following example, we consider PWM mode 1. The reference PWM signal OCxREF is high as long as TIMx_CNT <TIMx_CCRx else it becomes low. If the compare value in TIMx_CCRx is greater than the auto-reload value (in TIMx_ARR) then OCxREF is held at ‘1. If the compare value is 0 then OCxREF is held at ‘0. *Figure 463* shows some edge-aligned PWM waveforms in an example where TIMx_ARR=8.

Figure 463. Edge-aligned PWM waveforms (ARR=8)



Downcounting configuration

Downcounting is active when DIR bit in TIMx_CR1 register is high. Refer to *Downcounting mode on page 1668*.

In PWM mode 1, the reference signal ocxref is low as long as TIMx_CNT>TIMx_CCRx else it becomes high. If the compare value in TIMx_CCRx is greater than the auto-reload value in TIMx_ARR, then ocxref is held at 100%. PWM is not possible in this mode.

PWM center-aligned mode

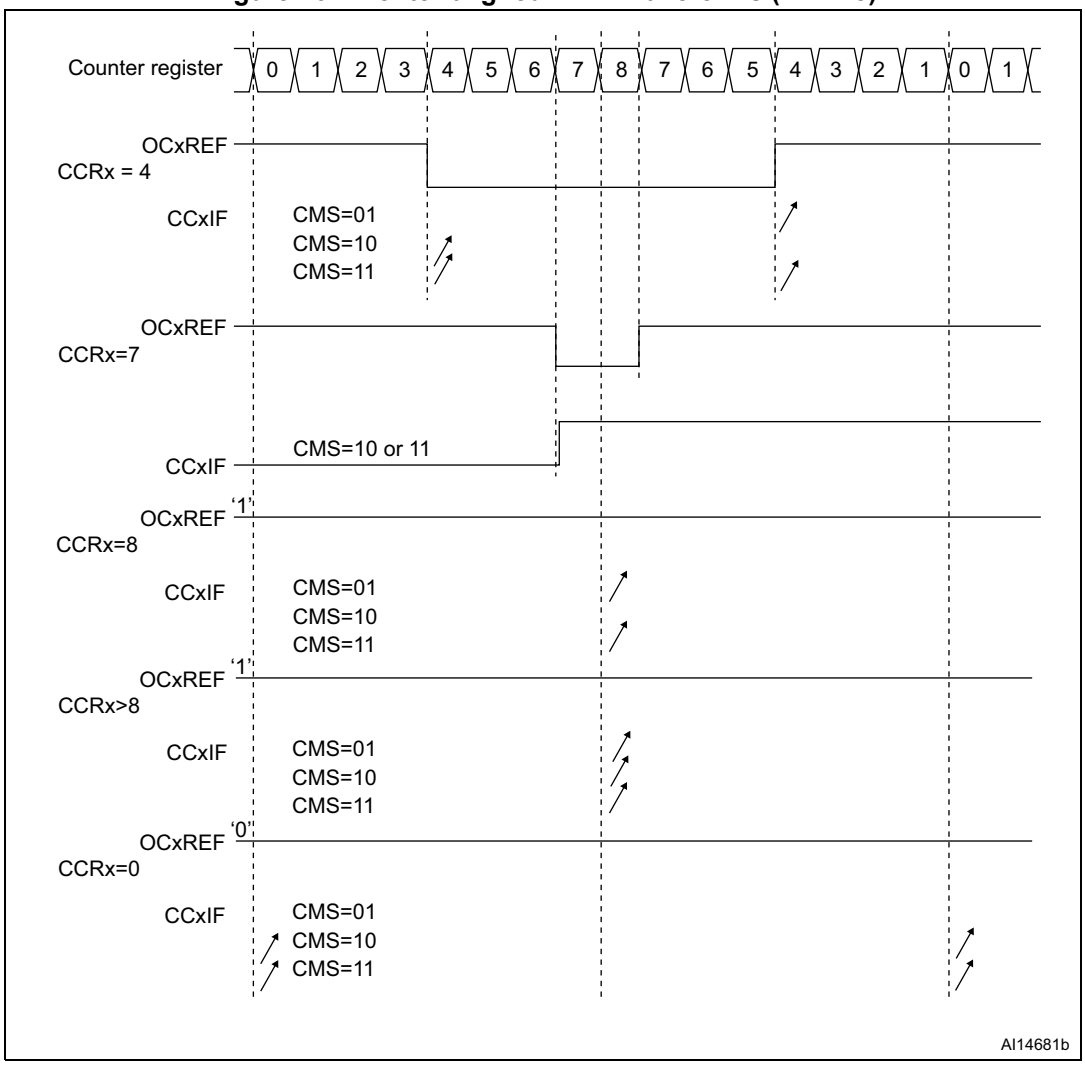
Center-aligned mode is active when the CMS bits in TIMx_CR1 register are different from ‘00 (all the remaining configurations having the same effect on the ocxref/OCx signals). The

compare flag is set when the counter counts up, when it counts down or both when it counts up and down depending on the CMS bits configuration. The direction bit (DIR) in the TIMx_CR1 register is updated by hardware and must not be changed by software. Refer to *Center-aligned mode (up/down counting) on page 1671*.

Figure 464 shows some center-aligned PWM waveforms in an example where:

- TIMx_ARR=8,
- PWM mode is the PWM mode 1,
- The flag is set when the counter counts down corresponding to the center-aligned mode 1 selected for CMS=01 in TIMx_CR1 register.

Figure 464. Center-aligned PWM waveforms (ARR=8)



Hints on using center-aligned mode:

- When starting in center-aligned mode, the current up-down configuration is used. It means that the counter counts up or down depending on the value written in the DIR bit

in the TIMx_CR1 register. Moreover, the DIR and CMS bits must not be changed at the same time by the software.

- Writing to the counter while running in center-aligned mode is not recommended as it can lead to unexpected results. In particular:
  - The direction is not updated if a value greater than the auto-reload value is written in the counter (TIMx_CNT>TIMx_ARR). For example, if the counter was counting up, it continues to count up.
  - The direction is updated if 0 or the TIMx_ARR value is written in the counter but no Update Event UEV is generated.
- The safest way to use center-aligned mode is to generate an update by software (setting the UG bit in the TIMx_EGR register) just before starting the counter and not to write the counter while it is running.

44.3.10 Asymmetric PWM mode

Asymmetric mode allows two center-aligned PWM signals to be generated with a programmable phase shift. While the frequency is determined by the value of the TIMx_ARR register, the duty cycle and the phase-shift are determined by a pair of TIMx_CCRx registers. One register controls the PWM during up-counting, the second during down counting, so that PWM is adjusted every half PWM cycle:

- OC1REFC (or OC2REFC) is controlled by TIMx_CCR1 and TIMx_CCR2
- OC3REFC (or OC4REFC) is controlled by TIMx_CCR3 and TIMx_CCR4

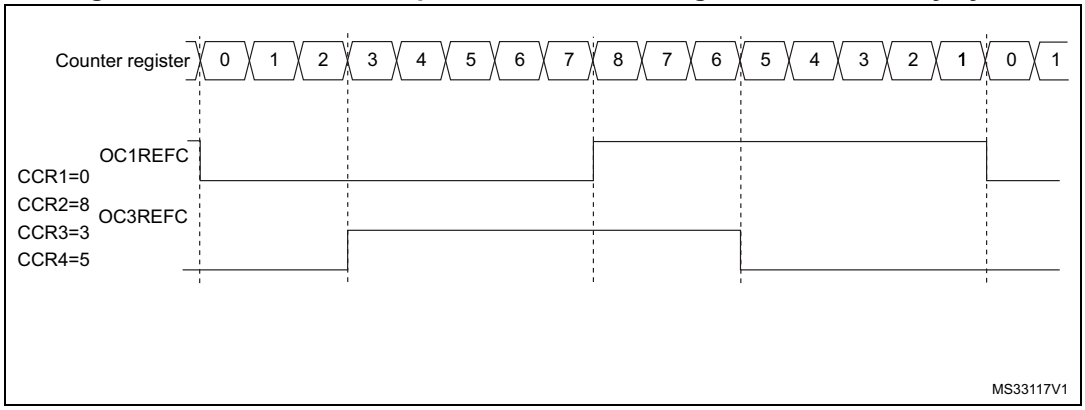
Asymmetric PWM mode can be selected independently on two channels (one OCx output per pair of CCR registers) by writing ‘1110’ (Asymmetric PWM mode 1) or ‘1111’ (Asymmetric PWM mode 2) in the OCxM bits in the TIMx_CCMRx register.

Note: The OCxM[3:0] bit field is split into two parts for compatibility reasons, the most significant bit is not contiguous with the 3 least significant ones.

When a given channel is used as asymmetric PWM channel, its secondary channel can also be used. For instance, if an OC1REFC signal is generated on channel 1 (Asymmetric PWM mode 1), it is possible to output either the OC2REF signal on channel 2, or an OC2REFC signal resulting from asymmetric PWM mode 2.

Figure 465 shows an example of signals that can be generated using Asymmetric PWM mode (channels 1 to 4 are configured in Asymmetric PWM mode 1).

Figure 465. Generation of 2 phase-shifted PWM signals with 50% duty cycle



44.3.11 Combined PWM mode

Combined PWM mode allows two edge or center-aligned PWM signals to be generated with programmable delay and phase shift between respective pulses. While the frequency is determined by the value of the TIMx_ARR register, the duty cycle and delay are determined by the two TIMx_CCRx registers. The resulting signals, OCxREFC, are made of an OR or AND logical combination of two reference PWMs:

– OC1REFC (or OC2REFC) is controlled by TIMx_CCR1 and TIMx_CCR2

– OC3REFC (or OC4REFC) is controlled by TIMx_CCR3 and TIMx_CCR4

Combined PWM mode can be selected independently on two channels (one OCx output per pair of CCR registers) by writing ‘1100’ (Combined PWM mode 1) or ‘1101’ (Combined PWM mode 2) in the OCxM bits in the TIMx_CCMRx register.

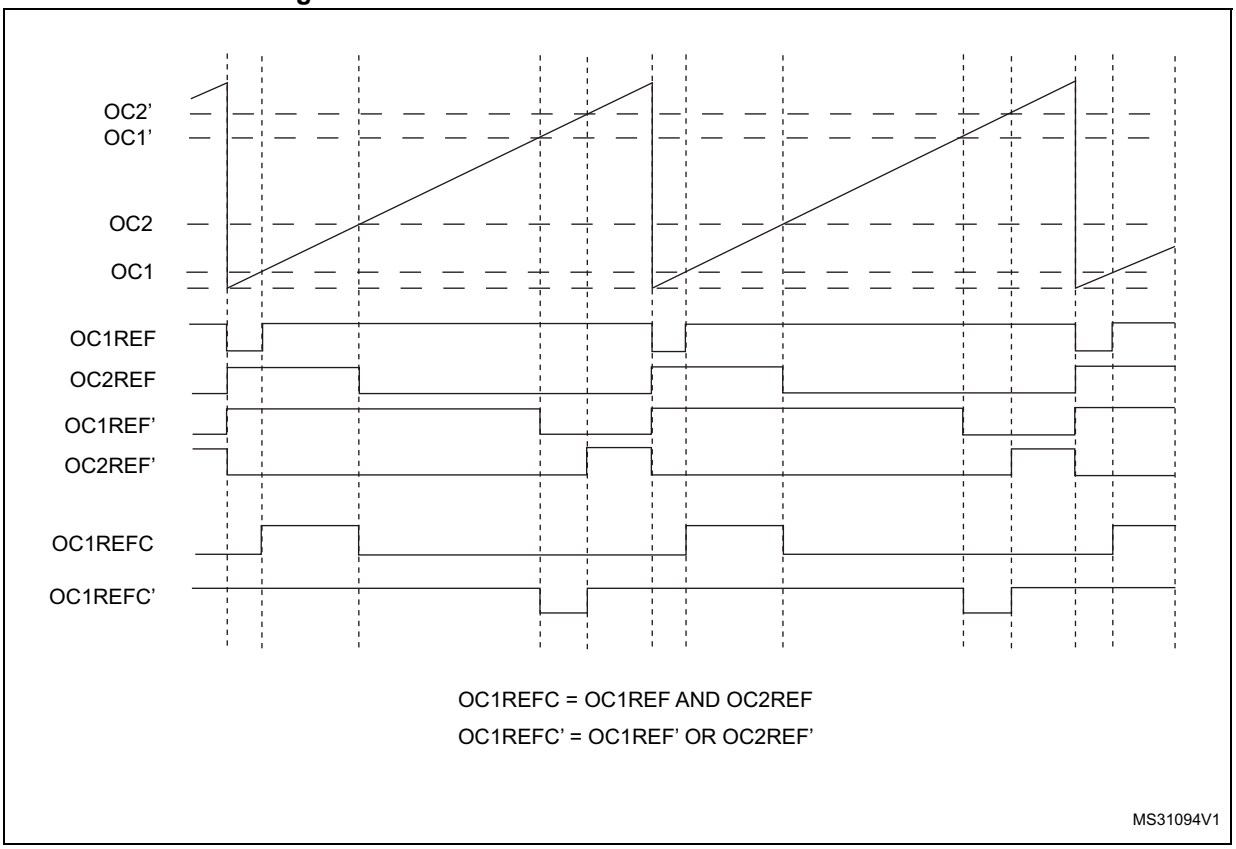
When a given channel is used as combined PWM channel, its secondary channel must be configured in the opposite PWM mode (for instance, one in Combined PWM mode 1 and the other in Combined PWM mode 2).

Note: The OCxM[3:0] bit field is split into two parts for compatibility reasons, the most significant bit is not contiguous with the 3 least significant ones.

Figure 466 shows an example of signals that can be generated using Asymmetric PWM mode, obtained with the following configuration:

- Channel 1 is configured in Combined PWM mode 2,
- Channel 2 is configured in PWM mode 1,
- Channel 3 is configured in Combined PWM mode 2,
- Channel 4 is configured in PWM mode 1

Figure 466. Combined PWM mode on channels 1 and 3



44.3.12 Clearing the OCxREF signal on an external event

The OCxREF signal of a given channel can be cleared when a high level is applied on the ocref_clr_int input (OCxCE enable bit in the corresponding TIMx_CCMRx register set to 1). OCxREF remains low until the next update event (UEV) occurs. This function can only be used in Output compare and PWM modes. It does not work in Forced mode.

The ocref_clr_int is connected to the ETRF signal (ETR after filtering).

The OCxREF signal for a given channel can be reset by applying a high level on the ETRF input (OCxCE enable bit set to 1 in the corresponding TIMx_CCMRx register). OCxREF remains low until the next update event (UEV) occurs.

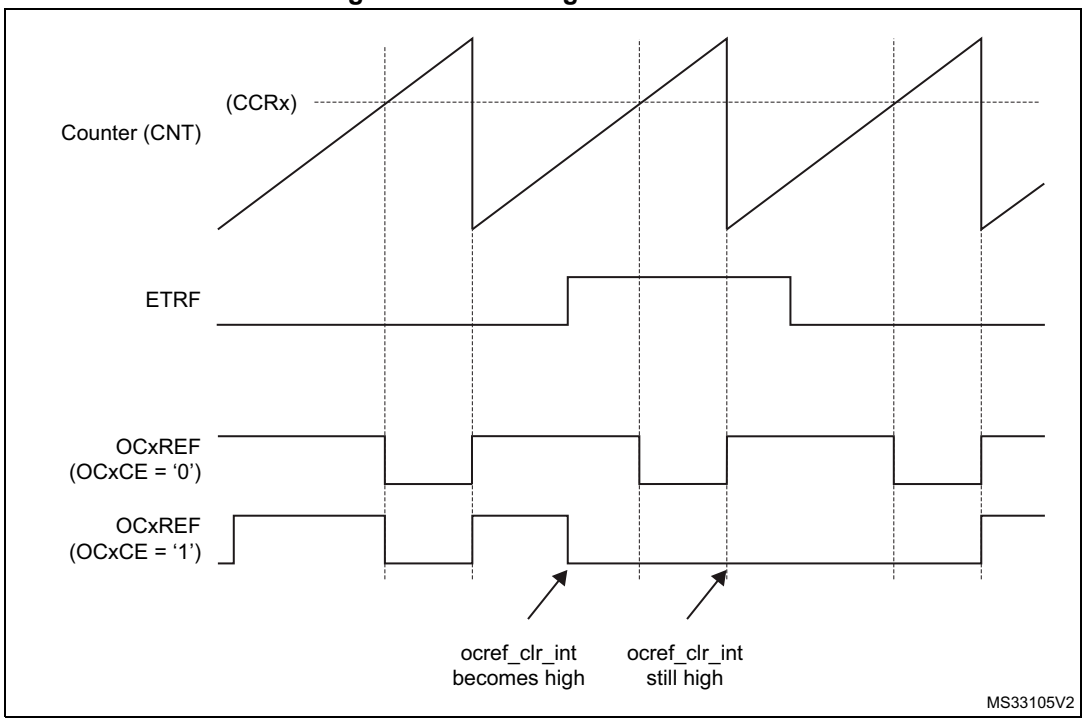
This function can be used only in the output compare and PWM modes. It does not work in forced mode.

For example, the OCxREF signal can be connected to the output of a comparator to be used for current handling. In this case, ETR must be configured as follows:

1. The external trigger prescaler should be kept off: bits ETPS[1:0] in the TIMx_SMCR register are cleared to 00.
2. The external clock mode 2 must be disabled: bit ECE in the TIM1_SMCR register is cleared to 0.
3. The external trigger polarity (ETP) and the external trigger filter (ETF) can be configured according to the application's needs.

Figure 467 shows the behavior of the OCxREF signal when the ETRF input becomes high, for both values of the OCxCE enable bit. In this example, the timer TIMx is programmed in PWM mode.

Figure 467. Clearing TIMx OCxREF



Note: In case of a PWM with a 100% duty cycle (if CCRx>ARR), OCxREF is enabled again at the next counter overflow.

44.3.13 One-pulse mode

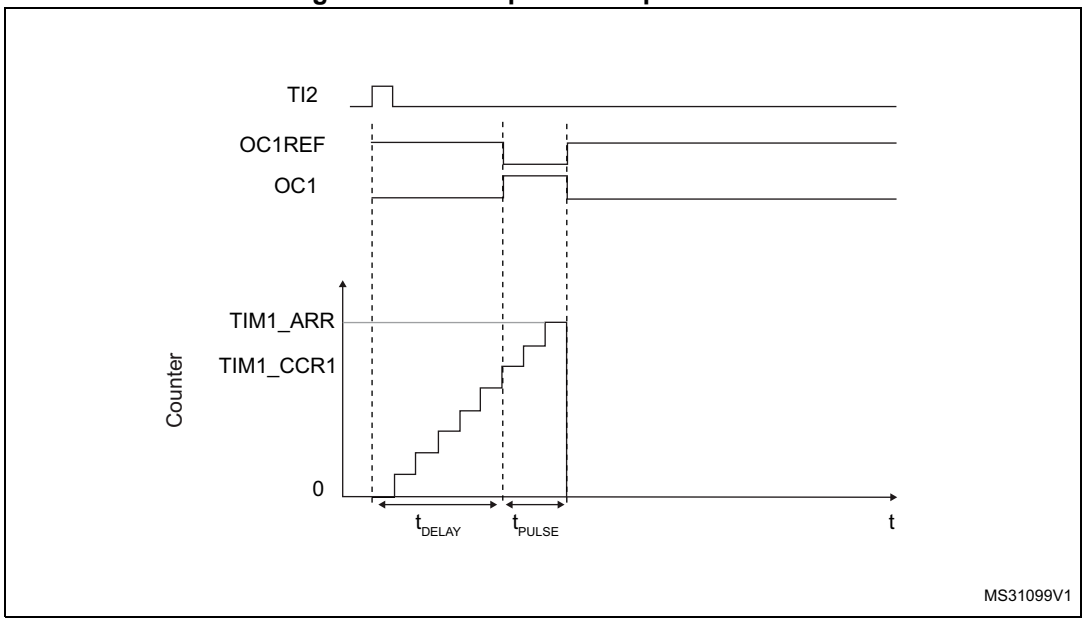
One-pulse mode (OPM) is a particular case of the previous modes. It allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length after a programmable delay.

Starting the counter can be controlled through the slave mode controller. Generating the waveform can be done in output compare mode or PWM mode. One-pulse mode is selected by setting the OPM bit in the TIMx_CR1 register. This makes the counter stop automatically at the next update event UEV.

A pulse can be correctly generated only if the compare value is different from the counter initial value. Before starting (when the timer is waiting for the trigger), the configuration must be:

- CNT<CCRx ≤ ARR (in particular, 0<CCRx),

Figure 468. Example of one-pulse mode.



For example one may want to generate a positive pulse on OC1 with a length of t_{PULSE} and after a delay of t_{DELAY} as soon as a positive edge is detected on the TI2 input pin.

Let's use TI2FP2 as trigger 1:

1. Select the proper TI2x source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Map TI2FP2 on TI2 by writing CC2S=01 in the TIMx_CCMR1 register.
3. TI2FP2 must detect a rising edge, write CC2P=0 and CC2NP='0' in the TIMx_CCER register.
4. Configure TI2FP2 as trigger for the slave mode controller (TRGI) by writing TS=00110 in the TIMx_SMCR register.
5. TI2FP2 is used to start the counter by writing SMS to '110 in the TIMx_SMCR register (trigger mode).

The OPM waveform is defined by writing the compare registers (taking into account the clock frequency and the counter prescaler).

- The t_{DELAY} is defined by the value written in the TIMx_CCR1 register.
- The t_{PULSE} is defined by the difference between the auto-reload value and the compare value (TIMx_ARR - TIMx_CCR1).
- Let's say one want to build a waveform with a transition from '0 to '1 when a compare match occurs and a transition from '1 to '0 when the counter reaches the auto-reload value. To do this PWM mode 2 must be enabled by writing OC1M=111 in the TIMx_CCMR1 register. Optionally the preload registers can be enabled by writing OC1PE=1 in the TIMx_CCMR1 register and ARPE in the TIMx_CR1 register. In this case one has to write the compare value in the TIMx_CCR1 register, the auto-reload value in the TIMx_ARR register, generate an update by setting the UG bit and wait for external trigger event on TI2. CC1P is written to '0 in this example.

In our example, the DIR and CMS bits in the TIMx_CR1 register should be low.

Since only 1 pulse (Single mode) is needed, a 1 must be written in the OPM bit in the TIMx_CR1 register to stop the counter at the next update event (when the counter rolls over from the auto-reload value back to 0). When OPM bit in the TIMx_CR1 register is set to '0', so the Repetitive Mode is selected.

Particular case: OCx fast enable:

In One-pulse mode, the edge detection on TIx input set the CEN bit which enables the counter. Then the comparison between the counter and the compare value makes the output toggle. But several clock cycles are needed for these operations and it limits the minimum delay t_{DELAY} min we can get.

If one wants to output a waveform with the minimum delay, the OCxFE bit can be set in the TIMx_CCMRx register. Then OCxRef (and OCx) is forced in response to the stimulus, without taking in account the comparison. Its new level is the same as if a compare match had occurred. OCxFE acts only if the channel is configured in PWM1 or PWM2 mode.

44.3.14 Retriggerable one pulse mode

This mode allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length, but with the following differences with Non-retriggerable one pulse mode described in *Section 44.3.13*:

- The pulse starts as soon as the trigger occurs (no programmable delay)
- The pulse is extended if a new trigger occurs before the previous one is completed

The timer must be in Slave mode, with the bits SMS[3:0] = '1000' (Combined Reset + trigger mode) in the TIMx_SMCR register, and the OCxM[3:0] bits set to '1000' or '1001' for Retriggerable OPM mode 1 or 2.

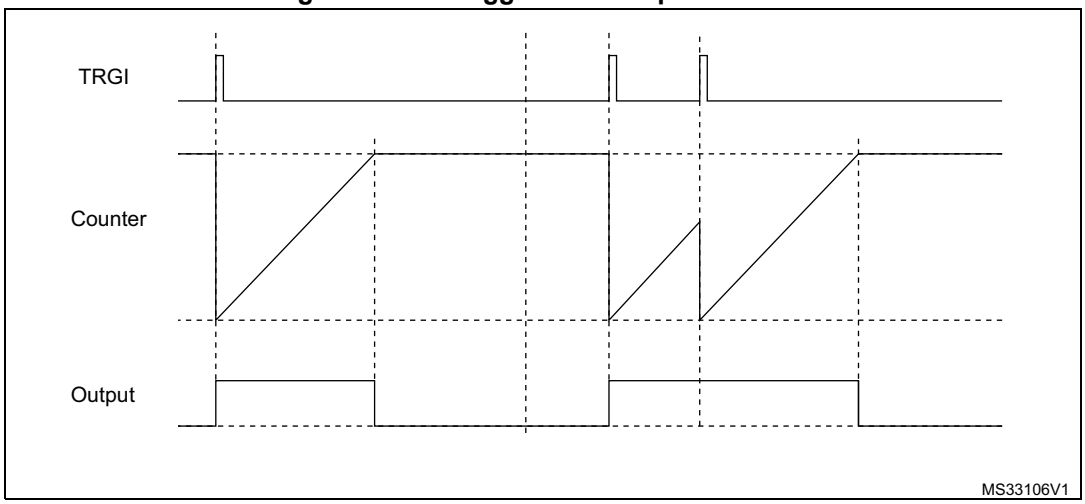
If the timer is configured in Up-counting mode, the corresponding CCRx must be set to 0 (the ARR register sets the pulse length). If the timer is configured in Down-counting mode CCRx must be above or equal to ARR.

Note: In retriggerable one pulse mode, the CCxIF flag is not significant.

The OCxM[3:0] and SMS[3:0] bit fields are split into two parts for compatibility reasons, the most significant bit is not contiguous with the 3 least significant ones.

This mode must not be used with center-aligned PWM modes. It is mandatory to have CMS[1:0] = 00 in TIMx_CR1.

Figure 469. Retriggerable one-pulse mode.



44.3.15 Encoder interface mode

To select Encoder Interface mode write SMS='001 in the TIMx_SMCR register if the counter is counting on TI2 edges only, SMS=010 if it is counting on TI1 edges only and SMS=011 if it is counting on both TI1 and TI2 edges.

Select the TI1 and TI2 polarity by programming the CC1P and CC2P bits in the TIMx_CCER register. CC1NP and CC2NP must be kept cleared. When needed, the input filter can be programmed as well. CC1NP and CC2NP must be kept low.

The two inputs TI1 and TI2 are used to interface to an incremental encoder. Refer to *Table 354*. The counter is clocked by each valid transition on TI1FP1 or TI2FP2 (TI1 and TI2 after input filter and polarity selection, TI1FP1=TI1 if not filtered and not inverted, TI2FP2=TI2 if not filtered and not inverted) assuming that it is enabled (CEN bit in TIMx_CR1 register written to '1). The sequence of transitions of the two inputs is evaluated and generates count pulses as well as the direction signal. Depending on the sequence the counter counts up or down, the DIR bit in the TIMx_CR1 register is modified by hardware accordingly. The DIR bit is calculated at each transition on any input (TI1 or TI2), whatever the counter is counting on TI1 only, TI2 only or both TI1 and TI2.

Encoder interface mode acts simply as an external clock with direction selection. This means that the counter just counts continuously between 0 and the auto-reload value in the TIMx_ARR register (0 to ARR or ARR down to 0 depending on the direction). So the TIMx_ARR must be configured before starting. In the same way, the capture, compare, prescaler, trigger output features continue to work as normal.

In this mode, the counter is modified automatically following the speed and the direction of the quadrature encoder and its content, therefore, always represents the encoder's position. The count direction correspond to the rotation direction of the connected sensor. The table summarizes the possible combinations, assuming TI1 and TI2 do not switch at the same time.

Table 354. Counting direction versus encoder signals

Active edge	Level on opposite signal (TI1FP1 for TI2, TI2FP2 for TI1)	TI1FP1 signal		TI2FP2 signal	
		Rising	Falling	Rising	Falling
Counting on TI1 only	High	Down	Up	No Count	No Count
	Low	Up	Down	No Count	No Count
Counting on TI2 only	High	No Count	No Count	Up	Down
	Low	No Count	No Count	Down	Up
Counting on TI1 and TI2	High	Down	Up	Up	Down
	Low	Up	Down	Down	Up

An external incremental encoder can be connected directly to the MCU without external interface logic. However, comparators are normally be used to convert the encoder's differential outputs to digital signals. This greatly increases noise immunity. The third encoder output which indicate the mechanical zero position, may be connected to an external interrupt input and trigger a counter reset.

Figure 470 gives an example of counter operation, showing count signal generation and direction control. It also shows how input jitter is compensated where both edges are selected. This might occur if the sensor is positioned near to one of the switching points. For this example we assume that the configuration is the following:

- CC1S= 01 (TIMx_CCMR1 register, TI1FP1 mapped on TI1)
- CC2S= 01 (TIMx_CCMR2 register, TI2FP2 mapped on TI2)
- CC1P and CC1NP = '0' (TIMx_CCER register, TI1FP1 noninverted, TI1FP1=TI1)
- CC2P and CC2NP = '0' (TIMx_CCER register, TI2FP2 noninverted, TI2FP2=TI2)
- SMS= 011 (TIMx_SMCR register, both inputs are active on both rising and falling edges)
- CEN= 1 (TIMx_CR1 register, Counter is enabled)

Figure 470. Example of counter operation in encoder interface mode

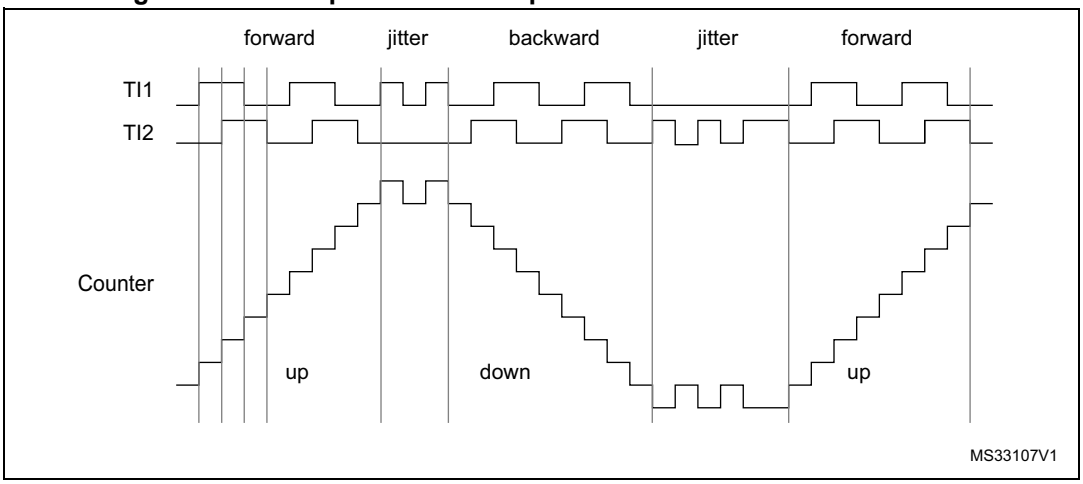
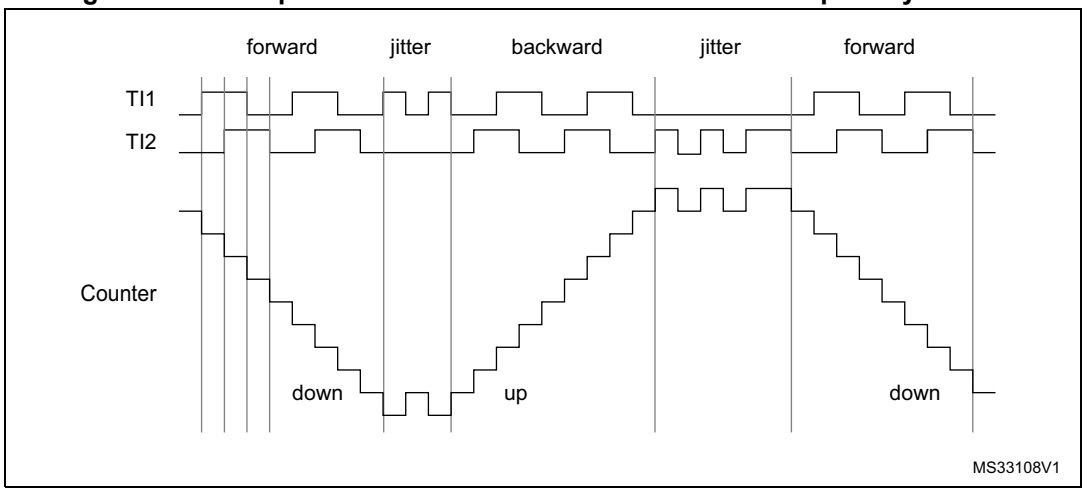


Figure 471 gives an example of counter behavior when TI1FP1 polarity is inverted (same configuration as above except CC1P=1).

Figure 471. Example of encoder interface mode with TI1FP1 polarity inverted



The timer, when configured in Encoder Interface mode provides information on the sensor's current position. Dynamic information can be obtained (speed, acceleration, deceleration) by measuring the period between two encoder events using a second timer configured in capture mode. The output of the encoder which indicates the mechanical zero can be used for this purpose. Depending on the time between two events, the counter can also be read at regular times. This can be done by latching the counter value into a third input capture register if available (then the capture signal must be periodic and can be generated by another timer). when available, it is also possible to read its value through a DMA request generated by a Real-Time clock.

44.3.16 UIF bit remapping

The IUFREMAP bit in the TIMx_CR1 register forces a continuous copy of the update interrupt flag (UIF) into bit 31 of the timer counter register's bit 31 (TIMxCNT[31]). This permits to atomically read both the counter value and a potential roll-over condition signaled by the UIFCPY flag. It eases the calculation of angular speed by avoiding race conditions caused, for instance, by a processing shared between a background task (counter reading) and an interrupt (update interrupt).

There is no latency between the UIF and UIFCPY flag assertions.

In 32-bit timer implementations, when the IUFREMAP bit is set, bit 31 of the counter is overwritten by the UIFCPY flag upon read access (the counter's most significant bit is only accessible in write mode).

44.3.17 Timer input XOR function

The TI1S bit in the TIM1xx_CR2 register, allows the input filter of channel 1 to be connected to the output of a XOR gate, combining the three input pins TIMx_CH1 to TIMx_CH3.

The XOR output can be used with all the timer input functions such as trigger or input capture.

An example of this feature used to interface Hall sensors is given in *Section 43.3.25: Interfacing with Hall sensors on page 1606*.

44.3.18 Timers and external trigger synchronization

The TIMx Timers can be synchronized with an external trigger in several modes: Reset mode, Gated mode and Trigger mode.

Slave mode: Reset mode

The counter and its prescaler can be reinitialized in response to an event on a trigger input. Moreover, if the URS bit from the TIMx_CR1 register is low, an update event UEV is generated. Then all the preloaded registers (TIMx_ARR, TIMx_CCRx) are updated.

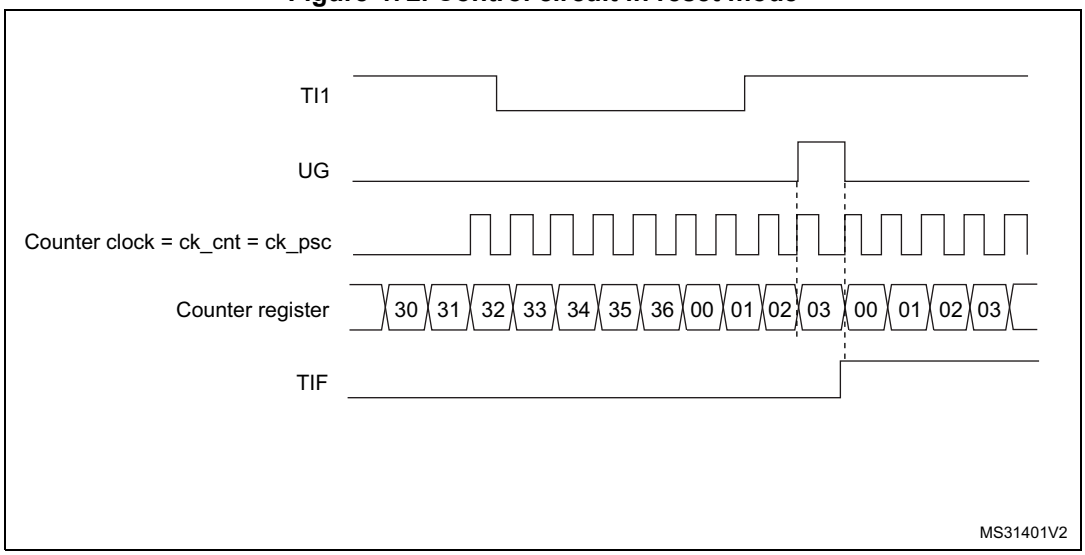
In the following example, the upcounter is cleared in response to a rising edge on TI1 input:

1. Configure the channel 1 to detect rising edges on TI1. Configure the input filter duration (in this example, we do not need any filter, so we keep IC1F=0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S = 01 in the TIMx_CCMR1 register. Write CC1P=0 and CC1NP=0 in TIMx_CCER register to validate the polarity (and detect rising edges only).
2. Configure the timer in reset mode by writing SMS=100 in TIMx_SMCR register. Select TI1 as the input source by writing TS=00101 in TIMx_SMCR register.
3. Start the counter by writing CEN=1 in the TIMx_CR1 register.

The counter starts counting on the internal clock, then behaves normally until TI1 rising edge. When TI1 rises, the counter is cleared and restarts from 0. In the meantime, the trigger flag is set (TIF bit in the TIMx_SR register) and an interrupt request, or a DMA request can be sent if enabled (depending on the TIE and TDE bits in TIMx_DIER register).

The following figure shows this behavior when the auto-reload register TIMx_ARR=0x36. The delay between the rising edge on TI1 and the actual reset of the counter is due to the resynchronization circuit on TI1 input.

Figure 472. Control circuit in reset mode



Slave mode: Gated mode

The counter can be enabled depending on the level of a selected input.

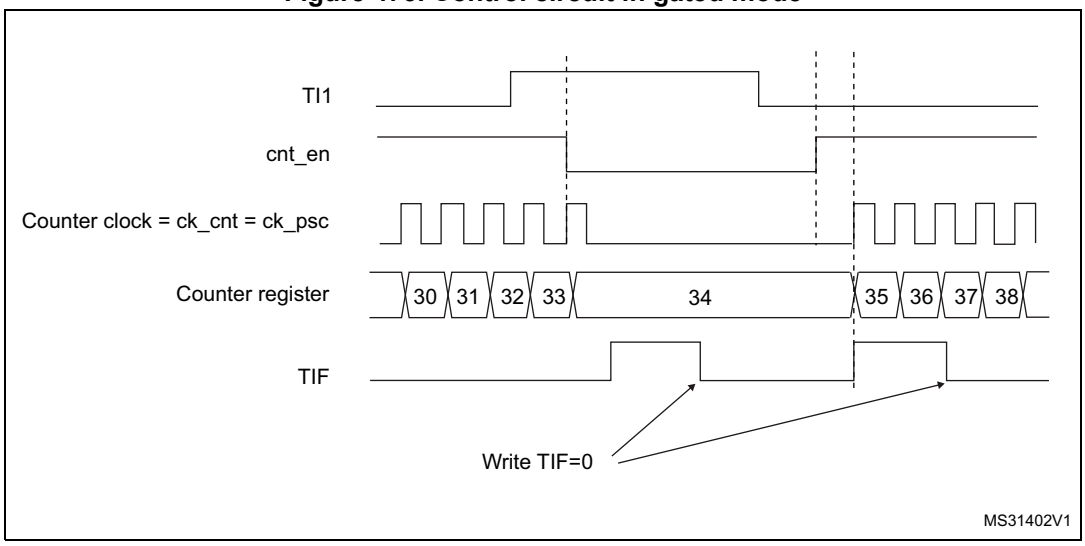
In the following example, the upcounter counts only when TI1 input is low:

1. Configure the channel 1 to detect low levels on TI1. Configure the input filter duration (in this example, we do not need any filter, so we keep IC1F=0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S=01 in TIMx_CCMR1 register. Write CC1P=1 and CC1NP=0 in TIMx_CCER register to validate the polarity (and detect low level only).
2. Configure the timer in gated mode by writing SMS=101 in TIMx_SMCR register. Select TI1 as the input source by writing TS=00101 in TIMx_SMCR register.
3. Enable the counter by writing CEN=1 in the TIMx_CR1 register (in gated mode, the counter doesn't start if CEN=0, whatever is the trigger input level).

The counter starts counting on the internal clock as long as TI1 is low and stops as soon as TI1 becomes high. The TIF flag in the TIMx_SR register is set both when the counter starts or stops.

The delay between the rising edge on TI1 and the actual stop of the counter is due to the resynchronization circuit on TI1 input.

Figure 473. Control circuit in gated mode



1. The configuration "CCxP=CCxNP=1" (detection of both rising and falling edges) does not have any effect in gated mode because gated mode acts on a level and not on an edge.

Note: The configuration "CCxP=CCxNP=1" (detection of both rising and falling edges) does not have any effect in gated mode because gated mode acts on a level and not on an edge.

Slave mode: Trigger mode

The counter can start in response to an event on a selected input.

In the following example, the upcounter starts in response to a rising edge on TI2 input:

1. Configure the channel 2 to detect rising edges on TI2. Configure the input filter duration (in this example, we do not need any filter, so we keep IC2F=0000). The capture prescaler is not used for triggering, so it does not need to be configured. CC2S bits are selecting the input capture source only, CC2S=01 in TIMx_CCMR1 register. Write

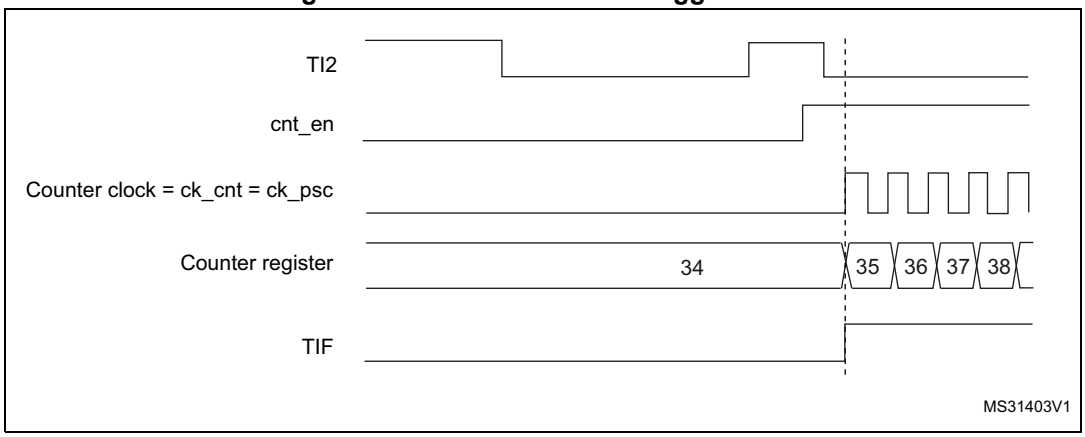
CC2P=1 and CC2NP=0 in TIMx_CCER register to validate the polarity (and detect low level only).

2. Configure the timer in trigger mode by writing SMS=110 in TIMx_SMCR register. Select TI2 as the input source by writing TS=00110 in TIMx_SMCR register.

When a rising edge occurs on TI2, the counter starts counting on the internal clock and the TIF flag is set.

The delay between the rising edge on TI2 and the actual start of the counter is due to the resynchronization circuit on TI2 input.

Figure 474. Control circuit in trigger mode



Slave mode: External Clock mode 2 + trigger mode

The external clock mode 2 can be used in addition to another slave mode (except external clock mode 1 and encoder mode). In this case, the ETR signal is used as external clock input, and another input can be selected as trigger input when operating in reset mode, gated mode or trigger mode. It is recommended not to select ETR as TRGI through the TS bits of TIMx_SMCR register.

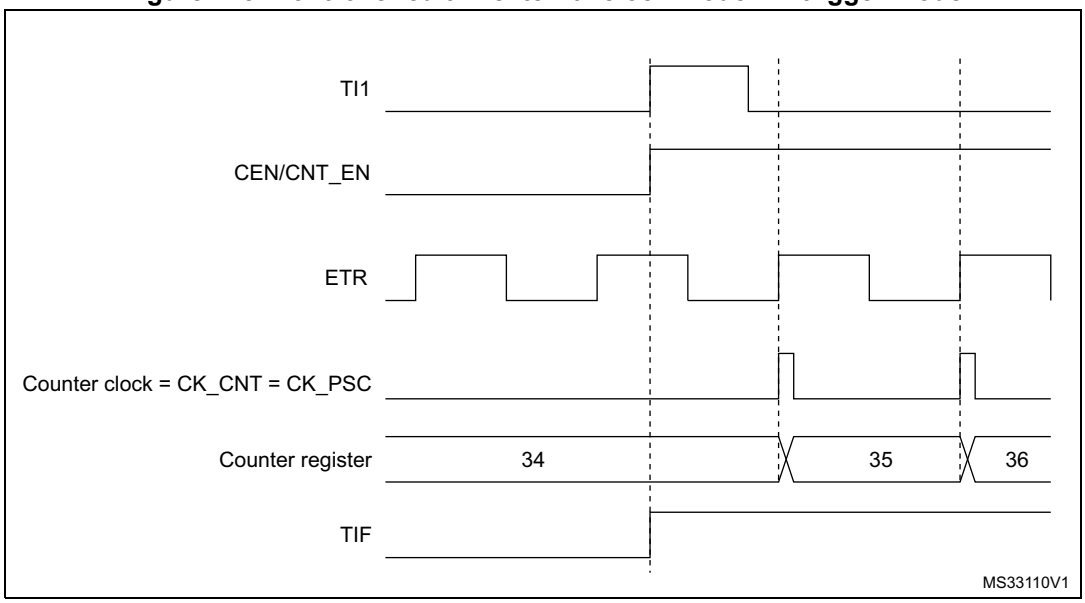
In the following example, the upcounter is incremented at each rising edge of the ETR signal as soon as a rising edge of TI1 occurs:

1. Configure the external trigger input circuit by programming the TIMx_SMCR register as follows:
   - ETF = 0000: no filter
   - ETPS=00: prescaler disabled
   - ETP=0: detection of rising edges on ETR and ECE=1 to enable the external clock mode 2.
2. Configure the channel 1 as follows, to detect rising edges on TI:
   - IC1F=0000: no filter.
   - The capture prescaler is not used for triggering and does not need to be configured.
   - CC1S=01in TIMx_CCMR1 register to select only the input capture source
   - CC1P=0 and CC1NP=0 in TIMx_CCER register to validate the polarity (and detect rising edge only).
3. Configure the timer in trigger mode by writing SMS=110 in TIMx_SMCR register. Select TI1 as the input source by writing TS=00101 in TIMx_SMCR register.

A rising edge on TI1 enables the counter and sets the TIF flag. The counter then counts on ETR rising edges.

The delay between the rising edge of the ETR signal and the actual reset of the counter is due to the resynchronization circuit on ETRP input.

Figure 475. Control circuit in external clock mode 2 + trigger mode



44.3.19 Timer synchronization

The TIMx timers are linked together internally for timer synchronization or chaining. When one Timer is configured in Master Mode, it can reset, start, stop or clock the counter of another Timer configured in Slave Mode.

Figure 476: Master/Slave timer example and *Figure 477: Master/slave connection example with 1 channel only timers* present an overview of the trigger selection and the master mode selection blocks.

Figure 476. Master/Slave timer example

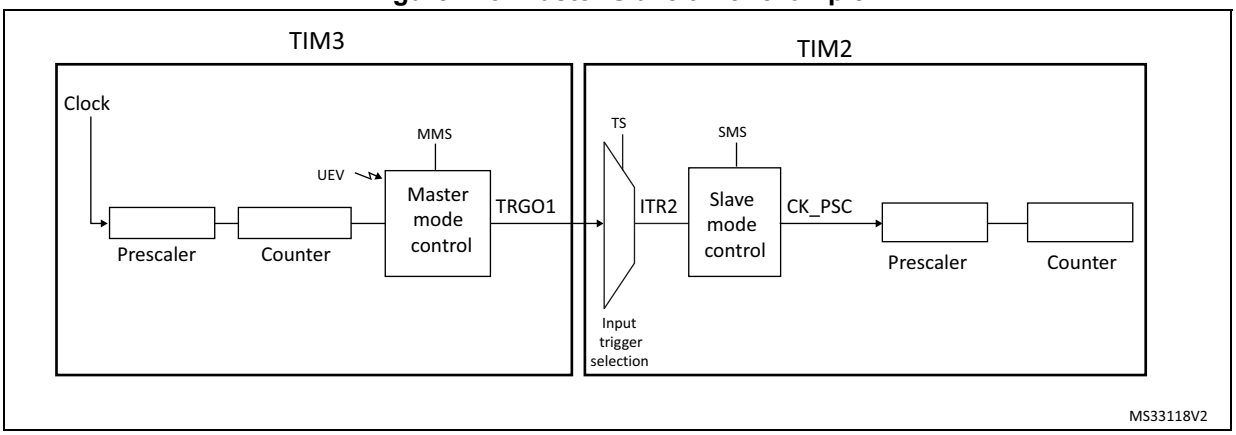
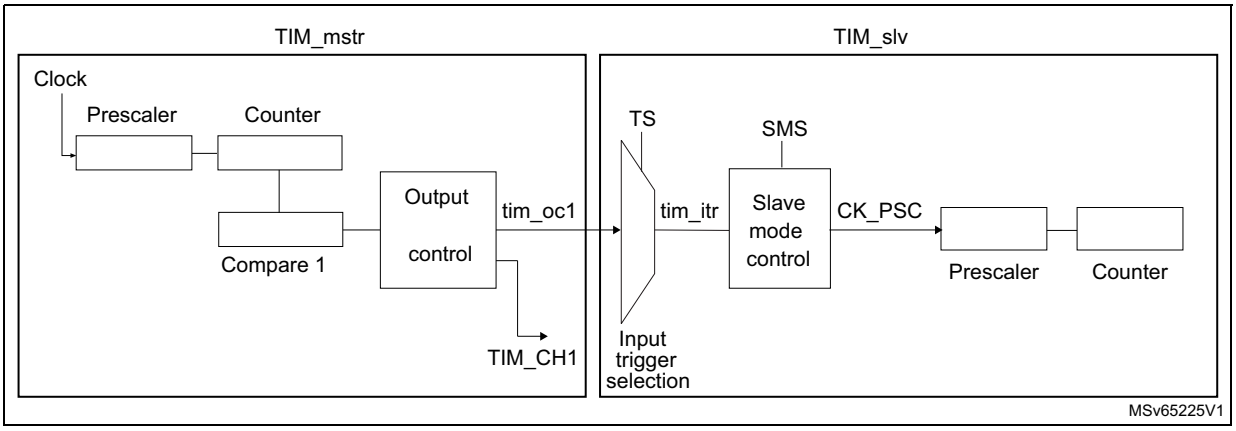


Figure 477. Master/slave connection example with 1 channel only timers



Note: The timers with one channel only (see Figure 477) do not feature a master mode. However, the OC1 output signal can be used to trigger some other timers (including timers described in other sections of this document). Check the "TIMx internal trigger connection" table of any TIMx_SMCR register on the device to identify which timers can be targeted as slave.
The OC1 signal pulse width must be programmed to be at least 2 clock cycles of the destination timer, to make sure the slave timer will detect the trigger.
For instance, if the destination's timer CK_INT clock is 4 times slower than the source timer, the OC1 pulse width must be 8 clock cycles.

Using one timer as prescaler for another timer

For example, TIM3 can be configured to act as a prescaler for TIM2. Refer to *Figure 476*. To do this:

1. Configure TIM3 in master mode so that it outputs a periodic trigger signal on each update event UEV. If MMS=010 is written in the TIM3_CR2 register, a rising edge is output on TRGO each time an update event is generated.
2. To connect the TRGO output of TIM3 to TIM2, TIM2 must be configured in slave mode using ITR2 as internal trigger. This is selected through the TS bits in the TIM2_SMCR register (writing TS=00010).
3. Then the slave mode controller must be put in external clock mode 1 (write SMS=111 in the TIM2_SMCR register). This causes TIM2 to be clocked by the rising edge of the periodic TIM3 trigger signal (which correspond to the TIM3 counter overflow).
4. Finally both timers must be enabled by setting their respective CEN bits (TIMx_CR1 register).

Note: If OCx is selected on TIM3 as the trigger output (MMS=1xx), its rising edge is used to clock the counter of TIM2.

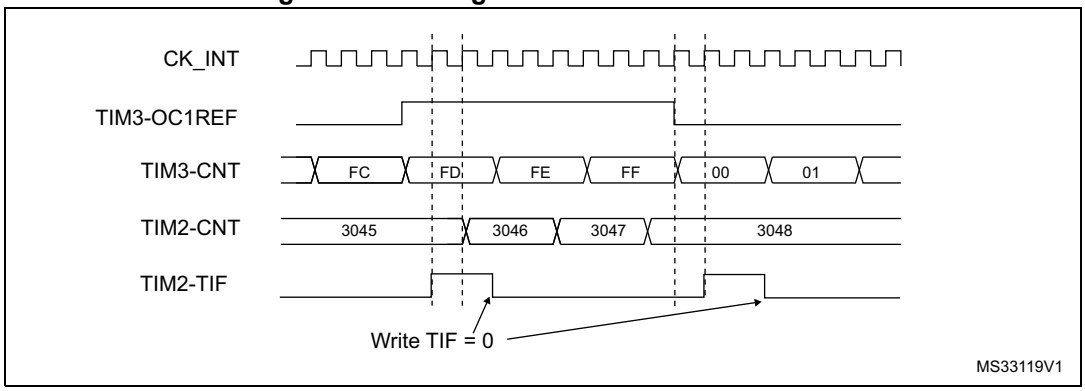
Using one timer to enable another timer

In this example, we control the enable of TIM2 with the output compare 1 of Timer 3. Refer to *Figure 476* for connections. TIM2 counts on the divided internal clock only when OC1REF of TIM3 is high. Both counter clock frequencies are divided by 3 by the prescaler compared to CK_INT ($f_{CK\_CNT} = f_{CK\_INT}/3$).

1. Configure TIM3 master mode to send its Output Compare 1 Reference (OC1REF) signal as trigger output (MMS=100 in the TIM3_CR2 register).
2. Configure the TIM3 OC1REF waveform (TIM3_CCMR1 register).
3. Configure TIM2 to get the input trigger from TIM3 (TS=00010 in the TIM2_SMCR register).
4. Configure TIM2 in gated mode (SMS=101 in TIM2_SMCR register).
5. Enable TIM2 by writing ‘1 in the CEN bit (TIM2_CR1 register).
6. Start TIM3 by writing ‘1 in the CEN bit (TIM3_CR1 register).

Note: The counter 2 clock is not synchronized with counter 1, this mode only affects the TIM2 counter enable signal.

Figure 478. Gating TIM2 with OC1REF of TIM3

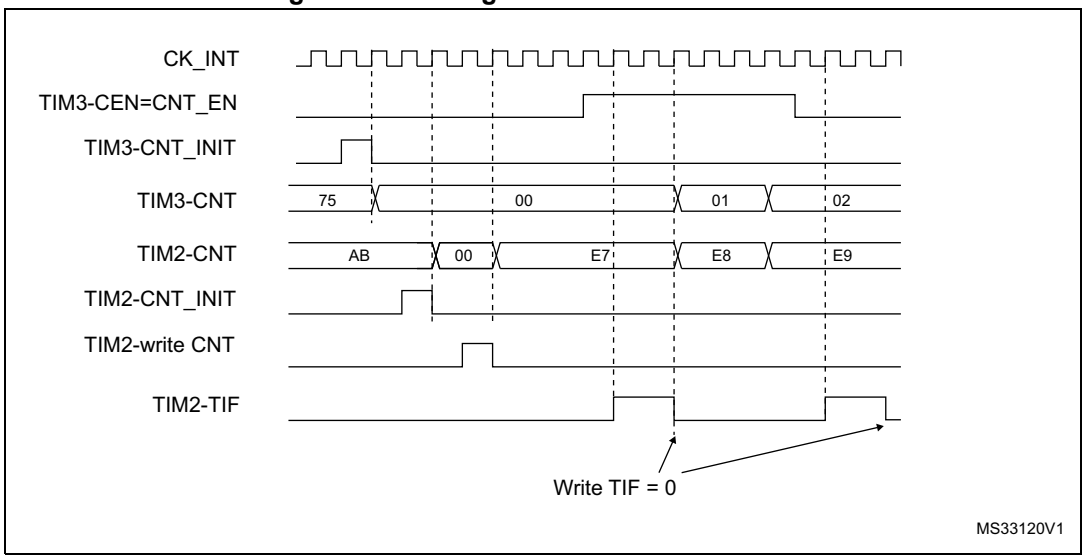


In the example in *Figure 478*, the TIM2 counter and prescaler are not initialized before being started. So they start counting from their current value. It is possible to start from a given value by resetting both timers before starting TIM3. Then any value can be written in the timer counters. The timers can easily be reset by software using the UG bit in the TIMx_EGR registers.

In the next example (refer to *Figure 479*), we synchronize TIM3 and TIM2. TIM3 is the master and starts from 0. TIM2 is the slave and starts from 0xE7. The prescaler ratio is the same for both timers. TIM2 stops when TIM3 is disabled by writing ‘0 to the CEN bit in the TIM3_CR1 register:

1. Configure TIM3 master mode to send its Output Compare 1 Reference (OC1REF) signal as trigger output (MMS=100 in the TIM3_CR2 register).
2. Configure the TIM3 OC1REF waveform (TIM3_CCMR1 register).
3. Configure TIM2 to get the input trigger from TIM3 (TS=00010 in the TIM2_SMCR register).
4. Configure TIM2 in gated mode (SMS=101 in TIM2_SMCR register).
5. Reset TIM3 by writing ‘1 in UG bit (TIM3_EGR register).
6. Reset TIM2 by writing ‘1 in UG bit (TIM2_EGR register).
7. Initialize TIM2 to 0xE7 by writing ‘0xE7’ in the TIM2 counter (TIM2_CNTL).
8. Enable TIM2 by writing ‘1 in the CEN bit (TIM2_CR1 register).
9. Start TIM3 by writing ‘1 in the CEN bit (TIM3_CR1 register).
10. Stop TIM3 by writing ‘0 in the CEN bit (TIM3_CR1 register).

Figure 479. Gating TIM2 with Enable of TIM3

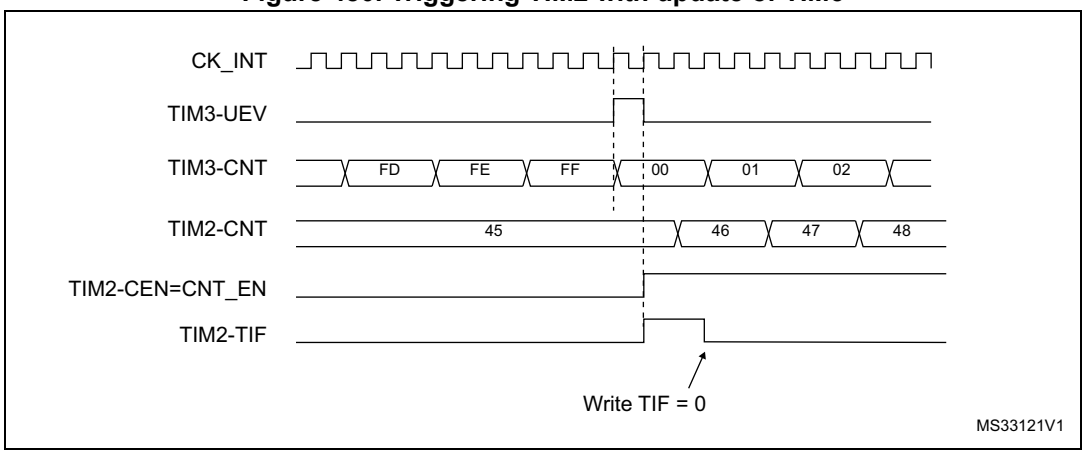


Using one timer to start another timer

In this example, we set the enable of Timer 2 with the update event of Timer 3. Refer to *Figure 476* for connections. Timer 2 starts counting from its current value (which can be non-zero) on the divided internal clock as soon as the update event is generated by Timer 1. When Timer 2 receives the trigger signal its CEN bit is automatically set and the counter counts until we write ‘0 to the CEN bit in the TIM2_CR1 register. Both counter clock frequencies are divided by 3 by the prescaler compared to CK_INT ($f_{CK\_CNT} = f_{CK\_INT}/3$).

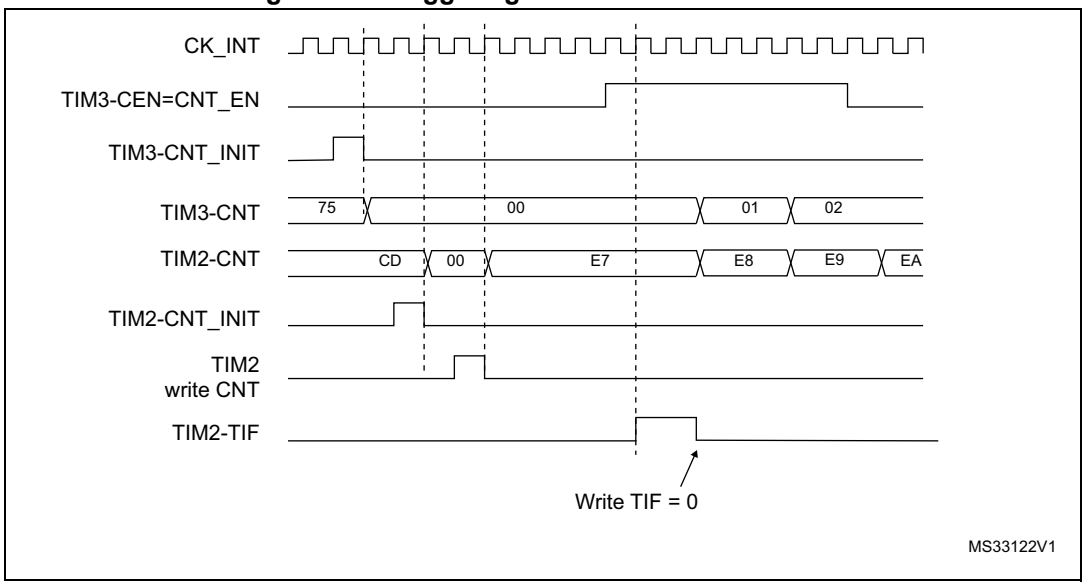
1. Configure TIM3 master mode to send its Update Event (UEV) as trigger output (MMS=010 in the TIM3_CR2 register).
2. Configure the TIM3 period (TIM3_ARR registers).
3. Configure TIM2 to get the input trigger from TIM3 (TS=00010 in the TIM2_SMCR register).
4. Configure TIM2 in trigger mode (SMS=110 in TIM2_SMCR register).
5. Start TIM3 by writing ‘1 in the CEN bit (TIM3_CR1 register).

Figure 480. Triggering TIM2 with update of TIM3



As in the previous example, both counters can be initialized before starting counting. *Figure 481* shows the behavior with the same configuration as in *Figure 480* but in trigger mode instead of gated mode (SMS=110 in the TIM2_SMCR register).

Figure 481. Triggering TIM2 with Enable of TIM3



Starting 2 timers synchronously in response to an external trigger

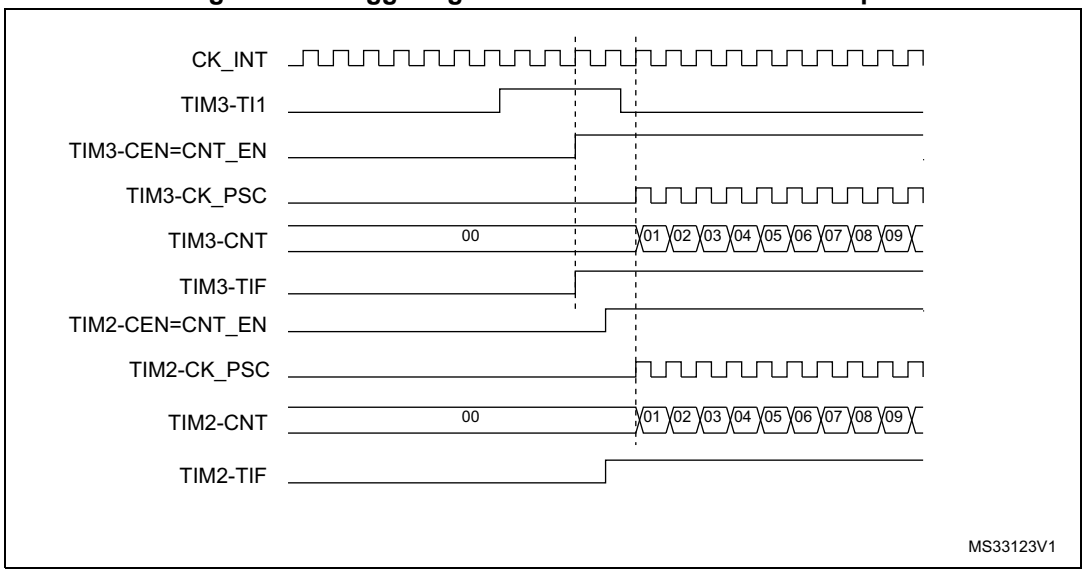
In this example, we set the enable of TIM3 when its TI1 input rises, and the enable of TIM2 with the enable of TIM3. Refer to *Figure 476* for connections. To ensure the counters are aligned, TIM3 must be configured in Master/Slave mode (slave with respect to TI1, master with respect to TIM2):

1. Configure TIM3 master mode to send its Enable as trigger output (MMS=001 in the TIM3_CR2 register).
2. Configure TIM3 slave mode to get the input trigger from TI1 (TS=00100 in the TIM3_SMCR register).
3. Configure TIM3 in trigger mode (SMS=110 in the TIM3_SMCR register).
4. Configure the TIM3 in Master/Slave mode by writing MSM=1 (TIM3_SMCR register).
5. Configure TIM2 to get the input trigger from TIM3 (TS=00000 in the TIM2_SMCR register).
6. Configure TIM2 in trigger mode (SMS=110 in the TIM2_SMCR register).

When a rising edge occurs on TI1 (TIM3), both counters starts counting synchronously on the internal clock and both TIF flags are set.

Note: In this example both timers are initialized before starting (by setting their respective UG bits). Both counters starts from 0, but an offset can easily be inserted between them by writing any of the counter registers (TIMx_CNT). One can see that the master/slave mode insert a delay between CNT_EN and CK_PSC on TIM3.

Figure 482. Triggering TIM3 and TIM2 with TIM3 TI1 input



Note: The clock of the slave peripherals (timer, ADC, ...) receiving the TRGO or the TRGO2 signals must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

44.3.20 DMA burst mode

The TIMx timers have the capability to generate multiple DMA requests upon a single event. The main purpose is to be able to re-program part of the timer multiple times without software overhead, but it can also be used to read several registers in a row, at regular intervals.

The DMA controller destination is unique and must point to the virtual register TIMx_DMAR. On a given timer event, the timer launches a sequence of DMA requests (burst). Each write into the TIMx_DMAR register is actually redirected to one of the timer registers.

The DBL[4:0] bits in the TIMx_DCR register set the DMA burst length. The timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address), i.e. the number of transfers (either in half-words or in bytes).

The DBA[4:0] bits in the TIMx_DCR registers define the DMA base address for DMA transfers (when read/write access are done through the TIMx_DMAR address). DBA is defined as an offset starting from the address of the TIMx_CR1 register:

Example:

00000: TIMx_CR1

00001: TIMx_CR2

00010: TIMx_SMCR

As an example, the timer DMA burst feature is used to update the contents of the CCRx registers (x = 2, 3, 4) upon an update event, with the DMA transferring half words into the CCRx registers.

This is done in the following steps:

1. Configure the corresponding DMA channel as follows:
   - DMA channel peripheral address is the DMAR register address
   - DMA channel memory address is the address of the buffer in the RAM containing the data to be transferred by DMA into CCRx registers.
   - Number of data to transfer = 3 (See note below).
   - Circular mode disabled.
2. Configure the DCR register by configuring the DBA and DBL bit fields as follows: DBL = 3 transfers, DBA = 0xE.
3. Enable the TIMx update DMA request (set the UDE bit in the DIER register).
4. Enable TIMx
5. Enable the DMA channel

This example is for the case where every CCRx register has to be updated once. If every CCRx register is to be updated twice for example, the number of data to transfer should be 6. Let's take the example of a buffer in the RAM containing data1, data2, data3, data4, data5 and data6. The data is transferred to the CCRx registers as follows: on the first update DMA request, data1 is transferred to CCR2, data2 is transferred to CCR3, data3 is transferred to CCR4 and on the second update DMA request, data4 is transferred to CCR2, data5 is transferred to CCR3 and data6 is transferred to CCR4.

Note: A null value can be written to the reserved registers.

44.3.21 Debug mode

When the microcontroller enters debug mode (Cortex®-M7 core halted), the TIMx counter either continues to work normally or stops, depending on TIMx configuration bit in DBGMCU module. For more details, refer to *Section 65.5.7: Microcontroller debug unit (DBGMCU)*.

For safety purposes, when the counter is stopped (TIMx = 1 in DBGMCU_APB1FZ2), the outputs are disabled.

44.4 TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by half-words (16-bit) or words (32-bit).

44.4.1 TIMx control register 1 (TIMx_CR1)(x = 2 to 5, 23, 24)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	UIFREMAP	Res.	CKD[1:0]		ARPE	CMS[1:0]		DIR	OPM	URS	UDIS	CEN
				rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **UIFREMAP**: UIF status bit remapping
0: No remapping. UIF status bit is not copied to TIMx_CNT register bit 31.
1: Remapping enabled. UIF status bit is copied to TIMx_CNT register bit 31.

Bit 10 Reserved, must be kept at reset value.

Bits 9:8 **CKD[1:0]**: Clock division
This bit-field indicates the division ratio between the timer clock (CK_INT) frequency and sampling clock used by the digital filters (ETR, TIx),
00: $t_{DTS} = t_{CK\_INT}$
01: $t_{DTS} = 2 \times t_{CK\_INT}$
10: $t_{DTS} = 4 \times t_{CK\_INT}$
11: Reserved

Bit 7 **ARPE**: Auto-reload preload enable
0: TIMx_ARR register is not buffered
1: TIMx_ARR register is buffered

Bits 6:5 **CMS[1:0]**: Center-aligned mode selection
00: Edge-aligned mode. The counter counts up or down depending on the direction bit (DIR).
01: Center-aligned mode 1. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS=00 in TIMx_CCMRx register) are set only when the counter is counting down.
10: Center-aligned mode 2. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS=00 in TIMx_CCMRx register) are set only when the counter is counting up.
11: Center-aligned mode 3. The counter counts up and down alternatively. Output compare interrupt flags of channels configured in output (CCxS=00 in TIMx_CCMRx register) are set both when the counter is counting up or down.

Note: It is not allowed to switch from edge-aligned mode to center-aligned mode as long as the counter is enabled (CEN=1)

Bit 4 **DIR**: Direction
0: Counter used as upcounter
1: Counter used as downcounter

Note: This bit is read only when the timer is configured in Center-aligned mode or Encoder mode.

Bit 3 **OPM**: One-pulse mode

0: Counter is not stopped at update event

1: Counter stops counting at the next update event (clearing the bit CEN)

Bit 2 **URS**: Update request source

This bit is set and cleared by software to select the UEV event sources.

0: Any of the following events generate an update interrupt or DMA request if enabled. These events can be:

– Counter overflow/underflow

– Setting the UG bit

– Update generation through the slave mode controller

1: Only counter overflow/underflow generates an update interrupt or DMA request if enabled.

Bit 1 **UDIS**: Update disable

This bit is set and cleared by software to enable/disable UEV event generation.

0: UEV enabled. The Update (UEV) event is generated by one of the following events:

– Counter overflow/underflow

– Setting the UG bit

– Update generation through the slave mode controller

Buffered registers are then loaded with their preload values.

1: UEV disabled. The Update event is not generated, shadow registers keep their value (ARR, PSC, CCRx). However the counter and the prescaler are reinitialized if the UG bit is set or if a hardware reset is received from the slave mode controller.

Bit 0 **CEN**: Counter enable

0: Counter disabled

1: Counter enabled

Note: External clock, gated mode and encoder mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.

CEN is cleared automatically in one-pulse mode, when an update event occurs.

44.4.2 TIMx control register 2 (TIMx_CR2)(x = 2 to 5, 23, 24)

Address offset: 0x04

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1S	MMS[2:0]			CCDS	Res.	Res.	Res.
								rw	rw	rw	rw	rw			

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **TI1S**: TI1 selection

0: The TIMx_CH1 pin is connected to TI1 input
1: The TIMx_CH1, CH2 and CH3 pins are connected to the TI1 input (XOR combination)
See also *Section 43.3.25: Interfacing with Hall sensors on page 1606*

Bits 6:4 **MMS[2:0]**: Master mode selection

These bits permit to select the information to be sent in master mode to slave timers for synchronization (TRGO). The combination is as follows:
000: **Reset** - the UG bit from the TIMx_EGR register is used as trigger output (TRGO). If the reset is generated by the trigger input (slave mode controller configured in reset mode) then the signal on TRGO is delayed compared to the actual reset.
001: **Enable** - the Counter enable signal, CNT_EN, is used as trigger output (TRGO). It is useful to start several timers at the same time or to control a window in which a slave timer is enabled. The Counter Enable signal is generated by a logic AND between CEN control bit and the trigger input when configured in gated mode.
When the Counter Enable signal is controlled by the trigger input, there is a delay on TRGO, except if the master/slave mode is selected (see the MSM bit description in TIMx_SMCR register).
010: **Update** - The update event is selected as trigger output (TRGO). For instance a master timer can then be used as a prescaler for a slave timer.
011: **Compare Pulse** - The trigger output send a positive pulse when the CC1IF flag is to be set (even if it was already high), as soon as a capture or a compare match occurred. (TRGO)
100: **Compare** - OC1REFC signal is used as trigger output (TRGO)
101: **Compare** - OC2REFC signal is used as trigger output (TRGO)
110: **Compare** - OC3REFC signal is used as trigger output (TRGO)
111: **Compare** - OC4REFC signal is used as trigger output (TRGO)

Note: The clock of the slave timer or ADC must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the master timer.

Bit 3 **CCDS**: Capture/compare DMA selection

0: CCx DMA request sent when CCx event occurs
1: CCx DMA requests sent when update event occurs

Bits 2:0 Reserved, must be kept at reset value.

44.4.3 TIMx slave mode control register (TIMx_SMCR)(x = 2 to 5, 23, 24)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS[4:3]		Res.	Res.	Res.	SMS[3]
										rw	rw				rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETP	ECE	ETPS[1:0]		ETF[3:0]				MSM	TS[2:0]			Res.	SMS[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 19:17 Reserved, must be kept at reset value.

Bit 15 **ETP**: External trigger polarity

This bit selects whether ETR or $\overline{\text{ETR}}$ is used for trigger operations

0: ETR is non-inverted, active at high level or rising edge

1: ETR is inverted, active at low level or falling edge

Bit 14 **ECE**: External clock enable

This bit enables External clock mode 2.

0: External clock mode 2 disabled

1: External clock mode 2 enabled. The counter is clocked by any active edge on the ETRF signal.

Note: Setting the ECE bit has the same effect as selecting external clock mode 1 with TRGI connected to ETRF (SMS=111 and TS=00111).

It is possible to simultaneously use external clock mode 2 with the following slave modes: reset mode, gated mode and trigger mode. Nevertheless, TRGI must not be connected to ETRF in this case (TS bits must not be 00111).

If external clock mode 1 and external clock mode 2 are enabled at the same time, the external clock input is ETRF.

Bits 13:12 **ETPS[1:0]**: External trigger prescaler

External trigger signal ETRP frequency must be at most 1/4 of CK_INT frequency. A prescaler can be enabled to reduce ETRP frequency. It is useful when inputting fast external clocks.

00: Prescaler OFF

01: ETRP frequency divided by 2

10: ETRP frequency divided by 4

11: ETRP frequency divided by 8

Bits 11:8 **ETF[3:0]**: External trigger filter

This bit-field then defines the frequency used to sample ETRP signal and the length of the digital filter applied to ETRP. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}
0001: $f_{SAMPLING}=f_{CK\_INT}$, N=2
0010: $f_{SAMPLING}=f_{CK\_INT}$, N=4
0011: $f_{SAMPLING}=f_{CK\_INT}$, N=8
0100: $f_{SAMPLING}=f_{DTS}/2$, N=6
0101: $f_{SAMPLING}=f_{DTS}/2$, N=8
0110: $f_{SAMPLING}=f_{DTS}/4$, N=6
0111: $f_{SAMPLING}=f_{DTS}/4$, N=8
1000: $f_{SAMPLING}=f_{DTS}/8$, N=6
1001: $f_{SAMPLING}=f_{DTS}/8$, N=8
1010: $f_{SAMPLING}=f_{DTS}/16$, N=5
1011: $f_{SAMPLING}=f_{DTS}/16$, N=6
1100: $f_{SAMPLING}=f_{DTS}/16$, N=8
1101: $f_{SAMPLING}=f_{DTS}/32$, N=5
1110: $f_{SAMPLING}=f_{DTS}/32$, N=6
1111: $f_{SAMPLING}=f_{DTS}/32$, N=8

Bit 7 **MSM**: Master/Slave mode

0: No action
1: The effect of an event on the trigger input (TRGI) is delayed to allow a perfect synchronization between the current timer and its slaves (through TRGO). It is useful if we want to synchronize several timers on a single external event.

Bits 21, 20, 6, 5, 4 **TS[4:0]**: Trigger selection

This bit-field selects the trigger input to be used to synchronize the counter.
00000: Internal Trigger 0 (ITR0)
00001: Internal Trigger 1 (ITR1)
00010: Internal Trigger 2 (ITR2)
00011: Internal Trigger 3 (ITR3)
00100: TI1 Edge Detector (TI1F_ED)
00101: Filtered Timer Input 1 (TI1FP1)
00110: Filtered Timer Input 2 (TI2FP2)
00111: External Trigger input (ETRF)
01000: Internal Trigger 4 (ITR4)
01001: Internal Trigger 5 (ITR5)
01010: Internal Trigger 6 (ITR6)
01011: Internal Trigger 7 (ITR7)
01100: Internal Trigger 8 (ITR8)
01101: Internal Trigger 9 (ITR9)
01110: Internal Trigger 10 (ITR10)
01111: Internal Trigger 11 (ITR11)
10000: Internal Trigger 12 (ITR12)
10001: Internal Trigger 13 (ITR13)
Others: Reserved
See *Table 355: TIMx internal trigger connection on page 1712* for more details on ITRx meaning for each Timer.

Note: These bits must be changed only when they are not used (e.g. when SMS=000) to avoid wrong edge detections at the transition.

Bit 3 Reserved, must be kept at reset value.

Bits 16, 2, 1, 0 **SMS[3:0]**: Slave mode selection

When external signals are selected the active edge of the trigger signal (TRGI) is linked to the polarity selected on the external input (see Input Control register and Control Register description.

0000: Slave mode disabled - if CEN = ‘1 then the prescaler is clocked directly by the internal clock.

0001: Encoder mode 1 - Counter counts up/down on TI1FP1 edge depending on TI2FP2 level.

0010: Encoder mode 2 - Counter counts up/down on TI2FP2 edge depending on TI1FP1 level.

0011: Encoder mode 3 - Counter counts up/down on both TI1FP1 and TI2FP2 edges depending on the level of the other input.

0100: Reset Mode - Rising edge of the selected trigger input (TRGI) reinitializes the counter and generates an update of the registers.

0101: Gated Mode - The counter clock is enabled when the trigger input (TRGI) is high. The counter stops (but is not reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

0110: Trigger Mode - The counter starts at a rising edge of the trigger TRGI (but it is not reset). Only the start of the counter is controlled.

0111: External Clock Mode 1 - Rising edges of the selected trigger (TRGI) clock the counter.

1000: Combined reset + trigger mode - Rising edge of the selected trigger input (TRGI) reinitializes the counter, generates an update of the registers and starts the counter.

Note: The gated mode must not be used if TI1F_ED is selected as the trigger input (TS=00100). Indeed, TI1F_ED outputs 1 pulse for each transition on TI1F, whereas the gated mode checks the level of the trigger signal.

Note: The clock of the slave peripherals (timer, ADC, ...) receiving the TRGO or the TRGO2 signals must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

Table 355. TIMx internal trigger connection

Slave TIM	ITR0	ITR1	ITR2	ITR3	ITR4	ITR5	ITR6	ITR7	ITR8	ITR9	ITR10	ITR11	ITR12	ITR13
TIM2	TIM1	TIM8	TIM3	TIM4	ETH PPS	USB1 OTG_ HS_ SOF	-	-	-	-	-	-	TIM23	TIM24
TIM3	TIM1	TIM2	TIM15	TIM4	ETH PPS	-	-	-	-	-	-	-	TIM23	TIM24
TIM4	TIM1	TIM2	TIM3	TIM8	-	-	-	-	-	-	-	-	TIM23	TIM24
TIM5	TIM1	TIM8	TIM3	TIM4	-	-	fdcan1 _soc	USB1 OTG_ HS_ SOF	-	-	-	-	TIM23	TIM24
TIM23	TIM1	TIM2	TIM3	TIM4	TIM5	TIM8	TIM12	TIM13 _OC1	TIM14 _OC1	TIM15	TIM16 _OC1	TIM17 _OC1	-	TIM24
TIM24	TIM1	TIM2	TIM3	TIM4	TIM5	TIM8	TIM12	TIM13 _OC1	TIM14 _OC1	TIM15	TIM16 _OC1	TIM17 _OC1	TIM23	-

44.4.4 TIMx DMA/Interrupt enable register (TIMx_DIER)(x = 2 to 5, 23, 24)

Address offset: 0x0C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TDE	Res.	CC4DE	CC3DE	CC2DE	CC1DE	UDE	Res.	TIE	Res.	CC4IE	CC3IE	CC2IE	CC1IE	UIE
	rw		rw	rw	rw	rw	rw		rw		rw	rw	rw	rw	rw

Bit 15 Reserved, must be kept at reset value.

Bit 14 **TDE**: Trigger DMA request enable
0: Trigger DMA request disabled.
1: Trigger DMA request enabled.

Bit 13 Reserved, must be kept at reset value.

Bit 12 **CC4DE**: Capture/Compare 4 DMA request enable
0: CC4 DMA request disabled.
1: CC4 DMA request enabled.

Bit 11 **CC3DE**: Capture/Compare 3 DMA request enable
0: CC3 DMA request disabled.
1: CC3 DMA request enabled.

Bit 10 **CC2DE**: Capture/Compare 2 DMA request enable
0: CC2 DMA request disabled.
1: CC2 DMA request enabled.

Bit 9 **CC1DE**: Capture/Compare 1 DMA request enable
0: CC1 DMA request disabled.
1: CC1 DMA request enabled.

Bit 8 **UDE**: Update DMA request enable
0: Update DMA request disabled.
1: Update DMA request enabled.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **TIE**: Trigger interrupt enable
0: Trigger interrupt disabled.
1: Trigger interrupt enabled.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **CC4IE**: Capture/Compare 4 interrupt enable
0: CC4 interrupt disabled.
1: CC4 interrupt enabled.

Bit 3 **CC3IE**: Capture/Compare 3 interrupt enable
0: CC3 interrupt disabled.
1: CC3 interrupt enabled.

Bit 2 **CC2IE**: Capture/Compare 2 interrupt enable
0: CC2 interrupt disabled.
1: CC2 interrupt enabled.

Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable
0: CC1 interrupt disabled.
1: CC1 interrupt enabled.

Bit 0 **UIE**: Update interrupt enable
0: Update interrupt disabled.
1: Update interrupt enabled.

44.4.5 TIMx status register (TIMx_SR)(x = 2 to 5, 23, 24)

Address offset: 0x10

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	CC4OF	CC3OF	CC2OF	CC1OF	Res.	Res.	TIF	Res.	CC4IF	CC3IF	CC2IF	CC1IF	UIF
			rc_w0	rc_w0	rc_w0	rc_w0			rc_w0		rc_w0	rc_w0	rc_w0	rc_w0	rc_w0

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **CC4OF**: Capture/Compare 4 overcapture flag
refer to CC1OF description

Bit 11 **CC3OF**: Capture/Compare 3 overcapture flag
refer to CC1OF description

Bit 10 **CC2OF**: Capture/compare 2 overcapture flag
refer to CC1OF description

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag
This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to ‘0’.
0: No overcapture has been detected.
1: The counter value has been captured in TIMx_CCR1 register while CC1IF flag was already set

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **TIF**: Trigger interrupt flag
This flag is set by hardware on the TRG trigger event (active edge detected on TRGI input when the slave mode controller is enabled in all modes but gated mode. It is set when the counter starts or stops when gated mode is selected. It is cleared by software.
0: No trigger event occurred.
1: Trigger interrupt pending.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **CC4IF**: Capture/Compare 4 interrupt flag
Refer to CC1IF description

Bit 3 **CC3IF**: Capture/Compare 3 interrupt flag
Refer to CC1IF description

Bit 2 **CC2IF**: Capture/Compare 2 interrupt flag
Refer to CC1IF description

Bit 1 **CC1IF**: Capture/compare 1 interrupt flag
This flag is set by hardware. It is cleared by software (input capture or output compare mode) or by reading the TIMx_CCR1 register (input capture mode only).
0: No compare match / No input capture occurred
1: A compare match or an input capture occurred
If channel CC1 is configured as output: this flag is set when the content of the counter TIMx_CNT matches the content of the TIMx_CCR1 register. When the content of TIMx_CCR1 is greater than the content of TIMx_ARR, the CC1IF bit goes high on the counter overflow (in up-counting and up/down-counting modes) or underflow (in down-counting mode). There are 3 possible options for flag setting in center-aligned mode, refer to the CMS bits in the TIMx_CR1 register for the full description.
If channel CC1 is configured as input: this bit is set when counter value has been captured in TIMx_CCR1 register (an edge has been detected on IC1, as per the edge sensitivity defined with the CC1P and CC1NP bits setting, in TIMx_CCER).

Bit 0 **UIF**: Update interrupt flag
This bit is set by hardware on an update event. It is cleared by software.
0: No update occurred
1: Update interrupt pending. This bit is set by hardware when the registers are updated:
At overflow or underflow (for TIM2 to TIM4) and if UDIS=0 in the TIMx_CR1 register.
When CNT is reinitialized by software using the UG bit in TIMx_EGR register, if URS=0 and UDIS=0 in the TIMx_CR1 register.
When CNT is reinitialized by a trigger event (refer to the synchro control register description), if URS=0 and UDIS=0 in the TIMx_CR1 register.

44.4.6 TIMx event generation register (TIMx_EGR)(x = 2 to 5, 23, 24)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TG	Res.	CC4G	CC3G	CC2G	CC1G	UG
									w		w	w	w	w	w

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **TG**: Trigger generation
This bit is set by software in order to generate an event, it is automatically cleared by hardware.
0: No action
1: The TIF flag is set in TIMx_SR register. Related interrupt or DMA transfer can occur if enabled.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **CC4G**: Capture/compare 4 generation
Refer to CC1G description

Bit 3 **CC3G**: Capture/compare 3 generation
Refer to CC1G description

Bit 2 **CC2G**: Capture/compare 2 generation
Refer to CC1G description

Bit 1 **CC1G**: Capture/compare 1 generation
This bit is set by software in order to generate an event, it is automatically cleared by hardware.
0: No action
1: A capture/compare event is generated on channel 1:
If channel CC1 is configured as output:
CC1IF flag is set, Corresponding interrupt or DMA request is sent if enabled.
If channel CC1 is configured as input:
The current value of the counter is captured in TIMx_CCR1 register. The CC1IF flag is set, the corresponding interrupt or DMA request is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation
This bit can be set by software, it is automatically cleared by hardware.
0: No action
1: Re-initialize the counter and generates an update of the registers. Note that the prescaler counter is cleared too (anyway the prescaler ratio is not affected). The counter is cleared if the center-aligned mode is selected or if DIR=0 (upcounting), else it takes the auto-reload value (TIMx_ARR) if DIR=1 (downcounting).

44.4.7 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1) (x = 2 to 5, 23, 24)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode.

Input capture mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IC2F[3:0]				IC2PSC[1:0]		CC2S[1:0]		IC1F[3:0]				IC1PSC[1:0]		CC1S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **IC2F[3:0]**: Input capture 2 filter

Bits 11:10 **IC2PSC[1:0]**: Input capture 2 prescaler

Bits 9:8 **CC2S[1:0]**: Capture/compare 2 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC2 channel is configured as output.

01: CC2 channel is configured as input, IC2 is mapped on TI2.

10: CC2 channel is configured as input, IC2 is mapped on TI1.

11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx_CCER).

Bits 7:4 **IC1F[3:0]**: Input capture 1 filter

This bit-field defines the frequency used to sample TI1 input and the length of the digital filter applied to TI1. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}

0001: $f_{SAMPLING}=f_{CK\_INT}$, N=2

0010: $f_{SAMPLING}=f_{CK\_INT}$, N=4

0011: $f_{SAMPLING}=f_{CK\_INT}$, N=8

0100: $f_{SAMPLING}=f_{DTS}/2$, N=6

0101: $f_{SAMPLING}=f_{DTS}/2$, N=8

0110: $f_{SAMPLING}=f_{DTS}/4$, N=6

0111: $f_{SAMPLING}=f_{DTS}/4$, N=8

1000: $f_{SAMPLING}=f_{DTS}/8$, N=6

1001: $f_{SAMPLING}=f_{DTS}/8$, N=8

1010: $f_{SAMPLING}=f_{DTS}/16$, N=5

1011: $f_{SAMPLING}=f_{DTS}/16$, N=6

1100: $f_{SAMPLING}=f_{DTS}/16$, N=8

1101: $f_{SAMPLING}=f_{DTS}/32$, N=5

1110: $f_{SAMPLING}=f_{DTS}/32$, N=6

1111: $f_{SAMPLING}=f_{DTS}/32$, N=8

Bits 3:2 **IC1PSC[1:0]**: Input capture 1 prescaler

This bit-field defines the ratio of the prescaler acting on CC1 input (IC1). The prescaler is reset as soon as CC1E=0 (TIMx_CCER register).

00: no prescaler, capture is done each time an edge is detected on the capture input

01: capture is done once every 2 events

10: capture is done once every 4 events

11: capture is done once every 8 events

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output

01: CC1 channel is configured as input, IC1 is mapped on TI1

10: CC1 channel is configured as input, IC1 is mapped on TI2

11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

44.4.8 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1) (x = 2 to 5, 23, 24)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode.

Output compare mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M [3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M [3]
							rw								rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC2CE	OC2M[2:0]			OC2PE	OC2FE	CC2S[1:0]		OC1CE	OC1M[2:0]			OC1PE	OC1FE	CC1S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 **OC2CE**: Output compare 2 clear enable

Bits 24, 14:12 **OC2M[3:0]**: Output compare 2 mode
refer to OC1M description on bits 6:4

Bit 11 **OC2PE**: Output compare 2 preload enable

Bit 10 **OC2FE**: Output compare 2 fast enable

Bits 9:8 **CC2S[1:0]**: Capture/Compare 2 selection
This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC2 channel is configured as output
01: CC2 channel is configured as input, IC2 is mapped on TI2
10: CC2 channel is configured as input, IC2 is mapped on TI1
11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode is working only if an internal trigger input is selected through the TS bit (TIMx_SMCR register)
Note: CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx_CCER).

Bit 7 **OC1CE**: Output compare 1 clear enable
0: OC1Ref is not affected by the ETRF input
1: OC1Ref is cleared as soon as a High level is detected on ETRF input

Bits 16, 6:4 **OC1M[3:0]**: Output compare 1 mode

These bits define the behavior of the output reference signal OC1REF from which OC1 and OC1N are derived. OC1REF is active high whereas OC1 and OC1N active level depends on CC1P and CC1NP bits.

0000: Frozen - The comparison between the output compare register TIMx_CCR1 and the counter TIMx_CNT has no effect on the outputs.(this mode is used to generate a timing base).

0001: Set channel 1 to active level on match. OC1REF signal is forced high when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0010: Set channel 1 to inactive level on match. OC1REF signal is forced low when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0011: Toggle - OC1REF toggles when TIMx_CNT=TIMx_CCR1.

0100: Force inactive level - OC1REF is forced low.

0101: Force active level - OC1REF is forced high.

0110: PWM mode 1 - In upcounting, channel 1 is active as long as TIMx_CNT<TIMx_CCR1 else inactive. In downcounting, channel 1 is inactive (OC1REF=‘0) as long as TIMx_CNT>TIMx_CCR1 else active (OC1REF=1).

0111: PWM mode 2 - In upcounting, channel 1 is inactive as long as TIMx_CNT<TIMx_CCR1 else active. In downcounting, channel 1 is active as long as TIMx_CNT>TIMx_CCR1 else inactive.

1000: Retriggerable OPM mode 1 - In up-counting mode, the channel is active until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes inactive again at the next update. In down-counting mode, the channel is inactive until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes inactive again at the next update.

1001: Retriggerable OPM mode 2 - In up-counting mode, the channel is inactive until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 2 and the channels becomes inactive again at the next update. In down-counting mode, the channel is active until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update.

1010: Reserved,

1011: Reserved,

1100: Combined PWM mode 1 - OC1REF has the same behavior as in PWM mode 1. OC1REFC is the logical OR between OC1REF and OC2REF.

1101: Combined PWM mode 2 - OC1REF has the same behavior as in PWM mode 2. OC1REFC is the logical AND between OC1REF and OC2REF.

1110: Asymmetric PWM mode 1 - OC1REF has the same behavior as in PWM mode 1. OC1REFC outputs OC1REF when the counter is counting up, OC2REF when it is counting down.

1111: Asymmetric PWM mode 2 - OC1REF has the same behavior as in PWM mode 2. OC1REFC outputs OC1REF when the counter is counting up, OC2REF when it is counting down.

Note: In PWM mode, the OCREF level changes only when the result of the comparison changes or when the output compare mode switches from “frozen” mode to “PWM” mode.

Note: The OC1M[3] bit is not contiguous, located in bit 16.

Bit 3 **OC1PE**: Output compare 1 preload enable

0: Preload register on TIMx_CCR1 disabled. TIMx_CCR1 can be written at anytime, the new value is taken in account immediately.
1: Preload register on TIMx_CCR1 enabled. Read/Write operations access the preload register. TIMx_CCR1 preload value is loaded in the active register at each update event.

Bit 2 **OC1FE**: Output compare 1 fast enable

This bit decreases the latency between a trigger event and a transition on the timer output. It must be used in one-pulse mode (OPM bit set in TIMx_CR1 register), to have the output pulse starting as soon as possible after the starting trigger.
0: CC1 behaves normally depending on counter and CCR1 values even when the trigger is ON. The minimum delay to activate CC1 output when an edge occurs on the trigger input is 5 clock cycles.
1: An active edge on the trigger input acts like a compare match on CC1 output. Then, OC is set to the compare level independently from the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OCFE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC1 channel is configured as output.
01: CC1 channel is configured as input, IC1 is mapped on TI1.
10: CC1 channel is configured as input, IC1 is mapped on TI2.
11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

44.4.9 TIMx capture/compare mode register 2 [alternate] (TIMx_CCMR2) (x = 2 to 5, 23, 24)

Address offset: 0x1C

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode.

Input capture mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IC4F[3:0]				IC4PSC[1:0]		CC4S[1:0]		IC3F[3:0]				IC3PSC[1:0]		CC3S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **IC4F[3:0]**: Input capture 4 filter

Bits 11:10 **IC4PSC[1:0]**: Input capture 4 prescaler

Bits 9:8 **CC4S[1:0]**: Capture/Compare 4 selection
This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC4 channel is configured as output
01: CC4 channel is configured as input, IC4 is mapped on TI4
10: CC4 channel is configured as input, IC4 is mapped on TI3
11: CC4 channel is configured as input, IC4 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)
Note: CC4S bits are writable only when the channel is OFF (CC4E = 0 in TIMx_CCER).

Bits 7:4 **IC3F[3:0]**: Input capture 3 filter

Bits 3:2 **IC3PSC[1:0]**: Input capture 3 prescaler

Bits 1:0 **CC3S[1:0]**: Capture/Compare 3 selection
This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC3 channel is configured as output
01: CC3 channel is configured as input, IC3 is mapped on TI3
10: CC3 channel is configured as input, IC3 is mapped on TI4
11: CC3 channel is configured as input, IC3 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)
Note: CC3S bits are writable only when the channel is OFF (CC3E = 0 in TIMx_CCER).

44.4.10 TIMx capture/compare mode register 2 [alternate] (TIMx_CCMR2) (x = 2 to 5, 23, 24)

Address offset: 0x1C

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode.

Output compare mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC4M [3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC3M [3]
							rw								rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OC4CE	OC4M[2:0]			OC4PE	OC4FE	CC4S[1:0]		OC3CE	OC3M[2:0]			OC3PE	OC3FE	CC3S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 **OC4CE**: Output compare 4 clear enable

Bits 24, 14:12 **OC4M[3:0]**: Output compare 4 mode
Refer to OC1M description (bits 6:4 in TIMx_CCMR1 register)

Bit 11 **OC4PE**: Output compare 4 preload enable

Bit 10 **OC4FE**: Output compare 4 fast enable

Bits 9:8 **CC4S[1:0]**: Capture/Compare 4 selection
This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC4 channel is configured as output
01: CC4 channel is configured as input, IC4 is mapped on TI4
10: CC4 channel is configured as input, IC4 is mapped on TI3
11: CC4 channel is configured as input, IC4 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)
Note: CC4S bits are writable only when the channel is OFF (CC4E = 0 in TIMx_CCER).

Bit 7 **OC3CE**: Output compare 3 clear enable

Bits 16, 6:4 **OC3M[3:0]**: Output compare 3 mode
Refer to OC1M description (bits 6:4 in TIMx_CCMR1 register)

Bit 3 **OC3PE**: Output compare 3 preload enable

Bit 2 **OC3FE**: Output compare 3 fast enable

Bits 1:0 **CC3S[1:0]**: Capture/Compare 3 selection
This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC3 channel is configured as output
01: CC3 channel is configured as input, IC3 is mapped on TI3
10: CC3 channel is configured as input, IC3 is mapped on TI4
11: CC3 channel is configured as input, IC3 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)
Note: CC3S bits are writable only when the channel is OFF (CC3E = 0 in TIMx_CCER).

44.4.11 TIMx capture/compare enable register (TIMx_CCER)(x = 2 to 5, 23, 24)

Address offset: 0x20

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CC4NP	Res.	CC4P	CC4E	CC3NP	Res.	CC3P	CC3E	CC2NP	Res.	CC2P	CC2E	CC1NP	Res.	CC1P	CC1E
rw		rw	rw	rw		rw	rw	rw		rw	rw	rw		rw	rw

Bit 15 **CC4NP**: *Capture/Compare 4 output Polarity.*
Refer to CC1NP description

Bit 14 Reserved, must be kept at reset value.

Bit 13 **CC4P**: *Capture/Compare 4 output Polarity.*
Refer to CC1P description

Bit 12 **CC4E**: *Capture/Compare 4 output enable.*
refer to CC1E description

Bit 11 **CC3NP**: *Capture/Compare 3 output Polarity.*
Refer to CC1NP description

Bit 10 Reserved, must be kept at reset value.

Bit 9 **CC3P**: *Capture/Compare 3 output Polarity.*
Refer to CC1P description

Bit 8 **CC3E**: *Capture/Compare 3 output enable.*
Refer to CC1E description

Bit 7 **CC2NP**: *Capture/Compare 2 output Polarity.*
Refer to CC1NP description

Bit 6 Reserved, must be kept at reset value.

Bit 5 **CC2P**: *Capture/Compare 2 output Polarity.*
refer to CC1P description

Bit 4 **CC2E**: *Capture/Compare 2 output enable.*
Refer to CC1E description

Bit 3 **CC1NP**: *Capture/Compare 1 output Polarity.*
CC1 channel configured as output: CC1NP must be kept cleared in this case.
CC1 channel configured as input: This bit is used in conjunction with CC1P to define TI1FP1/TI2FP1 polarity. refer to CC1P description.

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CC1P**: *Capture/Compare 1 output Polarity.*
0: OC1 active high (output mode) / Edge sensitivity selection (input mode, see below)
1: OC1 active low (output mode) / Edge sensitivity selection (input mode, see below)
When CC1 channel is configured as input, both CC1NP/CC1P bits select the active polarity of TI1FP1 and TI2FP1 for trigger or capture operations.
CC1NP=0, CC1P=0: non-inverted/rising edge. The circuit is sensitive to TIxFP1 rising edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger operation in gated mode or encoder mode).
CC1NP=0, CC1P=1: inverted/falling edge. The circuit is sensitive to TIxFP1 falling edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is inverted (trigger operation in gated mode or encoder mode).
CC1NP=1, CC1P=1: non-inverted/both edges. The circuit is sensitive to both TIxFP1 rising and falling edges (capture or trigger operations in reset, external clock or trigger mode), TIxFP1is not inverted (trigger operation in gated mode). This configuration must not be used in encoder mode.
CC1NP=1, CC1P=0: This configuration is reserved, it must not be used.

Bit 0 **CC1E**: *Capture/Compare 1 output enable.*
0: Capture mode disabled / OC1 is not active
1: Capture mode enabled / OC1 signal is output on the corresponding output pin

Table 356. Output control bit for standard OCx channels

CCxE bit	OCx output state
0	Output disabled (not driven by the timer: Hi-Z)
1	Output enabled (tim_ocx = tim_ocxref + Polarity)

Note: The state of the external IO pins connected to the standard OCx channels depends on the OCx channel state and the GPIO control and alternate function registers.

44.4.12 TIMx counter [alternate] (TIMx_CNT)(x = 2 to 5, 23, 24)

Bit 31 of this register has two possible definitions depending on the value of UIFREMAP in TIMx_CR1 register:

- This section is for UIFREMAP = 0
- Next section is for UIFREMAP = 1

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CNT[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **CNT[31:16]**: Most significant part counter value (TIM2, TIM5, TIM23 and TIM24)

Bits 15:0 **CNT[15:0]**: Least significant part of counter value

44.4.13 TIMx counter [alternate] (TIMx_CNT)(x = 2 to 5, 23, 24)

Bit 31 of this register has two possible definitions depending on the value of UIFREMAP in TIMx_CR1 register:

- Previous section is for UIFREMAP = 0
- This section is for UIFREMAP = 1

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIFCPY	CNT[30:16]														
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: UIF Copy

This bit is a read-only copy of the UIF bit of the TIMx_ISR register

Bits 30:16 **CNT[30:16]**: Most significant part counter value (TIM2, TIM5, TIM23 and TIM24)

Bits 15:0 **CNT[15:0]**: Least significant part of counter value

44.4.14 TIMx prescaler (TIMx_PSC)(x = 2 to 5, 23, 24)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency CK_CNT is equal to f_{CK_PSC} / (PSC[15:0] + 1).
PSC contains the value to be loaded in the active prescaler register at each update event (including when the counter is cleared through UG bit of TIMx_EGR register or through trigger controller when configured in “reset mode”).

44.4.15 TIMx auto-reload register (TIMx_ARR)(x = 2 to 5, 23, 24)

Address offset: 0x2C

Reset value: 0xFFFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ARR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **ARR[31:16]**: High auto-reload value (TIM2, TIM5, TIM23 and TIM24)

Bits 15:0 **ARR[15:0]**: Low Auto-reload value

ARR is the value to be loaded in the actual auto-reload register.
Refer to the *Section 44.3.1: Time-base unit on page 1663* for more details about ARR update and behavior.
The counter is blocked while the auto-reload value is null.

44.4.16 TIMx capture/compare register 1 (TIMx_CCR1)(x = 2 to 5, 23, 24)

Address offset: 0x34

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CCR1[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **CCR1[31:16]**: High Capture/Compare 1 value (TIM2, TIM5, TIM23 and TIM24)

Bits 15:0 **CCR1[15:0]**: Low Capture/Compare 1 value

If channel CC1 is configured as output:
CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value).
It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.
The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on OC1 output.

If channel CC1is configured as input:
CCR1 is the counter value transferred by the last input capture 1 event (IC1). The TIMx_CCR1 register is read-only and cannot be programmed.

44.4.17 TIMx capture/compare register 2 (TIMx_CCR2)(x = 2 to 5, 23, 24)

Address offset: 0x38

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CCR2[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **CCR2[31:16]**: High Capture/Compare 2 value (TIM2, TIM5, TIM23 and TIM24)

Bits 15:0 **CCR2[15:0]**: Low Capture/Compare 2 value

If channel CC2 is configured as output:
CCR2 is the value to be loaded in the actual capture/compare 2 register (preload value).
It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC2PE). Else the preload value is copied in the active capture/compare 2 register when an update event occurs.
The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signalled on OC2 output.
If channel CC2 is configured as input:
CCR2 is the counter value transferred by the last input capture 2 event (IC2). The TIMx_CCR2 register is read-only and cannot be programmed.

44.4.18 TIMx capture/compare register 3 (TIMx_CCR3)(x = 2 to 5, 23, 24)

Address offset: 0x3C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CCR3[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR3[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **CCR3[31:16]**: High Capture/Compare 3 value (TIM2, TIM5, TIM23 and TIM24)

Bits 15:0 **CCR3[15:0]**: Low Capture/Compare value

If channel CC3 is configured as output:
CCR3 is the value to be loaded in the actual capture/compare 3 register (preload value).
It is loaded permanently if the preload feature is not selected in the TIMx_CCMR2 register (bit OC3PE). Else the preload value is copied in the active capture/compare 3 register when an update event occurs.
The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signalled on OC3 output.
If channel CC3is configured as input:
CCR3 is the counter value transferred by the last input capture 3 event (IC3). The TIMx_CCR3 register is read-only and cannot be programmed.

44.4.19 TIMx capture/compare register 4 (TIMx_CCR4)(x = 2 to 5, 23, 24)

Address offset: 0x40

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CCR4[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR4[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **CCR4[31:16]**: High Capture/Compare 4 value (TIM2, TIM5, TIM23 and TIM24)

Bits 15:0 **CCR4[15:0]**: Low Capture/Compare value

1. if CC4 channel is configured as output (CC4S bits):
   CCR4 is the value to be loaded in the actual capture/compare 4 register (preload value).
   It is loaded permanently if the preload feature is not selected in the TIMx_CCMR2 register (bit OC4PE). Else the preload value is copied in the active capture/compare 4 register when an update event occurs.
   The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signalled on OC4 output.
2. if CC4 channel is configured as input (CC4S bits in TIMx_CCMR4 register):
   CCR4 is the counter value transferred by the last input capture 4 event (IC4). The TIMx_CCR4 register is read-only and cannot be programmed.

44.4.20 TIMx DMA control register (TIMx_DCR)(x = 2 to 5, 23, 24)

Address offset: 0x48

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **DBL[4:0]**: DMA burst length

This 5-bit vector defines the number of DMA transfers (the timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address).
00000: 1 transfer,
00001: 2 transfers,
00010: 3 transfers,
...
10001: 18 transfers.

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **DBA[4:0]**: DMA base address

This 5-bit vector defines the base-address for DMA transfers (when read/write access are done through the TIMx_DMAR address). DBA is defined as an offset starting from the address of the TIMx_CR1 register.
Example:
00000: TIMx_CR1
00001: TIMx_CR2
00010: TIMx_SMCR
...
Example: Let us consider the following transfer: DBL = 7 transfers & DBA = TIMx_CR1. In this case the transfer is done to/from 7 registers starting from the TIMx_CR1 address.

44.4.21 TIMx DMA address for full transfer (TIMx_DMAR)(x = 2 to 5, 23, 24)

Address offset: 0x4C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAB[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **DMAB[15:0]**: DMA register for burst accesses

A read or write operation to the DMAR register accesses the register located at the address

(TIMx_CR1 address) + (DBA + DMA index) x 4

where TIMx_CR1 address is the address of the control register 1, DBA is the DMA base address configured in TIMx_DCR register, DMA index is automatically controlled by the DMA transfer, and ranges from 0 to DBL (DBL configured in TIMx_DCR).

44.4.22 TIM2 alternate function option register 1 (TIM2_AF1)

Address offset: 0x60

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL[3:2]	
														rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETRSEL[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw														

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:14 **ETRSEL[3:0]**: ETR source selection
These bits select the ETR input source.
0000: ETR input is connected to I/O
0001: COMP1 output
0010: COMP2 output
0011: LSE
0100: SAI1 FS_A
0101: SAI1 FS_B
Others: Reserved

Bits 13:0 Reserved, must be kept at reset value.

44.4.23 TIM3 alternate function option register 1 (TIM3_AF1)

Address offset: 0x60

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL[3:2]	
														rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETRSEL[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw														

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:14 **ETRSEL[3:0]**: ETR source selection
These bits select the ETR input source.
0000: ETR input is connected to I/O
0001: COMP1 output
Others: Reserved

Bits 13:0 Reserved, must be kept at reset value.

44.4.24 TIM4 alternate function option register 1 (TIM4_AF1)

Address offset: 0x60

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL[3:2]	
														rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETRSEL[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw														

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:14 **ETRSEL[3:0]**: ETR source selection
These bits select the ETR input source.
0000: ETR input is connected to I/O
Others: Reserved

Bits 13:0 Reserved, must be kept at reset value.

44.4.25 TIM5 alternate function option register 1 (TIM5_AF1)

Address offset: 0x60

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL[3:2]	
														rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETRSEL[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw														

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:14 **ETRSEL[3:0]**: ETR source selection
These bits select the ETR input source.
0000: ETR input is connected to I/O
0001: SAI4 FS_A connected to ETR input
0010: SAI4 FS_B connected to ETR input
Others: Reserved

Bits 13:0 Reserved, must be kept at reset value.

44.4.26 TIM23 alternate function option register 1 (TIM23_AF1)

Address offset: 0x60

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL[3:2]	
														rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETRSEL[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw														

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:14 **ETRSEL[3:0]**: ETR source selection
These bits select the ETR input source.
0000: ETR input is connected to I/O
0001: COMP1 output
0010: COMP2 output
Others: Reserved

Bits 13:0 Reserved, must be kept at reset value.

44.4.27 TIM24 alternate function option register 1 (TIM24_AF1)

Address offset: 0x60

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL[3:2]	
														rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETRSEL[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw														

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:14 **ETRSEL[3:0]**: ETR source selection
These bits select the ETR input source.
0000: ETR input is connected to I/O
0001: SAI4 FS_A connected to ETR input
0010: SAI4 FS_B connected to ETR input
0011: SAI1 FS_A connected to ETR input
0100: SAI1 FS_B connected to ETR input
Others: Reserved

Bits 13:0 Reserved, must be kept at reset value.

44.4.28 TIM2 timer input selection register (TIM2_TISEL)

Address offset: 0x68

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **TI4SEL[3:0]**: TI4[0] to TI4[15] input selection
These bits select the TI4[0] to TI4[15] input source.
0000: TIM2_CH4 input
0001: COMP1 output
0010: COMP2 output
0011: COMP1 output OR COMP2 output
Others: Reserved

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **TI3SEL[3:0]**: TI3[0] to TI3[15] input selection
These bits select the TI3[0] to TI3[15] input source.
0000: TIM2_CH3 input
Others: Reserved

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: TI2[0] to TI2[15] input selection
These bits select the TI2[0] to TI2[15] input source.
0000: TIM2_CH2 input
Others: Reserved

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: TI1[0] to TI1[15] input selection
These bits select the TI1[0] to TI1[15] input source.
0000: TIM2_CH1 input
Others: Reserved

44.4.29 TIM3 timer input selection register (TIM3_TISEL)

Address offset: 0x68

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **TI4SEL[3:0]**: TI4[0] to TI4[15] input selection
These bits select the TI4[0] to TI4[15] input source.
0000: TIM3_CH4 input
Others: Reserved

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **TI3SEL[3:0]**: TI3[0] to TI3[15] input selection
These bits select the TI3[0] to TI3[15] input source.
0000: TIM3_CH3 input
Others: Reserved

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: TI2[0] to TI2[15] input selection
These bits select the TI2[0] to TI2[15] input source.
0000: TIM3_CH2 input
Others: Reserved

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: TI1[0] to TI1[15] input selection
These bits select the TI1[0] to TI1[15] input source.
0000: TIM3_CH1 input
0001: COMP1 output
0010: COMP2 output
0011: COMP1 output OR COMP2 output
Others: Reserved

44.4.30 TIM4 timer input selection register (TIM4_TISEL)

Address offset: 0x68

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **TI4SEL[3:0]**: TI4[0] to TI4[15] input selection
These bits select the TI4[0] to TI4[15] input source.
0000: TIM4_CH4 input
Others: Reserved

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **TI3SEL[3:0]**: TI3[0] to TI3[15] input selection
These bits select the TI3[0] to TI3[15] input source.
0000: TIM4_CH3 input
Others: Reserved

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: TI2[0] to TI2[15] input selection
These bits select the TI2[0] to TI2[15] input source.
0000: TIM4_CH2 input
Others: Reserved

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: TI1[0] to TI1[15] input selection
These bits select the TI1[0] to TI1[15] input source.
0000: TIM4_CH1 input
Others: Reserved

44.4.31 TIM5 timer input selection register (TIM5_TISEL)

Address offset: 0x68

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **TI4SEL[3:0]**: TI4[0] to TI4[15] input selection
These bits select the TI4[0] to TI4[15] input source.
0000: TIM5_CH4 input
Others: Reserved

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **TI3SEL[3:0]**: TI3[0] to TI3[15] input selection
These bits select the TI3[0] to TI3[15] input source.
0000: TIM5_CH3 input
Others: Reserved

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: TI2[0] to TI2[15] input selection
These bits select the TI2[0] to TI2[15] input source.
0000: TIM5_CH2 input
Others: Reserved

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: TI1[0] to TI1[15] input selection
These bits select the TI1[0] to TI1[15] input source.
0000: TIM5_CH1 input
0001: fdcan1_tmp
0010: fdcan1_rtp
Others: Reserved

44.4.32 TIM23 timer input selection register (TIM23_TISEL)

Address offset: 0x68

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **TI4SEL[3:0]**: TI4[0] to TI4[15] input selection
These bits select the TI4[0] to TI4[15] input source.
0000: TIM23_CH4 input
0001: COMP1 output
0010: COMP2 output
0011: COMP1 output OR COMP2 output
Others: Reserved

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **TI3SEL[3:0]**: TI3[0] to TI3[15] input selection
These bits select the TI3[0] to TI3[15] input source.
0000: TIM23_CH3 input
Others: Reserved

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: TI2[0] to TI2[15] input selection
These bits select the TI2[0] to TI2[15] input source.
0000: TIM23_CH2 input
Others: Reserved

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: TI1[0] to TI1[15] input selection
These bits select the TI1[0] to TI1[15] input source.
0000: TIM23_CH1 input
Others: Reserved

44.4.33 TIM24 timer input selection register (TIM24_TISEL)

Address offset: 0x68

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **TI4SEL[3:0]**: TI4[0] to TI4[15] input selection
These bits select the TI4[0] to TI4[15] input source.
0000: TIM24_CH4 input
Others: Reserved

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **TI3SEL[3:0]**: TI3[0] to TI3[15] input selection
These bits select the TI3[0] to TI3[15] input source.
0000: TIM24_CH3 input
Others: Reserved

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: TI2[0] to TI2[15] input selection
These bits select the TI2[0] to TI2[15] input source.
0000: TIM24_CH2 input
Others: Reserved

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: TI1[0] to TI1[15] input selection
These bits select the TI1[0] to TI1[15] input source.
0000: TIM24_CH1 input
0001: fdcan1_tmp
0010: fdcan1_rtp
0011: fdcan1_soc
Others: Reserved

44.4.34 TIMx register map

TIMx registers are mapped as described in the table below:

Table 357. TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**TIMx_CR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIFREMA	Res.	CKD [1:0]		ARPE	CMS [1:0]		DIR	OPM	URS	UDIS	CEN
	Reset value																					0		0	0	0	0	0	0	0	0	0	0
0x04	**TIMx_CR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1S	MMS[2:0]			CCDS	Res.	Res.	Res.
	Reset value																									0	0	0	0	0			
0x08	**TIMx_SMCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS [4:3]		Res.	Res.	Res.	SMS[3]	ETP	ECE	ETPS [1:0]		ETF[3:0]				MSM	TS[2:0]			Res.	SMS[2:0]		
	Reset value											0	0				0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
0x0C	**TIMx_DIER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDE	Res.	CC4DE	CC3DE	CC2DE	CC1DE	UDE	Res.	TIE	Res.	CC4IE	CC3IE	CC2IE	CC1IE	UIE
	Reset value																		0		0	0	0	0	0		0		0	0	0	0	0
0x10	**TIMx_SR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC4OF	CC3OF	CC2OF	CC1OF	Res.	Res.	TIF	Res.	CC4IF	CC3IF	CC2IF	CC1IF	UIF
	Reset value																				0	0	0	0			0		0	0	0	0	0
0x14	**TIMx_EGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TG	Res.	CC4G	CC3G	CC2G	CC1G	UG
	Reset value																										0		0	0	0	0	0
0x18	**TIMx_CCMR1** Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]	OC2CE	OC2M [2:0]			OC2PE	OC2FE	CC2S [1:0]		OC1CE	OC1M [2:0]			OC1PE	OC1FE	CC1S [1:0]	
	Reset value								0								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TIMx_CCMR1 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC2F[3:0]				IC2 PSC [1:0]		CC2S [1:0]		IC1F[3:0]				IC1 PSC [1:0]		CC1S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	**TIMx_CCMR2** Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC4M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC3M[3]	O24CE	OC4M [2:0]			OC4PE	OC4FE	CC4S [1:0]		OC3CE	OC3M [2:0]			OC3PE	OC3FE	CC3S [1:0]	
	Reset value								0								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TIMx_CCMR2 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC4F[3:0]				IC4 PSC [1:0]		CC4S [1:0]		IC3F[3:0]				IC3 PSC [1:0]		CC3S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	**TIMx_CCER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC4NP	Res.	CC4P	CC4E	CC3NP	Res.	CC3P	CC3E	CC2NP	Res.	CC2P	CC2E	CC1NP	Res.	CC1P	CC1E
	Reset value																	0		0	0	0		0	0	0		0	0	0		0	0

Table 357. TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x24	**TIMx_CNT**	CNT[31] or UIFCPY	CNT[30:16] (TIM2, TIM5, TIM23 and TIM24 only, reserved on the other timers)															CNT[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	**TIMx_PSC**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	**TIMx_ARR**	ARR[31:16] (TIM2, TIM5, TIM23 and TIM24 only, reserved on the other timers)																ARR[15:0]															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x30	Reserved																																
0x34	**TIMx_CCR1**	CCR1[31:16] (TIM2, TIM5, TIM23 and TIM24 only, reserved on the other timers)																CCR1[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x38	**TIMx_CCR2**	CCR2[31:16] (TIM2, TIM5, TIM23 and TIM24 only, reserved on the other timers)																CCR2[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x3C	**TIMx_CCR3**	CCR3[31:16] (TIM2, TIM5, TIM23 and TIM24 only, reserved on the other timers)																CCR3[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x40	**TIMx_CCR4**	CCR4[31:16] (TIM2, TIM5, TIM23 and TIM24 only, reserved on the other timers)																CCR4[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x44	Reserved																																
0x48	**TIMx_DCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBL[4:0]			Res.	Res.	Res.	DBA[4:0]						
	Reset value																				0	0	0	0	0				0	0	0	0	0
0x4C	**TIMx_DMAR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DMAB[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x60	**TIM2_AF1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL [3:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value															0	0	0	0														
0x60	**TIM3_AF1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL [3:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value															0	0	0	0														

Table 357. TIM2/TIM3/TIM4/TIM5/TIM23/TIM24 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x60	**TIM4_AF1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL [3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value															0	0	0	0														
0x60	**TIM5_AF1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL [3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value															0	0	0	0														
0x60	**TIM23_AF1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL [3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value															0	0	0	0														
0x60	**TIM24_AF1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ETRSEL [3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value															0	0	0	0														
0x68	**TIM2_TISEL**	Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]				Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value					0	0	0	0					0	0	0	0					0	0	0	0					0	0	0	0
0x68	**TIM3_TISEL**	Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]				Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value					0	0	0	0					0	0	0	0					0	0	0	0					0	0	0	0
0x68	**TIM4_TISEL**	Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]				Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value					0	0	0	0					0	0	0	0					0	0	0	0					0	0	0	0
0x68	**TIM5_TISEL**	Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]				Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value					0	0	0	0					0	0	0	0					0	0	0	0					0	0	0	0
0x68	**TIM23_TISEL**	Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]				Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value					0	0	0	0					0	0	0	0					0	0	0	0					0	0	0	0
0x68	**TIM24_TISEL**	Res.	Res.	Res.	Res.	TI4SEL[3:0]				Res.	Res.	Res.	Res.	TI3SEL[3:0]				Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value					0	0	0	0					0	0	0	0					0	0	0	0					0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

45 General-purpose timers (TIM12/TIM13/TIM14)

45.1 TIM12/TIM13/TIM14 introduction

The TIM12/TIM13/TIM14 general-purpose timers consist in a 16-bit auto-reload counter driven by a programmable prescaler.

They may be used for a variety of purposes, including measuring the pulse lengths of input signals (input capture) or generating output waveforms (output compare, PWM).

Pulse lengths and waveform periods can be modulated from a few microseconds to several milliseconds using the timer prescaler and the RCC clock controller prescalers.

The TIM12/TIM13/TIM14 timers are completely independent, and do not share any resources. They can be synchronized together as described in *Section 45.3.17: Timer synchronization (TIM12)*.

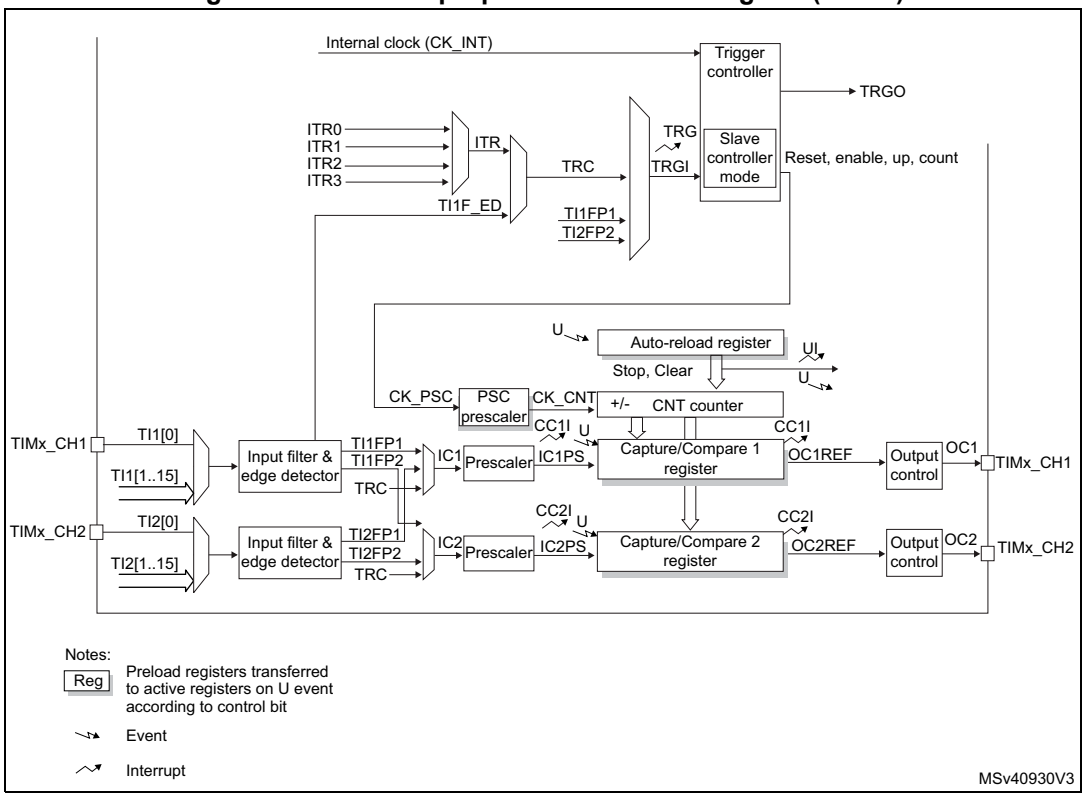
45.2 TIM12/TIM13/TIM14 main features

45.2.1 TIM12 main features

The features of the TIM12 general-purpose timer include:

- 16-bit auto-reload upcounter
- 16-bit programmable prescaler used to divide the counter clock frequency by any factor between 1 and 65536 (can be changed “on the fly”)
- Up to 2 independent channels for:
  - Input capture
  - Output compare
  - PWM generation (edge-aligned mode)
  - One-pulse mode output
- Synchronization circuit to control the timer with external signals and to interconnect several timers together
- Interrupt generation on the following events:
  - Update: counter overflow, counter initialization (by software or internal trigger)
  - Trigger event (counter start, stop, initialization or count by internal trigger)
  - Input capture
  - Output compare

Figure 483. General-purpose timer block diagram (TIM12)

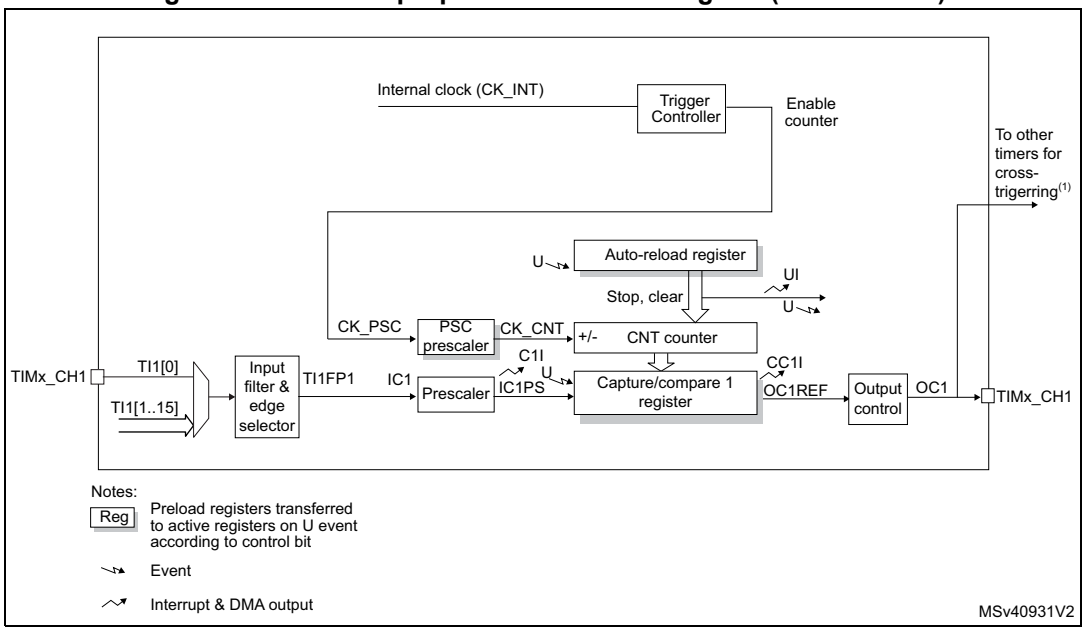


45.2.2 TIM13/TIM14 main features

The features of general-purpose timers TIM13/TIM14 include:

- 16-bit auto-reload upcounter
- 16-bit programmable prescaler used to divide the counter clock frequency by any factor between 1 and 65536 (can be changed “on the fly”)
- independent channel for:
  - Input capture
  - Output compare
  - PWM generation (edge-aligned mode)
  - One-pulse mode output
- Interrupt generation on the following events:
  - Update: counter overflow, counter initialization (by software)
  - Input capture
  - Output compare

Figure 484. General-purpose timer block diagram (TIM13/TIM14)



1. This signal can be used as trigger for some slave timers, see *Section 45.3.18: Using timer output as trigger for other timers (TIM13/TIM14)*.

45.3 TIM12/TIM13/TIM14 functional description

45.3.1 Time-base unit

The main block of the timer is a 16-bit up-counter with its related auto-reload register. The counter clock can be divided by a prescaler.

The counter, the auto-reload register and the prescaler register can be written or read by software. This is true even when the counter is running.

The time-base unit includes:

- Counter register (TIMx_CNT)
- Prescaler register (TIMx_PSC)
- Auto-reload register (TIMx_ARR)

The auto-reload register is preloaded. Writing to or reading from the auto-reload register accesses the preload register. The content of the preload register are transferred into the shadow register permanently or at each update event (UEV), depending on the auto-reload preload enable bit (ARPE) in TIMx_CR1 register. The update event is sent when the counter reaches the overflow and if the UDIS bit equals 0 in the TIMx_CR1 register. It can also be generated by software. The generation of the update event is described in details for each configuration.

The counter is clocked by the prescaler output CK_CNT, which is enabled only when the counter enable bit (CEN) in TIMx_CR1 register is set (refer also to the slave mode controller description to get more details on counter enabling).

Note that the counter starts counting 1 clock cycle after setting the CEN bit in the TIMx_CR1 register.

Prescaler description

The prescaler can divide the counter clock frequency by any factor between 1 and 65536. It is based on a 16-bit counter controlled through a 16-bit register (in the TIMx_PSC register). It can be changed on the fly as this control register is buffered. The new prescaler ratio is taken into account at the next update event.

Figure 485 and *Figure 486* give some examples of the counter behavior when the prescaler ratio is changed on the fly.

Figure 485. Counter timing diagram with prescaler division change from 1 to 2

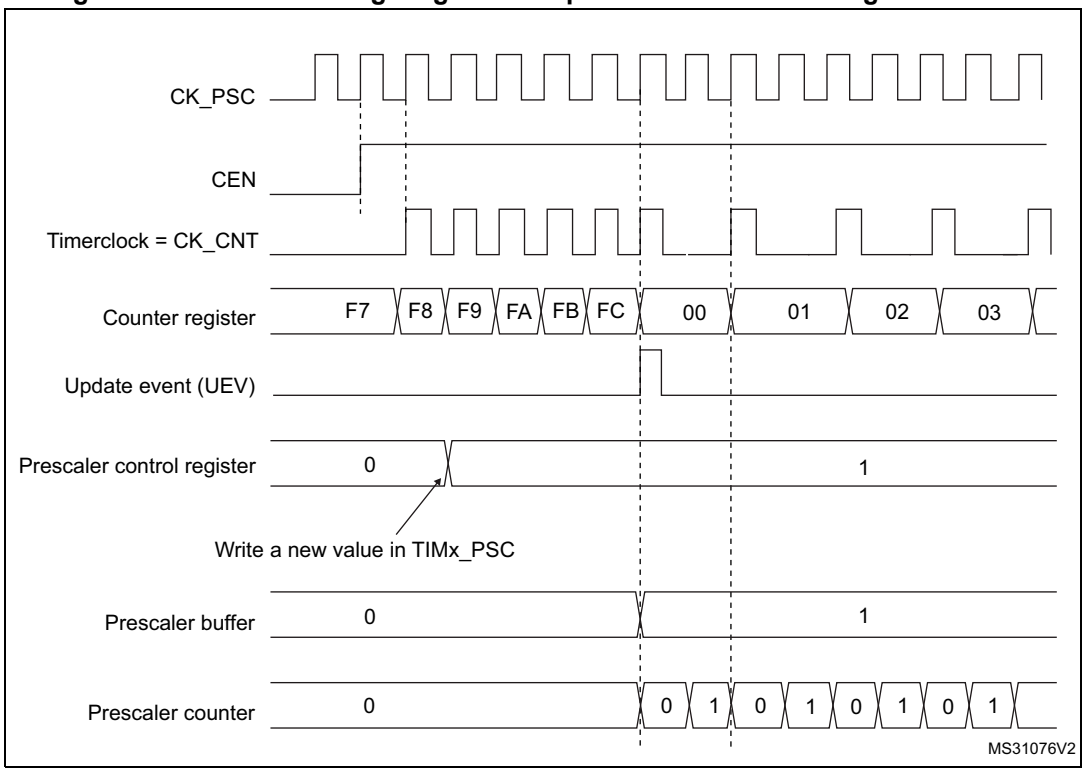
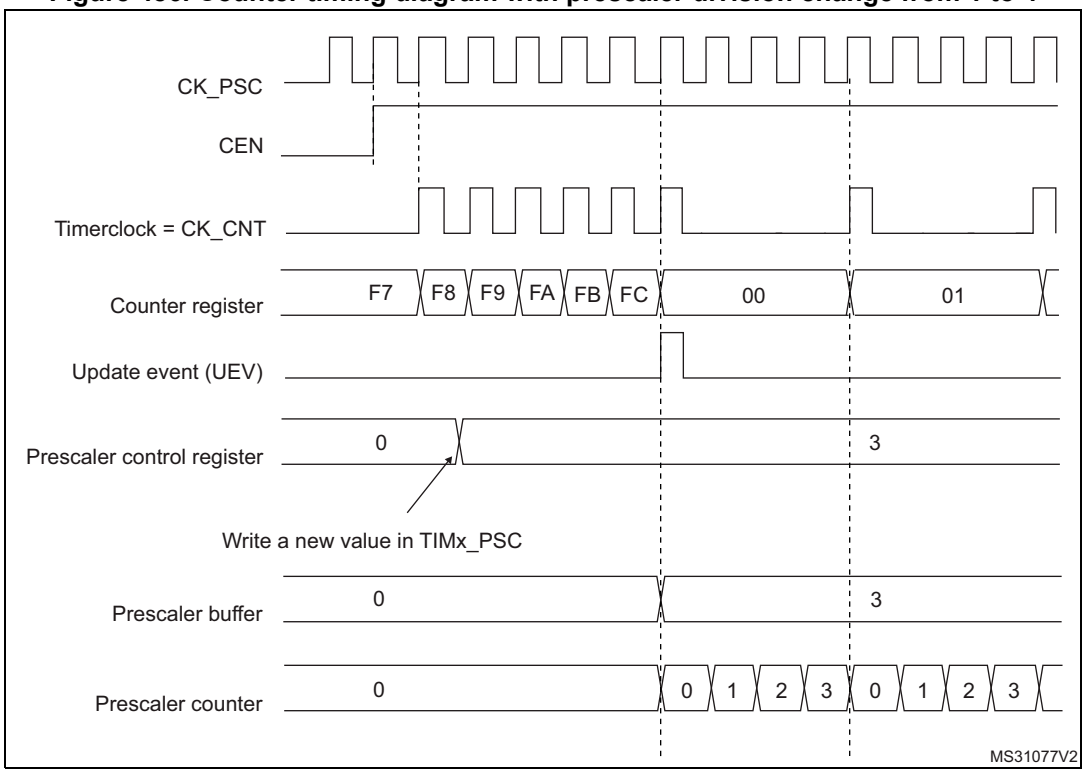


Figure 486. Counter timing diagram with prescaler division change from 1 to 4



45.3.2 Counter modes

Upcounting mode

In upcounting mode, the counter counts from 0 to the auto-reload value (content of the TIMx_ARR register), then restarts from 0 and generates a counter overflow event.

Setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller on TIM12) also generates an update event.

The UEV event can be disabled by software by setting the UDIS bit in the TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter restarts from 0, as well as the counter of the prescaler (but the prescale rate does not change). In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The auto-reload shadow register is updated with the preload value (TIMx_ARR),
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register).

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR=0x36.

Figure 487. Counter timing diagram, internal clock divided by 1

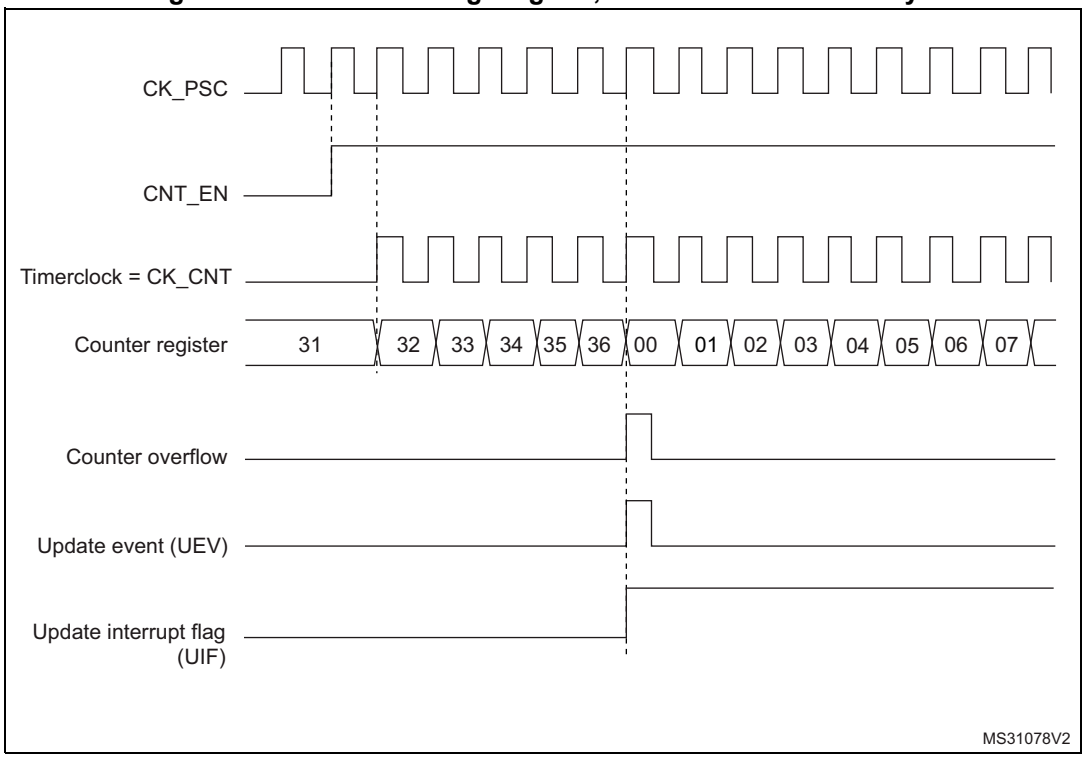


Figure 488. Counter timing diagram, internal clock divided by 2

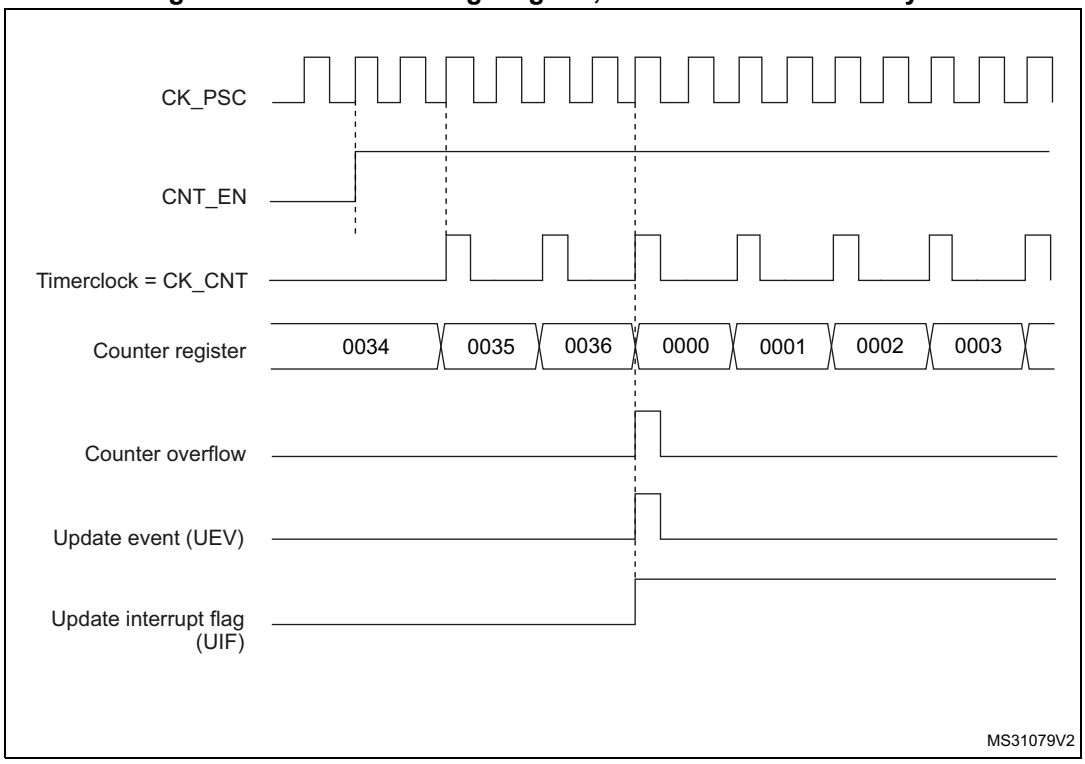


Figure 489. Counter timing diagram, internal clock divided by 4

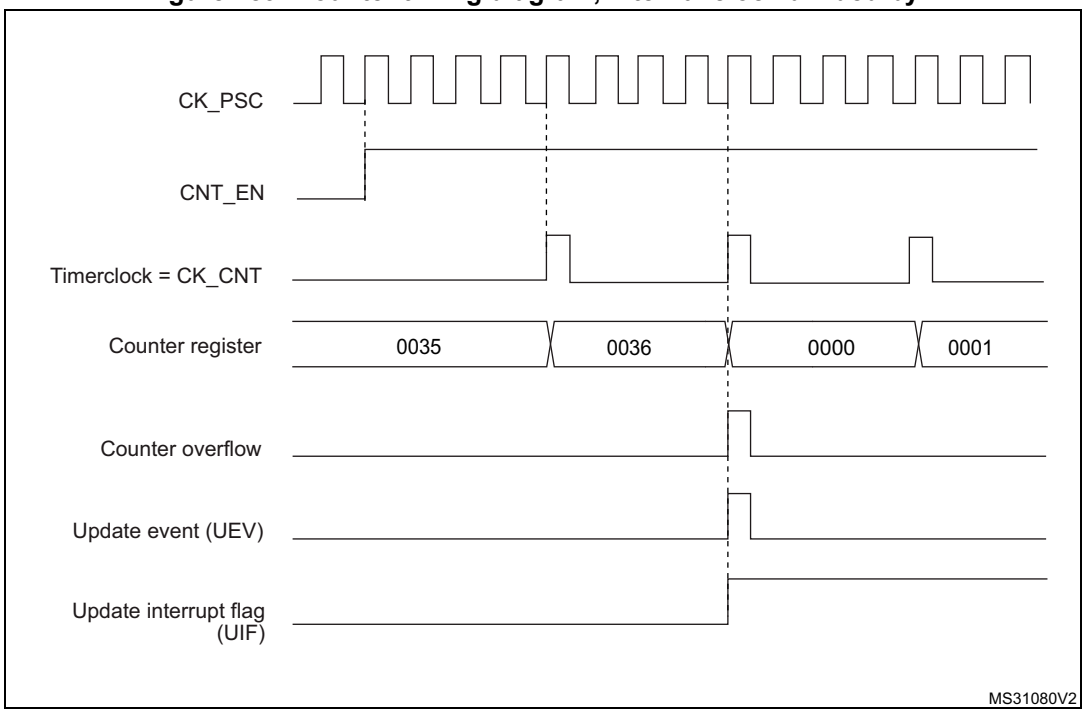


Figure 490. Counter timing diagram, internal clock divided by N

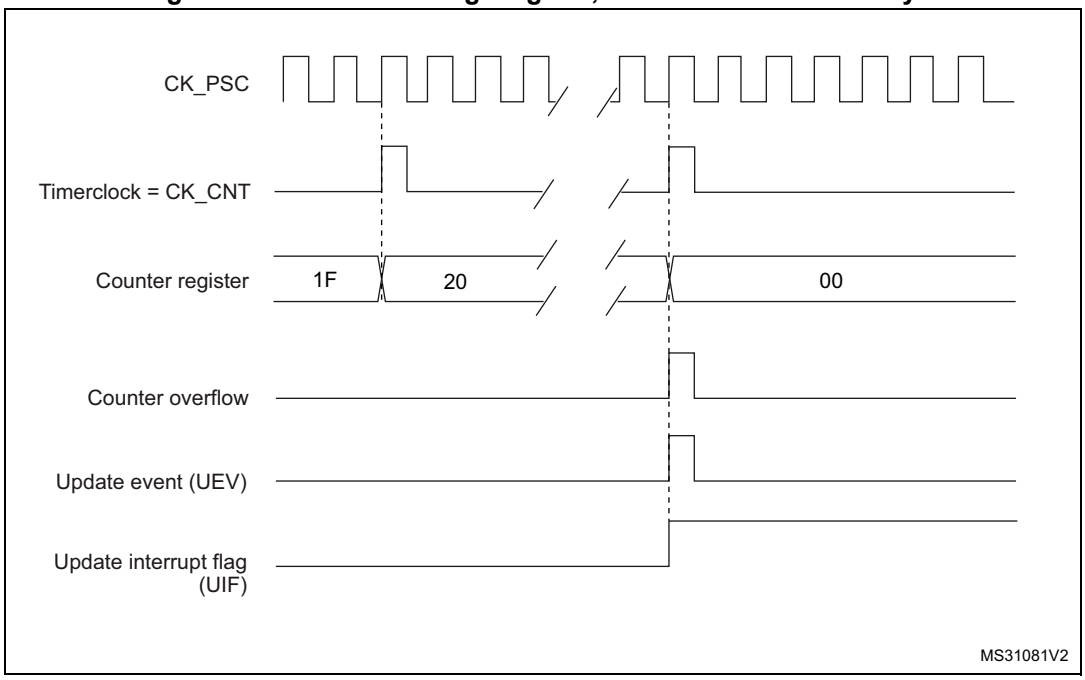


Figure 491. Counter timing diagram, update event when ARPE=0 (TIMx_ARR not preloaded)

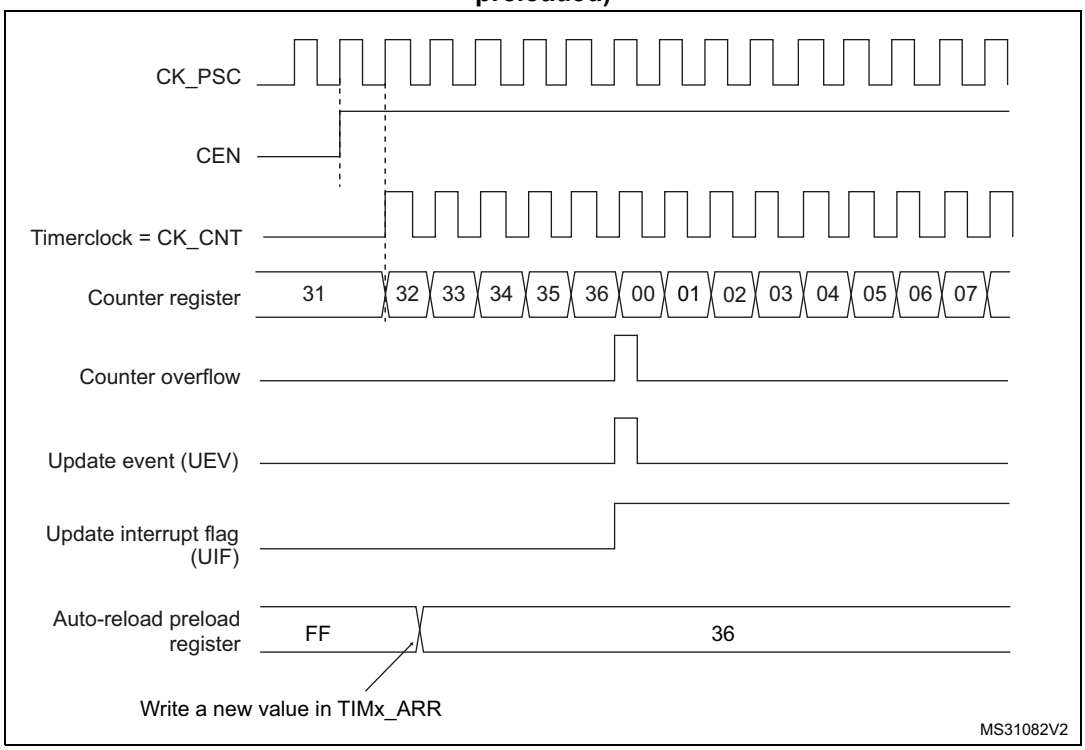
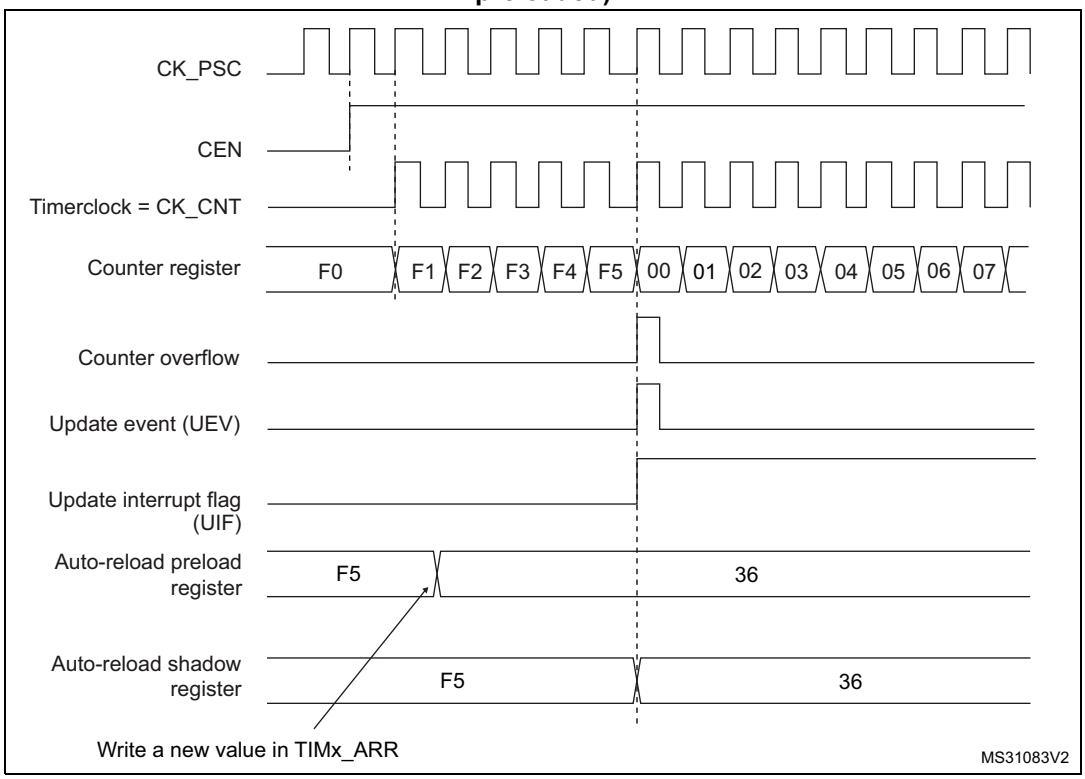


Figure 492. Counter timing diagram, update event when ARPE=1 (TIMx_ARR preloaded)



45.3.3 Clock selection

The counter clock can be provided by the following clock sources:

- Internal clock (CK_INT)
- External clock mode1 (for TIM12): external input pin (TIx)
- Internal trigger inputs (ITRx) (for TIM12): connecting the trigger output from another timer. For instance, another timer can be configured as a prescaler for TIM12. Refer to *Section : Using one timer as prescaler for another timer* for more details.

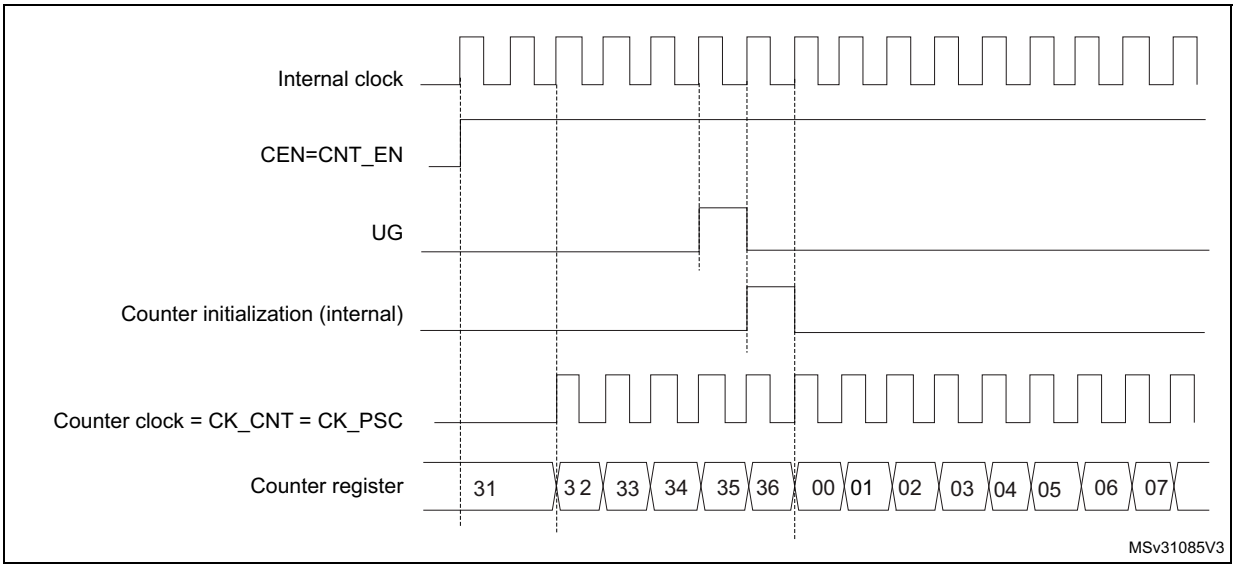
Internal clock source (CK_INT)

The internal clock source is the default clock source for TIM13/TIM14.

For TIM12, the internal clock source is selected when the slave mode controller is disabled (SMS='000'). The CEN bit in the TIMx_CR1 register and the UG bit in the TIMx_EGR register are then used as control bits and can be changed only by software (except for UG which remains cleared). As soon as the CEN bit is programmed to 1, the prescaler is clocked by the internal clock CK_INT.

Figure 493 shows the behavior of the control circuit and the upcounter in normal mode, without prescaler.

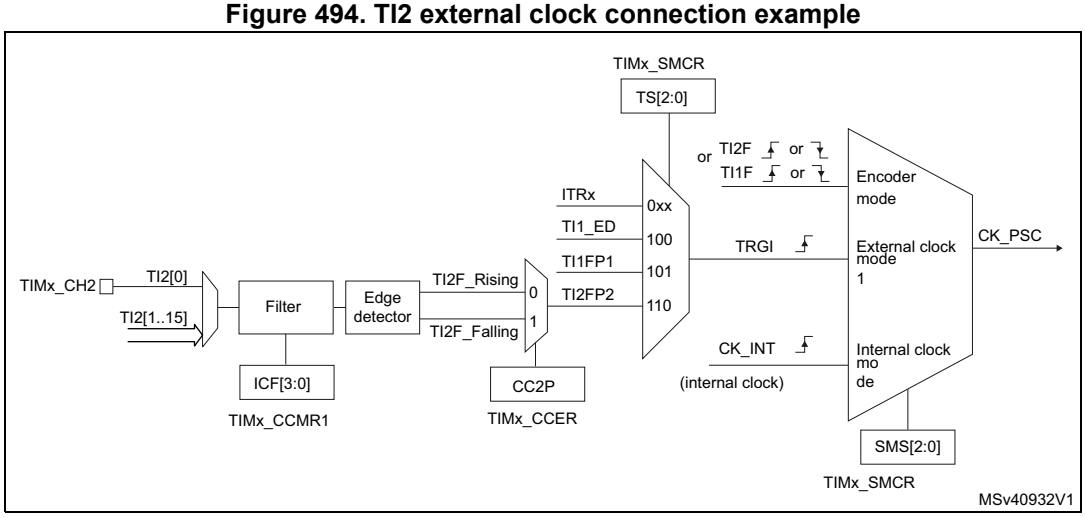
Figure 493. Control circuit in normal mode, internal clock divided by 1



External clock source mode 1 (TIM12)

This mode is selected when SMS='111' in the TIMx_SMCR register. The counter can count at each rising or falling edge on a selected input.

Figure 494. TI2 external clock connection example



For example, to configure the upcounter to count in response to a rising edge on the TI2 input, use the following procedure:

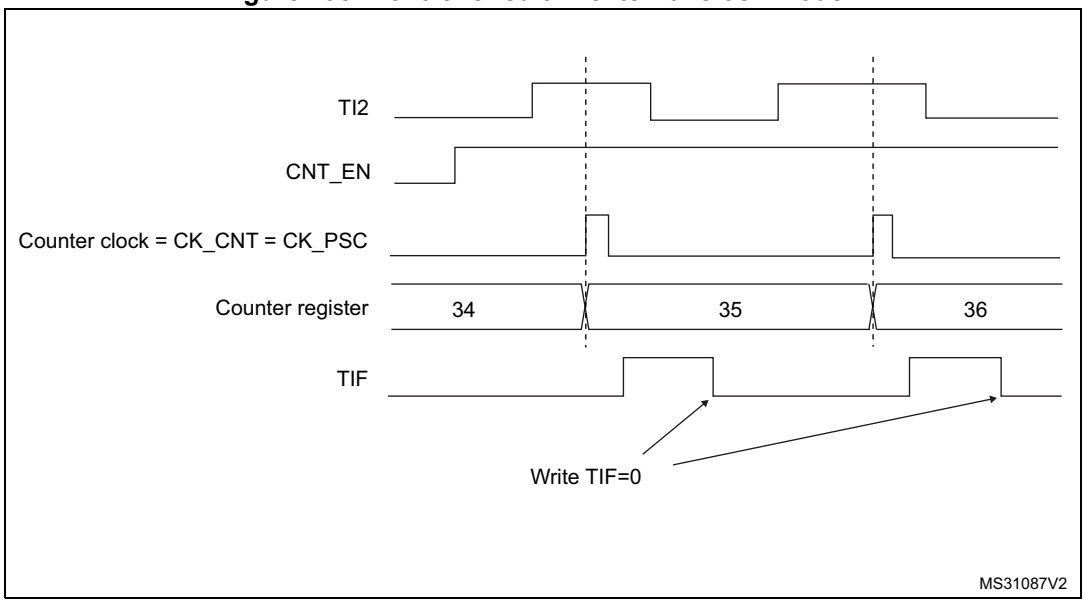
1. Select the proper TI2[x] source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Configure channel 2 to detect rising edges on the TI2 input by writing CC2S = ‘01’ in the TIMx_CCMR1 register.
3. Configure the input filter duration by writing the IC2F[3:0] bits in the TIMx_CCMR1 register (if no filter is needed, keep IC2F=’0000’).
4. Select the rising edge polarity by writing CC2P=’0’ and CC2NP=’0’ in the TIMx_CCER register.
5. Configure the timer in external clock mode 1 by writing SMS=’111’ in the TIMx_SMCR register.
6. Select TI2 as the trigger input source by writing TS=’110’ in the TIMx_SMCR register.
7. Enable the counter by writing CEN=’1’ in the TIMx_CR1 register.

Note: The capture prescaler is not used for triggering, so it does not need to be configured.

When a rising edge occurs on TI2, the counter counts once and the TIF flag is set.

The delay between the rising edge on TI2 and the actual clock of the counter is due to the resynchronization circuit on TI2 input.

Figure 495. Control circuit in external clock mode 1



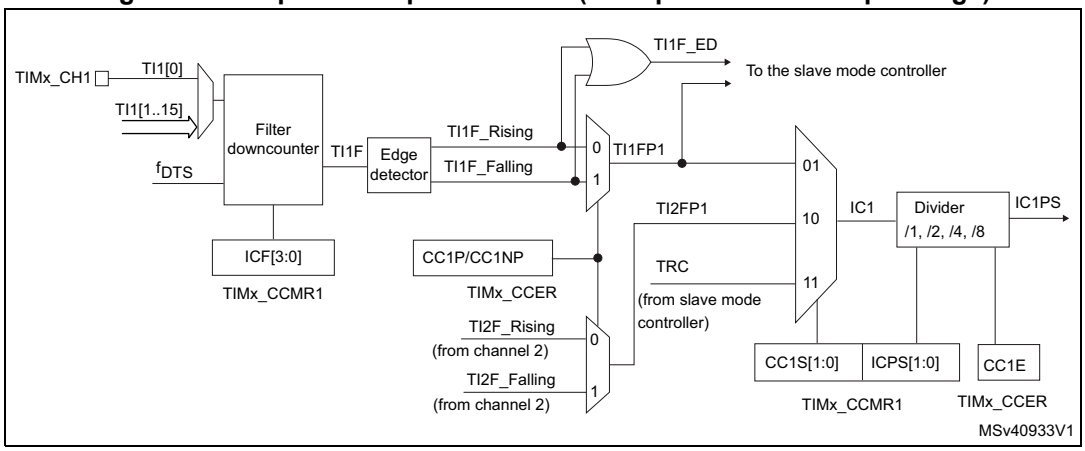
45.3.4 Capture/compare channels

Each Capture/Compare channel is built around a capture/compare register (including a shadow register), a input stage for capture (with digital filter, multiplexing and prescaler) and an output stage (with comparator and output control).

Figure 496 to *Figure 498* give an overview of one capture/compare channel.

The input stage samples the corresponding TIx input to generate a filtered signal TIxF. Then, an edge detector with polarity selection generates a signal (TIxFPx) which can be used as trigger input by the slave mode controller or as the capture command. It is prescaled before the capture register (ICxPS).

Figure 496. Capture/compare channel (example: channel 1 input stage)



The output stage generates an intermediate waveform which is then used for reference: OCxRef (active high). The polarity acts at the end of the chain.

Figure 497. Capture/compare channel 1 main circuit

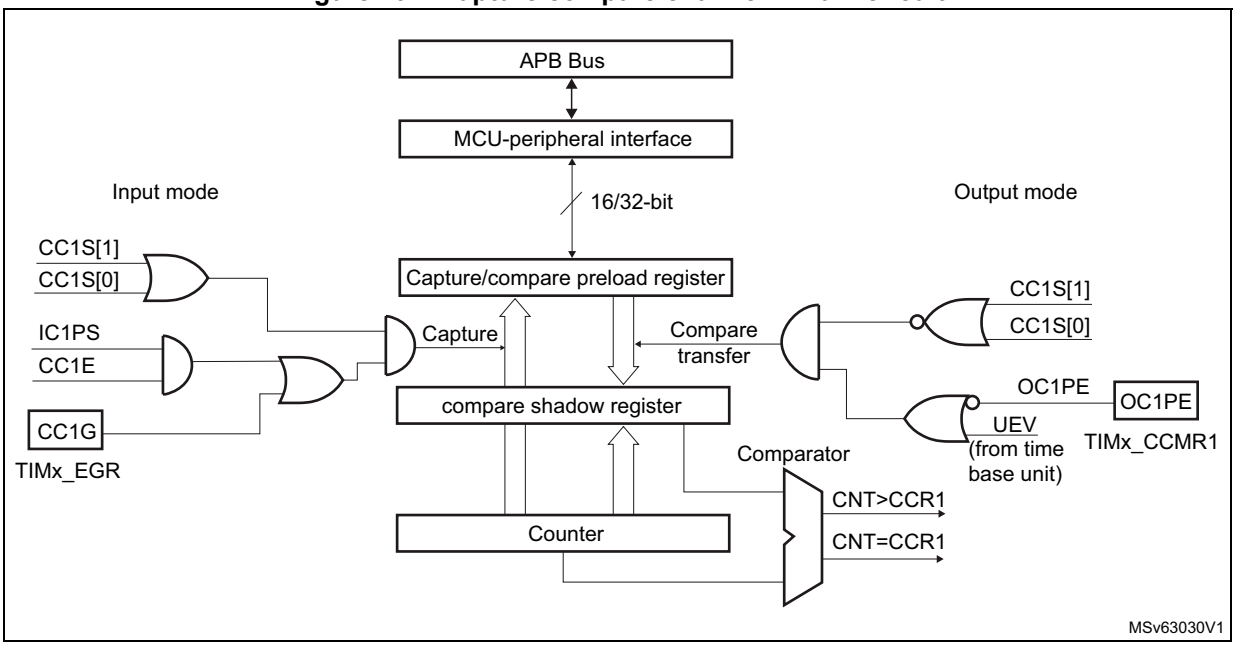
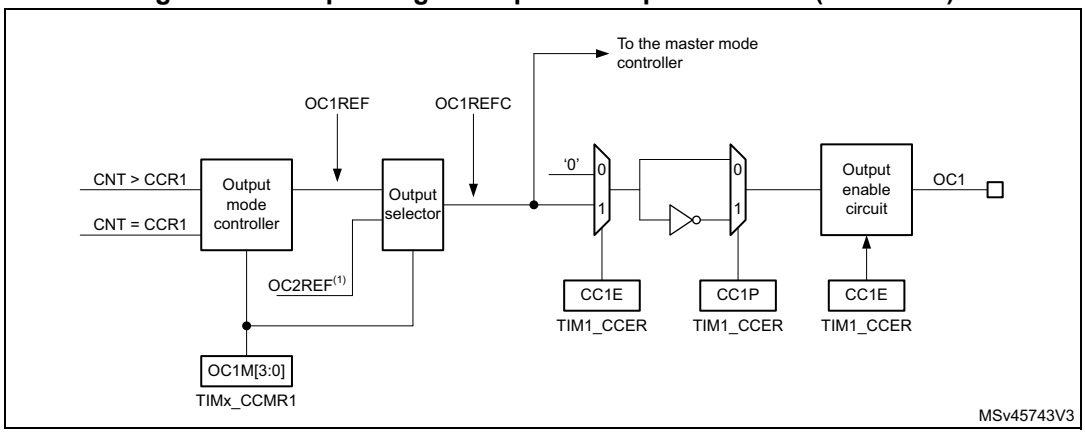


Figure 498. Output stage of capture/compare channel (channel 1)



1. Available on TIM12 only.

The capture/compare block is made of one preload register and one shadow register. Write and read always access the preload register.

In capture mode, captures are actually done in the shadow register, which is copied into the preload register.

In compare mode, the content of the preload register is copied into the shadow register which is compared to the counter.

45.3.5 Input capture mode

In Input capture mode, the Capture/Compare Registers (TIMx_CCRx) are used to latch the value of the counter after a transition detected by the corresponding ICx signal. When a capture occurs, the corresponding CCXIF flag (TIMx_SR register) is set and an interrupt or a DMA request can be sent if they are enabled. If a capture occurs while the CCxIF flag was already high, then the over-capture flag CCxOF (TIMx_SR register) is set. CCxIF can be cleared by software by writing it to '0' or by reading the captured data stored in the TIMx_CCRx register. CCxOF is cleared when it is written with 0.

The following example shows how to capture the counter value in TIMx_CCR1 when TI1 input rises. To do this, use the following procedure:

1. Select the proper TI1[x] source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input: TIMx_CCR1 must be linked to the TI1 input, so write the CC1S bits to '01' in the TIMx_CCMR1 register. As soon as CC1S becomes different from '00', the channel is configured in input mode and the TIMx_CCR1 register becomes read-only.
3. Program the appropriate input filter duration in relation with the signal connected to the timer (by programming the ICxF bits in the TIMx_CCMRx register if the input is one of the TIx inputs). Let's imagine that, when toggling, the input signal is not stable during at must 5 internal clock cycles. We must program a filter duration longer than these 5 clock cycles. We can validate a transition on TI1 when 8 consecutive samples with the

new level have been detected (sampled at f_{DTS} frequency). Then write IC1F bits to '0011' in the TIMx_CCMR1 register.

4. Select the edge of the active transition on the TI1 channel by programming CC1P and CC1NP bits to '00' in the TIMx_CCER register (rising edge in this case).
5. Program the input prescaler. In our example, we wish the capture to be performed at each valid transition, so the prescaler is disabled (write IC1PS bits to '00' in the TIMx_CCMR1 register).
6. Enable capture from the counter into the capture register by setting the CC1E bit in the TIMx_CCER register.
7. If needed, enable the related interrupt request by setting the CC1IE bit in the TIMx_DIER register.

When an input capture occurs:

- The TIMx_CCR1 register gets the value of the counter on the active transition.
- CC1IF flag is set (interrupt flag). CC1OF is also set if at least two consecutive captures occurred whereas the flag was not cleared.
- An interrupt is generated depending on the CC1IE bit.

In order to handle the overcapture, it is recommended to read the data before the overcapture flag. This is to avoid missing an overcapture which could happen after reading the flag and before reading the data.

Note: IC interrupt requests can be generated by software by setting the corresponding CCxG bit in the TIMx_EGR register.

45.3.6 PWM input mode (only for TIM12)

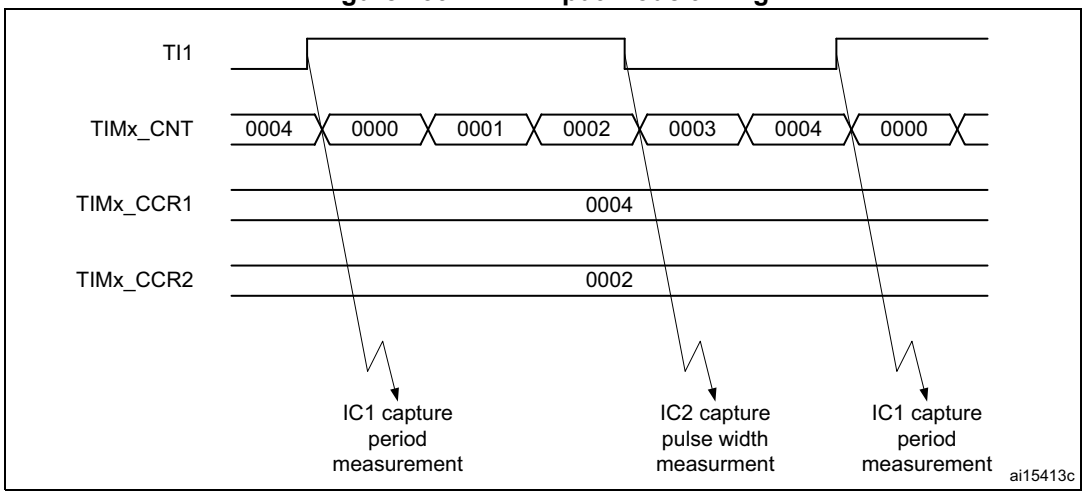
This mode is a particular case of input capture mode. The procedure is the same except:

- Two ICx signals are mapped on the same TIx input.
- These 2 ICx signals are active on edges with opposite polarity.
- One of the two TIxFP signals is selected as trigger input and the slave mode controller is configured in reset mode.

For example, one can measure the period (in TIMx_CCR1 register) and the duty cycle (in TIMx_CCR2 register) of the PWM applied on TI1 using the following procedure (depending on CK_INT frequency and prescaler value):

1. Select the proper TI1[x] source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input for TIMx_CCR1: write the CC1S bits to ‘01’ in the TIMx_CCMR1 register (TI1 selected).
3. Select the active polarity for TI1FP1 (used both for capture in TIMx_CCR1 and counter clear): program the CC1P and CC1NP bits to ‘00’ (active on rising edge).
4. Select the active input for TIMx_CCR2: write the CC2S bits to ‘10’ in the TIMx_CCMR1 register (TI1 selected).
5. Select the active polarity for TI1FP2 (used for capture in TIMx_CCR2): program the CC2P and CC2NP bits to ‘10’ (active on falling edge).
6. Select the valid trigger input: write the TS bits to ‘00101’ in the TIMx_SMCR register (TI1FP1 selected).
7. Configure the slave mode controller in reset mode: write the SMS bits to ‘100’ in the TIMx_SMCR register.
8. Enable the captures: write the CC1E and CC2E bits to ‘1’ in the TIMx_CCER register.

Figure 499. PWM input mode timing



1. The PWM input mode can be used only with the TIMx_CH1/TIMx_CH2 signals due to the fact that only TI1FP1 and TI2FP2 are connected to the slave mode controller.

45.3.7 Forced output mode

In output mode (CCxS bits = ‘00’ in the TIMx_CCMRx register), each output compare signal (OCxREF and then OCx) can be forced to active or inactive level directly by software, independently of any comparison between the output compare register and the counter.

To force an output compare signal (OCXREF/OCx) to its active level, one just needs to write ‘0101’ in the OCxM bits in the corresponding TIMx_CCMRx register. Thus OCXREF is forced high (OCxREF is always active high) and OCx get opposite value to CCxP polarity bit.

For example: CCxP=’0’ (OCx active high) => OCx is forced to high level.

The OCxREF signal can be forced low by writing the OCxM bits to ‘0100’ in the TIMx_CCMRx register.

Anyway, the comparison between the TIMx_CCRx shadow register and the counter is still performed and allows the flag to be set. Interrupt requests can be sent accordingly. This is described in the output compare mode section below.

45.3.8 Output compare mode

This function is used to control an output waveform or indicating when a period of time has elapsed.

When a match is found between the capture/compare register and the counter, the output compare function:

1. Assigns the corresponding output pin to a programmable value defined by the output compare mode (OCxM bits in the TIMx_CCMRx register) and the output polarity (CCxP bit in the TIMx_CCER register). The output pin can keep its level (OCxM=’0000’), be set active (OCxM=’0001’), be set inactive (OCxM=’0010’) or can toggle (OCxM=’0011’) on match.
2. Sets a flag in the interrupt status register (CCxIF bit in the TIMx_SR register).
3. Generates an interrupt if the corresponding interrupt mask is set (CCXIE bit in the TIMx_DIER register).

The TIMx_CCRx registers can be programmed with or without preload registers using the OCxPE bit in the TIMx_CCMRx register.

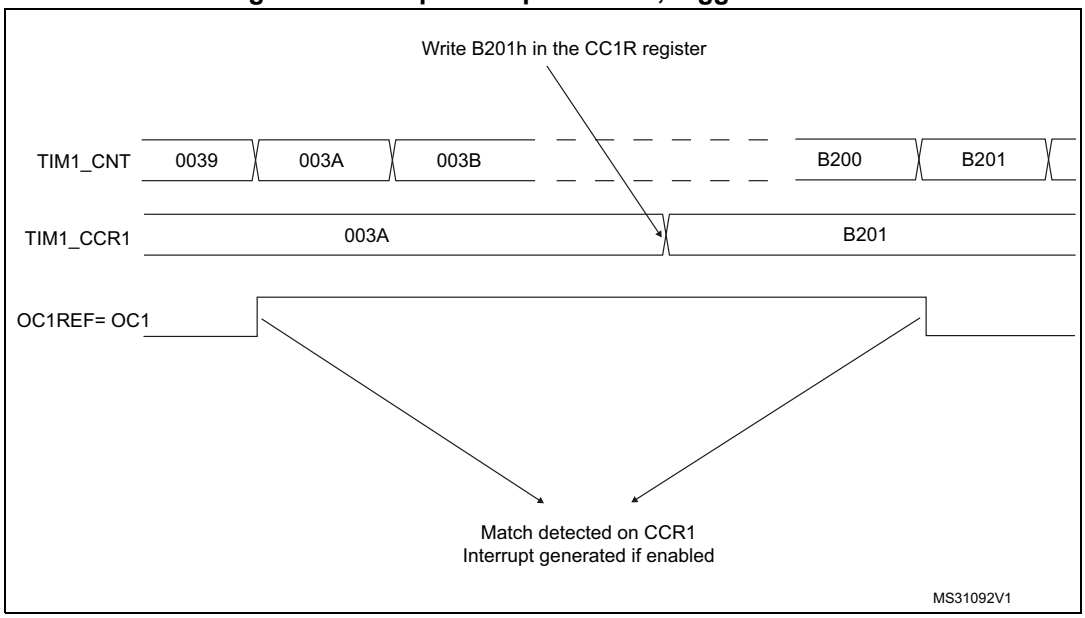
In output compare mode, the update event UEV has no effect on OCxREF and OCx output. The timing resolution is one count of the counter. Output compare mode can also be used to output a single pulse (in One-pulse mode).

Procedure:

1. Select the counter clock (internal, external, prescaler).
2. Write the desired data in the TIMx_ARR and TIMx_CCRx registers.
3. Set the CCxIE bit if an interrupt request is to be generated.
4. Select the output mode. For example:
   – Write OCxM = ‘0011’ to toggle OCx output pin when CNT matches CCRx
   – Write OCxPE = ‘0’ to disable preload register
   – Write CCxP = ‘0’ to select active high polarity
   – Write CCxE = ‘1’ to enable the output
5. Enable the counter by setting the CEN bit in the TIMx_CR1 register.

The TIMx_CCRx register can be updated at any time by software to control the output waveform, provided that the preload register is not enabled (OCxPE=’0’, else TIMx_CCRx shadow register is updated only at the next update event UEV). An example is given in *Figure 500*.

Figure 500. Output compare mode, toggle on OC1.



45.3.9 PWM mode

Pulse Width Modulation mode allows to generate a signal with a frequency determined by the value of the TIMx_ARR register and a duty cycle determined by the value of the TIMx_CCRx register.

The PWM mode can be selected independently on each channel (one PWM per OCx output) by writing ‘0110’ (PWM mode 1) or ‘0111’ (PWM mode 2) in the OCxM bits in the TIMx_CCMRx register. The corresponding preload register must be enabled by setting the OCxPE bit in the TIMx_CCMRx register, and eventually the auto-reload preload register (in upcounting or center-aligned modes) by setting the ARPE bit in the TIMx_CR1 register.

As the preload registers are transferred to the shadow registers only when an update event occurs, before starting the counter, all registers must be initialized by setting the UG bit in the TIMx_EGR register.

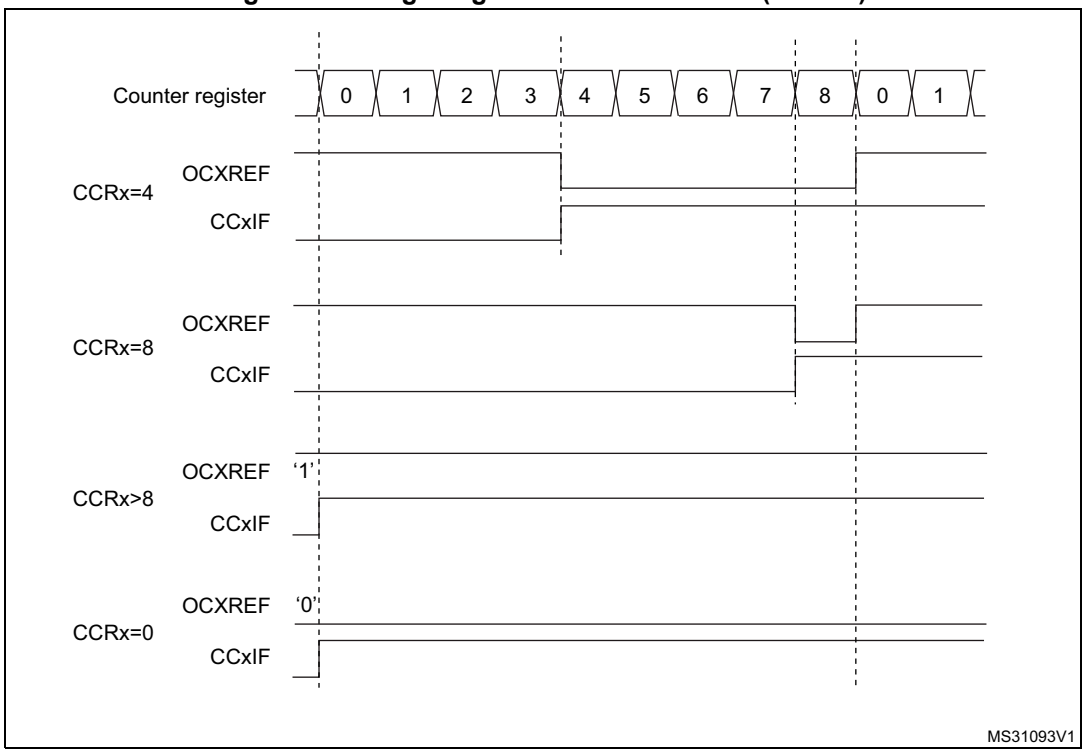
The OCx polarity is software programmable using the CCxP bit in the TIMx_CCER register. It can be programmed as active high or active low. The OCx output is enabled by the CCxE bit in the TIMx_CCER register. Refer to the TIMx_CCERx register description for more details.

In PWM mode (1 or 2), TIMx_CNT and TIMx_CCRx are always compared to determine whether TIMx_CNT ≤ TIMx_CCRx.

The timer is able to generate PWM in edge-aligned mode only since the counter is upcounting.

In the following example, we consider PWM mode 1. The reference PWM signal OCxREF is high as long as TIMx_CNT < TIMx_CCRx else it becomes low. If the compare value in TIMx_CCRx is greater than the auto-reload value (in TIMx_ARR) then OCxREF is held at ‘1’. If the compare value is 0 then OCxRef is held at ‘0’. *Figure 501* shows some edge-aligned PWM waveforms in an example where TIMx_ARR=8.

Figure 501. Edge-aligned PWM waveforms (ARR=8)



45.3.10 Combined PWM mode (TIM12 only)

Combined PWM mode allows two edge or center-aligned PWM signals to be generated with programmable delay and phase shift between respective pulses. While the frequency is determined by the value of the TIMx_ARR register, the duty cycle and delay are determined by the two TIMx_CCRx registers. The resulting signals, OCxREFC, are made of an OR or AND logical combination of two reference PWMs:

- OC1REFC (or OC2REFC) is controlled by the TIMx_CCR1 and TIMx_CCR2 registers

Combined PWM mode can be selected independently on two channels (one OCx output per pair of CCR registers) by writing '1100' (Combined PWM mode 1) or '1101' (Combined PWM mode 2) in the OCxM bits in the TIMx_CCMRx register.

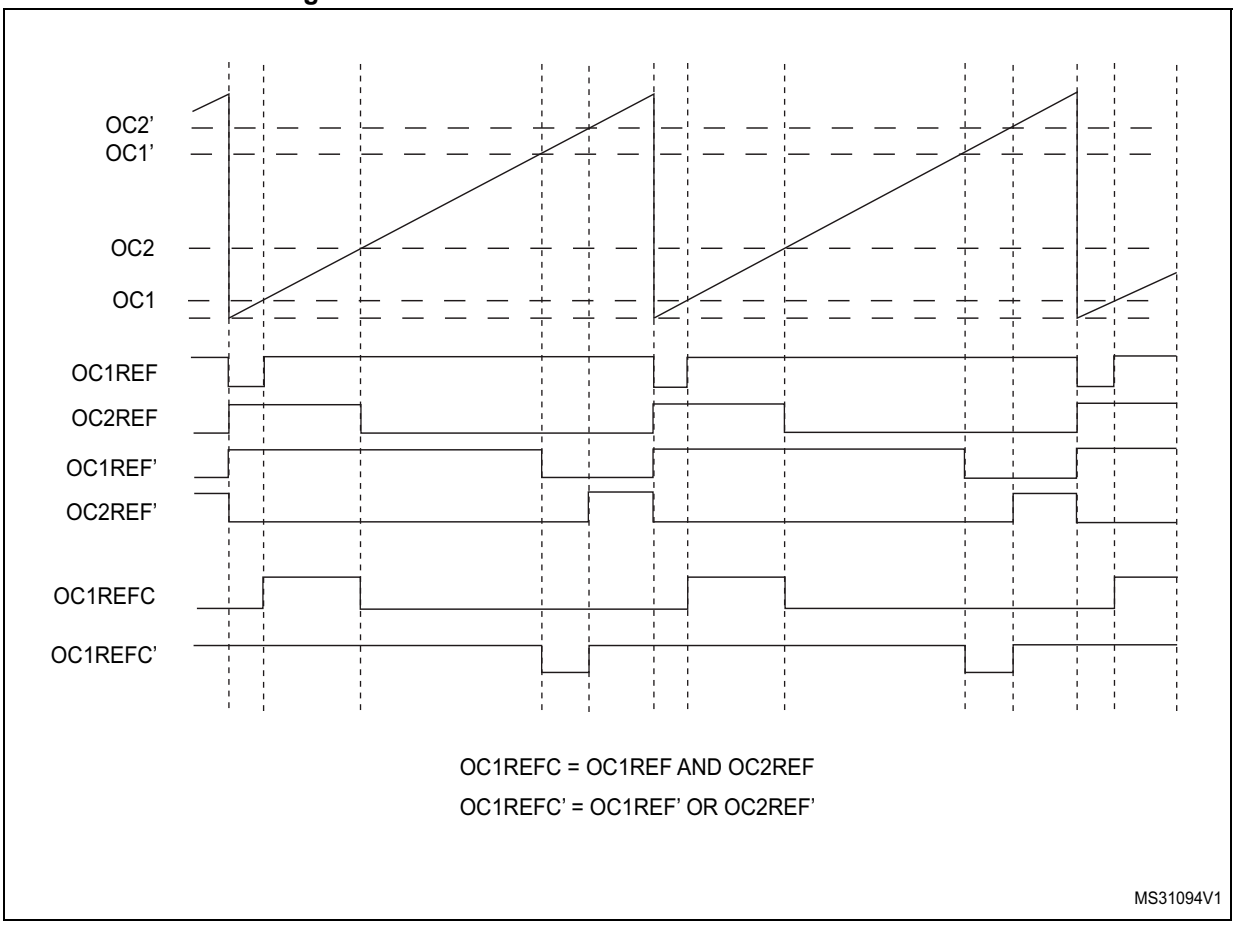
When a given channel is used as a combined PWM channel, its complementary channel must be configured in the opposite PWM mode (for instance, one in Combined PWM mode 1 and the other in Combined PWM mode 2).

Note: The OCxM[3:0] bit field is split into two parts for compatibility reasons, the most significant bit is not contiguous with the 3 least significant ones.

Figure 502 represents an example of signals that can be generated using combined PWM mode, obtained with the following configuration:

- Channel 1 is configured in Combined PWM mode 2,
- Channel 2 is configured in PWM mode 1,

Figure 502. Combined PWM mode on channel 1 and 2



45.3.11 One-pulse mode

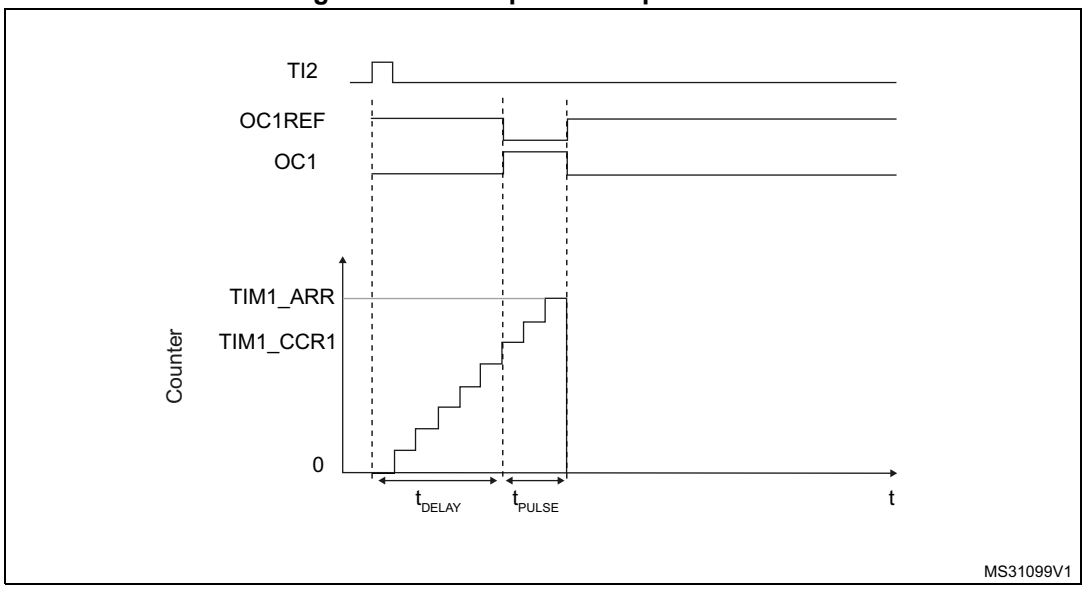
One-pulse mode (OPM) is a particular case of the previous modes. It allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length after a programmable delay.

Starting the counter can be controlled through the slave mode controller. Generating the waveform can be done in output compare mode or PWM mode. One-pulse mode is selected by setting the OPM bit in the TIMx_CR1 register. This makes the counter stop automatically at the next update event UEV.

A pulse can be correctly generated only if the compare value is different from the counter initial value. Before starting (when the timer is waiting for the trigger), the configuration must be as follows:

CNT < CCRx ≤ ARR (in particular, 0 < CCRx)

Figure 503. Example of one pulse mode.



For example one may want to generate a positive pulse on OC1 with a length of t_{PULSE} and after a delay of t_{DELAY} as soon as a positive edge is detected on the TI2 input pin.

Use TI2FP2 as trigger 1:

1. Select the proper TI2[x] source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Map TI2FP2 to TI2 by writing CC2S='01' in the TIMx_CCMR1 register.
3. TI2FP2 must detect a rising edge, write CC2P='0' and CC2NP='0' in the TIMx_CCER register.
4. Configure TI2FP2 as trigger for the slave mode controller (TRGI) by writing TS='00110' in the TIMx_SMCR register.
5. TI2FP2 is used to start the counter by writing SMS to '110' in the TIMx_SMCR register (trigger mode).

The OPM waveform is defined by writing the compare registers (taking into account the clock frequency and the counter prescaler).

- The t_{DELAY} is defined by the value written in the TIMx_CCR1 register.
- The t_{PULSE} is defined by the difference between the auto-reload value and the compare value (TIMx_ARR - TIMx_CCR1).
- Let's say one want to build a waveform with a transition from '0' to '1' when a compare match occurs and a transition from '1' to '0' when the counter reaches the auto-reload value. To do this PWM mode 2 must be enabled by writing OC1M='0111' in the TIMx_CCMR1 register. Optionally the preload registers can be enabled by writing OC1PE='1' in the TIMx_CCMR1 register and ARPE in the TIMx_CR1 register. In this case one has to write the compare value in the TIMx_CCR1 register, the auto-reload value in the TIMx_ARR register, generate an update by setting the UG bit and wait for external trigger event on TI2. CC1P is written to '0' in this example.

Since only 1 pulse (Single mode) is needed, a 1 must be written in the OPM bit in the TIMx_CR1 register to stop the counter at the next update event (when the counter rolls over from the auto-reload value back to 0). When OPM bit in the TIMx_CR1 register is set to '0', so the Repetitive Mode is selected.

Particular case: OCx fast enable

In One-pulse mode, the edge detection on TIx input set the CEN bit which enables the counter. Then the comparison between the counter and the compare value makes the output toggle. But several clock cycles are needed for these operations and it limits the minimum delay t_{DELAY} min we can get.

If one wants to output a waveform with the minimum delay, the OCxFE bit can be set in the TIMx_CCMRx register. Then OCxRef (and OCx) are forced in response to the stimulus, without taking in account the comparison. Its new level is the same as if a compare match had occurred. OCxFE acts only if the channel is configured in PWM1 or PWM2 mode.

45.3.12 Retriggerable one pulse mode (TIM12 only)

This mode allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length, but with the following differences with non-retriggerable one pulse mode described in *Section 45.3.11: One-pulse mode*:

- The pulse starts as soon as the trigger occurs (no programmable delay)
- The pulse is extended if a new trigger occurs before the previous one is completed

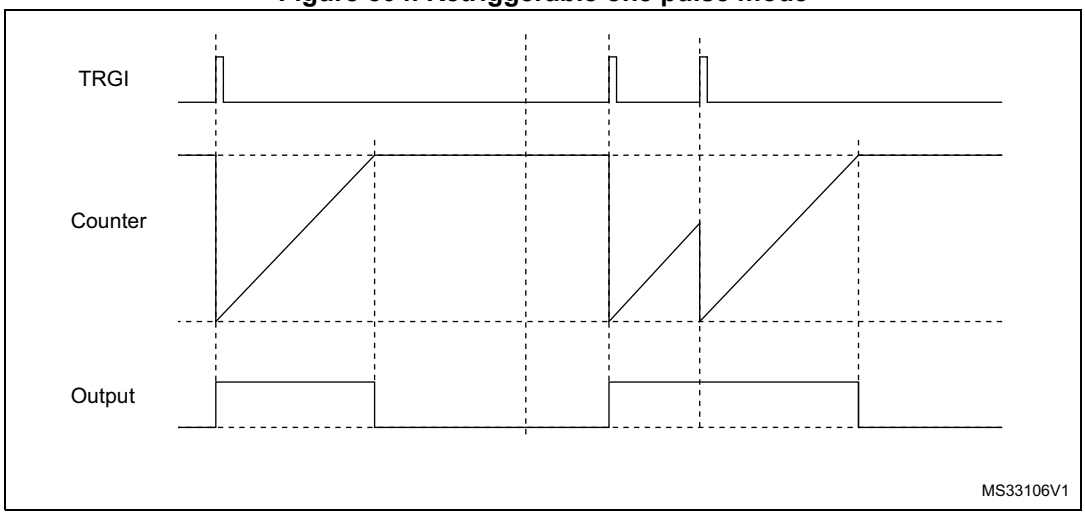
The timer must be in Slave mode, with the bits SMS[3:0] = ‘1000’ (Combined Reset + trigger mode) in the TIMx_SMCR register, and the OCxM[3:0] bits set to ‘1000’ or ‘1001’ for retrigerrable OPM mode 1 or 2.

If the timer is configured in up-counting mode, the corresponding CCRx must be set to 0 (the ARR register sets the pulse length). If the timer is configured in down-counting mode, CCRx must be above or equal to ARR.

Note: The OCxM[3:0] and SMS[3:0] bit fields are split into two parts for compatibility reasons, the most significant bit are not contiguous with the 3 least significant ones.

This mode must not be used with center-aligned PWM modes. It is mandatory to have CMS[1:0] = 00 in TIMx_CR1.

Figure 504. Retriggerable one pulse mode



45.3.13 UIF bit remapping

The IUFREMAP bit in the TIMx_CR1 register forces a continuous copy of the Update Interrupt Flag UIF into bit 31 of the timer counter register (TIMxCNT[31]). This allows to atomically read both the counter value and a potential roll-over condition signaled by the UIFCPY flag. In particular cases, it can ease the calculations by avoiding race conditions caused for instance by a processing shared between a background task (counter reading) and an interrupt (Update Interrupt).

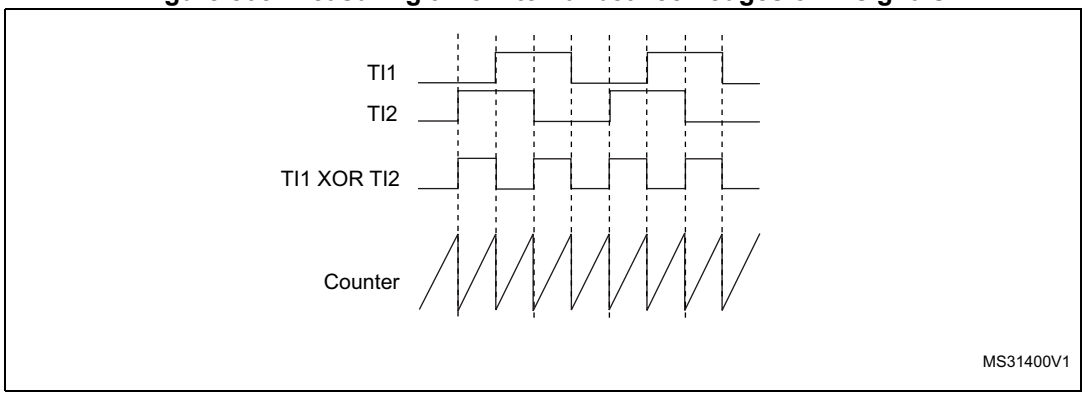
There is no latency between the assertions of the UIF and UIFCPY flags.

45.3.14 Timer input XOR function

The TI1S bit in the TIMx_CR2 register, allows the input filter of channel 1 to be connected to the output of a XOR gate, combining the two input pins TIMx_CH1 and TIMx_CH2.

The XOR output can be used with all the timer input functions such as trigger or input capture. It is useful for measuring the interval between the edges on two input signals, as shown in *Figure 505*.

Figure 505. Measuring time interval between edges on 2 signals



45.3.15 TIM12 external trigger synchronization

The TIM12 timer can be synchronized with an external trigger in several modes: Reset mode, Gated mode and Trigger mode.

Slave mode: Reset mode

The counter and its prescaler can be reinitialized in response to an event on a trigger input. Moreover, if the URS bit from the TIMx_CR1 register is low, an update event UEV is generated. Then all the preloaded registers (TIMx_ARR, TIMx_CCRx) are updated.

In the following example, the upcounter is cleared in response to a rising edge on TI1 input:

1. Configure the channel 1 to detect rising edges on TI1. Configure the input filter duration (in this example, we do not need any filter, so we keep IC1F='0000'). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S = '01' in the TIMx_CCMR1 register.

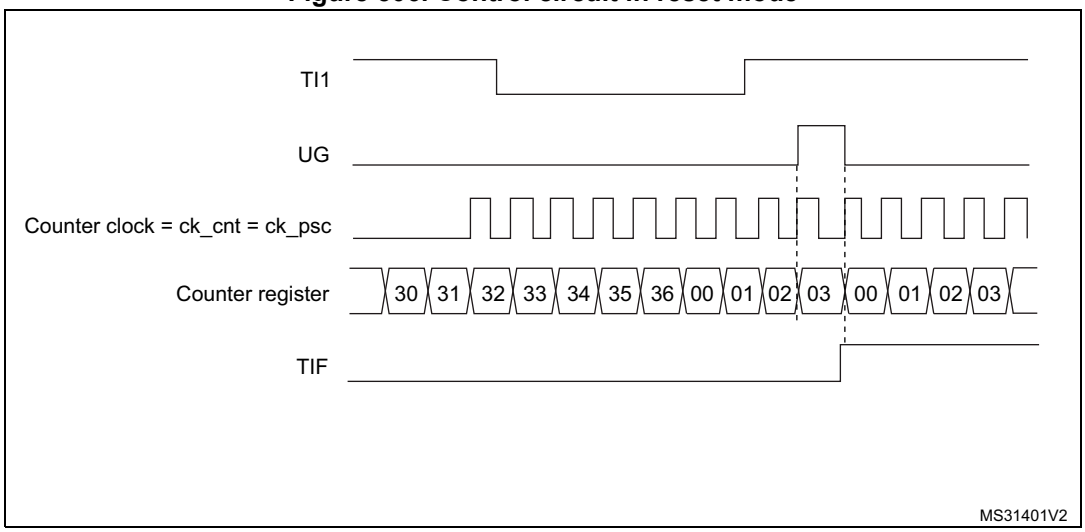
Program CC1P and CC1NP to ‘00’ in TIMx_CCER register to validate the polarity (and detect rising edges only).

2. Configure the timer in reset mode by writing SMS=’100’ in TIMx_SMCR register. Select TI1 as the input source by writing TS=’00101’ in TIMx_SMCR register.
3. Start the counter by writing CEN=’1’ in the TIMx_CR1 register.

The counter starts counting on the internal clock, then behaves normally until TI1 rising edge. When TI1 rises, the counter is cleared and restarts from 0. In the meantime, the trigger flag is set (TIF bit in the TIMx_SR register) and an interrupt request can be sent if enabled (depending on the TIE bit in TIMx_DIER register).

The following figure shows this behavior when the auto-reload register TIMx_ARR=0x36. The delay between the rising edge on TI1 and the actual reset of the counter is due to the resynchronization circuit on TI1 input.

Figure 506. Control circuit in reset mode



Slave mode: Gated mode

The counter can be enabled depending on the level of a selected input.

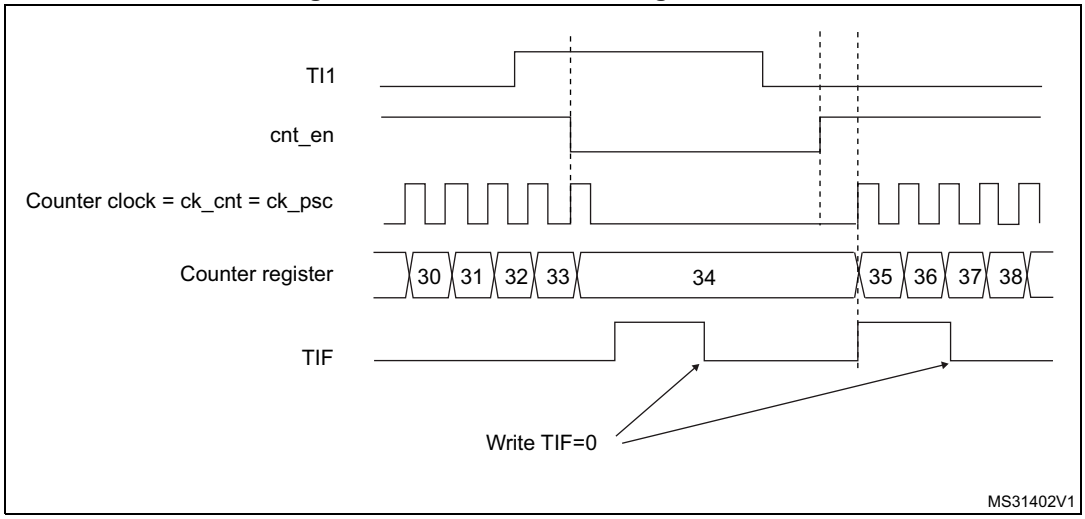
In the following example, the upcounter counts only when TI1 input is low:

1. Configure the channel 1 to detect low levels on TI1. Configure the input filter duration (in this example, we do not need any filter, so we keep IC1F=’0000’). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S=’01’ in TIMx_CCMR1 register. Program CC1P=’1’ and CC1NP=’0’ in TIMx_CCER register to validate the polarity (and detect low level only).
2. Configure the timer in gated mode by writing SMS=’101’ in TIMx_SMCR register. Select TI1 as the input source by writing TS=’00101’ in TIMx_SMCR register.
3. Enable the counter by writing CEN=’1’ in the TIMx_CR1 register (in gated mode, the counter doesn’t start if CEN=’0’, whatever is the trigger input level).

The counter starts counting on the internal clock as long as TI1 is low and stops as soon as TI1 becomes high. The TIF flag in the TIMx_SR register is set both when the counter starts or stops.

The delay between the rising edge on TI1 and the actual stop of the counter is due to the resynchronization circuit on TI1 input.

Figure 507. Control circuit in gated mode



Slave mode: Trigger mode

The counter can start in response to an event on a selected input.

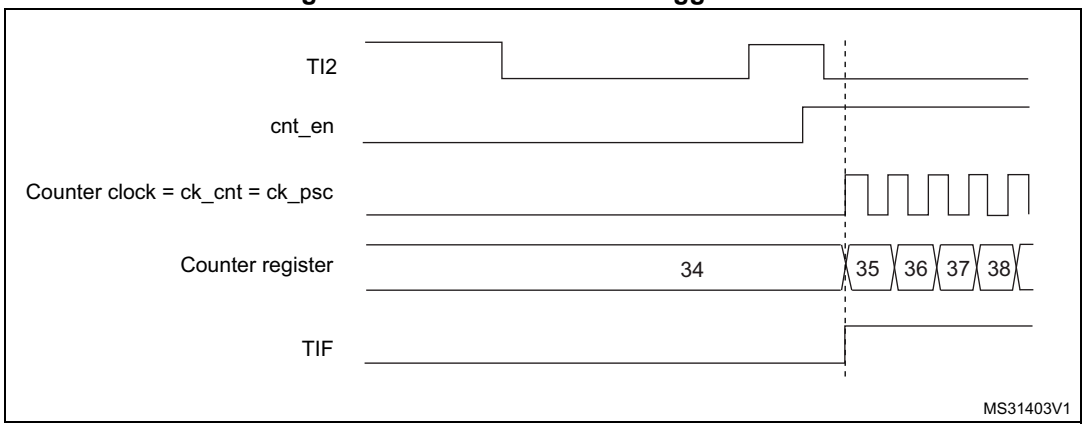
In the following example, the upcounter starts in response to a rising edge on TI2 input:

1. Configure the channel 2 to detect rising edges on TI2. Configure the input filter duration (in this example, we do not need any filter, so we keep IC2F=’0000’). The capture prescaler is not used for triggering, so it does not need to be configured. The CC2S bits are configured to select the input capture source only, CC2S=’01’ in TIMx_CCMR1 register. Program CC2P=’1’ and CC2NP=’0’ in TIMx_CCER register to validate the polarity (and detect low level only).
2. Configure the timer in trigger mode by writing SMS=’110’ in TIMx_SMCR register. Select TI2 as the input source by writing TS=’00110’ in TIMx_SMCR register.

When a rising edge occurs on TI2, the counter starts counting on the internal clock and the TIF flag is set.

The delay between the rising edge on TI2 and the actual start of the counter is due to the resynchronization circuit on TI2 input.

Figure 508. Control circuit in trigger mode



45.3.16 Slave mode – combined reset + trigger mode

In this case, a rising edge of the selected trigger input (TRGI) reinitializes the counter, generates an update of the registers, and starts the counter.

This mode is used for one-pulse mode.

45.3.17 Timer synchronization (TIM12)

The TIM timers are linked together internally for timer synchronization or chaining. Refer to *Section 44.3.19: Timer synchronization* for details.

Note: The clock of the slave timer must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the master timer.

45.3.18 Using timer output as trigger for other timers (TIM13/TIM14)

The timers with one channel only do not feature a master mode. However, the OC1 output signal can be used to trigger some other timers (including timers described in other sections of this document). Check the “TIMx internal trigger connection” table of any TIMx_SMCR register on the device to identify which timers can be targeted as slave.

The OC1 signal pulse width must be programmed to be at least 2 clock cycles of the destination timer, to make sure the slave timer will detect the trigger.

For instance, if the destination's timer CK_INT clock is 4 times slower than the source timer, the OC1 pulse width must be 8 clock cycles.

45.3.19 Debug mode

When the microcontroller enters debug mode (Cortex®-M7 core halted), the TIMx counter either continues to work normally or stops, depending on DBG_TIMx_STOP configuration bit in DBGMCU module. For more details, refer to *Section 65.5.7: Microcontroller debug unit (DBGMCU)*.

45.4 TIM12 registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions.

The peripheral registers have to be written by half-words (16 bits) or words (32 bits). Read accesses can be done by bytes (8 bits), half-words (16 bits) or words (32 bits).

45.4.1 TIM12 control register 1 (TIM12_CR1)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	UIFREMAP	Res.	CKD[1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
				rw		rw	rw	rw				rw	rw	rw	rw

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **UIFREMAP**: UIF status bit remapping
0: No remapping. UIF status bit is not copied to TIMx_CNT register bit 31.
1: Remapping enabled. UIF status bit is copied to TIMx_CNT register bit 31.

Bit 10 Reserved, must be kept at reset value.

Bits 9:8 **CKD[1:0]**: Clock division

This bit-field indicates the division ratio between the timer clock (CK_INT) frequency and sampling clock used by the digital filters (TIx),

00: $t_{DTS} = t_{CK\_INT}$
01: $t_{DTS} = 2 \times t_{CK\_INT}$
10: $t_{DTS} = 4 \times t_{CK\_INT}$
11: Reserved

Bit 7 **ARPE**: Auto-reload preload enable

0: TIMx_ARR register is not buffered.
1: TIMx_ARR register is buffered.

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **OPM**: One-pulse mode

0: Counter is not stopped on the update event
1: Counter stops counting on the next update event (clearing the CEN bit).

Bit 2 **URS**: Update request source

This bit is set and cleared by software to select the UEV event sources.

0: Any of the following events generates an update interrupt if enabled. These events can be:
- Counter overflow
- Setting the UG bit
- Update generation through the slave mode controller

1: Only counter overflow generates an update interrupt if enabled.

Bit 1 **UDIS**: Update disable

This bit is set and cleared by software to enable/disable update event (UEV) generation.

0: UEV enabled. An UEV is generated by one of the following events:
- Counter overflow
- Setting the UG bit

Buffered registers are then loaded with their preload values.

1: UEV disabled. No UEV is generated, shadow registers keep their value (ARR, PSC, CCRx). The counter and the prescaler are reinitialized if the UG bit is set.

Bit 0 **CEN**: Counter enable

0: Counter disabled
1: Counter enabled

CEN is cleared automatically in one-pulse mode, when an update event occurs.

Note: External clock and gated mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.

45.4.2 TIM12 control register 2 (TIM12_CR2)

Address offset: 0x04

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1S	MMS[2:0]			Res.	Res.	Res.	Res.
								rw	rw	rw	rw				

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **TI1S**: TI1 selection

0: The TIM12_CH1 pin is connected to TI1 input

1: The TIM12_CH1, CH2 pins are connected to the TI1 input (XOR combination)

Bits 6:4 **MMS[2:0]**: Master mode selection

These bits allow to select the information to be sent in master mode to slave timers for synchronization (TRGO). The combination is as follows:

000: Reset - the UG bit from the TIMx_EGR register is used as trigger output (TRGO). If the reset is generated by the trigger input (slave mode controller configured in reset mode) then the signal on TRGO is delayed compared to the actual reset.

001: Enable - the Counter Enable signal CNT_EN is used as trigger output (TRGO). It is useful to start several timers at the same time or to control a window in which a slave timer is enable. The Counter Enable signal is generated by a logic AND between CEN control bit and the trigger input when configured in gated mode. When the Counter Enable signal is controlled by the trigger input, there is a delay on TRGO, except if the master/slave mode is selected (see the MSM bit description in TIMx_SMCR register).

010: Update - The update event is selected as trigger output (TRGO). For instance a master timer can then be used as a prescaler for a slave timer.

011: Compare Pulse - The trigger output send a positive pulse when the CC1IF flag is to be set (even if it was already high), as soon as a capture or a compare match occurred. (TRGO).

100: Compare - OC1REFC signal is used as trigger output (TRGO).

101: Compare - OC2REFC signal is used as trigger output (TRGO).

Bits 3:0 Reserved, must be kept at reset value.

45.4.3 TIM12 slave mode control register (TIM12_SMCR)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS[4:3]		Res.	Res.	Res.	SMS[3]
										rw	rw				rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MSM	TS[2:0]			Res.	SMS[2:0]		
								rw	rw	rw	rw		rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 19:17 Reserved, must be kept at reset value.

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **MSM:** Master/Slave mode

0: No action

1: The effect of an event on the trigger input (TRGI) is delayed to allow a perfect synchronization between the current timer and its slaves (through TRGO). It is useful in order to synchronize several timers on a single external event.

Bits 21, 20, 6, 5, 4 **TS[4:0]:** Trigger selection

This TS[4:0] bitfield selects the trigger input to be used to synchronize the counter.

00000: Internal Trigger 0 (ITR0)

00001: Internal Trigger 1 (ITR1)

00010: Internal Trigger 2 (ITR2)

00011: Internal Trigger 3 (ITR3)

00100: TI1 Edge Detector (TI1F_ED)

00101: Filtered Timer Input 1 (TI1FP1)

00110: Filtered Timer Input 2 (TI2FP2)

Others: Reserved

See *Table 358: TIMx internal trigger connection on page 1768* for more details on the meaning of ITRx for each timer.

Note: These bits must be changed only when they are not used (e.g. when SMS='000') to avoid wrong edge detections at the transition.

Bit 3 Reserved, must be kept at reset value.

Bits 16, 2, 1, 0 **SMS[3:0]:** Slave mode selection

When external signals are selected the active edge of the trigger signal (TRGI) is linked to the polarity selected on the external input (see Input Control register and Control Register description.

0000: Slave mode disabled - if CEN = '1' then the prescaler is clocked directly by the internal clock.

0001: Reserved

0010: Reserved

0011: Reserved

0100: Reset Mode - Rising edge of the selected trigger input (TRGI) reinitializes the counter and generates an update of the registers.

0101: Gated Mode - The counter clock is enabled when the trigger input (TRGI) is high. The counter stops (but is not reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

0110: Trigger Mode - The counter starts at a rising edge of the trigger TRGI (but it is not reset). Only the start of the counter is controlled.

0111: External Clock Mode 1 - Rising edges of the selected trigger (TRGI) clock the counter.

1000: Combined reset + trigger mode - Rising edge of the selected trigger input (TRGI) reinitializes the counter, generates an update of the registers and starts the counter.

Other codes: reserved.

Note: The gated mode must not be used if TI1F_ED is selected as the trigger input (TS='00100'). Indeed, TI1F_ED outputs 1 pulse for each transition on TI1F, whereas the gated mode checks the level of the trigger signal.

Note: The clock of the slave timer must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the master timer.

Table 358. TIMx internal trigger connection

Slave TIM	ITR0 (TS = '00000')	ITR1 (TS = '00001')	ITR2 (TS = '00010')	ITR3 (TS = '00011')
TIM12	TIM4	TIM5	TIM13 OC1	TIM14 OC1

45.4.4 TIM12 Interrupt enable register (TIM12_DIER)

Address offset: 0x0C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TIE	Res.	Res.	Res.	CC2IE	CC1IE	UIE
									rw				rw	rw	rw

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **TIE**: Trigger interrupt enable
0: Trigger interrupt disabled.
1: Trigger interrupt enabled.

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **CC2IE**: Capture/Compare 2 interrupt enable
0: CC2 interrupt disabled.
1: CC2 interrupt enabled.

Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable
0: CC1 interrupt disabled.
1: CC1 interrupt enabled.

Bit 0 **UIE**: Update interrupt enable
0: Update interrupt disabled.
1: Update interrupt enabled.

45.4.5 TIM12 status register (TIM12_SR)

Address offset: 0x10

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	CC2OF	CC1OF	Res.	Res.	TIF	Res.	Res.	Res.	CC2IF	CC1IF	UIF
					rc_w0	rc_w0			rc_w0				rc_w0	rc_w0	rc_w0

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **CC2OF**: Capture/compare 2 overcapture flag
refer to CC1OF description

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag
This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to ‘0’.
0: No overcapture has been detected.
1: The counter value has been captured in TIMx_CCR1 register while CC1IF flag was already set

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **TIF**: Trigger interrupt flag

This flag is set by hardware on the TRG trigger event (active edge detected on TRGI input when the slave mode controller is enabled in all modes but gated mode. It is set when the counter starts or stops when gated mode is selected. It is cleared by software.
0: No trigger event occurred.
1: Trigger interrupt pending.

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **CC2IF**: Capture/Compare 2 interrupt flag

refer to CC1IF description

Bit 1 **CC1IF**: Capture/compare 1 interrupt flag

This flag is set by hardware. It is cleared by software (input capture or output compare mode) or by reading the TIMx_CCR1 register (input capture mode only).
0: No compare match / No input capture occurred
1: A compare match or an input capture occurred.
If channel CC1 is configured as output: this flag is set when he content of the counter TIMx_CNT matches the content of the TIMx_CCR1 register. When the content of TIMx_CCR1 is greater than the content of TIMx_ARR, the CC1IF bit goes high on the counter overflow (in up-counting and up/down-counting modes) or underflow (in down-counting mode). There are 3 possible options for flag setting in center-aligned mode, refer to the CMS bits in the TIMx_CR1 register for the full description.
If channel CC1 is configured as input: this bit is set when counter value has been captured in TIMx_CCR1 register (an edge has been detected on IC1, as per the edge sensitivity defined with the CC1P and CC1NP bits setting, in TIMx_CCER).

Bit 0 **UIF**: Update interrupt flag

This bit is set by hardware on an update event. It is cleared by software.
0: No update occurred.
1: Update interrupt pending. This bit is set by hardware when the registers are updated:
- At overflow and if UDIS='0' in the TIMx_CR1 register.
- When CNT is reinitialized by software using the UG bit in TIMx_EGR register, if URS='0' and UDIS='0' in the TIMx_CR1 register.
- When CNT is reinitialized by a trigger event (refer to the synchro control register description), if URS='0' and UDIS='0' in the TIMx_CR1 register.

45.4.6 TIM12 event generation register (TIM12_EGR)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TG	Res.	Res.	Res.	CC2G	CC1G	UG
									w				w	w	w

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **TG**: Trigger generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.
0: No action
1: The TIF flag is set in the TIMx_SR register. Related interrupt can occur if enabled

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **CC2G**: Capture/compare 2 generation
refer to CC1G description

Bit 1 **CC1G**: Capture/compare 1 generation
This bit is set by software to generate an event, it is automatically cleared by hardware.
0: No action
1: A capture/compare event is generated on channel 1:
If channel CC1 is configured as output:
the CC1IF flag is set, the corresponding interrupt is sent if enabled.
If channel CC1 is configured as input:
The current counter value is captured in the TIMx_CCR1 register. The CC1IF flag is set, the corresponding interrupt is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation
This bit can be set by software, it is automatically cleared by hardware.
0: No action
1: Re-initializes the counter and generates an update of the registers. The prescaler counter is also cleared and the prescaler ratio is not affected. The counter is cleared.

45.4.7 TIM12 capture/compare mode register 1 [alternate] (TIM12_CCMR1)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits in this register have different functions in input and output modes.

Input capture mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IC2F[3:0]				IC2PSC[1:0]		CC2S[1:0]		IC1F[3:0]				IC1PSC[1:0]		CC1S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **IC2F[3:0]**: Input capture 2 filter

Bits 11:10 **IC2PSC[1:0]**: Input capture 2 prescaler

Bits 9:8 **CC2S[1:0]**: Capture/compare 2 selection
This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC2 channel is configured as output
01: CC2 channel is configured as input, IC2 is mapped on TI2
10: CC2 channel is configured as input, IC2 is mapped on TI1
11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode works only if an internal trigger input is selected through the TS bit (TIMx_SMCR register)
Note: The CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx_CCER).

Bits 7:4 **IC1F[3:0]**: Input capture 1 filter

This bitfield defines the frequency used to sample the TI1 input and the length of the digital filter applied to TI1. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}

0001: $f_{SAMPLING}=f_{CK\_INT}$, N=2

0010: $f_{SAMPLING}=f_{CK\_INT}$, N=4

0011: $f_{SAMPLING}=f_{CK\_INT}$, N=8

0100: $f_{SAMPLING}=f_{DTS}/2$, N=6

0101: $f_{SAMPLING}=f_{DTS}/2$, N=8

0110: $f_{SAMPLING}=f_{DTS}/4$, N=6

0111: $f_{SAMPLING}=f_{DTS}/4$, N=8

1000: $f_{SAMPLING}=f_{DTS}/8$, N=6

1001: $f_{SAMPLING}=f_{DTS}/8$, N=8

1010: $f_{SAMPLING}=f_{DTS}/16$, N=5

1011: $f_{SAMPLING}=f_{DTS}/16$, N=6

1100: $f_{SAMPLING}=f_{DTS}/16$, N=8

1101: $f_{SAMPLING}=f_{DTS}/32$, N=5

1110: $f_{SAMPLING}=f_{DTS}/32$, N=6

1111: $f_{SAMPLING}=f_{DTS}/32$, N=8

Bits 3:2 **IC1PSC[1:0]**: Input capture 1 prescaler

This bitfield defines the ratio of the prescaler acting on the CC1 input (IC1).
The prescaler is reset as soon as CC1E='0' (TIMx_CCER register).
00: no prescaler, capture is done each time an edge is detected on the capture input
01: capture is done once every 2 events
10: capture is done once every 4 events
11: capture is done once every 8 events

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC1 channel is configured as output
01: CC1 channel is configured as input, IC1 is mapped on TI1
10: CC1 channel is configured as input, IC1 is mapped on TI2
11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: The CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

45.4.8 TIM12 capture/compare mode register 1 [alternate] (TIM12_CCMR1)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the

corresponding CCxS bits. All the other bits in this register have different functions in input and output modes.

Output compare mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M [3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M [3]
							rw								rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	OC2M[2:0]			OC2PE	OC2FE	CC2S[1:0]		Res.	OC1M[2:0]			OC1PE	OC1FE	CC1S[1:0]	
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 Reserved, must be kept at reset value.

Bits 24, 14:12 **OC2M[3:0]**: Output compare 2 mode
Refer to OC1M[3:0] for bit description.

Bit 11 **OC2PE**: Output compare 2 preload enable

Bit 10 **OC2FE**: Output compare 2 fast enable

Bits 9:8 **CC2S[1:0]**: Capture/Compare 2 selection
This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC2 channel is configured as output
01: CC2 channel is configured as input, IC2 is mapped on TI2
10: CC2 channel is configured as input, IC2 is mapped on TI1
11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode works only if an internal trigger input is selected through the TS bit (TIMx_SMCR register

Note: The CC2S bits are writable only when the channel is OFF (CC2E = 0 in TIMx_CCER).

Bit 7 Reserved, must be kept at reset value.

Bits 16, 6:4 **OC1M[3:0]**: Output compare 1 mode (refer to bit 16 for OC1M[3])

These bits define the behavior of the output reference signal OC1REF from which OC1 is derived. OC1REF is active high whereas the active level of OC1 depends on the CC1P.

0000: Frozen - The comparison between the output compare register TIMx_CCR1 and the counter TIMx_CNT has no effect on the outputs.(this mode is used to generate a timing base).

0001: Set channel 1 to active level on match. The OC1REF signal is forced high when the TIMx_CNT counter matches the capture/compare register 1 (TIMx_CCR1).

0010: Set channel 1 to inactive level on match. The OC1REF signal is forced low when the TIMx_CNT counter matches the capture/compare register 1 (TIMx_CCR1).

0011: Toggle - OC1REF toggles when TIMx_CNT=TIMx_CCR1

0100: Force inactive level - OC1REF is forced low

0101: Force active level - OC1REF is forced high

0110: PWM mode 1 - channel 1 is active as long as TIMx_CNT<TIMx_CCR1 else it is inactive

0111: PWM mode 2 - channel 1 is inactive as long as TIMx_CNT<TIMx_CCR1 else it is active

1000: Retrigerrable OPM mode 1 - The channel is active until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update.

1001: Retrigerrable OPM mode 2 - The channel is inactive until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 2 and the channels becomes inactive again at the next update.

1010: Reserved,

1011: Reserved,

1100: Combined PWM mode 1 - OC1REF has the same behavior as in PWM mode 1. OC1REFC is the logical OR between OC1REF and OC2REF.

1101: Combined PWM mode 2 - OC1REF has the same behavior as in PWM mode 2. OC1REFC is the logical AND between OC1REF and OC2REF.

1110: Reserved,

1111: Reserved

Note: In PWM mode 1 or 2, the OCREF level changes only when the result of the comparison changes or when the output compare mode switches from “frozen” mode to “PWM” mode.

Note: The OC1M[3] bit is not contiguous, located in bit 16.

Bit 3 **OC1PE**: Output compare 1 preload enable

0: Preload register on TIMx_CCR1 disabled. TIMx_CCR1 can be written at anytime, the new value is taken into account immediately

1: Preload register on TIMx_CCR1 enabled. Read/Write operations access the preload register. TIMx_CCR1 preload value is loaded into the active register at each update event

Bit 2 **OC1FE**: Output compare 1 fast enable

This bit decreases the latency between a trigger event and a transition on the timer output. It must be used in one-pulse mode (OPM bit set in TIMx_CR1 register), to have the output pulse starting as soon as possible after the starting trigger.

0: CC1 behaves normally depending on the counter and CCR1 values even when the trigger is ON. The minimum delay to activate the CC1 output when an edge occurs on the trigger input is 5 clock cycles

1: An active edge on the trigger input acts like a compare match on the CC1 output. Then, OC is set to the compare level independently of the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OC1FE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bitfield defines the direction of the channel (input/output) as well as the used input.
00: CC1 channel is configured as output
01: CC1 channel is configured as input, IC1 is mapped on TI1
10: CC1 channel is configured as input, IC1 is mapped on TI2
11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode works only if an internal trigger input is selected through the TS bit (TIMx_SMCR register)

Note: The CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

45.4.9 TIM12 capture/compare enable register (TIM12_CCER)

Address offset: 0x20

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2NP	Res.	CC2P	CC2E	CC1NP	Res.	CC1P	CC1E
								rw		rw	rw	rw		rw	rw

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **CC2NP**: Capture/Compare 2 output Polarity
Refer to CC1NP description

Bit 6 Reserved, must be kept at reset value.

Bit 5 **CC2P**: Capture/Compare 2 output Polarity
Refer to CC1P description

Bit 4 **CC2E**: Capture/Compare 2 output enable
Refer to CC1E description

Bit 3 **CC1NP**: Capture/Compare 1 complementary output Polarity
CC1 channel configured as output: CC1NP must be kept cleared
CC1 channel configured as input: CC1NP is used in conjunction with CC1P to define TI1FP1/TI2FP1 polarity (refer to CC1P description).

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CC1P**: Capture/Compare 1 output Polarity.

0: OC1 active high (output mode) / Edge sensitivity selection (input mode, see below)

1: OC1 active low (output mode) / Edge sensitivity selection (input mode, see below)

When CC1 channel is configured as input, both CC1NP/CC1P bits select the active polarity of TI1FP1 and TI2FP1 for trigger or capture operations.

CC1NP=0, CC1P=0: non-inverted/rising edge. The circuit is sensitive to TIxFP1 rising edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger operation in gated mode or encoder mode).

CC1NP=0, CC1P=1: inverted/falling edge. The circuit is sensitive to TIxFP1 falling edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is inverted (trigger operation in gated mode or encoder mode).

CC1NP=1, CC1P=1: non-inverted/both edges/ The circuit is sensitive to both TIxFP1 rising and falling edges (capture or trigger operations in reset, external clock or trigger mode), TIxFP1is not inverted (trigger operation in gated mode). This configuration must not be used in encoder mode.

CC1NP=1, CC1P=0: This configuration is reserved, it must not be used.

Bit 0 **CC1E**: Capture/Compare 1 output enable.

0: Capture mode disabled / OC1 is not active

1: Capture mode enabled / OC1 signal is output on the corresponding output pin

Table 359. Output control bit for standard OCx channels

CCxE bit	OCx output state
0	Output disabled (not driven by the timer: Hi-Z)
1	Output enabled (tim_ocx = tim_ocxref + Polarity)’

Note: The states of the external I/O pins connected to the standard OCx channels depend on the state of the OCx channel and on the GPIO registers.

45.4.10 TIM12 counter (TIM12_CNT)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIF CPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: UIF Copy

This bit is a read-only copy of the UIF bit in the TIMx_ISR register.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]**: Counter value

45.4.11 TIM12 prescaler (TIM12_PSC)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency CK_CNT is equal to f_{CK_PSC} / (PSC[15:0] + 1).
PSC contains the value to be loaded into the active prescaler register at each update event. (including when the counter is cleared through UG bit of TIMx_EGR register or through trigger controller when configured in “reset mode”).

45.4.12 TIM12 auto-reload register (TIM12_ARR)

Address offset: 0x2C

Reset value: 0xFFFF

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **ARR[15:0]**: Auto-reload value

ARR is the value to be loaded into the actual auto-reload register.
Refer to the *Section 45.3.1: Time-base unit on page 1743* for more details about ARR update and behavior.
The counter is blocked while the auto-reload value is null.

45.4.13 TIM12 capture/compare register 1 (TIM12_CCR1)

Address offset: 0x34

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR1[15:0]**: Capture/Compare 1 value

If channel CC1 is configured as output:
CCR1 is the value to be loaded into the actual capture/compare 1 register (preload value).
It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (OC1PE bit). Else the preload value is copied into the active capture/compare 1 register when an update event occurs.
The active capture/compare register contains the value to be compared to the TIMx_CNT counter and signaled on the OC1 output.
If channel CC1is configured as input:
CCR1 is the counter value transferred by the last input capture 1 event (IC1).

45.4.14 TIM12 capture/compare register 2 (TIM12_CCR2)

Address offset: 0x38

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR2[15:0]**: Capture/Compare 2 value

If channel CC2 is configured as output:

CCR2 is the value to be loaded into the actual capture/compare 2 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR2 register (OC2PE bit). Else the preload value is copied into the active capture/compare 2 register when an update event occurs.

The active capture/compare register contains the value to be compared to the TIMx_CNT counter and signalled on the OC2 output.

If channel CC2 is configured as input:

CCR2 is the counter value transferred by the last input capture 2 event (IC2).

45.4.15 TIM12 timer input selection register (TIM12_TISEL)

Address offset: 0x68

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: selects TI2[0] to TI2[15] input

0000: TIM12_CH2 input

Other: Reserved

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: selects TI1[0] to TI1[15] input

0000: TIM12_CH1 input

0001: spdifrx_frame_sync

Other: Reserved

45.4.16 TIM12 register map

TIM12 registers are mapped as 16-bit addressable registers as described below:

Table 360. TIM12 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**TIMx_CR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIFREMA	Res.	CKD [1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
	Reset value																					0		0	0	0				0	0	0	0
0x04	**TIM12_CR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1S	MMS[2:0]			Res.	Res.	Res.	Res.
	Reset value																									0	0	0	0				
0x08	**TIMx_SMCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS [4:3] Res.		Res.	Res.	Res.	SMS[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MSM	TS[2:0]			Res.	SMS[2:0]		
	Reset value											0	0				0									0	0	0	0		0	0	0
0x0C	**TIMx_DIER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TIE	Res.	Res.	Res.	CC2IE	CC1IE	UIE
	Reset value																						0				0				0	0	0
0x10	**TIMx_SR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2OF	CC1OF	Res.	Res.	TIF	Res.	Res.	Res.	CC2IF	CC1IF	UIF
	Reset value																						0	0			0				0	0	0
0x14	**TIMx_EGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TG	Res.	Res.	Res.	CC2G	CC1G	UG
	Reset value																										0				0	0	0
0x18	**TIMx_CCMR1** Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]	Res.	OC2M [2:0]			OC2PE	OC2FE	CC2S [1:0]		Res.	OC1M [2:0]			OC1PE	OC1FE	CC1S [1:0]	
	Reset value								0								0		0	0	0	0	0	0	0		0	0	0	0	0	0	0
	TIMx_CCMR1 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC2F[3:0]				IC2 PSC [1:0]		CC2S [1:0]		IC1F[3:0]				IC1 PSC [1:0]		CC1S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1C	Reserved	Res.																															
0x20	**TIMx_CCER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2NP	Res.	CC2P	CC2E	CC1NP	Res.	CC1P	CC1E
	Reset value																									0		0	0	0		0	0
0x24	**TIMx_CNT**	UIFCPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value	0																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	**TIMx_PSC**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 360. TIM12 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x2C	**TIMx_ARR**	Reserved																ARR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x30	Reserved	Reserved																															
0x34	**TIMx_CCR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x38	**TIMx_CCR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR2[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x3C to 0x64	Reserved	Res.																															
0x68	**TIM12_TISEL**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value																					0	0	0	0					0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

45.5 TIM13/TIM14 registers

The peripheral registers have to be written by half-words (16 bits) or words (32 bits). Read accesses can be done by bytes (8 bits), half-words (16 bits) or words (32 bits).

45.5.1 TIMx control register 1 (TIMx_CR1)(x = 13 to 14)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	UIFREMAP	Res.	CKD[1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
				rw		rw	rw	rw				rw	rw	rw	rw

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **UIFREMAP**: UIF status bit remapping
0: No remapping. UIF status bit is not copied to TIMx_CNT register bit 31.
1: Remapping enabled. UIF status bit is copied to TIMx_CNT register bit 31.

Bit 10 Reserved, must be kept at reset value.

Bits 9:8 **CKD[1:0]**: Clock division
This bit-field indicates the division ratio between the timer clock (CK_INT) frequency and sampling clock used by the digital filters (TIx),
00: $t_{DTS} = t_{CK\_INT}$
01: $t_{DTS} = 2 \times t_{CK\_INT}$
10: $t_{DTS} = 4 \times t_{CK\_INT}$
11: Reserved

Bit 7 **ARPE**: Auto-reload preload enable
0: TIMx_ARR register is not buffered
1: TIMx_ARR register is buffered

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **OPM**: One-pulse mode
0: Counter is not stopped on the update event
1: Counter stops counting on the next update event (clearing the CEN bit).

Bit 2 **URS**: Update request source

This bit is set and cleared by software to select the update interrupt (UEV) sources.

0: Any of the following events generate an UEV if enabled:

– Counter overflow

– Setting the UG bit

1: Only counter overflow generates an UEV if enabled.

Bit 1 **UDIS**: Update disable

This bit is set and cleared by software to enable/disable update interrupt (UEV) event generation.

0: UEV enabled. An UEV is generated by one of the following events:

– Counter overflow

– Setting the UG bit.

Buffered registers are then loaded with their preload values.

1: UEV disabled. No UEV is generated, shadow registers keep their value (ARR, PSC, CCRx). The counter and the prescaler are reinitialized if the UG bit is set.

Bit 0 **CEN**: Counter enable

0: Counter disabled

1: Counter enabled

Note: External clock and gated mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.

45.5.2 TIMx Interrupt enable register (TIMx_DIER)(x = 13 to 14)

Address offset: 0x0C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1IE	UIE
														rw	rw

Bits 15:2 Reserved, must be kept at reset value.

Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable

0: CC1 interrupt disabled

1: CC1 interrupt enabled

Bit 0 **UIE**: Update interrupt enable

0: Update interrupt disabled

1: Update interrupt enabled

45.5.3 TIMx status register (TIMx_SR)(x = 13 to 14)

Address offset: 0x10

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CC1OF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1IF	UIF
						rc_w0								rc_w0	rc_w0

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag

This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to ‘0’.
0: No overcapture has been detected.
1: The counter value has been captured in TIMx_CCR1 register while CC1IF flag was already set

Bits 8:2 Reserved, must be kept at reset value.

Bit 1 **CC1IF**: Capture/compare 1 interrupt flag

This flag is set by hardware. It is cleared by software (input capture or output compare mode) or by reading the TIMx_CCR1 register (input capture mode only).
0: No compare match / No input capture occurred
1: A compare match or an input capture occurred.
If channel CC1 is configured as output: this flag is set when he content of the counter TIMx_CNT matches the content of the TIMx_CCR1 register. When the content of TIMx_CCR1 is greater than the content of TIMx_ARR, the CC1IF bit goes high on the counter overflow (in up-counting and up/down-counting modes) or underflow (in down-counting mode). There are 3 possible options for flag setting in center-aligned mode, refer to the CMS bits in the TIMx_CR1 register for the full description.
If channel CC1 is configured as input: this bit is set when counter value has been captured in TIMx_CCR1 register (an edge has been detected on IC1, as per the edge sensitivity defined with the CC1P and CC1NP bits setting, in TIMx_CCER).

Bit 0 **UIF**: Update interrupt flag

This bit is set by hardware on an update event. It is cleared by software.
0: No update occurred.
1: Update interrupt pending. This bit is set by hardware when the registers are updated:
- At overflow and if UDIS=’0’ in the TIMx_CR1 register.
- When CNT is reinitialized by software using the UG bit in TIMx_EGR register, if URS=’0’ and UDIS=’0’ in the TIMx_CR1 register.

45.5.4 TIMx event generation register (TIMx_EGR)(x = 13 to 14)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1G	UG
														w	w

Bits 15:2 Reserved, must be kept at reset value.

Bit 1 **CC1G**: Capture/compare 1 generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.
0: No action
1: A capture/compare event is generated on channel 1:
If channel CC1 is configured as output:
CC1IF flag is set, Corresponding interrupt or is sent if enabled.
If channel CC1 is configured as input:
The current value of the counter is captured in TIMx_CCR1 register. The CC1IF flag is set, the corresponding interrupt is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation

This bit can be set by software, it is automatically cleared by hardware.
0: No action
1: Re-initialize the counter and generates an update of the registers. Note that the prescaler counter is cleared too (anyway the prescaler ratio is not affected). The counter is cleared.

45.5.5 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 13 to 14)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode.

Input capture mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC1F[3:0]				IC1PSC[1:0]		CC1S[1:0]	
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **IC1F[3:0]**: Input capture 1 filter

This bit-field defines the frequency used to sample TI1 input and the length of the digital filter applied to TI1. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}
0001: $f_{SAMPLING}=f_{CK\_INT}$, N=2
0010: $f_{SAMPLING}=f_{CK\_INT}$, N=4
0011: $f_{SAMPLING}=f_{CK\_INT}$, N=8
0100: $f_{SAMPLING}=f_{DTS}/2$, N=6
0101: $f_{SAMPLING}=f_{DTS}/2$, N=8
0110: $f_{SAMPLING}=f_{DTS}/4$, N=6
0111: $f_{SAMPLING}=f_{DTS}/4$, N=8
1000: $f_{SAMPLING}=f_{DTS}/8$, N=6
1001: $f_{SAMPLING}=f_{DTS}/8$, N=8
1010: $f_{SAMPLING}=f_{DTS}/16$, N=5
1011: $f_{SAMPLING}=f_{DTS}/16$, N=6
1100: $f_{SAMPLING}=f_{DTS}/16$, N=8
1101: $f_{SAMPLING}=f_{DTS}/32$, N=5
1110: $f_{SAMPLING}=f_{DTS}/32$, N=6
1111: $f_{SAMPLING}=f_{DTS}/32$, N=8

Bits 3:2 **IC1PSC[1:0]**: Input capture 1 prescaler

This bit-field defines the ratio of the prescaler acting on CC1 input (IC1).
The prescaler is reset as soon as CC1E='0' (TIMx_CCER register).
00: no prescaler, capture is done each time an edge is detected on the capture input
01: capture is done once every 2 events
10: capture is done once every 4 events
11: capture is done once every 8 events

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC1 channel is configured as output
01: CC1 channel is configured as input, IC1 is mapped on TI1
10: Reserved
11: Reserved

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

45.5.6 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 13 to 14)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the

corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode.

Output compare mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[2:0]			OC1PE	OC1FE	CC1S[1:0]	
									rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bits 15:7 Reserved, must be kept at reset value.

Bits 16, 6:4 **OC1M[3:0]**: Output compare 1 mode (refer to bit 16 for OC1M[3])

These bits define the behavior of the output reference signal OC1REF from which OC1 is derived. OC1REF is active high whereas OC1 active level depends on CC1P bit.

0000: Frozen. The comparison between the output compare register TIMx_CCR1 and the counter TIMx_CNT has no effect on the outputs.

0001: Set channel 1 to active level on match. OC1REF signal is forced high when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0010: Set channel 1 to inactive level on match. OC1REF signal is forced low when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0011: Toggle - OC1REF toggles when TIMx_CNT = TIMx_CCR1.

0100: Force inactive level - OC1REF is forced low.

0101: Force active level - OC1REF is forced high.

0110: PWM mode 1 - Channel 1 is active as long as TIMx_CNT < TIMx_CCR1 else inactive.

0111: PWM mode 2 - Channel 1 is inactive as long as TIMx_CNT < TIMx_CCR1 else active

Others: Reserved

Note: In PWM mode 1 or 2, the OCREF level changes when the result of the comparison changes or when the output compare mode switches from frozen to PWM mode.

Note: The OC1M[3] bit is not contiguous, located in bit 16.

Bit 3 **OC1PE**: Output compare 1 preload enable

0: Preload register on TIMx_CCR1 disabled. TIMx_CCR1 can be written at anytime, the new value is taken in account immediately.

1: Preload register on TIMx_CCR1 enabled. Read/Write operations access the preload register. TIMx_CCR1 preload value is loaded in the active register at each update event.

Bit 2 **OC1FE**: Output compare 1 fast enable

This bit decreases the latency between a trigger event and a transition on the timer output. It must be used in one-pulse mode (OPM bit set in TIMx_CR1 register), to have the output pulse starting as soon as possible after the starting trigger.

0: CC1 behaves normally depending on counter and CCR1 values even when the trigger is ON. The minimum delay to activate CC1 output when an edge occurs on the trigger input is 5 clock cycles.

1: An active edge on the trigger input acts like a compare match on CC1 output. OC is then set to the compare level independently of the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OC1FE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output.

01: CC1 channel is configured as input, IC1 is mapped on TI1.

10: Reserved.

11: Reserved.

Note: CC1S bits are writable only when the channel is OFF (CC1E = 0 in TIMx_CCER).

45.5.7 TIMx capture/compare enable register (TIMx_CCER)(x = 13 to 14)

Address offset: 0x20

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1NP	Res.	CC1P	CC1E
												rw		rw	rw

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **CC1NP**: Capture/Compare 1 complementary output Polarity.

CC1 channel configured as output: CC1NP must be kept cleared.

CC1 channel configured as input: CC1NP bit is used in conjunction with CC1P to define TI1FP1 polarity (refer to CC1P description).

Bit 2 Reserved, must be kept at reset value.

Bit 1 **CC1P**: Capture/Compare 1 output Polarity.

0: OC1 active high (output mode) / Edge sensitivity selection (input mode, see below)

1: OC1 active low (output mode) / Edge sensitivity selection (input mode, see below)

When CC1 channel is configured as input, both CC1NP/CC1P bits select the active polarity of TI1FP1 and TI2FP1 for trigger or capture operations.

CC1NP=0, CC1P=0: non-inverted/rising edge. The circuit is sensitive to TIxFP1 rising edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger operation in gated mode or encoder mode).

CC1NP=0, CC1P=1: inverted/falling edge. The circuit is sensitive to TIxFP1 falling edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is inverted (trigger operation in gated mode or encoder mode).

CC1NP=1, CC1P=1: non-inverted/both edges/ The circuit is sensitive to both TIxFP1 rising and falling edges (capture or trigger operations in reset, external clock or trigger mode), TIxFP1is not inverted (trigger operation in gated mode). This configuration must not be used in encoder mode.

CC1NP=1, CC1P=0:This configuration is reserved, it must not be used.

Bit 0 **CC1E**: Capture/Compare 1 output enable.

0: Capture mode disabled / OC1 is not active

1: Capture mode enabled / OC1 signal is output on the corresponding output pin

Table 361. Output control bit for standard OCx channels

CCxE bit	OCx output state
0	Output disabled (not driven by the timer: Hi-Z)
1	Output enabled (tim_ocx = tim_ocxref + Polarity)

Note: The state of the external I/O pins connected to the standard OCx channels depends on the OCx channel state and the GPIO registers.

45.5.8 TIMx counter (TIMx_CNT)(x = 13 to 14)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIF CPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: UIF Copy

This bit is a read-only copy of the UIF bit in the TIMx_ISR register.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]**: Counter value

45.5.9 TIMx prescaler (TIMx_PSC)(x = 13 to 14)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency CK_CNT is equal to f_{CK_PSC} / (PSC[15:0] + 1).

PSC contains the value to be loaded in the active prescaler register at each update event.

(including when the counter is cleared through UG bit of TIMx_EGR register or through trigger controller when configured in “reset mode”).

45.5.10 TIMx auto-reload register (TIMx_ARR)(x = 13 to 14)

Address offset: 0x2C

Reset value: 0xFFFF

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **ARR[15:0]**: Auto-reload value

ARR is the value to be loaded in the actual auto-reload register.

Refer to *Section 45.3.1: Time-base unit on page 1743* for more details about ARR update and behavior.

The counter is blocked while the auto-reload value is null.

45.5.11 TIMx capture/compare register 1 (TIMx_CCR1)(x = 13 to 14)

Address offset: 0x34

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR1[15:0]**: Capture/Compare 1 value

If channel CC1 is configured as output:
CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value).
It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.
The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on OC1 output.

If channel CC1is configured as input:
CCR1 is the counter value transferred by the last input capture 1 event (IC1).

45.5.12 TIM13 timer input selection register (TIM13_TISEL)

Address offset: 0x68

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1SEL[3:0]			
												rw	rw	rw	rw

Bits 15:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: selects TI1[0] to TI1[15] input
0000: TIM13_CH1 input
Other: Reserved

45.5.13 TIM14 timer input selection register (TIM14_TISEL)

Address offset: 0x68

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1SEL[3:0]			
												rw	rw	rw	rw

Bits 15:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: selects TI1[0] to TI1[15] input
0000: TIM14_CH1 input
Other: Reserved

45.5.14 TIM13/TIM14 register map

TIMx registers are mapped as 16-bit addressable registers as described in the tables below:

Table 362. TIM13/TIM14 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**TIMx_CR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIFREMA	Res.	CKD [1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
	Reset value																					0		0	0	0				0	0	0	0
0x04 to 0x08	Reserved	Res.																															
0x0C	**TIMx_DIER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1IE	UIE
	Reset value																															0	0
0x10	**TIMx_SR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1OF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1IF	UIF
	Reset value																							0								0	0
0x14	**TIMx_EGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1G	UG
	Reset value																															0	0
0x18	**TIMx_CCMR1** Output compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M [2:0]			OC1PE	OC1FE	CC1S [1:0]	
	Reset value																0										0	0	0	0	0	0	0
	TIMx_CCMR1 Input capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC1F[3:0]				IC1 PSC [1:0]		CC1S [1:0]	
	Reset value																									0	0	0	0	0	0	0	0
0x1C	Reserved	Res.																															
0x20	**TIMx_CCER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1NP	Res.	CC1P	CC1E
	Reset value																													0		0	0
0x24	**TIMx_CNT**	UIFCPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value	0																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	**TIMx_PSC**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	**TIMx_ARR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x30	Reserved	Res.																															

Table 362. TIM13/TIM14 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x34	**TIMx_CCR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x38 to 0x64	Reserved	Res.																															
0x68	**TIM13_TISEL**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value																													0	0	0	0
0x68	**TIM14_TISEL**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value																													0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

46 General-purpose timers (TIM15/TIM16/TIM17)

46.1 TIM15/TIM16/TIM17 introduction

The TIM15/TIM16/TIM17 timers consist of a 16-bit auto-reload counter driven by a programmable prescaler.

They may be used for a variety of purposes, including measuring the pulse lengths of input signals (input capture) or generating output waveforms (output compare, PWM, complementary PWM with dead-time insertion).

Pulse lengths and waveform periods can be modulated from a few microseconds to several milliseconds using the timer prescaler and the RCC clock controller prescalers.

The TIM15/TIM16/TIM17 timers are completely independent, and do not share any resources. TIM15 can be synchronized as described in *Section 46.4.23: Timer synchronization (TIM15)*.

46.2 TIM15 main features

TIM15 includes the following features:

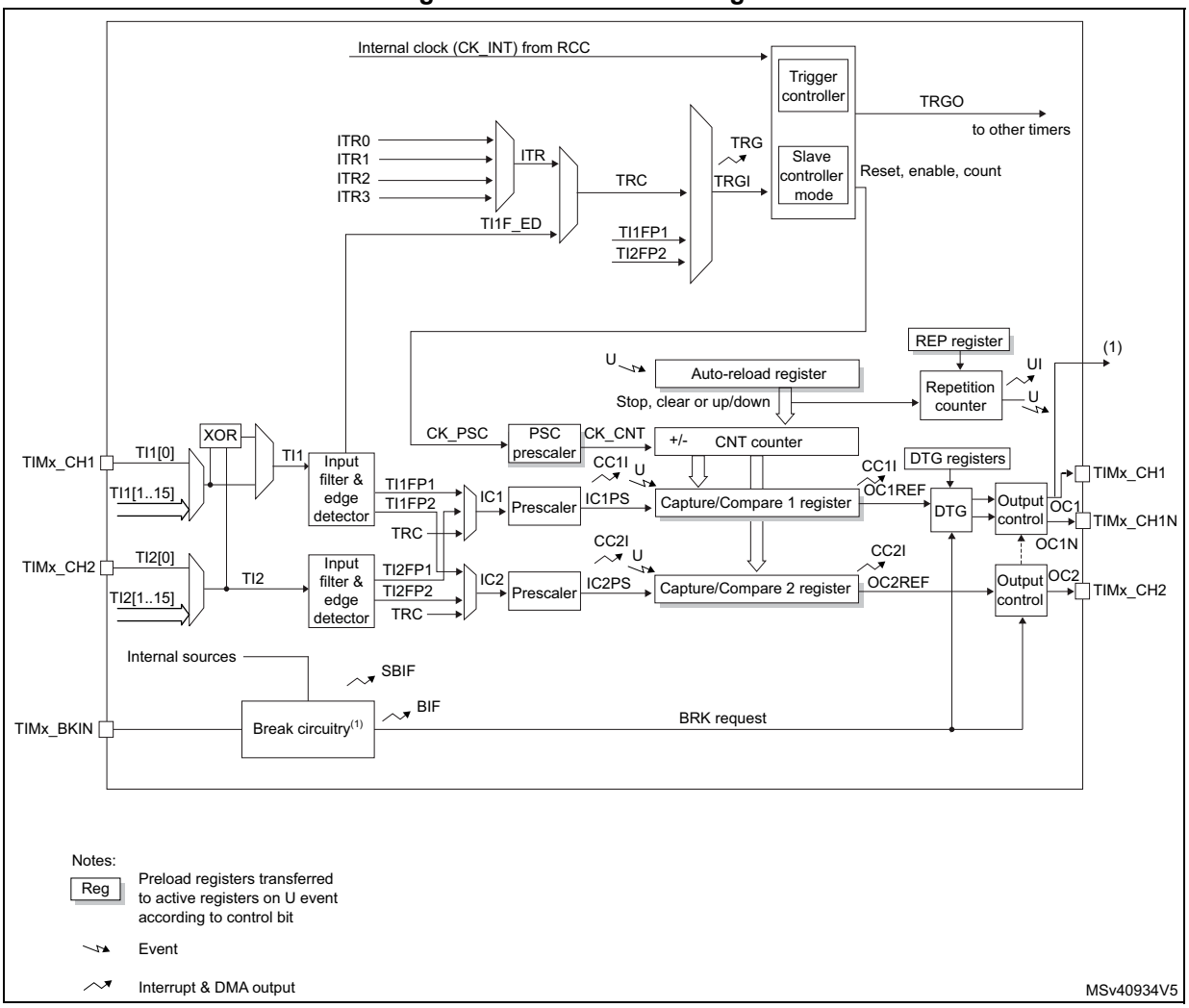
- 16-bit auto-reload upcounter
- 16-bit programmable prescaler used to divide (also “on the fly”) the counter clock frequency by any factor between 1 and 65535
- Up to 2 independent channels for:
  - Input capture
  - Output compare
  - PWM generation (edge mode)
  - One-pulse mode output
- Complementary outputs with programmable dead-time (for channel 1 only)
- Synchronization circuit to control the timer with external signals and to interconnect several timers together
- Repetition counter to update the timer registers only after a given number of cycles of the counter
- Break input to put the timer’s output signals in the reset state or a known state
- Interrupt/DMA generation on the following events:
  - Update: counter overflow, counter initialization (by software or internal/external trigger)
  - Trigger event (counter start, stop, initialization or count by internal/external trigger)
  - Input capture
  - Output compare
  - Break input (interrupt request)

46.3 TIM16/TIM17 main features

The TIM16/TIM17 timers include the following features:

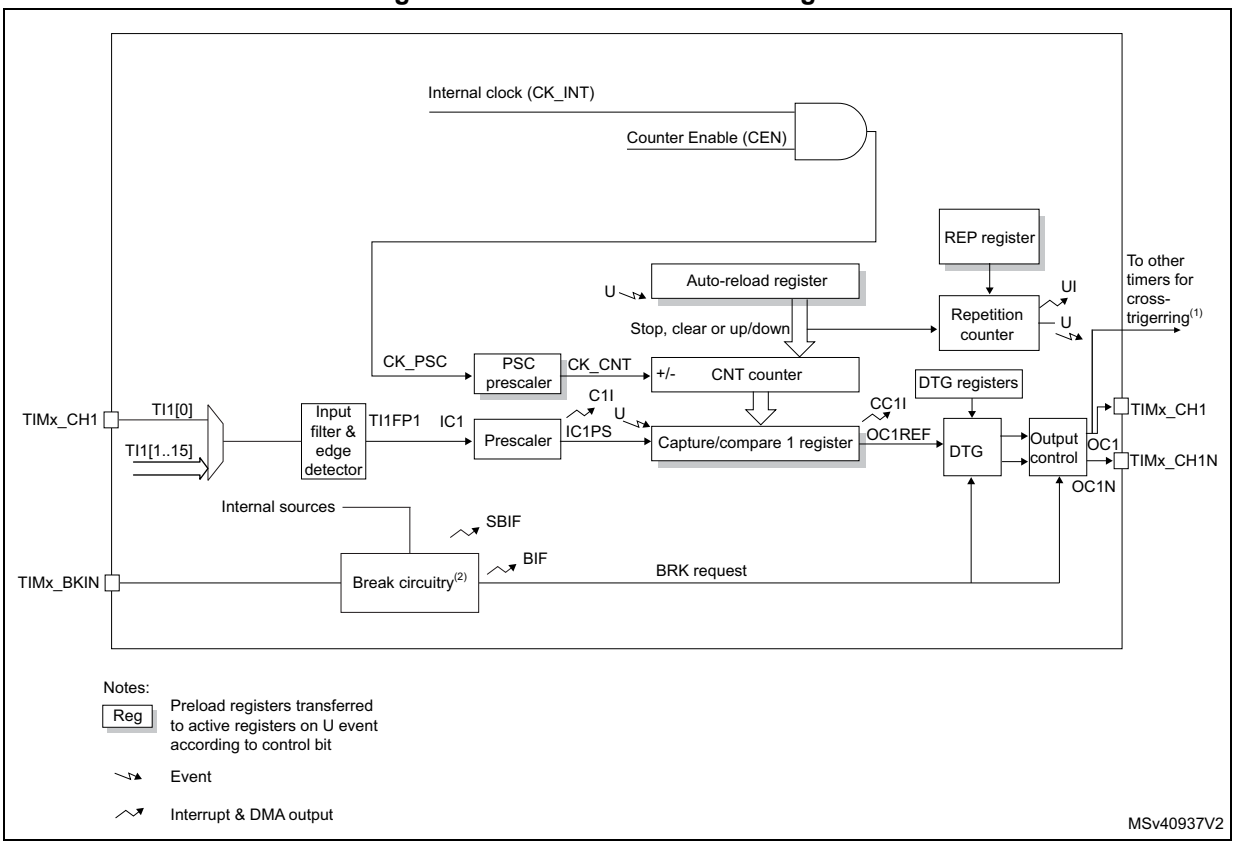
- 16-bit auto-reload upcounter
- 16-bit programmable prescaler used to divide (also “on the fly”) the counter clock frequency by any factor between 1 and 65535
- One channel for:
  - Input capture
  - Output compare
  - PWM generation (edge-aligned mode)
  - One-pulse mode output
- Complementary outputs with programmable dead-time
- Repetition counter to update the timer registers only after a given number of cycles of the counter
- Break input to put the timer’s output signals in the reset state or a known state
- Interrupt/DMA generation on the following events:
  - Update: counter overflow
  - Input capture
  - Output compare
  - Break input

Figure 509. TIM15 block diagram



1. The internal break event source can be:
   - A clock failure event generated by CSS. For further information on the CSS, refer to *Section 8.5.3: Clock security system (CSS)*
   - A PVD output
   - all SRAM and TCM double ECC errors
   - Flash double ECC error
   - Cortex®-M7 LOCKUP (Hardfault) output
   - COMP output

Figure 510. TIM16/TIM17 block diagram



1. This signal can be used as trigger for some slave timer, see *Section 46.4.24: Using timer output as trigger for other timers (TIM16/TIM17)*.
2. The internal break event source can be:
   - A clock failure event generated by CSS. For further information on the CSS, refer to *Section 8.5.3: Clock security system (CSS)*
   - A PVD output
   - all SRAM and TCM double ECC errors
   - Flash double ECC error
   - Cortex®-M7 LOCKUP (Hardfault) output
   - COMP output

46.4 TIM15/TIM16/TIM17 functional description

46.4.1 Time-base unit

The main block of the programmable advanced-control timer is a 16-bit upcounter with its related auto-reload register. The counter clock can be divided by a prescaler.

The counter, the auto-reload register and the prescaler register can be written or read by software. This is true even when the counter is running.

The time-base unit includes:

- Counter register (TIMx_CNT)
- Prescaler register (TIMx_PSC)
- Auto-reload register (TIMx_ARR)
- Repetition counter register (TIMx_RCR)

The auto-reload register is preloaded. Writing to or reading from the auto-reload register accesses the preload register. The content of the preload register are transferred into the shadow register permanently or at each update event (UEV), depending on the auto-reload preload enable bit (ARPE) in TIMx_CR1 register. The update event is sent when the counter reaches the overflow and if the UDIS bit equals 0 in the TIMx_CR1 register. It can also be generated by software. The generation of the update event is described in detailed for each configuration.

The counter is clocked by the prescaler output CK_CNT, which is enabled only when the counter enable bit (CEN) in TIMx_CR1 register is set (refer also to the slave mode controller description to get more details on counter enabling).

Note that the counter starts counting 1 clock cycle after setting the CEN bit in the TIMx_CR1 register.

Prescaler description

The prescaler can divide the counter clock frequency by any factor between 1 and 65536. It is based on a 16-bit counter controlled through a 16-bit register (in the TIMx_PSC register). It can be changed on the fly as this control register is buffered. The new prescaler ratio is taken into account at the next update event.

Figure 511 and *Figure 512* give some examples of the counter behavior when the prescaler ratio is changed on the fly:

Figure 511. Counter timing diagram with prescaler division change from 1 to 2

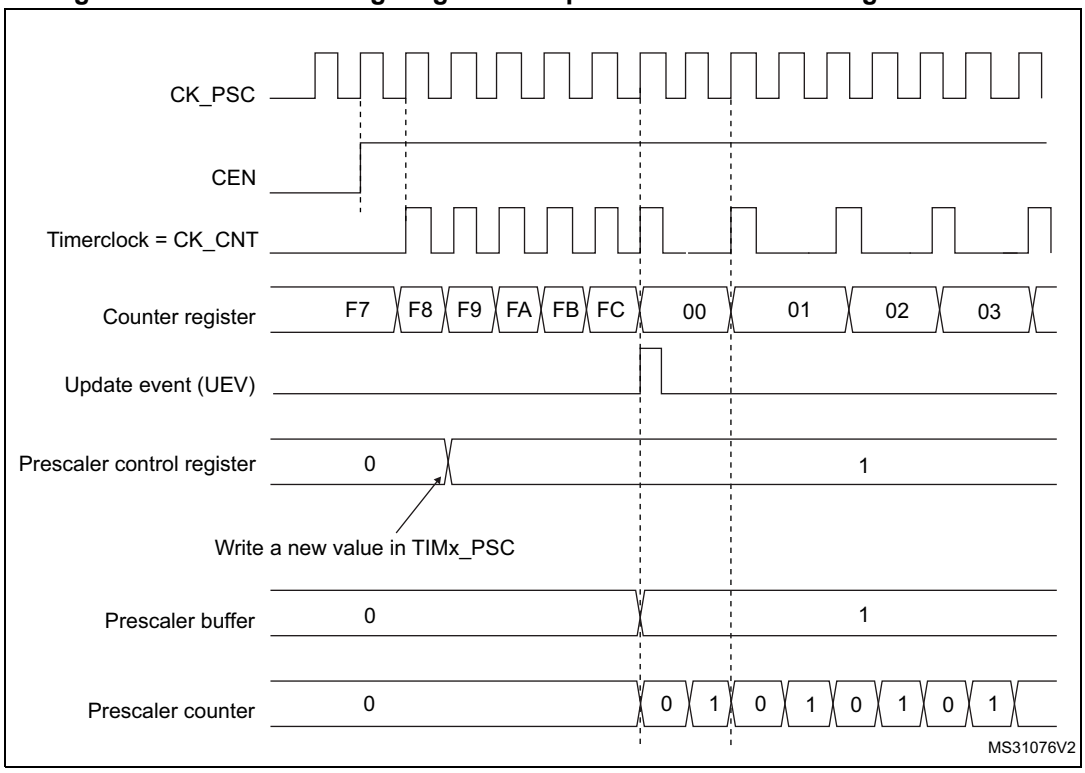
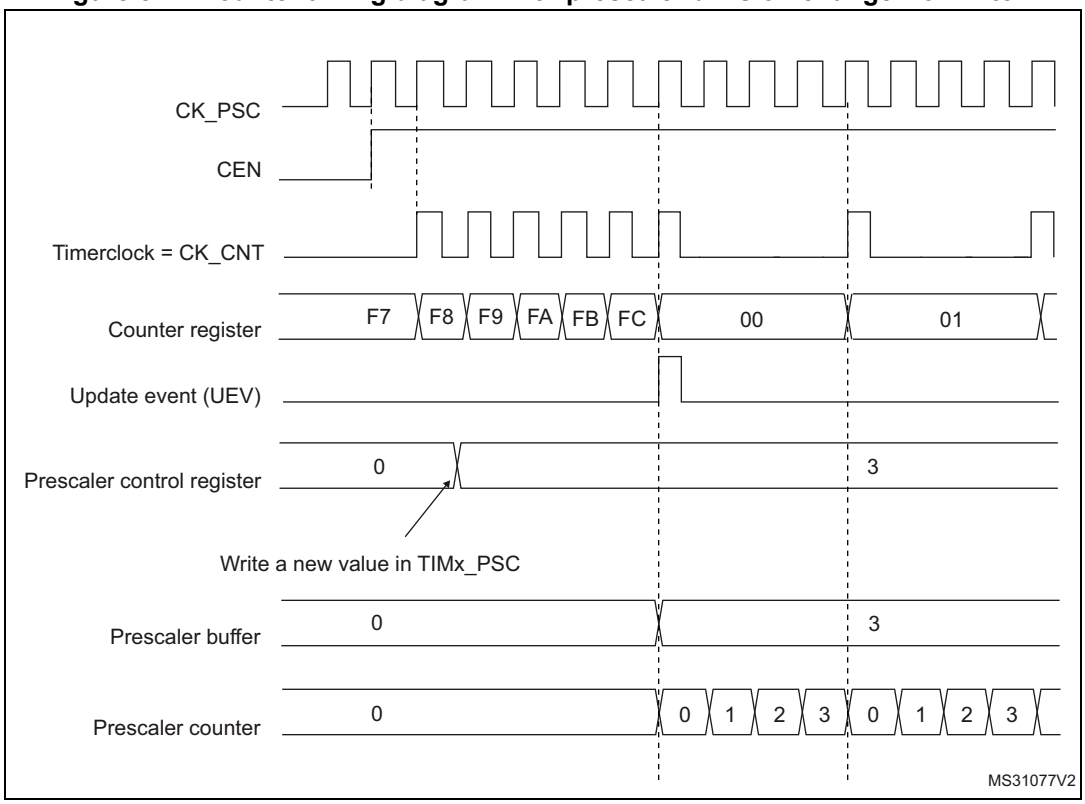


Figure 512. Counter timing diagram with prescaler division change from 1 to 4



46.4.2 Counter modes

Upcounting mode

In upcounting mode, the counter counts from 0 to the auto-reload value (content of the TIMx_ARR register), then restarts from 0 and generates a counter overflow event.

If the repetition counter is used, the update event (UEV) is generated after upcounting is repeated for the number of times programmed in the repetition counter register (TIMx_RCR). Else the update event is generated at each counter overflow.

Setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller) also generates an update event.

The UEV event can be disabled by software by setting the UDIS bit in the TIMx_CR1 register. This is to avoid updating the shadow registers while writing new values in the preload registers. Then no update event occurs until the UDIS bit has been written to 0. However, the counter restarts from 0, as well as the counter of the prescaler (but the prescale rate does not change). In addition, if the URS bit (update request selection) in TIMx_CR1 register is set, setting the UG bit generates an update event UEV but without setting the UIF flag (thus no interrupt or DMA request is sent). This is to avoid generating both update and capture interrupts when clearing the counter on the capture event.

When an update event occurs, all the registers are updated and the update flag (UIF bit in TIMx_SR register) is set (depending on the URS bit):

- The repetition counter is reloaded with the content of TIMx_RCR register,
- The auto-reload shadow register is updated with the preload value (TIMx_ARR),
- The buffer of the prescaler is reloaded with the preload value (content of the TIMx_PSC register).

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR=0x36.

Figure 513. Counter timing diagram, internal clock divided by 1

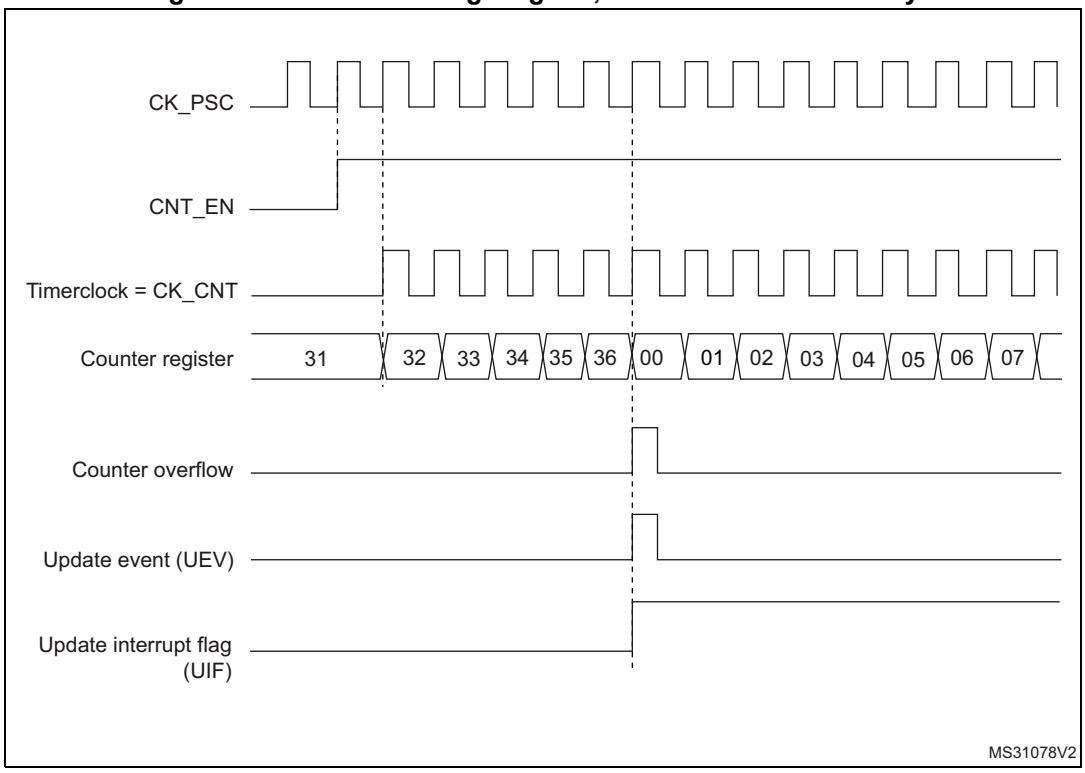


Figure 514. Counter timing diagram, internal clock divided by 2

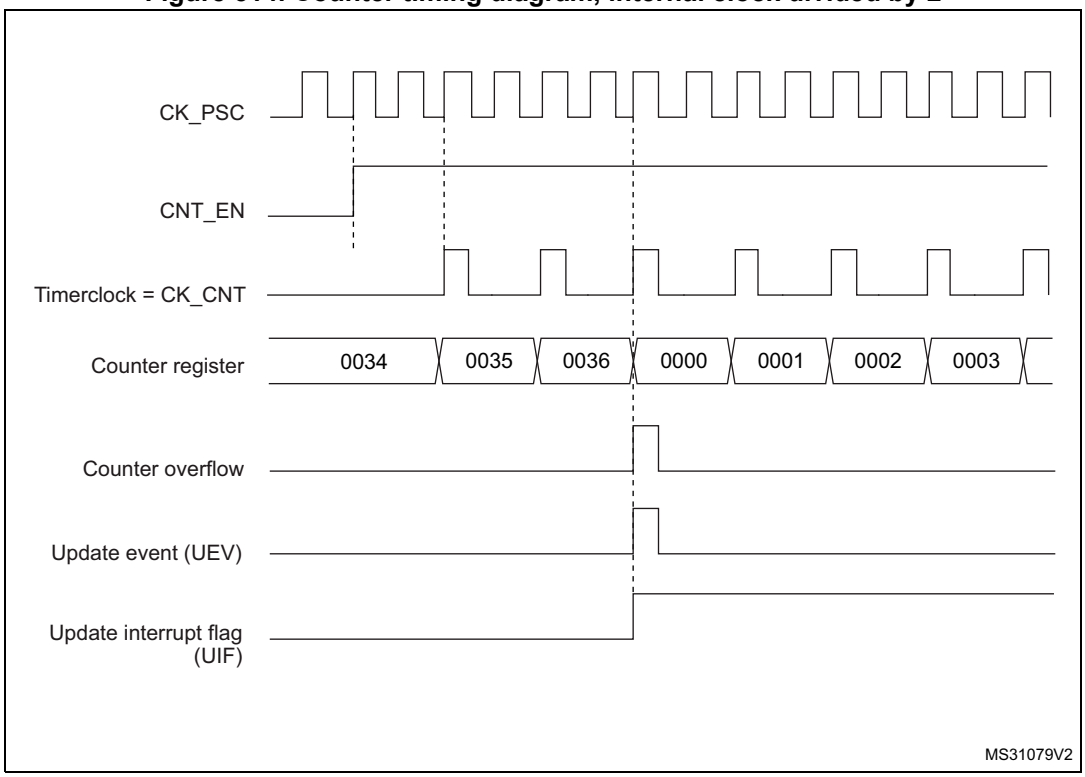


Figure 515. Counter timing diagram, internal clock divided by 4

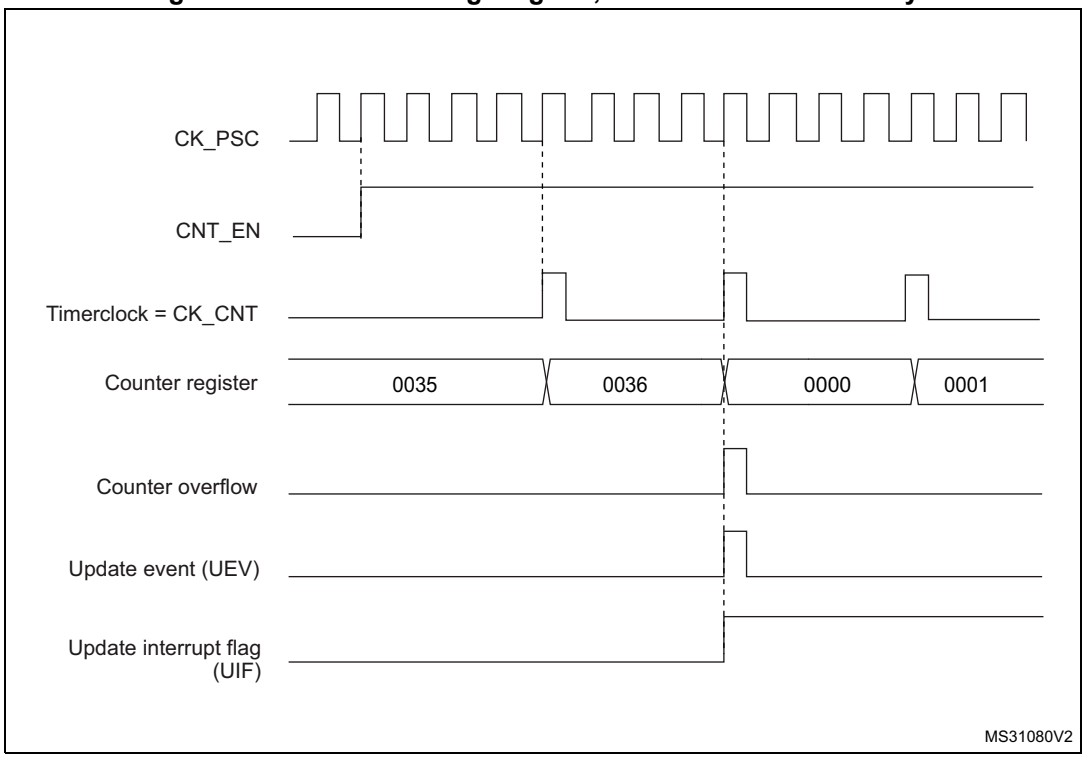


Figure 516. Counter timing diagram, internal clock divided by N

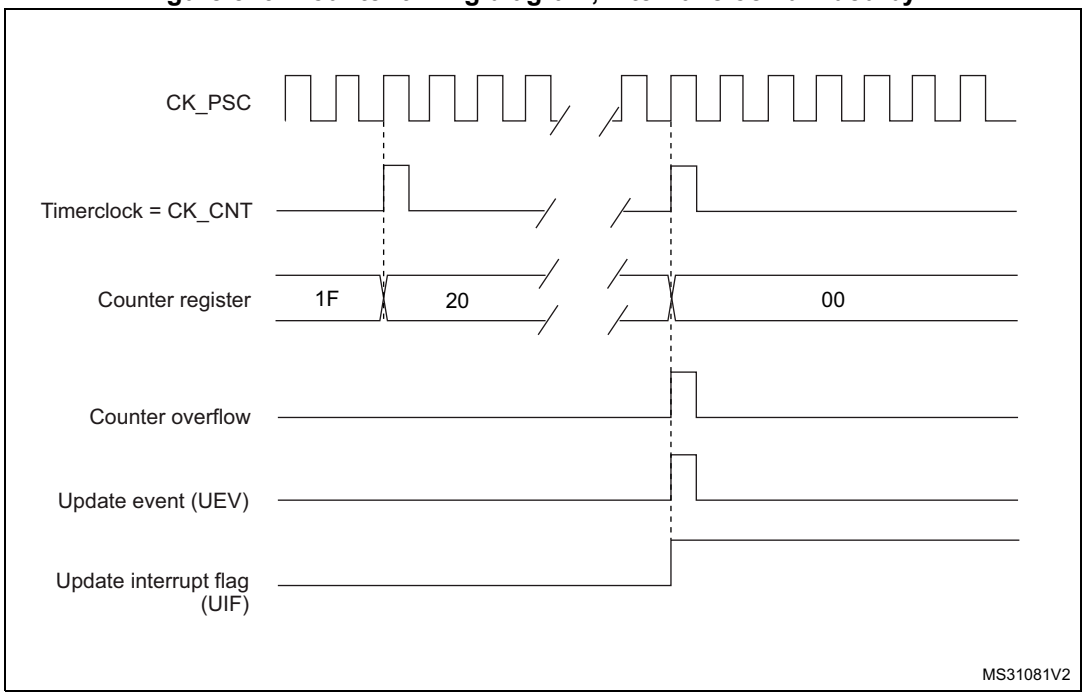


Figure 517. Counter timing diagram, update event when ARPE=0 (TIMx_ARR not preloaded)

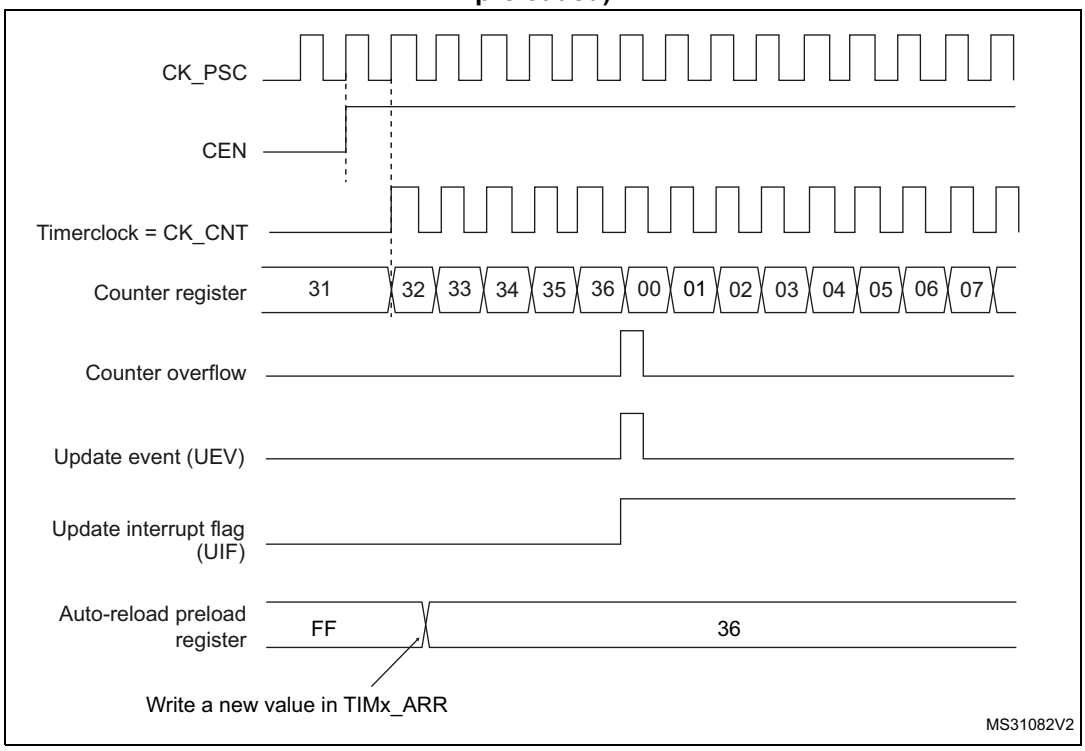
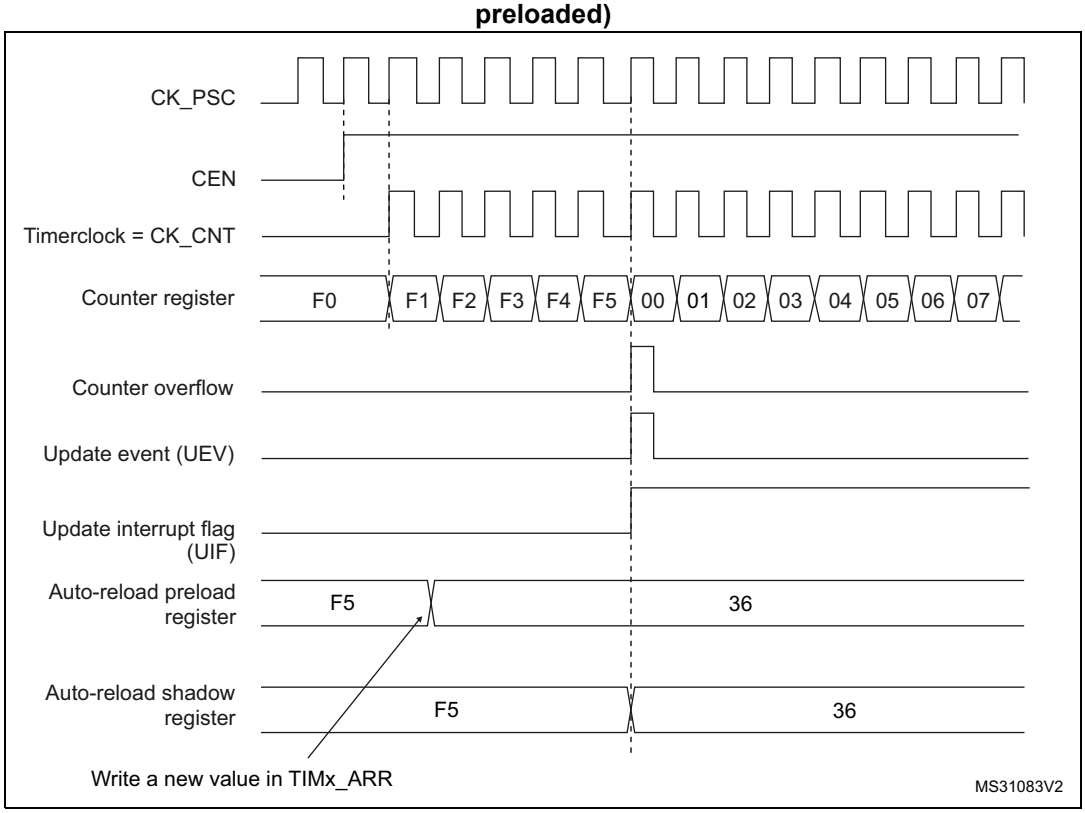


Figure 518. Counter timing diagram, update event when ARPE=1 (TIMx_ARR preloaded)



46.4.3 Repetition counter

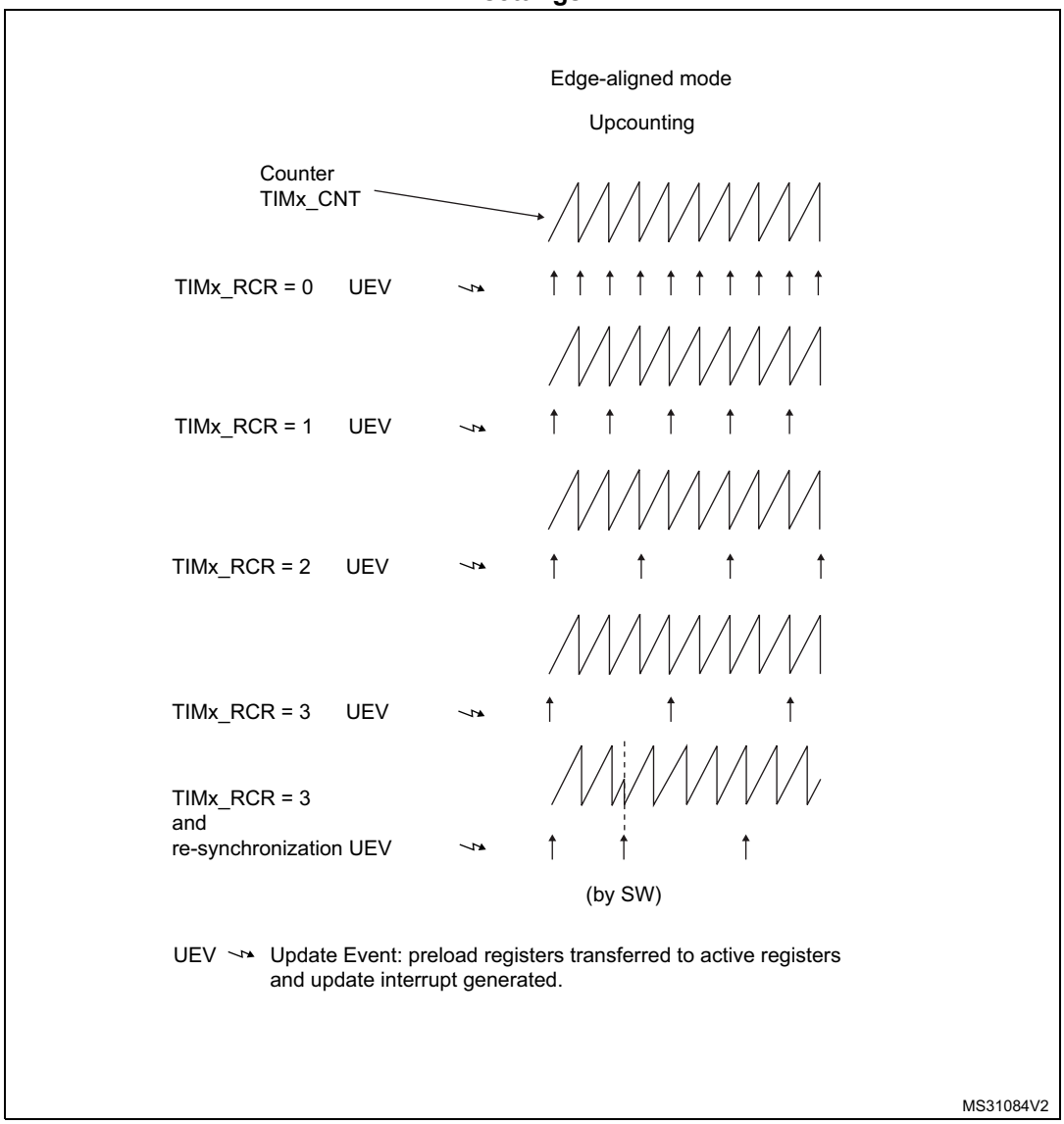
Section 46.4.1: Time-base unit describes how the update event (UEV) is generated with respect to the counter overflows. It is actually generated only when the repetition counter has reached zero. This can be useful when generating PWM signals.

This means that data are transferred from the preload registers to the shadow registers (TIMx_ARR auto-reload register, TIMx_PSC prescaler register, but also TIMx_CCRx capture/compare registers in compare mode) every N counter overflows, where N is the value in the TIMx_RCR repetition counter register.

The repetition counter is decremented at each counter overflow.

The repetition counter is an auto-reload type; the repetition rate is maintained as defined by the TIMx_RCR register value (refer to *Figure 519*). When the update event is generated by software (by setting the UG bit in TIMx_EGR register) or by hardware through the slave mode controller, it occurs immediately whatever the value of the repetition counter is and the repetition counter is reloaded with the content of the TIMx_RCR register.

Figure 519. Update rate examples depending on mode and TIMx_RCR register settings



46.4.4 Clock selection

The counter clock can be provided by the following clock sources:

- Internal clock (CK_INT)
- External clock mode1: external input pin
- Internal trigger inputs (ITRx) (only for TIM15): using one timer as the prescaler for another timer, for example, TIM1 can be configured to act as a prescaler for TIM15. Refer to *Using one timer as prescaler for another timer on page 1700* for more details.

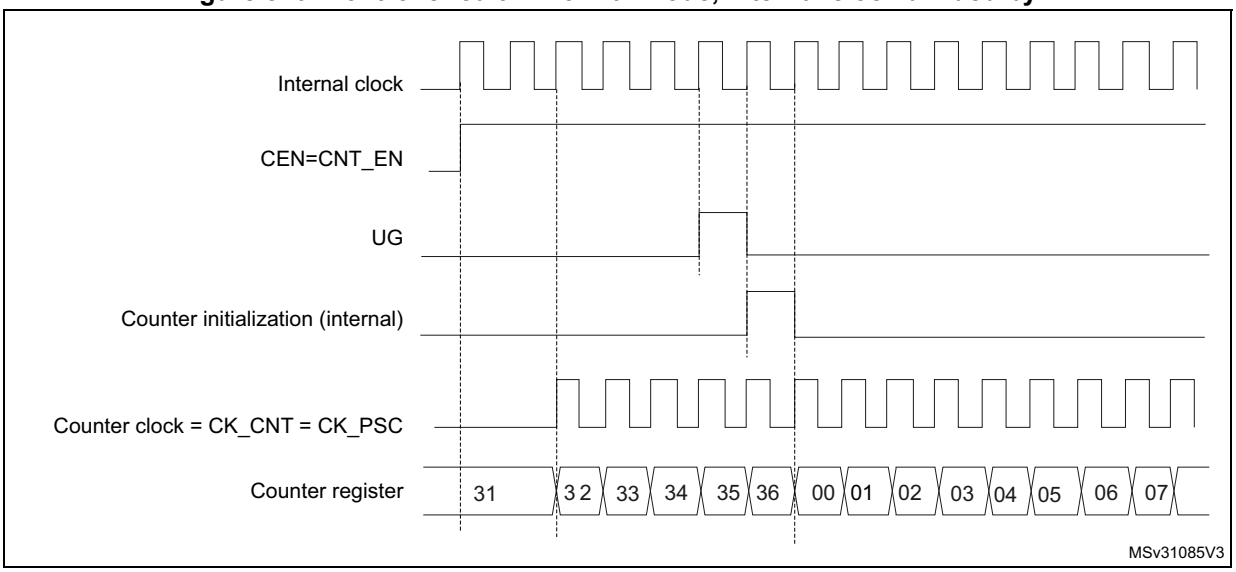
Internal clock source (CK_INT)

If the slave mode controller is disabled (SMS=000), then the CEN (in the TIMx_CR1 register) and UG bits (in the TIMx_EGR register) are actual control bits and can be changed

only by software (except UG which remains cleared automatically). As soon as the CEN bit is written to 1, the prescaler is clocked by the internal clock CK_INT.

Figure 520 shows the behavior of the control circuit and the upcounter in normal mode, without prescaler.

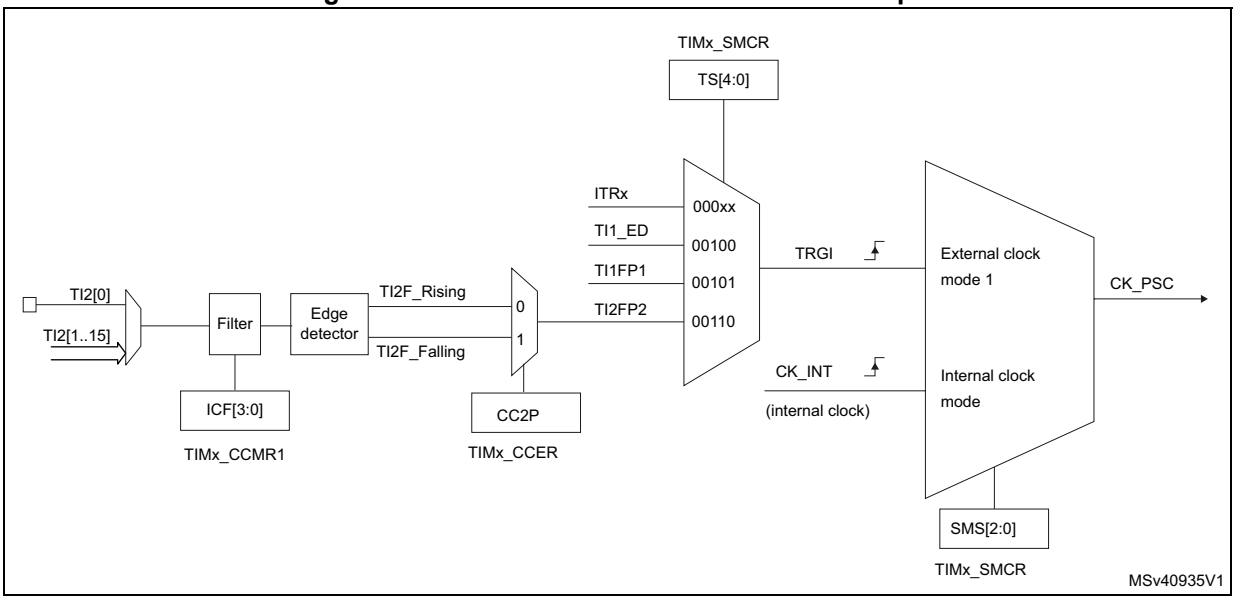
Figure 520. Control circuit in normal mode, internal clock divided by 1



External clock source mode 1

This mode is selected when SMS=111 in the TIMx_SMCR register. The counter can count at each rising or falling edge on a selected input.

Figure 521. TI2 external clock connection example



For example, to configure the upcounter to count in response to a rising edge on the TI2 input, use the following procedure:

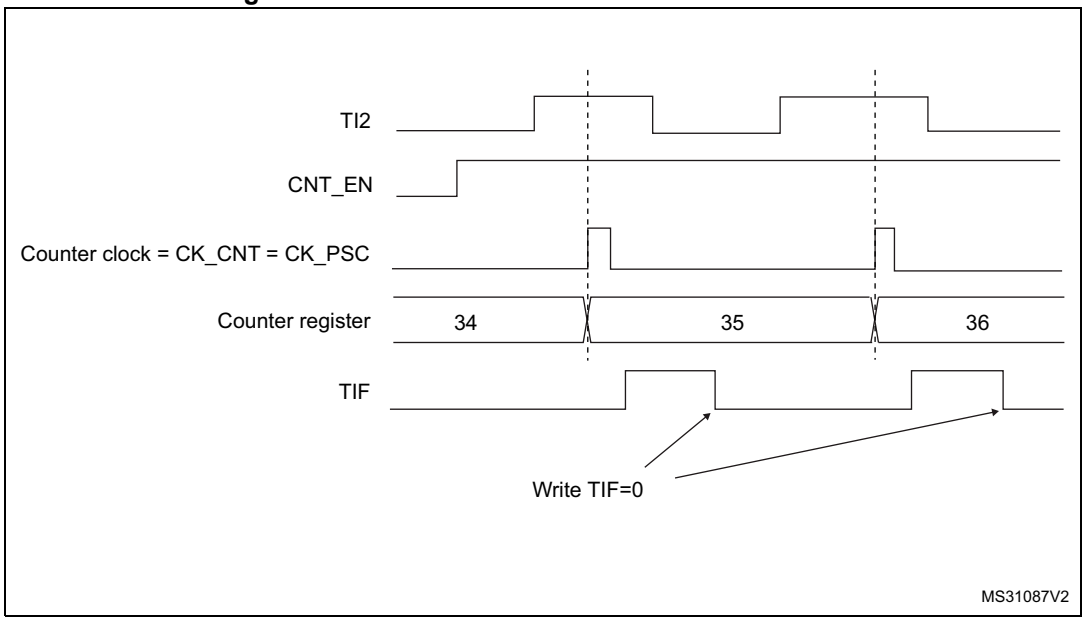
1. Select the proper TI2[x] source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Configure channel 2 to detect rising edges on the TI2 input by writing CC2S = ‘01’ in the TIMx_CCMR1 register.
3. Configure the input filter duration by writing the IC2F[3:0] bits in the TIMx_CCMR1 register (if no filter is needed, keep IC2F=0000).
4. Select rising edge polarity by writing CC2P=0 in the TIMx_CCER register.
5. Configure the timer in external clock mode 1 by writing SMS=111 in the TIMx_SMCR register.
6. Select TI2 as the trigger input source by writing TS=00110 in the TIMx_SMCR register.
7. Enable the counter by writing CEN=1 in the TIMx_CR1 register.

Note: The capture prescaler is not used for triggering, so it does not need to be configured.

When a rising edge occurs on TI2, the counter counts once and the TIF flag is set.

The delay between the rising edge on TI2 and the actual clock of the counter is due to the resynchronization circuit on TI2 input.

Figure 522. Control circuit in external clock mode 1



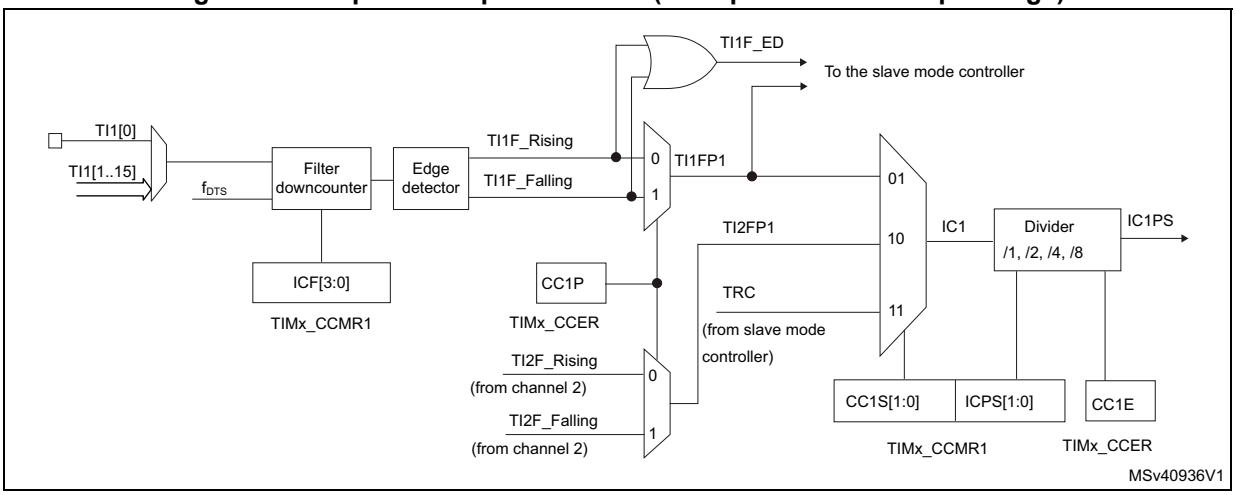
46.4.5 Capture/compare channels

Each Capture/Compare channel is built around a capture/compare register (including a shadow register), a input stage for capture (with digital filter, multiplexing and prescaler) and an output stage (with comparator and output control).

Figure 523 to *Figure 526* give an overview of one Capture/Compare channel.

The input stage samples the corresponding TIx input to generate a filtered signal TIxF. Then, an edge detector with polarity selection generates a signal (TIxFPx) which can be used as trigger input by the slave mode controller or as the capture command. It is prescaled before the capture register (ICxPS).

Figure 523. Capture/compare channel (example: channel 1 input stage)



The output stage generates an intermediate waveform which is then used for reference: OCxRef (active high). The polarity acts at the end of the chain.

Figure 524. Capture/compare channel 1 main circuit

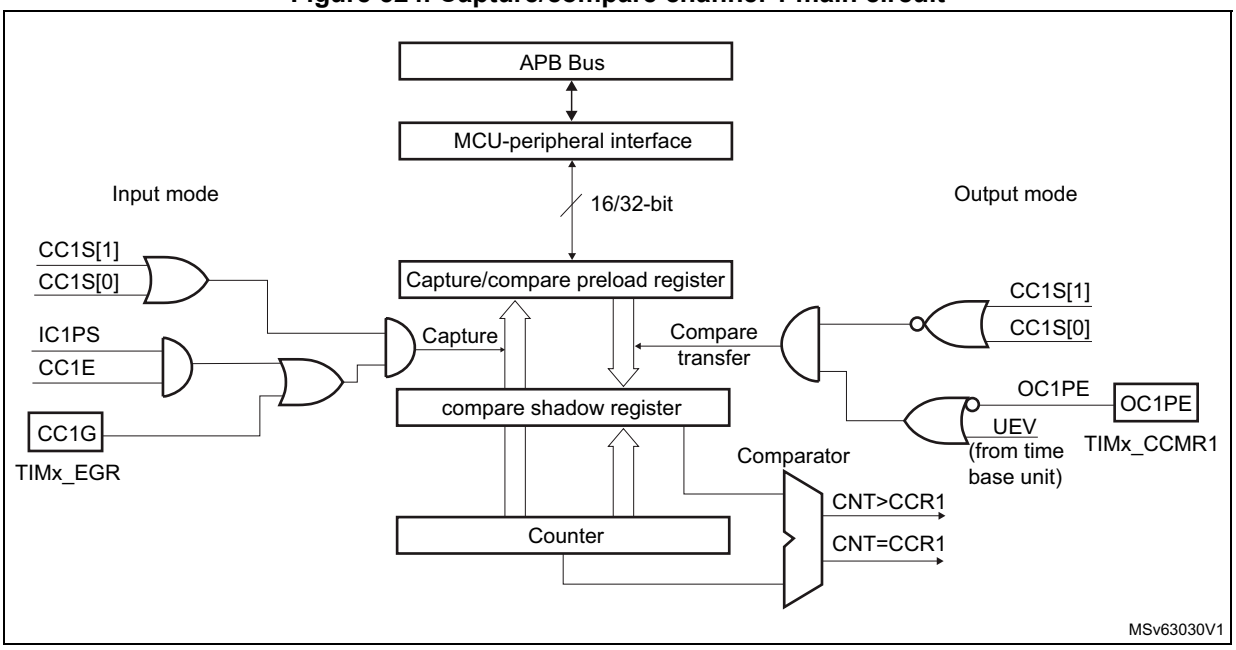


Figure 525. Output stage of capture/compare channel (channel 1)

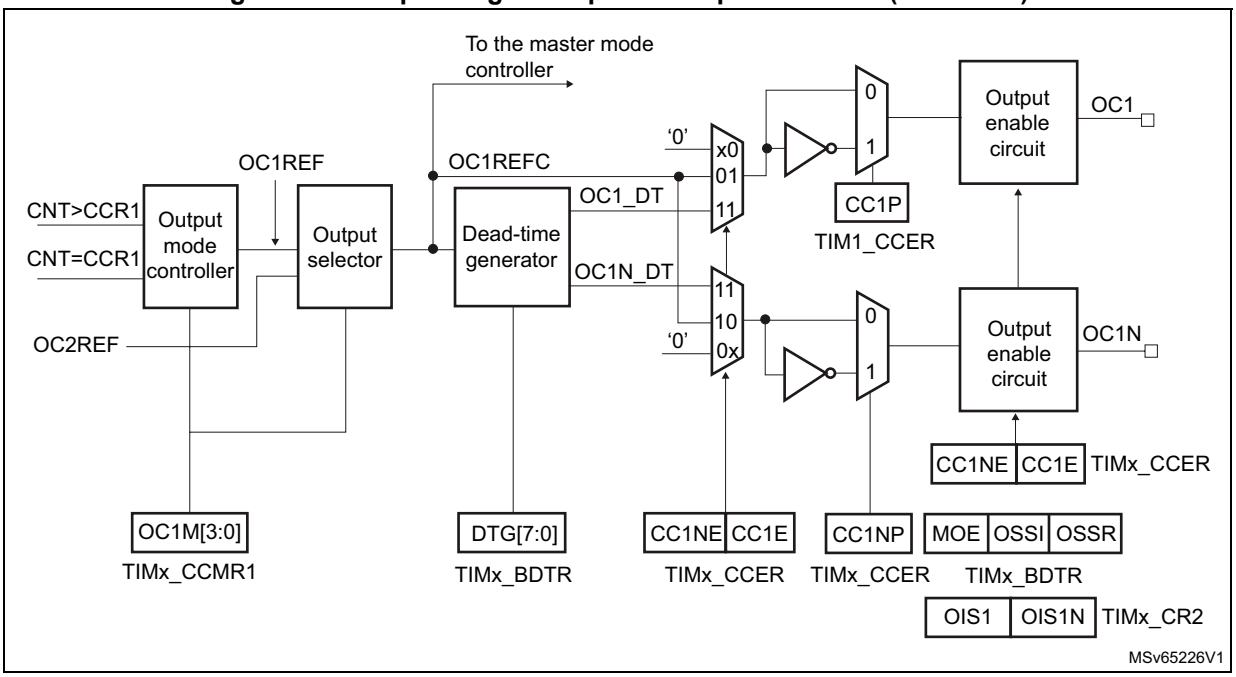
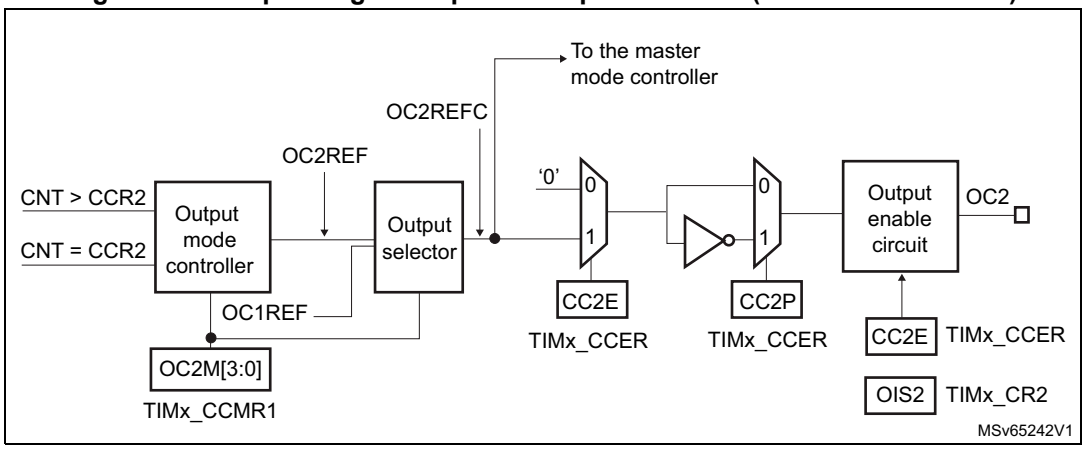


Figure 526. Output stage of capture/compare channel (channel 2 for TIM15)



The capture/compare block is made of one preload register and one shadow register. Write and read always access the preload register.

In capture mode, captures are actually done in the shadow register, which is copied into the preload register.

In compare mode, the content of the preload register is copied into the shadow register which is compared to the counter.

46.4.6 Input capture mode

In Input capture mode, the Capture/Compare registers (TIMx_CCRx) are used to latch the value of the counter after a transition detected by the corresponding ICx signal. When a capture occurs, the corresponding CCXIF flag (TIMx_SR register) is set and an interrupt or a DMA request can be sent if they are enabled. If a capture occurs while the CCxIF flag was

already high, then the over-capture flag CCxOF (TIMx_SR register) is set. CCxIF can be cleared by software by writing it to '0' or by reading the captured data stored in the TIMx_CCRx register. CCxOF is cleared when it is written with 0.

The following example shows how to capture the counter value in TIMx_CCR1 when TI1 input rises. To do this, use the following procedure:

1. Select the proper TI1x source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input: TIMx_CCR1 must be linked to the TI1 input, so write the CC1S bits to 01 in the TIMx_CCMR1 register. As soon as CC1S becomes different from 00, the channel is configured in input and the TIMx_CCR1 register becomes read-only.
3. Program the appropriate input filter duration in relation with the signal connected to the timer (when the input is one of the TIx (ICxF bits in the TIMx_CCMRx register). Let's imagine that, when toggling, the input signal is not stable during at least 5 internal clock cycles. We must program a filter duration longer than these 5 clock cycles. We can validate a transition on TI1 when 8 consecutive samples with the new level have been detected (sampled at f_{DTS} frequency). Then write IC1F bits to 0011 in the TIMx_CCMR1 register.
4. Select the edge of the active transition on the TI1 channel by writing CC1P bit to 0 in the TIMx_CCER register (rising edge in this case).
5. Program the input prescaler. In our example, we wish the capture to be performed at each valid transition, so the prescaler is disabled (write IC1PS bits to '00' in the TIMx_CCMR1 register).
6. Enable capture from the counter into the capture register by setting the CC1E bit in the TIMx_CCER register.
7. If needed, enable the related interrupt request by setting the CC1IE bit in the TIMx_DIER register, and/or the DMA request by setting the CC1DE bit in the TIMx_DIER register.

When an input capture occurs:

- The TIMx_CCR1 register gets the value of the counter on the active transition.
- CC1IF flag is set (interrupt flag). CC1OF is also set if at least two consecutive captures occurred whereas the flag was not cleared.
- An interrupt is generated depending on the CC1IE bit.
- A DMA request is generated depending on the CC1DE bit.

In order to handle the overcapture, it is recommended to read the data before the overcapture flag. This is to avoid missing an overcapture which could happen after reading the flag and before reading the data.

Note: IC interrupt and/or DMA requests can be generated by software by setting the corresponding CCxG bit in the TIMx_EGR register.

46.4.7 PWM input mode (only for TIM15)

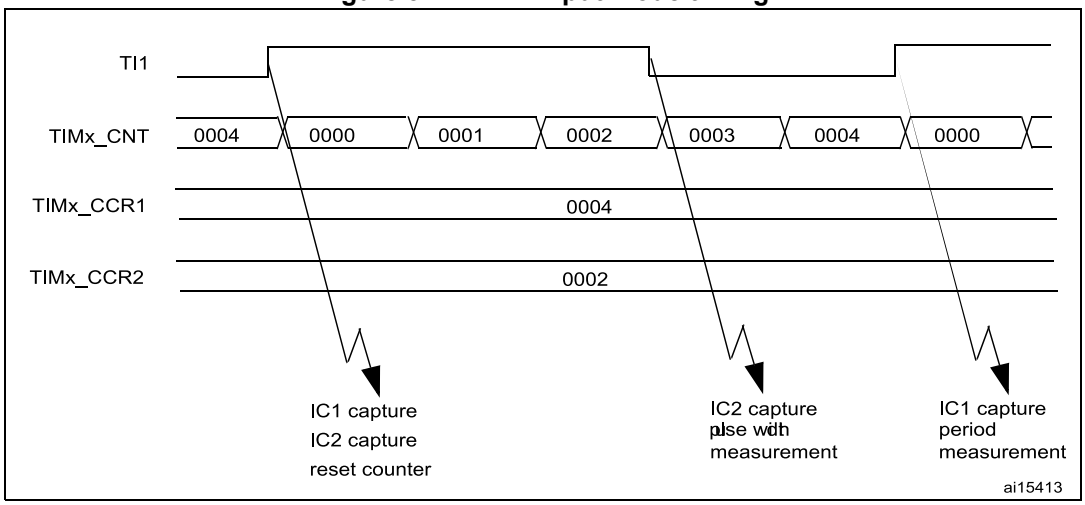
This mode is a particular case of input capture mode. The procedure is the same except:

- Two ICx signals are mapped on the same TIx input.
- These 2 ICx signals are active on edges with opposite polarity.
- One of the two TIxFP signals is selected as trigger input and the slave mode controller is configured in reset mode.

For example, one can measure the period (in TIMx_CCR1 register) and the duty cycle (in TIMx_CCR2 register) of the PWM applied on TI1 using the following procedure (depending on CK_INT frequency and prescaler value):

1. Select the proper TI1[x] source (internal or external) with the TI1SEL[3:0] bits in the TIMx_TISEL register.
2. Select the active input for TIMx_CCR1: write the CC1S bits to 01 in the TIMx_CCMR1 register (TI1 selected).
3. Select the active polarity for TI1FP1 (used both for capture in TIMx_CCR1 and counter clear): write the CC1P and CC1NP bits to '0' (active on rising edge).
4. Select the active input for TIMx_CCR2: write the CC2S bits to 10 in the TIMx_CCMR1 register (TI1 selected).
5. Select the active polarity for TI1FP2 (used for capture in TIMx_CCR2): write the CC2P and CC2NP bits to '10' (active on falling edge).
6. Select the valid trigger input: write the TS bits to 00101 in the TIMx_SMCR register (TI1FP1 selected).
7. Configure the slave mode controller in reset mode: write the SMS bits to 100 in the TIMx_SMCR register.
8. Enable the captures: write the CC1E and CC2E bits to '1' in the TIMx_CCER register.

Figure 527. PWM input mode timing



1. The PWM input mode can be used only with the TIMx_CH1/TIMx_CH2 signals due to the fact that only TI1FP1 and TI2FP2 are connected to the slave mode controller.

46.4.8 Forced output mode

In output mode (CCxS bits = 00 in the TIMx_CCMRx register), each output compare signal (OCxREF and then OCx/OCxN) can be forced to active or inactive level directly by software, independently of any comparison between the output compare register and the counter.

To force an output compare signal (OCXREF/OCx) to its active level, one just needs to write 101 in the OCxM bits in the corresponding TIMx_CCMRx register. Thus OCXREF is forced high (OCxREF is always active high) and OCx get opposite value to CCxP polarity bit.

For example: CCxP=0 (OCx active high) => OCx is forced to high level.

The OCxREF signal can be forced low by writing the OCxM bits to 100 in the TIMx_CCMRx register.

Anyway, the comparison between the TIMx_CCRx shadow register and the counter is still performed and allows the flag to be set. Interrupt and DMA requests can be sent accordingly. This is described in the output compare mode section below.

46.4.9 Output compare mode

This function is used to control an output waveform or indicating when a period of time has elapsed.

When a match is found between the capture/compare register and the counter, the output compare function:

- Assigns the corresponding output pin to a programmable value defined by the output compare mode (OCxM bits in the TIMx_CCMRx register) and the output polarity (CCxP bit in the TIMx_CCER register). The output pin can keep its level (OCXM=000), be set active (OCxM=001), be set inactive (OCxM=010) or can toggle (OCxM=011) on match.
- Sets a flag in the interrupt status register (CCxIF bit in the TIMx_SR register).
- Generates an interrupt if the corresponding interrupt mask is set (CCXIE bit in the TIMx_DIER register).
- Sends a DMA request if the corresponding enable bit is set (CCxDE bit in the TIMx_DIER register, CCDS bit in the TIMx_CR2 register for the DMA request selection).

The TIMx_CCRx registers can be programmed with or without preload registers using the OCxPE bit in the TIMx_CCMRx register.

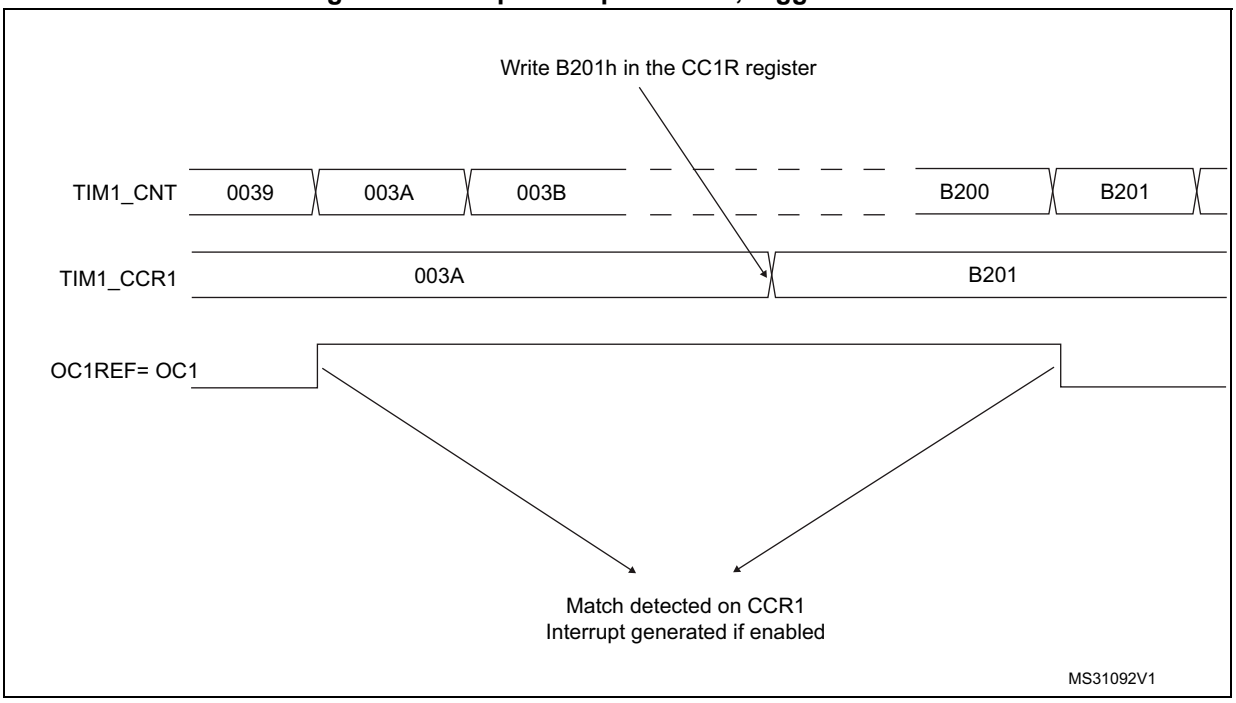
In output compare mode, the update event UEV has no effect on OCxREF and OCx output. The timing resolution is one count of the counter. Output compare mode can also be used to output a single pulse (in One-pulse mode).

Procedure

1. Select the counter clock (internal, external, prescaler).
2. Write the desired data in the TIMx_ARR and TIMx_CCRx registers.
3. Set the CCxIE bit if an interrupt request is to be generated.
4. Select the output mode. For example:
   - Write OCxM = 011 to toggle OCx output pin when CNT matches CCRx
   - Write OCxPE = 0 to disable preload register
   - Write CCxP = 0 to select active high polarity
   - Write CCxE = 1 to enable the output
5. Enable the counter by setting the CEN bit in the TIMx_CR1 register.

The TIMx_CCRx register can be updated at any time by software to control the output waveform, provided that the preload register is not enabled (OCxPE='0', else TIMx_CCRx shadow register is updated only at the next update event UEV). An example is given in *Figure 528*.

Figure 528. Output compare mode, toggle on OC1



46.4.10 PWM mode

Pulse Width Modulation mode allows a signal to be generated with a frequency determined by the value of the TIMx_ARR register and a duty cycle determined by the value of the TIMx_CCRx register.

The PWM mode can be selected independently on each channel (one PWM per OCx output) by writing ‘110’ (PWM mode 1) or ‘111’ (PWM mode 2) in the OCxM bits in the TIMx_CCMRx register. The corresponding preload register must be enabled by setting the OCxPE bit in the TIMx_CCMRx register, and eventually the auto-reload preload register (in upcounting or center-aligned modes) by setting the ARPE bit in the TIMx_CR1 register.

As the preload registers are transferred to the shadow registers only when an update event occurs, before starting the counter, all registers must be initialized by setting the UG bit in the TIMx_EGR register.

OCx polarity is software programmable using the CCxP bit in the TIMx_CCER register. It can be programmed as active high or active low. OCx output is enabled by a combination of the CCxE, CCxNE, MOE, OSSI and OSSR bits (TIMx_CCER and TIMx_BDTR registers). Refer to the TIMx_CCER register description for more details.

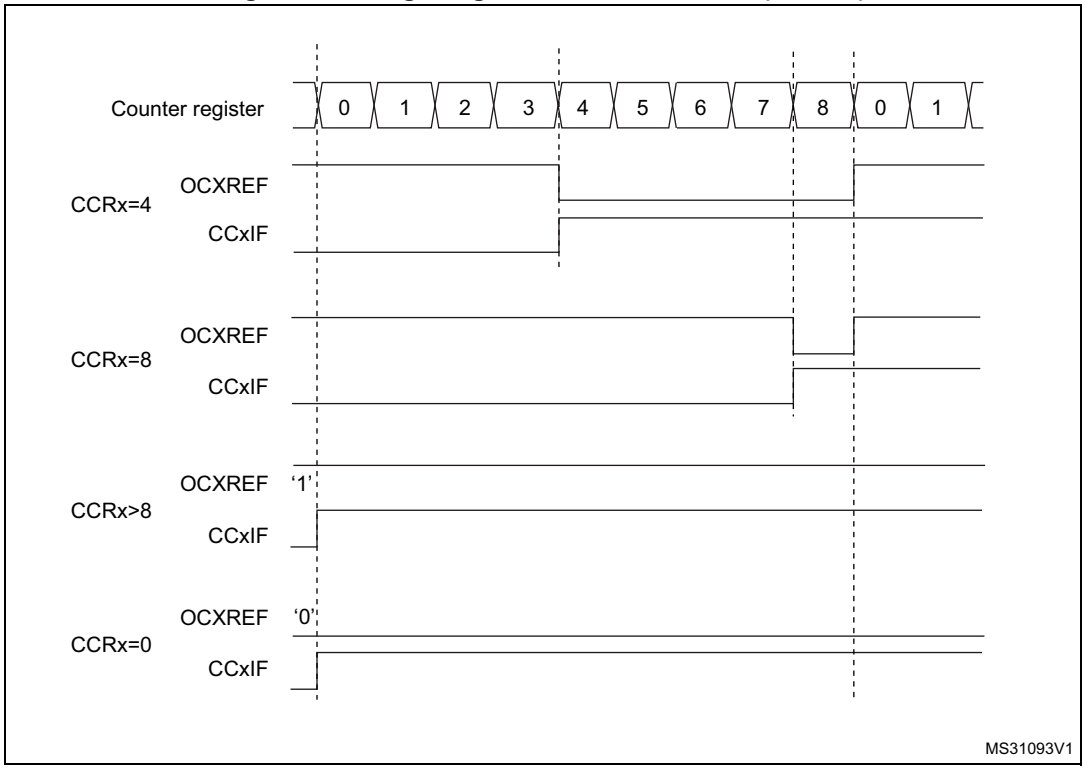
In PWM mode (1 or 2), TIMx_CNT and TIMx_CCRx are always compared to determine whether TIMx_CCRx ≤ TIMx_CNT or TIMx_CNT ≤ TIMx_CCRx (depending on the direction of the counter).

The TIM15/TIM16/TIM17 are capable of upcounting only. Refer to *Upcounting mode on page 1799*.

In the following example, we consider PWM mode 1. The reference PWM signal OCxREF is high as long as TIMx_CNT < TIMx_CCRx else it becomes low. If the compare value in TIMx_CCRx is greater than the auto-reload value (in TIMx_ARR) then OCxREF is held at

'1'. If the compare value is 0 then OCxRef is held at '0'. *Figure 529* shows some edge-aligned PWM waveforms in an example where TIMx_ARR=8.

Figure 529. Edge-aligned PWM waveforms (ARR=8)



46.4.11 Combined PWM mode (TIM15 only)

Combined PWM mode allows two edge or center-aligned PWM signals to be generated with programmable delay and phase shift between respective pulses. While the frequency is determined by the value of the TIMx_ARR register, the duty cycle and delay are determined by the two TIMx_CCRx registers. The resulting signals, OCxREFC, are made of an OR or AND logical combination of two reference PWMs:

- OC1REFC (or OC2REFC) is controlled by the TIMx_CCR1 and TIMx_CCR2 registers

Combined PWM mode can be selected independently on two channels (one OCx output per pair of CCR registers) by writing '1100' (Combined PWM mode 1) or '1101' (Combined PWM mode 2) in the OCxM bits in the TIMx_CCMRx register.

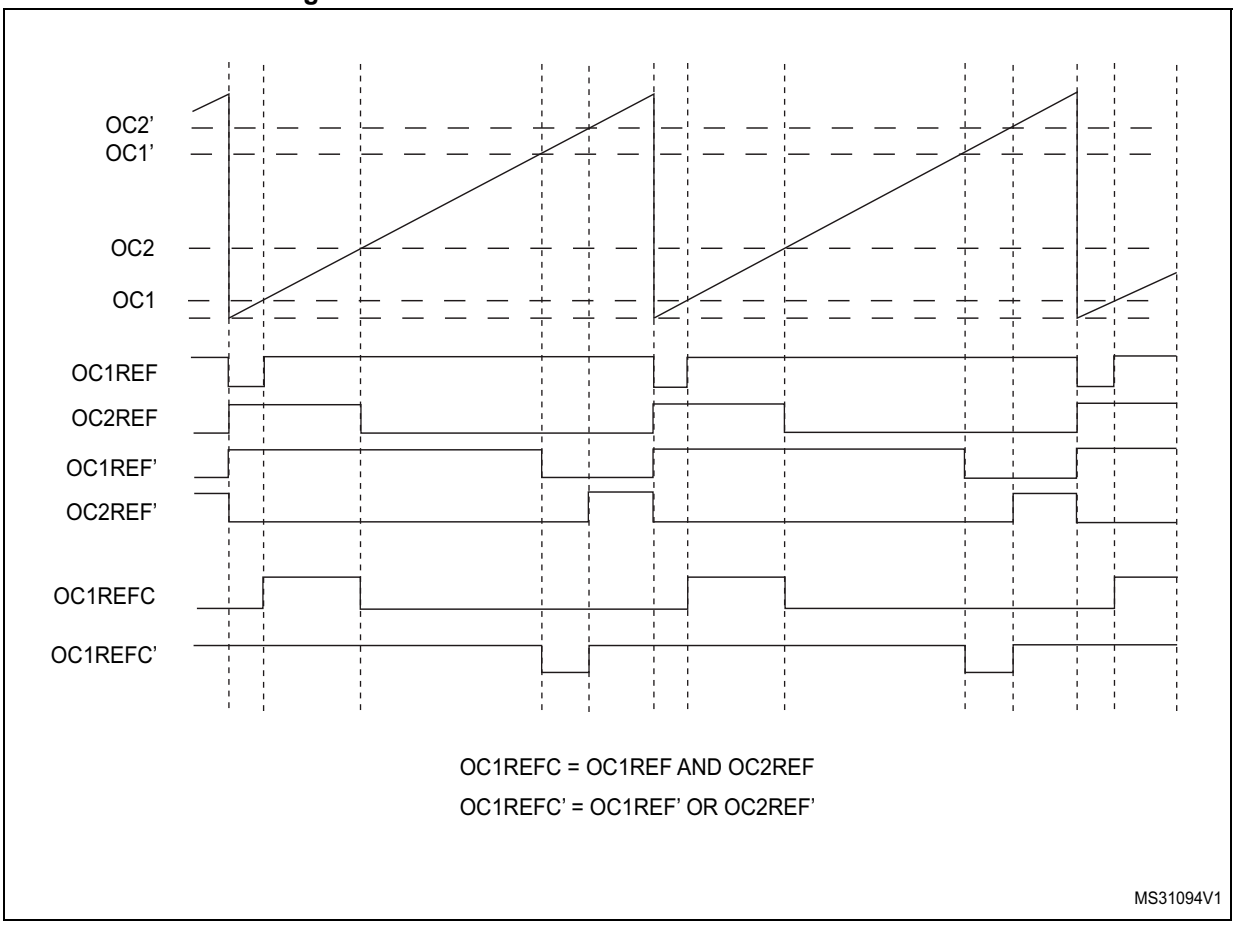
When a given channel is used as a combined PWM channel, its complementary channel must be configured in the opposite PWM mode (for instance, one in Combined PWM mode 1 and the other in Combined PWM mode 2).

Note: The OCxM[3:0] bit field is split into two parts for compatibility reasons, the most significant bit is not contiguous with the 3 least significant ones.

Figure 530 represents an example of signals that can be generated using Asymmetric PWM mode, obtained with the following configuration:

- Channel 1 is configured in Combined PWM mode 2,
- Channel 2 is configured in PWM mode 1,

Figure 530. Combined PWM mode on channel 1 and 2



46.4.12 Complementary outputs and dead-time insertion

The TIM15/TIM16/TIM17 general-purpose timers can output one complementary signal and manage the switching-off and switching-on of the outputs.

This time is generally known as dead-time and it has to be adjusted depending on the devices that are connected to the outputs and their characteristics (intrinsic delays of level-shifters, delays due to power switches...)

The polarity of the outputs (main output OCx or complementary OCxN) can be selected independently for each output. This is done by writing to the CCxP and CCxNP bits in the TIMx_CCER register.

The complementary signals OCx and OCxN are activated by a combination of several control bits: the CCxE and CCxNE bits in the TIMx_CCER register and the MOE, OISx, OISxN, OSSI and OSSR bits in the TIMx_BDTR and TIMx_CR2 registers. Refer to *Table 367: Output control bits for complementary OCx and OCxN channels with break feature (TIM16/17) on page 1870* for more details. In particular, the dead-time is activated when switching to the idle state (MOE falling down to 0).

Dead-time insertion is enabled by setting both CCxE and CCxNE bits, and the MOE bit if the break circuit is present. There is one 10-bit dead-time generator for each channel. From a

reference waveform OCxREF, it generates 2 outputs OCx and OCxN. If OCx and OCxN are active high:

- The OCx output signal is the same as the reference signal except for the rising edge, which is delayed relative to the reference rising edge.
- The OCxN output signal is the opposite of the reference signal except for the rising edge, which is delayed relative to the reference falling edge.

If the delay is greater than the width of the active output (OCx or OCxN) then the corresponding pulse is not generated.

The following figures show the relationships between the output signals of the dead-time generator and the reference signal OCxREF. (we suppose CCxP=0, CCxNP=0, MOE=1, CCxE=1 and CCxNE=1 in these examples)

Figure 531. Complementary output with dead-time insertion.

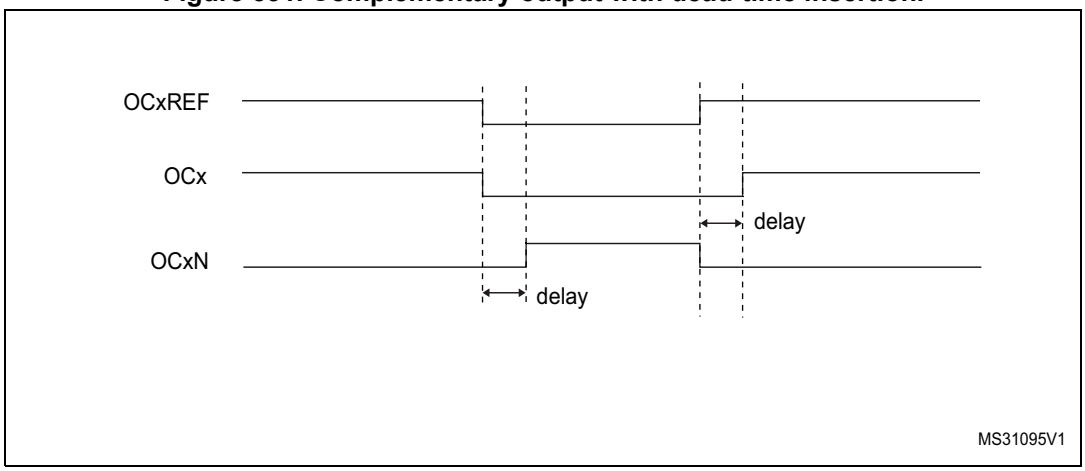


Figure 532. Dead-time waveforms with delay greater than the negative pulse.

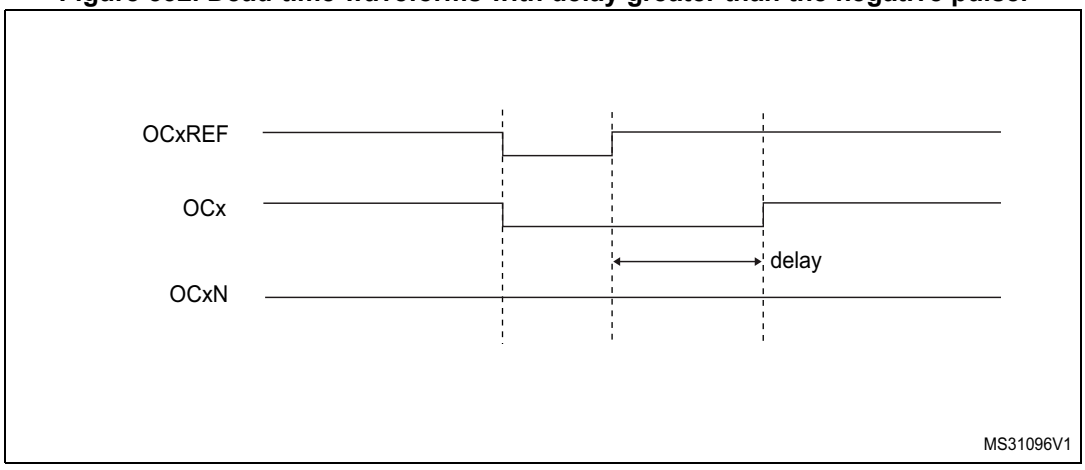
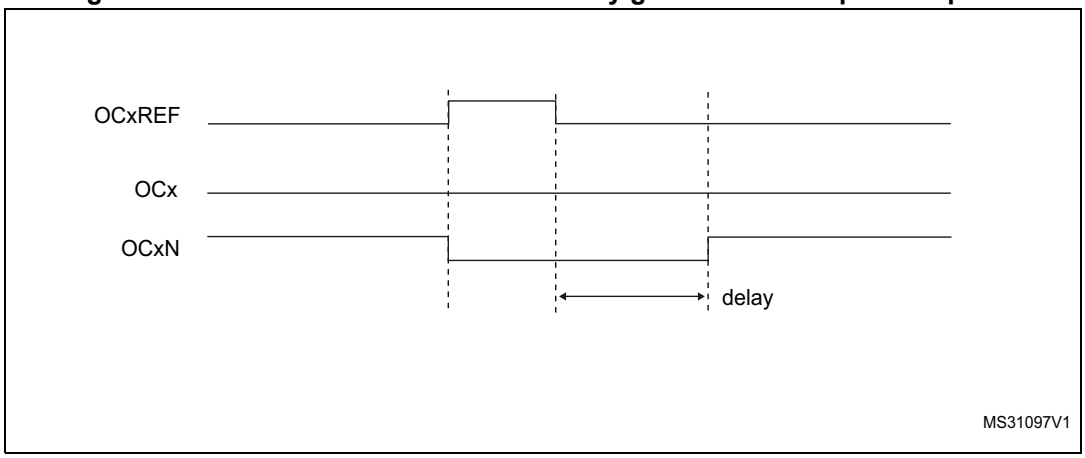


Figure 533. Dead-time waveforms with delay greater than the positive pulse.



The dead-time delay is the same for each of the channels and is programmable with the DTG bits in the TIMx_BDTR register. Refer to *Section 46.6.14: TIMx break and dead-time register (TIMx_BDTR)(x = 16 to 17) on page 1873* for delay calculation.

Re-directing OCxREF to OCx or OCxN

In output mode (forced, output compare or PWM), OCxREF can be re-directed to the OCx output or to OCxN output by configuring the CCxE and CCxNE bits in the TIMx_CCER register.

This allows a specific waveform to be sent (such as PWM or static active level) on one output while the complementary remains at its inactive level. Other alternative possibilities are to have both outputs at inactive level or both outputs active and complementary with dead-time.

Note: When only OCxN is enabled (CCxE=0, CCxNE=1), it is not complemented and becomes active as soon as OCxREF is high. For example, if CCxNP=0 then OCxN=OCxRef. On the other hand, when both OCx and OCxN are enabled (CCxE=CCxNE=1) OCx becomes active when OCxREF is high whereas OCxN is complemented and becomes active when OCxREF is low.

46.4.13 Using the break function

The purpose of the break function is to protect power switches driven by PWM signals generated with the TIM15/TIM16/TIM17 timers. The break input is usually connected to fault outputs of power stages and 3-phase inverters. When activated, the break circuitry shuts down the PWM outputs and forces them to a predefined safe state.

The break channel gathers both system-level fault (clock failure, parity error,...) and application fault (from input pins and built-in comparator), and can force the outputs to a predefined level (either active or inactive) after a deadtime duration.

The output enable signal and output levels during break are depending on several control bits:

- the MOE bit in TIMx_BDTR register allows to enable /disable the outputs by software and is reset in case of break or break2 event.
- the OSSI bit in the TIMx_BDTR register defines whether the timer controls the output in inactive state or releases the control to the GPIO controller (typically to have it in Hi-Z mode)
- the OISx and OISxN bits in the TIMx_CR2 register which are setting the output shut-down level, either active or inactive. The OCx and OCxN outputs cannot be set both to active level at a given time, whatever the OISx and OISxN values. Refer to *Table 365: Output control bits for complementary OCx and OCxN channels with break feature (TIM15) on page 1848* for more details.

When exiting from reset, the break circuit is disabled and the MOE bit is low. The break function is enabled by setting the BKE bit in the TIMx_BDTR register. The break input polarity can be selected by configuring the BKP bit in the same register. BKE and BKP can be modified at the same time. When the BKE and BKP bits are written, a delay of 1 APB clock cycle is applied before the writing is effective. Consequently, it is necessary to wait 1 APB clock period to correctly read back the bit after the write operation.

Because MOE falling edge can be asynchronous, a resynchronization circuit has been inserted between the actual signal (acting on the outputs) and the synchronous control bit (accessed in the TIMx_BDTR register). It results in some delays between the asynchronous and the synchronous signals. In particular, if MOE is set to 1 whereas it was low, a delay must be inserted (dummy instruction) before reading it correctly. This is because the write acts on the asynchronous signal whereas the read reflects the synchronous signal.

A programmable filter (BKF[3:0] bits in the TIMx_BDTR register allows to filter out spurious events.

The break can be generated from multiple sources which can be individually enabled and with programmable edge sensitivity, using the TIMx_OR2 register.

The sources for break (BRK) channel are:

- An external source connected to one of the BKIN pin (as per selection done in the GPIO alternate function registers), with polarity selection and optional digital filtering
- An internal source:
  - the output from a comparator, with polarity selection and optional digital filtering
  - the analog watchdog output of the DFSDM1 peripheral
  - A system break:

    - the Cortex®-M7 LOCKUP output

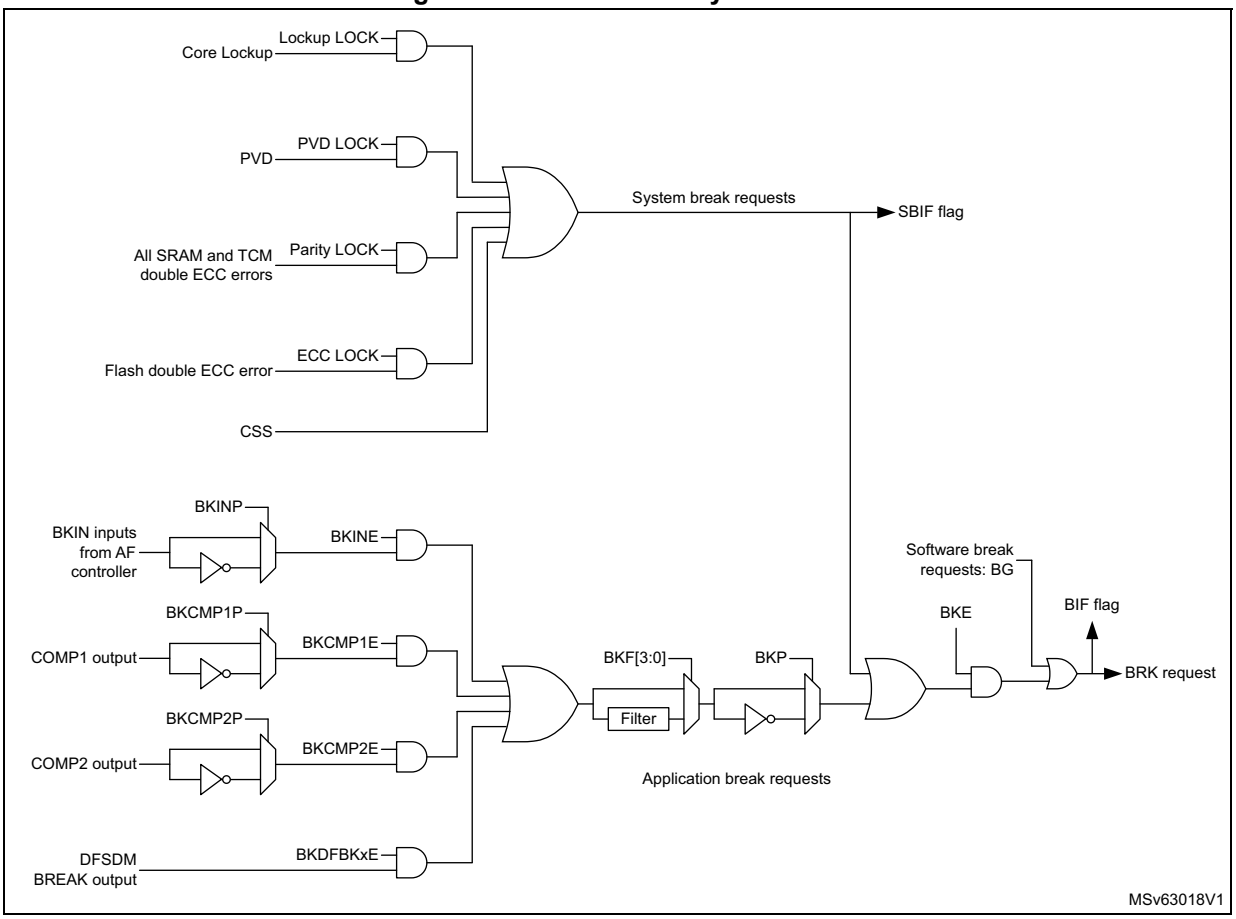
    - the PVD output

    - all SRAM and TCM double ECC errors (AXI-SRAM, ITCM, DTCM, SRAM1, SRAM2, SRAM3, SRAM4, BKRAM, refer to SYSCFG_CFGR register for details)

    - a Flash double ECC error

    - a clock failure event generated by the CSS detector

Figure 534. Break circuitry overview



Caution: An asynchronous (clockless) operation is only guaranteed when the programmable filter is disabled. If it is enabled, a fail safe clock mode (example, using the internal PLL and/or the CSS) must be used to guarantee that break events are handled.

When a break occurs (selected level on the break input):

- The MOE bit is cleared asynchronously, putting the outputs in inactive state, idle state or even releasing the control to the GPIO (selected by the OSSI bit). This feature functions even if the MCU oscillator is off.
- Each output channel is driven with the level programmed in the OISx bit in the TIMx_CR2 register as soon as MOE=0. If OSSI=0, the timer releases the output control (taken over by the GPIO) else the enable output remains high.
- When complementary outputs are used:
  - The outputs are first put in reset state inactive state (depending on the polarity). This is done asynchronously so that it works even if no clock is provided to the timer.
  - If the timer clock is still present, then the dead-time generator is reactivated in order to drive the outputs with the level programmed in the OISx and OISxN bits after a dead-time. Even in this case, OCx and OCxN cannot be driven to their

active level together. Note that because of the resynchronization on MOE, the dead-time duration is a bit longer than usual (around 2 ck_tim clock cycles).

– If OSSI=0 then the timer releases the enable outputs (taken over by the GPIO which forces a Hi-Z state) else the enable outputs remain or become high as soon as one of the CCxE or CCxNE bits is high.

- The break status flag (BIF bit in the TIMx_SR register) is set. An interrupt can be generated if the BIE bit in the TIMx_DIER register is set.
- If the AOE bit in the TIMx_BDTR register is set, the MOE bit is automatically set again at the next update event UEV. This can be used to perform a regulation, for instance. Else, MOE remains low until it is written with 1 again. In this case, it can be used for security and the break input can be connected to an alarm from power drivers, thermal sensors or any security components.

Note: If the MOE is reset by the CPU while the AOE bit is set, the outputs will be in idle state and forced to inactive level or Hi-Z depending on OSSI value.
If both the MOE and AOE bits are reset by the CPU, the outputs will be in disabled state and driven with the level programmed in the OISx bit in the TIMx_CR2 register.

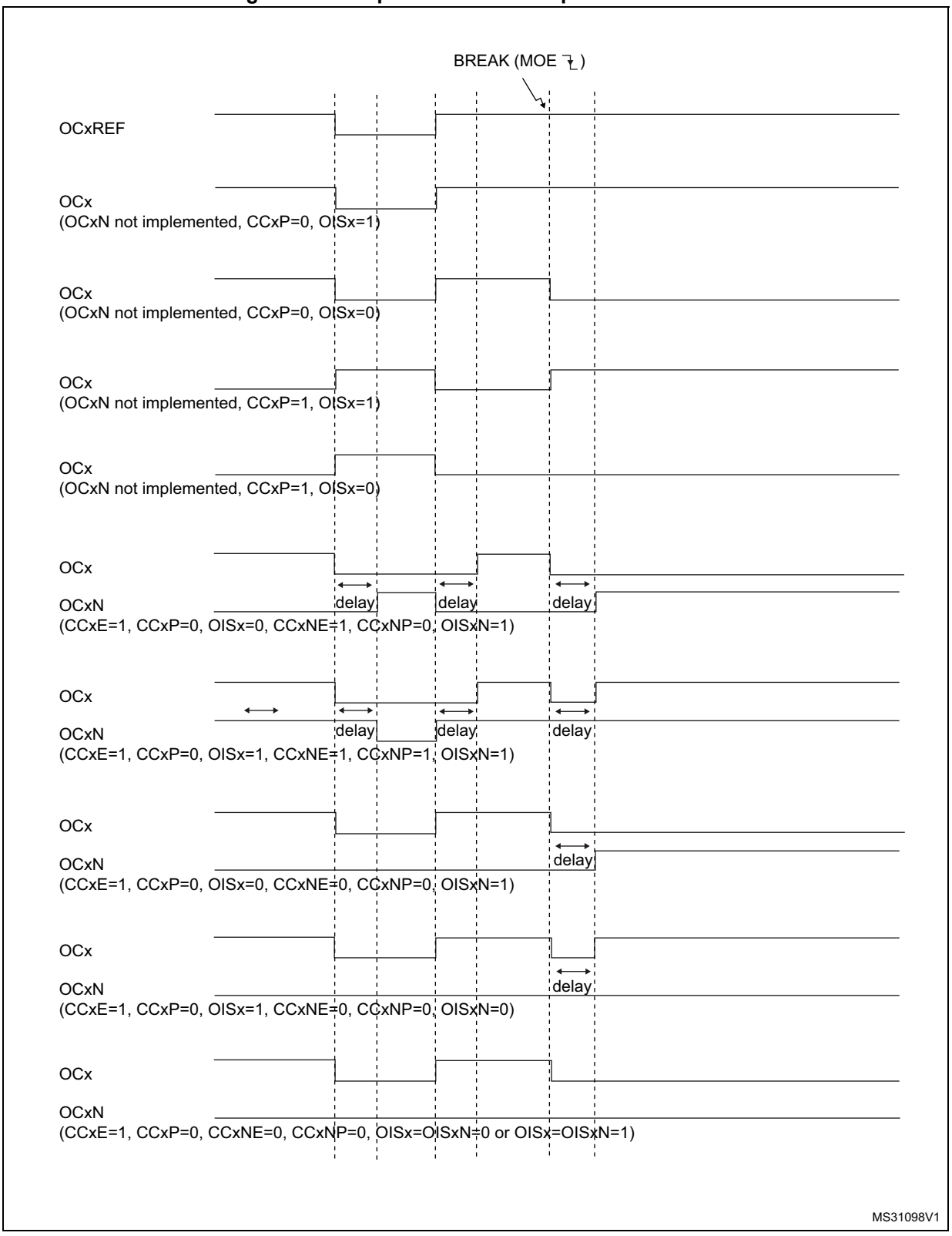
Note: The break inputs is acting on level. Thus, the MOE cannot be set while the break input is active (neither automatically nor by software). In the meantime, the status flag BIF cannot be cleared.

The break can be generated by the BRK input which has a programmable polarity and an enable bit BKE in the TIMx_BDTR register.

In addition to the break input and the output management, a write protection has been implemented inside the break circuit to safeguard the application. It allows the configuration of several parameters to be freezed (dead-time duration, OCx/OCxN polarities and state when disabled, OCxM configurations, break enable and polarity). The protection can be selected among 3 levels with the LOCK bits in the TIMx_BDTR register. Refer to *Section 46.6.14: TIMx break and dead-time register (TIMx_BDTR)(x = 16 to 17) on page 1873*. The LOCK bits can be written only once after an MCU reset.

The *Figure 535* shows an example of behavior of the outputs in response to a break.

Figure 535. Output behavior in response to a break



46.4.14 Bidirectional break inputs

The TIM15/TIM16/TIM17 are featuring bidirectional break I/Os, as represented on *Figure 536*.

They allow the following:

- A board-level global break signal available for signaling faults to external MCUs or gate drivers, with a unique pin being both an input and an output status pin
- Internal break sources and multiple external open drain comparator outputs ORed together to trigger a unique break event, when multiple internal and external break sources must be merged

The break input is configured in bidirectional mode using the BKBID bit in the TIMxBDTR register. The BKBID programming bit can be locked in read-only mode using the LOCK bits in the TIMxBDTR register (in LOCK level 1 or above).

The bidirectional mode requires the I/O to be configured in open-drain mode with active low polarity (using BKINP and BKP bits). Any break request coming either from system (e.g. CSS), from on-chip peripherals or from break inputs forces a low level on the break input to signal the fault event. The bidirectional mode is inhibited if the polarity bits are not correctly set (active high polarity), for safety purposes.

The break software event (BG) also causes the break I/O to be forced to '0' to indicate to the external components that the timer has entered in break state. However, this is valid only if the break is enabled (BKE = 1). When a software break event is generated with BKE = 0, the outputs are put in safe state and the break flag is set, but there is no effect on the break I/O.

A safe disarming mechanism prevents the system to be definitively locked-up (a low level on the break input triggers a break which enforces a low level on the same input).

When the BKDSRM bit is set to 1, this releases the break output to clear a fault signal and to give the possibility to re-arm the system.

At no point the break protection circuitry can be disabled:

- The break input path is always active: a break event is active even if the BKDSRM bit is set and the open drain control is released. This prevents the PWM output to be re-started as long as the break condition is present.
- The BKDSRM bit cannot disarm the break protection as long as the outputs are enabled (MOE bit is set) (see *Table 363*)

Table 363. Break protection disarming conditions

MOE	BKDIR	BKDSRM	Break protection state
0	0	X	Armed
0	1	0	Armed
0	1	1	Disarmed
1	X	X	Armed

Arming and re-arming break circuitry

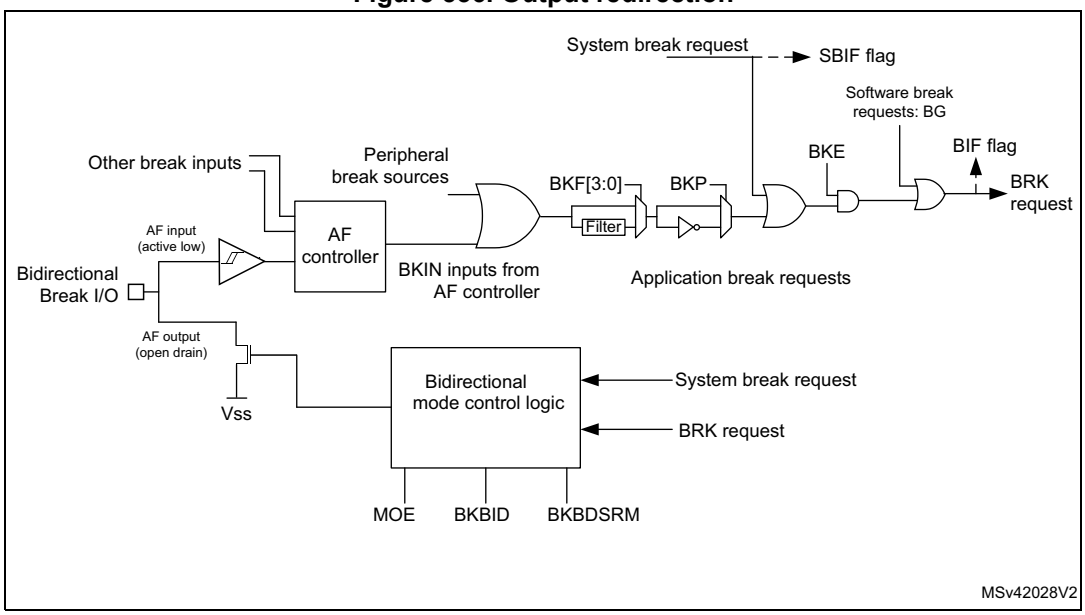
The break circuitry (in input or bidirectional mode) is armed by default (peripheral reset configuration).

The following procedure must be followed to re-arm the protection after a break event:

- The BKDSRM bit must be set to release the output control
- The software must wait until the system break condition disappears (if any) and clear the SBIF status flag (or clear it systematically before re-arming)
- The software must poll the BKDSRM bit until it is cleared by hardware (when the application break condition disappears)

From this point, the break circuitry is armed and active, and the MOE bit can be set to re-enable the PWM outputs.

Figure 536. Output redirection



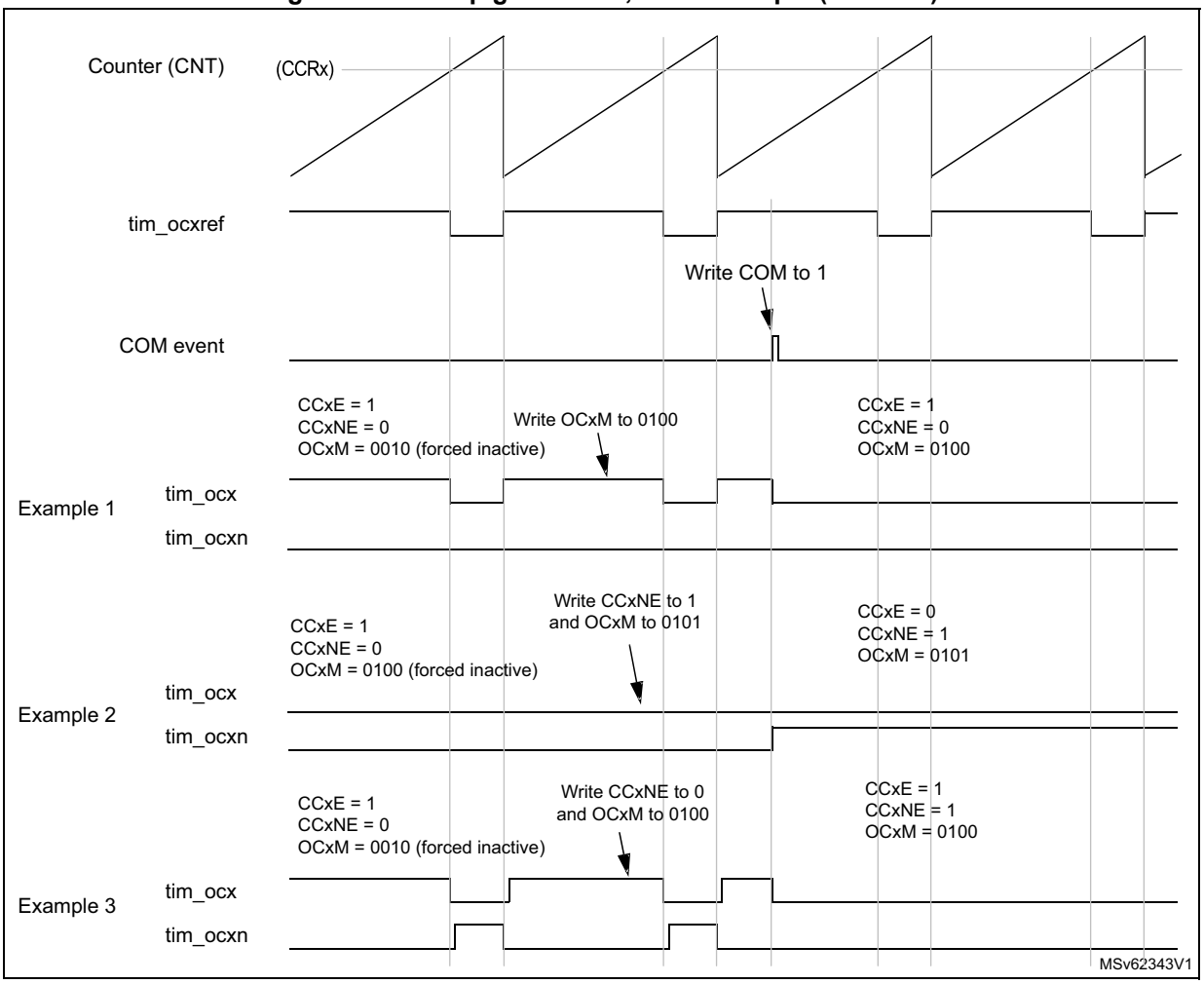
46.4.15 6-step PWM generation

When complementary outputs are used on a channel, preload bits are available on the OCxM, CCxE and CCxNE bits. The preload bits are transferred to the shadow bits at the COM commutation event. Thus one can program in advance the configuration for the next step and change the configuration of all the channels at the same time. COM can be generated by software by setting the COM bit in the TIMx_EGR register or by hardware (on tim_trgi rising edge).

A flag is set when the COM event occurs (COMIF bit in the TIMx_SR register), which can generate an interrupt (if the COMIE bit is set in the TIMx_DIER register) or a DMA request (if the COMDE bit is set in the TIMx_DIER register).

The *Figure 537* describes the behavior of the tim_ocx and tim_ocxn outputs when a COM event occurs, in 3 different examples of programmed configurations.

Figure 537. 6-step generation, COM example (OSSR=1)



46.4.16 One-pulse mode

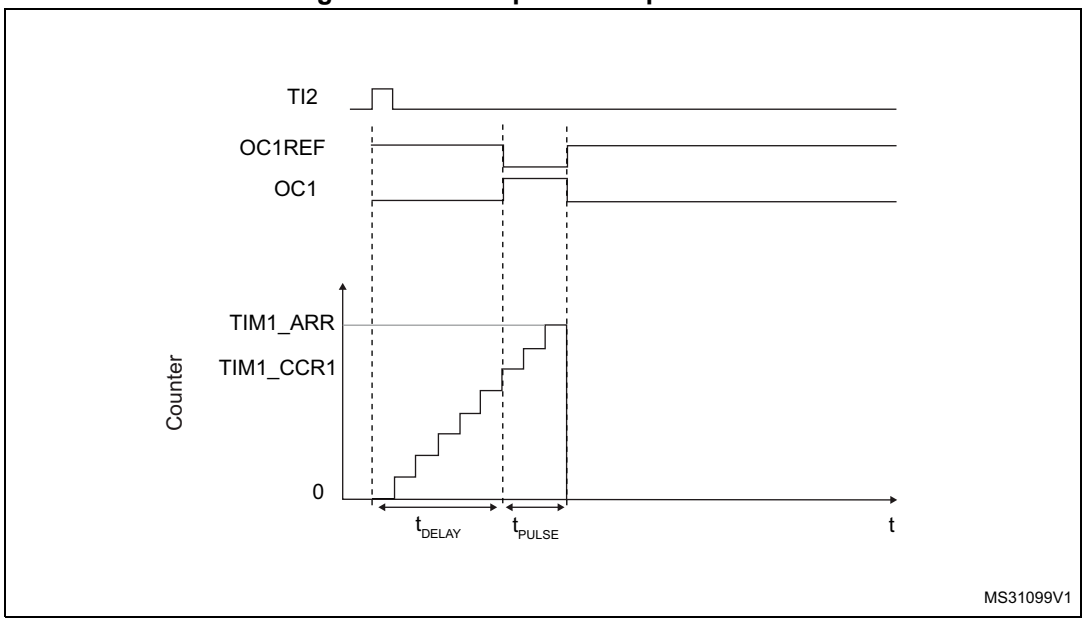
One-pulse mode (OPM) is a particular case of the previous modes. It allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length after a programmable delay.

Starting the counter can be controlled through the slave mode controller. Generating the waveform can be done in output compare mode or PWM mode. One-pulse mode is selected by setting the OPM bit in the TIMx_CR1 register. This makes the counter stop automatically at the next update event UEV.

A pulse can be correctly generated only if the compare value is different from the counter initial value. Before starting (when the timer is waiting for the trigger), the configuration must be:

- CNT < CCRx ≤ ARR (in particular, 0 < CCRx)

Figure 538. Example of one pulse mode



For example one may want to generate a positive pulse on OC1 with a length of t_{PULSE} and after a delay of t_{DELAY} as soon as a positive edge is detected on the TI2 input pin.

Let's use TI2FP2 as trigger 1:

1. Select the proper TI2[x] source (internal or external) with the TI2SEL[3:0] bits in the TIMx_TISEL register.
2. Map TI2FP2 to TI2 by writing CC2S='01' in the TIMx_CCMR1 register.
3. TI2FP2 must detect a rising edge, write CC2P='0' and CC2NP='0' in the TIMx_CCER register.
4. Configure TI2FP2 as trigger for the slave mode controller (TRGI) by writing TS='00110' in the TIMx_SMCR register.
5. TI2FP2 is used to start the counter by writing SMS to '110' in the TIMx_SMCR register (trigger mode).

The OPM waveform is defined by writing the compare registers (taking into account the clock frequency and the counter prescaler).

- The t_{DELAY} is defined by the value written in the TIMx_CCR1 register.
- The t_{PULSE} is defined by the difference between the auto-reload value and the compare value (TIMx_ARR - TIMx_CCR1).
- Let's say one want to build a waveform with a transition from '0' to '1' when a compare match occurs and a transition from '1' to '0' when the counter reaches the auto-reload value. To do this PWM mode 2 must be enabled by writing OC1M=111 in the TIMx_CCMR1 register. Optionally the preload registers can be enabled by writing OC1PE='1' in the TIMx_CCMR1 register and ARPE in the TIMx_CR1 register. In this case one has to write the compare value in the TIMx_CCR1 register, the auto-reload value in the TIMx_ARR register, generate an update by setting the UG bit and wait for external trigger event on TI2. CC1P is written to '0' in this example.

Since only 1 pulse is needed, a 1 must be written in the OPM bit in the TIMx_CR1 register to stop the counter at the next update event (when the counter rolls over from the auto-reload value back to 0).

Particular case: OCx fast enable

In One-pulse mode, the edge detection on TIx input set the CEN bit which enables the counter. Then the comparison between the counter and the compare value makes the output toggle. But several clock cycles are needed for these operations and it limits the minimum delay t_{DELAY} min we can get.

If one wants to output a waveform with the minimum delay, the OCxFE bit can be set in the TIMx_CCMRx register. Then OCxRef (and OCx) are forced in response to the stimulus, without taking in account the comparison. Its new level is the same as if a compare match had occurred. OCxFE acts only if the channel is configured in PWM1 or PWM2 mode.

46.4.17 Retriggerable one pulse mode (TIM15 only)

This mode allows the counter to be started in response to a stimulus and to generate a pulse with a programmable length, but with the following differences with Non-retriggerable one pulse mode described in *Section 46.4.16*:

- The pulse starts as soon as the trigger occurs (no programmable delay)
- The pulse is extended if a new trigger occurs before the previous one is completed

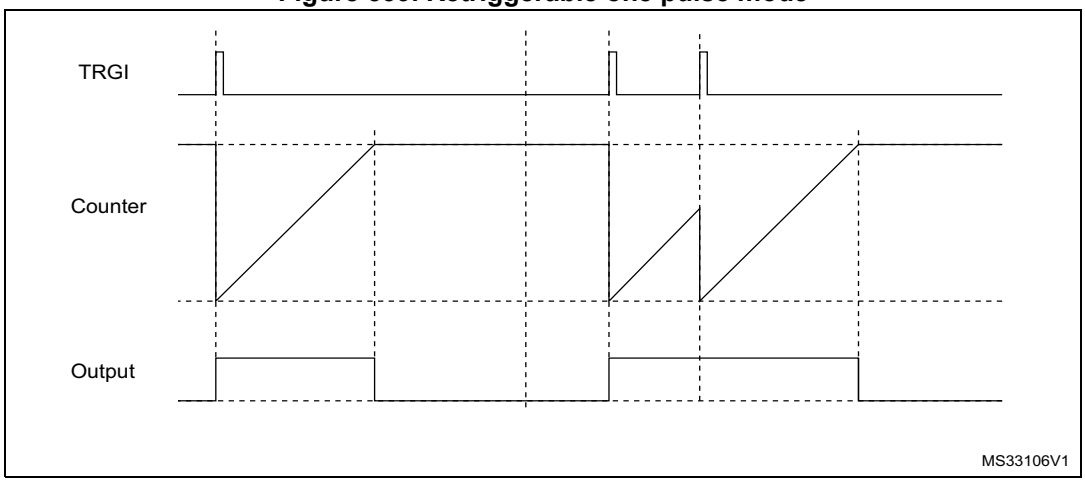
The timer must be in Slave mode, with the bits SMS[3:0] = ‘1000’ (Combined Reset + trigger mode) in the TIMx_SMCR register, and the OCxM[3:0] bits set to ‘1000’ or ‘1001’ for Retrigerrable OPM mode 1 or 2.

If the timer is configured in Up-counting mode, the corresponding CCRx must be set to 0 (the ARR register sets the pulse length). If the timer is configured in Down-counting mode, CCRx must be above or equal to ARR.

Note: The OCxM[3:0] and SMS[3:0] bit fields are split into two parts for compatibility reasons, the most significant bit are not contiguous with the 3 least significant ones.

This mode must not be used with center-aligned PWM modes. It is mandatory to have CMS[1:0] = 00 in TIMx_CR1.

Figure 539. Retriggerable one pulse mode



46.4.18 UIF bit remapping

The IUFREMAP bit in the TIMx_CR1 register forces a continuous copy of the Update Interrupt Flag UIF into bit 31 of the timer counter register (TIMxCNT[31]). This allows both

the counter value and a potential roll-over condition signaled by the UIFCPY flag, to be atomically read. In particular cases, it can ease the calculations by avoiding race conditions caused for instance by a processing shared between a background task (counter reading) and an interrupt (Update Interrupt).

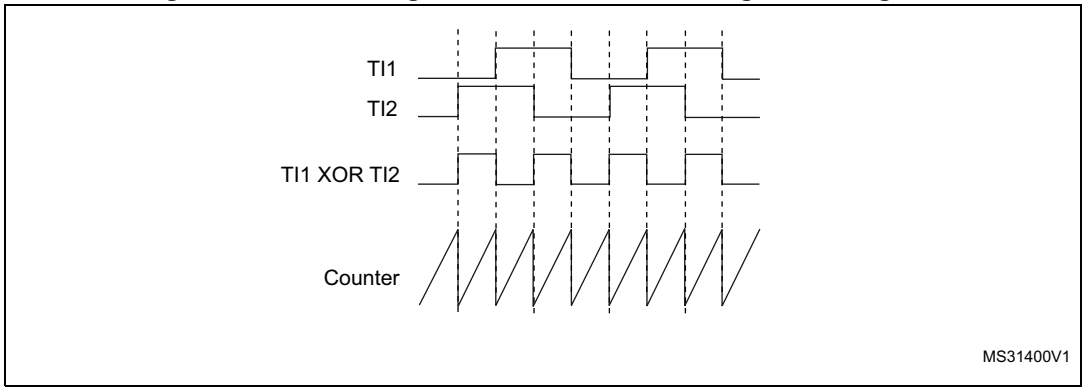
There is no latency between the assertions of the UIF and UIFCPY flags.

46.4.19 Timer input XOR function (TIM15 only)

The TI1S bit in the TIMx_CR2 register, allows the input filter of channel 1 to be connected to the output of a XOR gate, combining the two input pins TIMx_CH1 and TIMx_CH2.

The XOR output can be used with all the timer input functions such as trigger or input capture. It is useful for measuring the interval between the edges on two input signals, as shown in *Figure 540*.

Figure 540. Measuring time interval between edges on 2 signals



46.4.20 External trigger synchronization (TIM15 only)

The TIM timers are linked together internally for timer synchronization or chaining.

The TIM15 timer can be synchronized with an external trigger in several modes: Reset mode, Gated mode and Trigger mode.

Slave mode: Reset mode

The counter and its prescaler can be reinitialized in response to an event on a trigger input. Moreover, if the URS bit from the TIMx_CR1 register is low, an update event UEV is generated. Then all the preloaded registers (TIMx_ARR, TIMx_CCRx) are updated.

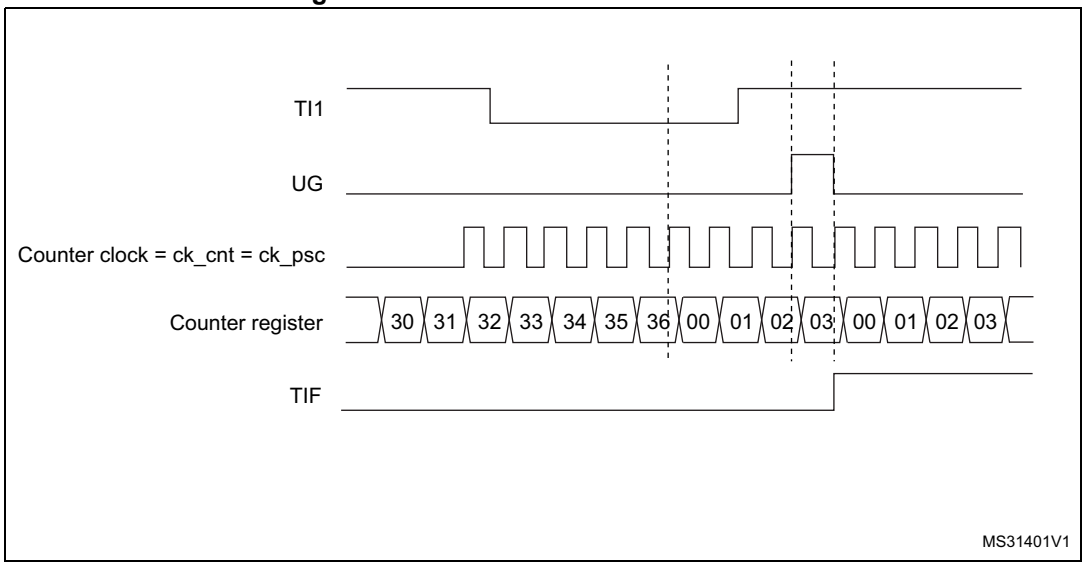
In the following example, the upcounter is cleared in response to a rising edge on TI1 input:

1. Configure the channel 1 to detect rising edges on TI1. Configure the input filter duration (in this example, we do not need any filter, so we keep IC1F=0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S = 01 in the TIMx_CCMR1 register. Write CC1P='0' and CC1NP='0' in the TIMx_CCER register to validate the polarity (and detect rising edges only).
2. Configure the timer in reset mode by writing SMS=100 in TIMx_SMCR register. Select TI1 as the input source by writing TS=00101 in TIMx_SMCR register.
3. Start the counter by writing CEN=1 in the TIMx_CR1 register.

The counter starts counting on the internal clock, then behaves normally until TI1 rising edge. When TI1 rises, the counter is cleared and restarts from 0. In the meantime, the trigger flag is set (TIF bit in the TIMx_SR register) and an interrupt request, or a DMA request can be sent if enabled (depending on the TIE and TDE bits in TIMx_DIER register).

The following figure shows this behavior when the auto-reload register TIMx_ARR=0x36. The delay between the rising edge on TI1 and the actual reset of the counter is due to the resynchronization circuit on TI1 input.

Figure 541. Control circuit in reset mode



Slave mode: Gated mode

The counter can be enabled depending on the level of a selected input.

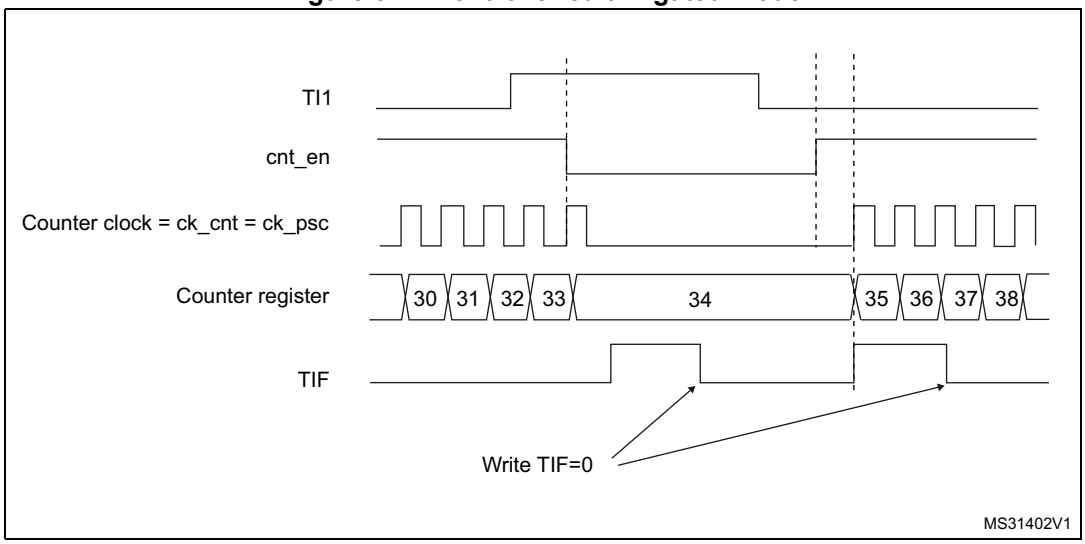
In the following example, the upcounter counts only when TI1 input is low:

1. Configure the channel 1 to detect low levels on TI1. Configure the input filter duration (in this example, we do not need any filter, so we keep IC1F=0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC1S bits select the input capture source only, CC1S=01 in TIMx_CCMR1 register. Write CC1P=1 and CC1NP = '0' in the TIMx_CCER register to validate the polarity (and detect low level only).
2. Configure the timer in gated mode by writing SMS=101 in TIMx_SMCR register. Select TI1 as the input source by writing TS=00101 in TIMx_SMCR register.
3. Enable the counter by writing CEN=1 in the TIMx_CR1 register (in gated mode, the counter doesn't start if CEN=0, whatever is the trigger input level).

The counter starts counting on the internal clock as long as TI1 is low and stops as soon as TI1 becomes high. The TIF flag in the TIMx_SR register is set both when the counter starts or stops.

The delay between the rising edge on TI1 and the actual stop of the counter is due to the resynchronization circuit on TI1 input.

Figure 542. Control circuit in gated mode



Slave mode: Trigger mode

The counter can start in response to an event on a selected input.

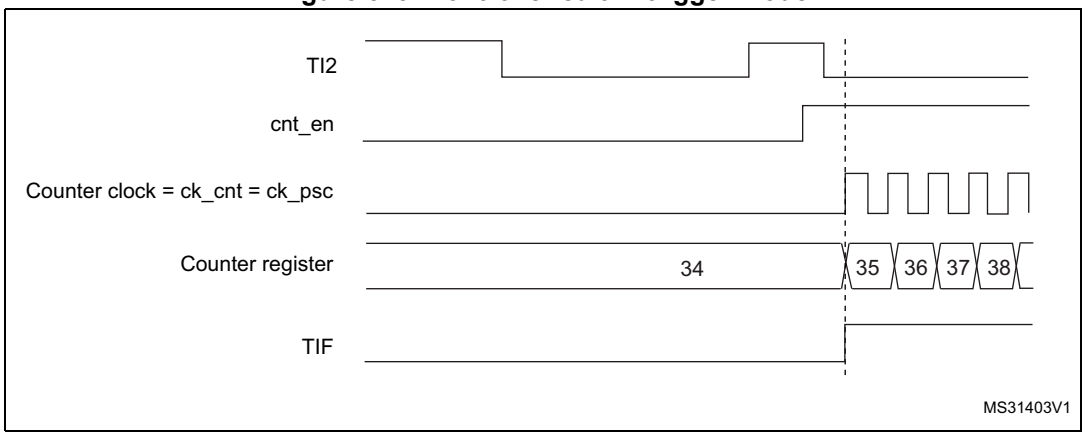
In the following example, the upcounter starts in response to a rising edge on TI2 input:

1. Configure the channel 2 to detect rising edges on TI2. Configure the input filter duration (in this example, we do not need any filter, so we keep IC2F=0000). The capture prescaler is not used for triggering, so it does not need to be configured. The CC2S bits are configured to select the input capture source only, CC2S=01 in TIMx_CCMR1 register. Write CC2P='1' and CC2NP='0' in the TIMx_CCER register to validate the polarity (and detect low level only).
2. Configure the timer in trigger mode by writing SMS=110 in the TIMx_SMCR register. Select TI2 as the input source by writing TS=00110 in the TIMx_SMCR register.

When a rising edge occurs on TI2, the counter starts counting on the internal clock and the TIF flag is set.

The delay between the rising edge on TI2 and the actual start of the counter is due to the resynchronization circuit on TI2 input.

Figure 543. Control circuit in trigger mode



46.4.21 Slave mode – combined reset + trigger mode

In this case, a rising edge of the selected trigger input (TRGI) reinitializes the counter, generates an update of the registers, and starts the counter.

This mode is used for one-pulse mode.

46.4.22 DMA burst mode

The TIMx timers have the capability to generate multiple DMA requests on a single event. The main purpose is to be able to re-program several timer registers multiple times without software overhead, but it can also be used to read several registers in a row, at regular intervals.

The DMA controller destination is unique and must point to the virtual register TIMx_DMAR. On a given timer event, the timer launches a sequence of DMA requests (burst). Each write into the TIMx_DMAR register is actually redirected to one of the timer registers.

The DBL[4:0] bits in the TIMx_DCR register set the DMA burst length. The timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address), i.e. the number of transfers (either in half-words or in bytes).

The DBA[4:0] bits in the TIMx_DCR registers define the DMA base address for DMA transfers (when read/write access are done through the TIMx_DMAR address). DBA is defined as an offset starting from the address of the TIMx_CR1 register.

Example:

00000: TIMx_CR1,

00001: TIMx_CR2,

00010: TIMx_SMCR,

For example, the timer DMA burst feature could be used to update the contents of the CCRx registers (x = 2, 3, 4) on an update event, with the DMA transferring half words into the CCRx registers.

This is done in the following steps:

1. Configure the corresponding DMA channel as follows:
   - DMA channel peripheral address is the DMAR register address
   - DMA channel memory address is the address of the buffer in the RAM containing the data to be transferred by DMA into the CCRx registers.
   - Number of data to transfer = 3 (See note below).
   - Circular mode disabled.
2. Configure the DCR register by configuring the DBA and DBL bit fields as follows: DBL = 3 transfers, DBA = 0xE.
3. Enable the TIMx update DMA request (set the UDE bit in the DIER register).
4. Enable TIMx
5. Enable the DMA channel

This example is for the case where every CCRx register is to be updated once. If every CCRx register is to be updated twice for example, the number of data to transfer should be 6. Let's take the example of a buffer in the RAM containing data1, data2, data3, data4, data5 and data6. The data is transferred to the CCRx registers as follows: on the first update DMA request, data1 is transferred to CCR2, data2 is transferred to CCR3, data3 is transferred to CCR4 and on the second update DMA request, data4 is transferred to CCR2, data5 is transferred to CCR3 and data6 is transferred to CCR4.

Note: A null value can be written to the reserved registers.

46.4.23 Timer synchronization (TIM15)

The TIMx timers are linked together internally for timer synchronization or chaining. Refer to *Section 44.3.19: Timer synchronization* for details.

Note: The clock of the slave peripherals (timer, ADC, ...) receiving the TRGO or the TRGO2 signals must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

46.4.24 Using timer output as trigger for other timers (TIM16/TIM17)

The timers with one channel only do not feature a master mode. However, the OC1 output signal can be used to trigger some other timers (including timers described in other sections of this document). Check the “TIMx internal trigger connection” table of any TIMx_SMCR register on the device to identify which timers can be targeted as slave.

The OC1 signal pulse width must be programmed to be at least 2 clock cycles of the destination timer, to make sure the slave timer will detect the trigger.

For instance, if the destination's timer CK_INT clock is 4 times slower than the source timer, the OC1 pulse width must be 8 clock cycles.

46.4.25 Debug mode

When the microcontroller enters debug mode (Cortex®-M7 core halted), the TIMx counter either continues to work normally or stops, depending on TIMx bit in DBGMCU module. For more details, refer to *Section 65.5.7: Microcontroller debug unit (DBGMCU)*.

For safety purposes, when the counter is stopped (TIMx = 1 in DBGMCU_APB2FZ1), the outputs are disabled (as if the MOE bit was reset). The outputs can either be forced to an inactive state (OSSI bit = 1), or have their control taken over by the GPIO controller (OSSI bit = 0) to force them to Hi-Z.

46.5 TIM15 registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by half-words (16-bit) or words (32-bit).

46.5.1 TIM15 control register 1 (TIM15_CR1)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	UIFREMAP	Res.	CKD[1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
				rw		rw	rw	rw				rw	rw	rw	rw

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **UIFREMAP**: UIF status bit remapping
0: No remapping. UIF status bit is not copied to TIMx_CNT register bit 31.
1: Remapping enabled. UIF status bit is copied to TIMx_CNT register bit 31.

Bit 10 Reserved, must be kept at reset value.

Bits 9:8 **CKD[1:0]**: Clock division
This bitfield indicates the division ratio between the timer clock (CK_INT) frequency and the dead-time and sampling clock (t_{DTS}) used by the dead-time generators and the digital filters (TIx)
00: $t_{DTS} = t_{CK\_INT}$
01: $t_{DTS} = 2 * t_{CK\_INT}$
10: $t_{DTS} = 4 * t_{CK\_INT}$
11: Reserved, do not program this value

Bit 7 **ARPE**: Auto-reload preload enable
0: TIMx_ARR register is not buffered
1: TIMx_ARR register is buffered

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **OPM**: One-pulse mode
0: Counter is not stopped at update event
1: Counter stops counting at the next update event (clearing the bit CEN)

Bit 2 **URS**: Update request source

This bit is set and cleared by software to select the UEV event sources.

0: Any of the following events generate an update interrupt if enabled. These events can be:

– Counter overflow/underflow

– Setting the UG bit

– Update generation through the slave mode controller

1: Only counter overflow/underflow generates an update interrupt if enabled

Bit 1 **UDIS**: Update disable

This bit is set and cleared by software to enable/disable UEV event generation.

0: UEV enabled. The Update (UEV) event is generated by one of the following events:

– Counter overflow/underflow

– Setting the UG bit

– Update generation through the slave mode controller

Buffered registers are then loaded with their preload values.

1: UEV disabled. The Update event is not generated, shadow registers keep their value (ARR, PSC, CCRx). However the counter and the prescaler are reinitialized if the UG bit is set or if a hardware reset is received from the slave mode controller.

Bit 0 **CEN**: Counter enable

0: Counter disabled

1: Counter enabled

Note: External clock and gated mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.

46.5.2 TIM15 control register 2 (TIM15_CR2)

Address offset: 0x04

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	OIS2	OIS1N	OIS1	TI1S	MMS[2:0]			CCDS	CCUS	Res.	CCPC
					rw	rw	rw	rw	rw	rw	rw	rw	rw		rw

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **OIS2:** Output idle state 2 (OC2 output)

0: OC2=0 when MOE=0

1: OC2=1 when MOE=0

Note: This bit cannot be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in the TIM15_BDTR register).

Bit 9 **OIS1N**: Output Idle state 1 (OC1N output)

0: OC1N=0 after a dead-time when MOE=0

1: OC1N=1 after a dead-time when MOE=0

Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 8 **OIS1**: Output Idle state 1 (OC1 output)

0: OC1=0 (after a dead-time if OC1N is implemented) when MOE=0

1: OC1=1 (after a dead-time if OC1N is implemented) when MOE=0

Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIM15_BDTR register).

Bit 7 **TI1S**: TI1 selection
0: The TIMx_CH1 pin is connected to TI1 input
1: The TIMx_CH1, CH2 pins are connected to the TI1 input (XOR combination)

Bits 6:4 **MMS[2:0]**: Master mode selection
These bits allow to select the information to be sent in master mode to slave timers for synchronization (TRGO). The combination is as follows:
000: **Reset** - the UG bit from the TIMx_EGR register is used as trigger output (TRGO). If the reset is generated by the trigger input (slave mode controller configured in reset mode) then the signal on TRGO is delayed compared to the actual reset.
001: **Enable** - the Counter Enable signal CNT_EN is used as trigger output (TRGO). It is useful to start several timers at the same time or to control a window in which a slave timer is enable. The Counter Enable signal is generated by a logic AND between CEN control bit and the trigger input when configured in gated mode. When the Counter Enable signal is controlled by the trigger input, there is a delay on TRGO, except if the master/slave mode is selected (see the MSM bit description in TIMx_SMCR register).
010: **Update** - The update event is selected as trigger output (TRGO). For instance a master timer can then be used as a prescaler for a slave timer.
011: **Compare Pulse** - The trigger output send a positive pulse when the CC1IF flag is to be set (even if it was already high), as soon as a capture or a compare match occurred. (TRGO).
100: **Compare** - OC1REFC signal is used as trigger output (TRGO).
101: **Compare** - OC2REFC signal is used as trigger output (TRGO).

Bit 3 **CCDS**: Capture/compare DMA selection
0: CCx DMA request sent when CCx event occurs
1: CCx DMA requests sent when update event occurs

Bit 2 **CCUS**: Capture/compare control update selection
0: When capture/compare control bits are preloaded (CCPC=1), they are updated by setting the COMG bit only.
1: When capture/compare control bits are preloaded (CCPC=1), they are updated by setting the COMG bit or when an rising edge occurs on TRGI.
Note: This bit acts only on channels that have a complementary output.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **CCPC**: Capture/compare preloaded control
0: CCxE, CCxNE and OCxM bits are not preloaded
1: CCxE, CCxNE and OCxM bits are preloaded, after having been written, they are updated only when a commutation event (COM) occurs (COMG bit set or rising edge detected on TRGI, depending on the CCUS bit).
Note: This bit acts only on channels that have a complementary output.

46.5.3 TIM15 slave mode control register (TIM15_SMCR)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS[4:3]		Res.	Res.	Res.	SMS[3]
										rw	rw				rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MSM	TS[2:0]			Res.	SMS[2:0]		
								rw	rw	rw	rw		rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 19:17 Reserved, must be kept at reset value.

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **MSM:** Master/slave mode

0: No action

1: The effect of an event on the trigger input (TRGI) is delayed to allow a perfect synchronization between the current timer and its slaves (through TRGO). It is useful if we want to synchronize several timers on a single external event.

Bits 21, 20, 6, 5, 4 **TS[4:0]:** Trigger selection

This bit field selects the trigger input to be used to synchronize the counter.

00000: Internal Trigger 0 (ITR0)

00001: Internal Trigger 1 (ITR1)

00010: Internal Trigger 2 (ITR2)

00011: Internal Trigger 3 (ITR3)

00100: TI1 Edge Detector (TI1F_ED)

00101: Filtered Timer Input 1 (TI1FP1)

00110: Filtered Timer Input 2 (TI2FP2)

Other: Reserved

See *Table 364: TIMx Internal trigger connection on page 1838* for more details on ITRx meaning for each Timer.

Note: These bits must be changed only when they are not used (e.g. when SMS=000) to avoid wrong edge detections at the transition.

Bit 3 Reserved, must be kept at reset value.

Bits 16, 2, 1, 0 **SMS[3:0]:** Slave mode selection

When external signals are selected the active edge of the trigger signal (TRGI) is linked to the polarity selected on the external input (see Input Control register and Control register description.

0000: Slave mode disabled - if CEN = ‘1’ then the prescaler is clocked directly by the internal clock.

0001: Reserved

0010: Reserved

0011: Reserved

0100: Reset Mode - Rising edge of the selected trigger input (TRGI) reinitializes the counter and generates an update of the registers.

0101: Gated Mode - The counter clock is enabled when the trigger input (TRGI) is high. The counter stops (but is not reset) as soon as the trigger becomes low. Both start and stop of the counter are controlled.

0110: Trigger Mode - The counter starts at a rising edge of the trigger TRGI (but it is not reset). Only the start of the counter is controlled.

0111: External Clock Mode 1 - Rising edges of the selected trigger (TRGI) clock the counter.

1000: Combined reset + trigger mode - Rising edge of the selected trigger input (TRGI) reinitializes the counter, generates an update of the registers and starts the counter.

Other codes: reserved.

Note: The gated mode must not be used if TI1F_ED is selected as the trigger input (TS=’00100’). Indeed, TI1F_ED outputs 1 pulse for each transition on TI1F, whereas the gated mode checks the level of the trigger signal.

Note: The clock of the slave peripherals (timer, ADC, ...) receiving the TRGO or the TRGO2 signals must be enabled prior to receive events from the master timer, and the clock frequency (prescaler) must not be changed on-the-fly while triggers are received from the master timer.

Table 364. TIMx Internal trigger connection

Slave TIM	ITR0 (TS = 00000)	ITR1 (TS = 00001)	ITR2 (TS = 00010)	ITR3 (TS = 00011)
TIM15	TIM1	TIM3	TIM16 OC1	TIM17 OC1

46.5.4 TIM15 DMA/interrupt enable register (TIM15_DIER)

Address offset: 0x0C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TDE	COMDE	Res.	Res.	Res.	CC1DE	UDE	BIE	TIE	COMIE	Res.	Res.	CC2IE	CC1IE	UIE
	rw	rw				rw	rw	rw	rw	rw			rw	rw	rw

Bit 15 Reserved, must be kept at reset value.

Bit 14 **TDE**: Trigger DMA request enable

0: Trigger DMA request disabled

1: Trigger DMA request enabled

Bit 13 **COMDE**: COM DMA request enable

0: COM DMA request disabled

1: COM DMA request enabled

Bits 12:10 Reserved, must be kept at reset value.

Bit 9 **CC1DE**: Capture/Compare 1 DMA request enable
0: CC1 DMA request disabled
1: CC1 DMA request enabled

Bit 8 **UDE**: Update DMA request enable
0: Update DMA request disabled
1: Update DMA request enabled

Bit 7 **BIE**: Break interrupt enable
0: Break interrupt disabled
1: Break interrupt enabled

Bit 6 **TIE**: Trigger interrupt enable
0: Trigger interrupt disabled
1: Trigger interrupt enabled

Bit 5 **COMIE:** COM interrupt enable
0: COM interrupt disabled
1: COM interrupt enabled

Bits 4:3 Reserved, must be kept at reset value.

Bit 2 **CC2IE**: Capture/Compare 2 interrupt enable
0: CC2 interrupt disabled
1: CC2 interrupt enabled

Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable
0: CC1 interrupt disabled
1: CC1 interrupt enabled

Bit 0 **UIE**: Update interrupt enable
0: Update interrupt disabled
1: Update interrupt enabled

46.5.5 TIM15 status register (TIM15_SR)

Address offset: 0x10

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	CC2OF	CC1OF	Res.	BIF	TIF	COMIF	Res.	Res.	CC2IF	CC1IF	UIF
					rc_w0	rc_w0		rc_w0	rc_w0	rc_w0			rc_w0	rc_w0	rc_w0

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **CC2OF**: Capture/Compare 2 overcapture flag
Refer to CC1OF description

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag
This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to ‘0’.
0: No overcapture has been detected
1: The counter value has been captured in TIMx_CCR1 register while CC1IF flag was already set

Bit 8 Reserved, must be kept at reset value.

Bit 7 **BIF**: Break interrupt flag

This flag is set by hardware as soon as the break input goes active. It can be cleared by software if the break input is not active.

0: No break event occurred

1: An active level has been detected on the break input

Bit 6 **TIF**: Trigger interrupt flag

This flag is set by hardware on the TRG trigger event (active edge detected on TRGI input when the slave mode controller is enabled in all modes but gated mode, both edges in case gated mode is selected). It is set when the counter starts or stops when gated mode is selected. It is cleared by software.

0: No trigger event occurred

1: Trigger interrupt pending

Bit 5 **COMIF:** COM interrupt flag

This flag is set by hardware on a COM event (once the capture/compare control bits –CCxE, CCxNE, OCxM– have been updated). It is cleared by software.

0: No COM event occurred

1: COM interrupt pending

Bits 4:3 Reserved, must be kept at reset value.

Bit 2 **CC2IF**: Capture/Compare 2 interrupt flag

refer to CC1IF description

Bit 1 **CC1IF**: Capture/Compare 1 interrupt flag

This flag is set by hardware. It is cleared by software (input capture or output compare mode) or by reading the TIMx_CCR1 register (input capture mode only).

0: No compare match / No input capture occurred

1: A compare match or an input capture occurred

If channel CC1 is configured as output: this flag is set when the content of the counter TIMx_CNT matches the content of the TIMx_CCR1 register. When the content of TIMx_CCR1 is greater than the content of TIMx_ARR, the CC1IF bit goes high on the counter overflow (in up-counting and up/down-counting modes) or underflow (in down-counting mode). There are 3 possible options for flag setting in center-aligned mode, refer to the CMS bits in the TIMx_CR1 register for the full description.

If channel CC1 is configured as input: this bit is set when counter value has been captured in TIMx_CCR1 register (an edge has been detected on IC1, as per the edge sensitivity defined with the CC1P and CC1NP bits setting, in TIMx_CCER).

Bit 0 **UIF**: Update interrupt flag

This bit is set by hardware on an update event. It is cleared by software.

0: No update occurred.

1: Update interrupt pending. This bit is set by hardware when the registers are updated:

– At overflow regarding the repetition counter value (update if repetition counter = 0) and if the UDIS=0 in the TIMx_CR1 register.

– When CNT is reinitialized by software using the UG bit in TIMx_EGR register, if URS=0 and UDIS=0 in the TIMx_CR1 register.

– When CNT is reinitialized by a trigger event (refer to *Section 46.5.3: TIM15 slave mode control register (TIM15_SMCR)*), if URS=0 and UDIS=0 in the TIMx_CR1 register.

46.5.6 TIM15 event generation register (TIM15_EGR)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BG	TG	COMG	Res.	Res.	CC2G	CC1G	UG
								w	w	rw			w	w	w

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **BG**: Break generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: A break event is generated. MOE bit is cleared and BIF flag is set. Related interrupt or DMA transfer can occur if enabled.

Bit 6 **TG**: Trigger generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: The TIF flag is set in TIMx_SR register. Related interrupt or DMA transfer can occur if enabled

Bit 5 **COMG:** Capture/Compare control update generation

This bit can be set by software, it is automatically cleared by hardware.

0: No action

1: When the CCPC bit is set, it is possible to update the CCxE, CCxNE and OCxM bits

Note: This bit acts only on channels that have a complementary output.

Bits 4:3 Reserved, must be kept at reset value.

Bit 2 **CC2G**: Capture/Compare 2 generation

Refer to CC1G description

Bit 1 **CC1G**: Capture/Compare 1 generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.

0: No action

1: A capture/compare event is generated on channel 1:

If channel CC1 is configured as output:

CC1IF flag is set, Corresponding interrupt or DMA request is sent if enabled.

If channel CC1 is configured as input:

The current value of the counter is captured in TIMx_CCR1 register. The CC1IF flag is set, the corresponding interrupt or DMA request is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation

This bit can be set by software, it is automatically cleared by hardware.

0: No action

1: Reinitialize the counter and generates an update of the registers. Note that the prescaler counter is cleared too (anyway the prescaler ratio is not affected).

46.5.7 TIM15 capture/compare mode register 1 [alternate] (TIM15_CCMR1)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode.

Input capture mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IC2F[3:0]				IC2PSC[1:0]		CC2S[1:0]		IC1F[3:0]				IC1PSC[1:0]		CC1S[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **IC2F[3:0]**: Input capture 2 filter

Bits 11:10 **IC2PSC[1:0]**: Input capture 2 prescaler

Bits 9:8 **CC2S[1:0]**: Capture/Compare 2 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC2 channel is configured as output
01: CC2 channel is configured as input, IC2 is mapped on TI2
10: CC2 channel is configured as input, IC2 is mapped on TI1
11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC2S bits are writable only when the channel is OFF (CC2E = '0' in TIMx_CCER).

Bits 7:4 **IC1F[3:0]**: Input capture 1 filter

This bit-field defines the frequency used to sample TI1 input and the length of the digital filter applied to TI1. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}
0001: $f_{SAMPLING}=f_{CK\_INT}$, N=2
0010: $f_{SAMPLING}=f_{CK\_INT}$, N=4
0011: $f_{SAMPLING}=f_{CK\_INT}$, N=8
0100: $f_{SAMPLING}=f_{DTS}/2$, N=6
0101: $f_{SAMPLING}=f_{DTS}/2$, N=8
0110: $f_{SAMPLING}=f_{DTS}/4$, N=6
0111: $f_{SAMPLING}=f_{DTS}/4$, N=8
1000: $f_{SAMPLING}=f_{DTS}/8$, N=6
1001: $f_{SAMPLING}=f_{DTS}/8$, N=8
1010: $f_{SAMPLING}=f_{DTS}/16$, N=5
1011: $f_{SAMPLING}=f_{DTS}/16$, N=6
1100: $f_{SAMPLING}=f_{DTS}/16$, N=8
1101: $f_{SAMPLING}=f_{DTS}/32$, N=5
1110: $f_{SAMPLING}=f_{DTS}/32$, N=6
1111: $f_{SAMPLING}=f_{DTS}/32$, N=8

Bits 3:2 **IC1PSC[1:0]**: Input capture 1 prescaler

This bit-field defines the ratio of the prescaler acting on CC1 input (IC1). The prescaler is reset as soon as CC1E='0' (TIMx_CCER register).

00: no prescaler, capture is done each time an edge is detected on the capture input
01: capture is done once every 2 events
10: capture is done once every 4 events
11: capture is done once every 8 events

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 Selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output
01: CC1 channel is configured as input, IC1 is mapped on TI1
10: CC1 channel is configured as input, IC1 is mapped on TI2
11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC1S bits are writable only when the channel is OFF (CC1E = '0' in TIMx_CCER).

46.5.8 TIM15 capture/compare mode register 1 [alternate] (TIM15_CCMR1)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode.

Output compare mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M [3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M [3]
							rw								rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	OC2M[2:0]			OC2 PE	OC2 FE	CC2S[1:0]		Res.	OC1M[2:0]			OC1 PE	OC1 FE	CC1S[1:0]	
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 23:17 Reserved, must be kept at reset value.

Bit 15 Reserved, must be kept at reset value.

Bits 24, 14:12 **OC2M[3:0]**: Output Compare 2 mode

Bit 11 **OC2PE**: Output Compare 2 preload enable

Bit 10 **OC2FE**: Output Compare 2 fast enable

Bits 9:8 **CC2S[1:0]**: Capture/Compare 2 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC2 channel is configured as output.
01: CC2 channel is configured as input, IC2 is mapped on TI2.
10: CC2 channel is configured as input, IC2 is mapped on TI1.
11: CC2 channel is configured as input, IC2 is mapped on TRC. This mode is working only if an internal trigger input is selected through the TS bit (TIMx_SMCR register)

Note: CC2S bits are writable only when the channel is OFF (CC2E = '0' in TIMx_CCER).

Bit 7 Reserved, must be kept at reset value.

Bits 16, 6:4 **OC1M[3:0]**: Output Compare 1 mode

These bits define the behavior of the output reference signal OC1REF from which OC1 and OC1N are derived. OC1REF is active high whereas OC1 and OC1N active level depends on CC1P and CC1NP bits.

0000: Frozen - The comparison between the output compare register TIMx_CCR1 and the counter TIMx_CNT has no effect on the outputs.

0001: Set channel 1 to active level on match. OC1REF signal is forced high when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0010: Set channel 1 to inactive level on match. OC1REF signal is forced low when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0011: Toggle - OC1REF toggles when TIMx_CNT=TIMx_CCR1.

0100: Force inactive level - OC1REF is forced low.

0101: Force active level - OC1REF is forced high.

0110: PWM mode 1 - Channel 1 is active as long as TIMx_CNT<TIMx_CCR1 else inactive.

0111: PWM mode 2 - Channel 1 is inactive as long as TIMx_CNT<TIMx_CCR1 else active.

1000: Retrigerrable OPM mode 1 - In up-counting mode, the channel is active until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update. In down-counting mode, the channel is inactive until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes inactive again at the next update.

1001: Retrigerrable OPM mode 2 - In up-counting mode, the channel is inactive until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 2 and the channels becomes inactive again at the next update. In down-counting mode, the channel is active until a trigger event is detected (on TRGI signal). Then, a comparison is performed as in PWM mode 1 and the channels becomes active again at the next update.

1010: Reserved

1011: Reserved

1100: Combined PWM mode 1 - OC1REF has the same behavior as in PWM mode 1. OC1REFC is the logical OR between OC1REF and OC2REF.

1101: Combined PWM mode 2 - OC1REF has the same behavior as in PWM mode 2. OC1REFC is the logical AND between OC1REF and OC2REF.

1110: Reserved,

1111: Reserved,

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S='00' (the channel is configured in output).

In PWM mode, the OCREF level changes only when the result of the comparison changes or when the output compare mode switches from "frozen" mode to "PWM" mode.

On channels that have a complementary output, this bit field is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the OC1M active bits take the new value from the preloaded bits only when a COM event is generated.

The OC1M[3] bit is not contiguous, located in bit 16.

Bit 3 **OC1PE**: Output Compare 1 preload enable

0: Preload register on TIMx_CCR1 disabled. TIMx_CCR1 can be written at anytime, the new value is taken in account immediately.

1: Preload register on TIMx_CCR1 enabled. Read/Write operations access the preload register. TIMx_CCR1 preload value is loaded in the active register at each update event.

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S='00' (the channel is configured in output).

Bit 2 **OC1FE**: Output Compare 1 fast enable

This bit decreases the latency between a trigger event and a transition on the timer output. It must be used in one-pulse mode (OPM bit set in TIMx_CR1 register), to have the output pulse starting as soon as possible after the starting trigger.

0: CC1 behaves normally depending on counter and CCR1 values even when the trigger is ON. The minimum delay to activate CC1 output when an edge occurs on the trigger input is 5 clock cycles.

1: An active edge on the trigger input acts like a compare match on CC1 output. Then, OC is set to the compare level independently of the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OCFE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.

00: CC1 channel is configured as output.

01: CC1 channel is configured as input, IC1 is mapped on TI1.

10: CC1 channel is configured as input, IC1 is mapped on TI2.

11: CC1 channel is configured as input, IC1 is mapped on TRC. This mode is working only if an internal trigger input is selected through TS bit (TIMx_SMCR register)

Note: CC1S bits are writable only when the channel is OFF (CC1E = '0' in TIMx_CCER).

46.5.9 TIM15 capture/compare enable register (TIM15_CCER)

Address offset: 0x20

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2NP	Res.	CC2P	CC2E	CC1NP	CC1NE	CC1P	CC1E
								rw		rw	rw	rw	rw	rw	rw

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **CC2NP**: Capture/Compare 2 complementary output polarity
Refer to CC1NP description

Bit 6 Reserved, must be kept at reset value.

Bit 5 **CC2P**: Capture/Compare 2 output polarity
Refer to CC1P description

Bit 4 **CC2E**: Capture/Compare 2 output enable
Refer to CC1E description

Bit 3 **CC1NP**: Capture/Compare 1 complementary output polarity

CC1 channel configured as output:

0: OC1N active high

1: OC1N active low

CC1 channel configured as input:

This bit is used in conjunction with CC1P to define the polarity of TI1FP1 and TI2FP1. Refer to CC1P description.

Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S="00" (the channel is configured in output).

On channels that have a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1NP active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Bit 2 **CC1NE**: Capture/Compare 1 complementary output enable

0: Off - OC1N is not active. OC1N level is then function of MOE, OSSI, OSSR, OIS1, OIS1N and CC1E bits.

1: On - OC1N signal is output on the corresponding output pin depending on MOE, OSSI, OSSR, OIS1, OIS1N and CC1E bits.

Bit 1 **CC1P**: Capture/Compare 1 output polarity

0: OC1 active high (output mode) / Edge sensitivity selection (input mode, see below)

1: OC1 active low (output mode) / Edge sensitivity selection (input mode, see below)

When CC1 channel is configured as input, both CC1NP/CC1P bits select the active polarity of TI1FP1 and TI2FP1 for trigger or capture operations.

CC1NP=0, CC1P=0: non-inverted/rising edge. The circuit is sensitive to TIxFP1 rising edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger operation in gated mode or encoder mode).

CC1NP=0, CC1P=1: inverted/falling edge. The circuit is sensitive to TIxFP1 falling edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is inverted (trigger operation in gated mode or encoder mode).

CC1NP=1, CC1P=1: non-inverted/both edges/ The circuit is sensitive to both TIxFP1 rising and falling edges (capture or trigger operations in reset, external clock or trigger mode), TIxFP1is not inverted (trigger operation in gated mode). This configuration must not be used in encoder mode.

CC1NP=1, CC1P=0: this configuration is reserved, it must not be used.

Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

On channels that have a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1P active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Bit 0 **CC1E**: Capture/Compare 1 output enable

0: Capture mode disabled / OC1 is not active (see below)

1: Capture mode enabled / OC1 signal is output on the corresponding output pin

When CC1 channel is configured as output, the OC1 level depends on MOE, OSSI, OSSR, OIS1, OIS1N and CC1NE bits, regardless of the CC1E bits state. Refer to *Table 365* for details.

Table 365. Output control bits for complementary OCx and OCxN channels with break feature (TIM15)

<table>
<tr><th colspan="5">Control bits</th><th colspan="2">Output states(1)</th></tr>
<tr><th>MOE bit</th><th>OSSI bit</th><th>OSSR bit</th><th>CCxE bit</th><th>CCxNE bit</th><th>OCx output state</th><th>OCxN output state</th></tr>
<tr><td rowspan="8">1</td><td rowspan="8">X</td><td>X</td><td>0</td><td>0</td><td colspan="2">Output Disabled (not driven by the timer: Hi-Z)
OCx=0
OCxN=0, OCxN_EN=0</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>Output Disabled (not driven by the timer: Hi-Z)
OCx=0</td><td>OCxREF + Polarity
OCxN=OCxREF XOR CCxNP</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>OCxREF + Polarity
OCx=OCxREF XOR CCxP</td><td>Output Disabled (not driven by the timer: Hi-Z)
OCxN=0</td></tr>
<tr><td>X</td><td>1</td><td>1</td><td>OCREF + Polarity + dead-time</td><td>Complementary to OCREF (not OCREF) + Polarity + dead-time</td></tr>
<tr><td>1</td><td>0</td><td>1</td><td>Off-State (output enabled with inactive state)
OCx=CCxP</td><td>OCxREF + Polarity
OCxN=OCxREF XOR CCxNP</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>OCxREF + Polarity
OCx=OCxREF xor CCxP,
OCx_EN=1</td><td>Off-State (output enabled with inactive state)
OCxN=CCxNP, OCxN_EN=1</td></tr>
<tr><td rowspan="5">0</td><td>0</td><td rowspan="5">X</td><td>X</td><td>X</td><td colspan="2" rowspan="2">Output disabled (not driven by the timer: Hi-Z)</td></tr>
<tr><td rowspan="4">1</td><td>0</td><td>0</td></tr>
<tr><td>0</td><td>1</td><td colspan="2" rowspan="3">Off-State (output enabled with inactive state)
Asynchronously: OCx=CCxP, OCxN=CCxNP
Then if the clock is present: OCx=OISx and OCxN=OISxN after a dead-time, assuming that OISx and OISxN do not correspond to OCX and OCxN both in active state</td></tr>
<tr><td>1</td><td>0</td></tr>
<tr><td>1</td><td>1</td></tr>
</table>

1. When both outputs of a channel are not used (control taken over by GPIO controller), the OISx, OISxN, CCxP and CCxNP bits must be kept cleared.

Note: The state of the external I/O pins connected to the complementary OCx and OCxN channels depends on the OCx and OCxN channel state and GPIO control and alternate function registers.

46.5.10 TIM15 counter (TIM15_CNT)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIF CPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: UIF Copy
This bit is a read-only copy of the UIF bit in the TIMx_ISR register.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]**: Counter value

46.5.11 TIM15 prescaler (TIM15_PSC)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value
The counter clock frequency (CK_CNT) is equal to f_{CK_PSC} / (PSC[15:0] + 1).
PSC contains the value to be loaded in the active prescaler register at each update event (including when the counter is cleared through UG bit of TIMx_EGR register or through trigger controller when configured in “reset mode”).

46.5.12 TIM15 auto-reload register (TIM15_ARR)

Address offset: 0x2C

Reset value: 0xFFFF

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **ARR[15:0]**: Auto-reload value
ARR is the value to be loaded in the actual auto-reload register.
Refer to the *Section 46.4.1: Time-base unit on page 1797* for more details about ARR update and behavior.
The counter is blocked while the auto-reload value is null.

46.5.13 TIM15 repetition counter register (TIM15_RCR)

Address offset: 0x30

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REP[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **REP[7:0]**: Repetition counter value

These bits allow the user to set-up the update rate of the compare registers (i.e. periodic transfers from preload to active registers) when preload registers are enable, as well as the update interrupt generation rate, if this interrupt is enable.

Each time the REP_CNT related downcounter reaches zero, an update event is generated and it restarts counting from REP value. As REP_CNT is reloaded with REP value only at the repetition update event U_RC, any write to the TIMx_RCR register is not taken in account until the next repetition update event.

It means in PWM mode (REP+1) corresponds to the number of PWM periods in edge-aligned mode.

46.5.14 TIM15 capture/compare register 1 (TIM15_CCR1)

Address offset: 0x34

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR1[15:0]**: Capture/Compare 1 value

If channel CC1 is configured as output:

CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on OC1 output.

If channel CC1 is configured as input:

CCR1 is the counter value transferred by the last input capture 1 event (IC1).

46.5.15 TIM15 capture/compare register 2 (TIM15_CCR2)

Address offset: 0x38

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR2[15:0]**: Capture/Compare 2 value

If channel CC2 is configured as output:

CCR2 is the value to be loaded in the actual capture/compare 2 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR2 register (bit OC2PE). Else the preload value is copied in the active capture/compare 2 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signalled on OC2 output.

If channel CC2 is configured as input:

CCR2 is the counter value transferred by the last input capture 2 event (IC2).

46.5.16 TIM15 break and dead-time register (TIM15_BDTR)

Address offset: 0x44

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	BKBID	Res.	BK DSRM	Res.	Res.	Res.	Res.	Res.	Res.	BKF[3:0]			
			rw		rw							rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK[1:0]		DTG[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Note: As the BKBID, BKDSRM, BKF[3:0], AOE, BKP, BKE, OSSI, OSSR and DTG[7:0] bits may be write-locked depending on the LOCK configuration, it may be necessary to configure all of them during the first write access to the TIMx_BDTR register.

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **BKBID**: Break Bidirectional

0: Break input BRK in input mode

1: Break input BRK in bidirectional mode

In the bidirectional mode (BKBID bit set to 1), the break input is configured both in input mode and in open drain output mode. Any active break event asserts a low logic level on the Break input to indicate an internal break event to external devices.

Note: This bit cannot be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 27 Reserved, must be kept at reset value.

Bit 26 **BKDSRM**: Break Disarm

0: Break input BRK is armed
1: Break input BRK is disarmed
This bit is cleared by hardware when no break source is active.
The BKDSRM bit must be set by software to release the bidirectional output control (open-drain output in Hi-Z state) and then be polled it until it is reset by hardware, indicating that the fault condition has disappeared.

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bits 25:20 Reserved, must be kept at reset value.

Bits 19:16 **BKF[3:0]**: Break filter

This bit-field defines the frequency used to sample the BRK input signal and the length of the digital filter applied to BRK. The digital filter is made of an event counter in which N events are needed to validate a transition on the output:
0000: No filter, BRK acts asynchronously
0001: $f_{SAMPLING}=f_{CK\_INT}$, N=2
0010: $f_{SAMPLING}=f_{CK\_INT}$, N=4
0011: $f_{SAMPLING}=f_{CK\_INT}$, N=8
0100: $f_{SAMPLING}=f_{DTS}/2$, N=6
0101: $f_{SAMPLING}=f_{DTS}/2$, N=8
0110: $f_{SAMPLING}=f_{DTS}/4$, N=6
0111: $f_{SAMPLING}=f_{DTS}/4$, N=8
1000: $f_{SAMPLING}=f_{DTS}/8$, N=6
1001: $f_{SAMPLING}=f_{DTS}/8$, N=8
1010: $f_{SAMPLING}=f_{DTS}/16$, N=5
1011: $f_{SAMPLING}=f_{DTS}/16$, N=6
1100: $f_{SAMPLING}=f_{DTS}/16$, N=8
1101: $f_{SAMPLING}=f_{DTS}/32$, N=5
1110: $f_{SAMPLING}=f_{DTS}/32$, N=6
1111: $f_{SAMPLING}=f_{DTS}/32$, N=8

Note: This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 15 **MOE**: Main output enable

This bit is cleared asynchronously by hardware as soon as the break input is active. It is set by software or automatically depending on the AOE bit. It is acting only on the channels which are configured in output.
0: OC and OCN outputs are disabled or forced to idle state depending on the OSSI bit.
1: OC and OCN outputs are enabled if their respective enable bits are set (CCxE, CCxNE in TIMx_CCER register)
See OC/OCN enable description for more details (*Section 46.5.9: TIM15 capture/compare enable register (TIM15_CCER) on page 1846*).

Bit 14 **AOE**: Automatic output enable

0: MOE can be set only by software
1: MOE can be set by software or automatically at the next update event (if the break input is not be active)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 13 **BKP**: Break polarity

0: Break input BRK is active low

1: Break input BRK is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 12 **BKE**: Break enable

0: Break inputs (BRK and CCS clock failure event) disabled

1; Break inputs (BRK and CCS clock failure event) enabled

This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 11 **OSSR**: Off-state selection for Run mode

This bit is used when MOE=1 on channels that have a complementary output which are configured as outputs. OSSR is not implemented if no complementary output is implemented in the timer.

See OC/OCN enable description for more details (*Section 46.5.9: TIM15 capture/compare enable register (TIM15_CCER) on page 1846*).

0: When inactive, OC/OCN outputs are disabled (the timer releases the output control which is taken over by the GPIO, which forces a Hi-Z state)

1: When inactive, OC/OCN outputs are enabled with their inactive level as soon as CCxE=1 or CCxNE=1 (the output is still controlled by the timer).

Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **OSSI**: Off-state selection for Idle mode

This bit is used when MOE=0 on channels configured as outputs.

See OC/OCN enable description for more details (*Section 46.5.9: TIM15 capture/compare enable register (TIM15_CCER) on page 1846*).

0: When inactive, OC/OCN outputs are disabled (OC/OCN enable output signal=0)

1: When inactive, OC/OCN outputs are forced first with their idle level as soon as CCxE=1 or CCxNE=1. OC/OCN enable output signal=1)

Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 9:8 **LOCK[1:0]**: Lock configuration

These bits offer a write protection against software errors.

00: LOCK OFF - No bit is write protected

01: LOCK Level 1 = DTG bits in TIMx_BDTR register, OISx and OISxN bits in TIMx_CR2 register and BKE/BKP/AOE bits in TIMx_BDTR register can no longer be written

10: LOCK Level 2 = LOCK Level 1 + CC Polarity bits (CCxP/CCxNP bits in TIMx_CCER register, as long as the related channel is configured in output through the CCxS bits) as well as OSSR and OSSI bits can no longer be written.

11: LOCK Level 3 = LOCK Level 2 + CC Control bits (OCxM and OCxPE bits in TIMx_CCMRx registers, as long as the related channel is configured in output through the CCxS bits) can no longer be written.

Note: The LOCK bits can be written only once after the reset. Once the TIMx_BDTR register has been written, their content is frozen until the next reset.

Bits 7:0 **DTG[7:0]**: Dead-time generator setup

This bit-field defines the duration of the dead-time inserted between the complementary outputs. DT correspond to this duration.

DTG[7:5] = 0xx => DT = DTG[7:0] x t_{dtg} with $t_{dtg} = t_{DTS}$

DTG[7:5] = 10x => DT = (64+DTG[5:0]) x t_{dtg} with $t_{dtg} = 2 \times t_{DTS}$

DTG[7:5] = 110 => DT = (32+DTG[4:0]) x t_{dtg} with $t_{dtg} = 8 \times t_{DTS}$

DTG[7:5] = 111 => DT = (32+DTG[4:0]) x t_{dtg} with $t_{dtg} = 16 \times t_{DTS}$

Example if t_{DTS} = 125 ns (8 MHz), dead-time possible values are:

0 to 15875 ns by 125 ns steps,

16 µs to 31750 ns by 250 ns steps,

32 µs to 63 µs by 1 µs steps,

64 µs to 126 µs by 2 µs steps

Note: This bit-field can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

46.5.17 TIM15 DMA control register (TIM15_DCR)

Address offset: 0x48

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **DBL[4:0]**: DMA burst length

This 5-bit field defines the length of DMA transfers (the timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address).

00000: 1 transfer,

00001: 2 transfers,

00010: 3 transfers,

...

10001: 18 transfers.

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **DBA[4:0]**: DMA base address

This 5-bit field defines the base-address for DMA transfers (when read/write access are done through the TIMx_DMAR address). DBA is defined as an offset starting from the address of the TIMx_CR1 register.

Example:

00000: TIMx_CR1,

00001: TIMx_CR2,

00010: TIMx_SMCR,

...

46.5.18 TIM15 DMA address for full transfer (TIM15_DMAR)

Address offset: 0x4C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAB[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **DMAB[15:0]**: DMA register for burst accesses

A read or write operation to the DMAR register accesses the register located at the address

(TIMx_CR1 address) + (DBA + DMA index) x 4

where TIMx_CR1 address is the address of the control register 1, DBA is the DMA base address configured in TIMx_DCR register, DMA index is automatically controlled by the DMA transfer, and ranges from 0 to DBL (DBL configured in TIMx_DCR).

46.5.19 TIM15 alternate register 1 (TIM15_AF1)

Address offset: 0x60

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	BKCMP2P	BKCMP1P	BKINP	BKDF1BK0E	Res.	Res.	Res.	Res.	Res.	BKCMP2E	BKCMP1E	BKINE
				rw	rw	rw	rw						rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **BKCMP2P**: BRK COMP2 input polarity

This bit selects the COMP2 input sensitivity. It must be programmed together with the BKP polarity bit.

0: COMP2 input is active low

1: COMP2 input is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **BKCMP1P**: BRK COMP1 input polarity

This bit selects the COMP1 input sensitivity. It must be programmed together with the BKP polarity bit.

0: COMP1 input is active low

1: COMP1 input is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 9 **BKINP**: BRK BKIN input polarity

This bit selects the BKIN alternate function input sensitivity. It must be programmed together with the BKP polarity bit.

0: BKIN input is active low

1: BKIN input is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 8 **BKDF1BK0E**: BRK dfsdm1_break[0] enable

This bit enables the dfsdm1_break[0] for the timer's BRK input. dfsdm1_break[0] output is 'ORed' with the other BRK sources.

0: dfsdm1_break[0]input disabled

1: dfsdm1_break[0]input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 7:3 Reserved, must be kept at reset value.

Bit 2 **BKCMP2E**: BRK COMP2 enable

This bit enables the COMP2 for the timer's BRK input. COMP2 output is 'ORed' with the other BRK sources.

0: COMP2 input disabled

1: COMP2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 1 **BKCMP1E**: BRK COMP1 enable

This bit enables the COMP1 for the timer's BRK input. COMP1 output is 'ORed' with the other BRK sources.

0: COMP1 input disabled

1: COMP1 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 0 **BKINE**: BRK BKIN input enable

This bit enables the BKIN alternate function input for the timer's BRK input. BKIN input is 'ORed' with the other BRK sources.

0: BKIN input disabled

1: BKIN input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

46.5.20 TIM15 input selection register (TIM15_TISEL)

Address offset: 0x68

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
				rw	rw	rw	rw					rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:8 **TI2SEL[3:0]**: selects TI2[0] to TI2[15] input

0000: TIM15_CH2 input

0001: TIM2_CH2 input

0010: TIM3_CH2 input

0011: TIM4_CH2 input

Others: Reserved

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: selects TI1[0] to TI1[15] input
0000: TIM15_CH1 input
0001: TIM2_CH1 input
0010: TIM3_CH1 input
0011: TIM4_CH1 input
0100: LSE
0101: CSI
0110: MCO2
Other: Reserved

46.5.21 TIM15 register map

TIM15 registers are mapped as 16-bit addressable registers as described in the table below:

Table 366. TIM15 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**TIM15_CR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIFREMA	Res.	CKD [1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
	Reset value																					0		0	0	0				0	0	0	0
0x04	**TIM15_CR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OIS2	OIS1N	OIS1	TI1S	MMS[2:0]			CCDS	CCUS	Res.	CCPC
	Reset value																						0	0	0	0	0	0	0	0	0		0
0x08	**TIM15_SMCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TS [4:3]		Res.	Res.	Res.	SMS[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MSM	TS[2:0]			Res.	SMS[2:0]		
	Reset value											0	0				0									0	0	0	0		0	0	0
0x0C	**TIM15_DIER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDE	COMDE	Res.	Res.	Res.	CC1DE	UDE	BIE	TIE	COMIE	Res.	Res.	CC2IE	CC1IE	UIE
	Reset value																		0	0				0	0	0	0	0			0	0	0
0x10	**TIM15_SR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2OF	CC1OF	Res.	BIF	TIF	COMIF	Res.	Res.	CC2IF	CC1IF	UIF
	Reset value																						0	0		0	0	0			0	0	0
0x14	**TIM15_EGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BG	TG	COMG	Res.	Res.	CC2G	CC1G	UG
	Reset value																									0	0	0			0	0	0

Table 366. TIM15 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x18	**TIM15_CCMR1** Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC2M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]	Res.	OC2M [2:0]			OC2PE	OC2FE	CC2S [1:0]		Res.	OC1M [2:0]			OC1PE	OC1FE	CC1S [1:0]	
	Reset value								0								0		0	0	0	0	0	0	0		0	0	0	0	0	0	0
	TIM15_CCMR1 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC2F[3:0]				IC2 PSC [1:0]		CC2S [1:0]		IC1F[3:0]				IC1 PSC [1:0]		CC1S [1:0]	
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	**TIM15_CCER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC2NP	Res.	CC2P	CC2E	CC1NP	CC1NE	CC1P	CC1E
	Reset value																									0		0	0	0	0	0	0
0x24	**TIM15_CNT**	UIFCPY or Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value	0																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	**TIM15_PSC**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	**TIM15_ARR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[15:0]															
	Reset value																	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x30	**TIM15_RCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REP[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x34	**TIM15_CCR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x38	**TIM15_CCR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR2[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x44	**TIM15_BDTR**	Res.	Res.	Res.	BKBID	Res.	BKDSRM	Res.	Res.	Res.	Res.	Res.	Res.	BKF[3:0]				MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK [1:0]		DTG[7:0]							
	Reset value				0		0							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x48	**TIM15_DCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
	Reset value																				0	0	0	0	0				0	0	0	0	0

Table 366. TIM15 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x4C	**TIM15_DMAR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DMAB[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x60	**TIM15_AF1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BKCMP2P	BKCMP1P	BKINP	BKDF1BK0E	Res.	Res.	Res.	Res.	Res.	BKCMP2E	BKCMP1E	BKINE
	Reset value																					0	0	0	0						0	0	1
0x68	**TIM15_TISEL**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI2SEL[3:0]				Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value																					0	0	0	0					0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

46.6 TIM16/TIM17 registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by half-words (16-bit) or words (32-bit).

46.6.1 TIMx control register 1 (TIMx_CR1)(x = 16 to 17)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	UIFREMAP	Res.	CKD[1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
				rw		rw	rw	rw				rw	rw	rw	rw

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **UIFREMAP**: UIF status bit remapping
0: No remapping. UIF status bit is not copied to TIMx_CNT register bit 31.
1: Remapping enabled. UIF status bit is copied to TIMx_CNT register bit 31.

Bit 10 Reserved, must be kept at reset value.

Bits 9:8 **CKD[1:0]**: Clock division
This bit-field indicates the division ratio between the timer clock (CK_INT) frequency and the dead-time and sampling clock (t_{DTS})used by the dead-time generators and the digital filters (TIx),
00: $t_{DTS} = t_{CK\_INT}$
01: $t_{DTS} = 2 * t_{CK\_INT}$
10: $t_{DTS} = 4 * t_{CK\_INT}$
11: Reserved, do not program this value

Bit 7 **ARPE**: Auto-reload preload enable
0: TIMx_ARR register is not buffered
1: TIMx_ARR register is buffered

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **OPM**: One pulse mode
0: Counter is not stopped at update event
1: Counter stops counting at the next update event (clearing the bit CEN)

Bit 2 **URS**: Update request source
This bit is set and cleared by software to select the UEV event sources.
0: Any of the following events generate an update interrupt or DMA request if enabled. These events can be:
- Counter overflow/underflow
- Setting the UG bit
- Update generation through the slave mode controller

1: Only counter overflow/underflow generates an update interrupt or DMA request if enabled.

Bit 1 **UDIS**: Update disable

This bit is set and cleared by software to enable/disable UEV event generation.

0: UEV enabled. The Update (UEV) event is generated by one of the following events:

– Counter overflow/underflow

– Setting the UG bit

– Update generation through the slave mode controller

Buffered registers are then loaded with their preload values.

1: UEV disabled. The Update event is not generated, shadow registers keep their value (ARR, PSC, CCRx). However the counter and the prescaler are reinitialized if the UG bit is set or if a hardware reset is received from the slave mode controller.

Bit 0 **CEN**: Counter enable

0: Counter disabled

1: Counter enabled

Note: External clock and gated mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.

46.6.2 TIMx control register 2 (TIMx_CR2)(x = 16 to 17)

Address offset: 0x04

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	OIS1N	OIS1	Res.	Res.	Res.	Res.	CCDS	CCUS	Res.	CCPC
						rw	rw					rw	rw		rw

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **OIS1N**: Output Idle state 1 (OC1N output)

0: OC1N=0 after a dead-time when MOE=0

1: OC1N=1 after a dead-time when MOE=0

Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 8 **OIS1**: Output Idle state 1 (OC1 output)

0: OC1=0 (after a dead-time if OC1N is implemented) when MOE=0

1: OC1=1 (after a dead-time if OC1N is implemented) when MOE=0

Note: This bit can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **CCDS**: Capture/compare DMA selection

0: CCx DMA request sent when CCx event occurs

1: CCx DMA requests sent when update event occurs

Bit 2 **CCUS**: Capture/compare control update selection

0: When capture/compare control bits are preloaded (CCPC=1), they are updated by setting the COMG bit only.

1: When capture/compare control bits are preloaded (CCPC=1), they are updated by setting the COMG bit or when an rising edge occurs on TRGI.

Note: This bit acts only on channels that have a complementary output.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **CCPC**: Capture/compare preloaded control
0: CCxE, CCxNE and OCxM bits are not preloaded
1: CCxE, CCxNE and OCxM bits are preloaded, after having been written, they are updated only when COM bit is set.
Note: This bit acts only on channels that have a complementary output.

46.6.3 TIMx DMA/interrupt enable register (TIMx_DIER)(x = 16 to 17)

Address offset: 0x0C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CC1DE	UDE	BIE	Res.	COMIE	Res.	Res.	Res.	CC1IE	UIE
						rw	rw	rw		rw				rw	rw

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **CC1DE**: Capture/Compare 1 DMA request enable
0: CC1 DMA request disabled
1: CC1 DMA request enabled

Bit 8 **UDE**: Update DMA request enable
0: Update DMA request disabled
1: Update DMA request enabled

Bit 7 **BIE**: Break interrupt enable
0: Break interrupt disabled
1: Break interrupt enabled

Bit 6 Reserved, must be kept at reset value.

Bit 5 **COMIE:** COM interrupt enable
0: COM interrupt disabled
1: COM interrupt enabled

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **CC1IE**: Capture/Compare 1 interrupt enable
0: CC1 interrupt disabled
1: CC1 interrupt enabled

Bit 0 **UIE**: Update interrupt enable
0: Update interrupt disabled
1: Update interrupt enabled

46.6.4 TIMx status register (TIMx_SR)(x = 16 to 17)

Address offset: 0x10

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CC1OF	Res.	BIF	Res.	COMIF	Res.	Res.	Res.	CC1IF	UIF
						rc_w0		rc_w0		rc_w0				rc_w0	rc_w0

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **CC1OF**: Capture/Compare 1 overcapture flag

This flag is set by hardware only when the corresponding channel is configured in input capture mode. It is cleared by software by writing it to ‘0’.
0: No overcapture has been detected
1: The counter value has been captured in TIMx_CCR1 register while CC1IF flag was already set

Bit 8 Reserved, must be kept at reset value.

Bit 7 **BIF**: Break interrupt flag

This flag is set by hardware as soon as the break input goes active. It can be cleared by software if the break input is not active.
0: No break event occurred
1: An active level has been detected on the break input

Bit 6 Reserved, must be kept at reset value.

Bit 5 **COMIF:** COM interrupt flag

This flag is set by hardware on a COM event (once the capture/compare control bits –CCxE, CCxNE, OCxM– have been updated). It is cleared by software.
0: No COM event occurred
1: COM interrupt pending

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **CC1IF**: Capture/Compare 1 interrupt flag

This flag is set by hardware. It is cleared by software (input capture or output compare mode) or by reading the TIMx_CCR1 register (input capture mode only).
0: No compare match / No input capture occurred
1: A compare match or an input capture occurred
If channel CC1 is configured as output: this flag is set when the content of the counter TIMx_CNT matches the content of the TIMx_CCR1 register. When the content of TIMx_CCR1 is greater than the content of TIMx_ARR, the CC1IF bit goes high on the counter overflow (in up-counting and up/down-counting modes) or underflow (in down-counting mode). There are 3 possible options for flag setting in center-aligned mode, refer to the CMS bits in the TIMx_CR1 register for the full description.
If channel CC1 is configured as input: this bit is set when counter value has been captured in TIMx_CCR1 register (an edge has been detected on IC1, as per the edge sensitivity defined with the CC1P and CC1NP bits setting, in TIMx_CCER).

Bit 0 **UIF**: Update interrupt flag

This bit is set by hardware on an update event. It is cleared by software.
0: No update occurred.
1: Update interrupt pending. This bit is set by hardware when the registers are updated:

– At overflow regarding the repetition counter value (update if repetition counter = 0) and if the UDIS=0 in the TIMx_CR1 register.
– When CNT is reinitialized by software using the UG bit in TIMx_EGR register, if URS=0 and UDIS=0 in the TIMx_CR1 register.

46.6.5 TIMx event generation register (TIMx_EGR)(x = 16 to 17)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BG	Res.	COMG	Res.	Res.	Res.	CC1G	UG
								w		w				w	w

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **BG**: Break generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.
0: No action.
1: A break event is generated. MOE bit is cleared and BIF flag is set. Related interrupt or DMA transfer can occur if enabled.

Bit 6 Reserved, must be kept at reset value.

Bit 5 **COMG:** Capture/Compare control update generation

This bit can be set by software, it is automatically cleared by hardware.
0: No action
1: When the CCPC bit is set, it is possible to update the CCxE, CCxNE and OCxM bits

Note: This bit acts only on channels that have a complementary output.

Bits 4:2 Reserved, must be kept at reset value.

Bit 1 **CC1G**: Capture/Compare 1 generation

This bit is set by software in order to generate an event, it is automatically cleared by hardware.
0: No action.
1: A capture/compare event is generated on channel 1:
If channel CC1 is configured as output:
CC1IF flag is set, Corresponding interrupt or DMA request is sent if enabled.
If channel CC1 is configured as input:
The current value of the counter is captured in TIMx_CCR1 register. The CC1IF flag is set, the corresponding interrupt or DMA request is sent if enabled. The CC1OF flag is set if the CC1IF flag was already high.

Bit 0 **UG**: Update generation

This bit can be set by software, it is automatically cleared by hardware.
0: No action.
1: Reinitialize the counter and generates an update of the registers. Note that the prescaler counter is cleared too (anyway the prescaler ratio is not affected).

46.6.6 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1) (x = 16 to 17)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for input capture mode (this section) or for output compare mode (next section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode.

Input capture mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC1F[3:0]				IC1PSC[1:0]		CC1S[1:0]	
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **IC1F[3:0]**: Input capture 1 filter

This bit-field defines the frequency used to sample TI1 input and the length of the digital filter applied to TI1. The digital filter is made of an event counter in which N consecutive events are needed to validate a transition on the output:

0000: No filter, sampling is done at f_{DTS}
0001: $f_{SAMPLING}=f_{CK\_INT}$, N=2
0010: $f_{SAMPLING}=f_{CK\_INT}$, N=4
0011: $f_{SAMPLING}=f_{CK\_INT}$, N=8
0100: $f_{SAMPLING}=f_{DTS}/2$, N=
0101: $f_{SAMPLING}=f_{DTS}/2$, N=8
0110: $f_{SAMPLING}=f_{DTS}/4$, N=6
0111: $f_{SAMPLING}=f_{DTS}/4$, N=8
1000: $f_{SAMPLING}=f_{DTS}/8$, N=6
1001: $f_{SAMPLING}=f_{DTS}/8$, N=8
1010: $f_{SAMPLING}=f_{DTS}/16$, N=5
1011: $f_{SAMPLING}=f_{DTS}/16$, N=6
1100: $f_{SAMPLING}=f_{DTS}/16$, N=8
1101: $f_{SAMPLING}=f_{DTS}/32$, N=5
1110: $f_{SAMPLING}=f_{DTS}/32$, N=6
1111: $f_{SAMPLING}=f_{DTS}/32$, N=8

Bits 3:2 **IC1PSC[1:0]**: Input capture 1 prescaler

This bit-field defines the ratio of the prescaler acting on CC1 input (IC1).
The prescaler is reset as soon as CC1E='0' (TIMx_CCER register).
00: no prescaler, capture is done each time an edge is detected on the capture input.
01: capture is done once every 2 events
10: capture is done once every 4 events
11: capture is done once every 8 events

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 Selection

This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC1 channel is configured as output
01: CC1 channel is configured as input, IC1 is mapped on TI1
Others: Reserved

Note: CC1S bits are writable only when the channel is OFF (CC1E = '0' in TIMx_CCER).

46.6.7 TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1) (x = 16 to 17)

Address offset: 0x18

Reset value: 0x0000 0000

The same register can be used for output compare mode (this section) or for input capture mode (previous section). The direction of a channel is defined by configuring the corresponding CCxS bits. All the other bits of this register have a different function in input and in output mode.

Output compare mode:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]
															rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[2:0]			OC1PE	OC1FE	CC1S[1:0]	
									rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bits 15:7 Reserved, must be kept at reset value.

Bits 16, 6:4 **OC1M[3:0]**: Output Compare 1 mode

These bits define the behavior of the output reference signal OC1REF from which OC1 and OC1N are derived. OC1REF is active high whereas OC1 and OC1N active level depends on CC1P and CC1NP bits.

0000: Frozen - The comparison between the output compare register TIMx_CCR1 and the counter TIMx_CNT has no effect on the outputs.

0001: Set channel 1 to active level on match. OC1REF signal is forced high when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0010: Set channel 1 to inactive level on match. OC1REF signal is forced low when the counter TIMx_CNT matches the capture/compare register 1 (TIMx_CCR1).

0011: Toggle - OC1REF toggles when TIMx_CNT=TIMx_CCR1.

0100: Force inactive level - OC1REF is forced low.

0101: Force active level - OC1REF is forced high.

0110: PWM mode 1 - Channel 1 is active as long as TIMx_CNT<TIMx_CCR1 else inactive.

0111: PWM mode 2 - Channel 1 is inactive as long as TIMx_CNT<TIMx_CCR1 else active.

All other values: Reserved

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S='00' (the channel is configured in output).

In PWM mode 1 or 2, the OCREF level changes only when the result of the comparison changes or when the output compare mode switches from "frozen" mode to "PWM" mode.

The OC1M[3] bit is not contiguous, located in bit 16.

Bit 3 **OC1PE**: Output Compare 1 preload enable

0: Preload register on TIMx_CCR1 disabled. TIMx_CCR1 can be written at anytime, the new value is taken in account immediately.

1: Preload register on TIMx_CCR1 enabled. Read/Write operations access the preload register. TIMx_CCR1 preload value is loaded in the active register at each update event.

Note: These bits can not be modified as long as LOCK level 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S='00' (the channel is configured in output).

Bit 2 **OC1FE**: Output Compare 1 fast enable

This bit decreases the latency between a trigger event and a transition on the timer output. It must be used in one-pulse mode (OPM bit set in TIMx_CR1 register), to have the output pulse starting as soon as possible after the starting trigger.

0: CC1 behaves normally depending on counter and CCR1 values even when the trigger is ON. The minimum delay to activate CC1 output when an edge occurs on the trigger input is 5 clock cycles.

1: An active edge on the trigger input acts like a compare match on CC1 output. Then, OC is set to the compare level independently of the result of the comparison. Delay to sample the trigger input and to activate CC1 output is reduced to 3 clock cycles. OC1FE acts only if the channel is configured in PWM1 or PWM2 mode.

Bits 1:0 **CC1S[1:0]**: Capture/Compare 1 selection

This bit-field defines the direction of the channel (input/output) as well as the used input.
00: CC1 channel is configured as output
01: CC1 channel is configured as input, IC1 is mapped on TI1
Others: Reserved

Note: CC1S bits are writable only when the channel is OFF (CC1E = '0' in TIMx_CCER).

46.6.8 TIMx capture/compare enable register (TIMx_CCER)(x = 16 to 17)

Address offset: 0x20

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1NP	CC1NE	CC1P	CC1E
												rw	rw	rw	rw

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **CC1NP**: Capture/Compare 1 complementary output polarity

CC1 channel configured as output:

0: OC1N active high
1: OC1N active low

CC1 channel configured as input:

This bit is used in conjunction with CC1P to define the polarity of TI1FP1 and TI2FP1. Refer to the description of CC1P.

Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register) and CC1S="00" (the channel is configured in output).

On channels that have a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1NP active bit takes the new value from the preloaded bit only when a commutation event is generated.

Bit 2 **CC1NE**: Capture/Compare 1 complementary output enable

0: Off - OC1N is not active. OC1N level is then function of MOE, OSSI, OSSR, OIS1, OIS1N and CC1E bits.

1: On - OC1N signal is output on the corresponding output pin depending on MOE, OSSI, OSSR, OIS1, OIS1N and CC1E bits.

Bit 1 **CC1P**: Capture/Compare 1 output polarity

0: OC1 active high (output mode) / Edge sensitivity selection (input mode, see below)

1: OC1 active low (output mode) / Edge sensitivity selection (input mode, see below)

When CC1 channel is configured as input, both CC1NP/CC1P bits select the active polarity of TI1FP1 and TI2FP1 for trigger or capture operations.

CC1NP=0, CC1P=0: non-inverted/rising edge. The circuit is sensitive to TIxFP1 rising edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is not inverted (trigger operation in gated mode or encoder mode).

CC1NP=0, CC1P=1: inverted/falling edge. The circuit is sensitive to TIxFP1 falling edge (capture or trigger operations in reset, external clock or trigger mode), TIxFP1 is inverted (trigger operation in gated mode or encoder mode).

CC1NP=1, CC1P=1: non-inverted/both edges/ The circuit is sensitive to both TIxFP1 rising and falling edges (capture or trigger operations in reset, external clock or trigger mode), TIxFP1is not inverted (trigger operation in gated mode). This configuration must not be used in encoder mode.

CC1NP=1, CC1P=0: this configuration is reserved, it must not be used.

Note: This bit is not writable as soon as LOCK level 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

On channels that have a complementary output, this bit is preloaded. If the CCPC bit is set in the TIMx_CR2 register then the CC1P active bit takes the new value from the preloaded bit only when a Commutation event is generated.

Bit 0 **CC1E**: Capture/Compare 1 output enable

0: Capture mode disabled / OC1 is not active (see below)

1: Capture mode enabled / OC1 signal is output on the corresponding output pin

When CC1 channel is configured as output, the OC1 level depends on MOE, OSSI, OSSR, OIS1, OIS1N and CC1NE bits, regardless of the CC1E bits state. Refer to *Table 367* for details.

Table 367. Output control bits for complementary OCx and OCxN channels with break feature (TIM16/17)

Control bits					Output states[1]	
MOE bit	OSSI bit	OSSR bit	CCxE bit	CCxNE bit	OCx output state	OCxN output state
1	X	X	0	0	Output Disabled (not driven by the timer: Hi-Z) OCx=0 OCxN=0, OCxN_EN=0	
		0	0	1	Output Disabled (not driven by the timer: Hi-Z) OCx=0	OCxREF + Polarity OCxN=OCxREF XOR CCxNP
		0	1	0	OCxREF + Polarity OCx=OCxREF XOR CCxP	Output Disabled (not driven by the timer: Hi-Z) OCxN=0
		X	1	1	OCREF + Polarity + dead-time	Complementary to OCREF (not OCREF) + Polarity + dead-time
		1	0	1	Off-State (output enabled with inactive state) OCx=CCxP	OCxREF + Polarity OCxN=OCxREF XOR CCxNP
		1	1	0	OCxREF + Polarity OCx=OCxREF XOR CCxP, OCx_EN=1	Off-State (output enabled with inactive state) OCxN=CCxNP, OCxN_EN=1
0	0	X	X	X	Output disabled (not driven by the timer: Hi-Z).	
	1		0	0		
			0	1	Off-State (output enabled with inactive state) Asynchronously: OCx=CCxP, OCxN=CCxNP Then if the clock is present: OCx=OISx and OCxN=OISxN after a dead-time, assuming that OISx and OISxN do not correspond to OCX and OCxN both in active state	
			1	0		
			1	1		

1. When both outputs of a channel are not used (control taken over by GPIO controller), the OISx, OISxN, CCxP and CCxNP bits must be kept cleared.

Note: The state of the external I/O pins connected to the complementary OCx and OCxN channels depends on the OCx and OCxN channel state and GPIO control and alternate function registers.

46.6.9 TIMx counter (TIMx_CNT)(x = 16 to 17)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIF CPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: UIF Copy

This bit is a read-only copy of the UIF bit of the TIMx_ISR register. If the UIFREMAP bit in TIMx_CR1 is reset, bit 31 is reserved and read as 0.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]**: Counter value

46.6.10 TIMx prescaler (TIMx_PSC)(x = 16 to 17)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value

The counter clock frequency (CK_CNT) is equal to f_{CK_PSC} / (PSC[15:0] + 1).
PSC contains the value to be loaded in the active prescaler register at each update event (including when the counter is cleared through UG bit of TIMx_EGR register or through trigger controller when configured in “reset mode”).

46.6.11 TIMx auto-reload register (TIMx_ARR)(x = 16 to 17)

Address offset: 0x2C

Reset value: 0xFFFF

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **ARR[15:0]**: Auto-reload value

ARR is the value to be loaded in the actual auto-reload register.
Refer to the *Section 46.4.1: Time-base unit on page 1797* for more details about ARR update and behavior.
The counter is blocked while the auto-reload value is null.

46.6.12 TIMx repetition counter register (TIMx_RCR)(x = 16 to 17)

Address offset: 0x30

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REP[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **REP[7:0]**: Repetition counter value

These bits allow the user to set-up the update rate of the compare registers (i.e. periodic transfers from preload to active registers) when preload registers are enable, as well as the update interrupt generation rate, if this interrupt is enable.

Each time the REP_CNT related downcounter reaches zero, an update event is generated and it restarts counting from REP value. As REP_CNT is reloaded with REP value only at the repetition update event U_RC, any write to the TIMx_RCR register is not taken in account until the next repetition update event.

It means in PWM mode (REP+1) corresponds to the number of PWM periods in edge-aligned mode.

46.6.13 TIMx capture/compare register 1 (TIMx_CCR1)(x = 16 to 17)

Address offset: 0x34

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CCR1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **CCR1[15:0]**: Capture/Compare 1 value

If channel CC1 is configured as output:

CCR1 is the value to be loaded in the actual capture/compare 1 register (preload value).

It is loaded permanently if the preload feature is not selected in the TIMx_CCMR1 register (bit OC1PE). Else the preload value is copied in the active capture/compare 1 register when an update event occurs.

The active capture/compare register contains the value to be compared to the counter TIMx_CNT and signaled on OC1 output.

If channel CC1 is configured as input:

CCR1 is the counter value transferred by the last input capture 1 event (IC1).

46.6.14 TIMx break and dead-time register (TIMx_BDTR)(x = 16 to 17)

Address offset: 0x44

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	BKBID	Res.	BK DSRM	Res.	Res.	Res.	Res.	Res.	Res.	BKF[3:0]			
			rw		rw							rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK[1:0]		DTG[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Note: As the BKBID, BKDSRM, BKF[3:0], AOE, BKP, BKE, OSSI, OSSR and DTG[7:0] bits may be write-locked depending on the LOCK configuration, it may be necessary to configure all of them during the first write access to the TIMx_BDTR register.

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **BKBID**: Break Bidirectional

0: Break input BRK in input mode
1: Break input BRK in bidirectional mode
In the bidirectional mode (BKBID bit set to 1), the break input is configured both in input mode and in open drain output mode. Any active break event asserts a low logic level on the Break input to indicate an internal break event to external devices.

Note: This bit cannot be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 27 Reserved, must be kept at reset value.

Bit 26 **BKDSRM**: Break Disarm

0: Break input BRK is armed
1: Break input BRK is disarmed
This bit is cleared by hardware when no break source is active.
The BKDSRM bit must be set by software to release the bidirectional output control (open-drain output in Hi-Z state) and then be polled it until it is reset by hardware, indicating that the fault condition has disappeared.

Note: Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bits 25:20 Reserved, must be kept at reset value.

Bits 19:16 **BKF[3:0]**: Break filter

This bit-field defines the frequency used to sample BRK input and the length of the digital filter applied to BRK. The digital filter is made of an event counter in which N events are needed to validate a transition on the output:
0000: No filter, BRK acts asynchronously
0001: $f_{SAMPLING}=f_{CK\_INT}$, N=2
0010: $f_{SAMPLING}=f_{CK\_INT}$, N=4
0011: $f_{SAMPLING}=f_{CK\_INT}$, N=8
0100: $f_{SAMPLING}=f_{DTS}/2$, N=6
0101: $f_{SAMPLING}=f_{DTS}/2$, N=8
0110: $f_{SAMPLING}=f_{DTS}/4$, N=6
0111: $f_{SAMPLING}=f_{DTS}/4$, N=8
1000: $f_{SAMPLING}=f_{DTS}/8$, N=6
1001: $f_{SAMPLING}=f_{DTS}/8$, N=8
1010: $f_{SAMPLING}=f_{DTS}/16$, N=5
1011: $f_{SAMPLING}=f_{DTS}/16$, N=6
1100: $f_{SAMPLING}=f_{DTS}/16$, N=8
1101: $f_{SAMPLING}=f_{DTS}/32$, N=5
1110: $f_{SAMPLING}=f_{DTS}/32$, N=6
1111: $f_{SAMPLING}=f_{DTS}/32$, N=8
This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 15 **MOE**: Main output enable

This bit is cleared asynchronously by hardware as soon as the break input is active. It is set by software or automatically depending on the AOE bit. It is acting only on the channels which are configured in output.
0: OC and OCN outputs are disabled or forced to idle state depending on the OSSI bit.
1: OC and OCN outputs are enabled if their respective enable bits are set (CCxE, CCxNE in TIMx_CCER register)
See OC/OCN enable description for more details (*Section 46.6.8: TIMx capture/compare enable register (TIMx_CCER)(x = 16 to 17) on page 1868*).

Bit 14 **AOE**: Automatic output enable

0: MOE can be set only by software
1: MOE can be set by software or automatically at the next update event (if the break input is not be active)

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 13 **BKP**: Break polarity

0: Break input BRK is active low
1: Break input BRK is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 12 **BKE**: Break enable

0: Break inputs (BRK and CCS clock failure event) disabled
1; Break inputs (BRK and CCS clock failure event) enabled

Note: This bit cannot be modified when LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Any write operation to this bit takes a delay of 1 APB clock cycle to become effective.

Bit 11 **OSSR**: Off-state selection for Run mode

This bit is used when MOE=1 on channels that have a complementary output which are configured as outputs. OSSR is not implemented if no complementary output is implemented in the timer.
See OC/OCN enable description for more details (*Section 46.6.8: TIMx capture/compare enable register (TIMx_CCER)(x = 16 to 17) on page 1868*).
0: When inactive, OC/OCN outputs are disabled (the timer releases the output control which is taken over by the GPIO, which forces a Hi-Z state)
1: When inactive, OC/OCN outputs are enabled with their inactive level as soon as CCxE=1 or CCxNE=1 (the output is still controlled by the timer).

Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **OSSI**: Off-state selection for Idle mode

This bit is used when MOE=0 on channels configured as outputs.
See OC/OCN enable description for more details (*Section 46.6.8: TIMx capture/compare enable register (TIMx_CCER)(x = 16 to 17) on page 1868*).
0: When inactive, OC/OCN outputs are disabled (OC/OCN enable output signal=0)
1: When inactive, OC/OCN outputs are forced first with their idle level as soon as CCxE=1 or CCxNE=1. OC/OCN enable output signal=1)

Note: This bit can not be modified as soon as the LOCK level 2 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 9:8 **LOCK[1:0]**: Lock configuration

These bits offer a write protection against software errors.
00: LOCK OFF - No bit is write protected
01: LOCK Level 1 = DTG bits in TIMx_BDTR register, OISx and OISxN bits in TIMx_CR2 register and BKE/BKP/AOE bits in TIMx_BDTR register can no longer be written.
10: LOCK Level 2 = LOCK Level 1 + CC Polarity bits (CCxP/CCxNP bits in TIMx_CCER register, as long as the related channel is configured in output through the CCxS bits) as well as OSSR and OSSI bits can no longer be written.
11: LOCK Level 3 = LOCK Level 2 + CC Control bits (OCxM and OCxPE bits in TIMx_CCMRx registers, as long as the related channel is configured in output through the CCxS bits) can no longer be written.

Note: The LOCK bits can be written only once after the reset. Once the TIMx_BDTR register has been written, their content is frozen until the next reset.

Bits 7:0 **DTG[7:0]**: Dead-time generator setup

This bit-field defines the duration of the dead-time inserted between the complementary outputs. DT correspond to this duration.
DTG[7:5] = 0xx => DT = DTG[7:0] x t_{dtg} with $t_{dtg} = t_{DTS}$
DTG[7:5] = 10x => DT = (64 + DTG[5:0]) x t_{dtg} with $t_{dtg} = 2 \times t_{DTS}$
DTG[7:5] = 110 => DT = (32 + DTG[4:0]) x t_{dtg} with $t_{dtg} = 8 \times t_{DTS}$
DTG[7:5] = 111 => DT = (32 + DTG[4:0]) x t_{dtg} with $t_{dtg} = 16 \times t_{DTS}$
Example if t_{DTS} = 125 ns (8 MHz), dead-time possible values are:
0 to 15875 ns by 125 ns steps,
16 µs to 31750 ns by 250 ns steps,
32 µs to 63 µs by 1 µs steps,
64 µs to 126 µs by 2 µs steps

Note: This bit-field can not be modified as long as LOCK level 1, 2 or 3 has been programmed (LOCK bits in TIMx_BDTR register).

46.6.15 TIMx DMA control register (TIMx_DCR)(x = 16 to 17)

Address offset: 0x48

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
			rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **DBL[4:0]**: DMA burst length

This 5-bit field defines the length of DMA transfers (the timer recognizes a burst transfer when a read or a write access is done to the TIMx_DMAR address), i.e. the number of transfers. Transfers can be in half-words or in bytes (see example below).
00000: 1 transfer,
00001: 2 transfers,
00010: 3 transfers,
...
10001: 18 transfers.

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **DBA[4:0]**: DMA base address

This 5-bit field defines the base-address for DMA transfers (when read/write access are done through the TIMx_DMAR address). DBA is defined as an offset starting from the address of the TIMx_CR1 register.
Example:
00000: TIMx_CR1,
00001: TIMx_CR2,
00010: TIMx_SMCR,
...

Example: Let us consider the following transfer: DBL = 7 transfers and DBA = TIMx_CR1. In this case the transfer is done to/from 7 registers starting from the TIMx_CR1 address.

46.6.16 TIMx DMA address for full transfer (TIMx_DMAR)(x = 16 to 17)

Address offset: 0x4C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAB[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **DMAB[15:0]**: DMA register for burst accesses

A read or write operation to the DMAR register accesses the register located at the address

(TIMx_CR1 address) + (DBA + DMA index) x 4

where TIMx_CR1 address is the address of the control register 1, DBA is the DMA base address configured in TIMx_DCR register, DMA index is automatically controlled by the DMA transfer, and ranges from 0 to DBL (DBL configured in TIMx_DCR).

46.6.17 TIM16 alternate function register 1 (TIM16_AF1)

Address offset: 0x60

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	BKCMP2P	BKCMP1P	BKINP	BKDF1BK1E	Res.	Res.	Res.	Res.	Res.	BKCMP2E	BKCMP1E	BKINE
				rw	rw	rw	rw						rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **BKCMP2P**: BRK COMP2 input polarity

This bit selects the COMP2 input sensitivity. It must be programmed together with the BKP polarity bit.

0: COMP2 input is active low

1: COMP2 input is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **BKCMP1P**: BRK COMP1 input polarity

This bit selects the COMP1 input sensitivity. It must be programmed together with the BKP polarity bit.

0: COMP1 input is active low

1: COMP1 input is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 9 **BKINP**: BRK BKIN input polarity

This bit selects the BKIN alternate function input sensitivity. It must be programmed together with the BKP polarity bit.

0: BKIN input is active low

1: BKIN input is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 8 **BKDFBK1E**: BRK dfsdm1_break[1] enable

This bit enables the dfsdm1_break[1] for the timer's BRK input. dfsdm1_break[1] output is 'ORed' with the other BRK sources.

0: dfsdm1_break[1] input disabled

1: dfsdm1_break[1] input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 7:3 Reserved, must be kept at reset value.

Bit 2 **BKCMP2E**: BRK COMP2 enable

This bit enables the COMP2 for the timer's BRK input. COMP2 output is 'ORed' with the other BRK sources.

0: COMP2 input disabled

1: COMP2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 1 **BKCMP1E**: BRK COMP1 enable

This bit enables the COMP1 for the timer's BRK input. COMP1 output is 'ORed' with the other BRK sources.

0: COMP1 input disabled

1: COMP1 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 0 **BKINE**: BRK BKIN input enable

This bit enables the BKIN alternate function input for the timer's BRK input. BKIN input is 'ORed' with the other BRK sources.

0: BKIN input disabled

1: BKIN input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

46.6.18 TIM16 input selection register (TIM16_TISEL)

Address offset: 0x68

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1SEL[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: selects TI1[0] to TI1[15] input

0000: TIM16_CH1 input

0001: LSI

0010: LSE

0011: WKUP_IT

Other: Reserved

46.6.19 TIM17 alternate function register 1 (TIM17_AF1)

Address offset: 0x60

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	BKCMP2P	BKCMP1P	BKINP	BKDF1BK2E	Res.	Res.	Res.	Res.	Res.	BKCMP2E	BKCMP1E	BKINE
				rw	rw	rw	rw						rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **BKCMP2P**: BRK COMP2 input polarity

This bit selects the COMP2 input sensitivity. It must be programmed together with the BKP polarity bit.

0: COMP2 input is active low

1: COMP2 input is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 10 **BKCMP1P**: BRK COMP1 input polarity

This bit selects the COMP1 input sensitivity. It must be programmed together with the BKP polarity bit.

0: COMP1 input is active low

1: COMP1 input is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 9 **BKINP**: BRK BKIN input polarity

This bit selects the BKIN alternate function input sensitivity. It must be programmed together with the BKP polarity bit.

0: BKIN input is active low

1: BKIN input is active high

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 8 **BKDF1BK2E**: BRK dfsdm1_break[2] enable

This bit enables the dfsdm1_break[2] for the timer's BRK input. dfsdm1_break[2] output is 'ORed' with the other BRK sources.

0: dfsdm1_break[2] input disabled

1: dfsdm1_break[2] input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bits 7:3 Reserved, must be kept at reset value.

Bit 2 **BKCMP2E**: BRK COMP2 enable

This bit enables the COMP2 for the timer's BRK input. COMP2 output is 'ORed' with the other BRK sources.

0: COMP2 input disabled

1: COMP2 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 1 **BKCMP1E**: BRK COMP1 enable

This bit enables the COMP1 for the timer's BRK input. COMP1 output is 'ORed' with the other BRK sources.

0: COMP1 input disabled

1: COMP1 input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

Bit 0 **BKINE**: BRK BKIN input enable

This bit enables the BKIN alternate function input for the timer's BRK input. BKIN input is 'ORed' with the other BRK sources.

0: BKIN input disabled

1: BKIN input enabled

Note: This bit can not be modified as long as LOCK level 1 has been programmed (LOCK bits in TIMx_BDTR register).

46.6.20 TIM17 input selection register (TIM17_TISEL)

Address offset: 0x68

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1SEL[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **TI1SEL[3:0]**: selects TI1[0] to TI1[15] input

0000: TIM17_CH1 input

0010: HSE_1MHz

0011: MCO1

Others: Reserved

46.6.21 TIM16/TIM17 register map

TIM16/TIM17 registers are mapped as 16-bit addressable registers as described in the table below:

Table 368. TIM16/TIM17 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**TIMx_CR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIFREMA	Res.	CKD [1:0]		ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
	Reset value																					0		0	0	0				0	0	0	0
0x04	**TIMx_CR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OIS1N	OIS1	Res.	Res.	Res.	Res.	CCDS	CCUS	Res.	CCPC
	Reset value																							0	0					0	0		0
0x0C	**TIMx_DIER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1DE	UDE	BIE	Res.	COMIE	Res.	Res.	Res.	CC1IE	UIE
	Reset value																							0	0	0		0				0	0
0x10	**TIMx_SR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1OF	Res.	BIF	Res.	COMIF	Res.	Res.	Res.	CC1IF	UIF
	Reset value																							0		0		0				0	0
0x14	**TIMx_EGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BG	Res.	COMG	Res.	Res.	Res.	CC1G	UG
	Reset value																									0		0				0	0
0x18	**TIMx_CCMR1** Output Compare mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M[3]	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OC1M [2:0]				OC1PE	OC1FE	CC1S [1:0]	
	Reset value																0										0	0	0		0	0	0	0
	TIMx_CCMR1 Input Capture mode	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IC1F[3:0]				IC1PSC [1:0]		CC1S [1:0]	
	Reset value																									0	0	0	0	0	0	0	0
0x20	**TIMx_CCER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC1NP	CC1NE	CC1P	CC1E
	Reset value																													0	0	0	0
0x24	**TIMx_CNT**	UIFCPY or Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value	0																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	**TIMx_PSC**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	**TIMx_ARR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[15:0]															
	Reset value																	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 368. TIM16/TIM17 register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x30	**TIMx_RCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REP[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x34	**TIMx_CCR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCR1[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x44	**TIMx_BDTR**	Res.	Res.	Res.	BKBID	Res.	BKDSRM	Res.	Res.	Res.	Res.	Res.	Res.	BKF[3:0]				MOE	AOE	BKP	BKE	OSSR	OSSI	LOCK [1:0]		DTG[7:0]							
	Reset value				0		0							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x48	**TIMx_DCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBL[4:0]					Res.	Res.	Res.	DBA[4:0]				
	Reset value																				0	0	0	0	0				0	0	0	0	0
0x4C	**TIMx_DMAR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DMAB[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x60	**TIM16_AF1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BKCMP2P	BKCMP1P	BKINP	BKDF1BK1E	Res.	Res.	Res.	Res.	Res.	BKCMP2E	BKCMP1E	BKINE
	Reset value																					0	0	0	0						0	0	1
0x60	**TIM17_AF1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BKCMP2P	BKCMP1P	BKINP	BKDF1BK2E	Res.	Res.	Res.	Res.	Res.	BKCMP2E	BKCMP1E	BKINE
	Reset value																					0	0	0	0						0	0	1
0x68	**TIM16_TISEL**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value																													0	0	0	0
0x68	**TIM17_TISEL**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TI1SEL[3:0]			
	Reset value																													0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

47 Basic timers (TIM6/TIM7)

47.1 TIM6/TIM7 introduction

The basic timers TIM6 and TIM7 consist of a 16-bit auto-reload counter driven by a programmable prescaler.

They may be used as generic timers for time base generation but they are also specifically used to drive the digital-to-analog converter (DAC). In fact, the timers are internally connected to the DAC and are able to drive it through their trigger outputs.

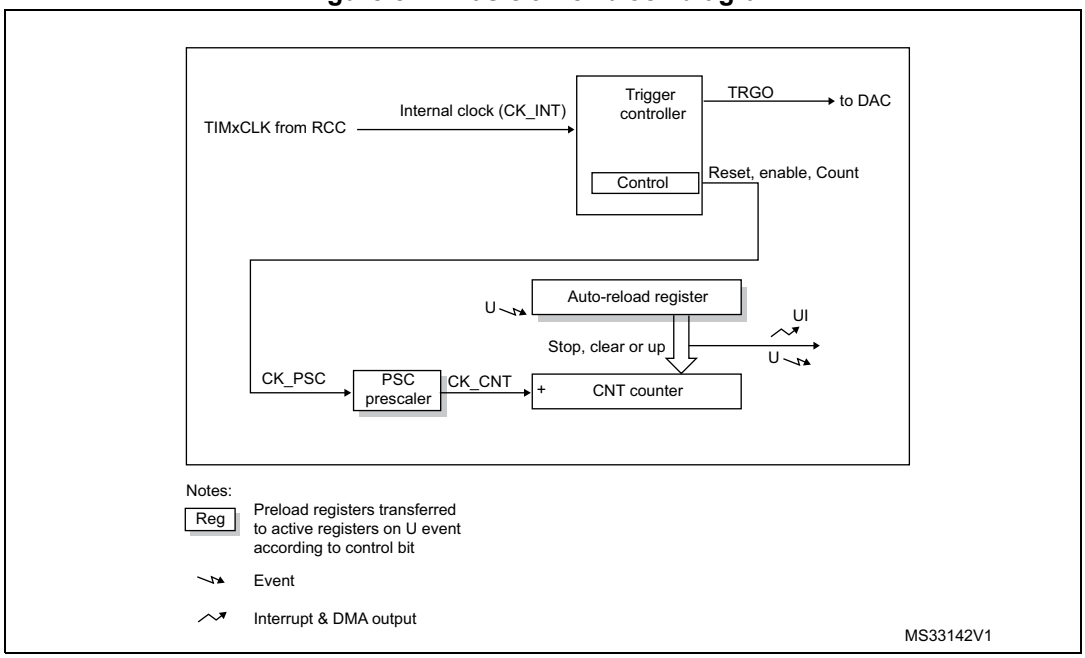
The timers are completely independent, and do not share any resources.

47.2 TIM6/TIM7 main features

Basic timer (TIM6/TIM7) features include:

- 16-bit auto-reload upcounter
- 16-bit programmable prescaler used to divide (also “on the fly”) the counter clock frequency by any factor between 1 and 65535
- Synchronization circuit to trigger the DAC
- Interrupt/DMA generation on the update event: counter overflow

Figure 544. Basic timer block diagram



47.3 TIM6/TIM7 functional description

47.3.1 Time-base unit

The main block of the programmable timer is a 16-bit upcounter with its related auto-reload register. The counter clock can be divided by a prescaler.

The counter, the auto-reload register and the prescaler register can be written or read by software. This is true even when the counter is running.

The time-base unit includes:

- Counter Register (TIMx_CNT)
- Prescaler Register (TIMx_PSC)
- Auto-Reload Register (TIMx_ARR)

The auto-reload register is preloaded. The preload register is accessed each time an attempt is made to write or read the auto-reload register. The contents of the preload register are transferred into the shadow register permanently or at each update event UEV, depending on the auto-reload preload enable bit (ARPE) in the TIMx_CR1 register. The update event is sent when the counter reaches the overflow value and if the UDIS bit equals 0 in the TIMx_CR1 register. It can also be generated by software. The generation of the update event is described in detail for each configuration.

The counter is clocked by the prescaler output CK_CNT, which is enabled only when the counter enable bit (CEN) in the TIMx_CR1 register is set.

Note that the actual counter enable signal CNT_EN is set 1 clock cycle after CEN.

Prescaler description

The prescaler can divide the counter clock frequency by any factor between 1 and 65536. It is based on a 16-bit counter controlled through a 16-bit register (in the TIMx_PSC register). It can be changed on the fly as the TIMx_PSC control register is buffered. The new prescaler ratio is taken into account at the next update event.

Figure 545 and *Figure 546* give some examples of the counter behavior when the prescaler ratio is changed on the fly.

Figure 545. Counter timing diagram with prescaler division change from 1 to 2

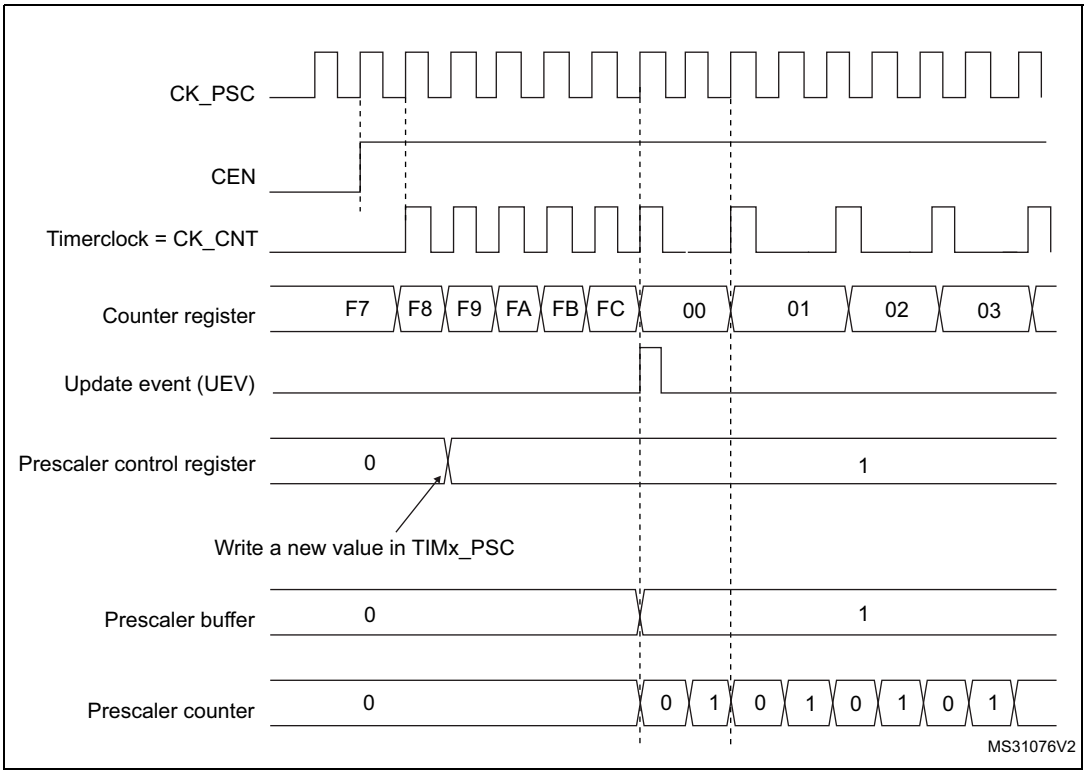
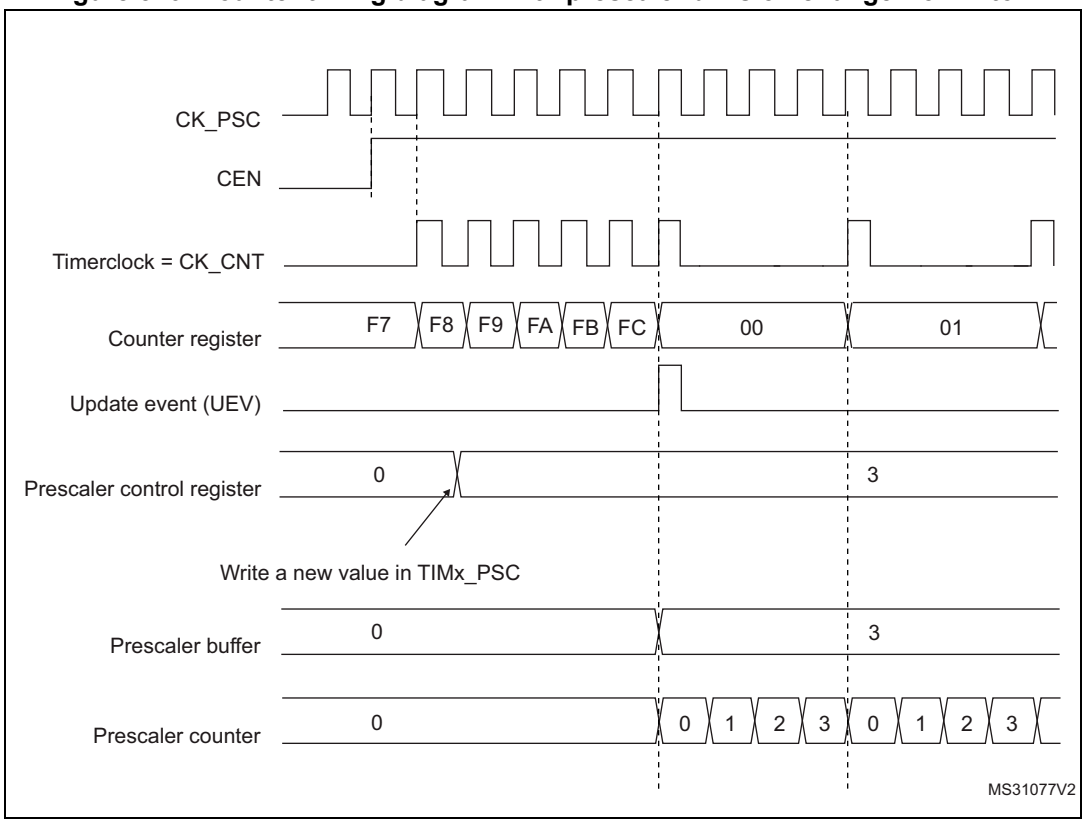


Figure 546. Counter timing diagram with prescaler division change from 1 to 4



47.3.2 Counting mode

The counter counts from 0 to the auto-reload value (contents of the TIMx_ARR register), then restarts from 0 and generates a counter overflow event.

An update event can be generate at each counter overflow or by setting the UG bit in the TIMx_EGR register (by software or by using the slave mode controller).

The UEV event can be disabled by software by setting the UDIS bit in the TIMx_CR1 register. This avoids updating the shadow registers while writing new values into the preload registers. In this way, no update event occurs until the UDIS bit has been written to 0, however, the counter and the prescaler counter both restart from 0 (but the prescale rate does not change). In addition, if the URS (update request selection) bit in the TIMx_CR1 register is set, setting the UG bit generates an update event UEV, but the UIF flag is not set (so no interrupt or DMA request is sent).

When an update event occurs, all the registers are updated and the update flag (UIF bit in the TIMx_SR register) is set (depending on the URS bit):

- The buffer of the prescaler is reloaded with the preload value (contents of the TIMx_PSC register)
- The auto-reload shadow register is updated with the preload value (TIMx_ARR)

The following figures show some examples of the counter behavior for different clock frequencies when TIMx_ARR = 0x36.

Figure 547. Counter timing diagram, internal clock divided by 1

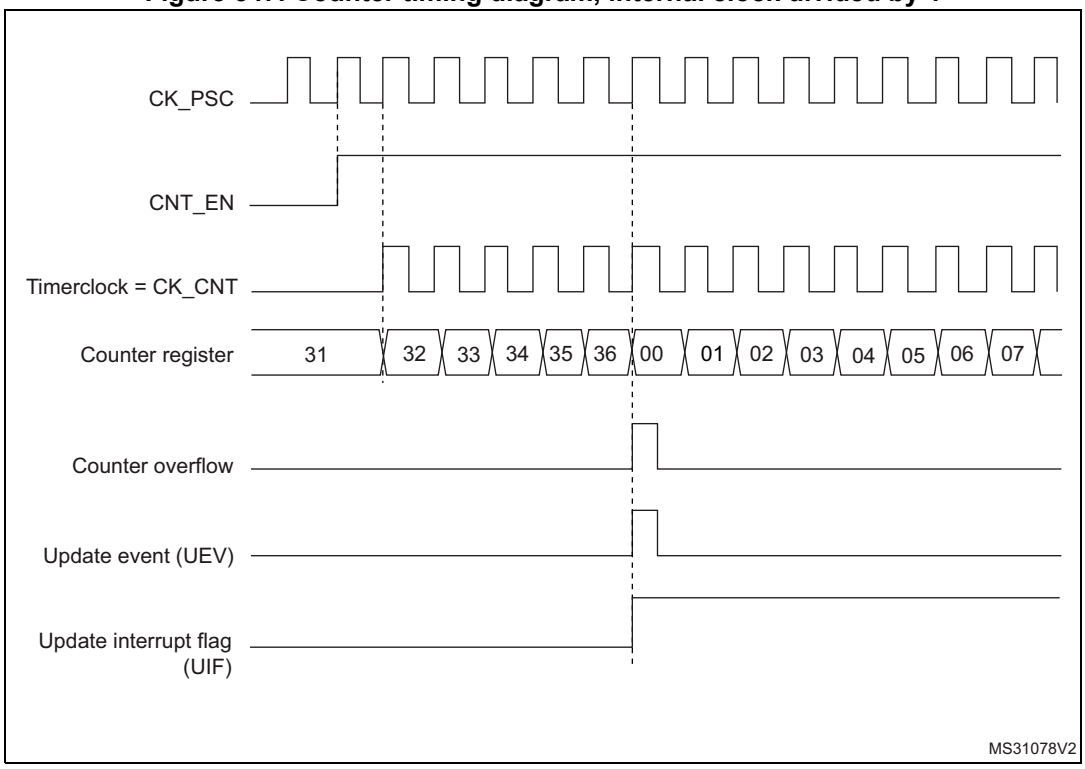


Figure 548. Counter timing diagram, internal clock divided by 2

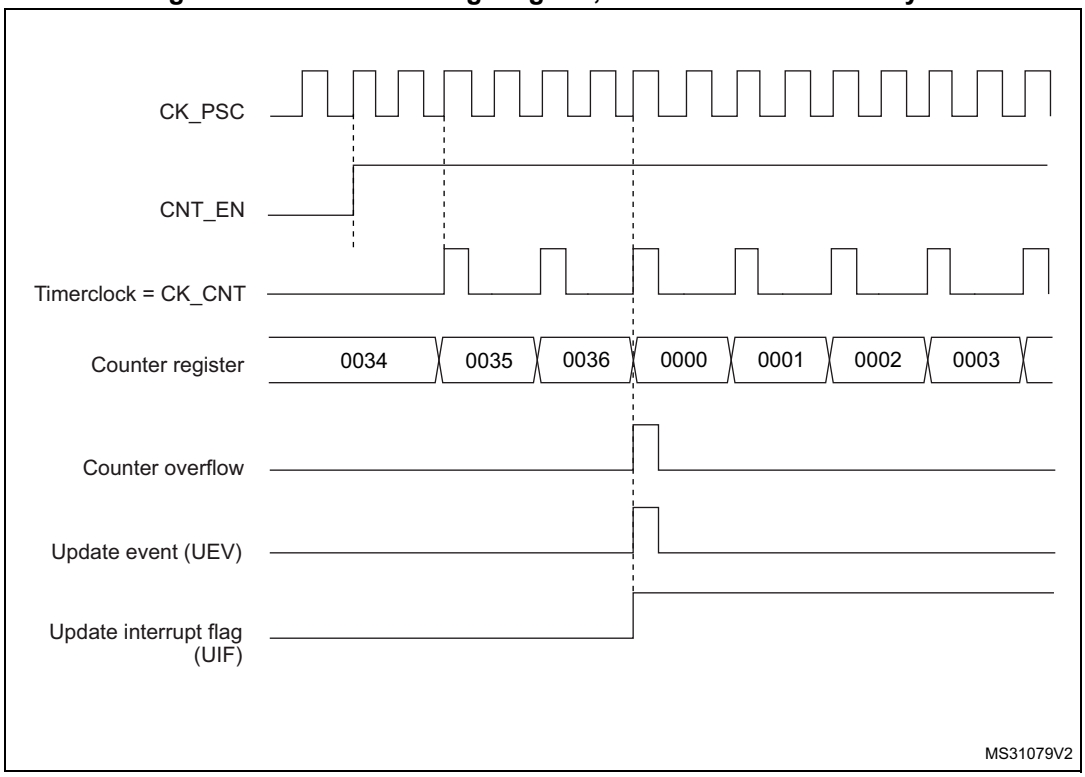


Figure 549. Counter timing diagram, internal clock divided by 4

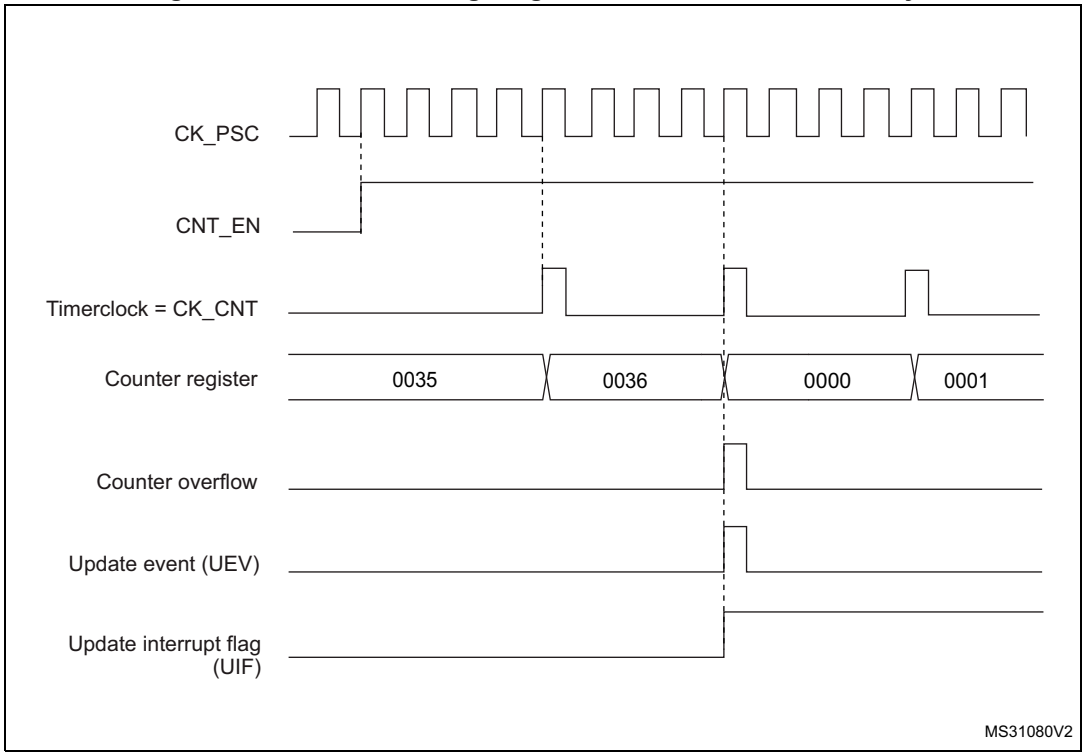


Figure 550. Counter timing diagram, internal clock divided by N

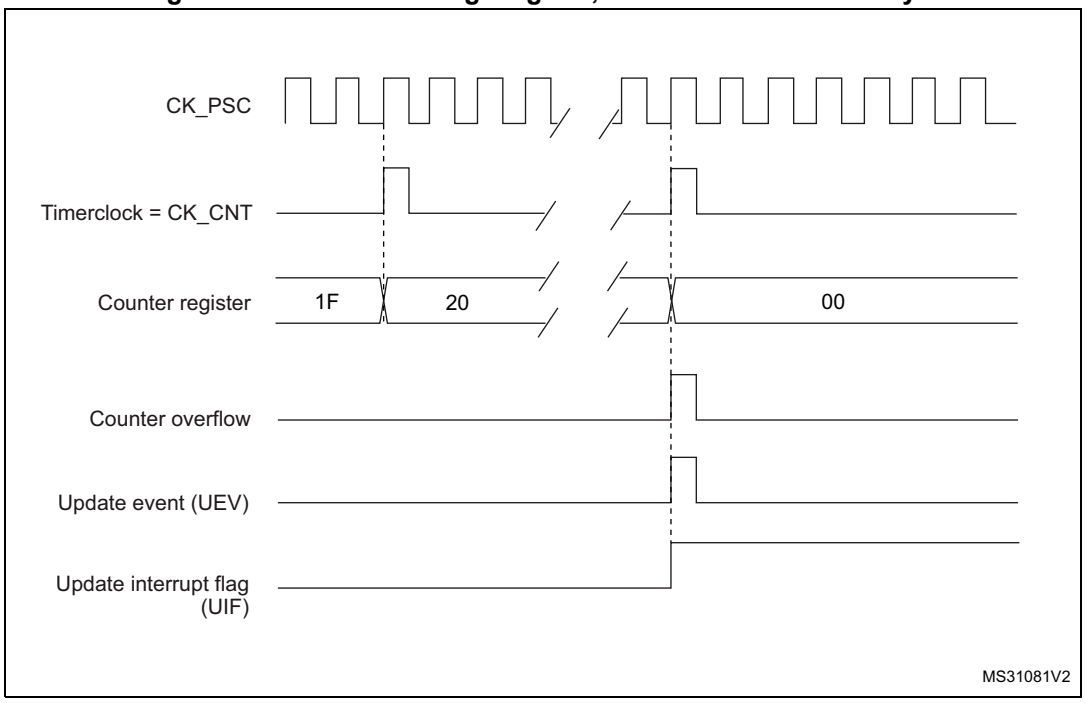


Figure 551. Counter timing diagram, update event when ARPE = 0 (TIMx_ARR not preloaded)

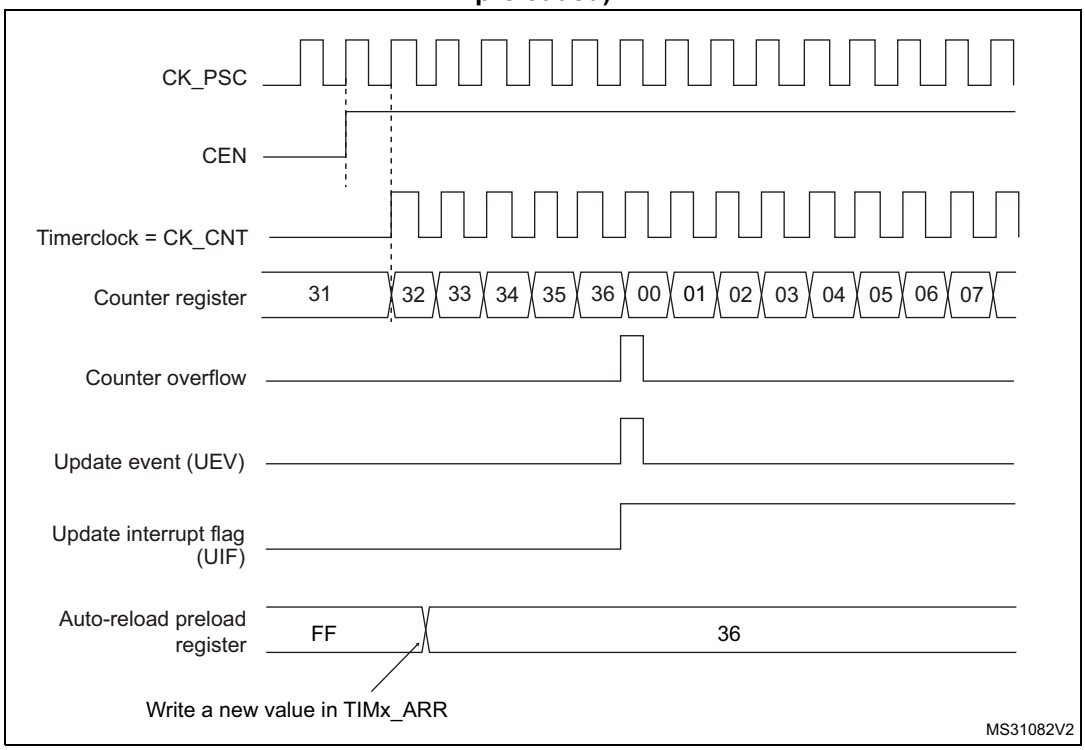
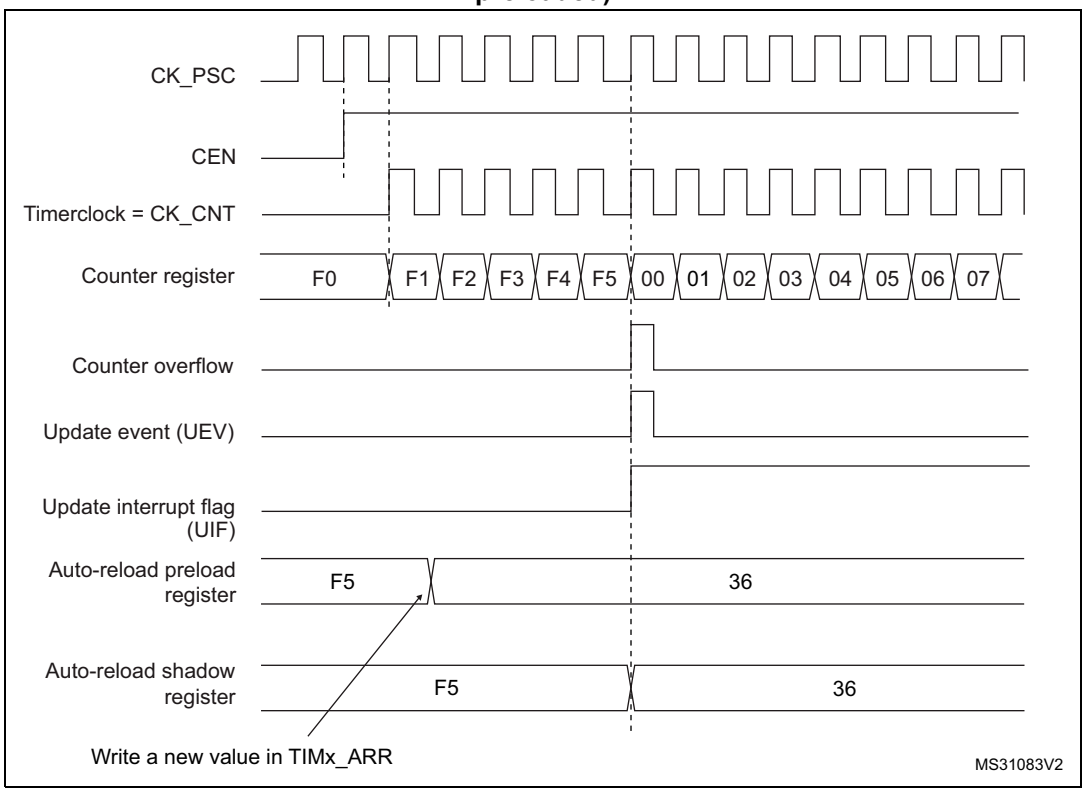


Figure 552. Counter timing diagram, update event when ARPE=1 (TIMx_ARR preloaded)



47.3.3 UIF bit remapping

The IUFREMAP bit in the TIMx_CR1 register forces a continuous copy of the Update Interrupt Flag UIF into the timer counter register's bit 31 (TIMxCNT[31]). This allows to atomically read both the counter value and a potential roll-over condition signaled by the UIFCPY flag. In particular cases, it can ease the calculations by avoiding race conditions caused for instance by a processing shared between a background task (counter reading) and an interrupt (Update Interrupt).

There is no latency between the assertions of the UIF and UIFCPY flags.

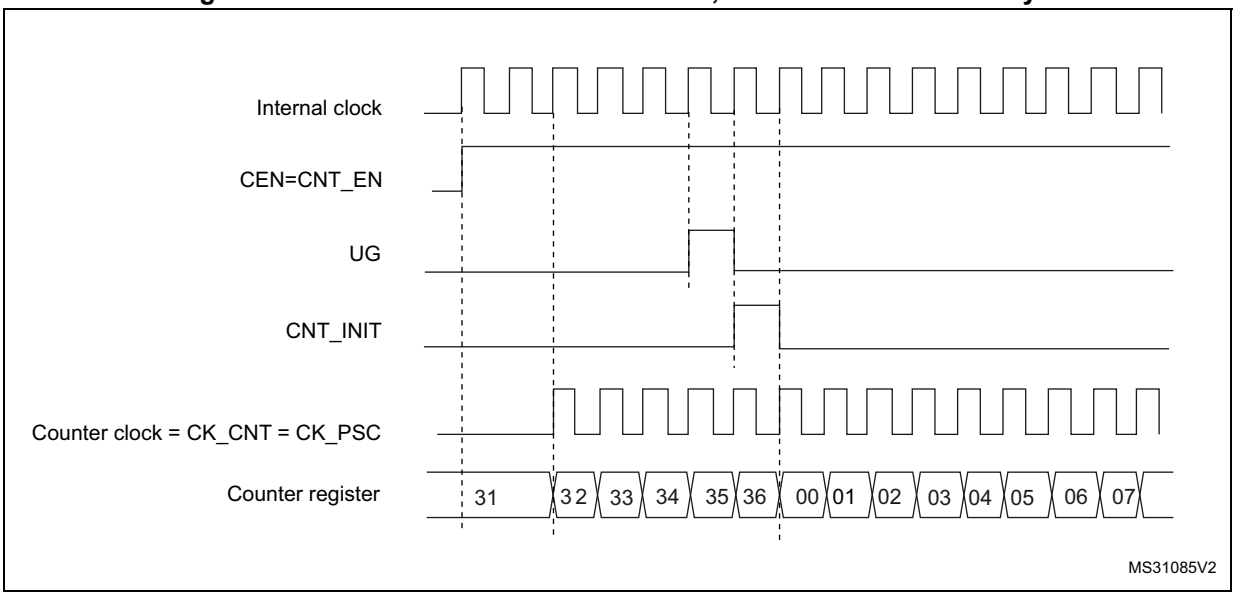
47.3.4 Clock source

The counter clock is provided by the Internal clock (CK_INT) source.

The CEN (in the TIMx_CR1 register) and UG bits (in the TIMx_EGR register) are actual control bits and can be changed only by software (except for UG that remains cleared automatically). As soon as the CEN bit is written to 1, the prescaler is clocked by the internal clock CK_INT.

Figure 553 shows the behavior of the control circuit and the upcounter in normal mode, without prescaler.

Figure 553. Control circuit in normal mode, internal clock divided by 1



47.3.5 Debug mode

When the microcontroller enters the debug mode (Cortex®-M7 core - halted), the TIMx counter either continues to work normally or stops, depending on the DBG_TIMx_STOP configuration bit in the DBGMCU module. For more details, refer to *Section 65.5.7: Microcontroller debug unit (DBGMCU)*.

47.4 TIM6/TIM7 registers

Refer to *Section 1.2 on page 104* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by half-words (16-bit) or words (32-bit).

47.4.1 TIMx control register 1 (TIMx_CR1)(x = 6 to 7)

Address offset: 0x00

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	UIFREMAP	Res.	Res.	Res.	ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
				rw				rw				rw	rw	rw	rw

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **UIFREMAP**: UIF status bit remapping
0: No remapping. UIF status bit is not copied to TIMx_CNT register bit 31.
1: Remapping enabled. UIF status bit is copied to TIMx_CNT register bit 31.

Bits 10:8 Reserved, must be kept at reset value.

Bit 7 **ARPE**: Auto-reload preload enable

0: TIMx_ARR register is not buffered.
1: TIMx_ARR register is buffered.

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **OPM**: One-pulse mode

0: Counter is not stopped at update event
1: Counter stops counting at the next update event (clearing the CEN bit).

Bit 2 **URS**: Update request source

This bit is set and cleared by software to select the UEV event sources.

0: Any of the following events generates an update interrupt or DMA request if enabled. These events can be:

- Counter overflow/underflow
- Setting the UG bit
- Update generation through the slave mode controller

1: Only counter overflow/underflow generates an update interrupt or DMA request if enabled.

Bit 1 **UDIS**: Update disable

This bit is set and cleared by software to enable/disable UEV event generation.

0: UEV enabled. The Update (UEV) event is generated by one of the following events:

- Counter overflow/underflow
- Setting the UG bit
- Update generation through the slave mode controller

Buffered registers are then loaded with their preload values.

1: UEV disabled. The Update event is not generated, shadow registers keep their value (ARR, PSC). However the counter and the prescaler are reinitialized if the UG bit is set or if a hardware reset is received from the slave mode controller.

Bit 0 **CEN**: Counter enable

0: Counter disabled
1: Counter enabled

Note: Gated mode can work only if the CEN bit has been previously set by software. However trigger mode can set the CEN bit automatically by hardware.

CEN is cleared automatically in one-pulse mode, when an update event occurs.

47.4.2 TIMx control register 2 (TIMx_CR2)(x = 6 to 7)

Address offset: 0x04

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MMS[2:0]			Res.	Res.	Res.	Res.
									rw	rw	rw				

Bits 15:7 Reserved, must be kept at reset value.

Bits 6:4 **MMS[2:0]**: Master mode selection

These bits are used to select the information to be sent in master mode to slave timers for synchronization (TRGO). The combination is as follows:

000: **Reset** - the UG bit from the TIMx_EGR register is used as a trigger output (TRGO). If reset is generated by the trigger input (slave mode controller configured in reset mode) then the signal on TRGO is delayed compared to the actual reset.

001: **Enable** - the Counter enable signal, CNT_EN, is used as a trigger output (TRGO). It is useful to start several timers at the same time or to control a window in which a slave timer is enabled. The Counter Enable signal is generated by a logic OR between CEN control bit and the trigger input when configured in gated mode.

When the Counter Enable signal is controlled by the trigger input, there is a delay on TRGO, except if the master/slave mode is selected (see the MSM bit description in the TIMx_SMCR register).

010: **Update** - The update event is selected as a trigger output (TRGO). For instance a master timer can then be used as a prescaler for a slave timer.

Note: The clock of the slave timer or ADC must be enabled prior to receive events from the master timer, and must not be changed on-the-fly while triggers are received from the master timer.

Bits 3:0 Reserved, must be kept at reset value.

47.4.3 TIMx DMA/Interrupt enable register (TIMx_DIER)(x = 6 to 7)

Address offset: 0x0C

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	UDE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIE
							rw								rw

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **UDE**: Update DMA request enable

0: Update DMA request disabled.
1: Update DMA request enabled.

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **UIE**: Update interrupt enable

0: Update interrupt disabled.
1: Update interrupt enabled.

47.4.4 TIMx status register (TIMx_SR)(x = 6 to 7)

Address offset: 0x10

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIF
															rc_w0

Bits 15:1 Reserved, must be kept at reset value.

Bit 0 **UIF**: Update interrupt flag

This bit is set by hardware on an update event. It is cleared by software.

0: No update occurred.

1: Update interrupt pending. This bit is set by hardware when the registers are updated:

– At overflow or underflow regarding the repetition counter value and if UDIS = 0 in the TIMx_CR1 register.

– When CNT is reinitialized by software using the UG bit in the TIMx_EGR register, if URS = 0 and UDIS = 0 in the TIMx_CR1 register.

47.4.5 TIMx event generation register (TIMx_EGR)(x = 6 to 7)

Address offset: 0x14

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UG
															w

Bits 15:1 Reserved, must be kept at reset value.

Bit 0 **UG**: Update generation

This bit can be set by software, it is automatically cleared by hardware.

0: No action.

1: Re-initializes the timer counter and generates an update of the registers. Note that the prescaler counter is cleared too (but the prescaler ratio is not affected).

47.4.6 TIMx counter (TIMx_CNT)(x = 6 to 7)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UIF CPY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **UIFCPY**: UIF Copy
This bit is a read-only copy of the UIF bit of the TIMx_ISR register. If the UIFREMAP bit in TIMx_CR1 is reset, bit 31 is reserved and read as 0.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]**: Counter value

47.4.7 TIMx prescaler (TIMx_PSC)(x = 6 to 7)

Address offset: 0x28

Reset value: 0x0000

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **PSC[15:0]**: Prescaler value
The counter clock frequency CK_CNT is equal to f_{CK_PSC} / (PSC[15:0] + 1).
PSC contains the value to be loaded into the active prescaler register at each update event.
(including when the counter is cleared through UG bit of TIMx_EGR register or through trigger controller when configured in “reset mode”).

47.4.8 TIMx auto-reload register (TIMx_ARR)(x = 6 to 7)

Address offset: 0x2C

Reset value: 0xFFFF

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 15:0 **ARR[15:0]**: Prescaler value
ARR is the value to be loaded into the actual auto-reload register.
Refer to *Section 47.3.1: Time-base unit on page 1884* for more details about ARR update and behavior.
The counter is blocked while the auto-reload value is null.

47.4.9 TIMx register map

TIMx registers are mapped as 16-bit addressable registers as described in the table below:

Table 369. TIMx register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**TIMx_CR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIFREMA	Res.	Res.	Res.	ARPE	Res.	Res.	Res.	OPM	URS	UDIS	CEN
	Reset value																					0				0				0	0	0	0
0x04	**TIMx_CR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MMS [2:0]			Res.	Res.	Res.	Res.
	Reset value																										0	0	0				
0x08	Reserved																																
0x0C	**TIMx_DIER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UDE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIE
	Reset value																								0								0
0x10	**TIMx_SR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UIF
	Reset value																																0
0x14	**TIMx_EGR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UG
	Reset value																																0
0x18-0x20	Reserved																																
0x24	**TIMx_CNT**	UIFCPY or Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value	0																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x28	**TIMx_PSC**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSC[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	**TIMx_ARR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[15:0]															
	Reset value																	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Refer to *Section 2.3 on page 131* for the register boundary addresses.

48 Low-power timer (LPTIM)

48.1 Introduction

The LPTIM is a 16-bit timer that benefits from the ultimate developments in power consumption reduction. Thanks to its diversity of clock sources, the LPTIM is able to keep running in all power modes except for Standby mode. Given its capability to run even with no internal clock source, the LPTIM can be used as a “Pulse Counter” which can be useful in some applications. Also, the LPTIM capability to wake up the system from low-power modes, makes it suitable to realize “Timeout functions” with extremely low power consumption.

The LPTIM introduces a flexible clock scheme that provides the needed functionalities and performance, while minimizing the power consumption.

48.2 LPTIM main features

- 16 bit upcounter
- 3-bit prescaler with 8 possible dividing factors (1,2,4,8,16,32,64,128)
- Selectable clock
  - Internal clock sources: configurable internal clock source (see RCC section)
  - External clock source over LPTIM input (working with no embedded oscillator running, used by Pulse Counter application)
- 16 bit ARR autoreload register
- 16 bit compare register
- Continuous/One-shot mode
- Selectable software/hardware input trigger
- Programmable Digital Glitch filter
- Configurable output: Pulse, PWM
- Configurable I/O polarity
- Encoder mode

48.3 LPTIM implementation

Table 370 describes LPTIM implementation on STM32H72x and STM32H73x devices.

Table 370. STM32H72x and STM32H73x LPTIM features

LPTIM modes/features(1)	LPTIM1	LPTIM2	LPTIM3	LPTIM4	LPTIM5
Encoder mode	X	X	-	-	-
Wakeup from Stop	X	X	X	X	X

1. X = supported.

48.4 LPTIM functional description

48.4.1 LPTIM block diagram

Figure 554. Low-power timer block diagram (LPTIM1 and LPTIM2)

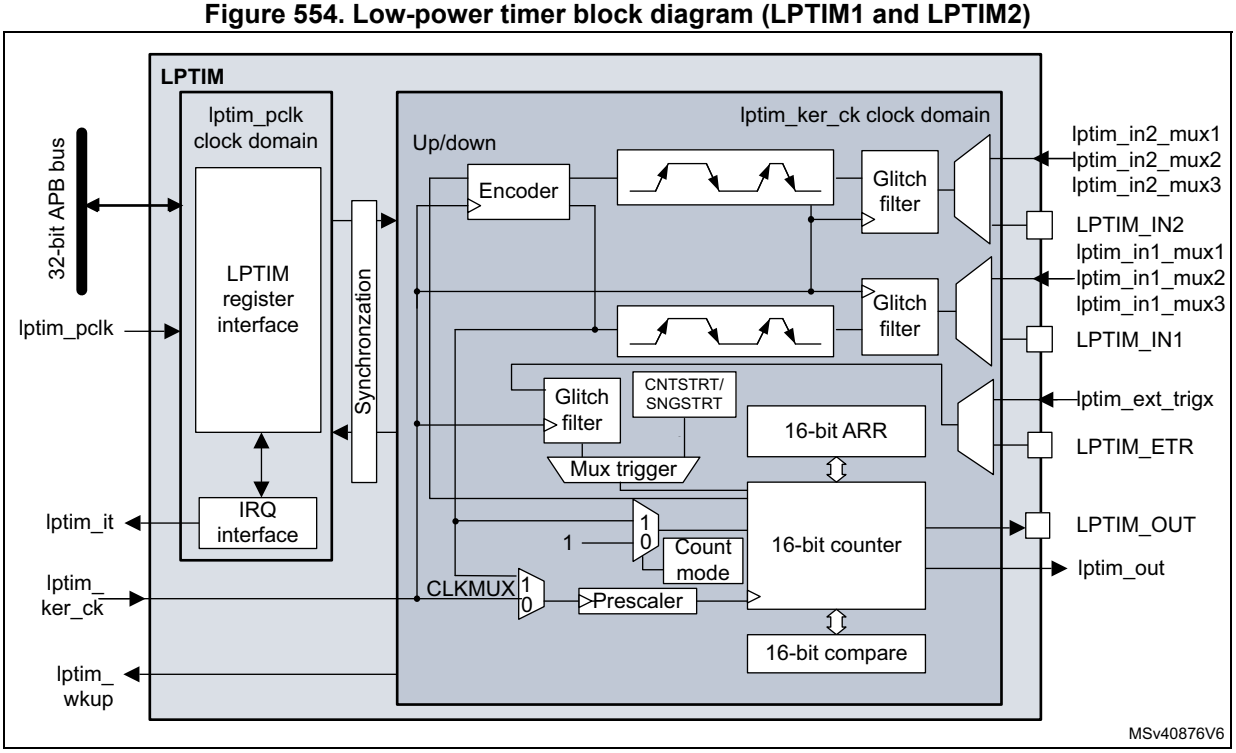


Figure 555. Low-power timer block diagram (LPTIM3)

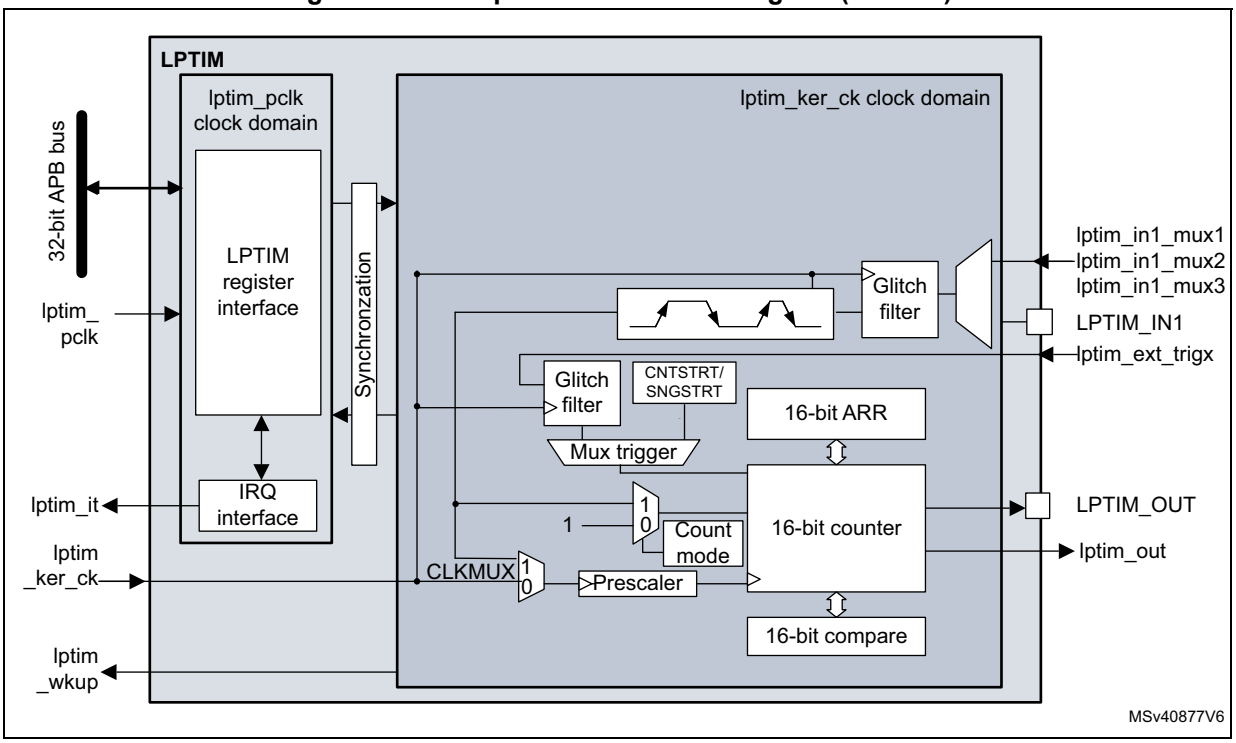
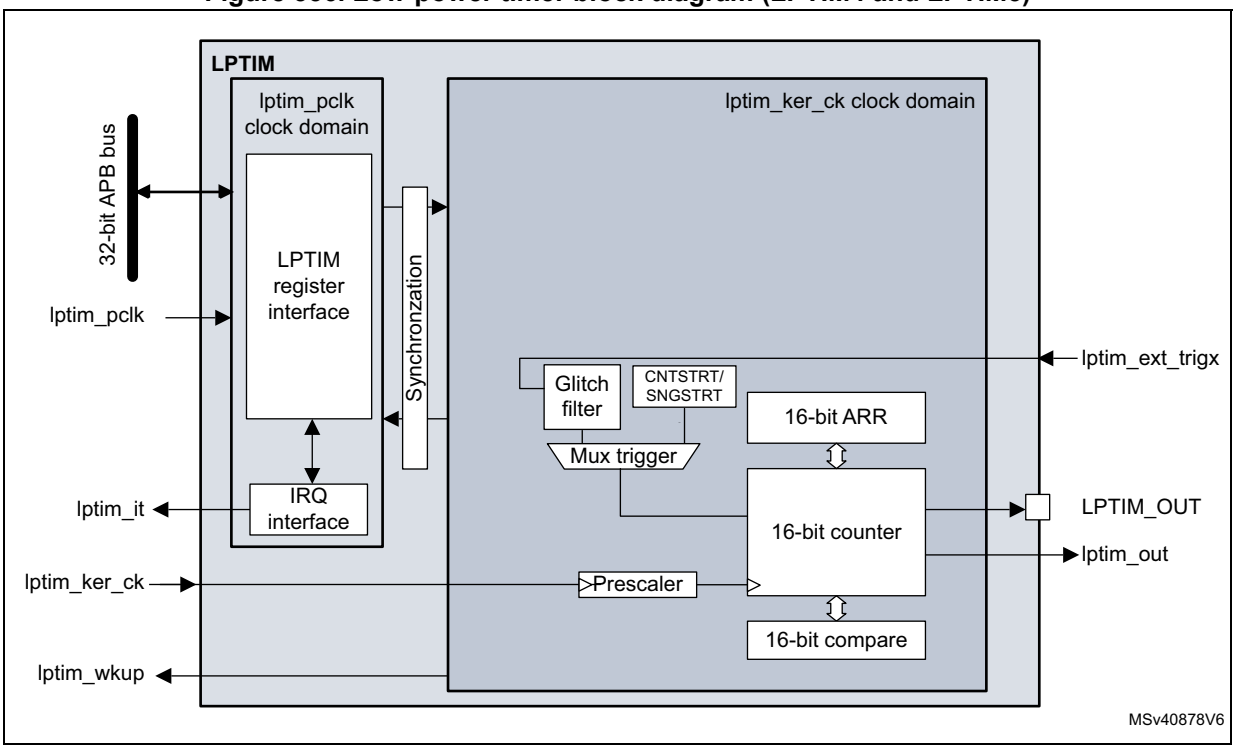


Figure 556. Low-power timer block diagram (LPTIM4 and LPTIM5)



48.4.2 LPTIM pins and internal signals

The following tables provide the list of LPTIM pins and internal signals, respectively.

Table 371. LPTIM input/output pins

Names	Signal type	Description
LPTIM_IN1	Digital input	LPTIM Input 1 from GPIO pin on mux input 0
LPTIM_IN2	Digital input	LPTIM Input 2 from GPIO pin on mux input 0
LPTIM_ETR	Digital input	LPTIM external trigger GPIO pin
LPTIM_OUT	Digital output	LPTIM Output GPIO pin

Table 372. LPTIM internal signals

Names	Signal type	Description
lptim_pclk	Digital input	LPTIM APB clock domain
lptim_ker_ck	Digital input	LPTIM kernel clock
lptim_in1_mux1	Digital input	Internal LPTIM input 1 connected to mux input 1
lptim_in1_mux2	Digital input	Internal LPTIM input 1 connected to mux input 2
lptim_in1_mux3	Digital input	Internal LPTIM input 1 connected to mux input 3
lptim_in2_mux1	Digital input	Internal LPTIM input 2 connected to mux input 1
lptim_in2_mux2	Digital input	Internal LPTIM input 2 connected to mux input 2
lptim_in2_mux3	Digital input	Internal LPTIM input 2 connected to mux input 3
lptim_ext_trigx	Digital input	LPTIM external trigger input x
lptim_out	Digital output	LPTIM counter output
lptim_it	Digital output	LPTIM global interrupt
lptim_wakeup	Digital output	LPTIM wakeup event

48.4.3 LPTIM input and trigger mapping

The LPTIM external trigger and input connections are detailed hereafter:

Table 373. LPTIM1 external trigger connection

TRIGSEL	External trigger
lptim_ext_trig0	GPIO pin as LPTIM1_ETR alternate function
lptim_ext_trig1	RTC_ALARMA
lptim_ext_trig2	RTC_ALARMB
lptim_ext_trig3	RTC_TAMP1_OUT
lptim_ext_trig4	Not connected
lptim_ext_trig5	RTC_TAMP3_OUT

Table 373. LPTIM1 external trigger connection (continued)

TRIGSEL	External trigger
lptim_ext_trig6	COMP1_OUT
lptim_ext_trig7	COMP2_OUT

Table 374. LPTIM2 external trigger connection

TRIGSEL	External trigger
lptim_ext_trig0	GPIO pin as LPTIM2_ETR alternate function
lptim_ext_trig1	RTC_ALARMA
lptim_ext_trig2	RTC_ALARMB
lptim_ext_trig3	RTC_TAMP1_OUT
lptim_ext_trig4	Not connected
lptim_ext_trig5	RTC_TAMP3_OUT
lptim_ext_trig6	COMP1_OUT
lptim_ext_trig7	COMP2_OUT

Table 375. LPTIM3 external trigger connection

TRIGSEL	External trigger
lptim_ext_trig0	LPTIM2_OUT
lptim_ext_trig1	Not connected
lptim_ext_trig2	LPTIM4_OUT
lptim_ext_trig3	LPTIM5_OUT
lptim_ext_trig4	SAI1_FS_A
lptim_ext_trig5	SAI1_FS_B
lptim_ext_trig6	Not connected
lptim_ext_trig7	Not connected

Table 376. LPTIM4 external trigger connection

TRIGSEL	External trigger
lptim_ext_trig0	LPTIM2_OUT
lptim_ext_trig1	LPTIM3_OUT
lptim_ext_trig2	Not connected
lptim_ext_trig3	LPTIM5_OUT
lptim_ext_trig4	SAI4_FS_A
lptim_ext_trig5	SAI4_FS_B

Table 376. LPTIM4 external trigger connection (continued)

TRIGSEL	External trigger
lptim_ext_trig6	Not connected
lptim_ext_trig7	Not connected

Table 377. LPTIM5 external trigger connection

TRIGSEL	External trigger
lptim_ext_trig0	LPTIM2_OUT
lptim_ext_trig1	LPTIM3_OUT
lptim_ext_trig2	LPTIM4_OUT
lptim_ext_trig3	SAI4_FS_A
lptim_ext_trig4	SAI4_FS_B
lptim_ext_trig5	Not connected
lptim_ext_trig6	Not connected
lptim_ext_trig7	Not connected

Table 378. LPTIM1 input 1 connection

lptim_in1_mux	LPTIM1 input 1 connected to
lptim_in1_mux0	GPIO pin as LPTIM1_IN1 alternate function
lptim_in1_mux1	COMP1_OUT
lptim_in1_mux2	Not connected
lptim_in1_mux3	Not connected

Table 379. LPTIM1 input 2 connection

lptim_in2_mux	LPTIM1 input 2 connected to
lptim_int2_mux0	GPIO pin as LPTIM1_IN2 alternate function
lptim_in2_mux1	COMP2_OUT
lptim_in2_mux2	Not connected
lptim_in2_mux3	Not connected

Table 380. LPTIM2 input 1 connection

lptim_in1_mux	LPTIM2 input 1 connected to
lptim_in1_mux0	GPIO pin as LPTIM2_IN1 alternate function
lptim_in1_mux1	COMP1_OUT
lptim_in1_mux2	COMP2_OUT
lptim_in1_mux3	COMP1_OUT OR COMP2_OUT

Table 381. LPTIM2 input 2 connection

lptim_in2_mux	LPTIM2 input 2 connected to
lptim_int2_mux0	GPIO pin as LPTIM2_IN2 alternate function
lptim_in2_mux1	COMP2_OUT
lptim_in2_mux2	Not connected
lptim_in2_mux3	Not connected

Table 382. LPTIM3 input 1 connection

lptim_in1_mux	LPTIM3 Input 1 connected to
lptim_in1_mux0	Not connected
lptim_in1_mux1	SAI4_FS_A
lptim_in1_mux2	SAI4_FS_B
lptim_in1_mux3	Not connected

48.4.4 LPTIM reset and clocks

The LPTIM can be clocked using several clock sources. It can be clocked using an internal clock signal which can be any configurable internal clock source selectable through the RCC (see RCC section for more details). Also, the LPTIM can be clocked using an external clock signal injected on its external Input1. When clocked with an external clock source, the LPTIM may run in one of these two possible configurations:

- The first configuration is when the LPTIM is clocked by an external signal but in the same time an internal clock signal is provided to the LPTIM from configurable internal clock source (see RCC section).
- The second configuration is when the LPTIM is solely clocked by an external clock source through its external Input1. This configuration is the one used to realize Timeout function or Pulse counter function when all the embedded oscillators are turned off after entering a low-power mode.

Programming the CKSEL and COUNTMODE bits allows controlling whether the LPTIM will use an external clock source or an internal one.

When configured to use an external clock source, the CKPOL bits are used to select the external clock signal active edge. If both edges are configured to be active ones, an internal clock signal should also be provided (first configuration). In this case, the internal clock signal frequency should be at least four times higher than the external clock signal frequency.

48.4.5 Glitch filter

The LPTIM inputs, either external (mapped to GPIOs) or internal (mapped on the chip-level to other embedded peripherals), are protected with digital filters that prevent any glitches and noise perturbations to propagate inside the LPTIM. This is in order to prevent spurious counts or triggers.

Before activating the digital filters, an internal clock source should first be provided to the LPTIM. This is necessary to guarantee the proper operation of the filters.

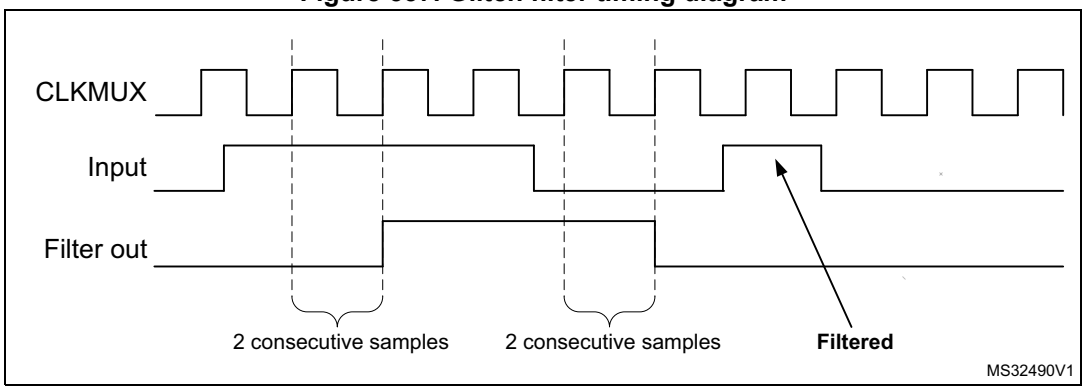
The digital filters are divided into two groups:

- The first group of digital filters protects the LPTIM external inputs. The digital filters sensitivity is controlled by the CKFLT bits
- The second group of digital filters protects the LPTIM internal trigger inputs. The digital filters sensitivity is controlled by the TRGFLT bits.

Note: The digital filters sensitivity is controlled by groups. It is not possible to configure each digital filter sensitivity separately inside the same group.

The filter sensitivity acts on the number of consecutive equal samples that should be detected on one of the LPTIM inputs to consider a signal level change as a valid transition. *Figure 557* shows an example of glitch filter behavior in case of a 2 consecutive samples programmed.

Figure 557. Glitch filter timing diagram



Note: In case no internal clock signal is provided, the digital filter must be deactivated by setting the CKFLT and TRGFLT bits to '0'. In that case, an external analog filter may be used to protect the LPTIM external inputs against glitches.

48.4.6 Prescaler

The LPTIM 16-bit counter is preceded by a configurable power-of-2 prescaler. The prescaler division ratio is controlled by the PRESC[2:0] 3-bit field. The table below lists all the possible division ratios:

Table 383. Prescaler division ratios

programming	dividing factor
000	/1
001	/2
010	/4
011	/8
100	/16
101	/32
110	/64
111	/128

48.4.7 Trigger multiplexer

The LPTIM counter may be started either by software or after the detection of an active edge on one of the 8 trigger inputs.

TRIGEN[1:0] is used to determine the LPTIM trigger source:

- When TRIGEN[1:0] equals ‘00’, The LPTIM counter is started as soon as one of the CNTSTRT or the SNGSTRT bits is set by software. The three remaining possible values for the TRIGEN[1:0] are used to configure the active edge used by the trigger inputs. The LPTIM counter starts as soon as an active edge is detected.
- When TRIGEN[1:0] is different than ‘00’, TRIGSEL[2:0] is used to select which of the 8 trigger inputs is used to start the counter.

The external triggers are considered asynchronous signals for the LPTIM. So after a trigger detection, a two-counter-clock period latency is needed before the timer starts running due to the synchronization.

If a new trigger event occurs when the timer is already started it will be ignored (unless timeout function is enabled).

Note: The timer must be enabled before setting the SNGSTRT/CNTSTRT bits. Any write on these bits when the timer is disabled will be discarded by hardware.

Note: When starting the counter by software (TRIGEN[1:0] = 00), there is a delay of 3 kernel clock cycles between the LPTIM_CR register update (set one of SNGSTRT or CNTSTRT bits) and the effective start of the counter.

48.4.8 Operating mode

The LPTIM features two operating modes:

- The Continuous mode: the timer is free running, the timer is started from a trigger event and never stops until the timer is disabled
- One-shot mode: the timer is started from a trigger event and stops when reaching the ARR value.

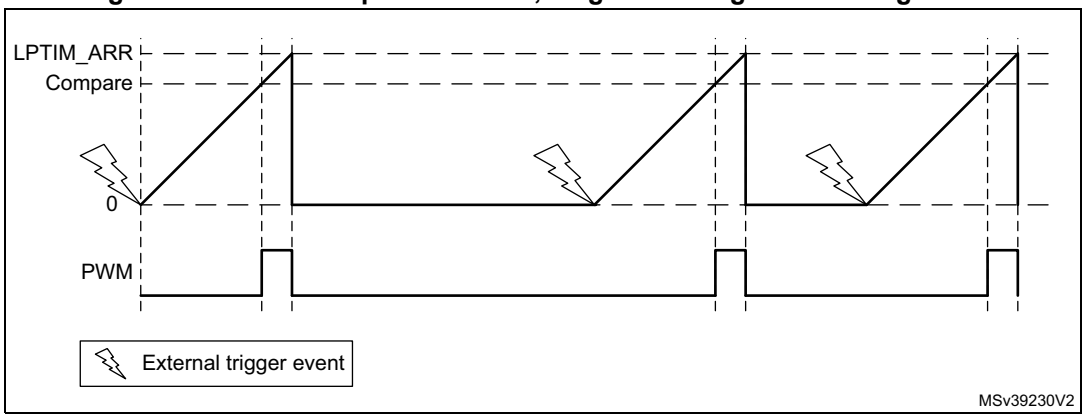
One-shot mode

To enable the one-shot counting, the SNGSTRT bit must be set.

A new trigger event will re-start the timer. Any trigger event occurring after the counter starts and before the counter reaches ARR will be discarded.

In case an external trigger is selected, each external trigger event arriving after the SNGSTRT bit is set, and after the counter register has stopped (contains zero value), will start the counter for a new one-shot counting cycle as shown in *Figure 558*.

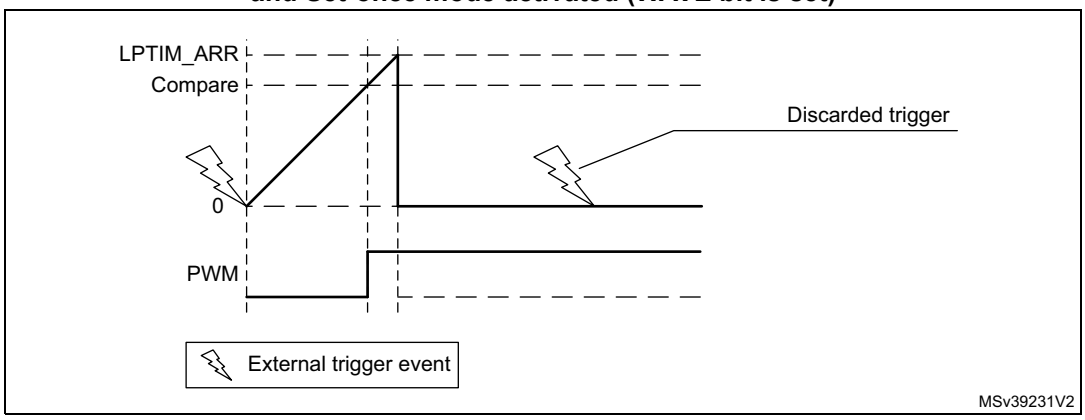
Figure 558. LPTIM output waveform, single counting mode configuration



- Set-once mode activated:

It should be noted that when the WAVE bit-field in the LPTIM_CFGR register is set, the Set-once mode is activated. In this case, the counter is only started once following the first trigger, and any subsequent trigger event is discarded as shown in *Figure 559*.

Figure 559. LPTIM output waveform, Single counting mode configuration and Set-once mode activated (WAVE bit is set)



In case of software start (TRIGEN[1:0] = ‘00’), the SNGSTRT setting will start the counter for one-shot counting.

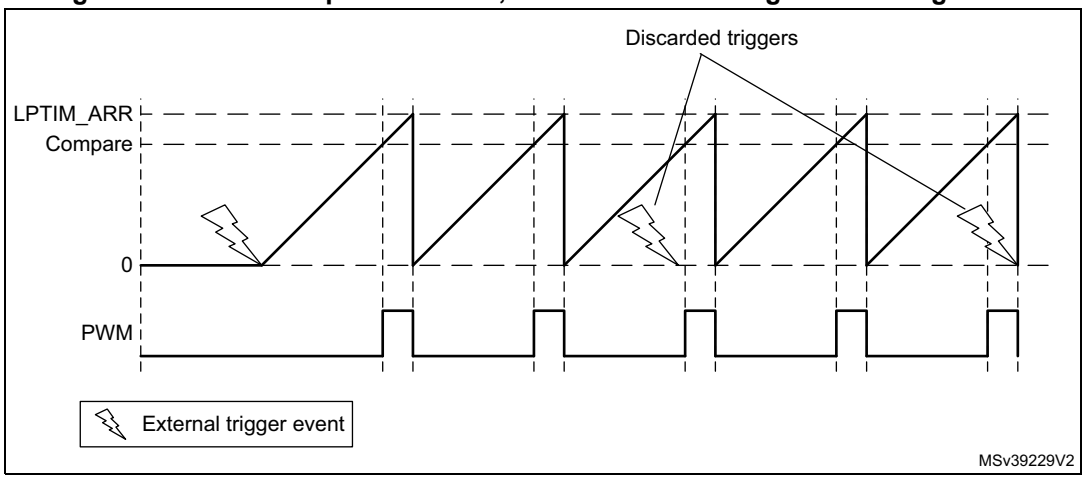
Continous mode

To enable the continuous counting, the CNTSTRT bit must be set.

In case an external trigger is selected, an external trigger event arriving after CNTSTRT is set will start the counter for continuous counting. Any subsequent external trigger event will be discarded as shown in *Figure 560*.

In case of software start (TRIGEN[1:0] = ‘00’), setting CNTSTRT will start the counter for continuous counting.

Figure 560. LPTIM output waveform, Continuous counting mode configuration



SNGSTRT and CNTSTRT bits can only be set when the timer is enabled (The ENABLE bit is set to ‘1’). It is possible to change “on the fly” from One-shot mode to Continuous mode.

If the Continuous mode was previously selected, setting SNGSTRT will switch the LPTIM to the One-shot mode. The counter (if active) will stop as soon as it reaches ARR.

If the One-shot mode was previously selected, setting CNTSTRT will switch the LPTIM to the Continuous mode. The counter (if active) will restart as soon as it reaches ARR.

48.4.9 Timeout function

The detection of an active edge on one selected trigger input can be used to reset the LPTIM counter. This feature is controlled through the TIMOUT bit.

The first trigger event will start the timer, any successive trigger event will reset the counter and the timer will restart.

A low-power timeout function can be realized. The timeout value corresponds to the compare value; if no trigger occurs within the expected time frame, the MCU is waked-up by the compare match event.

48.4.10 Waveform generation

Two 16-bit registers, the LPTIM_ARR (autoreload register) and LPTIM_CMP (compare register), are used to generate several different waveforms on LPTIM output

The timer can generate the following waveforms:

- The PWM mode: the LPTIM output is set as soon as the counter value in LPTIM_CNT exceeds the compare value in LPTIM_CMP. The LPTIM output is reset as soon as a match occurs between the LPTIM_ARR and the LPTIM_CNT registers.
- The One-pulse mode: the output waveform is similar to the one of the PWM mode for the first pulse, then the output is permanently reset
- The Set-once mode: the output waveform is similar to the One-pulse mode except that the output is kept to the last signal level (depends on the output configured polarity).

The above described modes require that the LPTIM_ARR register value be strictly greater than the LPTIM_CMP register value.

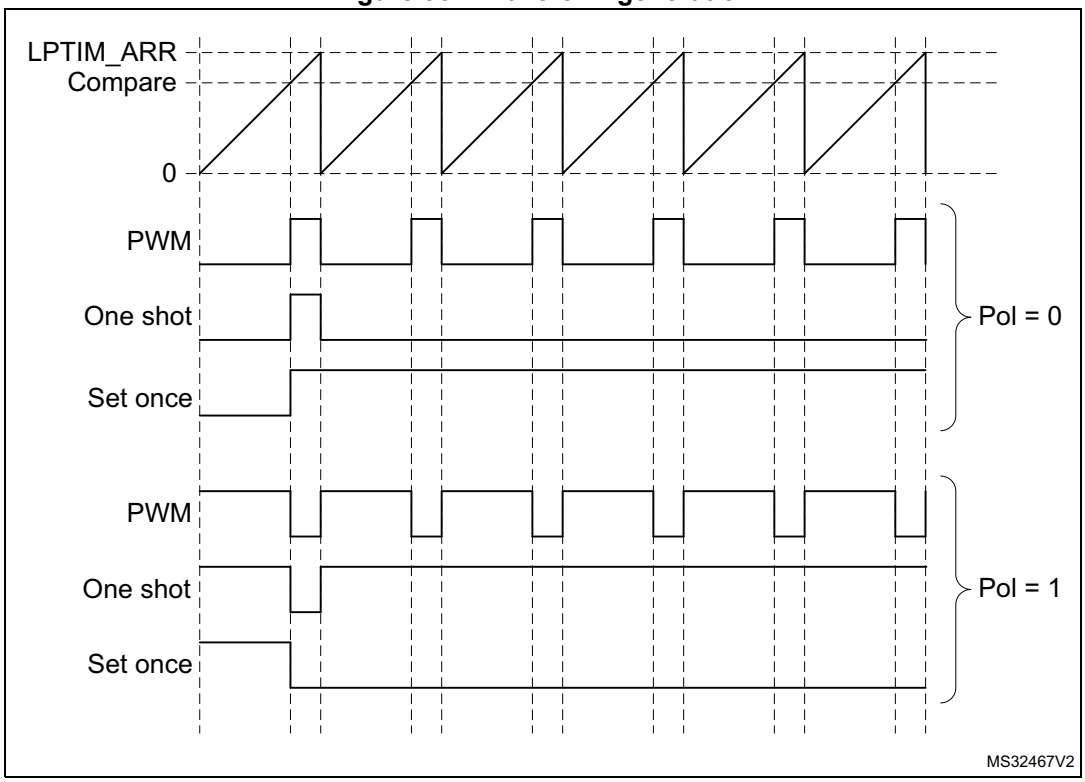
The LPTIM output waveform can be configured through the WAVE bit as follow:

- Resetting the WAVE bit to ‘0’ forces the LPTIM to generate either a PWM waveform or a One pulse waveform depending on which bit is set: CNTSTRT or SNGSTRT.
- Setting the WAVE bit to ‘1’ forces the LPTIM to generate a Set-once mode waveform.

The WAVPOL bit controls the LPTIM output polarity. The change takes effect immediately, so the output default value will change immediately after the polarity is re-configured, even before the timer is enabled.

Signals with frequencies up to the LPTIM clock frequency divided by 2 can be generated. *Figure 561* below shows the three possible waveforms that can be generated on the LPTIM output. Also, it shows the effect of the polarity change using the WAVPOL bit.

Figure 561. Waveform generation



48.4.11 Register update

The LPTIM_ARR register and LPTIM_CMP register are updated immediately after the APB bus write operation, or at the end of the current period if the timer is already started.

The PRELOAD bit controls how the LPTIM_ARR and the LPTIM_CMP registers are updated:

- When the PRELOAD bit is reset to ‘0’, the LPTIM_ARR and the LPTIM_CMP registers are immediately updated after any write access.
- When the PRELOAD bit is set to ‘1’, the LPTIM_ARR and the LPTIM_CMP registers are updated at the end of the current period, if the timer has been already started.

The LPTIM APB interface and the LPTIM kernel logic use different clocks, so there is some latency between the APB write and the moment when these values are available to the

counter comparator. Within this latency period, any additional write into these registers must be avoided.

The ARROK flag and the CMPOK flag in the LPTIM_ISR register indicate when the write operation is completed to respectively the LPTIM_ARR register and the LPTIM_CMP register.

After a write to the LPTIM_ARR register or the LPTIM_CMP register, a new write operation to the same register can only be performed when the previous write operation is completed. Any successive write before respectively the ARROK flag or the CMPOK flag be set, will lead to unpredictable results.

48.4.12 Counter mode

The LPTIM counter can be used to count external events on the LPTIM Input1 or it can be used to count internal clock cycles. The CKSEL and COUNTMODE bits control which source will be used for updating the counter.

In case the LPTIM is configured to count external events on Input1, the counter can be updated following a rising edge, falling edge or both edges depending on the value written to the CKPOL[1:0] bits.

The count modes below can be selected, depending on CKSEL and COUNTMODE values:

- CKSEL = 0: the LPTIM is clocked by an internal clock source
  - COUNTMODE = 0

    The LPTIM is configured to be clocked by an internal clock source and the LPTIM counter is configured to be updated following each internal clock pulse.
  - COUNTMODE = 1

    The LPTIM external Input1 is sampled with the internal clock provided to the LPTIM.

    Consequently, in order not to miss any event, the frequency of the changes on the external Input1 signal should never exceed the frequency of the internal clock provided to the LPTIM. Also, the internal clock provided to the LPTIM must not be prescaled (PRESC[2:0] = 000).
- CKSEL = 1: the LPTIM is clocked by an external clock source

  COUNTMODE value is don’t care.

  In this configuration, the LPTIM has no need for an internal clock source (except if the glitch filters are enabled). The signal injected on the LPTIM external Input1 is used as system clock for the LPTIM. This configuration is suitable for operation modes where no embedded oscillator is enabled.

  For this configuration, the LPTIM counter can be updated either on rising edges or falling edges of the input1 clock signal but not on both rising and falling edges.

  Since the signal injected on the LPTIM external Input1 is also used to clock the LPTIM kernel logic, there is some initial latency (after the LPTIM is enabled) before the counter is incremented. More precisely, the first five active edges on the LPTIM external Input1 (after LPTIM is enable) are lost.

48.4.13 Timer enable

The ENABLE bit located in the LPTIM_CR register is used to enable/disable the LPTIM kernel logic. After setting the ENABLE bit, a delay of two counter clock is needed before the LPTIM is actually enabled.

The LPTIM_CFGR and LPTIM_IER registers must be modified only when the LPTIM is disabled.

48.4.14 Timer counter reset

In order to reset the content of LPTIM_CNT register to zero, two reset mechanisms are implemented:

- The synchronous reset mechanism: the synchronous reset is controlled by the COUNTRST bit in the LPTIM_CR register. After setting the COUNTRST bit-field to '1', the reset signal is propagated in the LPTIM kernel clock domain. So it is important to note that a few clock pulses of the LPTIM kernel logic will elapse before the reset is taken into account. This will make the LPTIM counter count few extra pluses between the time when the reset is trigger and it become effective. Since the COUNTRST bit is located in the APB clock domain and the LPTIM counter is located in the LPTIM kernel clock domain, a delay of 3 clock cycles of the kernel clock is needed to synchronize the reset signal issued by the APB clock domain when writing '1' to the COUNTRST bit.
- The asynchronous reset mechanism: the asynchronous reset is controlled by the RSTARE bit located in the LPTIM_CR register. When this bit is set to '1', any read access to the LPTIM_CNT register will reset its content to zero. Asynchronous reset should be triggered within a timeframe in which no LPTIM core clock is provided. For example when LPTIM Input1 is used as external clock source, the asynchronous reset should be applied only when there is enough insurance that no toggle will occur on the LPTIM Input1.
  It should be noted that to read reliably the content of the LPTIM_CNT register two successive read accesses must be performed and compared. A read access can be considered reliable when the value of the two read accesses is equal. Unfortunately when asynchronous reset is enabled there is no possibility to read twice the LPTIM_CNT register.

Warning: There is no mechanism inside the LPTIM that prevents the two reset mechanisms from being used simultaneously. So developer should make sure that these two mechanisms are used exclusively.

48.4.15 Encoder mode

This mode allows handling signals from quadrature encoders used to detect angular position of rotary elements. Encoder interface mode acts simply as an external clock with direction selection. This means that the counter just counts continuously between 0 and the auto-reload value programmed into the LPTIM_ARR register (0 up to ARR or ARR down to 0 depending on the direction). Therefore LPTIM_ARR must be configured before starting the counter. From the two external input signals, Input1 and Input2, a clock signal is generated to clock the LPTIM counter. The phase between those two signals determines the counting direction.

The Encoder mode is only available when the LPTIM is clocked by an internal clock source. The signals frequency on both Input1 and Input2 inputs must not exceed the LPTIM internal clock frequency divided by 4. This is mandatory in order to guarantee a proper operation of the LPTIM.

Direction change is signalized by the two Down and Up flags in the LPTIM_ISR register. Also, an interrupt can be generated for both direction change events if enabled through the DOWNIE bit.

To activate the Encoder mode the ENC bit has to be set to ‘1’. The LPTIM must first be configured in Continuous mode.

When Encoder mode is active, the LPTIM counter is modified automatically following the speed and the direction of the incremental encoder. Therefore, its content always represents the encoder’s position. The count direction, signaled by the Up and Down flags, correspond to the rotation direction of the encoder rotor.

According to the edge sensitivity configured using the CKPOL[1:0] bits, different counting scenarios are possible. The following table summarizes the possible combinations, assuming that Input1 and Input2 do not switch at the same time.

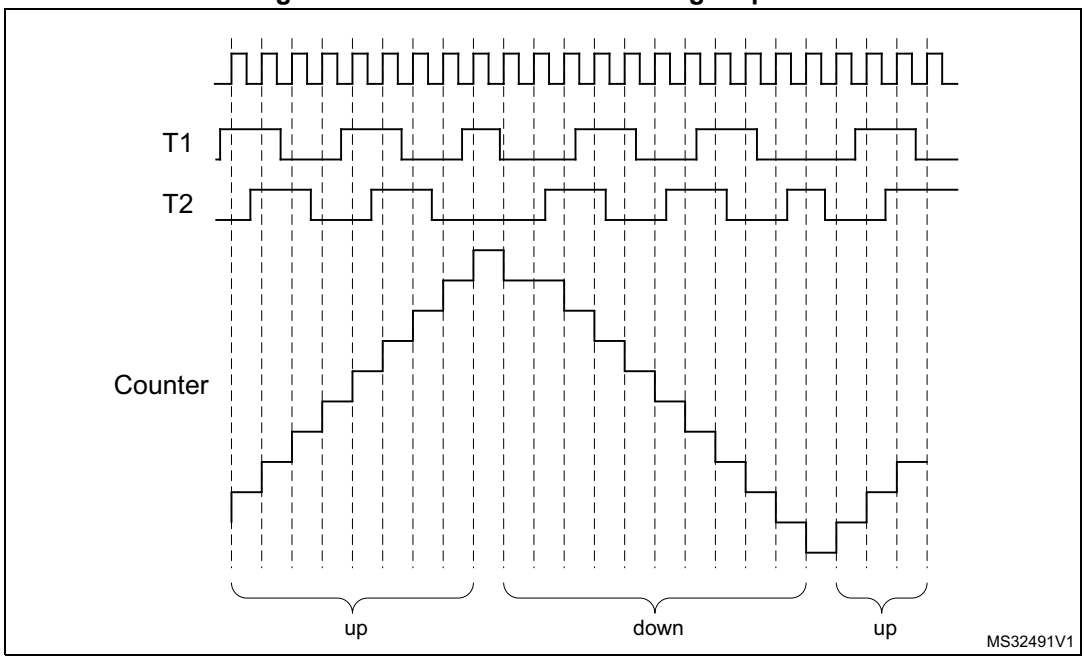
Table 384. Encoder counting scenarios

Active edge	Level on opposite signal (Input1 for Input2, Input2 for Input1)	Input1 signal		Input2 signal	
		Rising	Falling	Rising	Falling
Rising Edge	High	Down	No count	Up	No count
	Low	Up	No count	Down	No count
Falling Edge	High	No count	Up	No count	Down
	Low	No count	Down	No count	Up
Both Edges	High	Down	Up	Up	Down
	Low	Up	Down	Down	Up

The following figure shows a counting sequence for Encoder mode where both-edge sensitivity is configured.

Caution: In this mode the LPTIM must be clocked by an internal clock source, so the CKSEL bit must be maintained to its reset value which is equal to ‘0’. Also, the prescaler division ratio must be equal to its reset value which is 1 (PRESC[2:0] bits must be ‘000’).

Figure 562. Encoder mode counting sequence



48.4.16 Debug mode

When the microcontroller enters debug mode (core halted), the LPTIM counter either continues to work normally or stops, depending on the DBG_LPTIM_STOP configuration bit in the DBG module.

48.5 LPTIM low-power modes

Table 385. Effect of low-power modes on the LPTIM

Mode	Description
Sleep	No effect. LPTIM interrupts cause the device to exit Sleep mode.
Stop	If the LPTIM is clocked by an oscillator available in Stop mode, LPTIM is functional and the interrupts cause the device to exit the Stop mode (refer to *Section 48.3: LPTIM implementation*).
Standby	The LPTIM peripheral is powered down and must be reinitialized after exiting Standby mode.

48.6 LPTIM interrupts

The following events generate an interrupt/wake-up event, if they are enabled through the LPTIM_IER register:

- Compare match
- Auto-reload match (whatever the direction if encoder mode)
- External trigger event
- Autoreload register write completed
- Compare register write completed
- Direction change (encoder mode), programmable (up / down / both).

Note: If any bit in the LPTIM_IER register (Interrupt Enable Register) is set after that its corresponding flag in the LPTIM_ISR register (Status Register) is set, the interrupt is not asserted.

Table 386. Interrupt events

Interrupt event	Description
Compare match	Interrupt flag is raised when the content of the Counter register (LPTIM_CNT) matches the content of the compare register (LPTIM_CMP).
Auto-reload match	Interrupt flag is raised when the content of the Counter register (LPTIM_CNT) matches the content of the Auto-reload register (LPTIM_ARR).
External trigger event	Interrupt flag is raised when an external trigger event is detected
Auto-reload register update OK	Interrupt flag is raised when the write operation to the LPTIM_ARR register is complete.
Compare register update OK	Interrupt flag is raised when the write operation to the LPTIM_CMP register is complete.
Direction change	Used in Encoder mode. Two interrupt flags are embedded to signal direction change: – UP flag signals up-counting direction change – DOWN flag signals down-counting direction change.

48.7 LPTIM registers

The peripheral registers can only be accessed by words (32-bit).

48.7.1 LPTIM interrupt and status register (LPTIM_ISR)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DOWN	UP	ARR OK	CMP OK	EXT TRIG	ARRM	CMPM
									r	r	r	r	r	r	r

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **DOWN**: Counter direction change up to down

In Encoder mode, DOWN bit is set by hardware to inform application that the counter direction has changed from up to down. DOWN flag can be cleared by writing 1 to the DOWNCF bit in the LPTIM_ICR register.

Note: If the LPTIM does not support encoder mode feature, this bit is reserved. Please refer to Section 48.3: LPTIM implementation.

Bit 5 **UP**: Counter direction change down to up

In Encoder mode, UP bit is set by hardware to inform application that the counter direction has changed from down to up. UP flag can be cleared by writing 1 to the UPCF bit in the LPTIM_ICR register.

Note: If the LPTIM does not support encoder mode feature, this bit is reserved. Please refer to Section 48.3: LPTIM implementation.

Bit 4 **ARROK**: Autoreload register update OK

ARROK is set by hardware to inform application that the APB bus write operation to the LPTIM_ARR register has been successfully completed. ARROK flag can be cleared by writing 1 to the ARROKCF bit in the LPTIM_ICR register.

Bit 3 **CMPOK**: Compare register update OK

CMPOK is set by hardware to inform application that the APB bus write operation to the LPTIM_CMP register has been successfully completed. CMPOK flag can be cleared by writing 1 to the CMPOKCF bit in the LPTIM_ICR register.

Bit 2 **EXTTRIG**: External trigger edge event

EXTTRIG is set by hardware to inform application that a valid edge on the selected external trigger input has occurred. If the trigger is ignored because the timer has already started, then this flag is not set. EXTTRIG flag can be cleared by writing 1 to the EXTTRIGCF bit in the LPTIM_ICR register.

Bit 1 **ARRM**: Autoreload match

ARRM is set by hardware to inform application that LPTIM_CNT register's value reached the LPTIM_ARR register's value. ARRM flag can be cleared by writing 1 to the ARRMCF bit in the LPTIM_ICR register.

Bit 0 **CMPM**: Compare match

The CMPM bit is set by hardware to inform application that LPTIM_CNT register value reached the LPTIM_CMP register's value. CMPM flag can be cleared by writing 1 to the CMPMCF bit in the LPTIM_ICR register.

48.7.2 LPTIM interrupt clear register (LPTIM_ICR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DOWNCF	UPCF	ARROKCF	CMPOKCF	EXTTRIGCF	ARRMCF	CMPMCF
									w	w	w	w	w	w	w

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **DOWNCF**: Direction change to down clear flag

Writing 1 to this bit clear the DOWN flag in the LPTIM_ISR register.

Note: If the LPTIM does not support encoder mode feature, this bit is reserved. Please refer to Section 48.3: LPTIM implementation.

Bit 5 **UPCF**: Direction change to UP clear flag

Writing 1 to this bit clear the UP flag in the LPTIM_ISR register.

Note: If the LPTIM does not support encoder mode feature, this bit is reserved. Please refer to Section 48.3: LPTIM implementation.

Bit 4 **ARROKCF**: Autoreload register update OK clear flag

Writing 1 to this bit clears the ARROK flag in the LPTIM_ISR register

Bit 3 **CMPOKCF**: Compare register update OK clear flag

Writing 1 to this bit clears the CMPOK flag in the LPTIM_ISR register

Bit 2 **EXTTRIGCF**: External trigger valid edge clear flag

Writing 1 to this bit clears the EXTTRIG flag in the LPTIM_ISR register

Bit 1 **ARRMCF**: Autoreload match clear flag

Writing 1 to this bit clears the ARRM flag in the LPTIM_ISR register

Bit 0 **CMPMCF**: Compare match clear flag

Writing 1 to this bit clears the CMPM flag in the LPTIM_ISR register

48.7.3 LPTIM interrupt enable register (LPTIM_IER)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DOWNIE	UPIE	ARROKIE	CMPOKIE	EXTTRIGIE	ARRMIE	CMPMIE
									rw	rw	rw	rw	rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **DOWNIE**: Direction change to down Interrupt Enable
- 0: DOWN interrupt disabled
- 1: DOWN interrupt enabled

Note: If the LPTIM does not support encoder mode feature, this bit is reserved. Please refer to Section 48.3: LPTIM implementation.

Bit 5 **UPIE**: Direction change to UP Interrupt Enable
- 0: UP interrupt disabled
- 1: UP interrupt enabled

Note: If the LPTIM does not support encoder mode feature, this bit is reserved. Please refer to Section 48.3: LPTIM implementation.

Bit 4 **ARROKIE**: Autoreload register update OK Interrupt Enable
- 0: ARROK interrupt disabled
- 1: ARROK interrupt enabled

Bit 3 **CMPOKIE**: Compare register update OK Interrupt Enable
- 0: CMPOK interrupt disabled
- 1: CMPOK interrupt enabled

Bit 2 **EXTTRIGIE**: External trigger valid edge Interrupt Enable
- 0: EXTTRIG interrupt disabled
- 1: EXTTRIG interrupt enabled

Bit 1 **ARRMIE**: Autoreload match Interrupt Enable
- 0: ARRM interrupt disabled
- 1: ARRM interrupt enabled

Bit 0 **CMPMIE**: Compare match Interrupt Enable
- 0: CMPM interrupt disabled
- 1: CMPM interrupt enabled

Caution: The LPTIM_IER register must only be modified when the LPTIM is disabled (ENABLE bit reset to ‘0’)

48.7.4 LPTIM configuration register (LPTIM_CFGR)

Address offset: 0x00C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	ENC	COUNT MODE	PRELOAD	WAVPOL	WAVE	TIMOUT	TRIGEN[1:0]		Res.
							rw	rw	rw	rw	rw	rw	rw	rw	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRIGSEL[2:0]			Res.	PRESC[2:0]			Res.	TRGFLT[1:0]		Res.	CKFLT[1:0]		CKPOL[1:0]		CKSEL
rw	rw	rw		rw	rw	rw		rw	rw		rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 Reserved, must be kept at reset value.

Bits 28:25 Reserved, must be kept at reset value.

Bit 24 **ENC**: Encoder mode enable

The ENC bit controls the Encoder mode

0: Encoder mode disabled

1: Encoder mode enabled

Note: If the LPTIM does not support encoder mode feature, this bit is reserved. Please refer to Section 48.3: LPTIM implementation.

Bit 23 **COUNTMODE**: counter mode enabled

The COUNTMODE bit selects which clock source is used by the LPTIM to clock the counter:

0: the counter is incremented following each internal clock pulse

1: the counter is incremented following each valid clock pulse on the LPTIM external Input1

Bit 22 **PRELOAD**: Registers update mode

The PRELOAD bit controls the LPTIM_ARR and the LPTIM_CMP registers update modality

0: Registers are updated after each APB bus write access

1: Registers are updated at the end of the current LPTIM period

Bit 21 **WAVPOL**: Waveform shape polarity

The WAVEPOL bit controls the output polarity

0: The LPTIM output reflects the compare results between LPTIM_CNT and LPTIM_CMP registers

1: The LPTIM output reflects the inverse of the compare results between LPTIM_CNT and LPTIM_CMP registers

Bit 20 **WAVE**: Waveform shape

The WAVE bit controls the output shape

0: Deactivate Set-once mode

1: Activate the Set-once mode

Bit 19 **TIMOUT**: Timeout enable

The TIMOUT bit controls the Timeout feature

0: A trigger event arriving when the timer is already started will be ignored

1: A trigger event arriving when the timer is already started will reset and restart the counter

Bits 18:17 **TRIGEN[1:0]**: Trigger enable and polarity

The TRIGEN bits controls whether the LPTIM counter is started by an external trigger or not. If the external trigger option is selected, three configurations are possible for the trigger active edge:

00: software trigger (counting start is initiated by software)

01: rising edge is the active edge

10: falling edge is the active edge

11: both edges are active edges

Bit 16 Reserved, must be kept at reset value.

Bits 15:13 **TRIGSEL[2:0]**: Trigger selector

The TRIGSEL bits select the trigger source that will serve as a trigger event for the LPTIM among the below 8 available sources:

000: lptim_ext_trig0
001: lptim_ext_trig1
010: lptim_ext_trig2
011: lptim_ext_trig3
100: lptim_ext_trig4
101: lptim_ext_trig5
110: lptim_ext_trig6
111: lptim_ext_trig7

See *Section 48.4.3: LPTIM input and trigger mapping* for details.

Bit 12 Reserved, must be kept at reset value.

Bits 11:9 **PRESC[2:0]:** Clock prescaler

The PRESC bits configure the prescaler division factor. It can be one among the following division factors:

000: /1
001: /2
010: /4
011: /8
100: /16
101: /32
110: /64
111: /128

Bit 8 Reserved, must be kept at reset value.

Bits 7:6 **TRGFLT[1:0]:** Configurable digital filter for trigger

The TRGFLT value sets the number of consecutive equal samples that should be detected when a level change occurs on an internal trigger before it is considered as a valid level transition. An internal clock source must be present to use this feature

00: any trigger active level change is considered as a valid trigger
01: trigger active level change must be stable for at least 2 clock periods before it is considered as valid trigger.
10: trigger active level change must be stable for at least 4 clock periods before it is considered as valid trigger.
11: trigger active level change must be stable for at least 8 clock periods before it is considered as valid trigger.

Bit 5 Reserved, must be kept at reset value.

Bits 4:3 **CKFLT[1:0]:** Configurable digital filter for external clock

The CKFLT value sets the number of consecutive equal samples that should be detected when a level change occurs on an external clock signal before it is considered as a valid level transition. An internal clock source must be present to use this feature

00: any external clock signal level change is considered as a valid transition

01: external clock signal level change must be stable for at least 2 clock periods before it is considered as valid transition.

10: external clock signal level change must be stable for at least 4 clock periods before it is considered as valid transition.

11: external clock signal level change must be stable for at least 8 clock periods before it is considered as valid transition.

Bits 2:1 **CKPOL[1:0]:** Clock Polarity

If LPTIM is clocked by an external clock source:

When the LPTIM is clocked by an external clock source, CKPOL bits is used to configure the active edge or edges used by the counter:

00:the rising edge is the active edge used for counting.
If the LPTIM is configured in Encoder mode (ENC bit is set), the encoder sub-mode 1 is active.

01:the falling edge is the active edge used for counting
If the LPTIM is configured in Encoder mode (ENC bit is set), the encoder sub-mode 2 is active.

10:both edges are active edges. When both external clock signal edges are considered active ones, the LPTIM must also be clocked by an internal clock source with a frequency equal to at least four times the external clock frequency.
If the LPTIM is configured in Encoder mode (ENC bit is set), the encoder sub-mode 3 is active.

11:not allowed

Refer to *Section 48.4.15: Encoder mode* for more details about Encoder mode sub-modes.

Bit 0 **CKSEL:** Clock selector

The CKSEL bit selects which clock source the LPTIM will use:

0: LPTIM is clocked by internal clock source (APB clock or any of the embedded oscillators)

1: LPTIM is clocked by an external clock source through the LPTIM external Input1

Caution: The LPTIM_CFGR register must only be modified when the LPTIM is disabled (ENABLE bit reset to ‘0’).

48.7.5 LPTIM control register (LPTIM_CR)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RSTARE	COUNTRST	CNTSTRT	SNGSTRT	ENABLE
											rw	rs	rw	rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **RSTARE:** Reset after read enable

This bit is set and cleared by software. When RSTARE is set to '1', any read access to LPTIM_CNT register will asynchronously reset LPTIM_CNT register content.
This bit can be set only when the LPTIM is enabled.

Bit 3 **COUNTRST:** Counter reset

This bit is set by software and cleared by hardware. When set to '1' this bit will trigger a synchronous reset of the LPTIM_CNT counter register. Due to the synchronous nature of this reset, it only takes place after a synchronization delay of 3 LPTimer core clock cycles (LPTimer core clock may be different from APB clock).
This bit can be set only when the LPTIM is enabled. It is automatically reset by hardware.

Caution: COUNTRST must never be set to '1' by software before it is already cleared to '0' by hardware. Software should consequently check that COUNTRST bit is already cleared to '0' before attempting to set it to '1'.

Bit 2 **CNTSTRT:** Timer start in Continuous mode

This bit is set by software and cleared by hardware.
In case of software start (TRIGEN[1:0] = ‘00’), setting this bit starts the LPTIM in Continuous mode.
If the software start is disabled (TRIGEN[1:0] different than ‘00’), setting this bit starts the timer in Continuous mode as soon as an external trigger is detected.
If this bit is set when a single pulse mode counting is ongoing, then the timer will not stop at the next match between the LPTIM_ARR and LPTIM_CNT registers and the LPTIM counter keeps counting in Continuous mode.
This bit can be set only when the LPTIM is enabled. It will be automatically reset by hardware.

Bit 1 **SNGSTRT:** LPTIM start in Single mode

This bit is set by software and cleared by hardware.
In case of software start (TRIGEN[1:0] = ‘00’), setting this bit starts the LPTIM in single pulse mode.
If the software start is disabled (TRIGEN[1:0] different than ‘00’), setting this bit starts the LPTIM in single pulse mode as soon as an external trigger is detected.
If this bit is set when the LPTIM is in continuous counting mode, then the LPTIM will stop at the following match between LPTIM_ARR and LPTIM_CNT registers.
This bit can only be set when the LPTIM is enabled. It will be automatically reset by hardware.

Bit 0 **ENABLE:** LPTIM enable

The ENABLE bit is set and cleared by software.
0:LPTIM is disabled
1:LPTIM is enabled

48.7.6 LPTIM compare register (LPTIM_CMP)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CMP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **CMP[15:0]:** Compare value
CMP is the compare value used by the LPTIM.

Caution: The LPTIM_CMP register must only be modified when the LPTIM is enabled (ENABLE bit set to ‘1’).

48.7.7 LPTIM autoreload register (LPTIM_ARR)

Address offset: 0x018

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **ARR[15:0]:** Auto reload value
ARR is the autoreload value for the LPTIM.
This value must be strictly greater than the CMP[15:0] value.

Caution: The LPTIM_ARR register must only be modified when the LPTIM is enabled (ENABLE bit set to ‘1’).

48.7.8 LPTIM counter register (LPTIM_CNT)

Address offset: 0x01C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CNT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **CNT[15:0]:** Counter value

When the LPTIM is running with an asynchronous clock, reading the LPTIM_CNT register may return unreliable values. So in this case it is necessary to perform two consecutive read accesses and verify that the two returned values are identical.

It should be noted that for a reliable LPTIM_CNT register read access, two consecutive read accesses must be performed and compared. A read access can be considered reliable when the values of the two consecutive read accesses are equal.

48.7.9 LPTIM configuration register 2 (LPTIM_CFGR2)

Address offset: 0x024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IN2SEL[1:0]		Res.	Res.	IN1SEL[1:0]	
										rw	rw			rw	rw

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:4 **IN2SEL[1:0]:** LPTIM input 2 selection

The IN2SEL bits control the LPTIM Input 2 multiplexer, which connect LPTIM Input 2 to one of the available inputs.

00: lptim_in2_mux0

01: lptim_in2_mux1

10: lptim_in2_mux2

11: lptim_in2_mux3

For connection details refer to *Section 48.4.3: LPTIM input and trigger mapping*.

Note: If the LPTIM does not support encoder mode feature, these bits are reserved. Please refer to Section 48.3: LPTIM implementation.

Bits 3:2 Reserved, must be kept at reset value.

Bits 1:0 **IN1SEL[1:0]:** LPTIM input 1 selection

The IN1SEL bits control the LPTIM Input 1 multiplexer, which connects LPTIM Input 1 to one of the available inputs.

00: lptim_in1_mux0

01: lptim_in1_mux1

10: lptim_in1_mux2

11: lptim_in1_mux3

For connection details refer to *Section 48.4.3: LPTIM input and trigger mapping*.

Note: If LPTIM does not implement external input clock, these bits are reserved. Please refer to Section 48.3: LPTIM implementation.

Caution: The LPTIM_CFGR2 register must only be modified when the LPTIM is disabled (ENABLE bit reset to ‘0’).

48.7.10 LPTIM register map

The following table summarizes the LPTIM registers.

Table 387. LPTIM register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	LPTIM_ISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DOWN[1]	UP[1]	ARROK	CMPOK	EXTTRIG	ARRM	CMPM
	Reset value																										0	0	0	0	0	0	0
0x004	LPTIM_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DOWNCF[1]	UPCF[1]	ARROKCF	CMPOKCF	EXTTRIGCF	ARRMCF	CMPMCF
	Reset value																										0	0	0	0	0	0	0
0x008	LPTIM_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DOWNIE[1]	UPIE[1]	ARROKIE	CMPOKIE	EXTTRIGIE	ARRMIE	CMPMIE
	Reset value																										0	0	0	0	0	0	0
0x00C	LPTIM_CFGR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ENC[1]	COUNTMODE	PRELOAD	WAVEPOL	WAVE	TIMOUT	TRIGEN		Res.	TRIGSEL[2:0]			Res.	PRESC			Res.	TRGFLT		Res.	CKFLT		CKPOL		CKSEL
	Reset value								0	0	0	0	0	0	0	0		0	0	0		0	0	0		0	0		0	0	0	0	0
0x010	LPTIM_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RSTARE	COUNTRST	CNTSTRT	SNGSTRT	ENABLE
	Reset value																												0	0	0	0	0
0x014	LPTIM_CMP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMP[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x018	LPTIM_ARR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x01C	LPTIM_CNT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	LPTIM_CFGR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IN2SEL[1:0][1]		Res.	Res.	IN1SEL[1:0]	
	Reset value																											0	0			0	0

1. If LPTIM does not support encoder mode feature, this bit is reserved. Please refer to Section 48.3: LPTIM implementation.

Refer to *Section 2.3 on page 131* for the register boundary addresses.

49 System window watchdog (WWDG)

49.1 Introduction

The system window watchdog (WWDG) is used to detect the occurrence of a software fault, usually generated by external interference or by unforeseen logical conditions, which causes the application program to abandon its normal sequence. The watchdog circuit generates a reset on expiry of a programmed time period, unless the program refreshes the contents of the down-counter before the T6 bit becomes cleared. A reset is also generated if the 7-bit down-counter value (in the control register) is refreshed before the down-counter has reached the window register value. This implies that the counter must be refreshed in a limited window.

The WWDG clock is prescaled from the APB clock and has a configurable time-window that can be programmed to detect abnormally late or early application behavior.

The WWDG is best suited for applications which require the watchdog to react within an accurate timing window.

49.2 WWDG main features

- Programmable free-running down-counter
- Conditional reset
  - Reset (if watchdog activated) when the down-counter value becomes lower than 0x40
  - Reset (if watchdog activated) if the down-counter is reloaded outside the window (see *Figure 564*)
- Early wakeup interrupt (EWI): triggered (if enabled and the watchdog activated) when the down-counter is equal to 0x40.

49.3 WWDG implementation

Table 388. STM32H72x and STM32H73x WWDG features(1)

WWDG mode / feature	WWDG
Window function	X
Early wakeup interrupt generation	X
System reset generation(2)	X
Capability to work in system Stop	-
Capability to work in system Standby	-
Capability to be frozen when the microcontroller enters in Debug mode(3)	X
Option bytes to control the Hardware mode	-

1. “X” = supported, “-” = not supported.
2. Refer to the RCC section for additional information.
3. Controlled via DBG_WWDG_STOPbit of DBGMCU_APB3FZ1 register.

49.4 WWDG functional description

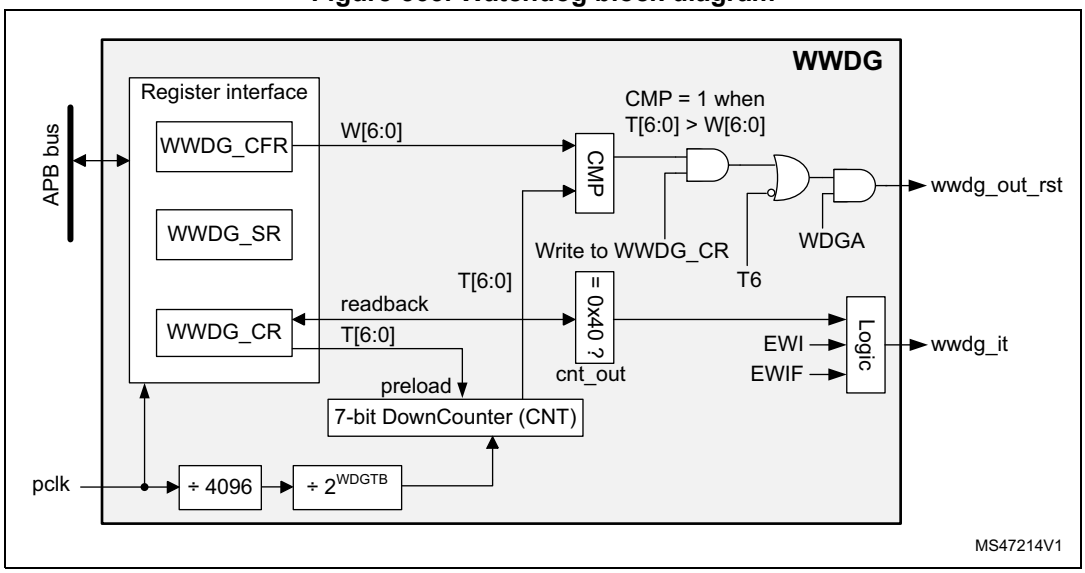
If the watchdog is activated (the WDGA bit is set in the WWDG_CR register) and when the 7-bit down-counter (T[6:0] bits) is decremented from 0x40 to 0x3F (T6 becomes cleared), it initiates a reset. If the software reloads the counter while the counter is greater than the value stored in the window register, then a reset is generated.

The application program must write in the WWDG_CR register at regular intervals during normal operation to prevent a reset. This operation must occur only when the counter value is lower than the window register value and higher than 0x3F. The value to be stored in the WWDG_CR register must be between 0xFF and 0xC0.

Refer to *Figure 563* and to *Section 49.4.2: WWDG internal signals* for the WWDG block diagram.

49.4.1 WWDG block diagram

Figure 563. Watchdog block diagram



49.4.2 WWDG internal signals

Table 389 gives the list of WWDG internal signals.

Table 389. WWDG internal input/output signals

Signal name	Signal type	Description
pclk	Digital input	APB bus clock
wwdg_out_rst	Digital output	WWDG reset signal output
wwdg_it	Digital output	WWDG early interrupt output

49.4.3 Enabling the watchdog

The watchdog is always disabled after a reset. It is enabled by setting the WDGA bit in the WWDG_CR register, then it cannot be disabled again except by a reset.

49.4.4 Controlling the down-counter

This down-counter is free-running, counting down even if the watchdog is disabled. When the watchdog is enabled, the T6 bit must be set to prevent generating an immediate reset.

The T[5:0] bits contain the number of increments that represent the time delay before the watchdog produces a reset. The timing varies between a minimum and a maximum value due to the unknown status of the prescaler when writing to the WWDG_CR register (see *Figure 564*). The *WWDG configuration register (WWDG_CFR)* contains the high limit of the window: to prevent a reset, the down-counter must be reloaded when its value is lower than the window register value and greater than 0x3F. *Figure 564* describes the window watchdog process.

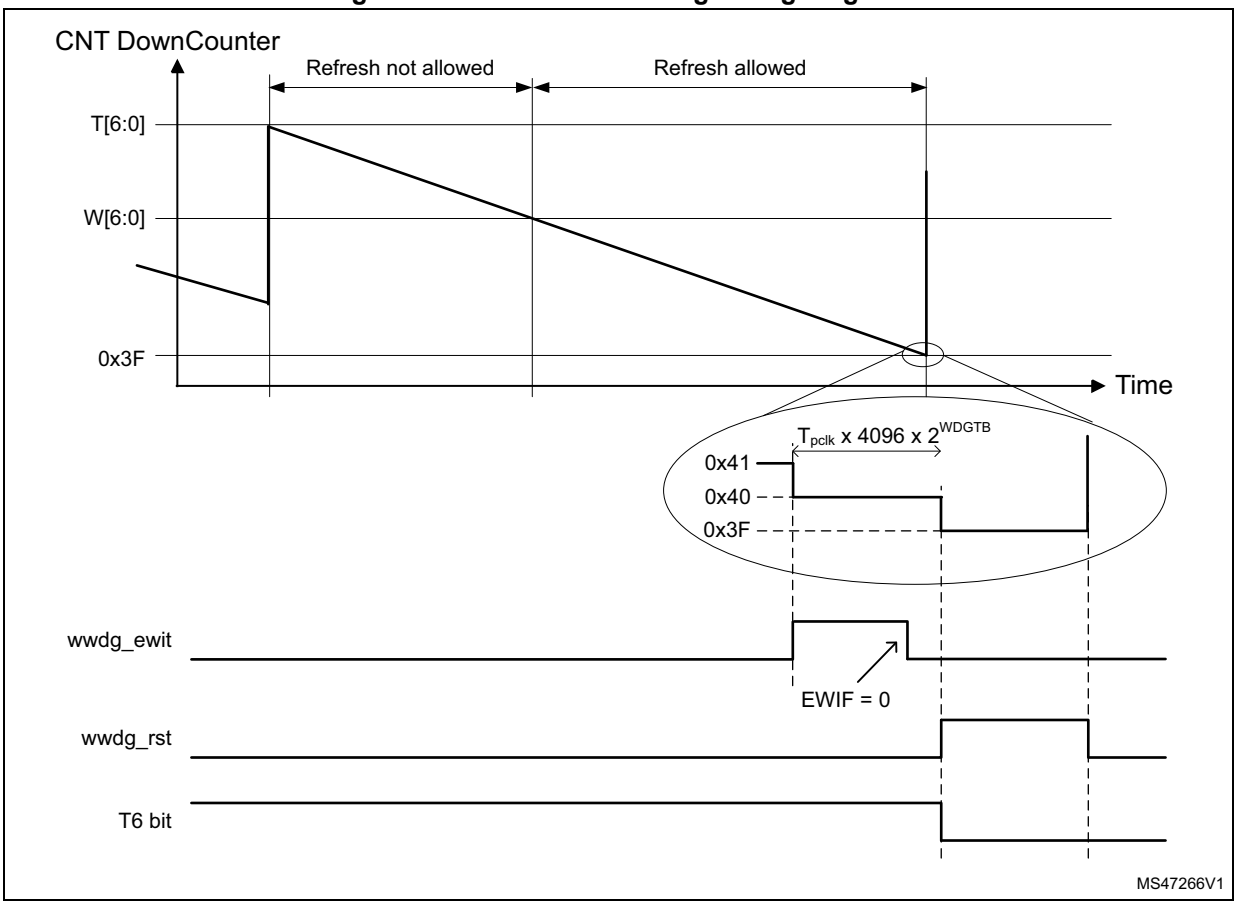
Note: The T6 bit can be used to generate a software reset (the WDGA bit is set and the T6 bit is cleared).

49.4.5 How to program the watchdog timeout

Use the formula in *Figure 564* to calculate the WWDG timeout.

Warning: When writing to the WWDG_CR register, always write 1 in the T6 bit to avoid generating an immediate reset.

Figure 564. Window watchdog timing diagram



The formula to calculate the timeout value is given by:

$$t_{WWDG} = t_{PCLK} \times 4096 \times 2^{WDGTB[2:0]} \times (T[5:0] + 1) \quad (ms)$$

where:

t_{WWDG}: WWDG timeout

t_{PCLK}: APB clock period measured in ms

4096: value corresponding to internal divider

As an example, if APB frequency is 48 MHz, WDGTB[2:0] is set to 3 and T[5:0] is set to 63:

$$t_{WWDG} = (1/48000) \times 4096 \times 2^{3} \times (63 + 1) = 43.69ms$$

Refer to the datasheet for the minimum and maximum values of t_{WWDG}.

49.4.6 Debug mode

When the CPU enters debug mode, WWDG counter either continues to work normally or stops, depending on debug settings. For more details refer to *Section 49.3: WWDG implementation* and to *Section 65: Debug infrastructure*.

49.5 WWDG interrupts

The early wakeup interrupt (EWI) can be used if specific safety operations or data logging must be performed before the actual reset is generated. The EWI interrupt is enabled by setting the EWI bit in the WWDG_CFR register. When the down-counter reaches the value 0x40, an EWI interrupt is generated and the corresponding interrupt service routine (ISR) can be used to trigger specific actions (such as communications or data logging) before resetting the device.

In some applications the EWI interrupt can be used to manage a software system check and/or system recovery/graceful degradation, without generating a WWDG reset. In this case the corresponding ISR has to reload the WWDG counter to avoid the WWDG reset, then trigger the required actions.

The EWI interrupt is cleared by writing '0' to the EWIF bit in the WWDG_SR register.

Note: When the EWI interrupt cannot be served (e.g. due to a system lock in a higher priority task) the WWDG reset is eventually generated.

49.6 WWDG registers

Refer to *Section 1.2 on page 104* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by halfwords (16-bit) or words (32-bit).

49.6.1 WWDG control register (WWDG_CR)

Address offset: 0x000

Reset value: 0x0000 007F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDGA	T[6:0]						
								rs	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **WDGA:** Activation bit

This bit is set by software and only cleared by hardware after a reset. When WDGA = 1, the watchdog can generate a reset.

0: Watchdog disabled

1: Watchdog enabled

Bits 6:0 **T[6:0]:** 7-bit counter (MSB to LSB)

These bits contain the value of the watchdog counter, decremented every (4096 x $2^{WDGTB[2:0]}$) PCLK cycles. A reset is produced when it is decremented from 0x40 to 0x3F (T6 becomes cleared).

49.6.2 WWDG configuration register (WWDG_CFR)

Address offset: 0x004

Reset value: 0x0000 007F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	WDGTB[2:0]			Res.	EWI	Res.	Res.	W[6:0]						
		rw	rw	rw		rs			rw	rw	rw	rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bits 13:11 **WDGTB[2:0]:** Timer base

The timebase of the prescaler can be modified as follows:
000: CK counter clock (PCLK div 4096) div 1
001: CK counter clock (PCLK div 4096) div 2
010: CK counter clock (PCLK div 4096) div 4
011: CK counter clock (PCLK div 4096) div 8
100: CK counter clock (PCLK div 4096) div 16
101: CK counter clock (PCLK div 4096) div 32
110: CK counter clock (PCLK div 4096) div 64
111: CK counter clock (PCLK div 4096) div 128

Bit 10 Reserved, must be kept at reset value.

Bit 9 **EWI:** Early wakeup interrupt

When set, an interrupt occurs whenever the counter reaches the value 0x40. This interrupt is only cleared by hardware after a reset.

Bits 8:7 Reserved, must be kept at reset value.

Bits 6:0 **W[6:0]:** 7-bit window value

These bits contain the window value to be compared with the down-counter.

49.6.3 WWDG status register (WWDG_SR)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EWIF
															rc_w0

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **EWIF:** Early wakeup interrupt flag

This bit is set by hardware when the counter has reached the value 0x40. It must be cleared by software by writing 0. Writing 1 has no effect. This bit is also set if the interrupt is not enabled.

49.6.4 WWDG register map

The following table gives the WWDG register map and reset values.

Table 390. WWDG register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**WWDG_CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDGA	T[6:0]						
	Reset value																									0	1	1	1	1	1	1	1
0x004	**WWDG_CFR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDGTB [2:0]			Res.	EWI	Res.	Res.	W[6:0]						
	Reset value																			0	0	0		0			1	1	1	1	1	1	1
0x008	**WWDG_SR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EWIF
	Reset value																																0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

50 Independent watchdog (IWDG)

50.1 Introduction

The devices feature an embedded watchdog peripheral that offers a combination of high safety level, timing accuracy and flexibility of use. The Independent watchdog peripheral detects and solves malfunctions due to software failure, and triggers system reset when the counter reaches a given timeout value.

The independent watchdog (IWDG) is clocked by its own dedicated low-speed clock (LSI) and thus stays active even if the main clock fails.

The IWDG is best suited for applications that require the watchdog to run as a totally independent process outside the main application, but have lower timing accuracy constraints. For further information on the window watchdog, refer to *Section 49 on page 1925*.

50.2 IWDG main features

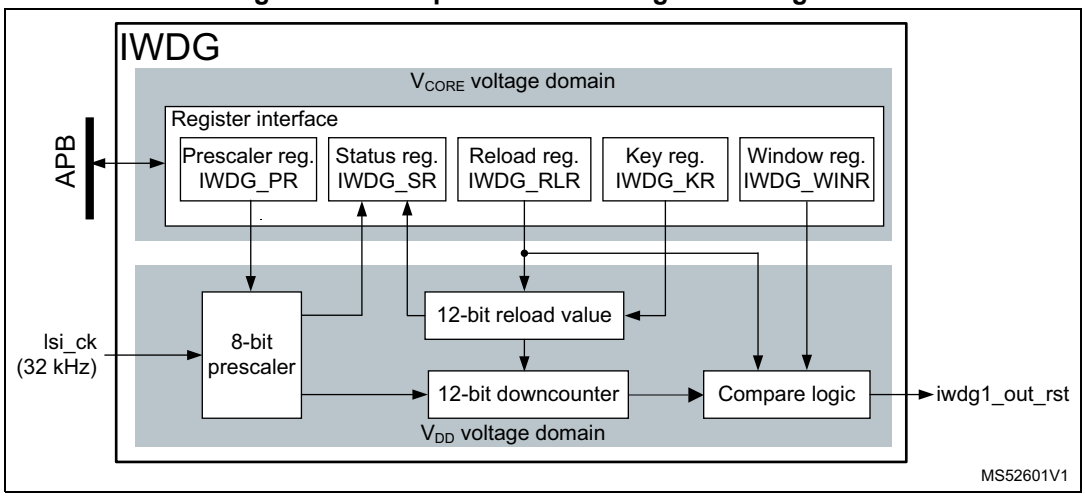
- Free-running downcounter
- Clocked from an independent RC oscillator (can operate in Standby and Stop modes)
- Conditional reset
  - Reset (if watchdog activated) when the downcounter value becomes lower than 0x000
  - Reset (if watchdog activated) if the downcounter is reloaded outside the window

50.3 IWDG functional description

50.3.1 IWDG block diagram

Figure 565 shows the functional blocks of the independent watchdog module.

Figure 565. Independent watchdog block diagram



1. The register interface is located in the V_{CORE} voltage domain. The watchdog function is located in the V_{DD} voltage domain, still functional in Stop and Standby modes.

When the independent watchdog is started by writing the value 0x0000 CCCC in the *IWDG key register (IWDG_KR)*, the counter starts counting down from the reset value of 0xFFF. When it reaches the end of count value (0x000) a reset signal is generated (IWDG reset).

Whenever the key value 0x0000 AAAA is written in the *IWDG key register (IWDG_KR)*, the IWDG_RLR value is reloaded in the counter and the watchdog reset is prevented.

Once running, the IWDG cannot be stopped.

50.3.2 IWDG internal signals

Table 391 gives the list of IWDG internal signals.

Table 391. IWDG internal input/output signals

Signal name	Signal type	Description
lsi_ck	Digital input	LSI clock
iwdg1_out_rst	Digital output	IWDG1 reset signal output

50.3.3 Window option

The IWDG can also work as a window watchdog by setting the appropriate window in the *IWDG window register (IWDG_WINR)*.

If the reload operation is performed while the counter is greater than the value stored in the *IWDG window register (IWDG_WINR)*, then a reset is provided.

The default value of the *IWDG window register (IWDG_WINR)* is 0x0000 0FFF, so if it is not updated, the window option is disabled.

As soon as the window value is changed, a reload operation is performed in order to reset the downcounter to the *IWDG reload register (IWDG_RLR)* value and ease the cycle number calculation to generate the next reload.

Configuring the IWDG when the window option is enabled

1. Enable the IWDG by writing 0x0000 CCCC in the *IWDG key register (IWDG_KR)*.
2. Enable register access by writing 0x0000 5555 in the *IWDG key register (IWDG_KR)*.
3. Write the IWDG prescaler by programming *IWDG prescaler register (IWDG_PR)* from 0 to 7.
4. Write the *IWDG reload register (IWDG_RLR)*.
5. Wait for the registers to be updated (IWDG_SR = 0x0000 0000).
6. Write to the *IWDG window register (IWDG_WINR)*. This automatically refreshes the counter value in the *IWDG reload register (IWDG_RLR)*.

Note: Writing the window value allows the counter value to be refreshed by the RLR when IWDG status register (IWDG_SR) is set to 0x0000 0000.

Configuring the IWDG when the window option is disabled

When the window option it is not used, the IWDG can be configured as follows:

1. Enable the IWDG by writing 0x0000 CCCC in the *IWDG key register (IWDG_KR)*.
2. Enable register access by writing 0x0000 5555 in the *IWDG key register (IWDG_KR)*.
3. Write the prescaler by programming the *IWDG prescaler register (IWDG_PR)* from 0 to 7.
4. Write the *IWDG reload register (IWDG_RLR)*.
5. Wait for the registers to be updated (IWDG_SR = 0x0000 0000).
6. Refresh the counter value with IWDG_RLR (IWDG_KR = 0x0000 AAAA).

50.3.4 Hardware watchdog

If the “Hardware watchdog” feature is enabled through the device option bits, the watchdog is automatically enabled at power-on, and generates a reset unless the *IWDG key register (IWDG_KR)* is written by the software before the counter reaches end of count or if the downcounter is reloaded inside the window.

50.3.5 Low-power freeze

Depending on the IWDG_FZ_STOP and IWDG_FZ_STBY options configuration, the IWDG can continue counting or not during the Stop mode and the Standby mode, respectively. If the IWDG is kept running during Stop or Standby modes, it can wake up the device from this mode. Refer to *Section : User and read protection option bytes* for more details.

50.3.6 Register access protection

Write access to *IWDG prescaler register (IWDG_PR)*, *IWDG reload register (IWDG_RLR)* and *IWDG window register (IWDG_WINR)* is protected. To modify them, the user must first write the code 0x0000 5555 in the *IWDG key register (IWDG_KR)*. A write access to this register with a different value breaks the sequence and register access is protected again. This is the case of the reload operation (writing 0x0000 AAAA).

A status register is available to indicate that an update of the prescaler or of the downcounter reload value or of the window value is ongoing.

50.3.7 Debug mode

When the device enters Debug mode (core halted), the IWDG counter either continues to work normally or stops, depending on the configuration of the corresponding bit in debug freeze register.

50.4 IWDG registers

Refer to *Section 1.2 on page 104* for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by half-words (16-bit) or words (32-bit).

50.4.1 IWDG key register (IWDG_KR)

Address offset: 0x00

Reset value: 0x0000 0000 (reset by Standby mode)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
KEY[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **KEY[15:0]:** Key value (write only, read 0x0000)

These bits must be written by software at regular intervals with the key value 0xAAAA, otherwise the watchdog generates a reset when the counter reaches 0.

Writing the key value 0x5555 to enable access to the IWDG_PR, IWDG_RLR and IWDG_WINR registers (see *Section 50.3.6: Register access protection*)

Writing the key value 0xCCCC starts the watchdog (except if the hardware watchdog option is selected)

50.4.2 IWDG prescaler register (IWDG_PR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PR[2:0]		
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **PR[2:0]:** Prescaler divider

These bits are write access protected see *Section 50.3.6: Register access protection*. They are written by software to select the prescaler divider feeding the counter clock. PVU bit of the *IWDG status register (IWDG_SR)* must be reset in order to be able to change the prescaler divider.

000: divider /4
001: divider /8
010: divider /16
011: divider /32
100: divider /64
101: divider /128
110: divider /256
111: divider /256

Note: Reading this register returns the prescaler value from the V_{DD} voltage domain. This value may not be up to date/valid if a write operation to this register is ongoing. For this reason the value read from this register is valid only when the PVU bit in the IWDG status register (IWDG_SR) is reset.

50.4.3 IWDG reload register (IWDG_RLR)

Address offset: 0x08

Reset value: 0x0000 0FFF (reset by Standby mode)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	RL[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **RL[11:0]:** Watchdog counter reload value

These bits are write access protected see *Register access protection*. They are written by software to define the value to be loaded in the watchdog counter each time the value 0xAAAA is written in the *IWDG key register (IWDG_KR)*. The watchdog counter counts down from this value. The timeout period is a function of this value and the clock prescaler. Refer to the datasheet for the timeout information.

The RVU bit in the *IWDG status register (IWDG_SR)* must be reset to be able to change the reload value.

Note: Reading this register returns the reload value from the V_{DD} voltage domain. This value may not be up to date/valid if a write operation to this register is ongoing on it. For this reason the value read from this register is valid only when the RVU bit in the IWDG status register (IWDG_SR) is reset.

50.4.4 IWDG status register (IWDG_SR)

Address offset: 0x0C

Reset value: 0x0000 0000 (not reset by Standby mode)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WVU	RVU	PVU
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **WVU:** Watchdog counter window value update

This bit is set by hardware to indicate that an update of the window value is ongoing. It is reset by hardware when the reload value update operation is completed in the V_{DD} voltage domain (takes up to five RC 40 kHz cycles).

Window value can be updated only when WVU bit is reset.

Bit 1 **RVU:** Watchdog counter reload value update

This bit is set by hardware to indicate that an update of the reload value is ongoing. It is reset by hardware when the reload value update operation is completed in the V_{DD} voltage domain (takes up to five RC 40 kHz cycles).

Reload value can be updated only when RVU bit is reset.

Bit 0 **PVU:** Watchdog prescaler value update

This bit is set by hardware to indicate that an update of the prescaler value is ongoing. It is reset by hardware when the prescaler update operation is completed in the V_{DD} voltage domain (takes up to five RC 40 kHz cycles).

Prescaler value can be updated only when PVU bit is reset.

Note: If several reload, prescaler, or window values are used by the application, it is mandatory to wait until RVU bit is reset before changing the reload value, to wait until PVU bit is reset before changing the prescaler value, and to wait until WVU bit is reset before changing the window value. However, after updating the prescaler and/or the reload/window value it is not necessary to wait until RVU or PVU or WVU is reset before continuing code execution except in case of low-power mode entry.

50.4.5 IWDG window register (IWDG_WINR)

Address offset: 0x10

Reset value: 0x0000 0FFF (reset by Standby mode)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	WIN[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **WIN[11:0]:** Watchdog counter window value

These bits are write access protected, see *Section 50.3.6*, they contain the high limit of the window value to be compared with the downcounter.

To prevent a reset, the downcounter must be reloaded when its value is lower than the window register value and greater than 0x0

The WVU bit in the *IWDG status register (IWDG_SR)* must be reset in order to be able to change the reload value.

Note: Reading this register returns the reload value from the V_{DD} voltage domain. This value may not be valid if a write operation to this register is ongoing. For this reason the value read from this register is valid only when the WVU bit in the IWDG status register (IWDG_SR) is reset.

50.4.6 IWDG register map

The following table gives the IWDG register map and reset values.

Table 392. IWDG register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**IWDG_KR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	KEY[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	**IWDG_PR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	PR[2:0]		
	Reset value																														0	0	0
0x08	**IWDG_RLR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	RL[11:0]											
	Reset value																					1	1	1	1	1	1	1	1	1	1	1	1
0x0C	**IWDG_SR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	WVU	RVU	PVU
	Reset value																														0	0	0
0x10	**IWDG_WINR**	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	WIN[11:0]											
	Reset value																					1	1	1	1	1	1	1	1	1	1	1	1

Refer to *Section 2.3 on page 131* for the register boundary addresses.

51 Real-time clock (RTC)

51.1 Introduction

The RTC provides an automatic wakeup to manage all low-power modes.

The real-time clock (RTC) is an independent BCD timer/counter. The RTC provides a time-of-day clock/calendar with programmable alarm interrupts.

The RTC includes also a periodic programmable wakeup flag with interrupt capability.

Two 32-bit registers contain the seconds, minutes, hours (12- or 24-hour format), day (day of week), date (day of month), month, and year, expressed in binary coded decimal format (BCD). The sub-seconds value is also available in binary format.

Compensations for 28-, 29- (leap year), 30-, and 31-day months are performed automatically. Daylight saving time compensation can also be performed.

Additional 32-bit registers contain the programmable alarm subseconds, seconds, minutes, hours, day, and date.

A digital calibration feature is available to compensate for any deviation in crystal oscillator accuracy.

After Backup domain reset, all RTC registers are protected against possible parasitic write accesses.

As long as the supply voltage remains in the operating range, the RTC never stops, regardless of the device status (Run mode, low-power mode or under reset).

51.2 RTC main features

The RTC unit main features are the following (see *Figure 567: Detailed RTC block diagram*):

- Calendar with subseconds, seconds, minutes, hours (12 or 24 format), day (day of week), date (day of month), month, and year.
- Daylight saving compensation programmable by software.
- Programmable alarm with interrupt function. The alarm can be triggered by any combination of the calendar fields.
- Automatic wakeup unit generating a periodic flag that triggers an automatic wakeup interrupt.
- Reference clock detection: a more precise second source clock (50 or 60 Hz) can be used to enhance the calendar precision.
- Accurate synchronization with an external clock using the subsecond shift feature.
- Digital calibration circuit (periodic counter correction): 0.95 ppm accuracy, obtained in a calibration window of several seconds
- Time-stamp function for event saving
- Tamper detection event with configurable filter and internal pull-up
- Maskable interrupts/events:
  - Alarm A
  - Alarm B
  - Wakeup interrupt
  - Time-stamp
  - Tamper detection
- 32 backup registers.

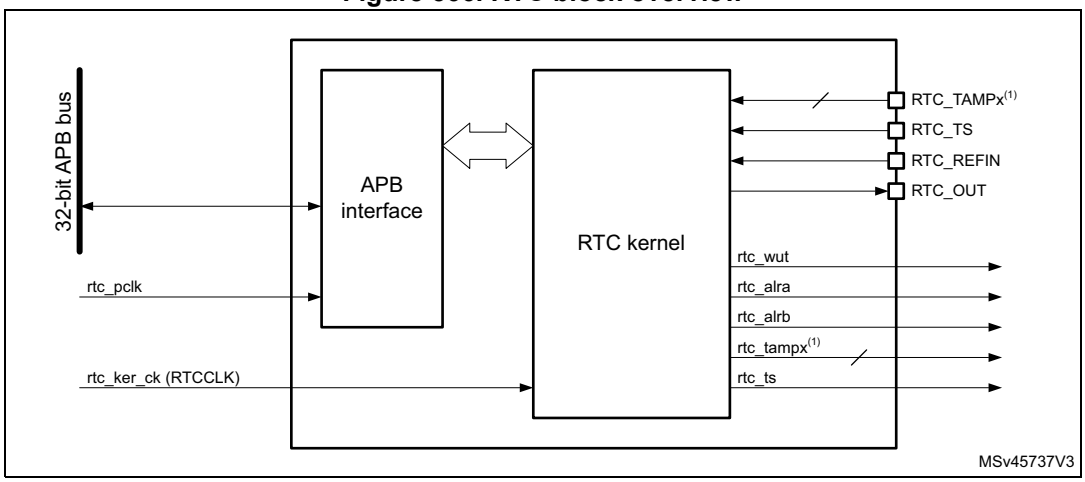
51.3 RTC implementation

The product integrates the RTC with only two tampers: RTC_TAMP1 and RTC_TAMP3.

51.4 RTC functional description

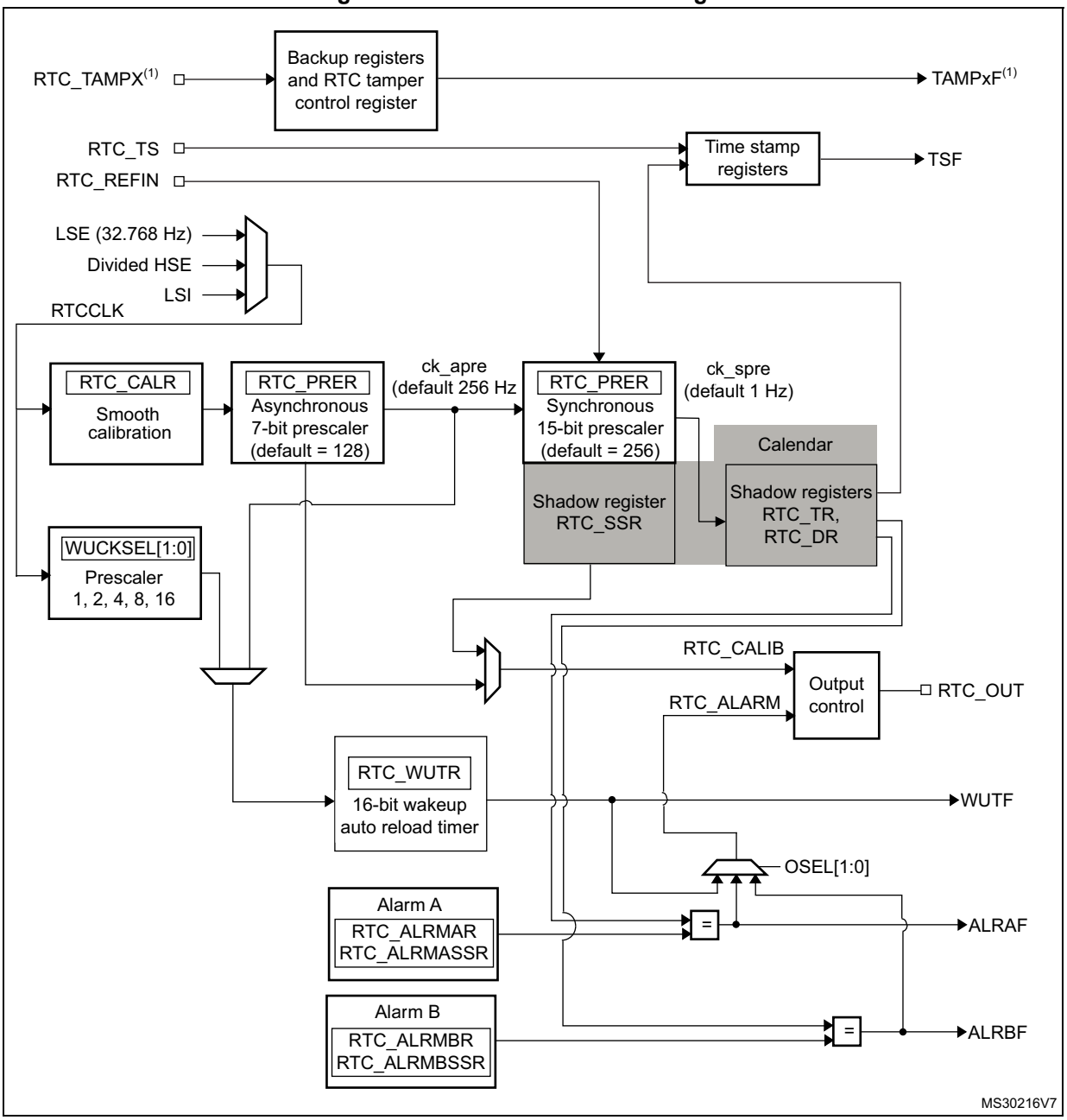
51.4.1 RTC block diagram

Figure 566. RTC block overview



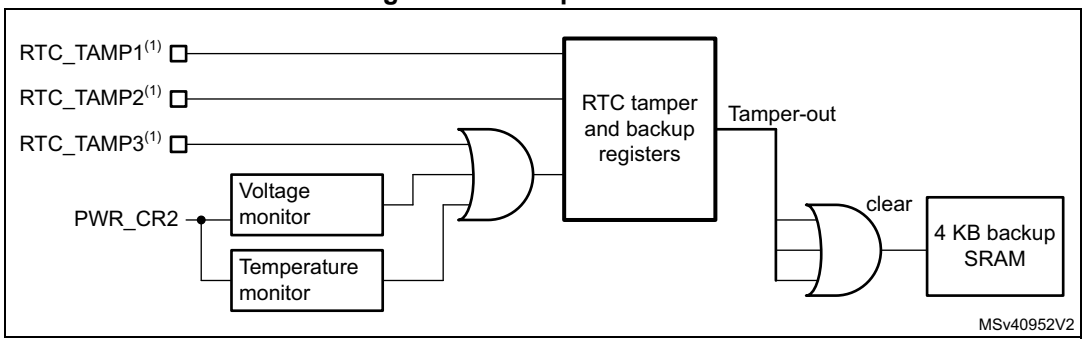
1. x is an integer index starting from 1, the number of tampers depends on devices.

Figure 567. Detailed RTC block diagram



1. x is an integer index starting from 1, the number of tampers depends on devices.

Figure 568. Tamper detection



1. Refer to device datasheet for RTC_TAMPx availability.

The RTC includes:

- Two alarms
- Two tamper events from I/Os
  - Tamper detection erases the backup registers and the backup RAM.
  - In addition, the tamper detection forbids software access to the backup SRAM until its erase operation is finished. Refer to *Section 51.4.15: Tamper detection*
  - The tamper3 event detection is generated either by an event on I/O, or by an over or under voltage of the RTC power supply domain, or by an over or under temperature detection. These voltage and temperature monitor detections are enabled in the *PWR control register 2 (PWR_CR2)*.
- One timestamp event from I/O
- Tamper event detection can generate a timestamp event
- Timestamp can be generated when a switch to V_{BAT} occurs
- 32 x 32-bit backup registers
  - The backup registers (RTC_BKPxR) are implemented in the RTC domain that remains powered-on by VBAT when the VDD power is switched off.
- Output functions: RTC_OUT which selects one of the following two outputs:
  - RTC_CALIB: 512 Hz or 1Hz clock output (with an LSE frequency of 32.768 kHz). This output is enabled by setting the COE bit in the RTC_CR register.
  - RTC_ALARM: This output is enabled by configuring the OSEL[1:0] bits in the RTC_CR register which select the Alarm A, Alarm B or Wakeup outputs.
- Input functions:
  - RTC_TS: timestamp event
  - RTC_TAMP1: tamper1 event detection
  - RTC_TAMP3: tamper3 event detection
  - RTC_REFIN: 50 or 60 Hz reference clock input

51.4.2 RTC pins and internal signals

Table 393. RTC pins and internal signals

Signal name	Signal type	Description
RTC_TS	Input	Timestamp input
RTC_TAMPx (x = 1,...)	Input	Tamper input

Table 393. RTC pins and internal signals (continued)

Signal name	Signal type	Description
RTC_REFIN	Input	Reference clock input
RTC_OUT	Output	RTC output
rtc_ker_ck *(RTCCLK)*	Internal input	RTC clock source (LSE clock, LSI clock and HSE clock)
rtc_pclk	Internal input	RTC APB interface clock
rtc_wut	Internal output	RTC wakeup event output for on chip peripherals
rtc_alra	Internal output	RTC Alarm A event output for on chip peripherals
rtc_alrb	Internal output	RTC Alarm B event output for on chip peripherals
rtc_tampx	Internal output	RTC Tamper x event output for on chip peripherals
rtc_ts	Internal output	RTC Timestamp event output for on chip peripherals

51.4.3 GPIOs controlled by the RTC

RTC_OUT, RTC_TS and RTC_TAMP1 are mapped on the same pin (PC13). PC13 pin configuration is controlled by the RTC, whatever the PC13 GPIO configuration, except for the RTC_ALARM output open-drain mode. The RTC functions mapped on PC13 are available in all low-power modes and in VBAT mode.

The output mechanism follows the priority order shown in *Table 394*.

Table 394. RTC pin PC13 configuration(1)

PC13 Pin configuration and function	OSEL[1:0] bits (RTC_ALARM output enable)	COE bit (RTC_CALIB output enable)	RTC_OUT_RMP bit	RTC_ALARM_TYPE bit	TAMP1E bit (RTC_TAMP1 input enable)	TSE bit (RTC_TS input enable)
RTC_ALARM output OD	01 or 10 or 11	Don't care	0	0	Don't care	Don't care
			1			
RTC_ALARM output PP	01 or 10 or 11	Don't care	0	1	Don't care	Don't care
			1			
RTC_CALIB output PP	00	1	0	Don't care	Don't care	Don't care
RTC_TAMP1 input floating	00	0	Don't care	Don't care	1	0
	00	1	1			
	01 or 10 or 11	0				
RTC_TS and RTC_TAMP1 input floating	00	0	Don't care	Don't care	1	1
	00	1	1			
	01 or 10 or 11	0				

Table 394. RTC pin PC13 configuration(1) (continued)

PC13 Pin configuration and function	OSEL[1:0] bits (RTC_ALARM output enable)	COE bit (RTC_CALIB output enable)	RTC_OUT_RMP bit	RTC_ALARM_TYPE bit	TAMP1E bit (RTC_TAMP1 input enable)	TSE bit (RTC_TS input enable)
RTC_TS input floating	00	0	Don't care	Don't care	0	1
	00	1	1			
	01 or 10 or 11	0				
Wakeup pin or Standard GPIO	00	0	Don't care	Don't care	0	0
	00	1	1			
	01 or 10 or 11	0				

1. OD: open drain; PP: push-pull.

In addition, it is possible to remap RTC_OUT on PB2 pin thanks to RTC_OUT_RMP bit. In this case it is mandatory to configure PB2 GPIO registers as alternate function with the correct type. The remap functions are shown in *Table 395*.

Table 395. RTC_OUT mapping

OSEL[1:0] bits (RTC_ALARM output enable)	COE bit (RTC_CALIB output enable)	RTC_OUT_RMP bit	RTC_OUT on PC13	RTC_OUT on PB2
00	0	0	-	-
00	1		RTC_CALIB	-
01 or 10 or 11	Don't care		RTC_ALARM	-
00	0	1	-	-
00	1		-	RTC_CALIB
01 or 10 or 11	0		-	RTC_ALARM
01 or 10 or 11	1		RTC_ALARM	RTC_CALIB

The table below summarizes the RTC pins and functions capability in all modes.

Table 396. RTC functions over modes

Pin	RTC functions	Functional in all low-power modes except Standby modes	Functional in Standby mode	Functional in VBAT mode
PC13	RTC_TAMP1 RTC_TS RTC_OUT	YES	YES	YES
PC1	RTC_TAMP3	YES	YES	YES
PB2	RTC_OUT	YES	NO	NO
PB15	RTC_REFIN	YES	NO	NO

51.4.4 Clock and prescalers

The RTC clock source (RTCCLK) is selected through the clock controller among the LSE clock, the LSI oscillator clock, and the HSE clock. For more information on the RTC clock source configuration, refer to *Section 49: Reset and Clock Control (RCC)*.

A programmable prescaler stage generates a 1 Hz clock which is used to update the calendar. To minimize power consumption, the prescaler is split into 2 programmable prescalers (see *Figure 567: Detailed RTC block diagram*):

- A 7-bit asynchronous prescaler configured through the PREDIV_A bits of the RTC_PRER register.
- A 15-bit synchronous prescaler configured through the PREDIV_S bits of the RTC_PRER register.

Note: When both prescalers are used, it is recommended to configure the asynchronous prescaler to a high value to minimize consumption.

The asynchronous prescaler division factor is set to 128, and the synchronous division factor to 256, to obtain an internal clock frequency of 1 Hz (ck_spre) with an LSE frequency of 32.768 kHz.

The minimum division factor is 1 and the maximum division factor is 2^{22}.

This corresponds to a maximum input frequency of around 4 MHz.

f_{ck_apre} is given by the following formula:

$$f_{CK\_APRE} = \frac{f_{RTCCLK}}{PREDIV\_A + 1}$$

The ck_apre clock is used to clock the binary RTC_SSR subseconds downcounter. When it reaches 0, RTC_SSR is reloaded with the content of PREDIV_S.

f_{ck_spre} is given by the following formula:

$$f_{CK\_SPRE} = \frac{f_{RTCCLK}}{(PREDIV\_S + 1) \times (PREDIV\_A + 1)}$$

The ck_spre clock can be used either to update the calendar or as timebase for the 16-bit wakeup auto-reload timer. To obtain short timeout periods, the 16-bit wakeup auto-reload timer can also run with the RTCCLK divided by the programmable 4-bit asynchronous prescaler (see *Section 51.4.7: Periodic auto-wakeup* for details).

51.4.5 Real-time clock and calendar

The RTC calendar time and date registers are accessed through shadow registers which are synchronized with PCLK (APB clock). They can also be accessed directly in order to avoid waiting for the synchronization duration.

- RTC_SSR for the subseconds
- RTC_TR for the time
- RTC_DR for the date

Every RTCCLK period, the current calendar value is copied into the shadow registers, and the RSF bit of RTC_ISR register is set (see *Section 51.7.4: RTC initialization and status*

register (RTC_ISR)). The copy is not performed in Stop and Standby mode. When exiting these modes, the shadow registers are updated after up to 1 RTCCLK period.

When the application reads the calendar registers, it accesses the content of the shadow registers. It is possible to make a direct access to the calendar registers by setting the BYPSHAD control bit in the RTC_CR register. By default, this bit is cleared, and the user accesses the shadow registers.

When reading the RTC_SSR, RTC_TR or RTC_DR registers in BYPSHAD=0 mode, the frequency of the APB clock (f_{APB}) must be at least 7 times the frequency of the RTC clock (f_{RTCCLK}).

The shadow registers are reset by system reset.

51.4.6 Programmable alarms

The RTC unit provides programmable alarm: Alarm A and Alarm B. The description below is given for Alarm A, but can be translated in the same way for Alarm B.

The programmable alarm function is enabled through the ALRAE bit in the RTC_CR register. The ALRAF is set to 1 if the calendar subseconds, seconds, minutes, hours, date or day match the values programmed in the alarm registers RTC_ALRMASSR and RTC_ALRMAR. Each calendar field can be independently selected through the MSKx bits of the RTC_ALRMAR register, and through the MASKSSx bits of the RTC_ALRMASSR register. The alarm interrupt is enabled through the ALRAIE bit in the RTC_CR register.

Caution: If the seconds field is selected (MSK1 bit reset in RTC_ALRMAR), the synchronous prescaler division factor set in the RTC_PRER register must be at least 3 to ensure correct behavior.

Alarm A and Alarm B (if enabled by bits OSEL[1:0] in RTC_CR register) can be routed to the RTC_ALARM output. RTC_ALARM output polarity can be configured through bit POL the RTC_CR register.

51.4.7 Periodic auto-wakeup

The periodic wakeup flag is generated by a 16-bit programmable auto-reload down-counter. The wakeup timer range can be extended to 17 bits.

The wakeup function is enabled through the WUTE bit in the RTC_CR register.

The wakeup timer clock input can be:

- RTC clock (RTCCLK) divided by 2, 4, 8, or 16.

  When RTCCLK is LSE(32.768kHz), this allows to configure the wakeup interrupt period from 122 µs to 32 s, with a resolution down to 61 µs.
- ck_spre (usually 1 Hz internal clock)

  When ck_spre frequency is 1Hz, this allows to achieve a wakeup time from 1 s to around 36 hours with one-second resolution. This large programmable time range is divided in 2 parts:
  - from 1s to 18 hours when WUCKSEL [2:1] = 10
  - and from around 18h to 36h when WUCKSEL[2:1] = 11. In this last case 2^{16} is added to the 16-bit counter current value.When the initialization sequence is complete (see *Programming the wakeup timer on page 1952*), the timer starts counting down.When the wakeup function is enabled, the down-counting remains active in low-power modes. In addition, when it reaches 0, the WUTF flag is set in

the RTC_ISR register, and the wakeup counter is automatically reloaded with its reload value (RTC_WUTR register value).

The WUTF flag must then be cleared by software.

When the periodic wakeup interrupt is enabled by setting the WUTIE bit in the RTC_CR register, it can exit the device from low-power modes.

The periodic wakeup flag can be routed to the RTC_ALARM output provided it has been enabled through bits OSEL[1:0] of RTC_CR register. RTC_ALARM output polarity can be configured through the POL bit in the RTC_CR register.

System reset, as well as low-power modes (Sleep, Stop and Standby) have no influence on the wakeup timer.

51.4.8 RTC initialization and configuration

RTC register access

The RTC registers are 32-bit registers. The APB interface introduces 2 wait-states in RTC register accesses except on read accesses to calendar shadow registers when BYPSHAD=0.

RTC register write protection

After system reset, the RTC registers are protected against parasitic write access by clearing the DBP bit in the PWR_CR1 register (refer to the power control section). DBP bit must be set in order to enable RTC registers write access.

After Backup domain reset, all the RTC registers are write-protected. Writing to the RTC registers is enabled by writing a key into the Write Protection register, RTC_WPR.

The following steps are required to unlock the write protection on all the RTC registers except for RTC_TAFCR, RTC_BKPxR, RTC_OR and RTC_ISR[13:8].

1. Write ‘0xCA’ into the RTC_WPR register.
2. Write ‘0x53’ into the RTC_WPR register.

Writing a wrong key reactivates the write protection.

The protection mechanism is not affected by system reset.

Calendar initialization and configuration

To program the initial time and date calendar values, including the time format and the prescaler configuration, the following sequence is required:

1. Set INIT bit to 1 in the RTC_ISR register to enter initialization mode. In this mode, the calendar counter is stopped and its value can be updated.
2. Poll INITF bit of in the RTC_ISR register. The initialization phase mode is entered when INITF is set to 1. It takes around 2 RTCCLK clock cycles (due to clock synchronization).
3. To generate a 1 Hz clock for the calendar counter, program both the prescaler factors in RTC_PRER register.
4. Load the initial time and date values in the shadow registers (RTC_TR and RTC_DR), and configure the time format (12 or 24 hours) through the FMT bit in the RTC_CR register.
5. Exit the initialization mode by clearing the INIT bit. The actual calendar counter value is then automatically loaded and the counting restarts after 4 RTCCLK clock cycles.

When the initialization sequence is complete, the calendar starts counting.

Note: After a system reset, the application can read the INITS flag in the RTC_ISR register to check if the calendar has been initialized or not. If this flag equals 0, the calendar has not been initialized since the year field is set at its Backup domain reset default value (0x00).

To read the calendar after initialization, the software must first check that the RSF flag is set in the RTC_ISR register.

Daylight saving time

The daylight saving time management is performed through bits SUB1H, ADD1H, and BKP of the RTC_CR register.

Using SUB1H or ADD1H, the software can subtract or add one hour to the calendar in one single operation without going through the initialization procedure.

In addition, the software can use the BKP bit to memorize this operation.

Programming the alarm

A similar procedure must be followed to program or update the programmable alarms. The procedure below is given for Alarm A but can be translated in the same way for Alarm B.

1. Clear ALRAE in RTC_CR to disable Alarm A.
2. Program the Alarm A registers (RTC_ALRMASSR/RTC_ALRMAR).
3. Set ALRAE in the RTC_CR register to enable Alarm A again.

Note: Each change of the RTC_CR register is taken into account after around 2 RTCCLK clock cycles due to clock synchronization.

Programming the wakeup timer

The following sequence is required to configure or change the wakeup timer auto-reload value (WUT[15:0] in RTC_WUTR):

1. Clear WUTE in RTC_CR to disable the wakeup timer.
2. Poll WUTWF until it is set in RTC_ISR to make sure the access to wakeup auto-reload counter and to WUCKSEL[2:0] bits is allowed. It takes around 2 RTCCLK clock cycles (due to clock synchronization).
3. Program the wakeup auto-reload value WUT[15:0], and the wakeup clock selection (WUCKSEL[2:0] bits in RTC_CR). Set WUTE in RTC_CR to enable the timer again. The wakeup timer restarts down-counting. The WUTWF bit is cleared up to 2 RTCCLK clock cycles after WUTE is cleared, due to clock synchronization.

51.4.9 Reading the calendar

When BYPSHAD control bit is cleared in the RTC_CR register

To read the RTC calendar registers (RTC_SSR, RTC_TR and RTC_DR) properly, the APB clock frequency (f_{PCLK}) must be equal to or greater than seven times the RTC clock frequency (f_{RTCCLK}). This ensures a secure behavior of the synchronization mechanism.

If the APB clock frequency is less than seven times the RTC clock frequency, the software must read the calendar time and date registers twice. If the second read of the RTC_TR gives the same result as the first read, this ensures that the data is correct. Otherwise a third

read access must be done. In any case the APB clock frequency must never be lower than the RTC clock frequency.

The RSF bit is set in RTC_ISR register each time the calendar registers are copied into the RTC_SSR, RTC_TR and RTC_DR shadow registers. The copy is performed every RTCCLK cycle. To ensure consistency between the 3 values, reading either RTC_SSR or RTC_TR locks the values in the higher-order calendar shadow registers until RTC_DR is read. In case the software makes read accesses to the calendar in a time interval smaller than 1 RTCCLK period: RSF must be cleared by software after the first calendar read, and then the software must wait until RSF is set before reading again the RTC_SSR, RTC_TR and RTC_DR registers.

After waking up from low-power mode (Stop or Standby), RSF must be cleared by software. The software must then wait until it is set again before reading the RTC_SSR, RTC_TR and RTC_DR registers.

The RSF bit must be cleared after wakeup and not before entering low-power mode.

After a system reset, the software must wait until RSF is set before reading the RTC_SSR, RTC_TR and RTC_DR registers. Indeed, a system reset resets the shadow registers to their default values.

After an initialization (refer to *Calendar initialization and configuration on page 1951*): the software must wait until RSF is set before reading the RTC_SSR, RTC_TR and RTC_DR registers.

After synchronization (refer to *Section 51.4.11: RTC synchronization*): the software must wait until RSF is set before reading the RTC_SSR, RTC_TR and RTC_DR registers.

When the BYPSHAD control bit is set in the RTC_CR register (bypass shadow registers)

Reading the calendar registers gives the values from the calendar counters directly, thus eliminating the need to wait for the RSF bit to be set. This is especially useful after exiting from low-power modes (STOP or Standby), since the shadow registers are not updated during these modes.

When the BYPSHAD bit is set to 1, the results of the different registers might not be coherent with each other if an RTCCLK edge occurs between two read accesses to the registers. Additionally, the value of one of the registers may be incorrect if an RTCCLK edge occurs during the read operation. The software must read all the registers twice, and then compare the results to confirm that the data is coherent and correct. Alternatively, the software can just compare the two results of the least-significant calendar register.

Note: While BYPSHAD=1, instructions which read the calendar registers require one extra APB cycle to complete.

51.4.10 Resetting the RTC

The calendar shadow registers (RTC_SSR, RTC_TR and RTC_DR) and some bits of the RTC status register (RTC_ISR) are reset to their default values by all available system reset sources.

On the contrary, the following registers are reset to their default values by a Backup domain reset and are not affected by a system reset: the RTC current calendar registers, the RTC control register (RTC_CR), the prescaler register (RTC_PRER), the RTC calibration register (RTC_CALR), the RTC shift register (RTC_SHIFTR), the RTC timestamp registers

(RTC_TSSSR, RTC_TSTR and RTC_TSDR), the RTC tamper and alternate function configuration register (RTC_TAFCR), the RTC backup registers (RTC_BKPxR), the wakeup timer register (RTC_WUTR), the Alarm A and Alarm B registers (RTC_ALRMASSR/RTC_ALRMAR and RTC_ALRMBSSR/RTC_ALRMBR), and the Option register (RTC_OR).

In addition, when it is clocked by the LSE, the RTC keeps on running under system reset if the reset source is different from the Backup domain reset one (refer to the RTC clock section of the Reset and clock controller for details on the list of RTC clock sources not affected by system reset). When a Backup domain reset occurs, the RTC is stopped and all the RTC registers are set to their reset values.

51.4.11 RTC synchronization

The RTC can be synchronized to a remote clock with a high degree of precision. After reading the sub-second field (RTC_SSR or RTC_TSSSR), a calculation can be made of the precise offset between the times being maintained by the remote clock and the RTC. The RTC can then be adjusted to eliminate this offset by “shifting” its clock by a fraction of a second using RTC_SHIFTR.

RTC_SSR contains the value of the synchronous prescaler counter. This allows one to calculate the exact time being maintained by the RTC down to a resolution of 1 / (PREDIV_S + 1) seconds. As a consequence, the resolution can be improved by increasing the synchronous prescaler value (PREDIV_S[14:0]. The maximum resolution allowed (30.52 µs with a 32768 Hz clock) is obtained with PREDIV_S set to 0x7FFF.

However, increasing PREDIV_S means that PREDIV_A must be decreased in order to maintain the synchronous prescaler output at 1 Hz. In this way, the frequency of the asynchronous prescaler output increases, which may increase the RTC dynamic consumption.

The RTC can be finely adjusted using the RTC shift control register (RTC_SHIFTR). Writing to RTC_SHIFTR can shift (either delay or advance) the clock by up to a second with a resolution of 1 / (PREDIV_S + 1) seconds. The shift operation consists of adding the SUBFS[14:0] value to the synchronous prescaler counter SS[15:0]: this will delay the clock. If at the same time the ADD1S bit is set, this results in adding one second and at the same time subtracting a fraction of second, so this will advance the clock.

Caution: Before initiating a shift operation, the user must check that SS[15] = 0 in order to ensure that no overflow will occur.

As soon as a shift operation is initiated by a write to the RTC_SHIFTR register, the SHPF flag is set by hardware to indicate that a shift operation is pending. This bit is cleared by hardware as soon as the shift operation has completed.

Caution: This synchronization feature is not compatible with the reference clock detection feature: firmware must not write to RTC_SHIFTR when REFCKON=1.

51.4.12 RTC reference clock detection

The update of the RTC calendar can be synchronized to a reference clock, RTC_REFIN, which is usually the mains frequency (50 or 60 Hz). The precision of the RTC_REFIN reference clock should be higher than the 32.768 kHz LSE clock. When the RTC_REFIN detection is enabled (REFCKON bit of RTC_CR set to 1), the calendar is still clocked by the LSE, and RTC_REFIN is used to compensate for the imprecision of the calendar update frequency (1 Hz).

Each 1 Hz clock edge is compared to the nearest RTC_REFIN clock edge (if one is found within a given time window). In most cases, the two clock edges are properly aligned. When the 1 Hz clock becomes misaligned due to the imprecision of the LSE clock, the RTC shifts the 1 Hz clock a bit so that future 1 Hz clock edges are aligned. Thanks to this mechanism, the calendar becomes as precise as the reference clock.

The RTC detects if the reference clock source is present by using the 256 Hz clock (ck_apre) generated from the 32.768 kHz quartz. The detection is performed during a time window around each of the calendar updates (every 1 s). The window equals 7 ck_apre periods when detecting the first reference clock edge. A smaller window of 3 ck_apre periods is used for subsequent calendar updates.

Each time the reference clock is detected in the window, the synchronous prescaler which outputs the ck_spre clock is forced to reload. This has no effect when the reference clock and the 1 Hz clock are aligned because the prescaler is being reloaded at the same moment. When the clocks are not aligned, the reload shifts future 1 Hz clock edges a little for them to be aligned with the reference clock.

If the reference clock halts (no reference clock edge occurred during the 3 ck_apre window), the calendar is updated continuously based solely on the LSE clock. The RTC then waits for the reference clock using a large 7 ck_apre period detection window centered on the ck_spre edge.

When the RTC_REFIN detection is enabled, PREDIV_A and PREDIV_S must be set to their default values:

- PREDIV_A = 0x007F
- PREVID_S = 0x00FF

Note: RTC_REFIN clock detection is not available in Standby mode.

51.4.13 RTC smooth digital calibration

The RTC frequency can be digitally calibrated with a resolution of about 0.954 ppm with a range from -487.1 ppm to +488.5 ppm. The correction of the frequency is performed using series of small adjustments (adding and/or subtracting individual RTCCLK pulses). These adjustments are fairly well distributed so that the RTC is well calibrated even when observed over short durations of time.

The smooth digital calibration is performed during a cycle of about 2^{20} RTCCLK pulses, or 32 seconds when the input frequency is 32768 Hz. This cycle is maintained by a 20-bit counter, cal_cnt[19:0], clocked by RTCCLK.

The smooth calibration register (RTC_CALR) specifies the number of RTCCLK clock cycles to be masked during the 32-second cycle:

- Setting the bit CALM[0] to 1 causes exactly one pulse to be masked during the 32-second cycle.
- Setting CALM[1] to 1 causes two additional cycles to be masked
- Setting CALM[2] to 1 causes four additional cycles to be masked
- and so on up to CALM[8] set to 1 which causes 256 clocks to be masked.

Note: CALM[8:0] (RTC_CALR) specifies the number of RTCCLK pulses to be masked during the 32-second cycle. Setting the bit CALM[0] to '1' causes exactly one pulse to be masked during the 32-second cycle at the moment when cal_cnt[19:0] is 0x80000; CALM[1]=1 causes two other cycles to be masked (when cal_cnt is 0x40000 and 0xC0000); CALM[2]=1

causes four other cycles to be masked (cal_cnt = 0x20000/0x60000/0xA0000/ 0xE0000); and so on up to CALM[8]=1 which causes 256 clocks to be masked (cal_cnt = 0xXX800).

While CALM allows the RTC frequency to be reduced by up to 487.1 ppm with fine resolution, the bit CALP can be used to increase the frequency by 488.5 ppm. Setting CALP to '1' effectively inserts an extra RTCCLK pulse every 2^{11} RTCCLK cycles, which means that 512 clocks are added during every 32-second cycle.

Using CALM together with CALP, an offset ranging from -511 to +512 RTCCLK cycles can be added during the 32-second cycle, which translates to a calibration range of -487.1 ppm to +488.5 ppm with a resolution of about 0.954 ppm.

The formula to calculate the effective calibrated frequency (F_{CAL}) given the input frequency (F_{RTCCLK}) is as follows:

$$F_{CAL} = F_{RTCCLK} \times [1 + (CALP \times 512 - CALM) / (2^{20} + CALM - CALP \times 512)]$$

Calibration when PREDIV_A<3

The CALP bit can not be set to 1 when the asynchronous prescaler value (PREDIV_A bits in RTC_PRER register) is less than 3. If CALP was already set to 1 and PREDIV_A bits are set to a value less than 3, CALP is ignored and the calibration operates as if CALP was equal to 0.

To perform a calibration with PREDIV_A less than 3, the synchronous prescaler value (PREDIV_S) should be reduced so that each second is accelerated by 8 RTCCLK clock cycles, which is equivalent to adding 256 clock cycles every 32 seconds. As a result, between 255 and 256 clock pulses (corresponding to a calibration range from 243.3 to 244.1 ppm) can effectively be added during each 32-second cycle using only the CALM bits.

With a nominal RTCCLK frequency of 32768 Hz, when PREDIV_A equals 1 (division factor of 2), PREDIV_S should be set to 16379 rather than 16383 (4 less). The only other interesting case is when PREDIV_A equals 0, PREDIV_S should be set to 32759 rather than 32767 (8 less).

If PREDIV_S is reduced in this way, the formula given the effective frequency of the

calibrated input clock is as follows:

$$F_{CAL} = F_{RTCCLK} \times [1 + (256 - CALM) / (2^{20} + CALM - 256)]$$

In this case, CALM[7:0] equals 0x100 (the midpoint of the CALM range) is the correct setting if RTCCLK is exactly 32768.00 Hz.

Verifying the RTC calibration

RTC precision is ensured by measuring the precise frequency of RTCCLK and calculating the correct CALM value and CALP values. An optional 1 Hz output is provided to allow applications to measure and verify the RTC precision.

Measuring the precise frequency of the RTC over a limited interval can result in a measurement error of up to 2 RTCCLK clock cycles over the measurement period, depending on how the digital calibration cycle is aligned with the measurement period.

However, this measurement error can be eliminated if the measurement period is the same length as the calibration cycle period. In this case, the only error observed is the error due to the resolution of the digital calibration.

- By default, the calibration cycle period is 32 seconds.

Using this mode and measuring the accuracy of the 1 Hz output over exactly 32 seconds guarantees that the measure is within 0.477 ppm (0.5 RTCCLK cycles over 32 seconds, due to the limitation of the calibration resolution).

- CALW16 bit of the RTC_CALR register can be set to 1 to force a 16- second calibration cycle period.

In this case, the RTC precision can be measured during 16 seconds with a maximum error of 0.954 ppm (0.5 RTCCLK cycles over 16 seconds). However, since the calibration resolution is reduced, the long term RTC precision is also reduced to 0.954 ppm: CALM[0] bit is stuck at 0 when CALW16 is set to 1.

- CALW8 bit of the RTC_CALR register can be set to 1 to force a 8- second calibration cycle period.

In this case, the RTC precision can be measured during 8 seconds with a maximum error of 1.907 ppm (0.5 RTCCLK cycles over 8s). The long term RTC precision is also reduced to 1.907 ppm: CALM[1:0] bits are stuck at 00 when CALW8 is set to 1.

Re-calibration on-the-fly

The calibration register (RTC_CALR) can be updated on-the-fly while RTC_ISR/INITF=0, by using the follow process:

1. Poll the RTC_ISR/RECALPF (re-calibration pending flag).
2. If it is set to 0, write a new value to RTC_CALR, if necessary. RECALPF is then automatically set to 1
3. Within three ck_apre cycles after the write operation to RTC_CALR, the new calibration settings take effect.

51.4.14 Time-stamp function

Time-stamp is enabled by setting the TSE or ITSE bits of RTC_CR register to 1.

When TSE is set:

The calendar is saved in the time-stamp registers (RTC_TSSSR, RTC_TSTR, RTC_TSDR) when a time-stamp event is detected on the RTC_TS pin.

When ITSE is set:

The calendar is saved in the time-stamp registers (RTC_TSSSR, RTC_TSTR, RTC_TSDR) when an internal time-stamp event is detected. The internal timestamp event is generated by the switch to the VBAT supply.

When a time-stamp event occurs, due to internal or external event, the time-stamp flag bit (TSF) in RTC_ISR register is set. In case the event is internal, the ITSF flag is also set in RTC_ISR register.

By setting the TSIE bit in the RTC_CR register, an interrupt is generated when a time-stamp event occurs.

If a new time-stamp event is detected while the time-stamp flag (TSF) is already set, the time-stamp overflow flag (TSOVF) flag is set and the time-stamp registers (RTC_TSTR and RTC_TSDR) maintain the results of the previous event.

Note: TSF is set 2 ck_apre cycles after the time-stamp event occurs due to synchronization process.

There is no delay in the setting of TSOVF. This means that if two time-stamp events are close together, TSOVF can be seen as '1' while TSF is still '0'. As a consequence, it is recommended to poll TSOVF only after TSF has been set.

Caution: If a time-stamp event occurs immediately after the TSF bit is supposed to be cleared, then both TSF and TSOVF bits are set.To avoid masking a time-stamp event occurring at the same moment, the application must not write ‘0’ into TSF bit unless it has already read it to ‘1’.

Optionally, a tamper event can cause a time-stamp to be recorded. See the description of the TAMPTS control bit in *Section 51.7.16: RTC tamper and alternate function configuration register (RTC_TAFCR)*.

51.4.15 Tamper detection

The RTC_TAMPx input events can be configured either for edge detection, or for level detection with filtering.

The tamper detection can be configured for the following purposes:

- erase the RTC backup registers and backup SRAM
- generate an interrupt, capable to wakeup from Stop and Standby modes

RTC backup registers

The backup registers (RTC_BKPxR) are not reset by system reset or when the device wakes up from Standby mode.

The backup registers are reset when a tamper detection event occurs (see *Section 51.7.20: RTC backup registers (RTC_BKPxR)* and *Tamper detection initialization on page 1958*).

Tamper detection initialization

Each input can be enabled by setting the corresponding TAMPxE bits to 1 in the RTC_TAMPCR register.

Each RTC_TAMPx tamper detection input is associated with a flag TAMPxF in the RTC_ISR register.

The TAMPxF flag is asserted after the tamper event on the pin, with the latency provided below:

- 3 ck_apre cycles when TAMPFLT differs from 0x0 (Level detection with filtering)
- 3 ck_apre cycles when TAMPTS=1 (Timestamp on tamper event)
- No latency when TAMPFLT=0x0 (Edge detection) and TAMPTS=0

A new tamper occurring on the same pin during this period and as long as TAMPxF is set cannot be detected.

By setting the TAMPIE bit in the RTC_TAMPCR register, an interrupt is generated when a tamper detection event occurs. .

Timestamp on tamper event

With TAMPTS set to ‘1’, any tamper event causes a timestamp to occur. In this case, either the TSF bit or the TSOVF bit are set in RTC_ISR, in the same manner as if a normal

timestamp event occurs. The affected tamper flag register TAMPxF is set at the same time that TSF or TSOVF is set.

Edge detection on tamper inputs

If the TAMPFLT bits are “00”, the RTC_TAMPx pins generate tamper detection events when either a rising edge or a falling edge is observed depending on the corresponding TAMPxTRG bit. The internal pull-up resistors on the RTC_TAMPx inputs are deactivated when edge detection is selected.

Caution: When using the edge detection, it is recommended to check by software the tamper pin level just after enabling the tamper detection (by reading the GPIO registers), and before writing sensitive values in the backup registers, to ensure that an active edge did not occur before enabling the tamper event detection.
When TAMPFLT="00" and TAMPxTRG = 0 (rising edge detection), a tamper event may be detected by hardware if the tamper input is already at high level before enabling the tamper detection.

After a tamper event has been detected and cleared, the RTC_TAMPx should be disabled and then re-enabled (TAMPxE set to 1) before re-programming the backup registers (RTC_BKPxR). This prevents the application from writing to the backup registers while the RTC_TAMPx input value still indicates a tamper detection. This is equivalent to a level detection on the RTC_TAMPx input.

Note: Tamper detection is still active when V_{DD} power is switched off. To avoid unwanted resetting of the backup registers, the pin to which the RTC_TAMPx is mapped should be externally tied to the correct level.

Level detection with filtering on RTC_TAMPx inputs

Level detection with filtering is performed by setting TAMPFLT to a non-zero value. A tamper detection event is generated when either 2, 4, or 8 (depending on TAMPFLT) consecutive samples are observed at the level designated by the TAMPxTRG bits.

The RTC_TAMPx inputs are precharged through the I/O internal pull-up resistance before its state is sampled, unless disabled by setting TAMPPUDIS to 1,The duration of the precharge is determined by the TAMPPRCH bits, allowing for larger capacitances on the RTC_TAMPx inputs.

The trade-off between tamper detection latency and power consumption through the pull-up can be optimized by using TAMPFREQ to determine the frequency of the sampling for level detection.

Note: Refer to the datasheets for the electrical characteristics of the pull-up resistors.

51.4.16 Calibration clock output

When the COE bit is set to 1 in the RTC_CR register, a reference clock is provided on the RTC_CALIB device output.

If the COSEL bit in the RTC_CR register is reset and PREDIV_A = 0x7F, the RTC_CALIB frequency is $f_{RTCCLK/64}$. This corresponds to a calibration output at 512 Hz for an RTCCLK frequency at 32.768 kHz. The RTC_CALIB duty cycle is irregular: there is a light jitter on falling edges. It is therefore recommended to use rising edges.

When COSEL is set and “PREDIV_S+1” is a non-zero multiple of 256 (i.e: PREDIV_S[7:0] = 0xFF), the RTC_CALIB frequency is fRTCCLK/(256 * (PREDIV_A+1)). This corresponds to a

calibration output at 1 Hz for prescaler default values (PREDIV_A = Ox7F, PREDIV_S = 0xFF), with an RTCCLK frequency at 32.768 kHz. The 1 Hz output is affected when a shift operation is on going and may toggle during the shift operation (SHPF=1).

Note: When COSEL bit is cleared, the RTC_CALIB output is the output of the 6th stage of the asynchronous prescaler.

When COSEL bit is set, the RTC_CALIB output is the output of the 8th stage of the synchronous prescaler.

51.4.17 Alarm output

The OSEL[1:0] control bits in the RTC_CR register are used to activate the alarm output RTC_ALARM, and to select the function which is output. These functions reflect the contents of the corresponding flags in the RTC_ISR register.

The polarity of the output is determined by the POL control bit in RTC_CR so that the opposite of the selected flag bit is output when POL is set to 1.

Alarm output

The RTC_ALARM pin can be configured in output open drain or output push-pull using the control bit RTC_ALARM_TYPE in the RTC_OR register.

Note: Once the RTC_ALARM output is enabled, it has priority over RTC_CALIB (COE bit is don't care and must be kept cleared).

51.5 RTC low-power modes

Table 397. Effect of low-power modes on RTC

Mode	Description
Stop	The RTC remains active when the RTC clock source is LSE or LSI. RTC alarm, RTC tamper event, RTC timestamp event, and RTC Wakeup cause the device to exit the Stop mode.
Standby	The RTC remains active when the RTC clock source is LSE or LSI. RTC alarm, RTC tamper event, RTC timestamp event, and RTC Wakeup cause the device to exit the Standby mode.

51.6 RTC interrupts

All RTC interrupts are connected to the EXTI controller. Refer to *Section 21: Extended interrupt and event controller (EXTI)*.

To enable the RTC Alarm interrupt, the following sequence is required:

1. Configure and enable the EXTI line corresponding to the RTC Alarm event in interrupt mode and select the rising edge sensitivity.
2. Configure and enable the RTC_ALARM IRQ channel in the NVIC.
3. Configure the RTC to generate RTC alarms.

To enable the RTC Tamper interrupt, the following sequence is required:

1. Configure and enable the EXTI line corresponding to the RTC Tamper event in interrupt mode and select the rising edge sensitivity.
2. Configure and Enable the RTC_TAMP_STAMP IRQ channel in the NVIC.
3. Configure the RTC to detect the RTC tamper event.

To enable the RTC TimeStamp interrupt, the following sequence is required:

1. Configure and enable the EXTI line corresponding to the RTC TimeStamp event in interrupt mode and select the rising edge sensitivity.
2. Configure and Enable the RTC_TAMP_STAMP IRQ channel in the NVIC.
3. Configure the RTC to detect the RTC time-stamp event.

To enable the Wakeup timer interrupt, the following sequence is required:

1. Configure and enable the EXTI line corresponding to the Wakeup timer even in interrupt mode and select the rising edge sensitivity.
2. Configure and Enable the RTC_WKUP IRQ channel in the NVIC.
3. Configure the RTC to detect the RTC Wakeup timer event.

Table 398. Interrupt control bits

Interrupt event	Event flag	Enable control bit	Exit from Sleep mode	Exit from Stop mode	Exit from Standby mode
Alarm A	ALRAF	ALRAIE	yes	yes(1)	yes(1)
Alarm B	ALRBF	ALRBIE	yes	yes(1)	yes(1)
RTC_TS input (timestamp)	TSF	TSIE	yes	yes(1)	yes(1)
RTC_TAMP1 input detection	TAMP1F	TAMPIE	yes	yes(1)	yes(1)
RTC_TAMP3 input detection	TAMP3F	TAMPIE	yes	yes(1)	yes(1)
Wakeup timer interrupt	WUTF	WUTIE	yes	yes(1)	yes(1)

1. Wakeup from STOP and Standby modes is possible only when the RTC clock source is LSE or LSI.

51.7 RTC registers

Refer to *Section 1.2 on page 104* of the reference manual for a list of abbreviations used in register descriptions.

The peripheral registers can be accessed by words (32-bit).

51.7.1 RTC time register (RTC_TR)

The RTC_TR is the calendar time shadow register. This register must be written in initialization mode only. Refer to *Calendar initialization and configuration on page 1951* and *Reading the calendar on page 1952*.

This register is write protected. The write access procedure is described in *RTC register write protection on page 1951*.

Address offset: 0x00

Backup domain reset value: 0x0000 0000

System reset: 0x0000 0000 when BYPSHAD = 0. Not affected when BYPSHAD = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PM	HT[1:0]		HU[3:0]			
									rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	MNT[2:0]			MNU[3:0]				Res.	ST[2:0]			SU[3:0]			
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **PM**: AM/PM notation
0: AM or 24-hour format
1: PM

Bits 21:20 **HT[1:0]**: Hour tens in BCD format

Bits 19:16 **HU[3:0]**: Hour units in BCD format

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **MNT[2:0]**: Minute tens in BCD format

Bits 11:8 **MNU[3:0]**: Minute units in BCD format

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **ST[2:0]**: Second tens in BCD format

Bits 3:0 **SU[3:0]**: Second units in BCD format

51.7.2 RTC date register (RTC_DR)

The RTC_DR is the calendar date shadow register. This register must be written in initialization mode only. Refer to *Calendar initialization and configuration on page 1951* and *Reading the calendar on page 1952*.

This register is write protected. The write access procedure is described in *RTC register write protection on page 1951*.

Address offset: 0x04

Backup domain reset value: 0x0000 2101

System reset: 0x0000 2101 when BYPSHAD = 0. Not affected when BYPSHAD = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	YT[3:0]				YU[3:0]			
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WDU[2:0]			MT	MU[3:0]				Res.	Res.	DT[1:0]		DU[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:20 **YT[3:0]**: Year tens in BCD format

Bits 19:16 **YU[3:0]**: Year units in BCD format

Bits 15:13 **WDU[2:0]**: Week day units
000: forbidden
001: Monday
...
111: Sunday

Bit 12 **MT**: Month tens in BCD format

Bits 11:8 **MU[3:0]**: Month units in BCD format

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **DT[1:0]**: Date tens in BCD format

Bits 3:0 **DU[3:0]**: Date units in BCD format

51.7.3 RTC control register (RTC_CR)

Address offset: 0x08

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	ITSE	COE	OSEL[1:0]		POL	COSEL	BKP	SUB1H	ADD1H
							rw	rw	rw	rw	rw	rw	rw	w	w

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSIE	WUTIE	ALRBIE	ALRAIE	TSE	WUTE	ALRBE	ALRAE	Res.	FMT	BYPS HAD	REFCKON	TSEDGE	WUCKSEL[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **ITSE**: timestamp on internal event enable
0: internal event timestamp disabled
1: internal event timestamp enabled

Bit 23 **COE**: Calibration output enable
This bit enables the RTC_CALIB output
0: Calibration output disabled
1: Calibration output enabled

Bits 22:21 **OSEL[1:0]**: Output selection
These bits are used to select the flag to be routed to RTC_ALARM output
00: Output disabled
01: Alarm A output enabled
10: Alarm B output enabled
11: Wakeup output enabled

Bit 20 **POL**: Output polarity
This bit is used to configure the polarity of RTC_ALARM output
0: The pin is high when ALRAF/ALRBF/WUTF is asserted (depending on OSEL[1:0])
1: The pin is low when ALRAF/ALRBF/WUTF is asserted (depending on OSEL[1:0]).

Bit 19 **COSEL**: Calibration output selection
When COE=1, this bit selects which signal is output on RTC_CALIB.
0: Calibration output is 512 Hz (with default prescaler setting)
1: Calibration output is 1 Hz (with default prescaler setting)
These frequencies are valid for RTCCLK at 32.768 kHz and prescalers at their default values (PREDIV_A=127 and PREDIV_S=255). Refer to *Section 51.4.16: Calibration clock output*

Bit 18 **BKP**: Backup
This bit can be written by the user to memorize whether the daylight saving time change has been performed or not.

Bit 17 **SUB1H**: *S*ubtract 1 hour (winter time change)

When this bit is set, 1 hour is subtracted to the calendar time if the current hour is not 0. This bit is always read as 0.

Setting this bit has no effect when current hour is 0.

0: No effect

1: Subtracts 1 hour to the current time. This can be used for winter time change outside initialization mode.

Bit 16 **ADD1H**: Add 1 hour (summer time change)

When this bit is set, 1 hour is added to the calendar time. This bit is always read as 0.

0: No effect

1: Adds 1 hour to the current time. This can be used for summer time change outside initialization mode.

Bit 15 **TSIE**: Time-stamp interrupt enable

0: Time-stamp Interrupt disable

1: Time-stamp Interrupt enable

Bit 14 **WUTIE**: Wakeup timer interrupt enable

0: Wakeup timer interrupt disabled

1: Wakeup timer interrupt enabled

Bit 13 **ALRBIE**: *Alarm B interrupt enable*

0: Alarm B Interrupt disable

1: Alarm B Interrupt enable

Bit 12 **ALRAIE**: Alarm A interrupt enable

0: Alarm A interrupt disabled

1: Alarm A interrupt enabled

Bit 11 **TSE**: timestamp enable

0: timestamp disable

1: timestamp enable

Bit 10 **WUTE**: Wakeup timer enable

0: Wakeup timer disabled

1: Wakeup timer enabled

Note: When the wakeup timer is disabled, wait for WUTWF=1 before enabling it again.

Bit 9 **ALRBE**: *Alarm B enable*

0: Alarm B disabled

1: Alarm B enabled

Bit 8 **ALRAE:** Alarm A enable

0: Alarm A disabled

1: Alarm A enabled

Bit 7 Reserved, must be kept at reset value.

Bit 6 **FMT**: Hour format

0: 24 hour/day format

1: AM/PM hour format

Bit 5 **BYPSHAD**: Bypass the shadow registers

0: Calendar values (when reading from RTC_SSR, RTC_TR, and RTC_DR) are taken from the shadow registers, which are updated once every two RTCCLK cycles.

1: Calendar values (when reading from RTC_SSR, RTC_TR, and RTC_DR) are taken directly from the calendar counters.

Note: If the frequency of the APB clock is less than seven times the frequency of RTCCLK, BYPSHAD must be set to '1'.

Bit 4 **REFCKON**: RTC_REFIN reference clock detection enable (50 or 60 Hz)

0: RTC_REFIN detection disabled

1: RTC_REFIN detection enabled

Note: PREDIV_S must be 0x00FF.

Bit 3 **TSEDGE**: Time-stamp event active edge

0: RTC_TS input rising edge generates a time-stamp event

1: RTC_TS input falling edge generates a time-stamp event

TSE must be reset when TSEDGE is changed to avoid unwanted TSF setting.

Bits 2:0 **WUCKSEL[2:0]**: Wakeup clock selection

000: RTC/16 clock is selected

001: RTC/8 clock is selected

010: RTC/4 clock is selected

011: RTC/2 clock is selected

10x: ck_spre (usually 1 Hz) clock is selected

11x: ck_spre (usually 1 Hz) clock is selected and 2^{16} is added to the WUT counter value (see note below)

Note: Bits 7, 6 and 4 of this register can be written in initialization mode only (RTC_ISR/INITF = 1).

WUT = Wakeup unit counter value. WUT = (0x0000 to 0xFFFF) + 0x10000 added when WUCKSEL[2:1 = 11].

Bits 2 to 0 of this register can be written only when RTC_CR WUTE bit = 0 and RTC_ISR WUTWF bit = 1.

It is recommended not to change the hour during the calendar hour increment as it could mask the incrementation of the calendar hour.

ADD1H and SUB1H changes are effective in the next second.

This register is write protected. The write access procedure is described in RTC register write protection on page 1951.

Caution: TSE must be reset when TSEDGE is changed to avoid spuriously setting of TSF.

51.7.4 RTC initialization and status register (RTC_ISR)

This register is write protected (except for RTC_ISR[13:8] bits). The write access procedure is described in *RTC register write protection on page 1951*.

Address offset: 0x0C

Backup domain reset value: 0x0000 0007

System reset: not affected except INIT, INITF, and RSF bits which are cleared to '0'

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ITSF	RECALPF
														rc_w0	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TAMP3F	Res.	TAMP1F	TSOVF	TSF	WUTF	ALRBF	ALRAF	INIT	INITF	RSF	INITS	SHPF	WUTWF	ALRBWF	ALRAWF
rc_w0		rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rc_w0	rw	r	rc_w0	r	r	r	r	r

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **ITSF**: Internal tTime-stamp flag

This flag is set by hardware when a time-stamp on the internal event occurs.

This flag is cleared by software by writing 0, and must be cleared together with TSF bit by writing 0 in both bits.

Bit 16 **RECALPF**: Recalibration pending Flag

The RECALPF status flag is automatically set to '1' when software writes to the RTC_CALR register, indicating that the RTC_CALR register is blocked. When the new calibration settings are taken into account, this bit returns to '0'. Refer to *Re-calibration on-the-fly*.

Bit 15 **TAMP3F**: RTC_TAMP3 detection flag

This flag is set by hardware when a tamper detection event is detected on the RTC_TAMP3 input.

It is cleared by software writing 0

Bit 14 Reserved, must be kept at reset value.

Bit 13 **TAMP1F**: RTC_TAMP1 detection flag

This flag is set by hardware when a tamper detection event is detected on the RTC_TAMP1 input.

It is cleared by software writing 0

Bit 12 **TSOVF**: Time-stamp overflow flag

This flag is set by hardware when a time-stamp event occurs while TSF is already set.

This flag is cleared by software by writing 0. It is recommended to check and then clear TSOVF only after clearing the TSF bit. Otherwise, an overflow might not be noticed if a time-stamp event occurs immediately before the TSF bit is cleared.

Bit 11 **TSF**: Time-stamp flag

This flag is set by hardware when a time-stamp event occurs.

This flag is cleared by software by writing 0. If ITSF flag is set, TSF must be cleared together with ITSF by writing 0 in both bits.

Bit 10 **WUTF**: Wakeup timer flag

This flag is set by hardware when the wakeup auto-reload counter reaches 0.

This flag is cleared by software by writing 0.

This flag must be cleared by software at least 1.5 RTCCLK periods before WUTF is set to 1 again.

Bit 9 **ALRBF**: Alarm B flag

This flag is set by hardware when the time/date registers (RTC_TR and RTC_DR) match the Alarm B register (RTC_ALRMBR).

This flag is cleared by software by writing 0.

Bit 8 **ALRAF**: Alarm A flag

This flag is set by hardware when the time/date registers (RTC_TR and RTC_DR) match the Alarm A register (RTC_ALRMAR).

This flag is cleared by software by writing 0.

Bit 7 **INIT**: Initialization mode

0: Free running mode

1: Initialization mode used to program time and date register (RTC_TR and RTC_DR), and prescaler register (RTC_PRER). Counters are stopped and start counting from the new value when INIT is reset.

Bit 6 **INITF**: Initialization flag

When this bit is set to 1, the RTC is in initialization state, and the time, date and prescaler registers can be updated.

0: Calendar registers update is not allowed

1: Calendar registers update is allowed

Bit 5 **RSF**: Registers synchronization flag

This bit is set by hardware each time the calendar registers are copied into the shadow registers (RTC_SSR, RTC_TR and RTC_DR). This bit is cleared by hardware in initialization mode, while a shift operation is pending (SHPF=1), or when in bypass shadow register mode (BYPSHAD=1). This bit can also be cleared by software.

It is cleared either by software or by hardware in initialization mode.

0: Calendar shadow registers not yet synchronized

1: Calendar shadow registers synchronized

Bit 4 **INITS**: Initialization status flag

This bit is set by hardware when the calendar year field is different from 0 (Backup domain reset state).

0: Calendar has not been initialized

1: Calendar has been initialized

Bit 3 **SHPF**: Shift operation pending

0: No shift operation is pending

1: A shift operation is pending

This flag is set by hardware as soon as a shift operation is initiated by a write to the RTC_SHIFTR register. It is cleared by hardware when the corresponding shift operation has been executed. Writing to the SHPF bit has no effect.

Bit 2 **WUTWF**: Wakeup timer write flag

This bit is set by hardware up to 2 RTCCLK cycles after the WUTE bit has been set to 0 in RTC_CR, and is cleared up to 2 RTCCLK cycles after the WUTE bit has been set to 1. The wakeup timer values can be changed when WUTE bit is cleared and WUTWF is set.

0: Wakeup timer configuration update not allowed

1: Wakeup timer configuration update allowed

Bit 1 **ALRBWF**: Alarm B write flag

This bit is set by hardware when Alarm B values can be changed, after the ALRBE bit has been set to 0 in RTC_CR.

It is cleared by hardware in initialization mode.

0: Alarm B update not allowed

1: Alarm B update allowed

Bit 0 **ALRAWF**: Alarm A write flag

This bit is set by hardware when Alarm A values can be changed, after the ALRAE bit has been set to 0 in RTC_CR.

It is cleared by hardware in initialization mode.

0: Alarm A update not allowed

1: Alarm A update allowed

Note: The bits ALRAF, ALRBF, WUTF and TSF are cleared 2 APB clock cycles after programming them to 0.

51.7.5 RTC prescaler register (RTC_PRER)

This register must be written in initialization mode only. The initialization must be performed in two separate write accesses. Refer to *Calendar initialization and configuration on page 1951*.

This register is write protected. The write access procedure is described in *RTC register write protection on page 1951*.

Address offset: 0x10

Backup domain reset value: 0x007F 00FF

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREDIV_A[6:0]						
									rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	PREDIV_S[14:0]														
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:16 **PREDIV_A[6:0]**: Asynchronous prescaler factor
This is the asynchronous division factor:
ck_apre frequency = RTCCLK frequency/(PREDIV_A+1)

Bit 15 Reserved, must be kept at reset value.

Bits 14:0 **PREDIV_S[14:0]**: Synchronous prescaler factor
This is the synchronous division factor:
ck_spre frequency = ck_apre frequency/(PREDIV_S+1)

51.7.6 RTC wakeup timer register (RTC_WUTR)

This register can be written only when WUTWF is set to 1 in RTC_ISR.

This register is write protected. The write access procedure is described in *RTC register write protection on page 1951*.

Address offset: 0x14

Backup domain reset value: 0x0000 FFFF

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WUT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **WUT[15:0]**: Wakeup auto-reload value bits

When the wakeup timer is enabled (WUTE set to 1), the WUTF flag is set every (WUT[15:0] + 1) ck_wut cycles. The ck_wut period is selected through WUCKSEL[2:0] bits of the RTC_CR register

When WUCKSEL[2] = 1, the wakeup timer becomes 17-bits and WUCKSEL[1] effectively becomes WUT[16] the most-significant bit to be reloaded into the timer.

The first assertion of WUTF occurs (WUT+1) ck_wut cycles after WUTE is set. Setting WUT[15:0] to 0x0000 with WUCKSEL[2:0] =011 (RTCCLK/2) is forbidden.

51.7.7 RTC alarm A register (RTC_ALRMAR)

This register can be written only when ALRAWF is set to 1 in RTC_ISR, or in initialization mode.

This register is write protected. The write access procedure is described in *RTC register write protection on page 1951*.

Address offset: 0x1C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MSK4	WDSEL	DT[1:0]		DU[3:0]				MSK3	PM	HT[1:0]		HU[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MSK2	MNT[2:0]			MNU[3:0]				MSK1	ST[2:0]			SU[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **MSK4**: Alarm A date mask
0: Alarm A set if the date/day match
1: Date/day don't care in Alarm A comparison

Bit 30 **WDSEL**: Week day selection
0: DU[3:0] represents the date units
1: DU[3:0] represents the week day. DT[1:0] is don't care.

Bits 29:28 **DT[1:0]**: Date tens in BCD format.

Bits 27:24 **DU[3:0]**: Date units or day in BCD format.

Bit 23 **MSK3**: Alarm A hours mask
0: Alarm A set if the hours match
1: Hours don't care in Alarm A comparison

Bit 22 **PM:** AM/PM notation
0: AM or 24-hour format
1: PM

Bits 21:20 **HT[1:0]**: Hour tens in BCD format.

Bits 19:16 **HU[3:0]**: Hour units in BCD format.

Bit 15 **MSK2**: Alarm A minutes mask
0: Alarm A set if the minutes match
1: Minutes don't care in Alarm A comparison

Bits 14:12 **MNT[2:0]**: Minute tens in BCD format.

Bits 11:8 **MNU[3:0]**: Minute units in BCD format.

Bit 7 **MSK1**: Alarm A seconds mask
0: Alarm A set if the seconds match
1: Seconds don't care in Alarm A comparison

Bits 6:4 **ST[2:0]**: Second tens in BCD format.

Bits 3:0 **SU[3:0]**: Second units in BCD format.

51.7.8 RTC alarm B register (RTC_ALRMBR)

This register can be written only when ALRBWF is set to 1 in RTC_ISR, or in initialization mode.

This register is write protected. The write access procedure is described in *RTC register write protection on page 1951*.

Address offset: 0x20

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MSK4	WDSEL	DT[1:0]		DU[3:0]				MSK3	PM	HT[1:0]		HU[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MSK2	MNT[2:0]			MNU[3:0]				MSK1	ST[2:0]			SU[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **MSK4**: Alarm B date mask
0: Alarm B set if the date and day match
1: Date and day don’t care in Alarm B comparison

Bit 30 **WDSEL**: Week day selection
0: DU[3:0] represents the date units
1: DU[3:0] represents the week day. DT[1:0] is don’t care.

Bits 29:28 **DT[1:0]**: Date tens in BCD format

Bits 27:24 **DU[3:0]**: Date units or day in BCD format

Bit 23 **MSK3**: Alarm B hours mask
0: Alarm B set if the hours match
1: Hours don’t care in Alarm B comparison

Bit 22 **PM:** AM/PM notation
0: AM or 24-hour format
1: PM

Bits 21:20 **HT[1:0]**: Hour tens in BCD format

Bits 19:16 **HU[3:0]**: Hour units in BCD format

Bit 15 **MSK2**: Alarm B minutes mask
0: Alarm B set if the minutes match
1: Minutes don’t care in Alarm B comparison

Bits 14:12 **MNT[2:0]**: Minute tens in BCD format

Bits 11:8 **MNU[3:0]**: Minute units in BCD format

Bit 7 **MSK1**: Alarm B seconds mask
0: Alarm B set if the seconds match
1: Seconds don’t care in Alarm B comparison

Bits 6:4 **ST[2:0]**: Second tens in BCD format

Bits 3:0 **SU[3:0]**: Second units in BCD format

51.7.9 RTC write protection register (RTC_WPR)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEY[7:0]							
								w	w	w	w	w	w	w	w

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **KEY[7:0]**: Write protection key

This byte is written by software.

Reading this byte always returns 0x00.

Refer to *RTC register write protection* for a description of how to unlock RTC register write protection.

51.7.10 RTC sub second register (RTC_SSR)

Address offset: 0x28

Backup domain reset value: 0x0000 0000

System reset: 0x0000 0000 when BYPSHAD = 0. Not affected when BYPSHAD = 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **SS[15:0]**: Sub second value

SS[15:0] is the value in the synchronous prescaler counter. The fraction of a second is given by the formula below:

Second fraction = (PREDIV_S - SS) / (PREDIV_S + 1)

Note: SS can be larger than PREDIV_S only after a shift operation. In that case, the correct time/date is one second less than as indicated by RTC_TR/RTC_DR.

51.7.11 RTC shift control register (RTC_SHIFTR)

This register is write protected. The write access procedure is described in *RTC register write protection on page 1951.*

Address offset: 0x2C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADD1S	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
w															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	SUBFS[14:0]														
	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bit 31 **ADD1S**: Add one second

0: No effect

1: Add one second to the clock/calendar

This bit is write only and is always read as zero. Writing to this bit has no effect when a shift operation is pending (when SHPF=1, in RTC_ISR).

This function is intended to be used with SUBFS (see description below) in order to effectively add a fraction of a second to the clock in an atomic operation.

Bits 30:15 Reserved, must be kept at reset value.

Bits 14:0 **SUBFS[14:0]**: Subtract a fraction of a second

These bits are write only and is always read as zero. Writing to this bit has no effect when a shift operation is pending (when SHPF=1, in RTC_ISR).

The value which is written to SUBFS is added to the synchronous prescaler counter. Since this counter counts down, this operation effectively subtracts from (delays) the clock by:

Delay (seconds) = SUBFS / (PREDIV_S + 1)

A fraction of a second can effectively be added to the clock (advancing the clock) when the ADD1S function is used in conjunction with SUBFS, effectively advancing the clock by:

Advance (seconds) = (1 - (SUBFS / (PREDIV_S + 1))).

Note: Writing to SUBFS causes RSF to be cleared. Software can then wait until RSF=1 to be sure that the shadow registers have been updated with the shifted time.

51.7.12 RTC timestamp time register (RTC_TSTR)

The content of this register is valid only when TSF is set to 1 in RTC_ISR. It is cleared when TSF bit is reset.

Address offset: 0x30

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PM	HT[1:0]		HU[3:0]			
									r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	MNT[2:0]			MNU[3:0]				Res.	ST[2:0]			SU[3:0]			
	r	r	r	r	r	r	r		r	r	r	r	r	r	r

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **PM:** AM/PM notation
0: AM or 24-hour format
1: PM

Bits 21:20 **HT[1:0]**: Hour tens in BCD format.

Bits 19:16 **HU[3:0]**: Hour units in BCD format.

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **MNT[2:0]**: Minute tens in BCD format.

Bits 11:8 **MNU[3:0]**: Minute units in BCD format.

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **ST[2:0]**: Second tens in BCD format.

Bits 3:0 **SU[3:0]**: Second units in BCD format.

51.7.13 RTC timestamp date register (RTC_TSDR)

The content of this register is valid only when TSF is set to 1 in RTC_ISR. It is cleared when TSF bit is reset.

Address offset: 0x34

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WDU[2:0]			MT	MU[3:0]				Res.	Res.	DT[1:0]		DU[3:0]			
r	r	r	r	r	r	r	r			r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:13 **WDU[2:0]**: Week day units

Bit 12 **MT**: Month tens in BCD format

Bits 11:8 **MU[3:0]**: Month units in BCD format

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **DT[1:0]**: Date tens in BCD format

Bits 3:0 **DU[3:0]**: Date units in BCD format

51.7.14 RTC time-stamp sub second register (RTC_TSSSR)

The content of this register is valid only when RTC_ISR/TSF is set. It is cleared when the RTC_ISR/TSF bit is reset.

Address offset: 0x38

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **SS[15:0]**: Sub second value

SS[15:0] is the value of the synchronous prescaler counter when the timestamp event occurred.

51.7.15 RTC calibration register (RTC_CALR)

This register is write protected. The write access procedure is described in *RTC register write protection on page 1951*.

Address offset: 0x3C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CALP	CALW8	CALW16	Res.	Res.	Res.	Res.	CALM[8:0]								
rw	rw	rw					rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **CALP**: Increase frequency of RTC by 488.5 ppm

0: No RTCCLK pulses are added.

1: One RTCCLK pulse is effectively inserted every 2^{11} pulses (frequency increased by 488.5 ppm).

This feature is intended to be used in conjunction with CALM, which lowers the frequency of the calendar with a fine resolution. if the input frequency is 32768 Hz, the number of RTCCLK pulses added during a 32-second window is calculated as follows: (512 * CALP) - CALM.

Refer to *Section 51.4.13: RTC smooth digital calibration*.

Bit 14 **CALW8:** Use an 8-second calibration cycle period

When CALW8 is set to ‘1’, the 8-second calibration cycle period is selected.

Note: CALM[1:0] are stuck at “00” when CALW8=’1’. Refer to Section 51.4.13: RTC smooth digital calibration.

Bit 13 **CALW16:** Use a 16-second calibration cycle period

When CALW16 is set to ‘1’, the 16-second calibration cycle period is selected.This bit must not be set to ‘1’ if CALW8=1.

Note: CALM[0] is stuck at ‘0’ when CALW16=’1’. Refer to Section 51.4.13: RTC smooth digital calibration.

Bits 12:9 Reserved, must be kept at reset value.

Bits 8:0 **CALM[8:0]**: Calibration minus

The frequency of the calendar is reduced by masking CALM out of 2^{20} RTCCLK pulses (32 seconds if the input frequency is 32768 Hz). This decreases the frequency of the calendar with a resolution of 0.9537 ppm.

To increase the frequency of the calendar, this feature should be used in conjunction with CALP. See *Section 51.4.13: RTC smooth digital calibration on page 1955*.

51.7.16 RTC tamper and alternate function configuration register (RTC_TAFCR)

Address offset: 0x40

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PC15 MODE	PC15 VALUE	PC14 MODE	PC14 VALUE	PC13 MODE	PC13 VALUE	Res.	Res.
								rw	rw	rw	rw	rw	rw		

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TAMPP UDIS	TAMPPRCH [1:0]		TAMPFLT[1:0]		TAMPFREQ[2:0]			TAMPT S	TAMP3 TRG	TAMP3 E	Res.	Res.	TAMPIE	TAMP1 TRG	TAMP1 E
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **PC15MODE**: PC15 mode

0: PC15 is controlled by the GPIO configuration registers. Consequently PC15 is floating in Standby mode.

1: PC15 is forced to push-pull output if LSE is disabled.

Bit 22 **PC15VALUE**: PC15 value

If the LSE is disabled and PC15MODE = 1, PC15VALUE configures the PC15 output data.

Bit 21 **PC14MODE**: PC14 mode

0: PC14 is controlled by the GPIO configuration registers. Consequently PC14 is floating in Standby mode.

1: PC14 is forced to push-pull output if LSE is disabled.

Bit 20 **PC14VALUE**: PC14 value

If the LSE is disabled and PC14MODE = 1, PC14VALUE configures the PC14 output data.

Bit 19 **PC13MODE**: PC13 mode

0: PC13 is controlled by the GPIO configuration registers. Consequently PC13 is floating in Standby mode.

1: PC13 is forced to push-pull output if all RTC functions are disabled.

Bit 18 **PC13VALUE**: RTC_ALARM output type/PC13 value

If PC13 is used to output RTC_ALARM, PC13VALUE configures the output configuration:

0: RTC_ALARM is an open-drain output

1: RTC_ALARM is a push-pull output

If all RTC functions are disabled and PC13MODE = 1, PC13VALUE configures the PC13 output data.

Bits 17:16 Reserved, must be kept at reset value.

Bit 15 **TAMPPUDIS**: RTC_TAMPx pull-up disable

This bit determines if each of the RTC_TAMPx pins are pre-charged before each sample.

0: Precharge RTC_TAMPx pins before sampling (enable internal pull-up)

1: Disable precharge of RTC_TAMPx pins.

Bits 14:13 **TAMPPRCH[1:0]**: RTC_TAMPx precharge duration

These bit determines the duration of time during which the pull-up/is activated before each sample. TAMPPRCH is valid for each of the RTC_TAMPx inputs.

0x0: 1 RTCCLK cycle
0x1: 2 RTCCLK cycles
0x2: 4 RTCCLK cycles
0x3: 8 RTCCLK cycles

Bits 12:11 **TAMPFLT[1:0]**: RTC_TAMPx filter count

These bits determines the number of consecutive samples at the specified level (TAMP*TRG) needed to activate a Tamper event. TAMPFLT is valid for each of the RTC_TAMPx inputs.

0x0: Tamper event is activated on edge of RTC_TAMPx input transitions to the active level (no internal pull-up on RTC_TAMPx input).
0x1: Tamper event is activated after 2 consecutive samples at the active level.
0x2: Tamper event is activated after 4 consecutive samples at the active level.
0x3: Tamper event is activated after 8 consecutive samples at the active level.

Bits 10:8 **TAMPFREQ[2:0]**: Tamper sampling frequency

Determines the frequency at which each of the RTC_TAMPx inputs are sampled.

0x0: RTCCLK / 32768 (1 Hz when RTCCLK = 32768 Hz)
0x1: RTCCLK / 16384 (2 Hz when RTCCLK = 32768 Hz)
0x2: RTCCLK / 8192 (4 Hz when RTCCLK = 32768 Hz)
0x3: RTCCLK / 4096 (8 Hz when RTCCLK = 32768 Hz)
0x4: RTCCLK / 2048 (16 Hz when RTCCLK = 32768 Hz)
0x5: RTCCLK / 1024 (32 Hz when RTCCLK = 32768 Hz)
0x6: RTCCLK / 512 (64 Hz when RTCCLK = 32768 Hz)
0x7: RTCCLK / 256 (128 Hz when RTCCLK = 32768 Hz)

Bit 7 **TAMPTS**: Activate timestamp on tamper detection event

0: Tamper detection event does not cause a timestamp to be saved
1: Save timestamp on tamper detection event

TAMPTS is valid even if TSE=0 in the RTC_CR register.

Bit 6 **TAMP3TRG**: Active level for RTC_TAMP3 input

if TAMPFLT != 00:
0: RTC_TAMP3 input staying low triggers a tamper detection event.
1: RTC_TAMP3 input staying high triggers a tamper detection event.
if TAMPFLT = 00:
0: RTC_TAMP3 input rising edge triggers a tamper detection event.
1: RTC_TAMP3input falling edge triggers a tamper detection event.

Bit 5 **TAMP3E**: RTC_TAMP3 detection enable

0: RTC_TAMP3 input detection disabled
1: RTC_TAMP3 input detection enabled

Bits 4:3 Reserved, must be kept at reset value.

Bit 2 **TAMPIE**: Tamper interrupt enable
0: Tamper interrupt disabled
1: Tamper interrupt enabled.

Bit 1 **TAMP1TRG**: Active level for RTC_TAMP1 input
If TAMPFLT != 00
0: RTC_TAMP1 input staying low triggers a tamper detection event.
1: RTC_TAMP1 input staying high triggers a tamper detection event.
if TAMPFLT = 00:
0: RTC_TAMP1 input rising edge triggers a tamper detection event.
1: RTC_TAMP1 input falling edge triggers a tamper detection event.

Bit 0 **TAMP1E**: RTC_TAMP1 input detection enable
0: RTC_TAMP1 detection disabled
1: RTC_TAMP1 detection enabled

Caution: When TAMPFLT = 0, TAMPxE must be reset when TAMPxTRG is changed to avoid spuriously setting TAMPxF.

51.7.17 RTC alarm A sub second register (RTC_ALRMASSR)

This register can be written only when ALRAE is reset in RTC_CR register, or in initialization mode.

This register is write protected. The write access procedure is described in *RTC register write protection on page 1951*

Address offset: 0x44

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	MASKSS[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
				rw	rw	rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	SS[14:0]														
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 MASKSS[3:0]: Mask the most-significant bits starting at this bit

0: No comparison on sub seconds for Alarm A. The alarm is set when the seconds unit is incremented (assuming that the rest of the fields match).
1: SS[14:1] are don't care in Alarm A comparison. Only SS[0] is compared.
2: SS[14:2] are don't care in Alarm A comparison. Only SS[1:0] are compared.
3: SS[14:3] are don't care in Alarm A comparison. Only SS[2:0] are compared.
...
12: SS[14:12] are don't care in Alarm A comparison. SS[11:0] are compared.
13: SS[14:13] are don't care in Alarm A comparison. SS[12:0] are compared.
14: SS[14] is don't care in Alarm A comparison. SS[13:0] are compared.
15: All 15 SS bits are compared and must match to activate alarm.
The overflow bits of the synchronous counter (bits 15) is never compared. This bit can be different from 0 only after a shift operation.

Bits 23:15 Reserved, must be kept at reset value.

Bits 14:0 SS[14:0]: Sub seconds value

This value is compared with the contents of the synchronous prescaler counter to determine if Alarm A is to be activated. Only bits 0 up MASKSS-1 are compared.

51.7.18 RTC alarm B sub second register (RTC_ALRMBSSR)

This register can be written only when ALRBE is reset in RTC_CR register, or in initialization mode.

This register is write protected.The write access procedure is described in *Section : RTC register write protection*.

Address offset: 0x48

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	MASKSS[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
				rw	rw	rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	SS[14:0]														
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:24 **MASKSS[3:0]**: Mask the most-significant bits starting at this bit

0x0: No comparison on sub seconds for Alarm B. The alarm is set when the seconds unit is incremented (assuming that the rest of the fields match).
0x1: SS[14:1] are don't care in Alarm B comparison. Only SS[0] is compared.
0x2: SS[14:2] are don't care in Alarm B comparison. Only SS[1:0] are compared.
0x3: SS[14:3] are don't care in Alarm B comparison. Only SS[2:0] are compared.
...
0xC: SS[14:12] are don't care in Alarm B comparison. SS[11:0] are compared.
0xD: SS[14:13] are don't care in Alarm B comparison. SS[12:0] are compared.
0xE: SS[14] is don't care in Alarm B comparison. SS[13:0] are compared.
0xF: All 15 SS bits are compared and must match to activate alarm.
The overflow bits of the synchronous counter (bits 15) is never compared. This bit can be different from 0 only after a shift operation.

Bits 23:15 Reserved, must be kept at reset value.

Bits 14:0 **SS[14:0]**: Sub seconds value

This value is compared with the contents of the synchronous prescaler counter to determine if Alarm B is to be activated. Only bits 0 up to MASKSS-1 are compared.

51.7.19 RTC option register (RTC_OR)

Address offset: 0x4C

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RTC_ OUT_ RMP	RTC_ ALARM _TYPE
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **RTC_OUT_RMP**: RTC_OUT remap

Setting this bit allows to remap the RTC outputs on PB2 as follows:
RTC_OUT_RMP = '0':
If OSEL/= '00': RTC_ALARM is output on PC13
If OSEL= '00' and COE = '1': RTC_CALIB is output on PC13
RTC_OUT_RMP = '1':
If OSEL /= '00' and COE = '0': RTC_ALARM is output on PB2
If OSEL = '00' and COE = '1': RTC_CALIB is output on PB2
If OSEL /= '00' and COE = '1': RTC_CALIB is output on PB2 and RTC_ALARM is output on PC13.

Bit 0 **RTC_ALARM_TYPE**: RTC_ALARM output type on PC13

This bit is set and cleared by software
0: RTC_ALARM, when mapped on PC13, is open-drain output
1: RTC_ALARM, when mapped on PC13, is push-pull output

51.7.20 RTC backup registers (RTC_BKPxR)

Address offset: 0x50 to 0xCC

Backup domain reset value: 0x0000 0000

System reset: not affected

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BKP[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BKP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	rw	rw

Bits 31:0 BKP[31:0]

The application can write or read data to and from these registers.
They are powered-on by V_{BAT} when V_{DD} is switched off, so that they are not reset by System reset, and their contents remain valid when the device operates in low-power mode.
This register is reset on a tamper detection event, as long as TAMPxF=1.

51.7.21 RTC register map

Table 399. RTC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**RTC_TR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PM	HT[1:0]		HU[3:0]				Res.	MNT[2:0]			MNU[3:0]				Res.	ST[2:0]			SU[3:0]			
	Reset value										0	0	0	0	0	0	0		0	0	0	0	0	0	0		0	0	0	0	0	0	0
0x04	**RTC_DR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	YT[3:0]				YU[3:0]				WDU[2:0]			MT	MU[3:0]				Res.	Res.	DT[1:0]		DU[3:0]			
	Reset value									0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1			0	0	0	0	0	1
0x08	**RTC_CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ITSE	COE	OSEL[1:0]		POL	COSEL	BKP	SUB1H	ADD1H	TSIE	WUTIE	ALRBIE	ALRAIE	TSE	WUTE	ALRBE	ALRAE	Res.	FMT	BYPSHAD	REFCKON	TSEDGE	WUCKSEL[2:0		
	Reset value								0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
0x0C	**RTC_ISR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ITSF	RECALPF	TAMP3F	Res.	TAMP1F	TSOVF	TSF	WUTF	ALRBF	ALRAF	INIT	INITF	RSF	INITS	SHPF	WUT WF	ALRBWF	ALRAWF
	Reset value															0	0	0		0	0	0	0	0	0	0	0	0	0	0	1	1	1
0x10	**RTC_PRER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREDIV_A[6:0]							PREDIV_S[14:0]															
	Reset value										1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
0x14	**RTC_WUTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WUT[15:0]															
	Reset value																	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x1C	**RTC_ALRMAR**	MSK4	WDSEL	DT[1:0]		DU[3:0]				MSK3	PM	HT[1:0]		HU[3:0]				MSK2	MNT[2:0]			MNU[3:0]				MSK1	ST[2:0]			SU[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	**RTC_ALRMBR**	MSK4	WDSEL	DT[1:0]		DU[3:0]				MSK3	PM	HT[1:0]		HU[3:0]				MSK2	MNT[2:0]			MNU[3:0]				MSK2	ST[2:0]			SU[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x24	**RTC_WPR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	KEY							
	Reset value																									0	0	0	0	0	0	0	0
0x28	**RTC_SSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SS[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x2C	**RTC_SHIFTR**	ADD1S	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBFS[14:0]														
	Reset value	0																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x30	**RTC_TSTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PM	HT[1:0]		HU[3:0]				Res.	MNT[2:0]			MNU[3:0]				Res.	ST[2:0]			SU[3:0]			
	Reset value										0	0	0	0	0	0	0		0	0	0	0	0	0	0		0	0	0	0	0	0	0

Table 399. RTC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x34	**RTC_TSDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDU[1:0]			MT	MU[3:0]				Res.	Res.	DT[1:0]		DU[3:0]			
	Reset value																	0	0	0	0	0	0	0	0			0	0	0	0	0	0
0x38	**RTC_TSSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SS[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x3C	**RTC_ CALR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CALP	CALW8	CALW16	Res.	Res.	Res.	Res.	CALM[8:0]								
	Reset value																	0	0	0					0	0	0	0	0	0	0	0	0
0x40	**RTC_TAFCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PC15MODE	PC15MODE	PC14VALUE	PC14MODE	PC13VALUE	PC13VALUE	Res.	Res.	TAMPPUDIS	TAMPPRCH[1:0]		TAMPFLT[1:0]			TAMPFREQ[2:0]		TAMPTS	TAMP3TRG	TAMP3E	Res.	Res.	TAMPIE	TAMP1TRG	TAMP1E
	Reset value									0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0			0	0	0
0x44	**RTC_ ALRMASSR**	Res.	Res.	Res.	Res.	MASKSS [3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SS[14:0]														
	Reset value					0	0	0	0										0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x48	**RTC_ ALRMBSSR**	Res.	Res.	Res.	Res.	MASKSS [3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SS[14:0]														
	Reset value					0	0	0	0										0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x4C	**RTC_ OR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RTC_OUT_RMP	RTC_ALARM_TYPE
	Reset value																															0	0
0x50 to 0xCC	**RTC_BKP0R**	BKP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	to **RTC_BKP31R**	BKP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

52 Inter-integrated circuit (I2C) interface

52.1 Introduction

The I^2C (inter-integrated circuit) bus interface handles communications between the microcontroller and the serial I^2C bus. It provides multimaster capability, and controls all I^2C bus-specific sequencing, protocol, arbitration and timing. It supports Standard-mode (Sm), Fast-mode (Fm) and Fast-mode Plus (Fm+).

It is also SMBus (system management bus) and PMBus (power management bus) compatible.

DMA can be used to reduce CPU overload.

52.2 I2C main features

- I^2C bus specification rev03 compatibility:
  - Slave and master modes
  - Multimaster capability
  - Standard-mode (up to 100 kHz)
  - Fast-mode (up to 400 kHz)
  - Fast-mode Plus (up to 1 MHz)
  - 7-bit and 10-bit addressing mode
  - Multiple 7-bit slave addresses (2 addresses, 1 with configurable mask)
  - All 7-bit addresses acknowledge mode
  - General call
  - Programmable setup and hold times
  - Easy to use event management
  - Optional clock stretching
  - Software reset
- 1-byte buffer with DMA capability
- Programmable analog and digital noise filters

The following additional features are also available depending on the product implementation (see *Section 52.3: I2C implementation*):

- SMBus specification rev 3.0 compatibility:
  - Hardware PEC (packet error checking) generation and verification with ACK control
  - Command and data acknowledge control
  - Address resolution protocol (ARP) support
  - Host and Device support
  - SMBus alert
  - Timeouts and idle condition detection
- PMBus rev 1.3 standard compatibility
- Independent clock: a choice of independent clock sources allowing the I2C communication speed to be independent from the i2c_pclk reprogramming
- Wakeup from Stop mode on address match.

52.3 I2C implementation

This manual describes the full set of features implemented in I2C peripheral. In the STM32H7xxx devices I2C1, I2C2, I2C3 and I2C4 implement the full set of features as shown in the following table.

Table 400. STM32H72x and STM32H73x I2C implementation

I2C features(1)	I2C1	I2C2	I2C3	I2C4	I2C5
7-bit addressing mode	X	X	X	X	X
10-bit addressing mode	X	X	X	X	X
Standard-mode (up to 100 kbit/s)	X	X	X	X	X
Fast-mode (up to 400 kbit/s)	X	X	X	X	X
Fast-mode Plus with 20mA output drive I/Os (up to 1 Mbit/s)	X	X	X	X	X
Independent clock	X	X	X	X	X
Wakeup from Stop mode	X	X	X	X	X
SMBus/PMBus	X	X	X	X	X

1. X = supported.

52.4 I2C functional description

In addition to receiving and transmitting data, this interface converts it from serial to parallel format and vice versa. The interrupts are enabled or disabled by software. The interface is connected to the I^2C bus by a data pin (SDA) and by a clock pin (SCL). It can be connected with a standard (up to 100 kHz), Fast-mode (up to 400 kHz) or Fast-mode Plus (up to 1 MHz) I^2C bus.

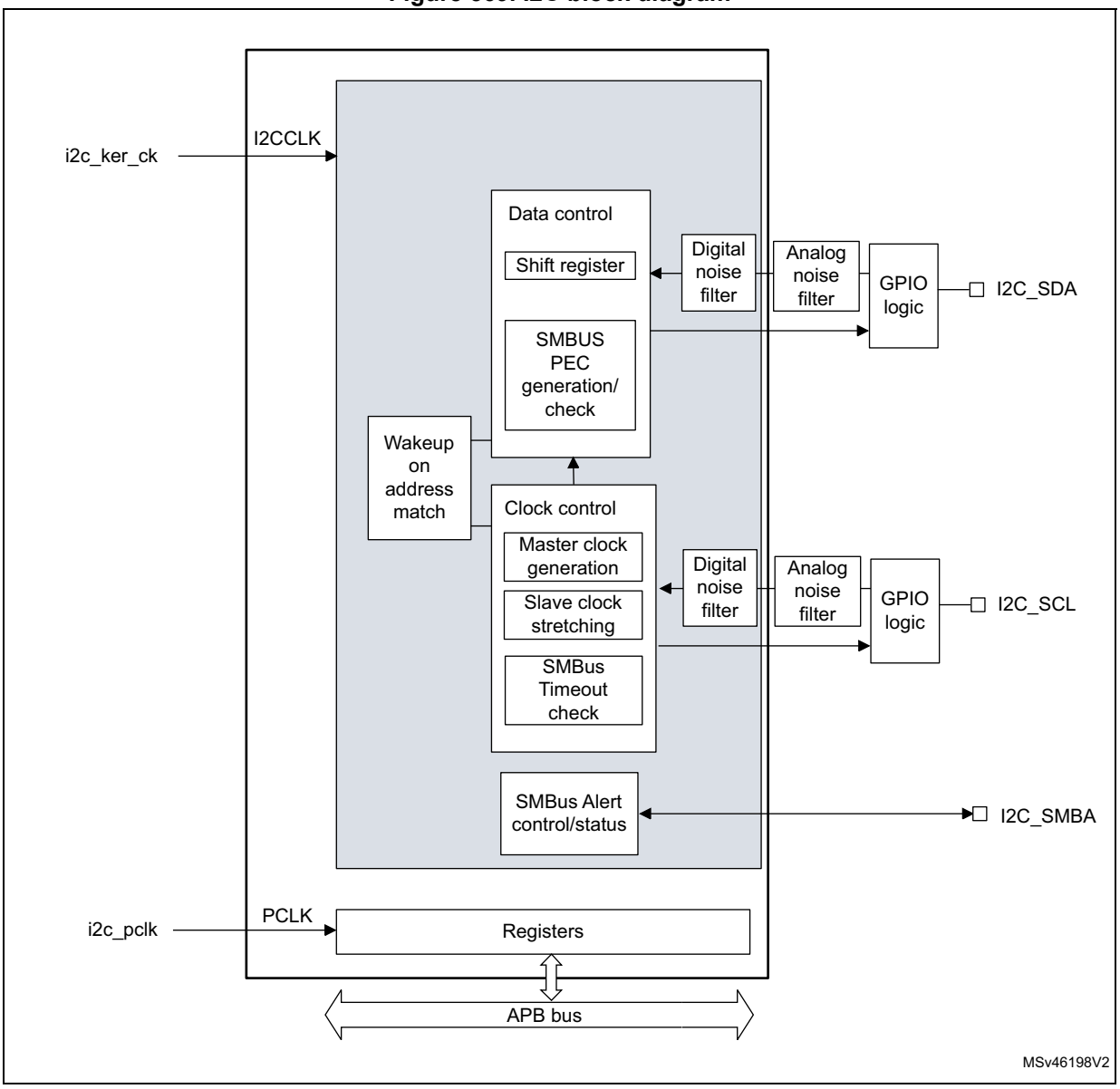
This interface can also be connected to a SMBus with the data pin (SDA) and clock pin (SCL).

If SMBus feature is supported: the additional optional SMBus Alert pin (SMBA) is also available.

52.4.1 I2C block diagram

The block diagram of the I2C interface is shown in *Figure 569*.

Figure 569. I2C block diagram



The I2C is clocked by an independent clock source which allows the I2C to operate independently from the i2c_pclk frequency.

For I2C I/Os supporting 20mA output current drive for Fast-mode Plus operation, the driving capability is enabled through control bits in the system configuration controller (SYSCFG). *Refer to Section 52.3: I2C implementation.*

52.4.2 I2C pins and internal signals

Table 401. I2C input/output pins

Pin name	Signal type	Description
I2C_SDA	Bidirectional	I2C data
I2C_SCL	Bidirectional	I2C clock
I2C_SMBA	Bidirectional	SMBus alert

Table 402. I2C internal input/output signals

Internal signal name	Signal type	Description
i2c_ker_ck	Input	I2C kernel clock, also named I2CCLK in this document
i2c_pclk	Input	I2C APB clock
i2c_it	Output	I2C interrupts, refer to *Table 416: I2C Interrupt requests* for the full list of interrupt sources
i2c_rx_dma	Output	I2C receive data DMA request (I2C_RX)
i2c_tx_dma	Output	I2C transmit data DMA request (I2C_TX)

52.4.3 I2C clock requirements

The I2C kernel is clocked by i2c_ker_ck.

The i2c_ker_ck period t_{I2CCLK} must respect the following conditions:

$t_{I2CCLK} < (t_{LOW} - t_{filters}) / 4$ and $t_{I2CCLK} < t_{HIGH}$

with:

t_{LOW}: SCL low time and t_{HIGH}: SCL high time

$t_{filters}$: when enabled, sum of the delays brought by the analog filter and by the digital filter.

Analog filter delay is maximum 260 ns. Digital filter delay is DNF x t_{I2CCLK}.

The i2c_pclk clock period t_{PCLK} must respect the following condition:

$t_{PCLK} < 4/3\ t_{SCL}$

with t_{SCL}: SCL period

Caution: When the I2C kernel is clocked by i2c_pclk, this clock must respect the conditions for t_{I2CCLK}.

52.4.4 Mode selection

The interface can operate in one of the four following modes:

- Slave transmitter
- Slave receiver
- Master transmitter
- Master receiver

By default, it operates in slave mode. The interface automatically switches from slave to master when it generates a START condition, and from master to slave if an arbitration loss or a STOP generation occurs, allowing multimaster capability.

Communication flow

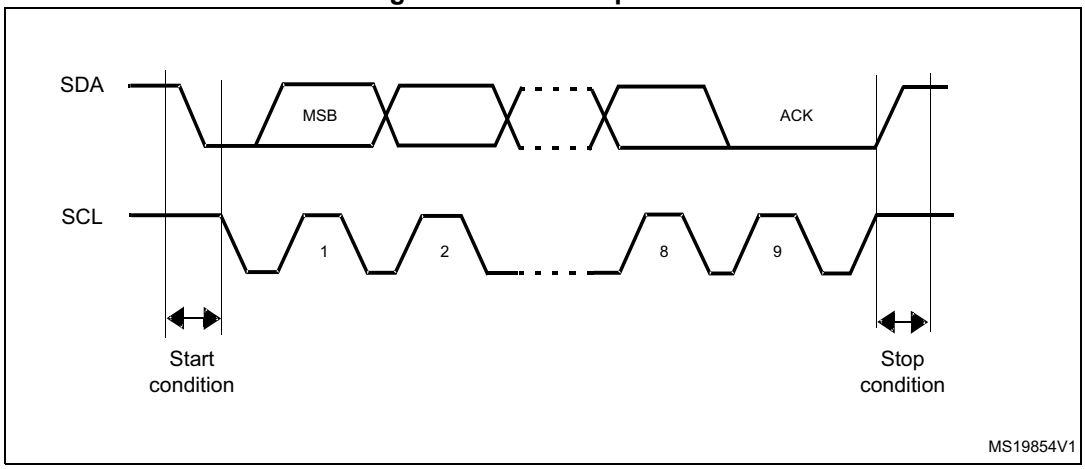
In Master mode, the I2C interface initiates a data transfer and generates the clock signal. A serial data transfer always begins with a START condition and ends with a STOP condition. Both START and STOP conditions are generated in master mode by software.

In Slave mode, the interface is capable of recognizing its own addresses (7 or 10-bit), and the general call address. The general call address detection can be enabled or disabled by software. The reserved SMBus addresses can also be enabled by software.

Data and addresses are transferred as 8-bit bytes, MSB first. The first byte(s) following the START condition contain the address (one in 7-bit mode, two in 10-bit mode). The address is always transmitted in Master mode.

A 9th clock pulse follows the 8 clock cycles of a byte transfer, during which the receiver must send an acknowledge bit to the transmitter. Refer to the following figure.

Figure 570. I^2C bus protocol



Acknowledge can be enabled or disabled by software. The I2C interface addresses can be selected by software.

52.4.5 I2C initialization

Enabling and disabling the peripheral

The I2C peripheral clock must be configured and enabled in the clock controller.

Then the I2C can be enabled by setting the PE bit in the I2C_CR1 register.

When the I2C is disabled (PE=0), the I^2C performs a software reset. Refer to *Section 52.4.6: Software reset* for more details.

Noise filters

Before enabling the I2C peripheral by setting the PE bit in I2C_CR1 register, the user must configure the noise filters, if needed. By default, an analog noise filter is present on the SDA and SCL inputs. This analog filter is compliant with the I^2C specification which requires the

suppression of spikes with a pulse width up to 50 ns in Fast-mode and Fast-mode Plus. The user can disable this analog filter by setting the ANFOFF bit, and/or select a digital filter by configuring the DNF[3:0] bit in the I2C_CR1 register.

When the digital filter is enabled, the level of the SCL or the SDA line is internally changed only if it remains stable for more than DNF x i2c_ker_ck periods. This allows spikes with a programmable length of 1 to 15 i2c_ker_ck periods to be suppressed.

Table 403. Comparison of analog vs. digital filters

-	Analog filter	Digital filter
Pulse width of suppressed spikes	≥ 50 ns	Programmable length from 1 to 15 I2C peripheral clocks
Benefits	Available in Stop mode	– Programmable length: extra filtering capability versus standard requirements – Stable length
Drawbacks	Variation vs. temperature, voltage, process	Wakeup from Stop mode on address match is not available when digital filter is enabled

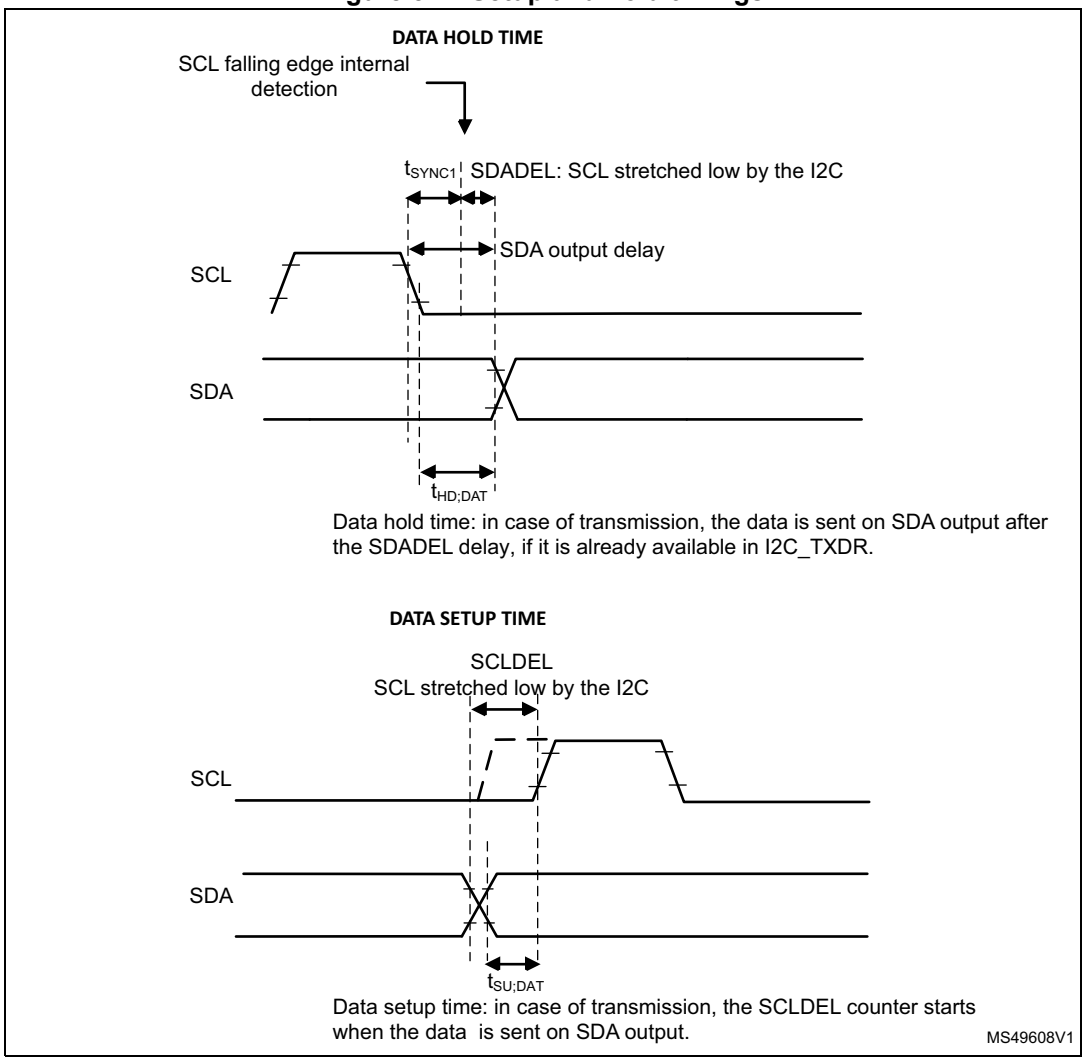
Caution: Changing the filter configuration is not allowed when the I2C is enabled.

I2C timings

The timings must be configured in order to guarantee a correct data hold and setup time, used in master and slave modes. This is done by programming the PRESC[3:0], SCLDEL[3:0] and SDADEL[3:0] bits in the I2C_TIMINGR register.

The STM32CubeMX tool calculates and provides the I2C_TIMINGR content in the I2C configuration window

Figure 571. Setup and hold timings



- When the SCL falling edge is internally detected, a delay is inserted before sending SDA output. This delay is t_{SDADEL} = SDADEL x t_{PRESC} + t_{I2CCLK} where t_{PRESC} = (PRESC+1) x t_{I2CCLK}.

  T_{SDADEL} impacts the hold time $t_{HD;DAT}$.

The total SDA output delay is:

t_{SYNC1} + {[SDADEL x (PRESC+1) + 1] x t_{I2CCLK} }

t_{SYNC1} duration depends on these parameters:

- SCL falling slope
- When enabled, input delay brought by the analog filter: $t_{AF(min)} < t_{AF} < t_{AF(max)}$
- When enabled, input delay brought by the digital filter: t_{DNF} = DNF x t_{I2CCLK}
- Delay due to SCL synchronization to i2c_ker_ck clock (2 to 3 i2c_ker_ck periods)

In order to bridge the undefined region of the SCL falling edge, the user must program SDADEL in such a way that:

$\{t_{f\ (max)} + t_{HD;DAT\ (min)} - t_{AF(min)} - [(DNF + 3) \times t_{I2CCLK}]\} / \{(PRESC + 1) \times t_{I2CCLK}\} \leq SDADEL$

$SDADEL \leq \{t_{HD;DAT\ (max)} - t_{AF(max)} - [(DNF+4) \times t_{I2CCLK}]\} / \{(PRESC + 1) \times t_{I2CCLK}\}$

Note: *$t_{AF(min)}$ / $t_{AF(max)}$ are part of the equation only when the analog filter is enabled. Refer to device datasheet for t_{AF} values.*

The maximum $t_{HD;DAT}$ can be 3.45 µs, 0.9 µs and 0.45 µs for Standard-mode, Fast-mode and Fast-mode Plus, but must be less than the maximum of $t_{VD;DAT}$ by a transition time. This maximum must only be met if the device does not stretch the LOW period (t_{LOW}) of the SCL signal. If the clock stretches the SCL, the data must be valid by the set-up time before it releases the clock.

The SDA rising edge is usually the worst case, so in this case the previous equation becomes:

$SDADEL \leq \{t_{VD;DAT\ (max)} - t_{r\ (max)} - 260\ ns - [(DNF+4) \times t_{I2CCLK}]\} / \{(PRESC + 1) \times t_{I2CCLK}\}$.

Note: *This condition can be violated when NOSTRETCH=0, because the device stretches SCL low to guarantee the set-up time, according to the SCLDEL value.*

Refer to *Table 404: I2C-SMBus specification data setup and hold times* for t_f, t_r, $t_{HD;DAT}$ and $t_{VD;DAT}$ standard values.

- After t_{SDADEL} delay, or after sending SDA output in case the slave had to stretch the clock because the data was not yet written in I2C_TXDR register, SCL line is kept at low level during the setup time. This setup time is t_{SCLDEL} = (SCLDEL+1) x t_{PRESC} where t_{PRESC} = (PRESC+1) x t_{I2CCLK}.

  t_{SCLDEL} impacts the setup time $t_{SU;DAT}$.

In order to bridge the undefined region of the SDA transition (rising edge usually worst case), the user must program SCLDEL in such a way that:

$\{[t_{r\ (max)} + t_{SU;DAT\ (min)}] / [(PRESC+1)] \times t_{I2CCLK}]\} - 1 <= SCLDEL$

Refer to *Table 404: I2C-SMBus specification data setup and hold times* for t_r and $t_{SU;DAT}$ standard values.

The SDA and SCL transition time values to be used are the ones in the application. Using the maximum values from the standard increases the constraints for the SDADEL and SCLDEL calculation, but ensures the feature whatever the application.

Note: At every clock pulse, after SCL falling edge detection, the I2C master or slave stretches SCL low during at least [(SDADEL+SCLDEL+1) x (PRESC+1) + 1] x t_{I2CCLK}, in both transmission and reception modes. In transmission mode, in case the data is not yet written in I2C_TXDR when SDADEL counter is finished, the I2C keeps on stretching SCL low until the next data is written. Then new data MSB is sent on SDA output, and SCLDEL counter starts, continuing stretching SCL low to guarantee the data setup time.

If NOSTRETCH=1 in slave mode, the SCL is not stretched. Consequently the SDADEL must be programmed in such a way to guarantee also a sufficient setup time.

Table 404. I^2C-SMBus specification data setup and hold times

Symbol	Parameter	Standard-mode (Sm)		Fast-mode (Fm)		Fast-mode Plus (Fm+)		SMBus		Unit
		Min.	Max	Min.	Max	Min.	Max	Min.	Max	
$t_{HD;DAT}$	Data hold time	0	-	0	-	0	-	0.3	-	µs
$t_{VD;DAT}$	Data valid time	-	3.45	-	0.9	-	0.45	-	-	
$t_{SU;DAT}$	Data setup time	250	-	100	-	50	-	250	-	ns
t_r	Rise time of both SDA and SCL signals	-	1000	-	300	-	120	-	1000	
t_f	Fall time of both SDA and SCL signals	-	300	-	300	-	120	-	300	

Additionally, in master mode, the SCL clock high and low levels must be configured by programming the PRESC[3:0], SCLH[7:0] and SCLL[7:0] bits in the I2C_TIMINGR register.

- When the SCL falling edge is internally detected, a delay is inserted before releasing the SCL output. This delay is t_{SCLL} = (SCLL+1) x t_{PRESC} where t_{PRESC} = (PRESC+1) x t_{I2CCLK}.
  t_{SCLL} impacts the SCL low time t_{LOW} .
- When the SCL rising edge is internally detected, a delay is inserted before forcing the SCL output to low level. This delay is t_{SCLH} = (SCLH+1) x t_{PRESC} where t_{PRESC} = (PRESC+1) x t_{I2CCLK}. t_{SCLH} impacts the SCL high time t_{HIGH} .

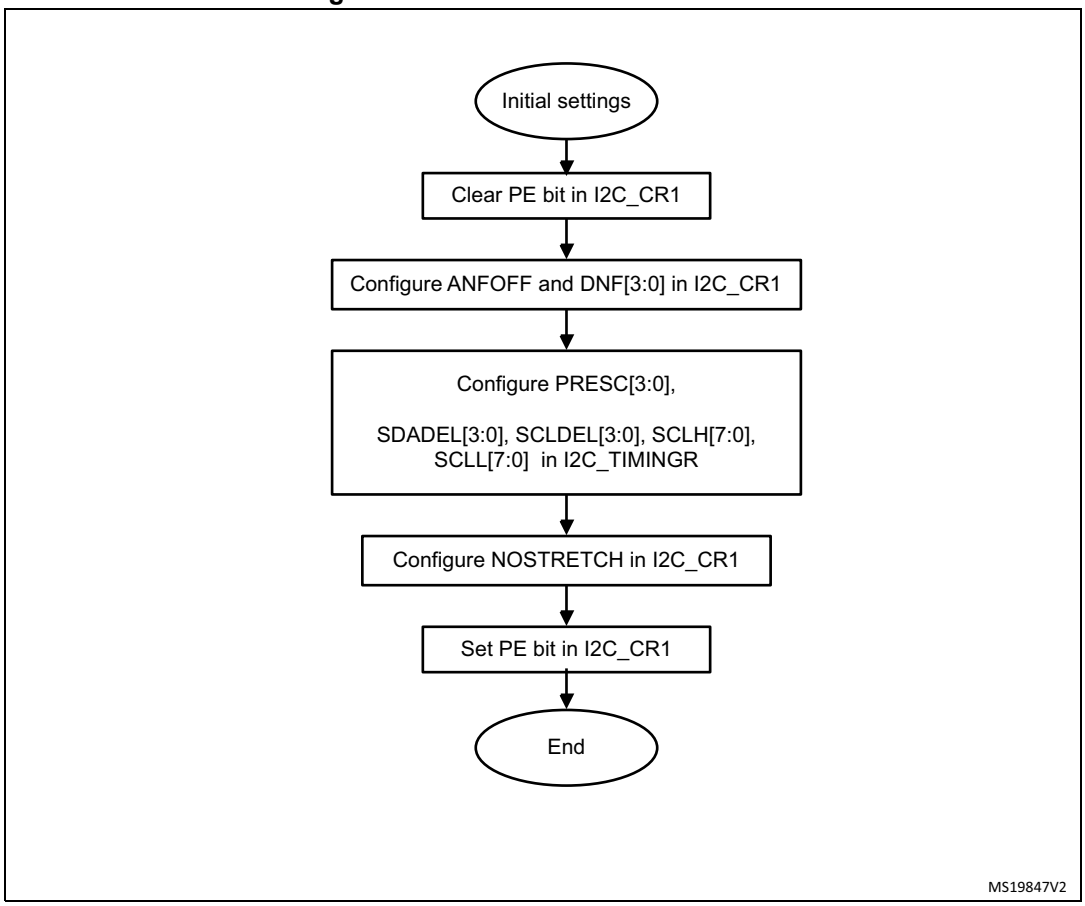
Refer to *I2C master initialization* for more details.

Caution: Changing the timing configuration is not allowed when the I2C is enabled.

The I2C slave NOSTRETCH mode must also be configured before enabling the peripheral. Refer to *I2C slave initialization* for more details.

Caution: Changing the NOSTRETCH configuration is not allowed when the I2C is enabled.

Figure 572. I2C initialization flowchart



52.4.6 Software reset

A software reset can be performed by clearing the PE bit in the I2C_CR1 register. In that case I2C lines SCL and SDA are released. Internal states machines are reset and communication control bits, as well as status bits come back to their reset value. The configuration registers are not impacted.

Here is the list of impacted register bits:

1. I2C_CR2 register: START, STOP, NACK
2. I2C_ISR register: BUSY, TXE, TXIS, RXNE, ADDR, NACKF, TCR, TC, STOPF, BERR, ARLO, OVR

and in addition when the SMBus feature is supported:

1. I2C_CR2 register: PECBYTE
2. I2C_ISR register: PECERR, TIMEOUT, ALERT

PE must be kept low during at least 3 APB clock cycles in order to perform the software reset. This is ensured by writing the following software sequence: - Write PE=0 - Check PE=0 - Write PE=1.

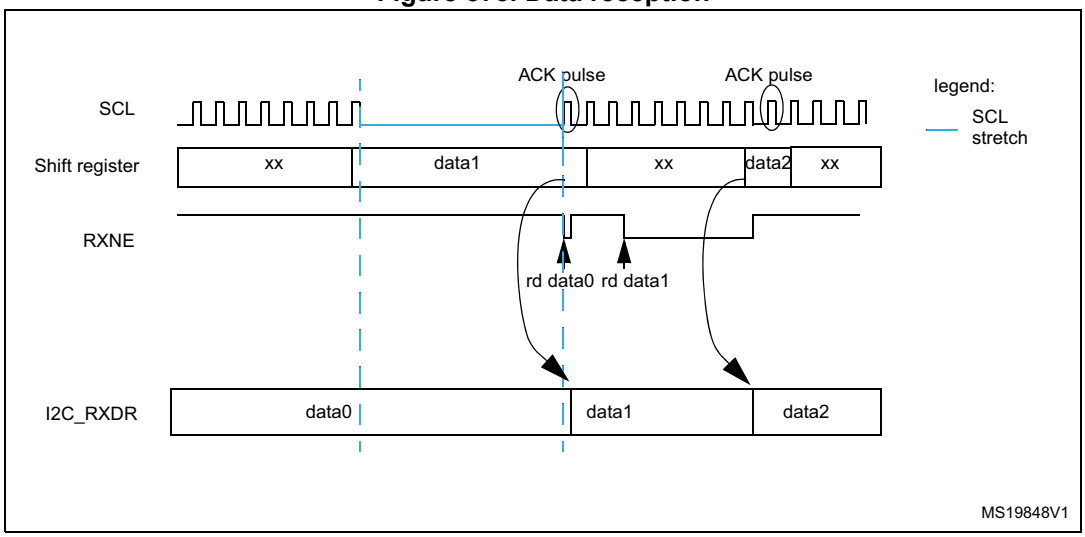
52.4.7 Data transfer

The data transfer is managed through transmit and receive data registers and a shift register.

Reception

The SDA input fills the shift register. After the 8th SCL pulse (when the complete data byte is received), the shift register is copied into I2C_RXDR register if it is empty (RXNE=0). If RXNE=1, meaning that the previous received data byte has not yet been read, the SCL line is stretched low until I2C_RXDR is read. The stretch is inserted between the 8th and 9th SCL pulse (before the acknowledge pulse).

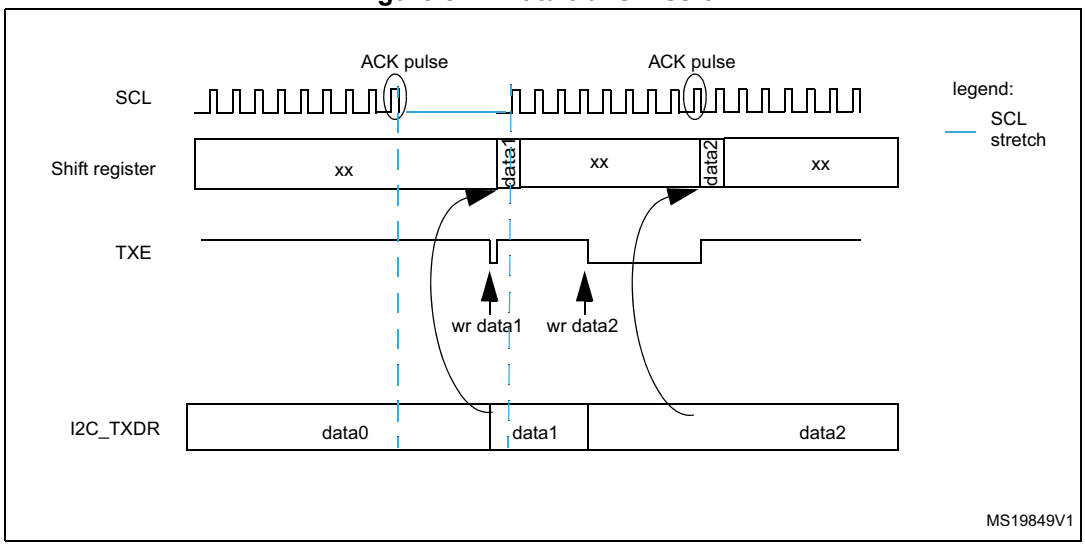
Figure 573. Data reception



Transmission

If the I2C_TXDR register is not empty (TXE=0), its content is copied into the shift register after the 9th SCL pulse (the Acknowledge pulse). Then the shift register content is shifted out on SDA line. If TXE=1, meaning that no data is written yet in I2C_TXDR, SCL line is stretched low until I2C_TXDR is written. The stretch is done after the 9th SCL pulse.

Figure 574. Data transmission



Hardware transfer management

The I2C has a byte counter embedded in hardware in order to manage byte transfer and to close the communication in various modes such as:

- NACK, STOP and ReSTART generation in master mode
- ACK control in slave receiver mode
- PEC generation/checking when SMBus feature is supported

The byte counter is always used in master mode. By default it is disabled in slave mode, but it can be enabled by software by setting the SBC (Slave Byte Control) bit in the I2C_CR2 register.

The number of bytes to be transferred is programmed in the NBYTES[7:0] bit field in the I2C_CR2 register. If the number of bytes to be transferred (NBYTES) is greater than 255, or if a receiver wants to control the acknowledge value of a received data byte, the reload mode must be selected by setting the RELOAD bit in the I2C_CR2 register. In this mode, the TCR flag is set when the number of bytes programmed in NBYTES is transferred, and an interrupt is generated if TCIE is set. SCL is stretched as long as TCR flag is set. TCR is cleared by software when NBYTES is written to a non-zero value.

When the NBYTES counter is reloaded with the last number of bytes, RELOAD bit must be cleared.

When RELOAD=0 in master mode, the counter can be used in 2 modes:

- **Automatic end mode** (AUTOEND = '1' in the I2C_CR2 register). In this mode, the master automatically sends a STOP condition once the number of bytes programmed in the NBYTES[7:0] bit field is transferred.
- **Software end mode** (AUTOEND = '0' in the I2C_CR2 register). In this mode, software action is expected once the number of bytes programmed in the NBYTES[7:0] bit field is transferred; the TC flag is set and an interrupt is generated if the TCIE bit is set. The SCL signal is stretched as long as the TC flag is set. The TC flag is cleared by software when the START or STOP bit is set in the I2C_CR2 register. This mode must be used when the master wants to send a RESTART condition.

Caution: The AUTOEND bit has no effect when the RELOAD bit is set.

Table 405. I2C configuration

Function	SBC bit	RELOAD bit	AUTOEND bit
Master Tx/Rx NBYTES + STOP	x	0	1
Master Tx/Rx + NBYTES + RESTART	x	0	0
Slave Tx/Rx all received bytes ACKed	0	x	x
Slave Rx with ACK control	1	1	x

52.4.8 I2C slave mode

I2C slave initialization

In order to work in slave mode, the user must enable at least one slave address. Two registers I2C_OAR1 and I2C_OAR2 are available in order to program the slave own addresses OA1 and OA2.

- OA1 can be configured either in 7-bit mode (by default) or in 10-bit addressing mode by setting the OA1MODE bit in the I2C_OAR1 register.

  OA1 is enabled by setting the OA1EN bit in the I2C_OAR1 register.
- If additional slave addresses are required, the 2nd slave address OA2 can be configured. Up to 7 OA2 LSB can be masked by configuring the OA2MSK[2:0] bits in the I2C_OAR2 register. Therefore for OA2MSK configured from 1 to 6, only OA2[7:2], OA2[7:3], OA2[7:4], OA2[7:5], OA2[7:6] or OA2[7] are compared with the received address. As soon as OA2MSK is not equal to 0, the address comparator for OA2 excludes the I2C reserved addresses (0000 XXX and 1111 XXX), which are not acknowledged. If OA2MSK=7, all received 7-bit addresses are acknowledged (except reserved addresses). OA2 is always a 7-bit address.

  These reserved addresses can be acknowledged if they are enabled by the specific enable bit, if they are programmed in the I2C_OAR1 or I2C_OAR2 register with OA2MSK=0.

  OA2 is enabled by setting the OA2EN bit in the I2C_OAR2 register.
- The general call address is enabled by setting the GCEN bit in the I2C_CR1 register.

When the I2C is selected by one of its enabled addresses, the ADDR interrupt status flag is set, and an interrupt is generated if the ADDRIE bit is set.

By default, the slave uses its clock stretching capability, which means that it stretches the SCL signal at low level when needed, in order to perform software actions. If the master does not support clock stretching, the I2C must be configured with NOSTRETCH=1 in the I2C_CR1 register.

After receiving an ADDR interrupt, if several addresses are enabled the user must read the ADDCODE[6:0] bits in the I2C_ISR register in order to check which address matched. DIR flag must also be checked in order to know the transfer direction.

Slave clock stretching (NOSTRETCH = 0)

In default mode, the I2C slave stretches the SCL clock in the following situations:

- When the ADDR flag is set: the received address matches with one of the enabled slave addresses. This stretch is released when the ADDR flag is cleared by software setting the ADDRCF bit.
- In transmission, if the previous data transmission is completed and no new data is written in I2C_TXDR register, or if the first data byte is not written when the ADDR flag is cleared (TXE=1). This stretch is released when the data is written to the I2C_TXDR register.
- In reception when the I2C_RXDR register is not read yet and a new data reception is completed. This stretch is released when I2C_RXDR is read.
- When TCR = 1 in Slave Byte Control mode, reload mode (SBC=1 and RELOAD=1), meaning that the last data byte has been transferred. This stretch is released when then TCR is cleared by writing a non-zero value in the NBYTES[7:0] field.
- After SCL falling edge detection, the I2C stretches SCL low during [(SDADEL+SCLDEL+1) x (PRESC+1) + 1] x t_{I2CCLK}.

Slave without clock stretching (NOSTRETCH = 1)

When NOSTRETCH = 1 in the I2C_CR1 register, the I2C slave does not stretch the SCL signal.

- The SCL clock is not stretched while the ADDR flag is set.
- In transmission, the data must be written in the I2C_TXDR register before the first SCL pulse corresponding to its transfer occurs. If not, an underrun occurs, the OVR flag is set in the I2C_ISR register and an interrupt is generated if the ERRIE bit is set in the I2C_CR1 register. The OVR flag is also set when the first data transmission starts and the STOPF bit is still set (has not been cleared). Therefore, if the user clears the STOPF flag of the previous transfer only after writing the first data to be transmitted in the next transfer, he ensures that the OVR status is provided, even for the first data to be transmitted.
- In reception, the data must be read from the I2C_RXDR register before the 9th SCL pulse (ACK pulse) of the next data byte occurs. If not an overrun occurs, the OVR flag is set in the I2C_ISR register and an interrupt is generated if the ERRIE bit is set in the I2C_CR1 register.

Slave byte control mode

In order to allow byte ACK control in slave reception mode, The Slave byte control mode must be enabled by setting the SBC bit in the I2C_CR1 register. This is required to be compliant with SMBus standards.

The Reload mode must be selected in order to allow byte ACK control in slave reception mode (RELOAD=1). To get control of each byte, NBYTES must be initialized to 0x1 in the ADDR interrupt subroutine, and reloaded to 0x1 after each received byte. When the byte is received, the TCR bit is set, stretching the SCL signal low between the 8th and 9th SCL pulses. The user can read the data from the I2C_RXDR register, and then decide to acknowledge it or not by configuring the ACK bit in the I2C_CR2 register. The SCL stretch is released by programming NBYTES to a non-zero value: the acknowledge or not-acknowledge is sent and next byte can be received.

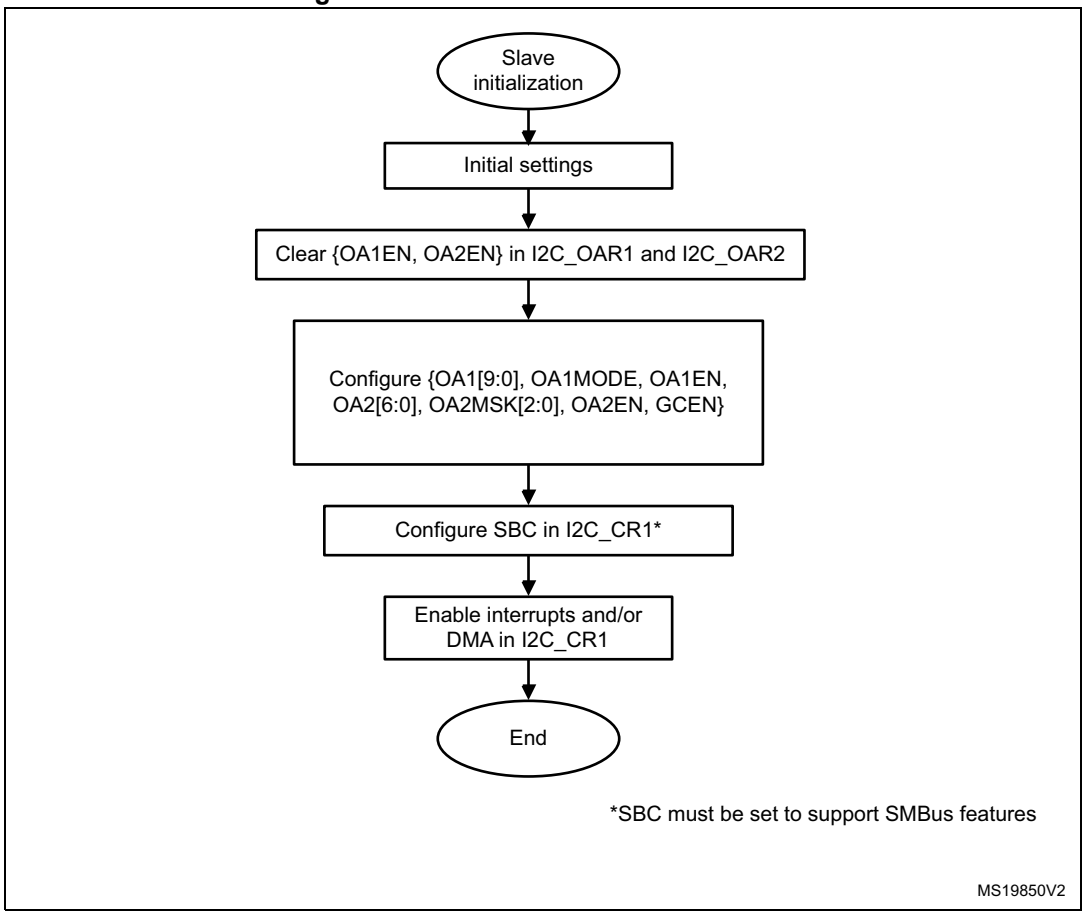
NBYTES can be loaded with a value greater than 0x1, and in this case, the reception flow is continuous during NBYTES data reception.

Note: The SBC bit must be configured when the I2C is disabled, or when the slave is not addressed, or when ADDR=1.

The RELOAD bit value can be changed when ADDR=1, or when TCR=1.

Caution: The Slave byte control mode is not compatible with NOSTRETCH mode. Setting SBC when NOSTRETCH=1 is not allowed.

Figure 575. Slave initialization flowchart



Slave transmitter

A transmit interrupt status (TXIS) is generated when the I2C_TXDR register becomes empty. An interrupt is generated if the TXIE bit is set in the I2C_CR1 register.

The TXIS bit is cleared when the I2C_TXDR register is written with the next data byte to be transmitted.

When a NACK is received, the NACKF bit is set in the I2C_ISR register and an interrupt is generated if the NACKIE bit is set in the I2C_CR1 register. The slave automatically releases the SCL and SDA lines in order to let the master perform a STOP or a RESTART condition. The TXIS bit is not set when a NACK is received.

When a STOP is received and the STOPIE bit is set in the I2C_CR1 register, the STOPF flag is set in the I2C_ISR register and an interrupt is generated. In most applications, the SBC bit is usually programmed to ‘0’. In this case, If TXE = 0 when the slave address is received (ADDR=1), the user can choose either to send the content of the I2C_TXDR register as the first data byte, or to flush the I2C_TXDR register by setting the TXE bit in order to program a new data byte.

In Slave byte control mode (SBC=1), the number of bytes to be transmitted must be programmed in NBYTES in the address match interrupt subroutine (ADDR=1). In this case, the number of TXIS events during the transfer corresponds to the value programmed in NBYTES.

Caution: When NOSTRETCH=1, the SCL clock is not stretched while the ADDR flag is set, so the user cannot flush the I2C_TXDR register content in the ADDR subroutine, in order to program the first data byte. The first data byte to be sent must be previously programmed in the I2C_TXDR register:

- This data can be the data written in the last TXIS event of the previous transmission message.
- If this data byte is not the one to be sent, the I2C_TXDR register can be flushed by setting the TXE bit in order to program a new data byte. The STOPF bit must be cleared only after these actions, in order to guarantee that they are executed before the first data transmission starts, following the address acknowledge.

  If STOPF is still set when the first data transmission starts, an underrun error is generated (the OVR flag is set).

  If a TXIS event is needed, (transmit interrupt or transmit DMA request), the user must set the TXIS bit in addition to the TXE bit, in order to generate a TXIS event.

Figure 576. Transfer sequence flowchart for I2C slave transmitter, NOSTRETCH= 0

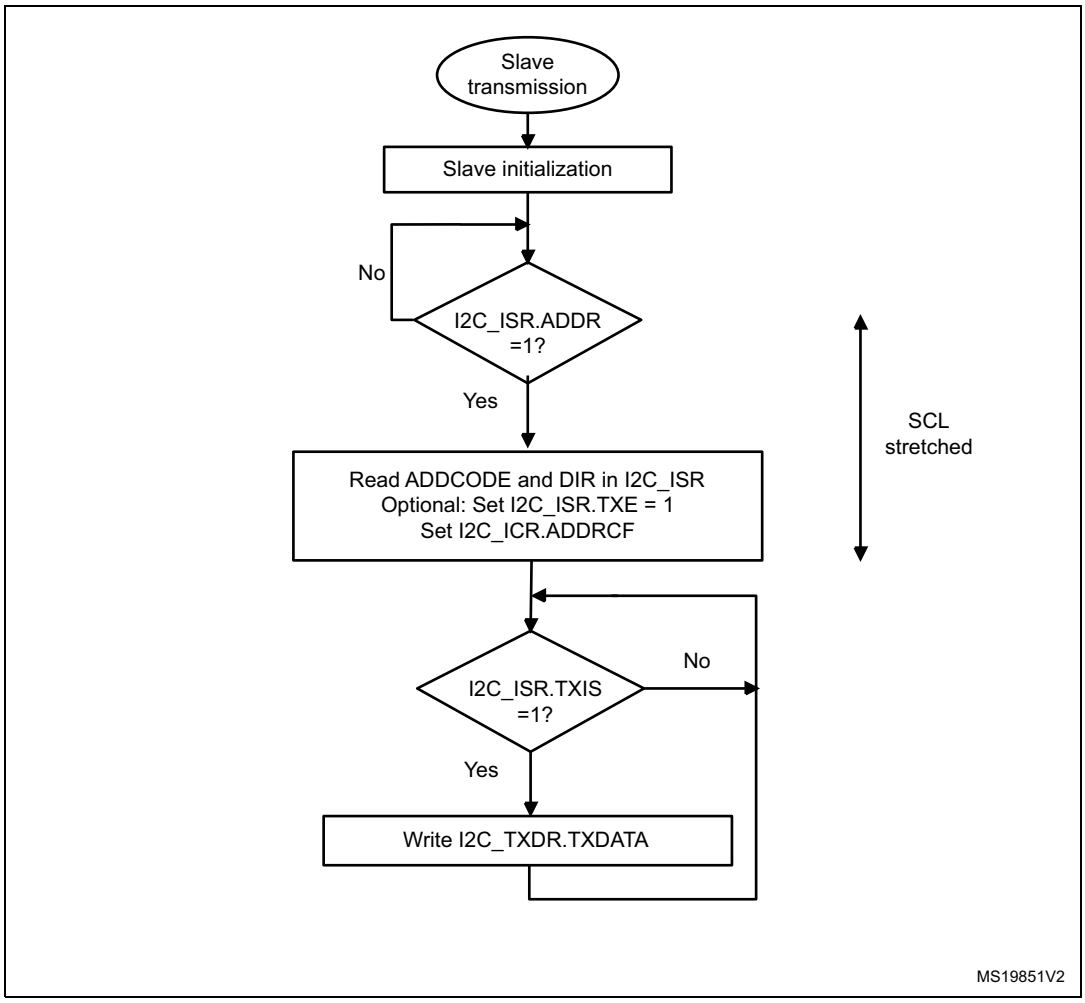


Figure 577. Transfer sequence flowchart for I2C slave transmitter, NOSTRETCH= 1

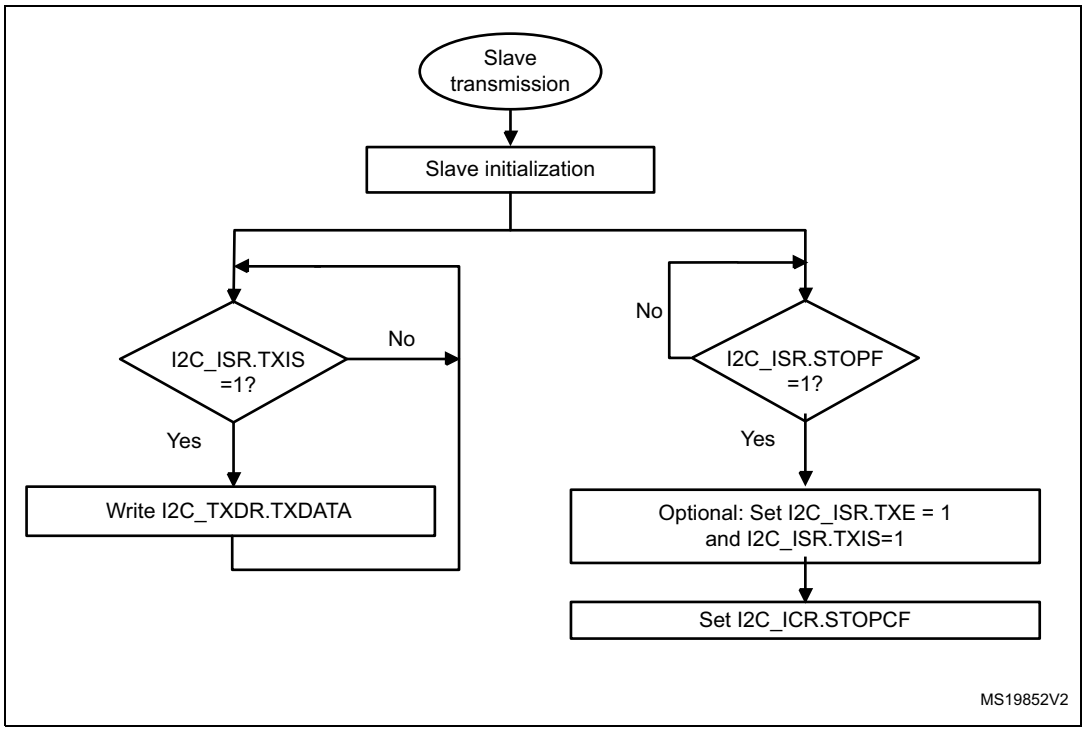
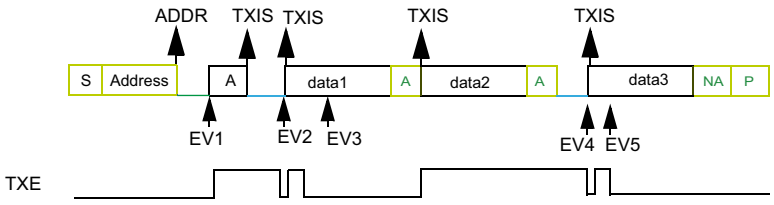


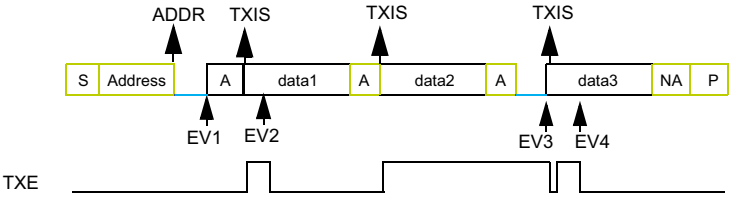
Figure 578. Transfer bus diagrams for I2C slave transmitter

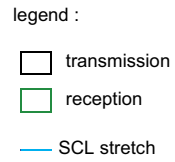
Example I2C slave transmitter 3 bytes with 1st data flushed, NOSTRETCH=0:



EV1: ADDR ISR: check ADDCODE and DIR, set TXE, set ADDRCF
EV2: TXIS ISR: wr data1
EV3: TXIS ISR: wr data2
EV4: TXIS ISR: wr data3
EV5: TXIS ISR: wr data4 (not sent)

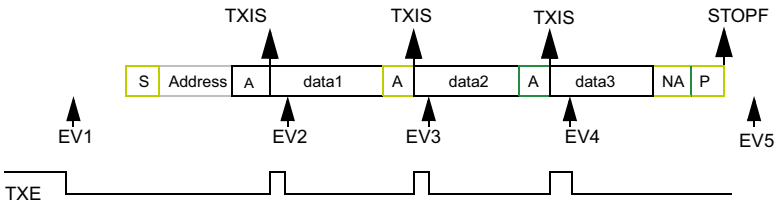
Example I2C slave transmitter 3 bytes without 1st data flush, NOSTRETCH=0:





EV1: ADDR ISR: check ADDCODE and DIR, set ADDRCF
EV2: TXIS ISR: wr data2
EV3: TXIS ISR: wr data3
EV4: TXIS ISR: wr data4 (not sent)

Example I2C slave transmitter 3 bytes, NOSTRETCH=1:



EV1: wr data1
EV2: TXIS ISR: wr data2
EV3: TXIS ISR: wr data3
EV4: TXIS ISR: wr data4 (not sent)
EV5: STOPF ISR: (optional: set TXE and TXIS), set STOPCF

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Slave receiver

RXNE is set in I2C_ISR when the I2C_RXDR is full, and generates an interrupt if RXIE is set in I2C_CR1. RXNE is cleared when I2C_RXDR is read.

When a STOP is received and STOPIE is set in I2C_CR1, STOPF is set in I2C_ISR and an interrupt is generated.

Figure 579. Transfer sequence flowchart for slave receiver with NOSTRETCH=0

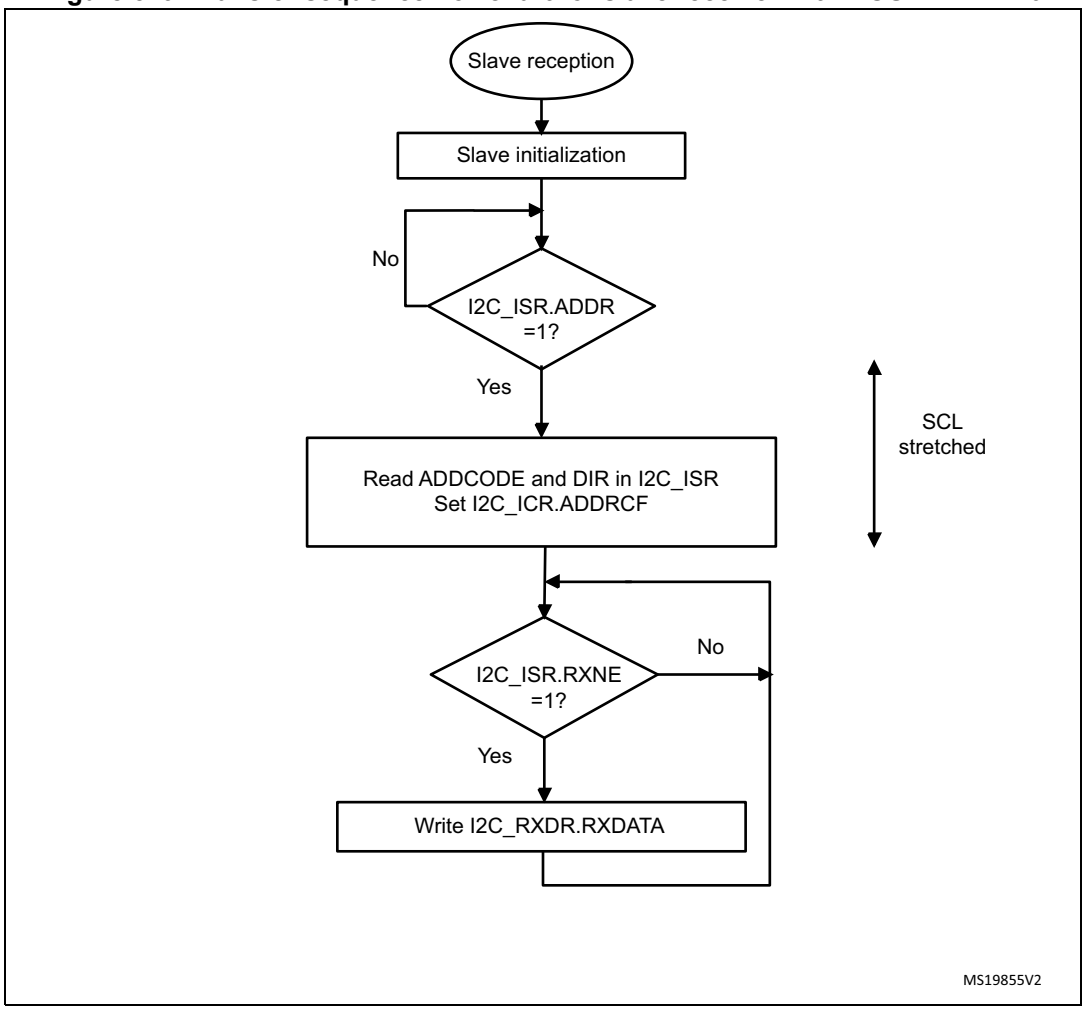


Figure 580. Transfer sequence flowchart for slave receiver with NOSTRETCH=1

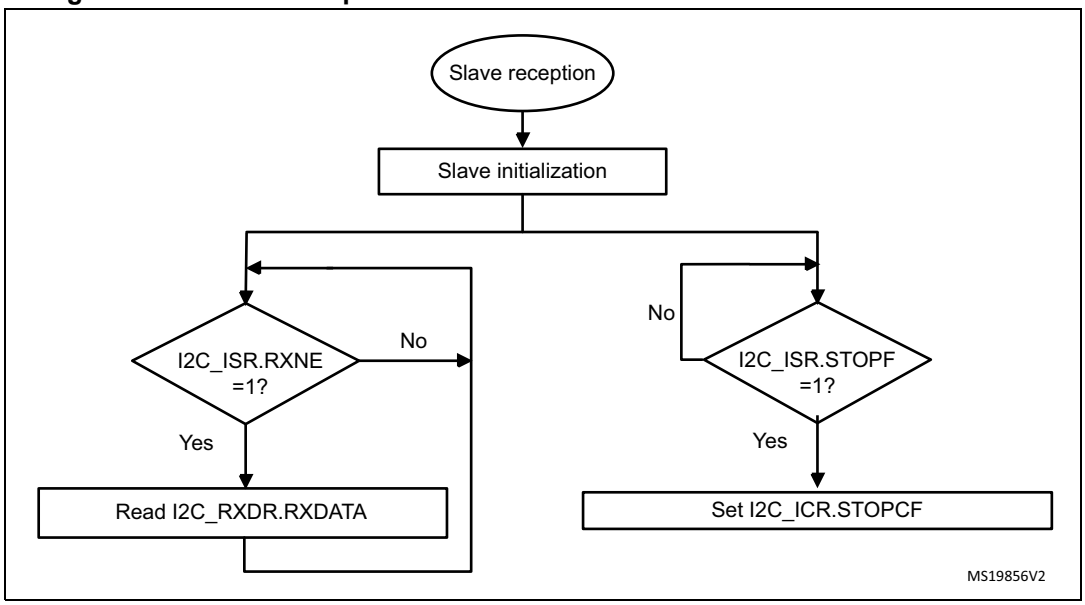
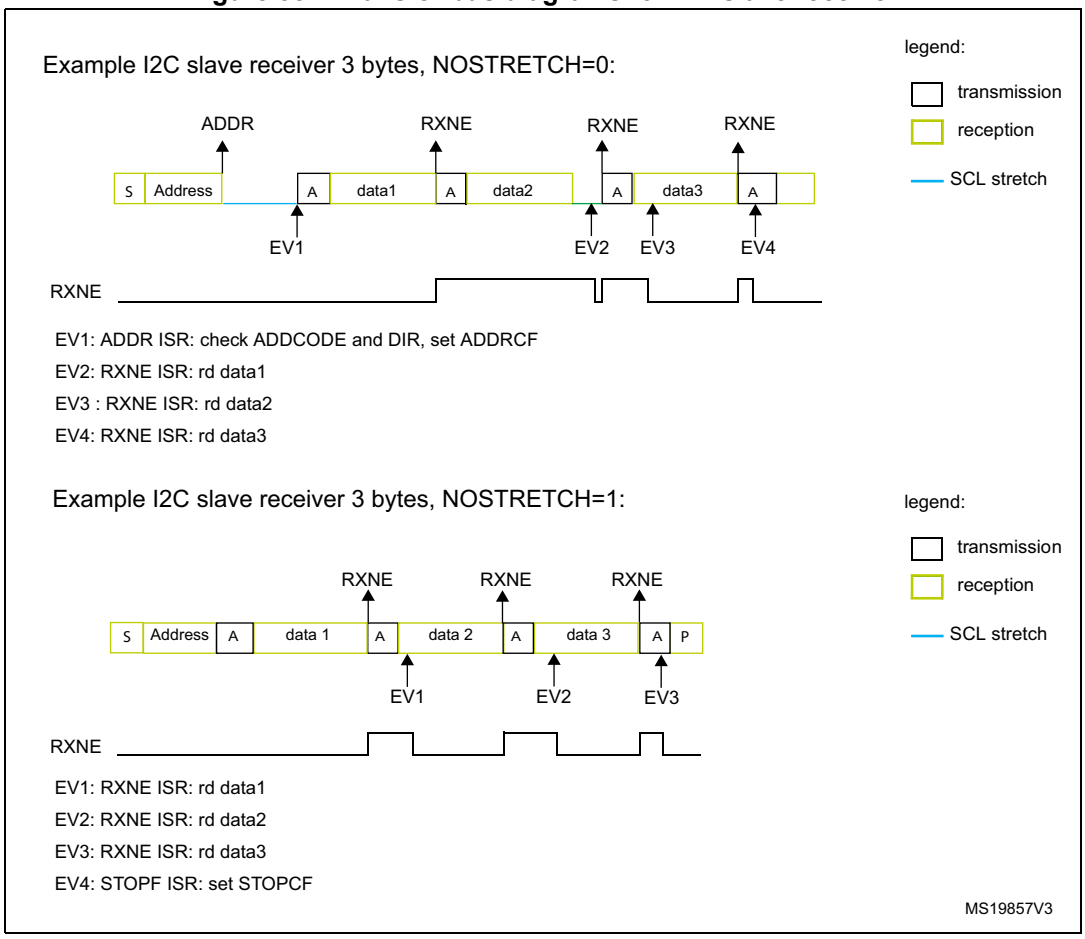


Figure 581. Transfer bus diagrams for I2C slave receiver



52.4.9 I2C master mode

I2C master initialization

Before enabling the peripheral, the I2C master clock must be configured by setting the SCLH and SCLL bits in the I2C_TIMINGR register.

The STM32CubeMX tool calculates and provides the I2C_TIMINGR content in the I2C Configuration window.

A clock synchronization mechanism is implemented in order to support multi-master environment and slave clock stretching.

In order to allow clock synchronization:

- The low level of the clock is counted using the SCLL counter, starting from the SCL low level internal detection.
- The high level of the clock is counted using the SCLH counter, starting from the SCL high level internal detection.

The I2C detects its own SCL low level after a t_{SYNC1} delay depending on the SCL falling edge, SCL input noise filters (analog + digital) and SCL synchronization to the I2CxCLK clock. The I2C releases SCL to high level once the SCLL counter reaches the value programmed in the SCLL[7:0] bits in the I2C_TIMINGR register.

The I2C detects its own SCL high level after a t_{SYNC2} delay depending on the SCL rising edge, SCL input noise filters (analog + digital) and SCL synchronization to I2CxCLK clock. The I2C ties SCL to low level once the SCLH counter is reached reaches the value programmed in the SCLH[7:0] bits in the I2C_TIMINGR register.

Consequently the master clock period is:

$t_{SCL} = t_{SYNC1} + t_{SYNC2} + \{[(SCLH+1) + (SCLL+1)] \times (PRESC+1) \times t_{I2CCLK}\}$

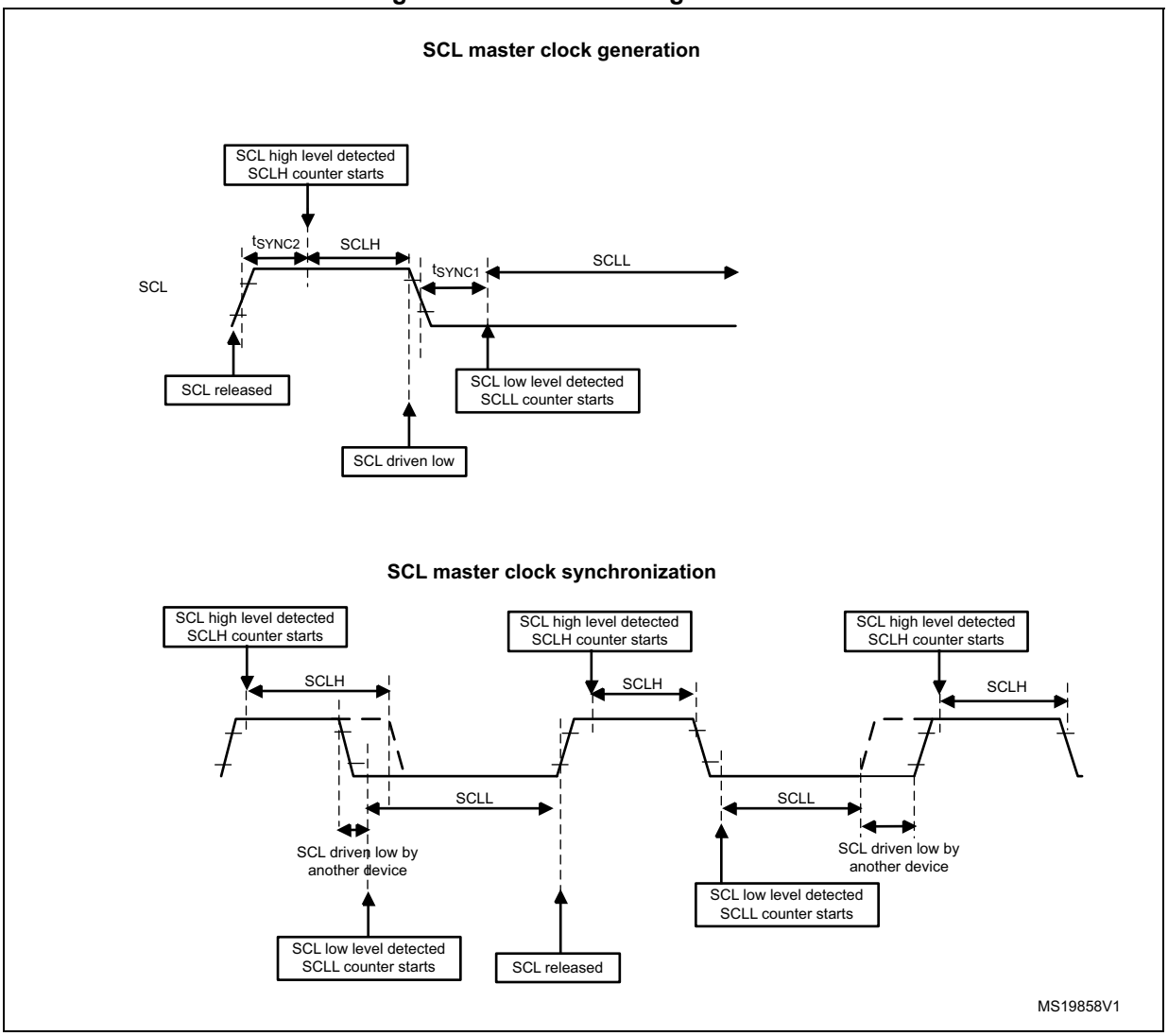
The duration of t_{SYNC1} depends on these parameters:

- SCL falling slope
- When enabled, input delay induced by the analog filter.
- When enabled, input delay induced by the digital filter: DNF x t_{I2CCLK}
- Delay due to SCL synchronization with i2c_ker_ck clock (2 to 3 i2c_ker_ck periods)

The duration of t_{SYNC2} depends on these parameters:

- SCL rising slope
- When enabled, input delay induced by the analog filter.
- When enabled, input delay induced by the digital filter: DNF x t_{I2CCLK}
- Delay due to SCL synchronization with i2c_ker_ck clock (2 to 3 i2c_ker_ck periods)

Figure 582. Master clock generation



Caution: In order to be I^{2}C or SMBus compliant, the master clock must respect the timings given the table below.

Table 406. I²C-SMBus specification clock timings

Symbol	Parameter	Standard-mode (Sm)		Fast-mode (Fm)		Fast-mode Plus (Fm+)		SMBus		Unit
		Min	Max	Min	Max	Min	Max	Min	Max	
f_{SCL}	SCL clock frequency	-	100	-	400	-	1000	-	100	kHz
$t_{HD:STA}$	Hold time (repeated) START condition	4.0	-	0.6	-	0.26	-	4.0	-	µs
$t_{SU:STA}$	Set-up time for a repeated START condition	4.7	-	0.6	-	0.26	-	4.7	-	µs
$t_{SU:STO}$	Set-up time for STOP condition	4.0	-	0.6	-	0.26	-	4.0	-	µs
t_{BUF}	Bus free time between a STOP and START condition	4.7	-	1.3	-	0.5	-	4.7	-	µs
t_{LOW}	Low period of the SCL clock	4.7	-	1.3	-	0.5	-	4.7	-	µs
t_{HIGH}	Period of the SCL clock	4.0	-	0.6	-	0.26	-	4.0	50	µs
t_r	Rise time of both SDA and SCL signals	-	1000	-	300	-	120	-	1000	ns
t_f	Fall time of both SDA and SCL signals	-	300	-	300	-	120	-	300	ns

Note: SCLL is also used to generate the t_{BUF} and $t_{SU:STA}$ timings.

SCLH is also used to generate the $t_{HD:STA}$ and $t_{SU:STO}$ timings.

Refer to *Section 52.4.10: I2C_TIMINGR register configuration examples* for examples of I2C_TIMINGR settings vs. i2c_ker_ck frequency.

Master communication initialization (address phase)

In order to initiate the communication, the user must program the following parameters for the addressed slave in the I2C_CR2 register:

- Addressing mode (7-bit or 10-bit): ADD10
- Slave address to be sent: SADD[9:0]
- Transfer direction: RD_WRN
- In case of 10-bit address read: HEAD10R bit. HEAD10R must be configure to indicate if the complete address sequence must be sent, or only the header in case of a direction change.
- The number of bytes to be transferred: NBYTES[7:0]. If the number of bytes is equal to or greater than 255 bytes, NBYTES[7:0] must initially be filled with 0xFF.

The user must then set the START bit in I2C_CR2 register. Changing all the above bits is not allowed when START bit is set.

Then the master automatically sends the START condition followed by the slave address as soon as it detects that the bus is free (BUSY = 0) and after a delay of t_{BUF}.

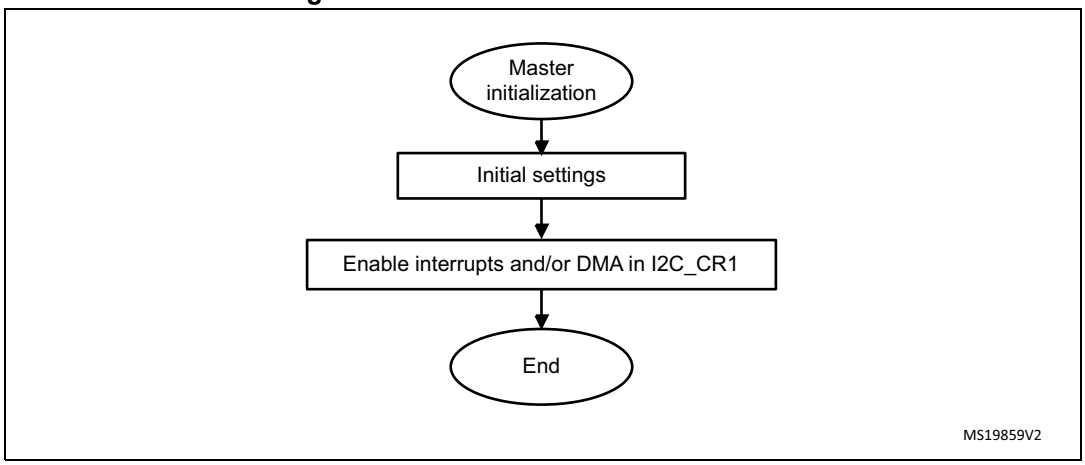
In case of an arbitration loss, the master automatically switches back to slave mode and can acknowledge its own address if it is addressed as a slave.

Note: The START bit is reset by hardware when the slave address has been sent on the bus, whatever the received acknowledge value. The START bit is also reset by hardware if an arbitration loss occurs.
In 10-bit addressing mode, when the Slave Address first 7 bits is NACKed by the slave, the

master re-launches automatically the slave address transmission until ACK is received. In this case ADDRCF must be set if a NACK is received from the slave, in order to stop sending the slave address.
If the I2C is addressed as a slave (ADDR=1) while the START bit is set, the I2C switches to slave mode and the START bit is cleared.

Note: The same procedure is applied for a Repeated Start condition. In this case BUSY=1.

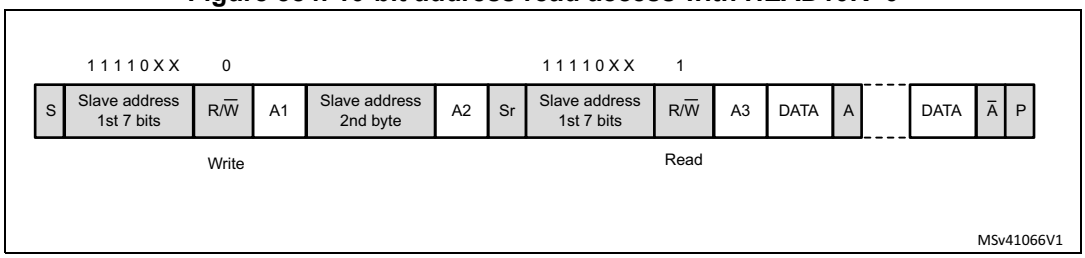
Figure 583. Master initialization flowchart



Initialization of a master receiver addressing a 10-bit address slave

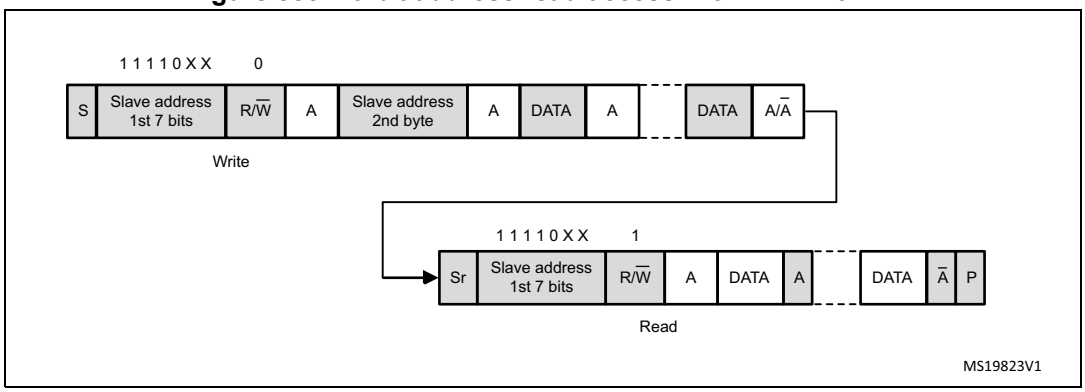
- If the slave address is in 10-bit format, the user can choose to send the complete read sequence by clearing the HEAD10R bit in the I2C_CR2 register. In this case the master automatically sends the following complete sequence after the START bit is set: (Re)Start + Slave address 10-bit header Write + Slave address 2nd byte + REStart + Slave address 10-bit header Read

Figure 584. 10-bit address read access with HEAD10R=0



- If the master addresses a 10-bit address slave, transmits data to this slave and then reads data from the same slave, a master transmission flow must be done first. Then a repeated start is set with the 10 bit slave address configured with HEAD10R=1. In this case the master sends this sequence: ReStart + Slave address 10-bit header Read.

Figure 585. 10-bit address read access with HEAD10R=1



Master transmitter

In the case of a write transfer, the TXIS flag is set after each byte transmission, after the 9th SCL pulse when an ACK is received.

A TXIS event generates an interrupt if the TXIE bit is set in the I2C_CR1 register. The flag is cleared when the I2C_TXDR register is written with the next data byte to be transmitted.

The number of TXIS events during the transfer corresponds to the value programmed in NBYTES[7:0]. If the total number of data bytes to be sent is greater than 255, reload mode must be selected by setting the RELOAD bit in the I2C_CR2 register. In this case, when NBYTES data have been transferred, the TCR flag is set and the SCL line is stretched low until NBYTES[7:0] is written to a non-zero value.

The TXIS flag is not set when a NACK is received.

- When RELOAD=0 and NBYTES data have been transferred:
  - In automatic end mode (AUTOEND=1), a STOP is automatically sent.
  - In software end mode (AUTOEND=0), the TC flag is set and the SCL line is stretched low in order to perform software actions:

    A RESTART condition can be requested by setting the START bit in the I2C_CR2 register with the proper slave address configuration, and number of bytes to be transferred. Setting the START bit clears the TC flag and the START condition is sent on the bus.

    A STOP condition can be requested by setting the STOP bit in the I2C_CR2 register. Setting the STOP bit clears the TC flag and the STOP condition is sent on the bus.
- If a NACK is received: the TXIS flag is not set, and a STOP condition is automatically sent after the NACK reception. the NACKF flag is set in the I2C_ISR register, and an interrupt is generated if the NACKIE bit is set.

Figure 586. Transfer sequence flowchart for I2C master transmitter for N≤255 bytes

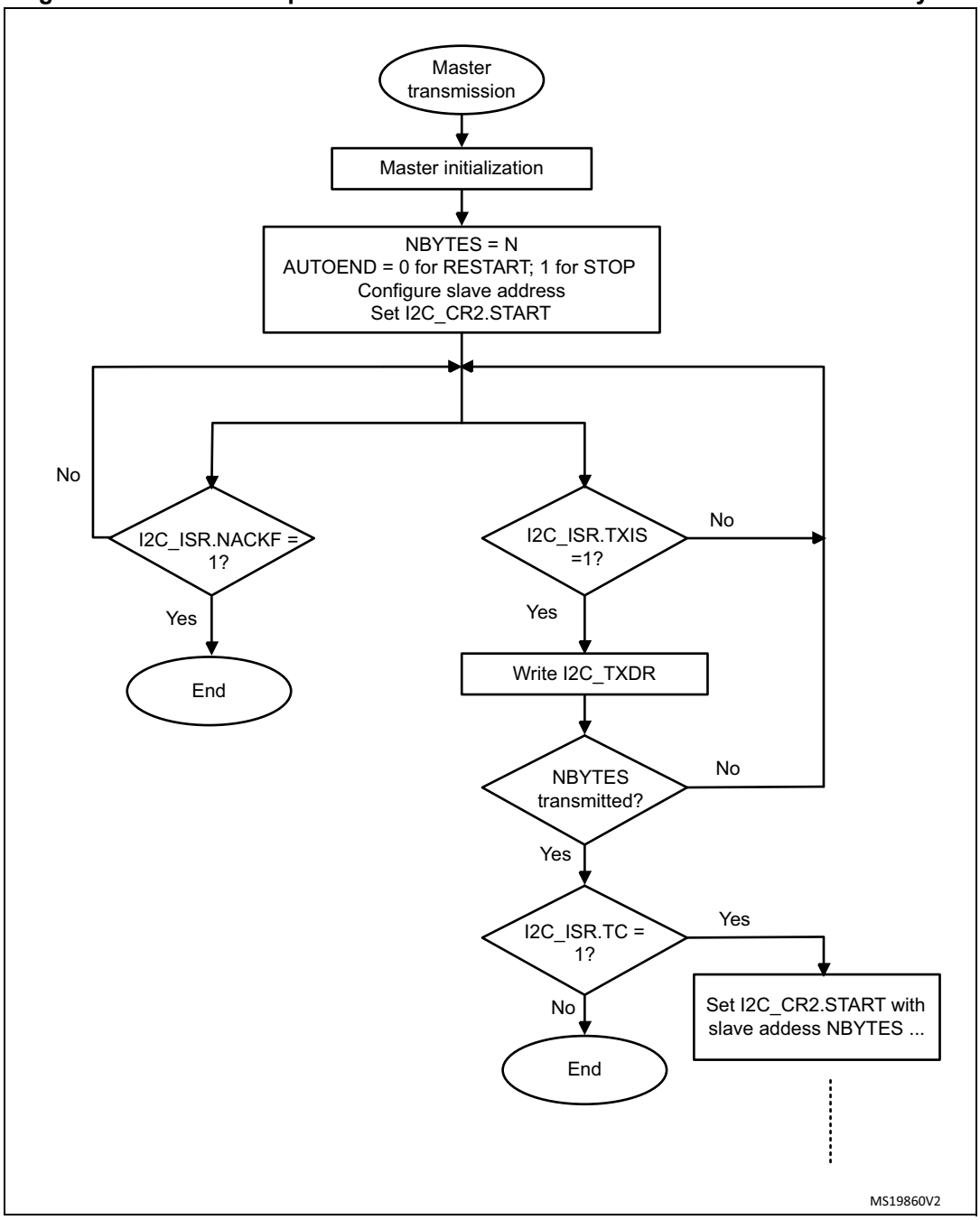


Figure 587. Transfer sequence flowchart for I2C master transmitter for N>255 bytes

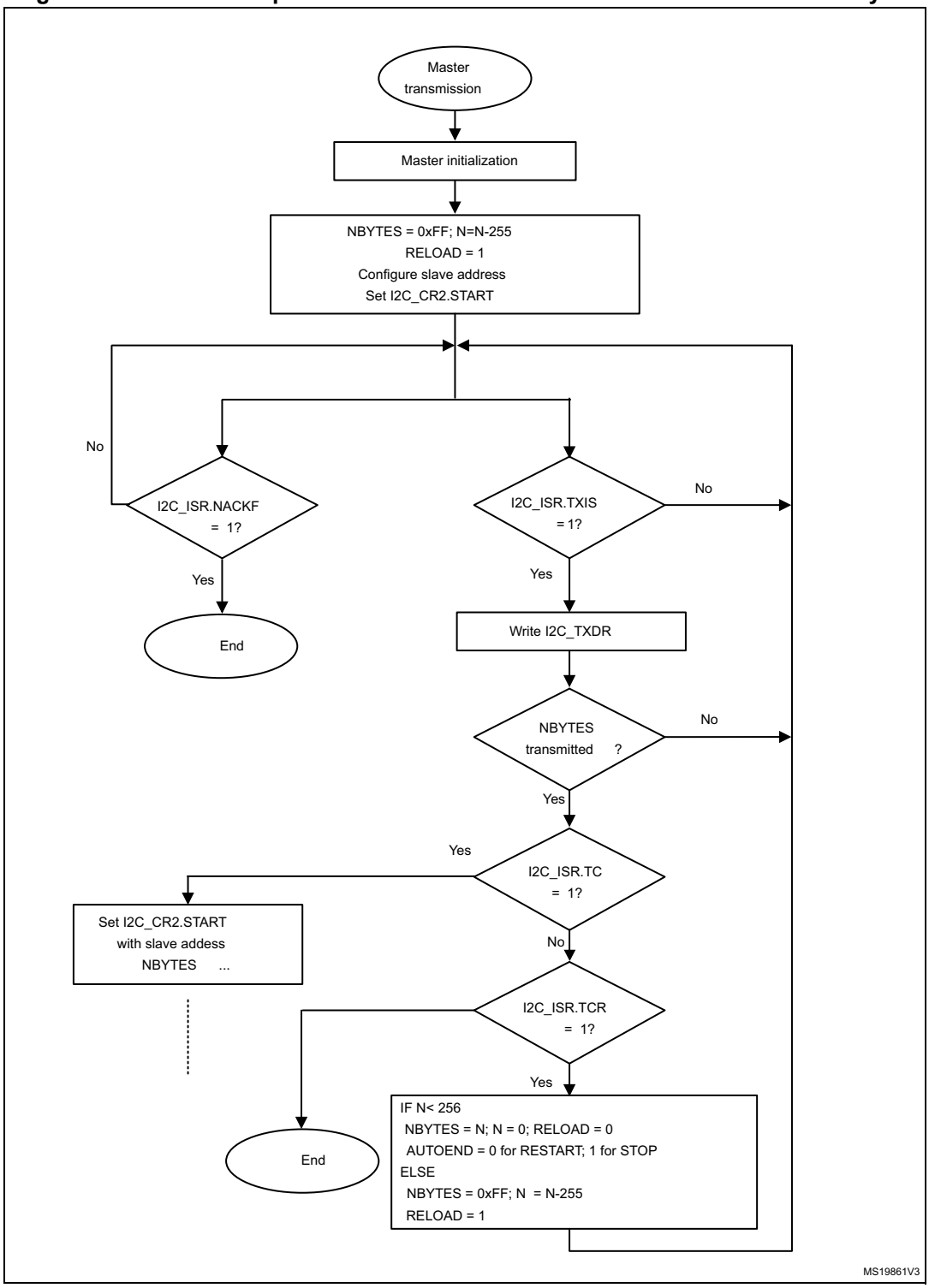
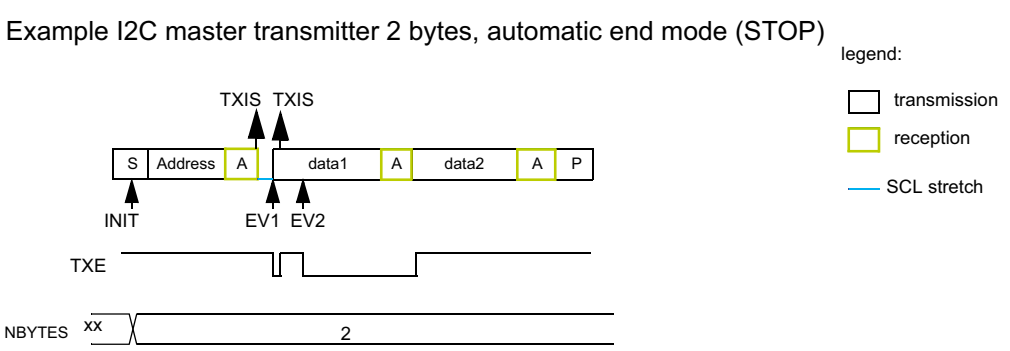


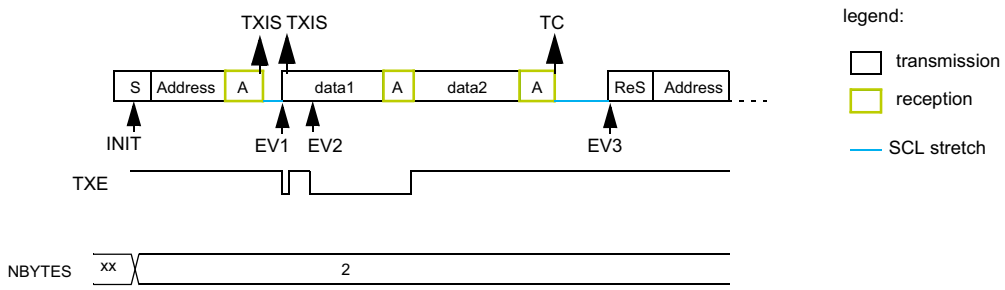
Figure 588. Transfer bus diagrams for I2C master transmitter

Example I2C master transmitter 2 bytes, automatic end mode (STOP)



INIT: program Slave address, program NBYTES = 2, AUTOEND=1, set START
EV1: TXIS ISR: wr data1
EV2: TXIS ISR: wr data2

Example I2C master transmitter 2 bytes, software end mode (RESTART)



INIT: program Slave address, program NBYTES = 2, AUTOEND=0, set START
EV1: TXIS ISR: wr data1
EV2: TXIS ISR: wr data2
EV3: TC ISR: program Slave address, program NBYTES = N, set START

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Master receiver

In the case of a read transfer, the RXNE flag is set after each byte reception, after the 8th SCL pulse. An RXNE event generates an interrupt if the RXIE bit is set in the I2C_CR1 register. The flag is cleared when I2C_RXDR is read.

If the total number of data bytes to be received is greater than 255, reload mode must be selected by setting the RELOAD bit in the I2C_CR2 register. In this case, when NBYTES[7:0] data have been transferred, the TCR flag is set and the SCL line is stretched low until NBYTES[7:0] is written to a non-zero value.

- When RELOAD=0 and NBYTES[7:0] data have been transferred:
  - In automatic end mode (AUTOEND=1), a NACK and a STOP are automatically sent after the last received byte.
  - In software end mode (AUTOEND=0), a NACK is automatically sent after the last received byte, the TC flag is set and the SCL line is stretched low in order to allow software actions:

    A RESTART condition can be requested by setting the START bit in the I2C_CR2 register with the proper slave address configuration, and number of bytes to be transferred. Setting the START bit clears the TC flag and the START condition, followed by slave address, are sent on the bus.

    A STOP condition can be requested by setting the STOP bit in the I2C_CR2 register. Setting the STOP bit clears the TC flag and the STOP condition is sent on the bus.

Figure 589. Transfer sequence flowchart for I2C master receiver for N≤255 bytes

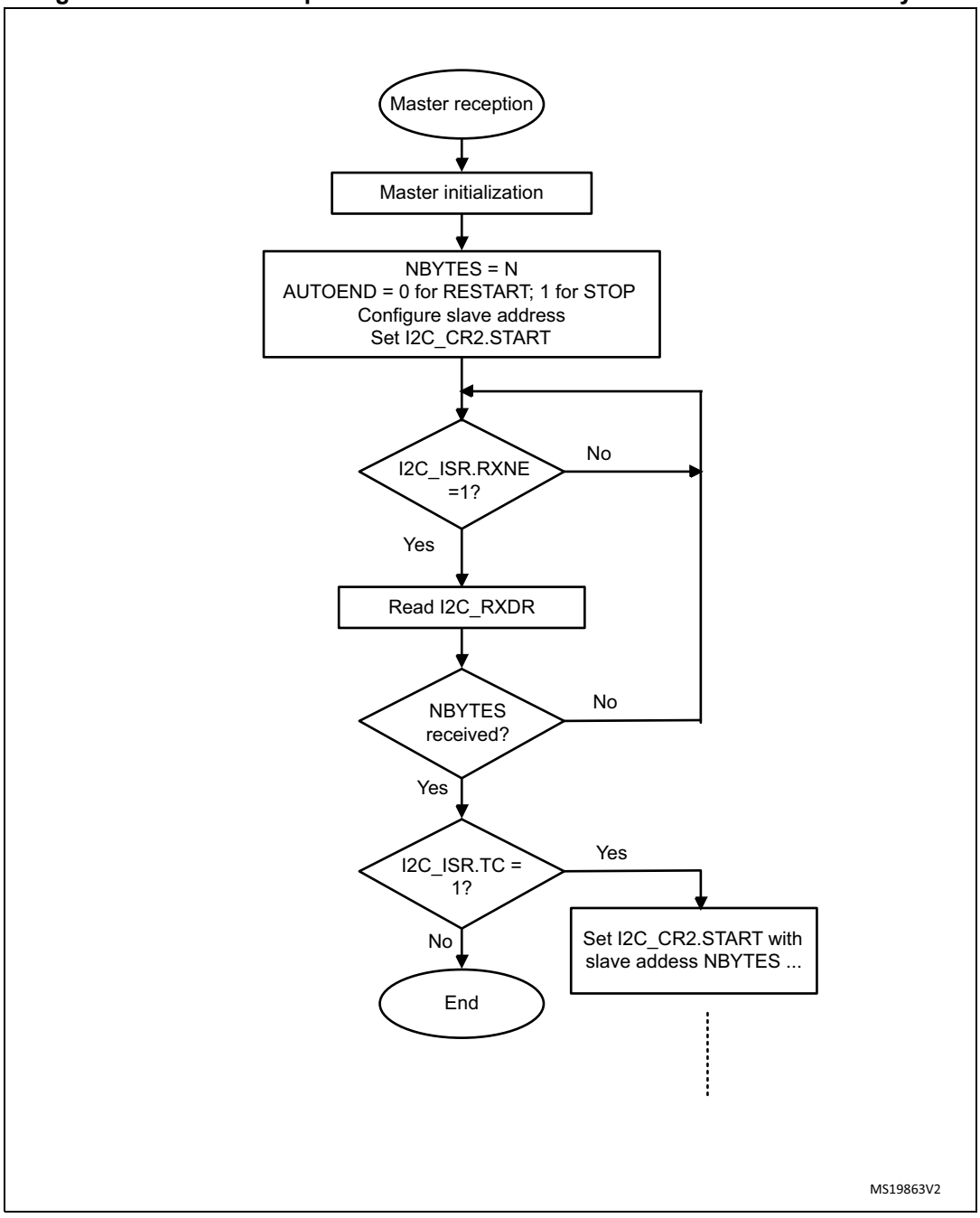


Figure 590. Transfer sequence flowchart for I2C master receiver for N >255 bytes

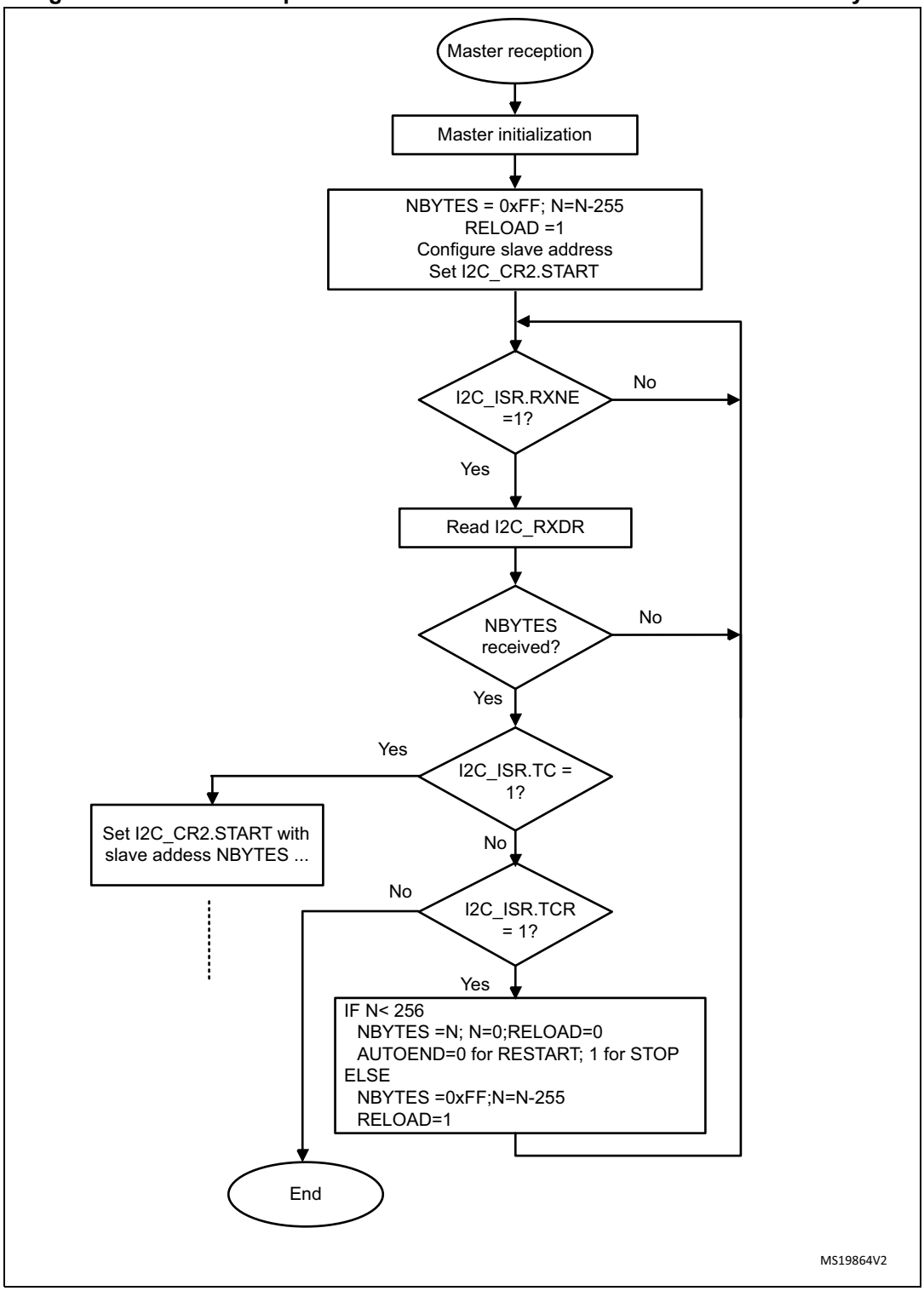
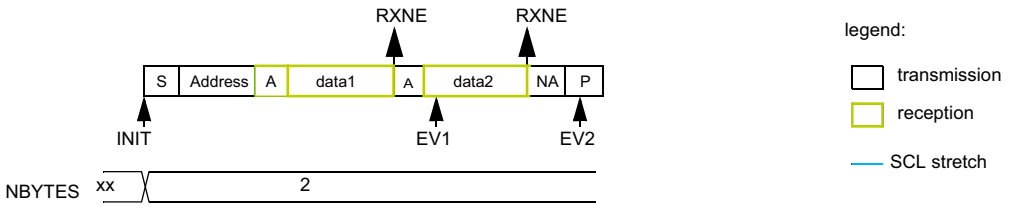


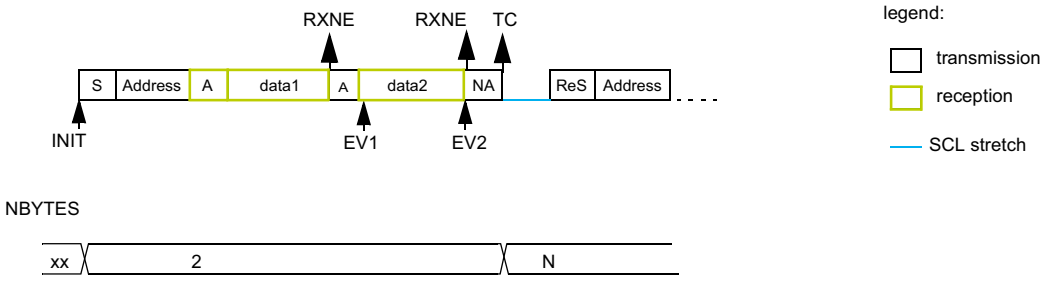
Figure 591. Transfer bus diagrams for I2C master receiver

Example I2C master receiver 2 bytes, automatic end mode (STOP)



INIT: program Slave address, program NBYTES = 2, AUTOEND=1, set START
EV1: RXNE ISR: rd data1
EV2: RXNE ISR: rd data2

Example I2C master receiver 2 bytes, software end mode (RESTART)



INIT: program Slave address, program NBYTES = 2, AUTOEND=0, set START
EV1: RXNE ISR: rd data1
EV2: RXNE ISR: read data2
EV3: TC ISR: program Slave address, program NBYTES = N, set START

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52.4.10 I2C_TIMINGR register configuration examples

The tables below provide examples of how to program the I2C_TIMINGR to obtain timings compliant with the I^2C specification. In order to get more accurate configuration values, the STM32CubeMX tool (I2C Configuration window) must be used.

Table 407. Examples of timing settings for f_{I2CCLK} = 8 MHz

Parameter	Standard-mode (Sm)		Fast-mode (Fm)	Fast-mode Plus (Fm+)
	10 kHz	100 kHz	400 kHz	500 kHz
PRESC	1	1	0	0
SCLL	0xC7	0x13	0x9	0x6
t_{SCLL}	200 x 250 ns = 50 µs	20 x 250 ns = 5.0 µs	10 x 125 ns = 1250 ns	7 x 125 ns = 875 ns
SCLH	0xC3	0xF	0x3	0x3
t_{SCLH}	196 x 250 ns = 49 µs	16 x 250 ns = 4.0µs	4 x 125 ns = 500 ns	4 x 125 ns = 500 ns
t_{SCL}(1)	~100 µs(2)	~10 µs(2)	~2500 ns(3)	~2000 ns(4)
SDADEL	0x2	0x2	0x1	0x0
t_{SDADEL}	2 x 250 ns = 500 ns	2 x 250 ns = 500 ns	1 x 125 ns = 125 ns	0 ns
SCLDEL	0x4	0x4	0x3	0x1
t_{SCLDEL}	5 x 250 ns = 1250 ns	5 x 250 ns = 1250 ns	4 x 125 ns = 500 ns	2 x 125 ns = 250 ns

1. SCL period t_{SCL} is greater than t_{SCLL} + t_{SCLH} due to SCL internal detection delay. Values provided for t_{SCL} are examples only.
2. t_{SYNC1} + t_{SYNC2} minimum value is 4 x t_{I2CCLK} = 500 ns. Example with t_{SYNC1} + t_{SYNC2} = 1000 ns.
3. t_{SYNC1} + t_{SYNC2} minimum value is 4 x t_{I2CCLK} = 500 ns. Example with t_{SYNC1} + t_{SYNC2} = 750 ns.
4. t_{SYNC1} + t_{SYNC2} minimum value is 4 x t_{I2CCLK} = 500 ns. Example with t_{SYNC1} + t_{SYNC2} = 655 ns.

Table 408. Examples of timings settings for f_{I2CCLK} = 16 MHz

Parameter	Standard-mode (Sm)		Fast-mode (Fm)	Fast-mode Plus (Fm+)
	10 kHz	100 kHz	400 kHz	1000 kHz
PRESC	3	3	1	0
SCLL	0xC7	0x13	0x9	0x4
t_{SCLL}	200 x 250 ns = 50 µs	20 x 250 ns = 5.0 µs	10 x 125 ns = 1250 ns	5 x 62.5 ns = 312.5 ns
SCLH	0xC3	0xF	0x3	0x2
t_{SCLH}	196 x 250 ns = 49 µs	16 x 250 ns = 4.0 µs	4 x 125 ns = 500 ns	3 x 62.5 ns = 187.5 ns
t_{SCL}(1)	~100 µs(2)	~10 µs(2)	~2500 ns(3)	~1000 ns(4)
SDADEL	0x2	0x2	0x2	0x0
t_{SDADEL}	2 x 250 ns = 500 ns	2 x 250 ns = 500 ns	2 x 125 ns = 250 ns	0 ns
SCLDEL	0x4	0x4	0x3	0x2
t_{SCLDEL}	5 x 250 ns = 1250 ns	5 x 250 ns = 1250 ns	4 x 125 ns = 500 ns	3 x 62.5 ns = 187.5 ns

1. SCL period t_{SCL} is greater than t_{SCLL} + t_{SCLH} due to SCL internal detection delay. Values provided for t_{SCL} are examples only.

2. $t_{SYNC1} + t_{SYNC2}$ minimum value is 4 x t_{I2CCLK} = 250 ns. Example with $t_{SYNC1} + t_{SYNC2}$ = 1000 ns.
3. $t_{SYNC1} + t_{SYNC2}$ minimum value is 4 x t_{I2CCLK} = 250 ns. Example with $t_{SYNC1} + t_{SYNC2}$ = 750 ns.
4. $t_{SYNC1} + t_{SYNC2}$ minimum value is 4 x t_{I2CCLK} = 250 ns. Example with $t_{SYNC1} + t_{SYNC2}$ = 500 ns.

Table 409. Examples of timings settings for f_{I2CCLK} = 48 MHz

Parameter	Standard-mode (Sm)		Fast-mode (Fm)	Fast-mode Plus (Fm+)
	10 kHz	100 kHz	400 kHz	1000 kHz
PRESC	0xB	0xB	5	5
SCLL	0xC7	0x13	0x9	0x3
t_{SCLL}	200 x 250 ns = 50 µs	20 x 250 ns = 5.0 µs	10 x 125 ns = 1250 ns	4 x 125 ns = 500 ns
SCLH	0xC3	0xF	0x3	0x1
t_{SCLH}	196 x 250 ns = 49 µs	16 x 250 ns = 4.0 µs	4 x 125 ns = 500 ns	2 x 125 ns = 250 ns
t_{SCL} (1)	~100 µs(2)	~10 µs(2)	~2500 ns(3)	~875 ns(4)
SDADEL	0x2	0x2	0x3	0x0
t_{SDADEL}	2 x 250 ns = 500 ns	2 x 250 ns = 500 ns	3 x 125 ns = 375 ns	0 ns
SCLDEL	0x4	0x4	0x3	0x1
t_{SCLDEL}	5 x 250 ns = 1250 ns	5 x 250 ns = 1250 ns	4 x 125 ns = 500 ns	2 x 125 ns = 250 ns

1. The SCL period t_{SCL} is greater than t_{SCLL} + t_{SCLH} due to the SCL internal detection delay. Values provided for t_{SCL} are only examples.
2. $t_{SYNC1} + t_{SYNC2}$ minimum value is 4x t_{I2CCLK} = 83.3 ns. Example with $t_{SYNC1} + t_{SYNC2}$ = 1000 ns
3. $t_{SYNC1} + t_{SYNC2}$ minimum value is 4x t_{I2CCLK} = 83.3 ns. Example with $t_{SYNC1} + t_{SYNC2}$ = 750 ns
4. $t_{SYNC1} + t_{SYNC2}$ minimum value is 4x t_{I2CCLK} = 83.3 ns. Example with $t_{SYNC1} + t_{SYNC2}$ = 250 ns

52.4.11 SMBus specific features

This section is relevant only when SMBus feature is supported. Refer to *Section 52.3: I2C implementation*.

Introduction

The system management bus (SMBus) is a two-wire interface through which various devices can communicate with each other and with the rest of the system. It is based on I^2C principles of operation. The SMBus provides a control bus for system and power management related tasks.

This peripheral is compatible with the SMBus specification (http://smbus.org).

The System Management Bus Specification refers to three types of devices.

- A slave is a device that receives or responds to a command.
- A master is a device that issues commands, generates the clocks and terminates the transfer.
- A host is a specialized master that provides the main interface to the system's CPU. A host must be a master-slave and must support the SMBus host notify protocol. Only one host is allowed in a system.

This peripheral can be configured as master or slave device, and also as a host.

Bus protocols

There are eleven possible command protocols for any given device. A device may use any or all of the eleven protocols to communicate. The protocols are Quick Command, Send Byte, Receive Byte, Write Byte, Write Word, Read Byte, Read Word, Process Call, Block Read, Block Write and Block Write-Block Read Process Call. These protocols should be implemented by the user software.

For more details of these protocols, refer to SMBus specification (http://smbus.org).

Address resolution protocol (ARP)

SMBus slave address conflicts can be resolved by dynamically assigning a new unique address to each slave device. In order to provide a mechanism to isolate each device for the purpose of address assignment each device must implement a unique device identifier (UDID). This 128-bit number is implemented by software.

This peripheral supports the Address Resolution Protocol (ARP). The SMBus Device Default Address (0b1100 001) is enabled by setting SMBDEN bit in I2C_CR1 register. The ARP commands should be implemented by the user software.

Arbitration is also performed in slave mode for ARP support.

For more details of the SMBus address resolution protocol, refer to SMBus specification (http://smbus.org).

Received command and data acknowledge control

A SMBus receiver must be able to NACK each received command or data. In order to allow the ACK control in slave mode, the Slave Byte Control mode must be enabled by setting SBC bit in I2C_CR1 register. Refer to *Slave byte control mode on page 2002* for more details.

Host notify protocol

This peripheral supports the host notify protocol by setting the SMBHEN bit in the I2C_CR1 register. In this case the host acknowledges the SMBus host address (0b0001 000).

When this protocol is used, the device acts as a master and the host as a slave.

SMBus alert

The SMBus ALERT optional signal is supported. A slave-only device can signal the host through the SMBALERT# pin that it wants to talk. The host processes the interrupt and simultaneously accesses all SMBALERT# devices through the alert response address (0b0001 100). Only the device(s) which pulled SMBALERT# low acknowledges the alert response address.

When configured as a slave device(SMBHEN=0), the SMBA pin is pulled low by setting the ALERTEN bit in the I2C_CR1 register. The Alert Response Address is enabled at the same time.

When configured as a host (SMBHEN=1), the ALERT flag is set in the I2C_ISR register when a falling edge is detected on the SMBA pin and ALERTEN=1. An interrupt is generated if the ERRIE bit is set in the I2C_CR1 register. When ALERTEN=0, the ALERT line is considered high even if the external SMBA pin is low.

If the SMBus ALERT pin is not needed, the SMBA pin can be used as a standard GPIO if ALERTEN=0.

Packet error checking

A packet error checking mechanism has been introduced in the SMBus specification to improve reliability and communication robustness. The packet error checking is implemented by appending a packet error code (PEC) at the end of each message transfer. The PEC is calculated by using the $C(x) = x_8 + x^2 + x + 1$ CRC-8 polynomial on all the message bytes (including addresses and read/write bits).

The peripheral embeds a hardware PEC calculator and allows a not acknowledge to be sent automatically when the received byte does not match with the hardware calculated PEC.

Timeouts

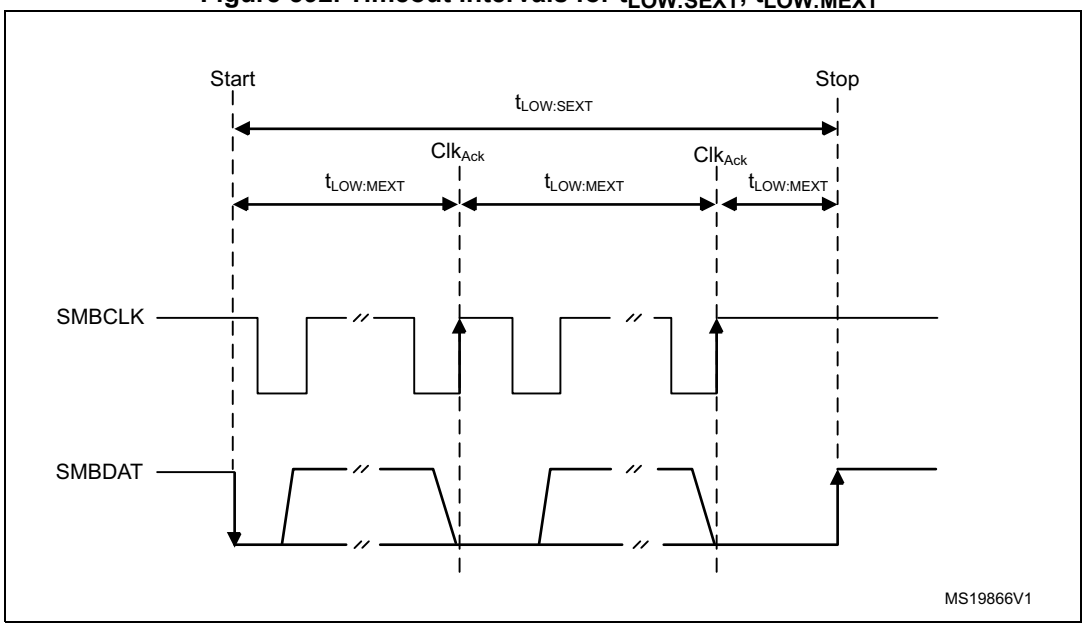
This peripheral embeds hardware timers in order to be compliant with the 3 timeouts defined in SMBus specification.

Table 410. SMBus timeout specifications

Symbol	Parameter	Limits		Unit
		Min	Max	
$t_{TIMEOUT}$	Detect clock low timeout	25	35	ms
$t_{LOW:SEXT}$(1)	Cumulative clock low extend time (slave device)	-	25	ms
$t_{LOW:MEXT}$(2)	Cumulative clock low extend time (master device)	-	10	ms

1. $t_{LOW:SEXT}$ is the cumulative time a given slave device is allowed to extend the clock cycles in one message from the initial START to the STOP. It is possible that, another slave device or the master also extends the clock causing the combined clock low extend time to be greater than $t_{LOW:SEXT}$. Therefore, this parameter is measured with the slave device as the sole target of a full-speed master.
2. $t_{LOW:MEXT}$ is the cumulative time a master device is allowed to extend its clock cycles within each byte of a message as defined from START-to-ACK, ACK-to-ACK, or ACK-to-STOP. It is possible that a slave device or another master also extends the clock causing the combined clock low time to be greater than $t_{LOW:MEXT}$ on a given byte. Therefore, this parameter is measured with a full speed slave device as the sole target of the master.

Figure 592. Timeout intervals for $t_{LOW:SEXT}$, $t_{LOW:MEXT}$



Bus idle detection

A master can assume that the bus is free if it detects that the clock and data signals have been high for t_{IDLE} greater than $t_{HIGH,MAX}$. (refer to *Table 404: I2C-SMBus specification data setup and hold times*)

This timing parameter covers the condition where a master has been dynamically added to the bus and may not have detected a state transition on the SMBCLK or SMBDAT lines. In this case, the master must wait long enough to ensure that a transfer is not currently in progress. The peripheral supports a hardware bus idle detection.

52.4.12 SMBus initialization

This section is relevant only when SMBus feature is supported. Refer to *Section 52.3: I2C implementation*.

In addition to I2C initialization, some other specific initialization must be done in order to perform SMBus communication:

Received command and data acknowledge control (Slave mode)

A SMBus receiver must be able to NACK each received command or data. In order to allow ACK control in slave mode, the Slave byte control mode must be enabled by setting the SBC bit in the I2C_CR1 register. Refer to *Slave byte control mode on page 2002* for more details.

Specific address (Slave mode)

The specific SMBus addresses must be enabled if needed. Refer to *Bus idle detection on page 2025* for more details.

- The SMBus device default address (0b1100 001) is enabled by setting the SMBDEN bit in the I2C_CR1 register.
- The SMBus host address (0b0001 000) is enabled by setting the SMBHEN bit in the I2C_CR1 register.
- The alert response address (0b0001100) is enabled by setting the ALERTEN bit in the I2C_CR1 register.

Packet error checking

PEC calculation is enabled by setting the PECEN bit in the I2C_CR1 register. Then the PEC transfer is managed with the help of a hardware byte counter: NBYTES[7:0] in the I2C_CR2 register. The PECEN bit must be configured before enabling the I2C.

The PEC transfer is managed with the hardware byte counter, so the SBC bit must be set when interfacing the SMBus in slave mode. The PEC is transferred after NBYTES-1 data have been transferred when the PECBYTE bit is set and the RELOAD bit is cleared. If RELOAD is set, PECBYTE has no effect.

Caution: Changing the PECEN configuration is not allowed when the I2C is enabled.

Table 411. SMBus with PEC configuration

Mode	SBC bit	RELOAD bit	AUTOEND bit	PECBYTE bit
Master Tx/Rx NBYTES + PEC+ STOP	x	0	1	1
Master Tx/Rx NBYTES + PEC + ReSTART	x	0	0	1
Slave Tx/Rx with PEC	1	0	x	1

Timeout detection

The timeout detection is enabled by setting the TIMOUTEN and TEXTEN bits in the I2C_TIMEOUTR register. The timers must be programmed in such a way that they detect a timeout before the maximum time given in the SMBus specification.

- $t_{TIMEOUT}$ check

  In order to enable the $t_{TIMEOUT}$ check, the 12-bit TIMEOUTA[11:0] bits must be programmed with the timer reload value in order to check the $t_{TIMEOUT}$ parameter. The TIDLE bit must be configured to ‘0’ in order to detect the SCL low level timeout.

  Then the timer is enabled by setting the TIMOUTEN in the I2C_TIMEOUTR register.

  If SCL is tied low for a time greater than (TIMEOUTA+1) x 2048 x t_{I2CCLK}, the TIMEOUT flag is set in the I2C_ISR register.

  Refer to *Table 412: Examples of TIMEOUTA settings for various i2c_ker_ck frequencies (max $t_{TIMEOUT}$ = 25 ms)*.

Caution: Changing the TIMEOUTA[11:0] bits and TIDLE bit configuration is not allowed when the TIMEOUTEN bit is set.

- $t_{LOW:SEXT}$ and $t_{LOW:MEXT}$ check

  Depending on if the peripheral is configured as a master or as a slave, The 12-bit TIMEOUTB timer must be configured in order to check $t_{LOW:SEXT}$ for a slave and $t_{LOW:MEXT}$ for a master. As the standard specifies only a maximum, the user can choose the same value for the both.

  Then the timer is enabled by setting the TEXTEN bit in the I2C_TIMEOUTR register.

  If the SMBus peripheral performs a cumulative SCL stretch for a time greater than (TIMEOUTB+1) x 2048 x t_{I2CCLK}, and in the timeout interval described in *Bus idle detection on page 2025* section, the TIMEOUT flag is set in the I2C_ISR register.

  Refer to *Table 413: Examples of TIMEOUTB settings for various i2c_ker_ck frequencies*

Caution: Changing the TIMEOUTB configuration is not allowed when the TEXTEN bit is set.

Bus idle detection

In order to enable the t_{IDLE} check, the 12-bit TIMEOUTA[11:0] field must be programmed with the timer reload value in order to obtain the t_{IDLE} parameter. The TIDLE bit must be configured to ‘1 in order to detect both SCL and SDA high level timeout.

Then the timer is enabled by setting the TIMOUTEN bit in the I2C_TIMEOUTR register.

If both the SCL and SDA lines remain high for a time greater than (TIMEOUTA+1) x 4 x t_{I2CCLK}, the TIMEOUT flag is set in the I2C_ISR register.

Refer to *Table 414: Examples of TIMEOUTA settings for various i2c_ker_ck frequencies (max t_{IDLE} = 50 µs)*

Caution: Changing the TIMEOUTA and TIDLE configuration is not allowed when the TIMEOUTEN is set.

52.4.13 SMBus: I2C_TIMEOUTR register configuration examples

This section is relevant only when SMBus feature is supported. Refer to *Section 52.3: I2C implementation*.

- Configuring the maximum duration of $t_{TIMEOUT}$ to 25 ms:

Table 412. Examples of TIMEOUTA settings for various i2c_ker_ck frequencies (max $t_{TIMEOUT}$ = 25 ms)

f_{I2CCLK}	TIMEOUTA[11:0] bits	TIDLE bit	TIMEOUTEN bit	$t_{TIMEOUT}$
8 MHz	0x61	0	1	98 x 2048 x 125 ns = 25 ms
16 MHz	0xC3	0	1	196 x 2048 x 62.5 ns = 25 ms
48 MHz	0x249	0	1	586 x 2048 x 20.08 ns = 25 ms

- Configuring the maximum duration of $t_{LOW:SEXT}$ and $t_{LOW:MEXT}$ to 8 ms:

Table 413. Examples of TIMEOUTB settings for various i2c_ker_ck frequencies

f_{I2CCLK}	TIMEOUTB[11:0] bits	TEXTEN bit	$t_{LOW:EXT}$
8 MHz	0x1F	1	32 x 2048 x 125 ns = 8 ms
16 MHz	0x3F	1	64 x 2048 x 62.5 ns = 8 ms
48 MHz	0xBB	1	188 x 2048 x 20.08 ns = 8 ms

- Configuring the maximum duration of t_{IDLE} to 50 µs

Table 414. Examples of TIMEOUTA settings for various i2c_ker_ck frequencies (max t_{IDLE} = 50 µs)

f_{I2CCLK}	TIMEOUTA[11:0] bits	TIDLE bit	TIMEOUTEN bit	t_{TIDLE}
8 MHz	0x63	1	1	100 x 4 x 125 ns = 50 µs
16 MHz	0xC7	1	1	200 x 4 x 62.5 ns = 50 µs
48 MHz	0x257	1	1	600 x 4 x 20.08 ns = 50 µs

52.4.14 SMBus slave mode

This section is relevant only when the SMBus feature is supported. Refer to *Section 52.3: I2C implementation*.

In addition to I2C slave transfer management (refer to *Section 52.4.8: I2C slave mode*) some additional software flowcharts are provided to support the SMBus.

SMBus slave transmitter

When the IP is used in SMBus, SBC must be programmed to ‘1’ in order to allow the PEC transmission at the end of the programmed number of data bytes. When the PECBYTE bit is set, the number of bytes programmed in NBYTES[7:0] includes the PEC transmission. In

that case the total number of TXIS interrupts is NBYTES-1 and the content of the I2C_PECR register is automatically transmitted if the master requests an extra byte after the NBYTES-1 data transfer.

Caution: The PECBYTE bit has no effect when the RELOAD bit is set.

Figure 593. Transfer sequence flowchart for SMBus slave transmitter N bytes + PEC

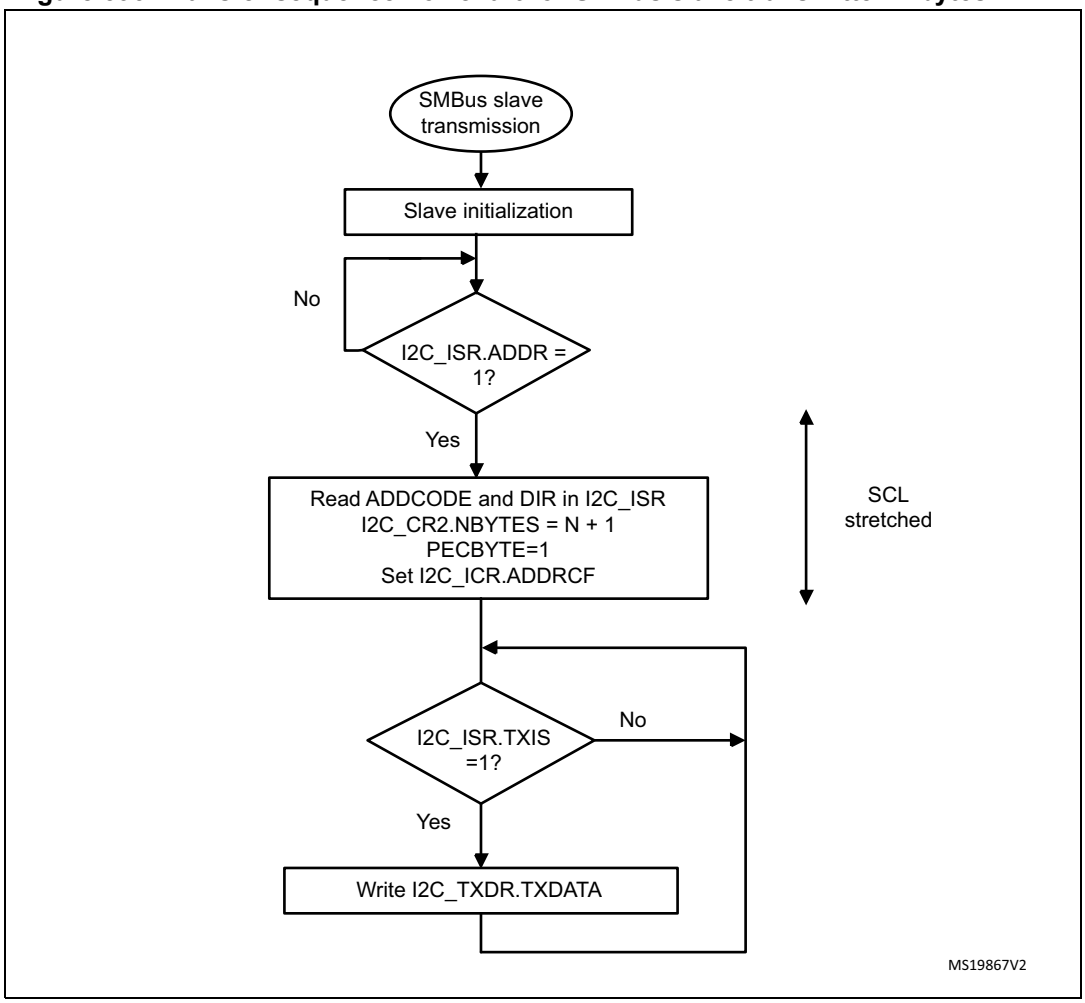
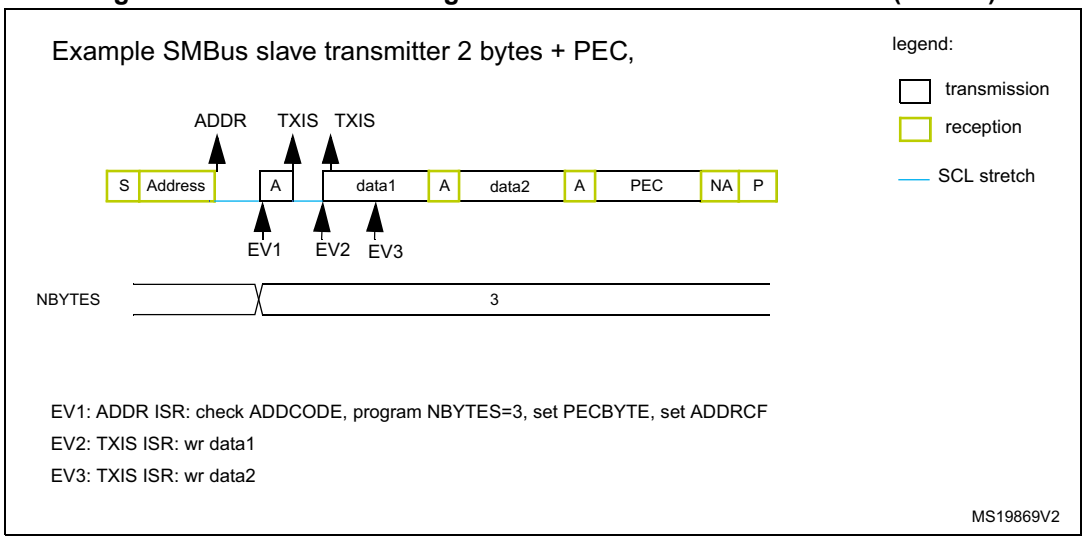


Figure 594. Transfer bus diagrams for SMBus slave transmitter (SBC=1)



SMBus Slave receiver

When the I2C is used in SMBus mode, SBC must be programmed to ‘1’ in order to allow the PEC checking at the end of the programmed number of data bytes. In order to allow the ACK control of each byte, the reload mode must be selected (RELOAD=1). Refer to *Slave byte control mode on page 2002* for more details.

In order to check the PEC byte, the RELOAD bit must be cleared and the PECBYTE bit must be set. In this case, after NBYTES-1 data have been received, the next received byte is compared with the internal I2C_PECR register content. A NACK is automatically generated if the comparison does not match, and an ACK is automatically generated if the comparison matches, whatever the ACK bit value. Once the PEC byte is received, it is copied into the I2C_RXDR register like any other data, and the RXNE flag is set.

In the case of a PEC mismatch, the PECERR flag is set and an interrupt is generated if the ERRIE bit is set in the I2C_CR1 register.

If no ACK software control is needed, the user can program PECBYTE=1 and, in the same write operation, program NBYTES with the number of bytes to be received in a continuous flow. After NBYTES-1 are received, the next received byte is checked as being the PEC.

Caution: The PECBYTE bit has no effect when the RELOAD bit is set.

Figure 595. Transfer sequence flowchart for SMBus slave receiver N Bytes + PEC

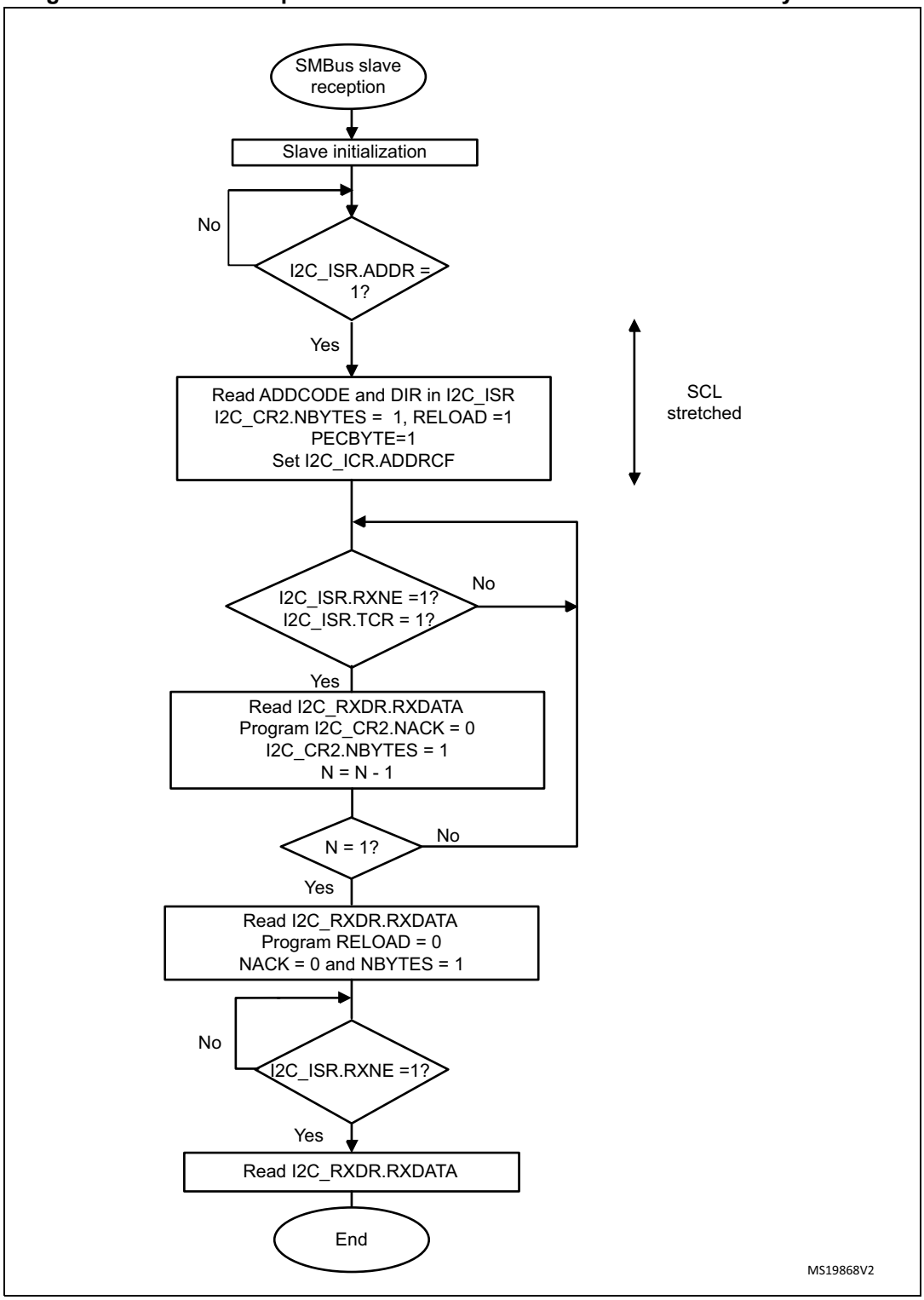
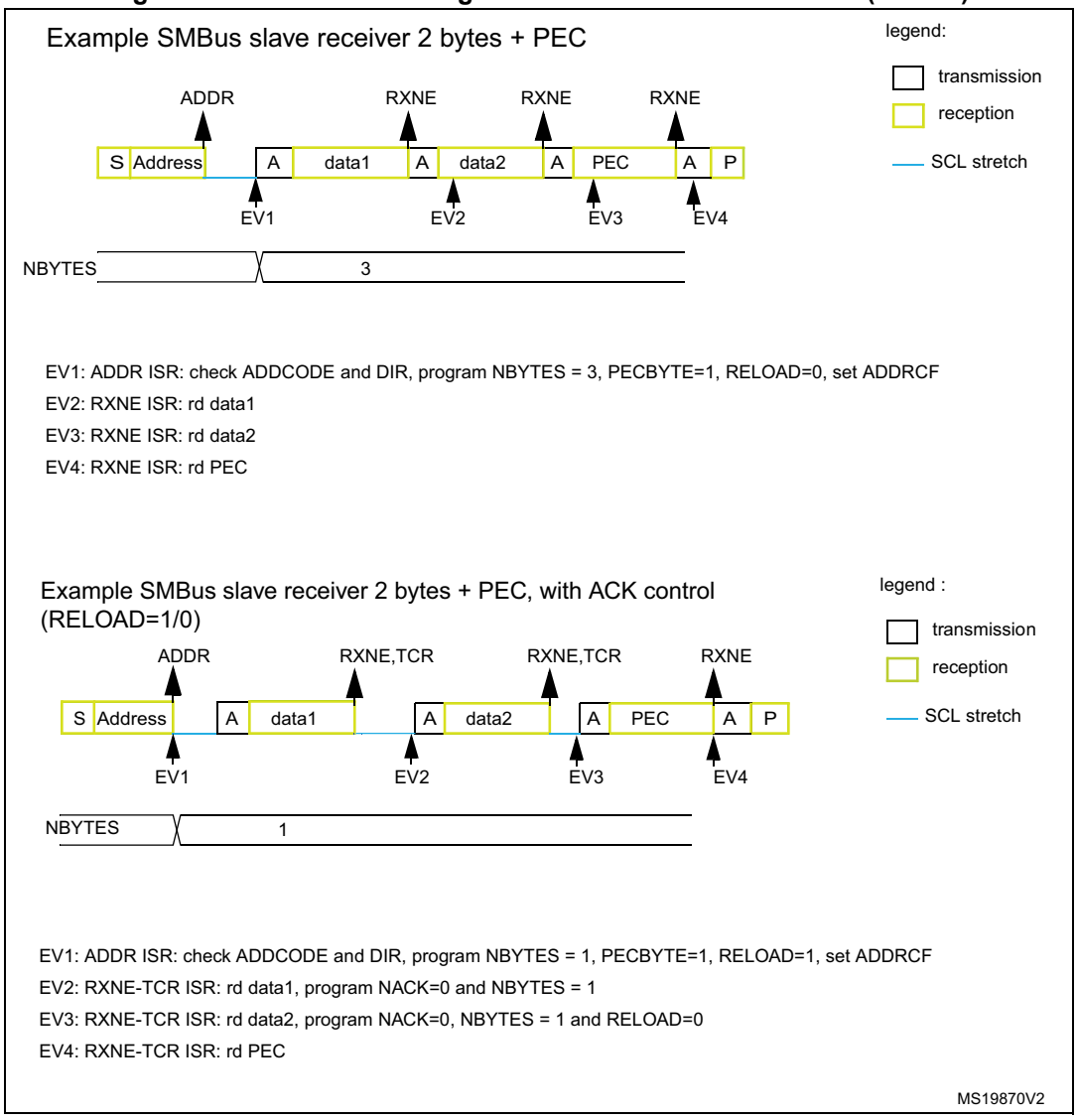


Figure 596. Bus transfer diagrams for SMBus slave receiver (SBC=1)



This section is relevant only when the SMBus feature is supported. Refer to *Section 52.3: I2C implementation*.

In addition to I2C master transfer management (refer to *Section 52.4.9: I2C master mode*) some additional software flowcharts are provided to support the SMBus.

SMBus master transmitter

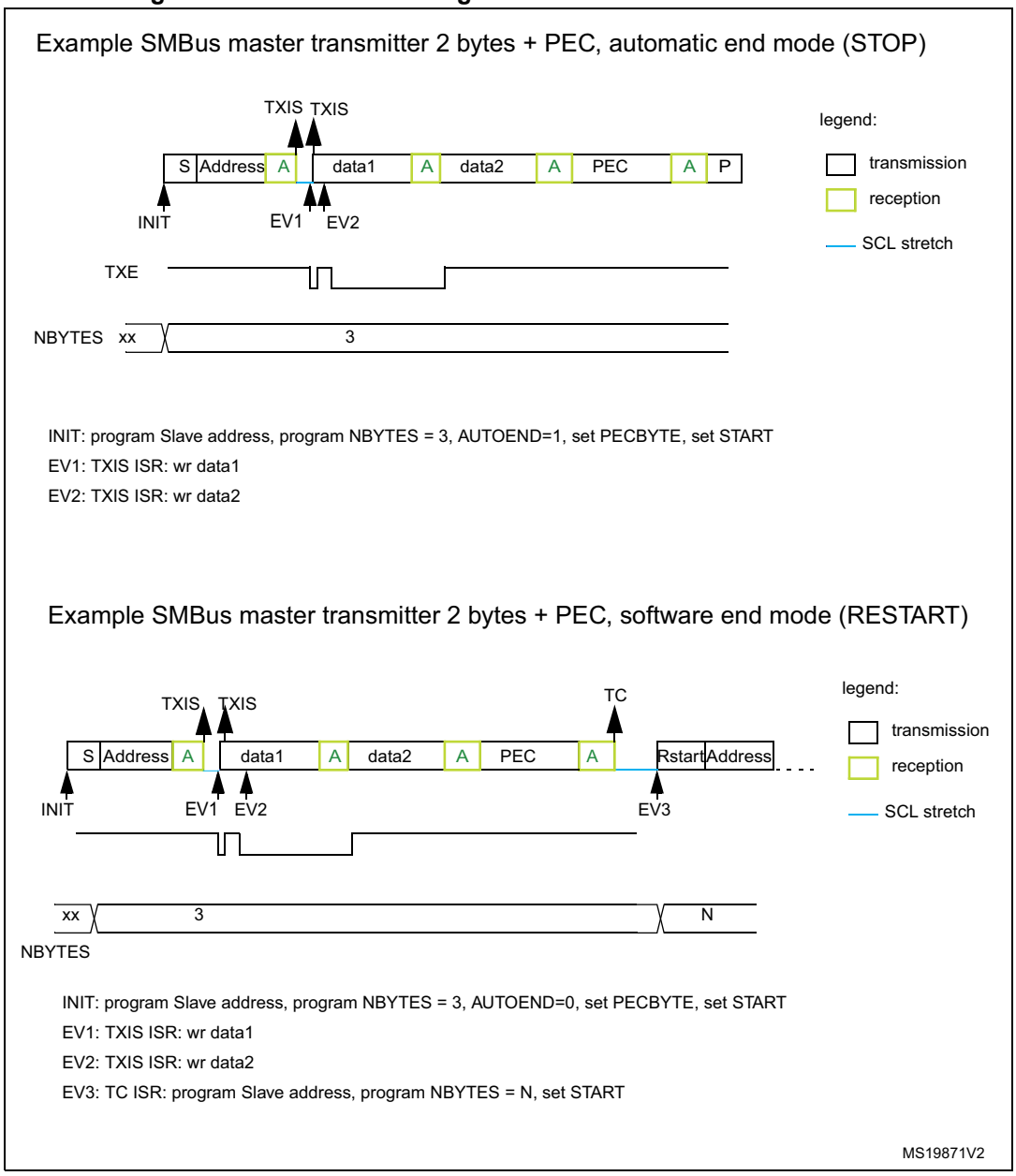
When the SMBus master wants to transmit the PEC, the PECBYTE bit must be set and the number of bytes must be programmed in the NBYTES[7:0] field, before setting the START bit. In this case the total number of TXIS interrupts is NBYTES-1. So if the PECBYTE bit is set when NBYTES=0x1, the content of the I2C_PECR register is automatically transmitted.

If the SMBus master wants to send a STOP condition after the PEC, automatic end mode must be selected (AUTOEND=1). In this case, the STOP condition automatically follows the PEC transmission.

When the SMBus master wants to send a RESTART condition after the PEC, software mode must be selected (AUTOEND=0). In this case, once NBYTES-1 have been transmitted, the I2C_PECR register content is transmitted and the TC flag is set after the PEC transmission, stretching the SCL line low. The RESTART condition must be programmed in the TC interrupt subroutine.

Caution: The PECBYTE bit has no effect when the RELOAD bit is set.

Figure 597. Bus transfer diagrams for SMBus master transmitter



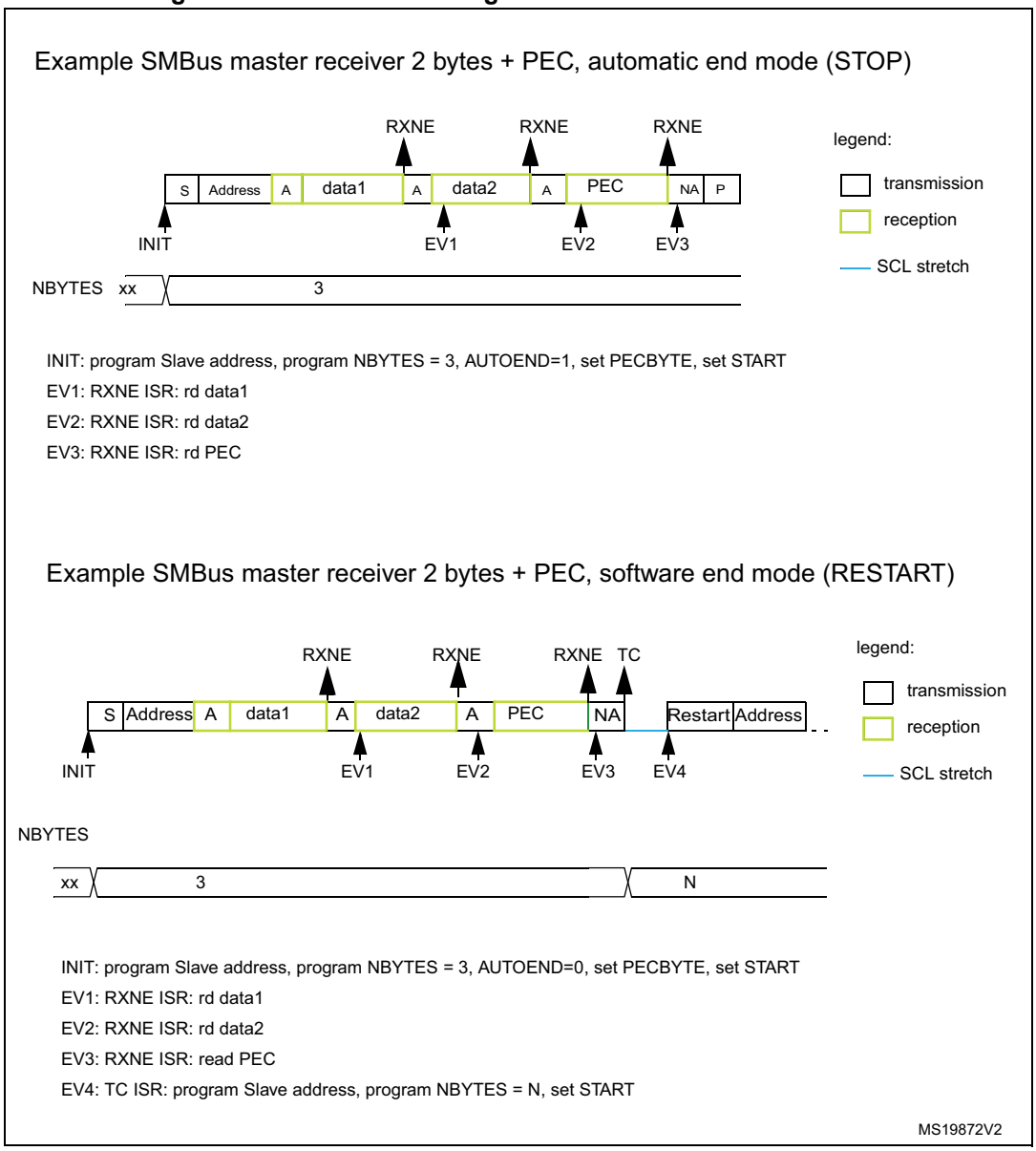
SMBus master receiver

When the SMBus master wants to receive the PEC followed by a STOP at the end of the transfer, automatic end mode can be selected (AUTOEND=1). The PECBYTE bit must be set and the slave address must be programmed, before setting the START bit. In this case, after NBYTES-1 data have been received, the next received byte is automatically checked versus the I2C_PECR register content. A NACK response is given to the PEC byte, followed by a STOP condition.

When the SMBus master receiver wants to receive the PEC byte followed by a RESTART condition at the end of the transfer, software mode must be selected (AUTOEND=0). The PECBYTE bit must be set and the slave address must be programmed, before setting the START bit. In this case, after NBYTES-1 data have been received, the next received byte is automatically checked versus the I2C_PECR register content. The TC flag is set after the PEC byte reception, stretching the SCL line low. The RESTART condition can be programmed in the TC interrupt subroutine.

Caution: The PECBYTE bit has no effect when the RELOAD bit is set.

Figure 598. Bus transfer diagrams for SMBus master receiver



52.4.15 Wakeup from Stop mode on address match

This section is relevant only when wakeup from Stop mode feature is supported. Refer to *Section 52.3: I2C implementation*.

The I2C is able to wakeup the MCU from Stop mode (APB clock is off), when it is addressed. All addressing modes are supported.

Wakeup from Stop mode is enabled by setting the WUPEN bit in the I2C_CR1 register. The HSI or CSI oscillator must be selected as the clock source for I2CCLK in order to allow wakeup from Stop mode.

During Stop mode, the HSI or CSI is switched off. When a START is detected, the I2C interface switches the HSI or CSI on, and stretches SCL low until HSI or CSI is woken up.

HSI or CSI is then used for the address reception.

In case of an address match, the I2C stretches SCL low during MCU wakeup time. The stretch is released when ADDR flag is cleared by software, and the transfer goes on normally.

If the address does not match, the HSI or CSI is switched off again and the MCU is not woken up.

Note: If the I2C clock is the system clock, or if WUPEN = 0, the HSI or CSI *is not switched on after a START is received.*

Only an ADDR interrupt can wakeup the MCU. Therefore do not enter Stop mode when the I2C is performing a transfer as a master, or as an addressed slave after the ADDR flag is set. This can be managed by clearing SLEEPDEEP bit in the ADDR interrupt routine and setting it again only after the STOPF flag is set.

Caution: The digital filter is not compatible with the wakeup from Stop mode feature. If the DNF bit is not equal to 0, setting the WUPEN bit has no effect.

Caution: This feature is available only when the I2C clock source is the HSI or CSI oscillator.

Caution: Clock stretching must be enabled (NOSTRETCH=0) to ensure proper operation of the wakeup from Stop mode feature.

Caution: If wakeup from Stop mode is disabled (WUPEN=0), the I2C peripheral must be disabled before entering Stop mode (PE=0).

52.4.16 Error conditions

The following errors are the error conditions which may cause communication to fail.

Bus error (BERR)

A bus error is detected when a START or a STOP condition is detected and is not located after a multiple of 9 SCL clock pulses. A START or a STOP condition is detected when a SDA edge occurs while SCL is high.

The bus error flag is set only if the I2C is involved in the transfer as master or addressed slave (i.e not during the address phase in slave mode).

In case of a misplaced START or RESTART detection in slave mode, the I2C enters address recognition state like for a correct START condition.

When a bus error is detected, the BERR flag is set in the I2C_ISR register, and an interrupt is generated if the ERRIE bit is set in the I2C_CR1 register.

Arbitration lost (ARLO)

An arbitration loss is detected when a high level is sent on the SDA line, but a low level is sampled on the SCL rising edge.

- In master mode, arbitration loss is detected during the address phase, data phase and data acknowledge phase. In this case, the SDA and SCL lines are released, the START control bit is cleared by hardware and the master switches automatically to slave mode.
- In slave mode, arbitration loss is detected during data phase and data acknowledge phase. In this case, the transfer is stopped, and the SCL and SDA lines are released.

When an arbitration loss is detected, the ARLO flag is set in the I2C_ISR register, and an interrupt is generated if the ERRIE bit is set in the I2C_CR1 register.

Overrun/underrun error (OVR)

An overrun or underrun error is detected in slave mode when NOSTRETCH=1 and:

- In reception when a new byte is received and the RXDR register has not been read yet. The new received byte is lost, and a NACK is automatically sent as a response to the new byte.
- In transmission:
  - When STOPF=1 and the first data byte should be sent. The content of the I2C_TXDR register is sent if TXE=0, 0xFF if not.
  - When a new byte must be sent and the I2C_TXDR register has not been written yet, 0xFF is sent.

When an overrun or underrun error is detected, the OVR flag is set in the I2C_ISR register, and an interrupt is generated if the ERRIE bit is set in the I2C_CR1 register.

Packet error checking error (PECERR)

This section is relevant only when the SMBus feature is supported. Refer to *Section 52.3: I2C implementation*.

A PEC error is detected when the received PEC byte does not match with the I2C_PECR register content. A NACK is automatically sent after the wrong PEC reception.

When a PEC error is detected, the PECERR flag is set in the I2C_ISR register, and an interrupt is generated if the ERRIE bit is set in the I2C_CR1 register.

Timeout Error (TIMEOUT)

This section is relevant only when the SMBus feature is supported. Refer to *Section 52.3: I2C implementation*.

A timeout error occurs for any of these conditions:

- TIDLE=0 and SCL remained low for the time defined in the TIMEOUTA[11:0] bits: this is used to detect a SMBus timeout.
- TIDLE=1 and both SDA and SCL remained high for the time defined in the TIMEOUTA [11:0] bits: this is used to detect a bus idle condition.
- Master cumulative clock low extend time reached the time defined in the TIMEOUTB[11:0] bits (SMBus $t_{LOW:MEXT}$ parameter)
- Slave cumulative clock low extend time reached the time defined in TIMEOUTB[11:0] bits (SMBus $t_{LOW:SEXT}$ parameter)

When a timeout violation is detected in master mode, a STOP condition is automatically sent.

When a timeout violation is detected in slave mode, SDA and SCL lines are automatically released.

When a timeout error is detected, the TIMEOUT flag is set in the I2C_ISR register, and an interrupt is generated if the ERRIE bit is set in the I2C_CR1 register.

Alert (ALERT)

This section is relevant only when the SMBus feature is supported. Refer to *Section 52.3: I2C implementation*.

The ALERT flag is set when the I2C interface is configured as a Host (SMBHEN=1), the alert pin detection is enabled (ALERTEN=1) and a falling edge is detected on the SMBA pin. An interrupt is generated if the ERRIE bit is set in the I2C_CR1 register.

52.4.17 DMA requests

Transmission using DMA

DMA (direct memory access) can be enabled for transmission by setting the TXDMAEN bit in the I2C_CR1 register. Data is loaded from an SRAM area configured using the DMA peripheral (see *Section 15: Direct memory access controller (DMA) on page 613*) to the I2C_TXDR register whenever the TXIS bit is set.

Only the data are transferred with DMA.

- In master mode: the initialization, the slave address, direction, number of bytes and START bit are programmed by software (the transmitted slave address cannot be transferred with DMA). When all data are transferred using DMA, the DMA must be initialized before setting the START bit. The end of transfer is managed with the NBYTES counter. Refer to *Master transmitter on page 2013*.
- In slave mode:
  - With NOSTRETCH=0, when all data are transferred using DMA, the DMA must be initialized before the address match event, or in ADDR interrupt subroutine, before clearing ADDR.
  - With NOSTRETCH=1, the DMA must be initialized before the address match event.
- For instances supporting SMBus: the PEC transfer is managed with NBYTES counter. Refer to *SMBus slave transmitter on page 2027* and *SMBus master transmitter on page 2031*.

Note: If DMA is used for transmission, the TXIE bit does not need to be enabled.

Reception using DMA

DMA (direct memory access) can be enabled for reception by setting the RXDMAEN bit in the I2C_CR1 register. Data is loaded from the I2C_RXDR register to an SRAM area configured using the DMA peripheral (refer to *Section 15: Direct memory access controller (DMA) on page 613*) whenever the RXNE bit is set. Only the data (including PEC) are transferred with DMA.

- In Master mode, the initialization, the slave address, direction, number of bytes and START bit are programmed by software. When all data are transferred using DMA, the

DMA must be initialized before setting the START bit. The end of transfer is managed with the NBYTES counter.

- In Slave mode with NOSTRETCH=0, when all data are transferred using DMA, the DMA must be initialized before the address match event, or in the ADDR interrupt subroutine, before clearing the ADDR flag.
- If SMBus is supported (see *Section 52.3: I2C implementation*): the PEC transfer is managed with the NBYTES counter. Refer to *SMBus Slave receiver on page 2029* and *SMBus master receiver on page 2033*.

Note: If DMA is used for reception, the RXIE bit does not need to be enabled.

52.4.18 Debug mode

When the microcontroller enters debug mode (core halted), the SMBus timeout either continues to work normally or stops, depending on the DBG_I2Cx_ configuration bits in the DBG module.

52.5 I2C low-power modes

Table 415. Effect of low-power modes on the I2C

Mode	Description
Sleep	No effect. I2C interrupts cause the device to exit the Sleep mode.
Stop(1)	The I2C registers content is kept. If WUPEN = 1 and I2C is clocked by an internal oscillator (HSI or CSI): the address recognition is functional. The I2C address match condition causes the device to exit the Stop mode. If WUPEN=0: the I2C must be disabled before entering Stop mode
Standby	The I2C peripheral is powered down and must be reinitialized after exiting Standby mode.

1. Refer to *Section 52.3: I2C implementation* for information about the Stop modes supported by each instance. If wakeup from a specific Stop mode is not supported, the instance must be disabled before entering this Stop mode.

52.6 I2C interrupts

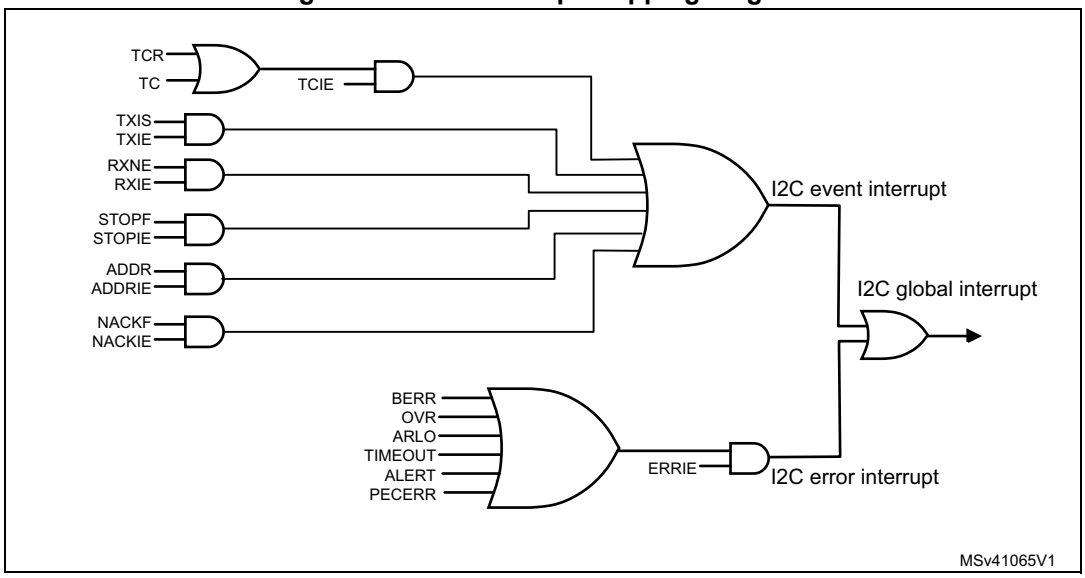
The table below gives the list of I2C interrupt requests.

Table 416. I2C Interrupt requests

Interrupt event	Event flag	Event flag/Interrupt clearing method	Interrupt enable control bit	Interrupt/Wakeup activated		
				i2c_event_it	i2c_error_it	i2c_wkup
Receive buffer not empty	RXNE	Read I2C_RXDR register	RXIE	Yes	No	No
Transmit buffer interrupt status	TXIS	Write I2C_TXDR register	TXIE			
Stop detection interrupt flag	STOPF	Write STOPCF=1	STOPIE			
Transfer Complete Reload	TCR	Write I2C_CR2 with NBYTES[7:0] ≠ 0	TCIE			
Transfer complete	TC	Write START=1 or STOP=1				
Address matched	ADDR	Write ADDRCF=1	ADDRIE			Yes(1)
NACK reception	NACKF	Write NACKCF=1	NACKIE			No
Bus error	BERR	Write BERRCF=1	ERRIE	N0	Yes	
Arbitration loss	ARLO	Write ARLOCF=1				
Overrun/Underrun	OVR	Write OVRCF=1				
PEC error	PECERR	Write PECERRCF=1				
Timeout/t_{LOW} error	TIMEOUT	Write TIMEOUTCF=1				
SMBus Alert	ALERT	Write ALERTCF=1				

1. If WUPEN is set.

Figure 599. I2C interrupt mapping diagram



52.7 I2C registers

Refer to *Section 1.2 on page 104* for a list of abbreviations used in register descriptions.

The peripheral registers are accessed by words (32-bit).

52.7.1 I2C control register 1 (I2C_CR1)

Address offset: 0x00

Reset value: 0x0000 0000

Access: No wait states, except if a write access occurs while a write access to this register is ongoing. In this case, wait states are inserted in the second write access until the previous one is completed. The latency of the second write access can be up to 2 x i2c_pclk + 6 x i2c_ker_ck.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PECEN	ALERT EN	SMBD EN	SMBH EN	GCEN	WUPE N	NOSTR ETCH	SBC
								rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXDMA EN	TXDMA EN	Res.	ANF OFF	DNF[3:0]				ERRIE	TCIE	STOP IE	NACK IE	ADDR IE	RXIE	TXIE	PE
rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **PECEN:** PEC enable

0: PEC calculation disabled

1: PEC calculation enabled

Note: If the SMBus feature is not supported, this bit is reserved and forced by hardware to '0'. Refer to Section 52.3: I2C implementation.

Bit 22 **ALERTEN**: SMBus alert enable

0: The SMBus alert pin (SMBA) is not supported in host mode (SMBHEN=1). In device mode (SMBHEN=0), the SMBA pin is released and the Alert Response Address header is disabled (0001100x followed by NACK).
1: The SMBus alert pin is supported in host mode (SMBHEN=1). In device mode (SMBHEN=0), the SMBA pin is driven low and the Alert Response Address header is enabled (0001100x followed by ACK).

Note: When ALERTEN=0, the SMBA pin can be used as a standard GPIO.
If the SMBus feature is not supported, this bit is reserved and forced by hardware to '0'. Refer to Section 52.3: I2C implementation.

Bit 21 **SMBDEN**: SMBus device default address enable

0: Device default address disabled. Address 0b1100001x is NACKed.
1: Device default address enabled. Address 0b1100001x is ACKed.

Note: If the SMBus feature is not supported, this bit is reserved and forced by hardware to '0'. Refer to Section 52.3: I2C implementation.

Bit 20 **SMBHEN**: SMBus host address enable

0: Host address disabled. Address 0b0001000x is NACKed.
1: Host address enabled. Address 0b0001000x is ACKed.

Note: If the SMBus feature is not supported, this bit is reserved and forced by hardware to '0'. Refer to Section 52.3: I2C implementation.

Bit 19 **GCEN**: General call enable

0: General call disabled. Address 0b00000000 is NACKed.
1: General call enabled. Address 0b00000000 is ACKed.

Bit 18 **WUPEN**: Wakeup from Stop mode enable

0: Wakeup from Stop mode disable.
1: Wakeup from Stop mode enable.

Note: If the Wakeup from Stop mode feature is not supported, this bit is reserved and forced by hardware to '0'. Refer to Section 52.3: I2C implementation.

Note: WUPEN can be set only when DNF = '0000'

Bit 17 **NOSTRETCH**: Clock stretching disable

This bit is used to disable clock stretching in slave mode. It must be kept cleared in master mode.
0: Clock stretching enabled
1: Clock stretching disabled

Note: This bit can only be programmed when the I2C is disabled (PE = 0).

Bit 16 **SBC**: Slave byte control

This bit is used to enable hardware byte control in slave mode.
0: Slave byte control disabled
1: Slave byte control enabled

Bit 15 **RXDMAEN**: DMA reception requests enable

0: DMA mode disabled for reception
1: DMA mode enabled for reception

Bit 14 **TXDMAEN**: DMA transmission requests enable

0: DMA mode disabled for transmission
1: DMA mode enabled for transmission

Bit 13 Reserved, must be kept at reset value.

Bit 12 **ANFOFF:** Analog noise filter OFF
0: Analog noise filter enabled
1: Analog noise filter disabled
Note: This bit can only be programmed when the I2C is disabled (PE = 0).

Bits 11:8 **DNF[3:0]**: Digital noise filter
These bits are used to configure the digital noise filter on SDA and SCL input. The digital filter, filters spikes with a length of up to DNF[3:0] * t_{I2CCLK}
0000: Digital filter disabled
0001: Digital filter enabled and filtering capability up to 1 t_{I2CCLK}
...
1111: digital filter enabled and filtering capability up to15 t_{I2CCLK}
Note: If the analog filter is also enabled, the digital filter is added to the analog filter.
This filter can only be programmed when the I2C is disabled (PE = 0).

Bit 7 **ERRIE**: Error interrupts enable
0: Error detection interrupts disabled
1: Error detection interrupts enabled
Note: Any of these errors generate an interrupt:
Arbitration Loss (ARLO)
Bus Error detection (BERR)
Overrun/Underrun (OVR)
Timeout detection (TIMEOUT)
PEC error detection (PECERR)
Alert pin event detection (ALERT)

Bit 6 **TCIE**: Transfer Complete interrupt enable
0: Transfer Complete interrupt disabled
1: Transfer Complete interrupt enabled
Note: Any of these events generate an interrupt:
Transfer Complete (TC)
Transfer Complete Reload (TCR)

Bit 5 **STOPIE**: Stop detection Interrupt enable
0: Stop detection (STOPF) interrupt disabled
1: Stop detection (STOPF) interrupt enabled

Bit 4 **NACKIE**: Not acknowledge received Interrupt enable
0: Not acknowledge (NACKF) received interrupts disabled
1: Not acknowledge (NACKF) received interrupts enabled

Bit 3 **ADDRIE**: Address match Interrupt enable (slave only)
0: Address match (ADDR) interrupts disabled
1: Address match (ADDR) interrupts enabled

Bit 2 **RXIE**: RX Interrupt enable
0: Receive (RXNE) interrupt disabled
1: Receive (RXNE) interrupt enabled

Bit 1 **TXIE**: TX Interrupt enable
0: Transmit (TXIS) interrupt disabled
1: Transmit (TXIS) interrupt enabled

Bit 0 **PE**: Peripheral enable
0: Peripheral disable
1: Peripheral enable
Note: When PE=0, the I2C SCL and SDA lines are released. Internal state machines and status bits are put back to their reset value. When cleared, PE must be kept low for at least 3 APB clock cycles.

52.7.2 I2C control register 2 (I2C_CR2)

Address offset: 0x04

Reset value: 0x0000 0000

Access: No wait states, except if a write access occurs while a write access to this register is ongoing. In this case, wait states are inserted in the second write access until the previous one is completed. The latency of the second write access can be up to 2 x i2c_pclk + 6 x i2c_ker_ck.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	PEC BYTE	AUTOEND	RELOAD	NBYTES[7:0]							
					rs	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NACK	STOP	START	HEAD10R	ADD10	RD_WRN	SADD[9:0]									
rs	rs	rs	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bit 26 **PECBYTE**: Packet error checking byte
This bit is set by software, and cleared by hardware when the PEC is transferred, or when a STOP condition or an Address matched is received, also when PE=0.
0: No PEC transfer.
1: PEC transmission/reception is requested
Note: Writing '0' to this bit has no effect.
This bit has no effect when RELOAD is set.
This bit has no effect is slave mode when SBC=0.
If the SMBus feature is not supported, this bit is reserved and forced by hardware to '0'. Refer to Section 52.3: I2C implementation.

Bit 25 **AUTOEND**: Automatic end mode (master mode)
This bit is set and cleared by software.
0: software end mode: TC flag is set when NBYTES data are transferred, stretching SCL low.
1: Automatic end mode: a STOP condition is automatically sent when NBYTES data are transferred.
Note: This bit has no effect in slave mode or when the RELOAD bit is set.

Bit 24 **RELOAD**: NBYTES reload mode
This bit is set and cleared by software.
0: The transfer is completed after the NBYTES data transfer (STOP or RESTART follows).
1: The transfer is not completed after the NBYTES data transfer (NBYTES is reloaded). TCR flag is set when NBYTES data are transferred, stretching SCL low.

Bits 23:16 **NBYTES[7:0]**: Number of bytes

The number of bytes to be transmitted/received is programmed there. This field is don't care in slave mode with SBC=0.

Note: Changing these bits when the START bit is set is not allowed.

Bit 15 **NACK**: NACK generation (slave mode)

The bit is set by software, cleared by hardware when the NACK is sent, or when a STOP condition or an Address matched is received, or when PE=0.

0: an ACK is sent after current received byte.

1: a NACK is sent after current received byte.

Note: Writing '0' to this bit has no effect.

This bit is used in slave mode only: in master receiver mode, NACK is automatically generated after last byte preceding STOP or RESTART condition, whatever the NACK bit value.

When an overrun occurs in slave receiver NOSTRETCH mode, a NACK is automatically generated whatever the NACK bit value.

When hardware PEC checking is enabled (PECBYTE=1), the PEC acknowledge value does not depend on the NACK value.

Bit 14 **STOP**: Stop generation (master mode)

The bit is set by software, cleared by hardware when a STOP condition is detected, or when PE = 0.

In Master Mode:

0: No Stop generation.

1: Stop generation after current byte transfer.

Note: Writing '0' to this bit has no effect.

Bit 13 **START**: Start generation

This bit is set by software, and cleared by hardware after the Start followed by the address sequence is sent, by an arbitration loss, by an address matched in slave mode, by a timeout error detection, or when PE = 0.

0: No Start generation.

1: Restart/Start generation:

If the I2C is already in master mode with AUTOEND = 0, setting this bit generates a Repeated Start condition when RELOAD=0, after the end of the NBYTES transfer.

Otherwise setting this bit generates a START condition once the bus is free.

Note: Writing '0' to this bit has no effect.

The START bit can be set even if the bus is BUSY or I2C is in slave mode.

This bit has no effect when RELOAD is set.

Bit 12 **HEAD10R**: 10-bit address header only read direction (master receiver mode)

0: The master sends the complete 10 bit slave address read sequence: Start + 2 bytes 10bit address in write direction + Restart + 1st 7 bits of the 10 bit address in read direction.

1: The master only sends the 1st 7 bits of the 10 bit address, followed by Read direction.

Note: Changing this bit when the START bit is set is not allowed.

Bit 11 **ADD10**: 10-bit addressing mode (master mode)

0: The master operates in 7-bit addressing mode,

1: The master operates in 10-bit addressing mode

Note: Changing this bit when the START bit is set is not allowed.

Bit 10 **RD_WRN**: Transfer direction (master mode)
0: Master requests a write transfer.
1: Master requests a read transfer.
Note: Changing this bit when the START bit is set is not allowed.

Bits 9:0 **SADD[9:0]**: Slave address (master mode)
In 7-bit addressing mode (ADD10 = 0):
SADD[7:1] should be written with the 7-bit slave address to be sent. The bits SADD[9], SADD[8] and SADD[0] are don't care.
In 10-bit addressing mode (ADD10 = 1):
SADD[9:0] should be written with the 10-bit slave address to be sent.
Note: Changing these bits when the START bit is set is not allowed.

52.7.3 I2C own address 1 register (I2C_OAR1)

Address offset: 0x08

Reset value: 0x0000 0000

Access: No wait states, except if a write access occurs while a write access to this register is ongoing. In this case, wait states are inserted in the second write access until the previous one is completed. The latency of the second write access can be up to 2 x i2c_pclk + 6 x i2c_ker_ck.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OA1EN	Res.	Res.	Res.	Res.	OA1 MODE	OA1[9:0]									
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **OA1EN**: Own Address 1 enable
0: Own address 1 disabled. The received slave address OA1 is NACKed.
1: Own address 1 enabled. The received slave address OA1 is ACKed.

Bits 14:11 Reserved, must be kept at reset value.

Bit 10 **OA1MODE**: Own Address 1 10-bit mode
0: Own address 1 is a 7-bit address.
1: Own address 1 is a 10-bit address.
Note: This bit can be written only when OA1EN=0.

Bits 9:0 **OA1[9:0]**: Interface own slave address
7-bit addressing mode: OA1[7:1] contains the 7-bit own slave address. The bits OA1[9], OA1[8] and OA1[0] are don't care.
10-bit addressing mode: OA1[9:0] contains the 10-bit own slave address.
Note: These bits can be written only when OA1EN=0.

52.7.4 I2C own address 2 register (I2C_OAR2)

Address offset: 0x0C

Reset value: 0x0000 0000

Access: No wait states, except if a write access occurs while a write access to this register is ongoing. In this case, wait states are inserted in the second write access until the previous one is completed. The latency of the second write access can be up to 2 x i2c_pclk + 6 x i2c_ker_ck.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OA2EN	Res.	Res.	Res.	Res.	OA2MSK[2:0]			OA2[7:1]							Res.
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **OA2EN**: Own Address 2 enable
0: Own address 2 disabled. The received slave address OA2 is NACKed.
1: Own address 2 enabled. The received slave address OA2 is ACKed.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:8 **OA2MSK[2:0]**: Own Address 2 masks
000: No mask
001: OA2[1] is masked and don't care. Only OA2[7:2] are compared.
010: OA2[2:1] are masked and don't care. Only OA2[7:3] are compared.
011: OA2[3:1] are masked and don't care. Only OA2[7:4] are compared.
100: OA2[4:1] are masked and don't care. Only OA2[7:5] are compared.
101: OA2[5:1] are masked and don't care. Only OA2[7:6] are compared.
110: OA2[6:1] are masked and don't care. Only OA2[7] is compared.
111: OA2[7:1] are masked and don't care. No comparison is done, and all (except reserved) 7-bit received addresses are acknowledged.

Note: These bits can be written only when OA2EN=0.

As soon as OA2MSK is not equal to 0, the reserved I2C addresses (0b0000xxx and 0b1111xxx) are not acknowledged even if the comparison matches.

Bits 7:1 **OA2[7:1]**: Interface address
7-bit addressing mode: 7-bit address

Note: These bits can be written only when OA2EN=0.

Bit 0 Reserved, must be kept at reset value.

52.7.5 I2C timing register (I2C_TIMINGR)

Address offset: 0x10

Reset value: 0x0000 0000

Access: No wait states

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PRESC[3:0]				Res.	Res.	Res.	Res.	SCLDEL[3:0]				SDADEL[3:0]			
rw	rw	rw	rw					rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SCLH[7:0]								SCLL[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 **PRESC[3:0]**: Timing prescaler

This field is used to prescale i2c_ker_ck in order to generate the clock period t_{PRESC} used for data setup and hold counters (refer to *I2C timings on page 1994*) and for SCL high and low level counters (refer to *I2C master initialization on page 2009*).

t_{PRESC} = (PRESC+1) x t_{I2CCLK}

Bits 27:24 Reserved, must be kept at reset value.

Bits 23:20 **SCLDEL[3:0]**: Data setup time

This field is used to generate a delay t_{SCLDEL} between SDA edge and SCL rising edge. In master mode and in slave mode with NOSTRETCH = 0, the SCL line is stretched low during t_{SCLDEL}.

t_{SCLDEL} = (SCLDEL+1) x t_{PRESC}

Note: t_{SCLDEL} is used to generate $t_{SU:DAT}$ timing.

Bits 19:16 **SDADEL[3:0]**: Data hold time

This field is used to generate the delay t_{SDADEL} between SCL falling edge and SDA edge. In master mode and in slave mode with NOSTRETCH = 0, the SCL line is stretched low during t_{SDADEL}.

t_{SDADEL}= SDADEL x t_{PRESC}

Note: SDADEL is used to generate $t_{HD:DAT}$ timing.

Bits 15:8 **SCLH[7:0]**: SCL high period (master mode)

This field is used to generate the SCL high period in master mode.

t_{SCLH} = (SCLH+1) x t_{PRESC}

Note: SCLH is also used to generate $t_{SU:STO}$ and $t_{HD:STA}$ timing.

Bits 7:0 **SCLL[7:0]**: SCL low period (master mode)

This field is used to generate the SCL low period in master mode.

t_{SCLL} = (SCLL+1) x t_{PRESC}

Note: SCLL is also used to generate t_{BUF} and $t_{SU:STA}$ timings.

Note: This register must be configured when the I2C is disabled (PE = 0).

Note: The STM32CubeMX tool calculates and provides the I2C_TIMINGR content in the I2C Configuration window.

52.7.6 I2C timeout register (I2C_TIMEOUTR)

Address offset: 0x14

Reset value: 0x0000 0000

Access: No wait states, except if a write access occurs while a write access to this register is ongoing. In this case, wait states are inserted in the second write access until the previous one is completed. The latency of the second write access can be up to 2 x i2c_pclk + 6 x i2c_ker_ck.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TEXTEN	Res.	Res.	Res.	TIMEOUTB[11:0]											
rw				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TIMOUTEN	Res.	Res.	TIDLE	TIMEOUTA[11:0]											
rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **TEXTEN**: Extended clock timeout enable
0: Extended clock timeout detection is disabled
1: Extended clock timeout detection is enabled. When a cumulative SCL stretch for more than $t_{LOW:EXT}$ is done by the I2C interface, a timeout error is detected (TIMEOUT=1).

Bits 30:28 Reserved, must be kept at reset value.

Bits 27:16 **TIMEOUTB[11:0]**: Bus timeout B
This field is used to configure the cumulative clock extension timeout:
In master mode, the master cumulative clock low extend time ($t_{LOW:MEXT}$) is detected
In slave mode, the slave cumulative clock low extend time ($t_{LOW:SEXT}$) is detected
$t_{LOW:EXT}$= (TIMEOUTB+1) x 2048 x t_{I2CCLK}
Note: These bits can be written only when TEXTEN=0.

Bit 15 **TIMOUTEN**: Clock timeout enable
0: SCL timeout detection is disabled
1: SCL timeout detection is enabled: when SCL is low for more than $t_{TIMEOUT}$ (TIDLE=0) or high for more than t_{IDLE} (TIDLE=1), a timeout error is detected (TIMEOUT=1).

Bits 14:13 Reserved, must be kept at reset value.

Bit 12 **TIDLE**: Idle clock timeout detection
0: TIMEOUTA is used to detect SCL low timeout
1: TIMEOUTA is used to detect both SCL and SDA high timeout (bus idle condition)
Note: This bit can be written only when TIMOUTEN=0.

Bits 11:0 **TIMEOUTA[11:0]**: Bus Timeout A
This field is used to configure:
The SCL low timeout condition $t_{TIMEOUT}$ when TIDLE=0
$t_{TIMEOUT}$= (TIMEOUTA+1) x 2048 x t_{I2CCLK}
The bus idle condition (both SCL and SDA high) when TIDLE=1
t_{IDLE}= (TIMEOUTA+1) x 4 x t_{I2CCLK}
Note: These bits can be written only when TIMOUTEN=0.

Note: If the SMBus feature is not supported, this register is reserved and forced by hardware to "0x00000000". Refer to Section 52.3: I2C implementation.

52.7.7 I2C interrupt and status register (I2C_ISR)

Address offset: 0x18

Reset value: 0x0000 0001

Access: No wait states

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDCODE[6:0]							DIR
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BUSY	Res.	ALERT	TIME OUT	PEC ERR	OVR	ARLO	BERR	TCR	TC	STOPF	NACKF	ADDR	RXNE	TXIS	TXE
r		r	r	r	r	r	r	r	r	r	r	r	r	rs	rs

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:17 **ADDCODE[6:0]**: Address match code (Slave mode)

These bits are updated with the received address when an address match event occurs (ADDR = 1).

In the case of a 10-bit address, ADDCODE provides the 10-bit header followed by the 2 MSBs of the address.

Bit 16 **DIR**: Transfer direction (Slave mode)

This flag is updated when an address match event occurs (ADDR=1).

0: Write transfer, slave enters receiver mode.

1: Read transfer, slave enters transmitter mode.

Bit 15 **BUSY**: Bus busy

This flag indicates that a communication is in progress on the bus. It is set by hardware when a START condition is detected. It is cleared by hardware when a STOP condition is detected, or when PE=0.

Bit 14 Reserved, must be kept at reset value.

Bit 13 **ALERT**: SMBus alert

This flag is set by hardware when SMBHEN=1 (SMBus host configuration), ALERTEN=1 and a SMBALERT event (falling edge) is detected on SMBA pin. It is cleared by software by setting the ALERTCF bit.

Note: This bit is cleared by hardware when PE=0.

If the SMBus feature is not supported, this bit is reserved and forced by hardware to '0'. Refer to Section 52.3: I2C implementation.

Bit 12 **TIMEOUT**: Timeout or t_{LOW} detection flag

This flag is set by hardware when a timeout or extended clock timeout occurred. It is cleared by software by setting the TIMEOUTCF bit.

Note: This bit is cleared by hardware when PE=0.

If the SMBus feature is not supported, this bit is reserved and forced by hardware to '0'. Refer to Section 52.3: I2C implementation.

Bit 11 **PECERR**: PEC Error in reception

This flag is set by hardware when the received PEC does not match with the PEC register content. A NACK is automatically sent after the wrong PEC reception. It is cleared by software by setting the PECCF bit.

Note: This bit is cleared by hardware when PE=0.

If the SMBus feature is not supported, this bit is reserved and forced by hardware to '0'. Refer to Section 52.3: I2C implementation.

Bit 10 **OVR**: Overrun/Underrun (slave mode)

This flag is set by hardware in slave mode with NOSTRETCH=1, when an overrun/underrun error occurs. It is cleared by software by setting the OVRCF bit.

Note: This bit is cleared by hardware when PE=0.

Bit 9 **ARLO**: Arbitration lost

This flag is set by hardware in case of arbitration loss. It is cleared by software by setting the ARLOCF bit.

Note: This bit is cleared by hardware when PE=0.

Bit 8 **BERR**: Bus error

This flag is set by hardware when a misplaced Start or STOP condition is detected whereas the peripheral is involved in the transfer. The flag is not set during the address phase in slave mode. It is cleared by software by setting *BERRCF bit.*

Note: This bit is cleared by hardware when PE=0.

Bit 7 **TCR**: Transfer Complete Reload

This flag is set by hardware when RELOAD=1 and NBYTES data have been transferred. It is cleared by software when NBYTES is written to a non-zero value.

Note: This bit is cleared by hardware when PE=0.

This flag is only for master mode, or for slave mode when the SBC bit is set.

Bit 6 **TC**: Transfer Complete (master mode)

This flag is set by hardware when RELOAD=0, AUTOEND=0 and NBYTES data have been transferred. It is cleared by software when START bit or STOP bit is set.

Note: This bit is cleared by hardware when PE=0.

Bit 5 **STOPF**: Stop detection flag

This flag is set by hardware when a STOP condition is detected on the bus and the peripheral is involved in this transfer:

- either as a master, provided that the STOP condition is generated by the peripheral.
- or as a slave, provided that the peripheral has been addressed previously during this transfer.

It is cleared by software by setting the STOPCF bit.

Note: This bit is cleared by hardware when PE=0.

Bit 4 **NACKF**: Not Acknowledge received flag

This flag is set by hardware when a NACK is received after a byte transmission. It is cleared by software by setting the NACKCF bit.

Note: This bit is cleared by hardware when PE=0.

Bit 3 **ADDR**: Address matched (slave mode)

This bit is set by hardware as soon as the received slave address matched with one of the enabled slave addresses. It is cleared by software by setting *ADDRCF bit.*

Note: This bit is cleared by hardware when PE=0.

Bit 2 **RXNE**: Receive data register not empty (receivers)

This bit is set by hardware when the received data is copied into the I2C_RXDR register, and is ready to be read. It is cleared when I2C_RXDR is read.

Note: This bit is cleared by hardware when PE=0.

Bit 1 **TXIS**: Transmit interrupt status (transmitters)

This bit is set by hardware when the I2C_TXDR register is empty and the data to be transmitted must be written in the I2C_TXDR register. It is cleared when the next data to be sent is written in the I2C_TXDR register.

This bit can be written to '1' by software when NOSTRETCH=1 only, in order to generate a TXIS event (interrupt if TXIE=1 or DMA request if TXDMAEN=1).

Note: This bit is cleared by hardware when PE=0.

Bit 0 **TXE**: Transmit data register empty (transmitters)

This bit is set by hardware when the I2C_TXDR register is empty. It is cleared when the next data to be sent is written in the I2C_TXDR register.

This bit can be written to '1' by software in order to flush the transmit data register I2C_TXDR.

Note: This bit is set by hardware when PE=0.

52.7.8 I2C interrupt clear register (I2C_ICR)

Address offset: 0x1C

Reset value: 0x0000 0000

Access: No wait states

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	ALERTCF	TIMOUTCF	PECCF	OVRCF	ARLOCF	BERRCF	Res.	Res.	STOPCF	NACKCF	ADDRCF	Res.	Res.	Res.
		w	w	w	w	w	w			w	w	w			

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **ALERTCF**: Alert flag clear

Writing 1 to this bit clears the ALERT flag in the I2C_ISR register.

Note: If the SMBus feature is not supported, this bit is reserved and forced by hardware to '0'. Refer to Section 52.3: I2C implementation.

Bit 12 **TIMOUTCF**: Timeout detection flag clear

Writing 1 to this bit clears the TIMEOUT flag in the I2C_ISR register.

Note: If the SMBus feature is not supported, this bit is reserved and forced by hardware to '0'. Refer to Section 52.3: I2C implementation.

Bit 11 **PECCF**: PEC Error flag clear

Writing 1 to this bit clears the PECERR flag in the I2C_ISR register.

Note: If the SMBus feature is not supported, this bit is reserved and forced by hardware to '0'. Refer to Section 52.3: I2C implementation.

Bit 10 **OVRCF**: Overrun/Underrun flag clear
Writing 1 to this bit clears the OVR flag in the I2C_ISR register.

Bit 9 **ARLOCF**: Arbitration lost flag clear
Writing 1 to this bit clears the ARLO flag in the I2C_ISR register.

Bit 8 **BERRCF**: Bus error flag clear
Writing 1 to this bit clears the BERRF flag in the I2C_ISR register.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **STOPCF**: STOP detection flag clear
Writing 1 to this bit clears the STOPF flag in the I2C_ISR register.

Bit 4 **NACKCF**: Not Acknowledge flag clear
Writing 1 to this bit clears the NACKF flag in I2C_ISR register.

Bit 3 **ADDRCF**: Address matched flag clear
Writing 1 to this bit clears the ADDR flag in the I2C_ISR register. Writing 1 to this bit also clears the START bit in the I2C_CR2 register.

Bits 2:0 Reserved, must be kept at reset value.

52.7.9 I2C PEC register (I2C_PECR)

Address offset: 0x20

Reset value: 0x0000 0000

Access: No wait states

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PEC[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PEC[7:0]:** Packet error checking register
This field contains the internal PEC when PECEN=1.
The PEC is cleared by hardware when PE=0.

Note: If the SMBus feature is not supported, this register is reserved and forced by hardware to "0x00000000". Refer to Section 52.3: I2C implementation.

52.7.10 I2C receive data register (I2C_RXDR)

Address offset: 0x24

Reset value: 0x0000 0000

Access: No wait states

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXDATA[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **RXDATA[7:0]:** 8-bit receive data
Data byte received from the I^2C bus

52.7.11 I2C transmit data register (I2C_TXDR)

Address offset: 0x28

Reset value: 0x0000 0000

Access: No wait states

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXDATA[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **TXDATA[7:0]:** 8-bit transmit data
Data byte to be transmitted to the I^2C bus
Note: These bits can be written only when TXE=1.

52.7.12 I2C register map

The table below provides the I2C register map and reset values.

Table 417. I2C register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0	**I2C_CR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PECEN	ALERTEN	SMBDEN	SMBHEN	GCEN	WUPEN	NOSTRETCH	SBC	RXDMAEN	TXDMAEN	Res.	ANFOFF	DNF[3:0]				ERRIE	TCIE	STOPIE	NACKIE	ADDRIE	RXIE	TXIE	PE
	Reset value									0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
0x4	**I2C_CR2**	Res.	Res.	Res.	Res.	Res.	PECBYTE	AUTOEND	RELOAD	NBYTES[7:0]								NACK	STOP	START	HEAD10R	ADD10	RD_WRN	SADD[9:0]									
	Reset value						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x8	**I2C_OAR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OA1EN	Res.	Res.	Res.	Res.	OA1MODE	OA1[9:0]									
	Reset value																	0					0	0	0	0	0	0	0	0	0	0	0
0xC	**I2C_OAR2**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OA2EN	Res.	Res.	Res.	Res.	OA2MSK [2:0]			OA2[7:1]							Res.
	Reset value																	0					0	0	0	0	0	0	0	0	0	0	
0x10	**I2C_TIMINGR**	PRESC[3:0]				Res.	Res.	Res.	Res.	SCLDEL [3:0]				SDADEL [3:0]				SCLH[7:0]								SCLL[7:0]							
	Reset value	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	**I2C_TIMEOUTR**	TEXTEN	Res.	Res.	Res.	TIMEOUTB[11:0]												TIMOUTEN	Res.	Res.	TIDLE	TIMEOUTA[11:0]											
	Reset value	0				0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	**I2C_ISR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDCODE[6:0]							DIR	BUSY	Res.	ALERT	TIMEOUT	PECERR	OVR	ARLO	BERR	TCR	TC	STOPF	NACKF	ADDR	RXNE	TXIS	TXE
	Reset value									0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x1C	**I2C_ICR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ALERTCF	TIMOUTCF	PECCF	OVRCF	ARLOCF	BERRCF	Res.	Res.	STOPCF	NACKCF	ADDRCF	Res.	Res.	Res.
	Reset value																			0	0	0	0	0	0			0	0	0			
0x20	**I2C_PECR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PEC[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x24	**I2C_RXDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXDATA[7:0]							
	Reset value																									0	0	0	0	0	0	0	0

Table 417. I2C register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x28	**I2C_TXDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXDATA[7:0]							
	Reset value																									0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

53 Universal synchronous/asynchronous receiver transmitter (USART/UART)

This section describes the universal synchronous asynchronous receiver transmitter (USART).

53.1 USART introduction

The USART offers a flexible means to perform Full-duplex data exchange with external equipments requiring an industry standard NRZ asynchronous serial data format. A very wide range of baud rates can be achieved through a fractional baud rate generator.

The USART supports both synchronous one-way and Half-duplex Single-wire communications, as well as LIN (local interconnection network), Smartcard protocol, IrDA (infrared data association) SIR ENDEC specifications, and Modem operations (CTS/RTS). Multiprocessor communications are also supported.

High-speed data communications are possible by using the DMA (direct memory access) for multibuffer configuration.

53.2 USART main features

- Full-duplex asynchronous communication
- NRZ standard format (mark/space)
- Configurable oversampling method by 16 or 8 to achieve the best compromise between speed and clock tolerance
- Baud rate generator systems
- Two internal FIFOs for transmit and receive data

  Each FIFO can be enabled/disabled by software and come with a status flag.
- A common programmable transmit and receive baud rate
- Dual clock domain with dedicated kernel clock for peripherals independent from PCLK
- Auto baud rate detection
- Programmable data word length (7, 8 or 9 bits)
- Programmable data order with MSB-first or LSB-first shifting
- Configurable stop bits (1 or 2 stop bits)
- Synchronous master/slave mode and clock output/input for synchronous communications
- SPI slave transmission underrun error flag
- Single-wire Half-duplex communications
- Continuous communications using DMA
- Received/transmitted bytes are buffered in reserved SRAM using centralized DMA.
- Separate enable bits for transmitter and receiver
- Separate signal polarity control for transmission and reception
- Swappable Tx/Rx pin configuration
- Hardware flow control for modem and RS-485 transceiver
- Communication control/error detection flags
- Parity control:
  - Transmits parity bit
  - Checks parity of received data byte
- Interrupt sources with flags
- Multiprocessor communications: wakeup from Mute mode by idle line detection or address mark detection
- Wakeup from Stop mode

53.3 USART extended features

- LIN master synchronous break send capability and LIN slave break detection capability
  - 13-bit break generation and 10/11 bit break detection when USART is hardware configured for LIN
- IrDA SIR encoder decoder supporting 3/16 bit duration for normal mode
- Smartcard mode
  - Supports the T = 0 and T = 1 asynchronous protocols for smartcards as defined in the ISO/IEC 7816-3 standard
  - 0.5 and 1.5 stop bits for Smartcard operation
- Support for Modbus communication
  - Timeout feature
  - CR/LF character recognition

53.4 USART implementation

The table below describes USART implementation on STM32H72x and STM32H73x devices. It also includes LPUART for comparison.

Table 418. USART / LPUART features

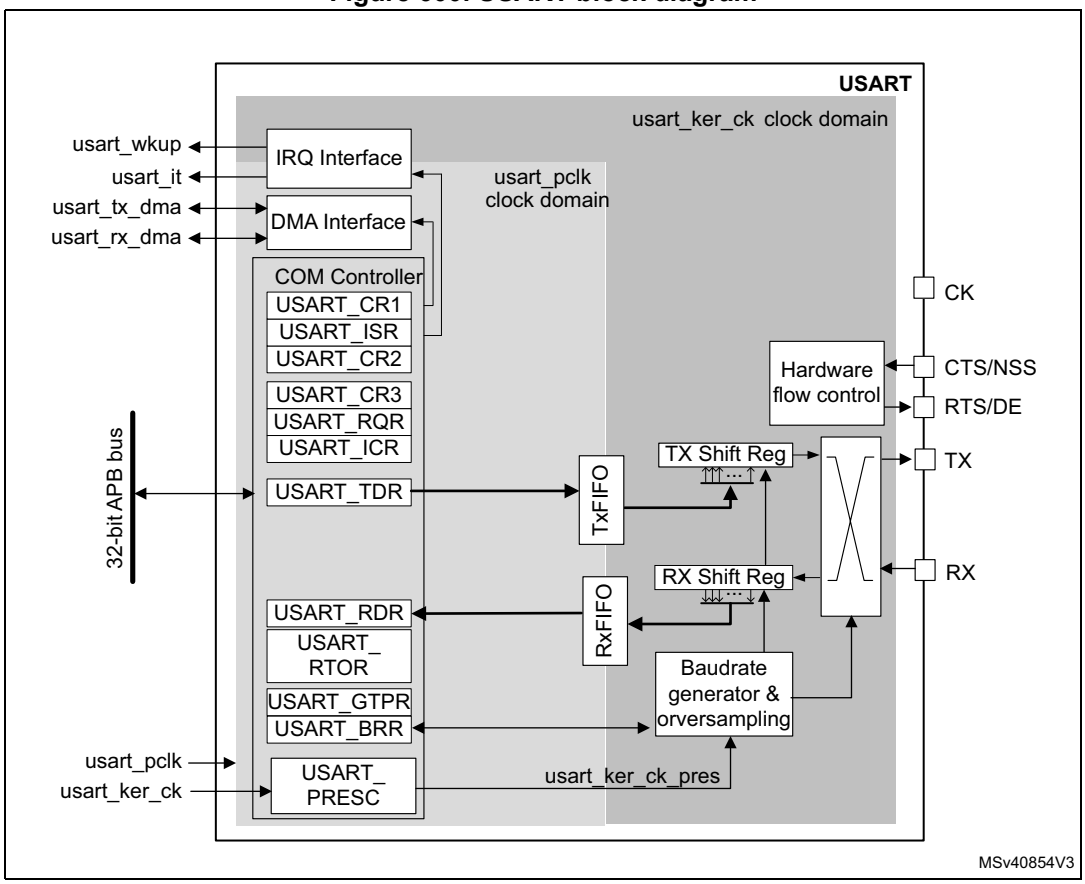
USART / LPUART modes/features(1)	USART1/2/3/6/10	UART4/5/7/8/9	LPUART1
Hardware flow control for modem	X	X	X
Continuous communication using DMA	X	X	X
Multiprocessor communication	X	X	X
Synchronous mode (Master/Slave)	X	-	-
Smartcard mode	X	-	-
Single-wire Half-duplex communication	X	X	X
IrDA SIR ENDEC block	X	X	-
LIN mode	X	X	-
Dual clock domain and wakeup from low-power mode	X	X	X
Receiver timeout interrupt	X	X	-
Modbus communication	X	X	-
Auto baud rate detection	X	X	-
Driver Enable	X	X	X
USART data length	7, 8 and 9 bits		
Tx/Rx FIFO	X	X	X
Tx/Rx FIFO size	16		

1. X = supported.

53.5 USART functional description

53.5.1 USART block diagram

Figure 600. USART block diagram



The simplified block diagram given in *Figure 600* shows two fully-independent clock domains:

- The **usart_pclk** clock domain

  The **usart_pclk** clock signal feeds the peripheral bus interface. It must be active when accesses to the USART registers are required.

- The **usart_ker_ck** kernel clock domain.

  The **usart_ker_ck** is the USART clock source. It is independent from **usart_pclk** and delivered by the RCC. The USART registers can consequently be written/read even when the **usart_ker_ck** clock is stopped.

  When the dual clock domain feature is disabled, the **usart_ker_ck** clock is the same as the **usart_pclk** clock.

There is no constraint between **usart_pclk** and **usart_ker_ck**: **usart_ker_ck** can be faster or slower than **usart_pclk**. The only limitation is the software ability to manage the communication fast enough.

When the USART operates in SPI slave mode, it handles data flow using the serial interface clock derived from the external CK signal provided by the external master SPI device. The **usart_ker_ck** clock must be at least 3 times faster than the clock on the CK input.

53.5.2 USART signals

USART bidirectional communications

USART bidirectional communications require a minimum of two pins: Receive Data In (RX) and Transmit Data Out (TX):

- **RX** (Receive Data Input)

  RX is the serial data input. Oversampling techniques are used for data recovery. They discriminate between valid incoming data and noise.

- **TX** (Transmit Data Output)

  When the transmitter is disabled, the output pin returns to its I/O port configuration. When the transmitter is enabled and no data needs to be transmitted, the TX pin is High. In Single-wire and Smartcard modes, this I/O is used to transmit and receive data.

RS232 Hardware flow control mode

The following pins are required in RS232 Hardware flow control mode:

- **CTS** (Clear To Send)

  When driven high, this signal blocks the data transmission at the end of the current transfer.

- **RTS** (Request To Send)

  When it is low, this signal indicates that the USART is ready to receive data.

RS485 Hardware control mode

The following pin is required in RS485 Hardware control mode:

- **DE** (Driver Enable)

  This signal activates the transmission mode of the external transceiver.

Note: DE and RTS share the same pin.

Synchronous master/slave mode and Smartcard mode

The following pin is required in synchronous master/slave mode and Smartcard mode:

- CK

  This pin acts as Clock output in Synchronous master and Smartcard modes.

  It acts as Clock input is Synchronous slave mode.

  In Synchronous Master mode, this pin outputs the transmitter data clock for synchronous transmission corresponding to SPI master mode (no clock pulses on start bit and stop bit, and a software option to send a clock pulse on the last data bit). In parallel, data can be received synchronously on RX pin. This mechanism can be used to control peripherals featuring shift registers (e.g. LCD drivers). The clock phase and polarity are software programmable.

  In Smartcard mode, CK output provides the clock to the smartcard.

- NSS

  This pin acts as Slave Select input in Synchronous slave mode.

Note: NSS and CTS share the same pin.

53.5.3 USART character description

The word length can be set to 7, 8 or 9 bits, by programming the M bits (M0: bit 12 and M1: bit 28) in the USART_CR1 register (see *Figure 601*):

- 7-bit character length: M[1:0] = ‘10’
- 8-bit character length: M[1:0] = ‘00’
- 9-bit character length: M[1:0] = ‘01’

Note: In 7-bit data length mode, the Smartcard mode, LIN master mode and Auto baud rate (0x7F and 0x55 frames detection) are not supported.

By default, the signal (TX or RX) is in low state during the start bit. It is in high state during the stop bit.

These values can be inverted, separately for each signal, through polarity configuration control.

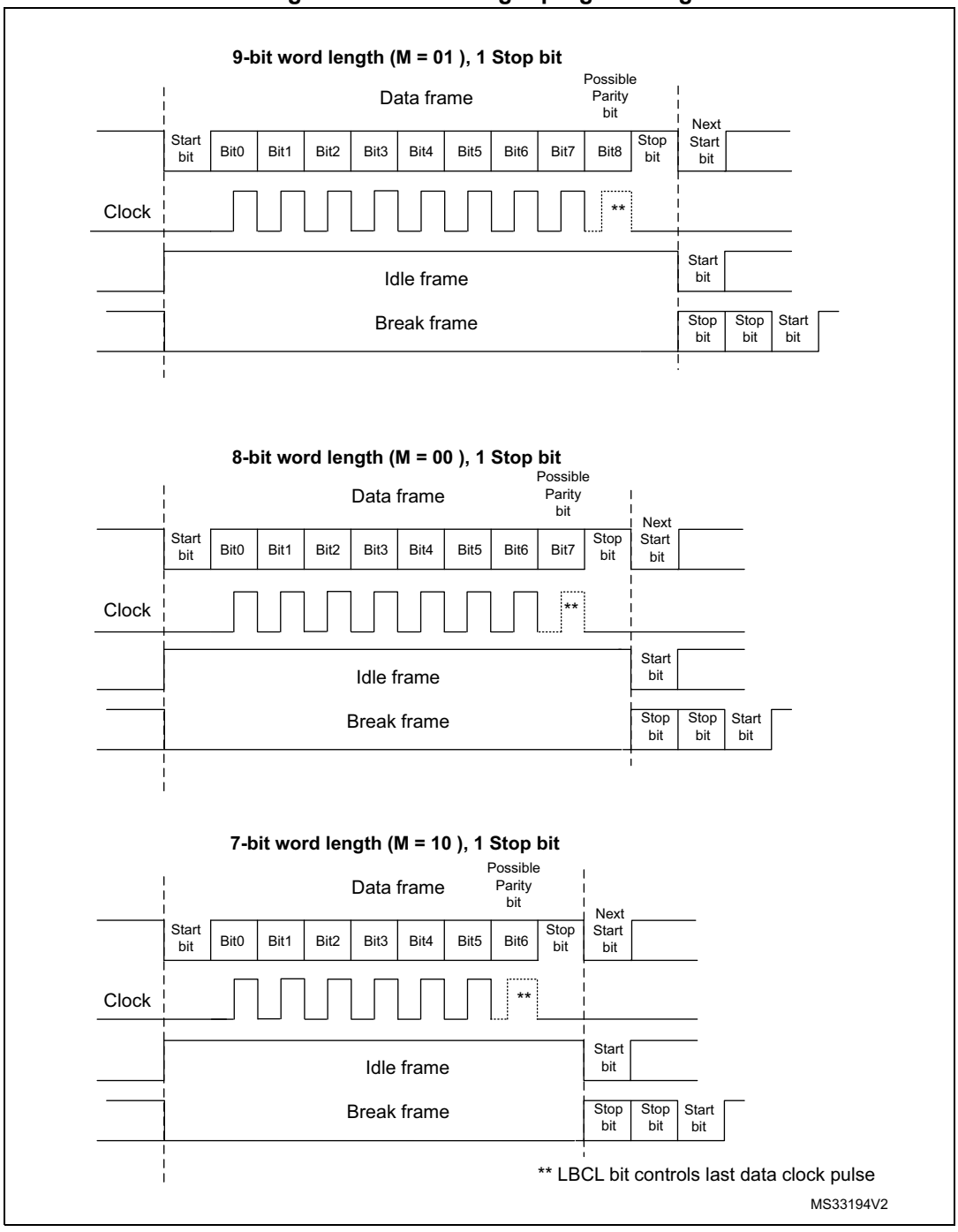
An ***Idle character*** is interpreted as an entire frame of “1”s (the number of “1”s includes the number of stop bits).

A ***Break character*** is interpreted on receiving “0”s for a frame period. At the end of the break frame, the transmitter inserts 2 stop bits.

Transmission and reception are driven by a common baud rate generator. The transmission and reception clock are generated when the enable bit is set for the transmitter and receiver, respectively.

A detailed description of each block is given below.

Figure 601. Word length programming



53.5.4 USART FIFOs and thresholds

The USART can operate in FIFO mode.

The USART comes with a Transmit FIFO (TXFIFO) and a Receive FIFO (RXFIFO). The FIFO mode is enabled by setting FIFOEN in USART_CR1 register (bit 29). This mode is supported only in UART, SPI and Smartcard modes.

Since the maximum data word length is 9 bits, the TXFIFO is 9-bit wide. However the RXFIFO default width is 12 bits. This is due to the fact that the receiver does not only store the data in the FIFO, but also the error flags associated to each character (Parity error, Noise error and Framing error flags).

Note: The received data is stored in the RXFIFO together with the corresponding flags. However, only the data are read when reading the RDR.

The status flags are available in the USART_ISR register.

It is possible to configure the TXFIFO and RXFIFO levels at which the Tx and RX interrupts are triggered. These thresholds are programmed through RXFTCFG and TXFTCFG bitfields in USART_CR3 control register.

In this case:

- The RXFT flag is set in the USART_ISR register and the corresponding interrupt (if enabled) is generated, when the number of received data in the RXFIFO reaches the threshold programmed in the RXFTCFG bits fields.

  This means that the RXFIFO is filled until the number of data in the RXFIFO is equal to the programmed threshold.

  RXFTCFG data have been received: one data in USART_RDR and (RXFTCFG - 1) data in the RXFIFO. As an example, when the RXFTCFG is programmed to ‘101’, the RXFT flag is set when a number of data corresponding to the FIFO size has been received (FIFO size -1 data in the RXFIFO and 1 data in the USART_RDR). As a result, the next received data is not set the overrun flag.
- The TXFT flag is set in the USART_ISR register and the corresponding interrupt (if enabled) is generated when the number of empty locations in the TXFIFO reaches the threshold programmed in the TXFTCFG bits fields.

  This means that the TXFIFO is emptied until the number of empty locations in the TXFIFO is equal to the programmed threshold.

53.5.5 USART transmitter

The transmitter can send data words of either 7 or 8 or 9 bits, depending on the M bit status. The Transmit Enable bit (TE) must be set in order to activate the transmitter function. The data in the transmit shift register is output on the TX pin while the corresponding clock pulses are output on the CK pin.

Character transmission

During an USART transmission, data shifts out the least significant bit first (default configuration) on the TX pin. In this mode, the USART_TDR register consists of a buffer (TDR) between the internal bus and the transmit shift register.

When FIFO mode is enabled, the data written to the transmit data register (USART_TDR) are queued in the TXFIFO.

Every character is preceded by a start bit which corresponds to a low logic level for one bit period. The character is terminated by a configurable number of stop bits.

The number of stop bits can be configured to 0.5, 1, 1.5 or 2.

Note: The TE bit must be set before writing the data to be transmitted to the USART_TDR.

The TE bit should not be reset during data transmission. Resetting the TE bit during the transmission corrupts the data on the TX pin as the baud rate counters get frozen. The current data being transmitted are then lost.

An idle frame is sent when the TE bit is enabled.

Configurable stop bits

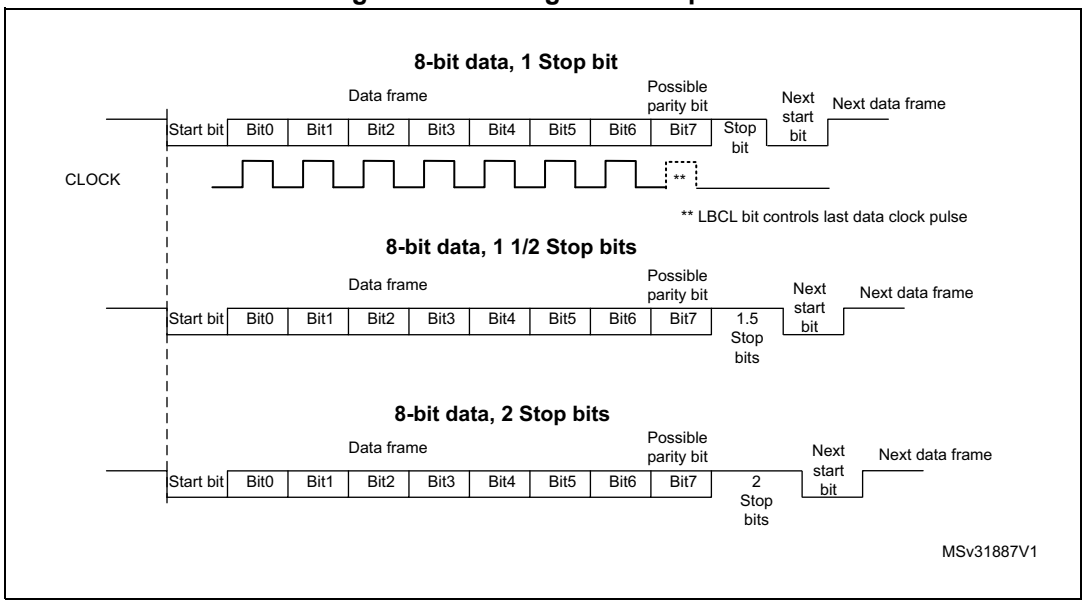
The number of stop bits to be transmitted with every character can be programmed in USART_CR2, bits 13,12.

- ***1 stop bit***: This is the default value of number of stop bits.
- ***2 stop bits***: This is supported by normal USART, Single-wire and Modem modes.
- ***1.5 stop bits***: To be used in Smartcard mode.

An idle frame transmission includes the stop bits.

A break transmission features 10 low bits (when M[1:0] = ‘00’) or 11 low bits (when M[1:0] = ‘01’) or 9 low bits (when M[1:0] = ‘10’) followed by 2 stop bits (see *Figure 602*). It is not possible to transmit long breaks (break of length greater than 9/10/11 low bits).

Figure 602. Configurable stop bits



Character transmission procedure

To transmit a character, follow the sequence below:

1. Program the M bits in USART_CR1 to define the word length.
2. Select the desired baud rate using the USART_BRR register.
3. Program the number of stop bits in USART_CR2.
4. Enable the USART by writing the UE bit in USART_CR1 register to 1.
5. Select DMA enable (DMAT) in USART_CR3 if multibuffer communication must take place. Configure the DMA register as explained in *Section 53.5.10: USART multiprocessor communication*.
6. Set the TE bit in USART_CR1 to send an idle frame as first transmission.
7. Write the data to send in the USART_TDR register. Repeat this for each data to be transmitted in case of single buffer.
   - When FIFO mode is disabled, writing a data to the USART_TDR clears the TXE flag.
   - When FIFO mode is enabled, writing a data to the USART_TDR adds one data to the TXFIFO. Write operations to the USART_TDR are performed when TXFNF flag is set. This flag remains set until the TXFIFO is full.
8. When the last data is written to the USART_TDR register, wait until TC = 1.
   - When FIFO mode is disabled, this indicates that the transmission of the last frame is complete.
   - When FIFO mode is enabled, this indicates that both TXFIFO and shift register are empty.

   This check is required to avoid corrupting the last transmission when the USART is disabled or enters Halt mode.

Single byte communication

- When FIFO mode is disabled

  Writing to the transmit data register always clears the TXE bit. The TXE flag is set by hardware. It indicates that:

  – the data have been moved from the USART_TDR register to the shift register and the data transmission has started;

  – the USART_TDR register is empty;

  – the next data can be written to the USART_TDR register without overwriting the previous data.

  This flag generates an interrupt if the TXEIE bit is set.

  When a transmission is ongoing, a write instruction to the USART_TDR register stores the data in the TDR buffer. It is then copied in the shift register at the end of the current transmission.

  When no transmission is ongoing, a write instruction to the USART_TDR register places the data in the shift register, the data transmission starts, and the TXE bit is set.

- When FIFO mode is enabled, the TXFNF (TXFIFO not full) flag is set by hardware to indicate that:

  – the TXFIFO is not full;

  – the USART_TDR register is empty;

  – the next data can be written to the USART_TDR register without overwriting the previous data. When a transmission is ongoing, a write operation to the USART_TDR register stores the data in the TXFIFO. Data are copied from the TXFIFO to the shift register at the end of the current transmission.

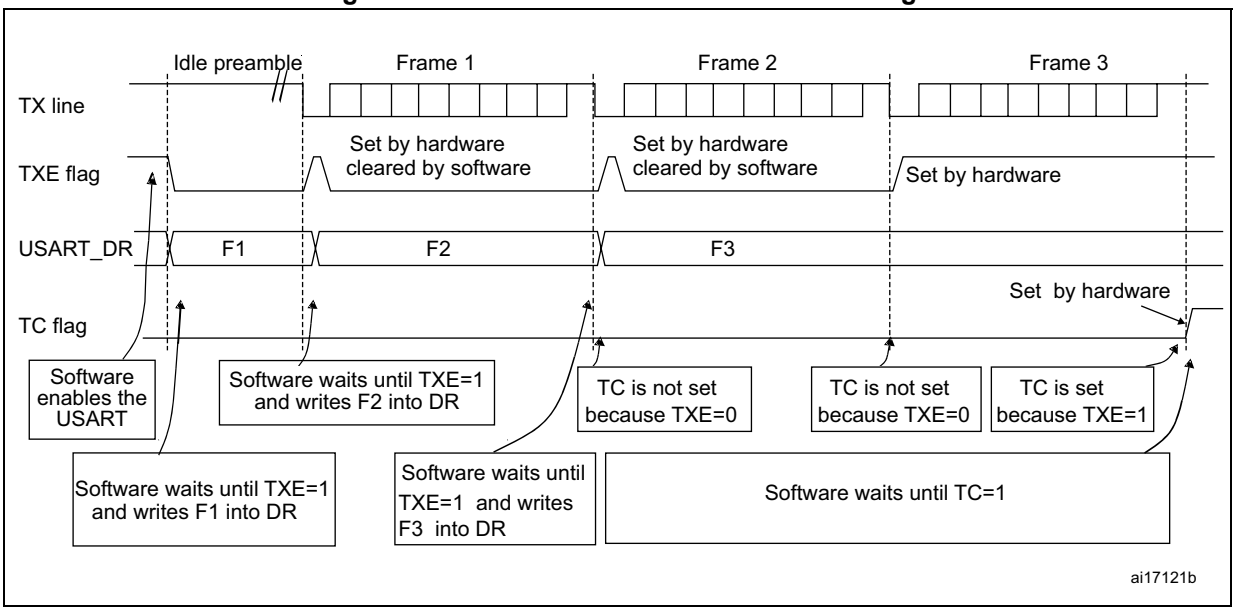
  When the TXFIFO is not full, the TXFNF flag stays at ‘1’ even after a write operation to USART_TDR register. It is cleared when the TXFIFO is full. This flag generates an interrupt if the TXFNFIE bit is set.

  Alternatively, interrupts can be generated and data can be written to the FIFO when the TXFIFO threshold is reached. In this case, the CPU can write a block of data defined by the programmed trigger level.

  If a frame is transmitted (after the stop bit) and the TXE flag (TXFE in case of FIFO mode) is set, the TC flag goes high. An interrupt is generated if the TCIE bit is set in the USART_CR1 register.

After writing the last data to the USART_TDR register, it is mandatory to wait until TC is set before disabling the USART or causing the device to enter the low-power mode (see *Figure 603: TC/TXE behavior when transmitting*).

Figure 603. TC/TXE behavior when transmitting



Note: When FIFO management is enabled, the TXFNF flag is used for data transmission.

Break characters

Setting the SBKRQ bit transmits a break character. The break frame length depends on the M bit (see *Figure 601*).

If a '1' is written to the SBKRQ bit, a break character is sent on the TX line after completing the current character transmission. The SBKF bit is set by the write operation and it is reset by hardware when the break character is completed (during the stop bits after the break character). The USART inserts a logic 1 signal (stop) for the duration of 2 bits at the end of the break frame to guarantee the recognition of the start bit of the next frame.

When the SBKRQ bit is set, the break character is sent at the end of the current transmission.

When FIFO mode is enabled, sending the break character has priority on sending data even if the TXFIFO is full.

Idle characters

Setting the TE bit drives the USART to send an idle frame before the first data frame.

53.5.6 USART receiver

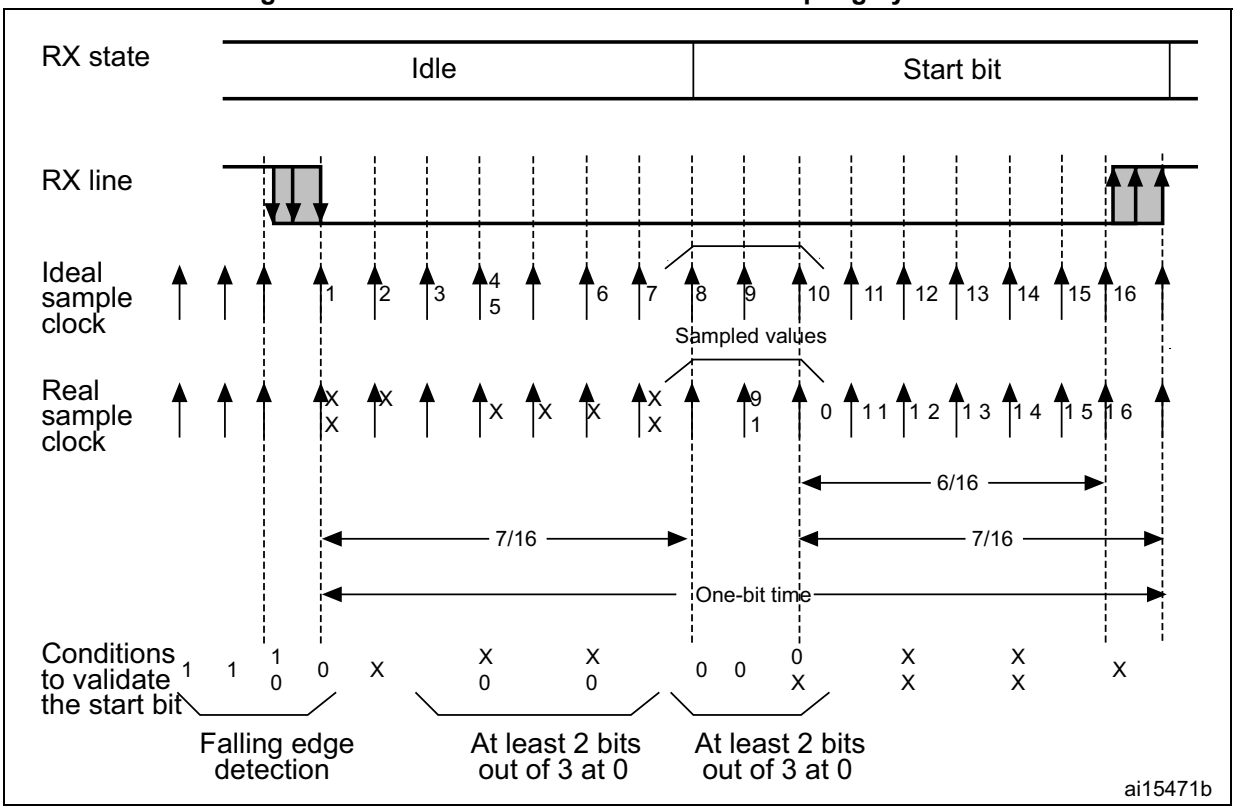
The USART can receive data words of either 7 or 8 or 9 bits depending on the M bits in the USART_CR1 register.

Start bit detection

The start bit detection sequence is the same when oversampling by 16 or by 8.

In the USART, the start bit is detected when a specific sequence of samples is recognized. This sequence is: 1 1 1 0 X 0 X 0X 0X 0 X 0X 0.

Figure 604. Start bit detection when oversampling by 16 or 8



Note: If the sequence is not complete, the start bit detection aborts and the receiver returns to the idle state (no flag is set), where it waits for a falling edge.

The start bit is confirmed (RXNE flag set and interrupt generated if RXNEIE = 1, or RXFNE flag set and interrupt generated if RXFNEIE = 1 if FIFO mode enabled) if the 3 sampled bits are at ‘0’ (first sampling on the 3rd, 5th and 7th bits finds the 3 bits at ‘0’ and second sampling on the 8th, 9th and 10th bits also finds the 3 bits at ‘0’).

The start bit is validated but the NE noise flag is set if,

a) for both samplings, 2 out of the 3 sampled bits are at ‘0’ (sampling on the 3rd, 5th and 7th bits and sampling on the 8th, 9th and 10th bits)

or

b) for one of the samplings (sampling on the 3rd, 5th and 7th bits or sampling on the 8th, 9th and 10th bits), 2 out of the 3 bits are found at ‘0’.

If neither of the above conditions are met, the start detection aborts and the receiver returns to the idle state (no flag is set).

Character reception

During an USART reception, data are shifted out least significant bit first (default configuration) through the RX pin.

Character reception procedure

To receive a character, follow the sequence below:

1. Program the M bits in USART_CR1 to define the word length.
2. Select the desired baud rate using the baud rate register USART_BRR
3. Program the number of stop bits in USART_CR2.
4. Enable the USART by writing the UE bit in USART_CR1 register to ‘1’.
5. Select DMA enable (DMAR) in USART_CR3 if multibuffer communication is to take place. Configure the DMA register as explained in *Section 53.5.10: USART multiprocessor communication*.
6. Set the RE bit USART_CR1. This enables the receiver which begins searching for a start bit.

When a character is received:

- When FIFO mode is disabled, the RXNE bit is set to indicate that the content of the shift register is transferred to the RDR. In other words, data have been received and can be read (as well as their associated error flags).
- When FIFO mode is enabled, the RXFNE bit is set to indicate that the RXFIFO is not empty. Reading the USART_RDR returns the oldest data entered in the RXFIFO. When a data is received, it is stored in the RXFIFO together with the corresponding error bits.
- An interrupt is generated if the RXNEIE (RXFNEIE when FIFO mode is enabled) bit is set.
- The error flags can be set if a frame error, noise, parity or an overrun error was detected during reception.
- In multibuffer communication mode:
  - When FIFO mode is disabled, the RXNE flag is set after every byte reception. It is cleared when the DMA reads the Receive data Register.
  - When FIFO mode is enabled, the RXFNE flag is set when the RXFIFO is not empty. After every DMA request, a data is retrieved from the RXFIFO. A DMA request is triggered when the RXFIFO is not empty i.e. when there are data to be read from the RXFIFO.
- In single buffer mode:
  - When FIFO mode is disabled, clearing the RXNE flag is done by performing a software read from the USART_RDR register. The RXNE flag can also be cleared by programming RXFRQ bit to ‘1’ in the USART_RQR register. The RXNE flag must be cleared before the end of the reception of the next character to avoid an overrun error.
  - When FIFO mode is enabled, the RXFNE is set when the RXFIFO is not empty. After every read operation from USART_RDR, a data is retrieved from the RXFIFO. When the RXFIFO is empty, the RXFNE flag is cleared. The RXFNE flag can also be cleared by programming RXFRQ bit to ‘1’ in USART_RQR. When the RXFIFO is full, the first entry in the RXFIFO must be read before the end of the reception of the next character, to avoid an overrun error. The RXFNE flag generates an interrupt if the RXFNEIE bit is set. Alternatively, interrupts can be

generated and data can be read from RXFIFO when the RXFIFO threshold is reached. In this case, the CPU can read a block of data defined by the programmed threshold.

Break character

When a break character is received, the USART handles it as a framing error.

Idle character

When an idle frame is detected, it is handled in the same way as a data character reception except that an interrupt is generated if the IDLEIE bit is set.

Overrun error

- FIFO mode disabled

  An overrun error occurs if a character is received and RXNE has not been reset.

  Data can not be transferred from the shift register to the RDR register until the RXNE bit is cleared. The RXN E flag is set after every byte reception.

  An overrun error occurs if RXNE flag is set when the next data is received or the previous DMA request has not been serviced. When an overrun error occurs:

  – the ORE bit is set;
  – the RDR content is not lost. The previous data is available by reading the USART_RDR register.
  – the shift register is overwritten. After that, any data received during overrun is lost.
  – an interrupt is generated if either the RXNEIE or the EIE bit is set.

- FIFO mode enabled

  An overrun error occurs when the shift register is ready to be transferred and the receive FIFO is full.

  Data can not be transferred from the shift register to the USART_RDR register until there is one free location in the RXFIFO. The RXFNE flag is set when the RXFIFO is not empty.

  An overrun error occurs if the RXFIFO is full and the shift register is ready to be transferred. When an overrun error occurs:

  – The ORE bit is set.
  – The first entry in the RXFIFO is not lost. It is available by reading the USART_RDR register.
  – The shift register is overwritten. After that point, any data received during overrun is lost.
  – An interrupt is generated if either the RXFNEIE or EIE bit is set.

The ORE bit is reset by setting the ORECF bit in the USART_ICR register.

Note: The ORE bit, when set, indicates that at least 1 data has been lost.

When the FIFO mode is disabled, there are two possibilities

- *if RXNE = 1, then the last valid data is stored in the receive register (RDR) and can be read,*
- *if RXNE = 0, the last valid data has already been read and there is nothing left to be read in the RDR register. This case can occur when the last valid data is read in the RDR register at the same time as the new (and lost) data is received.*

Selecting the clock source and the appropriate oversampling method

The choice of the clock source is done through the Clock Control system (see Section *Reset and clock control (RCC)*). The clock source must be selected through the UE bit before enabling the USART.

The clock source must be selected according to two criteria:

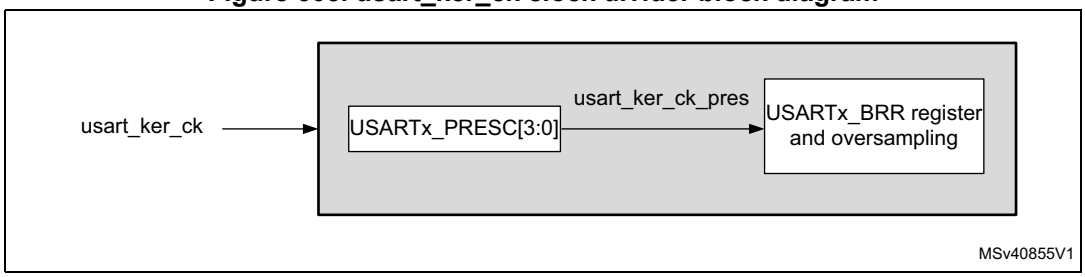
- Possible use of the USART in low-power mode
- Communication speed.

The clock source frequency is usart_ker_ck.

When the dual clock domain and the wakeup from low-power mode features are supported, the usart_ker_ck clock source can be configurable in the RCC (see Section *Reset and clock control (RCC)*). Otherwise the usart_ker_ck clock is the same as usart_pclk.

The usart_ker_ck clock can be divided by a programmable factor, defined in the USART_PRESC register.

Figure 605. usart_ker_ck clock divider block diagram



Some usart_ker_ck sources enable the USART to receive data while the MCU is in low-power mode. Depending on the received data and wakeup mode selected, the USART wakes up the MCU, when needed, in order to transfer the received data, by performing a software read to the USART_RDR register or by DMA.

For the other clock sources, the system must be active to enable USART communications.

The communication speed range (specially the maximum communication speed) is also determined by the clock source.

The receiver implements different user-configurable oversampling techniques (except in synchronous mode) for data recovery by discriminating between valid incoming data and noise. This enables obtaining the best a trade-off between the maximum communication speed and noise/clock inaccuracy immunity.

The oversampling method can be selected by programming the OVER8 bit in the USART_CR1 register either to 16 or 8 times the baud rate clock (see *Figure 606* and *Figure 607*).

Depending on your application:

- select oversampling by 8 (OVER8 = 1) to achieve higher speed (up to usart_ker_ck_pres/8). In this case the maximum receiver tolerance to clock deviation is reduced (refer to *Section 53.5.8: Tolerance of the USART receiver to clock deviation on page 2075*)
- select oversampling by 16 (OVER8 = 0) to increase the tolerance of the receiver to clock deviations. In this case, the maximum speed is limited to maximum

usart_ker_ck_pres/16 (where usart_ker_ck_pres is the USART input clock divided by a prescaler).

Programming the ONEBIT bit in the USART_CR3 register selects the method used to evaluate the logic level. Two options are available:

- The majority vote of the three samples in the center of the received bit. In this case, when the 3 samples used for the majority vote are not equal, the NE bit is set.
- A single sample in the center of the received bit

  Depending on your application:

  – select the three sample majority vote method (ONEBIT = 0) when operating in a noisy environment and reject the data when a noise is detected (refer to *Figure 419*) because this indicates that a glitch occurred during the sampling.

  – select the single sample method (ONEBIT = 1) when the line is noise-free to increase the receiver tolerance to clock deviations (see *Section 53.5.8: Tolerance of the USART receiver to clock deviation on page 2075*). In this case the NE bit is never set.

When noise is detected in a frame:

- The NE bit is set at the rising edge of the RXNE bit (RXFNE in case of FIFO mode enabled).
- The invalid data is transferred from the Shift register to the USART_RDR register.
- No interrupt is generated in case of single byte communication. However this bit rises at the same time as the RXNE bit (RXFNE in case of FIFO mode enabled) which itself generates an interrupt. In case of multibuffer communication an interrupt is issued if the EIE bit is set in the USART_CR3 register.

The NE bit is reset by setting NECF bit in USART_ICR register.

Note: Noise error is not supported in SPI mode.

Oversampling by 8 is not available in the Smartcard, IrDA and LIN modes. In those modes, the OVER8 bit is forced to '0 ' by hardware.

Figure 606. Data sampling when oversampling by 16

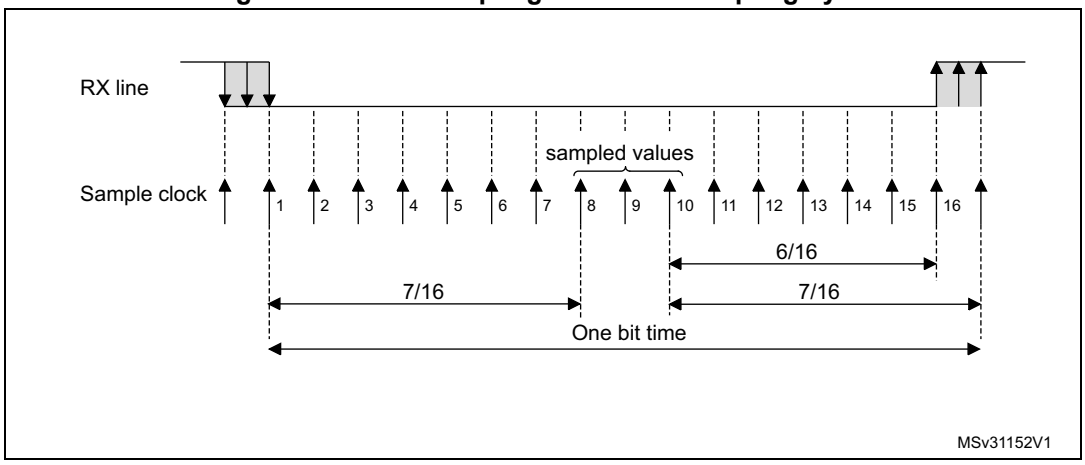


Figure 607. Data sampling when oversampling by 8

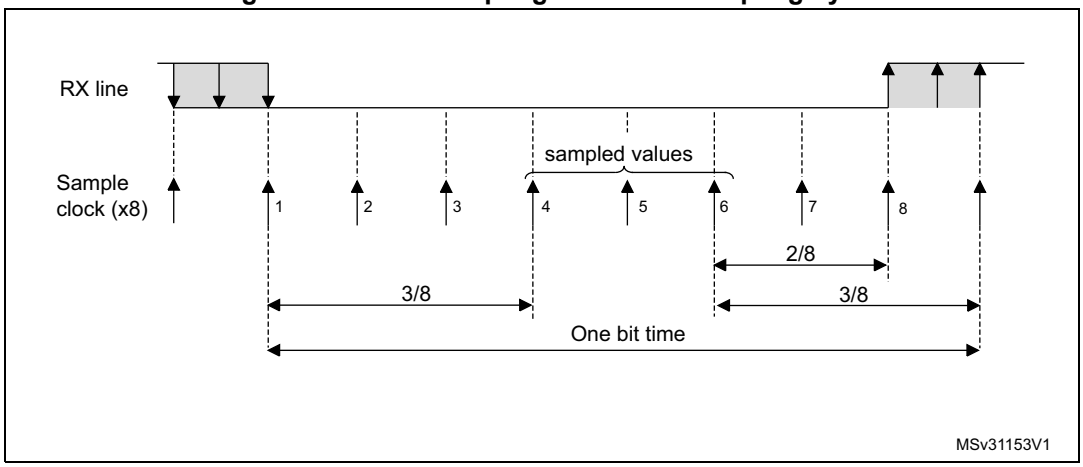


Table 419. Noise detection from sampled data

Sampled value	NE status	Received bit value
000	0	0
001	1	0
010	1	0
011	1	1
100	1	0
101	1	1
110	1	1
111	0	1

Framing error

A framing error is detected when the stop bit is not recognized on reception at the expected time, following either a de-synchronization or excessive noise.

When the framing error is detected:

- the FE bit is set by hardware;
- the invalid data is transferred from the Shift register to the USART_RDR register (RXFIFO in case FIFO mode is enabled).
- no interrupt is generated in case of single byte communication. However this bit rises at the same time as the RXNE bit (RXFNE in case FIFO mode is enabled) which itself generates an interrupt. In case of multibuffer communication an interrupt is issued if the EIE bit is set in the USART_CR3 register.

The FE bit is reset by writing ‘1’ to the FECF in the USART_ICR register.

Note: Framing error is not supported in SPI mode.

Configurable stop bits during reception

The number of stop bits to be received can be configured through the control bits of USART_CR: it can be either 1 or 2 in normal mode and 0.5 or 1.5 in Smartcard mode.

- **0.5 stop bit (reception in Smartcard mode)**: no sampling is done for 0.5 stop bit. As a consequence, no framing error and no break frame can be detected when 0.5 stop bit is selected.
- **1 stop bit**: sampling for 1 stop bit is done on the 8th, 9th and 10th samples.
- 1.5 stop bits (Smartcard mode)

  When transmitting in Smartcard mode, the device must check that the data are correctly sent. The receiver block must consequently be enabled (RE = 1 in USART_CR1) and the stop bit is checked to test if the Smartcard has detected a parity error.

  In the event of a parity error, the Smartcard forces the data signal low during the sampling (NACK signal), which is flagged as a framing error. The FE flag is then set through RXNE flag (RXFNE if the FIFO mode is enabled) at the end of the 1.5 stop bit. Sampling for 1.5 stop bits is done on the 16th, 17th and 18th samples (1 baud clock period after the beginning of the stop bit). The 1.5 stop bit can be broken into 2 parts: one 0.5 baud clock period during which nothing happens, followed by 1 normal stop bit period during which sampling occurs halfway through (refer to *Section 53.5.16: USART receiver timeout on page 2089* for more details).
- 2 stop bits

  Sampling for 2 stop bits is done on the 8th, 9th and 10th samples of the first stop bit.

  The framing error flag is set if a framing error is detected during the first stop bit.

  The second stop bit is not checked for framing error. The RXNE flag (RXFNE if the FIFO mode is enabled) is set at the end of the first stop bit.

53.5.7 USART baud rate generation

The baud rate for the receiver and transmitter (Rx and Tx) are both set to the value programmed in the USART_BRR register.

Equation 1: baud rate for standard USART (SPI mode included) (OVER8 = ‘0’ or ‘1’)

In case of oversampling by 16, the baud rate is given by the following formula:

$$\text{Tx/Rx baud} = \frac{\text{usart\_ker\_ckpres}}{\text{USARTDIV}}$$

In case of oversampling by 8, the baud rate is given by the following formula:

$$\text{Tx/Rx baud} = \frac{2 \times \text{usart\_ker\_ckpres}}{\text{USARTDIV}}$$

Equation 2: baud rate in Smartcard, LIN and IrDA modes (OVER8 = 0)

The baud rate is given by the following formula:

$$\text{Tx/Rx baud} = \frac{\text{usart\_ker\_ckpres}}{\text{USARTDIV}}$$

USARTDIV is an unsigned fixed point number that is coded on the USART_BRR register.

- When OVER8 = 0, BRR = USARTDIV.
- When OVER8 = 1
  - BRR[2:0] = USARTDIV[3:0] shifted 1 bit to the right.
  - BRR[3] must be kept cleared.
  - BRR[15:4] = USARTDIV[15:4]

Note: The baud counters are updated to the new value in the baud registers after a write operation to USART_BRR. Hence the baud rate register value should not be changed during communication.

In case of oversampling by 16 and 8, USARTDIV must be greater than or equal to 16.

How to derive USARTDIV from USART_BRR register values

Example 1

To obtain 9600 baud with usart_ker_ck_pres = 8 MHz:

- In case of oversampling by 16:
  USARTDIV = 8 000 000/9600
  BRR = USARTDIV = 0d833 = 0x0341
- In case of oversampling by 8:
  USARTDIV = 2 * 8 000 000/9600
  USARTDIV = 1666,66 (0d1667 = 0x683)
  BRR[3:0] = 0x3 >> 1 = 0x1
  BRR = 0x681

Example 2

To obtain 921.6 Kbaud with usart_ker_ck_pres = 48 MHz:

- In case of oversampling by 16:
  USARTDIV = 48 000 000/921 600
  BRR = USARTDIV = 0d52 = 0x34
- In case of oversampling by 8:
  USARTDIV = 2 * 48 000 000/921 600
  USARTDIV = 104 (0d104 = 0x68)
  BRR[3:0] = USARTDIV[3:0] >> 1 = 0x8 >> 1 = 0x4
  BRR = 0x64

53.5.8 Tolerance of the USART receiver to clock deviation

The USART asynchronous receiver operates correctly only if the total clock system deviation is less than the tolerance of the USART receiver.

The causes which contribute to the total deviation are:

- DTRA: deviation due to the transmitter error (which also includes the deviation of the transmitter's local oscillator)
- DQUANT: error due to the baud rate quantization of the receiver
- DREC: deviation of the receiver local oscillator
- DTCL: deviation due to the transmission line (generally due to the transceivers which can introduce an asymmetry between the low-to-high transition timing and the high-to-low transition timing)

$$DTRA + DQUANT + DREC + DTCL + DWU < USART\ receiver\ tolerance$$

where

DWU is the error due to sampling point deviation when the wakeup from low-power mode is used.

when M[1:0] = 01:

$$DWU = \frac{t_{WUUSART}}{11 \times Tbit}$$

when M[1:0] = 00:

$$DWU = \frac{t_{WUUSART}}{10 \times Tbit}$$

when M[1:0] = 10:

$$DWU = \frac{t_{WUUSART}}{9 \times Tbit}$$

$t_{WUUSART}$ is the time between the detection of the start bit falling edge and the instant when the clock (requested by the peripheral) is ready and reaching the peripheral, and the regulator is ready.

The USART receiver can receive data correctly at up to the maximum tolerated deviation specified in *Table 420*, *Table 421*, depending on the following settings:

- 9-, 10- or 11-bit character length defined by the M bits in the USART_CR1 register
- Oversampling by 8 or 16 defined by the OVER8 bit in the USART_CR1 register
- Bits BRR[3:0] of USART_BRR register are equal to or different from 0000.
- Use of 1 bit or 3 bits to sample the data, depending on the value of the ONEBIT bit in the USART_CR3 register.

Table 420. Tolerance of the USART receiver when BRR [3:0] = 0000

M bits	OVER8 bit = 0		OVER8 bit = 1	
	ONEBIT = 0	ONEBIT = 1	ONEBIT = 0	ONEBIT = 1
00	3.75%	4.375%	2.50%	3.75%
01	3.41%	3.97%	2.27%	3.41%
10	4.16%	4.86%	2.77%	4.16%

Table 421. Tolerance of the USART receiver when BRR[3:0] is different from 0000

M bits	OVER8 bit = 0		OVER8 bit = 1	
	ONEBIT = 0	ONEBIT = 1	ONEBIT = 0	ONEBIT = 1
00	3.33%	3.88%	2%	3%
01	3.03%	3.53%	1.82%	2.73%
10	3.7%	4.31%	2.22%	3.33%

Note: The data specified in Table 420 and Table 421 may slightly differ in the special case when the received frames contain some Idle frames of exactly 10-bit times when M bits = 00 (11-bit times when M = 01 or 9- bit times when M = 10).

53.5.9 USART Auto baud rate detection

The USART can detect and automatically set the USART_BRR register value based on the reception of one character. Automatic baud rate detection is useful under two circumstances:

- The communication speed of the system is not known in advance.
- The system is using a relatively low accuracy clock source and this mechanism enables the correct baud rate to be obtained without measuring the clock deviation.

The clock source frequency must be compatible with the expected communication speed.

- When oversampling by 16, the baud rate ranges from usart_ker_ck_pres/65535 and usart_ker_ck_pres/16.
- When oversampling by 8, the baud rate ranges from usart_ker_ck_pres/65535 and usart_ker_ck_pres/8.

Before activating the auto baud rate detection, the auto baud rate detection mode must be selected through the ABRMOD[1:0] field in the USART_CR2 register. There are four modes based on different character patterns. In these auto baud rate modes, the baud rate is measured several times during the synchronization data reception and each measurement is compared to the previous one.

These modes are the following:

- **Mode 0**: Any character starting with a bit at ‘1’.

  In this case the USART measures the duration of the start bit (falling edge to rising edge).
- **Mode 1:** Any character starting with a 10xx bit pattern.

  In this case, the USART measures the duration of the Start and of the 1st data bit. The measurement is done falling edge to falling edge, to ensure a better accuracy in the case of slow signal slopes.
- **Mode 2**: A 0x7F character frame (it may be a 0x7F character in LSB first mode or a 0xFE in MSB first mode).

  In this case, the baud rate is updated first at the end of the start bit (BRs), then at the end of bit 6 (based on the measurement done from falling edge to falling edge: BR6). Bit0 to bit6 are sampled at BRs while further bits of the character are sampled at BR6.
- **Mode 3**: A 0x55 character frame.

  In this case, the baud rate is updated first at the end of the start bit (BRs), then at the end of bit0 (based on the measurement done from falling edge to falling edge: BR0), and finally at the end of bit6 (BR6). Bit 0 is sampled at BRs, bit 1 to bit 6 are sampled at BR0, and further bits of the character are sampled at BR6. In parallel, another check is performed for each intermediate RX line transition. An error is generated if the transitions on RX are not sufficiently synchronized with the receiver (the receiver being based on the baud rate calculated on bit 0).

Prior to activating the auto baud rate detection, the USART_BRR register must be initialized by writing a non-zero baud rate value.

The automatic baud rate detection is activated by setting the ABREN bit in the USART_CR2 register. The USART then waits for the first character on the RX line. The auto baud rate operation completion is indicated by the setting of the ABRF flag in the USART_ISR register. If the line is noisy, the correct baud rate detection cannot be guaranteed. In this case the BRR value may be corrupted and the ABRE error flag is set. This also happens if the communication speed is not compatible with the automatic baud rate detection range (bit duration not between 16 and 65536 clock periods (oversampling by 16) and not between 8 and 65536 clock periods (oversampling by 8)).

The auto baud rate detection can be re-launched later by resetting the ABRF flag (by writing a ‘0’).

When FIFO management is disabled and an auto baud rate error occurs, the ABRE flag is set through RXNE and FE bits.

When FIFO management is enabled and an auto baud rate error occurs, the ABRE flag is set through RXFNE and FE bits.

If the FIFO mode is enabled, the auto baud rate detection should be made using the data on the first RXFIFO location. So, prior to launching the auto baud rate detection, make sure that the RXFIFO is empty by checking the RXFNE flag in USART_ISR register.

Note: The BRR value might be corrupted if the USART is disabled (UE = 0) during an auto baud rate operation.

53.5.10 USART multiprocessor communication

It is possible to perform USART multiprocessor communications (with several USARTs connected in a network). For instance one of the USARTs can be the master with its TX output connected to the RX inputs of the other USARTs, while the others are slaves with their respective TX outputs logically ANDed together and connected to the RX input of the master.

In multiprocessor configurations, it is often desirable that only the intended message recipient actively receives the full message contents, thus reducing redundant USART service overhead for all non addressed receivers.

The non-addressed devices can be placed in Mute mode by means of the muting function. To use the Mute mode feature, the MME bit must be set in the USART_CR1 register.

Note: When FIFO management is enabled and MME is already set, MME bit must not be cleared and then set again quickly (within two usart_ker_ck cycles), otherwise Mute mode might remain active.

When the Mute mode is enabled:

- none of the reception status bits can be set;
- all the receive interrupts are inhibited;
- the RWU bit in USART_ISR register is set to ‘1’. RWU can be controlled automatically by hardware or by software, through the MMRQ bit in the USART_RQR register, under certain conditions.

The USART can enter or exit from Mute mode using one of two methods, depending on the WAKE bit in the USART_CR1 register:

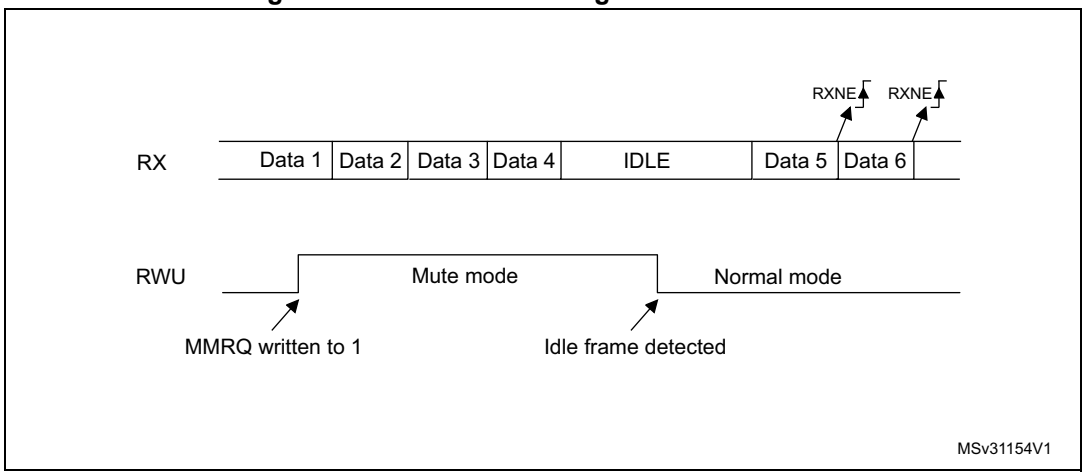
- Idle Line detection if the WAKE bit is reset,
- Address Mark detection if the WAKE bit is set.

Idle line detection (WAKE = 0)

The USART enters Mute mode when the MMRQ bit is written to ‘1’ and the RWU is automatically set.

The USART wakes up when an Idle frame is detected. The RWU bit is then cleared by hardware but the IDLE bit is not set in the USART_ISR register. An example of Mute mode behavior using Idle line detection is given in *Figure 608*.

Figure 608. Mute mode using Idle line detection



Note: If the MMRQ is set while the IDLE character has already elapsed, Mute mode is not entered (RWU is not set).

If the USART is activated while the line is IDLE, the idle state is detected after the duration of one IDLE frame (not only after the reception of one character frame).

4-bit/7-bit address mark detection (WAKE = 1)

In this mode, bytes are recognized as addresses if their MSB is a ‘1’, otherwise they are considered as data. In an address byte, the address of the targeted receiver is put in the 4 or 7 LSBs. The choice of 7 or 4 bit address detection is done using the ADDM7 bit. This 4-bit/7-bit word is compared by the receiver with its own address which is programmed in the ADD bits in the USART_CR2 register.

Note: In 7-bit and 9-bit data modes, address detection is done on 6-bit and 8-bit addresses (ADD[5:0] and ADD[7:0]) respectively.

The USART enters Mute mode when an address character is received which does not match its programmed address. In this case, the RWU bit is set by hardware. The RXNE flag is not set for this address byte and no interrupt or DMA request is issued when the USART enters Mute mode. When FIFO management is enabled, the software should ensure that there is at least one empty location in the RXFIFO before entering Mute mode.

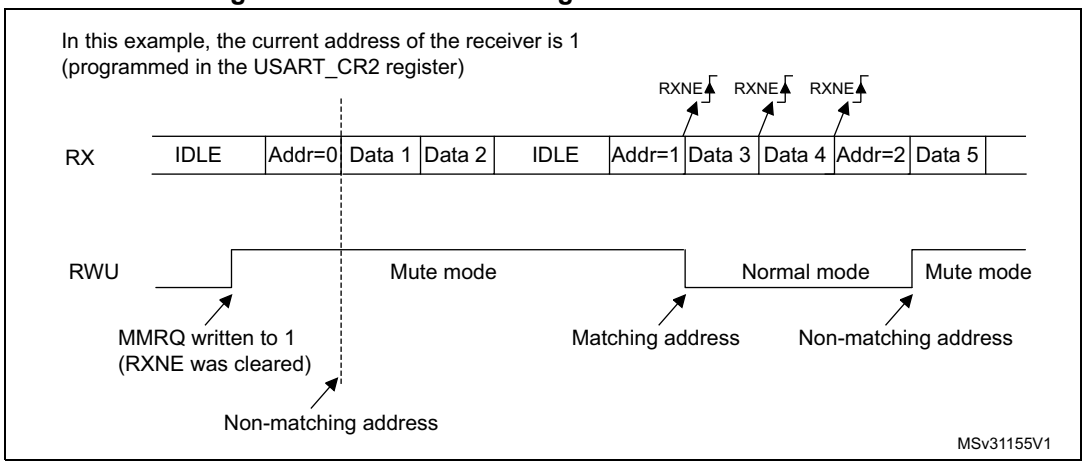
The USART also enters Mute mode when the MMRQ bit is written to 1. The RWU bit is also automatically set in this case.

The USART exits from Mute mode when an address character is received which matches the programmed address. Then the RWU bit is cleared and subsequent bytes are received normally. The RXNE/RXFNE bit is set for the address character since the RWU bit has been cleared.

Note: When FIFO management is enabled, when MMRQ is set while the receiver is sampling last bit of a data, this data may be received before effectively entering in Mute mode

An example of Mute mode behavior using address mark detection is given in *Figure 609*.

Figure 609. Mute mode using address mark detection



53.5.11 USART Modbus communication

The USART offers basic support for the implementation of Modbus/RTU and Modbus/ASCII protocols. Modbus/RTU is a Half-duplex, block-transfer protocol. The control part of the protocol (address recognition, block integrity control and command interpretation) must be implemented in software.

The USART offers basic support for the end of the block detection, without software overhead or other resources.

Modbus/RTU

In this mode, the end of one block is recognized by a “silence” (idle line) for more than 2 character times. This function is implemented through the programmable timeout function.

The timeout function and interrupt must be activated, through the RTOEN bit in the USART_CR2 register and the RTOIE in the USART_CR1 register. The value corresponding to a timeout of 2 character times (for example 22 x bit time) must be programmed in the RTO register. When the receive line is idle for this duration, after the last stop bit is received, an interrupt is generated, informing the software that the current block reception is completed.

Modbus/ASCII

In this mode, the end of a block is recognized by a specific (CR/LF) character sequence. The USART manages this mechanism using the character match function.

By programming the LF ASCII code in the ADD[7:0] field and by activating the character match interrupt (CMIE = 1), the software is informed when a LF has been received and can check the CR/LF in the DMA buffer.

53.5.12 USART parity control

Parity control (generation of parity bit in transmission and parity checking in reception) can be enabled by setting the PCE bit in the USART_CR1 register. Depending on the frame length defined by the M bits, the possible USART frame formats are as listed in *Table 422*.

Table 422. USART frame formats

M bits	PCE bit	USART frame(1)
00	0	| SB | 8 bit data | STB |
00	1	| SB | 7-bit data | PB | STB |
01	0	| SB | 9-bit data | STB |
01	1	| SB | 8-bit data PB | STB |
10	0	| SB | 7bit data | STB |
10	1	| SB | 6-bit data | PB | STB |

1. Legends: SB: start bit, STB: stop bit, PB: parity bit. In the data register, the PB is always taking the MSB position (8th or 7th, depending on the M bit value).

Even parity

The parity bit is calculated to obtain an even number of “1s” inside the frame of the 6, 7 or 8 LSB bits (depending on M bit values) and the parity bit.

As an example, if data = 00110101 and 4 bits are set, the parity bit is equal to 0 if even parity is selected (PS bit in USART_CR1 = 0).

Odd parity

The parity bit is calculated to obtain an odd number of “1s” inside the frame made of the 6, 7 or 8 LSB bits (depending on M bit values) and the parity bit.

As an example, if data = 00110101 and 4 bits set, then the parity bit is equal to 1 if odd parity is selected (PS bit in USART_CR1 = 1).

Parity checking in reception

If the parity check fails, the PE flag is set in the USART_ISR register and an interrupt is generated if PEIE is set in the USART_CR1 register. The PE flag is cleared by software writing 1 to the PECF in the USART_ICR register.

Parity generation in transmission

If the PCE bit is set in USART_CR1, then the MSB bit of the data written in the data register is transmitted but is changed by the parity bit (even number of “1s” if even parity is selected (PS = 0) or an odd number of “1s” if odd parity is selected (PS=1).

53.5.13 USART LIN (local interconnection network) mode

This section is relevant only when LIN mode is supported. Refer to *Section 53.4: USART implementation on page 2058*.

The LIN mode is selected by setting the LINEN bit in the USART_CR2 register. In LIN mode, the following bits must be kept cleared:

- CLKEN in the USART_CR2 register,
- STOP[1:0], SCEN, HDSEL and IREN in the USART_CR3 register.

LIN transmission

The procedure described in *Section 53.5.4* has to be applied for LIN Master transmission. It must be the same as for normal USART transmission with the following differences:

- Clear the M bit to configure 8-bit word length.
- Set the LINEN bit to enter LIN mode. In this case, setting the SBKRQ bit sends 13 ‘0 bits as a break character. Then two bits of value ‘1 are sent to enable the next start detection.

LIN reception

When LIN mode is enabled, the break detection circuit is activated. The detection is totally independent from the normal USART receiver. A break can be detected whenever it occurs, during Idle state or during a frame.

When the receiver is enabled (RE = 1 in USART_CR1), the circuit looks at the RX input for a start signal. The method for detecting start bits is the same when searching break characters or data. After a start bit has been detected, the circuit samples the next bits exactly like for the data (on the 8th, 9th and 10th samples). If 10 (when the LBDL = 0 in USART_CR2) or 11 (when LBDL = 1 in USART_CR2) consecutive bits are detected as ‘0, and are followed by a delimiter character, the LBDF flag is set in USART_ISR. If the LBDIE bit = 1, an interrupt is generated. Before validating the break, the delimiter is checked for as it signifies that the RX line has returned to a high level.

If a ‘1 is sampled before the 10 or 11 have occurred, the break detection circuit cancels the current detection and searches for a start bit again.

If the LIN mode is disabled (LINEN = 0), the receiver continues working as normal USART, without taking into account the break detection.

If the LIN mode is enabled (LINEN = 1), as soon as a framing error occurs (i.e. stop bit detected at ‘0, which is the case for any break frame), the receiver stops until the break detection circuit receives either a ‘1, if the break word was not complete, or a delimiter character if a break has been detected.

The behavior of the break detector state machine and the break flag is shown on the *Figure 610: Break detection in LIN mode (11-bit break length - LBDL bit is set) on page 2084*.

Examples of break frames are given on *Figure 611: Break detection in LIN mode vs. Framing error detection on page 2085*.

Figure 610. Break detection in LIN mode (11-bit break length - LBDL bit is set)

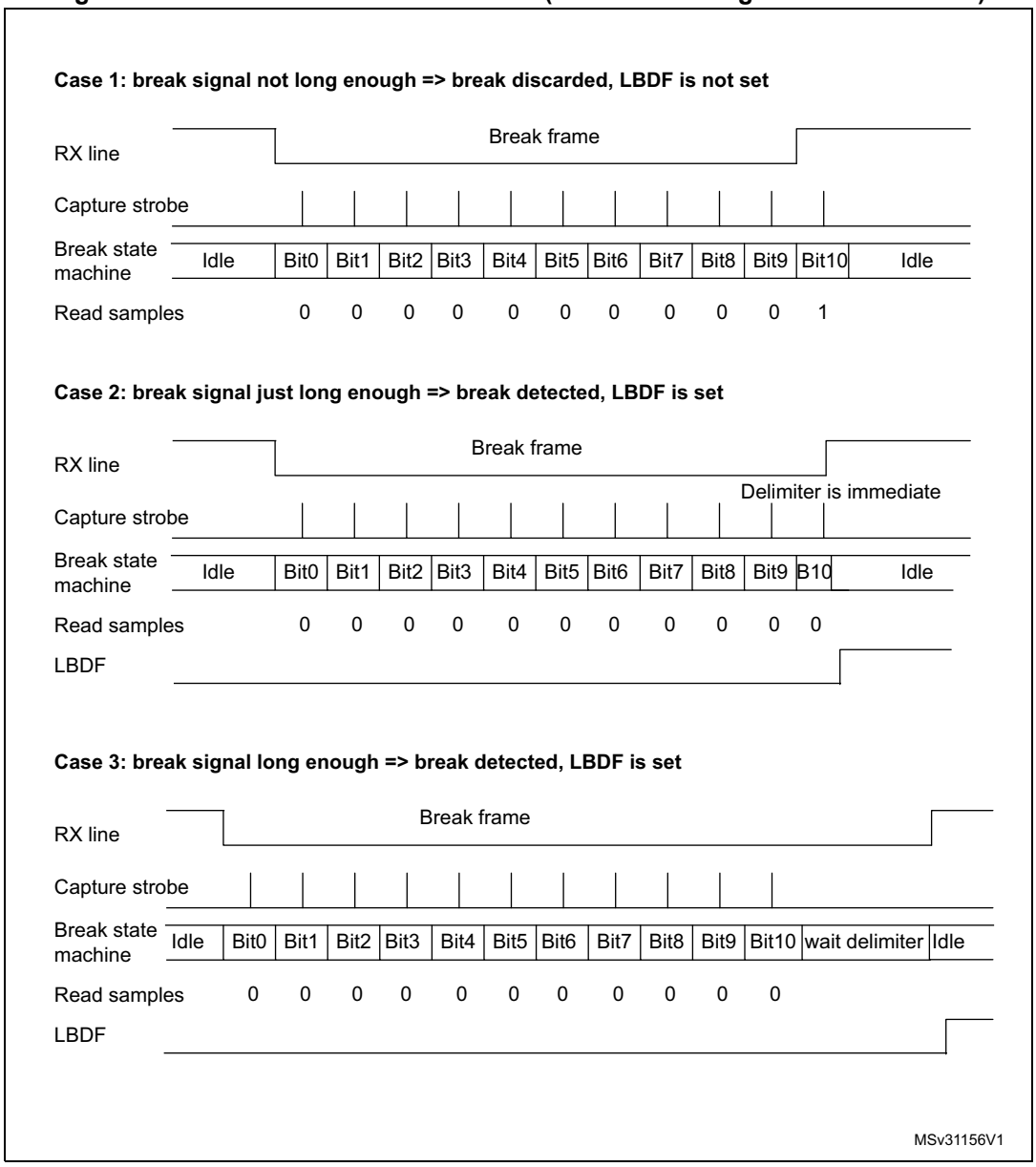
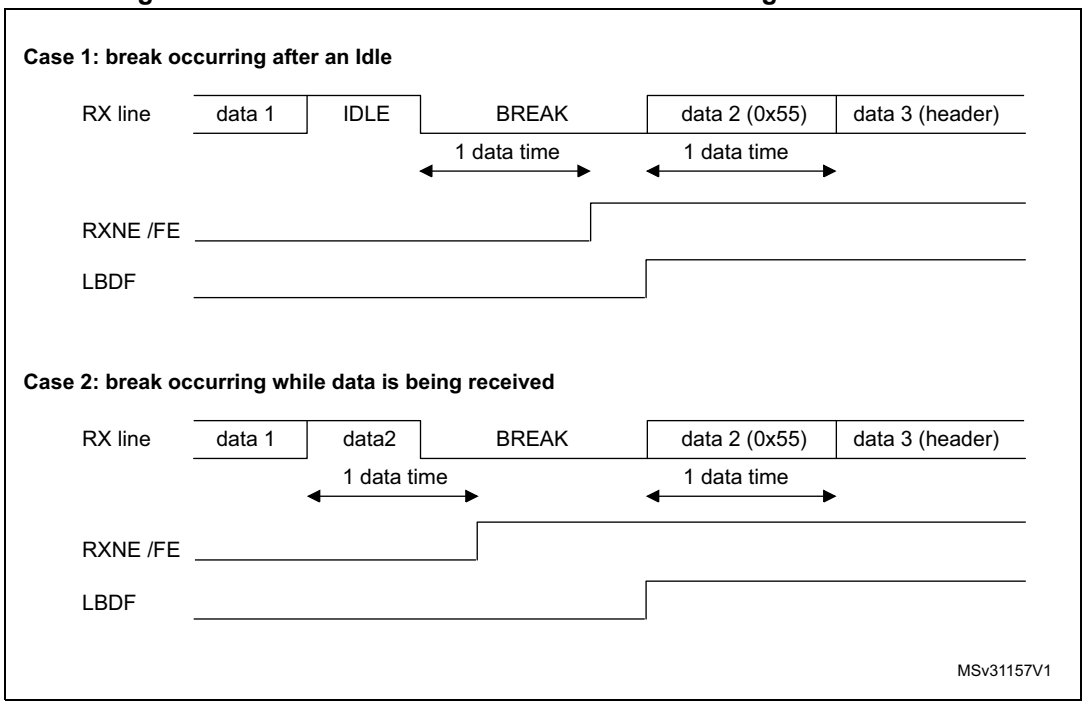


Figure 611. Break detection in LIN mode vs. Framing error detection



53.5.14 USART synchronous mode

Master mode

The synchronous master mode is selected by programming the CLKEN bit in the USART_CR2 register to '1'. In synchronous mode, the following bits must be kept cleared:

- LINEN bit in the USART_CR2 register,
- SCEN, HDSEL and IREN bits in the USART_CR3 register.

In this mode, the USART can be used to control bidirectional synchronous serial communications in master mode. The CK pin is the output of the USART transmitter clock. No clock pulses are sent to the CK pin during start bit and stop bit. Depending on the state of the LBCL bit in the USART_CR2 register, clock pulses are, or are not, generated during the last valid data bit (address mark). The CPOL bit in the USART_CR2 register is used to select the clock polarity, and the CPHA bit in the USART_CR2 register is used to select the phase of the external clock (see *Figure 612*, *Figure 613* and *Figure 614*).

During the Idle state, preamble and send break, the external CK clock is not activated.

In synchronous master mode, the USART transmitter operates exactly like in asynchronous mode. However, since CK is synchronized with TX (according to CPOL and CPHA), the data on TX is synchronous.

In synchronous master mode, the USART receiver operates in a different way compared to asynchronous mode. If RE is set to 1, the data are sampled on CK (rising or falling edge, depending on CPOL and CPHA), without any oversampling. A given setup and a hold time must be respected (which depends on the baud rate: 1/16 bit time).

Note: In master mode, the CK pin operates in conjunction with the TX pin. Thus, the clock is provided only if the transmitter is enabled (TE = 1) and data are being transmitted (USART_TDR data register written). This means that it is not possible to receive synchronous data without transmitting data.

Figure 612. USART example of synchronous master transmission

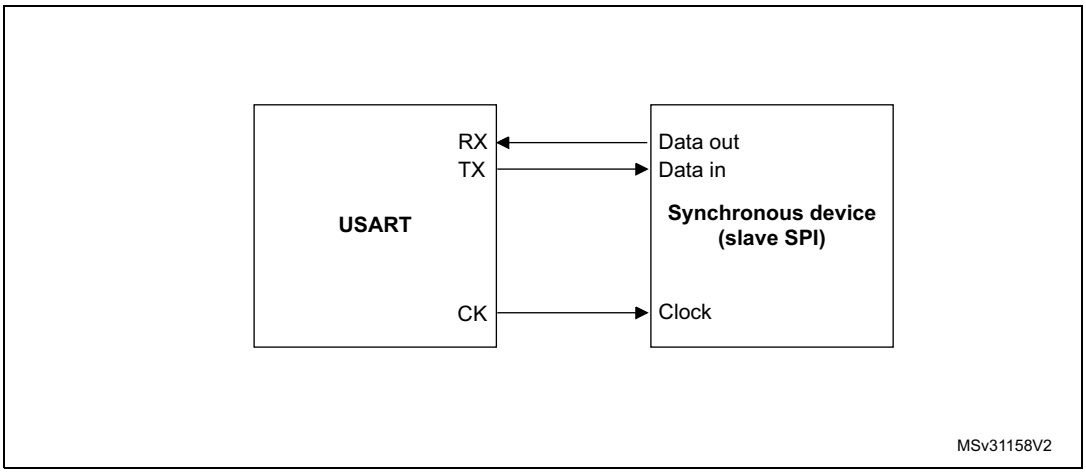


Figure 613. USART data clock timing diagram in synchronous master mode (M bits = 00)

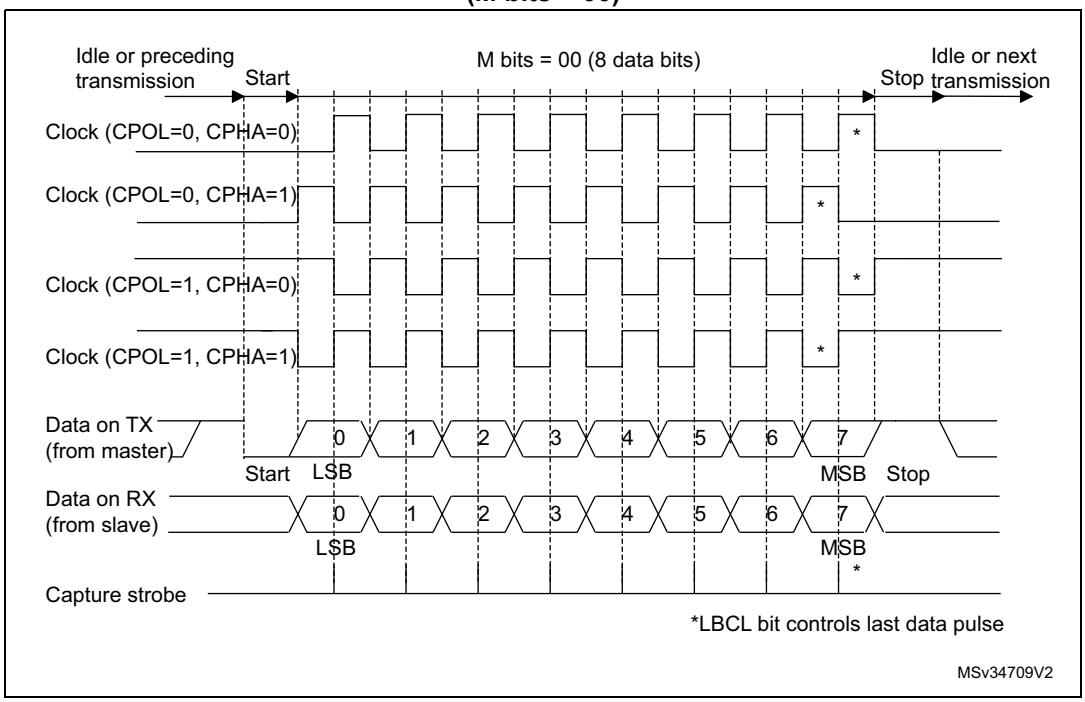
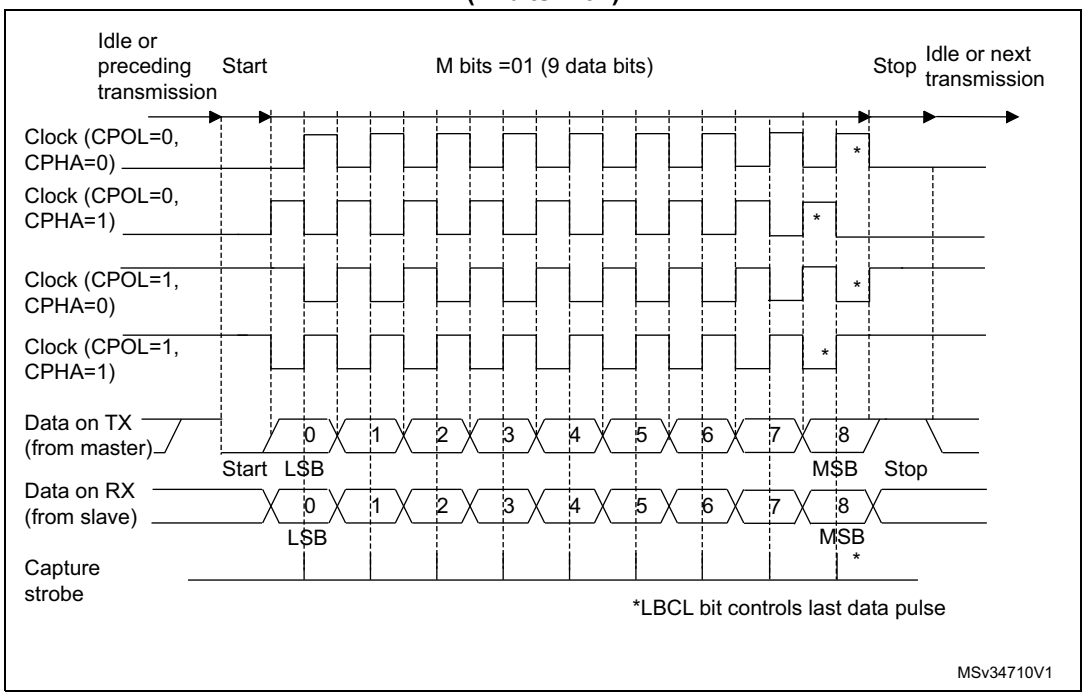


Figure 614. USART data clock timing diagram in synchronous master mode (M bits = 01)



Slave mode

The synchronous slave mode is selected by programming the SLVEN bit in the USART_CR2 register to ‘1’. In synchronous slave mode, the following bits must be kept cleared:

- LINEN and CLKEN bits in the USART_CR2 register,
- SCEN, HDSEL and IREN bits in the USART_CR3 register.

In this mode, the USART can be used to control bidirectional synchronous serial communications in slave mode. The CK pin is the input of the USART in slave mode.

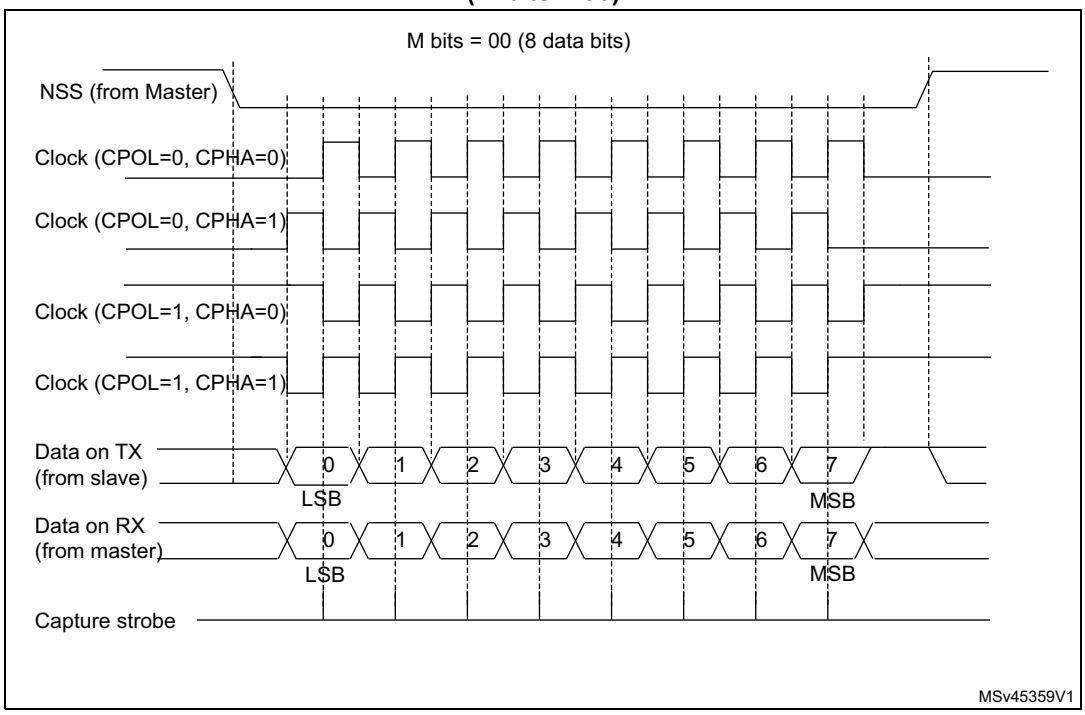
*Note: When the peripheral is used in SPI slave mode, the frequency of peripheral clock source (*usart_ker_ck_pres*) must be greater than 3 times the CK input frequency.*

The CPOL bit and the CPHA bit in the USART_CR2 register are used to select the clock polarity and the phase of the external clock, respectively (see *Figure 615*).

An underrun error flag is available in slave transmission mode. This flag is set when the first clock pulse for data transmission appears while the software has not yet loaded any value to USART_TDR.

The slave supports the hardware and software NSS management.

Figure 615. USART data clock timing diagram in synchronous slave mode (M bits = 00)



Slave Select (NSS) pin management

The hardware or software slave select management can be set through the DIS_NSS bit in the USART_CR2 register:

- Software NSS management (DIS_NSS = 1)

  The SPI slave is always selected and NSS input pin is ignored.

  The external NSS pin remains free for other application uses.
- Hardware NSS management (DIS_NSS = 0)

  The SPI slave selection depends on NSS input pin. The slave is selected when NSS is low and deselected when NSS is high.

Note: The LBCL (used only on SPI master mode), CPOL and CPHA bits have to be selected when the USART is disabled (UE = 0) to ensure that the clock pulses function correctly.

In SPI slave mode, the USART must be enabled before starting the master communications (or between frames while the clock is stable). Otherwise, if the USART slave is enabled while the master is in the middle of a frame, it becomes desynchronized with the master. The data register of the slave needs to be ready before the first edge of the communication clock or before the end of the ongoing communication, otherwise the SPI slave transmits zeros.

SPI Slave underrun error

When an underrun error occurs, the UDR flag is set in the USART_ISR register, and the SPI slave goes on sending the last data until the underrrun error flag is cleared by software.

The underrun flag is set at the beginning of the frame. An underrun error interrupt is triggered if EIE bit is set in the USART_CR3 register.

The underrun error flag is cleared by setting bit UDRCF in the USART_ICR register.

In case of underrun error, it is still possible to write to the TDR register. Clearing the underrun error enables sending new data.

If an underrun error occurred and there is no new data written in TDR, then the TC flag is set at the end of the frame.

Note: An underrun error may occur if the moment the data is written to the USART_TDR is too close to the first CK transmission edge. To avoid this underrun error, the USART_TDR should be written 3 usart_ker_ck *cycles before the first CK edge.*

53.5.15 USART single-wire Half-duplex communication

Single-wire Half-duplex mode is selected by setting the HDSEL bit in the USART_CR3 register. In this mode, the following bits must be kept cleared:

- LINEN and CLKEN bits in the USART_CR2 register,
- SCEN and IREN bits in the USART_CR3 register.

The USART can be configured to follow a Single-wire Half-duplex protocol where the TX and RX lines are internally connected. The selection between half- and Full-duplex communication is made with a control bit HDSEL in USART_CR3.

As soon as HDSEL is written to ‘1’:

- The TX and RX lines are internally connected.
- The RX pin is no longer used.
- The TX pin is always released when no data is transmitted. Thus, it acts as a standard I/O in idle or in reception. It means that the I/O must be configured so that TX is configured as alternate function open-drain with an external pull-up.

Apart from this, the communication protocol is similar to normal USART mode. Any conflict on the line must be managed by software (for instance by using a centralized arbiter). In particular, the transmission is never blocked by hardware and continues as soon as data are written in the data register while the TE bit is set.

53.5.16 USART receiver timeout

The receiver timeout feature is enabled by setting the RTOEN bit in the USART_CR2 control register.

The timeout duration is programmed using the RTO bitfields in the USART_RTOR register.

The receiver timeout counter starts counting:

- from the end of the stop bit if STOP = ‘00’ or STOP = ‘11’
- from the end of the second stop bit if STOP = ‘10’.
- from the beginning of the stop bit if STOP = ‘01’.

When the timeout duration has elapsed, the RTOF flag in the USART_ISR register is set. A timeout is generated if RTOIE bit in USART_CR1 register is set.

53.5.17 USART Smartcard mode

This section is relevant only when Smartcard mode is supported. Refer to *Section 53.4: USART implementation on page 2058*.

Smartcard mode is selected by setting the SCEN bit in the USART_CR3 register. In Smartcard mode, the following bits must be kept cleared:

- LINEN bit in the USART_CR2 register,
- HDSEL and IREN bits in the USART_CR3 register.

The CLKEN bit can also be set to provide a clock to the Smartcard.

The Smartcard interface is designed to support asynchronous Smartcard protocol as defined in the ISO 7816-3 standard. Both T = 0 (character mode) and T = 1 (block mode) are supported.

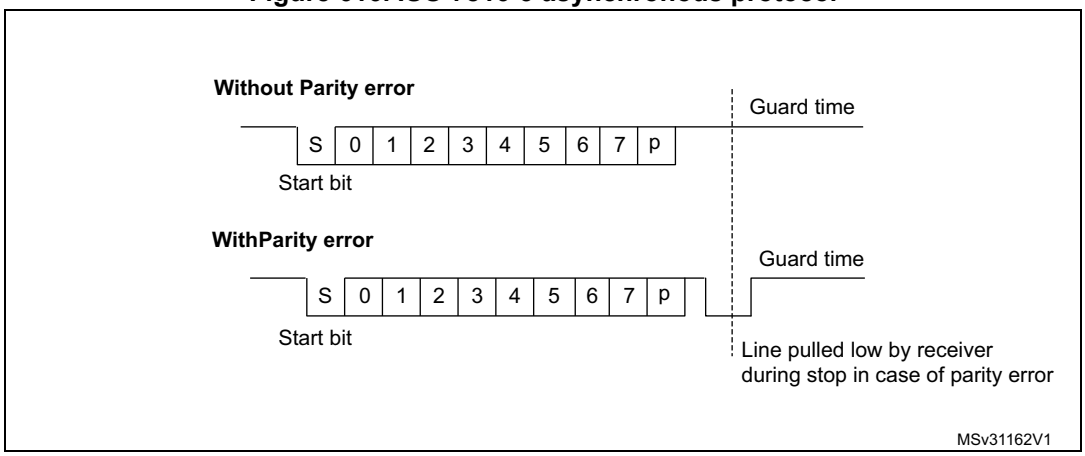
The USART should be configured as:

- 8 bits plus parity: M = 1 and PCE = 1 in the USART_CR1 register
- 1.5 stop bits when transmitting and receiving data: STOP = ’11’ in the USART_CR2 register. It is also possible to choose 0.5 stop bit for reception.

In T = 0 (character) mode, the parity error is indicated at the end of each character during the guard time period.

Figure 616 shows examples of what can be seen on the data line with and without parity error.

Figure 616. ISO 7816-3 asynchronous protocol



When connected to a Smartcard, the TX output of the USART drives a bidirectional line that is also driven by the Smartcard. The TX pin must be configured as open drain.

Smartcard mode implements a single wire half duplex communication protocol.

- Transmission of data from the transmit shift register is guaranteed to be delayed by a minimum of 1/2 baud clock. In normal operation a full transmit shift register starts shifting on the next baud clock edge. In Smartcard mode this transmission is further delayed by a guaranteed 1/2 baud clock.
- In transmission, if the Smartcard detects a parity error, it signals this condition to the USART by driving the line low (NACK). This NACK signal (pulling transmit line low for 1 baud clock) causes a framing error on the transmitter side (configured with 1.5 stop bits). The USART can handle automatic re-sending of data according to the protocol.

The number of retries is programmed in the SCARCNT bitfield. If the USART continues receiving the NACK after the programmed number of retries, it stops transmitting and signals the error as a framing error. The TXE bit (TXFNF bit in case FIFO mode is enabled) may be set using the TXFRQ bit in the USART_RQR register.

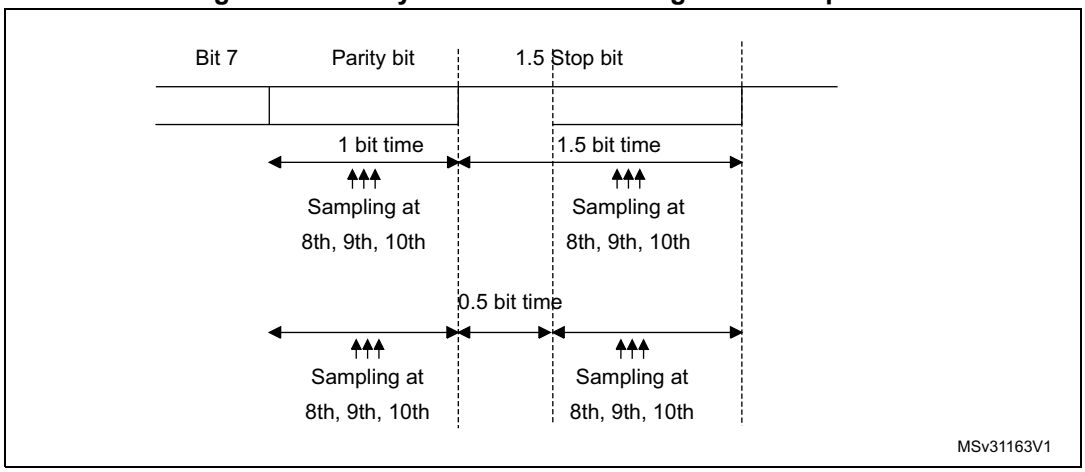
- Smartcard auto-retry in transmission: A delay of 2.5 baud periods is inserted between the NACK detection by the USART and the start bit of the repeated character. The TC bit is set immediately at the end of reception of the last repeated character (no guardtime). If the software wants to repeat it again, it must insure the minimum 2 baud periods required by the standard.
- If a parity error is detected during reception of a frame programmed with a 1.5 stop bit period, the transmit line is pulled low for a baud clock period after the completion of the receive frame. This is to indicate to the Smartcard that the data transmitted to the USART has not been correctly received. A parity error is NACKed by the receiver if the NACK control bit is set, otherwise a NACK is not transmitted (to be used in T = 1 mode). If the received character is erroneous, the RXNE (RXFNE in case FIFO mode is enabled)/receive DMA request is not activated. According to the protocol specification, the Smartcard must resend the same character. If the received character is still erroneous after the maximum number of retries specified in the SCARCNT bitfield, the USART stops transmitting the NACK and signals the error as a parity error.
- Smartcard auto-retry in reception: the BUSY flag remains set if the USART NACKs the card but the card doesn't repeat the character.
- In transmission, the USART inserts the Guard Time (as programmed in the Guard Time register) between two successive characters. As the Guard Time is measured after the stop bit of the previous character, the GT[7:0] register must be programmed to the desired CGT (Character Guard Time, as defined by the 7816-3 specification) minus 12 (the duration of one character).
- The assertion of the TC flag can be delayed by programming the Guard Time register. In normal operation, TC is asserted when the transmit shift register is empty and no further transmit requests are outstanding. In Smartcard mode an empty transmit shift register triggers the Guard Time counter to count up to the programmed value in the Guard Time register. TC is forced low during this time. When the Guard Time counter reaches the programmed value TC is asserted high. The TCBGT flag can be used to detect the end of data transfer without waiting for guard time completion. This flag is set just after the end of frame transmission and if no NACK has been received from the card.
- The deassertion of TC flag is unaffected by Smartcard mode.
- If a framing error is detected on the transmitter end (due to a NACK from the receiver), the NACK is not detected as a start bit by the receive block of the transmitter. According to the ISO protocol, the duration of the received NACK can be 1 or 2 baud clock periods.
- On the receiver side, if a parity error is detected and a NACK is transmitted the receiver does not detect the NACK as a start bit.

Note: Break characters are not significant in Smartcard mode. A 0x00 data with a framing error is treated as data and not as a break.

No Idle frame is transmitted when toggling the TE bit. The Idle frame (as defined for the other configurations) is not defined by the ISO protocol.

Figure 617 shows how the NACK signal is sampled by the USART. In this example the USART is transmitting data and is configured with 1.5 stop bits. The receiver part of the USART is enabled in order to check the integrity of the data and the NACK signal.

Figure 617. Parity error detection using the 1.5 stop bits



The USART can provide a clock to the Smartcard through the CK output. In Smartcard mode, CK is not associated to the communication but is simply derived from the internal peripheral input clock through a 5-bit prescaler. The division ratio is configured in the USART_GTPR register. CK frequency can be programmed from usart_ker_ck_pres/2 to usart_ker_ck_pres/62, where usart_ker_ck_pres is the peripheral input clock divided by a programmed prescaler.

Block mode (T = 1)

In T = 1 (block) mode, the parity error transmission can be deactivated by clearing the NACK bit in the USART_CR3 register.

When requesting a read from the Smartcard, in block mode, the software must program the RTOR register to the BWT (block wait time) - 11 value. If no answer is received from the card before the expiration of this period, a timeout interrupt is generated. If the first character is received before the expiration of the period, it is signaled by the RXNE/RXFNE interrupt.

Note: The RXNE/RXFNE interrupt must be enabled even when using the USART in DMA mode to read from the Smartcard in block mode. In parallel, the DMA must be enabled only after the first received byte.

After the reception of the first character (RXNE/RXFNE interrupt), the RTO register must be programmed to the CWT (character wait time -11 value), in order to enable the automatic check of the maximum wait time between two consecutive characters. This time is expressed in baud time units. If the Smartcard does not send a new character in less than the CWT period after the end of the previous character, the USART signals it to the software through the RTOF flag and interrupt (when RTOIE bit is set).

Note: As in the Smartcard protocol definition, the BWT/CWT values should be defined from the beginning (start bit) of the last character. The RTO register must be programmed to BWT - 11 or CWT -11, respectively, taking into account the length of the last character itself.

A block length counter is used to count all the characters received by the USART. This counter is reset when the USART is transmitting. The length of the block is communicated by the Smartcard in the third byte of the block (prologue field). This value must be programmed to the BLEN field in the USART_RTOR register. When using DMA mode, before the start of the block, this register field must be programmed to the minimum value

(0x0). With this value, an interrupt is generated after the 4th received character. The software must read the LEN field (third byte), its value must be read from the receive buffer.

In interrupt driven receive mode, the length of the block may be checked by software or by programming the BLEN value. However, before the start of the block, the maximum value of BLEN (0xFF) may be programmed. The real value is programmed after the reception of the third character.

If the block is using the LRC longitudinal redundancy check (1 epilogue byte), the BLEN = LEN. If the block is using the CRC mechanism (2 epilog bytes), BLEN = LEN+1 must be programmed. The total block length (including prologue, epilogue and information fields) equals BLEN+4. The end of the block is signaled to the software through the EOBF flag and interrupt (when EOBIE bit is set).

In case of an error in the block length, the end of the block is signaled by the RTO interrupt (Character Wait Time overflow).

Note: The error checking code (LRC/CRC) must be computed/verified by software.

Direct and inverse convention

The Smartcard protocol defines two conventions: direct and inverse.

The direct convention is defined as: LSB first, logical bit value of 1 corresponds to a H state of the line and parity is even. In order to use this convention, the following control bits must be programmed: MSBFIRST = 0, DATAINV = 0 (default values).

The inverse convention is defined as: MSB first, logical bit value 1 corresponds to an L state on the signal line and parity is even. In order to use this convention, the following control bits must be programmed: MSBFIRST = 1, DATAINV = 1.

Note: When logical data values are inverted (0 = H, 1 = L), the parity bit is also inverted in the same way.

In order to recognize the card convention, the card sends the initial character, TS, as the first character of the ATR (Answer To Reset) frame. The two possible patterns for the TS are: LHHL LLL LLH and LHHL HHH LLH.

- (H) LHHL LLL LLH sets up the inverse convention: state L encodes value 1 and moment 2 conveys the most significant bit (MSB first). When decoded by inverse convention, the conveyed byte is equal to '3F'.
- (H) LHHL HHH LLH sets up the direct convention: state H encodes value 1 and moment 2 conveys the least significant bit (LSB first). When decoded by direct convention, the conveyed byte is equal to '3B'.

Character parity is correct when there is an even number of bits set to 1 in the nine moments 2 to 10.

As the USART does not know which convention is used by the card, it needs to be able to recognize either pattern and act accordingly. The pattern recognition is not done in hardware, but through a software sequence. Moreover, assuming that the USART is configured in direct convention (default) and the card answers with the inverse convention, TS = LHHL LLL LLH results in a USART received character of 03 and an odd parity.

Therefore, two methods are available for TS pattern recognition:

Method 1

The USART is programmed in standard Smartcard mode/direct convention. In this case, the TS pattern reception generates a parity error interrupt and error signal to the card.

- The parity error interrupt informs the software that the card did not answer correctly in direct convention. Software then reprograms the USART for inverse convention
- In response to the error signal, the card retries the same TS character, and it is correctly received this time, by the reprogrammed USART.

Alternatively, in answer to the parity error interrupt, the software may decide to reprogram the USART and to also generate a new reset command to the card, then wait again for the TS.

Method 2

The USART is programmed in 9-bit/no-parity mode, no bit inversion. In this mode it receives any of the two TS patterns as:

(H) LHHL LLL LLH = 0x103: inverse convention to be chosen

(H) LHHL HHH LLH = 0x13B: direct convention to be chosen

The software checks the received character against these two patterns and, if any of them match, then programs the USART accordingly for the next character reception.

If none of the two is recognized, a card reset may be generated in order to restart the negotiation.

53.5.18 USART IrDA SIR ENDEC block

This section is relevant only when IrDA mode is supported. Refer to *Section 53.4: USART implementation on page 2058*.

IrDA mode is selected by setting the IREN bit in the USART_CR3 register. In IrDA mode, the following bits must be kept cleared:

- LINEN, STOP and CLKEN bits in the USART_CR2 register,
- SCEN and HDSEL bits in the USART_CR3 register.

The IrDA SIR physical layer specifies use of a Return to Zero, Inverted (RZI) modulation scheme that represents logic 0 as an infrared light pulse (see *Figure 618*).

The SIR Transmit encoder modulates the Non Return to Zero (NRZ) transmit bit stream output from USART. The output pulse stream is transmitted to an external output driver and infrared LED. USART supports only bit rates up to 115.2 kbaud for the SIR ENDEC. In normal mode the transmitted pulse width is specified as 3/16 of a bit period.

The SIR receive decoder demodulates the return-to-zero bit stream from the infrared detector and outputs the received NRZ serial bit stream to the USART. The decoder input is normally high (marking state) in the Idle state. The transmit encoder output has the opposite polarity to the decoder input. A start bit is detected when the decoder input is low.

- IrDA is a half duplex communication protocol. If the Transmitter is busy (when the USART is sending data to the IrDA encoder), any data on the IrDA receive line is ignored by the IrDA decoder and if the Receiver is busy (when the USART is receiving decoded data from the USART), data on the TX from the USART to IrDA is not

encoded. While receiving data, transmission should be avoided as the data to be transmitted could be corrupted.

- A ‘0‘ is transmitted as a high pulse and a ‘1’ is transmitted as a ‘0’. The width of the pulse is specified as 3/16th of the selected bit period in normal mode (see *Figure 619*).
- The SIR decoder converts the IrDA compliant receive signal into a bit stream for USART.
- The SIR receive logic interprets a high state as a logic one and low pulses as logic zeros.
- The transmit encoder output has the opposite polarity to the decoder input. The SIR output is in low state when Idle.
- The IrDA specification requires the acceptance of pulses greater than 1.41 µs. The acceptable pulse width is programmable. Glitch detection logic on the receiver end filters out pulses of width less than 2 PSC periods (PSC is the prescaler value programmed in the USART_GTPR). Pulses of width less than 1 PSC period are always rejected, but those of width greater than one and less than two periods may be accepted or rejected, those greater than two periods are accepted as a pulse. The IrDA encoder/decoder doesn’t work when PSC = 0.
- The receiver can communicate with a low-power transmitter.
- In IrDA mode, the stop bits in the USART_CR2 register must be configured to ‘1 stop bit’.

IrDA low-power mode

- Transmitter

  In low-power mode, the pulse width is not maintained at 3/16 of the bit period. Instead, the width of the pulse is 3 times the low-power baud rate which can be a minimum of 1.42 MHz. Generally, this value is 1.8432 MHz (1.42 MHz < PSC < 2.12 MHz). A low-power mode programmable divisor divides the system clock to achieve this value.
- Receiver

  Receiving in low-power mode is similar to receiving in normal mode. For glitch detection the USART should discard pulses of duration shorter than 1/PSC. A valid low is accepted only if its duration is greater than 2 periods of the IrDA low-power Baud clock (PSC value in the USART_GTPR).

Note: A pulse of width less than two and greater than one PSC period(s) may or may not be rejected.

The receiver set up time should be managed by software. The IrDA physical layer specification specifies a minimum of 10 ms delay between transmission and reception (IrDA is a half duplex protocol).

Figure 618. IrDA SIR ENDEC block diagram

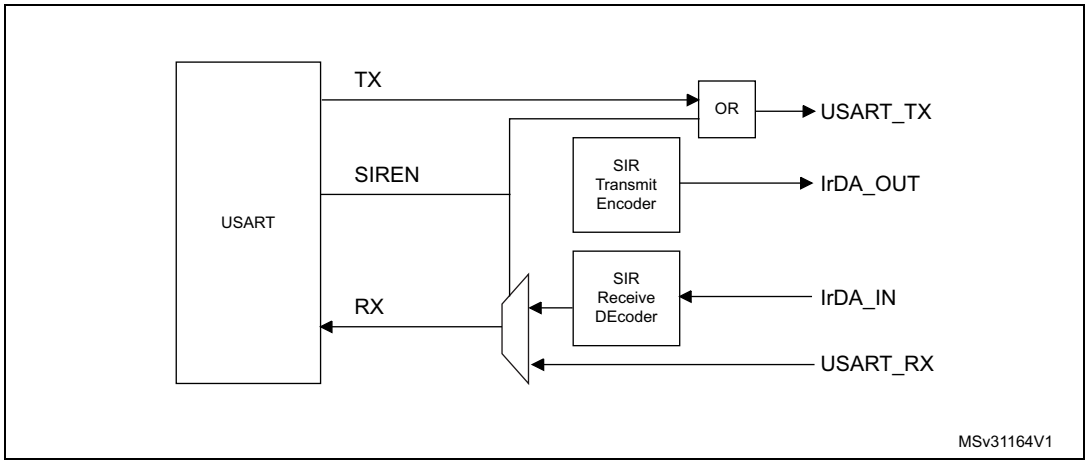
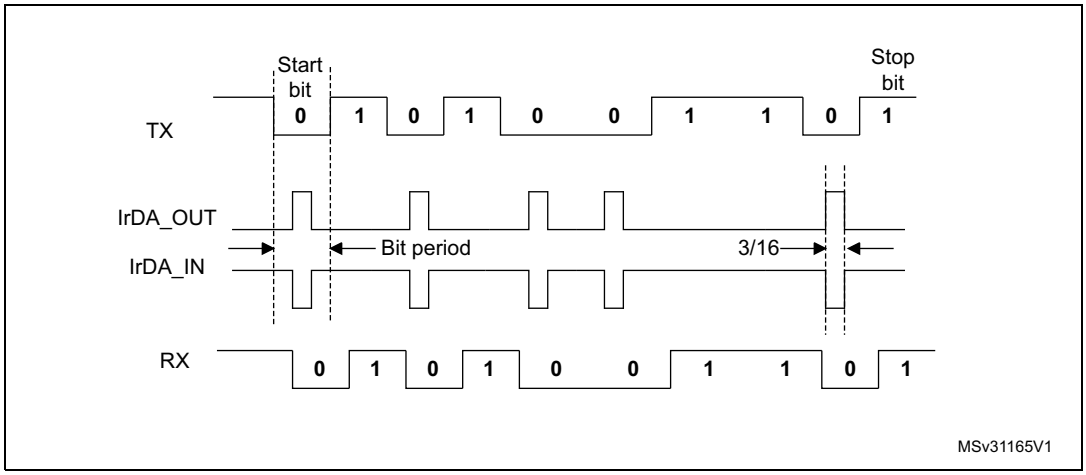


Figure 619. IrDA data modulation (3/16) - Normal mode



53.5.19 Continuous communication using USART and DMA

The USART is capable of performing continuous communications using the DMA. The DMA requests for Rx buffer and Tx buffer are generated independently.

Note: Refer to Section 53.4: USART implementation on page 2058 to determine if the DMA mode is supported. If DMA is not supported, use the USART as explained in Section 53.5.6. To perform continuous communications when the FIFO is disabled, clear the TXE/ RXNE flags in the USART_ISR register.

Transmission using DMA

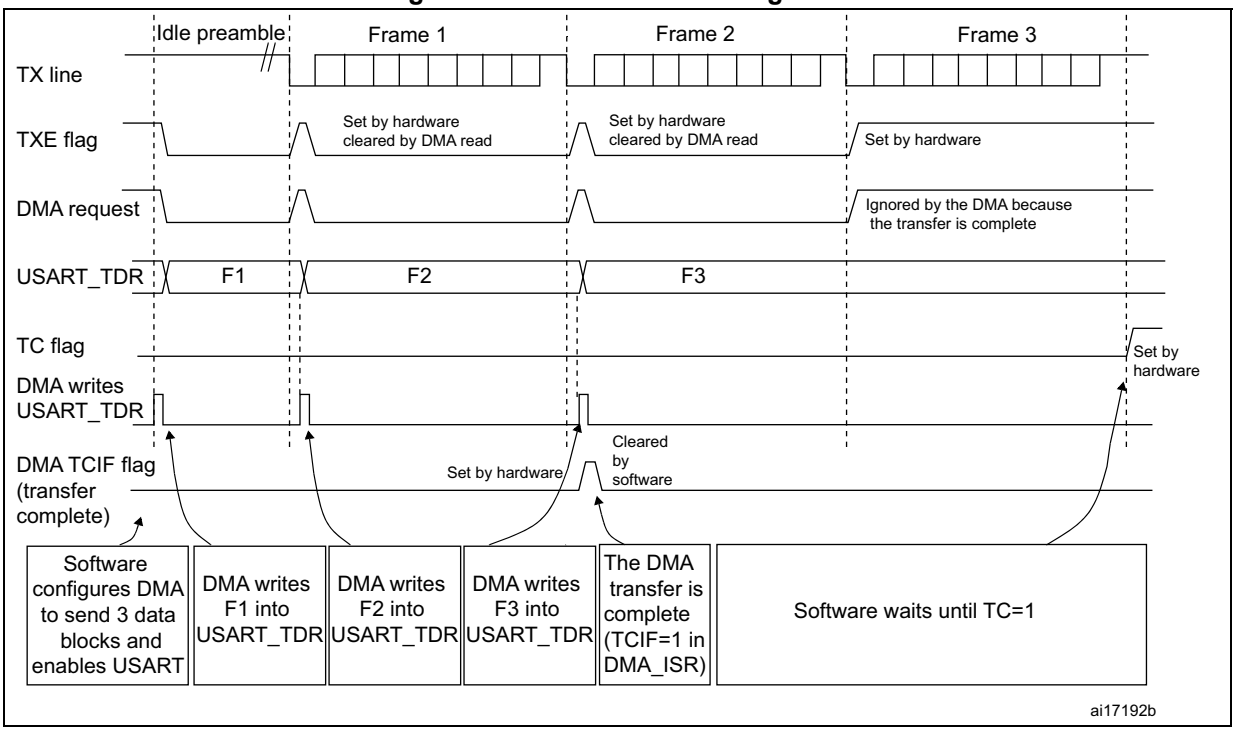
DMA mode can be enabled for transmission by setting DMAT bit in the USART_CR3 register. Data are loaded from an SRAM area configured using the DMA peripheral (refer to the corresponding *Direct memory access controller* section) to the USART_TDR register whenever the TXE flag (TXFNF flag if FIFO mode is enabled) is set. To map a DMA channel for USART transmission, use the following procedure (x denotes the channel number):

1. Write the USART_TDR register address in the DMA control register to configure it as the destination of the transfer. The data is moved to this address from memory after each TXE (or TXFNF if FIFO mode is enabled) event.
2. Write the memory address in the DMA control register to configure it as the source of the transfer. The data is loaded into the USART_TDR register from this memory area after each TXE (or TXFNF if FIFO mode is enabled) event.
3. Configure the total number of bytes to be transferred to the DMA control register.
4. Configure the channel priority in the DMA register
5. Configure DMA interrupt generation after half/ full transfer as required by the application.
6. Clear the TC flag in the USART_ISR register by setting the TCCF bit in the USART_ICR register.
7. Activate the channel in the DMA register.

When the number of data transfers programmed in the DMA Controller is reached, the DMA controller generates an interrupt on the DMA channel interrupt vector.

In transmission mode, once the DMA has written all the data to be transmitted (the TCIF flag is set in the DMA_ISR register), the TC flag can be monitored to make sure that the USART communication is complete. This is required to avoid corrupting the last transmission before disabling the USART or before the system enters a low-power mode when the peripheral clock is disabled. Software must wait until TC = 1. The TC flag remains cleared during all data transfers and it is set by hardware at the end of transmission of the last frame.

Figure 620. Transmission using DMA



Note: When FIFO management is enabled, the DMA request is triggered by Transmit FIFO not full (i.e. TXFNF = 1).

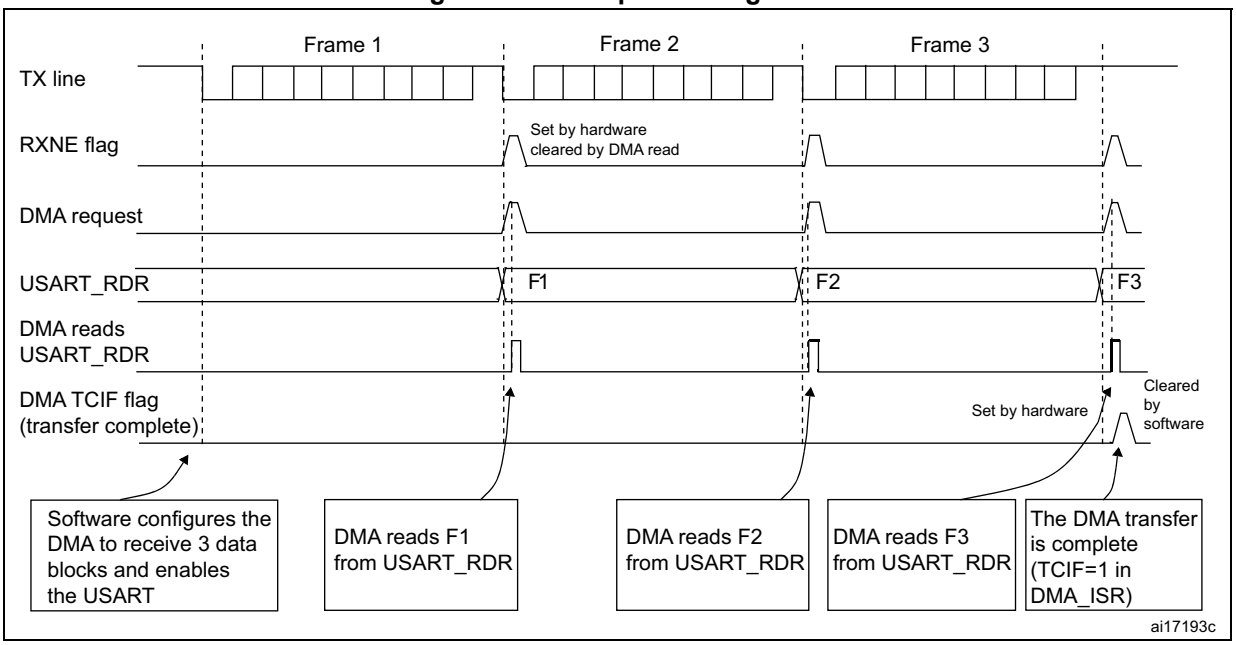
Reception using DMA

DMA mode can be enabled for reception by setting the DMAR bit in USART_CR3 register. Data are loaded from the USART_RDR register to an SRAM area configured using the DMA peripheral (refer to the corresponding *Direct memory access controller* section) whenever a data byte is received. To map a DMA channel for USART reception, use the following procedure:

1. Write the USART_RDR register address in the DMA control register to configure it as the source of the transfer. The data is moved from this address to the memory after each RXNE (RXFNE in case FIFO mode is enabled) event.
2. Write the memory address in the DMA control register to configure it as the destination of the transfer. The data is loaded from USART_RDR to this memory area after each RXNE (RXFNE in case FIFO mode is enabled) event.
3. Configure the total number of bytes to be transferred to the DMA control register.
4. Configure the channel priority in the DMA control register
5. Configure interrupt generation after half/ full transfer as required by the application.
6. Activate the channel in the DMA control register.

When the number of data transfers programmed in the DMA Controller is reached, the DMA controller generates an interrupt on the DMA channel interrupt vector.

Figure 621. Reception using DMA



Note: When FIFO management is enabled, the DMA request is triggered by Receive FIFO not empty (i.e. RXFNE = 1).

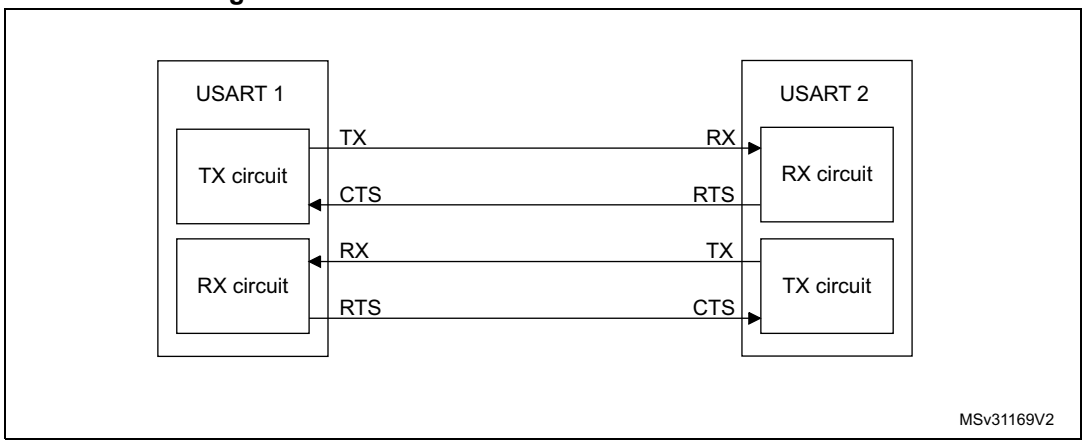
Error flagging and interrupt generation in multibuffer communication

If any error occurs during a transaction in multibuffer communication mode, the error flag is asserted after the current byte. An interrupt is generated if the interrupt enable flag is set. For framing error, overrun error and noise flag which are asserted with RXNE (RXFNE in case FIFO mode is enabled) in single byte reception, there is a separate error flag interrupt enable bit (EIE bit in the USART_CR3 register), which, if set, enables an interrupt after the current byte if any of these errors occur.

53.5.20 RS232 Hardware flow control and RS485 Driver Enable

It is possible to control the serial data flow between 2 devices by using the CTS input and the RTS output. The *Figure 622* shows how to connect 2 devices in this mode:

Figure 622. Hardware flow control between 2 USARTs

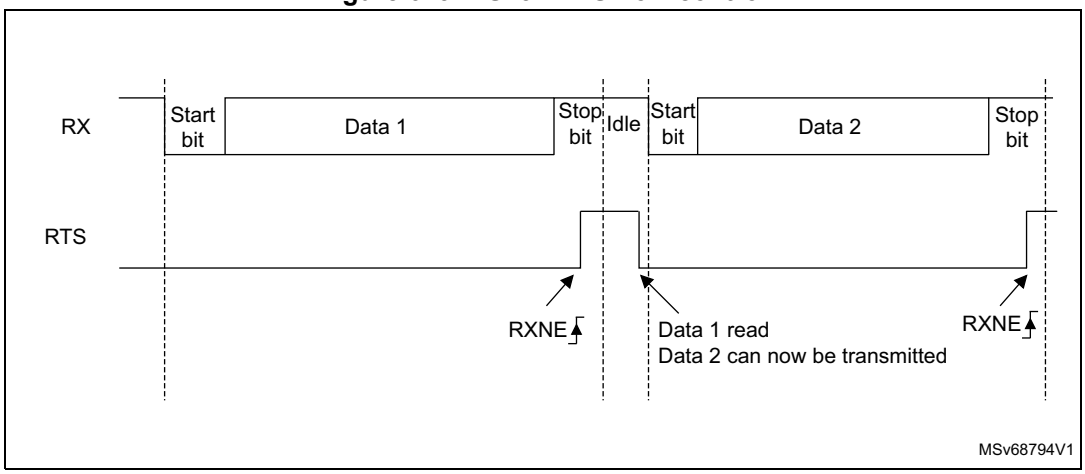


RS232 RTS and CTS flow control can be enabled independently by writing the RTSE and CTSE bits to ‘1’ in the USART_CR3 register.

RS232 RTS flow control

If the RTS flow control is enabled (RTSE = 1), then RTS is deasserted (tied low) as long as the USART receiver is ready to receive a new data. When the receive register is full, RTS is asserted, indicating that the transmission is expected to stop at the end of the current frame. *Figure 623* shows an example of communication with RTS flow control enabled.

Figure 623. RS232 RTS flow control



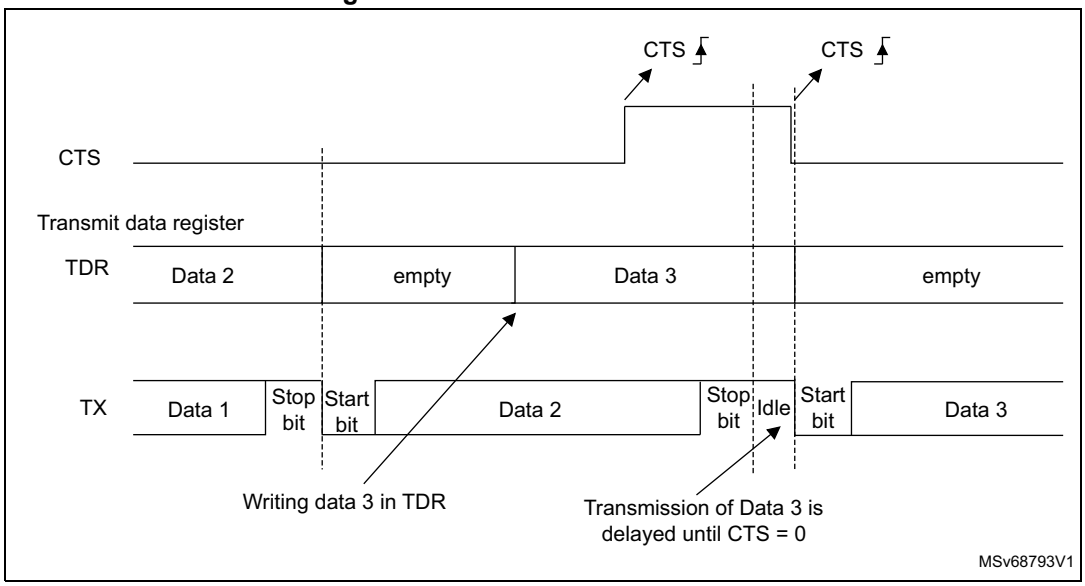
Note: When FIFO mode is enabled, RTS is asserted only when RXFIFO is full.

RS232 CTS flow control

If the CTS flow control is enabled (CTSE = 1), then the transmitter checks the CTS input before transmitting the next frame. If CTS is deasserted (tied low), then the next data is transmitted (assuming that data is to be transmitted, in other words, if TXE/TXFE = 0), else the transmission does not occur. When CTS is asserted during a transmission, the current transmission is completed before the transmitter stops.

When CTSE = 1, the CTSIF status bit is automatically set by hardware as soon as the CTS input toggles. It indicates when the receiver becomes ready or not ready for communication. An interrupt is generated if the CTSIE bit in the USART_CR3 register is set. *Figure 624* shows an example of communication with CTS flow control enabled.

Figure 624. RS232 CTS flow control



Note: For correct behavior, CTS must be deasserted at least 3 USART clock source periods before the end of the current character. In addition it should be noted that the CTSCF flag may not be set for pulses shorter than 2 x PCLK periods.

RS485 driver enable

The driver enable feature is enabled by setting bit DEM in the USART_CR3 control register. This enables the user to activate the external transceiver control, through the DE (Driver Enable) signal. The assertion time is the time between the activation of the DE signal and the beginning of the start bit. It is programmed using the DEAT [4:0] bitfields in the USART_CR1 control register. The deassertion time is the time between the end of the last stop bit, in a transmitted message, and the de-activation of the DE signal. It is programmed using the DEDT [4:0] bitfields in the USART_CR1 control register. The polarity of the DE signal can be configured using the DEP bit in the USART_CR3 control register.

In USART, the DEAT and DEDT are expressed in sample time units (1/8 or 1/16 bit time, depending on the oversampling rate).

53.5.21 USART low-power management

The USART has advanced low-power mode functions, that enables transferring properly data even when the usart_pclk clock is disabled.

The USART is able to wake up the MCU from low-power mode when the UESM bit is set.

When the usart_pclk is gated, the USART provides a wakeup interrupt (**usart_wkup**) if a specific action requiring the activation of the **usart_pclk** clock is needed:

- If FIFO mode is disabled

  usart_pclk clock has to be activated to empty the USART data register.

  In this case, the usart_wkup interrupt source is RXNE set to '1'. The RXNEIE bit must be set before entering low-power mode.
- If FIFO mode is enabled

  usart_pclk clock has to be activated to:
  - to fill the TXFIFO
  - or to empty the RXFIFO

  In this case, the usart_wkup interrupt source can be:
  - RXFIFO not empty. In this case, the RXFNEIE bit must be set before entering low-power mode.
  - RXFIFO full. In this case, the RXFFIE bit must be set before entering low-power mode, the number of received data corresponds to the RXFIFO size, and the RXFF flag is not set.
  - TXFIFO empty. In this case, the TXFEIE bit must be set before entering low-power mode.

  This enables sending/receiving the data in the TXFIFO/RXFIFO during low-power mode.

  To avoid overrun/underrun errors and transmit/receive data in low-power mode, the usart_wkup interrupt source can be one of the following events:
  - TXFIFO threshold reached. In this case, the TXFTIE bit must be set before entering low-power mode.
  - RXFIFO threshold reached. In this case, the RXFTIE bit must be set before entering low-power mode.

  For example, the application can set the threshold to the maximum RXFIFO size if the wakeup time is less than the time required to receive a single byte across the line.

  Using the RXFIFO full, TXFIFO empty, RXFIFO not empty and RXFIFO/TXFIFO threshold interrupts to wakeup the MCU from low-power mode enables doing as many USART transfers as possible during low-power mode with the benefit of optimizing consumption.

Alternatively, a specific **usart_wkup** interrupt can be selected through the WUS bitfields.

When the wakeup event is detected, the WUF flag is set by hardware and a **usart_wkup** interrupt is generated if the WUFIE bit is set.

Note: Before entering low-power mode, make sure that no USART transfers are ongoing. Checking the BUSY flag cannot ensure that low-power mode is never entered when data reception is ongoing.

The WUF flag is set when a wakeup event is detected, independently of whether the MCU is in low-power or active mode.

When entering low-power mode just after having initialized and enabled the receiver, the REACK bit must be checked to make sure the USART is enabled.

When DMA is used for reception, it must be disabled before entering low-power mode and re-enabled when exiting from low-power mode.

When the FIFO is enabled, waking up from low-power mode on address match is only possible when Mute mode is enabled.

Using Mute mode with low-power mode

If the USART is put into Mute mode before entering low-power mode:

- Wakeup from Mute mode on idle detection must not be used, because idle detection cannot work in low-power mode.
- If the wakeup from Mute mode on address match is used, then the low-power mode wakeup source must also be the address match. If the RXNE flag was set when entering the low-power mode, the interface remains in Mute mode upon address match and wake up from low-power mode.

Note: When FIFO management is enabled, Mute mode can be used with wakeup from low-power mode without any constraints (i.e.the two points mentioned above about Mute and low-power mode are valid only when FIFO management is disabled).

Wakeup from low-power mode when USART kernel clock (usart_ker_ck) is OFF in low-power mode

If during low-power mode, the usart_ker_ck clock is switched OFF when a falling edge on the USART receive line is detected, the USART interface requests the usart_ker_ck clock to be switched ON thanks to the usart_ker_ck_req signal. usart_ker_ck is then used for the frame reception.

If the wakeup event is verified, the MCU wakes up from low-power mode and data reception goes on normally.

If the wakeup event is not verified, usart_ker_ck is switched OFF again, the MCU is not woken up and remains in low-power mode, and the kernel clock request is released.

The example below shows the case of a wakeup event programmed to “address match detection” and FIFO management disabled.

Figure 625 shows the USART behavior when the wakeup event is verified.

Figure 625. Wakeup event verified (wakeup event = address match, FIFO disabled)

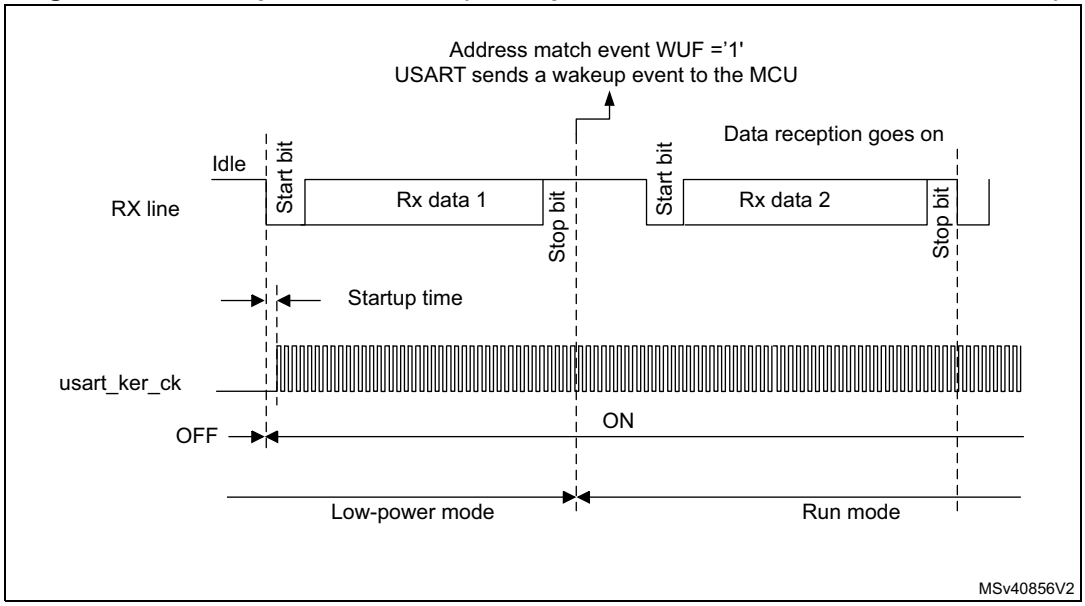
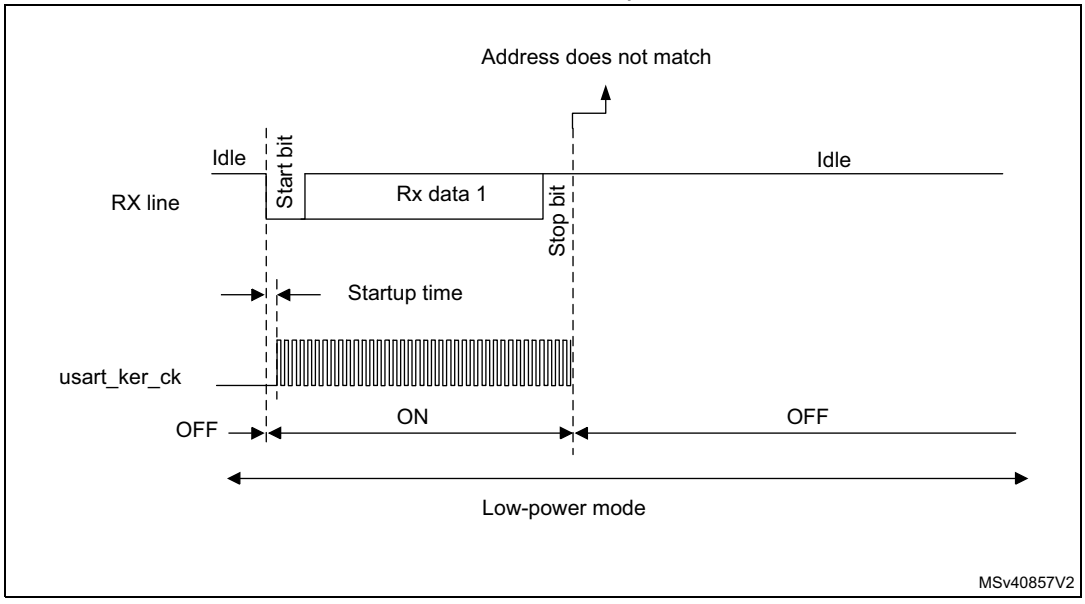


Figure 626 shows the USART behavior when the wakeup event is not verified.

Figure 626. Wakeup event not verified (wakeup event = address match, FIFO disabled)



Note: The figures above are valid when address match or any received frame is used as wakeup event. If the wakeup event is the start bit detection, the USART sends the wakeup event to the MCU at the end of the start bit.

Determining the maximum USART baud rate that enables to correctly wake up the device from low-power mode

The maximum baud rate that enables to correctly wake up the device from low-power mode depends on the wakeup time parameter (refer to the device datasheet) and on the USART receiver tolerance (see *Section 53.5.8: Tolerance of the USART receiver to clock deviation*).

Let us take the example of OVER8 = 0, M bits = '01', ONEBIT = 0 and BRR [3:0] = 0000.

In these conditions, according to *Table 420: Tolerance of the USART receiver when BRR [3:0] = 0000*, the USART receiver tolerance equals 3.41%.

DTRA + DQUANT + DREC + DTCL + DWU < USART receiver tolerance

$D_{WUmax} = t_{WUUSART} / (11 \times T_{bit\ Min})$

$T_{bit\ Min} = t_{WUUSART} / (11 \times D_{WUmax})$

where $t_{WUUSART}$ is the wakeup time from low-power mode.

If we consider the ideal case where DTRA, DQUANT, DREC and DTCL parameters are at 0%, the maximum value of DWU is 3.41%. In reality, we need to consider at least the usart_ker_ck inaccuracy.

For example, if HSI is used as usart_ker_ck, and the HSI inaccuracy is of 1%, then we obtain:

$t_{WUUSART}$ = 3 µs (values provided only as examples; for correct values, refer to the device datasheet).

D_{WUmax} = 3.41% - 1% = 2.41%

$T_{bit\ min}$ = 3 µs/ (11 x 2.41%) = 11.32 µs.

As a result, the maximum baud rate that enables to wakeup correctly from low-power mode is: 1/11.32 µs = 88.36 Kbaud.

53.6 USART in low-power modes

Table 423. Effect of low-power modes on the USART

Mode	Description
Sleep	No effect. USART interrupts cause the device to exit Sleep mode.
Stop(1)	The content of the USART registers is kept. The USART is able to wake up the microcontroller from Stop mode when the USART is clocked by an oscillator available in Stop mode.
Standby	The USART peripheral is powered down and must be reinitialized after exiting Standby mode.

1. Refer to *Section 53.4: USART implementation* to know if the wakeup from Stop mode is supported for a given peripheral instance. If an instance is not functional in a given Stop mode, it must be disabled before entering this Stop mode.

53.7 USART interrupts

Refer to *Table 424* for a detailed description of all USART interrupt requests.

Table 424. USART interrupt requests

Interrupt vector	Interrupt event	Event flag	Enable Control bit	Interrupt clear method	Exit from Sleep mode	Exit from Stop(1) modes	Exit from Standby mode
USART or UART	Transmit data register empty	TXE	TXEIE	Write TDR	Yes	No	No
	Transmit FIFO not Full	TXFNF	TXFNFIE	TXFIFO full		No	
	Transmit FIFO Empty	TXFE	TXFEIE	Write TDR or write 1 in TXFRQ		Yes	
	Transmit FIFO threshold reached	TXFT	TXFTIE	Write TDR		Yes	
	CTS interrupt	CTSIF	CTSIE	Write 1 in CTSCF		No	
	Transmission Complete	TC	TCIE	Write TDR or write 1 in TCCF		No	
	Transmission Complete Before Guard Time	TCBGT	TCBGTIE	Write TDR or write 1 in TCBGT		No	
USART or UART	Receive data register not empty (data ready to be read)	RXNE	RXNEIE	Read RDR or write 1 in RXFRQ	Yes	Yes	No
	Receive FIFO Not Empty	RXFNE	RXFNEIE	Read RDR until RXFIFO empty or write 1 in RXFRQ		Yes	
	Receive FIFO Full	RXFF(2)	RXFFIE	Read RDR		Yes	
	Receive FIFO threshold reached	RXFT	RXFTIE	Read RDR		Yes	
	Overrun error detected	ORE	RXNEIE/ RXFNEIE	Write 1 in ORECF		No	
	Idle line detected	IDLE	IDLEIE	Write 1 in IDLECF		No	
	Parity error	PE	PEIE	Write 1 in PECF		No	
	LIN break	LBDF	LBDIE	Write 1 in LBDCF		No	
	Noise error in multibuffer communication	NE	EIE	Write 1 in NFCF		No	
	Overrun error in multibuffer communication	ORE(3)		Write 1 in ORECF		No	
	Framing Error in multibuffer communication	FE		Write 1 in FECF		No	
	Character match	CMF	CMIE	Write 1 in CMCF		No	
	Receiver timeout	RTOF	RTOFIE	Write 1 in RTOCCF		No	
	End of Block	EOBF	EOBIE	Write 1 in EOBCF		No	
	Wakeup from low-power mode	WUF	WUFIE	Write 1 in WUC		Yes	
	SPI slave underrun error	UDR	EIE	Write 1 in UDRCF		No	

1. The USART can wake up the device from Stop mode only if the peripheral instance supports the Wakeup from Stop mode feature. Refer to *Section 53.4: USART implementation* for the list of supported Stop modes.

2. RXFF flag is asserted if the USART receives n+1 data (n being the RXFIFO size): n data in the RXFIFO and 1 data in USART_RDR. In Stop mode, USART_RDR is not clocked. As a result, this register is not written and once n data are received and written in the RXFIFO, the RXFF interrupt is asserted (RXFF flag is not set).
3. When OVRDIS = 0.

53.8 USART registers

Refer to *Section 1.2 on page 104* for a list of abbreviations used in register descriptions.

The peripheral registers have to be accessed by words (32 bits).

53.8.1 USART control register 1 [alternate] (USART_CR1)

Address offset: 0x00

Reset value: 0x0000 0000

The same register can be used in FIFO mode enabled (this section) and FIFO mode disabled (next section).

FIFO mode enabled

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXFFIE	TXFEIE	FIFOEN	M1	EOBIE	RTOIE	DEAT[4:0]					DEDT[4:0]				
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OVER8	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXFNFIE	TCIE	RXFNEIE	IDLEIE	TE	RE	UESM	UE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **RXFFIE**: RXFIFO Full interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated when RXFF = 1 in the USART_ISR register

Bit 30 **TXFEIE**: TXFIFO empty interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated when TXFE = 1 in the USART_ISR register

Bit 29 **FIFOEN**: FIFO mode enable
This bit is set and cleared by software.
0: FIFO mode is disabled.
1: FIFO mode is enabled.
This bitfield can only be written when the USART is disabled (UE = 0).

Note: FIFO mode can be used on standard UART communication, in SPI master/slave mode and in Smartcard modes only. It must not be enabled in IrDA and LIN modes.

Bit 28 **M1**: Word length

This bit must be used in conjunction with bit 12 (M0) to determine the word length. It is set or cleared by software.

M[1:0] = ‘00’: 1 start bit, 8 Data bits, n Stop bit

M[1:0] = ‘01’: 1 start bit, 9 Data bits, n Stop bit

M[1:0] = ‘10’: 1 start bit, 7 Data bits, n Stop bit

This bit can only be written when the USART is disabled (UE = 0).

Note: In 7-bits data length mode, the Smartcard mode, LIN master mode and Auto baud rate (0x7F and 0x55 frames detection) are not supported.

Bit 27 **EOBIE**: End of Block interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated when the EOBF flag is set in the USART_ISR register

Note: If the USART does not support Smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 26 **RTOIE**: Receiver timeout interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated when the RTOF bit is set in the USART_ISR register.

Note: If the USART does not support the Receiver timeout feature, this bit is reserved and must be kept at reset value. Section 53.4: USART implementation on page 2058.

Bits 25:21 **DEAT[4:0]**: Driver Enable assertion time

This 5-bit value defines the time between the activation of the DE (Driver Enable) signal and the beginning of the start bit. It is expressed in sample time units (1/8 or 1/16 bit time, depending on the oversampling rate).

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bits 20:16 **DEDT[4:0]**: Driver Enable deassertion time

This 5-bit value defines the time between the end of the last stop bit, in a transmitted message, and the de-activation of the DE (Driver Enable) signal. It is expressed in sample time units (1/8 or 1/16 bit time, depending on the oversampling rate).

If the USART_TDR register is written during the DEDT time, the new data is transmitted only when the DEDT and DEAT times have both elapsed.

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 15 **OVER8**: Oversampling mode

0: Oversampling by 16

1: Oversampling by 8

This bit can only be written when the USART is disabled (UE = 0).

Note: In LIN, IrDA and Smartcard modes, this bit must be kept cleared.

Bit 14 **CMIE**: Character match interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated when the CMF bit is set in the USART_ISR register.

Bit 13 **MME**: Mute mode enable

This bit enables the USART Mute mode function. When set, the USART can switch between active and Mute mode, as defined by the WAKE bit. It is set and cleared by software.

0: Receiver in active mode permanently

1: Receiver can switch between Mute mode and active mode.

Bit 12 **M0**: Word length

This bit is used in conjunction with bit 28 (M1) to determine the word length. It is set or cleared by software (refer to bit 28 (M1)description).

This bit can only be written when the USART is disabled (UE = 0).

Bit 11 **WAKE**: Receiver wakeup method

This bit determines the USART wakeup method from Mute mode. It is set or cleared by software.

0: Idle line

1: Address mark

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 10 **PCE**: Parity control enable

This bit selects the hardware parity control (generation and detection). When the parity control is enabled, the computed parity is inserted at the MSB position (9th bit if M = 1; 8th bit if M = 0) and the parity is checked on the received data. This bit is set and cleared by software. Once it is set, PCE is active after the current byte (in reception and in transmission).

0: Parity control disabled

1: Parity control enabled

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 9 **PS**: Parity selection

This bit selects the odd or even parity when the parity generation/detection is enabled (PCE bit set). It is set and cleared by software. The parity is selected after the current byte.

0: Even parity

1: Odd parity

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 8 **PEIE**: PE interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated whenever PE = 1 in the USART_ISR register

Bit 7 **TXFNFIE**: TXFIFO not full interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated whenever TXFNF =1 in the USART_ISR register

Bit 6 **TCIE**: Transmission complete interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated whenever TC = 1 in the USART_ISR register

Bit 5 **RXFNEIE**: RXFIFO not empty interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated whenever ORE = 1 or RXFNE = 1 in the USART_ISR register

Bit 4 **IDLEIE**: IDLE interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated whenever IDLE = 1 in the USART_ISR register

Bit 3 **TE**: Transmitter enable

This bit enables the transmitter. It is set and cleared by software.

0: Transmitter is disabled

1: Transmitter is enabled

Note: During transmission, a low pulse on the TE bit ('0' followed by '1') sends a preamble (idle line) after the current word, except in Smartcard mode. In order to generate an idle character, the TE must not be immediately written to '1'. To ensure the required duration, the software can poll the TEACK bit in the USART_ISR register.

In Smartcard mode, when TE is set, there is a 1 bit-time delay before the transmission starts.

Bit 2 **RE**: Receiver enable

This bit enables the receiver. It is set and cleared by software.

0: Receiver is disabled

1: Receiver is enabled and begins searching for a start bit

Bit 1 **UESM**: USART enable in low-power mode

When this bit is cleared, the USART cannot wake up the MCU from low-power mode.

When this bit is set, the USART can wake up the MCU from low-power mode.

This bit is set and cleared by software.

0: USART not able to wake up the MCU from low-power mode.

1: USART able to wake up the MCU from low-power mode.

Note: It is recommended to set the UESM bit just before entering low-power mode and clear it when exit from low-power mode.

If the USART does not support the wakeup from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 0 **UE**: USART enable

When this bit is cleared, the USART prescalers and outputs are stopped immediately, and all current operations are discarded. The USART configuration is kept, but all the USART_ISR status flags are reset. This bit is set and cleared by software.

0: USART prescaler and outputs disabled, low-power mode

1: USART enabled

Note: To enter low-power mode without generating errors on the line, the TE bit must be previously reset and the software must wait for the TC bit in the USART_ISR to be set before resetting the UE bit.

The DMA requests are also reset when UE = 0 so the DMA channel must be disabled before resetting the UE bit.

In Smartcard mode, (SCEN = 1), the CK is always available when CLKEN = 1, regardless of the UE bit value.

53.8.2 USART control register 1 [alternate] (USART_CR1)

Address offset: 0x00

Reset value: 0x0000 0000

The same register can be used in FIFO mode enabled (previous section) and FIFO mode disabled (this section).

FIFO mode disabled

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	FIFO EN	M1	EOBIE	RTOIE	DEAT[4:0]					DEDT[4:0]				
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OVER8	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXEIE	TCIE	RXNEIE	IDLEIE	TE	RE	UESM	UE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **FIFOEN**: FIFO mode enable

This bit is set and cleared by software.

0: FIFO mode is disabled.

1: FIFO mode is enabled.

This bitfield can only be written when the USART is disabled (UE = 0).

Note: FIFO mode can be used on standard UART communication, in SPI master/slave mode and in Smartcard modes only. It must not be enabled in IrDA and LIN modes.

Bit 28 **M1**: Word length

This bit must be used in conjunction with bit 12 (M0) to determine the word length. It is set or cleared by software.

M[1:0] = ‘00’: 1 start bit, 8 Data bits, n Stop bit

M[1:0] = ‘01’: 1 start bit, 9 Data bits, n Stop bit

M[1:0] = ‘10’: 1 start bit, 7 Data bits, n Stop bit

This bit can only be written when the USART is disabled (UE = 0).

Note: In 7-bits data length mode, the Smartcard mode, LIN master mode and Auto baud rate (0x7F and 0x55 frames detection) are not supported.

Bit 27 **EOBIE**: End of Block interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated when the EOBF flag is set in the USART_ISR register

Note: If the USART does not support Smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 26 **RTOIE**: Receiver timeout interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated when the RTOF bit is set in the USART_ISR register.

Note: If the USART does not support the Receiver timeout feature, this bit is reserved and must be kept at reset value. Section 53.4: USART implementation on page 2058.

Bits 25:21 **DEAT[4:0]**: Driver Enable assertion time

This 5-bit value defines the time between the activation of the DE (Driver Enable) signal and the beginning of the start bit. It is expressed in sample time units (1/8 or 1/16 bit time, depending on the oversampling rate).

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bits 20:16 **DEDT[4:0]**: Driver Enable deassertion time

This 5-bit value defines the time between the end of the last stop bit, in a transmitted message, and the de-activation of the DE (Driver Enable) signal. It is expressed in sample time units (1/8 or 1/16 bit time, depending on the oversampling rate).

If the USART_TDR register is written during the DEDT time, the new data is transmitted only when the DEDT and DEAT times have both elapsed.

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 15 **OVER8**: Oversampling mode

0: Oversampling by 16

1: Oversampling by 8

This bit can only be written when the USART is disabled (UE = 0).

Note: In LIN, IrDA and Smartcard modes, this bit must be kept cleared.

Bit 14 **CMIE**: Character match interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated when the CMF bit is set in the USART_ISR register.

Bit 13 **MME**: Mute mode enable

This bit enables the USART Mute mode function. When set, the USART can switch between active and Mute mode, as defined by the WAKE bit. It is set and cleared by software.

0: Receiver in active mode permanently

1: Receiver can switch between Mute mode and active mode.

Bit 12 **M0**: Word length

This bit is used in conjunction with bit 28 (M1) to determine the word length. It is set or cleared by software (refer to bit 28 (M1)description).

This bit can only be written when the USART is disabled (UE = 0).

Bit 11 **WAKE**: Receiver wakeup method

This bit determines the USART wakeup method from Mute mode. It is set or cleared by software.

0: Idle line

1: Address mark

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 10 **PCE**: Parity control enable

This bit selects the hardware parity control (generation and detection). When the parity control is enabled, the computed parity is inserted at the MSB position (9th bit if M = 1; 8th bit if M = 0) and the parity is checked on the received data. This bit is set and cleared by software. Once it is set, PCE is active after the current byte (in reception and in transmission).

0: Parity control disabled

1: Parity control enabled

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 9 **PS**: Parity selection

This bit selects the odd or even parity when the parity generation/detection is enabled (PCE bit set). It is set and cleared by software. The parity is selected after the current byte.

0: Even parity

1: Odd parity

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 8 **PEIE**: PE interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated whenever PE = 1 in the USART_ISR register

Bit 7 **TXEIE**: Transmit data register empty

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated whenever TXE =1 in the USART_ISR register

Bit 6 **TCIE**: Transmission complete interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated whenever TC = 1 in the USART_ISR register

Bit 5 **RXNEIE**: Receive data register not empty

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated whenever ORE = 1 or RXNE = 1 in the USART_ISR register

Bit 4 **IDLEIE**: IDLE interrupt enable

This bit is set and cleared by software.

0: Interrupt inhibited

1: USART interrupt generated whenever IDLE = 1 in the USART_ISR register

Bit 3 **TE**: Transmitter enable

This bit enables the transmitter. It is set and cleared by software.

0: Transmitter is disabled

1: Transmitter is enabled

Note: During transmission, a low pulse on the TE bit (‘0’ followed by ‘1’) sends a preamble (idle line) after the current word, except in Smartcard mode. In order to generate an idle character, the TE must not be immediately written to ‘1’. To ensure the required duration, the software can poll the TEACK bit in the USART_ISR register.

In Smartcard mode, when TE is set, there is a 1 bit-time delay before the transmission starts.

Bit 2 **RE**: Receiver enable

This bit enables the receiver. It is set and cleared by software.

0: Receiver is disabled

1: Receiver is enabled and begins searching for a start bit

Bit 1 **UESM**: USART enable in low-power mode

When this bit is cleared, the USART cannot wake up the MCU from low-power mode.

When this bit is set, the USART can wake up the MCU from low-power mode.

This bit is set and cleared by software.

0: USART not able to wake up the MCU from low-power mode.

1: USART able to wake up the MCU from low-power mode.

Note: It is recommended to set the UESM bit just before entering low-power mode and clear it when exit from low-power mode.

If the USART does not support the wakeup from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 0 **UE**: USART enable

When this bit is cleared, the USART prescalers and outputs are stopped immediately, and all current operations are discarded. The USART configuration is kept, but all the USART_ISR status flags are reset. This bit is set and cleared by software.

0: USART prescaler and outputs disabled, low-power mode

1: USART enabled

Note: To enter low-power mode without generating errors on the line, the TE bit must be previously reset and the software must wait for the TC bit in the USART_ISR to be set before resetting the UE bit.

The DMA requests are also reset when UE = 0 so the DMA channel must be disabled before resetting the UE bit.

In Smartcard mode, (SCEN = 1), the CK pin is always available when CLKEN = 1, regardless of the UE bit value.

53.8.3 USART control register 2 (USART_CR2)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADD[7:0]								RTOEN	ABRMOD[1:0]		ABREN	MSBFIRST	DATAINV	TXINV	RXINV
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SWAP	LINEN	STOP[1:0]		CLKEN	CPOL	CPHA	LBCL	Res.	LBDIE	LBDL	ADDM7	DIS_NSS	Res.	Res.	SLVEN
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw			rw

Bits 31:24 **ADD[7:0]**: Address of the USART node

These bits give the address of the USART node in Mute mode or a character code to be recognized in low-power or Run mode:

- In Mute mode: they are used in multiprocessor communication to wakeup from Mute mode with 4-bit/7-bit address mark detection. The MSB of the character sent by the transmitter should be equal to 1. In 4-bit address mark detection, only ADD[3:0] bits are used.
- In low-power mode: they are used for wake up from low-power mode on character match. When WUS[1:0] is programmed to 0b00 (WUF active on address match), the wakeup from low-power mode is performed when the received character corresponds to the character programmed through ADD[6:0] or ADD[3:0] bitfield (depending on ADDM7 bit), and WUF interrupt is enabled by setting WUFIE bit. The MSB of the character sent by transmitter should be equal to 1.
- In Run mode with Mute mode inactive (for example, end-of-block detection in ModBus protocol): the whole received character (8 bits) is compared to ADD[7:0] value and CMF flag is set on match. An interrupt is generated if the CMIE bit is set.

These bits can only be written when the reception is disabled (RE = 0) or when the USART is disabled (UE = 0).

Bit 23 **RTOEN**: Receiver timeout enable

This bit is set and cleared by software.

0: Receiver timeout feature disabled.

1: Receiver timeout feature enabled.

When this feature is enabled, the RTOF flag in the USART_ISR register is set if the RX line is idle (no reception) for the duration programmed in the RTOR (receiver timeout register).

Note: If the USART does not support the Receiver timeout feature, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bits 22:21 **ABRMOD[1:0]**: Auto baud rate mode

These bits are set and cleared by software.

00: Measurement of the start bit is used to detect the baud rate.

01: Falling edge to falling edge measurement (the received frame must start with a single bit = 1 and Frame = Start10xxxxxx)

10: 0x7F frame detection.

11: 0x55 frame detection

This bitfield can only be written when ABREN = 0 or the USART is disabled (UE = 0).

Note: If DATAINV = 1 and/or MSBFIRST = 1 the patterns must be the same on the line, for example 0xAA for MSBFIRST)

If the USART does not support the auto baud rate feature, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 20 **ABREN**: Auto baud rate enable

This bit is set and cleared by software.

0: Auto baud rate detection is disabled.

1: Auto baud rate detection is enabled.

Note: If the USART does not support the auto baud rate feature, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 19 **MSBFIRST**: Most significant bit first

This bit is set and cleared by software.

0: data is transmitted/received with data bit 0 first, following the start bit.

1: data is transmitted/received with the MSB (bit 7/8) first, following the start bit.

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 18 **DATAINV:** Binary data inversion

This bit is set and cleared by software.

0: Logical data from the data register are send/received in positive/direct logic. (1 = H, 0 = L)

1: Logical data from the data register are send/received in negative/inverse logic. (1 = L, 0 = H). The parity bit is also inverted.

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 17 **TXINV:** TX pin active level inversion

This bit is set and cleared by software.

0: TX pin signal works using the standard logic levels (V_{DD} =1/idle, Gnd = 0/mark)

1: TX pin signal values are inverted (V_{DD} =0/mark, Gnd = 1/idle).

This enables the use of an external inverter on the TX line.

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 16 **RXINV:** RX pin active level inversion

This bit is set and cleared by software.

0: RX pin signal works using the standard logic levels (V_{DD} =1/idle, Gnd = 0/mark)

1: RX pin signal values are inverted (V_{DD} =0/mark, Gnd = 1/idle).

This enables the use of an external inverter on the RX line.

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 15 **SWAP:** Swap TX/RX pins

This bit is set and cleared by software.

0: TX/RX pins are used as defined in standard pinout

1: The TX and RX pins functions are swapped. This enables to work in the case of a cross-wired connection to another UART.

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 14 **LINEN**: LIN mode enable

This bit is set and cleared by software.

0: LIN mode disabled

1: LIN mode enabled

The LIN mode enables the capability to send LIN synchronous breaks (13 low bits) using the SBKRQ bit in the USART_CR1 register, and to detect LIN Sync breaks.

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the USART does not support LIN mode, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bits 13:12 **STOP[1:0]**: stop bits

These bits are used for programming the stop bits.

00: 1 stop bit

01: 0.5 stop bit.

10: 2 stop bits

11: 1.5 stop bits

This bitfield can only be written when the USART is disabled (UE = 0).

Bit 11 **CLKEN**: Clock enable

This bit enables the user to enable the CK pin.

0: CK pin disabled

1: CK pin enabled

This bit can only be written when the USART is disabled (UE = 0).

Note: If neither synchronous mode nor Smartcard mode is supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

In Smartcard mode, in order to provide correctly the CK clock to the smartcard, the steps below must be respected:
UE = 0
SCEN = 1
GTPR configuration
CLKEN= 1
UE = 1

Bit 10 **CPOL**: Clock polarity

This bit enables the user to select the polarity of the clock output on the CK pin in synchronous mode. It works in conjunction with the CPHA bit to produce the desired clock/data relationship

0: Steady low value on CK pin outside transmission window

1: Steady high value on CK pin outside transmission window

This bit can only be written when the USART is disabled (UE = 0).

Note: If synchronous mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 9 **CPHA**: Clock phase

This bit is used to select the phase of the clock output on the CK pin in synchronous mode. It works in conjunction with the CPOL bit to produce the desired clock/data relationship (see *Figure 606* and *Figure 607*)

0: The first clock transition is the first data capture edge

1: The second clock transition is the first data capture edge

This bit can only be written when the USART is disabled (UE = 0).

Note: If synchronous mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 8 **LBCL**: Last bit clock pulse

This bit is used to select whether the clock pulse associated with the last data bit transmitted (MSB) has to be output on the CK pin in synchronous mode.

0: The clock pulse of the last data bit is not output to the CK pin

1: The clock pulse of the last data bit is output to the CK pin

Caution: The last bit is the 7th or 8th or 9th data bit transmitted depending on the 7 or 8 or 9 bit format selected by the M bit in the USART_CR1 register.

This bit can only be written when the USART is disabled (UE = 0).

Note: If synchronous mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **LBDIE**: LIN break detection interrupt enable

Break interrupt mask (break detection using break delimiter).

0: Interrupt is inhibited

1: An interrupt is generated whenever LBDF = 1 in the USART_ISR register

Note: If LIN mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 5 **LBDL**: LIN break detection length

This bit is for selection between 11 bit or 10 bit break detection.

0: 10-bit break detection

1: 11-bit break detection

This bit can only be written when the USART is disabled (UE = 0).

Note: If LIN mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 4 **ADDM7**: 7-bit Address Detection/4-bit Address Detection

This bit is for selection between 4-bit address detection or 7-bit address detection.

0: 4-bit address detection

1: 7-bit address detection (in 8-bit data mode)

This bit can only be written when the USART is disabled (UE = 0)

Note: In 7-bit and 9-bit data modes, the address detection is done on 6-bit and 8-bit address (ADD[5:0] and ADD[7:0]) respectively.

Bit 3 **DIS_NSS**:

When the DIS_NSS bit is set, the NSS pin input is ignored.

0: SPI slave selection depends on NSS input pin.

1: SPI slave is always selected and NSS input pin is ignored.

Note: When SPI slave mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bits 2:1 Reserved, must be kept at reset value.

Bit 0 **SLVEN**: Synchronous Slave mode enable

When the SLVEN bit is set, the synchronous slave mode is enabled.

0: Slave mode disabled.

1: Slave mode enabled.

Note: When SPI slave mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Note: The CPOL, CPHA and LBCL bits should not be written while the transmitter is enabled.

53.8.4 USART control register 3 (USART_CR3)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXFTCFG[2:0]			RXF TIE	RXFTCFG[2:0]			TCBG TIE	TXFTIE	WUFIE	WUS[1:0]		SCARCNT[2:0]			Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DEP	DEM	DDRE	OVR DIS	ONE BIT	CTSIE	CTSE	RTSE	DMAT	DMAR	SCEN	NACK	HD SEL	IRLP	IREN	EIE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 **TXFTCFG[2:0]:** TXFIFO threshold configuration
000:TXFIFO reaches 1/8 of its depth
001:TXFIFO reaches 1/4 of its depth
010:TXFIFO reaches 1/2 of its depth
011:TXFIFO reaches 3/4 of its depth
100:TXFIFO reaches 7/8 of its depth
101:TXFIFO becomes empty
Remaining combinations: Reserved

Bit 28 **RXFTIE**: RXFIFO threshold interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated when Receive FIFO reaches the threshold programmed in RXFTCFG.

Bits 27:25 **RXFTCFG[2:0]:** Receive FIFO threshold configuration
000:Receive FIFO reaches 1/8 of its depth
001:Receive FIFO reaches 1/4 of its depth
010:Receive FIFO reaches 1/2 of its depth
011:Receive FIFO reaches 3/4 of its depth
100:Receive FIFO reaches 7/8 of its depth
101:Receive FIFO becomes full
Remaining combinations: Reserved

Bit 24 **TCBGTIE**: Transmission Complete before guard time, interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated whenever TCBGT=1 in the USART_ISR register

Note: If the USART does not support the Smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 23 **TXFTIE**: TXFIFO threshold interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated when TXFIFO reaches the threshold programmed in TXFTCFG.

Bit 22 **WUFIE**: Wakeup from low-power mode interrupt enable
This bit is set and cleared by software.
0: Interrupt inhibited
1: USART interrupt generated whenever WUF = 1 in the USART_ISR register

Note: WUFIE must be set before entering in low-power mode.
The WUF interrupt is active only in low-power mode.
If the USART does not support the wakeup from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bits 21:20 **WUS[1:0]**: Wakeup from low-power mode interrupt flag selection

This bitfield specifies the event which activates the WUF (Wakeup from low-power mode flag).

00: WUF active on address match (as defined by ADD[7:0] and ADDM7)

01: Reserved.

10: WUF active on start bit detection

11: WUF active on RXNE/RXFNE.

This bitfield can only be written when the USART is disabled (UE = 0).

If the USART does not support the wakeup from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bits 19:17 **SCARCNT[2:0]**: Smartcard auto-retry count

This bitfield specifies the number of retries for transmission and reception in Smartcard mode.

In transmission mode, it specifies the number of automatic retransmission retries, before generating a transmission error (FE bit set).

In reception mode, it specifies the number or erroneous reception trials, before generating a reception error (RXNE/RXFNE and PE bits set).

This bitfield must be programmed only when the USART is disabled (UE = 0).

When the USART is enabled (UE = 1), this bitfield may only be written to 0x0, in order to stop retransmission.

0x0: retransmission disabled - No automatic retransmission in transmit mode.

0x1 to 0x7: number of automatic retransmission attempts (before signaling error)

Note: If Smartcard mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 16 Reserved, must be kept at reset value.

Bit 15 **DEP**: Driver enable polarity selection

0: DE signal is active high.

1: DE signal is active low.

This bit can only be written when the USART is disabled (UE = 0).

Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 14 **DEM**: Driver enable mode

This bit enables the user to activate the external transceiver control, through the DE signal.

0: DE function is disabled.

1: DE function is enabled. The DE signal is output on the RTS pin.

This bit can only be written when the USART is disabled (UE = 0).

Note: If the Driver Enable feature is not supported, this bit is reserved and must be kept at reset value. Section 53.4: USART implementation on page 2058.

Bit 13 **DDRE**: DMA Disable on Reception Error

0: DMA is not disabled in case of reception error. The corresponding error flag is set but RXNE is kept 0 preventing from overrun. As a consequence, the DMA request is not asserted, so the erroneous data is not transferred (no DMA request), but next correct received data is transferred (used for Smartcard mode).

1: DMA is disabled following a reception error. The corresponding error flag is set, as well as RXNE. The DMA request is masked until the error flag is cleared. This means that the software must first disable the DMA request (DMAR = 0) or clear RXNE/RXFNE is case FIFO mode is enabled) before clearing the error flag.

This bit can only be written when the USART is disabled (UE=0).

Note: The reception errors are: parity error, framing error or noise error.

Bit 12 **OVRDIS**: Overrun Disable

This bit is used to disable the receive overrun detection.

0: Overrun Error Flag, ORE, is set when received data is not read before receiving new data.

1: Overrun functionality is disabled. If new data is received while the RXNE flag is still set the ORE flag is not set and the new received data overwrites the previous content of the USART_RDR register. When FIFO mode is enabled, the RXFIFO is bypassed and data is written directly in USART_RDR register. Even when FIFO management is enabled, the RXNE flag is to be used.

This bit can only be written when the USART is disabled (UE = 0).

Note: This control bit enables checking the communication flow w/o reading the data

Bit 11 **ONEBIT**: One sample bit method enable

This bit enables the user to select the sample method. When the one sample bit method is selected the noise detection flag (NE) is disabled.

0: Three sample bit method

1: One sample bit method

This bit can only be written when the USART is disabled (UE = 0).

Bit 10 **CTSIE**: CTS interrupt enable

0: Interrupt is inhibited

1: An interrupt is generated whenever CTSIF = 1 in the USART_ISR register

Note: If the hardware flow control feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 9 **CTSE**: CTS enable

0: CTS hardware flow control disabled

1: CTS mode enabled, data is only transmitted when the CTS input is deasserted (tied to 0). If the CTS input is asserted while data is being transmitted, then the transmission is completed before stopping. If data is written into the data register while CTS is asserted, the transmission is postponed until CTS is deasserted.

This bit can only be written when the USART is disabled (UE = 0)

Note: If the hardware flow control feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 8 **RTSE**: RTS enable

0: RTS hardware flow control disabled

1: RTS output enabled, data is only requested when there is space in the receive buffer. The transmission of data is expected to cease after the current character has been transmitted. The RTS output is deasserted (pulled to 0) when data can be received.

This bit can only be written when the USART is disabled (UE = 0).

Note: If the hardware flow control feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 7 **DMAT**: DMA enable transmitter

This bit is set/reset by software

1: DMA mode is enabled for transmission

0: DMA mode is disabled for transmission

Bit 6 **DMAR**: DMA enable receiver

This bit is set/reset by software

1: DMA mode is enabled for reception

0: DMA mode is disabled for reception

Bit 5 **SCEN**: Smartcard mode enable

This bit is used for enabling Smartcard mode.

0: Smartcard Mode disabled

1: Smartcard Mode enabled

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the USART does not support Smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 4 **NACK**: Smartcard NACK enable

0: NACK transmission in case of parity error is disabled

1: NACK transmission during parity error is enabled

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If the USART does not support Smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 3 **HDSEL**: Half-duplex selection

Selection of Single-wire Half-duplex mode

0: Half duplex mode is not selected

1: Half duplex mode is selected

This bit can only be written when the USART is disabled (UE = 0).

Bit 2 **IRLP**: IrDA low-power

This bit is used for selecting between normal and low-power IrDA modes

0: Normal mode

1: Low-power mode

This bit can only be written when the USART is disabled (UE = 0).

Note: If IrDA mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 1 **IREN**: IrDA mode enable

This bit is set and cleared by software.

0: IrDA disabled

1: IrDA enabled

This bit can only be written when the USART is disabled (UE = 0).

Note: If IrDA mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 0 **EIE**: Error interrupt enable

Error Interrupt Enable Bit is required to enable interrupt generation in case of a framing error, overrun error noise flag or SPI slave underrun error (FE = 1 or ORE = 1 or NE = 1 or UDR = 1 in the USART_ISR register).

0: Interrupt inhibited

1: interrupt generated when FE = 1 or ORE = 1 or NE = 1 or UDR = 1 (in SPI slave mode) in the USART_ISR register.

53.8.5 USART baud rate register (USART_BRR)

This register can only be written when the USART is disabled (UE = 0). It may be automatically updated by hardware in auto baud rate detection mode.

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BRR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **BRR[15:0]**: USART baud rate

BRR[15:4]
BRR[15:4] = USARTDIV[15:4]
BRR[3:0]
When OVER8 = 0, BRR[3:0] = USARTDIV[3:0].
When OVER8 = 1:
BRR[2:0] = USARTDIV[3:0] shifted 1 bit to the right.
BRR[3] must be kept cleared.

53.8.6 USART guard time and prescaler register (USART_GTPR)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GT[7:0]								PSC[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **GT[7:0]**: Guard time value

This bitfield is used to program the Guard time value in terms of number of baud clock periods.

This is used in Smartcard mode. The Transmission Complete flag is set after this guard time value.

This bitfield can only be written when the USART is disabled (UE = 0).

Note: If Smartcard mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bits 7:0 **PSC[7:0]**: Prescaler value

In IrDA low-power and normal IrDA mode:

PSC[7:0] = IrDA Normal and Low-Power baud rate

PSC[7:0] is used to program the prescaler for dividing the USART source clock to achieve the low-power frequency: the source clock is divided by the value given in the register (8 significant bits):

In Smartcard mode:

PSC[4:0] = Prescaler value

PSC[4:0] is used to program the prescaler for dividing the USART source clock to provide the Smartcard clock. The value given in the register (5 significant bits) is multiplied by 2 to give the division factor of the source clock frequency:

00000: Reserved - do not program this value
00001: Divides the source clock by 1 (IrDA mode) / by 2 (Smarcard mode)
00010: Divides the source clock by 2 (IrDA mode) / by 4 (Smartcard mode)
00011: Divides the source clock by 3 (IrDA mode) / by 6 (Smartcard mode)
...
11111: Divides the source clock by 31 (IrDA mode) / by 62 (Smartcard mode)
0010 0000: Divides the source clock by 32 (IrDA mode)
...
1111 1111: Divides the source clock by 255 (IrDA mode)

This bitfield can only be written when the USART is disabled (UE = 0).

Note: Bits [7:5] must be kept cleared if Smartcard mode is used.

This bitfield is reserved and forced by hardware to '0' when the Smartcard and IrDA modes are not supported. Refer to Section 53.4: USART implementation on page 2058.

53.8.7 USART receiver timeout register (USART_RTOR)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BLEN[7:0]								RTO[23:16]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RTO[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **BLEN[7:0]**: Block Length

This bitfield gives the Block length in Smartcard T = 1 Reception. Its value equals the number of information characters + the length of the Epilogue Field (1-LEC/2-CRC) - 1.

Examples:

BLEN = 0: 0 information characters + LEC

BLEN = 1: 0 information characters + CRC

BLEN = 255: 254 information characters + CRC (total 256 characters))

In Smartcard mode, the Block length counter is reset when TXE = 0 (TXFE = 0 in case FIFO mode is enabled).

This bitfield can be used also in other modes. In this case, the Block length counter is reset when RE = 0 (receiver disabled) and/or when the EOBCF bit is written to 1.

Note: This value can be programmed after the start of the block reception (using the data from the LEN character in the Prologue Field). It must be programmed only once per received block.

Bits 23:0 **RTO[23:0]**: Receiver timeout value

This bitfield gives the Receiver timeout value in terms of number of bits during which there is no activity on the RX line.

In standard mode, the RTOF flag is set if, after the last received character, no new start bit is detected for more than the RTO value.

In Smartcard mode, this value is used to implement the CWT and BWT. See Smartcard chapter for more details. In the standard, the CWT/BWT measurement is done starting from the start bit of the last received character.

Note: This value must only be programmed once per received character.

Note: RTOR can be written on-the-fly. If the new value is lower than or equal to the counter, the RTOF flag is set.

This register is reserved and forced by hardware to "0x00000000" when the Receiver timeout feature is not supported. Refer to Section 53.4: USART implementation on page 2058.

53.8.8 USART request register (USART_RQR)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXFRQ	RXFRQ	MMRQ	SBKRQ	ABRRQ
											w	w	w	w	w

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **TXFRQ**: Transmit data flush request

When FIFO mode is disabled, writing '1' to this bit sets the TXE flag. This enables to discard the transmit data. This bit must be used only in Smartcard mode, when data have not been sent due to errors (NACK) and the FE flag is active in the USART_ISR register. If the USART does not support Smartcard mode, this bit is reserved and must be kept at reset value.

When FIFO is enabled, TXFRQ bit is set to flush the whole FIFO. This sets the TXFE flag (Transmit FIFO empty, bit 23 in the USART_ISR register). Flushing the Transmit FIFO is supported in both UART and Smartcard modes.

Note: In FIFO mode, the TXFNF flag is reset during the flush request until TxFIFO is empty in order to ensure that no data are written in the data register.

Bit 3 **RXFRQ**: Receive data flush request

Writing 1 to this bit empties the entire receive FIFO i.e. clears the bit RXFNE.

This enables to discard the received data without reading them, and avoid an overrun condition.

Bit 2 **MMRQ**: Mute mode request

Writing 1 to this bit puts the USART in Mute mode and resets the RWU flag.

Bit 1 **SBKRQ**: Send break request

Writing 1 to this bit sets the SBKF flag and request to send a BREAK on the line, as soon as the transmit machine is available.

Note: When the application needs to send the break character following all previously inserted data, including the ones not yet transmitted, the software should wait for the TXE flag assertion before setting the SBKRQ bit.

Bit 0 **ABRRQ**: Auto baud rate request

Writing 1 to this bit resets the ABRF and ABRE flags in the USART_ISR and requests an automatic baud rate measurement on the next received data frame.

Note: If the USART does not support the auto baud rate feature, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

53.8.9 USART interrupt and status register [alternate] (USART_ISR)

Address offset: 0x1C

Reset value: 0x0X80 00C0

X = 2 if FIFO/Smartcard mode is enabled

X = 0 if FIFO is enabled and Smartcard mode is disabled

The same register can be used in FIFO mode enabled (this section) and FIFO mode disabled (next section).

FIFO mode enabled

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TXFT	RXFT	TCBGT	RXFF	TXFE	RE ACK	TE ACK	WUF	RWU	SBKF	CMF	BUSY
				r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ABRF	ABRE	UDR	EOBF	RTOF	CTS	CTSIF	LBDF	TXFNF	TC	RXFNE	IDLE	ORE	NE	FE	PE
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **TXFT**: TXFIFO threshold flag

This bit is set by hardware when the TXFIFO reaches the threshold programmed in TXFTCFG of USART_CR3 register i.e. the TXFIFO contains TXFTCFG empty locations. An interrupt is generated if the TXFTIE bit = 1 (bit 31) in the USART_CR3 register.

0: TXFIFO does not reach the programmed threshold.

1: TXFIFO reached the programmed threshold.

Bit 26 **RXFT**: RXFIFO threshold flag

This bit is set by hardware when the threshold programmed in RXFTCFG in USART_CR3 register is reached. This means that there are (RXFTCFG - 1) data in the Receive FIFO and one data in the USART_RDR register. An interrupt is generated if the RXFTIE bit = 1 (bit 27) in the USART_CR3 register.

0: Receive FIFO does not reach the programmed threshold.

1: Receive FIFO reached the programmed threshold.

Note: When the RXFTCFG threshold is configured to '101', RXFT flag is set if 16 data are available i.e. 15 data in the RXFIFO and 1 data in the USART_RDR. Consequently, the 17th received data does not cause an overrun error. The overrun error occurs after receiving the 18th data.

Bit 25 **TCBGT:** Transmission complete before guard time flag

This bit is set when the last data written in the USART_TDR has been transmitted correctly out of the shift register.

It is set by hardware in Smartcard mode, if the transmission of a frame containing data is complete and if the smartcard did not send back any NACK. An interrupt is generated if TCBGTIE = 1 in the USART_CR3 register.

This bit is cleared by software, by writing 1 to the TCBGTCF in the USART_ICR register or by a write to the USART_TDR register.

0: Transmission is not complete or transmission is complete unsuccessfully (i.e. a NACK is received from the card)

1: Transmission is complete successfully (before Guard time completion and there is no NACK from the smart card).

Note: If the USART does not support the Smartcard mode, this bit is reserved and kept at reset value. If the USART supports the Smartcard mode and the Smartcard mode is enabled, the TCBGT reset value is '1'. Refer to Section 53.4: USART implementation on page 2058.

Bit 24 **RXFF**: RXFIFO full

This bit is set by hardware when the number of received data corresponds to RXFIFO size + 1 (RXFIFO full + 1 data in the USART_RDR register.

An interrupt is generated if the RXFFIE bit = 1 in the USART_CR1 register.

0: RXFIFO not full.

1: RXFIFO Full.

Bit 23 **TXFE**: TXFIFO empty

This bit is set by hardware when TXFIFO is empty. When the TXFIFO contains at least one data, this flag is cleared. The TXFE flag can also be set by writing 1 to the bit TXFRQ (bit 4) in the USART_RQR register.

An interrupt is generated if the TXFEIE bit = 1 (bit 30) in the USART_CR1 register.

0: TXFIFO not empty.

1: TXFIFO empty.

Bit 22 **REACK**: Receive enable acknowledge flag

This bit is set/reset by hardware, when the Receive Enable value is taken into account by the USART.

It can be used to verify that the USART is ready for reception before entering low-power mode.

Note: If the USART does not support the wakeup from Stop feature, this bit is reserved and kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 21 **TEACK**: Transmit enable acknowledge flag

This bit is set/reset by hardware, when the Transmit Enable value is taken into account by the USART.

It can be used when an idle frame request is generated by writing TE = 0, followed by TE = 1 in the USART_CR1 register, in order to respect the TE = 0 minimum period.

Bit 20 **WUF**: Wakeup from low-power mode flag

This bit is set by hardware, when a wakeup event is detected. The event is defined by the WUS bitfield. It is cleared by software, writing a 1 to the WUCF in the USART_ICR register.

An interrupt is generated if WUFIE = 1 in the USART_CR3 register.

Note: When UESM is cleared, WUF flag is also cleared.

The WUF interrupt is active only in low-power mode.

If the USART does not support the wakeup from Stop feature, this bit is reserved and kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 19 **RWU**: *Receiver wakeup from Mute mode*

This bit indicates if the USART is in Mute mode. It is cleared/set by hardware when a wakeup/mute sequence is recognized. The Mute mode control sequence (address or IDLE) is selected by the WAKE bit in the USART_CR1 register.

When wakeup on IDLE mode is selected, this bit can only be set by software, writing 1 to the MMRQ bit in the USART_RQR register.

0: Receiver in active mode

1: Receiver in Mute mode

Note: If the USART does not support the wakeup from Stop feature, this bit is reserved and kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 18 **SBKF**: Send break flag

This bit indicates that a send break character was requested. It is set by software, by writing 1 to the SBKRQ bit in the USART_CR3 register. It is automatically reset by hardware during the stop bit of break transmission.

0: Break character transmitted

1: Break character requested by setting SBKRQ bit in USART_RQR register

Bit 17 **CMF**: Character match flag

This bit is set by hardware, when a the character defined by ADD[7:0] is received. It is cleared by software, writing 1 to the CMCF in the USART_ICR register.

An interrupt is generated if CMIE = 1in the USART_CR1 register.

0: No Character match detected

1: Character Match detected

Bit 16 **BUSY**: Busy flag

This bit is set and reset by hardware. It is active when a communication is ongoing on the RX line (successful start bit detected). It is reset at the end of the reception (successful or not).

0: USART is idle (no reception)

1: Reception on going

Bit 15 **ABRF:** Auto baud rate flag

This bit is set by hardware when the automatic baud rate has been set (RXFNE is also set, generating an interrupt if RXFNEIE = 1) or when the auto baud rate operation was completed without success (ABRE = 1) (ABRE, RXFNE and FE are also set in this case)

It is cleared by software, in order to request a new auto baud rate detection, by writing 1 to the ABRRQ in the USART_RQR register.

Note: If the USART does not support the auto baud rate feature, this bit is reserved and kept at reset value.

Bit 14 **ABRE**: Auto baud rate error

This bit is set by hardware if the baud rate measurement failed (baud rate out of range or character comparison failed)

It is cleared by software, by writing 1 to the ABRRQ bit in the USART_RQR register.

Note: If the USART does not support the auto baud rate feature, this bit is reserved and kept at reset value.

Bit 13 **UDR**: SPI slave underrun error flag

In slave transmission mode, this flag is set when the first clock pulse for data transmission appears while the software has not yet loaded any value into USART_TDR. This flag is reset by setting UDRCF bit in the USART_ICR register.

0: No underrun error

1: underrun error

Note: If the USART does not support the SPI slave mode, this bit is reserved and kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 12 **EOBF**: End of block flag

This bit is set by hardware when a complete block has been received (for example T = 1 Smartcard mode). The detection is done when the number of received bytes (from the start of the block, including the prologue) is equal or greater than BLEN + 4.

An interrupt is generated if the EOBIE = 1 in the USART_CR1 register.

It is cleared by software, writing 1 to the EOBCF in the USART_ICR register.

0: End of Block not reached

1: End of Block (number of characters) reached

Note: If Smartcard mode is not supported, this bit is reserved and kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 11 **RTOF**: Receiver timeout

This bit is set by hardware when the timeout value, programmed in the RTOR register has lapsed, without any communication. It is cleared by software, writing 1 to the RTOCF bit in the USART_ICR register.

An interrupt is generated if RTOIE = 1 in the USART_CR2 register.

In Smartcard mode, the timeout corresponds to the CWT or BWT timings.

0: Timeout value not reached

1: Timeout value reached without any data reception

Note: If a time equal to the value programmed in RTOR register separates 2 characters, RTOF is not set. If this time exceeds this value + 2 sample times (2/16 or 2/8, depending on the oversampling method), RTOF flag is set.

The counter counts even if RE = 0 but RTOF is set only when RE = 1. If the timeout has already elapsed when RE is set, then RTOF is set.

If the USART does not support the Receiver timeout feature, this bit is reserved and kept at reset value.

Bit 10 **CTS**: CTS flag

This bit is set/reset by hardware. It is an inverted copy of the status of the CTS input pin.

0: CTS line set

1: CTS line reset

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 9 **CTSIF**: CTS interrupt flag

This bit is set by hardware when the CTS input toggles, if the CTSE bit is set. It is cleared by software, by writing 1 to the CTSCF bit in the USART_ICR register.

An interrupt is generated if CTSIE = 1 in the USART_CR3 register.

0: No change occurred on the CTS status line

1: A change occurred on the CTS status line

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 8 **LBDF**: LIN break detection flag

This bit is set by hardware when the LIN break is detected. It is cleared by software, by writing 1 to the LBDCF in the USART_ICR.

An interrupt is generated if LBDIE = 1 in the USART_CR2 register.

0: LIN Break not detected

1: LIN break detected

Note: If the USART does not support LIN mode, this bit is reserved and kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 7 **TXFNF:** TXFIFO not full

TXFNF is set by hardware when TXFIFO is not full meaning that data can be written in the USART_TDR. Every write operation to the USART_TDR places the data in the TXFIFO. This flag remains set until the TXFIFO is full. When the TXFIFO is full, this flag is cleared indicating that data can not be written into the USART_TDR.

An interrupt is generated if the TXFNFIE bit =1 in the USART_CR1 register.

0: Transmit FIFO is full

1: Transmit FIFO is not full

Note: The TXFNF is kept reset during the flush request until TXFIFO is empty. After sending the flush request (by setting TXFRQ bit), the flag TXFNF should be checked prior to writing in TXFIFO (TXFNF and TXFE are set at the same time).

This bit is used during single buffer transmission.

Bit 6 **TC**: Transmission complete

This bit indicates that the last data written in the USART_TDR has been transmitted out of the shift register.

It is set by hardware when the transmission of a frame containing data is complete and when TXFE is set.

An interrupt is generated if TCIE = 1 in the USART_CR1 register.

TC bit is is cleared by software, by writing 1 to the TCCF in the USART_ICR register or by a write to the USART_TDR register.

0: Transmission is not complete

1: Transmission is complete

Note: If TE bit is reset and no transmission is on going, the TC bit is immediately set.

Bit 5 **RXFNE**: RXFIFO not empty

RXFNE bit is set by hardware when the RXFIFO is not empty, meaning that data can be read from the USART_RDR register. Every read operation from the USART_RDR frees a location in the RXFIFO.

RXFNE is cleared when the RXFIFO is empty. The RXFNE flag can also be cleared by writing 1 to the RXFRQ in the USART_RQR register.

An interrupt is generated if RXFNEIE = 1 in the USART_CR1 register.

0: Data is not received

1: Received data is ready to be read.

Bit 4 **IDLE**: Idle line detected

This bit is set by hardware when an Idle Line is detected. An interrupt is generated if IDLEIE = 1 in the USART_CR1 register. It is cleared by software, writing 1 to the IDLECF in the USART_ICR register.

0: No Idle line is detected

1: Idle line is detected

Note: The IDLE bit is not set again until the RXFNE bit has been set (i.e. a new idle line occurs).

If Mute mode is enabled (MME = 1), IDLE is set if the USART is not mute (RWU = 0), whatever the Mute mode selected by the WAKE bit. If RWU = 1, IDLE is not set.

Bit 3 **ORE**: Overrun error

This bit is set by hardware when the data currently being received in the shift register is ready to be transferred into the USART_RDR register while RXFF = 1. It is cleared by a software, writing 1 to the ORECF, in the USART_ICR register.

An interrupt is generated if RXFNEIE = 1 or EIE = 1 in the USART_CR1 register.

0: No overrun error

1: Overrun error is detected

Note: When this bit is set, the USART_RDR register content is not lost but the shift register is overwritten. An interrupt is generated if the ORE flag is set during multi buffer communication if the EIE bit is set.

This bit is permanently forced to 0 (no overrun detection) when the bit OVRDIS is set in the USART_CR3 register.

Bit 2 **NE**: Noise detection flag

This bit is set by hardware when noise is detected on a received frame. It is cleared by software, writing 1 to the NECF bit in the USART_ICR register.

0: No noise is detected

1: Noise is detected

Note: This bit does not generate an interrupt as it appears at the same time as the RXFNE bit which itself generates an interrupt. An interrupt is generated when the NE flag is set during multi buffer communication if the EIE bit is set.

When the line is noise-free, the NE flag can be disabled by programming the ONEBIT bit to 1 to increase the USART tolerance to deviations (Refer to Section 53.5.8: Tolerance of the USART receiver to clock deviation on page 2075).

This error is associated with the character in the USART_RDR.

Bit 1 **FE**: Framing error

This bit is set by hardware when a de-synchronization, excessive noise or a break character is detected. It is cleared by software, writing 1 to the FECF bit in the USART_ICR register.

When transmitting data in Smartcard mode, this bit is set when the maximum number of transmit attempts is reached without success (the card NACKs the data frame).

An interrupt is generated if EIE = 1 in the USART_CR1 register.

0: No Framing error is detected

1: Framing error or break character is detected

Note: This error is associated with the character in the USART_RDR.

Bit 0 **PE**: Parity error

This bit is set by hardware when a parity error occurs in receiver mode. It is cleared by software, writing 1 to the PECF in the USART_ICR register.

An interrupt is generated if PEIE = 1 in the USART_CR1 register.

0: No parity error

1: Parity error

Note: This error is associated with the character in the USART_RDR.

53.8.10 USART interrupt and status register [alternate] (USART_ISR)

Address offset: 0x1C

Reset value: 0x0000 00C0

The same register can be used in FIFO mode enabled (previous section) and FIFO mode disabled (this section).

FIFO mode disabled

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	TCBGT	Res.	Res.	RE ACK	TE ACK	WUF	RWU	SBKF	CMF	BUSY
						r			r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ABRF	ABRE	UDR	EOBF	RTOF	CTS	CTSIF	LBDF	TXE	TC	RXNE	IDLE	ORE	NE	FE	PE
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **TCBGT:** Transmission complete before guard time flag

This bit is set when the last data written in the USART_TDR has been transmitted correctly out of the shift register.

It is set by hardware in Smartcard mode, if the transmission of a frame containing data is complete and if the smartcard did not send back any NACK. An interrupt is generated if TCBGTIE = 1 in the USART_CR3 register.

This bit is cleared by software, by writing 1 to the TCBGTCF in the USART_ICR register or by a write to the USART_TDR register.

0: Transmission is not complete or transmission is complete unsuccessfully (i.e. a NACK is received from the card)

1: Transmission is complete successfully (before Guard time completion and there is no NACK from the smart card).

Note: If the USART does not support the Smartcard mode, this bit is reserved and kept at reset value. If the USART supports the Smartcard mode and the Smartcard mode is enabled, the TCBGT reset value is '1'. Refer to Section 53.4: USART implementation on page 2058.

Bits 24:23 Reserved, must be kept at reset value.

Bit 22 **REACK**: Receive enable acknowledge flag

This bit is set/reset by hardware, when the Receive Enable value is taken into account by the USART.

It can be used to verify that the USART is ready for reception before entering low-power mode.

Note: If the USART does not support the wakeup from Stop feature, this bit is reserved and kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 21 **TEACK**: Transmit enable acknowledge flag

This bit is set/reset by hardware, when the Transmit Enable value is taken into account by the USART.

It can be used when an idle frame request is generated by writing TE = 0, followed by TE = 1 in the USART_CR1 register, in order to respect the TE = 0 minimum period.

Bit 20 **WUF**: Wakeup from low-power mode flag

This bit is set by hardware, when a wakeup event is detected. The event is defined by the WUS bitfield. It is cleared by software, writing a 1 to the WUCF in the USART_ICR register.

An interrupt is generated if WUFIE = 1 in the USART_CR3 register.

Note: When UESM is cleared, WUF flag is also cleared.

The WUF interrupt is active only in low-power mode.

If the USART does not support the wakeup from Stop feature, this bit is reserved and kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 19 **RWU**: *Receiver wakeup from Mute mode*

This bit indicates if the USART is in Mute mode. It is cleared/set by hardware when a wakeup/mute sequence is recognized. The Mute mode control sequence (address or IDLE) is selected by the WAKE bit in the USART_CR1 register.

When wakeup on IDLE mode is selected, this bit can only be set by software, writing 1 to the MMRQ bit in the USART_RQR register.

0: Receiver in active mode

1: Receiver in Mute mode

Note: If the USART does not support the wakeup from Stop feature, this bit is reserved and kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 18 **SBKF**: Send break flag

This bit indicates that a send break character was requested. It is set by software, by writing 1 to the SBKRQ bit in the USART_CR3 register. It is automatically reset by hardware during the stop bit of break transmission.

0: Break character transmitted

1: Break character requested by setting SBKRQ bit in USART_RQR register

Bit 17 **CMF**: Character match flag

This bit is set by hardware, when a the character defined by ADD[7:0] is received. It is cleared by software, writing 1 to the CMCF in the USART_ICR register.

An interrupt is generated if CMIE = 1in the USART_CR1 register.

0: No Character match detected

1: Character Match detected

Bit 16 **BUSY**: Busy flag

This bit is set and reset by hardware. It is active when a communication is ongoing on the RX line (successful start bit detected). It is reset at the end of the reception (successful or not).

0: USART is idle (no reception)

1: Reception on going

Bit 15 **ABRF:** Auto baud rate flag

This bit is set by hardware when the automatic baud rate has been set (RXNE is also set, generating an interrupt if RXNEIE = 1) or when the auto baud rate operation was completed without success (ABRE = 1) (ABRE, RXNE and FE are also set in this case)

It is cleared by software, in order to request a new auto baud rate detection, by writing 1 to the ABRRQ in the USART_RQR register.

Note: If the USART does not support the auto baud rate feature, this bit is reserved and kept at reset value.

Bit 14 **ABRE**: Auto baud rate error

This bit is set by hardware if the baud rate measurement failed (baud rate out of range or character comparison failed)

It is cleared by software, by writing 1 to the ABRRQ bit in the USART_RQR register.

Note: If the USART does not support the auto baud rate feature, this bit is reserved and kept at reset value.

Bit 13 **UDR**: SPI slave underrun error flag

In slave transmission mode, this flag is set when the first clock pulse for data transmission appears while the software has not yet loaded any value into USART_TDR. This flag is reset by setting UDRCF bit in the USART_ICR register.

0: No underrun error

1: underrun error

Note: If the USART does not support the SPI slave mode, this bit is reserved and kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 12 **EOBF**: End of block flag

This bit is set by hardware when a complete block has been received (for example T = 1 Smartcard mode). The detection is done when the number of received bytes (from the start of the block, including the prologue) is equal or greater than BLEN + 4.

An interrupt is generated if the EOBIE = 1 in the USART_CR1 register.

It is cleared by software, writing 1 to the EOBCF in the USART_ICR register.

0: End of Block not reached

1: End of Block (number of characters) reached

Note: If Smartcard mode is not supported, this bit is reserved and kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 11 **RTOF**: Receiver timeout

This bit is set by hardware when the timeout value, programmed in the RTOR register has lapsed, without any communication. It is cleared by software, writing 1 to the RTOCF bit in the USART_ICR register.

An interrupt is generated if RTOIE = 1 in the USART_CR2 register.

In Smartcard mode, the timeout corresponds to the CWT or BWT timings.

0: Timeout value not reached

1: Timeout value reached without any data reception

Note: If a time equal to the value programmed in RTOR register separates 2 characters, RTOF is not set. If this time exceeds this value + 2 sample times (2/16 or 2/8, depending on the oversampling method), RTOF flag is set.

The counter counts even if RE = 0 but RTOF is set only when RE = 1. If the timeout has already elapsed when RE is set, then RTOF is set.

If the USART does not support the Receiver timeout feature, this bit is reserved and kept at reset value.

Bit 10 **CTS**: CTS flag

This bit is set/reset by hardware. It is an inverted copy of the status of the CTS input pin.

0: CTS line set

1: CTS line reset

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 9 **CTSIF**: CTS interrupt flag

This bit is set by hardware when the CTS input toggles, if the CTSE bit is set. It is cleared by software, by writing 1 to the CTSCF bit in the USART_ICR register.

An interrupt is generated if CTSIE = 1 in the USART_CR3 register.

0: No change occurred on the CTS status line

1: A change occurred on the CTS status line

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 8 **LBDF**: LIN break detection flag

This bit is set by hardware when the LIN break is detected. It is cleared by software, by writing 1 to the LBDCF in the USART_ICR.

An interrupt is generated if LBDIE = 1 in the USART_CR2 register.

0: LIN Break not detected

1: LIN break detected

Note: If the USART does not support LIN mode, this bit is reserved and kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 7 **TXE:** Transmit data register empty

TXE is set by hardware when the content of the USART_TDR register has been transferred into the shift register. It is cleared by writing to the USART_TDR register. The TXE flag can also be set by writing 1 to the TXFRQ in the USART_RQR register, in order to discard the data (only in Smartcard T = 0 mode, in case of transmission failure).

An interrupt is generated if the TXEIE bit = 1 in the USART_CR1 register.

0: Data register full

1: Data register not full

Bit 6 **TC**: Transmission complete

This bit indicates that the last data written in the USART_TDR has been transmitted out of the shift register.

It is set by hardware when the transmission of a frame containing data is complete and when TXE is set.

An interrupt is generated if TCIE = 1 in the USART_CR1 register.

TC bit is is cleared by software, by writing 1 to the TCCF in the USART_ICR register or by a write to the USART_TDR register.

0: Transmission is not complete

1: Transmission is complete

Note: If TE bit is reset and no transmission is on going, the TC bit is set immediately.

Bit 5 **RXNE**: Read data register not empty

RXNE bit is set by hardware when the content of the USART_RDR shift register has been transferred to the USART_RDR register. It is cleared by reading from the USART_RDR register. The RXNE flag can also be cleared by writing 1 to the RXFRQ in the USART_RQR register.

An interrupt is generated if RXNEIE = 1 in the USART_CR1 register.

0: Data is not received

1: Received data is ready to be read.

Bit 4 **IDLE**: Idle line detected

This bit is set by hardware when an Idle Line is detected. An interrupt is generated if IDLEIE = 1 in the USART_CR1 register. It is cleared by software, writing 1 to the IDLECF in the USART_ICR register.

0: No Idle line is detected

1: Idle line is detected

Note: The IDLE bit is not set again until the RXNE bit has been set (i.e. a new idle line occurs).

If Mute mode is enabled (MME = 1), IDLE is set if the USART is not mute (RWU = 0), whatever the Mute mode selected by the WAKE bit. If RWU = 1, IDLE is not set.

Bit 3 **ORE**: Overrun error

This bit is set by hardware when the data currently being received in the shift register is ready to be transferred into the USART_RDR register while RXNE = 1. It is cleared by a software, writing 1 to the ORECF, in the USART_ICR register.

An interrupt is generated if RXNEIE = 1 or EIE = 1 in the USART_CR1 register.

0: No overrun error

1: Overrun error is detected

Note: When this bit is set, the USART_RDR register content is not lost but the shift register is overwritten. An interrupt is generated if the ORE flag is set during multi buffer communication if the EIE bit is set.

This bit is permanently forced to 0 (no overrun detection) when the bit OVRDIS is set in the USART_CR3 register.

Bit 2 **NE**: Noise detection flag

This bit is set by hardware when noise is detected on a received frame. It is cleared by software, writing 1 to the NECF bit in the USART_ICR register.

0: No noise is detected

1: Noise is detected

Note: This bit does not generate an interrupt as it appears at the same time as the RXNE bit which itself generates an interrupt. An interrupt is generated when the NE flag is set during multi buffer communication if the EIE bit is set.

When the line is noise-free, the NE flag can be disabled by programming the ONEBIT bit to 1 to increase the USART tolerance to deviations (Refer to Section 53.5.8: Tolerance of the USART receiver to clock deviation on page 2075).

Bit 1 **FE**: Framing error

This bit is set by hardware when a de-synchronization, excessive noise or a break character is detected. It is cleared by software, writing 1 to the FECF bit in the USART_ICR register.

When transmitting data in Smartcard mode, this bit is set when the maximum number of transmit attempts is reached without success (the card NACKs the data frame).

An interrupt is generated if EIE = 1 in the USART_CR1 register.

0: No Framing error is detected

1: Framing error or break character is detected

Bit 0 **PE**: Parity error

This bit is set by hardware when a parity error occurs in receiver mode. It is cleared by software, writing 1 to the PECF in the USART_ICR register.

An interrupt is generated if PEIE = 1 in the USART_CR1 register.

0: No parity error

1: Parity error

53.8.11 USART interrupt flag clear register (USART_ICR)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WUCF	Res.	Res.	CMCF	Res.
											w			w	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	UDRCF	EOBCF	RTOCF	Res.	CTSCF	LBDCF	TCBGTCF	TCCF	TXFECF	IDLECF	ORECF	NECF	FECF	PECF
		w	w	w		w	w	w	w	w	w	w	W	w	w

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **WUCF**: Wakeup from low-power mode clear flag

Writing 1 to this bit clears the WUF flag in the USART_ISR register.

Note: If the USART does not support the wakeup from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bits 19:18 Reserved, must be kept at reset value.

Bit 17 **CMCF**: Character match clear flag

Writing 1 to this bit clears the CMF flag in the USART_ISR register.

Bits 16:14 Reserved, must be kept at reset value.

Bit 13 **UDRCF**:SPI slave underrun clear flag
Writing 1 to this bit clears the UDRF flag in the USART_ISR register.
Note: If the USART does not support SPI slave mode, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058

Bit 12 **EOBCF**: End of block clear flag
Writing 1 to this bit clears the EOBF flag in the USART_ISR register.
Note: If the USART does not support Smartcard mode, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 11 **RTOCF**: Receiver timeout clear flag
Writing 1 to this bit clears the RTOF flag in the USART_ISR register.
Note: If the USART does not support the Receiver timeout feature, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 10 Reserved, must be kept at reset value.

Bit 9 **CTSCF**: CTS clear flag
Writing 1 to this bit clears the CTSIF flag in the USART_ISR register.
Note: If the hardware flow control feature is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 8 **LBDCF**: LIN break detection clear flag
Writing 1 to this bit clears the LBDF flag in the USART_ISR register.
Note: If LIN mode is not supported, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation on page 2058.

Bit 7 **TCBGTCF**: Transmission complete before Guard time clear flag
Writing 1 to this bit clears the TCBGT flag in the USART_ISR register.

Bit 6 **TCCF**: Transmission complete clear flag
Writing 1 to this bit clears the TC flag in the USART_ISR register.

Bit 5 **TXFECF**: TXFIFO empty clear flag
Writing 1 to this bit clears the TXFE flag in the USART_ISR register.

Bit 4 **IDLECF**: Idle line detected clear flag
Writing 1 to this bit clears the IDLE flag in the USART_ISR register.

Bit 3 **ORECF**: Overrun error clear flag
Writing 1 to this bit clears the ORE flag in the USART_ISR register.

Bit 2 **NECF**: Noise detected clear flag
Writing 1 to this bit clears the NE flag in the USART_ISR register.

Bit 1 **FECF**: Framing error clear flag
Writing 1 to this bit clears the FE flag in the USART_ISR register.

Bit 0 **PECF**: Parity error clear flag
Writing 1 to this bit clears the PE flag in the USART_ISR register.

53.8.12 USART receive data register (USART_RDR)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDR[8:0]								
							r	r	r	r	r	r	r	r	r

Bits 31:9 Reserved, must be kept at reset value.

Bits 8:0 **RDR[8:0]**: Receive data value

Contains the received data character.

The RDR register provides the parallel interface between the input shift register and the internal bus (see *Figure 600*).

When receiving with the parity enabled, the value read in the MSB bit is the received parity bit.

53.8.13 USART transmit data register (USART_TDR)

Address offset: 0x28

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDR[8:0]								
							rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bits 8:0 **TDR[8:0]**: Transmit data value

Contains the data character to be transmitted.

The USART_TDR register provides the parallel interface between the internal bus and the output shift register (see *Figure 600*).

When transmitting with the parity enabled (PCE bit set to 1 in the USART_CR1 register), the value written in the MSB (bit 7 or bit 8 depending on the data length) has no effect because it is replaced by the parity.

Note: This register must be written only when TXE/TXFNF = 1.

53.8.14 USART prescaler register (USART_PRESC)

This register can only be written when the USART is disabled (UE = 0).

Address offset: 0x2C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **PRESCALER[3:0]**: Clock prescaler

The USART input clock can be divided by a prescaler factor:

0000: input clock not divided
0001: input clock divided by 2
0010: input clock divided by 4
0011: input clock divided by 6
0100: input clock divided by 8
0101: input clock divided by 10
0110: input clock divided by 12
0111: input clock divided by 16
1000: input clock divided by 32
1001: input clock divided by 64
1010: input clock divided by 128
1011: input clock divided by 256
Remaining combinations: Reserved

Note: When PRESCALER is programmed with a value different of the allowed ones, programmed prescaler value is 1011 i.e. input clock divided by 256.

53.8.15 USART register map

The table below gives the USART register map and reset values.

Table 425. USART register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	USART_CR1 FIFO enabled	RXFFIE	TXFEIE	FIFOEN	M1	EOBIE	RTOIE	DEAT[4:0]					DEDT[4:0]					OVER8	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXFNFIE	TCIE	RXFNEIE	IDLEIE	TE	RE	UESM	UE
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00	USART_CR1 FIFO disabled	Res.	Res.	FIFOEN	M1	EOBIE	RTOIE	DEAT[4:0]					DEDT[4:0]					OVER8	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXEIE	TCIE	RXNEIE	IDLEIE	TE	RE	UESM	UE
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	USART_CR2	ADD[7:0]								RTOEN	ABRMOD[1:0]		ABREN	MSBFIRST	DATAINV	TXINV	RXINV	SWAP	LINEN	STOP [1:0]		CLKEN	CPOL	CPHA	LBCL	Res.	LBDIE	LBDL	ADDM7	DIS_NSS	Res.	Res.	SLVEN
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0			0
0x08	USART_CR3	TXFTCFG[2:0]			RXFTIE	RXFTCFG[2:0]			TCBGTIE	TXFTIE	WUFIE	WUS [1:0]		SCAR CNT2:0]			Res.	DEP	DEM	DDRE	OVRDIS	ONEBIT	CTSIE	CTSE	RTSE	DMAT	DMAR	SCEN	NACK	HDSEL	IRLP	IREN	EIE
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	USART_BRR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BRR[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	USART_GTPR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GT[7:0]								PSC[7:0]							
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	USART_RTOR	BLEN[7:0]								RTO[23:0]																							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18	USART_RQR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXFRQ	RXFRQ	MMRQ	SBKRQ	ABRRQ
	Reset value																												0	0	0	0	0
0x1C	USART_ISR FIFO mode enabled	Res.	Res.	Res.	Res.	TXFT	RXFT	TCBGT	RXFF	TXFE	REACK	TEACK	WUF	RWU	SBKF	CMF	BUSY	ABRF	ABRE	UDR	EOBF	RTOF	CTS	CTSIF	LBDF	TXFNF	TC	RXFNE	IDLE	ORE	NE	FE	PE
	Reset value					X	X	X	X	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
0x1C	USART_ISR FIFO mode disabled	Res.	Res.	Res.	Res.	Res.	Res.	TCBGT	Res.	Res.	REACK	TEACK	WUF	RWU	SBKF	CMF	BUSY	ABRF	ABRE	UDR	EOBF	RTOF	CTS	CTSIF	LBDF	TXE	TC	RXNE	IDLE	ORE	NE	FE	PE
	Reset value							0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
0x20	USART_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WUCF	Res.	Res.	CMCF	Res.	Res.	Res.	UDRCF	EOBCF	RTOCF	Res.	CTSCF	LBDCF	TCBGTCF	TCCF	TXFECF	IDLECF	ORECF	NECF	FECF	PECF
	Reset value												0			0				0	0	0		0	0	0	0	0	0	0	0	0	0
0x24	USART_RDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDR[8:0]								
	Reset value																								0	0	0	0	0	0	0	0	0

Table 425. USART register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x28	USART_TDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDR[8:0]								
	Reset value																								0	0	0	0	0	0	0	0	0
0x2C	USART_PRESC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[3:0]			
	Reset value																													0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

54 Low-power universal asynchronous receiver transmitter (LPUART)

This section describes the low-power universal asynchronous receiver transmitted (LPUART).

54.1 LPUART introduction

The LPUART is an UART which enables bidirectional UART communications with a limited power consumption. Only 32.768 kHz LSE clock is required to enable UART communications up to 9600 baud. Higher baud rates can be reached when the LPUART is clocked by clock sources different from the LSE clock.

Even when the device is in low-power mode, the LPUART can wait for an incoming UART frame while having an extremely low energy consumption. The LPUART includes all necessary hardware support to make asynchronous serial communications possible with minimum power consumption.

It supports Half-duplex Single-wire communications and modem operations (CTS/RTS).

It also supports multiprocessor communications.

DMA (direct memory access) can be used for data transmission/reception.

54.2 LPUART main features

- Full-duplex asynchronous communications
- NRZ standard format (mark/space)
- Programmable baud rate
- From 300 baud to 9600 baud using a 32.768 kHz clock source.
- Higher baud rates can be achieved by using a higher frequency clock source
- Two internal FIFOs to transmit and receive data

  Each FIFO can be enabled/disabled by software and come with status flags for FIFOs states.
- Dual clock domain with dedicated kernel clock for peripherals independent from PCLK.
- Programmable data word length (7 or 8 or 9 bits)
- Programmable data order with MSB-first or LSB-first shifting
- Configurable stop bits (1 or 2 stop bits)
- Single-wire Half-duplex communications
- Continuous communications using DMA
- Received/transmitted bytes are buffered in reserved SRAM using centralized DMA.
- Separate enable bits for transmitter and receiver
- Separate signal polarity control for transmission and reception
- Swappable Tx/Rx pin configuration
- Hardware flow control for modem and RS-485 transceiver
- Transfer detection flags:
  - Receive buffer full
  - Transmit buffer empty
  - Busy and end of transmission flags
- Parity control:
  - Transmits parity bit
  - Checks parity of received data byte
- Four error detection flags:
  - Overrun error
  - Noise detection
  - Frame error
  - Parity error
- Interrupt sources with flags
- Multiprocessor communications: wakeup from Mute mode by idle line detection or address mark detection

54.3 LPUART implementation

Below the description of LPUART implementation in comparison with USART.

Table 426. USART / LPUART features

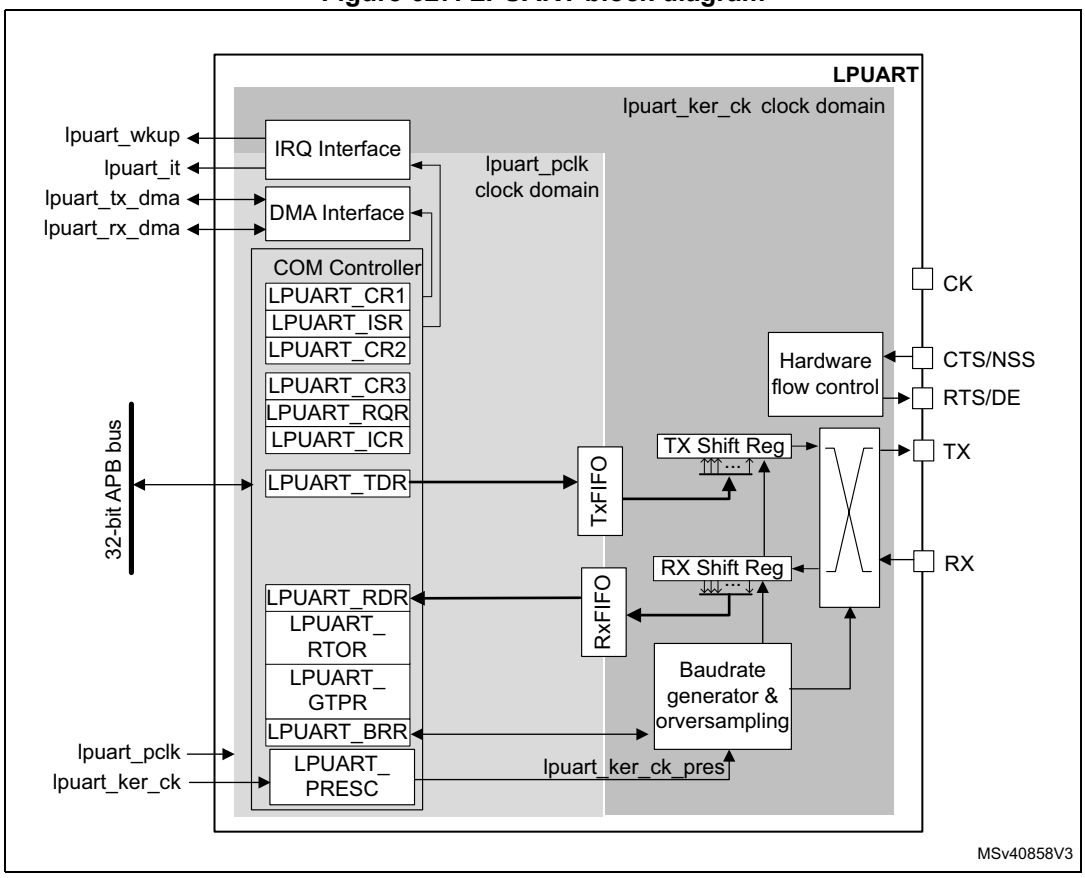
USART /LPUART modes/features(1)	USART1/2/3/6/10	UART4/5/7/8/9	LPUART1
Hardware flow control for modem	X	X	X
Continuous communication using DMA	X	X	X
Multiprocessor communication	X	X	X
Synchronous mode (Master/Slave)	X	-	-
Smartcard mode	X	-	-
Single-wire Half-duplex communication	X	X	X
IrDA SIR ENDEC block	X	X	-
LIN mode	X	X	-
Dual clock domain and wakeup from low-power mode	X	X	X
Receiver timeout interrupt	X	X	-
Modbus communication	X	X	-
Auto baud rate detection	X	X	-
Driver Enable	X	X	X
USART data length	7, 8 and 9 bits		
Tx/Rx FIFO	X	X	X
Tx/Rx FIFO size	16		

1. X = supported.

54.4 LPUART functional description

54.4.1 LPUART block diagram

Figure 627. LPUART block diagram



The simplified block diagram given in *Figure 627* shows two fully independent clock domains:

- The **lpuart_pclk** clock domain

  The **lpuart_pclk** clock signal feeds the peripheral bus interface. It must be active when accesses to the LPUART registers are required.

- The **lpuart_ker_ck** kernel clock domain

  The **lpuart_ker_ck** is the LPUART clock source. It is independent of the **lpuart_pclk** and delivered by the RCC. So, the LPUART registers can be written/read even when the **lpuart_ker_ck** is stopped.

  When the dual clock domain feature is disabled, the **lpuart_ker_ck i**s the same as the lpuart_pclk clock.

There is no constraint between **lpuart_pclk** and **lpuart_ker_ck**: **lpuart_ker_ck** can be faster or slower than **lpuart_pclk**, with no more limitation than the ability for the software to manage the communication fast enough.

54.4.2 LPUART signals

LPUART bidirectional communications requires a minimum of two pins: Receive Data In (RX) and Transmit Data Out (TX):

- **RX** (Receive Data Input)

  RX is the serial data input.
- **TX (**Transmit Data Output)

  When the transmitter is disabled, the output pin returns to its I/O port configuration. When the transmitter is enabled and nothing is to be transmitted, the TX pin is at high level. In Single-wire mode, this I/O is used to transmit and receive the data.

RS232 hardware flow control mode

The following pins are required in RS232 Hardware flow control mode:

- **CTS (**Clear To Send)

  When driven high, this signal blocks the data transmission at the end of the current transfer.
- **RTS** (Request to send)

  When it is low, this signal indicates that the USART is ready to receive data.

RS485 hardware flow control mode

The following pin is required in RS485 Hardware control mode:

- **DE** (Driver Enable)

  This signal activates the transmission mode of the external transceiver.

Note: DE and RTS share the same pin.

54.4.3 LPUART character description

The word length can be set to 7 or 8 or 9 bits, by programming the M bits (M0: bit 12 and M1: bit 28) in the LPUART_CR1 register (see *Figure 601*).

- 7-bit character length: M[1:0] = ‘10’
- 8-bit character length: M[1:0] = ‘00’
- 9-bit character length: M[1:0] = ‘01’

By default, the signal (TX or RX) is in low state during the start bit. It is in high state during the stop bit.

These values can be inverted, separately for each signal, through polarity configuration control.

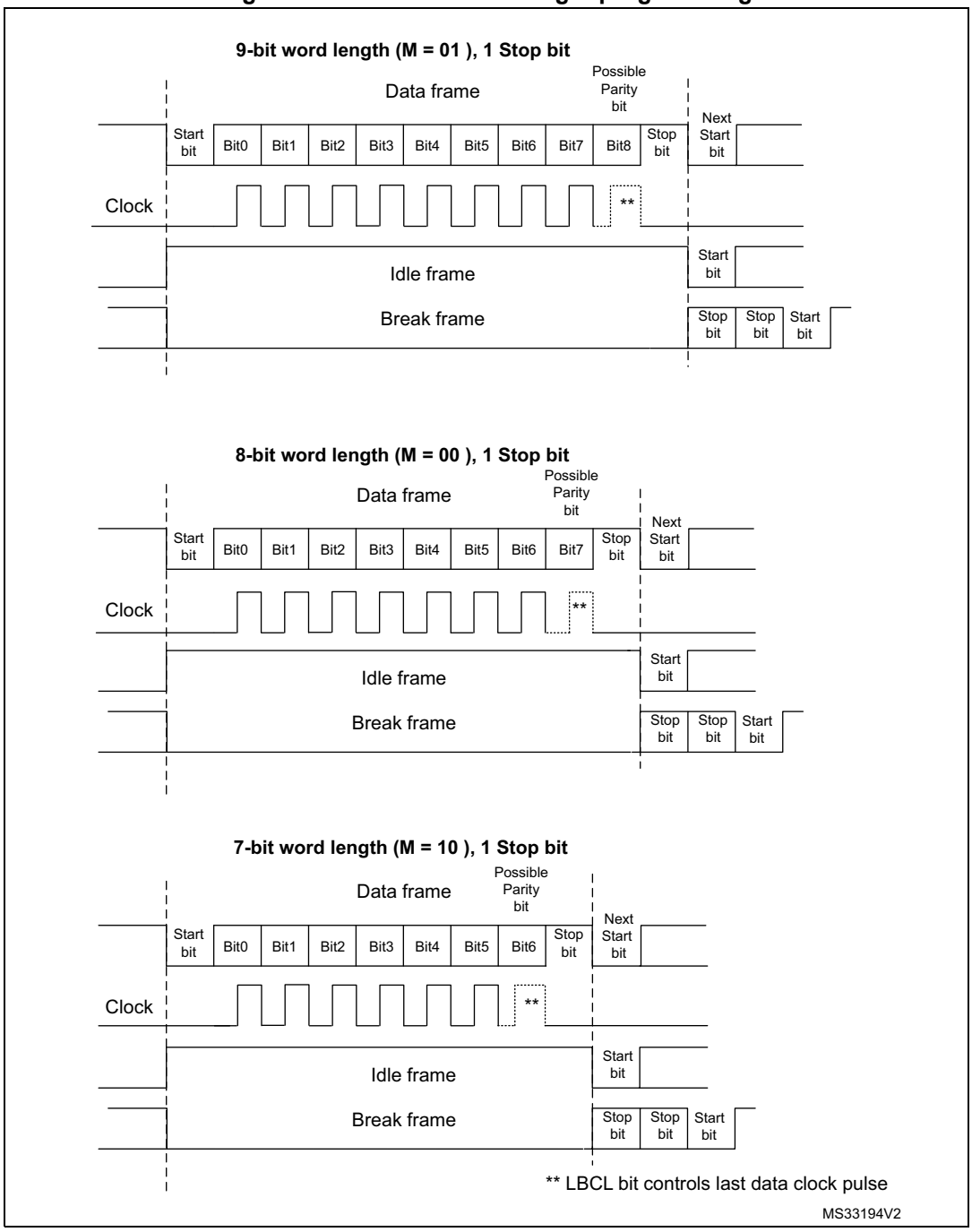
An ***Idle character*** is interpreted as an entire frame of “1”s. (The number of “1” ‘s includes the number of stop bits).

A ***Break character*** is interpreted on receiving “0”s for a frame period. At the end of the break frame, the transmitter inserts 2 stop bits.

Transmission and reception are driven by a common baud rate generator. The transmission and reception clocks are generated when the enable bit is set for the transmitter and receiver, respectively.

The details of each block is given below.

Figure 628. LPUART word length programming



54.4.4 LPUART FIFOs and thresholds

The LPUART can operate in FIFO mode.

The LPUART comes with a Transmit FIFO (TXFIFO) and a Receive FIFO (RXFIFO). The FIFO mode is enabled by setting FIFOEN bit (bit 29) in LPUART_CR1 register.

Since the maximum data word length is 9 bits, the TXFIFO is 9-bit wide. However the RXFIFO default width is 12 bits. This is due to the fact that the receiver does not only store

the data in the FIFO, but also the error flags associated to each character (Parity error, Noise error and Framing error flags).

Note: The received data is stored in the RXFIFO together with the corresponding flags. However, only the data are read when reading the RDR.

The status flags are available in the LPUART_ISR register.

It is possible to define the TXFIFO and RXFIFO levels at which the Tx and RX interrupts are triggered. These thresholds are programmed through RXFTCFG and TXFTCFG bitfields in LPUART_CR3 control register.

In this case:

- The RXFT flag is set in the LPUART_ISR register and the corresponding interrupt (if enabled) is generated, when the number of received data in the RXFIFO reaches the threshold programmed in the RXFTCFG bits fields.

  This means that the RXFIFO is filled until the number of data in the RXFIFO is equal to the programmed threshold.

  RXFTCFG data have been received: one data in LPUART_RDR and (RXFTCFG - 1) data in the RXFIFO. As an example, when the RXFTCFG is programmed to '101', the RXFT flag is set when a number of data corresponding to the FIFO size has been received: FIFO size - 1 data in the RXFIFO and 1 data in the LPUART_RDR. As a result, the next received data does not set the overrun flag.
- The TXFT flag is set in the LPUART_ISR register and the corresponding interrupt (if enabled) is generated when the number of empty locations in the TXFIFO reaches the threshold programmed in the TXFTCFG bits fields.

  This means that the TXFIFO is emptied until the number of empty locations in the TXFIFO is equal to the programmed threshold.

54.4.5 LPUART transmitter

The transmitter can send data words of either 7 or 8 or 9 bits, depending on the M bit status. The Transmit Enable bit (TE) must be set in order to activate the transmitter function. The data in the transmit shift register is output on the TX pin.

Character transmission

During an LPUART transmission, data shifts out least significant bit first (default configuration) on the TX pin. In this mode, the LPUART_TDR register consists of a buffer (TDR) between the internal bus and the transmit shift register (see *Figure 627*).

When FIFO mode is enabled, the data written to the LPUART_TDR register are queued in the TXFIFO.

Every character is preceded by a start bit which corresponds to a low logic level for one bit period. The character is terminated by a configurable number of stop bits.

The number of stop bits can be 1 or 2.

Note: The TE bit must be set before writing the data to be transmitted to the LPUART_TDR.

The TE bit should not be reset during data transmission. Resetting the TE bit during the transmission corrupts the data on the TX pin as the baud rate counters is frozen. The current data being transmitted are lost.

An idle frame is sent after the TE bit is enabled.

Configurable stop bits

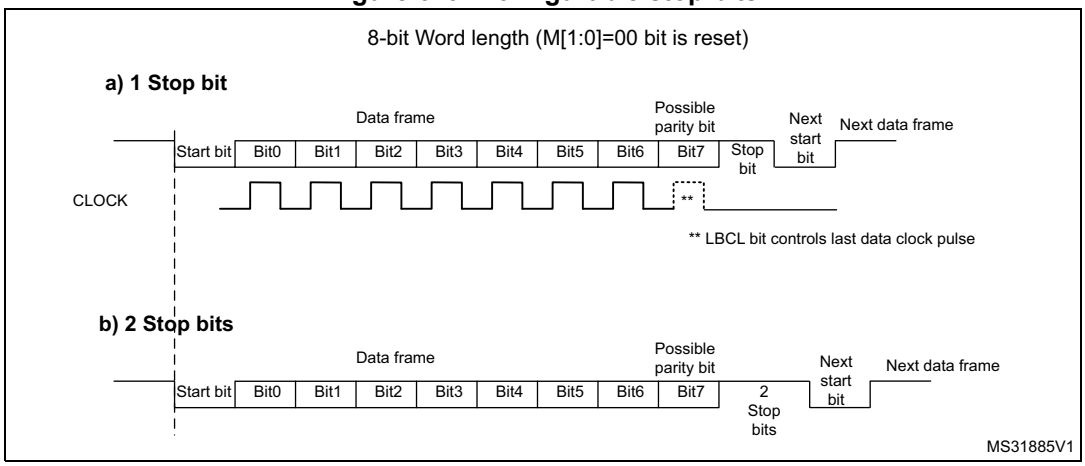
The number of stop bits to be transmitted with every character can be programmed in LPUART_CR2 (bits 13,12).

- ***1 stop bit***: This is the default value of number of stop bits.
- ***2 Stop bits***: This is supported by normal LPUART, Single-wire and Modem modes.

An idle frame transmission includes the stop bits.

A break transmission is 10 low bits (when M[1:0] = ‘00’) or 11 low bits (when M[1:0] = ‘01’) or 9 low bits (when M[1:0] = ‘10’) followed by 2 stop bits. It is not possible to transmit long breaks (break of length greater than 9/10/11 low bits).

Figure 629. Configurable stop bits



Character transmission procedure

To transmit a character, follow the sequence below:

1. Program the M bits in LPUART_CR1 to define the word length.
2. Select the desired baud rate using the LPUART_BRR register.
3. Program the number of stop bits in LPUART_CR2.
4. Enable the LPUART by writing the UE bit in LPUART_CR1 register to ‘1’.
5. Select DMA enable (DMAT) in LPUART_CR3 if Multi buffer Communication is to take place. Configure the DMA register as explained in *Section 53.5.10: USART multiprocessor communication*.
6. Set the TE bit in LPUART_CR1 to send an idle frame as first transmission.
7. Write the data to send in the LPUART_TDR register. Repeat this operation for each data to be transmitted in case of single buffer.
   - When FIFO mode is disabled, writing a data in the LPUART_TDR clears the TXE flag.
   - When FIFO mode is enabled, writing a data in the LPUART_TDR adds one data to the TXFIFO. Write operations to the LPUART_TDR are performed when TXFNF flag is set. This flag remains set until the TXFIFO is full.
8. When the last data is written to the LPUART_TDR register, wait until TC = 1. This indicates that the transmission of the last frame is complete.
   - When FIFO mode is disabled, this indicates that the transmission of the last frame is complete.

– When FIFO mode is enabled, this indicates that both TXFIFO and shift register are empty.

This check is required to avoid corrupting the last transmission when the LPUART is disabled or enters Halt mode.

Single byte communication

- When FIFO mode disabled:

  Writing to the transmit data register always clears the TXE bit. The TXE flag is set by hardware to indicate that:

  – the data have been moved from the LPUART_TDR register to the shift register and data transmission has started;

  – the LPUART_TDR register is empty;

  – the next data can be written to the LPUART_TDR register without overwriting the previous data.

  The TXE flag generates an interrupt if the TXEIE bit is set.

  When a transmission is ongoing, a write instruction to the LPUART_TDR register stores the data in the TDR register, which is copied to the shift register at the end of the current transmission.

  When no transmission is ongoing, a write instruction to the LPUART_TDR register places the data in the shift register, the data transmission starts, and the TXE bit is set.

- When FIFO mode is enabled, the TXFNF (TXFIFO Not Full) flag is set by hardware to indicate that:

  – the TXFIFO is not full;

  – the LPUART_TDR register is empty;

  – the next data can be written to the LPUART_TDR register without overwriting the previous data. When a transmission is ongoing, a write operation to the LPUART_TDR register stores the data in the TXFIFO. Data are copied from the TXFIFO to the shift register at the end of the current transmission.

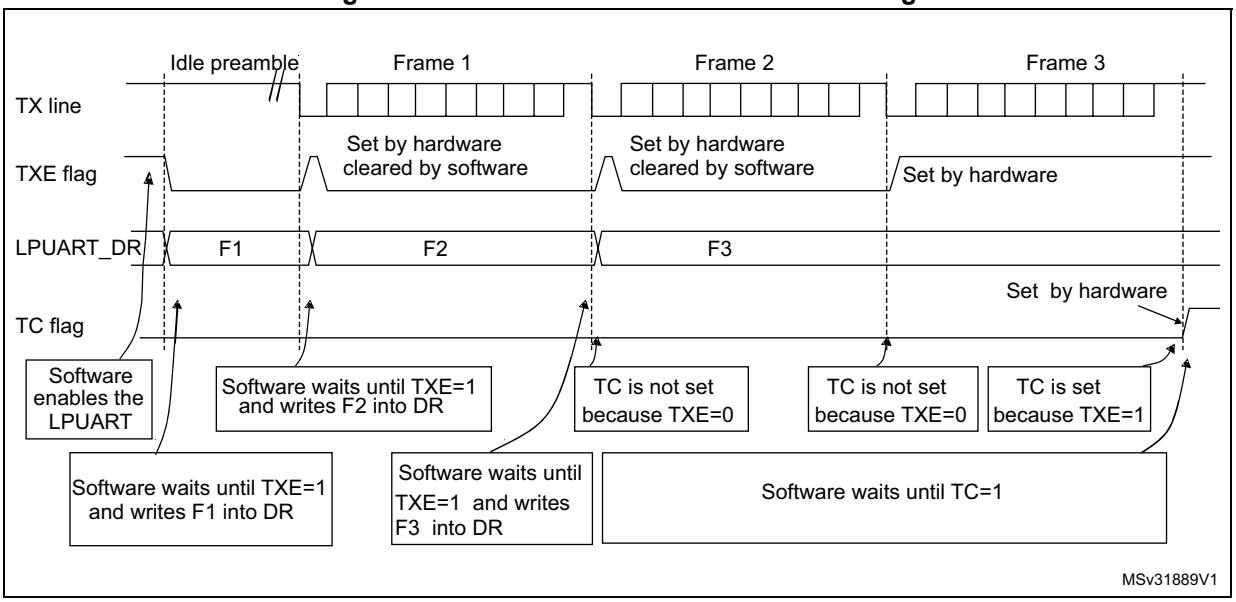
  When the TXFIFO is not full, the TXFNF flag stays at ‘1’ even after a write in LPUART_TDR. It is cleared when the TXFIFO is full. This flag generates an interrupt if TXFNEIE bit is set.

  Alternatively, interrupts can be generated and data can be written to the TXFIFO when the TXFIFO threshold is reached. In this case, the CPU can write a block of data defined by the programmed threshold.

  If a frame is transmitted (after the stop bit) and the TXE flag (TXFE is case of FIFO mode) is set, the TC bit goes high. An interrupt is generated if the TCIE bit is set in the LPUART_CR1 register.

  After writing the last data in the LPUART_TDR register, it is mandatory to wait for TC = 1 before disabling the LPUART or causing the device to enter the low-power mode (see *Figure 630: TC/TXE behavior when transmitting*).

Figure 630. TC/TXE behavior when transmitting



Note: When FIFO management is enabled, the TXFNF flag is used for data transmission.

Break characters

Setting the SBKRQ bit transmits a break character. The break frame length depends on the M bits (see *Figure 628*).

If a ‘1’ is written to the SBKRQ bit, a break character is sent on the TX line after completing the current character transmission. The SBKF bit is set by the write operation and it is reset by hardware when the break character is completed (during the stop bits after the break character). The LPUART inserts a logic 1 signal (STOP) for the duration of 2 bits at the end of the break frame to guarantee the recognition of the start bit of the next frame.

When the SBKRQ bit is set, the break character is sent at the end of the current transmission.

When FIFO mode is enabled, sending the break character has priority on sending data even if the TXFIFO is full.

Idle characters

Setting the TE bit drives the LPUART to send an idle frame before the first data frame.

54.4.6 LPUART receiver

The LPUART can receive data words of either 7 or 8 or 9 bits depending on the M bits in the LPUART_CR1 register.

Start bit detection

In the LPUART, the start bit is detected when a falling edge occurs on the Rx line, followed by a sample taken in the middle of the start bit to confirm that it is still ‘0’. If the start sample is at ‘1’, then the noise error flag (NE) is set, then the start bit is discarded and the receiver waits for a new start bit. Else, the receiver continues to sample all incoming bits normally.

Character reception

During an LPUART reception, data are shifted in least significant bit first (default configuration) through the RX pin. In this mode, the LPUART_RDR register consists of a buffer (RDR) between the internal bus and the received shift register.

Character reception procedure

To receive a character, follow the sequence below:

1. Program the M bits in LPUART_CR1 to define the word length.
2. Select the desired baud rate using the baud rate register LPUART_BRR
3. Program the number of stop bits in LPUART_CR2.
4. Enable the LPUART by writing the UE bit in LPUART_CR1 register to ‘1’.
5. Select DMA enable (DMAR) in LPUART_CR3 if multibuffer communication is to take place. Configure the DMA register as explained in *Section 53.5.10: USART multiprocessor communication*.
6. Set the RE bit LPUART_CR1. This enables the receiver which begins searching for a start bit.

When a character is received

- When FIFO mode is disabled, the RXNE bit is set. It indicates that the content of the shift register is transferred to the RDR. In other words, data has been received and can be read (as well as its associated error flags).
- When FIFO mode is enabled, the RXFNE bit is set indicating that the RXFIFO is not empty. Reading the LPUART_RDR returns the oldest data entered in the RXFIFO. When a data is received, it is stored in the RXFIFO, together with the corresponding error bits.
- An interrupt is generated if the RXNEIE (RXFNEIE in case of FIFO mode) bit is set.
- The error flags can be set if a frame error, noise or an overrun error has been detected during reception.
- In multibuffer communication mode:
  - When FIFO mode is disabled, the RXNE flag is set after every byte received and is cleared by the DMA read of the Receive Data Register.
  - When FIFO mode is enabled, the RXFNE flag is set when the RXFIFO is not empty. After every DMA request, a data is retrieved from the RXFIFO. DMA request is triggered by RXFIFO is not empty i.e. there is a data in the RXFIFO to be read.
- In single buffer mode:
  - When FIFO mode is disabled, clearing the RXNE flag is done by performing a software read from the LPUART_RDR register. The RXNE flag can also be cleared by writing 1 to the RXFRQ in the LPUART_RQR register. The RXNE bit must be cleared before the end of the reception of the next character to avoid an overrun error.
  - When FIFO mode is enabled, the RXFNE flag is set when the RXFIFO is not empty. After every read operation from the LPUART_RDR register, a data is retrieved from the RXFIFO. When the RXFIFO is empty, the RXFNE flag is cleared. The RXFNE flag can also be cleared by writing 1 to the RXFRQ bit in the LPUART_RQR register. When the RXFIFO is full, the first entry in the RXFIFO must be read before the end of the reception of the next character to avoid an overrun error. The RXFNE flag generates an interrupt if the RXFNEIE bit is set.

Alternatively, interrupts can be generated and data can be read from RXFIFO when the RXFIFO threshold is reached. In this case, the CPU can read a block of data defined by the programmed threshold.

Break character

When a break character is received, the LPUART handles it as a framing error.

Idle character

When an idle frame is detected, it is handled in the same way as a data character reception except that an interrupt is generated if the IDLEIE bit is set.

Overrun error

- FIFO mode disabled

  An overrun error occurs when a character is received when RXNE has not been reset.

  Data can not be transferred from the shift register to the RDR register until the RXNE bit is cleared. The RXNE flag is set after every byte received.

  An overrun error occurs if RXNE flag is set when the next data is received or the previous DMA request has not been serviced. When an overrun error occurs:

  – the ORE bit is set;
  – the RDR content is not lost. The previous data is available when a read to LPUART_RDR is performed.;
  – the shift register is overwritten. After that, any data received during overrun is lost.
  – an interrupt is generated if either the RXNEIE bit or EIE bit is set.

- FIFO mode enabled

  An overrun error occurs when the shift register is ready to be transferred when the receive FIFO is full.

  Data can not be transferred from the shift register to the LPUART_RDR register until there is one free location in the RXFIFO. The RXFNE flag is set when the RXFIFO is not empty.

  An overrun error occurs if the RXFIFO is full and the shift register is ready to be transferred. When an overrun error occurs:

  – the ORE bit is set;
  – the first entry in the RXFIFO is not lost. It is available when a read to LPUART_RDR is performed.
  – the shift register is overwritten. After that, any data received during overrun is lost.
  – an interrupt is generated if either the RXFNEIE bit or EIE bit is set.

The ORE bit is reset by setting the ORECF bit in the ICR register.

Note: The ORE bit, when set, indicates that at least 1 data has been lost. T

When the FIFO mode is disabled, there are two possibilities

- *if RXNE = 1, then the last valid data is stored in the receive register (RDR) and can be read,*
- *if RXNE = 0, then the last valid data has already been read and there is nothing left to be read in the RDR. This case can occur when the last valid data is read in the RDR at the same time as the new (and lost) data is received.*

Selecting the clock source

The choice of the clock source is done through the Clock Control system (see *Section Reset and clock controller (RCC)*). The clock source must be selected through the UE bit, before enabling the LPUART.

The clock source must be selected according to two criteria:

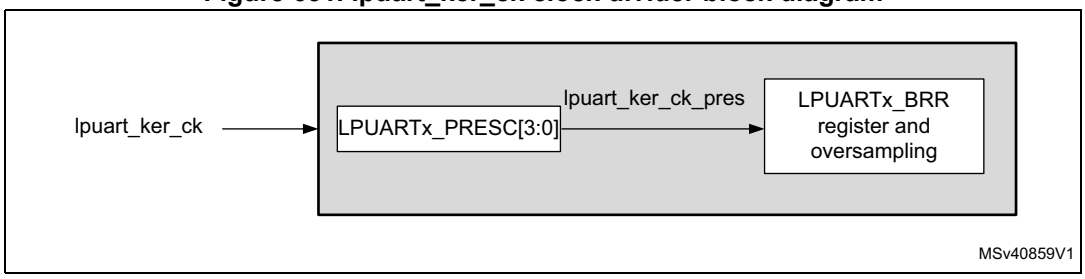
- Possible use of the LPUART in low-power mode
- Communication speed.

The clock source frequency is lpuart_ker_ck.

When the dual clock domain and the wakeup from low-power mode features are supported, the lpuart_ker_ck clock source can be configured in the RCC (see *Section Reset and clock controller (RCC)*). Otherwise, the lpuart_ker_ck is the same as lpuart_pclk.

The lpuart_ker_ck can be divided by a programmable factor in the LPUART_PRESC register.

Figure 631. lpuart_ker_ck clock divider block diagram



Some lpuart_ker_ck sources enable the LPUART to receive data while the MCU is in low-power mode. Depending on the received data and wakeup mode selection, the LPUART wakes up the MCU, when needed, in order to transfer the received data by software reading the LPUART_RDR register or by DMA.

For the other clock sources, the system must be active to enable LPUART communications.

The communication speed range (specially the maximum communication speed) is also determined by the clock source.

The receiver samples each incoming bit as close as possible to the middle of the bit-period. Only a single sample is taken of each of the incoming bits.

Note: There is no noise detection for data.

Framing error

A framing error is detected when the stop bit is not recognized on reception at the expected time, following either a de-synchronization or excessive noise.

When the framing error is detected:

- the FE bit is set by hardware;
- the invalid data is transferred from the Shift register to the LPUART_RDR register.
- no interrupt is generated in case of single byte communication. However this bit rises at the same time as the RXNE bit which itself generates an interrupt. In case of

multibuffer communication, an interrupt is issued if the EIE bit is set in the LPUART_CR3 register.

The FE bit is reset by writing 1 to the FECF in the LPUART_ICR register.

Configurable stop bits during reception

The number of stop bits to be received can be configured through the control bits of LPUART_CR2: it can be either 1 or 2 in normal mode.

- **1 stop bit**: sampling for 1 stop bit is done on the 8th, 9th and 10th samples.
- **2 stop bits**: sampling for the 2 stop bits is done in the middle of the second stop bit. The RXNE and FE flags are set just after this sample i.e. during the second stop bit. The first stop bit is not checked for framing error.

54.4.7 LPUART baud rate generation

The baud rate for the receiver and transmitter (Rx and Tx) are both set to the value programmed in the LPUART_BRR register.

$$\text{Tx/Rx baud} = \frac{256 \times \text{lpuartckpres}}{\text{LPUARTDIV}}$$

LPUARTDIV is defined in the LPUART_BRR register.

Note: The baud counters are updated to the new value in the baud registers after a write operation to LPUART_BRR. Hence the baud rate register value should not be changed during communication.

It is forbidden to write values lower than 0x300 in the LPUART_BRR register.

f_{CK} must range from 3 x baud rate to 4096 x baud rate.

The maximum baud rate that can be reached when the LPUART clock source is the LSE, is 9600 baud. Higher baud rates can be reached when the LPUART is clocked by clock sources different from the LSE clock. For example, if the LPUART clock source frequency is 100 MHz, the maximum baud rate that can be reached is about 33 Mbaud.

Table 427. Error calculation for programmed baud rates at lpuart_ker_ck_pres = 32.768 kHz

Baud rate		lpuart_ker_ck_pres = 32.768 kHz		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired) B.rate / Desired B.rate
1	300 bauds	300 baud	0x6D3A	0
2	600 baud	600 baud	0x369D	0
3	1200 baud	1200.087 baud	0x1B4E	0.007
4	2400 baud	2400.17 baud	0xDA7	0.007
5	4800 baud	4801.72 baud	0x6D3	0.035
6	9600 baud	9608.94 baud	0x369	0.093

Table 428. Error calculation for programmed baud rates at f_{CK} = 100 MHz

Baud rate		f_{CK} = 100MHz		
S.No	Desired	Actual	Value programmed in the baud rate register	% Error = (Calculated - Desired) B.rate / Desired B.rate
1	38400 Baud	38400,04 Baud	A2C2A	0,0001
2	57600 Baud	57600,06 Baud	6C81C	0,0001
3	115200 Baud	115200,12 Baud	3640E	0,0001
4	230400 Baud	230400,23 Baud	1B207	0,0001
5	460800 Baud	460804,61 Baud	D903	0,001
6	921600 Baud	921625,81 Baud	6C81	0,0028
7	4000 KBaud	4000000,00 Baud	1900	0
8	10000 Kbaud	10000000,00 Baud	A00	0
9	20000 Kbaud	20000000,00 Baud	500	0
10	33000 Kbaud	33032258,06 Baud	307	0,1

54.4.8 Tolerance of the LPUART receiver to clock deviation

The asynchronous receiver of the LPUART works correctly only if the total clock system deviation is less than the tolerance of the LPUART receiver. The causes which contribute to the total deviation are:

- DTRA: deviation due to the transmitter error (which also includes the deviation of the transmitter's local oscillator)
- DQUANT: error due to the baud rate quantization of the receiver
- DREC: deviation of the receiver local oscillator
- DTCL: deviation due to the transmission line (generally due to the transceivers which can introduce an asymmetry between the low-to-high transition timing and the high-to-low transition timing)

$$DTRA + DQUANT + DREC + DTCL + DWU < \text{LPUART receiver tolerance}$$

where

DWU is the error due to sampling point deviation when the wakeup from low-power mode is used.

The LPUART receiver can receive data correctly at up to the maximum tolerated deviation specified in *Table 429*:

- Number of Stop bits defined through STOP[1:0] bits in the LPUART_CR2 register
- LPUART_BRR register value.

Table 429. Tolerance of the LPUART receiver

M bits	768 < BRR < 1024	1024 < BRR < 2048	2048 < BRR < 4096	4096 ≤ BRR
8 bits (M = 00'), 1 Stop bit	1.82%	2.56%	3.90%	4.42%
9 bits (M = 01'), 1 Stop bit	1.69%	2.33%	2.53%	4.14%
7 bits (M = '10'), 1 Stop bit	2.08%	2.86%	4.35%	4.42%
8 bits (M = 00'), 2 Stop bit	2.08%	2.86%	4.35%	4.42%
9 bits (M = 01'), 2 Stop bit	1.82%	2.56%	3.90%	4.42%
7 bits (M = '10'), 2 Stop bit	2.34%	3.23%	4.92%	4.42%

Note: The data specified in Table 429 may slightly differ in the special case when the received frames contain some Idle frames of exactly 10-bit times when M bits = '00' (11-bit times when M = '01' or 9- bit times when M = '10').

54.4.9 LPUART multiprocessor communication

It is possible to perform LPUART multiprocessor communications (with several LPUARTs connected in a network). For instance one of the LPUARTs can be the master, with its TX output connected to the RX inputs of the other LPUARTs. The others are slaves, with their respective TX outputs are logically ANDed together and connected to the RX input of the master.

In multiprocessor configurations it is often desirable that only the intended message recipient actively receives the full message contents, thus reducing redundant LPUART service overhead for all non addressed receivers.

The non addressed devices can be placed in Mute mode by means of the muting function. To use the Mute mode feature, the MME bit must be set in the LPUART_CR1 register.

Note: When FIFO management is enabled and MME is already set, MME bit must not be cleared and then set again quickly (within two lpuart_ker_ck *cycles), otherwise Mute mode might remain active.*

When the Mute mode is enabled:

- none of the reception status bits can be set;
- all the receive interrupts are inhibited;
- the RWU bit in LPUART_ISR register is set to '1'. RWU can be controlled automatically by hardware or by software, through the MMRQ bit in the LPUART_RQR register, under certain conditions.

The LPUART can enter or exit from Mute mode using one of two methods, depending on the WAKE bit in the LPUART_CR1 register:

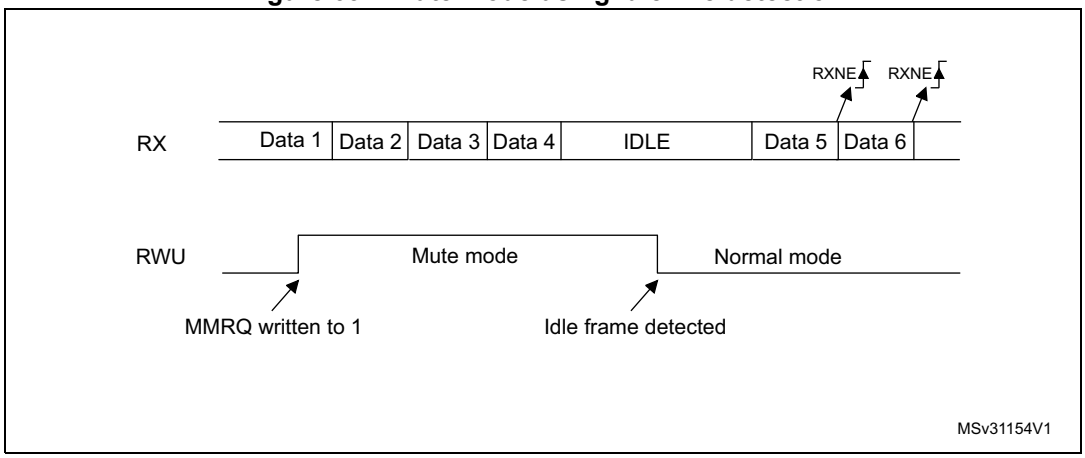
- Idle Line detection if the WAKE bit is reset,
- Address Mark detection if the WAKE bit is set.

Idle line detection (WAKE = 0)

The LPUART enters Mute mode when the MMRQ bit is written to 1 and the RWU is automatically set.

The LPUART wakes up when an Idle frame is detected. The RWU bit is then cleared by hardware but the IDLE bit is not set in the LPUART_ISR register. An example of Mute mode behavior using Idle line detection is given in *Figure 632*.

Figure 632. Mute mode using Idle line detection



Note: If the MMRQ is set while the IDLE character has already elapsed, the Mute mode is not entered (RWU is not set).

If the LPUART is activated while the line is IDLE, the idle state is detected after the duration of one IDLE frame (not only after the reception of one character frame).

4-bit/7-bit address mark detection (WAKE = 1)

In this mode, bytes are recognized as addresses if their MSB is a ‘1’ otherwise they are considered as data. In an address byte, the address of the targeted receiver is put in the 4 or 7 LSBs. The choice of 7 or 4 bit address detection is done using the ADDM7 bit. This 4-bit/7-bit word is compared by the receiver with its own address which is programmed in the ADD bits in the LPUART_CR2 register.

Note: In 7-bit and 9-bit data modes, address detection is done on 6-bit and 8-bit addresses (ADD[5:0] and ADD[7:0]) respectively.

The LPUART enters Mute mode when an address character is received which does not match its programmed address. In this case, the RWU bit is set by hardware. The RXNE flag is not set for this address byte and no interrupt or DMA request is issued when the LPUART enters Mute mode.

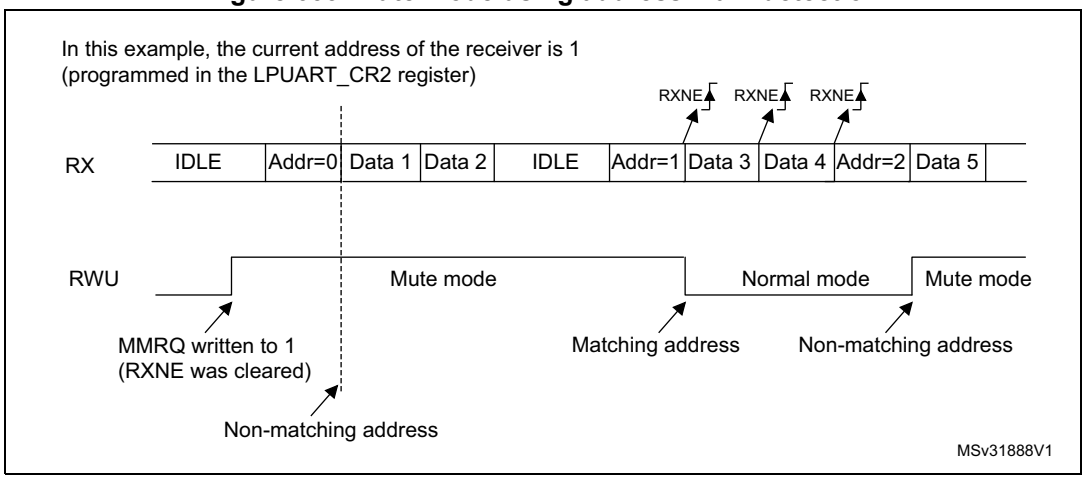
The LPUART also enters Mute mode when the MMRQ bit is written to ‘1’. The RWU bit is also automatically set in this case.

The LPUART exits from Mute mode when an address character is received which matches the programmed address. Then the RWU bit is cleared and subsequent bytes are received normally. The RXNE/RXFNE bit is set for the address character since the RWU bit has been cleared.

Note: When FIFO management is enabled, when MMRQ bit is set while the receiver is sampling the last bit of a data, this data may be received before effectively entering in Mute mode.

An example of Mute mode behavior using address mark detection is given in *Figure 633*.

Figure 633. Mute mode using address mark detection



54.4.10 LPUART parity control

Parity control (generation of parity bit in transmission and parity checking in reception) can be enabled by setting the PCE bit in the LPUART_CR1 register. Depending on the frame length defined by the M bits, the possible LPUART frame formats are as listed in *Table 430*.

Table 430: LPUART frame formats

M bits	PCE bit	LPUART frame(1)
00	0	| SB | 8 bit data | STB |
00	1	| SB | 7-bit data | PB | STB |
01	0	| SB | 9-bit data | STB |
01	1	| SB | 8-bit data PB | STB |
10	0	| SB | 7bit data | STB |
10	1	| SB | 6-bit data | PB | STB |

1. Legends: SB: start bit, STB: stop bit, PB: parity bit.
2. In the data register, the PB is always taking the MSB position (8th or 7th, depending on the M bit value).

Even parity

The parity bit is calculated to obtain an even number of “1s” inside the frame which is made of the 6, 7 or 8 LSB bits (depending on M bit values) and the parity bit.

As an example, if data equal 00110101, and 4 bits are set, then the parity bit is equal to 0 if even parity is selected (PS bit in LPUART_CR1 = 0).

Odd parity

The parity bit is calculated to obtain an odd number of “1s” inside the frame made of the 6, 7 or 8 LSB bits (depending on M bit values) and the parity bit.

As an example, if data equal 00110101 and 4 bits set, then the parity bit is equal to 1 if odd parity is selected (PS bit in LPUART_CR1 = 1).

Parity checking in reception

If the parity check fails, the PE flag is set in the LPUART_ISR register and an interrupt is generated if PEIE is set in the LPUART_CR1 register. The PE flag is cleared by software writing 1 to the PECF in the LPUART_ICR register.

Parity generation in transmission

If the PCE bit is set in LPUART_CR1, then the MSB bit of the data written in the data register is transmitted but is changed by the parity bit (even number of “1s” if even parity is selected (PS = 0) or an odd number of “1s” if odd parity is selected (PS = 1)).

54.4.11 LPUART single-wire Half-duplex communication

Single-wire Half-duplex mode is selected by setting the HDSEL bit in the LPUART_CR3 register. In this mode, the following bits must be kept cleared:

- LINEN and CLKEN bits in the LPUART_CR2 register,
- SCEN and IREN bits in the LPUART_CR3 register.

The LPUART can be configured to follow a Single-wire Half-duplex protocol where the TX and RX lines are internally connected. The selection between half- and Full-duplex communication is made with a control bit HDSEL in LPUART_CR3.

As soon as HDSEL is written to ‘1’:

- The TX and RX lines are internally connected.
- The RX pin is no longer used
- The TX pin is always released when no data is transmitted. Thus, it acts as a standard I/O in idle or in reception. It means that the I/O must be configured so that TX is configured as alternate function open-drain with an external pull-up.

Apart from this, the communication protocol is similar to normal LPUART mode. Any conflict on the line must be managed by software (for instance by using a centralized arbiter). In particular, the transmission is never blocked by hardware and continues as soon as data is written in the data register while the TE bit is set.

Note: In LPUART communications, in the case of 1-stop bit configuration, the RXNE flag is set in the middle of the stop bit.

54.4.12 Continuous communication using DMA and LPUART

The LPUART is capable of performing continuous communication using the DMA. The DMA requests for Rx buffer and Tx buffer are generated independently.

Note: Refer to Section 53.4: USART implementation on page 2058 to determine if the DMA mode is supported. If DMA is not supported, use the LPUSRT as explained in Section 53.5.6. To perform continuous communication. When FIFO is disabled, you can clear the TXE/ RXNE flags in the LPUART_ISR register.

Transmission using DMA

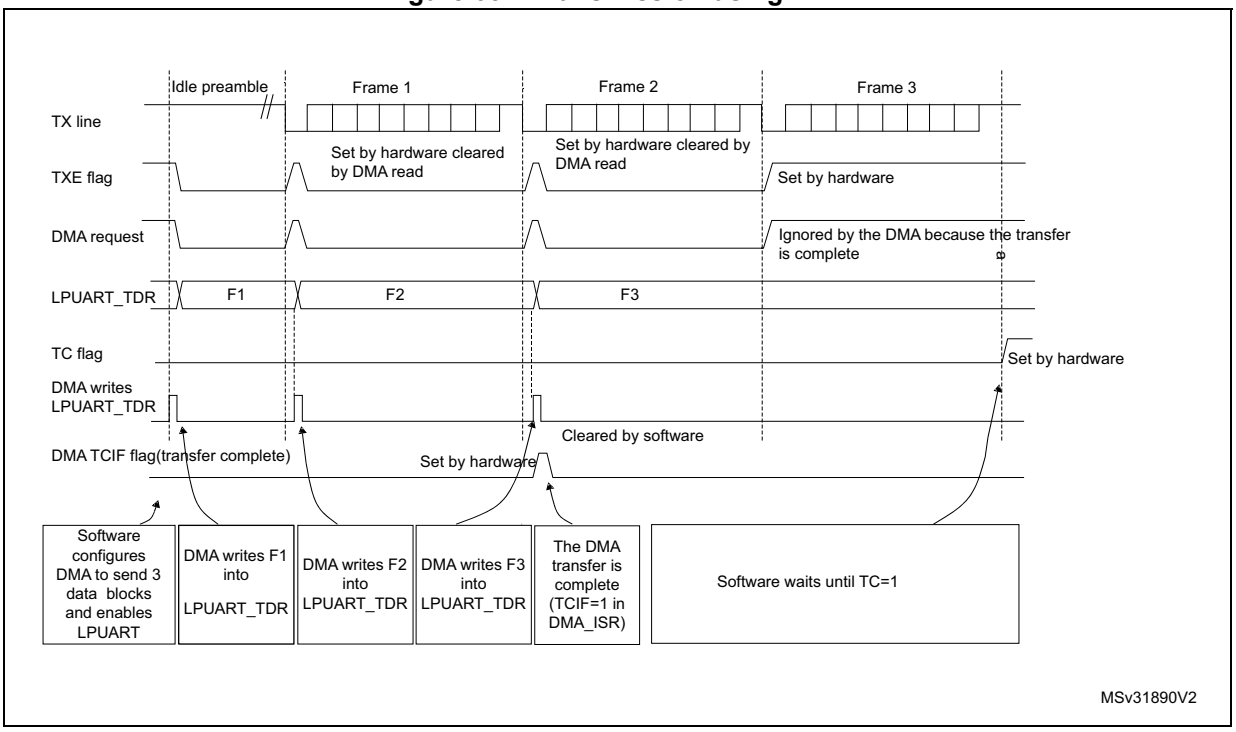
DMA mode can be enabled for transmission by setting DMAT bit in the LPUART_CR3 register. Data are loaded from an SRAM area configured using the DMA peripheral (refer to the corresponding *Direct memory access controller* section) to the LPUART_TDR register whenever the TXE flag (TXFNF flag if FIFO mode is enabled) is set. To map a DMA channel for LPUART transmission, use the following procedure (x denotes the channel number):

1. Write the LPUART_TDR register address in the DMA control register to configure it as the destination of the transfer. The data is moved to this address from memory after each TXE (or TXFNF if FIFO mode is enabled) event.
2. Write the memory address in the DMA control register to configure it as the source of the transfer. The data is loaded into the LPUART_TDR register from this memory area after each TXE (or TXFNF if FIFO mode is enabled) event.
3. Configure the total number of bytes to be transferred to the DMA control register.
4. Configure the channel priority in the DMA register
5. Configure DMA interrupt generation after half/ full transfer as required by the application.
6. Clear the TC flag in the LPUART_ISR register by setting the TCCF bit in the LPUART_ICR register.
7. Activate the channel in the DMA register.

When the number of data transfers programmed in the DMA Controller is reached, the DMA controller generates an interrupt on the DMA channel interrupt vector.

In transmission mode, once the DMA has written all the data to be transmitted (the TCIF flag is set in the DMA_ISR register), the TC flag can be monitored to make sure that the LPUART communication is complete. This is required to avoid corrupting the last transmission before disabling the LPUART or entering low-power mode. Software must wait until TC = 1. The TC flag remains cleared during all data transfers and it is set by hardware at the end of transmission of the last frame.

Figure 634. Transmission using DMA



Note: When FIFO management is enabled, the DMA request is triggered by Transmit FIFO not full (i.e. TXFNF = 1).

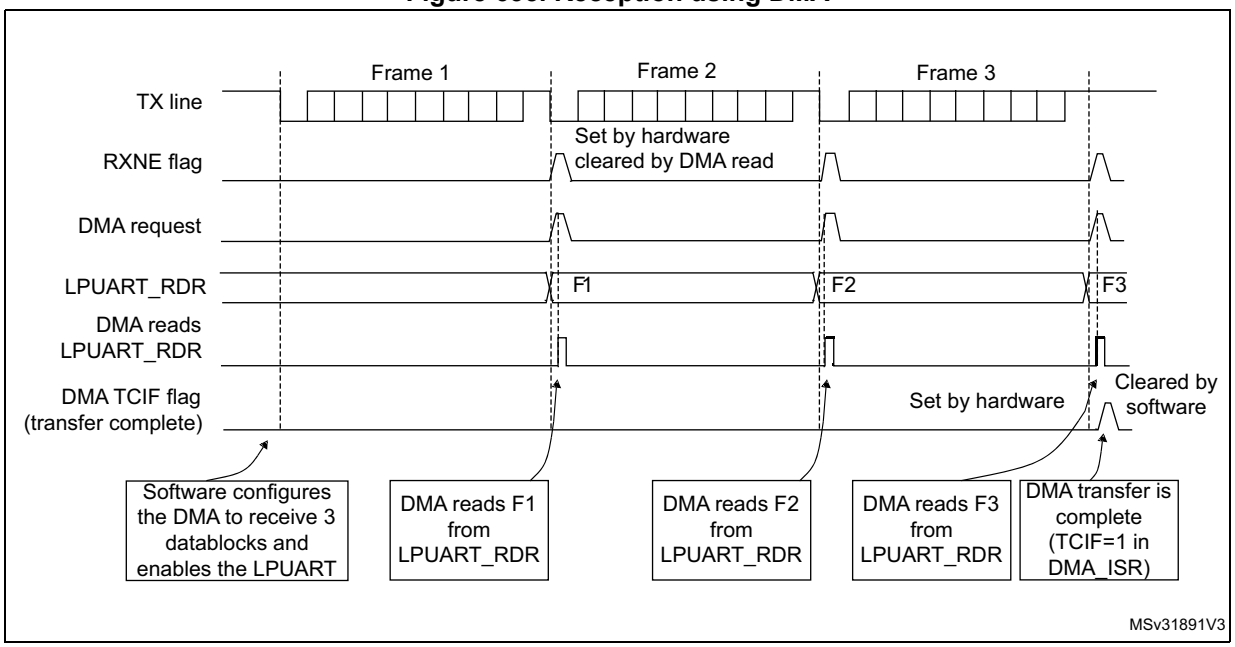
Reception using DMA

DMA mode can be enabled for reception by setting the DMAR bit in LPUART_CR3 register. Data are loaded from the LPUART_RDR register to a SRAM area configured using the DMA peripheral (refer to the corresponding *Direct memory access controller (DMA)* section) whenever a data byte is received. To map a DMA channel for LPUART reception, use the following procedure:

1. Write the LPUART_RDR register address in the DMA control register to configure it as the source of the transfer. The data is moved from this address to the memory after each RXNE (RXFNE in case FIFO mode is enabled) event.
2. Write the memory address in the DMA control register to configure it as the destination of the transfer. The data is loaded from LPUART_RDR to this memory area after each RXNE (RXFNE in case FIFO mode is enabled) event.
3. Configure the total number of bytes to be transferred to the DMA control register.
4. Configure the channel priority in the DMA control register
5. Configure interrupt generation after half/ full transfer as required by the application.
6. Activate the channel in the DMA control register.

When the number of data transfers programmed in the DMA Controller is reached, the DMA controller generates an interrupt on the DMA channel interrupt vector.

Figure 635. Reception using DMA



Note: When FIFO management is enabled, the DMA request is triggered by Receive FIFO not empty (i.e. RXFNE = 1).

Error flagging and interrupt generation in multibuffer communication

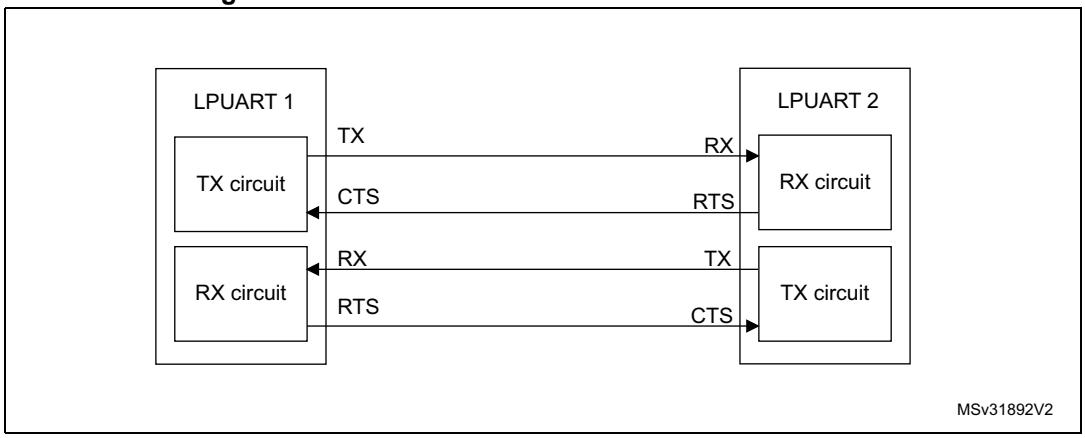
If any error occurs during a transaction In multibuffer communication mode, the error flag is asserted after the current byte. An interrupt is generated if the interrupt enable flag is set. For framing error, overrun error and noise flag which are asserted with RXNE (RXFNE in case FIFO mode is enabled) in single byte reception, there is a separate error flag interrupt

enable bit (EIE bit in the LPUART_CR3 register), which, if set, enables an interrupt after the current byte if any of these errors occur.

54.4.13 RS232 Hardware flow control and RS485 Driver Enable

It is possible to control the serial data flow between 2 devices by using the CTS input and the RTS output. The *Figure 622* shows how to connect 2 devices in this mode:

Figure 636. Hardware flow control between 2 LPUARTs

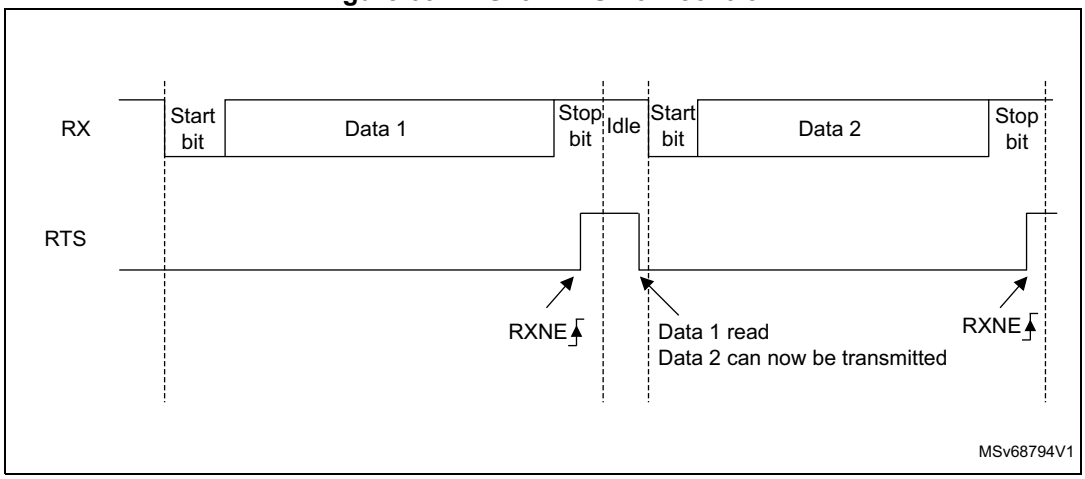


RS232 RTS and CTS flow control can be enabled independently by writing the RTSE and CTSE bits respectively to 1 (in the LPUART_CR3 register).

RS232 RTS flow control

If the RTS flow control is enabled (RTSE = 1), then RTS is deasserted (tied low) as long as the LPUART receiver is ready to receive a new data. When the receive register is full, RTS is asserted, indicating that the transmission is expected to stop at the end of the current frame. *Figure 637* shows an example of communication with RTS flow control enabled.

Figure 637. RS232 RTS flow control



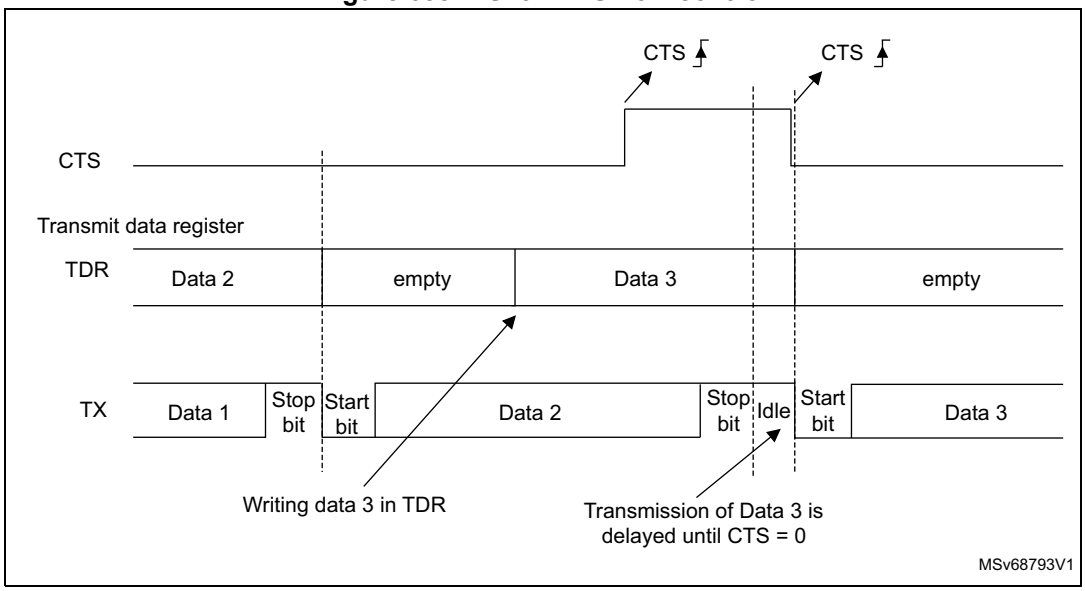
Note: When FIFO mode is enabled, RTS is asserted only when RXFIFO is full.

RS232 CTS flow control

If the CTS flow control is enabled (CTSE = 1), then the transmitter checks the CTS input before transmitting the next frame. If CTS is deasserted (tied low), then the next data is transmitted (assuming that data is to be transmitted, in other words, if TXE/TXFE = 0), else the transmission does not occur. When CTS is asserted during a transmission, the current transmission is completed before the transmitter stops.

When CTSE = 1, the CTSIF status bit is automatically set by hardware as soon as the CTS input toggles. It indicates when the receiver becomes ready or not ready for communication. An interrupt is generated if the CTSIE bit in the LPUART_CR3 register is set. *Figure 638* shows an example of communication with CTS flow control enabled.

Figure 638. RS232 CTS flow control



Note: For correct behavior, CTS must be deasserted at least 3 LPUART clock source periods before the end of the current character. In addition it should be noted that the CTSCF flag may not be set for pulses shorter than 2 x PCLK periods.

RS485 driver enable

The driver enable feature is enabled by setting bit DEM in the LPUART_CR3 control register. This enables activating the external transceiver control, through the DE (Driver Enable) signal. The assertion time is the time between the activation of the DE signal and the beginning of the start bit. It is programmed using the DEAT [4:0] bitfields in the LPUART_CR1 control register. The deassertion time is the time between the end of the last stop bit, in a transmitted message, and the de-activation of the DE signal. It is programmed using the DEDT [4:0] bitfields in the LPUART_CR1 control register. The polarity of the DE signal can be configured using the DEP bit in the LPUART_CR3 control register.

The LPUART DEAT and DEDT are expressed in LPUART clock source (f_{CK}) cycles:

- The Driver enable assertion time equals
  - (1 + (DEAT x P)) x f_{CK}, if P # 0
  - (1 + DEAT) x f_{CK} , if P = 0
- The Driver enable deassertion time equals
  - (1 + (DEDT x P)) x f_{CK}, if P # 0
  - (1 + DEDT) x f_{CK}, if P = 0

where P = BRR[20:11]

54.4.14 LPUART low-power management

The LPUART has advanced low-power mode functions that enable it to transfer properly data even when the lpuart_pclk clock is disabled.
The LPUART is able to wake up the MCU from low-power mode when the UESM bit is set.
When the lpuart_pclk is gated, the LPUART provides a wakeup interrupt (lpuart_wkup) if a specific action requiring the activation of the lpuart_pclk clock is needed:

- If FIFO mode is disabled

  luart_pclk clock has to be activated to empty the LPUART data register.

  In this case, the lpuart_wkup interrupt source is the RXNE set to ‘1’. The RXNEIE bit must be set before entering low-power mode.

- If FIFO mode is enabled

  luart_pclk clock has to be activated
  - to fill the TXFIFO
  - or to empty the RXFIFO

  In this case, the lpuart_wkup interrupt source can be:
  - RXFIFO not empty. In this case, the RXFNEIE bit must be set before entering low-power mode.
  - RXFIFO full. In this case, the RXFFIE bit must be set before entering low-power mode, the number of received data corresponds to the RXFIFO size, and the RXFF flag is not set .
  - TXFIFO empty. In this case, the TXFEIE bit must be set before entering low-power mode.

  This enables sending/receiving the data in the TXFIFO/RXFIFO during low-power mode.

  To avoid overrun/underrun errors and transmit/receive data in low-power mode, the lpuart_wkup interrupt source can be one of the following events:
  - TXFIFO threshold reached. In this case, the TXFTIE bit must be set before entering low-power mode.
  - RXFIFO threshold reached. In this case, the RXFTIE bit must be set before entering low-power mode.

  For example, the application can set the threshold to the maximum RXFIFO size if the wakeup time is less than the time to receive a single byte across the line.

  Using the RXFIFO full, TXFIFO empty, RXFIFO not empty and RXFIFO/TXFIFO threshold interrupts to wakeup the MCU from low-power mode enables doing as many LPUART transfers as possible during low-power mode with the benefit of optimizing consumption.

Alternatively, a specific lpuart_wkup interrupt may be selected through the WUS bitfields.

When the wakeup event is detected, the WUF flag is set by hardware and lpuart_wkup interrupt is generated if the WUFIE bit is set.

Note: Before entering low-power mode, make sure that no LPUART transfer is ongoing. Checking the BUSY flag cannot ensure that low-power mode is never entered when data reception is ongoing.

The WUF flag is set when a wakeup event is detected, independently of whether the MCU is in low-power or in an active mode.

When entering low-power mode just after having initialized and enabled the receiver, the REACK bit must be checked to ensure the LPUART is actually enabled.

When DMA is used for reception, it must be disabled before entering low-power mode and re-enabled upon exit from low-power mode.

When FIFO is enabled, the wakeup from low-power mode on address match is only possible when Mute mode is enabled.

Using Mute mode with low-power mode

If the LPUART is put into Mute mode before entering low-power mode:

- Wakeup from Mute mode on idle detection must not be used, because idle detection cannot work in low-power mode.
- If the wakeup from Mute mode on address match is used, then the low-power mode wakeup source from must also be the address match. If the RXNE flag was set when entering the low-power mode, the interface remains in Mute mode upon address match and wake up from low-power mode.

Note: When FIFO management is enabled, Mute mode is used with wakeup from low-power mode without any constraints (i.e.the two points mentioned above about mute and low-power mode are valid only when FIFO management is disabled).

Wakeup from low-power mode when LPUART kernel clock lpuart_ker_ck is OFF in low-power mode

If during low-power mode, the lpuart_ker_ck clock is switched OFF, when a falling edge on the LPUART receive line is detected, the LPUART interface requests the lpuart_ker_ck clock to be switched ON thanks to the lpuart_ker_ck_req signal. The lpuart_ker_ck is then used for the frame reception.

If the wakeup event is verified, the MCU wakes up from low-power mode and data reception goes on normally.

If the wakeup event is not verified, the lpuart_ker_ck is switched OFF again, the MCU is not waken up and stays in low-power mode and the kernel clock request is released.

The example below shows the case of wakeup event programmed to “address match detection” and FIFO management disabled.

Figure 639 shows the behavior when the wakeup event is verified.

Figure 639. Wakeup event verified (wakeup event = address match, FIFO disabled)

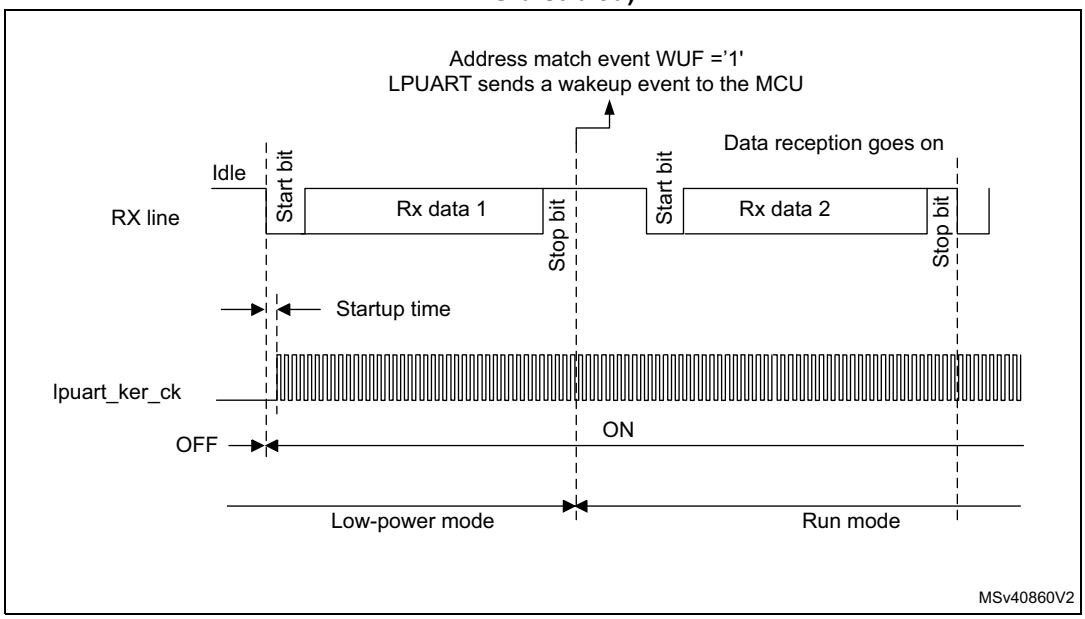
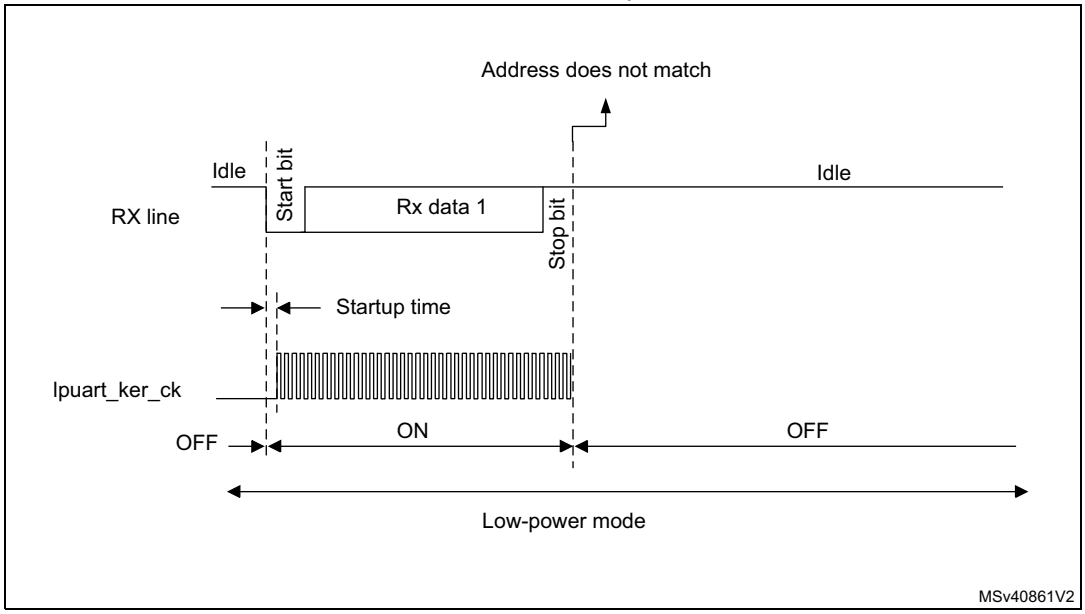


Figure 640 shows the behavior when the wakeup event is not verified.

Figure 640. Wakeup event not verified (wakeup event = address match, FIFO disabled)



Note: The above figures are valid when address match or any received frame is used as wakeup event. In the case the wakeup event is the start bit detection, the LPUART sends the wakeup event to the MCU at the end of the start bit.

Determining the maximum LPUART baud rate that enables to correctly wake up the MCU from low-power mode

The maximum baud rate that enables to correctly wake up the MCU from low-power mode depends on the wakeup time parameter (refer to the device datasheet) and on the LPUART receiver tolerance (see *Section 54.4.8: Tolerance of the LPUART receiver to clock deviation*).

Let us take the example of OVER8 = 0, M bits = '01', ONEBIT = 0 and BRR [3:0] = 0000.

In these conditions, according to *Table 429: Tolerance of the LPUART receiver*, the LPUART receiver tolerance equals 3.41%.

DTRA + DQUANT + DREC + DTCL + DWU < LPUART receiver tolerance

$D_{WUmax} = t_{WULPUART} / (11 \times T_{bit\ Min})$

$T_{bit\ Min} = t_{WULPUART} / (11 \times D_{WUmax})$

where $t_{WULPUART}$ is the wakeup time from low-power mode.

If we consider the ideal case where DTRA, DQUANT, DREC and DTCL parameters are at 0%, the maximum value of DWU is 3.41%. In reality, we need to consider at least the lpuart_ker_ck inaccuracy.

For example, if HSI is used as lpuart_ker_ck, and the HSI inaccuracy is of 1%, then we obtain:

$t_{WULPUART}$ = 3 µs (values provided only as examples; for correct values, refer to the device datasheet).

D_{WUmax} = 3.41% - 1% = 2.41%

$T_{bit\ min}$ = 3 µs/ (11 x 2.41%) = 11.32 µs.

As a result, the maximum baud rate that enables to wakeup correctly from low-power mode is: 1/11.32 µs = 88.36 kbaud.

54.5 LPUART in low-power modes

Table 431. Effect of low-power modes on the LPUART

Mode	Description
Sleep	No effect. LPUART interrupts cause the device to exit Sleep mode.
Stop(1)	The content of the LPUART registers is kept. The LPUART is able to wake up the microcontroller from Stop mode when the LPUART is clocked by an oscillator available in Stop mode.
Standby	The LPUART peripheral is powered down and must be reinitialized after exiting Standby mode.

1. Refer to *Section 54.3: LPUART implementation* to know if the wakeup from Stop mode is supported for a given peripheral instance. If an instance is not functional in a given Stop mode, it must be disabled before entering this Stop mode.

54.6 LPUART interrupts

Refer to *Table 432* for a detailed description of all LPUART interrupt requests.

Table 432. LPUART interrupt requests

Interrupt vector	Interrupt event	Event flag	Enable Control bit	Interrupt clear method	Exit from Sleep mode	Exit from Stop(1) modes	Exit from Standby mode
LPUART	Transmit data register empty	TXE	TXEIE	Write TDR	Yes	No	No
	Transmit FIFO Not Full	TXFNF	TXFNFIE	TXFIFO full		No	
	Transmit FIFO Empty	TXFE	TXFEIE	Write TDR or write 1 in TXFRQ		Yes	
	Transmit FIFO threshold reached	TXFT	TXFTIE	Write TDR		Yes	
	CTS interrupt	CTSIF	CTSIE	Write 1 in CTSCF		No	
	Transmission Complete	TC	TCIE	Write TDR or write 1 in TCCF		No	
	Receive data register not empty (data ready to be read)	RXNE	RXNEIE	Read RDR or write 1 in RXFRQ	Yes	Yes	
	Receive FIFO Not Empty	RXFNE	RXFNEIE	Read RDR until RXFIFO empty or write 1 in RXFRQ		Yes	
	Receive FIFO Full	RXFF(2)	RXFFIE	Read RDR		Yes	
	Receive FIFO threshold reached	RXFT	RXFTIE	Read RDR		Yes	
	Overrun error detected	ORE	RX-NEIE/RX FNEIE	Write 1 in ORECF		No	
	Idle line detected	IDLE	IDLEIE	Write 1 in IDLECF		No	
	Parity error	PE	PEIE	Write 1 in PECF		No	
	Noise error in multibuffer communication.	NE	EIE	Write 1 in NFCF		No	
	Overrun error in multibuffer communication.	ORE(3)		Write 1 in ORECF		No	
	Framing Error in multibuffer communication.	FE		Write 1 in FECF		No	
	Character match	CMF	CMIE	Write 1 in CMCF		No	
	Wakeup from low-power mode	WUF	WUFIE	Write 1 in WUC		Yes	

1. The LPUART can wake up the device from Stop mode only if the peripheral instance supports the Wakeup from Stop mode feature. Refer to *Section 54.3: LPUART implementation* for the list of supported Stop modes.
2. RXFF flag is asserted if the LPUART receives n+1 data (n being the RXFIFO size): n data in the RXFIFO and 1 data in LPUART_RDR. In Stop mode, LPUART_RDR is not clocked. As a result, this register is not written and once n data are received and written in the RXFIFO, the RXFF interrupt is asserted (RXFF flag is not set).
3. When OVRDIS = 0.

54.7 LPUART registers

Refer to *Section 1.2 on page 104* for a list of abbreviations used in register descriptions.

The peripheral registers have to be accessed by words (32 bits).

54.7.1 LPUART control register 1 [alternate] (LPUART_CR1)

Address offset: 0x00

Reset value: 0x0000 0000

The same register can be used in FIFO mode enabled (this section) and FIFO mode disabled (next section).

FIFO mode enabled

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXFFIE	TXFEIE	FIFOEN	M1	Res.	Res.	DEAT[4:0]					DEDT[4:0]				
rw	rw	rw	rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXFNFIE	TCIE	RXFNEIE	IDLEIE	TE	RE	UESM	UE
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **RXFFIE:**RXFIFO Full interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: An LPUART interrupt is generated when RXFF = 1 in the LPUART_ISR register

Bit 30 **TXFEIE:**TXFIFO empty interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: An LPUART interrupt is generated when TXFE = 1 in the LPUART_ISR register

Bit 29 **FIFOEN:**FIFO mode enable
This bit is set and cleared by software.
0: FIFO mode is disabled.
1: FIFO mode is enabled.

Bit 28 **M1**: Word length

This bit must be used in conjunction with bit 12 (M0) to determine the word length. It is set or cleared by software.

M[1:0] = ‘00’: 1 Start bit, 8 Data bits, n Stop bit

M[1:0] = ‘01’: 1 Start bit, 9 Data bits, n Stop bit

M[1:0] = ‘10’: 1 Start bit, 7 Data bits, n Stop bit

This bit can only be written when the LPUART is disabled (UE = 0).

Note: In 7-bit data length mode, the Smartcard mode, LIN master mode and Auto baud rate (0x7F and 0x55 frames detection) are not supported.

Bits 27:26 Reserved, must be kept at reset value.

Bits 25:21 **DEAT[4:0]**: Driver Enable assertion time

This 5-bit value defines the time between the activation of the DE (Driver Enable) signal and the beginning of the start bit. It is expressed in lpuart_ker_ck clock cycles. For more details, refer *Section 53.5.20: RS232 Hardware flow control and RS485 Driver Enable*.

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bits 20:16 **DEDT[4:0]**: Driver Enable deassertion time

This 5-bit value defines the time between the end of the last stop bit, in a transmitted message, and the de-activation of the DE (Driver Enable) signal.It is expressed in lpuart_ker_ck clock cycles. For more details, refer *Section 54.4.13: RS232 Hardware flow control and RS485 Driver Enable*.

If the LPUART_TDR register is written during the DEDT time, the new data is transmitted only when the DEDT and DEAT times have both elapsed.

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 15 Reserved, must be kept at reset value.

Bit 14 **CMIE**: Character match interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: A LPUART interrupt is generated when the CMF bit is set in the LPUART_ISR register.

Bit 13 **MME**: Mute mode enable

This bit activates the Mute mode function of the LPUART. When set, the LPUART can switch between the active and Mute modes, as defined by the WAKE bit. It is set and cleared by software.

0: Receiver in active mode permanently

1: Receiver can switch between Mute mode and active mode.

Bit 12 **M0**: Word length

This bit is used in conjunction with bit 28 (M1) to determine the word length. It is set or cleared by software (refer to bit 28 (M1) description).

This bit can only be written when the LPUART is disabled (UE = 0).

Bit 11 **WAKE**: Receiver wakeup method

This bit determines the LPUART wakeup method from Mute mode. It is set or cleared by software.

0: Idle line

1: Address mark

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 10 **PCE**: Parity control enable

This bit selects the hardware parity control (generation and detection). When the parity control is enabled, the computed parity is inserted at the MSB position (9th bit if M = 1; 8th bit if M = 0) and parity is checked on the received data. This bit is set and cleared by software. Once it is set, PCE is active after the current byte (in reception and in transmission).

0: Parity control disabled

1: Parity control enabled

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 9 **PS**: Parity selection

This bit selects the odd or even parity when the parity generation/detection is enabled (PCE bit set). It is set and cleared by software. The parity is selected after the current byte.

0: Even parity

1: Odd parity

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 8 **PEIE**: PE interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: An LPUART interrupt is generated whenever PE = 1 in the LPUART_ISR register

Bit 7 **TXFNFIE**: TXFIFO not full interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: A LPUART interrupt is generated whenever TXE/TXFNF =1 in the LPUART_ISR register

Bit 6 **TCIE**: Transmission complete interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: An LPUART interrupt is generated whenever TC = 1 in the LPUART_ISR register

Bit 5 **RXFNEIE**: RXFIFO not empty interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: A LPUART interrupt is generated whenever ORE = 1 or RXNE/RXFNE = 1 in the LPUART_ISR register

Bit 4 **IDLEIE**: IDLE interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: An LPUART interrupt is generated whenever IDLE = 1 in the LPUART_ISR register

Bit 3 **TE**: Transmitter enable

This bit enables the transmitter. It is set and cleared by software.

0: Transmitter is disabled

1: Transmitter is enabled

Note: During transmission, a low pulse on the TE bit (“0” followed by “1”) sends a preamble (idle line) after the current word. In order to generate an idle character, the TE must not be immediately written to 1. In order to ensure the required duration, the software can poll the TEACK bit in the LPUART_ISR register.

When TE is set there is a 1 bit-time delay before the transmission starts.

Bit 2 **RE**: Receiver enable

This bit enables the receiver. It is set and cleared by software.

0: Receiver is disabled

1: Receiver is enabled and begins searching for a start bit

Bit 1 **UESM**: LPUART enable in Stop mode

When this bit is cleared, the LPUART is not able to wake up the MCU from low-power mode.

When this bit is set, the LPUART is able to wake up the MCU from low-power mode, provided that the LPUART clock selection is HSI or LSE in the RCC.

This bit is set and cleared by software.

0: LPUART not able to wake up the MCU from low-power mode.

1: LPUART able to wake up the MCU from low-power mode. When this function is active, the clock source for the LPUART must be HSI or LSE (see RCC chapter)

Note: It is recommended to set the UESM bit just before entering low-power mode and clear it on exit from low-power mode.

Bit 0 **UE**: LPUART enable

When this bit is cleared, the LPUART prescalers and outputs are stopped immediately, and current operations are discarded. The configuration of the LPUART is kept, but all the status flags, in the LPUART_ISR are reset. This bit is set and cleared by software.

0: LPUART prescaler and outputs disabled, low-power mode

1: LPUART enabled

Note: To enter low-power mode without generating errors on the line, the TE bit must be reset before and the software must wait for the TC bit in the LPUART_ISR to be set before resetting the UE bit.

The DMA requests are also reset when UE = 0 so the DMA channel must be disabled before resetting the UE bit.

54.7.2 LPUART control register 1 [alternate] (LPUART_CR1)

Address offset: 0x00

Reset value: 0x0000 0000

The same register can be used in FIFO mode enabled (previous section) and FIFO mode disabled (this section).

FIFO mode disabled

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	FIFO EN	M1	Res.	Res.	DEAT[4:0]					DEDT[4:0]				
		rw	rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXEIE	TCIE	RXNEIE	IDLEIE	TE	RE	UESM	UE
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **FIFOEN:**FIFO mode enable

This bit is set and cleared by software.

0: FIFO mode is disabled.

1: FIFO mode is enabled.

Bit 28 **M1**: Word length

This bit must be used in conjunction with bit 12 (M0) to determine the word length. It is set or cleared by software.

M[1:0] = ‘00’: 1 Start bit, 8 Data bits, n Stop bit

M[1:0] = ‘01’: 1 Start bit, 9 Data bits, n Stop bit

M[1:0] = ‘10’: 1 Start bit, 7 Data bits, n Stop bit

This bit can only be written when the LPUART is disabled (UE = 0).

Note: In 7-bit data length mode, the Smartcard mode, LIN master mode and Auto baud rate (0x7F and 0x55 frames detection) are not supported.

Bits 27:26 Reserved, must be kept at reset value.

Bits 25:21 **DEAT[4:0]**: Driver Enable assertion time

This 5-bit value defines the time between the activation of the DE (Driver Enable) signal and the beginning of the start bit. It is expressed in lpuart_ker_ck clock cycles. For more details, refer *Section 53.5.20: RS232 Hardware flow control and RS485 Driver Enable*.

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bits 20:16 **DEDT[4:0]**: Driver Enable deassertion time

This 5-bit value defines the time between the end of the last stop bit, in a transmitted message, and the de-activation of the DE (Driver Enable) signal.It is expressed in lpuart_ker_ck clock cycles. For more details, refer *Section 54.4.13: RS232 Hardware flow control and RS485 Driver Enable*.

If the LPUART_TDR register is written during the DEDT time, the new data is transmitted only when the DEDT and DEAT times have both elapsed.

This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 15 Reserved, must be kept at reset value.

Bit 14 **CMIE**: Character match interrupt enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: A LPUART interrupt is generated when the CMF bit is set in the LPUART_ISR register.

Bit 13 **MME**: Mute mode enable

This bit activates the Mute mode function of the LPUART. When set, the LPUART can switch between the active and Mute modes, as defined by the WAKE bit. It is set and cleared by software.

0: Receiver in active mode permanently

1: Receiver can switch between Mute mode and active mode.

Bit 12 **M0**: Word length

This bit is used in conjunction with bit 28 (M1) to determine the word length. It is set or cleared by software (refer to bit 28 (M1) description).

This bit can only be written when the LPUART is disabled (UE = 0).

Bit 11 **WAKE**: Receiver wakeup method
This bit determines the LPUART wakeup method from Mute mode. It is set or cleared by software.
0: Idle line
1: Address mark
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 10 **PCE**: Parity control enable
This bit selects the hardware parity control (generation and detection). When the parity control is enabled, the computed parity is inserted at the MSB position (9th bit if M = 1; 8th bit if M = 0) and parity is checked on the received data. This bit is set and cleared by software. Once it is set, PCE is active after the current byte (in reception and in transmission).
0: Parity control disabled
1: Parity control enabled
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 9 **PS**: Parity selection
This bit selects the odd or even parity when the parity generation/detection is enabled (PCE bit set). It is set and cleared by software. The parity is selected after the current byte.
0: Even parity
1: Odd parity
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 8 **PEIE**: PE interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: An LPUART interrupt is generated whenever PE = 1 in the LPUART_ISR register

Bit 7 **TXEIE**: Transmit data register empty
This bit is set and cleared by software.
0: Interrupt is inhibited
1: A LPUART interrupt is generated whenever TXE/TXFNF =1 in the LPUART_ISR register

Bit 6 **TCIE**: Transmission complete interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: An LPUART interrupt is generated whenever TC = 1 in the LPUART_ISR register

Bit 5 **RXNEIE**: Receive data register not empty
This bit is set and cleared by software.
0: Interrupt is inhibited
1: A LPUART interrupt is generated whenever ORE = 1 or RXNE/RXFNE = 1 in the LPUART_ISR register

Bit 4 **IDLEIE**: IDLE interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: An LPUART interrupt is generated whenever IDLE = 1 in the LPUART_ISR register

Bit 3 **TE**: Transmitter enable

This bit enables the transmitter. It is set and cleared by software.

0: Transmitter is disabled

1: Transmitter is enabled

Note: During transmission, a low pulse on the TE bit (“0” followed by “1”) sends a preamble (idle line) after the current word. In order to generate an idle character, the TE must not be immediately written to 1. In order to ensure the required duration, the software can poll the TEACK bit in the LPUART_ISR register.

When TE is set there is a 1 bit-time delay before the transmission starts.

Bit 2 **RE**: Receiver enable

This bit enables the receiver. It is set and cleared by software.

0: Receiver is disabled

1: Receiver is enabled and begins searching for a start bit

Bit 1 **UESM**: LPUART enable in Stop mode

When this bit is cleared, the LPUART is not able to wake up the MCU from low-power mode.

When this bit is set, the LPUART is able to wake up the MCU from low-power mode, provided that the LPUART clock selection is HSI or LSE in the RCC.

This bit is set and cleared by software.

0: LPUART not able to wake up the MCU from low-power mode.

1: LPUART able to wake up the MCU from low-power mode. When this function is active, the clock source for the LPUART must be HSI or LSE (see RCC chapter)

Note: It is recommended to set the UESM bit just before entering low-power mode and clear it on exit from low-power mode.

Bit 0 **UE**: LPUART enable

When this bit is cleared, the LPUART prescalers and outputs are stopped immediately, and current operations are discarded. The configuration of the LPUART is kept, but all the status flags, in the LPUART_ISR are reset. This bit is set and cleared by software.

0: LPUART prescaler and outputs disabled, low-power mode

1: LPUART enabled

Note: To enter low-power mode without generating errors on the line, the TE bit must be reset before and the software must wait for the TC bit in the LPUART_ISR to be set before resetting the UE bit.

The DMA requests are also reset when UE = 0 so the DMA channel must be disabled before resetting the UE bit.

54.7.3 LPUART control register 2 (LPUART_CR2)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADD[7:0]								Res.	Res.	Res.	Res.	MSBFIRST	DATAINV	TXINV	RXINV
rw	rw	rw	rw	rw	rw	rw	rw					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SWAP	Res.	STOP[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDM7	Res.	Res.	Res.	Res.
rw		rw	rw								rw				

Bits 31:24 **ADD[7:0]**: Address of the LPUART node

These bits give the address of the LPUART node in Mute mode or a character code to be recognized in low-power or Run mode:

- In Mute mode: they are used in multiprocessor communication to wakeup from Mute mode with 4-bit/7-bit address mark detection. The MSB of the character sent by the transmitter should be equal to 1. In 4-bit address mark detection, only ADD[3:0] bits are used.
- In low-power mode: they are used for wake up from low-power mode on character match. When WUS[1:0] is programmed to 0b00 (WUF active on address match), the wakeup from low-power mode is performed when the received character corresponds to the character programmed through ADD[6:0] or ADD[3:0] bitfield (depending on ADDM7 bit), and WUF interrupt is enabled by setting WUFIE bit. The MSB of the character sent by transmitter should be equal to 1.
- In Run mode with Mute mode inactive (for example, end-of-block detection in ModBus protocol): the whole received character (8 bits) is compared to ADD[7:0] value and CMF flag is set on match. An interrupt is generated if the CMIE bit is set.

These bits can only be written when the reception is disabled (RE = 0) or when the USART is disabled (UE = 0).

Bits 23:20 Reserved, must be kept at reset value.

Bit 19 **MSBFIRST**: Most significant bit first

This bit is set and cleared by software.
0: data is transmitted/received with data bit 0 first, following the start bit.
1: data is transmitted/received with the MSB (bit 7/8) first, following the start bit.
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 18 **DATAINV:** Binary data inversion

This bit is set and cleared by software.
0: Logical data from the data register are send/received in positive/direct logic. (1 = H, 0 = L)
1: Logical data from the data register are send/received in negative/inverse logic. (1 = L, 0 = H). The parity bit is also inverted.
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 17 **TXINV:** TX pin active level inversion

This bit is set and cleared by software.
0: TX pin signal works using the standard logic levels (V_{DD} = 1/idle, Gnd = 0/mark)
1: TX pin signal values are inverted (V_{DD} = 0/mark, Gnd = 1/idle).
This enables the use of an external inverter on the TX line.
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 16 **RXINV:** RX pin active level inversion

This bit is set and cleared by software.
0: RX pin signal works using the standard logic levels (V_{DD} = 1/idle, Gnd = 0/mark)
1: RX pin signal values are inverted (V_{DD} = 0/mark, Gnd = 1/idle).
This enables the use of an external inverter on the RX line.
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 15 **SWAP:** Swap TX/RX pins

This bit is set and cleared by software.
0: TX/RX pins are used as defined in standard pinout
1: The TX and RX pins functions are swapped. This enables to work in the case of a cross-wired connection to another UART.
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bit 14 Reserved, must be kept at reset value.

Bits 13:12 **STOP[1:0]**: STOP bits
These bits are used for programming the stop bits.
00: 1 stop bit
01: Reserved.
10: 2 stop bits
11: Reserved
This bitfield can only be written when the LPUART is disabled (UE = 0).

Bits 11:5 Reserved, must be kept at reset value.

Bit 4 **ADDM7**:7-bit Address Detection/4-bit Address Detection
This bit is for selection between 4-bit address detection or 7-bit address detection.
0: 4-bit address detection
1: 7-bit address detection (in 8-bit data mode)
This bit can only be written when the LPUART is disabled (UE = 0)
Note: In 7-bit and 9-bit data modes, the address detection is done on 6-bit and 8-bit address (ADD[5:0] and ADD[7:0]) respectively.

Bits 3:0 Reserved, must be kept at reset value.

54.7.4 LPUART control register 3 (LPUART_CR3)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXFTCFG[2:0]			RXFTIE	RXFTCFG[2:0]			Res.	TXFTIE	WUFIE	WUS[1:0]		Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DEP	DEM	DDRE	OVRDIS	Res.	CTSIE	CTSE	RTSE	DMAT	DMAR	Res.	Res.	HDSEL	Res.	Res.	EIE
rw	rw	rw	rw		rw	rw	rw	rw	rw			rw			rw

Bits 31:29 **TXFTCFG[2:0]:** TXFIFO threshold configuration
000:TXFIFO reaches 1/8 of its depth.
001:TXFIFO reaches 1/4 of its depth.
110:TXFIFO reaches 1/2 of its depth.
011:TXFIFO reaches 3/4 of its depth.
100:TXFIFO reaches 7/8 of its depth.
101:TXFIFO becomes empty.
Remaining combinations: Reserved.

Bit 28 **RXFTIE**: RXFIFO threshold interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: An LPUART interrupt is generated when Receive FIFO reaches the threshold programmed in RXFTCFG.

Bits 27:25 **RXFTCFG[2:0]:** Receive FIFO threshold configuration
000:Receive FIFO reaches 1/8 of its depth.
001:Receive FIFO reaches 1/4 of its depth.
110:Receive FIFO reaches 1/2 of its depth.
011:Receive FIFO reaches 3/4 of its depth.
100:Receive FIFO reaches 7/8 of its depth.
101:Receive FIFO becomes full.
Remaining combinations: Reserved.

Bit 24 Reserved, must be kept at reset value.

Bit 23 **TXFTIE**: TXFIFO threshold interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: A LPUART interrupt is generated when TXFIFO reaches the threshold programmed in TXFTCFG.

Bit 22 **WUFIE**: Wakeup from low-power mode interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: An LPUART interrupt is generated whenever WUF = 1 in the LPUART_ISR register

Note: WUFIE must be set before entering in low-power mode.
The WUF interrupt is active only in low-power mode.
If the LPUART does not support the wakeup from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation.

Bits 21:20 **WUS[1:0]**: Wakeup from low-power mode interrupt flag selection
This bitfield specifies the event which activates the WUF (Wakeup from low-power mode flag).
00: WUF active on address match (as defined by ADD[7:0] and ADDM7)
01:Reserved.
10: WUF active on Start bit detection
11: WUF active on RXNE.
This bitfield can only be written when the LPUART is disabled (UE = 0).

Note: If the LPUART does not support the wakeup from Stop feature, this bit is reserved and must be kept at reset value. Refer to Section 53.4: USART implementation.

Bits 19:16 Reserved, must be kept at reset value.

Bit 15 **DEP**: Driver enable polarity selection
0: DE signal is active high.
1: DE signal is active low.
This bit can only be written when the LPUART is disabled (UE = 0).

Bit 14 **DEM**: Driver enable mode
This bit enables the user to activate the external transceiver control, through the DE signal.
0: DE function is disabled.
1: DE function is enabled. The DE signal is output on the RTS pin.
This bit can only be written when the LPUART is disabled (UE = 0).

Bit 13 **DDRE**: DMA Disable on Reception Error
0: DMA is not disabled in case of reception error. The corresponding error flag is set but RXNE is kept 0 preventing from overrun. As a consequence, the DMA request is not asserted, so the erroneous data is not transferred (no DMA request), but next correct received data is transferred.
1: DMA is disabled following a reception error. The corresponding error flag is set, as well as RXNE. The DMA request is masked until the error flag is cleared. This means that the software must first disable the DMA request (DMAR = 0) or clear RXNE before clearing the error flag.
This bit can only be written when the LPUART is disabled (UE = 0).
Note: The reception errors are: parity error, framing error or noise error.

Bit 12 **OVRDIS**: Overrun Disable
This bit is used to disable the receive overrun detection.
0: Overrun Error Flag, ORE is set when received data is not read before receiving new data.
1: Overrun functionality is disabled. If new data is received while the RXNE flag is still set the ORE flag is not set and the new received data overwrites the previous content of the LPUART_RDR register.
This bit can only be written when the LPUART is disabled (UE = 0).
Note: This control bit enables checking the communication flow w/o reading the data.

Bit 11 Reserved, must be kept at reset value.

Bit 10 **CTSIE**: CTS interrupt enable
0: Interrupt is inhibited
1: An interrupt is generated whenever CTSIF = 1 in the LPUART_ISR register

Bit 9 **CTSE**: CTS enable
0: CTS hardware flow control disabled
1: CTS mode enabled, data is only transmitted when the CTS input is deasserted (tied to 0). If the CTS input is asserted while data is being transmitted, then the transmission is completed before stopping. If data is written into the data register while CTS is asserted, the transmission is postponed until CTS is deasserted.
This bit can only be written when the LPUART is disabled (UE = 0)

Bit 8 **RTSE**: RTS enable
0: RTS hardware flow control disabled
1: RTS output enabled, data is only requested when there is space in the receive buffer. The transmission of data is expected to cease after the current character has been transmitted. The RTS output is deasserted (pulled to 0) when data can be received.
This bit can only be written when the LPUART is disabled (UE = 0).

Bit 7 **DMAT**: DMA enable transmitter
This bit is set/reset by software
1: DMA mode is enabled for transmission
0: DMA mode is disabled for transmission

Bit 6 **DMAR**: DMA enable receiver
This bit is set/reset by software
1: DMA mode is enabled for reception
0: DMA mode is disabled for reception

Bits 5:4 Reserved, must be kept at reset value.

Bit 3 **HDSEL**: Half-duplex selection
Selection of Single-wire Half-duplex mode
0: Half duplex mode is not selected
1: Half duplex mode is selected
This bit can only be written when the LPUART is disabled (UE = 0).

Bits 2:1 Reserved, must be kept at reset value.

Bit 0 **EIE**: Error interrupt enable
Error Interrupt Enable Bit is required to enable interrupt generation in case of a framing error, overrun error or noise flag (FE = 1 or ORE = 1 or NE = 1 in the LPUART_ISR register).
0: Interrupt is inhibited
1: An interrupt is generated when FE = 1 or ORE = 1 or NE = 1 in the LPUART_ISR register.

54.7.5 LPUART baud rate register (LPUART_BRR)

This register can only be written when the LPUART is disabled (UE = 0). It may be automatically updated by hardware in auto baud rate detection mode.

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BRR[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BRR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **BRR[19:0]**: LPUART baud rate

Note: It is forbidden to write values lower than 0x300 in the LPUART_BRR register.

Provided that LPUART_BRR must be ≧ 0x300 and LPUART_BRR is 20 bits, a care should be taken when generating high baud rates using high fck values. fck must be in the range [3 x baud rate..4096 x baud rate].

54.7.6 LPUART request register (LPUART_RQR)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXFRQ	RXFRQ	MMRQ	SBKRQ	Res.
											w	w	w	w	

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **TXFRQ**: Transmit data flush request

This bit is used when FIFO mode is enabled. TXFRQ bit is set to flush the whole FIFO. This sets the flag TXFE (TXFIFO empty, bit 23 in the LPUART_ISR register).

Note: In FIFO mode, the TXFNF flag is reset during the flush request until TxFIFO is empty in order to ensure that no data are written in the data register.

Bit 3 **RXFRQ**: Receive data flush request

Writing 1 to this bit clears the RXNE flag.

This enables discarding the received data without reading it, and avoid an overrun condition.

Bit 2 **MMRQ**: Mute mode request

Writing 1 to this bit puts the LPUART in Mute mode and resets the RWU flag.

Bit 1 **SBKRQ**: Send break request

Writing 1 to this bit sets the SBKF flag and request to send a BREAK on the line, as soon as the transmit machine is available.

Note: If the application needs to send the break character following all previously inserted data, including the ones not yet transmitted, the software should wait for the TXE flag assertion before setting the SBKRQ bit.

Bit 0 Reserved, must be kept at reset value.

54.7.7 LPUART interrupt and status register [alternate] (LPUART_ISR)

Address offset: 0x1C

Reset value: 0x0080 00C0

The same register can be used in FIFO mode enabled (this section) and FIFO mode disabled (next section).

FIFO mode enabled

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TXFT	RXFT	Res.	RXFF	TXFE	REACK	TEACK	WUF	RWU	SBKF	CMF	BUSY
				r	r		r	r	r	r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	CTS	CTSIF	Res.	TXFNF	TC	RXFNE	IDLE	ORE	NE	FE	PE
					r	r		r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **TXFT**: TXFIFO threshold flag

This bit is set by hardware when the TXFIFO reaches the threshold programmed in TXFTCFG in LPUART_CR3 register i.e. the TXFIFO contains TXFTCFG empty locations. An interrupt is generated if the TXFTIE bit = 1 (bit 31) in the LPUART_CR3 register.

0: TXFIFO does not reach the programmed threshold.

1: TXFIFO reached the programmed threshold.

Bit 26 **RXFT**: RXFIFO threshold flag

This bit is set by hardware when the RXFIFO reaches the threshold programmed in RXFTCFG in LPUART_CR3 register i.e. the Receive FIFO contains RXFTCFG data. An interrupt is generated if the RXFTIE bit = 1 (bit 27) in the LPUART_CR3 register.

0: Receive FIFO does not reach the programmed threshold.

1: Receive FIFO reached the programmed threshold.

Bit 25 Reserved, must be kept at reset value.

Bit 24 **RXFF**: RXFIFO full

This bit is set by hardware when the number of received data corresponds to RXFIFO size + 1 (RXFIFO full + 1 data in the LPUART_RDR register.

An interrupt is generated if the RXFFIE bit = 1 in the LPUART_CR1 register.

0: RXFIFO is not full

1: RXFIFO is full

Bit 23 **TXFE**: TXFIFO empty

This bit is set by hardware when TXFIFO is empty. When the TXFIFO contains at least one data, this flag is cleared. The TXFE flag can also be set by writing 1 to the bit TXFRQ (bit 4) in the LPUART_RQR register.

An interrupt is generated if the TXFEIE bit = 1 (bit 30) in the LPUART_CR1 register.

0: TXFIFO is not empty

1: TXFIFO is empty

Bit 22 **REACK**: Receive enable acknowledge flag

This bit is set/reset by hardware, when the Receive Enable value is taken into account by the LPUART.

It can be used to verify that the LPUART is ready for reception before entering low-power mode.

Note: If the LPUART does not support the wakeup from Stop feature, this bit is reserved and kept at reset value.

Bit 21 **TEACK**: Transmit enable acknowledge flag

This bit is set/reset by hardware, when the Transmit Enable value is taken into account by the LPUART.

It can be used when an idle frame request is generated by writing TE = 0, followed by TE = 1 in the LPUART_CR1 register, in order to respect the TE = 0 minimum period.

Bit 20 **WUF**: Wakeup from low-power mode flag

This bit is set by hardware, when a wakeup event is detected. The event is defined by the WUS bitfield. It is cleared by software, writing a 1 to the WUCF in the LPUART_ICR register.

An interrupt is generated if WUFIE = 1 in the LPUART_CR3 register.

Note: When UESM is cleared, WUF flag is also cleared.

The WUF interrupt is active only in low-power mode.

If the LPUART does not support the wakeup from Stop feature, this bit is reserved and kept at reset value

Bit 19 **RWU**: *Receiver wakeup from Mute mode*

This bit indicates if the LPUART is in Mute mode. It is cleared/set by hardware when a wakeup/mute sequence is recognized. The Mute mode control sequence (address or IDLE) is selected by the WAKE bit in the LPUART_CR1 register.

When wakeup on IDLE mode is selected, this bit can only be set by software, writing 1 to the MMRQ bit in the LPUART_RQR register.

0: Receiver in Active mode

1: Receiver in Mute mode

Note: If the LPUART does not support the wakeup from Stop feature, this bit is reserved and kept at reset value.

Bit 18 **SBKF**: Send break flag

This bit indicates that a send break character was requested. It is set by software, by writing 1 to the SBKRQ bit in the LPUART_CR3 register. It is automatically reset by hardware during the stop bit of break transmission.

0: Break character transmitted

1: Break character requested by setting SBKRQ bit in LPUART_RQR register

Bit 17 **CMF**: Character match flag

This bit is set by hardware, when a the character defined by ADD[7:0] is received. It is cleared by software, writing 1 to the CMCF in the LPUART_ICR register.

An interrupt is generated if CMIE = 1in the LPUART_CR1 register.

0: No Character match detected

1: Character Match detected

Bit 16 **BUSY**: Busy flag

This bit is set and reset by hardware. It is active when a communication is ongoing on the RX line (successful start bit detected). It is reset at the end of the reception (successful or not).

0: LPUART is idle (no reception)

1: Reception on going

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **CTS**: CTS flag

This bit is set/reset by hardware. It is an inverted copy of the status of the CTS input pin.

0: CTS line set

1: CTS line reset

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 9 **CTSIF**: CTS interrupt flag

This bit is set by hardware when the CTS input toggles, if the CTSE bit is set. It is cleared by software, by writing 1 to the CTSCF bit in the LPUART_ICR register.

An interrupt is generated if CTSIE = 1 in the LPUART_CR3 register.

0: No change occurred on the CTS status line

1: A change occurred on the CTS status line

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 8 Reserved, must be kept at reset value.

Bit 7 **TXFNF:** TXFIFO not full

TXFNF is set by hardware when TXFIFO is not full, and so data can be written in the LPUART_TDR. Every write in the LPUART_TDR places the data in the TXFIFO. This flag remains set until the TXFIFO is full. When the TXFIFO is full, this flag is cleared indicating that data can not be written into the LPUART_TDR.

The TXFNF is kept reset during the flush request until TXFIFO is empty. After sending the flush request (by setting TXFRQ bit), the flag TXFNF should be checked prior to writing in TXFIFO (TXFNF and TXFE are set at the same time).

An interrupt is generated if the TXFNFIE bit = 1 in the LPUART_CR1 register.

0: Data register is full/Transmit FIFO is full.

1: Data register/Transmit FIFO is not full.

Note: This bit is used during single buffer transmission.

Bit 6 **TC**: Transmission complete

This bit is set by hardware if the transmission of a frame containing data is complete and if TXFF is set. An interrupt is generated if TCIE = 1 in the LPUART_CR1 register. It is cleared by software, writing 1 to the TCCF in the LPUART_ICR register or by a write to the LPUART_TDR register.

An interrupt is generated if TCIE = 1 in the LPUART_CR1 register.

0: Transmission is not complete

1: Transmission is complete

Note: If TE bit is reset and no transmission is on going, the TC bit is set immediately.

Bit 5 **RXFNE**: RXFIFO not empty

RXFNE bit is set by hardware when the RXFIFO is not empty, and so data can be read from the LPUART_RDR register. Every read of the LPUART_RDR frees a location in the RXFIFO. It is cleared when the RXFIFO is empty.

The RXFNE flag can also be cleared by writing 1 to the RXFRQ in the LPUART_RQR register.

An interrupt is generated if RXFNEIE = 1 in the LPUART_CR1 register.

0: Data is not received

1: Received data is ready to be read.

Bit 4 **IDLE**: Idle line detected

This bit is set by hardware when an Idle line is detected. An interrupt is generated if IDLEIE = 1 in the LPUART_CR1 register. It is cleared by software, writing 1 to the IDLECF in the LPUART_ICR register.

0: No Idle line is detected

1: Idle line is detected

Note: The IDLE bit is not set again until the RXFNE bit has been set (i.e. a new idle line occurs).

If Mute mode is enabled (MME = 1), IDLE is set if the LPUART is not mute (RWU = 0), whatever the Mute mode selected by the WAKE bit. If RWU = 1, IDLE is not set.

Bit 3 **ORE**: Overrun error

This bit is set by hardware when the data currently being received in the shift register is ready to be transferred into the LPUART_RDR register while RXFF = 1. It is cleared by a software, writing 1 to the ORECF, in the LPUART_ICR register.

An interrupt is generated if RXFNEIE = 1 or EIE = 1 in the LPUART_CR1 register.

0: No overrun error

1: Overrun error is detected

Note: When this bit is set, the LPUART_RDR register content is not lost but the shift register is overwritten. An interrupt is generated if the ORE flag is set during multi buffer communication if the EIE bit is set.

This bit is permanently forced to 0 (no overrun detection) when the bit OVRDIS is set in the LPUART_CR3 register.

Bit 2 **NE:** Start bit noise detection flag

This bit is set by hardware when noise is detected on the start bit of a received frame. It is cleared by software, writing 1 to the NECF bit in the LPUART_ICR register.

0: No noise is detected

1: Noise is detected

Note: This bit does not generate an interrupt as it appears at the same time as the RXFNE bit which itself generates an interrupt. An interrupt is generated when the NE flag is set during multi buffer communication if the EIE bit is set.

This error is associated with the character in the LPUART_RDR.

Bit 1 **FE**: Framing error

This bit is set by hardware when a de-synchronization, excessive noise or a break character is detected. It is cleared by software, writing 1 to the FECF bit in the LPUART_ICR register.

When transmitting data in Smartcard mode, this bit is set when the maximum number of transmit attempts is reached without success (the card NACKs the data frame).

An interrupt is generated if EIE = 1 in the LPUART_CR1 register.

0: No Framing error is detected

1: Framing error or break character is detected

Note: This error is associated with the character in the LPUART_RDR.

Bit 0 **PE**: Parity error

This bit is set by hardware when a parity error occurs in receiver mode. It is cleared by software, writing 1 to the PECF in the LPUART_ICR register.

An interrupt is generated if PEIE = 1 in the LPUART_CR1 register.

0: No parity error

1: Parity error

Note: This error is associated with the character in the LPUART_RDR.

54.7.8 LPUART interrupt and status register [alternate] (LPUART_ISR)

Address offset: 0x1C

Reset value: 0x0000 00C0

The same register can be used in FIFO mode enabled (previous section) and FIFO mode disabled (this section).

FIFO mode disabled

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REACK	TEACK	WUF	RWU	SBKF	CMF	BUSY
									r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	CTS	CTSIF	Res.	TXE	TC	RXNE	IDLE	ORE	NE	FE	PE
					r	r		r	r	r	r	r	r	r	r

Bits 31:23 Reserved, must be kept at reset value.

Bit 22 **REACK**: Receive enable acknowledge flag

This bit is set/reset by hardware when the Receive Enable value is taken into account by the LPUART.

It can be used to verify that the LPUART is ready for reception before entering low-power mode.

Note: If the LPUART does not support the wakeup from Stop feature, this bit is reserved and kept at reset value.

Bit 21 **TEACK**: Transmit enable acknowledge flag

This bit is set/reset by hardware, when the Transmit Enable value is taken into account by the LPUART.

It can be used when an idle frame request is generated by writing TE = 0, followed by TE = 1 in the LPUART_CR1 register, in order to respect the TE = 0 minimum period.

Bit 20 **WUF**: Wakeup from low-power mode flag

This bit is set by hardware, when a wakeup event is detected. The event is defined by the WUS bitfield. It is cleared by software, writing a 1 to the WUCF in the LPUART_ICR register.

An interrupt is generated if WUFIE = 1 in the LPUART_CR3 register.

Note: When UESM is cleared, WUF flag is also cleared.

The WUF interrupt is active only in low-power mode.

If the LPUART does not support the wakeup from Stop feature, this bit is reserved and kept at reset value

Bit 19 **RWU**: *Receiver wakeup from Mute mode*

This bit indicates if the LPUART is in Mute mode. It is cleared/set by hardware when a wakeup/mute sequence is recognized. The Mute mode control sequence (address or IDLE) is selected by the WAKE bit in the LPUART_CR1 register.

When wakeup on IDLE mode is selected, this bit can only be set by software, writing 1 to the MMRQ bit in the LPUART_RQR register.

0: Receiver in active mode

1: Receiver in Mute mode

Note: If the LPUART does not support the wakeup from Stop feature, this bit is reserved and kept at reset value.

Bit 18 **SBKF**: Send break flag

This bit indicates that a send break character was requested. It is set by software, by writing 1 to the SBKRQ bit in the LPUART_CR3 register. It is automatically reset by hardware during the stop bit of break transmission.

0: Break character transmitted

1: Break character requested by setting SBKRQ bit in LPUART_RQR register

Bit 17 **CMF**: Character match flag

This bit is set by hardware, when a the character defined by ADD[7:0] is received. It is cleared by software, writing 1 to the CMCF in the LPUART_ICR register.

An interrupt is generated if CMIE = 1in the LPUART_CR1 register.

0: No Character match detected

1: Character Match detected

Bit 16 **BUSY**: Busy flag

This bit is set and reset by hardware. It is active when a communication is ongoing on the RX line (successful start bit detected). It is reset at the end of the reception (successful or not).

0: LPUART is idle (no reception)

1: Reception on going

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **CTS**: CTS flag

This bit is set/reset by hardware. It is an inverted copy of the status of the CTS input pin.

0: CTS line set

1: CTS line reset

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 9 **CTSIF**: CTS interrupt flag

This bit is set by hardware when the CTS input toggles, if the CTSE bit is set. It is cleared by software, by writing 1 to the CTSCF bit in the LPUART_ICR register.

An interrupt is generated if CTSIE = 1 in the LPUART_CR3 register.

0: No change occurred on the CTS status line

1: A change occurred on the CTS status line

Note: If the hardware flow control feature is not supported, this bit is reserved and kept at reset value.

Bit 8 Reserved, must be kept at reset value.

Bit 7 **TXE:** Transmit data register empty/TXFIFO not full

TXE is set by hardware when the content of the LPUART_TDR register has been transferred into the shift register. It is cleared by a write to the LPUART_TDR register.

An interrupt is generated if the TXEIE bit =1 in the LPUART_CR1 register.

0: Data register full

1: Data register not full

Note: This bit is used during single buffer transmission.

Bit 6 **TC**: Transmission complete

This bit is set by hardware if the transmission of a frame containing data is complete and if TXE is set. An interrupt is generated if TCIE = 1 in the LPUART_CR1 register. It is cleared by software, writing 1 to the TCCF in the LPUART_ICR register or by a write to the LPUART_TDR register.

An interrupt is generated if TCIE = 1 in the LPUART_CR1 register.

0: Transmission is not complete

1: Transmission is complete

Note: If TE bit is reset and no transmission is on going, the TC bit is immediately set.

Bit 5 **RXNE**: Read data register not empty

RXNE bit is set by hardware when the content of the LPUART_RDR shift register has been transferred to the LPUART_RDR register. It is cleared by reading from the LPUART_RDR register. The RXNE flag can also be cleared by writing 1 to the RXFRQ in the LPUART_RQR register.

An interrupt is generated if RXNEIE = 1 in the LPUART_CR1 register.

0: Data is not received

1: Received data is ready to be read.

Bit 4 **IDLE**: Idle line detected

This bit is set by hardware when an Idle Line is detected. An interrupt is generated if IDLEIE = 1 in the LPUART_CR1 register. It is cleared by software, writing 1 to the IDLECF in the LPUART_ICR register.

0: No Idle line is detected

1: Idle line is detected

Note: The IDLE bit is not set again until the RXNE bit has been set (i.e. a new idle line occurs).

If Mute mode is enabled (MME = 1), IDLE is set if the LPUART is not mute (RWU = 0), whatever the Mute mode selected by the WAKE bit. If RWU = 1, IDLE is not set.

Bit 3 **ORE**: Overrun error

This bit is set by hardware when the data currently being received in the shift register is ready to be transferred into the LPUART_RDR register while RXNE = 1. It is cleared by a software, writing 1 to the ORECF, in the LPUART_ICR register.

An interrupt is generated if RXNEIE = 1 or EIE = 1 in the LPUART_CR1 register.

0: No overrun error

1: Overrun error is detected

Note: When this bit is set, the LPUART_RDR register content is not lost but the shift register is overwritten. An interrupt is generated if the ORE flag is set during multi buffer communication if the EIE bit is set.

This bit is permanently forced to 0 (no overrun detection) when the bit OVRDIS is set in the LPUART_CR3 register.

Bit 2 **NE:** Start bit noise detection flag

This bit is set by hardware when noise is detected on the start bit of a received frame. It is cleared by software, writing 1 to the NECF bit in the LPUART_ICR register.

0: No noise is detected

1: Noise is detected

Note: This bit does not generate an interrupt as it appears at the same time as the RXNE bit which itself generates an interrupt. An interrupt is generated when the NE flag is set during multi buffer communication if the EIE bit is set.

Bit 1 **FE**: Framing error

This bit is set by hardware when a de-synchronization, excessive noise or a break character is detected. It is cleared by software, writing 1 to the FECF bit in the LPUART_ICR register.

When transmitting data in Smartcard mode, this bit is set when the maximum number of transmit attempts is reached without success (the card NACKs the data frame).

An interrupt is generated if EIE = 1 in the LPUART_CR1 register.

0: No Framing error is detected

1: Framing error or break character is detected

Bit 0 **PE**: Parity error

This bit is set by hardware when a parity error occurs in receiver mode. It is cleared by software, writing 1 to the PECF in the LPUART_ICR register.

An interrupt is generated if PEIE = 1 in the LPUART_CR1 register.

0: No parity error

1: Parity error

54.7.9 LPUART interrupt flag clear register (LPUART_ICR)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WUCF	Res.	Res.	CMCF	Res.
											w			w	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CTSCF	Res.	Res.	TCCF	Res.	IDLECF	ORECF	NECF	FECF	PECF
						w			w		w	w	w	w	w

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **WUCF**: Wakeup from low-power mode clear flag

Writing 1 to this bit clears the WUF flag in the LPUART_ISR register.

Note: If the LPUART does not support the wakeup from Stop feature, this bit is reserved and kept at reset value. Refer to Section 53.4: USART implementation.

Bits 19:18 Reserved, must be kept at reset value.

Bit 17 **CMCF**: Character match clear flag

Writing 1 to this bit clears the CMF flag in the LPUART_ISR register.

Bits 16:10 Reserved, must be kept at reset value.

Bit 9 **CTSCF**: CTS clear flag

Writing 1 to this bit clears the CTSIF flag in the LPUART_ISR register.

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **TCCF**: Transmission complete clear flag
Writing 1 to this bit clears the TC flag in the LPUART_ISR register.

Bit 5 Reserved, must be kept at reset value.

Bit 4 **IDLECF**: Idle line detected clear flag
Writing 1 to this bit clears the IDLE flag in the LPUART_ISR register.

Bit 3 **ORECF**: Overrun error clear flag
Writing 1 to this bit clears the ORE flag in the LPUART_ISR register.

Bit 2 **NECF**: Noise detected clear flag
Writing 1 to this bit clears the NE flag in the LPUART_ISR register.

Bit 1 **FECF**: Framing error clear flag
Writing 1 to this bit clears the FE flag in the LPUART_ISR register.

Bit 0 **PECF**: Parity error clear flag
Writing 1 to this bit clears the PE flag in the LPUART_ISR register.

54.7.10 LPUART receive data register (LPUART_RDR)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDR[8:0]								
							r	r	r	r	r	r	r	r	r

Bits 31:9 Reserved, must be kept at reset value.

Bits 8:0 **RDR[8:0]**: Receive data value
Contains the received data character.
The RDR register provides the parallel interface between the input shift register and the internal bus (see *Figure 627*).
When receiving with the parity enabled, the value read in the MSB bit is the received parity bit.

54.7.11 LPUART transmit data register (LPUART_TDR)

Address offset: 0x28

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDR[8:0]								
							rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bits 8:0 **TDR[8:0]**: Transmit data value

Contains the data character to be transmitted.

The TDR register provides the parallel interface between the internal bus and the output shift register (see *Figure 627*).

When transmitting with the parity enabled (PCE bit set to 1 in the LPUART_CR1 register), the value written in the MSB (bit 7 or bit 8 depending on the data length) has no effect because it is replaced by the parity.

Note: This register must be written only when TXE/TXFNF = 1.

54.7.12 LPUART prescaler register (LPUART_PRESC)

This register can only be written when the LPUART is disabled (UE = 0).

Address offset: 0x2C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **PRESCALER[3:0]**: Clock prescaler

The LPUART input clock can be divided by a prescaler:

0000: input clock not divided
0001: input clock divided by 2
0010: input clock divided by 4
0011: input clock divided by 6
0100: input clock divided by 8
0101: input clock divided by 10
0110: input clock divided by 12
0111: input clock divided by 16
1000: input clock divided by 32
1001: input clock divided by 64
1010: input clock divided by 128
1011: input clock divided by 256
Remaining combinations: Reserved.

Note: When PRESCALER is programmed with a value different of the allowed ones, programmed prescaler value is 1011 i.e. input clock divided by 256.

54.7.13 LPUART register map

The table below gives the LPUART register map and reset values.

Table 433. LPUART register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	LPUART_CR1 FIFO mode enabled	RXFFIE	TXFEIE	FIFOEN	M1	Res.	Res.	DEAT[4:0]					DEDT[4:0]					Res.	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXFNFIE	TCIE	RXFNEIE	IDLEIE	TE	RE	UESM	UE
	Reset value	0	0	0	0			0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00	LPUART_CR1 FIFO mode disabled	Res.	Res.	FIFOEN	M1	Res.	Res.	DEAT[4:0]					DEDT[4:0]					Res.	CMIE	MME	M0	WAKE	PCE	PS	PEIE	TXEIE	TCIE	RXNEIE	IDLEIE	TE	RE	UESM	UE
	Reset value			0	0			0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	LPUART_CR2	ADD[7:0]								Res.	Res.	Res.	Res.	MSBFIRST	DATAINV	TXINV	RXINV	SWAP	Res.	STOP [1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDM7	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0					0	0	0	0	0		0	0								0				
0x08	LPUART_CR3	TXFTCFG[2:0]			RXFTIE	RXFTCFG[2:0]			Res.	TXFTIE	WUFIE	WUS [1:0]		Res.	Res.	Res.	Res.	DEP	DEM	DDRE	OVRDIS	Res.	CTSIE	CTSE	RTSE	DMAT	DMAR	Res.	Res.	HDSEL	Res.	Res.	EIE
	Reset value	0	0	0	0	0	0	0		0	0	0	0					0	0	0	0		0	0	0	0	0			0			0
0x0C	LPUART_BRR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BRR[19:0]																			
	Reset value																		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10-0x14	Reserved																																
0x18	LPUART_RQR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXFRQ	RXFRQ	MMRQ	SBKRQ	Res.
	Reset value																												0	0	0	0	
0x1C	LPUART_ISR FIFO mode enabled	Res.	Res.	Res.	Res.	TXFT	RXFT	Res.	RXFF	TXFF	REACK	TEACK	WUF	RWU	SBKF	CMF	BUSY	Res.	Res.	Res.	Res.	Res.	CTS	CTSIF	Res.	TXFNF	TC	RXFNE	IDLE	ORE	NE	FE	PE
	Reset value					0	0		0	1	0	0	0	0	0	0	0						0	0		1	1	0	0	0	0	0	0
0x1C	LPUART_ISR FIFO mode disabled	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REACK	TEACK	WUF	RWU	SBKF	CMF	BUSY	Res.	Res.	Res.	Res.	Res.	CTS	CTSIF	Res.	TXE	TC	RXNE	IDLE	ORE	NE	FE	PE
	Reset value										0	0	0	0	0	0	0						0	0		1	1	0	0	0	0	0	0
0x20	LPUART_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WUCF	Res.	Res.	CMCF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CTSCF	Res.	Res.	TCCF	Res.	IDLECF	ORECF	NECF	FECF	PECF
	Reset value												0			0								0			0		0	0	0	0	0
0x24	LPUART_RDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDR[8:0]								
	Reset value																								0	0	0	0	0	0	0	0	0
0x28	LPUART_TDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDR[8:0]								
	Reset value																								0	0	0	0	0	0	0	0	0

Table 433. LPUART register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x2C	LPUART_PRESC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[3:0]			
	Reset value																													0	0	0	0

Refer to *Section 2.3: Memory organization* for the register boundary addresses.

55 Serial peripheral interface (SPI)

55.1 Introduction

The serial peripheral interface (SPI) can be used to communicate with external devices while using the specific synchronous protocol. The (SPI) interface supports a half-duplex, full-duplex and simplex synchronous, serial communication with external devices. The interface can be configured as master or slave and is capable of operating in multi slave or multi master configurations. In case of master configuration it provides the communication clock (SCK) to the external slave device. The slave select signal can be provided by the master and accepted by the slave optionally, too. The Motorola data format is used by default, but some other specific modes are supported as well.

55.2 SPI main features

- Full-duplex synchronous transfers on three lines
- Half-duplex synchronous transfer on two lines (with bidirectional data line)
- Simplex synchronous transfers on two lines (with unidirectional data line)
- From 4-bit up to 32-bit data size selection
- Multi master or multi slave mode capability
- Dual clock domain, separated clock for the peripheral kernel which can be independent of APB bus clock
- 8 master mode baud rate prescalers up to kernel frequency/2
- Protection of configuration and setting
- Hardware or software management of SS for both master and slave
- Adjustable minimum delays between data and between SS and data flow
- Configurable SS signal polarity and timing, MISO x MOSI swap capability
- Programmable clock polarity and phase
- Programmable data order with MSB-first or LSB-first shifting
- Programmable number of data within a transaction to control SS and CRC
- Dedicated transmission and reception flags with interrupt capability
- Slave's transmission and/or reception capability in Stop mode (no clock provided to the peripheral) with wake up
- SPI Motorola and TI formats support
- Hardware CRC feature can verify integrity of the communication at the end of transaction by:
  - Adding CRC value at Tx mode
  - Automatic CRC error checking for Rx mode
- Error detection with interrupt capability in case of data overrun, CRC error, data underrun, the mode fault and the frame error at dependency on the operating mode
- Two multiply of 8-bit embedded Rx and Tx FIFOs (FIFO size depends on instance)
- Configurable FIFO thresholds (data packing)
- Capability to handle data streams by system DMA controller
- Configurable behavior at slave underrun condition (support of cascaded circular buffers)

55.3 SPI implementation

Table 434. STM32H72x/3x SPI features

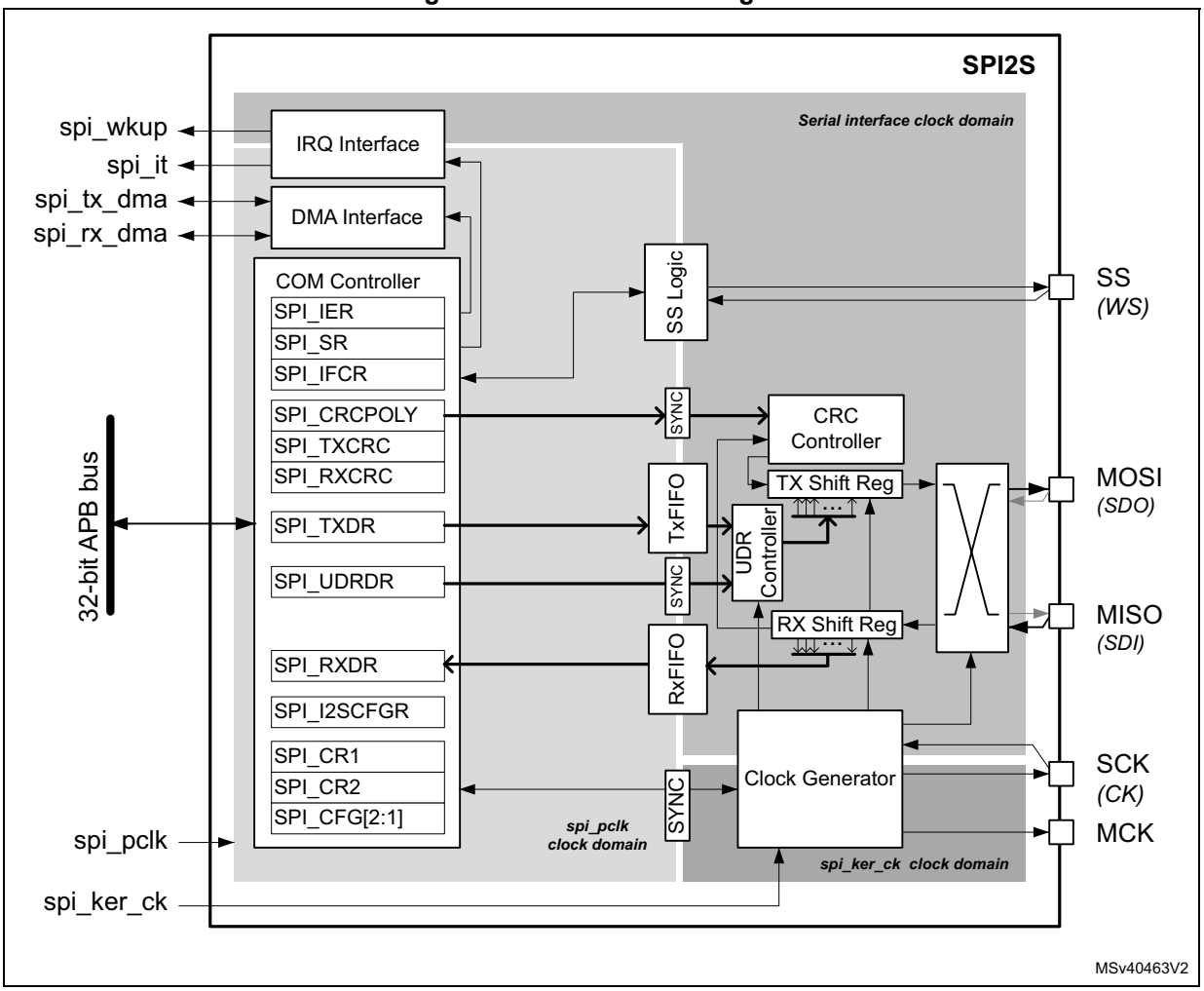
SPI modes/features	SPI2S1	SPI2S2	SPI2S3	SPI4	SPI5	SPI2S6
Rx & Tx FIFO size [x 8-bit]	16	16	16	8	8	8
Maximum configurable data and CRC size [bits]	32	32	32	16	16	16
I2S feature	Yes	Yes	Yes	No	No	Yes

55.4 SPI functional description

55.4.1 SPI block diagram

The SPI allows a synchronous, serial communication between the MCU and external devices. The application software can manage the communication by polling the status flag or using a dedicated SPI interrupt. The main elements of SPI and their interactions are shown in the following block diagram at *Figure 641*.

Figure 641. SPI2S block diagram



The simplified scheme of *Figure 641* shows three fully independent clock domains:

- The **spi_pclk** clock domain,
- The **spi_ker_ck** kernel clock domain,
- The serial interface clock domain,

All the control and status signals between these domains are strictly synchronized. There is no specific constraint concerning the frequency ratio between these clock signals. The user has to consider a ratio compatible with the data flow speed in order to avoid any data underrun or overrun events only.

The **spi_pclk** clock signal feeds the peripheral bus interface. It has to be active when it accesses to the SPI registers are required.

The SPI master needs the **spi_ker_ck** kernel clock coming from RCC active during communication to feed the serial interface SCK clock via the clock generator divider.

The SPI working in slave mode handles data flow using the serial interface clock derived from the external SCK signal provided by external master SPI device. That is why the SPI slave is able to receive and send data even when the **spi_pclk** and **spi_ker_ck** clock signals are inactive.

As a consequence, a specific slave logic working within the serial interface clock domain needs some additional traffic to be setup correctly (e.g. when underrun or overrun is evaluated see *Section 55.5.2: SPI error flags* for details). This cannot be done when the bus becomes into idle. At specific case the slave even requires the clock generator working (see *Section 55.5.1: TI mode*).

55.4.2 SPI signals

Four I/O pins are dedicated to SPI communication with external devices.

- **MISO:** Master In / Slave Out data. In the general case, this pin is used to transmit data in slave mode and receive data in master mode.
- **MOSI:** Master Out / Slave In data. In the general case, this pin is used to transmit data in master mode and receive data in slave mode.
- **SCK:** Serial Clock output pin for SPI masters and input pin for SPI slaves.
- **SS:** Slave select pin. Depending on the SPI and SS settings, this pin can be used to either:
  - Select an individual slave device for communication
  - Synchronize the data frame or
  - Detect a conflict between multiple masters

  See *Section 55.4.7: Slave select (SS) pin management* for details.

The SPI bus allows the communication between one master device and one or more slave devices. The bus consists of at least two wires: one for the clock signal and the other for synchronous data transfer. Other signals can be added depending on the data exchange between SPI nodes and their slave select signal management. the functionality between MOSI and MISO pins can be inverted in any SPI mode (see the IOSWP bit at SPI_CFG2 register).

All these pins are shared with I2S if this mode is implemented at the instance. See *Section 55.9.2: Pin sharing with SPI function*.

55.4.3 SPI communication general aspects

The SPI allows the MCU to communicate using different configurations, depending on the device targeted and the application requirements. These configurations use 2 or 3 wires (with software SS management) or 3/4 wires (with hardware SS management). The communication is always initiated and controlled by the master. The master provides a clock signal on the SCK line and selects or synchronizes slave(s) for communication by SS line when it is managed by HW. The data between the master and the slave flow on the MOSI and/or MISO lines. The direction of data flow is highlighted by black arrows at the following topology figures.

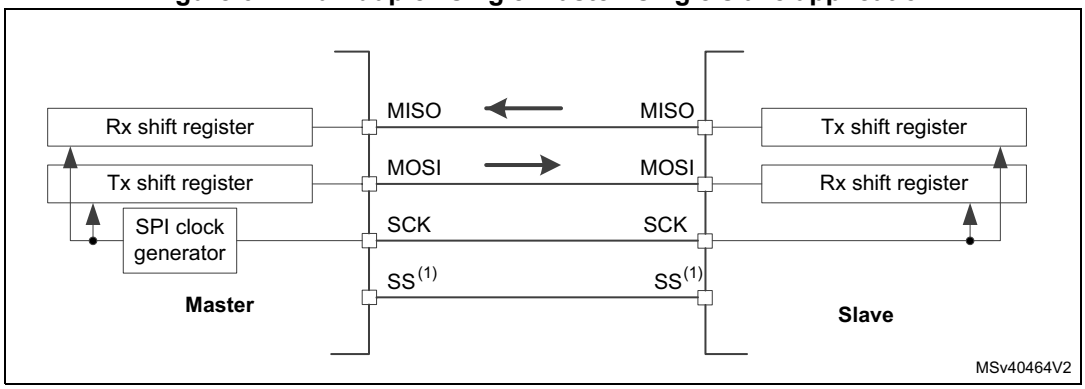
55.4.4 Communications between one master and one slave

The communication flow may use one of 3 possible modes: full-duplex (3 wires), half-duplex (2 wires) or simplex (2 wires). The SS signal is optional in single master-slave configuration and is often not connected between the two communication nodes. Nevertheless, the SS signal can be helpful at this configuration to synchronize the data flow and it is used by default at some specific SPI modes (e.g. TI mode).

Full-duplex communication

By default, the SPI is configured for full-duplex communication (bits COMM[1:0]=00 in the SPI_CFG2 register). In this configuration, the shift registers of the master and slave are linked using two unidirectional lines between the MOSI and the MISO pins. During the SPI communication, the data are shifted synchronously on the SCK clock edges provided by the master. The master transmits the data to be sent to the slave via the MOSI line and receives data from the slave via the MISO line simultaneously. When the data frame transfer is complete (all the bits are shifted) the information between the master and slave is exchanged.

Figure 642. Full-duplex single master/ single slave application

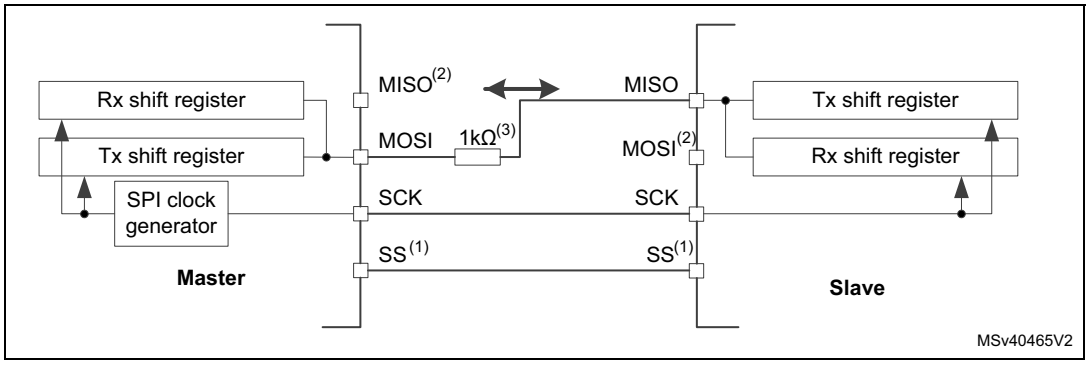


1. To apply SS pins interconnection is not mandatory to make the SPI interface working (see *Section 55.4.7: Slave select (SS) pin management* for details).

Half-duplex communication

The SPI can communicate in half-duplex mode by setting COMM[1:0]=11 in the SPI_CFG2 register. In this configuration, one single cross connection line is used to link the shift registers of the master and slave together. During this communication, the data are synchronously shifted between the shift registers on the SCK clock edge in the transfer direction selected reciprocally by both master and slave with the HDDIR bit in their SPI_CR1 registers. Note that the SPI has to be disabled when changing direction of the communication. In this configuration, the MISO pin at master and the MOSI pin at slave are free for other application uses and act as GPIOs.

Figure 643. Half-duplex single master/ single slave application



1. To apply SS pins interconnection is not mandatory to make the SPI interface working (see *Section 55.4.7:*

Slave select (SS) pin management for details).

2. In this configuration, the MISO pin at master and MOSI pin at slave can be used as GPIOs
3. A critical situation can happen when communication direction is changed not synchronously between two nodes working at bidirectional mode and new transmitter accesses the common data line while former transmitter still keeps an opposite value on the line (the value depends on SPI configuration and communicated data). Both nodes can fight with opposite outputs levels on the line temporary till next node change its direction setting correspondingly, too. It is suggested to insert serial resistance between MISO and MOSI pins at this mode to protect the outputs and limit the current blowing between them at this situation,

Simplex communications

The SPI can communicate in simplex mode by setting the SPI in transmit-only or in receive-only using the COMM[1:0] field in the SPI_CFG2 register. In this configuration, only one line is used for the transfer between the shift registers of the master and slave. The remaining MISO or MOSI pins pair is not used for communication and can be used as standard GPIOs.

- Transmit-only mode: COMM[1:0]=01

  The master in transmit-only mode generates the clock as long as there are data available in the TxFIFO and the master transfer is on-going.

  The slave in transmit only mode sends data as long as it receives a clock on the SCK pin and the SS pin (or SW managed internal signal) is active (see *Section 55.4.7: Slave select (SS) pin management*).

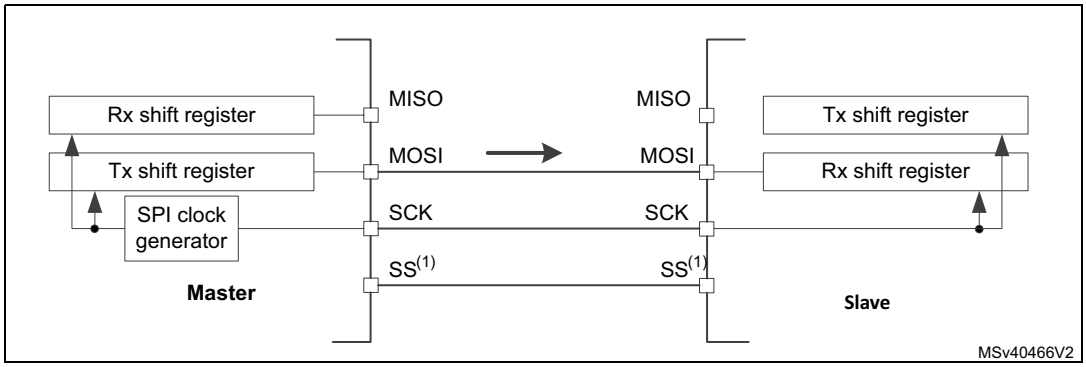
- **Receive-only mode: COMM[1:0]=10**

  In master mode, the MOSI output is disabled and may be used as GPIO. The clock signal is generated continuously as long as the SPI is enabled and the CSTART bit in the SPI_CR1 register is set. The clock is stopped either by SW explicitly requesting this by setting the CSUSP bit in the SPI_CR1 register or automatically when the RxFIFO is full, when the MASRX bit in the SPI_CR1 is set.

  In slave configuration, the MISO output is disabled and the pin can be used as a GPIO. The slave continues to receive data from the MOSI pin while its slave select signal is active (see *Section 55.4.7: Slave select (SS) pin management*).

Note: At whatever master and slave modes, the data pin dedicated for transmission can be replaced by the data pin dedicated for reception and vice versa by changing the IOSWP bit value in the SPI_CFG2 register. (This bit may only be modified when the SPI is disabled). Any simplex communication can be replaced by a variant of the half duplex communication with a constant setting of the transaction direction (bidirectional mode is enabled, while the HDDIR bit is never changed).

Figure 644. Simplex single master/single slave application (master in transmit-only/ slave in receive-only mode)

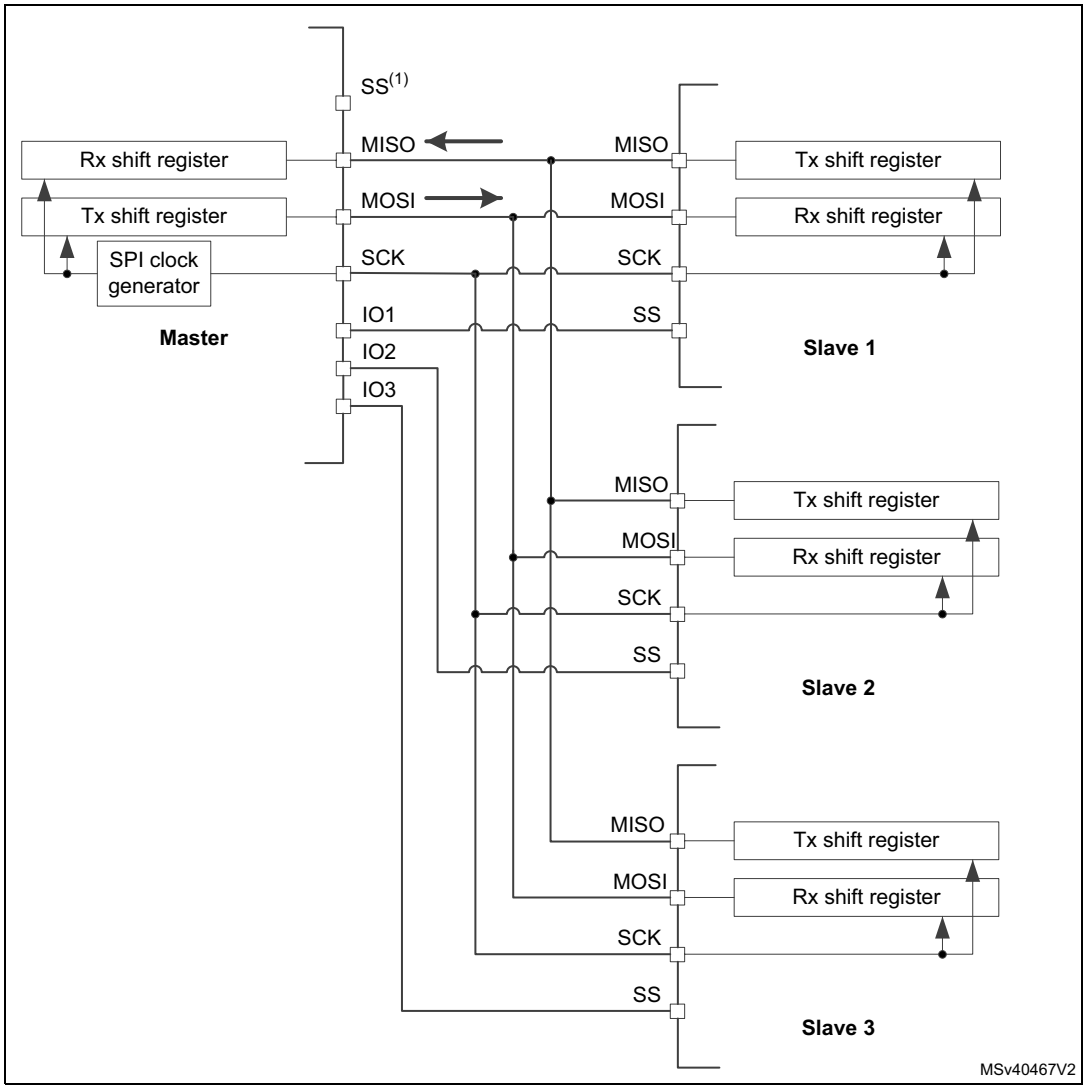


1. To apply SS pins interconnection is not mandatory to make the SPI interface working (see *Section 55.4.7: Slave select (SS) pin management* for details).
2. In this configuration, both the MISO pins can be used as GPIOs.

55.4.5 Standard multi-slave communication

In a configuration with two or more independent slaves, the master uses a star topology with dedicated GPIO pins to manage the chip select lines for each slave separately (see *Figure 645.*). The master must select one of the slaves individually by pulling low the GPIO connected to the slave SS input (only one slave can control data on common MISO line at time). When this is done, a communication between the master and the selected slave is established. Except the simplicity, the advantage of this topology is that a specific SPI configuration can be applied for each slave as all the communication sessions are performed separately just within single master-slave pair. Optionally, when there is no need to read any information from slaves, the master can transmit the same information to the multiple slaves.

Figure 645. Master and three independent slaves at star topology



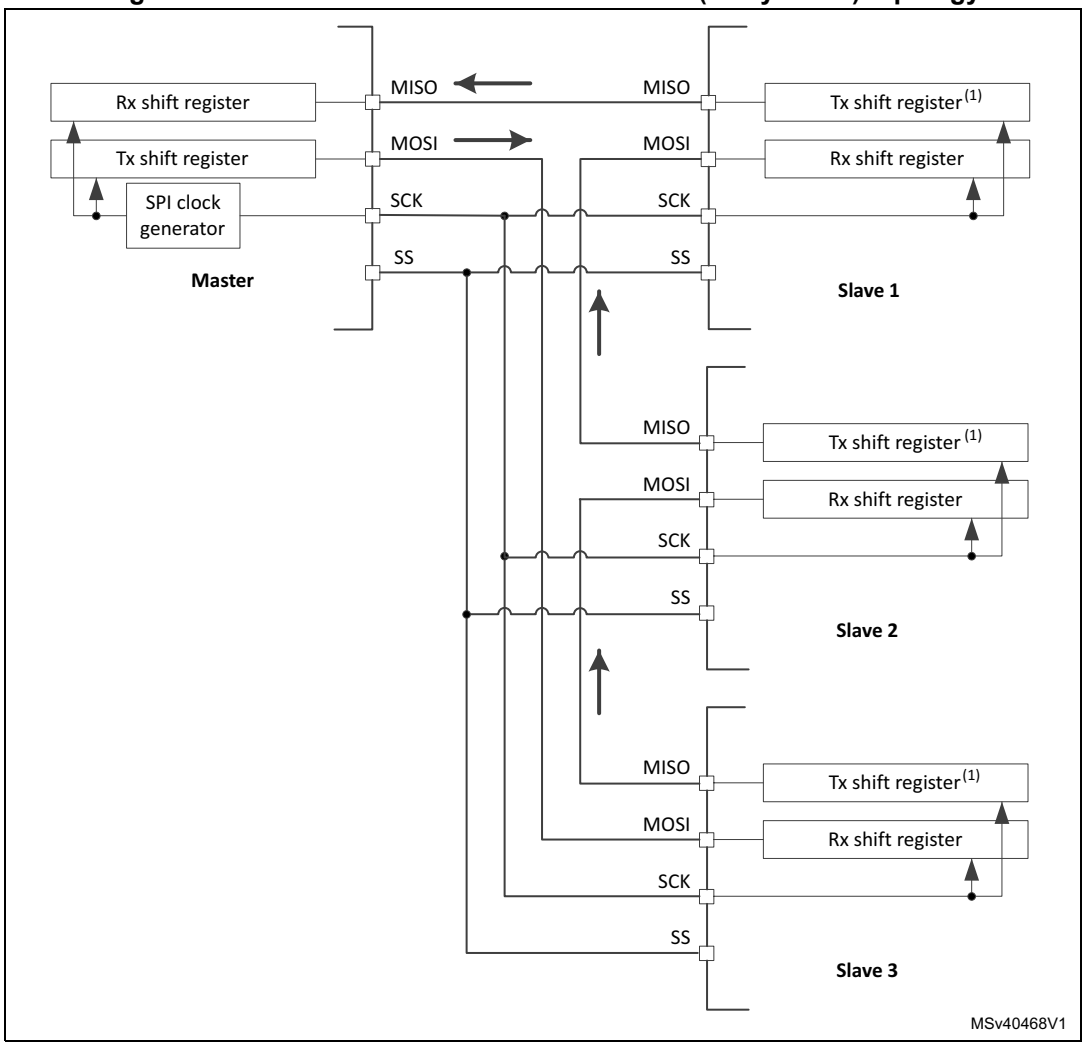
1. Master single SS pin hardware output functionality cannot support this topology (to be replaced by set of

GPIOs under SW control) and user should avoid SPI AF setting at the pin (see *Section 55.4.7: Slave select (SS) pin management* for details).

2. If the application cannot ensure that no more than a single SS active signal is provided by the master at time, it is better to configure the MISO pins into open drain configuration with an external pull-up at MISO line to prevent any conflict between interconnected outputs of the slaves on the line. Else the push-pull configuration can be applied without an extra resistor for the slaves. (see *Section 11.3.7: I/O alternate function input/output on page 974*.)

The master can handle the SPI communication with all the slaves in time when a circular topology is applied (see *Figure 646*). All the slaves behave like simple shift registers applied at serial chain under common slave select and clock control. All the information is shifted simultaneously around the circle while returning back to the master. Sessions have fixed the length where the number of data frames transacted by the master is equal to the number of slaves. Then when a first data frame is transacted in the chain, the master just sends information dedicated for the last slave node in the chain via the first slave node input while the first information received by the master comes from the last node output at this time. Correspondingly, the lastly transacted data finishing the session is dedicated for the first slave node while its firstly outgoing data just reaches the master input after its circling around the chain passing through all the other slaves during the session. The data format configuration and clock setting has to be the same for all the nodes in the chain at this topology. As the receive and transmit shift registers are separated internally, a trick with intentional underrun has to be applied at the TxFIFO slaves when information is transacted between the receiver and the transmitter by hardware. In this case, the transmission underrun feature is configured at a mode repeating lastly received data frame (UDRCFG[1:0]=01). A session can start optionally with a single data pattern written into the TxFIFO by each slave (usually slave status information is applied) before the session starts. In this case the underrun happens in fact after this first data frame is transacted (underrun detection has to be set at end of data transaction at slaves UDRDET[1:0]=01). To be able to clear the internal underrun condition immediately and restart the session by the TxFIFO content again, the user has to disable and enable the SPI between sessions and fill the TxFIFO by a new single data pattern.

Figure 646. Master and three slaves at circular (daisy chain) topology



1. Underrun feature is used at slaves at this configuration when slaves are able to transmit data received previously into the Rx shift register once their TxFIFOs become empty.

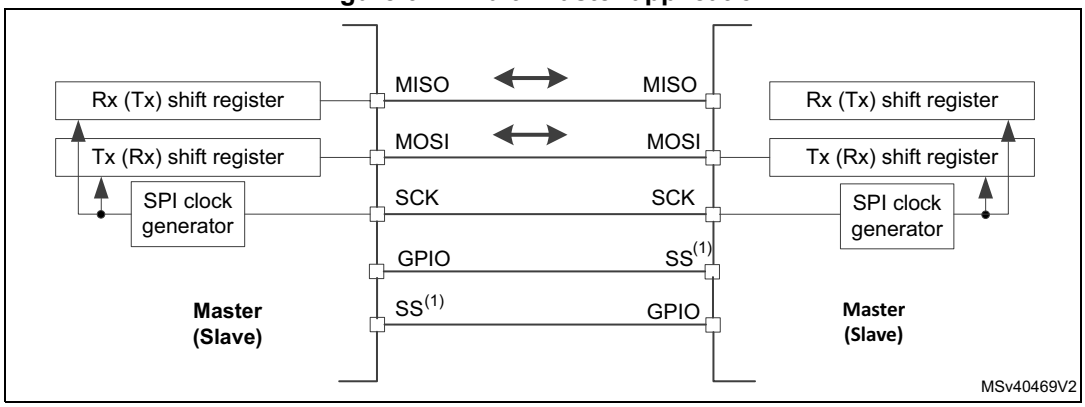
55.4.6 Multi-master communication

Unless the SPI bus is not designed for a multi-master capability primarily, the user can use build in feature which detects a potential conflict between two nodes trying to master the bus at the same time. For this detection, the SS pin is used configured at hardware input mode. The connection of more than two SPI nodes working at this mode is impossible as only one node can apply its output on a common data line at time.

When nodes are non active, both stay at slave mode by default. Once one node wants to overtake control on the bus, it switches itself into master mode and applies active level on the slave select input of the other node via the dedicated GPIO pin. After the session is completed, the active slave select signal is released and the node mastering the bus temporary returns back to passive slave mode waiting for next session start.

If potentially both nodes raised their mastering request at the same time a bus conflict event appears (see mode fault MODF event). Then the user can apply some simple arbitration process (e.g. to postpone next attempt by predefined different time-outs applied at both nodes).

Figure 647. Multi-master application



1. The SS pin is configured at hardware input mode at both nodes. Its active level enable the MISO line output control as passive node is configured as a slave.

55.4.7 Slave select (SS) pin management

In slave mode, the SS works as a standard ‘chip select’ input and lets the slave communicate with the master. In master mode, the SS can be used either as an output or an input. As an input it can prevent a multi master bus collision, and as an output it can drive a slave select signal of a single slave. The SS signal can be managed internally (software management of the SS input) or externally when both the SS input and output are associated with the SS pin (hardware SS management). The user can configure which level of this input/output external signal (present on the SS pin) is considered as active one by the SSIOP bit setting. The SS level is considered as active if it is equal to SSIOP.

The hardware or software slave select management can be set using the SSM bit in the SPI_CFG2 register:

- **Software SS management (SSM = 1)**: in this configuration, slave select information is driven internally by the SSI bit value in the register SPI_CR1. The external SS pin is free for other application uses (as GPIO or other alternate function).
- **Hardware SS management (SSM = 0)**: in this case, there are two possible configurations. The configuration used depends on the SS output configuration (SSOE bit in register SPI_CFG2).
  - **SS output enable (SSOE = 1)**: this configuration is only used when the MCU is set as master. The SS pin is managed by the hardware. The functionality is tied to CSTART and EOT control. As a consequence, the master must apply proper TSIZE>0 setting to control the SS output correctly. Even if SPI AF is not applied at the SS pin (it can be used as a standard GPIO then), SSOE=1 setting should be kept anyway to assure default SS input level and prevent any mode fault evaluation at input of the master SS internal logic applicable at a multi-master topology exclusively.

    a) When SSOM = 0 and SP = 000, the SS signal is driven to the active level as soon as the master transfer starts (CSTART=1) and it is kept active until its EOT flag is set or the transmission is suspended.

    b) When SP = 001, a pulse is generated as defined by the TI mode.

    c) When SSOM=1, SP=000 and MIDI>1 the SS is pulsed inactive between data frames, and kept inactive for a number of SPI clock periods defined by the MIDI value decremented by one (1 to 14).

  - **SS output disable (SSM=0, SSOE = 0)**:

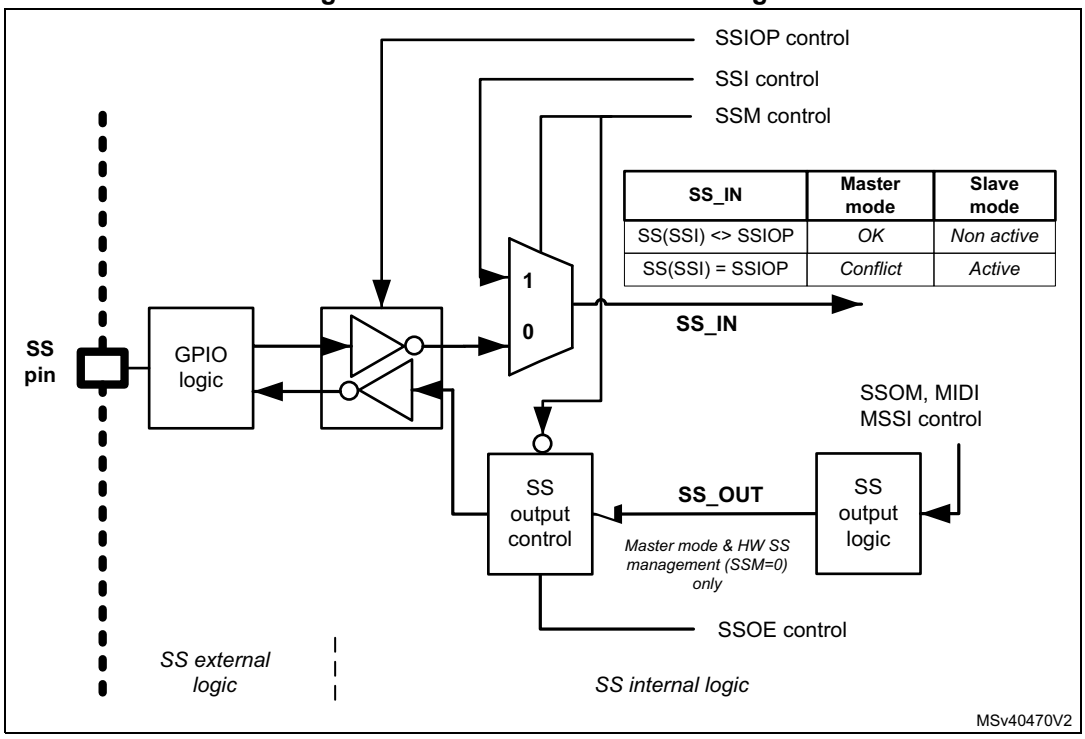
    a) if the microcontroller is acting as the master on the bus, this configuration allows multi master capability. If the SS pin is pulled into an active level in this mode, the SPI enters master mode fault state and the SPI device is automatically reconfigured in slave mode (MASTER=0).

    b) In slave mode, the SS pin works as a standard ‘chip select’ input and the slave is selected while the SS line is at its active level.

Note: The purpose of automatic switching into Slave mode at mode fault condition is to avoid the possible conflicts on data and clock line. As the SPE is automatically reset at this condition, both Rx and Tx FIFOs are flushed and current data is lost.

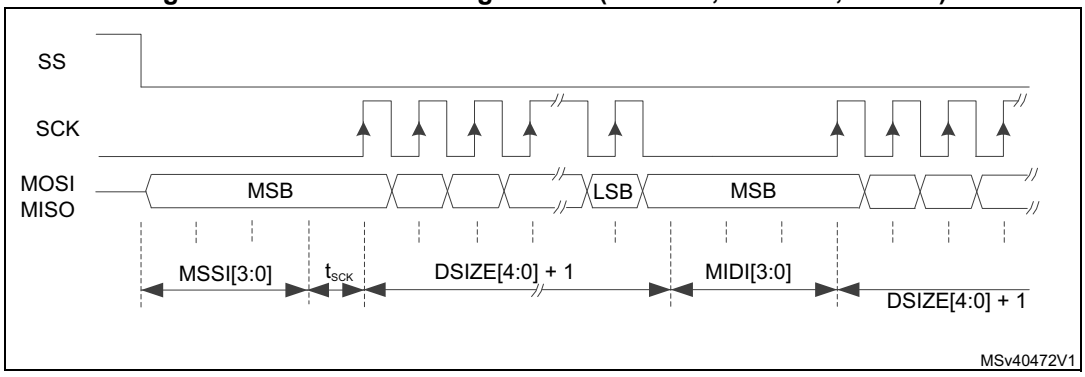
Note: When the SPI slave is enabled at the hardware SS management mode, all the traffics are ignored even in case of the SS is found at active level till the slave detects a start of the SS signal (its transition from non-active to active level) just synchronizing the slave with the master. That is why the hardware management mode cannot be used when the external SS pin is fixed. There is no such protection at the SS software management. Then the SSI bit must be changed when there is no traffic on the bus and the SCK signal is at idle state level between transfers exclusively in this case.

Figure 648. Scheme of SS control logic



When a hardware output SS control is applied (SSM=0, SSOE=1), by configuration of MIDI[3:0] and MSSI[3:0] bit fields the user can control timing of the SS signal between data frames and insert an extra delay at begin of every transaction (to separate the SS and clock starts). This can be useful when the slave needs to slow down the flow to obtain sufficient room for correct data handling (see *Figure 649: Data flow timing control (SSOE=1, SSOM=0, SSM=0)*

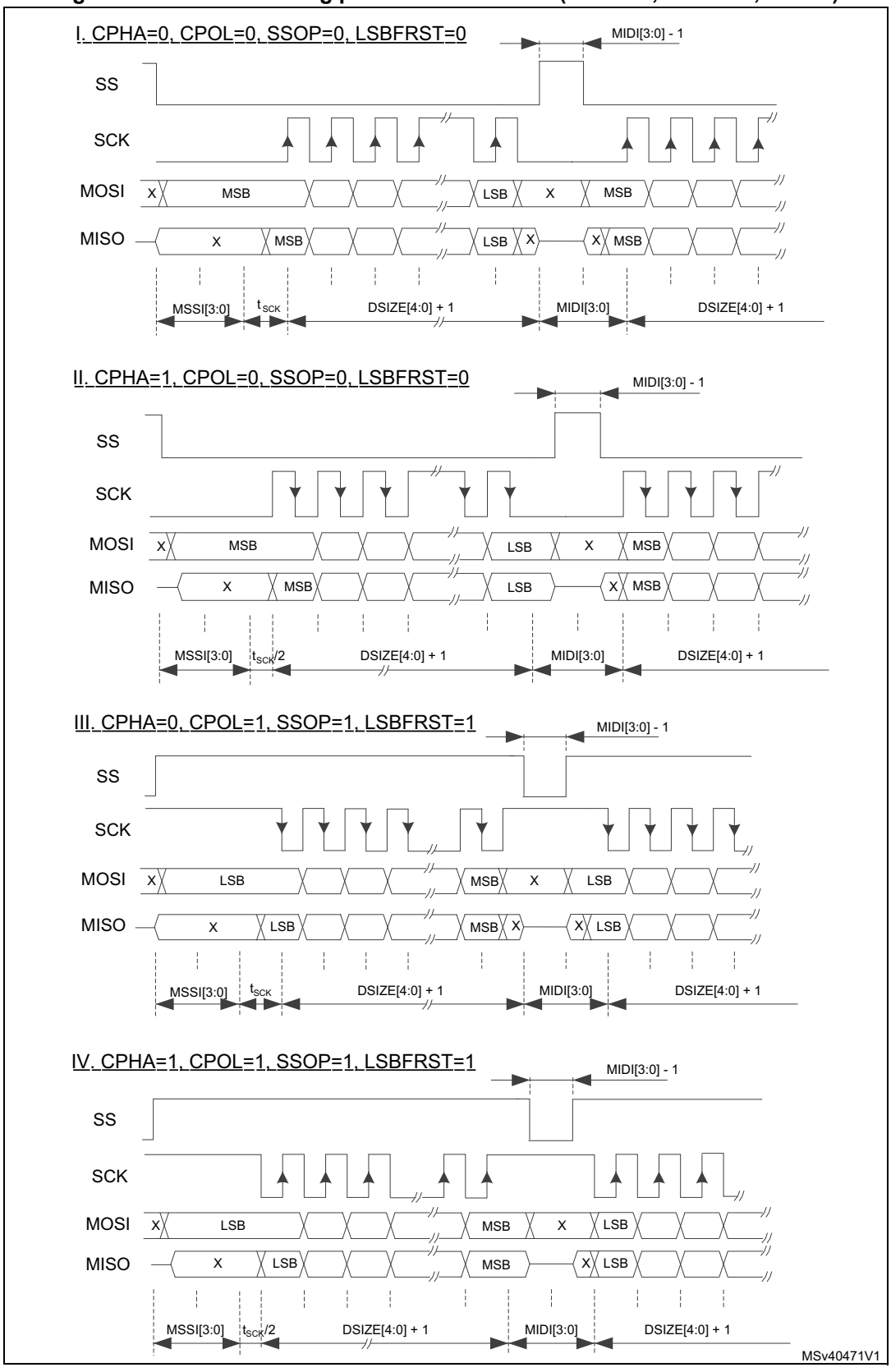
Figure 649. Data flow timing control (SSOE=1, SSOM=0, SSM=0)



1. MSSI[3:0]=0011, MIDI[3:0]=0011 (SCK flow is continuous when MIDI[3;0]=0).
2. CPHA=0, CPOL=0, SSOP=0, LSBFRST=0.

Additionally, bit SSOM=1 setting invokes specific mode which interleaves pulses between data frames if there is a sufficient space to provide them (MIDI[3:0] has to be set greater then one SPI period). Some configuration examples are shown at *Figure 650: SS interleaving pulses between data (SSOE=1, SSOM=1,SSM=0)*.

Figure 650. SS interleaving pulses between data (SSOE=1, SSOM=1,SSM=0)



1. MSSI[3:0]=0010, MIDI[3:0]=0010.
2. SS interleaves between data when MIDI[3:0]>1.

55.4.8 Communication formats

During SPI communication, receive and transmit operations are performed simultaneously. The serial clock (SCK) synchronizes the shifting and sampling of the information on the data lines. The communication format depends on the clock phase, the clock polarity and the data frame format. To be able to communicate together, the master and slave devices must follow the same communication format and be synchronized correctly.

Clock phase and polarity controls

Four possible timing relationships may be chosen by software, using the CPOL and CPHA bits in the SPI_CFG2 register. The CPOL (clock polarity) bit controls the idle state value of the clock when no data are being transferred. This bit affects both master and slave modes. If CPOL is reset, the SCK pin has a low-level idle state. If CPOL is set, the SCK pin has a high-level idle state.

If the CPHA bit is set, the second edge on the SCK pin captures the first data bit transacted (falling edge if the CPOL bit is reset, rising edge if the CPOL bit is set). Data are latched on each occurrence of this clock transition type. If the CPHA bit is reset, the first edge on the SCK pin captures the first data bit transacted (falling edge if the CPOL bit is set, rising edge if the CPOL bit is reset). Data are latched on each occurrence of this clock transition type.

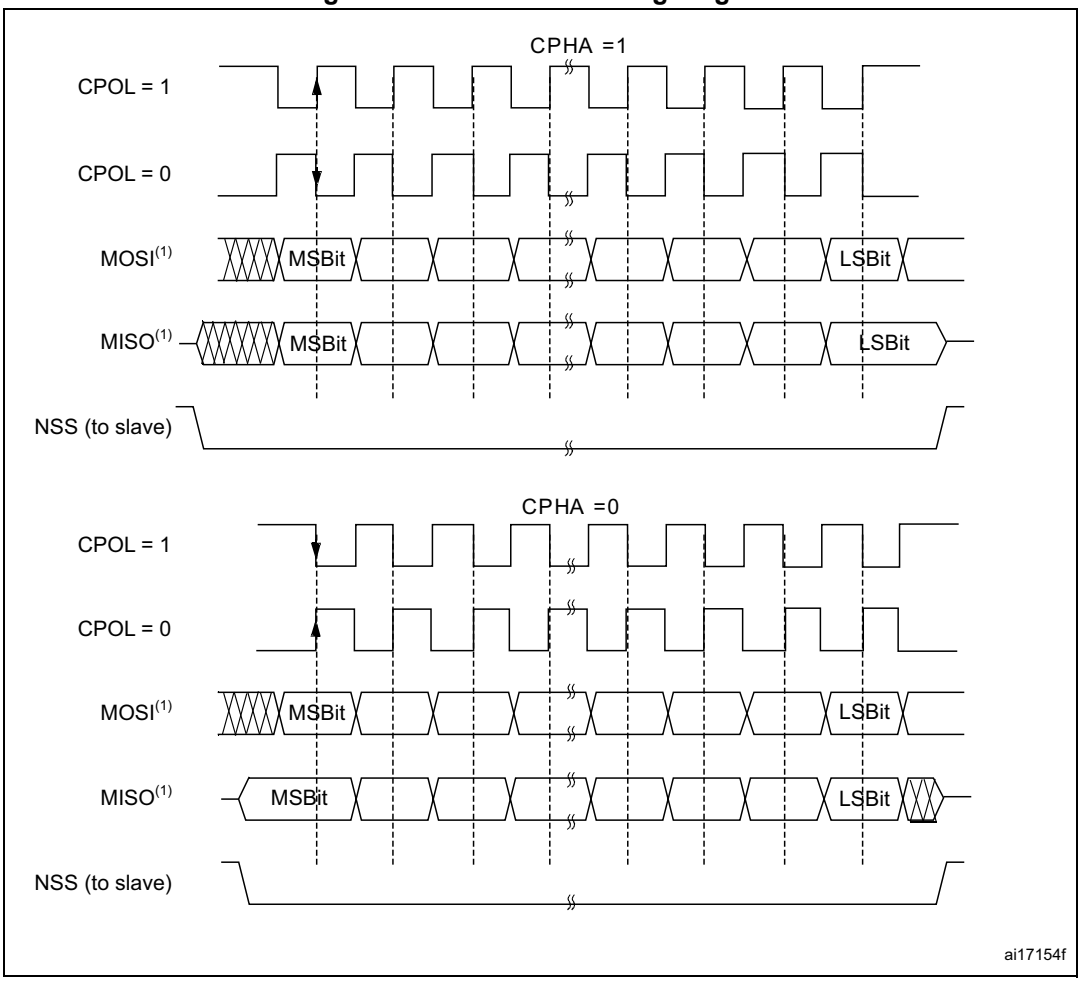
The combination of the CPOL (clock polarity) and CPHA (clock phase) bits selects the data capture clock edges (dotted lines at *Figure 651: Data clock timing diagram*).

Figure 651, shows an SPI full-duplex transfer with the four combinations of the CPHA and CPOL bits.

Note: Prior to changing the CPOL/CPHA bits the SPI must be disabled by resetting the SPE bit.

The idle state of SCK must correspond to the polarity selected in the SPI_CFG2 register (by pulling the SCK pin up if CPOL=1 or pulling it down if CPOL=0).

Figure 651. Data clock timing diagram



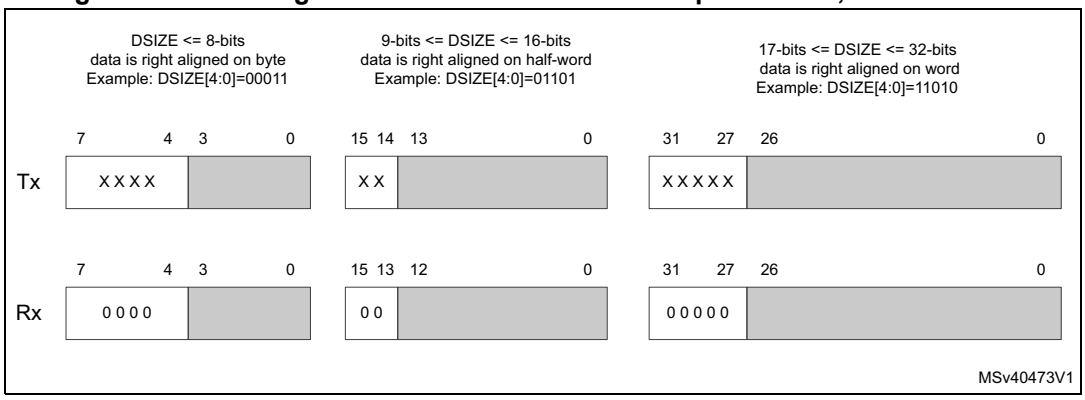
1. The order of data bits depends on LSBFRST bit setting.

Data frame format

The SPI shift register can be set up to shift out MSB-first or LSB-first, depending on the value of the LSBFRST bit in SPI_CFG2 register. The data frame size is chosen by using the DSIZE[4:0] bits. It can be set from 4-bit up to 32-bit length and the setting applies for both transmission and reception. When the SPI_TXDR/SPI_RXDR registers are accessed, data frames are always right-aligned into either a byte (if the data fit into a byte), a half-word or a word (see *Figure 652*).

If the access is a multiple of the configured data size, data packing is applied automatically. During communication, only bits within the data frame are clocked and transferred.

Figure 652. Data alignment when data size is not equal to 8-bit, 16-bit or 32-bit



Note: The minimum data length is 4 bits. If a data length of less than 4 bits is selected, it is forced to an 4-bit data frame size.

55.4.9 Configuration of SPI

The configuration procedure is almost the same for the master and the slave. For specific mode setups, follow the dedicated chapters. When a standard communication has to be initialized, perform these steps prior SPI is enabled:

1. Write the proper GPIO registers: Configure GPIO alternate functions at MOSI, MISO, SCK and SS pins if applied.
2. Write to the SPI_CFG1 and SPI_CFG2 registers to set up proper values of all not reserved bits and bit fields included there with next exceptions:
   a) SSOM, SSOE, MBR[2:0], MIDI[3:0] and MSSI[3:0] are required and taken into account at master mode exclusively.
   b) UDRDET[1:0] and UDRCFG[1:0] are required and taken into account at slave mode only. The MBR[2:0] setting is taken into account only when slave is configured at TI mode.
   c) CRCSIZE[4:0] is required if CRCEN is set,
   d) CPOL, CPHA, LSBFRST, SSOM, SSOE, SSIOP, MSSI, MIDI and SSM are not required at TI mode.
   e) Once the AFCNTR bit is set at SPI_CFG2 register, all the SPI outputs start to be propagated onto the associated GPIO pins regardless the peripheral enable so any later configurations changes of the SPI_CFG1 and SPI_CFG2 registers can affect level of signals at these pins.
   f) The I2SMOD bit at SPI_I2SCFGR register has to be kept cleared to prevent any unexpected influence of occasional I2S configuration.
3. Write to the SPI_CR2 register to select length of the transfer, if it is not known TSIZE has to be programmed to zero.
4. Write to SPI_CRCPOLY and into TCRCINI, RCRCINI and CRC33_17 bits at SPI_CR1 register to configure the CRC polynomial and CRC calculation if needed.
5. Configure DMA streams dedicated for the SPI Tx and Rx in DMA registers if the DMA streams are used (see chapter Communication using DMA).
6. Configure SSI, HDDIR and MASRX at SPI_CR1 register if required.
7. Program the IOLOCK bit in the SPI_CFG1 register if the configuration protection is required (for safety).

55.4.10 Procedure for enabling SPI

It is recommended to configure and enable the SPI slave before the master sends the clock but there is no impact if the configuration and enabling procedure is done while a traffic is ongoing on the bus suppose SS signal is managed by hardware at slave or kept inactive by slave's software when software management of the SS signal is applied (see *Section 55.4.7: Slave select (SS) pin management*). The data register of the slave transmitter must contain data to be sent before the master starts its clocking.The SCK signal must be settled to idle state level corresponding to the selected polarity before the SPI slave is selected by SS else following transaction may be desynchronized.

When the SPI slave is enabled at the hardware SS management mode all the traffics are ignored even in case of the SS is found at active level till the slave detects a start of the SS signal (its transition from non-active to active level) just synchronizing the slave with the master. That is why the hardware management mode cannot be used when external SS pin is fixed. There is no such protection at the SS software management. In this case the SSI bit must be changed when there is no traffic on the bus and the SCK signal is at idle state level between transfers exclusively in this case.

The master at full duplex (or in any transmit-only mode) starts to communicate when the SPI is enabled, the CSTART bit is set and the TxFIFO is not empty, or with the next write to TxFIFO.

In any master receive only mode, the master starts to communicate and the clock starts running after the SPI is enabled and the CSTART bit is set.

For handling DMA, see *Section 55.4.14: Communication using DMA (direct memory addressing)*.

55.4.11 SPI data transmission and reception procedures

The setting of data communication format follows the basic principle that sure number of data with a flexible size must be transferred within a session (transaction) while, optionally, the data handling can be cumulated effectively into a single access of the SPI data registers (data packing) or even grouped into a sequence of such services if data is collected at consistent bigger data packets. The data handling services are based upon FIFO packet occupancy events. That is why the complete data packet must be serviced exclusively upon a dedicated packet flag.

To understand better the next detailed content of this section, the user should capture the configuration impact and meaning of the following items at first:

Data size (DSIZE)- defines data frame (sets the number of bits at single data frame).

FIFO threshold (FTHLV) - defines data packet, sets the number of data frames at single data packet and so the occurrence of the packet occupancy events to handle SPI data registers either by software or by DMA.

Data access – a way how to handle the SPI data register content when the transfer data between the application and the SPI FIFOs upon a packet event. It depends on the packet size configuration. Optionally, multiply data can be handled effectively by a single access of the register (by data packing) or by sequence of such accesses (when servicing a bigger data packet).

FIFO size – capacity or space to absorb available data. It depends on the data size and the internal hardware efficiency how the data is compressed and organized within this space. The FTHLV setting must respect the FIFO capacity to store two data packets at least.

Transaction size (TSIZE) – defines total number of data frames involved at a transaction session overall possibly covered by several data packet services. There is no need to align this number with the packet size (handling of a last not aligned data packet is supported if TSIZE is programmed properly).

Data handling via RxFIFO and TxFIFO

All SPI data transitions pass through the embedded FIFOs organized by bytes (N x 8-bit). The size of the FIFOs (N) is product and the peripheral instance dependent. This enables the SPI to work in a continuous flow, and prevents overruns when the data frame size is short or the interrupt/DMA latency is too long. Each direction has its own FIFO called TxFIFO and RxFIFO, respectively.

The handling of the FIFOs content is based on servicing data packet events exclusively raised by dedicated FIFO packet occupancy flags (TXP, RXP or DXP). The flags occurrence depends on the data exchange mode (duplex, simplex), the data frame size (number of bits in the frame) and how data are organized at data packets. The frequency of the packet events can be decreased significantly when data are organized into packets via defining the FIFOs threshold. Several data frames grouped at packet can be then handled effectively based on a single FIFO occupancy packet event either by a single SPI data register access or their sequence what consumes less system performance. The user can control the access type by casting the data register address to force a concrete CPU instruction applied for the register read or write. The access then can be 8-bit, 16-bit or 32-bit but single data frame must be always accessed at least. It is crucial to keep the setting of the packet size (FTHLVL) and the data size (DSIZE) always balanced with the applied data registers access (no matter if a single access or their sequence is applied) just to apply and complete service of a single data packet upon its event. This principle, occurrence and clearing capabilities of the FIFO occupancy flags are common no matter if DMA, interrupt, or polling is applied.

A read access to the SPI_RXDR register returns the oldest value stored in the RxFIFO that has not been read yet. A write access to the SPI_TXDR stores the written data in the TxFIFO at the end of a send queue.

A read access to the SPI_RXDR register must be managed by the RXP event. This flag is set by hardware when at least one complete data packet (defined as receiver threshold by FTHLV[3:0] bits at the SPI_CFG1 register) is available at the reception FIFO while reception is active. The RXP is cleared as soon as less data than a complete single packet is available in the RxFIFO, when reading SPI_RXDR by software or by DMA.

The RXP triggers an interrupt if the RXPIE bit is set.

Upon setting of the RXP flag, the application performs the due number of SPI data register reads to download the content of one data packet. Once a complete data packet is downloaded, the application software or DMA checks the RXP value to see if other packets are pending into the receive FIFO and, if so, downloads them packet by packet until the RXP reads 0. RxFIFO can store up to N data frames (for frame size =< 8-bit), N/2 data frames (for 8-bit < frame =< 16-bit), N/3 data frames (for 16-bit < frame =< 24-bit) or N/4 data frames (if data frame >24-bit) where N is the size of the FIFO in bytes.

At the end of a reception, it may happen that some data may still be available in the RxFIFO, without reaching the FTHLV level, thus the RXP is not set. In this case, the number of remaining RX data frames in the FIFO is indicated by RXWNE and RXPLVL fields in the SPI_SR register. It happens when number of the last data received in a transfer cannot fully accomplish the configured packet size in the case transfer size and packet size are not aligned. Nevertheless the application software can still perform the standard number of reads from the RxFIFO used for the previous complete data packets without drawbacks:

only the consistent data (completed data frames) are popped from the RxFIFO while redundant reads (or any uncompleted data) are reading 0. Thanks to that, the application software can treat all the data in a transfer in the same way and is off-loaded to foresee the reception of the last data in a transfer and from calculating the due number of reads to be popped from RxFIFO.

In a similar way, write access of a data frame to be transmitted is managed by the TXP event. This flag is set by hardware when there is enough space for the application to push at least one complete data packet (defined at FTHLV[3:0] bits at SPI_CFG1 register) into the transmission FIFO while transmission is active. The TXP is cleared as soon as the TxFIFO is filled by software a/o by DMA and space currently available for any next complete data packet is lost. This can lead to oscillations of the TXP signal when data are released out from the TxFIFO while a new packet is stored frame by frame. Any write to the TxFIFO is ignored when there is no sufficient room to store at least a single data frame (TXP event is not respected), when TXTF is set or when the SPI is disabled.

The TXP triggers an interrupt if the TXPIE bit is set or a/o a DMA request if TXDMAEN is set. The TXPIE mask is cleared by hardware when the TXTF flag is set.

Upon setting of the TXP flag application software performs the due number of SPI data register writes to upload the content of one entire data packet. Once new complete data packet is uploaded, the application software or DMA checks the TXP value to see if other packets can be pushed into the TxFIFO and, if so, uploads them packet by packet until TXP reads 0 at the end of any packet load.

The number of last data in a transfer can be shorter than the configured packet size in the case when the transfer size and the packet size are not aligned. Nevertheless the application can still perform the standard number of data register writes used for the previous packets without drawbacks: only the consistent data are pushed into the TxFIFO while redundant writes are discarded. Thanks to that, the application software can treat all the data in a transfer in the same way and is off-loaded to foresee the transmission of the last data in a transfer and from calculating the due number of writes to push the last data into TxFIFO. Just for the last data case, the TXP event is asserted by SPI once there is enough space into TxFIFO to store remaining data to complete current transfer.

Both TXP and RXP events can be polled or handled by interrupts. The DXP bit can be monitored as a common TXP and RXP event at full duplex mode.

Upon setting of the DXP flag the application software performs the due number of writes to the SPI data register to upload the content of one entire data packet for transmission, followed by the same number of reads from the SPI data register to download the content of one data packet. Once one data packet is uploaded and one is downloaded, the application software or DMA checks the DXP value to see if other packets can be pushed and popped in sequence and, if so, uploads/downloads them packet by packet until DXP reads 0.

The DXP triggers an interrupt if the DXPIE bit is set. The DXPIE mask is cleared by hardware when the TXTF flag is set.

The DXP is useful in Full-Duplex communication in order to optimize performance in data uploading/downloading, and reducing the number of interrupts or DMA sequences required to support an SPI transfer thus minimizing the request for CPU bandwidth and system power especially when SPI is operated in Stop mode.

When relay on the DXP interrupt exclusively, the user must consider the drawback of such a simplification when TXP and RXP events are serviced by common procedures because the TXP services are delayed by purpose in this case. This is due to fact that the TXP events precedes the reception RXP ones normally to allow the TXP servicing prior transaction of

the last frame fully emptying the TxFIFO else master cannot provide a continuous SCK clock flow and the slave can even face an underrun condition. The possible solution is to pre-fill the TxFIFO by few data packets ahead prior the session starts and to handle all the data received after the TXTF event by EOT exclusively at the end of the transaction (as TXTF suppresses the DXP interrupts at the end of the transaction). In case of CRC computation is enabled, the user must calculate with additional space to accommodate the CRC frame at RxFIFO when relying on EOT exclusively at the end of transaction.

Another way to manage the data exchange is to use DMA (see *Communication using DMA (direct memory addressing)*).

If the next data is received when the RxFIFO is full, an overrun event occurs (see description of OVR flag at *Section 55.5.2: SPI error flags*). An overrun event can be polled or handled by an interrupt.

This may happen in slave mode or master mode (full duplex or receive only with MASRX = 0). In master receive only mode, with MASRX = 1, the generated clock stops automatically when the RxFIFO is full, therefore overrun is prevented.

Both RxFIFO and TxFIFO content is kept flushed when SPI is disabled (SPE=0).

Transaction handling

A few data frames can be passed at single transaction to complete a message. The user can handle number of data within a message thanks to values stored into TSIZE and TSER fields. In principle, the transaction of a message starts when the SPI is enabled by setting CSTART bit and finishes when the total number of required data is transacted. The end of transaction controls the CRC and the hardware SS management when applied. To restart the internal state machine properly, SPI is strongly suggested to be disabled and re-enabled before next transaction starts despite its setting is not changed. If TSIZE is kept at zero while CSTART is set, an endless transaction is initialized (no control of transfer size is applied). During an endless transaction, the number of transacted data aligned with FIFOs threshold is supported exclusively. If the number of data (or its grouping into packets) is unpredictable, the user must keep the FIFO threshold setting (packet size) at single data (FTHLV=0) to assure that each data frame raises its own packet event to be serviced by the application or DMA.

The transaction can be suspended at any time thanks to CSUSP which clears the CSTART bit. SPI must be always disabled after such software suspension and re-enabled before the next transaction starts.

In master mode, the user can extend the number of data within the current session. When the number of data programmed into TSIZE is transacted and if TSER contains a non-zero value, the content of TSER is copied into TSIZE, and TSER value is cleared automatically. The transaction is then extended by a number of data corresponding to the value reloaded into TSIZE. The EOT event is not raised in this case as the transaction continues. After the reload operation, the TSERF flag is set and an interrupt is raised if TSERFIE is set. The user can write the next non-zero value into TSER after the TSER is cleared by hardware but stil before the next reload occurs, so an unlimited number of data can be transacted while repeating this process.

When any data extension is applied, it always starts by aligned data packet. That is why it is suggested to keep number of data to be extended always aligned with packet size else the last data packet just before the extension is applied has to be handled as an incomplete one (see data packing chapter). If overall number of data is not aligned, the user must implement

the rest not aligned number of data into TSER just at the last extension cycle and then handle the last incomplete packet of data standardly within EOT event handler.

For example, if the user wants to transfer 23 bytes while applies data number extension at configuration of 8-bit data size, data packet set to 4 data and 32-bit access to FIFO is used then whatever next sequence is correct

- TSIZE=16 TSER=7;
- TSIZE=12 TSER=8; last extensionTSER=3;

As the last not aligned MSB byte is ignored just within the last (6th) access of the FIFO.

When a not aligned sequence is applied for data to be extended like at the following cases

- TSIZE=15 TSER=8 or
- TSIZE=8 TSER=7; last extension TSER=8;

The MSB byte is ignored within the 4th access of the FIFO while the other accesses handle always 4 data at the FIFO.

When the transmission is enabled, a sequence begins and continues while any data is present in the TxFIFO of the master. The clock signal is provided permanently by the master until TxFIFO becomes empty, then it stops, waiting for additional data.

In receive-only modes, half duplex (COMM[1:0]=11, HDDIR=0) or simplex (COMM[1:0]=10) the master starts the sequence when SPI is enabled and transaction is released by setting the CSTART bit. The clock signal is provided by the master and it does not stop until either SPI or receive-only mode is disabled/suspended by the master. The master receives data frames permanently up to this moment. The reception can be suspended either by SW control, writing 1 to the CSUSP bit in the SPI_CR1 register, or automatically when MASRX=1 and RxFIFO becomes full. The reception is automatically stopped also when the number of frames programmed in TSIZE and TSER fields of the SPI_CR2 register has been completed.

In order to disable the master receive only mode, the SPI must be suspended at first. When the SPI is suspended, the current frame is completed, before changing the configuration.

Caution: If SPE is written to 0 at master, while reception is ongoing without any suspending, the clock is stopped without completing the current frame, and the RxFIFO is flushed.

While the master can provide all the transactions in continuous mode (SCK signal is continuous) it has to respect slave capability to handle data flow and its content at anytime. When necessary, the master must slow down the communication and provide either a slower clock or separate frames or data sessions with sufficient delays by MIDI[3:0] bits setting or provide an initial delay by setting MSSI[1:0] which postpones any transaction start to give slave sufficient room for preparing data. Be aware data from the slave are always transacted and processed by the master even if the slave could not prepare it correctly in time. It is preferable for the slave to use DMA, especially when data frames are short, FIFO is accessed by bytes and the SPI bus rate is high.

In order to add some SW control on the SPI communication flow from a slave transmitter node, a specific value written in the SPI_UDRDR (SPI Underrun Data Register) may be used. On slave side, when TxFIFO becomes empty, this value is sent out automatically as next data and may be interpreted by SW on the master receiver side (either simply dropped or interpreted as a XOFF like command, in order to suspend the master receiver by SW).

At multi-slave star topology, a single slave can be only enabled for the output data at a time. The slave just selected for the communication with the master needs to detect a change of its SS input into active level before the communication with the master starts. In a single

slave system it is not necessary to control the slave with SS, but it is often better to provide the pulse here too, to synchronize the slave with the beginning of each data sequence. The SS can be managed by both software and hardware (*Section 55.4.7: Slave select (SS) pin management*).

55.4.12 Procedure for disabling the SPI

When SPI is disabled, it is mandatory to follow the disable procedures described in this paragraph.

At the master mode, it is important to do this before the system enters a low-power mode when the peripheral clock is stopped. Otherwise, ongoing transactions may be corrupted in this case.

In slave mode, the SPI communication can continue when the **spi_pclk** and **spi_ker_ck** clocks are stopped, without interruption, until any end of communication or data service request condition is reached. The **spi_pclk** can generally be stopped by setting the system into STOP mode. Refer to the RCC section for further information.

The master in full duplex or transmit only mode can finish any transaction when it stops providing data for transmission. In this case, the clock stops after the last data transaction. TXC flag can be polled (or interrupt enabled with EOTIE=1) in order to wait for the last data frame to be sent.

When the master is in any receive only mode, in order to stop the peripheral, the SPI communication must be first suspended, by setting CSUSP to 1.

The data received but not read remain stored in RxFIFO when the SPI is suspended.

When SPI is disabled, RxFIFO is flushed. To prevent losing unread data, the user has to ensure that RxFIFO is empty when disabling the SPI, by reading all remaining data (as indicated by the RXP, RXWNE and RXPLVL fields in the SPI_SR register).

The standard disable procedure is based on polling EOT and/or TXC status to check if a transmission session is (fully) completed. This check can be done in specific cases, too, when it is necessary to identify the end of ongoing transactions, for example:

- When the master handles SS signal by a GPIO not related to SPI (for example at case of multi-slave star topology) and it has to provide proper end of SS pulse for slave, or
- When transaction streams from DMA or FIFO are completed while the last data frame or CRC frame transaction is still ongoing in the peripheral bus.

When TSIZE>0, EOT and TXC signals are equal so the polling of EOT is reliable at whatever SPI communication mode to check end of the bus activity. When TSIZE=0, the user has to check TXC, SUSP or FIFO occupancy flags in according with the applied SPI mode and way of the data flow termination.

The correct disable procedure in master mode, except when receive only mode is used, is:

1. Wait until TXC=1 and/or EOT=1 (no more data to transmit and last data frame sent). When CRC is used, it is sent automatically after the last data in the block is processed. TXC/EOT is set when CRC frame is completed in this case. When a transmission is suspended the software has to wait till CSTART bit is cleared.
2. Read all RxFIFO data (until RXWNE=0 and RXPLVL=00)
3. Disable the SPI (SPE=0).

The correct disable procedure for master receive only modes is:

1. Wait on EOT or break the receive flow by suspending SPI (CSUSP=1)
2. Wait until SUSP=1 (the last data frame is processed) if receive flow is suspended.
3. Read all RxFIFO data (until RXWNE=0 and RXPLVL=00)
4. Disable the SPI (SPE=0).

In slave mode, any on going data are lost when disabling the SPI.

55.4.13 Data packing

From user point of view there are two ways of data packing which can overlay each other:

- Type of access when data are written to TxFIFO or read from RxFIFO
  Multiple data can be pushed or fetched effectively by single access if data size is multiplied less than access performed upon SPI_TXDR or SPI_RXDR registers.
- Number of data to be handled during the single software service
  It is convenient to group data into packets and cumulate the FIFO services overall the data packet content exclusively instead of handling data frame by frame separately. The user can define packets by FIFO threshold settings. Then all the FIFO occupancy events are related to that threshold level while required services are signalized by proper flags with interrupt and/or wake up capabilities.

When the data frame size fits into one byte (less than or equal to 8 bits), the data packing is used automatically when any read or write 16-bit or 32-bit access is performed on the SPI_RXDR/SPI_TXDR register. The multiple data frame pattern is handled in parallel in this case. At first, the SPI operates using the pattern stored in the LSB of the accessed word, then with the other data stored in the MSB. *Figure 653* provides an example of data packing mode sequence handling. While DSIZE[3:0] is configured to 4-bit there, two or four data frames are written in the TxFIFO after the single 16-bit or 32-bit access the SPI_TXDR register of the transmitter.

When the data frame size is between 9-bit and 16-bit, data packing is used automatically when a 32-bit access is done. the least significant half-word is used first. (regardless of the LSBFRST value)

This sequence can generate two or four RXP events in the receiver if the RxFIFO threshold is set to 1 frame (and data is read on a frame basis, unpacked), or it can generate a single RXP event if the FTHLV[3:0] field in the SPI_CFG1 register is programmed to a multiple of the frames to be read in a packed mode (16-bit or 32-bit read access).

The data are aligned in accordance with *Figure 652: Data alignment when data size is not equal to 8-bit, 16-bit or 32-bit*. The valid bits are performed on the bus exclusively. Unused bits are not cared at transmitter while padded by zeros at receiver.

When short data frames (<8-bit or < 16-bit) are used together with a larger data access mode (16-bit or 32-bit), the FTHLV value must be programmed as a multiple of the number of frames/data access (i.e. multiple of 4 if 32-bit access is used to up to 8-bit frames or multiple of 2 if 16-bit access is used to up to 8-bit frames or 32-bit access to up to 16-bit frames.).

The RxFIFO threshold setting must always be higher than the following read access size, as spurious extra data would be read otherwise.

The FIFO data access less than the configured data size is forbidden. One complete data frame has to be always accessed at minimum.

A specific problem appears if an incomplete data packet is available at FIFO: less than 4x8-bit frames or one single 16-bit frame is available.

There are two ways of dealing with this problem:

A. without using TSIZE field

On transmitter side, writing the last data frame of any odd sequence with an 8-bit/16-bit access to SPI_TXDR is enough.

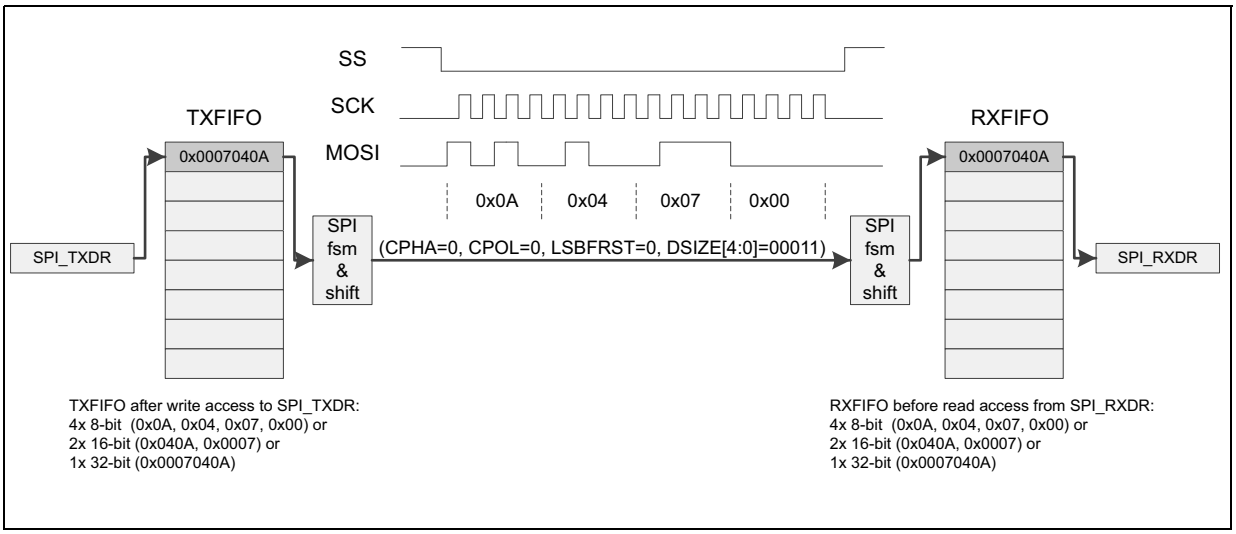
On receiver side, the remaining data may be read by any access. Any extra data read are padded with zeros. Polling the RXWNE and RXPLVL may be used to detect when the RX data are available in the RxFIFO. (a time out may be used at system level in order to detect the polling)

B. using the TSIZE field

On transmitter side, the transaction is stopped by the master when it faces EOT event.

In reception, the RXP flag is not set when EOT is set. In the case when the number of data to be received (TSIZE) is not a multiple of packet size, the number of remaining data is indicated by the RXWNE and RXPLVL fields in the SPI_SR register. The remaining data can be read by any access. Any extra read is padded by zeros.

Figure 653. Packing data in FIFO for transmission and reception



1. DSIZE[3:0] is configured to 4-bit, data is right aligned, valid bits are performed only on the bus, their order depends on LSBFRST, if it is set, the order is reversed at all the data frames.

55.4.14 Communication using DMA (direct memory addressing)

To operate at its maximum speed and to facilitate the data register read/write process required to avoid overrun, the SPI features a DMA capability, which implements a simple request/acknowledge protocol.

A DMA access is requested when the TXDMAEN or RXDMAEN enable bits in the SPI_CFG1 register are set. Separate requests must be issued to the Tx and Rx buffers to fulfill the service of the defined packet.

- In transmission, a series of DMA requests is triggered each time TXP is set to 1. The DMA then performs series of writes to the SPI_TXDR register.
- In reception, a series of DMA requests is triggered each time RXP is set to 1. The DMA then performs series of reads from the SPI_RXDR register. When EOT is set at the end of transaction and last data packet is incomplete then DMA request is activated automatically in according with RXWNE and RXPLVL[1:0] setting to read rest of data.

If the SPI is programmed in receive only mode, UDR is never set.

If the SPI is programmed in a transmit mode, TXP and UDR can be eventually set at slave side, because transmit data may not be available. In this case, some data are sent on the TX line according with the UDR management selection.

When the SPI is used at a simplex mode, the user must enable the adequate DMA channel only while keeping the complementary unused channel and disabled.

If the SPI is programmed in transmit only mode, RXP and OVR are never set.

If the SPI is programmed in full-duplex mode, RXP and OVR are eventually set, because received data are not read.

In transmission mode, when the DMA or the user has written all the data to be transmitted (the TXTF flag is set at SPI_SR register), the EOT (or TXC at case TISEZE=0) flag can be monitored to ensure that the SPI communication is complete. This is required to avoid corrupting the last transmission before disabling the SPI or before disabling the **spi_pclk** in master mode. The software must first wait until EOT=1 and/or TXC=1.

When starting communication using DMA, to prevent DMA channel management raising error events, these steps must be followed in order:

1. Enable DMA Rx buffer in the RXDMAEN bit in the SPI_CFG1 register, if DMA Rx is used.
2. Enable DMA requests for Tx and Rx in DMA registers, if the DMA is used.
3. Enable DMA Tx buffer in the TXDMAEN bit in the SPI_CFG1 register, if DMA Tx is used.
4. Enable the SPI by setting the SPE bit.

To close communication it is mandatory to follow these steps in order:

1. Disable DMA request for Tx and Rx in the DMA registers, if the DMA issued.
2. Disable the SPI by following the SPI disable procedure.
3. Disable DMA Tx and Rx buffers by clearing the TXDMAEN and RXDMAEN bits in the SPI_CFG1 register, if DMA Tx and/or DMA Rx are used.

Data packing with DMA

If the transfers are managed by DMA (TXDMAEN and RXDMAEN set in the SPI_CFG1 register) the packing mode is enabled/disabled automatically depending on the PSIZE value configured for SPI TX and the SPI RX DMA channel.

If the DMA channel PSIZE value is equal to 16-bit or 32-bit and SPI data size is less than or equal to 8-bit, then packing mode is enabled. Similarly, If the DMA channel PSIZE value is equal to 32-bit and SPI data size is less than or equal to 16-bit, then packing mode is enabled.The DMA then automatically manages the write operations to the SPI_TXDR register.

Regardless data packing mode is used and the number of data to transfer is not a multiple of the DMA data size (16-bit or 32-bit) while the frame size is smaller, DMA completes the transfer automatically in according with the TSIZE field setting.

Alternatively, last data frames may be written by software, in the single/unpacked mode.

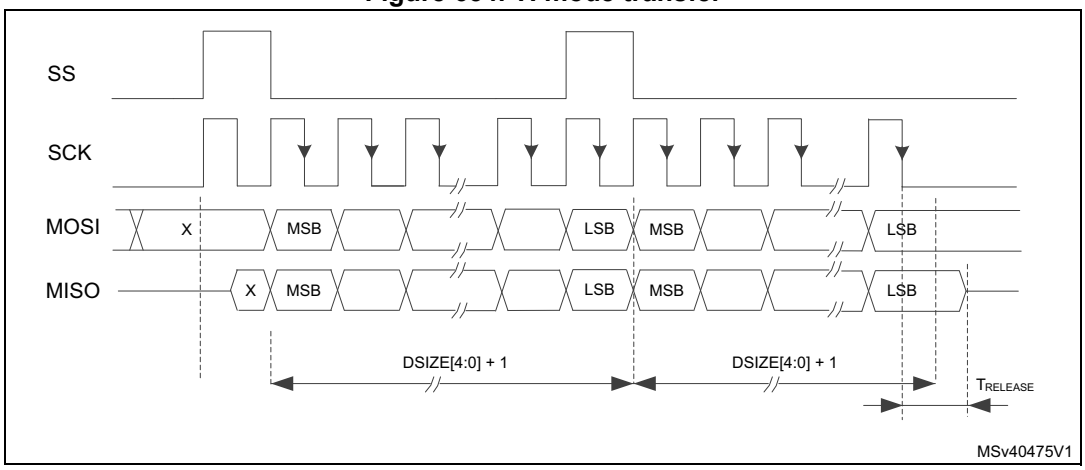
To configure any DMA data access less than the configured data size is forbidden. One complete data frame has to be always accessed at minimum.

55.5 SPI specific modes and control

55.5.1 TI mode

By specific setting of the SP[2:0] bit field at the SPI_CFG2 register the SPI can be configured to be compliant with TI protocol. The SCK and SS signals polarity, phase and flow as well as the bits order are fixed so the setting of CPOL, CPHA, LSBFRST, SSOM, SSOE, SSIOP and SSM is not required when the SPI is at TI mode configuration. The SS signal synchronizes the protocol by pulses over the LSB data bit as it is shown at the *Figure 654: TI mode transfer*.

Figure 654. TI mode transfer



In slave mode, the clock generator is used to define time when the slave output at MISO pin becomes to HiZ when the current transaction finishes. The master baud rate setting (MBR[2:0] at SPI_CFG1) is applied and any baud rate can be used to determine this moment with optimal flexibility. The delay for the MISO signal to become HiZ (TRELEASE) depends on internal re-synchronization, too, which takes next additional 2-4 periods of the clock signal feeding the generator. It is given by formula:

$$\frac{Tbaud}{2} + 2 \times Tspi\_ker\_ck \leq Trelease \leq \frac{Tbaud}{2} + 4 \times Tspi\_ker\_ck$$

If the slave detects misplaced SS pulse during data transaction the TIFRE flag is set.

55.5.2 SPI error flags

An SPI interrupt is generated if one of the following error flags is set and interrupt is enabled by setting the corresponding Interrupt Enable bit.

Overrun flag (OVR)

An overrun condition occurs when data are received by a master or slave and the RxFIFO has not enough space to store these received data. This can happen if the software or the DMA did not have enough time to read the previously received data (stored in the RxFIFO).

When an overrun condition occurs, the OVR flag is set and the newly received value does not overwrite the previous one in the RxFIFO. The newly received value is discarded and all

data transmitted subsequently are lost. OVR flag triggers an interrupt if OVRIE bit is set. Clearing the OVR bit is done by a writing 1 to the OVRC bit in the SPI_IFCR. To prevent any next overrun event the clearing must be done after RxFIFO is emptied by software reads. It is suggested to release the RxFIFO space as much as possible, this means to read out all the available data packets based on the RXP flag indication. At master mode, the user can prevent the RxFIFO overrun by automatic communication suspend (MASRX bit).

Underrun flag (UDR)

At a slave-transmitting mode, the underrun condition is captured internally by hardware if no data is available for transmission in the slave TxFIFO at the moment specified by UDRDET bits. The UDR flag setting is then propagated into the status register by hardware (see note below). UDR triggers an interrupt if the UDRIE bit is set.

Once the underrun is captured next provided data for transmission depends on the UDRCFG bits. The slave can provide out either data stored lastly to its TxFIFO or the data received previously from the master or a constant pattern stored by the user at the UDRDR register. The second configuration can be used at circular topography structure (see *Figure 646*). Standard transmission is re-enabled once the software clears the UDR flag and this clearing is propagated into SPI logic by hardware. The user must write some data into TxFIFO prior clearing UDR flag to prevent any next underrun condition occurrence capture.

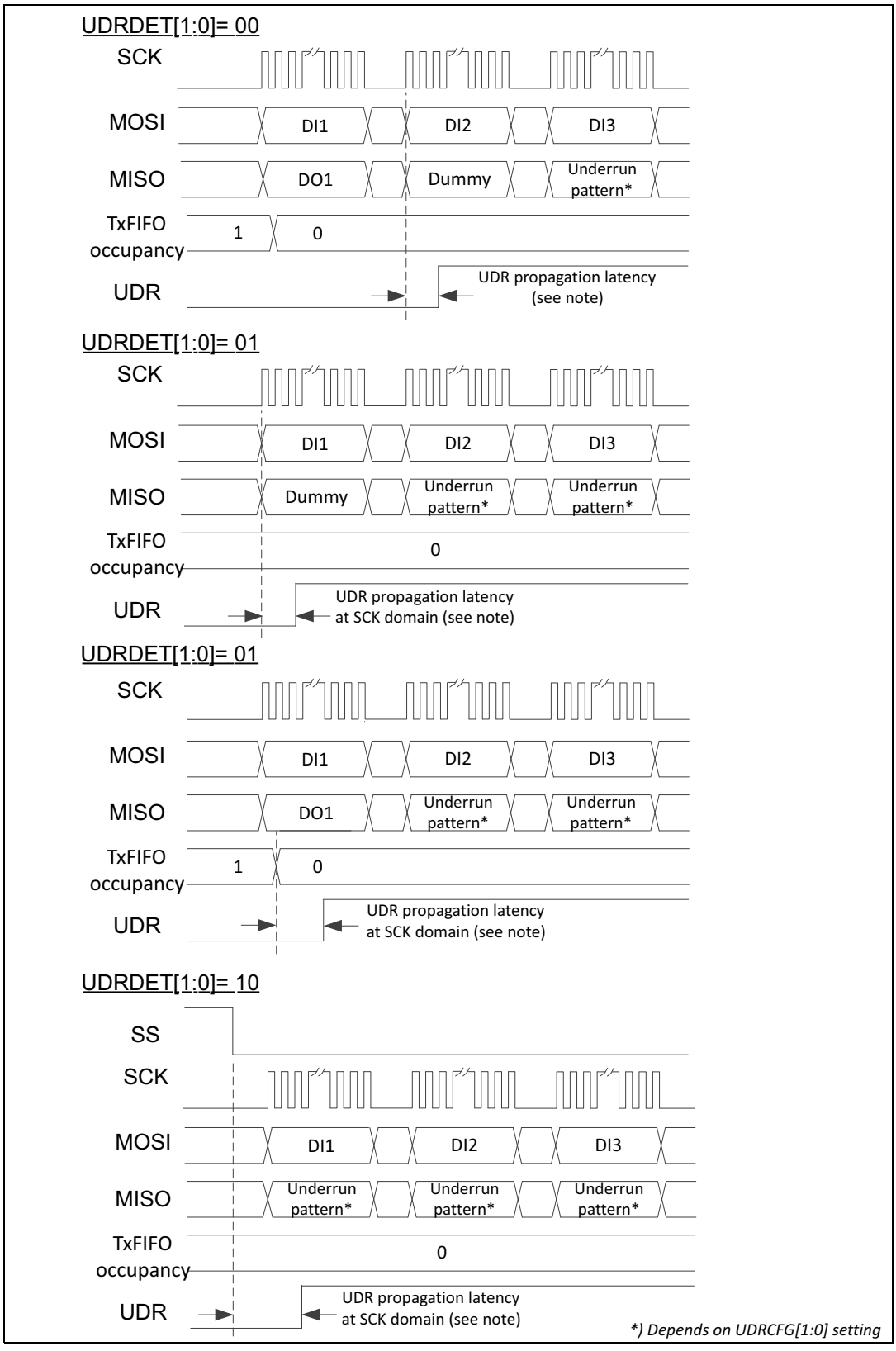
When the configuration UDRDET[1:0]=00 is applied, the underrun condition is evaluated whenever master starts to communicate a new data frame while TxFIFO is empty. Then single additional dummy (accidental) data is always inserted between last valid data and proper underrun pattern defined by UDRCFG[1:0]. This does not happen when any other UDRDET[1:0] configuration is applied suppose the slave's TxFIFO is not empty when underrun condition is checked (see *Figure 655: Optional configurations of slave's behavior at detection of underrun condition*).

The data transacted by slave is unpredictable especially when the transaction starts or continues while TxFIFO is empty and underrun condition is either not yet captured or just cleared. Typically, this is the case when UDRDET[1:0]=00 or SPI is just enabled or when a transaction with a defined size just starts. First bits can be corrupted in this case, as well, when slave software writes first data into the empty TxFIFO too close prior the data transaction starts (propagation of the data into TxFIFO takes few APB clock cycles). If the user cannot ensure to write data into the empty TxFIFO in time the UDRDET[1:0]=00 setting must be avoided.

To handle the underrun control feature correctly the user must avoid next critical encroachments especially

- Any fill of empty TxFIFO when master starts clocking (at UDRDET[1:0]=00 especially)
- Any clear of UDR flag while TxFIFO is empty
- Any setting of UDRDET[1:0]=00 together with UDRCFG[1:0]=10 (to avoid repetition of undefined dummy data)
- Any setting of UDRDET[1:0]=10 when underrun must be detected after each data frame while SS signal does not toggle between the frames
- Any setting of UDRDET[1:0]=10 while SS is managed by software

Figure 655. Optional configurations of slave's behavior at detection of underrun condition



Note: The hardware propagation of an UDR event needs additional traffic on the bus. It always takes few extra SPI clock cycles after the event happens (both underrun captured by hardware and cleared by software). If clearing of the UDR flag by software is applied close to the end of data frame transaction or when the SCK line is at idle in between the frames, the next extra underrun pattern is sent initially by slave prior the valid data from TxFIFO becomes transacted again. The user can prevent this by SPI disable/enable action between sessions to restart the underrun logic and so initiate the next session by the valid data.

Mode fault (MODF)

Mode fault occurs when the master device has its internal SS signal (SS pin in SS hardware mode, or SSI bit in SS software mode) pulled low. This automatically affects the SPI interface in the following ways:

- The MODF bit is set and the interrupt request is triggered if the MODFIE bit is set.
- The SPE bit is forced to zero while MODF bit is set. This blocks all the peripheral outputs and disables the SPI interface.
- The MASTER bit is cleared, thus forcing the device into slave mode.

MODF is cleared by writing 1 to the MODFC bit in the SPI_IFCR.

To avoid any multiple slave conflicts in a system comprising several MCUs, the SS pin must be pulled to its non-active level before re-enabling the SPI, by setting the SPE bit.

As a security, hardware does not allow the SPE bit to be set while the MODF bit is set. In a slave device the MODF bit cannot be set except as the result of a previous multi master conflict.

A correct SW procedure when master overtakes the bus at multi master system must be the following one:

- Switch into master mode while SSOE=0
  (potential conflict can appear when another master occupies the bus. MODF is raised in this case which prevents any next node switching into master mode)
- Put GPIO pin dedicated for another master SS control into active level
- Perform data transaction
- Put GPIO pin dedicated for another master SS control into non active level
- Switch back to slave mode

CRC error (CRCE)

This flag is used to verify the validity of the value received when the CRCEN bit in the SPI_CFG1 register is set. The CRCE flag in the SPI_SR register is set if the value received in the shift register does not match the receiver SPI_RXCRC value, after the last data is received (as defined by TSIZE). The CRCE flag triggers an interrupt if RCEIE bit is set. Clearing the bit CRCE is done by a writing 1 to the CRCEC bit in the SPI_IFCR.

TI mode frame format error (TIFRE)

A TI mode frame format error is detected when an SS pulse occurs during an ongoing communication when the SPI is operating in slave mode and configured to conform to the TI mode protocol. When this error occurs, the TIFRE flag is set in the SPI_SR register. The SPI is not disabled when an error occurs, the SS pulse is ignored, and the SPI waits for the next SS pulse before starting a new transfer. The data may be corrupted since the error detection may result in the loss of few data bytes.

The TIFRE flag is cleared by writing 1 to the TIFREC bit in the SPI_IFCR. If the TIFREIE bit is set, an interrupt is generated on the SS error detection. As data consistency is no longer guaranteed, communication must be re-initiated by software between master and slave.

55.5.3 CRC computation

Two separate 33-bit or two separate 17-bit CRC calculators are implemented in order to check the reliability of transmitted and received data. The SPI offers any CRC polynomial length from 5 to 33 bits when maximum data size is 32-bit and from 5 to 17 bits for the peripheral instances where maximum data size is limited to 16-bit. The length of the polynomial is defined by the most significant bit of the value stored at the CRCPOLY register. It has to be set greater than data frame length defined at DSIZE field. When maximum data size is applied, the CRC33_17 bit has to be set additionally to define the most significant bit of the polynomial string while keep its size always greater than data. The CRCSIZE field in the SPI_CFG1 then defines how many the most significant bits from CRC calculation registers are transacted and compared as CRC frame. It is defined independently from the data frame length, but it must be either equal or an integer multiple of the data frame size while its size cannot exceed the maximum data size of the instance.

To fully benefit from the CRC calculation capability, the polynomial length setting must correspond to the CRC pattern size, else the bits unused at the calculation are transacted and expected all zero at the end of the CRC pattern if its size is set greater than the polynomial length.

CRC principle

The CRC calculation is enabled by setting the CRCEN bit in the SPI_CFG1 register before the SPI is enabled (SPE = 1). The CRC value is then calculated using the CRC polynomial defined by the CRCPOLY register and CRC33_17 bit. When SPI is enabled, the CRC polynomial can be changed but only in case when there is no traffic on the bus.

The CRC computation is done, bit by bit, on the sampling clock edge defined by the CPHA and CPOL bits in the SPI_CR1 register. The calculated CRC value is checked automatically at the end of the data block defined by the SPI_CR2 register exclusively.

When a mismatch is detected between the CRC calculated internally on the received data and the CRC received from the transmitter, a CRCERR flag is set to indicate a data corruption error. The right procedure for handling the CRC depends on the SPI configuration and the chosen transfer management.

CRC transfer management

Communication starts and continues normally until the last data frame has to be sent or received in the SPI_DR register.

The length of the transfer has to be defined by TSIZE and TSER. When the desired number of data is transacted, the TXCRC is transmitted and the data received on the line are compared to the RXCRC value.

TSIZE cannot be set to 0xFFFF value if CRC is enabled. A correct way of sending e.g. 65535 data with CRC is to set:

- TSIZE= 0xFFFE and TSER=1 when data packet is configured to keep one data respective
- TSIZE= 0xFFFC and TSER=3 when data packet keeps 4 data (to ensure the TSIZE value aligned with packet size when its extension is applied).

In transmission, the CRC computation is frozen during CRC transaction and the TXCRC is transmitted, in a frame of length equal to the CRCSIZE field value.

In reception, the RXCRC is also frozen when desired number of data is transacted. Information to be compared with the RXCRC register content is then received in a frame of length equal to the CRCSIZE value.

Once the CRC frame is completed, an automatic check is performed comparing the received CRC value and the value calculated in the SPI_RXCRC register. Software has to check the CRCERR flag in the SPI_SR register to determine if the data transfers were corrupted or not. Software clears the CRCERR flag by writing 1 to the CRCERRC.

The user takes no care about any flushing redundant CRC information, it is done automatically.

Resetting the SPI_TXCRC and SPI_RXCRC values

The SPI_TXCRC and SPI_RXCRC values are initialized automatically when new data is sampled after a CRC phase. This allows the use of DMA circular mode in order to transfer data without any interruption (several data blocks covered by intermediate CRC checking phases). Initialization patterns for receiver and transmitter can be configured either to zero or to all ones in dependency on setting bits TCRCINI and RCRCINI at SPI_CR1 register.

The CRC values are reset when the SPI is disabled.

55.6 Low-power mode management

The SPI has advanced low-power mode functions allowing it to transfer properly data between the FIFOs and the serial interface even when the **spi_pclk** clock is disabled.

In master mode the **spi_ker_ck** kernel clock is needed in order to provide the timings of the serial interface.

In slave mode, the **spi_ker_ck** clock can be removed as well during the transfer of data between the FIFOs and the serial interface. In this mode the clock is provided by the external SPI device.

When the **spi_pclk** clock is gated, (and the **spi_ker_ck** clock as well if the SPI is in slave), the SPI provides a wakeup event signal (**spi_wkup**) if a specific action requiring the activation of the **spi_pclk** clock is needed, such as:

- To fill-up the TxFIFO,
- To empty the RxFIFO,
- Other signaling: end of transfer, errors...

The generation of **spi_ker_ck** and **spi_pclk** clock are controlled by the RCC block according to register settings and the processors modes. Refer to the RCC section for details.

The **spi_pclk** clock request stays pending till a flag with enabled interrupt is set. That is why it is important to service these pending requests and clear their flag as soon as possible at system sensitive to the low power consumption especially and the application must acknowledge all pending interrupts events before switching the SPI to low-power mode (i.e. removing **spi_pclk**).

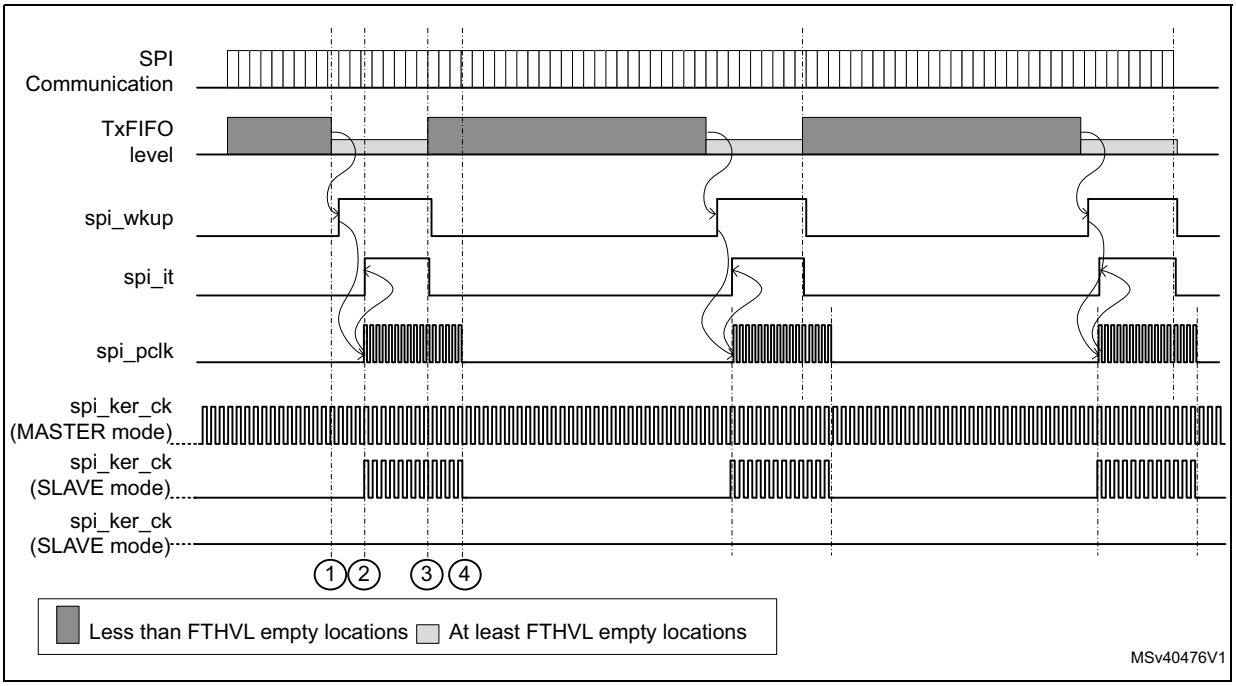
The *Figure 656* shows an example of the clock handling when the SPI2S is working in low-power mode. The example is given for a transmit mode.

In master mode the **spi_ker_ck** clock is required for the timing generation.

The *Figure 656* shows two kinds of supported scenarios for the handling of the **spi_ker_ck** kernel clock in slave mode:

- In most of the slave modes, the **spi_ker_ck** kernel clock can be disabled,
- In some products, the **spi_ker_ck** kernel clock activation may follow the system state.

Figure 656. Low-power mode application example



The figure clearly shows that the **spi_pclk** must be provided to the SPI2S, when data need to be transferred from the memory to the SPI2S TxFIFO. Here is the description of the most important steps:

- **Step 1**
  The TxFIFO level goes below the programmed threshold, this event (TXP) activates the **spi_wkup** signal. This signal is generally used to wake-up the system from low-power mode, and thus to activate the bus clock (**spi_pclk**).
- **Step 2**
  When **spi_pclk** is activated, the **spi_it** is also activated, and the product is ready to fill-up the TxFIFO either by DMA or by software. Note as well that for some product the system wake-up automatically enables the **spi_ker_ck** kernel clock as well.
- **Step 3**
  When the amount of empty locations in the TxFIFO is less than FTHLV, then the **spi_wkup** and **spi_it** signals are deactivated, but the fill-up of the TxFIFO may

continue. Note that **spi_wkup** falling edge is aligned with the serial interface clock domain, and the falling edge of the **spi_it** is aligned with the **spi_pclk** clock domain.

- **Step 4**
  The fill-up of the TxFIFO is completed; the software can switch the system back to low-power mode until the next **spi_wkup** occurs.

55.7 SPI wakeup and interrupts

Table 435 gives an overview of the SPI events capable to generate interrupt events (**spi_it**). Some of them feature wake-up from low-power mode capability additionally (**spi_wkup**).

Most of them can be enabled and disabled independently while using specific interrupt enable control bits.

The flags associated with the events are cleared by specific methods. Refer to the description of SPI registers for more details about the event flags. All the pending interrupt requests stay active if the SPI is disabled. A not cleared request with an enabled interrupt generates a spi_pclk clock request and so increases the overall consumption.

Table 435. SPI wakeup and interrupt requests

Interrupt event	Event flag(1)	Enable Control bit	Event clear method	Interrupt/Wakeup activated	
				spi_it	spi_wkup
TxFIFO ready to be loaded (space available for one data packet - FIFO threshold)	TXP	TXPIE	TXP cleared by hardware when TxFIFO contains less than FTHLV empty locations	YES	YES
Data received in RxFIFO (one data packet available - FIFO threshold)	RXP	RXPIE	RXP cleared by hardware when RxFIFO contains less than FTHLV samples		YES
Both TXP and RXP active	DXP	DXPIE	When TXP or RXP are cleared		YES
Transmission Transfer Filled	TXTF	TXTFIE	Writing TXTFC to 1		NO
Underrun	UDR	UDRIE	Writing UDRC to 1		YES
Overrun	OVR	OVRIE	Writing OVRC to 1		YES
CRC Error	CRCE	CRCEIE	Writing CRCEC to 1		YES
TI Frame Format Error	TIFRE	TIFREIE	Writing TIFREC to 1		NO
Mode Fault	MODF	MODFIE	Writing MODFC to 1		NO
End Of Transfer (full transfer sequence completed - based on TSIZE value)	EOT	EOTIE	Writing EOTC to 1		YES
Master mode suspended	SUSP		Writing SUSPC to 1		YES
TxFIFO transmission complete (TxFIFO empty)	TXC(2)		TXC cleared by HW when a transmission activity starts on the bus		NO
TSER value transferred to TSIZE (new value may be loaded to TSER)	TSERF	TSERFIE	Writing TSERFC to 1		NO

1. Refer to SPI2S register description for more details about the event flags.
2. The TXC flag behavior depends on the TSIZE setting. When TSIZE>0, the flag fully follows the EOT one including its clearing by EOTC.

55.8 I2S main features

- Full duplex communication
- Half-duplex communication (only transmitter or receiver)
- Master or slave operations
- 8-bit programmable linear prescaler
- Data length may be 16, 24 or 32 bits
- Channel length can be 16 or 32 in master, any value in slave
- Programmable clock polarity
- Error flags signaling for improved reliability: Underrun, Overrun and Frame Error
- Embedded Rx and TxFIFOs
- Supported I^2S protocols:
  - I^2S Philips standard
  - MSB-Justified standard (Left-Justified)
  - LSB-Justified standard (Right-Justified)
  - PCM standard (with short and long frame synchronization)
- Data ordering programmable (LSb or MSb first)
- DMA capability for transmission and reception
- Master clock can be output to drive an external audio component. The ratio is fixed at 256 x F_{WS} (where F_{WS} is the audio sampling frequency)

55.9 I2S functional description

55.9.1 I2S general description

The block diagram shown on *Figure 641* also applies for I2S mode.

The SPI/I2S block can work on I2S/PCM mode, when the bit I2SMOD is set to 1. A dedicated register (SPI_I2SCFGR) is available for configuring the dedicated I2S parameters, which include the clock generator, and the serial link interface.

The I2S/PCM function uses the clock generator to produce the communication clock when the SPI/I2S is set in master mode. This clock generator is also the source of the master clock output (MCK).

Resources such as RxFIFO, TxFIFO, DMA and parts of interrupt signaling are shared with SPI function. The low-power mode function is also available in I2S mode, refer to *Section 55.6: Low-power mode management* and *Section 55.10: I2S wakeup and interrupts*.

55.9.2 Pin sharing with SPI function

The I2S shares four common pins with the SPI:

- SDO: Serial Data Output (mapped on the MOSI pin) to transmit the audio samples in master, and to receive the audio sample in slave. Refer to *Section : Serial Data Line swapping on page 2240*.
- SDI: Serial Data Input (mapped on the MISO pin) to receive the audio samples in master, and to transmit the audio sample in slave. Refer to *Section : Serial Data Line swapping on page 2240*.
- WS: Word Select (mapped on the SS pin) is the frame synchronization. It is configured as output in master mode, and as input for slave mode.
- CK: Serial Clock (mapped on the SCK pin) is the serial bit clock. It is configured as output in master mode, and as input for slave mode.

An additional pin can be used when a master clock output is needed for some external audio devices:

- MCK: Master Clock (mapped separately) is used, when the I2S is configured in master mode. The master clock rate is fixed to 256 x F_{WS}, where F_{WS} is the audio sampling frequency.

55.9.3 Bits and fields usable in I2S/PCM mode

When the I2S/PCM mode is selected (I2SMOD = ‘1’), some bit fields are no longer relevant, and must be forced to a specific value in order to guarantee the behavior of the I2S/PCM function. *Table 436* shows the list of bits and fields available in the I2S/PCM mode, and indicates which must be forced to a specific value.

Table 436. Bit fields usable in PCM/I2S mode

Register name	Bit fields usable in PCM/I2S Mode	Constraints on other bit fields
SPI/I2S control register 1 (SPI_CR1)	IOLOCK, CSUSP, CSTART	Other fields set to their reset values
SPI control register 2 (SPI_CR2)	-	Set to reset value
SPI configuration register 1 (SPI_CFG1)	TXDMAEN, RXDMAEN, FTHLV	Other fields set to their reset values
SPI configuration register 2 (SPI_CFG2)	AFCNTR, LSBFRST, IOSWP	Other fields set to their reset values
SPI/I2S interrupt enable register (SPI_IER)	TIFREIE, OVRIE, UDRIE, TXPIE, RXPIE	
SPI/I2S status register (SPI_SR)	RXWNE, RXPLVL, SUSP, TIFRE, OVR, UDR, TXP, RXP	Other flags not relevant
SPI/I2S interrupt/status flags clear register (SPI_IFCR)	SUSPC, TIFREC, OVRC, UDRC	Other fields set to their reset values
SPI/I2S transmit data register (SPI_TXDR)	The complete register	-
SPI/I2S receive data register (SPI_RXDR)	The complete register	-
SPI polynomial register (SPI_CRCPOLY)	-	Set to reset value
SPI transmitter CRC register (SPI_TXCRC)	-	
SPI receiver CRC register (SPI_RXCRC)	-	
SPI underrun data register (SPI_UDRDR)	-	
SPI/I2S configuration register (SPI_I2SCFGR)	The complete register	-

55.9.4 Slave and master modes

The SPI/I2S block supports master and slave mode for both I2S and PCM protocols.
In master mode, both CK, WS and MCK signals are set to output.

In slave mode, both CK and WS signals are set to input. The signal MCK is not used in slave mode.

In order to improve the robustness of the SPI/I2S block in slave mode, the peripheral re-synchronizes each reception and transmission on WS signal. This means that:

- In I2S Philips standard, the shift-in or shift-out of each data is triggered one bit clock after each transition of WS.
- In I2S MSB justified standard, the shift-in or shift-out of each data is triggered as soon as a transition of WS is detected.
- In PCM standard, the shift-in or shift-out of each data is triggered one bit clock after the rising edge WS.

Note: This re-synchronization mechanism is not available for the I2S LSB justified standard.

Note: Note as well that there is no need to provide a kernel clock when the SPI/I2S is configured in slave mode.

55.9.5 Supported audio protocols

The I2S/PCM interface supports four audio standards, configurable using the I2SSTD[1:0] and PCMSYNC bits in the SPI_I2SCFGR register.

In the I2S protocol, the audio data are time-multiplexed on two channels: the left channel and the right channel. The WS signal is used to indicate which channel shall be considered as the left, and which one is the right.

In I2S master mode, four frames formats are supported:

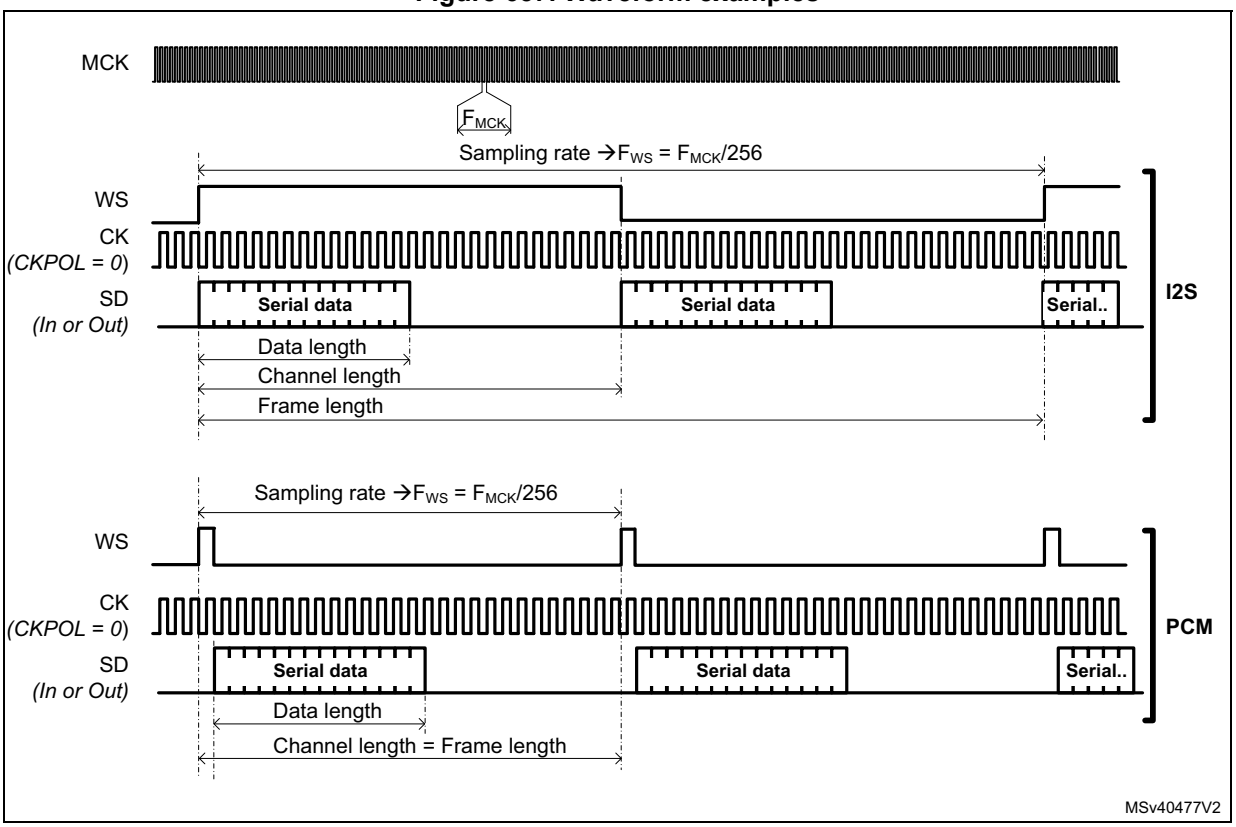
- 16-bit data packed in a 16-bit channel
- 16-bit data packed in a 32-bit channel
- 24-bit data packed in a 32-bit channel
- 32-bit data packed in a 32-bit channel

In PCM master mode, three frames formats are supported:

- 16-bit data packed in a 16-bit channel
- 16-bit data packed in a 32-bit channel
- 24-bit data packed in a 32-bit channel

The figure hereafter shows the main definition used in this section: data length, channel length and frame length.

Figure 657. Waveform examples

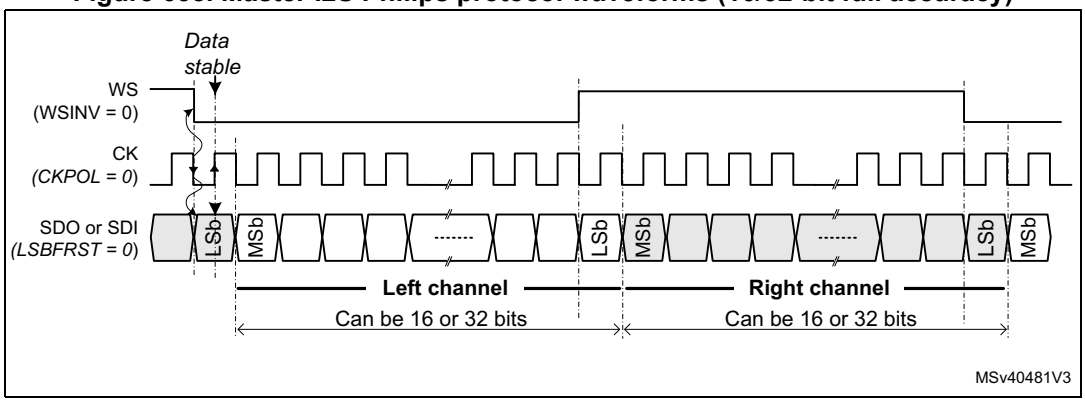


I²S Philips standard

The I2S Philips standard is selected by setting I2SSTD to 0b00. This standard is supported in master and slave mode.

In this standard, the WS signal toggles one CK clock cycle before the first bit (MSb in I2S Philips standard) is available. A falling edge transition of WS indicates that the next data transfered is the left channel, and a rising edge transition indicates that the next data transfered is the right channel.

Figure 658. Master I2S Philips protocol waveforms (16/32-bit full accuracy)

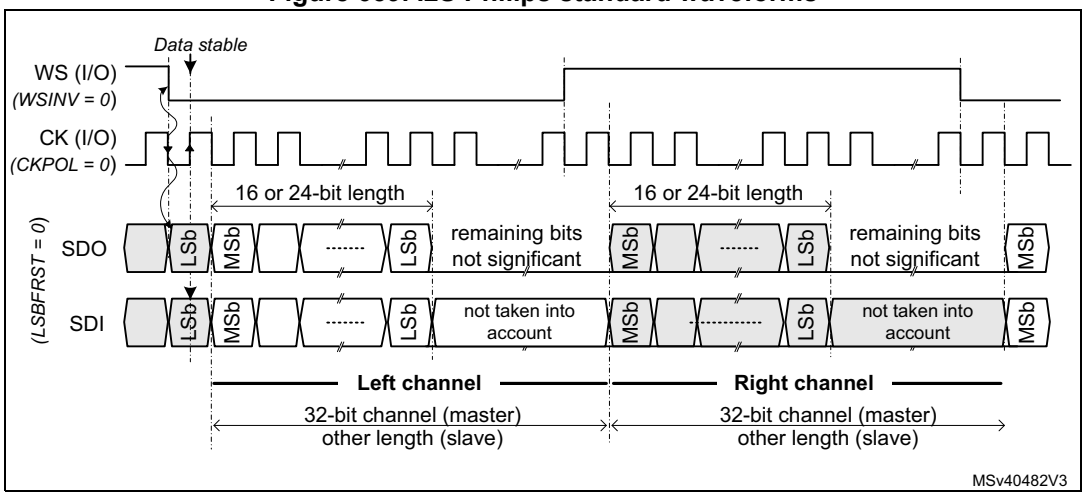


CKPOL is set to 0 in order to match the I2S Philips protocol. See *Selection of the CK sampling edge* for information concerning the handling of WS signal.

Figure 658 shows an example of waveform generated by the SPI/I2S in the case where the channel length is equal to the data length. More precisely, this is true when CHLEN = 0 and DATLEN = 0b00 or when CHLEN = 1 and DATLEN = 0b10.

See *Control of the WS Inversion* for information concerning the handling of WS signal.

Figure 659. I2S Philips standard waveforms

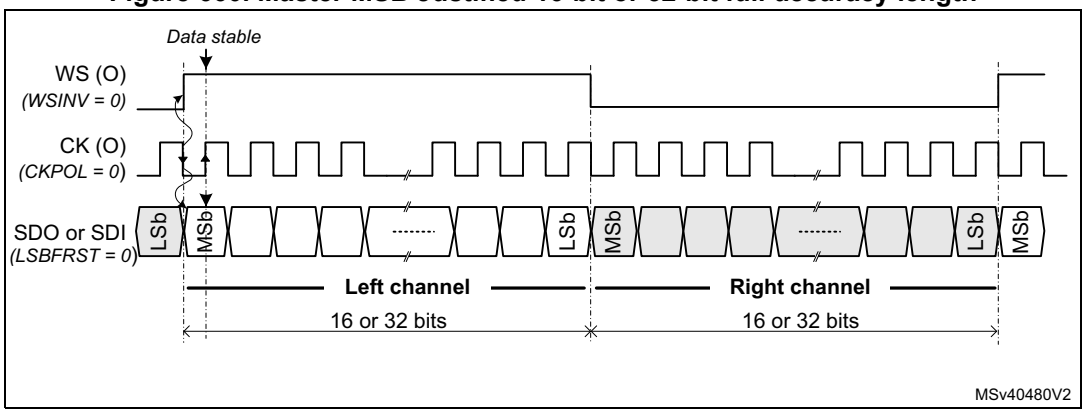


In the case where the channel length is bigger than the data length, the remaining bits are forced to zero when the SPI/I2S is configured in transmit mode. This is applicable for both master and slave mode.

MSB justified standard

For this standard, the WS signal toggles when the first data bit, is provided. The data transfered represents the left channel if WS is high, and the right channel if WS is low.

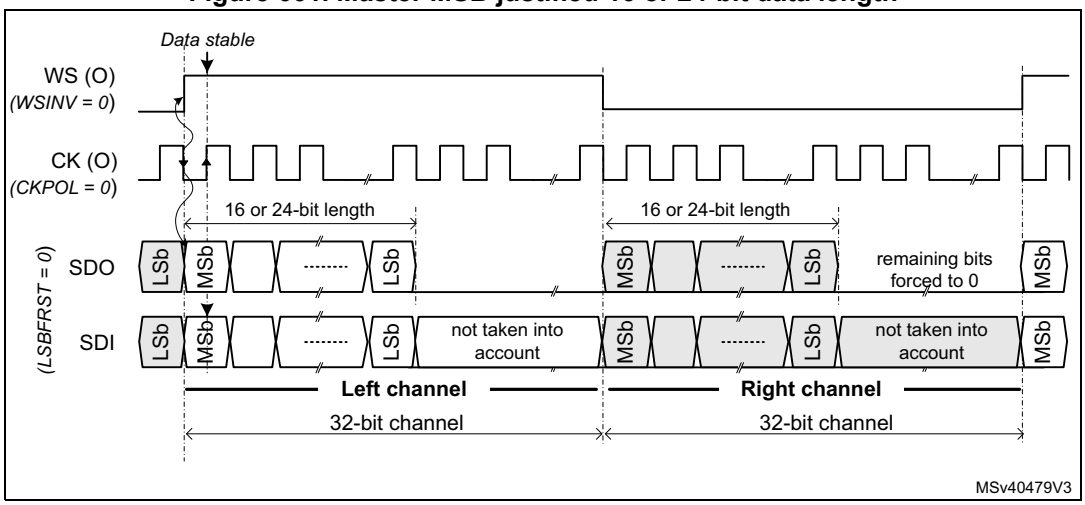
Figure 660. Master MSB Justified 16-bit or 32-bit full-accuracy length



CKPOL is set to 0 in order to match the I2S MSB justified protocol. See *Selection of the CK sampling edge* for information concerning the handling of WS signal.

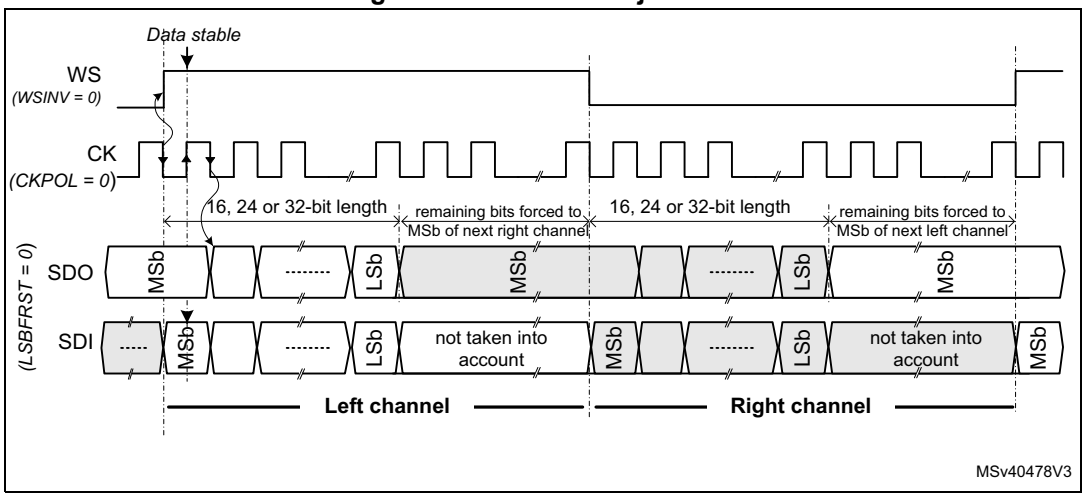
See *Control of the WS Inversion* for information concerning the handling of WS signal.

Figure 661. Master MSB justified 16 or 24-bit data length



In the case where the channel length is bigger than the data length, the remaining bits are forced to zero when the SPI/I2S is configured in master transmit mode. In slave transmit the remaining bits are forced to the value of the first bit of the next data to be generated in order to avoid timing issues (see *Figure 662*).

Figure 662. Slave MSB justified

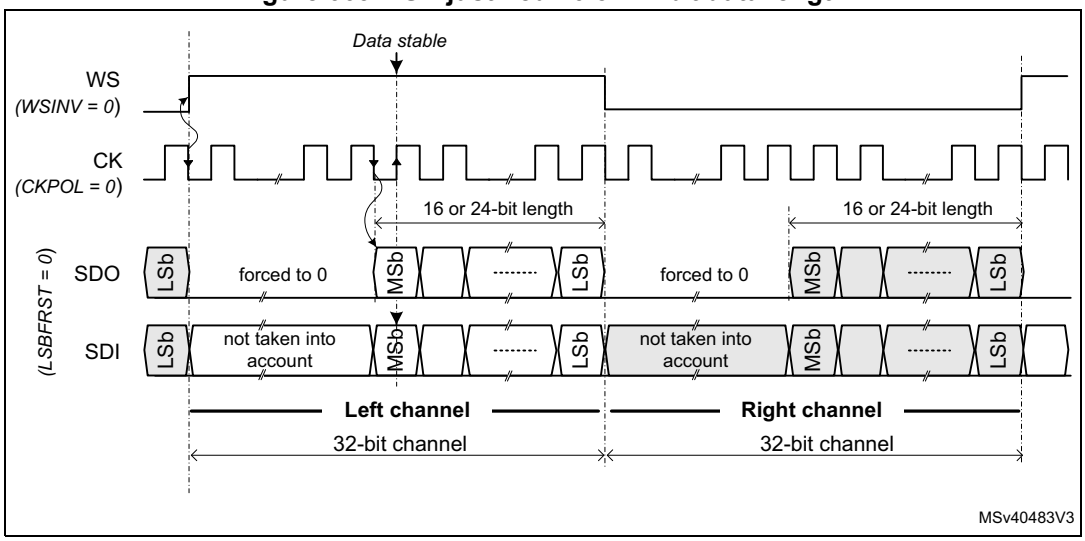


LSB justified standard

This standard is similar to the MSB justified standard in master mode (no difference for the 16 and 32-bit full-accuracy frame formats). The LSB justified 16 or 32-bit full-accuracy format give similar waveforms than MSB justified mode (see *Figure 660*) because the channel and data have the same length.

Note: In the LSB justified format, only 16 and 32-bit channel length are supported in master and slave mode. This is due to the fact that it is not possible to transfer properly the data if the channel length is not known by transmitter and receiver side.

Figure 663. LSB justified 16 or 24-bit data length



CKPOL is set to 0 in order to match the I2S LSB justified protocol. See *Selection of the CK sampling edge* for information concerning the handling of WS signal.

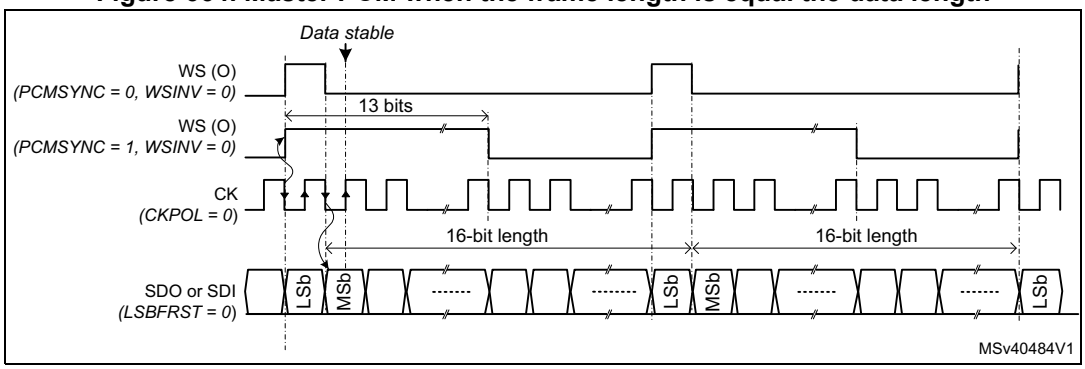
See *Control of the WS Inversion* for information concerning the handling of WS signal.

PCM standard

For the PCM standard, there is no need to use channel-side information. The two PCM modes (short and long frame) are available and configurable using the PCMSYNC bit in SPI_I2SCFGR register.

Note: The difference between the PCM long and short frame, is just the width of the frame synchronization: for both protocols, the active edge of the frame is generated (or is expected for the Slave mode) one CK clock cycle before the first bit.

Figure 664. Master PCM when the frame length is equal the data length



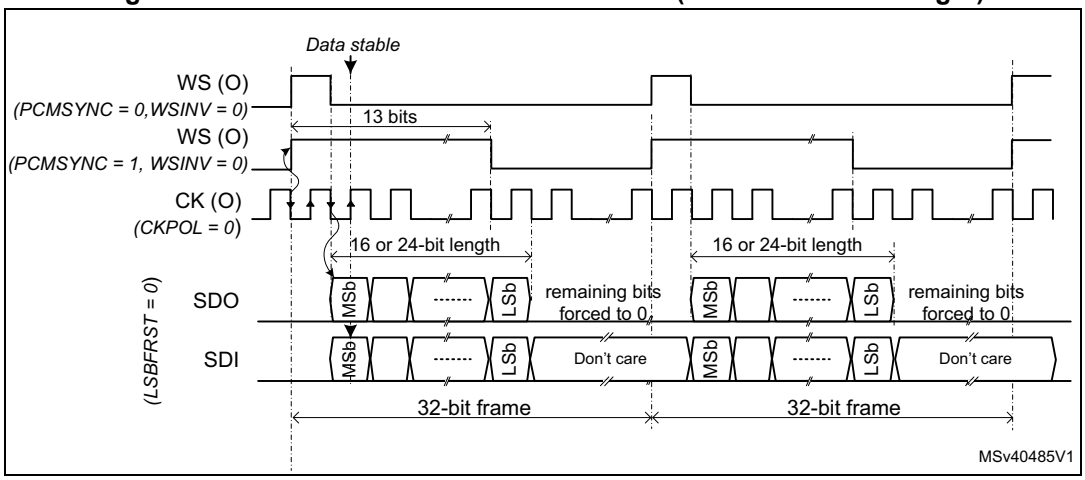
For long frame synchronization, the WS signal assertion time is fixed to 13 bits in master mode.

A data size of 16 or 24 bits can be used when the channel length is set to 32 bits.

For short frame synchronization, the WS synchronization signal is only one cycle long.

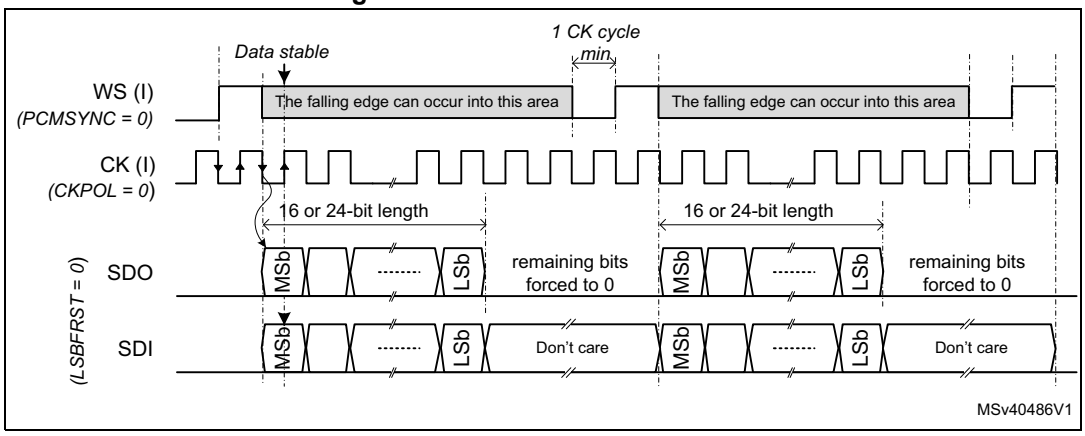
See *Control of the WS Inversion* for information concerning the handling of WS signal.

Figure 665. Master PCM standard waveforms (16 or 24-bit data length)



If the PCM protocol is used in slave mode, frame lengths can be different from 16 or 32 bits. As shown in *Figure 666*, in slave mode various pulse widths of WS can be accepted as the start of frame is detected by a rising edge of WS. The only constraint is that the WS must go back to its inactive state for at least one CK cycle.

Figure 666. Slave PCM waveforms



CKPOL is set to 0 in order to match the PCM protocol. See *Selection of the CK sampling edge* for information concerning the handling of WS signal.

55.9.6 Additional Serial Interface Flexibility

Variable frame length in slave

In slave mode, channel lengths different from 16 or 32 bits can be accepted, as long as the channel length is bigger than the data length. This is true for all protocols except for I2S LSB justified protocol.

Data ordering

For all data formats and communication standards, it is possible to select the data ordering (MSb or LSb first) thanks to the bit LSBFRST located into *SPI configuration register 2 (SPI_CFG2)*.

Selection of the CK sampling edge

The CKPOL bit located into *SPI/I2S configuration register (SPI_I2SCFGR)* allows the user to choose the sampling edge polarity of the CK for slave and master modes, for all protocols.

- When CKPOL = 0, serial data SDO and WS (when master) are changed on the falling edge of CK and the serial data SDI and WS (when slave) are read on the rising edge.
- When CKPOL = 1, serial data SDO and WS (when master) are changed on the rising edge of CK and the serial data SDI and WS (when slave) are read on the falling edge.

Control of the WS Inversion

It is possible to invert the default WS signal polarity for master and slave modes, for all protocols, by setting WSINV to 1. By default the WS polarity is the following:

- In I2S Philips Standard, WS is low for left channel, and high for right channel
- In MSB/LSB justified mode, WS is high for left channel, and low for right channel
- In PCM mode, the start of frame is indicated by a rising edge of WS.

When WSINV is set to 1, the WS polarity is inverted, then:

- In I2S Philips Standard, WS is high for left channel, and low for right channel
- In MSB/LSB justified mode, WS is low for left channel, and high for right channel
- In PCM mode, the start of frame is indicated by a falling edge of WS.

WSINV is located into *SPI/I2S configuration register (SPI_I2SCFGR)*.

Control of the IOs

The SPI/I2S block allows the settling of the WS and CK signals to their inactive state before enabling the SPI/I2S thanks to the AFCNTR bit of *SPI configuration register 2 (SPI_CFG2)*.

This can be done by programming CKPOL and WSINV using the following sequence:

Assuming that AFCNTR is initially set to 0

– Set I2SMOD = 1, (In order to inform the hardware that the CK and WS polarity is controlled via CKPOL and WSINV).
– Set bits CKPOL and WSINV to the wanted value.
– Set AFCNTR = 1.
Then the inactive level of CK and WS IOs is set according to CKPOL and WSINV values, even if the SPI/I2S is not yet enabled.
– Then performs the activation sequence of the I2S/PCM

Table 437 shows the level of WS and CK signals, when the AFCNTR bit is set to 1, and before the SPI/I2S block is enabled (i.e. inactive level). Note that the level of WS depends also on the protocol selected.

Table 437. WS and CK level before SPI/I2S is enabled when AFCNTR = 1

WSINV	I2SSTD		WS level before SPI/I2S is enabled
0	I2S Std (00)	→	High
	Others	→	Low
1	I2S Std (00)	→	Low
	Others	→	High

CKPOL		CK level before SPI/I2S is enabled
0	→	Low
1	→	High

Note: The bit AFCNTR shall not be set to 1, when the SPI2S is in slave mode.

Serial Data Line swapping

The SPI/I2S offers the possibility to swap the function of SDI and SDO lines thanks to IOSWP bit located into *SPI configuration register 2 (SPI_CFG2)*. *Table 438* gives details on this feature.

Table 438. Serial data line swapping

Configuration	IOSWP	SDI direction	SDO direction
Master/slave RX	0	IN	-
	1	-	IN

Table 438. Serial data line swapping (continued)

Configuration	IOSWP	SDI direction	SDO direction
Master/slave TX	0	-	OUT
	1	OUT	-
Master/slave Full-duplex	0	IN	OUT
	1	OUT	IN

For simplification, the waveforms shown in the *I2S functional description* section have been done with IOSWP = 0.

55.9.7 Start-up sequence

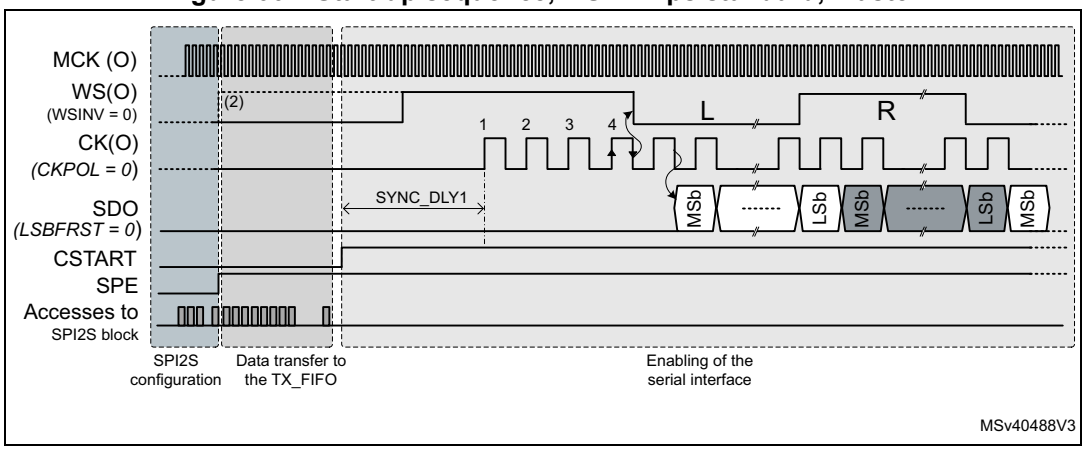
When the bit SPE is set to 0, the user is not allowed to read and write into the SPI_RXDR and SPI_TXDR registers, but the access to other registers is allowed.

When the application wants to use the SPI/I2S block the user has to proceed as follow:

1. Insure that the SPE is set to 0, otherwise write SPE to 0.
2. Program all the configuration and control registers according to the wanted configuration. Refer to *Section 55.9.16* for detailed programming examples.
3. Set the SPE bit to 1, in order to activate the SPI/I2S block. When this bit is set, the serial interface is still disabled, but the DMA and interrupt services are working, allowing for example, the data transfer into the TxFIFO.
4. Set bit CSTART to 1, in order to activate the serial interface.

As shown in *Figure 667*, in I2S Philips standard master TX, the generation of the WS, MCK and CK signals is started as soon as the bit CSTART is set to 1 and the TxFIFO is not empty. Note that the bit clock CK is activated 4 rising edges before the falling edge of WS in order to insure that the external slave device can detect properly WS transition. Other standards behave similarly.

Figure 667. Start-up sequence, I2S Philips standard, master



1. In this figure, the MCK is enabled before setting the bit SPE to 1. See *MCK Generation* for more information.
2. Note that the level of WS and CK signals are controlled by the SPI/I2S block during the configuration phase as soon as the AFCNTR bit is set to 1

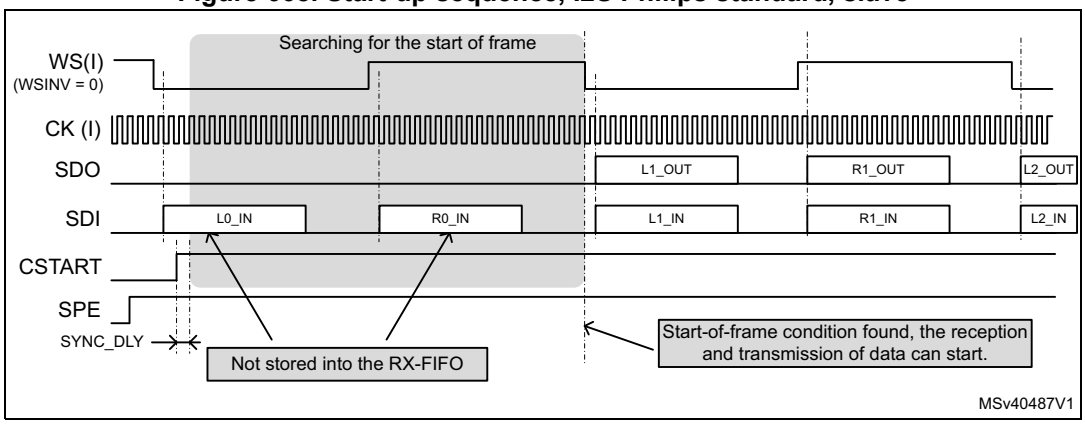
Note: Due to clock domain resynchronization, the CSTART bit is taken into account by the hardware after about 3 periods of CK clock (SYNC_DLY1).

In slave mode, once the bit CSTART is set to 1, the data transfer starts when the start-of-frame condition is met:

- For I2S Philips standard, the start-of-frame condition is a falling edge of WS signal. The transmission/reception starts one bit clock later.
  If WSINV = 1, then the start-of-frame condition is a rising edge.
- For other protocols, the start-of-frame condition is a rising edge of WS signal. The transmission/reception starts at rising edge of WS for MSB aligned protocol.The transmission/reception starts one bit clock later for PCM protocol.
  If WSINV = 1, then the start-of-frame condition is a falling edge.

Figure 668 shows an example of start-up sequence in I2S Philips standard, slave mode.

Figure 668. Start-up sequence, I2S Philips standard, slave



Note: Due to clock domain resynchronization, the CSTART bit is taken into account by the hardware after 2 periods of CK clock (SYNC_DLY).

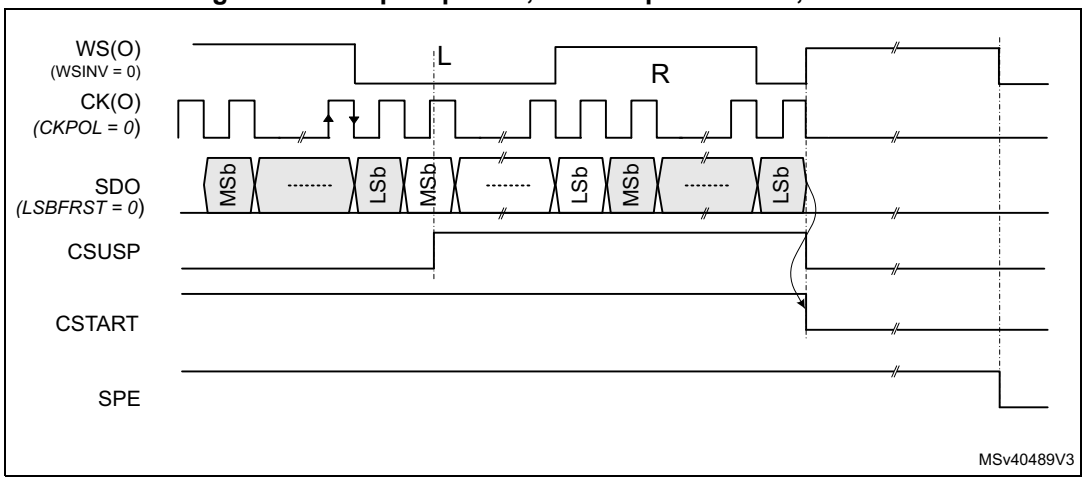
55.9.8 Stop sequence

The application can stop the I2S/PCM transfers by setting the SPE bit to 0. In that case the communication is stopped immediately, without waiting for the end of the current frame.

In master mode it is also possible to stop the I2S/PCM transfers at the end of the current frame. For that purpose, the user has to set the bit CSUSP to 1, and polls the CSTART bit until it goes to 0. The CSTART bit goes to 0 when the current stereo (if an I2S mode was selected) or mono sample are completely shifted in or out. Then the SPE bit can be set to 0.

The *Figure 669* shows an example of stop sequence in the case of master mode. The CSUSP bit is set to 1, during the transmission of left sample, the transfer continue until the last bit of the right sample is transferred. Then CSTART and CSUSP go back to 0, CK and WS signals go back to their inactive state, and the user can set SPE to 0.

Figure 669. Stop sequence, I2S Philips standard, master

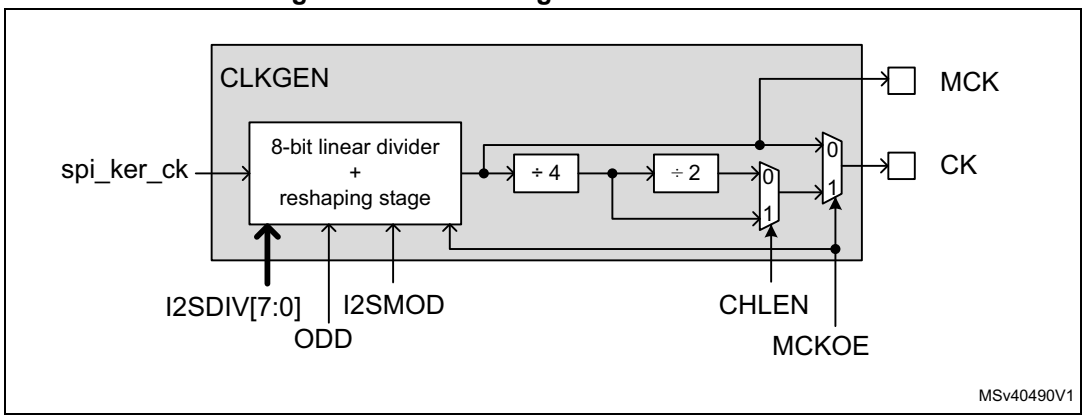


Note: In slave mode, the stop sequence is only controlled by the SPE bit.

55.9.9 Clock generator

When the I2S or PCM is configured in master mode, the user needs to program the clock generator in order to produce the Frame Synchronization (WS), the bit clock (CK) and the master clock (MCK) at the desired frequency.
If the I2S or PCM is used in slave mode, there is no need to configure the clock generator.

Figure 670. I²S clock generator architecture



The frequency generated on MCK, CK and WS depends mainly on I2SDIV, ODD, CHLEN and MCKOE. The bit MCKOE indicates if a master clock need to be generated or not. The master clock has a frequency 256 times higher than the frame synchronization. This master clock is often required to provide a reference clock to external audio codecs.

Note: In master mode, there is no specific constraints on the ratio between the bus clock rate (F_{pclk}) and the bit clock (F_{CK}). The bus clock frequency must be high enough in order to support the data throughput.

When the master clock is generated (MCKOE = 1), the frequency of the frame synchronization is given by the following formula in I2S mode:

$$F_{WS} = \frac{F_{i2s\_clk}}{256 \times \{(2 \times I2SDIV) + ODD\}}$$

and by this formula in PCM mode:

$$F_{WS} = \frac{F_{i2s\_clk}}{128 \times \{(2 \times I2SDIV) + ODD\}}$$

In addition, the frequency of the MCK (F_{MCK}) is given by the formula:

$$F_{MCK} = \frac{F_{i2s\_clk}}{\{(2 \times I2SDIV) + ODD\}}$$

When the master clock is disabled (MCKOE = 0), the frequency of the frame synchronization is given by the following formula in I2S mode:

$$F_{WS} = \frac{F_{i2s\_clk}}{32 \times (CHLEN + 1) \times \{(2 \times I2SDIV) + ODD\}}$$

And by this formula in PCM mode:

$$F_{WS} = \frac{F_{i2s\_clk}}{16 \times (CHLEN + 1) \times \{(2 \times I2SDIV) + ODD\}}$$

Where F_{WS} is the frequency of the frame synchronization, and F_{i2s_clk} is the frequency of the kernel clock provided to the SPI/I2S block.

Note: CHLEN and ODD can be either 0 or 1.
I2SDIV can take any values from 0 to 255 when ODD = 0, but when ODD = 1, the value I2SDIV = 1 is not allowed.

When I2SDIV = 0, then {(2 x I2SDIV) + ODD} is forced to 1.

Note: When {(2 x I2SDIV) + ODD} is odd, the duty cycle of MCK or the CK signals is not 50%. Care must be taken when odd ratio is used: it can impact margin on setup and hold time. For example if {(2 x I2SDIV) + ODD} = 5, then the duty cycle can be 40%.

Table 439 provides examples of clock generator programming for I2S modes.

MCK Generation

The master clock MCK can be generated regardless to the SPE bit. The MCK generating is controlled by the following bits:

- I2SMOD must equal to 1,
- I2SCFG must select a master mode,
- MCKOE must be set to 1

Table 439. CLKGEN programming examples for usual I2S frequencies

i2s_clk (MHz)	Channel length (bits)	I2SDIV	ODD	MCK	Sampling rate: F_{WS} (kHz)
12.288	16	12	0	No	16
12.288	32	6	0		16
12.288	16	6	0		32
12.288	32	3	0		32
49.152	16	16	0		48
49.152	32	8	0		48
49.152	16	8	0		96
49.152	32	4	0		96
49.152	16	4	0		192
49.152	32	2	0		192
4.096	16 or 32	0	-	Yes	16
24.576	16 or 32	3	0		
49.152	16 or 32	3	0		32
12.288	16 or 32	0	-		48
49.152	16 or 32	2	0		
61.44	16 or 32	2	1		
98.304	16 or 32	2	0		96
196.608	16 or 32	2	0		192

55.9.10 Internal FIFOs

The I2S interface can use a dedicated FIFO for the RX and the TX path. The samples to transmit can be written into the TxFIFO via the SPI_TXDR register. The reading of RxFIFO is performed via the SPI_RXDR register.

Data alignment and ordering

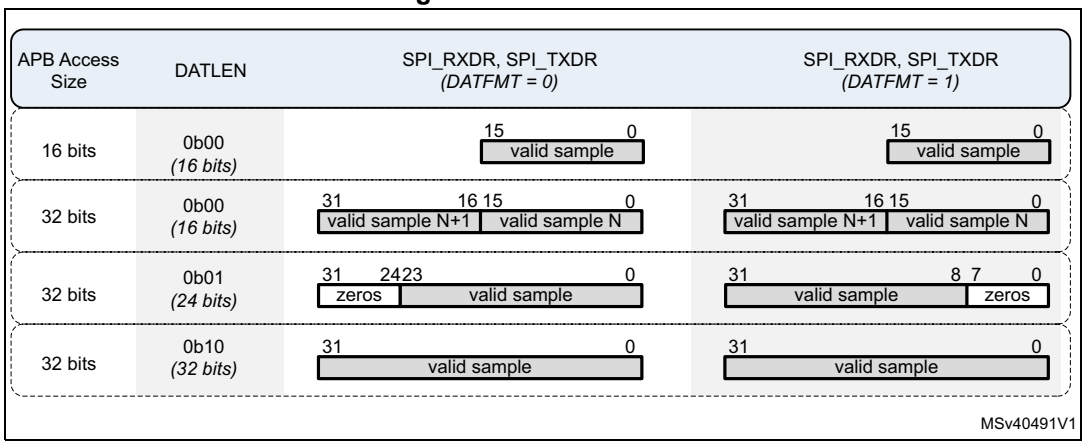
It is possible to select the data alignment into the SPI_RXDR and SPI_TXDR registers thanks to the DATFMT bit.

Note as well that the format of the data located into the SPI_RXDR or SPI_TXDR depends as well on the way those registers are accessed via the APB bus.

Figure 671 shows the allowed settings between APB access sizes, DATFMT and DATLEN.

Note: Caution shall be taken when the APB access size is 32 bits, and DATLEN = 0. For read operation the RxFIFO must contain at least two data, otherwise the read data are invalid. In the same way, for write operation, the TxFIFO must have at least two empty locations, otherwise a data can be lost.

Figure 671. Data Format



1. In I2S mode, the sample N represents the left sample, and the sample N+1 is the right sample.

It is possible to generate an interrupt or a DMA request according to a programmable FIFO threshold levels. The FIFO threshold is common to RX and TxFIFOs can be adjusted via FTHLV.

In I2S mode, the left and right audio samples are interleaved into the FIFOs. It means that for transmit operations, the user has to start to fill-up the TxFIFO with a left sample, followed by a right sample, and so on. For receive mode, the first data read from the RxFIFO is supposed to represent a left channel, the next one is a right channel, and so on.

Note that the read and write pointers of the FIFOs are reset when the bit SPE is set to 0.

Refer to *Section 55.9.11* and *Section 55.9.15* for additional information.

FIFO size optimization

The basic element of the FIFO is the byte. This allows an optimization of the FIFO locations. For example when the data size is fixed to 24 bits, each audio sample takes 3 basic FIFO elements.

For example, a FIFO with 16 basic elements can have a depth of:

- 8 samples, if the DATLEN = 0 (16 bits),
- 5 samples, if the DATLEN = 1 (24 bits),
- 4 samples, if the DATLEN = 2 (32 bits).

55.9.11 FIFOs status flags

Two status flags are provided for the application to fully monitor the state of the I2S interface. Both flags can generate an interrupt request. The receive interrupt is generated if RXPIE bit is enabled, the transmit interrupt is generated if TXPIE bit is enabled. Those bits are located into the SPI_IER register.

TxFIFO threshold reached (TXP)

When set, this flag indicates that the TxFIFO contains at least FTHLV empty locations. thus FTHLV new data to be transmitted can be written into SPI_TXDR. The TXP flag is reset when the amount of empty locations is lower than FTHLV. Note that TXP = 1, when the I2S is disabled (SPE bit is reset).

RxFIFO threshold reached (RXP)

When set, this flag indicates that there is at least FTHLV valid data into the RxFIFO, thus the user can read those data via SPI_RXDR. It is reset when the RxFIFO contains less than FTHLV data.

See *Section 55.10* for additional information on interrupt function in I2S mode.

55.9.12 Handling of underrun situation

In transmit mode, the UDR flag is set when a new data needs to be loaded into the shift register while the TxFIFO is already empty. In such a situation at least a data is lost.

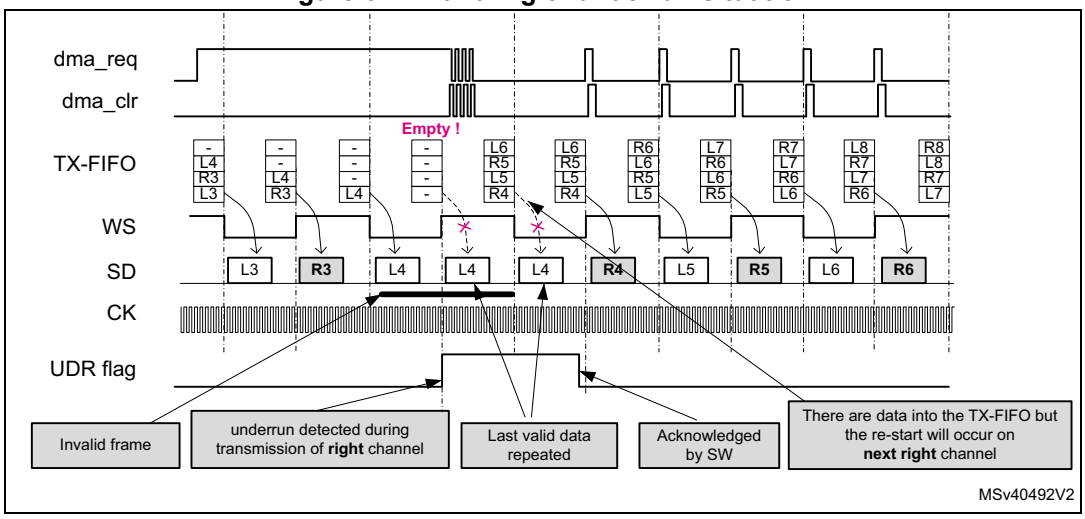
In I2S mode, there is a hardware mechanism in order to prevent misalignment situation (left and right channel swapped). As shown in the following figure, when an underrun occurs, the peripheral re-plays the last valid data on left and right channels as long as conditions of restart are not met. The transmission restarts:

- When there is enough data into the TxFIFO, and
- When the UDR flag is cleared by the software,

Then the next data transmitted is:

- A right channel if the underrun occurred when a right channel data needed to be transmitted, or
- A left channel if the underrun occurred when a left channel data needed to be transmitted.

Figure 672. Handling of underrun situation



The UDR flag can trigger an interrupt if the UDRIE bit in the SPI_IER register is set. The UDR bit is cleared by writing UDRC bit of SPI_IFCR register to 1.

When the block is configured in PCM mode, this re-alignment mechanism is not activated.

Note: An underrun situation can occur in master or slave mode. In master mode, when an underrun occurs, the WS, CK and MCK signal are not gated.

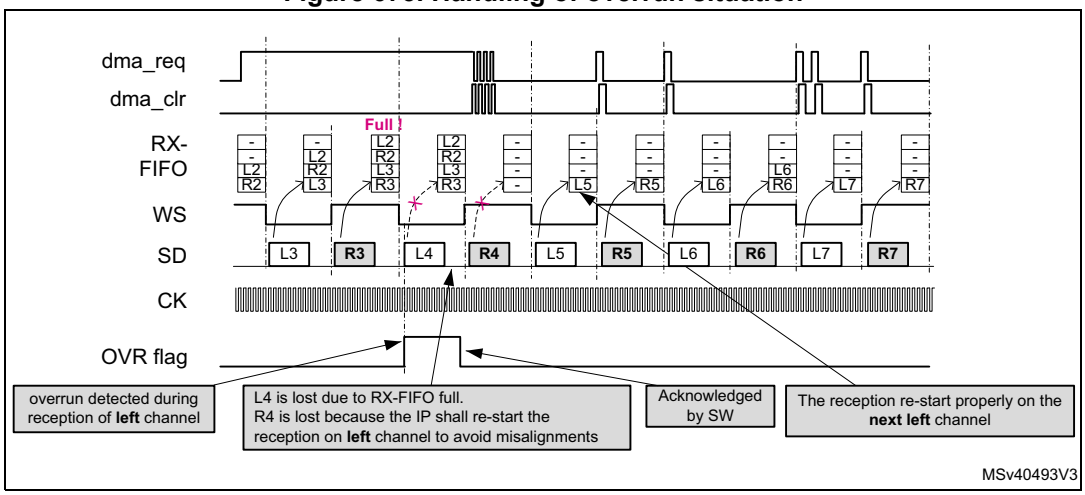
Due to resynchronization, any change on the UDR flag is taken into account by the hardware after at least 2 periods of CK clock.

55.9.13 Handling of overrun situation

The OVR flag is set when received data need to written into the RxFIFO, while the RxFIFO is already full. As a result, some incoming data are lost.

In I2S mode, there is a hardware mechanism in order to prevent misalignment situation (left and right channel swapped). As shown in the following figure, when an overrun occurs, the peripheral stops writing data into the RxFIFO as long as conditions of restart are not met. When there is enough room into the RxFIFO, and the OVR flag is cleared, the block starts by writing next the right channel into the RxFIFO if the overrun occurred when a right channel data was received or by writing the next left channel if the overrun occurred when a left channel data was received.

Figure 673. Handling of overrun situation



An interrupt may be generated if the OVRIE bit is set in the SPI_IER register. The OVR bit is cleared by writing OVRC bit of SPI_IFCR register to 1.

When the block is configured in PCM mode, this re-alignment mechanism is not activated

Note: An overrun situation can occur in master or slave mode. In master mode, when an overrun occurs, the WS, CK and MCK signal are not gated.

55.9.14 Frame error detection

When configured in slave mode, the SPI/I2S block detects two kinds of frame errors:

- A frame synchronization received while the shift-in or shift-out of the previous data is not completed (early frame error). This mode is selected with FIXCH = 0.
- A frame synchronization occurring at an unexpected position. This mode is selected with FIXCH = 1.

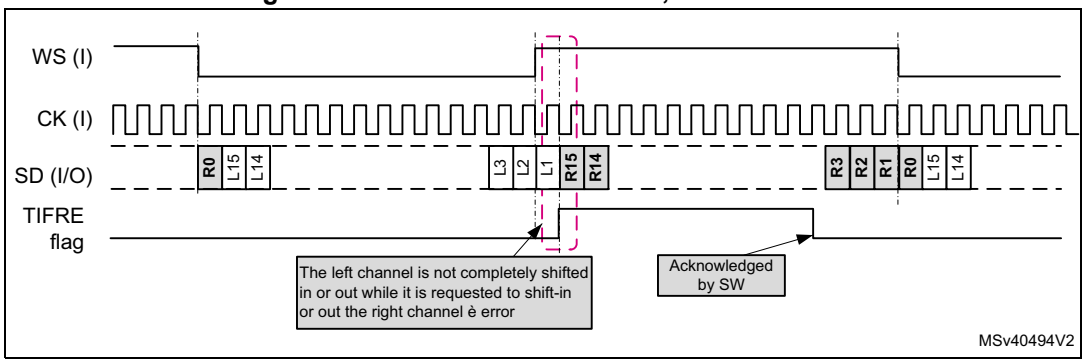
In slave mode, if the frame length provided by the external master device is different from 32 or 64 bits, the user has to set FIXCH to 0. As the SPI/I2S synchronize each transfer with the WS there is no misalignment risk, but in a noisy environment, if a glitch occurs in the CK signal, a sample may be affected and the application is not aware of this.

If the frame length provided by the external master device is equal to 32 or 64 bits, then the user can set FIXCH to 1 and adjust accordingly CHLEN. As the SPI/I2S synchronize each transfer with the WS there is still no misalignment risk, and if the amount of bit clock

between each channel boundary is different from CHLEN, the frame error flag (TIFRE) is set to 1.

Figure 674 shows an example of frame error detection. The SPI/I2S block is in slave mode and the amount of bit clock periods for left channel are not enough to shift-in or shift-out the data. The figure shows that the on-going transfer is interrupted and the next one is started in order to remain aligned to the WS signal.

Figure 674. Frame error detection, with FIXCH=0

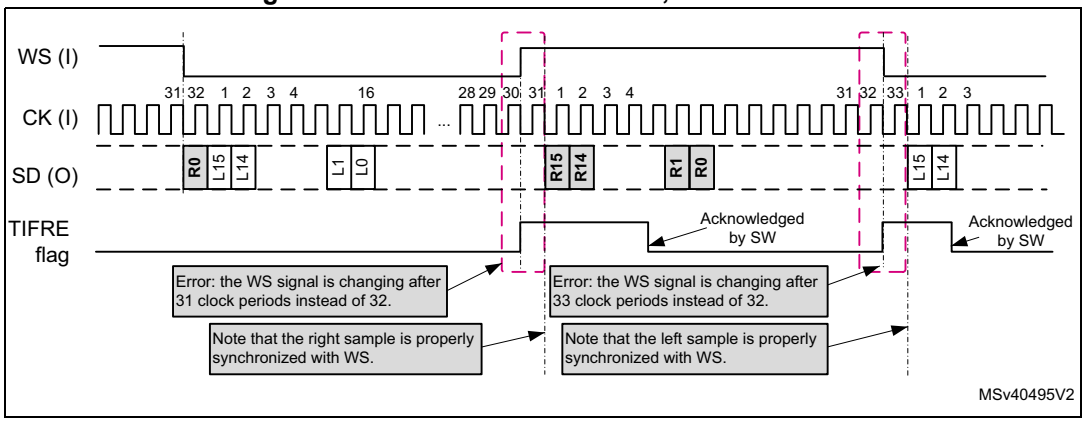


An interrupt can be generated if the TIFREIE bit is set. The frame error flag (TIFRE) is cleared by writing the TIFREC bit of the SPI_IFCR register to 1.

It is possible to extend the coverage of the frame error flag by setting the bit FIXCH to 1. When this bit is set to 1, then the SPI/I2S is expecting fixed channel lengths in slave mode. This means that the expected channel length can be 16 or 32 bits, according to CHLEN. As shown in *Figure 675*, in this mode the SPI/I2S block is able to detect if the WS signal is changing at the expected moment (too early or too late).

Note: *Figure 674* and *Figure 675* show the mechanism for the slave transmit mode, but this is also true for slave receive and slave full-duplex.

Figure 675. Frame error detection, with FIXCH=1



The frame error detection can be generally due to noisy environment disturbing the good reception of WS or CK signals.

Note: *The SPI/I2S is not able to recover properly if an overrun and an early frame occur within the same frame. In this case the user has to disable and re-enable the SPI/I2S.*

55.9.15 DMA Interface

The I2S/PCM mode shares the same DMA requests lines than the SPI function. There is a separated DMA channel for TX and RX paths. Each DMA channel can be enabled via RXDMAEN and TXDMAEN bits of SPI_CFG1 register.

In receive mode, the DMA interface is working as follow:

1. The hardware evaluates the RxFIFO level,
2. If the RxFIFO contains at least FTHLV samples, then FTHLV DMA requests are generated,
   – When the FTHLV DMA requests are completed, the hardware loops to step 1
3. If the RxFIFO contains less than FTHLV samples, no DMA request is generated, and the hardware loop to step 1

In transmit mode, the DMA interface is working as follow:

1. The hardware evaluates the TxFIFO level,
2. If the TxFIFO contains at least FTHLV empty locations, then FTHLV DMA requests are generated,
   – When the FTHLV DMA requests are completed, the hardware loops to step 1
3. If the TxFIFO contains less than FTHLV empty locations, no DMA request is generated, and the hardware loop to step 1

55.9.16 Programing examples

Master I2S Philips standard, transmit

This example shows how to program the interface for supporting the Philips I2S standard in master transmit mode, with a sampling rate of 48 kHz, using the master clock. The assumption taken is that SPI/I2S is receiving a kernel clock (i2s_clk) of 61.44 MHz from the clock controller of the circuit.

Start Procedure

1. Enable the bus interface clock (pclk or hclk), release the reset signal if needed in order to be able to program the SPI/I2S block.
2. Insure that the SPI/I2S block receives properly a kernel frequency (at 61.44 MHz in this example).
3. Insure that SPE is set to 0.
4. Program the clock generator in order to provide the MCK clock and to have a frame synchronization rate at exactly 48 kHz. So I2SDIV = 2, ODD = 1, and MCKOE = 1.
5. Program the serial interface protocol: CKPOL = 0, WSINV = 0, LSBFRST = 0, CHLEN = 1 (32 bits per channel) DATLEN = 1 (24 bits), I2SSTD = 0 (Philips Standard), I2SCFG = 2 (master transmit), I2SMOD = 1, for I2S/PCM mode. The register SPI_I2SCFGR must be updated before going to next steps.
6. Adjust the FIFO threshold, by setting the wanted value into FTHLV. For example if a threshold of 2 audio samples is required, FTHLV = 1.
7. Clear all status flag registers.
8. Enable the flags who shall generate an interrupt such as UDRIE. Note that TIFRE is not meaningful in master mode.
9. If the data transfer uses DMA:
   a) Program the DMA peripheral,
   b) Initialize the memory buffer with valid audio samples,
   c) Enable the DMA channel,
10. If the data transfer is done via interrupt, then the user has to enable the interrupt by setting the TXPIE bit to 1.
11. Set SPE to 1, as soon as this bit is set to one the following actions may happen:
    – If the interrupt generation is enabled, the SPI/I2S generates an interrupt request allowing the interrupt handler to fill-up the TxFIFO.
    – If the DMA transfer are enabled (TXDMAEN = 1), the SPI/I2S generates DMA requests in order to fill-up the TxFIFO
12. Finally, the user has to insure that the TxFIFO is not empty before enabling the serial interface. This is important in order to avoid an underrun condition when the interface is enabled. Then the SPI/I2S block can be enabled by setting the bit CSTART to 1. CSTART bit is located into SPI_CR1 register.

Stop Procedure in master mode

1. Set the bit CSUSP to 1, in order to stop on-going transfers
2. Check the value of CSTART bit until it goes to 0
3. Stop DMA peripheral, bus clock...
4. Set bit SPE to 0 in order to disable the SPI/I2S block

Master I2S MSB Aligned, full-duplex

This example shows how to program the interface for supporting the I2S MSB aligned protocol in master full-duplex mode, with a sampling rate of 48 kHz, without using the master clock. We took the assumption that the SPI/I2S is receiving a kernel clock (i2s_clk) of 12.288 MHz from the clock controller of the circuit.

Procedure

1. Enable the bus interface clock (pclk or hclk), release the reset signal if needed in order to be able to program the SPI/I2S block.
2. Insure that the SPI/I2S block receives properly a kernel frequency (at 12.288 MHz in this example).
3. Insure that SPE is set to 0.
4. Program the clock generator in order to provide the MCK clock, and to have a frame synchronization rate at exactly 48 kHz. So I2SDIV = 2, ODD = 0, and MCKOE = 0.
5. Program the serial interface protocol: CKPOL = 0, WSINV = 0, LSBFRST = 0, CHLEN = 1 (32 bits per channel) DATLEN = 1 (24 bits), I2SSTD = 1 (MSB Justified), I2SCFG = 5 (master Full-duplex), I2SMOD = 1, for I2S/PCM mode. The register SPI_I2SCFGR must be updated before going to next steps.
6. Adjust the FIFO threshold, by setting the wanted value into FTHLV. For example if a threshold of 2 audio samples is required, FTHLV = 1.
7. Clear all status flag registers.
8. Enable the flags who shall generate an interrupt such as UDRIE. Note that TIFRE is not meaningful in master mode.
9. If the data transfer uses DMA:
   – Program the DMA peripheral: two channels, one for RX and one for TX
   – Initialize the memory buffer with valid audio samples for TX path
   – Enable the DMA channels,
   – In the SPI/I2S block, enable the DMA by setting the TXDMAEN and RXDMAEN bits to 1. As soon as these bits are set to 1, the SPI/I2S start to fill-up the TxFIFO by sending DMA requests
10. If the data transfer is done via interrupt, then the user has to enable the interrupt by setting the TXPIE and RXPIE bits to 1.
11. Set SPE to 1, as soon as this bit is set to one the following actions may happen:
    – If the interrupt generation is enabled, the SPI/I2S generates an interrupt request allowing the interrupt handler to fill-up the TxFIFO.
    – If the DMA transfer are enabled, the SPI/I2S generates DMA requests in order to fill-up the TxFIFO
12. Finally, the user has to insure that the TxFIFO is not empty before enabling the serial interface. This is important in order to avoid an underrun condition when the interface is enabled. Then the SPI/I2S block can be enabled by setting the bit CSTART to 1. CSTART bit is located into SPI_CR1 register.

Refer to *Stop Procedure in master mode* for details on the stop sequence.

55.9.17 Slave I2S Philips standard, receive

This example shows how to program the interface for supporting the I2S Philips standard protocol in slave receiver mode, with a sampling rate of 48 kHz. Note that in slave mode the SPI/I2S block cannot control the sample rate of the received samples. In this example we took the assumption that the external master device is delivering an I2S frame structure with a channel length of 24 bits. So we cannot use the capability offered for frame error detection when FIXCH is set to 1.

Procedure

1. Enable the bus interface clock (pclk or hclk), release the reset signal if needed in order to be able to program the SPI/I2S block.
2. Insure that SPE is set to 0.
3. Program the serial interface protocol: CKPOL = 0, WSINV = 0, LSBFRST = 0, FIXCH = 0 (because channel length is different from 16 and 32 bits), DATLEN = 0 (16 bits), I2SSTD = 0 (Philips protocol), I2SCFG = 1 (slave RX), I2SMOD = 1, for I2S mode. The register SPI_I2SCFGR must be properly programmed before going to next steps.
4. Adjust the FIFO threshold, by setting the wanted value into FTHLV. For example if a threshold of 2 audio samples is required, FTHLV = 1.
5. Clear all status flag registers.
6. Enable the flags who shall generate an interrupt such as UDRIE and TIFRE.
7. If the data transfer uses DMA:
   – Program the DMA peripheral: one RX channel
   – Enable the DMA channel,
   – In the SPI/I2S block, enable the DMA by setting the RXDMAEN bit to 1.
8. If the data transfer is done via interrupt, then the user has to enable the interrupt by setting the RXPIE bit to 1.
9. Set SPE to 1.
10. Finally the user can set the bit CSTART to 1 in order to enable the serial interface. The SPI/I2S starts to store data into the RxFIFO on the next occurrence of left data transmitted by the external master device.

Stop Procedure in slave mode

1. Set bit SPE to 0 in order to disable the SPI/I2S block
2. Stop DMA peripheral, bus clock...

55.10 I2S wakeup and interrupts

In PCM/I2S mode an interrupt (**spi_it**) or a wakeup event signal (**spi_wkup**) can be generated according to the events described in the *Table 440*.

Interrupt events can be enabled and disabled separately.

Table 440. I2S interrupt requests

Interrupt event	Event flag	Enable control bit	Event clear method	Interrupt/Wakeup activated	
				spi_it	spi_wkup
TxFIFO threshold reached	TXP	TXPIE	TXP flag is cleared when the TxFIFO contains less than FTHLV empty locations	YES	YES
RxFIFO threshold reached	RXP	RXPIE	RXP flag is cleared when the RxFIFO contains less than FTHLV samples		
Overrun error	OVR	OVRIE	OVR is cleared by writing OVRC to 1		
Underrun error	UDR	UDRIE	UDR is cleared by writing UDRC to 1		
Frame error flag	TIFRE	TIFREIE	TIFRE is cleared by writing TIFREC to 1		NO

55.11 SPI/I2S registers

55.11.1 SPI/I2S control register 1 (SPI_CR1)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IO LOCK
															rs
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TCRC INI	RCRC INI	CRC33 _17	SSI	HDDIR	CSUSP	C START	MAS RX	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SPE
rw	rw	rw	rw	rw	w	rs	rw								rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **IOLOCK**: locking the AF configuration of associated IOs

This bit is set by software and cleared by hardware whenever SPE bit is changed from 1 to 0.

0: AF configuration is not locked

1: AF configuration is locked

When this bit is set, the SPI_CFG2 register content cannot be modified. This bit can be set when SPI is disabled only else it is write protected. It is cleared and cannot be set when the MODF bit is set.

Bit 15 **TCRCINI**: CRC calculation initialization pattern control for transmitter

0: All zero pattern is applied

1: All ones pattern is applied

Bit 14 **RCRCINI**: CRC calculation initialization pattern control for receiver

0: all zero pattern is applied

1: all ones pattern is applied

Bit 13 **CRC33_17**: 32-bit CRC polynomial configuration

0: full size (33-bit or 17-bit) CRC polynomial is not used

1: full size (33-bit or 17-bit) CRC polynomial is used

Bit 12 **SSI:** internal SS signal input level

This bit has an effect only when the SSM bit is set. The value of this bit is forced onto the peripheral SS input and the I/O value of the SS pin is ignored.

Bit 11 **HDDIR:** Rx/Tx direction at Half-duplex mode

In Half-Duplex configuration the HDDIR bit establishes the Rx/Tx direction of the data transfer. This bit is ignored in Full-Duplex or any Simplex configuration.

0: SPI is Receiver

1: SPI is transmitter

Bit 10 **CSUSP:** master suspend request

This bit reads as zero.

In master mode, when this bit is set by software, CSTART bit is reset at the end of the current frame and SPI communication is suspended. The user has to check SUSP flag to check end of the frame transaction.

The master mode communication must be suspended (using this bit or keeping TXDR empty) before disabling the SPI or going to low-power mode.

After software suspension, the SUSP flag has to be cleared and the SPI disabled and re-enabled before any next transaction starts.

Bit 9 **CSTART:** master transfer start

This bit is set by software to start an SPI or I2S/PCM communication. In SPI mode, it is cleared by hardware when End Of Transfer (EOT) flag is set or when a transaction suspend request is accepted. In I2S/PCM mode, it is also cleared by hardware as described in the section stop sequence.

0: master transfer is at idle

1: master transfer is on-going or temporary suspended by automatic suspend

In SPI mode, the bit is taken into account at master mode only. If transmission is enabled, communication starts or continues only if any data is available in the transmission FIFO.

Bit 8 **MASRX:** master automatic SUSP in Receive mode

This bit is set and cleared by software to control continuous SPI transfer in master receiver mode and automatic management in order to avoid overrun condition.

0: SPI flow/clock generation is continuous, regardless of overrun condition. (data are lost)

1: SPI flow is suspended temporary on RxFIFO full condition, before reaching overrun condition. The SUSP flag is set when SPI communication is suspended.

When SPI communication is suspended by hardware automatically, it could happen that few bits of next frame are already clocked out due to internal synchronization delay.

That is why the automatic suspension is not quite reliable when size of data drops below 8 bits. In this case, a safe suspension can be achieved by combination with delay inserted between data frames applied when MIDI parameter keeps a non zero value; sum of data size and the interleaved SPI cycles must always produce interval at length of 8 SPI clock periods at minimum. After software clearing of the SUSP bit, the communication resumes and continues by subsequent bits transaction without any next constraint. Prior the SUSP bit is cleared, the user must release the RxFIFO space as much as possible by reading out all the data packets available at RxFIFO based on the RXP flag indication to prevent any subsequent suspension.

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **SPE:** serial peripheral enable

This bit is set by and cleared by software.

0: serial peripheral disabled.

1: serial peripheral enabled

When SPE=1, the SPI data transfer is enabled, the configuration registers SPI_CFG1, SPI_CFG2, CRCPOLY and UDRDR and the IOLOCK bit in SPI_CR1 are write protected. They can be changed only when SPE=0.

When SPE=0 any SPI operation is stopped and disabled, all the not cleared requests with enabled interrupt stay pending and propagates the spi_plck clock request, the SS output is deactivated at master, internal state machine is reseted, all the FIFOs content is flushed, CRC calculation initialized, receive data register is read zero.

SPE is cleared and cannot be set when MODF error flag is active.

55.11.2 SPI control register 2 (SPI_CR2)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TSER[15:0]															
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSIZE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **TSER[15:0]**: number of data transfer extension to be reload into TSIZE just when a previous number of data stored at TSIZE is transacted

This register can be set by software when its content is cleared only. It is cleared by hardware once TSIZE reload is done. The TSER value must be programmed in advance before CTSIZE counter reaches zero otherwise the reload is not taken into account and traffic terminates with normal EOT event.

Bits 15:0 **TSIZE[15:0]**: number of data at current transfer

When these bits are changed by software, the SPI must be disabled. The field can be updated by hardware optionally, too, to be reloaded by the TSER value if applicable.
Endless transaction is initialized when CSTART is set while zero value is stored at TSIZE.
TSIZE cannot be set to 0xFFFF value when CRC is enabled.

55.11.3 SPI configuration register 1 (SPI_CFG1)

Address offset: 0x08

Reset value: 0x0007 0007

Content of this register is write protected when SPI is enabled, except TXDMAEN and RXDMAEN bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	MBR[2:0]			Res.	Res.	Res.	Res.	Res.	CRC EN	Res.	CRCSIZE[4:0]				
	rw	rw	rw						rw		rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TX DMA EN	RX DMA EN	Res.	UDRDET[1:0]		UDRCFG[1:0]		FTHLV[3:0]				DSIZE[4:0]				
rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:28 **MBR[2:0]:** master baud rate
000: SPI master clock/2
001: SPI master clock/4
010: SPI master clock/8
011: SPI master clock/16
100: SPI master clock/32
101: SPI master clock/64
110: SPI master clock/128
111: SPI master clock/256
Note: MBR setting is considered at slave working at TI mode, too (see Section 55.5.1: TI mode).

Bits 27:23 Reserved, must be kept at reset value.

Bit 22 **CRCEN:** hardware CRC computation enable
0: CRC calculation disabled
1: CRC calculation Enabled

Bit 21 Reserved, must be kept at reset value.

Bits 20:16 **CRCSIZE[4:0]:** length of CRC frame to be transacted and compared
Most significant bits are taken into account from polynomial calculation when CRC result is transacted or compared. The length of the polynomial is not affected by this setting.
00000: reserved
00001: reserved
00010: reserved
00011: 4-bits
00100: 5-bits
00101: 6-bits
00110: 7-bits
00111: 8-bits
.....
11101: 30-bits
11110: 31-bits
11111: 32-bits
The value must be set equal or multiply of data size (DSIZE[4:0]). Its maximum size cannot exceed the DSIZE maximum at the instance.
Note: If crc calculation is disabled by CRCEN=0, the CRCSIZE field must be kept at its default setting.
Note: The most significant bit at CRCSIZE bit field is reserved at the peripheral instances where the data size is limited to 16-bit.

Bit 15 **TXDMAEN:** Tx DMA stream enable
0: Tx DMA disabled
1: Tx DMA enabled

Bit 14 **RXDMAEN:** Rx DMA stream enable
0: Rx-DMA disabled
1: Rx-DMA enabled

Bit 13 Reserved, must be kept at reset value.

Bits 12:11 **UDRDET[1:0]:** detection of underrun condition at slave transmitter
00: underrun is detected at begin of data frame (no protection of 1-st bit)
01: underrun is detected at end of last data frame
10: underrun is detected by begin of active SS signal
11: reserved
For more details see *Figure 655: Optional configurations of slave's behavior at detection of underrun condition*.

Bits 10:9 **UDRCFG[1:0]:** behavior of slave transmitter at underrun condition
00: slave sends a constant pattern defined by the user at SPI_UDRDR register
01: slave repeats lastly received data frame from master
10: slave repeats its lastly transmitted data frame
11: reserved
When slave is configured at transmit only mode (COMM[1:0]=01), slave repeats all zeros pattern at UDRCFG[1:0]=01 setting.
For more details see *Figure 655: Optional configurations of slave's behavior at detection of underrun condition*.

Bits 8:5 **FTHLV[3:0]:** FIFO threshold level
Defines number of data frames at single data packet. The size of the packet must not exceed 1/2 of FIFO space.
0000: 1-data
0001: 2-data
0010: 3-data
0011: 4-data
0100: 5-data
0101: 6-data
0110: 7-data
0111: 8-data
1000: 9-data
1001: 10-data
1010: 11-data
1011: 12-data
1100: 13-data
1101: 14-data
1110: 15-data
1111: 16-data
SPI interface is more efficient if configured packet sizes are aligned with data register access parallelism:
– If SPI data register is accessed as a 16-bit register and DSIZE<=8bit, better to select FTHLV=2, 4, 6 etc,
– If SPI data register is accessed as a 32-bit register and DSIZE>8bit, better to select FTHLV=2, 4, 6 etc, while if DSIZE<=8bit, better to select FTHLV=4, 8, 12 etc

Bits 4:0 **DSIZE[4:0]:** number of bits in at single SPI data frame

00000: not used
00001: not used
00010: not used
00011: 4-bits
00100: 5-bits
00101: 6-bits
00110: 7-bits
00111: 8-bits
.....
11101: 30-bits
11110: 31-bits
11111: 32-bits

Note: The most significant bit at DSIZE bit field is reserved at the peripheral instances where data size is limited to 16-bit.

55.11.4 SPI configuration register 2 (SPI_CFG2)

Address offset: 0x0C

Reset value: 0x0000 0000

The content of this register is write protected when SPI is enabled or IOLOCK bit is set at SPI_CR1 register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AF CNTR	SSOM	SSOE	SSIOP	Res.	SSM	CPOL	CPHA	LSB FRST	MAS TER	SP[2:0]			COMM[1:0]		Res.
rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IOSWP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MIDI[3:0]				MSSI[3:0]			
rw								rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **AFCNTR:** alternate function GPIOs control

This bit is taken into account when SPE=0 only

0: the peripheral takes no control of GPIOs while it is disabled

1: the peripheral keeps always control of all associated GPIOs

When SPI master has to be disabled temporary for a specific configuration reason (e.g. CRC reset, CPHA or HDDIR change) setting this bit prevents any glitches on the associated outputs configured at alternate function mode by keeping them forced at state corresponding the current SPI configuration. This bit must be never used at slave mode as any slave transmitter must not force its MISO output once the SPI is disabled.

Note: This bit can be also used in PCM and I2S modes.

Bit 30 **SSOM**: SS output management in master mode

This bit is taken into account in master mode when SSOE is enabled. It allows to configure SS output between two consecutive data transfers.

0: SS is kept at active level till data transfer is completed, it becomes inactive with EOT flag

1: SPI data frames are interleaved with SS non active pulses when MIDI[3:0]>1

Bit 29 **SSOE:** SS output enable
This bit is taken into account at master mode only
0: SS output is disabled and the SPI can work in multi-master configuration
1: SS output is enabled. The SPI cannot work in a multi-master environment. It forces the SS pin at inactive level after the transfer is completed or SPI is disabled with respect to SSOM, MIDI, MSSI, SSIOP bits setting

Bit 28 **SSIOP:** SS input/output polarity
0: low level is active for SS signal
1: high level is active for SS signal

Bit 27 Reserved, must be kept at reset value.

Bit 26 **SSM:** software management of SS signal input
0: SS input value is determined by the SS PAD
1: SS input value is determined by the SSI bit
When master uses hardware SS output (SSM=0 and SSOE=1), the SS signal input is forced to non active state internally to prevent master mode fault error.

Bit 25 **CPOL:** clock polarity
0: SCK signal is at 0 when idle
1: SCK signal is at 1 when idle

Bit 24 **CPHA:** clock phase
0: the first clock transition is the first data capture edge
1: the second clock transition is the first data capture edge

Bit 23 **LSBFRST:** data frame format
0: MSB transmitted first
1: LSB transmitted first
Note: This bit can be also used in PCM and I2S modes.

Bit 22 **MASTER:** SPI master
0: SPI Slave
1: SPI Master

Bits 21:19 **SP[2:0]:** Serial protocol
000: SPI Motorola
001: SPI TI
others: Reserved, must not be used

Bits 18:17 **COMM[1:0]:** SPI communication mode
00: full-duplex
01: simplex transmitter
10: simplex receiver
11: half-duplex

Bit 16 Reserved, must be kept at reset value.

Bit 15 **IOSWP:** swap functionality of MISO and MOSI pins
0: no swap
1: MOSI and MISO are swapped
When this bit is set, the function of MISO and MOSI pins alternate functions are inverted. Original MISO pin becomes MOSI and original MOSI pin becomes MISO.
Note: This bit can be also used in PCM and I2S modes.

Bits 14:8 Reserved, must be kept at reset value.

Bits 7:4 **MIDI[3:0]**: master Inter-Data Idleness

Specifies minimum time delay (expressed in SPI clock cycles periods) inserted between two consecutive data frames in master mode.

0000: no delay

0001: 1 clock cycle period delay

...

1111: 15 clock cycle periods delay

Note: This feature is not supported in TI mode.

Bits 3:0 **MSSI[3:0]**: master SS idleness

Specifies an extra delay, expressed in number of SPI clock cycle periods, inserted additionally between active edge of SS and first data of a session start in master mode when SSOE is enabled.

0000: no extra delay

0001: 1 clock cycle period delay added

...

1111: 15 clock cycle periods delay added

Note: This feature is not supported in TI mode.

55.11.5 SPI/I2S interrupt enable register (SPI_IER)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	TSERFIE	MODFIE	TIFREIE	CRCEIE	OVRIE	UDRIE	TXTFIE	EOTIE	DXPIE	TXPIE	RXPIE
					rw	rw	rw	rw	rw	rw	rw	rw	rs	rs	rw

Bits 31:11 Reserved, must be kept at reset value.

Bit 10 **TSERFIE**: additional number of transactions reload interrupt enable

0: TSERF interrupt disabled

1: TSERF interrupt enabled

Bit 9 **MODFIE**: mode fault interrupt enable

0: MODF interrupt disabled

1: MODF interrupt enabled

Bit 8 **TIFREIE**: TIFRE interrupt enable

0: TIFRE interrupt disabled

1: TIFRE interrupt enabled

Bit 7 **CRCEIE:** CRC error interrupt enable

0: CRC interrupt disabled

1: CRC interrupt enabled

Bit 6 **OVRIE:** OVR interrupt enable

0: OVR interrupt disabled

1: OVR interrupt enabled

Bit 5 **UDRIE:** UDR interrupt enable
0: UDR interrupt disabled
1: UDR interrupt enabled

Bit 4 **TXTFIE:** TXTFIE interrupt enable
0: TXTF interrupt disabled
1: TXTF interrupt enabled

Bit 3 **EOTIE:** EOT, SUSP and TXC interrupt enable
0: EOT/SUSP/TXC interrupt disabled
1: EOT/SUSP/TXC interrupt enabled

Bit 2 **DXPIE**: DXP interrupt enabled
DXPIE is set by software and cleared by TXTF flag set event.
0: DXP interrupt disabled
1: DXP interrupt enabled

Bit 1 **TXPIE:** TXP interrupt enable
TXPIE is set by software and cleared by TXTF flag set event.
0: TXP interrupt disabled
1: TXP interrupt enabled

Bit 0 **RXPIE:** RXP Interrupt Enable
0: RXP interrupt disabled
1: RXP interrupt enabled

55.11.6 SPI/I2S status register (SPI_SR)

Address offset: 0x14

Reset value: 0x0000 1002

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CTSIZE[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXWNE	RXPLVL[1:0]		TXC	SUSP	TSERF	MODF	TIFRE	CRCE	OVR	UDR	TXTF	EOT	DXP	TXP	RXP
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **CTSIZE[15:0]**: number of data frames remaining in current TSIZE session
The value is not quite reliable when traffic is ongoing on bus and at LP mode too.

Bit 15 **RXWNE:** RxFIFO word not empty
0: less than four bytes of RxFIFO space is occupied by data
1: at least four bytes of RxFIFO space is occupied by data

Note: This bit value does not depend on DSIZE setting and keeps together with RXPLVL[1:0] information about RxFIFO occupancy by residual data.

Bits 14:13 **RXPLVL[1:0]:** RxFIFO packing leveL

When RXWNE=0 and data size is set up to 16-bit, the value gives number of remaining data frames persisting at RxFIFO.

00: no next frame is available at RxFIFO

01: 1 frame is available

10: 2 frames are available*

11: 3 frames are available*

(*) optional count when the data size is set up to 8-bit.

When the frame size is greater than 16-bit, these bits read as 00. In consequence, the single data frame received at the FIFO cannot be detected neither by RWNE nor by RXPLVL bits if data size is set from 17 to 24 bits. The user then must apply other methods like TSIZE>0 or FTHLV=0.

Bit 12 **TXC:** TxFIFO transmission complete

The flag behavior depends on TSIZE setting.

When TSIZE=0 the TXC is changed by hardware exclusively and it raises each time the TxFIFO becomes empty and there is no activity on the bus.

If TSIZE <>0 there is no specific reason to monitor TXC as it just copies the EOT flag value including its software clearing. The TXC generates an interrupt when EOTIE is set.

0: Current data transaction is still ongoing, data is available in TxFIFO or last frame transmission is on going.

1: Last TxFIFO frame transmission completed

Bit 11 **SUSP:** suspension status

In Master mode, SUSP is set by hardware when a CSUSP request is done, either as soon as the current frame is completed after CSUSP request is done or at master automatic suspend receive mode (MASRX bit is set at SPI_CR1 register) on RxFIFO full condition.

SUSP generates an interrupt when EOTIE is set.

This bit has to be cleared prior SPI is disabled by write 1 to SUSPC bit at SPI_IFCR

0: SPI not suspended (master mode active or other mode).

1: Master mode is suspended (current frame completed)

Bit 10 **TSERF**: additional number of SPI data to be transacted was reload

This bit is cleared by write 1 to TSERFC bit at SPI_IFCR or by writing the TSER[15:0] (SPI_CR2) register

0: no acceptation

1: additional number of data accepted, current transaction continues

Bit 9 **MODF**: mode fault

0: no mode fault

1: mode fault detected

This bit is cleared by write 1 to MODFC bit at SPI_IFCR. When MODF is set, the SPE and IOLOCK bits at the SPI_CR1 register are reset and their setting is blocked.

Bit 8 **TIFRE**: TI frame format error

0: no TI Frame Error

1: TI Frame Error detected

This bit is cleared by write 1 to TIFREC bit at SPI_IFCR

Bit 7 **CRCE:** CRC error

0: no CRC error

1: CRC error detected

This bit is cleared by write 1 to CRCEC bit at SPI_IFCR

Bit 6 **OVR:** overrun
0: no overrun
1: overrun detected
This bit is cleared by write 1 to OVRC bit at SPI_IFCR

Bit 5 **UDR:** underrun at slave transmission mode
0: no underrun
1: underrun detected
This bit is cleared by write 1 to UDRC bit at SPI_IFCR
Note: UDR flag applies to Slave mode only

Bit 4 **TXTF:** transmission transfer filled
0: upload of TxFIFO is on-going or not started
1: TxFIFO upload is finished
TXTF is set by hardware as soon as all of the data packets in a transfer have been submitted for transmission by application software or DMA, that is when TSIZE number of data have been pushed into the TxFIFO.
This bit is cleared by software write 1 to TXTFC bit at SPI_IFCR
TXTF flag triggers an interrupt if TXTFIE bit is set.
TXTF setting clears the TXIE and DXPIE masks so to off-load application software from calculating when to disable TXP and DXP interrupts.

Bit 3 **EOT:** end of transfer
EOT is set by hardware as soon as a full transfer is complete, that is when TSIZE number of data have been transmitted and/or received on the SPI. EOT is cleared by software write 1 to EOTC bit at SPI_IFCR.
EOT flag triggers an interrupt if EOTIE bit is set.
If DXP flag is used until TXTF flag is set and DXPIE is cleared, EOT can be used to download the last packets contained into RxFIFO in one-shot.
0: transfer is on-going or not started
1: transfer complete
In master, EOT event terminates the data transaction and handles SS output optionally. When CRC is applied, the EOT event is extended over the CRC frame transaction.

Bit 2 **DXP**: duplex packet
0: TxFIFO is Full and/or RxFIFO is Empty
1: Both TxFIFO has space for write and RxFIFO contains for read a single packet at least
The DXP flag is set whenever both TXP and RXP flags are set regardless the SPI mode.

Bit 1 **TXP:** Tx-packet space available
0: there is not enough space to locate next data packet at TxFIFO
1: TxFIFO has enough free location to host 1 data packet
TXP flag is changed by hardware. It monitors overall space currently available at TxFIFO if SPI is enabled. It has to be checked once a complete data packet is stored at TxFIFO.

Bit 0 **RXP:** Rx-packet available
0: RxFIFO is empty or a not complete data packet is received
1: RxFIFO contains at least 1 data packet
RXP flag is changed by hardware. It monitors number of overall data currently available at RxFIFO if SPI is enabled. It has to be checked once a data packet is completely read out from RxFIFO.

55.11.7 SPI/I2S interrupt/status flags clear register (SPI_IFCR)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	SUSPC	TSERFC	MODFC	TIFREC	CRCEC	OVRC	UDRC	TXTFC	EOTC	Res.	Res.	Res.
				w	w	w	w	w	w	w	w	w			

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **SUSPC:** SUSPend flag clear
Writing a 1 into this bit clears SUSP flag in the SPI_SR register

Bit 10 **TSERFC**: TSERFC flag clear
Writing a 1 into this bit clears TSERF flag in the SPI_SR register
Note: *TSERF is also reset by writing the TSER[15:0] (SPI_CR2) register*

Bit 9 **MODFC**: mode fault flag clear
Writing a 1 into this bit clears MODF flag in the SPI_SR register

Bit 8 **TIFREC**: TI frame format error flag clear
Writing a 1 into this bit clears TIFRE flag in the SPI_SR register

Bit 7 **CRCEC:** CRC error flag clear
Writing a 1 into this bit clears CRCE flag in the SPI_SR register

Bit 6 **OVRC:** overrun flag clear
Writing a 1 into this bit clears OVR flag in the SPI_SR register

Bit 5 **UDRC:** underrun flag clear
Writing a 1 into this bit clears UDR flag in the SPI_SR register

Bit 4 **TXTFC:** transmission Transfer Filled flag clear
Writing a 1 into this bit clears TXTF flag in the SPI_SR register

Bit 3 **EOTC:** end of transfer flag clear
Writing a 1 into this bit clears EOT flag in the SPI_SR register

Bits 2:0 Reserved, must be kept at reset value.

55.11.8 SPI/I2S transmit data register (SPI_TXDR)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXDR[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXDR[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **TXDR[31:0]:** transmit data register

The register serves as an interface with TxFIFO. A write to it accesses TxFIFO.

Note: data is always right-aligned. Unused bits are ignored when writing to the register, and read as zero when the register is read.

Note: DR can be accessed byte-wise (8-bit access): in this case only one data-byte is written by single access.

halfword-wise (16 bit access) in this case 2 data-bytes or 1 halfword-data can be written by single access.

word-wise (32 bit access). In this case 4 data-bytes or 2 halfword-data or word-data can be written by single access.

Write access of this register less than the configured data size is forbidden.

55.11.9 SPI/I2S receive data register (SPI_RXDR)

Address offset: 0x30

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXDR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXDR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXDR[31:0]:** receive data register

The register serves as an interface with RxFIFO. When it is read, RxFIFO is accessed.

Note: Data is always right-aligned. Unused bits are read as zero when the register is read. Writing to the register is ignored.

Note: DR can be accessed byte-wise (8-bit access): in this case only one data-byte is read by single access.

halfword-wise (16 bit access) in this case 2 data-bytes or 1 halfword-data can be read by single access

word-wise (32 bit access). In this case 4 data-bytes or 2 halfword-data or word-data can be read by single access.

Read access of this register less than the configured data size is forbidden.

55.11.10 SPI polynomial register (SPI_CRCPOLY)

Address offset: 0x40

Reset value: 0x0000 0107

The content of this register is write protected when SPI is enabled.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CRCPOLY[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CRCPOLY[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CRCPOLY[31:0]:** CRC polynomial register

This register contains the polynomial for the CRC calculation.

The default 9-bit polynomial setting 0x107 corresponds to default 8-bit setting of DSIZE. It is compatible with setting 0x07 used at some other ST products with fixed length of the polynomial string where the most significant bit of the string is always kept hidden.

Length of the polynomial is given by the most significant bit of the value stored at this register. It has to be set greater than DSIZE. CRC33_17 bit has to be set additionally with CRCPOLY register when DSIZE is configured to maximum 32-bit or 16-bit size and CRC is enabled (to keep polynomial length grater than data size).

Bits 31-16 are reserved at the peripheral instances with data size limited to 16-bit. There is no constrain when 32-bit access is applied at these addresses. Reserved bits 31-16 are always read zero while any write to them is ignored.

55.11.11 SPI transmitter CRC register (SPI_TXCRC)

Address offset: 0x44

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXCRC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXCRC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXCRC[31:0]:** CRC register for transmitter

When CRC calculation is enabled, the TXCRC[31:0] bits contain the computed CRC value of the subsequently transmitted bytes. CRC calculation is initialized when the CRCEN bit of SPI_CR1 is written to 1 or when a data block is transacted completely. The CRC is calculated serially using the polynomial programmed in the SPI_CRCPOLY register.

The number of bits considered at calculation depends on SPI_CRCPOLY register and CRCSIZE bits settings at SPI_CFG1 register.

Note: A read to this register when the communication is ongoing could return an incorrect value.

Not used for the I^2S mode.

Bits 31-16 are reserved at the peripheral instances with data size limited to 16-bit. There is no constrain when 32-bit access is applied at these addresses. Reserved bits 31-16 are always read zero while any write to them is ignored.

Note: The configuration of CRCSIZE bit field is not taken into account when the content of this register is read by software. No masking is applied for unused bits at this case.

55.11.12 SPI receiver CRC register (SPI_RXCRC)

Address offset: 0x48

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXCRC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXCRC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXCRC[31:0]:** CRC register for receiver

When CRC calculation is enabled, the RXCRC[31:0] bits contain the computed CRC value of the subsequently received bytes. CRC calculation is initialized when the CRCEN bit of SPI_CR1 is written to 1 or when a data block is transacted completely. The CRC is calculated serially using the polynomial programmed in the SPI_CRCPOLY register.

The number of bits considered at calculation depends on SPI_CRCPOLY register and CRCSIZE bits settings at SPI_CFG1 register.

Note: A read to this register when the communication is ongoing could return an incorrect value.

Not used for the I^2S mode.

Bits 31-16 are reserved at the peripheral instances with data size limited to 16-bit. There is no constrain when 32-bit access is applied at these addresses. Reserved bits 31-16 are always read zero while any write to them is ignored.

Note: The configuration of CRCSIZE bit field is not taken into account when the content of this register is read by software. No masking is applied for unused bits at this case.

55.11.13 SPI underrun data register (SPI_UDRDR)

Address offset: 0x4C

Reset value: 0x0000 0000

The content of this register is write protected when SPI is enabled.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
UDRDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
UDRDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **UDRDR[31:0]:** data at slave underrun condition

The register is taken into account at slave mode and at underrun condition only. The number of bits considered depends on DSIZE bit settings at SPI_CFG1 register. Underrun condition handling depends on setting if UDRDET and UDRCFG bits at SPI_CFG1 register. Bits 31-16 are reserved at the peripheral instances with data size limited to 16-bit. There is no constrain when 32-bit access is applied at these addresses. Reserved bits 31-16 are always read zero while any write to them is ignored.

55.11.14 SPI/I2S configuration register (SPI_I2SCFGR)

Address offset: 0x50

Reset value: 0x0000 0000

Note: All documented bits in this register must be configured when the I2S is disabled (SPE = 0). These bits are not used in SPI mode except for I2SMOD which needs to be kept at 0 in SPI mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	MCK OE	ODD	I2SDIV[7:0]							
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	DAT FMT	WSINV	FIXCH	CKPOL	CHLEN	DATLEN[1:0]		PCM SYNC	Res.	I2SSTD[1:0]		I2SCFG[2:0]			I2S MOD
	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **MCKOE**: master clock output enable

0: Master clock output is disabled

1: Master clock output is enabled

Bit 24 **ODD**: odd factor for the prescaler

0: Real divider value is = I2SDIV *2

1: Real divider value is = (I2SDIV * 2) + 1

Refer to *Section 55.9.9: Clock generator* for details

Bits 23:16 **I2SDIV[7:0]**: I^2S linear prescaler
I2SDIV can take any values except the value 1, when ODD is also equal to 1.
Refer to *Section 55.9.9: Clock generator* for details

Bit 15 Reserved, must be kept at reset value.

Bit 14 **DATFMT**: data format
0: the data inside the SPI_RXDR or SPI_TXDR are right aligned
1: the data inside the SPI_RXDR or SPI_TXDR are left aligned.

Bit 13 **WSINV**: Word select inversion
This bit is used to invert the default polarity of WS signal.
0: in I2S Philips standard, Left channel is transfered when WS is low, and right channel when WS is high.
In MSB or LSB justified mode, Left channel is transfered when WS is high, and right channel when WS is low.
In PCM mode the start of frame is indicated by a rising edge.
1: in I2S Philips standard, Left channel is transfered when WS is high, and right channel when WS is low.
In MSB or LSB justified mode, Left channel is transfered when WS is low, and right channel when WS is high.
In PCM mode the start of frame is indicated by a falling edge.

Bit 12 **FIXCH**: fixed channel length in slave
0: the channel length in slave mode is different from 16 or 32 bits (CHLEN not taken into account)
1: the channel length in slave mode is supposed to be 16 or 32 bits (according to CHLEN)

Bit 11 **CKPOL**: serial audio clock polarity
0: the signals generated by the SPI/I2S (i.e. SDO and WS) are changed on the falling edge of CK and the signals received by the SPI/I2S (i.e. SDI and WS) are read of the rising edge of CK.
1: the signals generated by the SPI/I2S (i.e. SDO and WS) are changed on the rising edge of CK and the signals received by the SPI/I2S (i.e. SDI and WS) are read of the falling edge of CK.

Bit 10 **CHLEN**: channel length (number of bits per audio channel)
0: 16-bit wide
1: 32-bit wide
The bit write operation has a meaning only if DATLEN = 00 otherwise the channel length is fixed to 32-bit by hardware whatever the value filled in.

Bits 9:8 **DATLEN[1:0]**: data length to be transferred
00: 16-bit data length
01: 24-bit data length
10: 32-bit data length
11: not allowed

Bit 7 **PCMSYNC**: PCM frame synchronization
0: short frame synchronization
1: long frame synchronization

Bit 6 Reserved, must be kept at reset value.

Bits 5:4 **I2SSTD[1:0]**: I^2S standard selection
00: I^2S Philips standard.
01: MSB justified standard (left justified)
10: LSB justified standard (right justified)
11: PCM standard
For more details on I^2S standards, refer to *Section 55.9.5: Supported audio protocols*

Bits 3:1 **I2SCFG[2:0]**: I2S configuration mode
000: slave - transmit
001: slave - receive
010: master - transmit
011: master - receive
100: slave - full duplex
101: master - full duplex
others, not used

Bit 0 **I2SMOD**: I2S mode selection
0: SPI mode is selected
1: I2S/PCM mode is selected

55.12 SPI register map and reset values

Table 441. SPI register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**SPI_CR1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IOLOCK	TCRCINI	RCRCINI	CRC33_17	SSI	HDDIR	CSUSP	CSTART	MASRX	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SPE
	Reset value																0	0	0	0	0	0	0	0	0								0
0x04	**SPI_CR2**	TSER[15:0]																TSIZE[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	**SPI_CFG1**	Res.	MBR[2:0]			Res.	Res.	Res.	Res.	Res.	CRCEN	Res.	CRCSIZE[4:0]					TXDMAEN	RXDMAEN	Res.	UDRDET[1:0]		UDRCFG[1:0]		FTHLV[3:0]				DSIZE[4:0]				
	Reset value		0	0	0						0		1	1	1	1	1	0	0		0	0	0	0	0	0	0	0	0	0	1	1	1
0x0C	**SPI_CFG2**	AFCNTR	SSOM	SSOE	SSIOP	Res.	SSM	CPOL	CPHA	LSBFRST	MASTER	SP[2:0]			COMM[1:0]		Res.	IOSWP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MIDI[3:0]				MSSI[3:0]			
	Reset value	0	0	0	0		0	0	0	0	0	0	0	0	0	0		0								0	0	0	0	0	0	0	0
0x10	**SPI_IER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSERFIE	MODFIE	TIFREIE	CRCEIE	OVRIE	UDRIE	TXTFIE	EOTIE	DXPIE	TXPIE	RXPIE
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x14	**SPI_SR**	CTSIZE[15:0]																RXWNE	RXPLVL[1:0]		TXC	SUSP	TSERF	MODF	TIFRE	CRCE	OVR	UDR	TXTF	EOT	DPXP	TXP	RXP
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
0x18	**SPI_IFCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUSPC	TSERFC	MODFC	TIFREC	CRCEC	OVRC	UDRC	TXTFC	EOTC	Res.	Res.	Res.
	Reset value																					0	0	0	0	0	0	0	0	0			
0x20	**SPI_TXDR**	TXDR[31:16]																TXDR[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x24 - 0x2C	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																																
0x30	**SPI_RXDR**	RXDR[31:16]																RXDR[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x34 - 0x3C	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																																
0x40	**SPI_CRCPOLY**	CRCPOLY[31:16](1)																CRCPOLY[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1
0x44	**SPI_TXCRC**	TXCRC[31:16](1)																TXCRC[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x48	**SPI_RXCRC**	RXCRC[31:16](1)																RXCRC[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x4C	**SPI_UDRDR**	UDRDR[31:16](1)																UDRDR[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 441. SPI register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x50	**SPI_I2SCFGR**	Res.	Res.	Res.	Res.	Res.	Res.	MCKOE	ODD	I2SDIV[7:0]								Res.	DATFMT	WSINV	FIXCH	CKPOL	CHLEN	DATLEN[1:0]		PCMSYNC	Res.	I2SSTD[1:0]		I2SCFG[2:0]			I2SMOD
	Reset value							0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0		0	0	0	0	0	0

1. Bits 31-16 are reserved at the peripheral instances with data size limited to 16-bit. There is no constrain when 32-bit access is applied at these addresses. Reserved bits 31-16 are always read zero while any write to them is ignored. *Refer to Table register boundary addresses.*

Refer to *Section 2.3 on page 131* for the register boundary addresses.

56 Serial audio interface (SAI)

56.1 Introduction

The SAI interface (serial audio interface) offers a wide set of audio protocols due to its flexibility and wide range of configurations. Many stereo or mono audio applications may be targeted. I2S standards, LSB or MSB-justified, PCM/DSP, TDM, and AC'97 protocols may be addressed for example. SPDIF output is offered when the audio block is configured as a transmitter.

To bring this level of flexibility and reconfigurability, the SAI contains two independent audio subblocks. Each block has it own clock generator and I/O line controller.

The SAI works in master or slave configuration. The audio subblocks are either receiver or transmitter and work synchronously or not (with respect to the other one).

The SAI can be connected with other SAIs to work synchronously.

56.2 SAI main features

- Two independent audio subblocks which can be transmitters or receivers with their respective FIFO.
- 8-word integrated FIFOs for each audio subblock.
- Synchronous or asynchronous mode between the audio subblocks.
- Possible synchronization between multiple SAIs.
- Master or slave configuration independent for both audio subblocks.
- Clock generator for each audio block to target independent audio frequency sampling when both audio subblocks are configured in master mode.
- Data size configurable: 8-, 10-, 16-, 20-, 24-, 32-bit.
- Audio protocol: I2S, LSB or MSB-justified, PCM/DSP, TDM, AC'97
- PDM interface, supporting up to 4 microphone pairs
- SPDIF output available if required.
- Up to 16 slots available with configurable size.
- Number of bits by frame can be configurable.
- Frame synchronization active level configurable (offset, bit length, level).
- First active bit position in the slot is configurable.
- LSB first or MSB first for data transfer.
- Mute mode.
- Stereo/Mono audio frame capability.
- Communication clock strobing edge configurable (SCK).
- Error flags with associated interrupts if enabled respectively.
  - Overrun and underrun detection,
  - Anticipated frame synchronization signal detection in slave mode,
  - Late frame synchronization signal detection in slave mode,
  - Codec not ready for the AC'97 mode in reception.

- Interrupt sources when enabled:
  - Errors,
  - FIFO requests.
- 2-channel DMA interface.

56.3 SAI implementation

Table 442. STM32H72x/73x SAI features (1)

SAI features	SAI1	SAI4
I2S, LSB or MSB-justified, PCM/DSP, TDM, AC'97	X	X
FIFO size	8 words	8 words
SPDIF	X	X
PDM	X(2)	X(2)

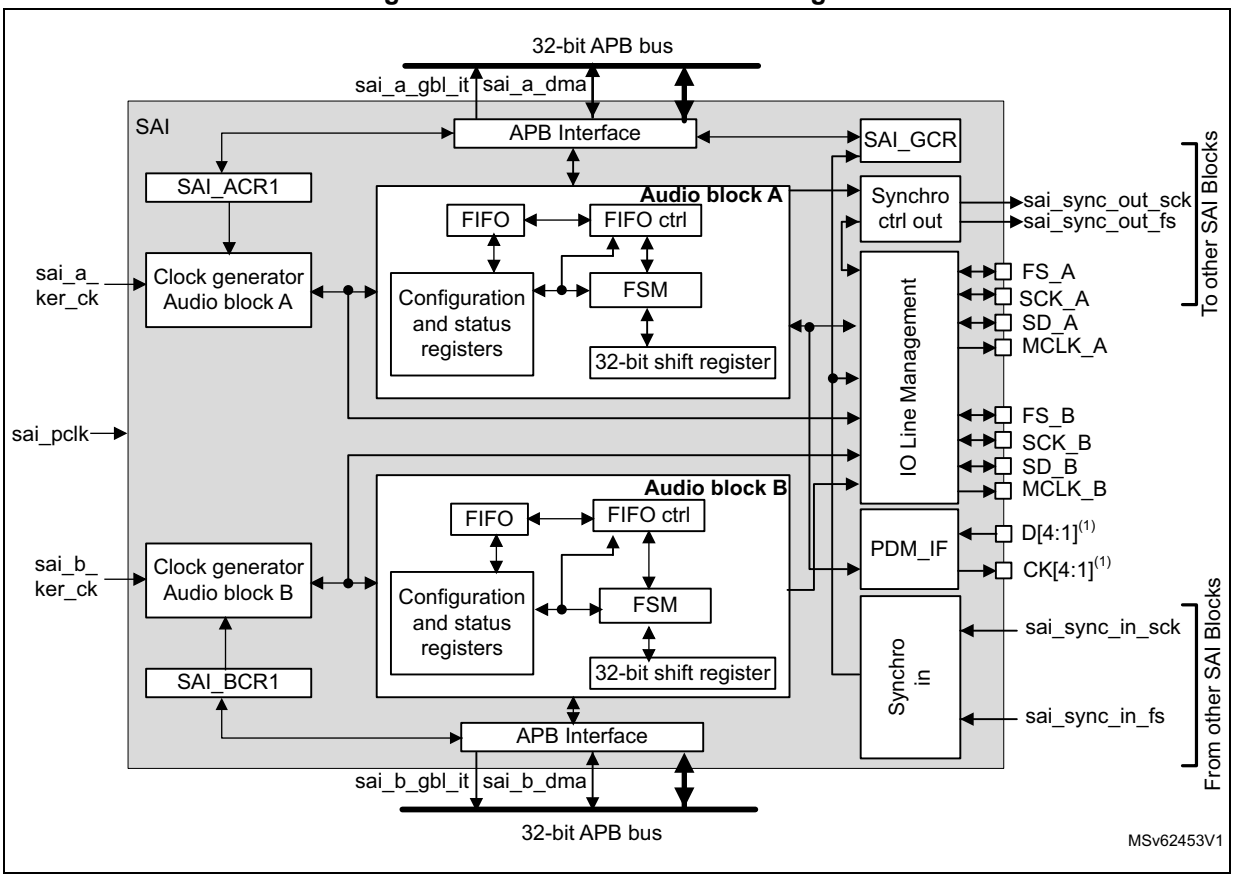
1. 'X' = supported, '-' = not supported.
2. Only signals D[3:1], and CK[2:1] are available.

56.4 SAI functional description

56.4.1 SAI block diagram

Figure 676 shows the SAI block diagram while *Table 443* and *Table 444* list SAI internal and external signals.

Figure 676. SAI functional block diagram



1. These signals might not be available for all SAI instances. Refer to *Section 56.3: SAI implementation* for details.

The SAI is mainly composed of two audio subblocks with their own clock generator. Each audio block integrates a 32-bit shift register controlled by their own functional state machine. Data are stored or read from the dedicated FIFO. FIFO may be accessed by the CPU, or by DMA in order to leave the CPU free during the communication. Each audio block is independent. They can be synchronous with each other.

An I/O line controller manages a set of 4 dedicated pins (SD, SCK, FS, MCLK) for a given audio block in the SAI. Some of these pins can be shared if the two subblocks are declared as synchronous to leave some free to be used as general purpose I/Os. The MCLK pin can be output, or not, depending on the application, the decoder requirement and whether the audio block is configured as the master.

If one SAI is configured to operate synchronously with another one, even more I/Os can be freed (except for pins SD_x).

The functional state machine can be configured to address a wide range of audio protocols. Some registers are present to set-up the desired protocols (audio frame waveform generator).

The audio subblock can be a transmitter or receiver, in master or slave mode. The master mode means the SCK_x bit clock and the frame synchronization signal are generated from the SAI, whereas in slave mode, they come from another external or internal master. There is a particular case for which the FS signal direction is not directly linked to the master or slave mode definition. In AC'97 protocol, it is an SAI output even if the SAI (link controller) is set-up to consume the SCK clock (and so to be in Slave mode).

Note: For ease of reading of this section, the notation SAI_x refers to SAI_A or SAI_B, where 'x' represents the SAI A or B subblock.

56.4.2 SAI pins and internal signals

Table 443. SAI internal input/output signals

Internal signal name	Signal type	Description
sai_a_gbl_it/ sai_b_gbl_it	Output	Audio block A and B global interrupts.
sai_a_dma, sai_b_dma	Input/output	Audio block A and B DMA acknowledges and requests.
sai_sync_out_sck, sai_sync_out_fs	Output	Internal clock and frame synchronization output signals exchanged with other SAI blocks.
sai_sync_in_sck, sai_sync_in_fs	Input	Internal clock and frame synchronization input signals exchanged with other SAI blocks.
sai_a_ker_ck/ sai_b_ker_ck	Input	Audio block A/B kernel clock.
sai_pclk	Input	APB clock.

Table 444. SAI input/output pins

Name	Signal type	Comments
SAI_SCK_A/B	Input/output	Audio block A/B bit clock.
SAI_MCLK_A/B	Output	Audio block A/B master clock.
SAI_SD_A/B	Input/output	Data line for block A/B.
SAI_FS_A/B	Input/output	Frame synchronization line for audio block A/B.
SAI_CK[4:1]	Output	PDM bitstream clock(1).
SAI_D[4:1]	Input	PDM bitstream data(1).

1. These signals might not be available in all SAI instances. Please refer to *Section 56.3: SAI implementation* for details.

56.4.3 Main SAI modes

Each audio subblock of the SAI can be configured to be master or slave via MODE bits in the SAI_xCR1 register of the selected audio block.

Master mode

In master mode, the SAI delivers the timing signals to the external connected device:

- The bit clock and the frame synchronization are output on pin SCK_x and FS_x, respectively.
- If needed, the SAI can also generate a master clock on MCLK_x pin.

Both SCK_x, FS_x and MCLK_x are configured as outputs.

Slave mode

The SAI expects to receive timing signals from an external device.

- If the SAI subblock is configured in asynchronous mode, then SCK_x and FS_x pins are configured as inputs.
- If the SAI subblock is configured to operate synchronously with another SAI interface or with the second audio subblock, the corresponding SCK_x and FS_x pins are left free to be used as general purpose I/Os.

In slave mode, MCLK_x pin is not used and can be assigned to another function.

It is recommended to enable the slave device before enabling the master.

Configuring and enabling SAI modes

Each audio subblock can be independently defined as a transmitter or receiver through the MODE bit in the SAI_xCR1 register of the corresponding audio block. As a result, SAI_SD_x pin is respectively configured as an output or an input.

Two master audio blocks in the same SAI can be configured with two different MCLK and SCK clock frequencies. In this case they have to be configured in asynchronous mode.

Each of the audio blocks in the SAI are enabled by SAIEN bit in the SAI_xCR1 register. As soon as this bit is active, the transmitter or the receiver is sensitive to the activity on the clock line, data line and synchronization line in slave mode.

In master TX mode, enabling the audio block immediately generates the bit clock for the external slaves even if there is no data in the FIFO, However FS signal generation is conditioned by the presence of data in the FIFO. After the FIFO receives the first data to transmit, this data is output to external slaves. If there is no data to transmit in the FIFO, 0 values are then sent in the audio frame with an underrun flag generation.

In slave mode, the audio frame starts when the audio block is enabled and when a start of frame is detected.

In Slave TX mode, no underrun event is possible on the first frame after the audio block is enabled, because the mandatory operating sequence in this case is:

1. Write into the SAI_xDR (by software or by DMA).
2. Wait until the FIFO threshold *(*FLH) flag is different from 0b000 (FIFO empty).
3. Enable the audio block in slave transmitter mode.

56.4.4 SAI synchronization mode

There are two levels of synchronization, either at audio subblock level or at SAI level.

Internal synchronization

An audio subblock can be configured to operate synchronously with the second audio subblock in the same SAI. In this case, the bit clock and the frame synchronization signals are shared to reduce the number of external pins used for the communication. The audio block configured in synchronous mode sees its own SCK_x, FS_x, and MCLK_x pins released back as GPIOs while the audio block configured in asynchronous mode is the one for which FS_x and SCK_x ad MCLK_x I/O pins are relevant (if the audio block is considered as master).

Typically, the audio block in synchronous mode can be used to configure the SAI in full duplex mode. One of the two audio blocks can be configured as a master and the other as slave, or both as slaves with one asynchronous block (corresponding SYNCEN[1:0] bits set to 00 in SAI_xCR1) and one synchronous block (corresponding SYNCEN[1:0] bits set to 01 in the SAI_xCR1).

Note: Due to internal resynchronization stages, PCLK APB frequency must be higher than twice the bit rate clock frequency.

External synchronization

The audio subblocks can also be configured to operate synchronously with another SAI. This can be done as follow:

1. The SAI, which is configured as the source from which the other SAI is synchronized, has to define which of its audio subblock is supposed to provide the FS and SCK signals to other SAI. This is done by programming SYNCOUT[1:0] bits.
2. The SAI which receives the synchronization signals, has to select which SAI provides the synchronization by setting the proper value on SYNCIN[1:0] bits. For each of the two SAI audio subblocks, the user must then specify if it operates synchronously with the other SAI via the SYNCEN bit.

Note: SYNCIN[1:0] and SYNCOUT[1:0] bits are located into the SAI_GCR register, and SYNCEN bits into SAI_xCR1 register.

If both audio subblocks in a given SAI need to be synchronized with another SAI, it is possible to choose one of the following configurations:

- Configure each audio block to be synchronous with another SAI block through the SYNCEN[1:0] bits.
- Configure one audio block to be synchronous with another SAI through the SYNCEN[1:0] bits. The other audio block is then configured as synchronous with the second SAI audio block through SYNCEN[1:0] bits.

The following table shows how to select the proper synchronization signal depending on the SAI block used. For example SAI4 can select the synchronization from SAI1 by setting SAI4 SYNCIN to 0. If SAI1 wants to select the synchronization coming from SAI4, SAI1 SYNCIN must be set to 3. Positions noted as ‘Reserved’ must not be used.

Table 445. External synchronization selection

Block instance	SYNCIN= 3	SYNCIN= 2	SYNCIN= 1	SYNCIN= 0
SAI1	SAI4 sync.	Reserved	Reserved	Reserved
SAI4	Reserved	Reserved	Reserved	SAI1 sync

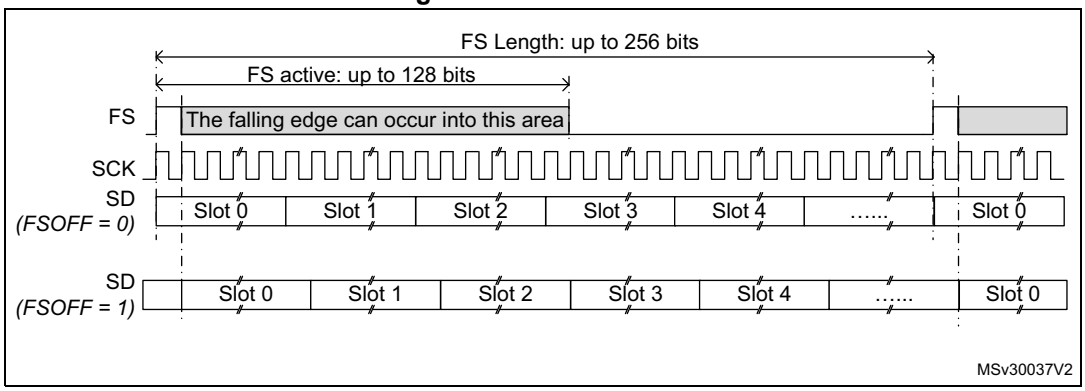
56.4.5 Audio data size

The audio frame can target different data sizes by configuring bit DS[2:0] in the SAI_xCR1 register. The data sizes may be 8, 10, 16, 20, 24 or 32 bits. During the transfer, either the MSB or the LSB of the data are sent first, depending on the configuration of bit LSBFIRST in the SAI_xCR1 register.

56.4.6 Frame synchronization

The FS signal acts as the Frame synchronization signal in the audio frame (start of frame). The shape of this signal is completely configurable in order to target the different audio protocols with their own specificities concerning this Frame synchronization behavior. This reconfigurability is done using register SAI_xFRCR. *Figure 677* illustrates this flexibility.

Figure 677. Audio frame



In AC'97 mode or in SPDIF mode (bit PRTCFG[1:0] = 10 or PRTCFG[1:0] = 01 in the SAI_xCR1 register), the frame synchronization shape is forced to match the AC'97 protocol. The SAI_xFRCR register value is ignored.

Each audio block is independent and consequently each one requires a specific configuration.

Frame length

- Master mode

  The audio frame length can be configured to up to 256 bit clock cycles, by setting FRL[7:0] field in the SAI_xFRCR register.

  If the frame length is greater than the number of declared slots for the frame, the remaining bits to transmit is extended to 0 or the SD line is released to HI-z depending the state of bit TRIS in the SAI_xCR2 register (refer to *FS signal role*). In reception mode, the remaining bit is ignored.

  If bit NODIV is cleared, (FRL+1) must be equal to a power of 2, from 8 to 256, to ensure that an audio frame contains an integer number of MCLK pulses per bit clock cycle.

  If bit NODIV is set, the (FRL+1) field can take any value from 8 to 256. Refer to *Section 56.4.8: SAI clock generator*".

- Slave mode

  The audio frame length is mainly used to specify to the slave the number of bit clock cycles per audio frame sent by the external master. It is used mainly to detect from the master any anticipated or late occurrence of the Frame synchronization signal during an ongoing audio frame. In this case an error is generated. For more details refer to *Section 56.4.14: Error flags*.

  In slave mode, there are no constraints on the FRL[7:0] configuration in the SAI_xFRCR register.

The number of bits in the frame is equal to FRL[7:0] + 1.

The minimum number of bits to transfer in an audio frame is 8.

Frame synchronization polarity

FSPOL bit in the SAI_xFRCR register sets the active polarity of the FS pin from which a frame is started. The start of frame is edge sensitive.

In slave mode, the audio block waits for a valid frame to start transmitting or receiving. Start of frame is synchronized to this signal. It is effective only if the start of frame is not detected during an ongoing communication and assimilated to an anticipated start of frame (refer to *Section 56.4.14: Error flags*).

In master mode, the frame synchronization is sent continuously each time an audio frame is complete until the SAIEN bit in the SAI_xCR1 register is cleared. If no data are present in the FIFO at the end of the previous audio frame, an underrun condition is managed as described in *Section 56.4.14: Error flags*), but the audio communication flow is not interrupted.

Frame synchronization active level length

The FSALL[6:0] bits of the SAI_xFRCR register allow configuring the length of the active level of the Frame synchronization signal. The length can be set from 1 to 128 bit clock cycles.

As an example, the active length can be half of the frame length in I2S, LSB or MSB-justified modes, or one-bit wide for PCM/DSP or TDM.

Frame synchronization offset

Depending on the audio protocol targeted in the application, the Frame synchronization signal can be asserted when transmitting the last bit or the first bit of the audio frame (this is the case in I2S standard protocol and in MSB-justified protocol, respectively). FSOFF bit in the SAI_xFRCR register allows to choose one of the two configurations.

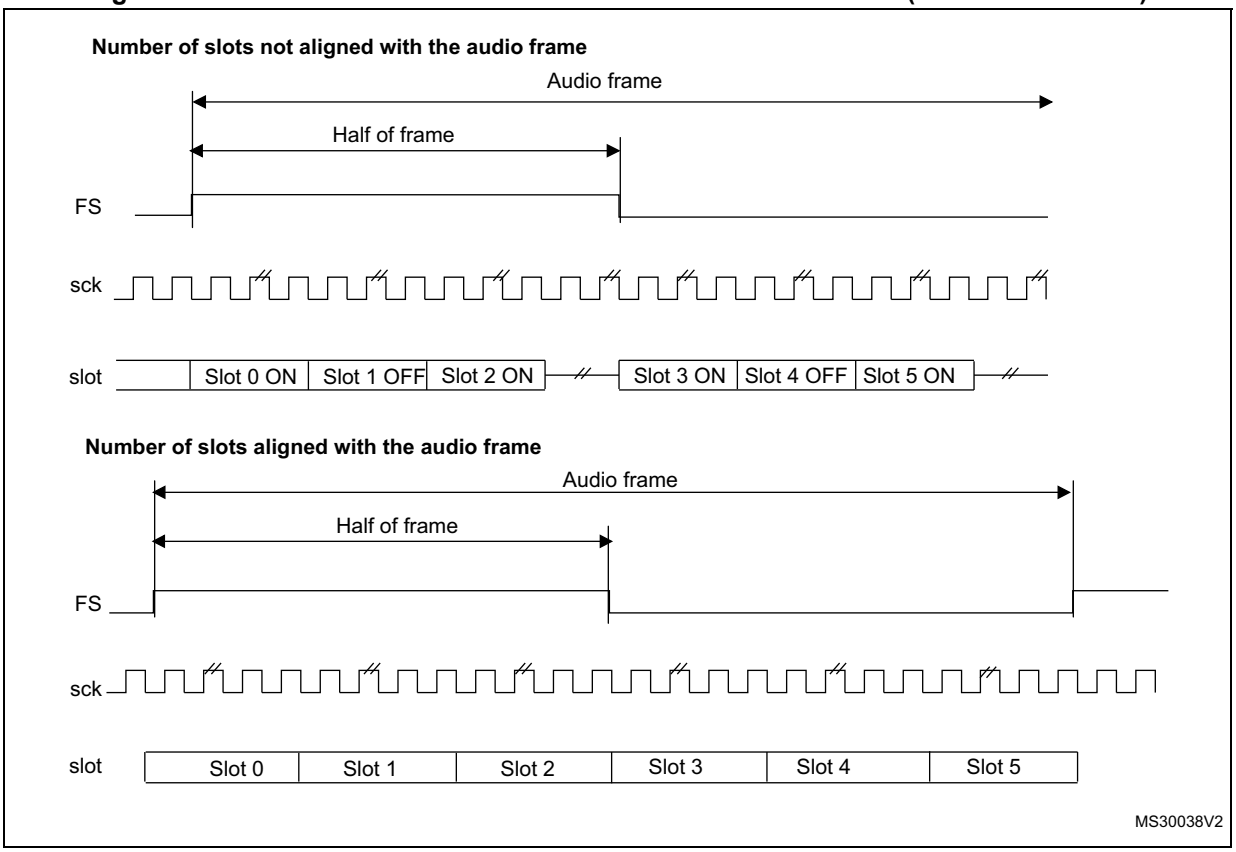
FS signal role

The FS signal can have a different meaning depending on the FS function. FSDEF bit in the SAI_xFRCR register selects which meaning it has:

- 0: start of frame, like for instance the PCM/DSP, TDM, AC'97, audio protocols,
- 1: start of frame and channel side identification within the audio frame like for the I2S, the MSB or LSB-justified protocols.

When the FS signal is considered as a start of frame and channel side identification within the frame, the number of declared slots must be considered to be half the number for the left channel and half the number for the right channel. If the number of bit clock cycles on half audio frame is greater than the number of slots dedicated to a channel side, and TRIS = 0, 0 is sent for transmission for the remaining bit clock cycles in the SAI_xCR2 register. Otherwise if TRIS = 1, the SD line is released to HI-Z. In reception mode, the remaining bit clock cycles are not considered until the channel side changes.

Figure 678. FS role is start of frame + channel side identification (FSDEF = TRIS = 1)

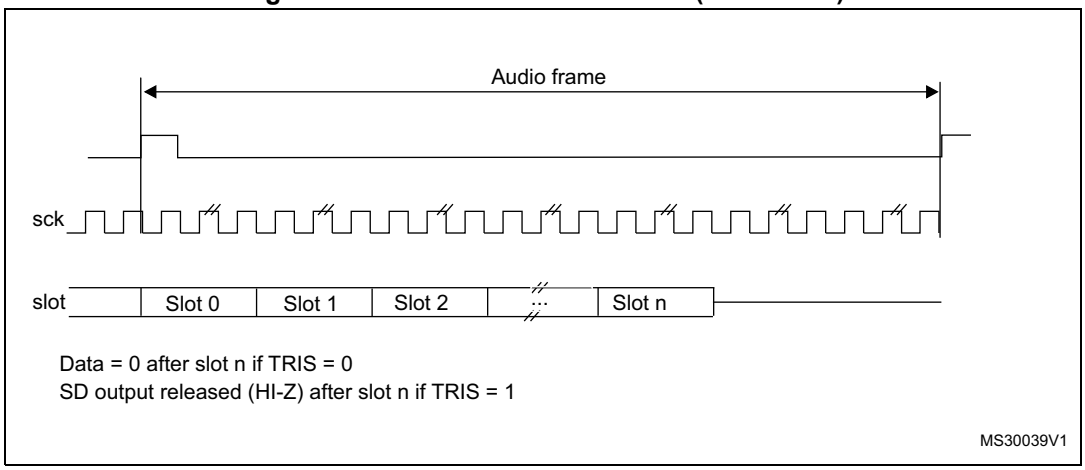


1. The frame length should be even.

If FSDEF bit in SAI_xFRCR is kept clear, so FS signal is equivalent to a start of frame, and if the number of slots defined in NBSLOT[3:0] in SAI_xSLOTR multiplied by the number of bits by slot configured in SLOTSZ[1:0] in SAI_xSLOTR is less than the frame size (bit FRL[7:0] in the SAI_xFRCR register), then:

- if TRIS = 0 in the SAI_xCR2 register, the remaining bit after the last slot is forced to 0 until the end of frame in case of transmitter,
- if TRIS = 1, the line is released to HI-Z during the transfer of these remaining bits. In reception mode, these bits are discarded.

Figure 679. FS role is start of frame (FSDEF = 0)



The FS signal is not used when the audio block in transmitter mode is configured to get the SPDIF output on the SD line. The corresponding FS I/O is released and left free for other purposes.

56.4.7 Slot configuration

The slot is the basic element in the audio frame. The number of slots in the audio frame is equal to NBSLOT[3:0] + 1.

The maximum number of slots per audio frame is fixed at 16.

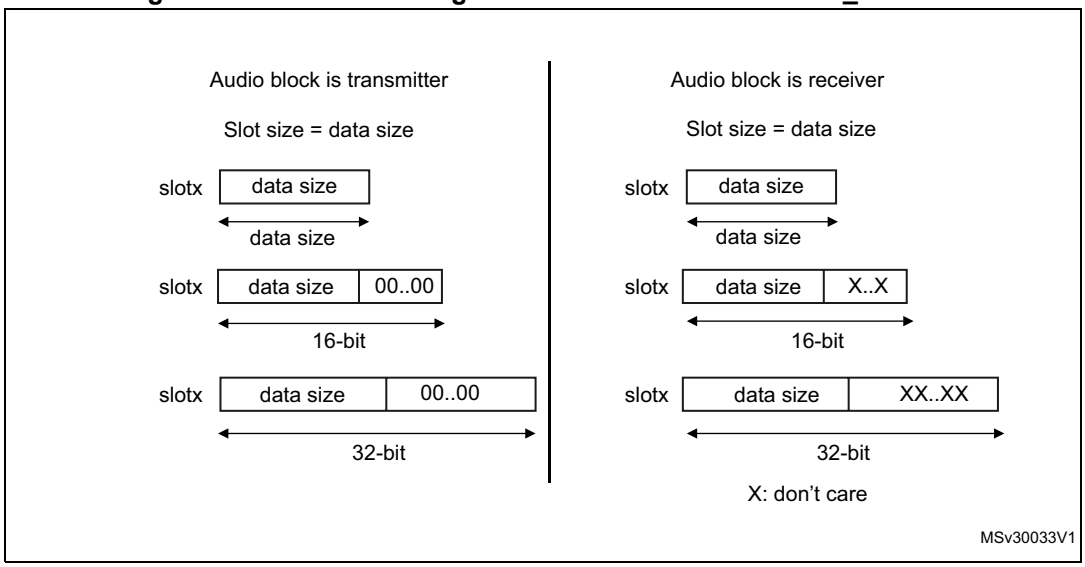
For AC'97 protocol or SPDIF (when bit PRTCFG[1:0] = 10 or PRTCFG[1:0] = 01), the number of slots is automatically set to target the protocol specification, and the value of NBSLOT[3:0] is ignored.

Each slot can be defined as a valid slot, or not, by setting SLOTEN[15:0] bits of the SAI_xSLOTR register.

When a invalid slot is transferred, the SD data line is either forced to 0 or released to HI-z depending on TRIS bit configuration (refer to *Output data line management on an inactive slot*) in transmitter mode. In receiver mode, the received value from the end of this slot is ignored. Consequently, there is no FIFO access and so no request to read or write the FIFO linked to this inactive slot status.

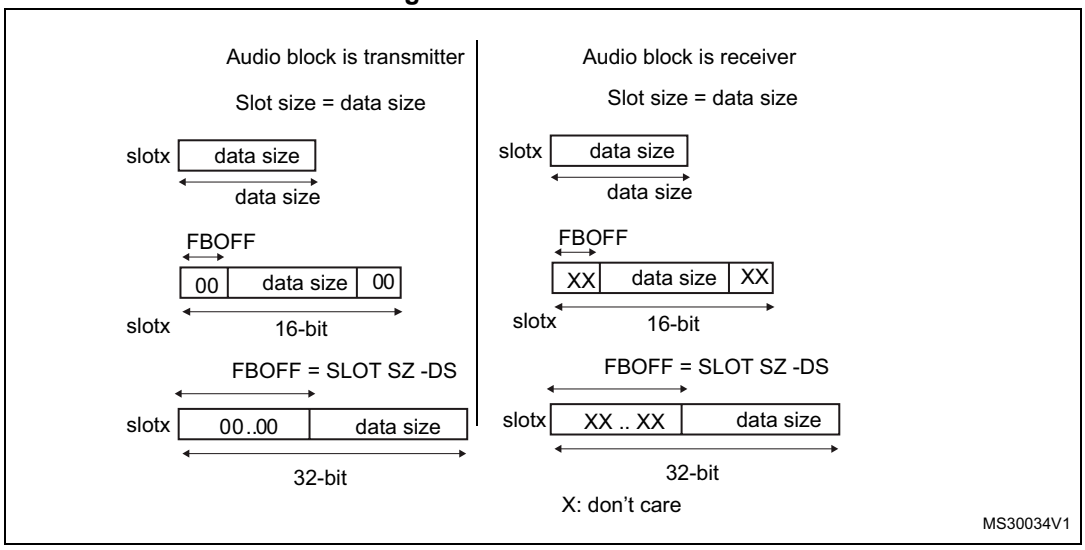
The slot size is also configurable as shown in *Figure 680.* The size of the slots is selected by setting SLOTSZ[1:0] bits in the SAI_xSLOTR register. The size is applied identically for each slot in an audio frame.

Figure 680. Slot size configuration with FBOFF = 0 in SAI_xSLOTR



It is possible to choose the position of the first data bit to transfer within the slots. This offset is configured by FBOFF[4:0] bits in the SAI_xSLOTR register. 0 values are injected in transmitter mode from the beginning of the slot until this offset position is reached. In reception, the bit in the offset phase is ignored. This feature targets the LSB justified protocol (if the offset is equal to the slot size minus the data size).

Figure 681. First bit offset



It is mandatory to respect the following conditions to avoid bad SAI behavior:

FBOFF ≤(SLOTSZ - DS),

DS ≤SLOTSZ,

NBSLOT x SLOTSZ ≤FRL (frame length),

The number of slots must be even when bit FSDEF in the SAI_xFRCR register is set.

In AC'97 and SPDIF protocol (bit PRTCFG[1:0] = 10 or PRTCFG[1:0] = 01), the slot size is automatically set as defined in *Section 56.4.11: AC'97 link controller*.

56.4.8 SAI clock generator

Each audio block has its own clock generator. The clock generator builds the master clock (MCLK_x) and bit clock (SCK_x) signals from the sai_x_ker_ck. The sai_x_ker_ck clock is delivered by the clock controller of the product (RCC).

Generation of the master clock (MCLK_x)

The clock generator provides the master clock (MCLK_x) when the audio block is defined as Master or Slave. The master clock is generated as soon as the MCKEN bit is set to 1 even if the SAIEN bit for the corresponding block is set to 0. This feature can be useful if the MCLK_x clock is used as system clock for an external audio device, since it allows generating the MCLK_x before activating the audio stream.

To generate a master clock on MCLK_x output before transferring the audio samples, the user application has to follow the sequence below:

1. Check that SAIEN = 0.
2. Program the MCKDIV[5:0] divider to the required value.
3. Set the MCKEN bit to 1.
4. Later, the application can configure other parts of the SAI, and sets the SAIEN bit to 1 to start the transfer of audio samples.

To avoid disturbances on the clock generated on MCLK_x output, the following operations are not recommended:

- Changing MCKDIV when MCKEN = 1
- Setting MCKEN to 0 if the SAIEN = 1

The SAI guarantees that there is no spurs on MCLK_x output when the MCLK_x is switched ON and OFF via MCKEN bit (with SAIEN = 0).

Table 446 shows MCLK_x activation conditions.

Table 446. MCLK_x activation conditions

MCLKEN	NODIV	SAIEN for block x	MCLK_x
0	X	0	
1			Enabled
0	1	1	
1			Enabled
X	0		Enabled

Note: MCLK_x can also be generated in AC'97 mode, when MCLKEN is set to 1.

Generation of the bit clock (SCK_x)

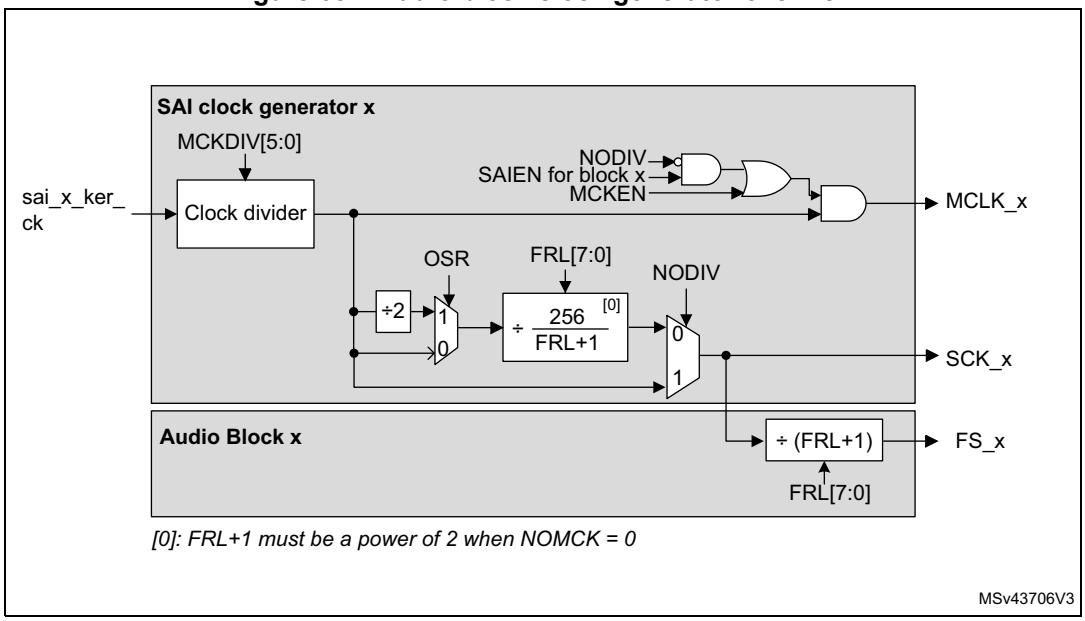
The clock generator provides the bit clock (SCK_x) when the audio block is defined as Master. The frame synchronization (FS_x) is also derived from the signals provided by the clock generator.

In Slave mode, the value of NODIV and OSR fields are ignored, and the SCK_x clock is not generated.

The bit clock strobing edge of SCK_x can be configured through the CKSTR fields, which is functional both in master and slave mode.

Figure 682 illustrates the architecture of the audio block clock generator.

Figure 682. Audio block clock generator overview



The NODIV bit must be used to force the ratio between the master clock (MCLK_x) and the frame synchronization (FS_x) frequency to 256 or 512.

- If NODIV is set to 0, the frequency ratio between the frame synchronization and the master clock is fixed to 512 or 256, according to OSR value, but the frame length must be a power of 2. More details are given hereafter.
- If NODIV is set to 1, the application can adjust the frequency of the bit clock (SCK_x) via MCKDIV. In addition there is no restriction on the frame length value as long as the frame length is bigger or equal to 8 (i.e. FRL[7:0] > 6). The frame synchronization frequency depends on MCKDIV and frame length (FRL[7:0]). In that case, the frequency of the MCLK_x is equal to the SCK_x.

The NODIV, MCKEN, SAIEN, OVR, CKSTR and MCKDIV[5:0] bits belong to the SAI_xCR1 register, while FRL[7:0] belongs to SAI_xFRCR.

Clock generator programming when NODIV = 0

In that case, MCLK_x frequency is:

- $F_{MCLK\_x} = 256 \times F_{FS\_x}$ if OSR = 0
- $F_{MCLK\_x} = 512 \times F_{FS\_x}$ if OSR = 1

When MCKDIV is different from 0, MCLK_x frequency is given by the formula below:

$$F_{MCLK\_x} = \frac{F_{sai\_x\_ker\_ck}}{MCKDIV}$$

The frame synchronization frequency is given by:

$$F_{FS\_x} = \frac{F_{sai\_x\_ker\_ck}}{MCKDIV \times (OSR + 1) \times 256}$$

The bit clock frequency (SCK_x) is given by the following formula:

$$F_{SCK\_x} = \frac{F_{sai\_x\_ker\_ck} \times (FRL + 1)}{MCKDIV \times (OSR + 1) \times 256}$$

Note: When NODIV is equal to 0, (FRL+1) must be a power of two. In addition (FRL+1) must range between 8 and 256. (FRL +1) represents the number of bit clock in the audio frame.

When MCKDIV division ratio is odd, the MCLK duty cycle is not 50%. The bit clock signal (SCK_x) can also have a duty cycle different from 50% if MCKDIV is odd, if OSR is equal to 0, and if (FRL+1) = 2^8.

It is recommended, to program MCKDIV to an even value or to big values (higher than 10).

Note that MCKDIV = 0 gives the same result as MCKDIV = 1.

Clock generator programming when NODIV = 1

When MCKDIV is different from 0, the frequency of the bit clock (SCK_x) is given in the formula below:

$$F_{SCK\_x} = F_{MCLK\_x} = \frac{F_{sai\_x\_ker\_ck}}{MCKDIV}$$

The frequency of the frame synchronization (FS_x) in given by the following formula:

$$F_{FS\_x} = \frac{F_{sai\_x\_ker\_ck}}{(FRL + 1) \times MCKDIV}$$

Note: When NODIV is set to 1, (FRL+1) can take any values from 8 to 256.

Note that MCKDIV = 0 gives the same result as MCKDIV = 1.

Clock generator programming examples

Table 447 gives programming examples for 48, 96 and 192 kHz.

Table 447. Clock generator programming examples

Input sai_x_ker_ck clock frequency	MCLK	F_{MCLK}/ F_{FS}	FRL (1)	OSR	NODIV	MCKEN	MCKDIV[5:0]	Audio Sampling frequency (F_{FS})
98.304 MHz	Y	512	2^N-1	1	0	1	0 or 1	192 kHz
		512	2^N-1	1	0	1	2	96 kHz
		512	2^N-1	1	0	1	4	48 kHz
		256	2^N-1	0	0	1	2	192 kHz
		256	2^N-1	0	0	1	4	96 kHz
		256	2^N-1	0	0	1	8	48 kHz
	N	-	63	-	1	0	8	192 kHz
		-	63	-	1	0	16	96 kHz
		-	63	-	1	0	32	48 kHz

1. N is an integer value between 3 and 8.

56.4.9 Internal FIFOs

Each audio block in the SAI has its own FIFO. Depending if the block is defined to be a transmitter or a receiver, the FIFO can be written or read, respectively. There is therefore only one FIFO request linked to FREQ bit in the SAI_xSR register.

An interrupt is generated if FREQIE bit is enabled in the SAI_xIM register. This depends on:

- FIFO threshold setting (FLVL bits in SAI_xCR2)
- Communication direction (transmitter or receiver). Refer to *Interrupt generation in transmitter mode* and *Interrupt generation in reception mode*.

Interrupt generation in transmitter mode

The interrupt generation depends on the FIFO configuration in transmitter mode:

- When the FIFO threshold bits in SAI_xCR2 register are configured as FIFO empty (FTH[2:0] set to 0b000), an interrupt is generated (FREQ bit set by hardware to 1 in SAI_xSR register) if no data are available in SAI_xDR register (FLVL[2:0] bits in SAI_xSR is less than 001b). This Interrupt (FREQ bit in SAI_xSR register) is cleared by hardware when the FIFO is no more empty (FLVL[2:0] bits in SAI_xSR are different from 0b000) i.e one or more data are stored in the FIFO.
- When the FIFO threshold bits in SAI_xCR2 register are configured as FIFO quarter full (FTH[2:0] set to 001b), an interrupt is generated (FREQ bit set by hardware to 1 in SAI_xSR register) if less than a quarter of the FIFO contains data (FLVL[2:0] bits in SAI_xSR are less than 0b010). This Interrupt (FREQ bit in SAI_xSR register) is cleared by hardware when at least a quarter of the FIFO contains data (FLVL[2:0] bits in SAI_xSR are higher or equal to 0b010).
- When the FIFO threshold bits in SAI_xCR2 register are configured as FIFO half full (FTH[2:0] set to 0b010), an interrupt is generated (FREQ bit set by hardware to 1 in

SAI_xSR register) if less than half of the FIFO contains data (FLVL[2:0] bits in SAI_xSR are less than 011b). This Interrupt (FREQ bit in SAI_xSR register) is cleared by hardware when at least half of the FIFO contains data (FLVL[2:0] bits in SAI_xSR are higher or equal to 011b).

- When the FIFO threshold bits in SAI_xCR2 register are configured as FIFO three quarter (FTH[2:0] set to 011b), an interrupt is generated (FREQ bit is set by hardware to 1 in SAI_xSR register) if less than three quarters of the FIFO contain data (FLVL[2:0] bits in SAI_xSR are less than 0b100). This Interrupt (FREQ bit in SAI_xSR register) is cleared by hardware when at least three quarters of the FIFO contain data (FLVL[2:0] bits in SAI_xSR are higher or equal to 0b100).
- When the FIFO threshold bits in SAI_xCR2 register are configured as FIFO full (FTH[2:0] set to 0b100), an interrupt is generated (FREQ bit is set by hardware to 1 in SAI_xSR register) if the FIFO is not full (FLVL[2:0] bits in SAI_xSR is less than 101b). This Interrupt (FREQ bit in SAI_xSR register) is cleared by hardware when the FIFO is full (FLVL[2:0] bits in SAI_xSR is equal to 101b value).

Interrupt generation in reception mode

The interrupt generation depends on the FIFO configuration in reception mode:

- When the FIFO threshold bits in SAI_xCR2 register are configured as FIFO empty (FTH[2:0] set to 0b000), an interrupt is generated (FREQ bit is set by hardware to 1 in SAI_xSR register) if at least one data is available in SAI_xDR register(FLVL[2:0] bits in SAI_xSR is higher or equal to 001b). This Interrupt (FREQ bit in SAI_xSR register) is cleared by hardware when the FIFO becomes empty (FLVL[2:0] bits in SAI_xSR is equal to 0b000) i.e no data are stored in FIFO.
- When the FIFO threshold bits in SAI_xCR2 register are configured as FIFO quarter fully (FTH[2:0] set to 001b), an interrupt is generated (FREQ bit is set by hardware to 1 in SAI_xSR register) if at least one quarter of the FIFO data locations are available (FLVL[2:0] bits in SAI_xSR is higher or equal to 0b010). This Interrupt (FREQ bit in SAI_xSR register) is cleared by hardware when less than a quarter of the FIFO data locations become available (FLVL[2:0] bits in SAI_xSR is less than 0b010).
- When the FIFO threshold bits in SAI_xCR2 register are configured as FIFO half fully (FTH[2:0] set to 0b010 value), an interrupt is generated (FREQ bit is set by hardware to 1 in SAI_xSR register) if at least half of the FIFO data locations are available (FLVL[2:0] bits in SAI_xSR is higher or equal to 011b). This Interrupt (FREQ bit in SAI_xSR register) is cleared by hardware when less than half of the FIFO data locations become available (FLVL[2:0] bits in SAI_xSR is less than 011b).
- When the FIFO threshold bits in SAI_xCR2 register are configured as FIFO three quarter full(FTH[2:0] set to 011b value), an interrupt is generated (FREQ bit is set by hardware to 1 in SAI_xSR register) if at least three quarters of the FIFO data locations are available (FLVL[2:0] bits in SAI_xSR is higher or equal to 0b100). This Interrupt (FREQ bit in SAI_xSR register) is cleared by hardware when the FIFO has less than three quarters of the FIFO data locations avalable(FLVL[2:0] bits in SAI_xSR is less than 0b100).
- When the FIFO threshold bits in SAI_xCR2 register are configured as FIFO full(FTH[2:0] set to 0b100), an interrupt is generated (FREQ bit is set by hardware to 1 in SAI_xSR register) if the FIFO is full (FLVL[2:0] bits in SAI_xSR is equal to 101b). This Interrupt (FREQ bit in SAI_xSR register) is cleared by hardware when the FIFO is not full (FLVL[2:0] bits in SAI_xSR is less than 101b).

Like interrupt generation, the SAI can use the DMA if DMAEN bit in the SAI_xCR1 register is set. The FREQ bit assertion mechanism is the same as the interrupt generation mechanism described above for FREQIE.

Each FIFO is an 8-word FIFO. Each read or write operation from/to the FIFO targets one word FIFO location whatever the access size. Each FIFO word contains one audio slot. FIFO pointers are incremented by one word after each access to the SAI_xDR register.

Data should be right aligned when it is written in the SAI_xDR.

Data received are right aligned in the SAI_xDR.

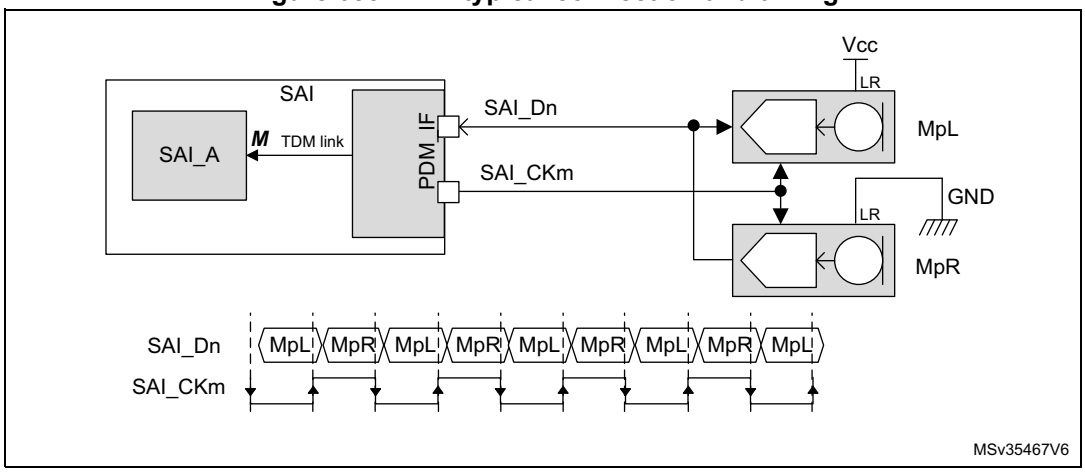
The FIFO pointers can be reinitialized when the SAI is disabled by setting bit FFLUSH in the SAI_xCR2 register. If FFLUSH is set when the SAI is enabled the data present in the FIFO are lost automatically.

56.4.10 PDM interface

The PDM (Pulse Density Modulation) interface is provided in order to support digital microphones. Up to 4 digital microphone pairs can be connected in parallel. Depending on product implementation, less microphones can be supported (refer to *Section 56.3: SAI implementation*).

Figure 683 shows a typical connection of a digital microphone pair via a PDM interface. Both microphones share the same bitstream clock and data line. Thanks to a configuration pin (LR), a microphone can provide valid data on SAI_CK[m] rising edge while the other provides valid data on SAI_CK[m] falling edge (m being the number of clock lines).

Figure 683. PDM typical connection and timing



1. **n** refers to the number of data lines and **p** to the number of microphone pairs.

The PDM function is intended to be used in conjunction with SAI_A subblock configured in TDM master mode. It cannot be used with SAI_B subblock. The PDM interface uses the timing signals provided by the TDM interface of SAI_A and adapts them to generate a bitstream clock (SAI_CK[m]).

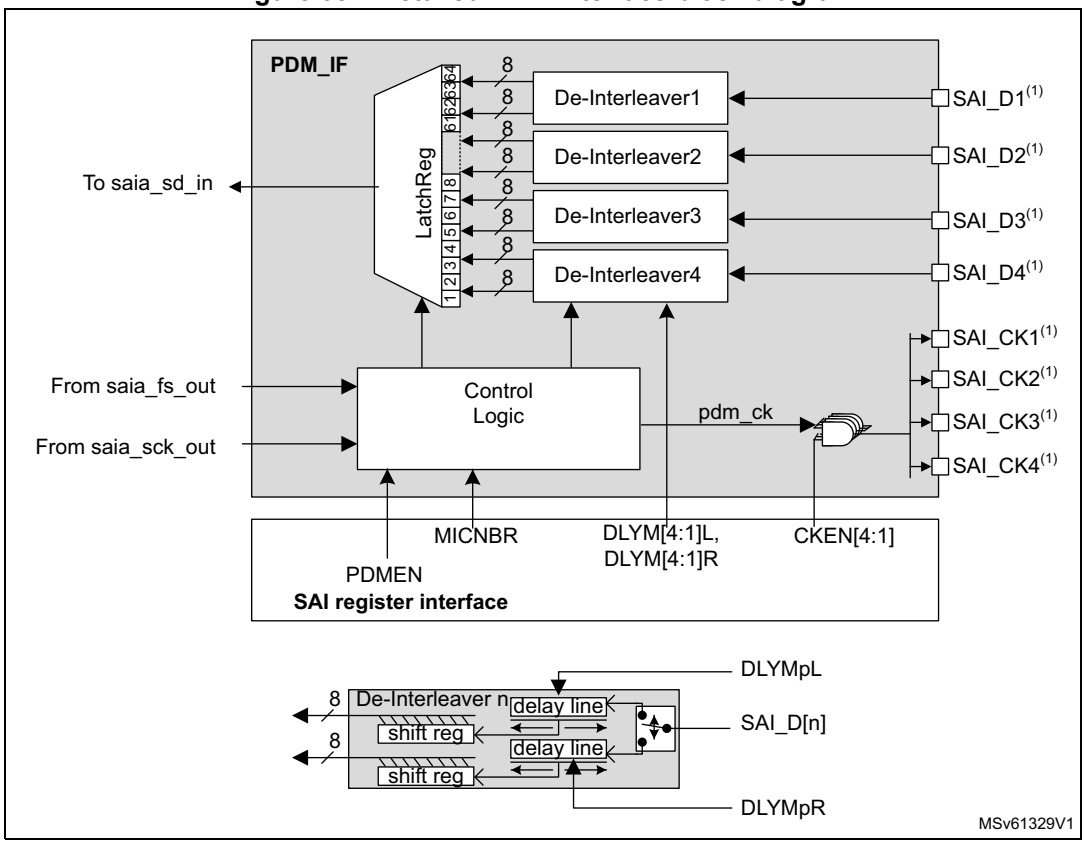
The data processing sequence into the PDM is the following:

1. The PDM interface builds the bitstream clock from the bit clock received from the TDM interface of SAI_A.
2. The bitstream data received from the microphones (SAI_D[n]) are de-interleaved and go through a 7-bit delay line in order to fine-tune the delay of each microphone with the accuracy of the bitstream clock.
3. The shift registers translate each serial bitstream into bytes.
4. The last operation consists in shifting-out the resulting bytes to SAI_A via the serial data line of the TDM interface.

Figure 684 hereafter shows the block diagram of PDM interface, with a detailed view of a de-interleaver.

Note: The PDM interface *does not embed the decimation filter required to build-up the PCM audio samples from the bitstream. It is up to the application software to perform this operation.*

Figure 684. Detailed PDM interface block diagram



1. These signals might not be available in all SAI instances. Please refer to *Section 56.3: SAI implementation* for details.
2. **n** refers to the number of data lines and **p** to the number of microphone pairs.

The PDM interface can be enabled through the PDMEN bit in SAI_PDMCR register. However the PDM interface must be enabled prior to enabling SAI_A block.

To reduce the memory footprint, the user can select the amount of microphones the application needs. This can be done through MICNBR[1:0] bits. It is possible to select

between 2,4,6 or 8 microphones. For example, if the application is using 3 microphones, the user has to select 4.

Enabling the PDM interface

To enable the PDM interface, follow the sequence below:

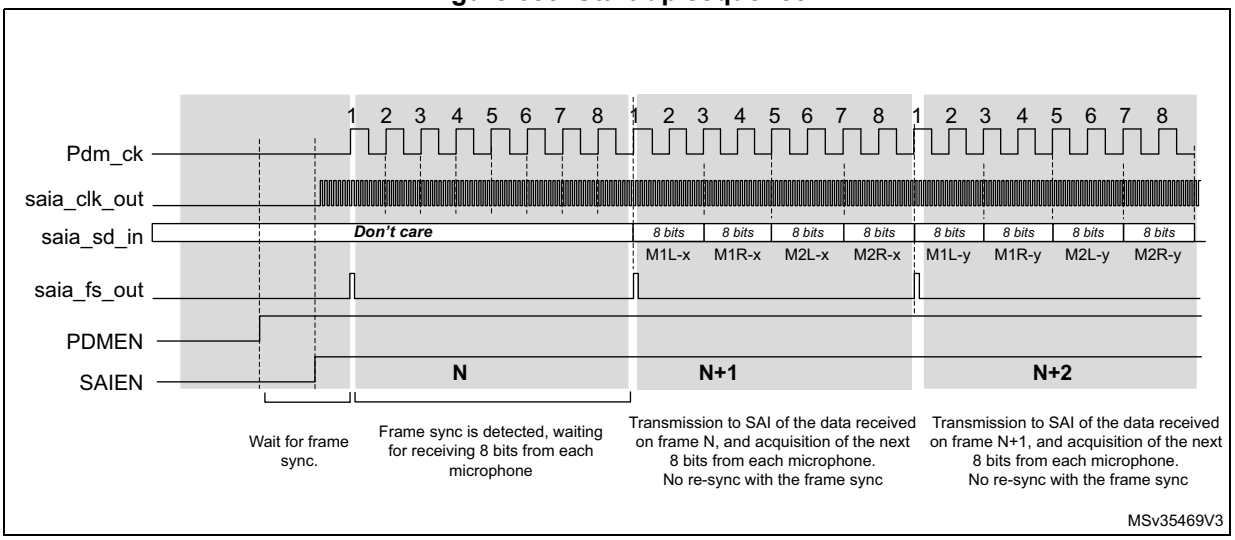
1. Configure SAI_A in TDM master mode (see *Table 448*).
2. Configure the PDM interface as follows:
   a) Define the number of digital microphones via MICNBR.
   b) Enable the bitstream clock needed in the application by setting the corresponding bits on CKEN to 1.
3. Enable the PDM interface, via PDMEN bit.
4. Enable the SAI_A.

Note: Once the PDM interface and SAI_A are enabled, the first 2 TDMA frames received on SAI_ADR are invalid and must be dropped.

Start-up sequence

Figure 685 shows the start-up sequence: Once the PDM interface is enabled, it waits for the frame synchronization event prior to starting the acquisition of the microphone samples. After 8 SAI_CK clock periods, a data byte coming from each microphone is available, and transferred to the SAI, via the TDM interface.

Figure 685. Start-up sequence



SAI_ADR data format

The arrangement of the data coming from the microphone into the SAI_ADR register depends on the following parameters:

- The amount of microphones
- The slot width selected
- LSBFIRST bit.

The slot width defines the amount of significant bits into each word available into the SAI_ADR.

When a slot width of 32 bits is selected, each data available into the SAI_ADR contains 32 useful bits. This reduces the amount of words stored into the memory. However the counterpart is that the software has to perform some operations to de-interleave the data of each microphone.

In the other hand, when the slot width is set to 8 bits, each data available into the SAI_ADR contain 8 useful bits. This increases the amount of words stored into the memory. However, it offers the advantage to avoid extra processing since each word contains information from one microphone.

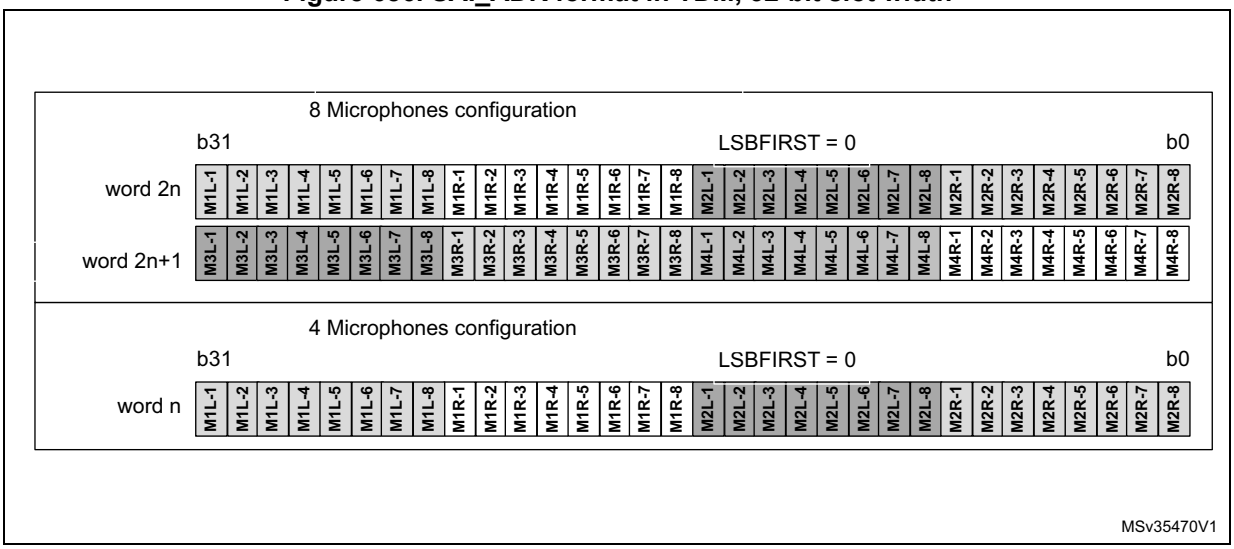
SAI_ADR data format example

- **32-bit slot width** (DS = 0b111 and SLOTSZ = 0). Refer to *Figure 686*.

  For an 8 microphone configuration, two consecutive words read from the SAI_ADR register contain a data byte from each microphone.

  For a 4 microphones configuration, each word read from the SAI_ADR register contains a data byte from each microphone.

Figure 686. SAI_ADR format in TDM, 32-bit slot width

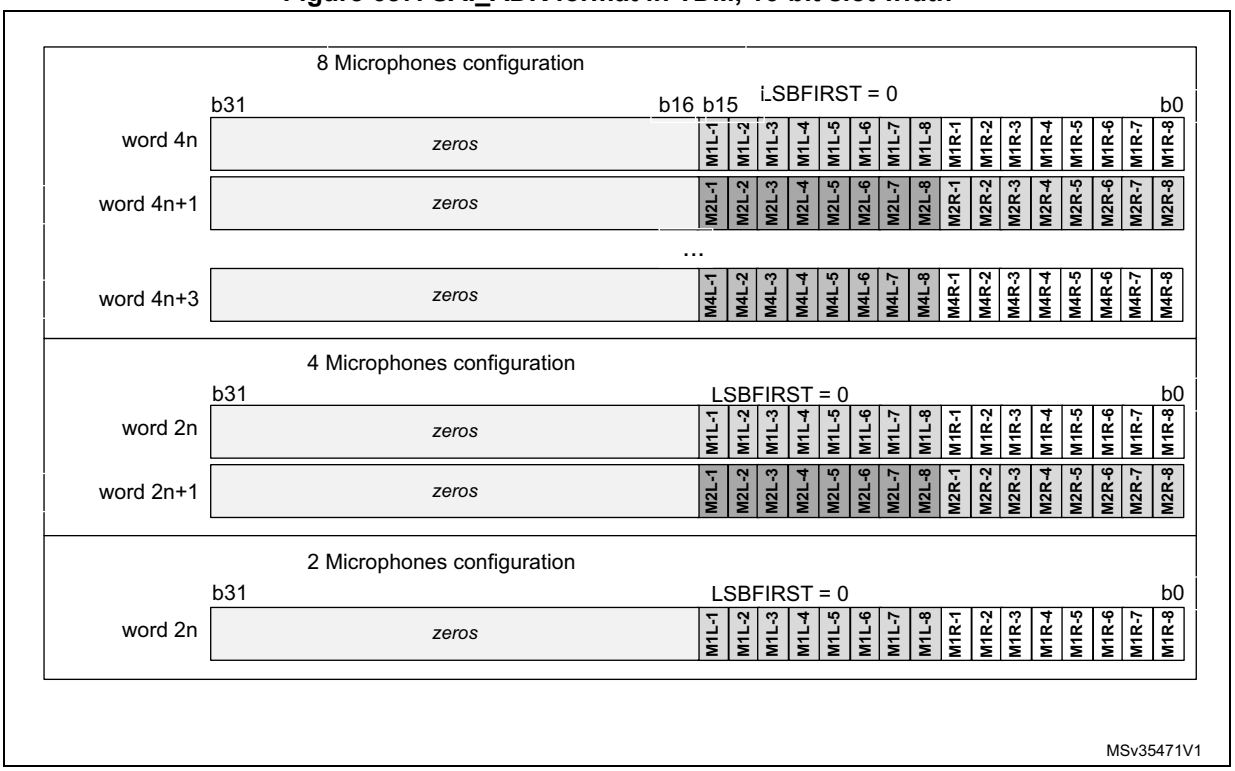


- **16-bit slot width** (DS = 0b100 and SLOTSZ = 0). Refer to *Figure 687*.

  For an 8 microphone configuration, four consecutive words read from the SAI_ADR register contain a data byte from each microphone. Note that the 16-bit data of SAI_ADR are right aligned.

  For 4 or 2 microphone configuration, the SAI behavior is similar to 8-microphone configurations. Up to 2 words of 16 bits are required to acquire a byte from 4 microphones and a single word for 2 microphones.

Figure 687. SAI_ADR format in TDM, 16-bit slot width

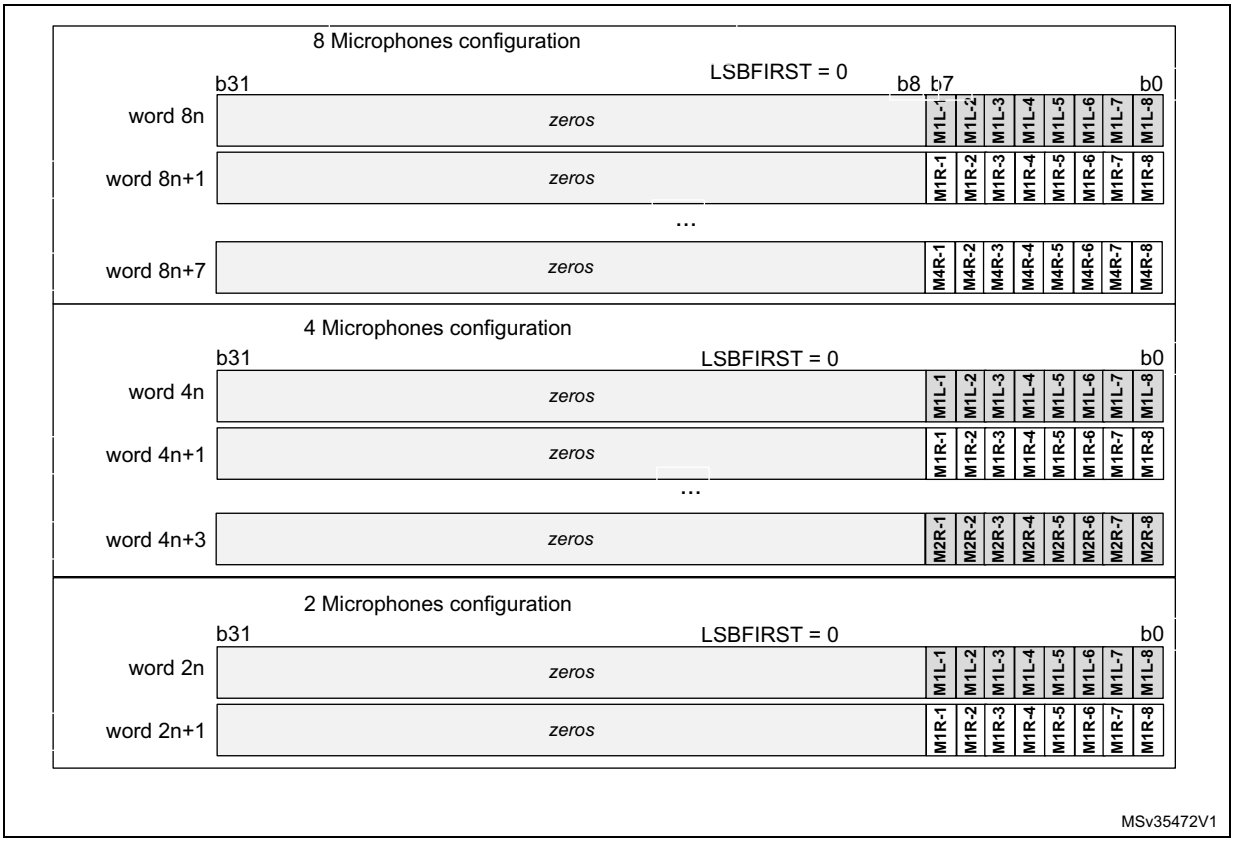


- **Using a 8-bit slot width** (DS = 0b010 and SLOTSZ = 0). Refer to *Figure 688*.

  For an 8 microphone configuration, 8 consecutive words read from the SAI_ADR register contain a byte of data from each microphone. Note that the 8-bit data of SAI_ADR are right aligned.

  For 4 or 2 microphone configuration, the SAI behavior is similar to 8 microphone configurations. Up to 4 words of 8 bits are required to acquire a byte from 4 microphones and 2 words from 2 microphones.

Figure 688. SAI_ADR format in TDM, 8-bit slot width



TDM configuration for PDM interface

SAI_A TDM interface is internally connected to the PDM interface to get the microphone samples. The user application must configure the PDM interface as shown in *Table 448* to ensure a good connection with the PDM interface.

Table 448. TDM settings

Bit Fields	Values	Comments
MODE	0b01	Mode must be MASTER receiver
PRTCFG	0b00	Free protocol for TDM
DS	X	To be adjusted according to the required data format, in accordance to the frame length and the number of slots (FRL and NBSLOT). See *Table 449*.
LSBFIRST	X	This parameter can be used according to the wanted data format
CKSTR	0	Signal transitions occur on the rising edge of the SCK_A bit clock. Signals are stable on the falling edge of the bit clock.
MONO	0	Stereo mode
FRL	X	To be adjusted according to the number of microphones (MICNBR). See *Table 449*.
FSALL	0	Pulse width is one bit clock cycle
FSDEF	0	FS signal is a start of frame

Table 448. TDM settings (continued)

Bit Fields	Values	Comments
FSPOL	1	FS is active High
FSOFF	0	FS is asserted on the first bit of slot 0
FBOFF	0	No offset on slot
SLOTSZ	0	Slot size = data size
NBSLOT	X	To be adjusted according to the required data format, in accordance to the slot size, and the frame length (FRL and DS). See *Table 449*.
SLOTEN	X	To be adjusted according to NBSLOT
NODIV	1	No need to generate a master clock MCLK
MCKDIV	X	Depends on the frequency provided to sai_a_ker_ck input. This parameter must be adjusted to generate the proper bitstream clock frequency. See *Table 449*.

Adjusting the bitstream clock rate

To properly program the SAI TDM interface, the user application must take into account the settings given in *Table 448*, and follow the below sequence:

1. Adjust the bit clock frequency (F_{SCK_A}) according to the required frequency for the PDM bitstream clock, using the following formula:

$$F_{SCK\_A} = F_{PDM\_CK} \times (MICNBR + 1) \times 2$$

   MICNBR can be 0,1,2 or 3 (0 = 2 microphones., see *Section 56.6.18*)

2. Set the frame length (FRL) using the following formula

$$FRL = (16 \times (MICNBR + 1)) - 1$$

3. Configure the slot size (DS) to a multiple of (FRL+1).

Table 449. TDM frame configuration examples(1)(2)

Microphone sampling rate	Nber of microphones	Wanted SAI_CKn frequency	bit clock (SCK_A) frequency	Frame sync. (FS_A) frequency	FRL	DS	NBSLOT	Comments
48 kHz	up to 8	3.072 MHz	24.576 MHz	384 kHz	63	0b111	1	2 slots of 32 bits per frame
		3.072 MHz	24.576 MHz	384 kHz	63	0b100	3	4 slots of 16 bits per frame
		3.072 MHz	24.576 MHz	384 kHz	63	0b010	7	8 slots of 8 bits per frame
	up to 6	3.072 MHz	18.432 MHz	384 kHz	47	0b110	1	2 slots of 24 bits per frame
		3.072 MHz	18.432 MHz	384 kHz	47	0b100	2	3 slots of 16 bits per frame
		3.072 MHz	18.432 MHz	384 kHz	47	0b010	5	6 slots of 8 bits per frame
	up to 4	3.072 MHz	12.288 MHz	384 kHz	31	0b111	0	1 slot of 32 bits per frame
		3.072 MHz	12.288 MHz	384 kHz	31	0b100	1	2 slots of 16 bits per frame
		3.072 MHz	12.288 MHz	384 kHz	31	0b010	3	4 slots of 8 bits per frame
	up to 2	3.072 MHz	6.144 MHz	384 kHz	15	0b100	0	1 slots of 16 bits per frame
		3.072 MHz	6.144 MHz	384 kHz	15	0b010	1	2 slots of 8 bits per frame
16 kHz	up to 8	1.024 MHz	8.192 MHz	128 kHz	63	0b111	1	2 slots of 32 bits per frame
		1.024 MHz	8.192 MHz	128 kHz	63	0b100	3	4 slots of 16 bits per frame
		1.024 MHz	8.192 MHz	128 kHz	63	0b010	7	8 slots of 8 bits per frame
	up to 6	1.024 MHz	6.144 MHz	128 kHz	47	0b110	1	2 slots of 24 bits per frame
		1.024 MHz	6.144 MHz	128 kHz	47	0b010	5	6 slots of 8 bits per frame
	up to 4	1.024 MHz	4.096 MHz	128 kHz	31	0b111	0	1 slot of 32 bits per frame
		1.024 MHz	4.096 MHz	128 kHz	31	0b100	1	2 slots of 16 bits per frame
		1.024 MHz	4.096 MHz	128 kHz	31	0b010	3	4 slots of 8 bits per frame
	up to 2	1.024 MHz	2.048 MHz	128 kHz	15	0b100	0	1 slot of 16 bits per frame
		1.024 MHz	2.048 MHz	128 kHz	15	0b010	1	2 slots of 8 bits per frame

1. Refer to *Table 448: TDM settings* for additional information on TDM configuration. The sai_a_ker_ck clock frequency provided to the SAI must be a multiple of the SCK_A frequency, and MCKDIV should be programmed accordingly.
2. The above sai_a_ker_ck frequencies are given as examples only. Refer to section *Reset and clock controller (RCC) to check if they can be generated on the device.*
3. The table above gives allowed settings for a decimation ratio of 64.

Adjusting the delay lines

When the PDM interface is enabled, the application can adjust on-the-fly the delay cells of each microphone input via SAI_PDMDLY register.

The new delays values become effective after two TDM frames.

56.4.11 AC’97 link controller

The SAI is able to work as an AC’97 link controller. In this protocol:

- The slot number and the slot size are fixed.
- The frame synchronization signal is perfectly defined and has a fixed shape.

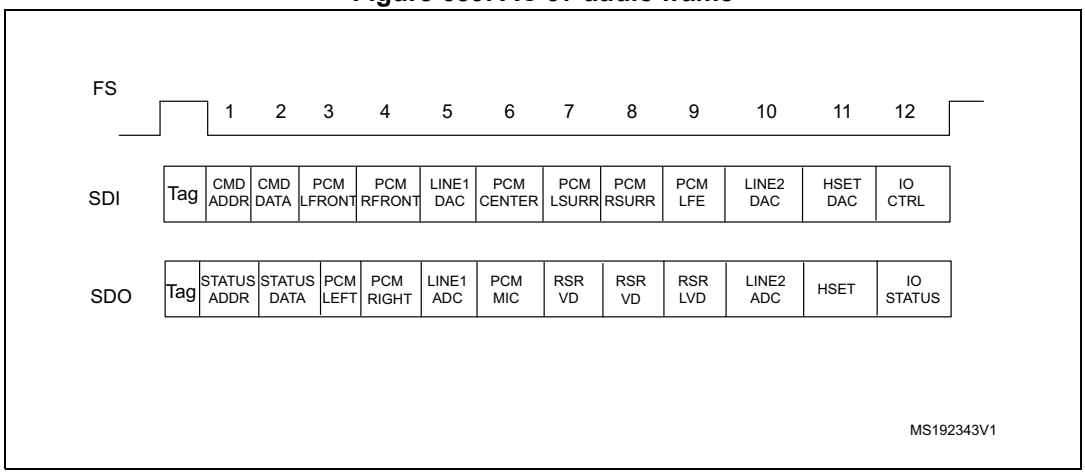
To select this protocol, set PRTCFG[1:0] bits in the SAI_xCR1 register to 10. When AC’97 mode is selected, only data sizes of 16 or 20 bits can be used, otherwise the SAI behavior is not guaranteed.

- NBSLOT[3:0] and SLOTSZ[1:0] bits are consequently ignored.
- The number of slots is fixed to 13 slots. The first one is 16-bit wide and all the others are 20-bit wide (data slots).
- FBOFF[4:0] bits in the SAI_xSLOTR register are ignored.
- The SAI_xFRCR register is ignored.
- The MCLK is not used.

The FS signal from the block defined as asynchronous is configured automatically as an output, since the AC’97 controller link drives the FS signal whatever the master or slave configuration.

Figure 689 shows an AC’97 audio frame structure.

Figure 689. AC’97 audio frame



Note: In AC’97 protocol, bit 2 of the tag is reserved (always 0), so bit 2 of the TAG is forced to 0 level whatever the value written in the SAI FIFO.

For more details about tag representation, refer to the AC’97 protocol standard.

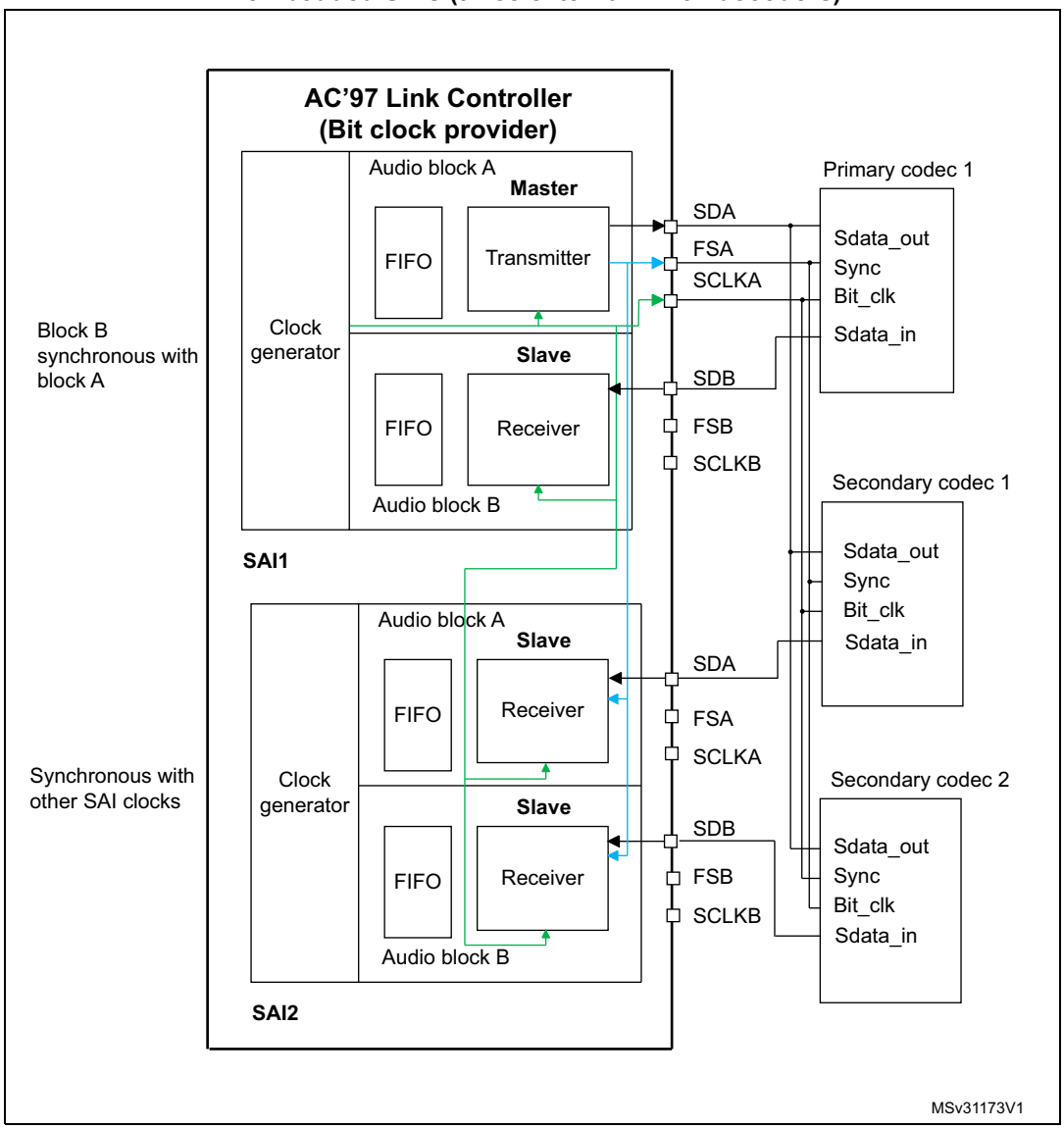
One SAI can be used to target an AC’97 point-to-point communication.

Using two SAIs (for devices featuring two embedded SAIs) allows controlling three external AC’97 decoders as illustrated in *Figure 690*.

In SAI1, the audio block A must be declared as asynchronous master transmitter whereas the audio block B is defined to be slave receiver and internally synchronous to the audio block A.

The SAI2 is configured for audio block A and B both synchronous with the external SAI1 in slave receiver mode.

Figure 690. Example of typical AC'97 configuration on devices featuring at least 2 embedded SAIs (three external AC'97 decoders)



In receiver mode, the SAI acting as an AC'97 link controller requires no FIFO request and so no data storage in the FIFO when the Codec ready bit in the slot 0 is decoded low. If bit CNRDYIE is enabled in the SAI_xIM register, flag CNRDY is set in the SAI_xSR register and an interrupt is generated. This flag is dedicated to the AC'97 protocol.

Clock generator programming in AC'97 mode

In AC'97 mode, the frame length is fixed at 256 bits, and its frequency must be set to 48 kHz. The formulas given in *Section 56.4.8: SAI clock generator* must be used with FRL = 255, in order to generate the proper frame rate (F_{FS_x}).

56.4.12 SPDIF output

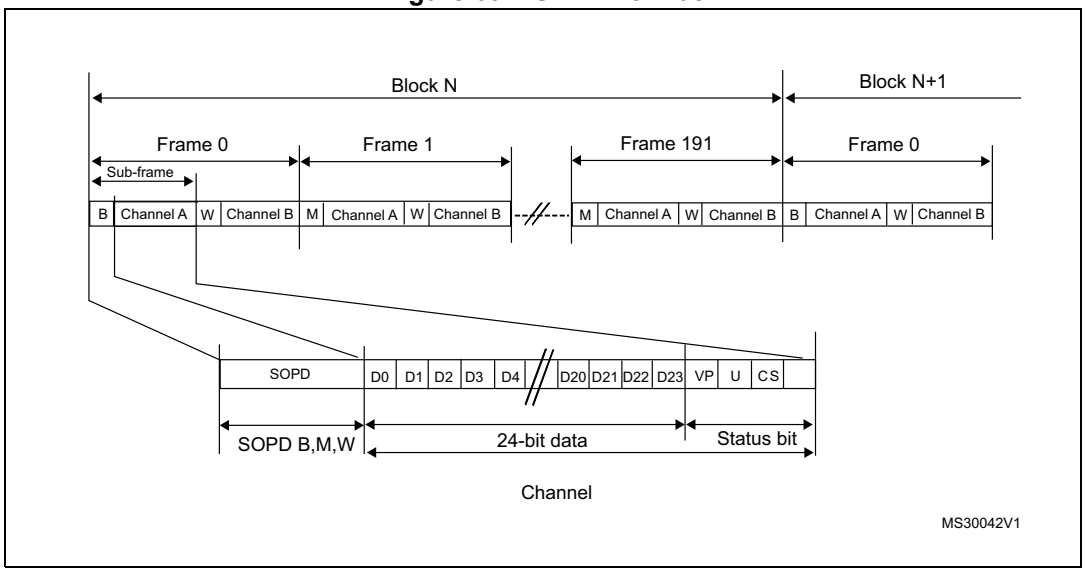
The SPDIF interface is available in transmitter mode only. It supports the audio IEC60958.

To select SPDIF mode, set PRTCFG[1:0] bit to 01 in the SAI_xCR1 register.

For SPDIF protocol:

- Only SD data line is enabled.
- FS, SCK, MCLK I/Os pins are left free.
- MODE[1] bit is forced to 0 to select the master mode in order to enable the clock generator of the SAI and manage the data rate on the SD line.
- The data size is forced to 24 bits. The value set in DS[2:0] bits in the SAI_xCR1 register is ignored.
- The clock generator must be configured to define the symbol-rate, knowing that the bit clock should be twice the symbol-rate. The data is coded in Manchester protocol.
- The SAI_xFRCR and SAI_xSLOTR registers are ignored. The SAI is configured internally to match the SPDIF protocol requirements as shown in *Figure 691*.

Figure 691. SPDIF format



A SPDIF block contains 192 frames. Each frame is composed of two 32-bit sub-frames, generally one for the left channel and one for the right channel. Each sub-frame is composed of a SOPD pattern (4-bit) to specify if the sub-frame is the start of a block (and so is identifying a channel A) or if it is identifying a channel A somewhere in the block, or if it is referring to channel B (see *Table 450*). The next 28 bits of channel information are composed of 24 bits data + 4 status bits.

Table 450. SOPD pattern

SOPD	Preamble coding		Description
	last bit is 0	last bit is 1	
B	11101000	00010111	Channel A data at the start of block
W	11100100	00011011	Channel B data somewhere in the block
M	11100010	00011101	Channel A data

The data stored in SAI_xDR has to be filled as follows:

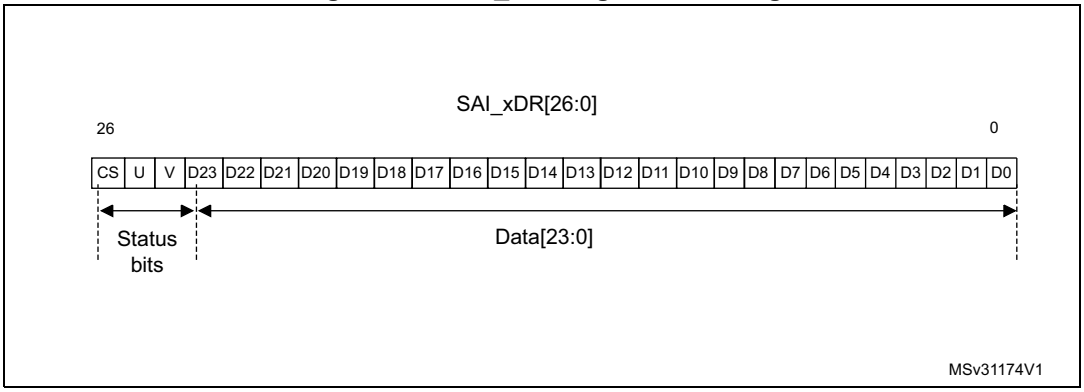
- SAI_xDR[26:24] contain the Channel status, User and Validity bits.
- SAI_xDR[23:0] contain the 24-bit data for the considered channel.

If the data size is 20 bits, then data must be mapped on SAI_xDR[23:4].

If the data size is 16 bits, then data must be mapped on SAI_xDR[23:8].

SAI_xDR[23] always represents the MSB.

Figure 692. SAI_xDR register ordering



Note: The transfer is performed always with LSB first.

The SAI first sends the adequate preamble for each sub-frame in a block. The SAI_xDR is then sent on the SD line (manchester coded). The SAI ends the sub-frame by transferring the Parity bit calculated as described in *Table 451*.

Table 451. Parity bit calculation

SAI_xDR[26:0]	Parity bit P value transferred
odd number of 0	0
odd number of 1	1

The underrun is the only error flag available in the SAI_xSR register for SPDIF mode since the SAI can only operate in transmitter mode. As a result, the following sequence should be

executed to recover from an underrun error detected via the underrun interrupt or the underrun status bit:

1. Disable the DMA stream (via the DMA peripheral) if the DMA is used.
2. Disable the SAI and check that the peripheral is physically disabled by polling the SAIEN bit in SAI_xCR1 register.
3. Clear the COVRUNDR flag in the SAI_xCLRFR register.
4. Flush the FIFO by setting the FFLUSH bit in SAI_xCR2.

   The software needs to point to the address of the future data corresponding to a start of new block (data for preamble B). If the DMA is used, the DMA source base address pointer should be updated accordingly.
5. Enable again the DMA stream (DMA peripheral) if the DMA used to manage data transfers according to the new source base address.
6. Enable again the SAI by setting SAIEN bit in SAI_xCR1 register.

Clock generator programming in SPDIF generator mode

For the SPDIF generator, the SAI provides a bit clock twice faster as the symbol-rate. The table hereafter shows usual examples of symbol rates with respect to the audio sampling rate.

Table 452. Audio sampling frequency versus symbol rates

Audio sampling frequencies (F_S)	Symbol-rate
44.1 kHz	2.8224 MHz
48 kHz	3.072 MHz
96 kHz	6.144 MHz
192 kHz	12.288 MHz

More generally, the relationship between the audio sampling frequency (F_S) and the bit clock rate (F_{SCK_X}) is given by the formula:

$$F_S = \frac{F_{SCK\_x}}{128}$$

The bit clock rate is obtained as follows:

$$F_{SCK\_x} = \frac{F_{sai\_x\_ker\_ck}}{MCKDIV}$$

Note: The above formulas are valid only if NODIV is set to 1 in SAI_ACR1 register.

56.4.13 Specific features

The SAI interface embeds specific features which can be useful depending on the audio protocol selected. These functions are accessible through specific bits of the SAI_xCR2 register.

Mute mode

The mute mode can be used when the audio subblock is a transmitter or a receiver.

Audio subblock in transmission mode

In transmitter mode, the mute mode can be selected at anytime. The mute mode is active for entire audio frames. The MUTE bit in the SAI_xCR2 register enables the mute mode when it is set during an ongoing frame.

The mute mode bit is strobed only at the end of the frame. If it is set at this time, the mute mode is active at the beginning of the new audio frame and for a complete frame, until the next end of frame. The bit is then strobed to determine if the next frame is still a mute frame.

If the number of slots set through NBSLOT[3:0] bits in the SAI_xSLOTR register is lower than or equal to 2, it is possible to specify if the value sent in mute mode is 0 or if it is the last value of each slot. The selection is done via MUTEVAL bit in the SAI_xCR2 register.

If the number of slots set in NBSLOT[3:0] bits in the SAI_xSLOTR register is greater than 2, MUTEVAL bit in the SAI_xCR2 is meaningless as 0 values are sent on each bit on each slot.

The FIFO pointers are still incremented in mute mode. This means that data present in the FIFO and for which the mute mode is requested are discarded.

Audio subblock in reception mode

In reception mode, it is possible to detect a mute mode sent from the external transmitter when all the declared and valid slots of the audio frame receive 0 for a given consecutive number of audio frames (MUTECNT[5:0] bits in the SAI_xCR2 register).

When the number of MUTE frames is detected, the MUTEDET flag in the SAI_xSR register is set and an interrupt can be generated if MUTEDETIE bit is set in SAI_xCR2.

The mute frame counter is cleared when the audio subblock is disabled or when a valid slot receives at least one data in an audio frame. The interrupt is generated just once, when the counter reaches the value specified in MUTECNT[5:0] bits. The interrupt event is then reinitialized when the counter is cleared.

Note: The mute mode is not available for SPDIF audio blocks.

Mono/stereo mode

In transmitter mode, the mono mode can be addressed, without any data preprocessing in memory, assuming the number of slots is equal to 2 (NBSLOT[3:0] = 0001 in SAI_xSLOTR). In this case, the access time to and from the FIFO is reduced by 2 since the data for slot 0 is duplicated into data slot 1.

To enable the mono mode,

1. Set MONO bit to 1 in the SAI_xCR1 register.
2. Set NBSLOT to 1 and SLOTEN to 3 in SAI_xSLOTR.

In reception mode, the MONO bit can be set and is meaningful only if the number of slots is equal to 2 as in transmitter mode. When it is set, only slot 0 data are stored in the FIFO. The data belonging to slot 1 are discarded since, in this case, it is supposed to be the same as the previous slot. If the data flow in reception mode is a real stereo audio flow with a distinct and different left and right data, the MONO bit is meaningless. The conversion from the output stereo file to the equivalent mono file is done by software.

Companding mode

Telecommunication applications can require to process the data to be transmitted or received using a data companding algorithm.

Depending on the COMP[1:0] bits in the SAI_xCR2 register (used only when Free protocol mode is selected), the application software can choose to process or not the data before sending it on SD serial output line (compression) or to expand the data after the reception on SD serial input line (expansion) as illustrated in *Figure 693*. The two companding modes supported are the µ-Law and the A-Law log which are a part of the CCITT G.711 recommendation.

The companding standard used in the United States and Japan is the µ-Law. It supports 14 bits of dynamic range (COMP[1:0] = 10 in the SAI_xCR2 register).

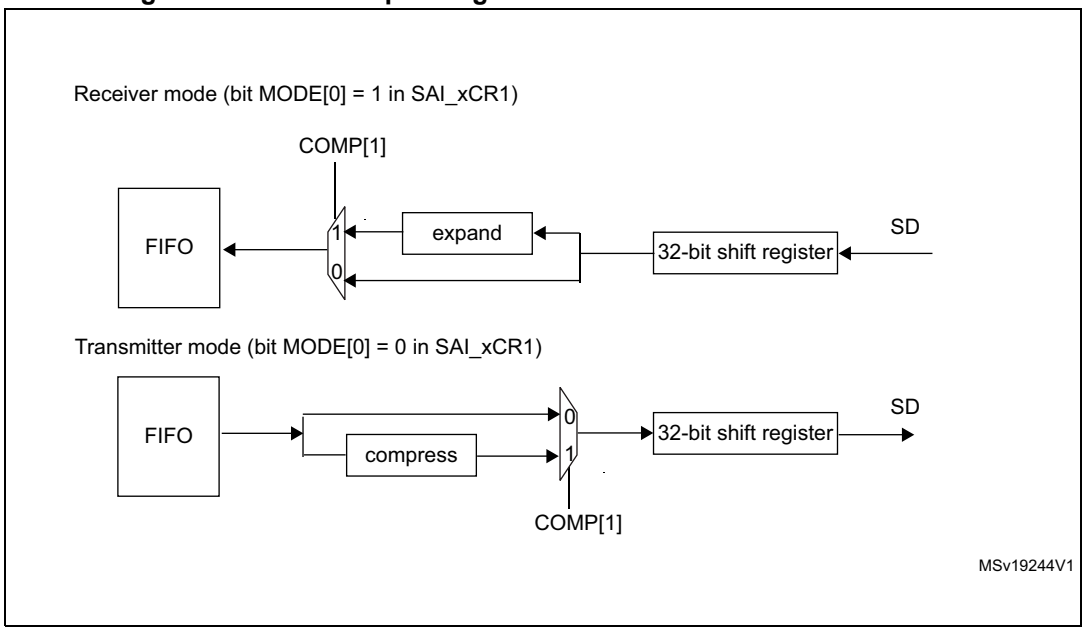
The European companding standard is A-Law and supports 13 bits of dynamic range (COMP[1:0] = 11 in the SAI_xCR2 register).

Both µ-Law or A-Law companding standard can be computed based on 1’s complement or 2’s complement representation depending on the CPL bit setting in the SAI_xCR2 register.

In µ-Law and A-Law standards, data are coded as 8 bits with MSB alignment. Companded data are always 8-bit wide. For this reason, DS[2:0] bits in the SAI_xCR1 register are forced to 010 when the SAI audio block is enabled (SAIEN bit = 1 in the SAI_xCR1 register) and when one of these two companding modes selected through the COMP[1:0] bits.

If no companding processing is required, COMP[1:0] bits should be kept clear.

Figure 693. Data companding hardware in an audio block in the SAI



1. Not applicable when AC'97 or SPDIF are selected.

Expansion and compression mode are automatically selected through the SAI_xCR2:

- If the SAI audio block is configured to be a transmitter, and if the COMP[1] bit is set in the SAI_xCR2 register, the compression mode is applied.
- If the SAI audio block is declared as a receiver, the expansion algorithm is applied.

Output data line management on an inactive slot

In transmitter mode, it is possible to choose the behavior of the SD line output when an inactive slot is sent on the data line (via TRIS bit).

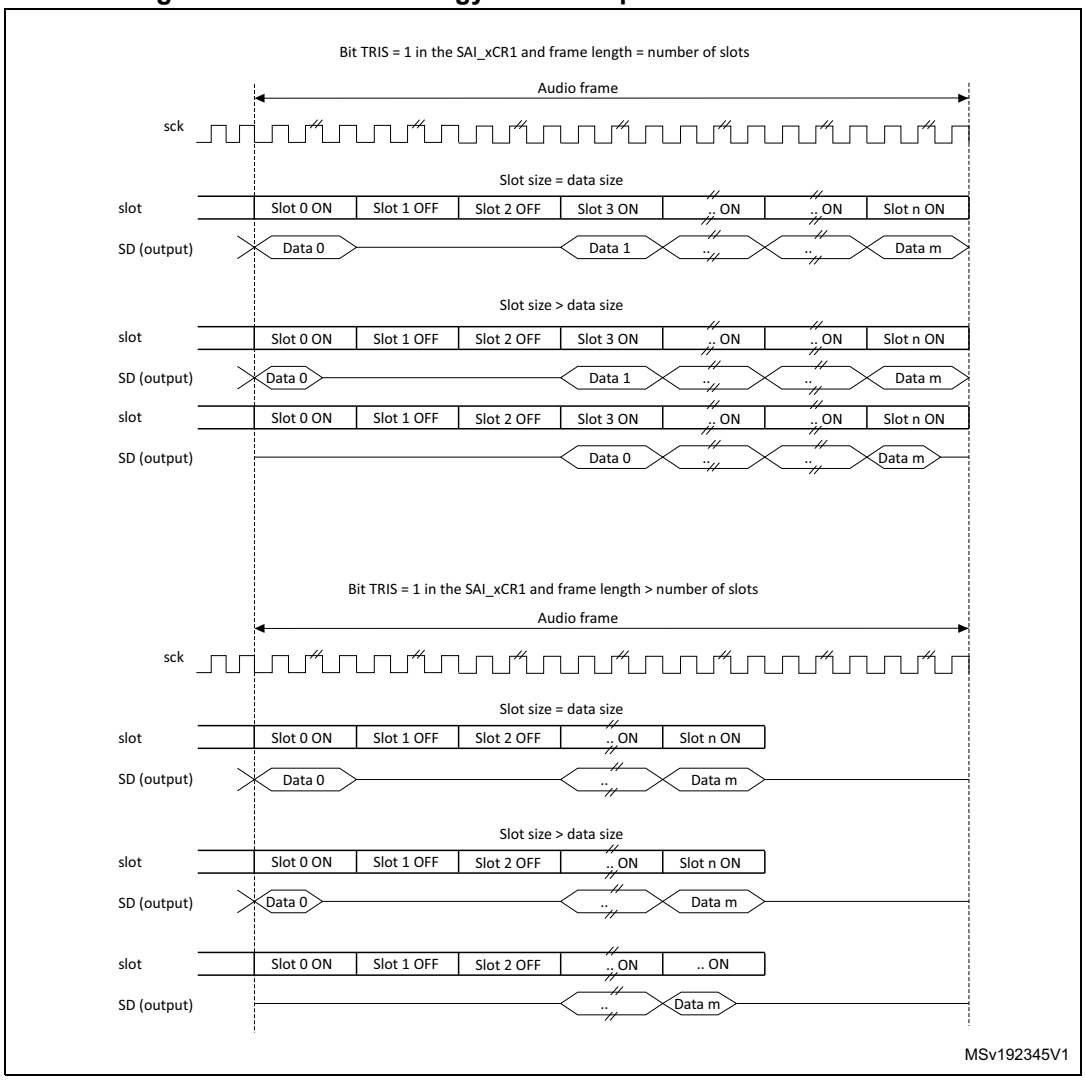
- Either the SAI forces 0 on the SD output line when an inactive slot is transmitted, or
- The line is released in HI-z state at the end of the last bit of data transferred, to release the line for other transmitters connected to this node.

It is important to note that the two transmitters cannot attempt to drive the same SD output pin simultaneously, which could result in a short circuit. To ensure a gap between transmissions, if the data is lower than 32-bit, the data can be extended to 32-bit by setting bit SLOTSZ[1:0] = 10 in the SAI_xSLOTR register. The SD output pin is then tri-stated at the end of the LSB of the active slot (during the padding to 0 phase to extend the data to 32-bit) if the following slot is declared inactive.

In addition, if the number of slots multiplied by the slot size is lower than the frame length, the SD output line is tri-stated when the padding to 0 is done to complete the audio frame.

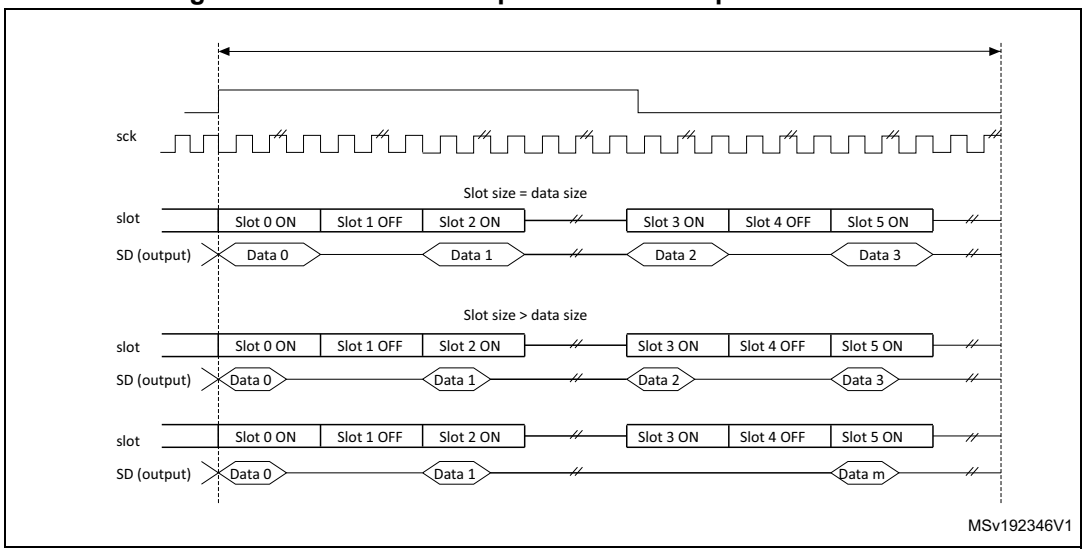
Figure 694 illustrates these behaviors.

Figure 694. Tristate strategy on SD output line on an inactive slot



When the selected audio protocol uses the FS signal as a start of frame and a channel side identification (bit FSDEF = 1 in the SAI_xFRCR register), the tristate mode is managed according to *Figure 695* (where bit TRIS in the SAI_xCR1 register = 1, and FSDEF=1, and half frame length is higher than number of slots/2, and NBSLOT=6).

Figure 695. Tristate on output data line in a protocol like I2S



If the TRIS bit in the SAI_xCR2 register is cleared, all the High impedance states on the SD output line on *Figure 694* and *Figure 695* are replaced by a drive with a value of 0.

56.4.14 Error flags

The SAI implements the following error flags:

- FIFO overrun/underrun
- Anticipated frame synchronization detection
- Late frame synchronization detection
- Codec not ready (AC'97 exclusively)
- Wrong clock configuration in master mode.

FIFO overrun/underrun (OVRUDR)

The FIFO overrun/underrun bit is called OVRUDR in the SAI_xSR register.

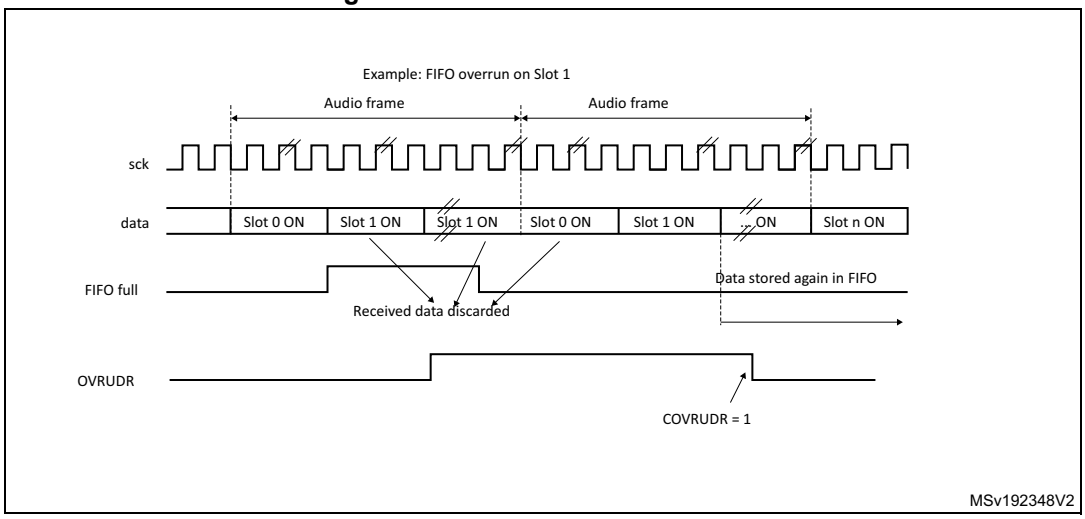
The overrun or underrun errors share the same bit since an audio block can be either receiver or transmitter and each audio block in a given SAI has its own SAI_xSR register.

Overrun

When the audio block is configured as receiver, an overrun condition may appear if data are received in an audio frame when the FIFO is full and not able to store the received data. In this case, the received data are lost, the flag OVRUDR in the SAI_xSR register is set and an interrupt is generated if OVRUDRIE bit is set in the SAI_xIM register. The slot number, from which the overrun occurs, is stored internally. No more data are stored into the FIFO until it becomes free to store new data. When the FIFO has at least one data free, the SAI audio block receiver stores new data (from new audio frame) from the slot number which was stored internally when the overrun condition was detected. This avoids data slot de-alignment in the destination memory (refer to *Figure 696*).

The OVRUDR flag is cleared when COVRUDR bit is set in the SAI_xCLRFR register.

Figure 696. Overrun detection error



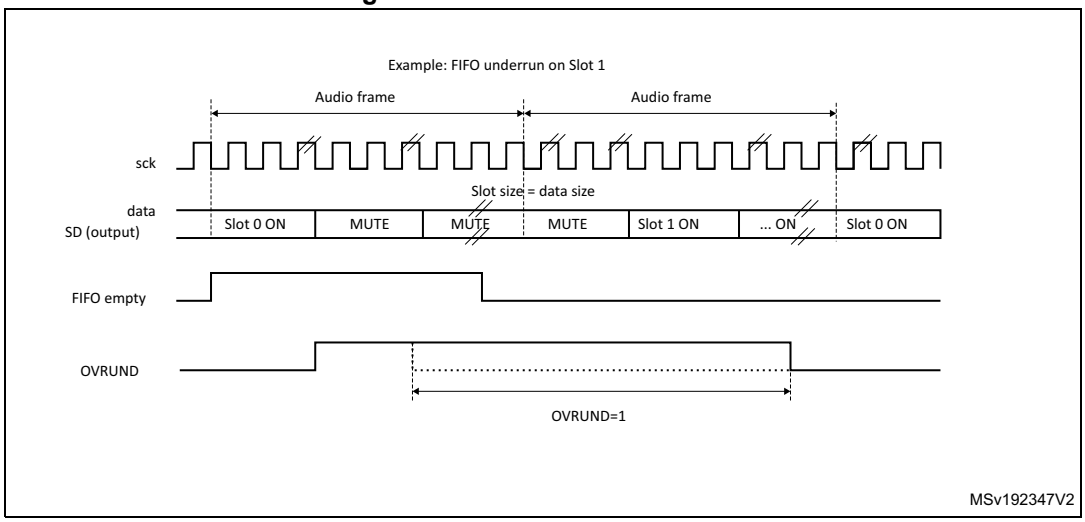
Underrun

An underrun may occur when the audio block in the SAI is a transmitter and the FIFO is empty when data need to be transmitted. If an underrun is detected, the slot number for which the event occurs is stored and MUTE value (00) is sent until the FIFO is ready to transmit the data corresponding to the slot for which the underrun was detected (refer to *Figure 697*). This avoids desynchronization between the memory pointer and the slot in the audio frame.

The underrun event sets the OVRUDR flag in the SAI_xSR register and an interrupt is generated if the OVRUDRIE bit is set in the SAI_xIM register. To clear this flag, set COVRUDR bit in the SAI_xCLRFR register.

The underrun event can occur when the audio subblock is configured as master or slave.

Figure 697. FIFO underrun event



Anticipated frame synchronization detection (AFSDET)

The AFSDET flag is used only in slave mode. It is never asserted in master mode. It indicates that a frame synchronization (FS) has been detected earlier than expected since the frame length, the frame polarity, the frame offset are defined and known.

Anticipated frame detection sets the AFSDET flag in the SAI_xSR register.

This detection has no effect on the current audio frame which is not sensitive to the anticipated FS. This means that “parasitic” events on signal FS are flagged without any perturbation of the current audio frame.

An interrupt is generated if the AFSDETIE bit is set in the SAI_xIM register. To clear the AFSDET flag, CAFSDET bit must be set in the SAI_xCLRFR register.

To resynchronize with the master after an anticipated frame detection error, four steps are required:

1. Disable the SAI block by resetting SAIEN bit in SAI_xCR1 register. To make sure the SAI is disabled, read back the SAIEN bit and check it is set to 0.
2. Flush the FIFO via FFLUS bit in SAI_xCR2 register.
3. Enable again the SAI peripheral (SAIEN bit set to 1).
4. The SAI block waits for the assertion on FS to restart the synchronization with master.

Note: The AFSDET flag is not asserted in AC’97 mode since the SAI audio block acts as a link controller and generates the FS signal even when declared as slave.It has no meaning in SPDIF mode since the FS signal is not used.

Late frame synchronization detection

The LFSDET flag in the SAI_xSR register can be set only when the SAI audio block operates as a slave. The frame length, the frame polarity and the frame offset configuration are known in register SAI_xFRCR.

If the external master does not send the FS signal at the expecting time thus generating the signal too late, the LFSDET flag is set and an interrupt is generated if LFSDETIE bit is set in the SAI_xIM register.

The LFSDET flag is cleared when CLFSDET bit is set in the SAI_xCLRFR register.

The late frame synchronization detection flag is set when the corresponding error is detected. The SAI needs to be resynchronized with the master (see sequence described in *Anticipated frame synchronization detection (AFSDET)*).

In a noisy environment, glitches on the SCK clock may be wrongly detected by the audio block state machine and shift the SAI data at a wrong frame position. This event can be detected by the SAI and reported as a late frame synchronization detection error.

There is no corruption if the external master is not managing the audio data frame transfer in continuous mode, which should not be the case in most applications. In this case, the LFSDET flag is set.

Note: The LFSDET flag is not asserted in AC’97 mode since the SAI audio block acts as a link controller and generates the FS signal even when declared as slave.It has no meaning in SPDIF mode since the signal FS is not used by the protocol.

Codec not ready (CNRDY AC'97)

The CNRDY flag in the SAI_xSR register is relevant only if the SAI audio block is configured to operate in AC'97 mode (PRTCFG[1:0] = 10 in the SAI_xCR1 register). If CNRDYIE bit is set in the SAI_xIM register, an interrupt is generated when the CNRDY flag is set.

CNRDY is asserted when the Codec is not ready to communicate during the reception of the TAG 0 (slot0) of the AC'97 audio frame. In this case, no data are automatically stored into the FIFO since the Codec is not ready, until the TAG 0 indicates that the Codec is ready. All the active slots defined in the SAI_xSLOTR register are captured when the Codec is ready.

To clear CNRDY flag, CCNRDY bit must be set in the SAI_xCLRFR register.

Wrong clock configuration in master mode (with NODIV = 0)

When the audio block operates as a master (MODE[1] = 0) and NODIV bit is equal to 0, the WCKCFG flag is set as soon as the SAI is enabled if the following conditions are met:

- (FRL+1) is not a power of 2, and
- (FRL+1) is not between 8 and 256.

MODE, NODIV, and SAIEN bits belong to SAI_xCR1 register and FRL to SAI_xFRCR register.

If WCKCFGIE bit is set, an interrupt is generated when WCKCFG flag is set in the SAI_xSR register. To clear this flag, set CWCKCFG bit in the SAI_xCLRFR register.

When WCKCFG bit is set, the audio block is automatically disabled, thus performing a hardware clear of SAIEN bit.

56.4.15 Disabling the SAI

The SAI audio block can be disabled at any moment by clearing SAIEN bit in the SAI_xCR1 register. All the already started frames are automatically completed before the SAI is stops working. SAIEN bit remains High until the SAI is completely switched-off at the end of the current audio frame transfer.

If an audio block in the SAI operates synchronously with the other one, the one which is the master must be disabled first.

56.4.16 SAI DMA interface

To free the CPU and to optimize bus bandwidth, each SAI audio block has an independent DMA interface to read/write from/to the SAI_xDR register (to access the internal FIFO). There is one DMA channel per audio subblock supporting basic DMA request/acknowledge protocol.

To configure the audio subblock for DMA transfer, set DMAEN bit in the SAI_xCR1 register. The DMA request is managed directly by the FIFO controller depending on the FIFO threshold level (for more details refer to *Section 56.4.9: Internal FIFOs*). DMA transfer direction is linked to the SAI audio subblock configuration:

- If the audio block operates as a transmitter, the audio block FIFO controller outputs a DMA request to load the FIFO with data written in the SAI_xDR register.
- If the audio block is operates as a receiver, the DMA request is related to read operations from the SAI_xDR register.

Follow the sequence below to configure the SAI interface in DMA mode:

1. Configure SAI and FIFO threshold levels to specify when the DMA request is launched.
2. Configure SAI DMA channel.
3. Enable the DMA.
4. Enable the SAI interface.

Note: Before configuring the SAI block, the SAI DMA channel must be disabled.

56.5 SAI interrupts

The SAI supports 7 interrupt sources as shown in *Table 453*.

Table 453. SAI interrupt sources

Interrupt acronym	Interrupt source	Interrupt group	Audio block mode	Interrupt enable	Interrupt clear
SAI	FREQ	FREQ	Master or slave Receiver or transmitter	FREQIE in SAI_xIM register	Depends on: – FIFO threshold setting (FLVL bits in SAI_xCR2) – Communication direction (transmitter or receiver) For more details refer to *Section 56.4.9: Internal FIFOs*
	OVRUDR	ERROR	Master or slave Receiver or transmitter	OVRUDRIE in SAI_xIM register	COVRUDR = 1 in SAI_xCLRFR register
	AFSDET	ERROR	Slave (not used in AC'97 mode and SPDIF mode)	AFSDETIE in SAI_xIM register	CAFSDET = 1 in SAI_xCLRFR register
	LFSDET	ERROR	Slave (not used in AC'97 mode and SPDIF mode)	LFSDETIE in SAI_xIM register	CLFSDET = 1 in SAI_xCLRFR register
	CNRDY	ERROR	Slave (only in AC'97 mode)	CNRDYIE in SAI_xIM register	CCNRDY = 1 in SAI_xCLRFR register
	MUTEDET	MUTE	Master or slave Receiver mode only	MUTEDETIE in SAI_xIM register	CMUTEDET = 1 in SAI_xCLRFR register
	WCKCFG	ERROR	Master with NODIV = 0 in SAI_xCR1 register	WCKCFGIE in SAI_xIM register	CWCKCFG = 1 in SAI_xCLRFR register

Follow the sequence below to enable an interrupt:

1. Disable SAI interrupt.
2. Configure SAI.
3. Configure SAI interrupt source.
4. Enable SAI.

56.6 SAI registers

The peripheral registers have to be accessed by words (32 bits).

56.6.1 SAI global configuration register (SAI_GCR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYNCOUT[1:0]		Res.	Res.	SYNCIN[1:0]	
										rw	rw			rw	rw

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:4 **SYNCOUT[1:0]**: Synchronization outputs

These bits are set and cleared by software.

00: No synchronization output signals. SYNCOUT[1:0] should be configured as “No synchronization output signals” when audio block is configured as SPDIF

01: Block A used for further synchronization for others SAI

10: Block B used for further synchronization for others SAI

11: Reserved. These bits must be set when both audio block (A and B) are disabled.

Bits 3:2 Reserved, must be kept at reset value.

Bits 1:0 **SYNCIN[1:0]**: Synchronization inputs

These bits are set and cleared by software.

Refer to *Table 445: External synchronization selection* for information on how to program this field.

These bits must be set when both audio blocks (A and B) are disabled.

They are meaningful if one of the two audio blocks is defined to operate in synchronous mode with an external SAI (SYNCEN[1:0] = 10 in SAI_ACR1 or in SAI_BCR1 registers).

56.6.2 SAI configuration register 1 (SAI_ACR1)

Address offset: 0x004

Reset value: 0x0000 0040

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	MCKEN	OSR	MCKDIV[5:0]						NODIV	Res.	DMAEN	SAIEN
				rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	OUTDRIV	MONO	SYNCEN[1:0]		CKSTR	LSBFIRST	DS[2:0]			Res.	PRTCFG[1:0]		MODE[1:0]	
		rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **MCKEN:** Master clock generation enable
0: The master clock is not generated
1: The master clock is generated independently of SAIEN bit

Bit 26 **OSR:** Oversampling ratio for master clock
This bit is meaningful only when NODIV bit is set to 0.
0: Master clock frequency = F_{FS} x 256
1: Master clock frequency = F_{FS} x 512

Bits 25:20 **MCKDIV[5:0]**: Master clock divider
These bits are set and cleared by software.
000000: Divides by 1 the kernel clock input (sai_x_ker_ck).
Otherwise, The master clock frequency is calculated according to the formula given in *Section 56.4.8: SAI clock generator*.
These bits have no meaning when the audio block is slave.
They have to be configured when the audio block is disabled.

Bit 19 **NODIV:** No divider
This bit is set and cleared by software.
0: the ratio between the Master clock generator and frame synchronization is fixed to 256 or 512
1: the ratio between the Master clock generator and frame synchronization depends on FRL[7:0]

Bit 18 Reserved, must be kept at reset value.

Bit 17 **DMAEN**: DMA enable
This bit is set and cleared by software.
0: DMA disabled
1: DMA enabled
Note: Since the audio block defaults to operate as a transmitter after reset, the MODE[1:0] bits must be configured before setting DMAEN to avoid a DMA request in receiver mode.

Bit 16 **SAIEN**: Audio block enable
This bit is set by software.
To switch off the audio block, the application software must program this bit to 0 and poll the bit till it reads back 0, meaning that the block is completely disabled. Before setting this bit to 1, check that it is set to 0, otherwise the enable command is not taken into account.
This bit allows controlling the state of the SAI audio block. If it is disabled when an audio frame transfer is ongoing, the ongoing transfer completes and the cell is fully disabled at the end of this audio frame transfer.
0: SAI audio block disabled
1: SAI audio block enabled.
Note: When the SAI block (A or B) is configured in master mode, the clock must be present on the SAI block input before setting SAIEN bit.

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **OUTDRIV**: Output drive
This bit is set and cleared by software.
0: Audio block output driven when SAIEN is set
1: Audio block output driven immediately after the setting of this bit.
Note: This bit has to be set before enabling the audio block and after the audio block configuration.

Bit 12 **MONO**: Mono mode

This bit is set and cleared by software. It is meaningful only when the number of slots is equal to 2. When the mono mode is selected, slot 0 data are duplicated on slot 1 when the audio block operates as a transmitter. In reception mode, the slot1 is discarded and only the data received from slot 0 are stored. Refer to *Section : Mono/stereo mode* for more details.

0: Stereo mode

1: Mono mode.

Bits 11:10 **SYNCEN[1:0]:** Synchronization enable

These bits are set and cleared by software. They must be configured when the audio subblock is disabled.

00: audio subblock in asynchronous mode.

01: audio subblock is synchronous with the other internal audio subblock. In this case, the audio subblock must be configured in slave mode

10: audio subblock is synchronous with an external SAI embedded peripheral. In this case the audio subblock should be configured in Slave mode.

11: Reserved

Note: The audio subblock should be configured as asynchronous when SPDIF mode is enabled.

Bit 9 **CKSTR:** Clock strobing edge

This bit is set and cleared by software. It must be configured when the audio block is disabled. This bit has no meaning in SPDIF audio protocol.

0: Signals generated by the SAI change on SCK rising edge, while signals received by the SAI are sampled on the SCK falling edge.

1: Signals generated by the SAI change on SCK falling edge, while signals received by the SAI are sampled on the SCK rising edge.

Bit 8 **LSBFIRST:** Least significant bit first

This bit is set and cleared by software. It must be configured when the audio block is disabled. This bit has no meaning in AC'97 audio protocol since AC'97 data are always transferred with the MSB first. This bit has no meaning in SPDIF audio protocol since in SPDIF data are always transferred with LSB first.

0: Data are transferred with MSB first

1: Data are transferred with LSB first

Bits 7:5 **DS[2:0]:** Data size

These bits are set and cleared by software. These bits are ignored when the SPDIF protocols are selected (bit PRTCFG[1:0]), because the frame and the data size are fixed in such case. When the companding mode is selected through COMP[1:0] bits, DS[1:0] are ignored since the data size is fixed to 8 bits by the algorithm.

These bits must be configured when the audio block is disabled.

000: Reserved

001: Reserved

010: 8 bits

011: 10 bits

100: 16 bits

101: 20 bits

110: 24 bits

111: 32 bits

Bit 4 Reserved, must be kept at reset value.

Bits 3:2 **PRTCFG[1:0]:** Protocol configuration

These bits are set and cleared by software. These bits have to be configured when the audio block is disabled.

00: Free protocol. Free protocol allows to use the powerful configuration of the audio block to address a specific audio protocol (such as I2S, LSB/MSB justified, TDM, PCM/DSP...) by setting most of the configuration register bits as well as frame configuration register.

01: SPDIF protocol

10: AC'97 protocol

11: Reserved

Bits 1:0 **MODE[1:0]:** SAIx audio block mode

These bits are set and cleared by software. They must be configured when SAIx audio block is disabled.

00: Master transmitter

01: Master receiver

10: Slave transmitter

11: Slave receiver

Note: When the audio block is configured in SPDIF mode, the master transmitter mode is forced (MODE[1:0] = 00).

56.6.3 SAI configuration register 1 (SAI_BCR1)

Address offset: 0x024

Reset value: 0x0000 0040

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	MCKEN	OSR	MCKDIV[5:0]						NODIV	Res.	DMAEN	SAIEN
				rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	OUTDRIV	MONO	SYNCEN[1:0]		CKSTR	LSBFIRST	DS[2:0]			Res.	PRTCFG[1:0]		MODE[1:0]	
		rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **MCKEN:** Master clock generation enable

0: The master clock is not generated

1: The master clock is generated independently of SAIEN bit

Bit 26 **OSR:** Oversampling ratio for master clock

This bit is meaningful only when NODIV bit is set to 0.

0: Master clock frequency = F_{FS} x 256

1: Master clock frequency = F_{FS} x 512

Bits 25:20 **MCKDIV[5:0]**: Master clock divider

These bits are set and cleared by software.

000000: Divides by 1 the kernel clock input (sai_x_ker_ck).

Otherwise, The master clock frequency is calculated according to the formula given in *Section 56.4.8: SAI clock generator*.

These bits have no meaning when the audio block is slave.

They have to be configured when the audio block is disabled.

Bit 19 **NODIV:** No divider

This bit is set and cleared by software.

0: the ratio between the Master clock generator and frame synchronization is fixed to 256 or 512

1: the ratio between the Master clock generator and frame synchronization depends on FRL[7:0]

Bit 18 Reserved, must be kept at reset value.

Bit 17 **DMAEN**: DMA enable

This bit is set and cleared by software.

0: DMA disabled

1: DMA enabled

Note: Since the audio block defaults to operate as a transmitter after reset, the MODE[1:0] bits must be configured before setting DMAEN to avoid a DMA request in receiver mode.

Bit 16 **SAIEN**: Audio block enable

This bit is set by software.

To switch off the audio block, the application software must program this bit to 0 and poll the bit till it reads back 0, meaning that the block is completely disabled. Before setting this bit to 1, check that it is set to 0, otherwise the enable command is not taken into account.

This bit allows controlling the state of the SAI audio block. If it is disabled when an audio frame transfer is ongoing, the ongoing transfer completes and the cell is fully disabled at the end of this audio frame transfer.

0: SAI audio block disabled

1: SAI audio block enabled.

Note: When the SAI block (A or B) is configured in master mode, the clock must be present on the SAI block input before setting SAIEN bit.

Bits 15:14 Reserved, must be kept at reset value.

Bit 13 **OUTDRIV**: Output drive

This bit is set and cleared by software.

0: Audio block output driven when SAIEN is set

1: Audio block output driven immediately after the setting of this bit.

Note: This bit has to be set before enabling the audio block and after the audio block configuration.

Bit 12 **MONO**: Mono mode

This bit is set and cleared by software. It is meaningful only when the number of slots is equal to 2. When the mono mode is selected, slot 0 data are duplicated on slot 1 when the audio block operates as a transmitter. In reception mode, the slot1 is discarded and only the data received from slot 0 are stored. Refer to *Section : Mono/stereo mode* for more details.

0: Stereo mode

1: Mono mode.

Bits 11:10 **SYNCEN[1:0]:** Synchronization enable

These bits are set and cleared by software. They must be configured when the audio subblock is disabled.

00: audio subblock in asynchronous mode.

01: audio subblock is synchronous with the other internal audio subblock. In this case, the audio subblock must be configured in slave mode

10: audio subblock is synchronous with an external SAI embedded peripheral. In this case the audio subblock should be configured in Slave mode.

11: Reserved

Note: The audio subblock should be configured as asynchronous when SPDIF mode is enabled.

Bit 9 **CKSTR:** Clock strobing edge

This bit is set and cleared by software. It must be configured when the audio block is disabled. This bit has no meaning in SPDIF audio protocol.

0: Signals generated by the SAI change on SCK rising edge, while signals received by the SAI are sampled on the SCK falling edge.

1: Signals generated by the SAI change on SCK falling edge, while signals received by the SAI are sampled on the SCK rising edge.

Bit 8 **LSBFIRST:** Least significant bit first

This bit is set and cleared by software. It must be configured when the audio block is disabled. This bit has no meaning in AC'97 audio protocol since AC'97 data are always transferred with the MSB first. This bit has no meaning in SPDIF audio protocol since in SPDIF data are always transferred with LSB first.

0: Data are transferred with MSB first

1: Data are transferred with LSB first

Bits 7:5 **DS[2:0]:** Data size

These bits are set and cleared by software. These bits are ignored when the SPDIF protocols are selected (bit PRTCFG[1:0]), because the frame and the data size are fixed in such case. When the companding mode is selected through COMP[1:0] bits, DS[1:0] are ignored since the data size is fixed to 8 bits by the algorithm.

These bits must be configured when the audio block is disabled.

000: Reserved

001: Reserved

010: 8 bits

011: 10 bits

100: 16 bits

101: 20 bits

110: 24 bits

111: 32 bits

Bit 4 Reserved, must be kept at reset value.

Bits 3:2 **PRTCFG[1:0]:** Protocol configuration

These bits are set and cleared by software. These bits have to be configured when the audio block is disabled.

00: Free protocol. Free protocol allows to use the powerful config uration of the audio block to address a specific audio protocol (such as I2S, LSB/MSB justified, TDM, PCM/DSP...) by setting most of the configuration register bits as well as frame configuration register.

01: SPDIF protocol

10: AC'97 protocol

11: Reserved

Bits 1:0 **MODE[1:0]:** SAIx audio block mode

These bits are set and cleared by software. They must be configured when SAIx audio block is disabled.

00: Master transmitter

01: Master receiver

10: Slave transmitter

11: Slave receiver

Note: When the audio block is configured in SPDIF mode, the master transmitter mode is forced (MODE[1:0] = 00). In Master transmitter mode, the audio block starts generating the FS and the clocks immediately.

56.6.4 SAI configuration register 2 (SAI_ACR2)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
COMP[1:0]		CPL	MUTECNT[5:0]						MUTE VAL	MUTE	TRIS	F FLUSH	FTH[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:14 **COMP[1:0]**: Companding mode.

These bits are set and cleared by software. The µ-Law and the A-Law log are a part of the CCITT G.711 recommendation, the type of complement that is used depends on *CPL bit*.
The data expansion or data compression are determined by the state of bit MODE[0].
The data compression is applied if the audio block is configured as a transmitter.
The data expansion is automatically applied when the audio block is configured as a receiver.
Refer to *Section : Companding mode* for more details.
00: No companding algorithm
01: Reserved.
10: µ-Law algorithm
11: A-Law algorithm

Note: Companding mode is applicable only when Free protocol mode is selected.

Bit 13 **CPL**: Complement bit.

This bit is set and cleared by software.
It defines the type of complement to be used for companding mode
0: 1’s complement representation.
1: 2’s complement representation.

Note: This bit has effect only when the companding mode is µ-Law algorithm or A-Law algorithm.

Bits 12:7 **MUTECNT[5:0]**: Mute counter.

These bits are set and cleared by software. They are used only in reception mode.
The value set in these bits is compared to the number of consecutive mute frames detected in reception. When the number of mute frames is equal to this value, the flag MUTEDET is set and an interrupt is generated if bit MUTEDETIE is set.
Refer to *Section : Mute mode* for more details.

Bit 6 **MUTEVAL**: Mute value.

This bit is set and cleared by software.It must be written before enabling the audio block: SAIEN. This bit is meaningful only when the audio block operates as a transmitter, the number of slots is lower or equal to 2 and the MUTE bit is set.

If more slots are declared, the bit value sent during the transmission in mute mode is equal to 0, whatever the value of MUTEVAL.

if the number of slot is lower or equal to 2 and MUTEVAL = 1, the MUTE value transmitted for each slot is the one sent during the previous frame.

Refer to *Section : Mute mode* for more details.

0: Bit value 0 is sent during the mute mode.

1: Last values are sent during the mute mode.

Note: This bit is meaningless and should not be used for SPDIF audio blocks.

Bit 5 **MUTE:** Mute.

This bit is set and cleared by software. It is meaningful only when the audio block operates as a transmitter. The MUTE value is linked to value of MUTEVAL if the number of slots is lower or equal to 2, or equal to 0 if it is greater than 2.

Refer to *Section : Mute mode* for more details.

0: No mute mode.

1: Mute mode enabled.

Note: This bit is meaningless and should not be used for SPDIF audio blocks.

Bit 4 **TRIS**: Tristate management on data line.

This bit is set and cleared by software. It is meaningful only if the audio block is configured as a transmitter. This bit is not used when the audio block is configured in SPDIF mode. It should be configured when SAI is disabled.

Refer to *Section : Output data line management on an inactive slot* for more details.

0: SD output line is still driven by the SAI when a slot is inactive.

1: SD output line is released (HI-Z) at the end of the last data bit of the last active slot if the next one is inactive.

Bit 3 **FFLUSH:** FIFO flush.

This bit is set by software. It is always read as 0. This bit should be configured when the SAI is disabled.

0: No FIFO flush.

1: FIFO flush. Programming this bit to 1 triggers the FIFO Flush. All the internal FIFO pointers (read and write) are cleared. In this case data still present in the FIFO are lost (no more transmission or received data lost). Before flushing, SAI DMA stream/interrupt must be disabled

Bits 2:0 **FTH[2:0]:** FIFO threshold.

This bit is set and cleared by software.

000: FIFO empty

001: ¼ FIFO

010: ½ FIFO

011: ¾ FIFO

100: FIFO full

101: Reserved

110: Reserved

111: Reserved

56.6.5 SAI configuration register 2 (SAI_BCR2)

Address offset: 0x028

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
COMP[1:0]		CPL	MUTECNT[5:0]						MUTE VAL	MUTE	TRIS	F FLUSH	FTH[2:0]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	w	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:14 **COMP[1:0]**: Companding mode.

These bits are set and cleared by software. The µ-Law and the A-Law log are a part of the CCITT G.711 recommendation, the type of complement that is used depends on *CPL bit*.
The data expansion or data compression are determined by the state of bit MODE[0].
The data compression is applied if the audio block is configured as a transmitter.
The data expansion is automatically applied when the audio block is configured as a receiver.
Refer to *Section : Companding mode* for more details.
00: No companding algorithm
01: Reserved.
10: µ-Law algorithm
11: A-Law algorithm

Note: Companding mode is applicable only when Free protocol mode is selected.

Bit 13 **CPL**: Complement bit.

This bit is set and cleared by software.
It defines the type of complement to be used for companding mode
0: 1’s complement representation.
1: 2’s complement representation.

Note: This bit has effect only when the companding mode is µ-Law algorithm or A-Law algorithm.

Bits 12:7 **MUTECNT[5:0]**: Mute counter.

These bits are set and cleared by software. They are used only in reception mode.
The value set in these bits is compared to the number of consecutive mute frames detected in reception. When the number of mute frames is equal to this value, the flag MUTEDET is set and an interrupt is generated if bit MUTEDETIE is set.
Refer to *Section : Mute mode* for more details.

Bit 6 **MUTEVAL**: Mute value.

This bit is set and cleared by software.It must be written before enabling the audio block: SAIEN. This bit is meaningful only when the audio block operates as a transmitter, the number of slots is lower or equal to 2 and the MUTE bit is set.

If more slots are declared, the bit value sent during the transmission in mute mode is equal to 0, whatever the value of MUTEVAL.

if the number of slot is lower or equal to 2 and MUTEVAL = 1, the MUTE value transmitted for each slot is the one sent during the previous frame.

Refer to *Section : Mute mode* for more details.

0: Bit value 0 is sent during the mute mode.

1: Last values are sent during the mute mode.

Note: This bit is meaningless and should not be used for SPDIF audio blocks.

Bit 5 **MUTE:** Mute.

This bit is set and cleared by software. It is meaningful only when the audio block operates as a transmitter. The MUTE value is linked to value of MUTEVAL if the number of slots is lower or equal to 2, or equal to 0 if it is greater than 2.

Refer to *Section : Mute mode* for more details.

0: No mute mode.

1: Mute mode enabled.

Note: This bit is meaningless and should not be used for SPDIF audio blocks.

Bit 4 **TRIS**: Tristate management on data line.

This bit is set and cleared by software. It is meaningful only if the audio block is configured as a transmitter. This bit is not used when the audio block is configured in SPDIF mode. It should be configured when SAI is disabled.

Refer to *Section : Output data line management on an inactive slot* for more details.

0: SD output line is still driven by the SAI when a slot is inactive.

1: SD output line is released (HI-Z) at the end of the last data bit of the last active slot if the next one is inactive.

Bit 3 **FFLUSH:** FIFO flush.

This bit is set by software. It is always read as 0. This bit should be configured when the SAI is disabled.

0: No FIFO flush.

1: FIFO flush. Programming this bit to 1 triggers the FIFO Flush. All the internal FIFO pointers (read and write) are cleared. In this case data still present in the FIFO are lost (no more transmission or received data lost). Before flushing, SAI DMA stream/interrupt must be disabled

Bits 2:0 **FTH[2:0]:** FIFO threshold.

This bit is set and cleared by software.

000: FIFO empty

001: ¼ FIFO

010: ½ FIFO

011: ¾ FIFO

100: FIFO full

101: Reserved

110: Reserved

111: Reserved

56.6.6 SAI frame configuration register (SAI_AFRCR)

Address offset: 0x00C

Reset value: 0x0000 0007

Note: This register has no meaning in AC'97 and SPDIF audio protocol.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSOFF	FSPOL	FSDEF
													rw	rw	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	FSALL[6:0]							FRL[7:0]							
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **FSOFF**: Frame synchronization offset.

This bit is set and cleared by software. It is meaningless and is not used in AC'97 or SPDIF audio block configuration. This bit must be configured when the audio block is disabled.

0: FS is asserted on the first bit of the slot 0.

1: FS is asserted one bit before the first bit of the slot 0.

Bit 17 **FSPOL**: Frame synchronization polarity.

This bit is set and cleared by software. It is used to configure the level of the start of frame on the FS signal. It is meaningless and is not used in AC'97 or SPDIF audio block configuration.

This bit must be configured when the audio block is disabled.

0: FS is active low (falling edge)

1: FS is active high (rising edge)

Bit 16 **FSDEF**: Frame synchronization definition.

This bit is set and cleared by software.

0: FS signal is a start frame signal

1: FS signal is a start of frame signal + channel side identification

When the bit is set, the number of slots defined in the SAI_xSLOTR register has to be even. It means that half of this number of slots are dedicated to the left channel and the other slots for the right channel (e.g: this bit has to be set for I2S or MSB/LSB-justified protocols...).

This bit is meaningless and is not used in AC'97 or SPDIF audio block configuration. It must be configured when the audio block is disabled.

Bit 15 Reserved, must be kept at reset value.

Bits 14:8 **FSALL[6:0]**: Frame synchronization active level length.

These bits are set and cleared by software. They specify the length in number of bit clock (SCK) + 1 (FSALL[6:0] + 1) of the active level of the FS signal in the audio frame

These bits are meaningless and are not used in AC'97 or SPDIF audio block configuration.

They must be configured when the audio block is disabled.

Bits 7:0 **FRL[7:0]**: Frame length.

These bits are set and cleared by software. They define the audio frame length expressed in number of SCK clock cycles: the number of bits in the frame is equal to FRL[7:0] + 1.

The minimum number of bits to transfer in an audio frame must be equal to 8, otherwise the audio block behaves in an unexpected way. This is the case when the data size is 8 bits and only one slot 0 is defined in NBSLOT[4:0] of SAI_xSLOTR register (NBSLOT[3:0] = 0000).

In master mode, if the master clock (available on MCLK_x pin) is used, the frame length should be aligned with a number equal to a power of 2, ranging from 8 to 256. When the master clock is not used (NODIV = 1), it is recommended to program the frame length to an value ranging from 8 to 256.

These bits are meaningless and are not used in AC'97 or SPDIF audio block configuration. They must be configured when the audio block is disabled.

56.6.7 SAI frame configuration register (SAI_BFRCR)

Address offset: 0x02C

Reset value: 0x0000 0007

Note: This register has no meaning in AC'97 and SPDIF audio protocol

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSOFF	FSPOL	FSDEF
													rw	rw	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	FSALL[6:0]							FRL[7:0]							
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **FSOFF**: Frame synchronization offset.

This bit is set and cleared by software. It is meaningless and is not used in AC'97 or SPDIF audio block configuration. This bit must be configured when the audio block is disabled.

0: FS is asserted on the first bit of the slot 0.

1: FS is asserted one bit before the first bit of the slot 0.

Bit 17 **FSPOL**: Frame synchronization polarity.

This bit is set and cleared by software. It is used to configure the level of the start of frame on the FS signal. It is meaningless and is not used in AC'97 or SPDIF audio block configuration.

This bit must be configured when the audio block is disabled.

0: FS is active low (falling edge)

1: FS is active high (rising edge)

Bit 16 **FSDEF**: Frame synchronization definition.
This bit is set and cleared by software.
0: FS signal is a start frame signal
1: FS signal is a start of frame signal + channel side identification
When the bit is set, the number of slots defined in the SAI_xSLOTR register has to be even. It means that half of this number of slots is dedicated to the left channel and the other slots for the right channel (e.g: this bit has to be set for I2S or MSB/LSB-justified protocols...).
This bit is meaningless and is not used in AC'97 or SPDIF audio block configuration. It must be configured when the audio block is disabled.

Bit 15 Reserved, must be kept at reset value.

Bits 14:8 **FSALL[6:0]**: Frame synchronization active level length.
These bits are set and cleared by software. They specify the length in number of bit clock (SCK) + 1 (FSALL[6:0] + 1) of the active level of the FS signal in the audio frame
These bits are meaningless and are not used in AC'97 or SPDIF audio block configuration. They must be configured when the audio block is disabled.

Bits 7:0 **FRL[7:0]**: Frame length.
These bits are set and cleared by software. They define the audio frame length expressed in number of SCK clock cycles: the number of bits in the frame is equal to FRL[7:0] + 1.
The minimum number of bits to transfer in an audio frame must be equal to 8, otherwise the audio block behaves in an unexpected way. This is the case when the data size is 8 bits and only one slot 0 is defined in NBSLOT[4:0] of SAI_xSLOTR register (NBSLOT[3:0] = 0000).
In master mode, if the master clock (available on MCLK_x pin) is used, the frame length should be aligned with a number equal to a power of 2, ranging from 8 to 256. When the master clock is not used (NODIV = 1), it is recommended to program the frame length to an value ranging from 8 to 256.
These bits are meaningless and are not used in AC'97 or SPDIF audio block configuration.

56.6.8 SAI slot register (SAI_ASLOTR)

Address offset: 0x010

Reset value: 0x0000 0000

Note: This register has no meaning in AC'97 and SPDIF audio protocol.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SLOTEN[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	NBSLOT[3:0]				SLOTSZ[1:0]		Res.	FBOFF[4:0]				
				rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bits 31:16 **SLOTEN[15:0]**: Slot enable.
These bits are set and cleared by software.
Each SLOTEN bit corresponds to a slot position from 0 to 15 (maximum 16 slots).
0: Inactive slot.
1: Active slot.
The slot must be enabled when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **NBSLOT[3:0]**: Number of slots in an audio frame.
These bits are set and cleared by software.
The value set in this bitfield represents the number of slots + 1 in the audio frame (including the number of inactive slots). The maximum number of slots is 16.
The number of slots should be even if FSDEF bit in the SAI_xFRCR register is set.
The number of slots must be configured when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.

Bits 7:6 **SLOTSZ[1:0]**: Slot size
This bits is set and cleared by software.
The slot size must be higher or equal to the data size. If this condition is not respected, the behavior of the SAI is undetermined.
Refer to *Output data line management on an inactive slot* for information on how to drive SD line.
These bits must be set when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.
00: The slot size is equivalent to the data size (specified in DS[3:0] in the SAI_xCR1 register).
01: 16-bit
10: 32-bit
11: Reserved

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **FBOFF[4:0]**: First bit offset
These bits are set and cleared by software.
The value set in this bitfield defines the position of the first data transfer bit in the slot. It represents an offset value. In transmission mode, the bits outside the data field are forced to 0. In reception mode, the extra received bits are discarded.
These bits must be set when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.

56.6.9 SAI slot register (SAI_BSLOTR)

Address offset: 0x030

Reset value: 0x0000 0000

Note: This register has no meaning in AC'97 and SPDIF audio protocol.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SLOTEN[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	NBSLOT[3:0]				SLOTSZ[1:0]		Res.	FBOFF[4:0]				
				rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bits 31:16 **SLOTEN[15:0]**: Slot enable.
These bits are set and cleared by software.
Each SLOTEN bit corresponds to a slot position from 0 to 15 (maximum 16 slots).
0: Inactive slot.
1: Active slot.
The slot must be enabled when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **NBSLOT[3:0]**: Number of slots in an audio frame.
These bits are set and cleared by software.
The value set in this bitfield represents the number of slots + 1 in the audio frame (including the number of inactive slots). The maximum number of slots is 16.
The number of slots should be even if FSDEF bit in the SAI_xFRCR register is set.
The number of slots must be configured when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.

Bits 7:6 **SLOTSZ[1:0]**: Slot size
This bits is set and cleared by software.
The slot size must be higher or equal to the data size. If this condition is not respected, the behavior of the SAI is undetermined.
Refer to *Output data line management on an inactive slot* for information on how to drive SD line.
These bits must be set when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.
00: The slot size is equivalent to the data size (specified in DS[3:0] in the SAI_xCR1 register).
01: 16-bit
10: 32-bit
11: Reserved

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **FBOFF[4:0]**: First bit offset
These bits are set and cleared by software.
The value set in this bitfield defines the position of the first data transfer bit in the slot. It represents an offset value. In transmission mode, the bits outside the data field are forced to 0. In reception mode, the extra received bits are discarded.
These bits must be set when the audio block is disabled.
They are ignored in AC'97 or SPDIF mode.

56.6.10 SAI interrupt mask register (SAI_AIM)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LFSDETIE	AFSDETIE	CNRDYIE	FREQIE	WCKCFGIE	MUTEDETIE	OVRUDRIE
									rw	rw	rw	rw	rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **LFSDETIE**: Late frame synchronization detection interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the LFSDET bit is set in the SAI_xSR register.
This bit is meaningless in AC'97, SPDIF mode or when the audio block operates as a master.

Bit 5 **AFSDETIE**: Anticipated frame synchronization detection interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the AFSDET bit in the SAI_xSR register is set.
This bit is meaningless in AC'97, SPDIF mode or when the audio block operates as a master.

Bit 4 **CNRDYIE**: Codec not ready interrupt enable (AC'97).
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When the interrupt is enabled, the audio block detects in the slot 0 (tag0) of the AC'97 frame if the Codec connected to this line is ready or not. If it is not ready, the CNRDY flag in the SAI_xSR register is set and an interrupt is generated.
This bit has a meaning only if the AC'97 mode is selected through PRTCFG[1:0] bits and the audio block is operates as a receiver.

Bit 3 **FREQIE**: FIFO request interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the FREQ bit in the SAI_xSR register is set.
Since the audio block defaults to operate as a transmitter after reset, the MODE bit must be configured before setting FREQIE to avoid a parasitic interrupt in receiver mode,

Bit 2 **WCKCFGIE**: Wrong clock configuration interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
This bit is taken into account only if the audio block is configured as a master (MODE[1] = 0) and NODIV = 0.
It generates an interrupt if the WCKCFG flag in the SAI_xSR register is set.
Note: This bit is used only in Free protocol mode *and is meaningless in other modes.*

Bit 1 **MUTEDETIE**: Mute detection interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the MUTEDET bit in the SAI_xSR register is set.
This bit has a meaning only if the audio block is configured in receiver mode.

Bit 0 **OVRUDRIE**: Overrun/underrun interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the OVRUDR bit in the SAI_xSR register is set.

56.6.11 SAI interrupt mask register (SAI_BIM)

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LFSDETIE	AFSDETIE	CNRDYIE	FREQIE	WCKCFGIE	MUTEDETIE	OVRUDRIE
									rw	rw	rw	rw	rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **LFSDETIE**: Late frame synchronization detection interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the LFSDET bit is set in the SAI_xSR register.
This bit is meaningless in AC’97, SPDIF mode or when the audio block operates as a master.

Bit 5 **AFSDETIE**: Anticipated frame synchronization detection interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the AFSDET bit in the SAI_xSR register is set.
This bit is meaningless in AC’97, SPDIF mode or when the audio block operates as a master.

Bit 4 **CNRDYIE**: Codec not ready interrupt enable (AC’97).
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When the interrupt is enabled, the audio block detects in the slot 0 (tag0) of the AC’97 frame if the Codec connected to this line is ready or not. If it is not ready, the CNRDY flag in the SAI_xSR register is set and an interrupt is generated.
This bit has a meaning only if the AC’97 mode is selected through PRTCFG[1:0] bits and the audio block is operates as a receiver.

Bit 3 **FREQIE**: FIFO request interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the FREQ bit in the SAI_xSR register is set.
Since the audio block defaults to operate as a transmitter after reset, the MODE bit must be configured before setting FREQIE to avoid a parasitic interrupt in receiver mode,

Bit 2 **WCKCFGIE**: Wrong clock configuration interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
This bit is taken into account only if the audio block is configured as a master (MODE[1] = 0) and NODIV = 0.
It generates an interrupt if the WCKCFG flag in the SAI_xSR register is set.
Note: This bit is used only in Free protocol mode and is meaningless in other modes.

Bit 1 **MUTEDETIE**: Mute detection interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the MUTEDET bit in the SAI_xSR register is set.
This bit has a meaning only if the audio block is configured in receiver mode.

Bit 0 **OVRUDRIE**: Overrun/underrun interrupt enable.
This bit is set and cleared by software.
0: Interrupt is disabled
1: Interrupt is enabled
When this bit is set, an interrupt is generated if the OVRUDR bit in the SAI_xSR register is set.

56.6.12 SAI status register (SAI_ASR)

Address offset: 0x018

Reset value: 0x0000 0008

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLVL[2:0]		
													r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LFSDET	AFSDET	CNRDY	FREQ	WCKCFG	MUTEDET	OVRUDR
									r	r	r	r	r	r	r

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **FLVL[2:0]**: FIFO level threshold.
This bit is read only. The FIFO level threshold flag is managed only by hardware and its setting depends on SAI block configuration (transmitter or receiver mode).
000: FIFO empty (transmitter and receiver modes)
001: FIFO ≤ ¼ but not empty (transmitter mode), FIFO < ¼ but not empty (receiver mode)
010: ¼ < FIFO ≤ ½ (transmitter mode), ¼ ≤ FIFO < ½ (receiver mode)
011: ½ < FIFO ≤ ¾ (transmitter mode), ½ ≤ FIFO < ¾ (receiver mode)
100: ¾ < FIFO but not full (transmitter mode), ¾ ≤ FIFO but not full (receiver mode)
101: FIFO full (transmitter and receiver modes)
Others: Reserved

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **LFSDET**: Late frame synchronization detection.
This bit is read only.
0: No error.
1: Frame synchronization signal is not present at the right time.
This flag can be set only if the audio block is configured in slave mode.
It is not used in AC’97 or SPDIF mode.
It can generate an interrupt if LFSDETIE bit is set in the SAI_xIM register.
This flag is cleared when the software sets bit CLFSDET in SAI_xCLRFR register

Bit 5 **AFSDET**: Anticipated frame synchronization detection.
This bit is read only.
0: No error.
1: Frame synchronization signal is detected earlier than expected.
This flag can be set only if the audio block is configured in slave mode.
It is not used in AC’97 or SPDIF mode.
It can generate an interrupt if AFSDETIE bit is set in SAI_xIM register.
This flag is cleared when the software sets CAFSDET bit in SAI_xCLRFR register.

Bit 4 **CNRDY**: Codec not ready.
This bit is read only.
0: External AC’97 Codec is ready
1: External AC’97 Codec is not ready
This bit is used only when the AC’97 audio protocol is selected in the SAI_xCR1 register and configured in receiver mode.
It can generate an interrupt if CNRDYIE bit is set in SAI_xIM register.
This flag is cleared when the software sets CCNRDY bit in SAI_xCLRFR register.

Bit 3 **FREQ**: FIFO request.
This bit is read only.
0: No FIFO request.
1: FIFO request to read or to write the SAI_xDR.
The request depends on the audio block configuration:
– If the block is configured in transmission mode, the FIFO request is related to a write request operation in the SAI_xDR.
– If the block configured in reception, the FIFO request related to a read request operation from the SAI_xDR.
This flag can generate an interrupt if FREQIE bit is set in SAI_xIM register.

Bit 2 **WCKCFG**: Wrong clock configuration flag.
This bit is read only.
0: Clock configuration is correct
1: Clock configuration does not respect the rule concerning the frame length specification defined in *Section 56.4.6: Frame synchronization* (configuration of FRL[7:0] bit in the SAI_xFRCR register)
This bit is used only when the audio block operates in master mode (MODE[1] = 0) and NODIV = 0.
It can generate an interrupt if WCKCFGIE bit is set in SAI_xIM register.
This flag is cleared when the software sets CWCKCFG bit in SAI_xCLRFR register.

Bit 1 **MUTEDET**: Mute detection.
This bit is read only.
0: No MUTE detection on the SD input line
1: MUTE value detected on the SD input line (0 value) for a specified number of consecutive audio frame
This flag is set if consecutive 0 values are received in each slot of a given audio frame and for a consecutive number of audio frames (set in the MUTECNT bit in the SAI_xCR2 register).
It can generate an interrupt if MUTEDETIE bit is set in SAI_xIM register.
This flag is cleared when the software sets bit CMUTEDET in the SAI_xCLRFR register.

Bit 0 **OVRUDR**: Overrun / underrun.
This bit is read only.
0: No overrun/underrun error.
1: Overrun/underrun error detection.
The overrun and underrun conditions can occur only when the audio block is configured as a receiver and a transmitter, respectively.
It can generate an interrupt if OVRUDRIE bit is set in SAI_xIM register.
This flag is cleared when the software sets COVRUDR bit in SAI_xCLRFR register.

56.6.13 SAI status register (SAI_BSR)

Address offset: 0x038

Reset value: 0x0000 0008

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLVL[2:0]		
													r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LFSDET	AFSDET	CNRDY	FREQ	WCKCFG	MUTEDET	OVRUDR
									r	r	r	r	r	r	r

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **FLVL[2:0]**: FIFO level threshold.
This bit is read only. The FIFO level threshold flag is managed only by hardware and its setting depends on SAI block configuration (transmitter or receiver mode).
000: FIFO empty (transmitter and receiver modes)
001: FIFO ≤ ¼ but not empty (transmitter mode), FIFO < ¼ but not empty (receiver mode)
010: ¼ < FIFO ≤ ½ (transmitter mode), ¼ ≤ FIFO < ½ (receiver mode)
011: ½ < FIFO ≤ ¾ (transmitter mode), ½ ≤ FIFO < ¾ (receiver mode)
100: ¾ < FIFO but not full (transmitter mode), ¾ ≤ FIFO but not full (receiver mode)
101: FIFO full (transmitter and receiver modes)
Others: Reserved

Bits 15:7 Reserved, must be kept at reset value.

Bit 6 **LFSDET**: Late frame synchronization detection.
This bit is read only.
0: No error.
1: Frame synchronization signal is not present at the right time.
This flag can be set only if the audio block is configured in slave mode.
It is not used in AC'97 or SPDIF mode.
It can generate an interrupt if LFSDETIE bit is set in the SAI_xIM register.
This flag is cleared when the software sets bit CLFSDET in SAI_xCLRFR register

Bit 5 **AFSDET**: Anticipated frame synchronization detection.
This bit is read only.
0: No error.
1: Frame synchronization signal is detected earlier than expected.
This flag can be set only if the audio block is configured in slave mode.
It is not used in AC'97or SPDIF mode.
It can generate an interrupt if AFSDETIE bit is set in SAI_xIM register.
This flag is cleared when the software sets CAFSDET bit in SAI_xCLRFR register.

Bit 4 **CNRDY**: Codec not ready.
This bit is read only.
0: External AC'97 Codec is ready
1: External AC'97 Codec is not ready
This bit is used only when the AC'97 audio protocol is selected in the SAI_xCR1 register and configured in receiver mode.
It can generate an interrupt if CNRDYIE bit is set in SAI_xIM register.
This flag is cleared when the software sets CCNRDY bit in SAI_xCLRFR register.

Bit 3 **FREQ**: FIFO request.
This bit is read only.
0: No FIFO request.
1: FIFO request to read or to write the SAI_xDR.
The request depends on the audio block configuration:
– If the block is configured in transmission mode, the FIFO request is related to a write request operation in the SAI_xDR.
– If the block configured in reception, the FIFO request related to a read request operation from the SAI_xDR.
This flag can generate an interrupt if FREQIE bit is set in SAI_xIM register.

Bit 2 **WCKCFG**: Wrong clock configuration flag.
This bit is read only.
0: Clock configuration is correct
1: Clock configuration does not respect the rule concerning the frame length specification defined in *Section 56.4.6: Frame synchronization* (configuration of FRL[7:0] bit in the SAI_xFRCR register)
This bit is used only when the audio block operates in master mode (MODE[1] = 0) and NODIV = 0.
It can generate an interrupt if WCKCFGIE bit is set in SAI_xIM register.
This flag is cleared when the software sets CWCKCFG bit in SAI_xCLRFR register.

Bit 1 **MUTEDET**: Mute detection.
This bit is read only.
0: No MUTE detection on the SD input line
1: MUTE value detected on the SD input line (0 value) for a specified number of consecutive audio frame
This flag is set if consecutive 0 values are received in each slot of a given audio frame and for a consecutive number of audio frames (set in the MUTECNT bit in the SAI_xCR2 register).
It can generate an interrupt if MUTEDETIE bit is set in SAI_xIM register.
This flag is cleared when the software sets bit CMUTEDET in the SAI_xCLRFR register.

Bit 0 **OVRUDR**: Overrun / underrun.
This bit is read only.
0: No overrun/underrun error.
1: Overrun/underrun error detection.
The overrun and underrun conditions can occur only when the audio block is configured as a receiver and a transmitter, respectively.
It can generate an interrupt if OVRUDRIE bit is set in SAI_xIM register.
This flag is cleared when the software sets COVRUDR bit in SAI_xCLRFR register.

56.6.14 SAI clear flag register (SAI_ACLRFR)

Address offset: 0x01C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLFSDET	CAFSDET	CCNRDY	Res.	CWCKCFG	CMUTEDET	COVRUDR
									w	w	w		w	w	w

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **CLFSDET**: Clear late frame synchronization detection flag.
This bit is write only.
Programming this bit to 1 clears the LFSDET flag in the SAI_xSR register.
This bit is not used in AC'97 or SPDIF mode
Reading this bit always returns the value 0.

Bit 5 **CAFSDET**: Clear anticipated frame synchronization detection flag.
This bit is write only.
Programming this bit to 1 clears the AFSDET flag in the SAI_xSR register.
It is not used in AC'97 or SPDIF mode.
Reading this bit always returns the value 0.

Bit 4 **CCNRDY**: Clear Codec not ready flag.
This bit is write only.
Programming this bit to 1 clears the CNRDY flag in the SAI_xSR register.
This bit is used only when the AC'97 audio protocol is selected in the SAI_xCR1 register.
Reading this bit always returns the value 0.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **CWCKCFG**: Clear wrong clock configuration flag.
This bit is write only.
Programming this bit to 1 clears the WCKCFG flag in the SAI_xSR register.
This bit is used only when the audio block is set as master (MODE[1] = 0) and NODIV = 0 in the SAI_xCR1 register.
Reading this bit always returns the value 0.

Bit 1 **CMUTEDET**: Mute detection flag.
This bit is write only.
Programming this bit to 1 clears the MUTEDET flag in the SAI_xSR register.
Reading this bit always returns the value 0.

Bit 0 **COVRUDR**: Clear overrun / underrun.
This bit is write only.
Programming this bit to 1 clears the OVRUDR flag in the SAI_xSR register.
Reading this bit always returns the value 0.

56.6.15 SAI clear flag register (SAI_BCLRFR)

Address offset: 0x03C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLFSDET	CAFSDET	CCNRDY	Res.	CWCKCFG	CMUTEDET	COVRUDR
									w	w	w		w	w	w

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **CLFSDET**: Clear late frame synchronization detection flag.
This bit is write only.
Programming this bit to 1 clears the LFSDET flag in the SAI_xSR register.
This bit is not used in AC'97or SPDIF mode
Reading this bit always returns the value 0.

Bit 5 **CAFSDET**: Clear anticipated frame synchronization detection flag.
This bit is write only.
Programming this bit to 1 clears the AFSDET flag in the SAI_xSR register.
It is not used in AC'97or SPDIF mode.
Reading this bit always returns the value 0.

Bit 4 **CCNRDY**: Clear Codec not ready flag.
This bit is write only.
Programming this bit to 1 clears the CNRDY flag in the SAI_xSR register.
This bit is used only when the AC'97 audio protocol is selected in the SAI_xCR1 register.
Reading this bit always returns the value 0.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **CWCKCFG**: Clear wrong clock configuration flag.
This bit is write only.
Programming this bit to 1 clears the WCKCFG flag in the SAI_xSR register.
This bit is used only when the audio block is set as master (MODE[1] = 0) and NODIV = 0 in the SAI_xCR1 register.
Reading this bit always returns the value 0.

Bit 1 **CMUTEDET**: Mute detection flag.
This bit is write only.
Programming this bit to 1 clears the MUTEDET flag in the SAI_xSR register.
Reading this bit always returns the value 0.

Bit 0 **COVRUDR**: Clear overrun / underrun.
This bit is write only.
Programming this bit to 1 clears the OVRUDR flag in the SAI_xSR register.
Reading this bit always returns the value 0.

56.6.16 SAI data register (SAI_ADR)

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DATA[31:0]**: Data
A write to this register loads the FIFO provided the FIFO is not full.
A read from this register empties the FIFO if the FIFO is not empty.

56.6.17 SAI data register (SAI_BDR)

Address offset: 0x040

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DATA[31:0]**: Data
A write to this register loads the FIFO provided the FIFO is not full.
A read from this register empties the FIFO if the FIFO is not empty.

56.6.18 SAI PDM control register (SAI_PDMCR)

Address offset: 0x0044

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CKEN2	CKEN1	Res.	Res.	MICNBR[1:0]		Res.	Res.	Res.	PDMEN
						rw	rw			rw	rw				rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **CKEN2**: Clock enable of bitstream clock number 2
This bit is set and cleared by software.
0: SAI_CK2 clock disabled
1: SAI_CK2 clock enabled

Note: It is not recommended to configure this bit when PDMEN = 1.
SAI_CK2 might not be available for all SAI instances. Refer to Section 56.3: SAI implementation for details.

Bit 8 **CKEN1**: Clock enable of bitstream clock number 1
This bit is set and cleared by software.
0: SAI_CK1 clock disabled
1: SAI_CK1 clock enabled
Note: It is not recommended to configure this bit when PDMEN = 1.
SAI_CK1 might not be available for all SAI instances. Refer to Section 56.3: SAI implementation for details.

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **MICNBR[1:0]**: Number of microphones
This bit is set and cleared by software.
00: Configuration with 2 microphones
01: Configuration with 4 microphones
10: Configuration with 6 microphones
11: Configuration with 8 microphones
*Note: It is not recommended to configure this field when PDMEN = 1.**
The complete set of data lines might not be available for all SAI instances. Refer to Section 56.3: SAI implementation for details.

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **PDMEN**: PDM enable
This bit is set and cleared by software. This bit allows to control the state of the PDM interface block. Make sure that the SAI in already operating in TDM master mode before enabling the PDM interface.
0: PDM interface disabled
1: PDM interface enabled

56.6.19 SAI PDM delay register (SAI_PDMDLY)

Address offset: 0x0048

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	DLYM4R[2:0]			Res.	DLYM4L[2:0]			Res.	DLYM3R[2:0]			Res.	DLYM3L[2:0]		
	rw	rw	rw		rw	rw	rw		rw	rw	rw		rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	DLYM2R[2:0]			Res.	DLYM2L[2:0]			Res.	DLYM1R[2:0]			Res.	DLYM1L[2:0]		
	rw	rw	rw		rw	rw	rw		rw	rw	rw		rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:28 **DLYM4R[2:0]**: Delay line for second microphone of **pair 4**

This bit is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 T_{SAI_CK} periods

This field can be changed on-the-fly.

Note: This field can be used only if D4 line is available.Refer to Section 56.3: SAI implementation to check if it is available.

Bit 27 Reserved, must be kept at reset value.

Bits 26:24 **DLYM4L[2:0]**: Delay line for first microphone of pair 4

This bit is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 of T_{SAI_CK} periods

This field can be changed on-the-fly.

Note: This field can be used only if D4 line is available.Refer to Section 56.3: SAI implementation to check if it is available.

Bit 23 Reserved, must be kept at reset value.

Bits 22:20 **DLYM3R[2:0]**: Delay line for second microphone of pair 3

This bit is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 T_{SAI_CK} periods

This field can be changed on-the-fly.

Note: This field can be used only if D3 line is available.Refer to Section 56.3: SAI implementation to check if it is available.

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **DLYM3L[2:0]**: Delay line for first microphone of pair 3

This bit is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 T_{SAI_CK} periods

This field can be changed on-the-fly.

Note: This field can be used only if D3 line is available.Refer to Section 56.3: SAI implementation to check if it is available.

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **DLYM2R[2:0]**: Delay line for second microphone of pair 2
This bit is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 T_{SAI_CK} periods

This field can be changed on-the-fly.

Note: This field can be used only if D2 line is available.Refer to Section 56.3: SAI implementation to check if it is available.

Bit 11 Reserved, must be kept at reset value.

Bits 10:8 **DLYM2L[2:0]**: Delay line for first microphone of pair 2
This bit is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 T_{SAI_CK} periods

This field can be changed on-the-fly.

Note: This field can be used only if D2 line is available.Refer to Section 56.3: SAI implementation to check if it is available.

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **DLYM1R[2:0]**: Delay line adjust for second microphone of pair 1
This bit is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 T_{SAI_CK} periods

This field can be changed on-the-fly.

Note: This field can be used only if D1 line is available.Refer to Section 56.3: SAI implementation to check if it is available.

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **DLYM1L[2:0]**: Delay line adjust for first microphone of pair 1
This bit is set and cleared by software.
000: No delay
001: Delay of 1 T_{SAI_CK} period
010: Delay of 2 T_{SAI_CK} periods
...
111: Delay of 7 T_{SAI_CK} periods

This field can be changed on-the-fly.

Note: This field can be used only if D1 line is available.Refer to Section 56.3: SAI implementation to check if it is available.

56.6.20 SAI register map

Table 454. SAI register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0000	SAI_GCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYNCOUT[1:0]		Res.	Res.	SYNCIN[1:0]	
	Reset value																											0	0			0	0
0x0004 or 0x0024	SAI_xCR1	Res.	Res.	Res.	Res.	MCKEN	OSR	MCKDIV[5:0]						NODIV	Res.	DMAEN	SAIEN	Res.	Res.	OUTDRIV	MONO	SYNCEN[1:0]		CKSTR	LSBFIRST	DS[2:0]		Res.	PRTCFG[1:0]		MODE[1:0]	
	Reset value					0	0	0	0	0	0	0	0	0		0	0			0	0	0	0	0	0	0	1	0		0	0	0	0
0x0008 or 0x0028	SAI_xCR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COMP[1:0]		CPL	MUTECN[5:0]						MUTE VAL	MUTE	TRIS	FFLUS	FTH[2:0]		
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x000C or 0x002C	SAI_xFRCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSOFF	FSPOL	FSDEF	Res.	FSALL[6:0]							FRL[7:0]							
	Reset value														0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
0x0010 or 0x0030	SAI_xSLOTR	SLOTEN[15:0]																Res.	Res.	Res.	Res.	NBSLOT[3:0]				SLOTSZ[1:0]		Res.	FBOFF[4:0]				
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0		0	0	0	0	0
0x0014 or 0x0034	SAI_xIM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LFSDETIE	AFSDETIE	CNRDYIE	FREQIE	WCKCFGIE	MUTEDETIE	OVRUDRIE
	Reset value																										0	0	0	0	0	0	0
0x0018 or 0x0038	SAI_xSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FLVL[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LFSDET	AFSDET	CNRDY	FREQ	WCKCFG	MUTEDET	OVRUDR
	Reset value														0	0	0										0	0	0	0	1	0	0
0x001C or 0x003C	SAI_xCLRFR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLFSDET	CAFSDET	CCNRDY	Res.	CWCKCFG	CMUTEDET	COVRUDR
	Reset value																										0	0	0		0	0	0
0x0020 or 0x0040	SAI_xDR	DATA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0044	SAI_PDMCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CKEN2	CKEN1	Res.	Res.	MICNBR[1:0]		Res.	Res.	Res.	PDMEN
	Reset value																							0	0			0	0				0

Table 454. SAI register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0048	SAI_PDMDLY	Res.	DLYM4R[2:0]			Res.	DLYM4L[2:0]			Res.	DLYM3R[2:0]			Res.	DLYM3L[2:0]			Res.	DLYM2R[2:0]			Res.	DLYM2L[2:0]			Res.	DLYM1R[2:0]			Res.	DLYM1L[2:0]		
	Reset value		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

57 SPDIF receiver interface (SPDIFRX)

57.1 SPDIFRX interface introduction

The SPDIFRX interface handles S/PDIF audio protocol.

57.2 SPDIFRX main features

- Up to 4 inputs available
- Automatic symbol rate detection
- Maximum symbol rate: 12.288 MHz
- Stereo stream from 8 to 192 kHz[a] supported
- Supports audio IEC-60958 and IEC-61937, consumer applications
- Parity bit management
- Communication using DMA for audio samples
- Communication using DMA for control and user channel information
- Interrupt capabilities

57.3 SPDIFRX functional description

The SPDIFRX peripheral, is designed to receive an S/PDIF flow compliant with IEC-60958 and IEC-61937. These standards support simple stereo streams up to high sample rate, and compressed multi-channel surround sound, such as those defined by Dolby or DTS.

The receiver provides all the necessary features to detect the symbol rate, and decode the incoming data. It is possible to use a dedicated path for the user and channel information in order to ease the interface handling. *Figure 698* shows a simplified block diagram.

The SPDIFRX_DC block is responsible of the decoding of the S/PDIF stream received from SPDIFRX_IN[4:1] inputs. This block re-sample the incoming signal, decode the manchester stream, recognize frames, sub-frames and blocks elements. It delivers to the REG_IF part, decoded data, and associated status flags.

This peripheral can be fully controlled via the APB1 bus, and can handle two DMA channels:

- A DMA channel dedicated to the transfer of audio samples
- A DMA channel dedicated to the transfer of IEC60958 channel status and user information

Interrupt services are also available either as an alternative function to the DMA, or for signaling error or key status of the peripheral.

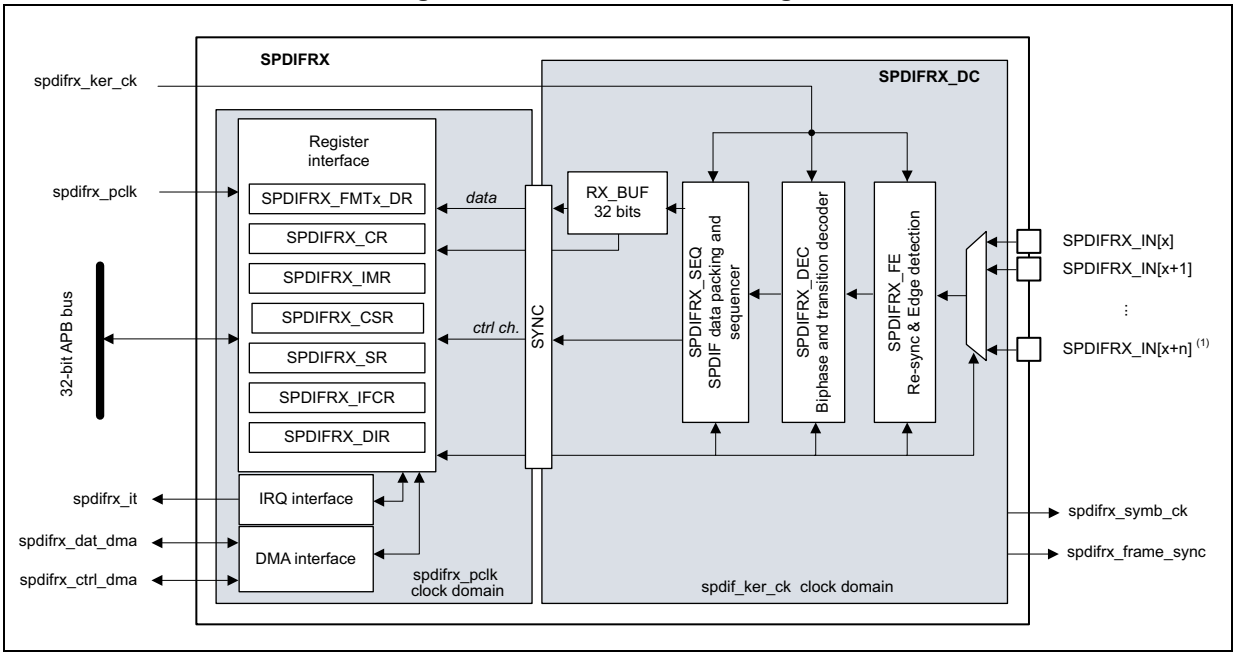
The SPDIFRX also offers a signal named **spdifrx_frame_sync**, which toggles every time that a sub-frame's preamble is detected. So the duty cycle is 50%, and the frequency equal to the frame rate.

This signal can be connected to timer events, in order to compute frequency drift.

a. Check the RCC capabilities in order to verify which sampling rates can be supported.

In addition the SPDIFRX also provides a signal named **spdifrx_symb_ck** toggling at the symbol rate.

Figure 698. SPDIFRX block diagram



1. 'n' is fixed to 4, and 'x' is set to 1.

57.3.1 SPDIFRX pins and internal signals

Table 455 lists the SPDIFRX internal input/output signals, *Table 456* the SPDIFRX pins (alternate functions).

Table 455. SPDIFRX internal input/output signals

Signal name	Signal type	Description
spdifrx_ker_ck	Digital input	SPDIFRX kernel clock
spdifrx_pclk	Digital input	SPDIFRX register interface clock
spdifrx_it	Digital output	SPDIFRX global interrupt
spdifrx_dat_dma	Digital input/output	SPDIFRX DMA request (and acknowledge) for data transfer
spdifrx_ctrl_dma	Digital input/output	SPDIFRX DMA request (and acknowledge) for channel status and user information transfer
spdifrx_frame_sync	Digital output	SPDIFRX frame rate synchronization signal
spdifrx_symb_ck	Digital output	SPDIFRX channel symbol clock

Table 456. SPDIFRX pins

Signal name	Signal type	Description
SPDIFRX_IN1	Digital input	Input 1 for S/PDIF signal
SPDIFRX_IN2	Digital input	Input 2 for S/PDIF signal
SPDIFRX_IN3	Digital input	Input 3 for S/PDIF signal
SPDIFRX_IN4	Digital input	Input 4 for S/PDIF signal

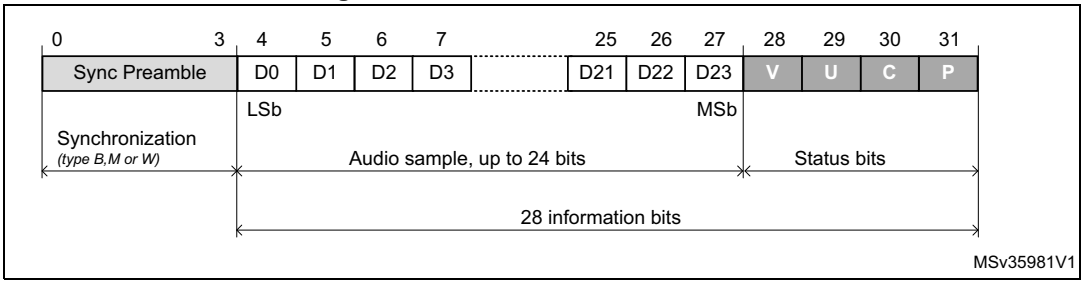
57.3.2 S/PDIF protocol (IEC-60958)

S/PDIF block

A S/PDIF frame is composed of two sub-frames (see *Figure 699*). Each sub-frame contains 32 bits (or time slots):

- Bits 0 to 3 carry one of the synchronization preambles
- Bits 4 to 27 carry the audio sample word in linear 2's complement representation. The most significant bit (MSB) is carried by bit 27. When a 20-bit coding range is used, bits 8 to 27 carry the audio sample word with the LSB in bit 8.
- Bit 28 (validity bit “V”) indicates if the data is valid (for converting it to analog for example)
- Bit 29 (user data bit “U”) carries the user data information like the number of tracks of a Compact Disk.
- Bit 30 (channel status bit “C”) carries the channel status information like sample rate and protection against copy.
- Bit 31 (parity bit “P”) carries a parity bit such that bits 4 to 31 inclusive carry an even number of ones and an even number of zeroes (even parity).

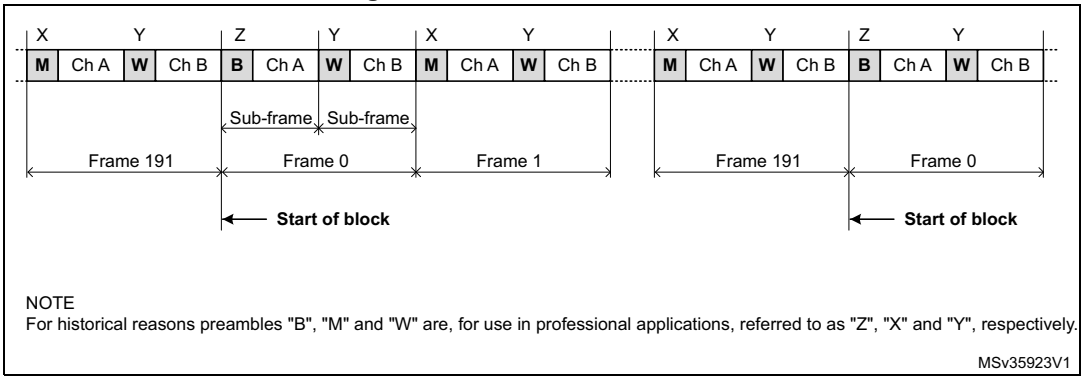
Figure 699. S/PDIF sub-frame format



For linear coded audio applications, the first sub-frame (left or “A” channel in stereophonic operation and primary channel in monophonic operation) normally starts with preamble “M”. However, the preamble changes to preamble “B” once every 192 frames to identify the start of the block structure used to organize the channel status and user information. The second sub-frame (right or “B” channel in stereophonic operation and secondary channel in monophonic operation) always starts with preamble “W”.

A S/PDIF block contains 192 pairs of sub-frames of 32 bits.

Figure 700. S/PDIF block format



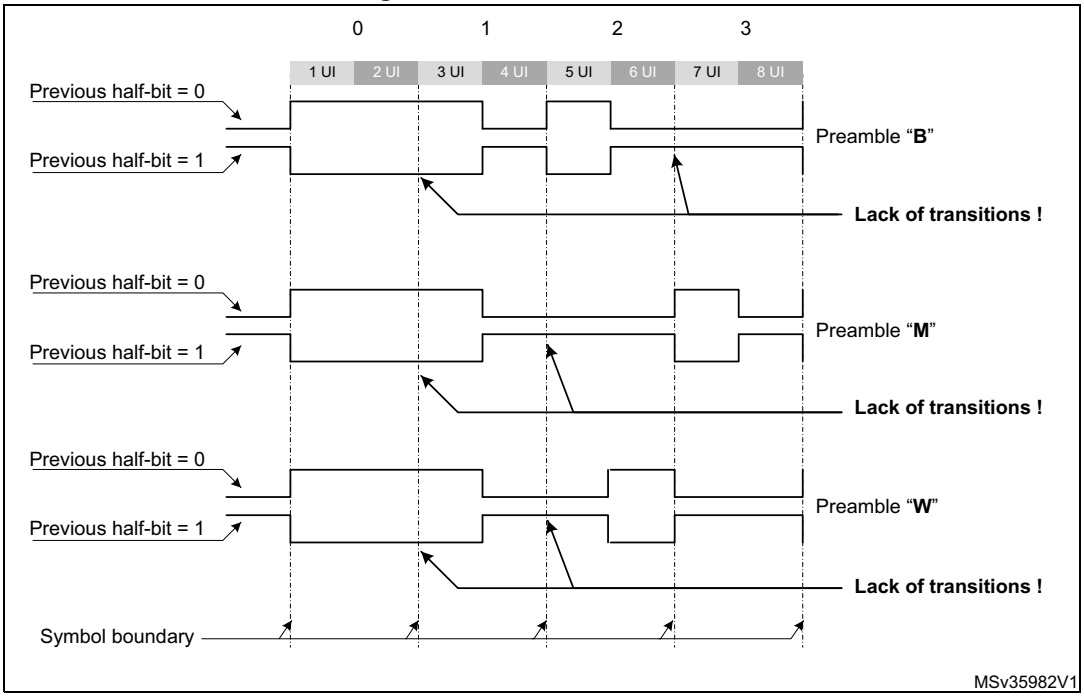
NOTE
For historical reasons preambles "B", "M" and "W" are, for use in professional applications, referred to as "Z", "X" and "Y", respectively.

MSv35923V1

Synchronization preambles

The preambles patterns are inverted or not according to the previous half-bit value. This previous half-bit value is the level of the line before enabling a transfer for the first “B” preamble of the first frame. For the others preambles, this previous half-bit value is the second half-bit of the parity bit of the previous sub-frame. The preambles patterns B, M and W are described in the *Figure 701*.

Figure 701. S/PDIF Preambles



MSv35982V1

Coding of information bits

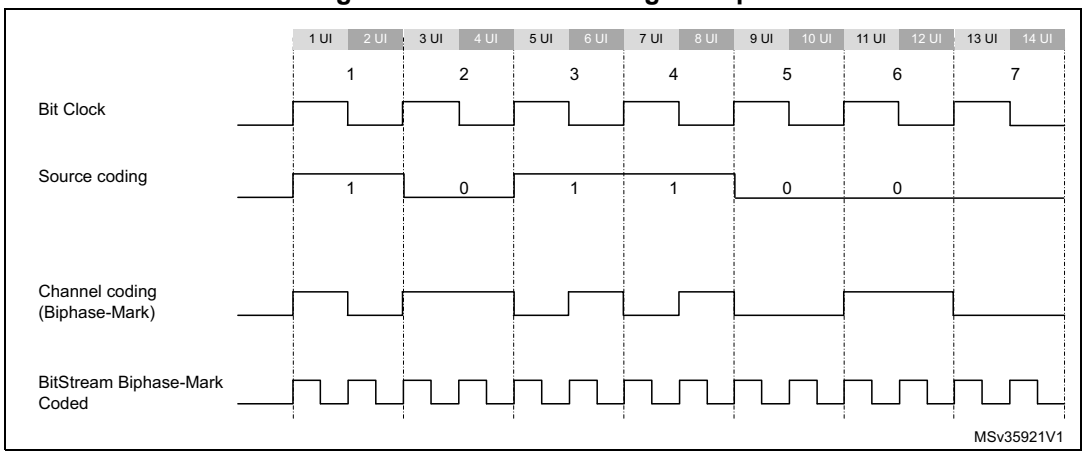
In order to minimize the DC component value on the transmission line, and to facilitate clock recovery from the data stream, bits 4 to 31 are encoded in biphase-mark.

Each bit to be transmitted is represented by a symbol comprising two consecutive binary states. The first state of a symbol is always different from the second state of the previous symbol. The second state of the symbol is identical to the first if the bit to be transmitted is

logical 0. However, it is different if the bit is logical 1. These states are named “UI” (unit interval) in the IEC-60958 specification.

The 24 data bits are transferred LSB first.

Figure 702. Channel coding example



57.3.3 SPDIFRX decoder (SPDIFRX_DC)

Main principle

The technique used by the SPDIFRX in order to decode the S/PDIF stream is based on the measurement of the time interval between two consecutive edges. Three kinds of time intervals may be found into an S/PDIF stream:

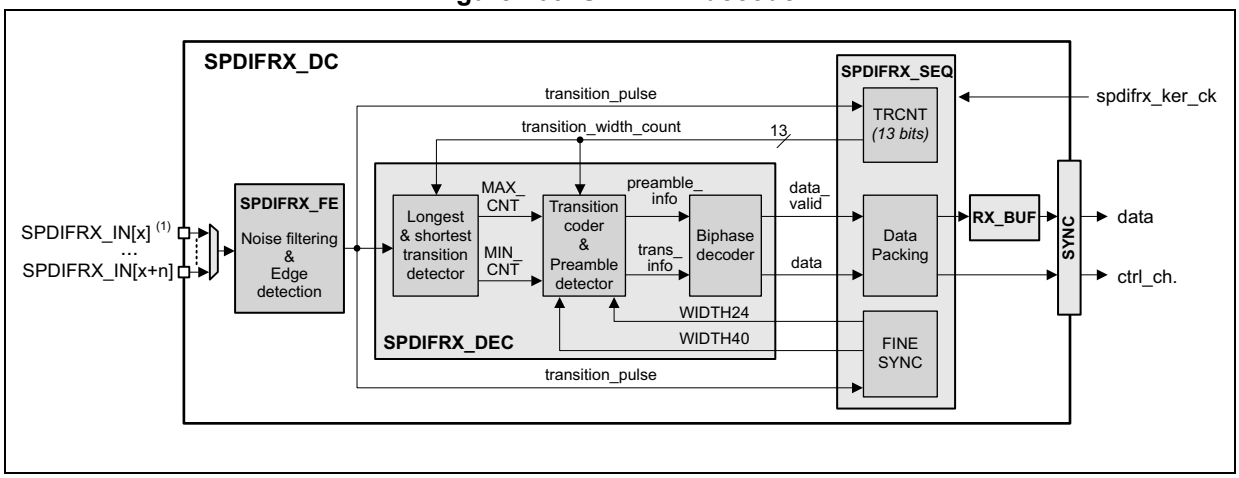
- The long time interval, having a duration of 3 x UI, noted TL. It appears only during preambles.
- The medium time interval, having a duration of 2 x UI, noted TM. It appears both in some preambles or into the information field.
- The short time interval, having a duration of 1 x UI, noted TS. It appears both in some preambles or into the information field.

The SPDIFRX_DC block is responsible of the decoding of the received S/PDIF stream. It takes care of the following functions:

- Resampling and filtering of the incoming signal
- Estimation of the time-intervals
- Estimation of the symbol rate and synchronization
- Decoding of the serial data, and check of integrity
- Detection of the block, and sub-frame preambles
- Continuous tracking of the symbol rate

Figure 703 gives a detailed view of the SPDIFRX decoder.

Figure 703. SPDIFRX decoder



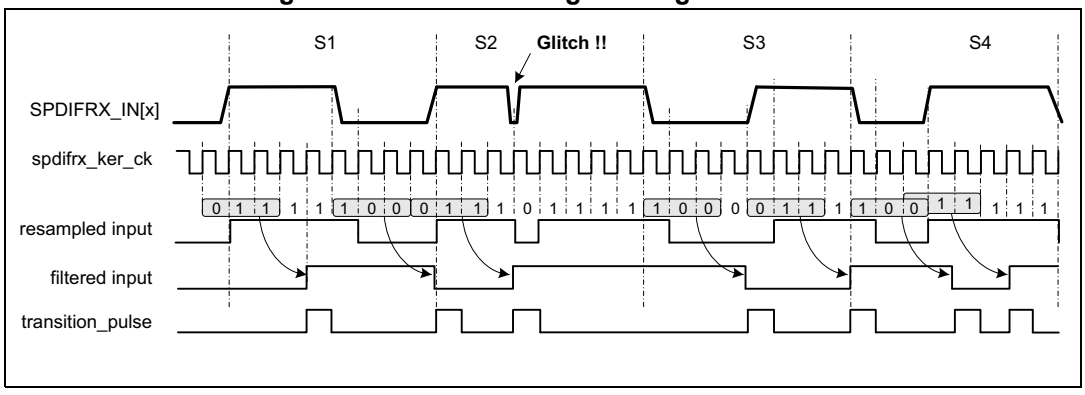
1. 'n' is fixed to 4, and 'x' is set to 1.

Noise filtering and rising/falling edge detection

The S/PDIF signal received on the selected SPDIFRX_IN is re-sampled using the spdifrx_ker_ck clock (acquisition clock). A simple filtering is applied in order cancel spurs. This is performed by the stage detecting the edge transitions. The edge transitions are detected as follow:

- A rising edge is detected when the sequence 0 followed by two 1 is sampled.
- A falling edge is detected when the sequence 1 followed by two 0 is sampled.
- After a rising edge, a falling edge sequence is expected.
- After a falling edge, a rising edge sequence is expected.

Figure 704. Noise filtering and edge detection



Longest and shortest transition detector

The **longest and shortest transition detector** block detects the maximum (MAX_CNT) and minimum (MIN_CNT) duration between two transitions. The TRCNT counter is used to measure the time interval duration. It is clocked by the spdifrx_ker_ck signal. On every transition pulse, the counter value is stored and the counter is reset to start counting again.

The maximum duration is normally found during the preamble period. This maximum duration is sent out as MAX_CNT. The minimum duration is sent out as MIN_CNT.

The search of the longest and shortest transition is stopped when the transition timer expires. The transition timer is like a watchdog timer that generates a trigger after 70 transitions of the incoming signal. Note that counting 70 transitions insures a delay a bit longer than a sub-frame.

Note that when the TRCNT overflows due to a too long time interval between two pulses, the SPDIFRX is stopped and the flag TERR of SPDIFRX_SR register is set to 1.

Transition coder and preamble detector

The **transition coder and preamble detector** block receives the MAX_CNT and MIN_CNT. It also receives the current transition width from the TRCNT counter (see *Figure 703*). This block encodes the current transition width by comparing the current transition width with two different thresholds, names TH_{HI} and TH_{LO}.

- If the current transition width is less than (TH_{LO} - 1), then the data received is half part of data bit ‘1’, and is coded as TS.
- If the current transition width is greater than (TH_{LO} - 1), and less than TH_{HI}, then the data received is data bit ‘0’, and is coded as TM.
- If the current transition width is greater than TH_{HI}, then the data received is the long pulse of preambles, and is coded as TL.
- Else an error code is generated (FERR flag is set).

The thresholds TH_{HI} and TH_{LO} are elaborated using two different methods.

If the peripheral is doing its initial synchronization (‘coarse synchronization’), then the thresholds are computed as follow:

- TH_{LO} = MAX_CNT / 2.
- TH_{HI} = MIN_CNT + MAX_CNT / 2.

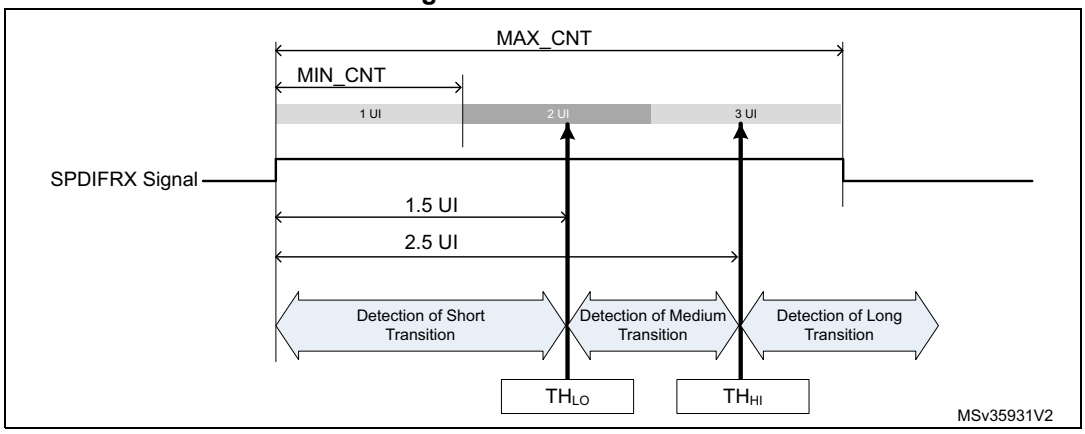
Once the ‘coarse synchronization’ is completed, then the SPDIFRX uses a more accurate reference in order to elaborate the thresholds. The SPDIFRX measures the length of 24 symbols (WIDTH24) for defining TH_{LO} and the length of 40 symbols (WIDTH40) for TH_{HI}. TH_{HI} and TH_{LO} are computed as follow:

- TH_{LO} = (WIDTH24) / 32
- TH_{HI} = (WIDTH40) / 32

This second synchronization phase is called the ‘fine synchronization’. Refer to *Figure 707* for additional information.

As shown in the figure hereafter, TH_{LO} is ideally equal to 1.5 UI, and to TH_{HI} 2.5 UI.

Figure 705. Thresholds



The preamble detector checks four consecutive transitions of a specific sequence to determine if they form the part of preamble. Let us say TRANS0, TRANS1, TRANS2 and TRANS3 represent four consecutive transitions encoded as mentioned above. *Table 457* shows the values of these four transitions to form a preamble. Absence of this pattern indicates that these transitions form part of the data in the sub frame and bi-phase decoder decode them.

Table 457. Transition sequence for preamble

Preamble type	Biphase data pattern	TRANS3	TRANS2	TRANS1	TRANS0
Preamble B	11101000	TL	TS	TS	TL
Preamble M	11100010	TL	TL	TS	TS
Preamble W	11100100	TL	TM	TS	TM

Bi-phase decoder

The Bi-phase decoder decodes the input bi-phase marked data stream using the transition information provided by the **transition coder and preamble detector** block. It first waits for the preamble detection information. After the preamble detection, it decodes the following transition information:

- If the incoming transition information is TM then it is decoded as a ‘0’.
- Two consecutive TS are decoded as a ‘1’.
- Any other transition sequence generates an error signal (FERR set to 1).

After decoding 28 data bits this way, this module looks for the following preamble data. If the new preamble is not what is expected, then this block generates an error signal (FERR set to 1). Refer to *Section 57.3.9: Reception errors*, for additional information on error flags.

Data packing

This block is responsible of the decoding of the IEC-60958 frames and blocks. It also handles the writing into the RX_BUF or into SPDIFRX_CSR register.

57.3.4 SPDIFRX tolerance to clock deviation

The SPDIFRX tolerance to clock deviation depends on the number of sample clock cycles in one bit slot. The fastest spdifrx_ker_ck is, the more robust the reception is. The ratio between spdifrx_ker_ck frequency and the symbol rate must be at least 11.

Two kinds of phenomenon (at least) can degrade the reception quality:

- The cycle-to-cycle jitter which reflects the difference of transition length between two consecutive transitions.
- The long term jitter which reflects a cumulative effect of the cycle-to-cycle jitter. It can be seen as a low-frequency symbol modulation.

57.3.5 SPDIFRX synchronization

The synchronization phase starts when setting SPDIFRXEN to 01 or 11. *Figure 706* shows the synchronization process.

If the bit WFA of SPDIFRX_CR register is set to 1, then the peripheral must first detect activity on the selected SPDIFRX_IN line before starting the synchronization process. The activity detection is performed by detecting four transitions on the selected SPDIFRX_IN. The peripheral remains in this state until transitions are not detected. This function can be particularly helpful because the SPDIFRX switches in COARSE SYNC mode only if activity is present on the selected SPDIFRX_IN input, avoiding synchronization errors. See *Section 57.4: Programming procedures* for additional information.
The user can still set the SPDIFRX into STATE_IDLE by setting SPDIFRXEN to 0. If the WFA is set to 0, the peripheral starts the coarse synchronization without checking activity.

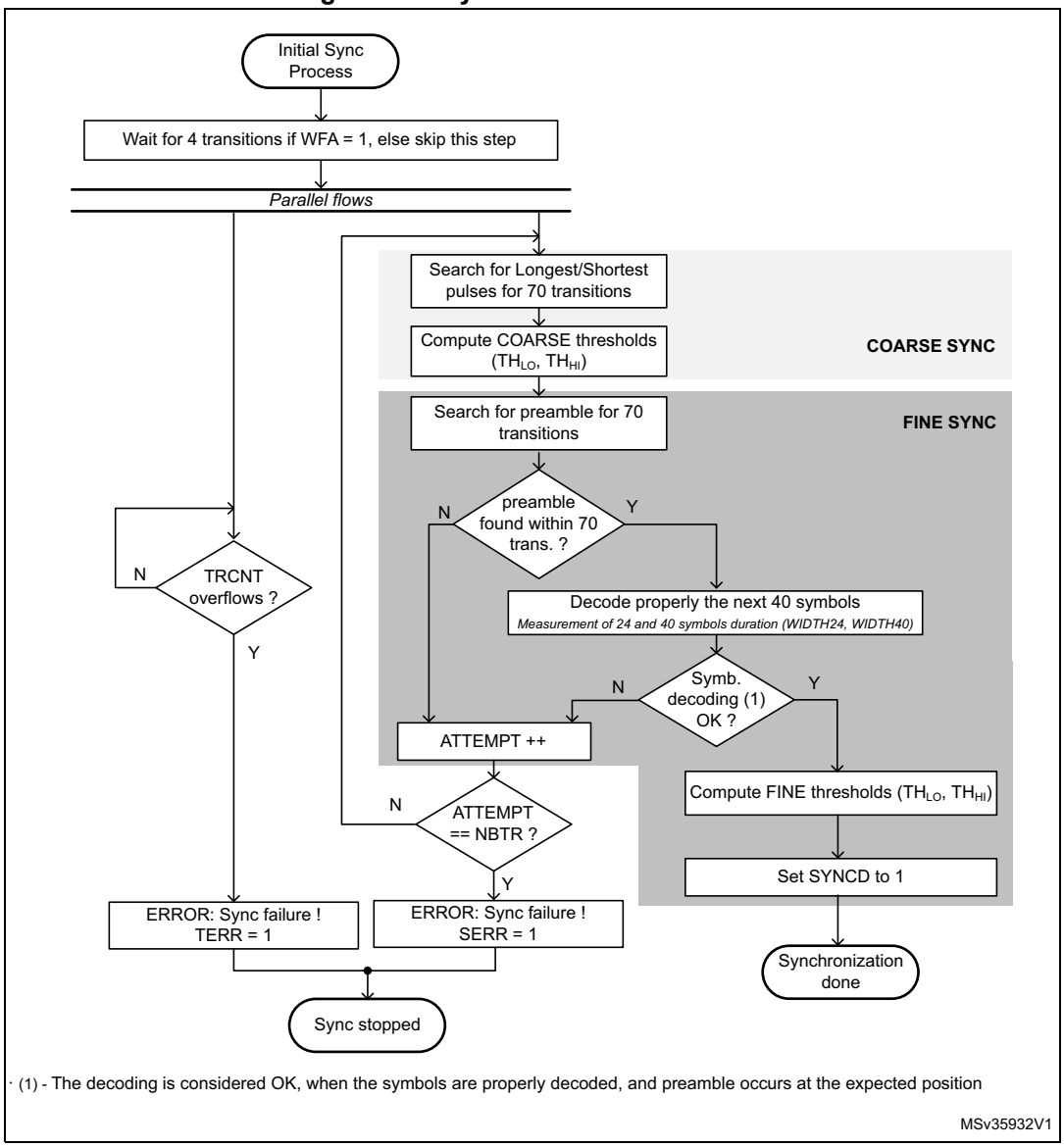
The next step consists on doing a first estimate of the thresholds (COARSE SYNC), in order to perform the fine synchronization (FINE SYNC). Due to disturbances of the SPDIFRX line, it can happen that the process is not executed first time right. For this purpose, the user can program the number of allowed re-tries (NBTR) before setting SERR error flag.
When the SPDIFRX is able to measure properly the duration of 24 and 40 consecutive symbols then the FINE SYNC is completed, the threshold values are updated, and the flag SYNCD is set to 1. Refer to *Section : Transition coder and preamble detector* for additional information.

Two kinds of errors are detected:

- An overflow of the TRCNT, which generally means that there is no valid S/PDIF stream in the input line. This overflow is indicated by TERR flag.
- The number of retries reached the programmed value. This means that strong jitter is present on the S/PDIF signal. This error is indicated by SERR flag.

When the first FINE SYNC is completed, the reception of channel status (C) and user data (U) starts when the next “B” preamble is detected (see *Figure 710*).Then the user can read IEC-60958 C and U bits through SPDIFRX_CSR register. According to this information the user can then select the proper settings for DRFMT and RXSTEO. For example if the user detects that the current audio stream transports encoded data, then he can put RXSTEO to 0, and DRFMT to 10 prior to start data reception. Note that DRFMT and RXSTEO cannot be modified when SPDIFRXEN = 11. Writes to these fields are ignored if SPDIFRXEN is already 11, though these field can be changed with the same write instruction that causes SPDIFRXEN to become 11.
Then the SPDIFRX waits for SPDIFRXEN = 11 and the “B” preamble before starting saving audio samples.

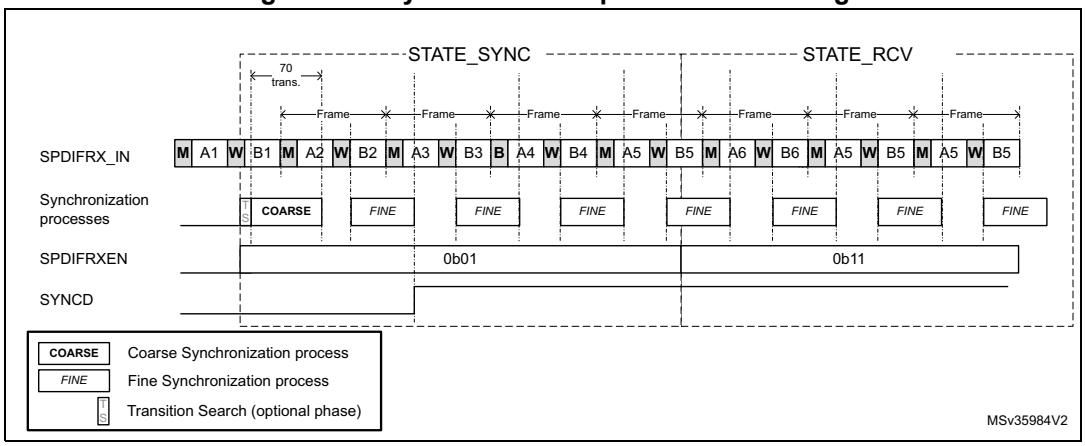
Figure 706. Synchronization flowchart



Refer to *Frame structure and synchronization error* for additional information concerning TRCNT overflow.

The FINE SYNC process is re-triggered every frame in order to update thresholds as shown in *Figure 707* in order to continuously track S/PDIF synchronization.

Figure 707. Synchronization process scheduling



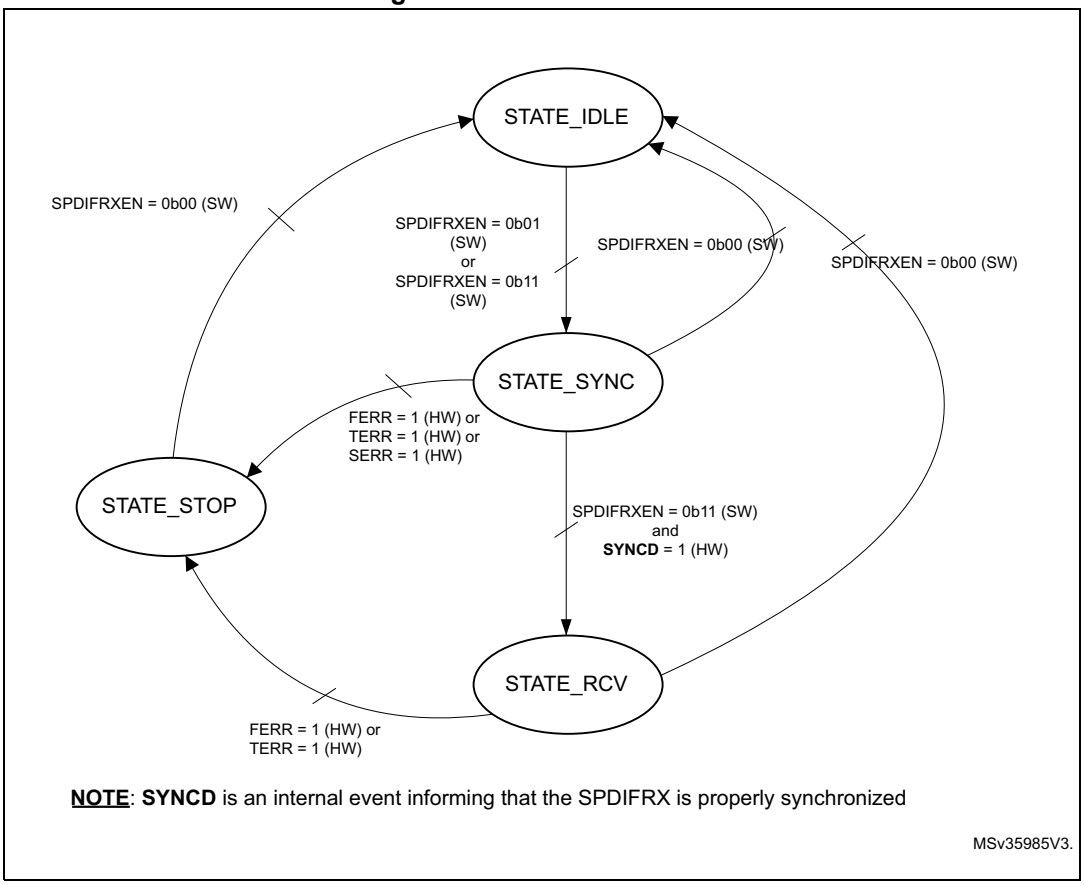
57.3.6 SPDIFRX handling

The software can control the state of the SPDIFRX through SPDIFRXEN field. The SPDIFRX can be into one of the following states:

- STATE_IDLE:
  The peripheral is disabled, the spdifrx_ker_ck domain is reset. The spdifrx_pclk domain is functional.
- STATE_SYNC:
  The peripheral is synchronized to the stream, thresholds are updated regularly, user and channel status can be read via interrupt of DMA. The audio samples are not provided to receive buffer.
- STATE_RCV:
  The peripheral is synchronized to the stream, thresholds are updated regularly, user, channel status and audio samples can be read via interrupt or DMA channels. When SPDIFRXEN goes to 11, the SPDIFRX waits for “B” preamble before starting saving audio samples.
- STOP_STATE:
  The peripheral is no longer synchronized, the reception of the user, channel status and audio samples are stopped. It is expected that the software re-starts the SPDIFRX.

Figure 708 shows the possible states of the SPDIFRX, and how to transition from one state to the other. The bits under software control are followed by the mention “(SW)”, the bits under SPDIFRX control are followed by the mention “(HW)”.

Figure 708. SPDIFRX States



When SPDIFRX is in STATE_IDLE:

- The software can transition to STATE_SYNC by setting SPDIFRXEN to 01 or 11

When SPDIFRX is in STATE_SYNC:

- If the synchronization fails or if the received data are not properly decoded with no chance of recovery without a re-synchronization (FERR or SERR or TERR = 1), the SPDIFRX goes to STATE_STOP, and waits for software acknowledge.
- When the synchronization phase is completed, if SPDIFRXEN = 01 the peripheral remains in this state.
- At any time the software can set SPDIFRXEN to 0, then SPDIFRX returns immediately to STATE_IDLE. If a DMA transfer is on-going, it will properly be completed.
- The SPDIFRX goes to STATE_RCV if SPDIFRXEN = 11 and if the SYNCD = 1

When SPDIFRX is in STATE_RCV:

- If the received data are not properly decoded with no chance of recovery without a re-synchronization (FERR or SERR or TERR = 1), the SPDIFRX goes to STATE_STOP, and waits for software acknowledge.
- At any time the software can set SPDIFRXEN to 0, then SPDIFRX returns immediately to STATE_IDLE. If a DMA transfer is on-going, it will properly be completed.

When SPDIFRX is in STATE_STOP:

- The SPDIFRX stops reception and synchronization, and waits for the software to set the bit SPDIFRXEN to 0, in order to clear the error flags.

When SPDIFRXEN is set to 0, the SPDIFRX is disabled, meaning that all the state machines are reset, and RX_BUF is flushed. Note as well that flags FERR, SERR and TERR are reset.

57.3.7 Data reception management

The SPDIFRX offers a double buffer for the audio sample reception. A 32-bit buffer located into the spdifrx_ker_ck clock domain (RX_BUF), and the SPDIFRX_FMTx_DR register. The valid data contained into the RX_BUF are immediately transferred into SPDIFRX_FMTx_DR if SPDIFRX_FMTx_DR is empty.

The valid data contained into the RX_BUF are transferred into SPDIFRX_FMTx_DR when the two following conditions are reached:

- The transition between the parity bit (P) and the next preamble is detected (this indicated that the word is completely received).
- The SPDIFRX_FMTx_DR is empty.

Having a 2-word buffer gives more flexibility for the latency constraint.

The maximum latency allowed is $T_{SAMPLE} - 2T_{PCLK} - 2T_{spdifrx\_ker\_ck}$

Where T_{SAMPLE} is the audio sampling rate of the received stereo audio samples, T_{PCLK} is the period of spdifrx_pclk clock, and $T_{spdifrx\_ker\_ck}$ is the period of spdifrx_ker_ck clock.

The SPDIFRX offers the possibility to use either DMA (spdifrx_dat_dma and spdifrx_ctrl_dma) or interrupts for transferring the audio samples into the memory. The recommended option is DMA, refer to *Section 57.3.12: DMA interface* for additional information.

The SPDIFRX offers several way on handling the received data. The user can either have a separate flow for control information and audio samples, or get them all together.

For each sub-frame, the data reception register SPDIFRX_FMTx_DR contains the 24 data bits, and optionally the V, U, C, PE status bits, and the PT (see *Mixing data and control flow*).

Note that PE bit stands for parity rrror bit, and is set to 1 when a parity error is detected in the decoded sub-frame.
The PT field carries the preamble type (B, M or W).

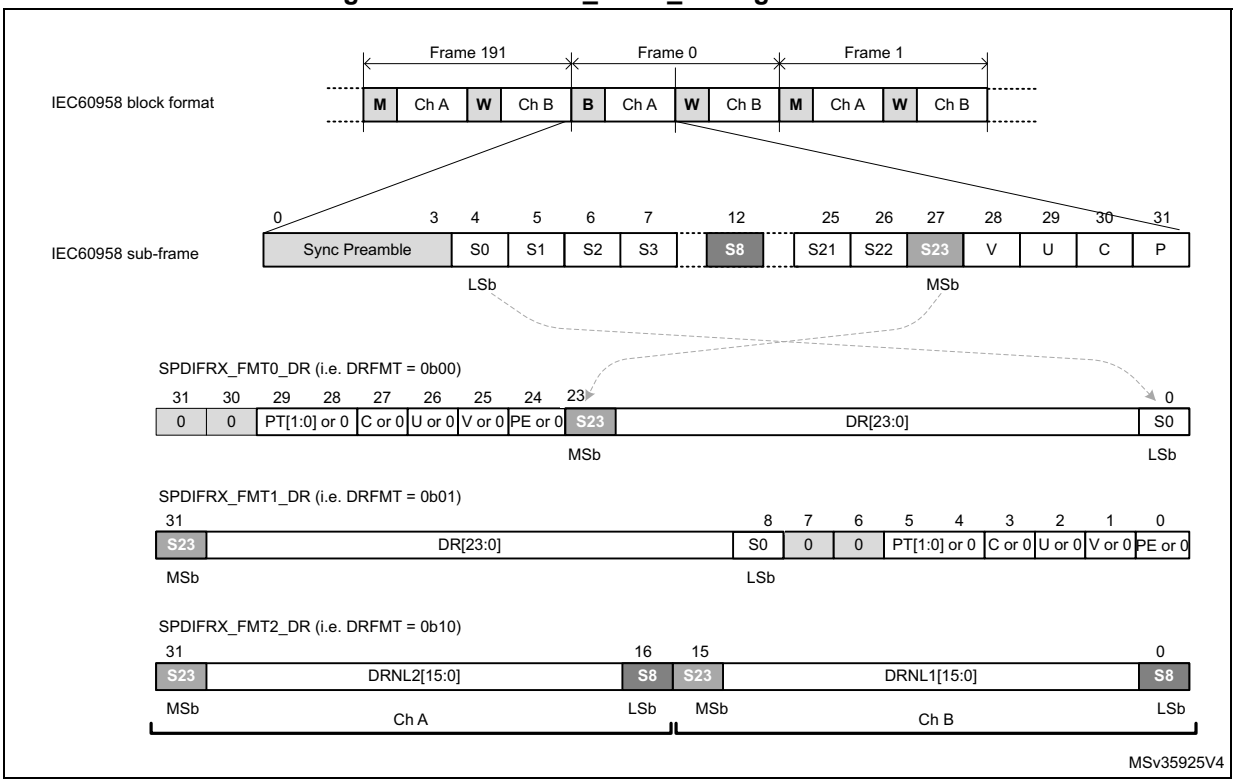
V, U and C are a direct copy of the value received from the S/PDIF interface.

The bit DRFMT allows the selection between 3 audio formats as shown in *Figure 709*.

This document describes 3 data registers: SPDIFRX_FMTx[2:0] (x = 2 to 0), but in reality there is only one physical data register, having 3 possible formats:

- When DRFMT = 0, the format of the data register is the one described by SPDIFRX_FMT0_DR
- When DRFMT = 1, the format of the data register is the one described by SPDIFRX_FMT1_DR
- When DRFMT = 2, the format of the data register is the one described by SPDIFRX_FMT2_DR"

Figure 709. SPDIFRX_FMTx_DR register format



Setting DRFMT to 00 or 01, offers the possibility to have the data either right or left aligned into the SPDIFRX_FMTx_DR register. The status information can be enabled or forced to zero according to the way the software wants to handle them.

The format given by DRFMT= 10 is interesting in non-linear mode, as only 16 bits per sub-frame are used. By using this format, the data of two consecutive sub-frames are stored into SPDIFRX_FMTx_DR, dividing by two the amount of memory footprint. Note that when RXSTEO = 1, there is no misalignment risks (i.e. data from ChA are always stored into SPDIFRX_FMTx_DR[31:16]). If RXSTEO = 0, then there is a misalignment risk is case of overrun situation. In that case SPDIFRX_FMTx_DR[31:16] always contain the oldest value and SPDIFRX_FMTx_DR[15:0] the more recent value (see *Figure 711*).

In this format the status information cannot be mixed with data, but the user can still get them through SPDIFRX_CSR register, and use a dedicated DMA channel or interrupt to transfer them to memory (see *Section 57.3.8: Dedicated control flow*)

Mixing data and control flow

The user can choose to use this mode in order to get the full flexibility of the handling of the control flow. The user can select which field must be kept into the data register (SPDIFRX_FMTx_DR).

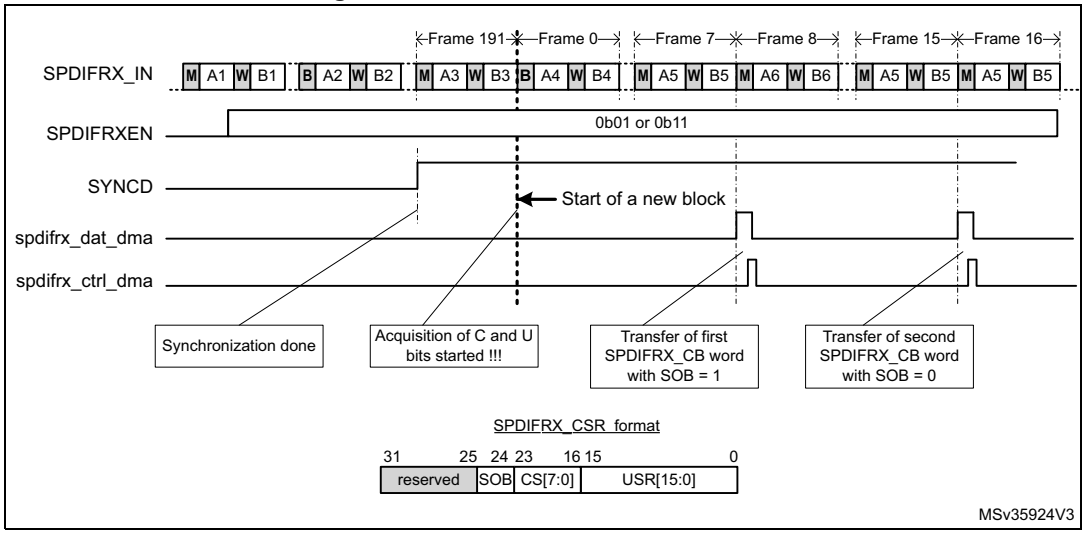
- When bit PMSK = 1, the parity error information is masked (set to 0), otherwise it is copied into SPDIFRX_FMTx_DR.
- When bit VMSK = 1, the validity information is masked (set to 0), otherwise it is copied into SPDIFRX_FMTx_DR.
- When bit CUMSK = 1, the channel status, and used data information are masked (set to 0), otherwise they are copied into SPDIFRX_FMTx_DR.
- When bit PTMSK = 1, the preamble type is masked (set to 0), otherwise it is copied into SPDIFRX_FMTx_DR.

57.3.8 Dedicated control flow

The SPDIFRX offers the possibility to catch both user data and channel status information via a dedicated DMA channel. This feature allows the SPDIFRX to acquire continuously the channel status and user information. The acquisition starts at the beginning of a IEC 60958 block. Two fields are available to control this path: CBDMAEN and SPDIFRXEN. When SPDIFRXEN is set to 01 or 0x11, the acquisition is started, after completion of the synchronization phase. When 8 channel status and 16 user data bits are received, they are packed and stored into SPDIFRX_CSR register. A DMA request is triggered if the bit CBDMAEN is set to 1 (see *Figure 710*).

If CS[0] corresponds to the first bit of a new block, the bit SOB is set to 1. Refer to *Section 57.5.8: Channel status register (SPDIFRX_CSR)*. A bit is available (CHSEL) in order to select if the user wants to select channel status information (C) from the channel A or B.

Figure 710. Channel/user data format



Note: Once the first start of block is detected (B preamble), the SPDIFRX is checking the preamble type every 8 frames.

Note: Overrun error on SPDIFRX_FMTx_DR register does not affect this path.

57.3.9 Reception errors

Frame structure and synchronization error

The SPDIFRX, detects errors, when one of the following condition occurs:

- The FERR bit is set to 1 on the following conditions:
  - For each of the 28 information bits, if one symbol transition sequence is not correct: for example if short pulses are not grouped by pairs.
  - If preambles occur to an unexpected place, or an expected preamble is not received.
- The SERR bit is set when the synchronization fails, because the number of re-tries exceeded the programmed value.
- The TERR bit is set when the counter used to estimate the width between two transitions overflows (TRCNT).
  The overflow occurs when no transition is detected during 8192 periods of spdifrx_ker_ck clock. It represents at most a time interval of 11.6 frames.

When one of those flags goes to 1, the traffic on selected SPDIFRX_IN is then ignored, an interrupt is generated if the IFEIE bit of the SPDIFRX_CR register is set.

The normal procedure when one of those errors occur is:

- Set SPDIFRXEN to 0 in order to clear the error flags
- Set SPDIFRXEN to 01 or 11 in order to restart the SPDIFRX

Refer to *Figure 708* for additional information.

Parity error

For each sub-frame, an even number of zeros and ones is expected inside the 28 information bits. If not, the parity error bit PERR is set in the SPDIFRX_SR register and an interrupt is generated if the parity interrupt enable PERRIE bit is set in the SPDIFRX_CR register. The reception of the incoming data is not paused, and the SPDIFRX continue to deliver data to SPDIFRX_FMTx_DR even if the interrupt is still pending.

The interrupt is acknowledged by clearing the PERR flag through PERRCF bit.

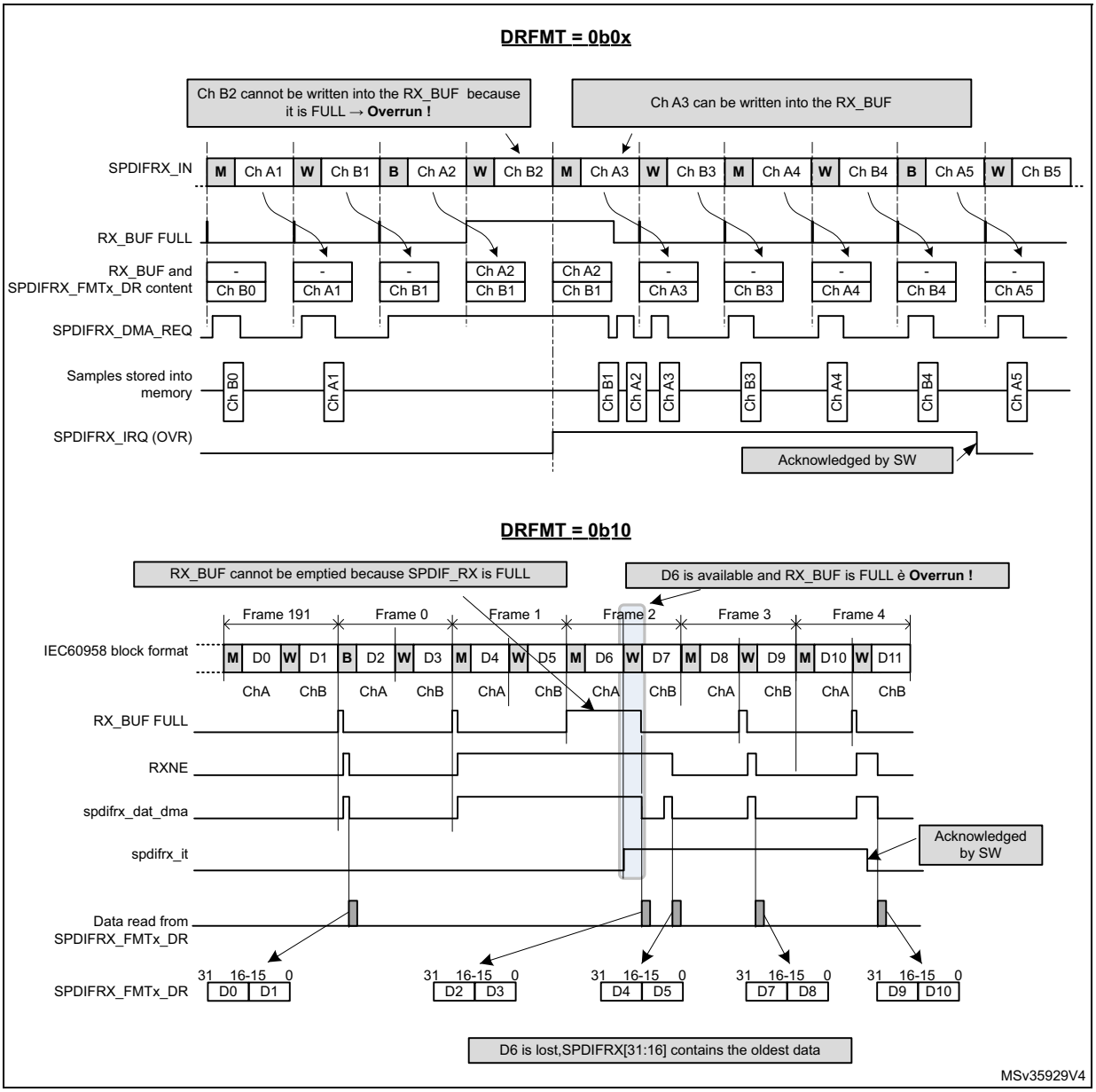
If the software wants to guarantee the coherency between the data read in the SPDIFRX_FMTx_DR register and the value of the bit PERR, the bit PMSK must be set to 0.

Overrun error

If both SPDIFRX_FMTx_DR and RX_BUF are full, while the SPDIFRX_DC needs to write a new sample in RX_BUF, this new sample is dropped, and an overrun condition is triggered. The overrun error flag OVR is set in the SPDIFRX_SR register and an interrupt is generated if the OVRIE bit of the SPDIFRX_CR register is set.

If the RXSTEO bit is set to 0, then as soon as the RX_BUF is empty, the SPDIFRX stores the next incoming data, even if the OVR flag is still pending. The main purpose is to reduce as much as possible the amount of lost samples. Note that the behavior is similar independently of DRFMT value. See *Figure 711*.

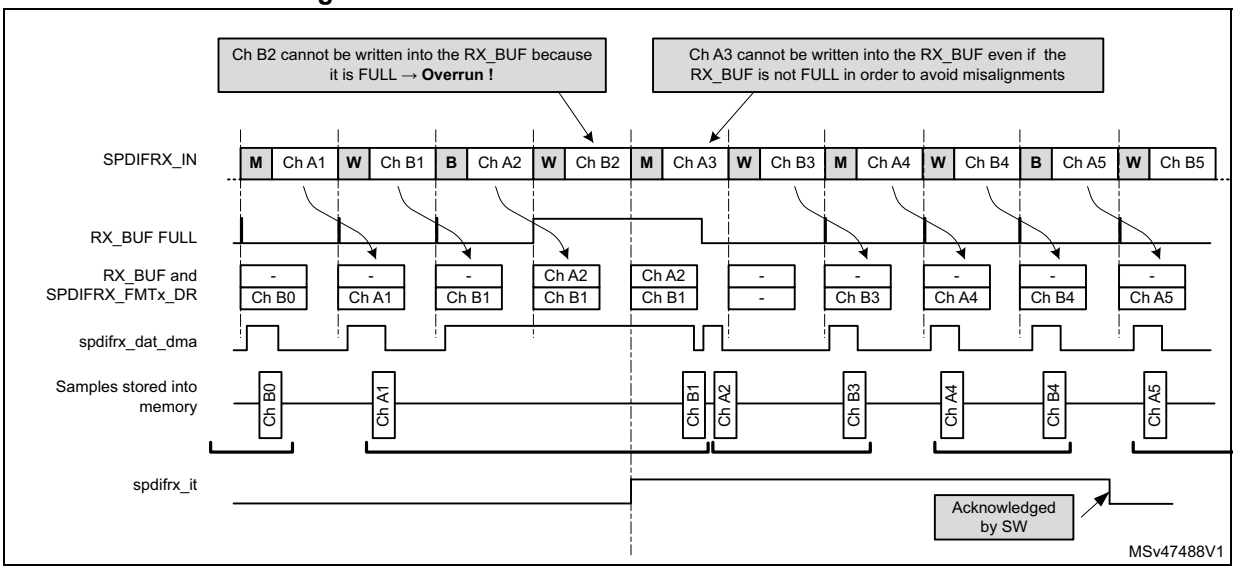
Figure 711. S/PDIF overrun error when RXSTEO = 0



If the RXSTEO bit is set to 1, it means that stereo data are transported, then the SPDIFRX has to avoid misalignment between left and right channels. So the peripheral has to drop a second sample even if there is room inside the RX_BUF in order to avoid misalignment. Then the incoming samples can be written normally into the RX_BUF even if the OVR flag is still pending. Refer to *Figure 712*.

The OVR flag is cleared by software, by setting the OVRCF bit to 1.

Figure 712. S/PDIF overrun error when RXSTEO = 1



57.3.10 Clocking strategy

The SPDIFRX block needs two different clocks:

- The APB clock (spdifrx_pclk), which is used for the register interface,
- The spdifrx_ker_ck which is mainly used by the SPDIFRX_DC part. Those clocks are not supposed to be phase locked, so all signals crossing those clock domains are re-synchronized (SYNC block on *Figure 698*).

In order to decode properly the incoming S/PDIF stream the SPDIFRX_DC must re-sample the received data with a clock at least 11 times higher than the maximum symbol rate, or 704 times higher than the audio sample rate. For example if the user expects to receive a symbol rate to up to 12.288 MHz, the sample rate must be at least 135.2 MHz. The clock used by the SPDIFRX_DC is the spdifrx_ker_ck.

The frequency of the spdifrx_pclk must be at least equal to the symbol rate.

Table 458. Minimum spdifrx_ker_ck frequency versus audio sampling rate(1)

Symbol rate	Minimum spdifrx_ker_ck frequency	Comments
3.072 MHz	33.8 MHz	For 48 kHz stream
6.144 MHz	67.6 MHz	For 96 kHz stream
12.288 MHz	135.2 MHz	For 192 kHz stream

1. Check the RCC capabilities in order to verify which sampling rates can be supported.

57.3.11 Symbol clock generation

The SPDIFRX block provides a symbol clock on signal named **spdifrx_symb_ck**, which can be used as the reference kernel clock for another audio device such as SAI or SPI/I2S. It can be used for SPDIFRX to I2S bridge function.

The symbol clock is built using the values of WIDTH24, WIDTH40 and the symbol boundaries.

- During the reception of the sub-frame sync preambles, the falling and rising edges of the symbol clock are built from the WIDTH24 and WIDTH40 values. Note that WIDTH24 and WIDTH40 are also used for the generation of the symbol clock, when the SPDIFRX is STATE_STOP or STATE_IDLE. See *Table 459* for details.
- During the reception of the sub-frame payload, the SPDIFRX uses the symbols boundaries to generate the rising edge, the WIDTH24 and WIDTH40 values for the generation of the falling edge.

The duty cycle of the symbol clock is close to 50% during the reception of the sub-frame payload. However, the duty cycle can be altered when the SPDIFRX transitions from a symbol clock generated with WIDTH24 and WIDTH40 to a clock generated by the symbol clock boundaries or vice-versa.

The symbol clock has an important jitter mainly due to:

- The re-sampling of the S/PDIF signal with spdifrx_ker_ck clock
- The transition of the symbol clock generation mode

For that reason the application must consider the quality degradation if the symbol clock is used as the reference clock for A/D or D/A converters.

The generation of this symbol clock is controlled by the CKSEN bit. When CKSEN = ‘1’, the clock symbol is generated when the SPDIFRX completes successfully the first fine synchronization (SYNCD = 1), and when it receives correct data from the selected SPDIFRX input.

When the SPDIFRX goes to STATE_STOP, or STATE_IDLE, the symbol clock is gated if the bit CKSBKPEN = ‘0’. If the CKSBKPEN = ‘1’, then a backup symbol clock is still generated if the SPDIFRX is properly synchronized (i.e. valid values available for WIDTH24 and WIDTH40). *Table 459* gives more details on the conditions controlling the generation of the symbol clock.

Table 459. Conditions of spdifrx_symb_ck generation

SPDIFRX states and conditions	CKSEN	CKSBKPEN	spdifrx_symb_ck state
Any state	0	X	Disabled

Table 459. Conditions of spdifrx_symb_ck generation (continued)

SPDIFRX states and conditions	CKSEN	CKSBKPEN	spdifrx_symb_ck state
– SPDIFRX in STATE_SYNC and completing successfully the fine synchronization (SYNCD = '1') or, – SPDIFRX in STATE_RCV, and valid data are received via the selected SPDIFRX input.	1	0	Enabled
– SPDIFRX in STATE_IDLE or, – SPDIFRX in STATE_STOP or, – SPDIFRX did not complete the fine synchronization (on-going) – SPDIFRX is in STATE_RCV, but no data (transitions) detected on the selected SPDIFRX input.		0	Disabled
– SPDIFRX in STATE_IDLE, but with valid values for WIDTH40 and WIDTH24 or – SPDIFRX in STATE_SYNC and completing successfully the fine synchronization (SYNCD = '1') or, – SPDIFRX in STATE_SYNC the on-going fine synchronization is not completed, but WIDTH40 and WIDTH24 contain the valid values from the previous synchronization or, – SPDIFRX in STATE_RCV, and valid data are received via the selected SPDIFRX input or, – SPDIFRX in STATE_STOP, but with valid values for WIDTH40 and WIDTH24.	1	1	Enabled
– SPDIFRX in IDLE, with invalid values for WIDTH40 and WIDTH24 or, – SPDIFRX in STOP with invalid values for WIDTH40 and WIDTH24 (SERR = '1') or, – SPDIFRX in STATE_SYNC with invalid values for WIDTH40 and WIDTH24, and did not completed the on-going fine synchronization or, – SPDIFRX in STATE_RCV and no transitions detected on the selected SPDIFRX input			Disabled

Note that when the flag SERR is set to ‘1’, neither the symbol clock nor the backup clock can be generated, since there is no synchronization.

Note that when both CKSEN and CKSBKPEN are set to ‘1’, the symbol clock looses some transitions when the SPDIFRX switches from STATE_SYNC or STATE_RCV to STATE_STOP, or STATE_IDLE.

The bits CKSEN and CKSBKPEN are located into *Control register (SPDIFRX_CR)*.

57.3.12 DMA interface

The SPDIFRX interface is able to perform communication using the DMA.

Note: The user must refer to product specifications for availability of the DMA controller.

The SPDIFRX offers two independent DMA channels:

- A DMA channel dedicated to the data transfer
- A DMA channel dedicated to the channel status and user data transfer

The DMA mode for the data can be enabled for reception by setting the RXDMAEN bit in the SPDIFRX_CR register. In this case, as soon as the SPDIFRX_FMTx_DR is not empty, the SPDIFRX interface sends a transfer request to the DMA. The DMA reads the data received through the SPDIFRX_FMTx_DR register without CPU intervention.

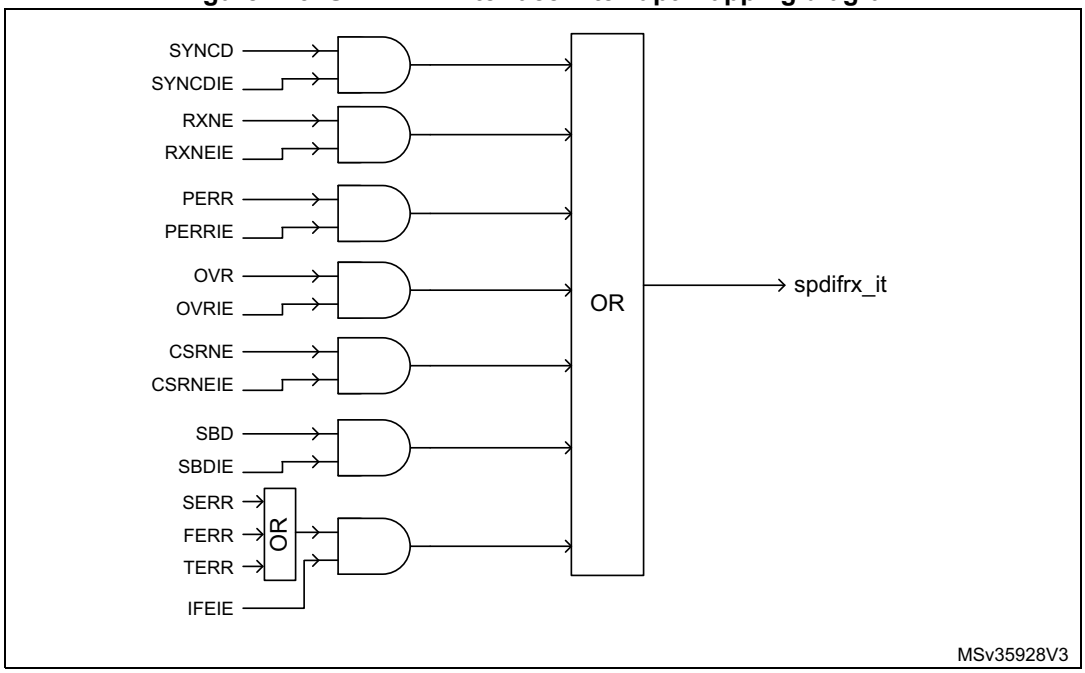
For the use of DMA for the control data refer to *Section 57.3.8: Dedicated control flow*.

57.3.13 Interrupt generation

An interrupt line is shared between:

- Reception events for data flow (RXNE)
- Reception event for control flow (CSRNE)
- Data corruption detection (PERR)
- Transfer flow interruption (OVR)
- Frame structure and synchronization errors (SERR, TERR and FERR)
- Start of new block interrupt (SBD)
- Synchronization done (SYNCD)

Figure 713. SPDIFRX interface interrupt mapping diagram



Clearing interrupt source

- RXNE is cleared when SPDIFRX_FMTx_DR register is read
- CSRNE is cleared when SPDIFRX_CSR register is read
- FERR is cleared when SPDIFRXEN is set to 0
- SERR is cleared when SPDIFRXEN is set to 0
- TERR is cleared when SPDIFRXEN is set to 0
- Others are cleared through SPDIFRX_IFCR register

Note: The SBD event can only occur when the SPDIFRX is synchronized to the input stream (SYNCD = 1).

The SBD flag behavior is not guaranteed when the sub-frame which contains the B preamble is lost due to an overrun.

57.3.14 Register protection

The SPDIFRX block embeds some hardware protection avoid erroneous use of control registers. The table hereafter shows the bit field properties according to the SPDIFRX state.

Table 460. Bit field property versus SPDIFRX state

Registers	Field	SPDIFRXEN		
		00 (STATE_IDLE)	01 (STATE_SYNC)	11 (STATE_RCV)
SPDIFRX_CR	INSEL	rw	r	r
	WFA	rw	r	r
	NBTR	rw	r	r
	CHSEL	rw	r	r
	CBDMAEN	rw	rw	rw
	PTMSK	rw	rw	rw
	CUMSK	rw	rw	rw
	VMSK	rw	rw	rw
	PMSK	rw	rw	rw
	DRFMT	rw	rw	r
	RXSTEO	rw	rw	r
	RXDMAEN	rw	rw	rw
SPDIFRX_IMR	All fields	rw	rw	rw

The table clearly shows that fields such as INSEL must be programmed when the SPDIFRX is in STATE_IDLE. In the others SPDIFRX states, the hardware prevents writing to this field.

Note: Even if the hardware allows the writing of CBDMAEN and RXDMAEN “on-the-fly”, it is not recommended to enable the DMA when the SPDIFRX already receives data.

Note: Each of the mask bits (such as PMSK, VMSK) can be changed “on-the-fly” at any SPDIFRX state, but any change does not affect data which are already hold in SPDIFRX_FMTx_DR.

57.4 Programming procedures

The following example illustrates a complete activation sequence of the SPDIFRX block. The data path and channel status and user information both use a dedicated DMA channel. The activation sequence is then split into the following steps:

- Wait for valid data on the selected SPDIFRX_IN input
- Synchronize to the S/PDIF stream
- Read the channel status and user information in order to setup the complete audio path
- Start data acquisition

A simple way to check if valid data are available into the SPDIFRX_IN line is to switch the SPDIFRX into the STATE_SYNC, with bit WFA set to 1. The description hereafter focuses on detection. It is also possible to implement this function as follows:

- The software has to check from time to time (i.e. every 100 ms for example) if the SPDIFRX can find synchronization. This can be done by checking if the bit TERR is set. When it is set it indicates that no activity as been found.
- Connect the SPDIFRX_IN input to an external interrupt event block in order to detect transitions of SPDIFRX_IN line. When activity is detected, then SPDIFRXEN can be set to 01 or 11.

  For those two implementations, the bit WFA is set to 0.

57.4.1 Initialization phase

- The initialization function looks like this:
- Configure the DMA transfer for both audio samples and IEC60958 channel status and user information (DMA channel selection and activation, priority, number of data to transfer, circular/no circular mode, DMA interrupts)
- Configure the destination address:
  - Configure the address of the SPDIFRX_CSR register as source address for IEC60958 channel status and user information
  - Configure the address of the SPDIFRX_FMTx_DR register as source address for audio samples
  - Enable the generation of the spdifrx_ker_ck. Refer to *Table 458* in order to define the minimum clock frequency versus supported audio sampling rate.
    Note that the audio sampling rate of the received stream is not known in advance. This means that the user has to select a spdifrx_ker_ck frequency at least 704 times higher than the maximum audio sampling rate the application is supposed to handle: for example if the application is able to handle streams to up to 96 kHz, then $F_{spdifrx\_ker\_ck}$ must be at least 704 x 96 kHz = 67.6 MHz
- Enable interrupt for errors and event signaling (IFEIE = SYNCDIE = OVRIE, PERRIE = 1, others set to 0). Note that SYNCDIE can be set to 0.
- Configure the SPDIFRX_CR register:
  - INSEL must select the wanted input
  - NBTR = 2, WFA = 1 (16 re-tries allowed, wait for activity before going to synchronization phase),
  - PTMSK = CUMSK = 1 (Preamble, C and U bits are not mixed with data)
  - VMSK = PMSK = 0 (Parity error and validity bit mixed with data)
  - CHSEL = 0 (channels status are read from sub-frame A)
  - DRFMT = 01 (data aligned to the left)
  - RXSTEO = 1 (expected stereo mode linear)
  - CBDMAEN = RXDMAEN = 1 (enable DMA channels)
  - SPDIFRXEN = 01 (switch SPDIFRX to STATE_SYNC)
- The CPU can enter in WFI mode

Then the CPU receives interrupts coming either from DMA or SPDIFRX.

57.4.2 Handling of interrupts coming from SPDIFRX

When an interrupt from the SPDIFRX is received, then the software has to check what is the source of the interrupt by reading the SPDIFRX_SR register.

- If SYNCD is set to 1, then it means that the synchronization is properly completed. No action has to be performed in our case as the DMA is already programmed. The software just needs to wait for DMA interrupt in order to read channel status information.
  The SYNCD flag must be cleared by setting SYNCDCF bit of SPDIFRX_IFCR register to 1.
- If TERR or SERR or FERR are set to 1, the software has to set SPDIFRXEN to 0, and re-start from the initialization phase.
  - TERR indicates that a time-out occurs either during synchronization phase or after.
  - SERR indicates that the synchronization fails because the maximum allowed re-tries are reached.
  - FERR indicates that the reading of information after synchronization fails (such as unexpected preamble, bad data decoding).
- If PERR is set to 1, it means that a parity error is detected, so one of the received audio sample or the channel status or user data bits are corrupted. The action taken here depends on the application: one action can be to drop the current channel status block as it is not reliable. There is no need to re-start from the initialization phase, as the synchronization is not lost.
  The PERR flag must be cleared by setting PERRCF bit of SPDIFRX_IFCR register to 1.

57.4.3 Handling of interrupts coming from DMA

If an interrupt comes from the DMA channel used of the channel status (SPDIFRX_CSR):

If no error occurred (that is PERR), the CPU can start the decoding of channel information. For example bit 1 of the channel status informs the user if the current stream is linear or not. This information is very important in order to set-up the proper processing chain. In the same way, bits 24 to 27 of the channel status give the sampling frequency of the stream incoming stream.

Thanks to that information, the user can then configure the RXSTEO bit and DRFMT field prior to start the data reception. For example if the current stream is non linear PCM then RXSTEO is set to 0, and DRFMT is set to 10. Then the user can enable the data reception by setting SPDIFRXEN to 11.

The SOB bit, when set to 1 indicates the start of a new block. This information helps the software to identify the bit 0 of the channel status. Note that if the DMA generates an interrupt every time 24 values are transferred into the memory, then the first word always corresponds to the start of a new block.

If an interrupt comes from the DMA channel used of the audio samples (SPDIFRX_FMTx_DR):

The process performed here depends of the data type (linear or non-linear), and on the data format selected.

For example in linear mode, if PE or V bit is set a special processing can be performed locally in order to avoid spurs on output. In non-linear mode those bits are not important as data frame have their own checksum.

57.5 SPDIFRX interface registers

57.5.1 Control register (SPDIFRX_CR)

Only 32-bit accesses are allowed in this register.

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CKSBKPEN	CKSEN	Res.	INSEL[2:0]		
										rw	rw		rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	WFA	NBTR[1:0]		CHSEL	CBDMAEN	PTMSK	CUMSK	VMSK	PMSK	DRFMT[1:0]		RXSTEO	RXDMAEN	SPDIFRXEN[1:0]	
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **CKSBKPEN**: Backup Symbol Clock Enable
This bit is set/reset by software
1: The SPDIFRX generates a backup symbol clock if CKSEN = ‘1’
0: The SPDIFRX does not generate a backup symbol clock

Bit 20 **CKSEN**: Symbol Clock Enable
This bit is set/reset by software
1: The SPDIFRX generates a symbol clock
0: The SPDIFRX does not generate a symbol clock

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **INSEL[2:0]**: SPDIFRX input selection(1)
000: SPDIFRX_IN1 selected
001: SPDIFRX_IN2 selected
010: SPDIFRX_IN3 selected
011: SPDIFRX_IN4 selected
other: reserved

Bit 15 Reserved, must be kept at reset value.

Bit 14 **WFA**: Wait for activity(1)
This bit is set/reset by software
1: The SPDIFRX waits for activity on SPDIFRX_IN line (4 transitions) before performing the synchronization
0: The SPDIFRX does not wait for activity on SPDIFRX_IN line before performing the synchronization

Bits 13:12 **NBTR[1:0]**: Maximum allowed re-tries during synchronization phase(1)
00: No re-try is allowed (only one attempt)
01: 3 re-tries allowed
10: 15 re-tries allowed
11: 63 re-tries allowed

Bit 11 **CHSEL**: Channel selection(1)
This bit is set/reset by software
1: The control flow takes the channel status from channel B
0: The control flow takes the channel status from channel A

Bit 10 **CBDMAEN**: Control buffer DMA enable for control flow(1)
This bit is set/reset by software
1: DMA mode is enabled for reception of channel status and used data information.
0: DMA mode is disabled for reception of channel status and used data information.
When this bit is set, the DMA request is made whenever the CSRNE flag is set.

Bit 9 **PTMSK**: Mask of preamble type bits(1)
This bit is set/reset by software
1: The preamble type bits are not copied into the SPDIFRX_FMTx_DR, zeros are written instead
0: The preamble type bits are copied into the SPDIFRX_FMTx_DR

Bit 8 **CUMSK**: Mask of channel status and user bits(1)
This bit is set/reset by software
1: The channel status and user bits are not copied into the SPDIFRX_FMTx_DR, zeros are written instead
0: The channel status and user bits are copied into the SPDIFRX_FMTx_DR

Bit 7 **VMSK**: Mask of validity bit(1)
This bit is set/reset by software
1: The validity bit is not copied into the SPDIFRX_FMTx_DR, a zero is written instead
0: The validity bit is copied into the SPDIFRX_FMTx_DR

Bit 6 **PMSK**: Mask parity error bit(1)
This bit is set/reset by software
1: The parity error bit is not copied into the SPDIFRX_FMTx_DR, a zero is written instead
0: The parity error bit is copied into the SPDIFRX_FMTx_DR

Bits 5:4 **DRFMT[1:0]**: RX data format(1)
This bit is set/reset by software
11: reserved
10: Data sample are packed by setting two 16-bit sample into a 32-bit word
01: Data samples are aligned in the left (MSB)
00: Data samples are aligned in the right (LSB)

Bit 3 **RXSTEO**: Stereo mode(1)

This bit is set/reset by software

1: The peripheral is in STEREO mode

0: The peripheral is in MONO mode

This bit is used in case of overrun situation in order to handle misalignment

Bit 2 **RXDMAEN**: Receiver DMA enable for data flow(1)

This bit is set/reset by software

1: DMA mode is enabled for reception.

0: DMA mode is disabled for reception.

When this bit is set, the DMA request is made whenever the RXNE flag is set.

Bits 1:0 **SPDIFRXEN[1:0]**: Peripheral block enable(1)

This field is modified by software.

It must be used to change the peripheral phase among the three possible states: STATE_IDLE, STATE_SYNC and STATE_RCV.

00: Disable SPDIFRX (STATE_IDLE).

01: Enable SPDIFRX synchronization only

10: Reserved

11: Enable SPDIF Receiver

Note: it is not possible to transition from STATE_RCV to STATE_SYNC, the user must first go the STATE_IDLE.
it is possible to transition from STATE_IDLE to STATE_RCV: in that case the peripheral transitions from STATE_IDLE to STATE_SYNC and as soon as the synchronization is performed goes to STATE_RCV.

1. Refer to *Section 57.3.14: Register protection* for additional information on fields properties.

57.5.2 Interrupt mask register (SPDIFRX_IMR)

Address offset: 0x04

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IFE IE	SYNCD IE	SBLK IE	OVR IE	PERR IE	CSRNE IE	RXNE IE
									rw	rw	rw	rw	rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **IFEIE**: Serial Interface Error Interrupt Enable

This bit is set and cleared by software.

0: Interrupt is inhibited

1: A SPDIFRX interface interrupt is generated whenever SERR=1, TERR=1 or FERR=1 in the SPDIFRX_SR register.

Bit 5 **SYNCDIE**: Synchronization Done

This bit is set and cleared by software.

0: Interrupt is inhibited

1: A SPDIFRX interface interrupt is generated whenever SYNCD = 1 in the SPDIFRX_SR register.

Bit 4 **SBLKIE**: Synchronization Block Detected Interrupt Enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: A SPDIFRX interface interrupt is generated whenever SBD = 1 in the SPDIFRX_SR register.

Bit 3 **OVRIE**: Overrun error Interrupt Enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: A SPDIFRX interface interrupt is generated whenever OVR=1 in the SPDIFRX_SR register

Bit 2 **PERRIE**: Parity error interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: A SPDIFRX interface interrupt is generated whenever PERR=1 in the SPDIFRX_SR register

Bit 1 **CSRNEIE: Control Buffer Ready Interrupt Enable**
This bit is set and cleared by software.
0: Interrupt is inhibited
1: A SPDIFRX interface interrupt is generated whenever CSRNE = 1 in the SPDIFRX_SR register.

Bit 0 **RXNEIE**: RXNE interrupt enable
This bit is set and cleared by software.
0: Interrupt is inhibited
1: A SPDIFRX interface interrupt is generated whenever RXNE=1 in the SPDIFRX_SR register

57.5.3 Status register (SPDIFRX_SR)

Address offset: 0x08

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	WIDTH5[14:0]														
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	TERR	SERR	FERR	SYNCD	SBD	OVR	PERR	CSRNE	RXNE
							r	r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:16 **WIDTH5[14:0]**: duration of 5 symbols counted with spdifrx_ker_ck
This value represents the amount of spdifrx_ker_ck clock periods contained on a length of 5 consecutive symbols. This value can be used to estimate the S/PDIF symbol rate. Its accuracy is limited by the frequency of spdifrx_ker_ck.
For example if the spdifrx_ker_ck is fixed to 84 MHz, and WIDTH5 = 147d. The estimated sampling rate of the S/PDIF stream is:
Fs = 5 x $F_{spdifrx\_ker\_ck}$ / (WIDTH5 x 64) ~ 44.6 kHz, so the closest standard sampling rate is 44.1 kHz.
Note that WIDTH5 is updated by the hardware when SYNCD goes high, and then every frame.

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **TERR**: time-out error

This bit is set by hardware when the counter TRCNT reaches its max value. It indicates that the time interval between two transitions is too long. It generally indicates that there is no valid signal on SPDIFRX_IN input.

This flag is cleared by writing SPDIFRXEN to 0

An interrupt is generated if IFEIE=1 in the SPDIFRX_IMR register

0: No sequence error is detected

1: Sequence error is detected

Bit 7 **SERR**: synchronization error

This bit is set by hardware when the synchronization fails due to amount of re-tries for NBTR.

This flag is cleared by writing SPDIFRXEN to 0

An interrupt is generated if IFEIE=1 in the SPDIFRX_IMR register.

0: No synchronization error is detected

1: Synchronization error is detected

Bit 6 **FERR**: framing error

This bit is set by hardware when an error occurs during data reception: such as preamble not at the expected place, short transition not grouped by pairs.

This is set by the hardware only if the synchronization is completed (SYNCD = 1).

This flag is cleared by writing SPDIFRXEN to 0

An interrupt is generated if IFEIE=1 in the SPDIFRX_IMR register.

0: no Manchester Violation detected

1: Manchester Violation detected

Bit 5 **SYNCD**: synchronization done

This bit is set by hardware when the initial synchronization phase is properly completed.

This flag is cleared by writing a 1 to its corresponding bit on SPDIFRX_IFCR register.

An interrupt is generated if SYNCDIE = 1 in the SPDIFRX_IMR register

0: Synchronization is pending

1: Synchronization is completed

Bit 4 **SBD**: synchronization block detected

This bit is set by hardware when a “B” preamble is detected

This flag is cleared by writing a 1 to its corresponding bit on SPDIFRX_IFCR register.

An interrupt is generated if SBLKIE = 1 in the SPDIFRX_IMR register

0: No “B” preamble detected

1: “B” preamble is detected

Bit 3 **OVR**: overrun error

This bit is set by hardware when a received data is ready to be transferred in the SPDIFRX_FMTx_DR register while RXNE = 1 and both SPDIFRX_FMTx_DR and RX_BUF are full.

This flag is cleared by writing a 1 to its corresponding bit on SPDIFRX_IFCR register.

An interrupt is generated if OVRIE=1 in the SPDIFRX_IMR register.

0: No Overrun error

1: Overrun error is detected

Note: When this bit is set, the SPDIFRX_FMTx_DR register content is not lost but the last data received are.

Bit 2 **PERR**: parity error
This bit is set by hardware when the data and status bits of the sub-frame received contain an odd number of 0 and 1.
This flag is cleared by writing a 1 to its corresponding bit on SPDIFRX_IFCR register.
An interrupt is generated if PIE = 1 in the SPDIFRX_IMR register.
0: No parity error
1: Parity error

Bit 1 **CSRNE**: the control buffer register is not empty
This bit is set by hardware when a valid control information is ready.
This flag is cleared when reading SPDIFRX_CSR register.
An interrupt is generated if CBRDYIE = 1 in the SPDIFRX_IMR register
0: No control word available on SPDIFRX_CSR register
1: A control word is available on SPDIFRX_CSR register

Bit 0 **RXNE**: read data register not empty
This bit is set by hardware when a valid data is available into SPDIFRX_FMTx_DR register.
This flag is cleared by reading the SPDIFRX_FMTx_DR register.
An interrupt is generated if RXNEIE=1 in the SPDIFRX_IMR register.
0: Data is not received
1: Received data is ready to be read.

57.5.4 Interrupt flag clear register (SPDIFRX_IFCR)

Address offset: 0x0C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYNCDCF	SBDCF	OVRCF	PERRCF	Res.	Res.
										w	w	w	w		

Bits 31:6 Reserved, must be kept at reset value.

Bit 5 **SYNCDCF**: clears the synchronization done flag
Writing 1 in this bit clears the flag SYNCD in the SPDIFRX_SR register.
Reading this bit always returns the value 0.

Bit 4 **SBDCF**: clears the synchronization block detected flag
Writing 1 in this bit clears the flag SBD in the SPDIFRX_SR register.
Reading this bit always returns the value 0.

Bit 3 **OVRCF**: clears the overrun error flag
Writing 1 in this bit clears the flag OVR in the SPDIFRX_SR register.
Reading this bit always returns the value 0.

Bit 2 **PERRCF**: clears the parity error flag
Writing 1 in this bit clears the flag PERR in the SPDIFRX_SR register.
Reading this bit always returns the value 0.

Bits 1:0 Reserved, must be kept at reset value.

57.5.5 Data input register (SPDIFRX_FMT0_DR)

Address offset: 0x10

Reset value: 0x0000 0000

This register can take 3 different formats according to DRFMT. Here is the format when DRFMT = 00:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	PT[1:0]		C	U	V	PE	DR[23:16]							
		r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:28 **PT[1:0]:** preamble type

These bits indicate the preamble received.

00: not used

01: Preamble B received

10: Preamble M received

11: Preamble W received

Note that if PTMSK = 1, this field is forced to zero

Bit 27 **C**: channel status bit

Contains the received channel status bit, if CUMSK = 0, otherwise it is forced to 0

Bit 26 **U**: user bit

Contains the received user bit, if CUMSK = 0, otherwise it is forced to 0

Bit 25 **V**: validity bit

Contains the received validity bit if VMSK = 0, otherwise it is forced to 0

Bit 24 **PE**: parity error bit

Contains a copy of PERR bit if PMSK = 0, otherwise it is forced to 0

Bits 23:0 **DR[23:0]**: data value

Contains the 24 received data bits, aligned on D[23]

57.5.6 Data input register (SPDIFRX_FMT1_DR)

Address offset: 0x10

Reset value: 0x0000 0000

This register can take 3 different formats according to DRFMT. Here is the format when DRFMT = 01:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DR[23:8]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DR[7:0]								Res.	Res.	PT[1:0]		C	U	V	PE
r	r	r	r	r	r	r	r			r	r	r	r	r	r

Bits 31:8 **DR[23:0]**: data value
Contains the 24 received data bits, aligned on D[23]

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:4 **PT[1:0]:** preamble type
These bits indicate the preamble received.
00: not used
01: preamble B received
10: preamble M received
11: preamble W received
Note that if PTMSK = 1, this field is forced to zero

Bit 3 **C**: channel Status bit
Contains the received channel status bit, if CUMSK = 0, otherwise it is forced to 0

Bit 2 **U**: user bit
Contains the received user bit, if CUMSK = 0, otherwise it is forced to 0

Bit 1 **V**: validity bit
Contains the received validity bit if VMSK = 0, otherwise it is forced to 0

Bit 0 **PE**: parity error bit
Contains a copy of PERR bit if PMSK = 0, otherwise it is forced to 0

57.5.7 Data input register (SPDIFRX_FMT2_DR)

Address offset: 0x10

Reset value: 0x0000 0000

This register can take 3 different formats according to DRFMT.

The data format proposed when DRFMT = 10, is dedicated to non-linear mode, as only 16 bits are used (bits 23 to 8 from S/PDIF sub-frame).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DRNL2[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DRNL1[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **DRNL2[15:0]**: data value
This field contains the channel A

Bits 15:0 **DRNL1[15:0]**: data value
This field contains the channel B

57.5.8 Channel status register (SPDIFRX_CSR)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	SOB	CS[7:0]							
							r	r	r	r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **SOB**: start of block
This bit indicates if the bit CS[0] corresponds to the first bit of a new block
0: CS[0] is not the first bit of a new block
1: CS[0] is the first bit of a new block

Bits 23:16 **CS[7:0]**: channel A status information
Bit CS[0] is the oldest value

Bits 15:0 **USR[15:0]**: user data information
Bit USR[0] is the oldest value, and comes from channel A, USR[1] comes channel B.
So USR[n] bits come from channel A is n is even, otherwise they come from channel B.

57.5.9 Debug information register (SPDIFRX_DIR)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	TLO[12:0]												
			r	r	r	r	r	r	r	r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	THI[12:0]												
			r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:16 **TLO[12:0]**: threshold LOW (TLO = 1.5 x UI / $T_{spdifrx\_ker\_ck}$)
This field contains the current threshold LOW estimation. This value can be used to estimate the sampling rate of the received stream. The accuracy of TLO is limited to a period of the spdifrx_ker_ck. The sampling rate can be estimated as follow:
Sampling Rate = [2 x TLO x $T_{spdifrx\_ker\_ck}$ +/- $T_{spdifrx\_ker\_ck}$] x 2/3
Note that TLO is updated by the hardware when SYNCD goes high, and then every frame.

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:0 **THI[12:0]**: threshold HIGH (THI = 2.5 x UI / $T_{spdifrx\_ker\_ck}$)
This field contains the current threshold HIGH estimation. This value can be used to estimate the sampling rate of the received stream. The accuracy of THI is limited to a period of the spdifrx_ker_ck. The sampling rate can be estimated as follow:
Sampling Rate = [2 x THI x $T_{spdifrx\_ker\_ck}$ +/- $T_{spdifrx\_ker\_ck}$] x 2/5
Note that THI is updated by the hardware when SYNCD goes high, and then every frame.

57.5.10 SPDIFRX interface register map

Table 461. SPDIFRX interface register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**SPDIFRX_CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CKSBKPEN	CKSEN	Res.	INSEL[2:0]			Res.	WFA	NBTR[1:0]		CHSEL	CBDMAEN	PTMSK	CUMSK	VMSK	PMSK	DRFMT[1:0]		RXSTEO	RXDMAEN	SPDIFRXEN[1:0]	
	Reset value											0	0		0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x04	**SPDIFRX_IMR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IFEIE	SYNCDIE	SBLKIE	OVRIE	PERRIE	CSRNEIE	RXNEIE
	Reset value																										0	0	0	0	0	0	0
0x08	**SPDIFRX_SR**	Res.	WIDTH5[14:0]															Res.	Res.	Res.	Res.	Res.	Res.	Res.	TERR	SERR	FERR	SYNCD	SBD	OVR	PERR	CSRNE	RXNE
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								0	0	0	0	0	0	0	0	0
0x0C	**SPDIFRX_IFCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYNCDCF	SBDCF	OVRCF	PERRCF	Res.	Res.
	Reset value																											0	0	0	0		
0x10	**SPDIFRX_FMT0_DR**	Res.	Res.	PT[1:0]		C	U	V	PE	DR[23:0]																							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	**SPDIFRX_FMT1_DR**	DR[23:0]																Res.										PT[1:0]		C	U	V	PE
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	**SPDIFRX_FMT2_DR**	DRNL2[15:0]																DRNL1[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	**SPDIFRX_CSR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SOB	CS[7:0]								USR[15:0]															
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 461. SPDIFRX interface register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x18	**SPDIFRX_DIR**	Res	Res	Res	TLO[12:0]													Res	Res	Res	THI[12:0]												
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

58 Single wire protocol master interface (SWPMI)

58.1 Introduction

The single wire protocol master interface (SWPMI) is the master interface corresponding to the contactless front-end (CLF) defined in the ETSI TS 102 613 technical specification.

The principle of the Single wire protocol (SWP) is based on the transmission of digital information in full duplex mode:

- S1 signal (from Master to Slave) is transmitted by a digital modulation (L or H) in the voltage domain (refer to *Figure 714: S1 signal coding*),
- S2 signal (from Slave to Master) is transmitted by a digital modulation (L or H) in the current domain (refer to *Figure 715: S2 signal coding*).

Figure 714. S1 signal coding

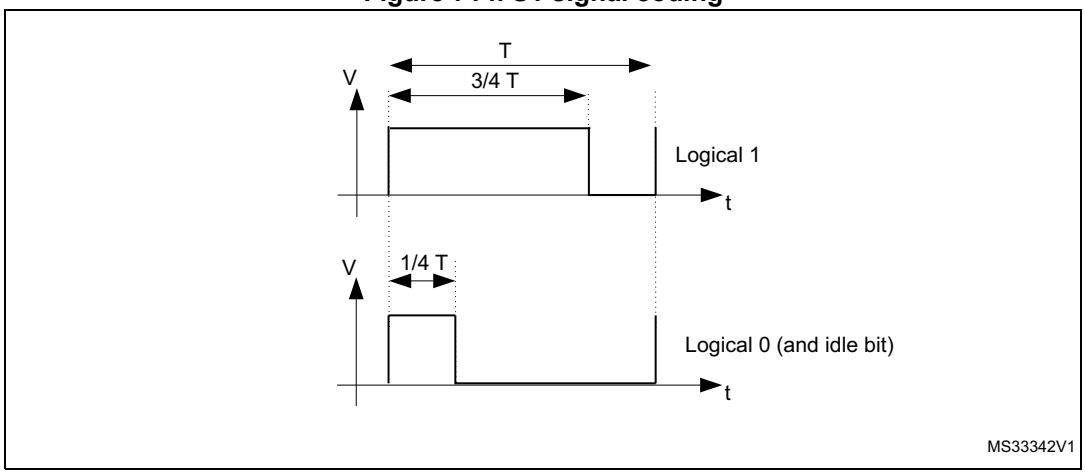
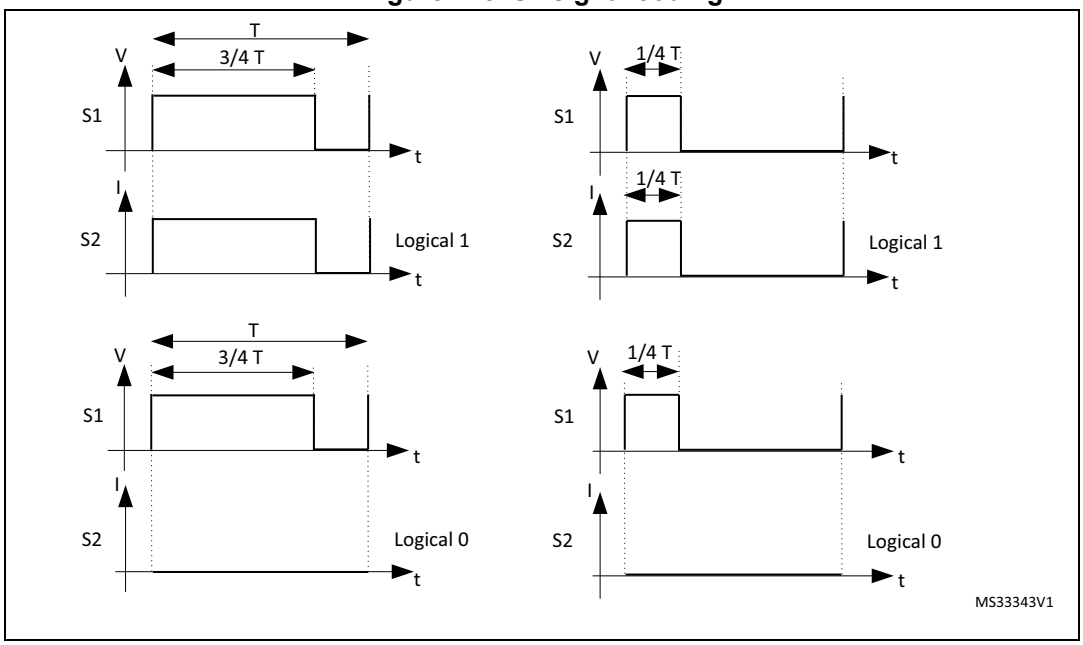


Figure 715. S2 signal coding



58.2 SWPMI main features

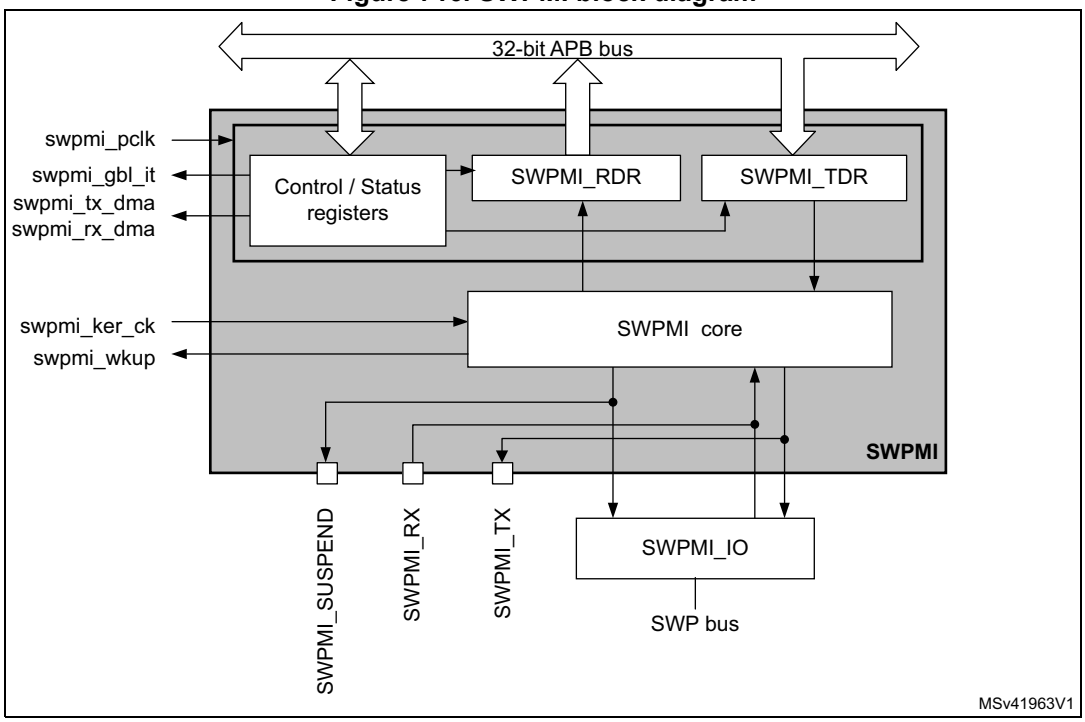
The SWPMI module main features are the following (see *Figure 58.3.4: SWP bus states*):

- Full-duplex communication mode
- Automatic SWP bus state management
- Automatic handling of Start of frame (SOF)
- Automatic handling of End of frame (EOF)
- Automatic handling of stuffing bits
- Automatic CRC-16 calculation and generation in transmission
- Automatic CRC-16 calculation and checking in reception
- 32-bit Transmit data register
- 32-bit Receive data register
- Multi software buffer mode for efficient DMA implementation and multi frame buffering
- Configurable bit-rate up to 2 Mbit/s
- Configurable interrupts
- CRC error, underrun, overrun flags
- Frame reception and transmission complete flags
- Slave resume detection flag
- Loopback mode for test purpose
- Embedded SWPMI_IO transceiver compliant with ETSI TS 102 613 technical specification
- Dedicated mode to output SWPMI_RX, SWPMI_TX and SWPMI_SUSPEND signals on GPIOs, in case of external transceiver connection

58.3 SWPMI functional description

58.3.1 SWPMI block diagram

Figure 716. SWPMI block diagram



Refer to the bit SWPSELSWPMISEL in *Section 8.7.19: RCC domain 2 kernel clock configuration register (RCC_D2CCIP1R)* to select the swpmi_ker_ck (SWPMI core clock source).

Note: In order to support the exit from Stop mode by a RESUME by slave, it is mandatory to select HSI for swpmi_ker_ck. If this feature is not required, swpmi_pclk can be selected, and SWPMI must be disabled before entering the Stop mode.

58.3.2 SWPMI pins and internal signals

Table 462 lists the SWPMI slave inputs and output signals connected to package pins or balls, while *Table 463* shows the internal SWPMI signals.

Table 462. SWPMI input/output signals connected to package pins or balls

Signal name	Signal type	Description
SWPMI_SUSPEND	Digital output	SWPMI suspend signal
SWPMI_TX	Digital output	SWPMI transmit signal

Table 462. SWPMI input/output signals connected to package pins or balls

Signal name	Signal type	Description
SWPMI_RX	Digital input	SWPMI receive signal
SWPMI_IO	Input and output	Internal SWPMI transceiver.

Table 463. SWPMI internal input/output signals

Signal name	Signal type	Description
swpmi_pclk	Digital input	APB clock
swpmi_ker_ck	Digital input	SWPMI kernel clock
swpmi_wkup	Digital output	SWPMI wakeup signal
swpmi_gbl_it	Digital output	SWPMI interrupt signal
swpmi_tx_dma	Digital output	SWPMI DMA transmit request
swpmi_rx_dma	Digital output	SWPMI DMA receive request

58.3.3 SWP initialization and activation

The initialization and activation will set the SWPMI_IO state from low to high.

When using the internal transceiver, the procedure is the following:

1. Configure the SWP_CLASS bit in SWPMI_OR register according to the VDD voltage (3 V or 1.8 V),
2. Set SWPTEN in SWPMI_CR register to enable the SWPMI_IO transceiver and set the SWPMI_IO to low level (SWP bus DEACTIVATED)
3. Wait for the RDYF flag in SWPMI_SR register to be set (polling the flag or enabling the interrupt with RDYIE bit in SWPMI_IER register),
4. Set SWPACT bit in SWPMI_CR register to ACTIVATE the SWP i.e. to move from DEACTIVATED to SUSPENDED.

58.3.4 SWP bus states

The SWP bus can have the following states: DEACTIVATED, SUSPENDED, ACTIVATED.

Several transitions are possible:

- ACTIVATE: transition from DEACTIVATED to SUSPENDED state,
- SUSPEND: transition from ACTIVATED to SUSPENDED state,
- RESUME by master: transition from SUSPENDED to ACTIVATED state initiated by the master,
- RESUME by slave: transition from SUSPENDED to ACTIVATED state initiated by the slave,
- DEACTIVATE: transition from SUSPENDED to DEACTIVATED state.

ACTIVATE

During and just after reset, the SWPMI_IO is configured in analog mode. Refer to *Section 58.3.3: SWP initialization and activation* to activate the SWP bus.

SUSPEND

The SWP bus stays in the ACTIVATED state as long as there is a communication with the slave, either in transmission or in reception. The SWP bus switches back to the SUSPENDED state as soon as there is no more transmission or reception activity, after 7 idle bits.

RESUME by master

Once the SWPMI is enabled, the user can request a SWPMI frame transmission. The SWPMI first sends a transition sequence and 8 idle bits (RESUME by master) before starting the frame transmission. The SWP moves from the SUSPENDED to ACTIVATED state after the RESUME by master (refer to *Figure 717: SWP bus states*).

RESUME by slave

Once the SWPMI is enabled, the SWP can also move from the SUSPENDED to ACTIVATED state if the SWPMI receives a RESUME from the slave. The RESUME by slave sets the SRF flag in the SWPMI_ISR register.

DEACTIVATE

Deactivate request

If no more communication is required, and if SWP is in the SUSPENDED mode, the user can request to switch the SWP to the DEACTIVATED mode by disabling the SWPMI peripheral. The software must set DEACT bit in the SWPMI_CR register in order to request the DEACTIVATED mode. If no RESUME by slave is detected by SWPMI, the DEACTF flag is set in the SWPMI_ISR register and the SWPACT bit is cleared in the SWPMI_ICR register. In case a RESUME by slave is detected by the SWPMI while the software is setting DEACT bit, the SRF flag is set in the SWPMI_ISR register, DEACTF is kept cleared, SWPACT is kept set and DEACT bit is cleared.

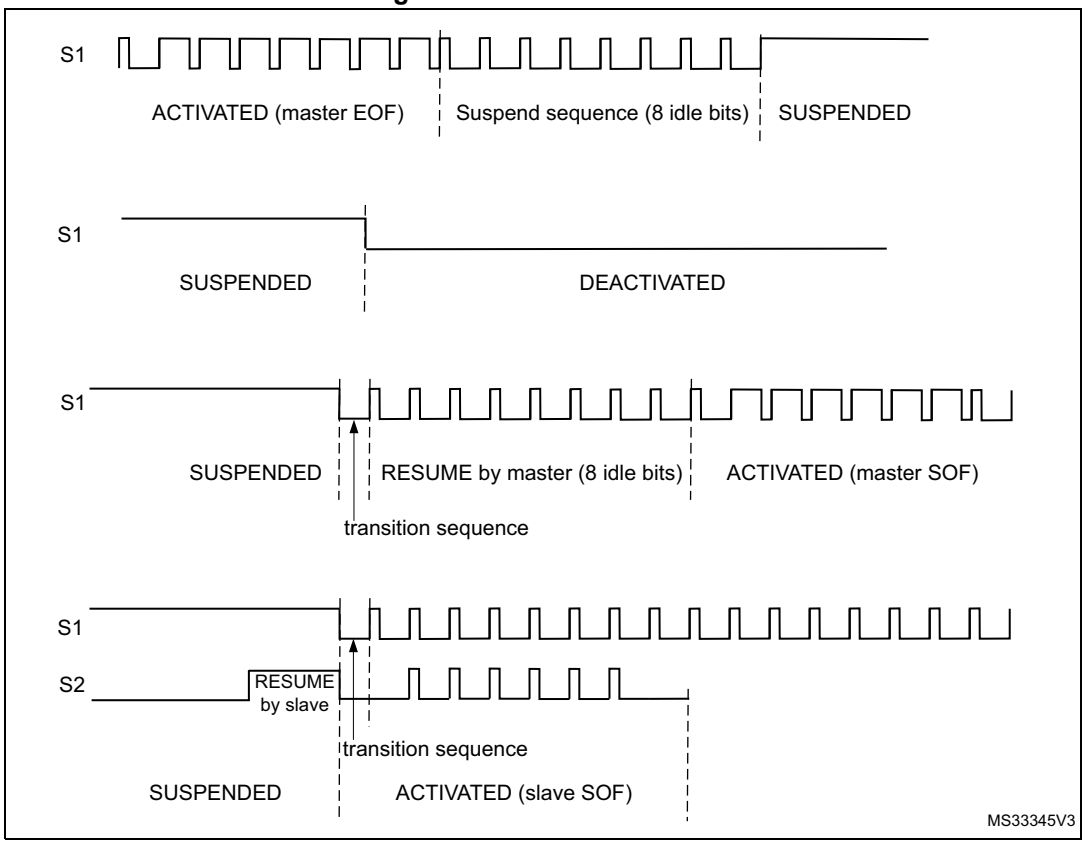
In order to activate SWP again, the software must clear DEACT bit in the SWPMI_CR register before setting SWPACT bit.

Deactivate mode

In order to switch the SWP to the DEACTIVATED mode immediately, ignoring any possible incoming RESUME by slave, the user must clear SWPACT bit in the SWPMI_CR register.

Note: In order to further reduce current consumption, configure the SWPMI_IO port as output push pull low in GPIO controller and then clear the SWPTEN bit in SWPMI_CR register (refer to Section 8: General-purpose I/Os (GPIO)).

Figure 717. SWP bus states



58.3.5 SWPMI_IO (internal transceiver) bypass

A SWPMI_IO (transceiver), compliant with ETSI TS 102 613 technical specification, is embedded in the microcontroller. Nevertheless, this is possible to bypass it by setting SWP_TBYP bit in SWPMI_OR register. In this case, the SWPMI_IO is disabled and the SWPMI_RX, SWPMI_TX and SWPMI_SUSPEND signals are available as alternate functions on three GPIOs (refer to “Pinouts and pin description” in product datasheet). This configuration is selected to connect an external transceiver.

Note: In SWPMI_IO bypass mode, SWPTEN bit in SWPMI_CR register must be kept cleared.

58.3.6 SWPMI bit rate

The bit rate must be set in the SWPMI_BRR register, according to the following formula:

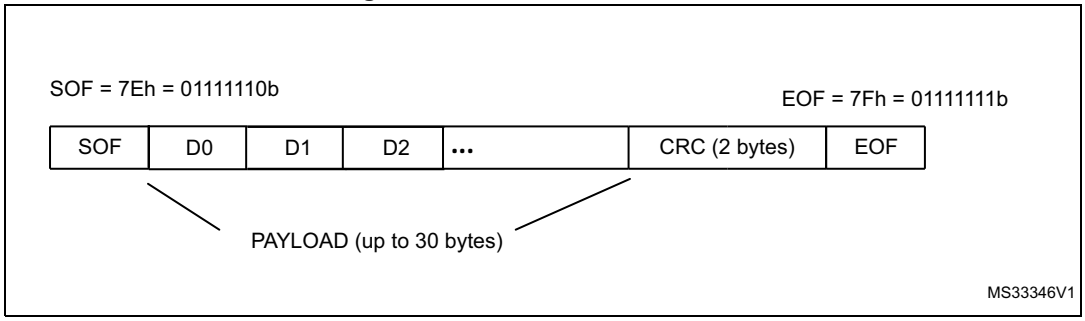
$F_{SWP} = F_{swpmi\_ker\_ck} / ((BR[7:0]+1)x4)$

Note: The maximum bitrate is 2 Mbit/s.

58.3.7 SWPMI frame handling

The SWP frame is composed of a Start of frame (SOF), a Payload from 1 to 30 bytes, a 16-bit CRC and an End of frame (EOF) (Refer to *Figure 718: SWP frame structure*).

Figure 718. SWP frame structure



The SWPMI embeds one 32-bit data register for transmission (SWPMI_TDR), and one 32-bit data register for reception (SWPMI_RDR).

In transmission, the SOF insertion, the CRC calculation and insertion, and the EOF insertion are managed automatically by the SWPMI. The user only has to provide the Payload content and size. A frame transmission starts as soon as data is written into the SWPMI_TDR register. Dedicated flags indicate an empty transmit data register and a complete frame transmission event.

In reception, the SOF deletion, the CRC calculation and checking, and the EOF deletion are managed automatically by the SWPMI. The user only has to read the Payload content and size. Dedicated flags indicate a full receive data register, a complete frame reception and possibly CRC error events.

The stuffing bits insertion (in transmission) and stuffing bits deletion (in reception) are managed automatically by the SWPMI core. These operations are transparent for the user.

58.3.8 Transmission procedure

Before starting any frame transmission, the user must activate the SWP. Refer to *Section 58.3.3: SWP initialization and activation*.

There are several possible software implementations for a frame transmission: No software buffer mode, Single software buffer mode, and Multi software buffer mode.

The software buffer usage requires the use of a DMA channel to transfer data from the software buffer in the RAM memory to the transmit data register in the SWPMI peripheral.

No software buffer mode

This mode does not require the use of DMA. The SWP frame transmission handling is done by polling status flags in the main loop or inside the SWPMI interrupt routine. There is a 32-bit transmit data register (SWPMI_TDR) in the SWPMI, thus writing to this register will trigger the transmission of up to 4 bytes.

The No software buffer mode is selected by clearing TXDMA bit in the SWPMI_CR register.

The frame transmission is started by the first write to the SWPMI_TDR register. The low significant byte of the first 32-bit word (bits [7:0]) written into the SWPMI_TDR register) indicates the number of data bytes in the payload, and the 3 other bytes of this word must

contain the first 3 bytes of the payload (bits [15:8] contain the first byte of the payload, bits [23:16] the second byte and bits [31:24] the third byte). Then, the following writes to the SWPMI_TDR register will only contain the following payload data bytes, up to 4 for each write.

Note: The low significant byte of the first 32-bit word written into the SWPMI_TDR register is coding the number of data bytes in the payload. This number could be from 1 to 30. Any other value in the low significant byte will be ignored and the transmission will not start.

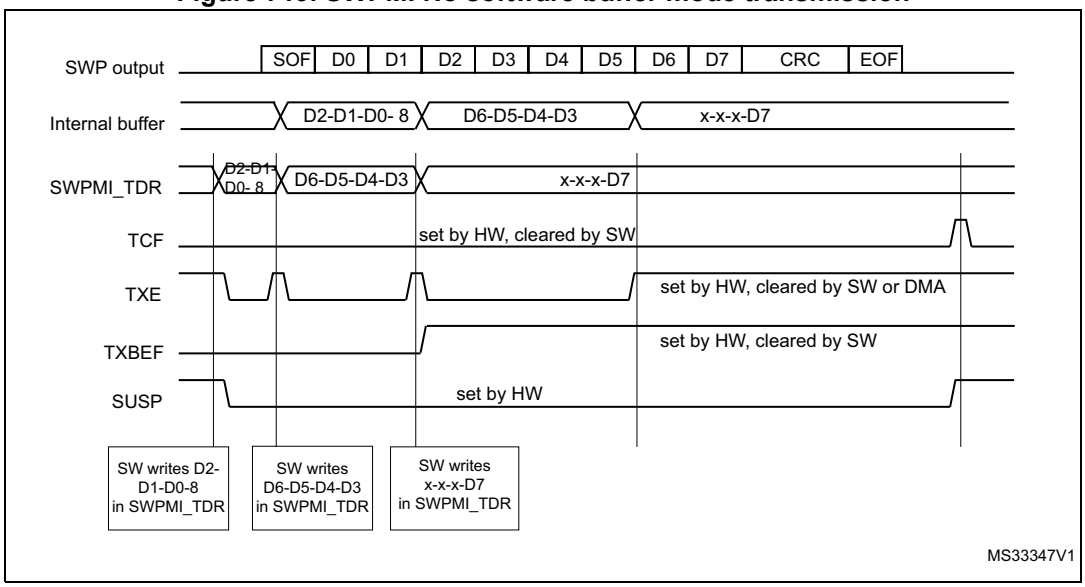
Writing to the SWPMI_TDR register will induce the following actions:

- Send the transition sequence and 8 idle bits (RESUME by master) if the SWP bus state is SUPENDED (this will not happen if the SWP bus state is already ACTIVATED),
- Send a Start of frame (SOF),
- Send the payload according to the SWPMI_TRD register content. If the number of bytes in the payload is greater than 3, the SWPMI_TDR needs to be refilled by software, each time the TXE flag in the SWPMI_ISR register is set, and as long as the TXBEF flag is not set in the SWPMI_ISR register,
- Send the 16-bit CRC, automatically calculated by the SWPMI core,
- Send an End of frame (EOF).

The TXE flag is cleared automatically when the software is writing to the SWPMI_TDR register.

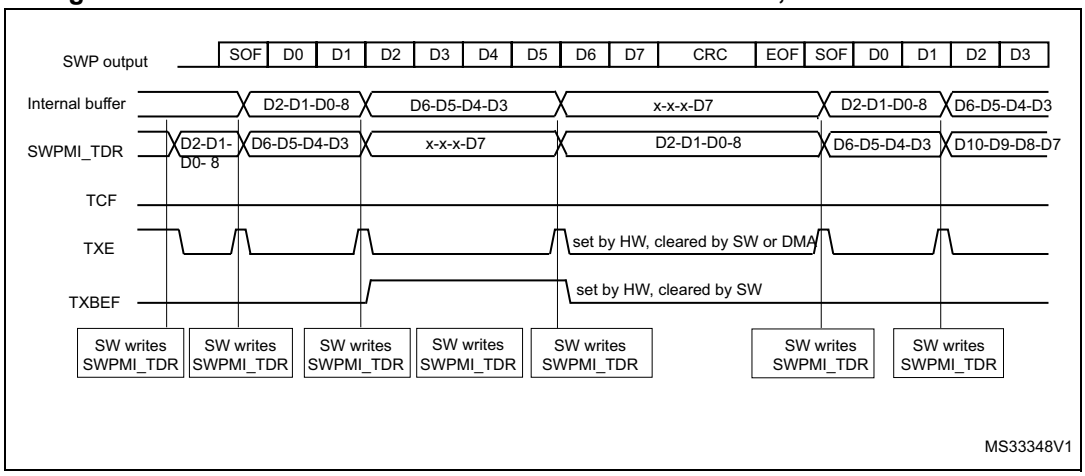
Once the complete frame is sent, provided that no other frame transmission has been requested (i.e. SWPMI_TDR has not been written again after the TXBEF flag setting), TCF and SUSP flags are set in the SWPMI_ISR register 7 idle bits after the EOF transmission, and an interrupt is generated if TCIE bit is set in the SWPMI_IER register (refer to *Figure 719: SWPMI No software buffer mode transmission*).

Figure 719. SWPMI No software buffer mode transmission



If another frame transmission is requested before the end of the EOF transmission, the TCF flag is not set and the frame will be consecutive to the previous one, with only one idle bit in between (refer to *Figure 720: SWPMI No software buffer mode transmission, consecutive frames*).

Figure 720. SWPMI No software buffer mode transmission, consecutive frames



Single software buffer mode

This mode allows to transmit a complete SWP frame without a CPU intervention, using the DMA. The DMA will refill the 32-bit SWPMI_TDR register, and the software can poll the end of the frame transmission using the SWPMI_TXBEF flag.

The Single software buffer mode is selected by setting TXDMA bit and clearing TXMODE bit in the SWPMI_CR register.

The DMA channel or stream must be configured in following mode (refer to DMA section):

- memory to memory mode disabled,
- memory increment mode enabled,
- memory size set to 32-bit,
- peripheral size set to 32-bit,
- peripheral increment mode disabled,
- circular mode disabled,
- data transfer direction set to read from memory.
- the number of words to be transfered must be set according to the SWP frame length,
- the source address is the SWP frame buffer in RAM,
- the destination address is the SWPMI_TDR register.

Then the user must:

1. Set TXDMA bit in the SWPMI_CR register,
2. Set TXBEIE bit in the SWPMI_IER register,
3. Fill the buffer in the RAM memory (with the number of data bytes in the payload on the least significant byte of the first word),
4. Enable stream or channel in DMA module to start DMA transfer and frame transmission.

A DMA request is issued by SWPMI when TXE flag in SWPMI_ISR is set. The TXE flag is cleared automatically when the DMA is writing to the SWPMI_TDR register.

In the SWPMI interrupt routine, the user must check TXBEF bit in the SWPMI_ISR register. If it is set, and if another frame needs to be transmitted, the user must:

1. Disable stream or channel in DMA module
2. Update the buffer in the RAM memory with the content of the next frame to be sent
3. Configure the total number of words to be transferred in DMA module
4. Enable stream or channel in DMA module to start next frame transmission
5. Set CTXBEF bit in the SWPMI_ICR register to clear the TXBEF flag

Multi software buffer mode

This mode allows to work with several frame buffers in the RAM memory, in order to ensure a continuous transmission, keeping a very low CPU load, and allowing more latency for buffer update by software thanks to the DMA. The software can check the DMA counters at any time and update SWP frames accordingly in the RAM memory.

The Multi software buffer mode must be used in combination with DMA in circular mode.

Each transmission buffer in the RAM memory must have a fixed length of eight 32-bit words, whatever the number of bytes in the SWP frame payload. The transmission buffers in the RAM memory must be filled by the software, keeping an offset of 8 between two consecutive ones. The first data byte of the buffer is the number of bytes of the frame payload. See the buffer example in *Figure 721: SWPMI Multi software buffer mode transmission*

The Multi software buffer mode is selected by setting both TXDMA and TXMODE bits in SWPMI_CR register.

For example, in order to work with 4 transmission buffers, the user must configure the DMA as follows:

The DMA channel or stream must be configured in following mode (refer to DMA section):

- memory to memory mode disabled,
- memory increment mode enabled,
- memory size set to 32-bit,
- peripheral size set to 32-bit,
- peripheral increment mode disabled,
- circular mode enabled,
- data transfer direction set to read from memory,
- the number of words to be transfered must be set to 32 (8 words per buffer),
- the source address is the buffer1 in RAM,
- the destination address is the SWPMI_TDR register.

Then, the user must:

1. Set TXDMA in the SWPMI_CR register
2. Set TXBEIE in the SWPMI_IER register
3. Fill buffer1, buffer2, buffer3 and buffer4 in the RAM memory (with the number of data bytes in the payload on the least significant byte of the first word)
4. Enable stream or channel in DMA module to start DMA.

In the SWPMI interrupt routine, the user must check TXBEF bit in the SWPMI_ISR register. If it is set, the user must set CTXBEF bit in SWPMI_ICR register to clear TXBEF flag and the user can update buffer1 in the RAM memory.

In the next SWPMI interrupt routine occurrence, the user will update buffer2, and so on.

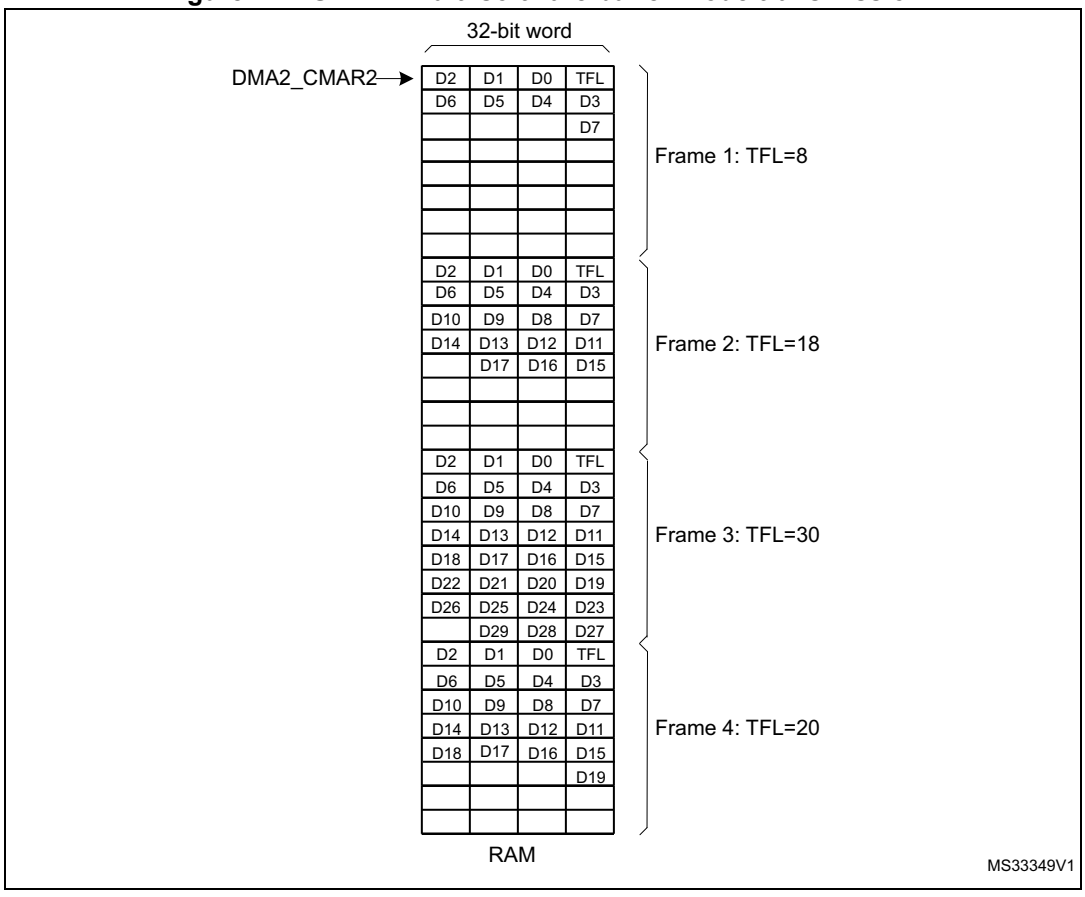
The Software can also read the DMA counter (number of data to transfer) in the DMA registers in order to retrieve the frame which has already been transferred from the RAM memory and transmitted. For example, if the software works with 4 transmission buffers, and if the DMA counter equals 17, it means that two buffers are ready for updating in the RAM area. This is useful in case several frames are sent before the software can handle the SWPMI interrupt. If this happens, the software will have to update several buffers.

When there are no more frames to transmit, the user must disable the circular mode in the DMA module. The transmission will stop at the end of the buffer4 transmission.

If the transmission needs to stop before (for example at the end of buffer2), the user must set the low significant byte of the first word to 0 in buffer3 and buffer4.

TXDMA bit in the SWPMI_CR register will be cleared by hardware as soon as the number of data bytes in the payload is read as 0 in the least significant byte of the first word.

Figure 721. SWPMI Multi software buffer mode transmission



58.3.9 Reception procedure

Before starting any frame reception, the user must activate the SWP (refer to *Section 58.3.3: SWP initialization and activation*.

Once SWPACT bit is set in the SWPMI_CR register, a RESUME from slave state sets the SRF flag in the SWPMI_ISR register and automatically enables the SWPMI for the frame reception.

If the SWP bus is already in the ACTIVATED state (for example because a frame transmission is ongoing), the SWPMI core does not need any RESUME by slave state, and the reception can take place immediately.

There are several possible software implementations for a frame reception:

- No software buffer mode,
- Single software buffer mode,
- Multi software buffer mode.

The software buffer usage requires the use of a DMA channel to transfer data from the receive data register in the SWPMI peripheral to the software buffer in the RAM memory.

No software buffer mode

This mode does not require the use of DMA. The SWP frame reception handling is done by polling status flags in the main loop or inside the SWPMI interrupt routine. There is a 32-bit receive data register (SWPMI_RDR) in the SWPMI, allowing to receive up to 4 bytes before reading this register.

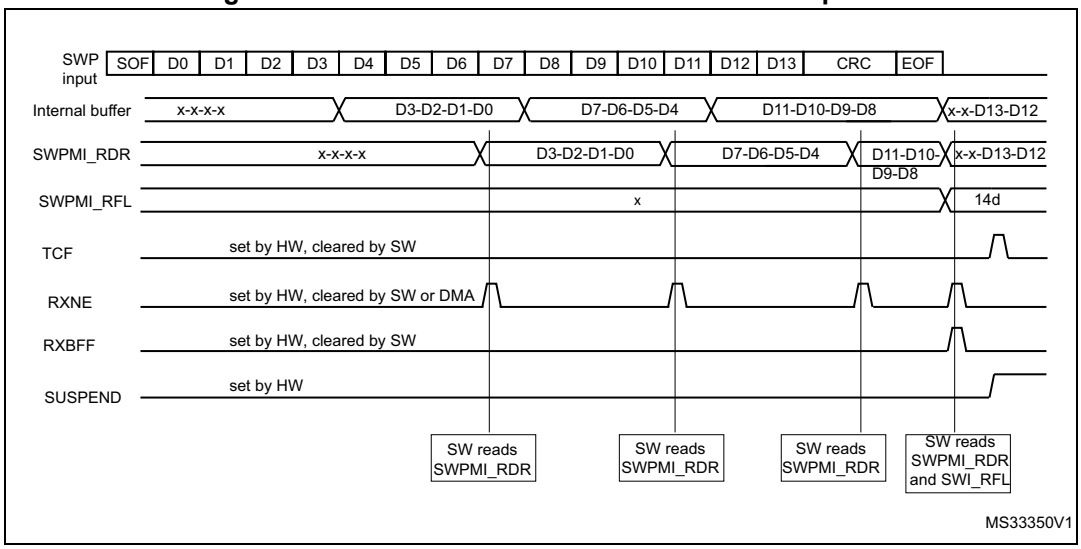
The No software buffer mode is selected by resetting RXDMA bit in the SWPMI_CR register.

Once a Start of frame (SOF) is received, the following bytes (payload) are stored in the SWPMI_RDR register. Once the SWPMI_RDR is full, the RXNE flag is set in SWPMI_ISR and an interrupt is generated if RIE bit is set in SWPMI_IER register. The user can read the SWPMI_RDR register and the RXNE flag is cleared automatically when the software is reading the SWPMI_RDR register.

Once the complete frame has been received, including the CRC and the End of frame (EOF), both RXNE and RXBFF flags are set in the SWPMI_ISR register. The user must read the last byte(s) of the payload in the SWPMI_RDR register and set CRXBFF flag in SWPMI_ICR in order to clear the RXBFF flag. The number of data bytes in the payload is available in the SWPMI_RFL register. Again, the RXNE flag is reset automatically when the software is reading the SWPMI_RDR register (refer to *Figure 722: SWPMI No software buffer mode reception*).

Reading the SWPMI_RDR register while RXNE is cleared will return 0.

Figure 722. SWPMI No software buffer mode reception



Single software buffer mode

This mode allows to receive a complete SWP frame without any CPU intervention using the DMA. The DMA transfers received data from the 32-bit SWPMI_RDR register to the RAM memory, and the software can poll the end of the frame reception using the SWPMI_RBFF flag.

The Single software buffer mode is selected by setting RXDMA bit and clearing RXMODE bit in the SWPMI_CR register.

The DMA must be configured as follows:

The DMA channel or stream must be configured in following mode (refer to DMA section):

- memory to memory mode disabled,
- memory increment mode enabled,
- memory size set to 32-bit,
- peripheral size set to 32-bit,
- peripheral increment mode disabled,
- circular mode disabled,
- data transfer direction set to read from peripheral,
- the number of words to be transfered must be set to 8,
- the source address is the SWPMI_RDR register,
- the destination address is the SWP frame buffer in RAM.

Then the user must:

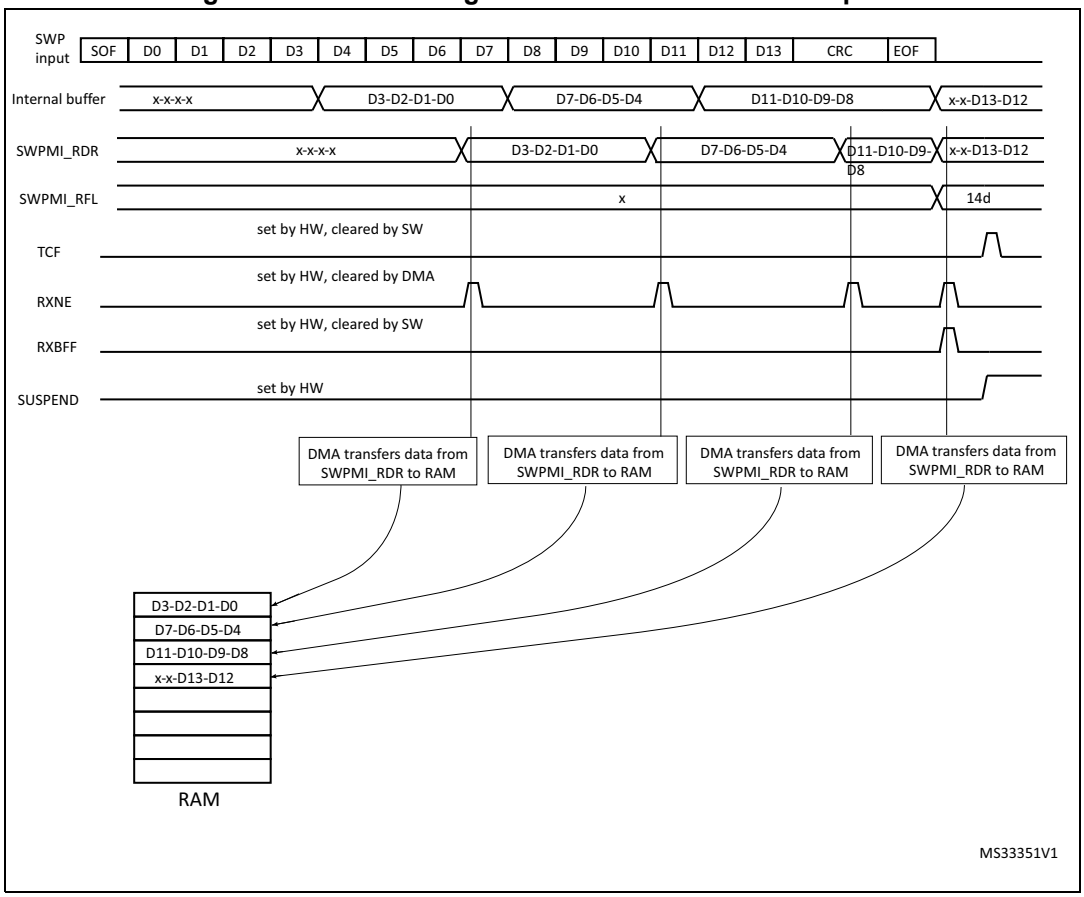
1. Set RXDMA bit in the SWPMI_CR register
2. Set RXBFIE bit in the SWPMI_IER register
3. Enable stream or channel in DMA module.

A DMA request is issued by SWPMI when RXNE flag is set in SWPMI_ISR. The RXNE flag is cleared automatically when the DMA is reading the SWPMI_RDR register.

In the SWPMI interrupt routine, the user must check RXBFF bit in the SWPMI_ISR register. If it is set, the user must:

1. Disable stream or channel in DMA module
2. Read the number of bytes in the received frame payload in the SWPMI_RFL register
3. Read the frame payload in the RAM buffer
4. Enable stream or channel in DMA module
5. Set CRXBFF bit in the SWPMI_ICR register to clear RXBFF flag (refer to *Figure 723: SWPMI single software buffer mode reception*).

Figure 723. SWPMI single software buffer mode reception



Multi software buffer mode

This mode allows to work with several frame buffers in the RAM memory, in order to ensure a continuous reception, keeping a very low CPU load, using the DMA. The frame payloads are stored in the RAM memory, together with the frame status flags. The software can check the DMA counters and status flags at any time to handle the received SWP frames in the RAM memory.

The Multi software buffer mode must be used in combination with the DMA in circular mode.

The Multi software buffer mode is selected by setting both RXDMA and RXMODE bits in SWPMI_CR register.

In order to work with n reception buffers in RAM, the DMA channel or stream must be configured in following mode (refer to DMA section):

- memory to memory mode disabled,
- memory increment mode enabled,
- memory size set to 32-bit,
- peripheral size set to 32-bit,
- peripheral increment mode disabled,
- circular mode enabled,
- data transfer direction set to read from peripheral,
- the number of words to be transfered must be set to 8 x n (8 words per buffer),
- the source address is the SWPMI_TDR register,
- the destination address is the buffer1 address in RAM

Then the user must:

1. Set RXDMA in the SWPMI_CR register
2. Set RXBFIE in the SWPMI_IER register
3. Enable stream or channel in the DMA module.

In the SWPMI interrupt routine, the user must check RXBFF in the SWPMI_ISR register. If it is set, the user must set CRXBFF bit in the SWPMI_ICR register to clear RXBFF flag and the user can read the first frame payload received in the first buffer (at the RAM address set in DMA2_CMAR1).

The number of data bytes in the payload is available in bits [23:16] of the last 8th word.

In the next SWPMI interrupt routine occurrence, the user will read the second frame received in the second buffer (address set in DMA2_CMAR1 + 8), and so on (refer to *Figure 724: SWPMI Multi software buffer mode reception*).

In case the application software cannot ensure to handle the SMPMI interrupt before the next frame reception, each buffer status is available in the most significant byte of the 8th buffer word:

- The CRC error flag (equivalent to RXBERF flag in the SWPMI_ISR register) is available in bit 24 of the 8th word. Refer to *Section 58.3.10: Error management* for an CRC error description.
- The receive overrun flag (equivalent to RXOVRF flag in the SWPMI_ISR register) is available in bit 25 of the 8th word. Refer to *Section 58.3.10: Error management* for an overrun error description.
- The receive buffer full flag (equivalent to RXBFF flag in the SWPMI_ISR register) is available in bit 26 of the 8th word.

In case of a CRC error, both RXBFF and RXBERF flags are set, thus bit 24 and bit 26 are set.

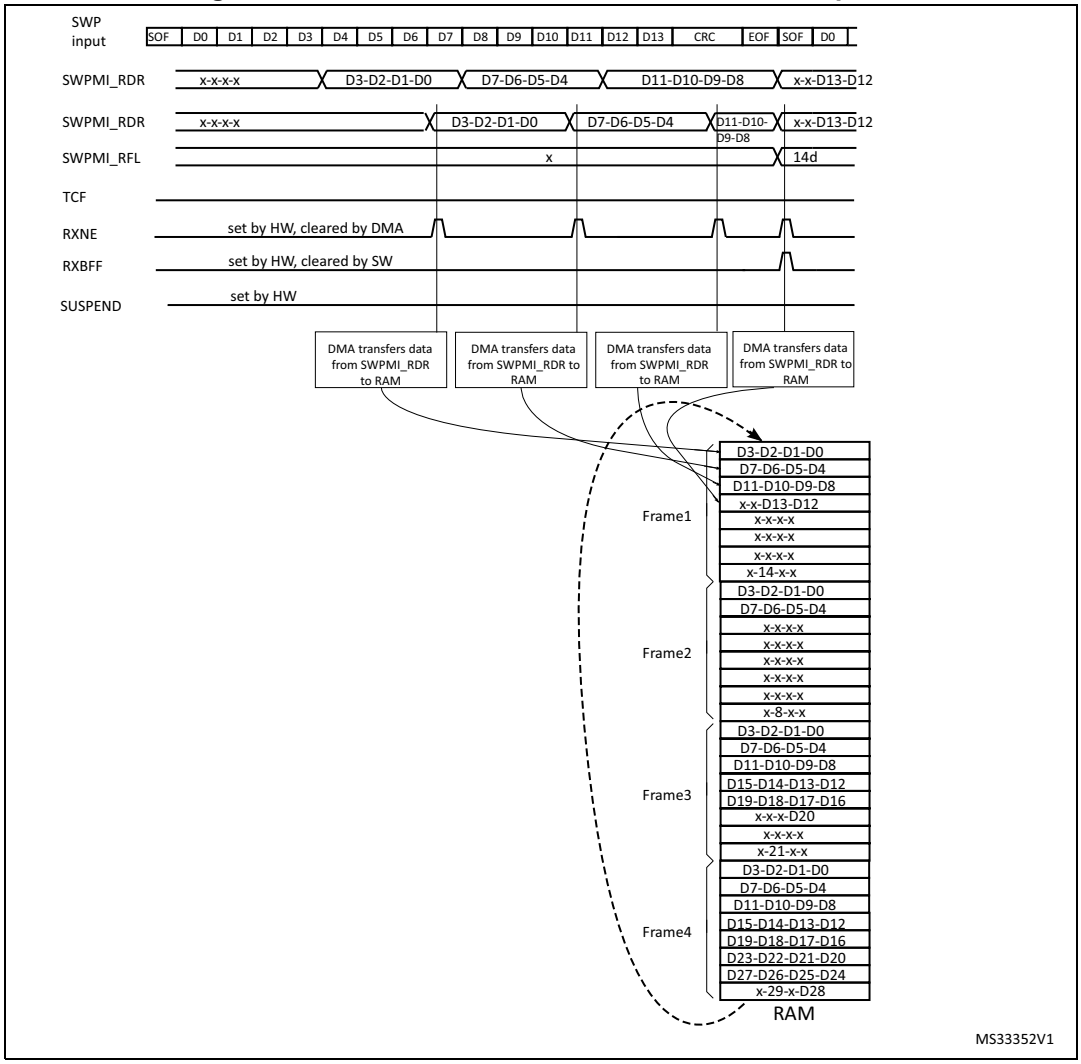
In case of an overrun, an overrun flag is set, thus bit 25 is set. The receive buffer full flag is set only in case of an overrun during the last word reception; then, both bit 25 and bit 26 are set for the current and the next frame reception.

The software can also read the DMA counter (number of data to transfer) in the DMA registers in order to retrieve the frame which has already been received and transferred into the RAM memory through DMA. For example, if the software works with 4 reception buffers,

and if the DMA counter equals 17, it means that two buffers are ready for reading in the RAM area.

In Multi software buffer reception mode, if the software is reading bits 24, 25 and 26 of the 8th word, it does not need to clear RXBERF, RXOVRF and RXBFF flags after each frame reception.

Figure 724. SWPMI Multi software buffer mode reception



58.3.10 Error management

Underrun during payload transmission

During the transmission of the frame payload, a transmit underrun is indicated by the TXUNRF flag in the SWPMI_ISR register. An interrupt is generated if TXBUNREIE bit is set in the SWPMI_IER register.

If a transmit underrun occurs, the SWPMI stops the payload transmission and sends a corrupted CRC (the first bit of the first CRC byte sent is inverted), followed by an EOF. If DMA is used, TXDMA bit in the SWPMI_CR register is automatically cleared.

Any further write to the SWPMI_TDR register while TXUNRF is set will be ignored. The user must set CTXUNRF bit in the SWPMI_ICR register to clear TXUNRF flag.

Overrun during payload reception

During the reception of the frame payload, a receive overrun is indicated by RXOVRF flag in the SWPMI_ISR register. If a receive overrun occurs, the SWPMI does not update SWPMI_RDR with the incoming data. The incoming data will be lost.

The reception carries on up to the EOF and, if the overrun condition disappears, the RXBFF flag is set. When RXBFF flag is set, the user can check the RXOVRF flag. The user must set CRXOVRF bit in the SWPMI_ICR register to clear RXBOVRF flag.

If the user wants to detect the overrun immediately, RXBOVREIE bit in the SWPMI_IER register can be set in order to generate an interrupt as soon as the overrun occurs.

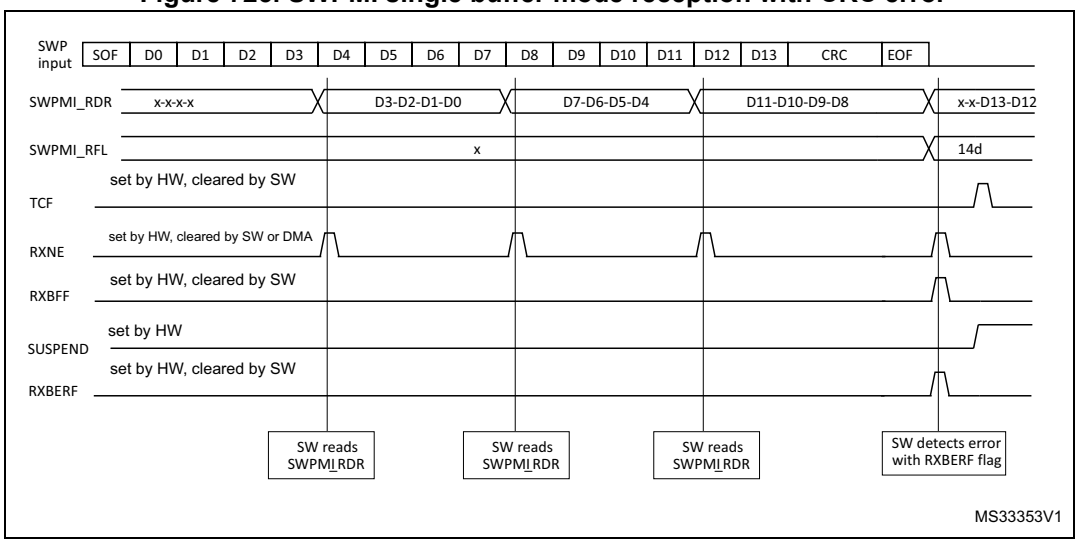
The RXOVRF flag is set at the same time as the RXNE flag, two SWPMI_RDR reads after the overrun event occurred. It indicates that at least one received byte was lost, and the loaded word in SWPMI_RDR contains the bytes received just before the overrun.

In Multi software buffer mode, if RXOVRF flag is set for the last word of the received frame, then the overrun bit (bit 25 of the 8th word) is set for both the current and the next frame.

CRC error during payload reception

Once the two CRC bytes have been received, if the CRC is wrong, the RXBERF flag in the SWPMI_ISR register is set after the EOF reception. An interrupt is generated if RXBEIE bit in the SWPMI_IER register is set (refer to*Figure 725: SWPMI single buffer mode reception with CRC error*).The user must set CRXBERF bit in SWPMI_ICR to clear RXBERF flag.

Figure 725. SWPMI single buffer mode reception with CRC error



Missing or corrupted stuffing bit during payload reception

When a stuffing bit is missing or is corrupted in the payload, RXBERF and RXBFF flags are set in SWPMI_ISR after the EOF reception.

Corrupted EOF reception

Once an SOF has been received, the SWPMI accumulates the received bytes until the reception of an EOF (ignoring any possible SOF). Once an EOF has been received, the SWPMI is ready to start a new frame reception and waits for an SOF.

In case of a corrupted EOF, RXBERF and RXBFF flags will bet set in the SWPMI_ISR register after the next EOF reception.

Note: In case of a corrupted EOF reception, the payload reception carries on, thus the number of bytes in the payload might get the value 31 if the number of received bytes is greater than 30. The number of bytes in the payload is read in the SWPMI_RFL register or in bits [23:16] of the 8th word of the buffer in the RAM memory, depending on the operating mode.

58.3.11 Loopback mode

The loopback mode can be used for test purposes. The user must set LPBK bit in the SWPMI_CR register in order to enable the loopback mode.

When the loopback mode is enabled, SWPMI_TX and SWPMI_RX signals are connected together. As a consequence, all frames sent by the SWPMI will be received back.

58.4 SWPMI low-power modes

Table 464. Effect of low-power modes on SWPMI

Mode	Description
Sleep	No effect. SWPMI interrupts cause the device to exit the Sleep mode.
Stop	A RESUME from SUSPENDED mode issued by the slave can wake up the device from Stop mode if the swpmi_ker_ck is HSI (refer to *Section 58.3.1: SWPMI block diagram*).
Standby	The SWPMI is stopped.

58.5 SWPMI interrupts

All SWPMI interrupts are connected to the NVIC.

To enable the SWPMI interrupt, the following sequence is required:

1. Configure and enable the SWPMI interrupt channel in the NVIC
2. Configure the SWPMI to generate SWPMI interrupts (refer to the SWPMI_IER register).

Table 465. Interrupt control bits

Interrupt event	Event flag	Enable control bit	Exit the Sleep mode	Exit the Stop mode	Exit the Standby mode
Receive buffer full	RXBFF	RXBFIE	yes	no	no
Transmit buffer empty	TXBEF	TXBEIE	yes	no	no
Receive buffer error (CRC error)	RXBERF	RXBEIE	yes	no	no
Receive buffer overrun	RXOVRF	RXBOVEREIE	yes	no	no
Transmit buffer underrun	TXUNRF	TXBUNREIE	yes	no	no
Receive data register not empty	RXNE	RIE	yes	no	no
Transmit data register full	TXE	TIE	yes	no	no
Transfer complete flag	TCF	TCIE	yes	no	no
Slave resume flag	SRF	SRIE	yes	yes (1)	no
Transceiver ready flag	RDYF	RDYIE	yes	no	no

1. If HSI is selected for swpmi_ker_ck.

58.6 SWPMI registers

Refer to *Section 1.2* of the reference manual for a list of abbreviations used in register descriptions.

The peripheral registers can only be accessed by words (32-bit).

58.6.1 SWPMI configuration/control register (SWPMI_CR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	SWP EN	DEACT	Res.	Res.	Res.	Res.	SWP ACT	LPBK	TXMOD E	RXMO DE	TXDMA	RXDMA
				rw	rw					rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **SWPTEN**: Single wire protocol master transceiver enable

This bit is used to enable the transceiver and control the SWPMI_IO with SWPMI (refer to *Section 58.3.3: SWP initialization and activation*).

0: SPWMI_IO pin is controlled by GPIO controller

1: SWPMI_IO transceiver is controlled by SWPMI

Bit 10 **DEACT**: Single wire protocol master interface deactivate

This bit is used to request the SWP DEACTIVATED state. Setting this bit has the same effect as clearing the SWPACT, except that a possible incoming RESUME by slave will keep the SWP in the ACTIVATED state.

Bits 9:6 Reserved, must be kept at reset value.

Bit 5 **SWPACT**: Single wire protocol master interface activate

This bit is used to activate the SWP bus (refer to *Section 58.3.3: SWP initialization and activation*).

0: SWPMI_IO is pulled down to ground, SWP bus is switched to DEACTIVATED state

1: SWPMI_IO is released, SWP bus is switched to SUSPENDED state

To be able to set SWPACT bit, DEACT bit must be have been cleared previously.

Bit 4 **LPBK**: Loopback mode enable

This bit is used to enable the loopback mode

0: Loopback mode is disabled

1: Loopback mode is enabled

Note: This bit cannot be written while SWPACT bit is set.

Bit 3 **TXMODE**: Transmission buffering mode

This bit is used to choose the transmission buffering mode. This bit is relevant only when TXDMA bit is set (refer to *Table 466: Buffer modes selection for transmission/reception*).

0: SWPMI is configured in Single software buffer mode for transmission

1: SWPMI is configured in Multi software buffer mode for transmission.

Note: This bit cannot be written while SWPACT bit is set.

Bit 2 **RXMODE**: Reception buffering mode

This bit is used to choose the reception buffering mode. This bit is relevant only when TXDMA bit is set (refer to *Table 466: Buffer modes selection for transmission/reception*).

0: SWPMI is configured in Single software buffer mode for reception

1: SWPMI is configured in Multi software buffer mode for reception.

Note: This bit cannot be written while SWPACT bit is set.

Bit 1 **TXDMA**: Transmission DMA enable

This bit is used to enable the DMA mode in transmission

0: DMA is disabled for transmission

1: DMA is enabled for transmission

Note: TXDMA is automatically cleared if the payload size of the transmitted frame is given as 0x00 (in the least significant byte of TDR for the first word of a frame). TXDMA is also automatically cleared on underrun events (when TXUNRF flag is set in the SWP_ISR register)

Bit 0 **RXDMA**: Reception DMA enable

This bit is used to enable the DMA mode in reception

0: DMA is disabled for reception

1: DMA is enabled for reception

Table 466. Buffer modes selection for transmission/reception

Buffer mode	No software buffer	Single software buffer	Multi software buffer
RXMODE/TXMODE	x	0	1
RXDMA/TXDMA	0	1	1

58.6.2 SWPMI Bitrate register (SWPMI_BRR)

Address offset: 0x04

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BR[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **BR[7:0]**: Bitrate prescaler

This field must be programmed to set SWP bus bitrate, taking into account the $F_{swpmi\_ker\_ck}$ programmed in the RCC (Reset and Clock Control), according to the following formula:

$F_{SWP} = F_{swpmi\_ker\_ck} / ((BR[7:0]+1)x4)$

Note: The programmed bitrate must stay within the following range: from 100 kbit/s up to 2 Mbit/s.

BR[7:0] cannot be written while SWPACT bit is set in the SWPMI_CR register.

58.6.3 SWPMI Interrupt and Status register (SWPMI_ISR)

Address offset: 0x0C

Reset value: 0x0000 02C2

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	RDYF	DEACTF	SUSP	SRF	TCF	TXE	RXNE	TXUNRF	RXOVRF	RXBERF	TXBEF	RXBFF
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **RDYF**: transceiver ready flag

This bit is set by hardware as soon as transceiver is ready. After setting the SWPTEN bit in SWPMI_CR register to enable the SWPMI_IO transceiver, software must wait for this flag to be set before setting the SWPACT bit to activate the SWP bus.

0: transceiver not ready

1: transceiver ready

Bit 10 **DEACTF**: DEACTIVATED flag

This bit is a status flag, acknowledging the request to enter the DEACTIVATED mode.

0: SWP bus is in ACTIVATED or SUSPENDED state

1: SWP bus is in DEACTIVATED state

If a RESUME by slave state is detected by the SWPMI while DEACT bit is set by software, the SRF flag will be set, DEACTF will not be set and SWP will move in ACTIVATED state.

Bit 9 **SUSP**: SUSPEND flag

This bit is a status flag, reporting the SWP bus state

0: SWP bus is in ACTIVATED state

1: SWP bus is in SUSPENDED or DEACTIVATED state

Bit 8 **SRF**: Slave resume flag

This bit is set by hardware to indicate a RESUME by slave detection. It is cleared by software, writing 1 to CSRF bit in the SWPMI_ICR register.

0: No Resume by slave state detected

1: A Resume by slave state has been detected during the SWP bus SUSPENDED state

Bit 7 **TCF**: Transfer complete flag

This flag is set by hardware as soon as both transmission and reception are completed and SWP is switched to the SUSPENDED state. It is cleared by software, writing 1 to CTCF bit in the SWPMI_ICR register.

0: Transmission or reception is not completed

1: Both transmission and reception are completed and SWP is switched to the SUSPENDED state

Bit 6 **TXE**: Transmit data register empty

This flag indicates the transmit data register status

0: Data written in transmit data register SWPMI_TDR is not transmitted yet

1: Data written in transmit data register SWPMI_TDR has been transmitted and SWPMI_TDR can be written to again

Bit 5 **RXNE**: Receive data register not empty

This flag indicates the receive data register status

0: Data is not received in the SWPMI_RDR register

1: Received data is ready to be read in the SWPMI_RDR register

Bit 4 **TXUNRF**: Transmit underrun error flag

This flag is set by hardware to indicate an underrun during the payload transmission i.e. SWPMI_TDR has not been written in time by the software or the DMA. It is cleared by software, writing 1 to the CTXUNRF bit in the SWPMI_ICR register.

0: No underrun error in transmission

1: Underrun error in transmission detected

Bit 3 **RXOVRF**: Receive overrun error flag

This flag is set by hardware to indicate an overrun during the payload reception, i.e. SWPMI_RDR has not be read in time by the software or the DMA. It is cleared by software, writing 1 to CRXOVRF bit in the SWPMI_ICR register.

0: No overrun in reception

1: Overrun in reception detected

Bit 2 **RXBERF**: Receive CRC error flag

This flag is set by hardware to indicate a CRC error in the received frame. It is set synchronously with RXBFF flag. It is cleared by software, writing 1 to CRXBERF bit in the SWPMI_ICR register.

0: No CRC error in reception

1: CRC error in reception detected

Bit 1 **TXBEF**: Transmit buffer empty flag

This flag is set by hardware to indicate that no more SWPMI_TDR update is required to complete the current frame transmission. It is cleared by software, writing 1 to CTXBEF bit in the SWPMI_ICR register.

0: Frame transmission buffer no yet emptied

1: Frame transmission buffer has been emptied

Bit 0 **RXBFF**: Receive buffer full flag

This flag is set by hardware when the final word for the frame under reception is available in SWPMI_RDR. It is cleared by software, writing 1 to CRXBFF bit in the SWPMI_ICR register.

0: The last word of the frame under reception has not yet arrived in SWPMI_RDR

1: The last word of the frame under reception has arrived in SWPMI_RDR

58.6.4 SWPMI Interrupt Flag Clear register (SWPMI_ICR)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	CRDYF	Res.	Res.	CSRF	CTCF	Res.	Res.	CTXUNRF	CRXOVRF	CRXBERF	CTXBEF	CRXBFF
				rc_w1			rc_w1	rc_w1			rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **CRDYF** Clear transceiver ready flag
Writing 1 to this bit clears the RDYF flag in the SWPMI_ISR register
Writing 0 to this bit does not have any effect

Bits 10:9 Reserved, must be kept at reset value.

Bit 8 **CSRF**: Clear slave resume flag
Writing 1 to this bit clears the SRF flag in the SWPMI_ISR register
Writing 0 to this bit does not have any effect

Bit 7 **CTCF**: Clear transfer complete flag
Writing 1 to this bit clears the TCF flag in the SWPMI_ISR register
Writing 0 to this bit does not have any effect

Bits 6:5 Reserved, must be kept at reset value.

Bit 4 **CTXUNRF**: Clear transmit underrun error flag
Writing 1 to this bit clears the TXUNRF flag in the SWPMI_ISR register
Writing 0 to this bit does not have any effect

Bit 3 **CRXOVRF**: Clear receive overrun error flag
Writing 1 to this bit clears the RXBOCREF flag in the SWPMI_ISR register
Writing 0 to this bit does not have any effect

Bit 2 **CRXBERF**: Clear receive CRC error flag
Writing 1 to this bit clears the RXBERF flag in the SWPMI_ISR register
Writing 0 to this bit does not have any effect

Bit 1 **CTXBEF**: Clear transmit buffer empty flag
Writing 1 to this bit clears the TXBEF flag in the SWPMI_ISR register
Writing 0 to this bit does not have any effect

Bit 0 **CRXBFF**: Clear receive buffer full flag
Writing 1 to this bit clears the RXBFF flag in the SWPMI_ISR register
Writing 0 to this bit does not have any effect

58.6.5 SWPMI Interrupt Enable register (SMPMI_IER)

Address offset: 0x14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	RDYIE	Res.	Res.	SRIE	TCIE	TIE	RIE	TXUNREIE	RXOVREIE	RXBEIE	TXBERIE	RXBFIE
				rw			rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **RDYIE**: Transceiver ready interrupt enable
0: Interrupt is inhibited
1: A SWPMI interrupt is generated whenever RDYF flag is set in the SWPMI_ISR register

Bits 10:9 Reserved, must be kept at reset value.

Bit 8 **SRIE**: Slave resume interrupt enable
0: Interrupt is inhibited
1: An SWPMI interrupt is generated whenever SRF flag is set in the SWPMI_ISR register

Bit 7 **TCIE**: Transmit complete interrupt enable
0: Interrupt is inhibited
1: An SWPMI interrupt is generated whenever TCF flag is set in the SWPMI_ISR register

Bit 6 **TIE**: Transmit interrupt enable
0: Interrupt is inhibited
1: An SWPMI interrupt is generated whenever TXE flag is set in the SWPMI_ISR register

Bit 5 **RIE**: Receive interrupt enable
0: Interrupt is inhibited
1: An SWPMI interrupt is generated whenever RXNE flag is set in the SWPMI_ISR register

Bit 4 **TXUNRIE**: Transmit underrun error interrupt enable
0: Interrupt is inhibited
1: An SWPMI interrupt is generated whenever TXBUNRF flag is set in the SWPMI_ISR register

Bit 3 **RXOVRIE**: Receive overrun error interrupt enable
0: Interrupt is inhibited
1: An SWPMI interrupt is generated whenever RXBOVRF flag is set in the SWPMI_ISR register

Bit 2 **RXBERIE**: Receive CRC error interrupt enable
0: Interrupt is inhibited
1: An SWPMI interrupt is generated whenever RXBERF flag is set in the SWPMI_ISR register

Bit 1 **TXBEIE**: Transmit buffer empty interrupt enable
0: Interrupt is inhibited
1: An SWPMI interrupt is generated whenever TXBEF flag is set in the SWPMI_ISR register

Bit 0 **RXBFIE**: Receive buffer full interrupt enable
0: Interrupt is inhibited
1: An SWPMI interrupt is generated whenever RXBFF flag is set in the SWPMI_ISR register

58.6.6 SWPMI Receive Frame Length register (SWPMI_RFL)

Address offset: 0x18

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFL[4:0]				
											r	r	r	r	r

Bits 31:5 Reserved, must be kept at reset value.

Bits 4:0 **RFL[4:0]**: Receive frame length

RFL[4:0] is the number of data bytes in the payload of the received frame. The two least significant bits RFL[1:0] give the number of relevant bytes for the last SWPMI_RDR register read.

58.6.7 SWPMI Transmit data register (SWPMI_TDR)

Address offset: 0x1C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TD[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TD[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **TD[31:0]**: Transmit data

Contains the data to be transmitted.

Writing to this register triggers the SOF transmission or the next payload data transmission, and clears the TXE flag.

58.6.8 SWPMI Receive data register (SWPMI_RDR)

Address offset: 0x20

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RD[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RD[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RD[31:0]**: received data
Contains the received data
Reading this register is clearing the RXNE flag.

58.6.9 SWPMI Option register (SWPMI_OR)

Address offset: 0x24

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
														SWP_ CLASS	SWP_ TBYP
														rw	rw

Bits 31:2 Reserved, must be kept at reset value

Bit 1 **SWP_CLASS**: SWP class selection
This bit is used to select the SWP class (refer to *Section 58.3.3: SWP initialization and activation*).
0: Class C: SWPMI_IO uses directly VDD voltage to operate in class C.
This configuration must be selected when VDD is in the range [1.62 V to 1.98 V]
1: Class B: SWPMI_IO uses an internal voltage regulator to operate in class B.
This configuration must be selected when VDD is in the range [2.70 V to 3.30 V]

Bit 0 **SWP_TBYP**: SWP transceiver bypass
This bit is used to bypass the internal transceiver (SWPMI_IO), and connect an external transceiver.
0: Internal transceiver is enabled. The external interface for SWPMI is SWPMI_IO (SWPMI_RX, SWPMI_TX and SWPMI_SUSPEND signals are not available on GPIOs)
1: Internal transceiver is disabled. SWPMI_RX, SWPMI_TX and SWPMI_SUSPEND signals are available as alternate function on GPIOs. This configuration is selected to connect an external transceiver

58.6.10 SWPMI register map and reset value table

Table 467. SWPMI register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	SWPMI_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWPTEN	DEACT	Res.	Res.	Res.	Res.	SWPACT	LPBK	TXMODE	RXMODE	TXDMA	RXDMA
	Reset value																					0	0					0	0	0	0	0	0
0x04	SWPMI_BRR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BRR[7:0]							
	Reset value																									0	0	0	0	0	0	0	1
0x08	RESERVED	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value																																
0x0C	SWPMI_ISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDYF	DEACTF	SUSP	SRF	TCF	TXE	RXNE	TXUNRF	RXOVRF	RXBERF	TXBEF	RXBFF
	Reset value																					0	0	1	0	1	1	0	0	0	0	1	0
0x10	SWPMI_ICR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CRDYF	Res.	Res.	CSRF	CTCF	Res.	Res.	CTXUNRF	CRXOVRF	CRXBERF	CTXBEF	CRXBFF
	Reset value																					0			0	0			0	0	0	0	0
0x14	SWPMI_IER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RDYIE	Res.	Res.	SRIE	TCIE	TIE	RIE	TXUNRIE	RXOVRIE	RXBERIE	TXBEIE	RXBFIE
	Reset value																					0			0	0	0	0	0	0	0	0	0
0x18	SWPMI_RFL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFL[4:0]				
	Reset value																												0	0	0	0	0
0x1C	SWPMI_TDR	TD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x20	SWPMI_RDR	RD[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x24	SWPMI_OR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWP_CLASS	SWP_TBYP
	Reset value																															0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

59 Management data input/output (MDIOS)

59.1 MDIOS introduction

An MDIO bus can be useful in systems where a master chip needs to manage (configure and get status data from) one or multiple slave chips. The bus protocol uses only two signals:

- MDC: the management data clock
- MDIO: the data line carrying the opcode (write or read), the slave (port) address, the MDIOS register address, and the data

In each transaction, the master either reads the contents of an MDIOS register in one of its slaves, or it writes data to an MDIOS register in one of its slaves.

The MDIOS peripheral serves as a slave interface to an MDIO bus. An MDIO master can use the MDC/MDIO lines to write and read 32 16-bit MDIOS registers which are held in the MDIOS. These MDIOS registers are managed by the firmware, thus allowing the MDIO master to configure the application running on the STM32 and get status information from it.

The MDIOS can operate in Stop mode, optionally waking up the STM32 if the MDIO master performs a read or a write to one of its MDIOS registers.

59.2 MDIOS main features

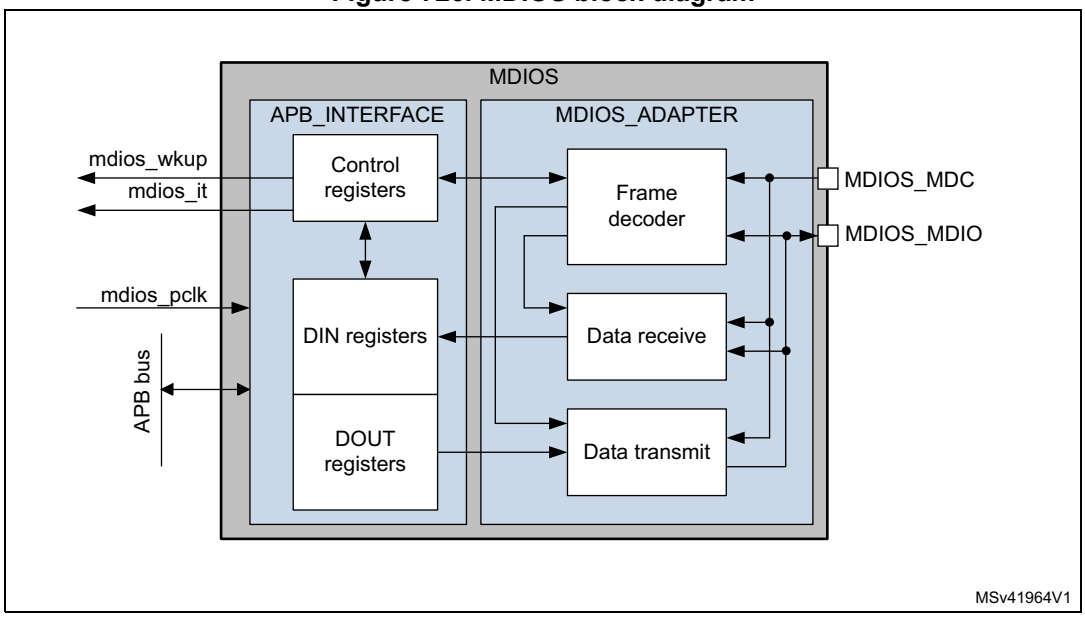
The MDIOS includes the following features:

- 32 MDIOS registers addresses, each of which is managed using separate input and output data registers:
  - 32 x 16-bit firmware read/write, MDIOS read-only output data registers
  - 32 x 16-bit firmware read-only, MDIOS write-only input data registers
- Configurable slave (port) address
- Independently maskable interrupts/events:
  - MDIOS register write
  - MDIOS register read
  - MDIOS protocol error
- Able to operate in and wake up from Stop mode

59.3 MDIOS functional description

59.3.1 MDIOS block diagram

Figure 726. MDIOS block diagram



59.3.2 MDIOS pins and internal signals

Table 468 lists the MDIOS inputs and output signals connected to package pins or balls, while *Table 469* shows the internal PWR signals.

Table 468. MDIOS input/output signals connected to package pins or balls

Signal name	Signal type	Description
MDIOS_MDC	Digital input	MDIO master clock
MDIOS_MDIO	Digital input/ output	MDIO signal (opcode, address, input/output data)

Table 469. MDIOS internal input/output signals

Signal name	Signal type	Description
mdios_wkup	Digital output	MDIOS wakeup signal
mdios_it	Digital output	MDIOS interrupt signal
mdios_pclk	Digital input	APB clock

59.3.3 MDIOS protocol

The MDIOS protocol uses two signals:

1. MDIOS_MDC: the clock, always driven by the master
2. MDIOS_MDIO: signal carrying the opcode, address, and bidirectional data

Each transaction is performed using a “frame”. Each frame contains 32 bits: 14 control bits, 2 turn-around bits, and then 16 data bits, each passed serially.

- 14 control bits, driven by the master
  - 2 start bits: always “01”
  - 2 opcode bits: read=”10”, write=”01”
  - 5 port address bits, indicating which slave device is being addressed
  - 5 MDIOS register address bits, up to 32 MDIOS registers can be addressed in each slave
- 2 turn-around state bits
  - On write operations, the master drives “10”
  - On read operations, the first bit is high-impedance, and the second bit is driven by the slave to ‘0’
- 16 data bits
  - On write operations, data written to slave’s MDIOS register is driven by the master
  - On read operations, data read from slave’s MDIOS register is driven by the slave

Each frame is usually preceded by a preamble, where the MDIOS stays at ‘1’ for 32 MDC clocks. The master can continue to keep MDIO at ‘1’, indicating the “idle” condition, when it has no frame to send.

When MDIO signal is driven by the master, MDIOS samples it using the rising edge of MDC. When MDIOS drives MDIO, the output changes on the rising edge of MDC.

Figure 727. MDIO protocol write frame waveform

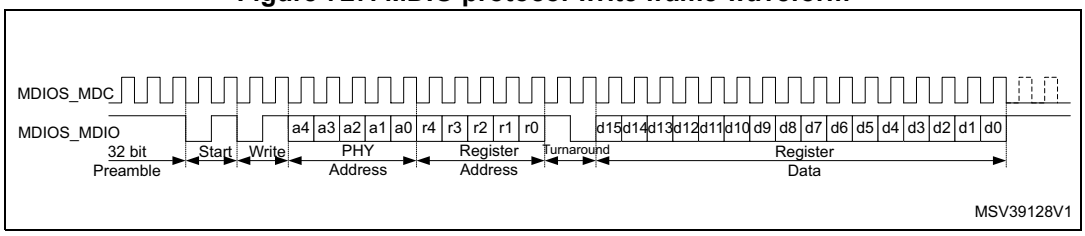
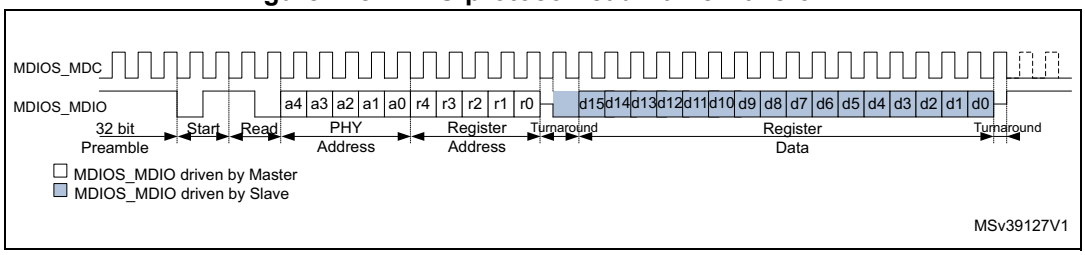


Figure 728. MDIO protocol read frame waveform



59.3.4 MDIOS enabling and disabling

The MDIOS is enabled by setting the EN bit in the MDIOS_CR register. When EN=1, the MDIOS monitors the MDIO bus and service frames addressed to one of its MDIOS registers.

When the MDIOS is enabled (setting EN to ‘1’), the same write operation to the MDIOS_CR register must properly set the PORT_ADDRESS[4:0] field to indicate the slave port address. A frame is ignored by the MDIOS if its port address is not the same as PORT_ADDRESS[4:0] (presumably intended for another slave).

When EN=0, the MDIOS ignores the frames being transmitted on the MDC/MDIO lines, and the IP is in a reduced consumption mode. Clearing EN also clears all of the DIN registers. If EN is cleared while the MDIOS is driving read data, it immediately releases the bus and does not drive the rest of the data. If EN is cleared while the MDIOS is receiving a frame, the frame is aborted and the data is lost.

When the MDIOS is enabled, then disabled and subsequently re-enabled, the status flags are not cleared. For a correct operation the firmware shall clear the status flag before re-enabling the MDIOS.

59.3.5 MDIOS data

From the point of view of the MDIO master, there are 32 16-bit MDIOS registers in the MDIOS which can be written and read. In reality, for each MDIOS register ‘n’ there are two sets of registers: DINn[15:0] and DOUTn[15:0].

Input data

When the MDIO master transmits a frame which writes to MDIOS register ‘n’ in the MDIOS, it is the DINn[15:0] register which is updated with the incoming data. The DIN registers (DIN0 - DIN31) can be read by the firmware, but they can be written only by the MDIO master via the MDIO bus.

The contents of DINn change immediately after the MDC rising edge when the last data bit is sampled.

If the firmware happens to read the contents of DINn at the moment that it is being updated, there is a possibility that the value read is corrupted (a bit-by-bit cross between the old value and the new value). For this reason, **the firmware must assure that two subsequent reads from the same DINn register give the same value and assure that the data is stable when it is read**. In the very worst case, the firmware needs to read DINn four times: first to get the old value, second to get an incoherent value (when reading at the moment the register changes), third to get the new value, and forth to confirm the new value.

If the firmware uses the WRF interrupt and can guarantee that it reads the DINn register before any new MDIOS write frame completes, the firmware can perform a single read.

If the MDIO master performs a write operation with a register address that is greater than 31, the MDIOS ignores the frame (the data is not saved and no flag is set).

Output data

When the MDIOS receives a frame which requests to read register ‘n’, it returns the value found in the DOUTn[15:0] register. Thus, if the MDIO master expects to read the same value which it previously wrote to MDIOS register ‘n’, the firmware must copy the data from DINn to DOUTn each time new data is written to DINn. For correct operation, the firmware must copy the data to the DOUTn register within a preamble (if the master sends preambles before each frame) plus 15 cycles time.

When an MDIOS register is read via the MDIO bus, the MDIOS passes the 16-bit value (from the corresponding DOUTn register) to the MDIOS clock domain during the 15th cycle of the read frame. If the firmware attempts to write the DOUTn register while the MDIO Master is currently reading MDIOS register ‘n’, then the firmware write operation is ignored if it occurs during the 15th cycle of the frame (during a one-MDC-cycle window). Therefore, **after writing a DOUTn register, the firmware must read back the same DOUTn register and confirm that the value was actually written**. If the DOUTn register does not contain the value which was written, then the firmware can simply try writing and re-reading again.

If the MDIOS frequency is very slow compared to the mdios_pclk frequency, then it might be best not to tie up the CPU by continuously writing and re-reading a DOUT register. Please note that the read flag (RDFn) is set as soon as the DOUTn value is passed to the MDIOS clock domain. Thus, when a write to DOUTn is ignored (when the value read back is not the value which was just written), then the firmware can use a read interrupt to know when it is able to write DOUTn.

Here is a procedure which can be used if the MDC clock is very slow:

1. Write DOUTn.
2. Assure that all of the read flags are zero (MDIOS_RDFR = 0x0000). Clear the flags if necessary using MDIOS_CRDFR.
3. Read back the same DOUTn register and compare the value with the value which was written in step 1.
4. If the values are the same, then the procedure is done. Otherwise, continue to step 5.
5. Enable read interrupts by setting the RDIE bit in MDIOS_CR1.
6. In the interrupt routine, assure that RDFn is set. (no other read flags are set before bit n).
7. There is a 31 cycle + preamble time window (if the master sends a preamble before each frame) to write DOUTn safely without doing a read-back and compare. If this maximum delay cannot be guaranteed, go back to step #1.

If the MDIO master performs a read operation with a register address which is greater than 31, the MDIOS returns a data value of all zeros.

59.3.6 MDIOS APB frequency

Whenever the firmware reads from an MDIOS_DINRn register or writes to an MDIOS_DOUTRn register, the frequency of the APB bus must be at least 1.5 times the MDC frequency. For example, if MDC is at 20MHz, the APB must be at 30MHz or faster.

59.3.7 Write/read flags and interrupts

When MDIOS register ‘n’ is written via the MDIO bus, the WRFn bit in the MDIOS_WRFR register is set. WRFn becomes ‘1’ a the moment that DINn is updated, which is when the last data bit is sampled on a write frame. An interrupt is generated if WRIEN=1 (in the MDIOS_CR register). WRFn is cleared by software by writing ‘1’ to CWRFn (in the MDIOS_CWRFR register).

When MDIOS register ‘n’ is read via the MDIO bus, the RDFn bit in the MDIOS_RDFR register is set. RDFn becomes ‘1’ at the moment that DOUTn is copied to the MDC clock domain, which is on the 15th cycle of a read frame. An interrupt is generated if RDIEN=1 (in the MDIOS_CR register). RDFn is cleared by software by writing ‘1’ to CRDFn (in the MDIOS_CRDFR register).

59.3.8 MDIOS error management

There are three types of errors with their corresponding error flags:

- Preamble error: PERF (bit 0 of MDIOS_SR register)
- Start error: SERF (bit 1 of MDIOS_SR register)
- Turnaround error: TERF (bit 2 of MDIOS_SR register)

Each error flag is set by hardware when the corresponding error condition occurs. Each flag can be cleared by writing ‘1’ to the corresponding bit in the clear flag register (MDIOS_CLRFR).

An interrupt occurs if any of the three error flags is set while EIE=1 (MDIOS_CR).

Besides setting an error flag, the MDIOS performs no action for a frame in which an error is detected: the DINn registers are not updated and the MDIO line is not forced during the data phase.

For a given frame, errors do not accumulate. For example, if a preamble error is detected, no check is done for a start error or a turnaround error for the rest of the current frame.

When DPC=0, following an detected error, all new frames and errors are ignored until a complete full preamble has been detected.

When DPC=1 (Disable Preamble Check, MDIOS_CR[7]), all frames and new errors are ignored as long as one of the error flags is set. As soon as the error bit is cleared, the MDIOS starts looking for a start sequence. Thus, the application must clear the error flag only when it is sure that no frame is currently in progress. Otherwise, the MDIOS likely misinterprets the bits being sent and becomes desynchronized with the master.

Preamble errors

A preamble error occurs when a start sequence begins (with MDIO sampled at ‘0’) without being immediately preceded by a preamble (MDIO sampled at ‘1’ for at least 32 consecutive clocks).

Preamble errors are not reported after the MDIOS is first enabled (EN=1 in MDIOS_CR) until after a full preamble is received. This is to avoid an error condition when the peripheral frame detection is enabled while a preamble or frame is already in progress. In this case, the MDIOS ignores the first frame (since it did not first detect a full preamble), but does not set PERF.

If the DPC bit (Disable Preamble Check, MDIOS_CR[7]) is set, then the MDIO Master can send frames without preceding preambles and no preamble error is signaled. When DPC=1, the application must assure that the master is not in the process of sending a frame at the moment that the MDIOS is enabled (EN is set). Otherwise, the slave might become desynchronized with the master.

Start errors

A start error occurs when an illegal start sequence occurs or if an illegal command is given. The start sequence must always be “01”, and the command must be either “01” (write) or “10” (read).

As with preamble errors, start errors are not reported until after a full preamble is received.

Turnaround errors

A turnaround error occurs when an error is detected in the turnaround bits of write frames. The 15th bit of the write frame must be ‘1’ and the 16th bit must be ‘0’.

Turnaround errors are only reported after a full preamble is received, there is no start error, the port address in the current frame matches and the register address is in the supported range 0 to 31.

59.3.9 MDIOS in Stop mode

The MDIOS can operate in Stop mode, responding to all reads, performing all writes, and causing the STM32 to wakeup from Stop mode on MDIOS interrupts.

59.3.10 MDIOS interrupts

There is a single interrupt vector for the three types of interrupts (write, read, and error). Any of these interrupt sources can wake the STM32 up from Stop mode. All interrupt flags need to be cleared in order to clear the interrupt line.

Table 470. Interrupt control bits

Interrupt event	Event flag	Enable control bit
Write interrupt	WRF[31:0]	WRIE
Read interrupt	RDF[31:0]	RDIE
Error interrupt	PERF (preamble), SERF (start), TERF (turnaround)	EIE

59.4 MDIOS registers

59.4.1 MDIOS configuration register (MDIOS_CR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	PORT_ADDRESS[4:0]					DPC	Res.	Res.	Res.	EIE	RDIE	WRIE	EN
			rw	rw	rw	rw	rw	rw				rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:8 **PORT_ADDRESS[4:0]**: slave address

Can be written only when the peripheral is disabled (EN=0).

If the address given by the MDIO master matches PORT_ADRESS[4:0], then the MDIOS services the frame. Otherwise the frame is ignored.

Bit 7 **DPC**: disable preamble check

0: MDIO master must give preamble before each frame.

1: MDIO master can send each frame without a preceding preamble, and the MDIOS does not signal a preamble error.

Note: When this bit is set, the application must be sure that no frame is currently in progress when the MDIOS is enabled. Otherwise, the MDIOS can become desynchronized with the master.

This bit cannot be changed unless EN = 0 (though it can be changed at the same time that EN is being set).

Bits 6:4 Reserved, must be kept at reset value.

Bit 3 **EIE**: error interrupt enable

0: Interrupt is disabled.

1: Interrupt is enabled.

Note: When this bit is set, an interrupt is generated if any of the error flags (PERF, SERF, or TERF in the MDIOS_SR register) is set.

Bit 2 **RDIE**: register read interrupt enable

0: Interrupt is disabled.

1: Interrupt is enabled.

Note: When this bit is set, an interrupt is generated if any of the read flags (RDF[31:0] in the MDIOS_RDFR register) is set.

Bit 1 **WRIE**: register write interrupt enable

0: Interrupt is disabled.

1: Interrupt is enabled.

Note: When this bit is set, an interrupt is generated if any of the read flags (WRF[31:0] in the MDIOS_WRFR register) is set.

Bit 0 **EN**: peripheral enable

0: MDIOS is disabled.

1: MDIOS is enabled and monitoring the MDIO bus (MDC/MDIO).

59.4.2 MDIOS write flag register (MDIOS_WRFR)

Address offset: 0x04

Power-on reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WRF[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WRF[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **WRF[31:0]**: write flags for MDIOS registers 0 to 31.

Each bit is set by hardware when the MDIO master performs a write to the corresponding MDIOS register. An interrupt is generated if WRIE (in MDIOS_CR) is set.

Each bit is cleared by software by writing ‘1’ to the corresponding CWRF bit in the MDIOS_CWRFR register.

For WRFn:

0: MDIOS register n is not written by the MDIO master.

1: MDIOS register n is written by the MDIO master and the data is available in DINn[15:0] in the MDIOS_DINRn register.

59.4.3 MDIOS clear write flag register (MDIOS_CWRFR)

Address offset: 0x08

Power-on reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CWRF[31:16]															
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CWRF[15:0]															
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:0 **CWRF[31:0]**: clear the write flag

Writing 1 to CWRFn clears the WRFn bit in the MDIOS_WRF register.

59.4.4 MDIOS read flag register (MDIOS_RDFR)

Address offset: 0x0C

Power-on reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RDF[**31**:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDF[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RDF[31:0]**: read flags for MDIOS registers 0 to 31.

Each bit is set by hardware when the MDIO master performs a read from the corresponding MDIOS register. An interrupt is generated if RDIE (in MDIOS_CR) is set.

Each bit is cleared by software by writing ‘1’ to the corresponding CRDF bit in the MDIOS_CRDFR register.

For RDFn:

0: MDIOS register n is not read by the MDIO master.

1: MDIOS register n is read by the MDIO master.

59.4.5 MDIOS clear read flag register (MDIOS_CRDFR)

Address offset: 0x10

Power-on reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CRDF[31:16]															
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CRDF[15:0]															
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:0 **CRDF[31:0]**: clear the read flag

Writing 1 to CRDFn clears the RDFn bit in the MDIOS_RDF register.

59.4.6 MDIOS status register (MDIOS_SR)

Address offset: 0x14

Power-on reset value: 0x0000 0000

Writes to this register have no effect.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TERF	SERF	PERF
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **TERF**: turnaround error flag

0: No turnaround error has occurred.

1: A turnaround error has occurred.

Note: Writing 1 to CTERF (MDIOS_CLRFR) clears this bit.

Bit 1 **SERF**: start error flag

0: No start error has occurred.

1: A start error has occurred.

Note: Writing 1 to CSERF (MDIOS_CLRFR) clears this bit.

Bit 0 **PERF**: preamble error flag
0: No preamble error has occurred.
1: A preamble error has occurred.
Note: Writing 1 to CPERF (MDIOS_CLRFR) clears this bit.
This bit is not set if DPC (disable preamble check, MDIOS_CR[7]) is set.

59.4.7 MDIOS clear flag register (MDIOS_CLRFR)

Address offset: 0x18

Power-on reset value: 0x0000 0000

Reads on this register returns all zeros.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CTERF	CSERF	CPERF
													rc_w1	rc_w1	rc_w1

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **CTERF**: clear the turnaround error flag
Writing 1 to this bit clears the TERF flag (in MDIOS_SR).
When DPC = 1 (MDIOS_CR[7]), the TERF flag must be cleared only when there is not a frame already in progress.

Bit 1 **CSERF**: clear the start error flag
Writing 1 to this bit clears the SERF flag (in MDIOS_SR).
When DPC = 1 (MDIOS_CR[7]), the SERF flag must be cleared only when there is not a frame already in progress.

Bit 0 **CPERF**: clear the preamble error flag
Writing 1 to this bit clears the PERF flag (in MDIOS_SR).

59.4.8 MDIOS input data register x (MDIOS_DINRx)

Address offset: 0x100 + 0x04 * x, (x = 0 to 31)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DINn[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **DINn[15:0]**: input data received from MDIO master during write frames
This field is written by hardware with the 16-bit data received in a write frame which is addressed to MDIOS register n.

59.4.9 MDIOS output data register x (MDIOS_DOUTRx)

Address offset: 0x180 + 0x04 * x, (x = 0 to 31)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DOUTn[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **DOUTn[15:0]**: output data sent to MDIO Master during read frames
This field is written by software. These 16 bits are serially output on the MDIO bus during read frames which address the MDIOS register n.

59.4.10 MDIOS register map

Table 471. MDIOS register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	MDIOS_CR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PORT_ADDRESS[4:0]					DPC	Res.	Res.	Res.	EIE	RDIE	WRIE	EN
	Reset value																				0	0	0	0	0	0				0	0	0	0
0x04	MDIOS_WRFR	WRF[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x08	MDIOS_CWRFR	CWRF[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0C	MDIOS_RDFR	RDF[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x10	MDIOS_CRDFR	CRDF[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	MDIOS_SR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TERF	SERF	PERF
	Reset value																														0	0	0
0x18	MDIOS_CLRFR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CTERF	CSERF	CPERF
	Reset value																														0	0	0
0x1C - 0xFC	Reserved	Reserved																															

Table 471. MDIOS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x100 + 0x04 * x (x=0 to 31) Last address: 0x17C	MDIOS_DINRx	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIN0[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x180 + 0x04 * x (x=0 to 31) Last address: 0x1FC	MDIOS_DOUTRx	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DOUT0[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

60 Secure digital input/output MultiMediaCard interface (SDMMC)

60.1 SDMMC main features

The SD/SDIO, embedded MultiMediaCard (*e*•MMC) host interface (SDMMC) provides an interface between the AHB bus and SD memory cards, SDIO cards and *e*•MMC devices.

The MultiMediaCard system specifications are available through the MultiMediaCard Association website at www.jedec.org, published by the MMCA technical committee.

SD memory card and SD I/O card system specifications are available through the SD card Association website at www.sdcard.org.

The SDMMC features include the following:

- Compliance with *Embedded MultiMediaCard System Specification Version 4.51*. Card support for three different databus modes: 1-bit (default), 4-bit and 8-bit.(HS200 SDMMC_CK speed limited to maximum allowed I/O speed)
- Full compatibility with previous versions of MultiMediaCards (backward compatibility).
- Full compliance with *SD memory card specifications version 4.1.* (SDR104 SDMMC_CK speed limited to maximum allowed I/O speed, SPI mode and UHS-II mode not supported).
- Full compliance with *SDIO card specification version 4.0.* Card support for two different databus modes: 1-bit (default) and 4-bit. (SDR104 SDMMC_CK speed limited to maximum allowed I/O speed, SPI mode and UHS-II mode not supported).
- Data transfer up to 208 Mbyte/s for the 8-bit mode. (depending maximum allowed I/O speed).
- Data and command output enable signals to control external bidirectional drivers.

The MultiMediaCard/SD bus connects cards to the host.

The current version of the SDMMC supports only one SD/SDIO/*e*•MMC card at any one time and a stack of *e*•MMC.

60.2 SDMMC implementation

Table 472. SDMMC features

SDMMC modes/features(1)	SDMMC1	SDMMC2
Variable delay (SDR104, HS200)	X	X
SDMMC_CKIN	X	-
SDMMC_CDIR, SDMMC_D0DIR	X	-
SDMMC_D123DIR	X	-
MDMA data transfer end	X	-
MDMA command end	X	-
MDMA buffer end	X	-

1. X = supported.

60.3 SDMMC bus topology

Communication over the bus is based on command/response and data transfers.

The basic transaction on the SD/SDIO/*e*•MMC bus is the command/response transaction. These types of bus transaction transfer their information directly within the command or response structure. In addition, some operations have a data token.

Data transfers are done in the following ways:

- Block mode: data block(s) with block size 2^N bytes with N in the range 0-14.
- SDIO multibyte mode: single data block with block size range 1-512 bytes
- *e*•MMC Stream mode: continuous data stream

Data transfers to/from *e*•MMC cards are done in data blocks or streams.

Figure 729. SDMMC "no response" and "no data" operations

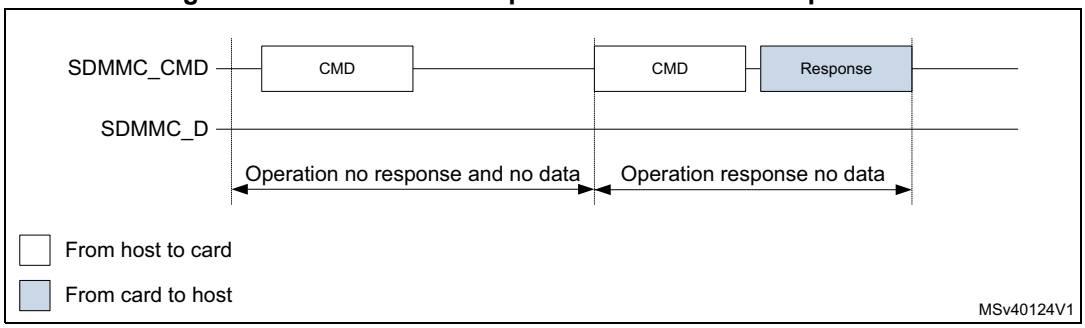
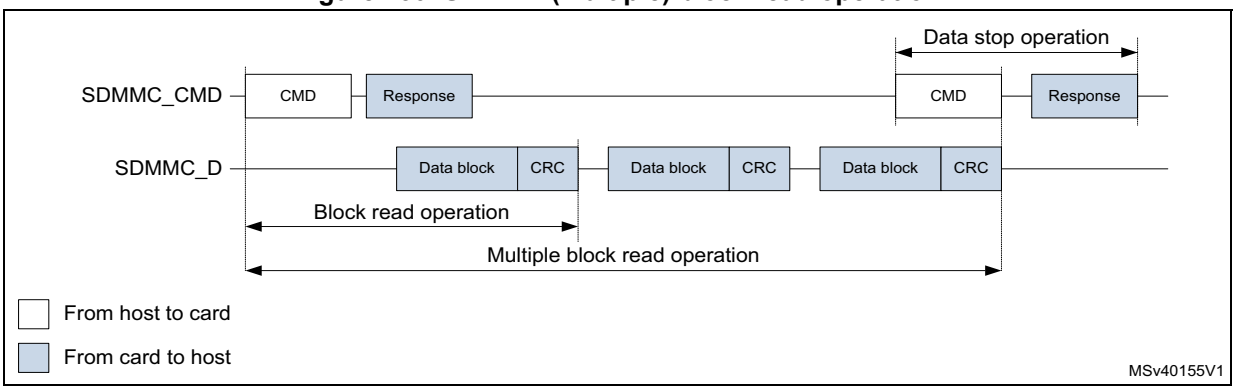
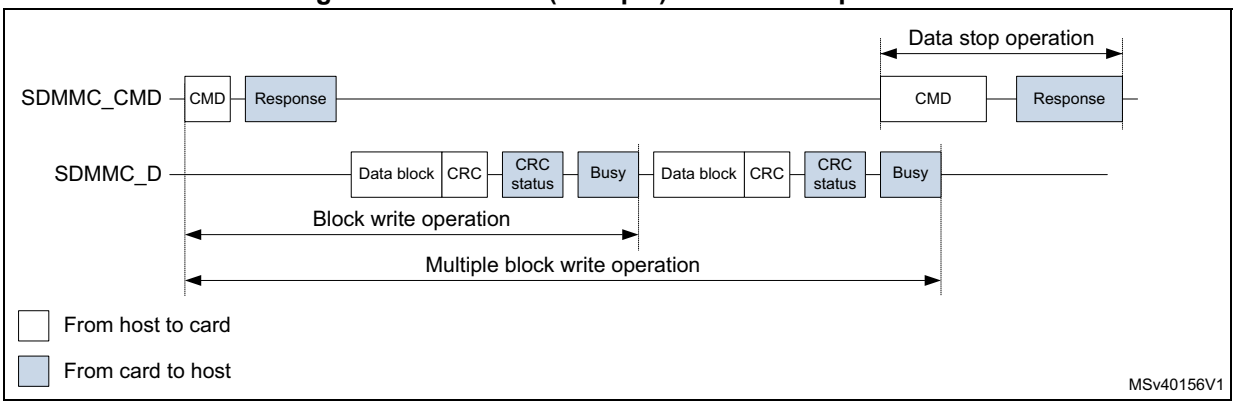


Figure 730. SDMMC (multiple) block read operation



Note: The Stop Transmission command is not required at the end of a e•MMC multiple block read with predefined block count.

Figure 731. SDMMC (multiple) block write operation



Note: The Stop Transmission command is not required at the end of an e•MMC multiple block write with predefined block count.

Note: The SDMMC does not send any data as long as the Busy signal is asserted (SDMMC_D0 pulled low).

Figure 732. SDMMC (sequential) stream read operation

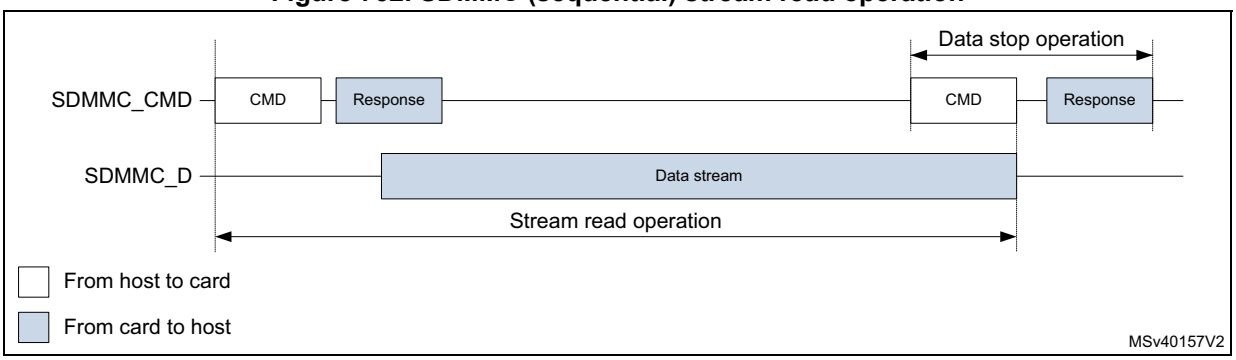
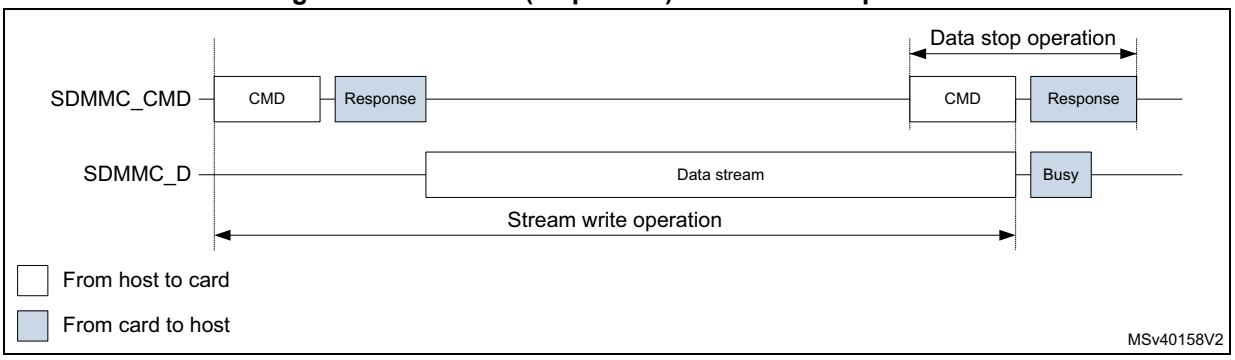


Figure 733. SDMMC (sequential) stream write operation



Stream data transfer operates only in a 1-bit wide bit bus configuration on SDMMC_D0 in single data rate modes (DS, HS, and SDR).

60.4 SDMMC operation modes

Table 473. SDMMC operation modes SD & SDIO

SDIO Bus Speed modes(1)(2)	Max Bus Speed (3) [Mbyte/s]	Max Clock frequency [MHz](4)	Signal Voltage [V]
DS (Default Speed)	12.5	25	3.3
HS (High Speed)	25	50	3.3
SDR12	12.5	25	1.8
SDR25	25	50	1.8
DDR50	50	50	1.8
SDR50	50	100	1.8
SDR104	104	208	1.8

1. SDR single data rate signaling.
2. DDR double data rate signaling. (data is sampled on both SDMMC_CK clock edges).
3. SDIO bus speed with 4bit bus width.
4. Maximum frequency depending on maximum allowed IO speed.

SDR104 mode requires variable delay support using sampling point tuning. The use of variable delay is optional for SDR50 mode.

Table 474. SDMMC operation modes *e*•MMC

e•MMC bus speed modes (1)(2)	Max bus speed (3) [Mbyte/s]	Max clock frequency [MHz](4)	Signal voltage [V]
Legacy compatible	26	26	3/1.8/1.2V
High speed SDR	52	52	3/1.8/1.2V
High speed DDR	104	52	3/1.8/1.2V
High speed HS200	200	200	1.8/1.2V

1. SDR single data rate signaling.
2. DDR double data rate signaling. (data is sampled on both SDMMC_CK clock edges).
3. *e*•MMC bus speed with 8bit bus width.
4. Maximum frequency depending on maximum allowed IO speed.

HS200 mode requires variable delay support using sampling point tuning.

60.5 SDMMC functional description

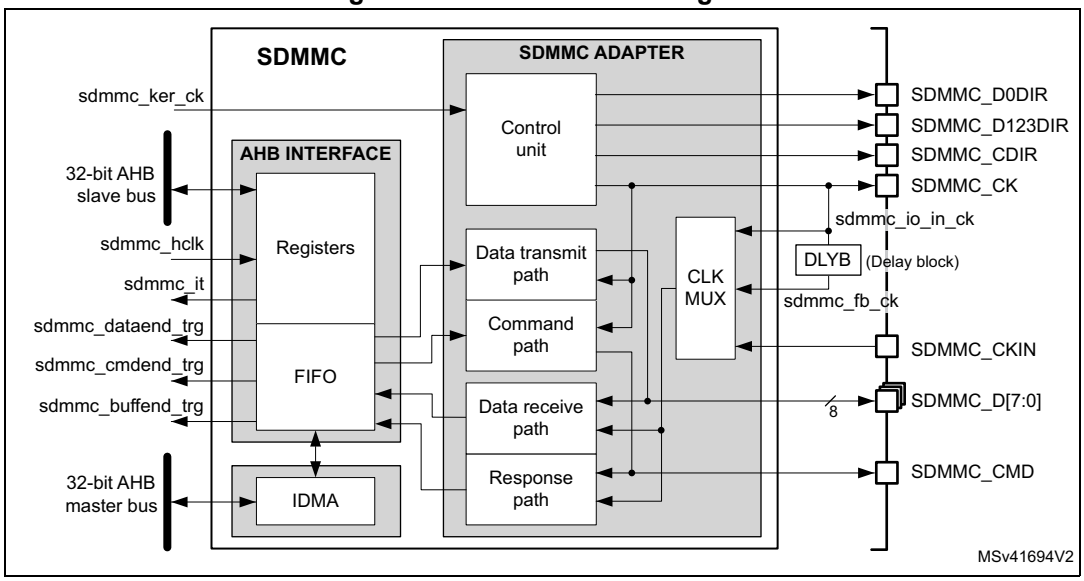
The SDMMC consists of four parts:

- The AHB slave interface accesses the SDMMC adapter registers, and generates interrupt signals and IDMA control signals.
- The SDMMC adapter block provides all functions specific to the *e*•MMC/SD/SD I/O card such as the clock generation unit, command and data transfer.
- The internal DMA (IDMA) block with its AHB master interface.
- A delay block (DLYB) taking care of the receive data sample clock alignment. The delay block is NOT part of the SDMMC. A delay block is mandatory when supporting SDR104 or HS200.

60.5.1 SDMMC block diagram

Figure 734 shows the SDMMC block diagram.

Figure 734. SDMMC block diagram



60.5.2 SDMMC pins and internal signals

Table 475 lists the SDMMC internal input/output signals, *Table 476* the SDMMC pins (alternate functions).

Table 475. SDMMC internal input/output signals

Signal name	Signal type	Description
sdmmc_ker_ck	Digital input	SDMMC kernel clock
sdmmc_hclk	Digital input	AHB clock
sdmmc_it	Digital output	SDMMC global interrupt
sdmmc_dataend_trg	Digital output	SDMMC data end trigger for MDMA
sdmmc_cmdend_trg	Digital output	SDMMC command end trigger for MDMA

Table 475. SDMMC internal input/output signals (continued)

Signal name	Signal type	Description
sdmmc_buffend_trg	Digital output	SDMMC internal DMA buffer end trigger for MDMA
sdmmc_io_in_ck	Digital input	SD/SDIO/*e*•MMC card feedback clock. This signal is internally connected to the SDMMC_CK pin (for DS and HS modes).
sdmmc_fb_ck	Digital input	SD/SDIO/*e*•MMC card tuned feedback clock after DLYB delay block (for SDR50, DDR50, SDR104, HS200)

Table 476. SDMMC pins

Signal name	Signal type	Description
SDMMC_CK	Digital output	Clock to SD/SDIO/*e*•MMC card
SDMMC_CKIN	Digital input	Clock feedback from an external driver for SD/SDIO/*e*•MMC card. (for SDR12, SDR25, SDR50, DDR50)
SDMMC_CMD	Digital input/output	SD/SDIO/*e*•MMC card bidirectional command/response signal.
SDMMC_CDIR	Digital output	SD/SDIO/*e*•MMC card I/O direction indication for the SDMMC_CMD signal.
SDMMC_D[7:0]	Digital input/output	SD/SDIO/*e*•MMC card bidirectional data lines.
SDMMC_D0DIR	Digital output	SD/SDIO/*e*•MMC card I/O direction indication for the SDMMC_D0 data line.
SDMMC_D123DIR	Digital output	SD/SDIO/*e*•MMC card I/O direction indication for the data lines SDMMC_D[3:1].

60.5.3 General description

The **SDMMC_D[7:0]** lines have different operating modes:

- By default, SDMMC_D0 line is used for data transfer. After initialization, the host can change the databus width.
- For an *e*•MMC, 1-bit (SDMMC_D0), 4-bit (SDMMC_D[3:0]) or 8-bit (SDMMC_D[7:0]) data bus widths can be used.
- For an SD or an SDIO card, 1-bit (SDMMC_D0) or 4-bit (SDMMC_D[3:0]) can be used. All data lines operate in push-pull mode.

To allow the connection of an external driver (a voltage switch transceiver), the direction of data flow on the data lines is indicated with I/O direction signals. The **SDMMC_D0DIR** signal indicates the I/O direction for the SDMMC_D0 data line, the **SDMMC_D123DIR** for the SDMMC_D[3:1] data lines.

SDMMC_CMD only operates in push-pull mode:

To allow the connection of an external driver (a voltage switch transceiver), the direction of data flow on the SDMMC_CMD line is indicated with the I/O direction signal **SDMMC_CDIR**.

SDMMC_CK clock to the card originates from **sdmmc_ker_ck**:

- When the sdmmc_ker_ck clock has 50 % duty cycle, it can be used even in bypass mode (CLKDIV = 0).
- When the sdmmc_ker_ck duty cycle is not 50 %, the CLKDIV must be used to divide it by 2 or more (CLKDIV > 0).
- The phase relation between the SDMMC_CMD / SDMMC_D[7:0] outputs and the SDMMC_CK can be selected through the NEGEDGE bit. The phase relation depends on the CLKDIV, NEGEDGE, and DDR settings. See *Figure 735*.

Figure 735. SDMMC Command and data phase relation

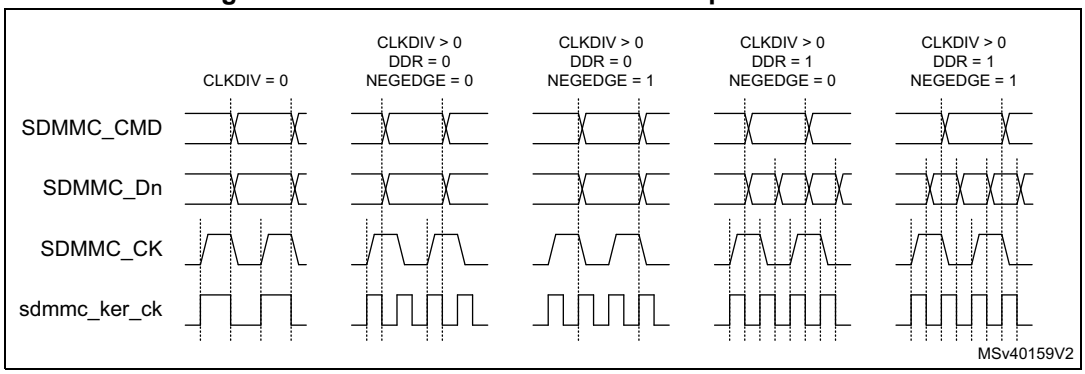


Table 477. SDMMC Command and data phase selection

CLKDIV	DDR	NEGEDGE	SDMMC_CK	Command out	Data out
0	x	x	= sdmmc_ker_ck	generated on sdmmc_ker_ck falling edge	
>0	0	0	generated on sdmmc_ker_ck rising edge	generated on sdmmc_ker_ck falling edge succeeding the SDMMC_CK rising edge.	
		1		generated on the same sdmmc_ker_ck rising edge that generates the SDMMC_CK falling edge.	
	1	0		generated on sdmmc_ker_ck falling edge succeeding the SDMMC_CK rising edge.	generated on sdmmc_ker_ck falling edge succeeding a SDMMC_CK edge.
		1		generated on the same sdmmc_ker_ck rising edge that generates the SDMMC_CK falling edge.	

By default, the **sdmmc_io_in_ck** feedback clock input is selected for sampling incoming data in the SDMMC receive path. It is derived from the SDMMC_CK pin.

For tuning the phase of the sampling clock to accommodate the receive data timing, the DLYB delay block available on the device can be connected between **sdmmc_io_in_ck** signal (DLYB input dlyb_in_ck) and **sdmmc_fb_ck** clock input of SDMMC (DLYB output dlyb_out_ck). Selecting the **sdmmc_fb_ck** clock input in the receive path then enables using the phase-tuned sampling clock for the incoming data. This is required for SDMMC to support the SDR104 and HS200 operating mode and optional for SDR50 and DDR50 modes.

When using an external driver (a voltage switch transceiver), the SDMMC_CKIN feedback clock input can be selected to sample the receive data.

For an SD/SDIO/*e*•MMC card, the clock frequency can vary between 0 and 208 MHz (limited by maximum I/O speed).

Depending on the selected bus mode (SDR or DDR), one bit or two bits are transferred on SDMMC_D[7:0] lines with each clock cycle. The SDMMC_CMD line transfers only one bit per clock cycle.

60.5.4 SDMMC adapter

The SDMMC adapter (see *Figure 734: SDMMC block diagram*) is a multimedia/secure digital memory card bus master that provides an interface to a MultiMediaCard stack or to a secure digital memory card. It consists of the following subunits:

- Control unit
- Data transmit path
- Command path
- Data receive path
- Response path
- Receive data path clock multiplexer
- Delay block (DLYB), external to the SDMMC
- Adapter register block
- Data FIFO
- Internal DMA (IDMA)

Note: The adapter registers and FIFO use the AHB clock domain (sdmmc_hclk). The control unit, command path and data transmit path use the SDMMC adapter clock domain (sdmmc_ker_ck). The response path and data receive path use the SDMMC adapter feedback clock domain from the sdmmc_io_in_ck, or SDMMC_CKIN, or from the sdmmc_fb_ck generated by DLYB.

The DLYB delay block on the device can be used in conjunction with the SDMMC adapter, to tune the phase of the sampling clock for incoming data in SDMMC receive mode. It is required for the SDMMC to support the SDR104 and HS200 operating mode and optional for SDR50 and DDR50 modes.

Adapter register block

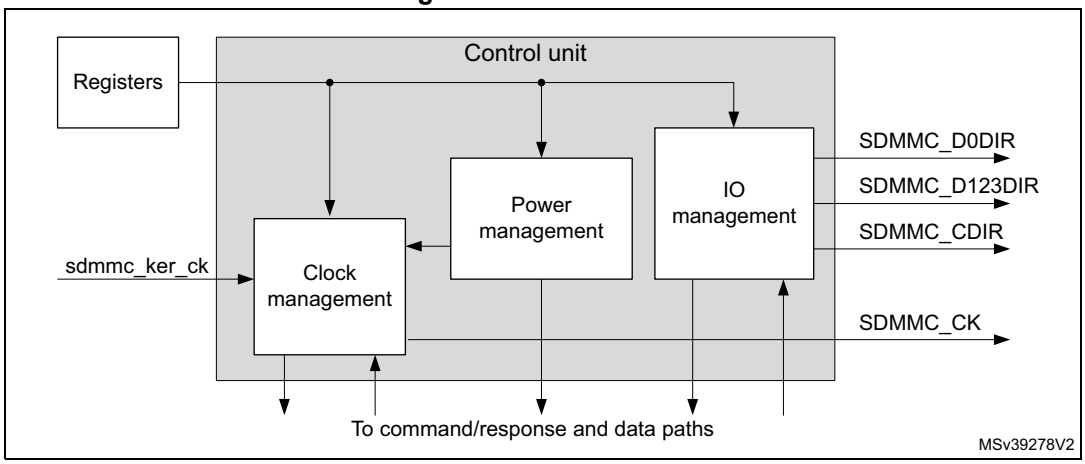
The adapter register block contains all system control registers, the SDMMC command and response registers and the data FIFO.

This block also generates the signals from the corresponding bit location in the SDMMC Clear register that clear the static flags in the SDMMC adapter.

Control unit

The control unit illustrated in *Figure 736*, contains the power management functions, the SDMMC_CK clock management with divider, and the I/O direction management.

Figure 736. Control unit



The power management subunit disables the card bus output signals during the power-off and power-up phases.

There are three power phases:

- power-off
- power-up
- power-on

The clock management subunit uses the sdmmc_ker_ck to generate the SDMMC_CK and provides the division control. It also takes care of stopping the SDMMC_CK for i.e. flow control.

The clock outputs are inactive:

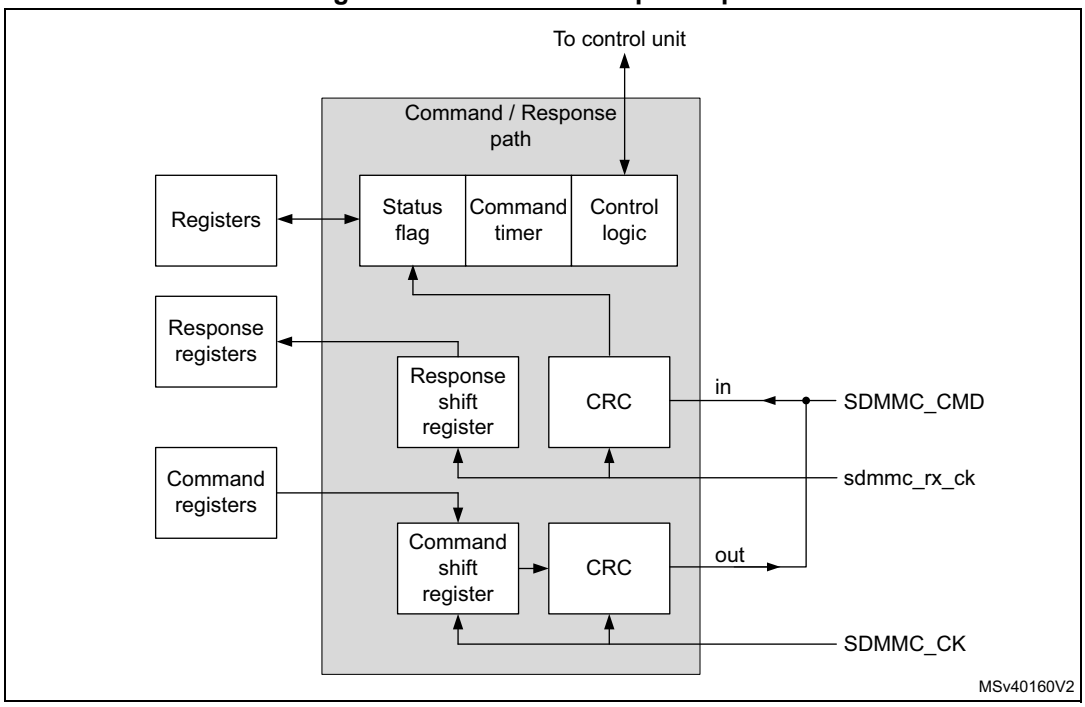
- after reset
- during the power-off or power-up phases
- if the power saving mode (register bit PWRSAV) is enabled and the card bus is in the Idle state for eight clock periods. The clock is stopped eight cycles after both the command/response CPSM and data path DPSM subunits have enter the Idle phase. The clock is restarted when the command/response CPSM or data path DPSM is activated (enabled).

The I/O management subunit takes care of the SDMMC_Dn and SDMMC_CMD I/O direction signals, which controls the external voltage transceiver.

Command/response path

The command/response path subunit transfers commands and responses on the SDMMC_CMD line. The command path is clocked on the SDMMC_CK and sends commands to the card,. The response path is clocked on the sdmmc_rx_ck and receives responses from the card.

Figure 737. Command/response path

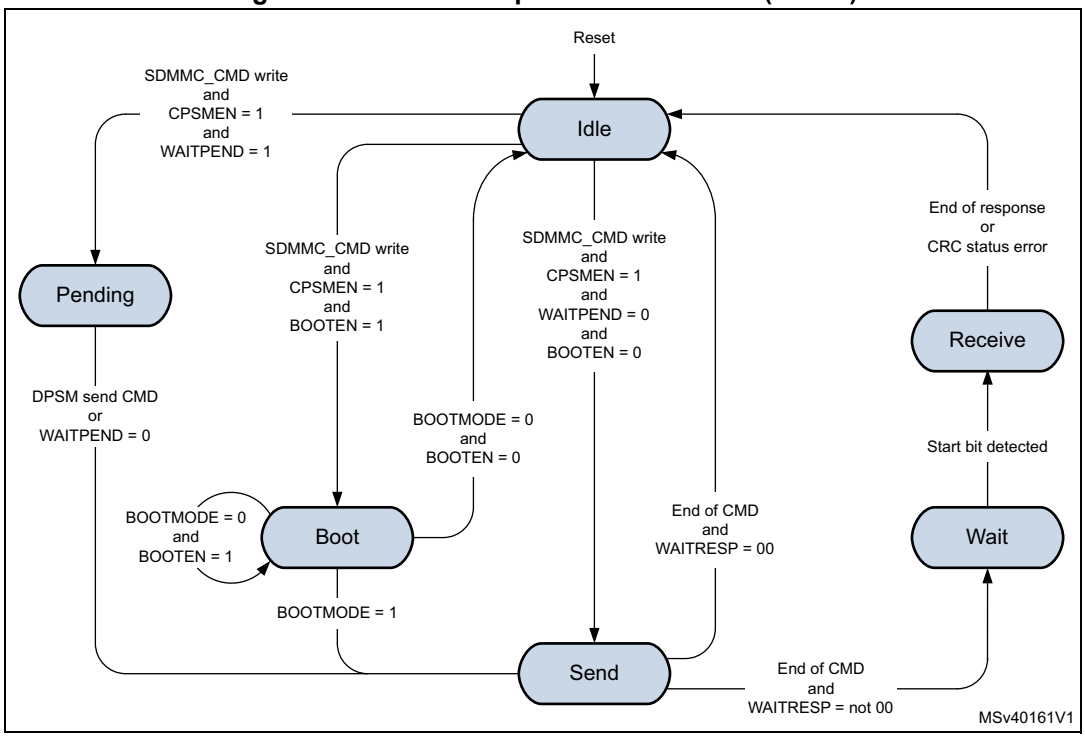


Command/response path state machine (CPSM)

- When the command register is written to and the enable bit is set, command transfer starts. When the command has been sent the CRC is appended and the command path state machine (CPSM) sets the status flags and:
  - if a response is not required enters the Idle state.
  - If a response is required, it waits for the response.
- When the response is received,
  - for a response with CRC, the received CRC code and the internally generated code are compared, and the appropriate status flag is set according the result.
  - for a response without CRC, no CRC is checked, and the appropriate status flag is not set.

When ever the CPSM is active, i.e. not in the Idle state, the CPSMACT bit is set.

Figure 738. Command path state machine (CPSM)



- **Idle**: The command path is inactive. When the command control register is written and the enable bit (CPSMEN) is set, the CPSM activates the SDMMC_CK clock (when stopped due to power save PWRSAV bit) and moves
  - to the Send state when WAITPEND = 0 & BOOTEN = 0.
  - to the Pending state when WAITPEND = 1.
  - to the Boot state when BOOTEN = 1.
- **Send**: The command is sent and the CRC is appended.
  - When CMDTRANS bit is set or when BOOTEN bit is set and BOOTMODE is alternative boot, and the DTDIR = receive, the CPSM DataEnable signal is issued to the DPSM at the end of the command.
  - When the CMDTRANS bit is set and the CMDSUSPEND bit is 0 the interrupt period is terminated at the end of the command.
  - When CMDSTOP bit is set the CPSM Abort signal is issued to the DPSM at the end of the command.
  - If no response is expected (WAITRESP = 00) the CPSM moves to the Idle state and the CMDSENT flag is set. When BOOTMODE = 1 & BOOTEN = 0 the CMDSENT flag is delayed 56 cycles after the command end bit, otherwise the

CMDSENT flag is generated immediately after the command end bit.
The RESPCMDR and RESPxR registers are not modified.

– If a command response is expected (WAITRESP = not 00) the CPSM moves to the Wait state and start the response timeout.

- **Wait**: The command path waits for a response.
  – When WAITINT bit is 0 the command timer starts running and the CPSM waits for a start bit.
  a) If a start bit is detected before the timeout the CPSM moves to the Receive state.
  b) If the timeout is reached before the CPSM detect a response start bit, the timeout flag (CTIMEOUT) is set and the CPSM moves to the Idle state.
  The RESPCMDR and RESPxR registers are not modified.
  – When WAITINT bit is 1, the timer is disabled and the CPSM waits for an interrupt request (response start bit) from one of the cards.
  a) When a start bit is detected the CPSM moves to the Receive state.
  b) When writing WAITINT to 0 (interrupt mode abort), the host sends a response by its self and on detecting the start bit the CPSM move to the Receive state.
- **Receive**: The command response is received. Depending the response mode bits WAITRESP in the command control register, the response can be either short or long, with CRC or without CRC. The received CRC code when present is verified against the internally generated CRC code.
  – When the CMDSUSPEND bit is set and the SDIO Response bit BS = 0 (response bit [39]), the interrupt period is started after the response.
  When the CMDSUSPEND bit is cleared, or the CMDSUSPEND bit is 1 and the SDIO Response bit BS = 1 (response bit [39]), there is no interrupt period started.
  – When the CMDTRANS bit is set and the CMDSUSPEND bit is set and the SDIO Response bit DF= 1 (response bit [32]) the interrupt period is terminated after the response.
  – When the CRC status passes or no CRC is present the CMDREND flag is set, the CPSM moves to the Idle state.
  The RESPCMDR and RESPxR registers are updated with received response.
  - When BOOTMODE = 1 & BOOTEN = 0 the CMDREND flag is delayed 56 cycles after the response end bit, otherwise the CMDREND flag is generated immediately after the response end bit.
  - When CMDTRANS bit is set and the DTDIR = transmit, the CPSM DataEnable signal is issued to the DPSM at the end of the command response.
  – When the CRC status fails the CCRCFAIL flag is set and the CPSM moves to the Idle state.
  The RESPCMDR and RESPxR registers are updated with received response.
- **Pending**: According the pending WAITPEND bit in the command register, the CPSM enters the pending state.
  – When DATALENGTH =< 5 bytes the CPSM moves to the Sent state and generates the DataEnable signal to start the data transfer aligned with the CMD12 Stop Transmission command.
  – When DATALENGTH > 5 bytes, the CPSM DataEnable signal is issued to the DPSM to start the data transfer. The CPSM waits for a send CMD signal from the

DPSM before moving to the Send state. This enables i.e. the CMD12 Stop Transmission command to be sent aligned with the data.

– When writing WAITPEND to 0, the CPSM moves to the Send state.

- **Boot**: If the BOOTEN bit is set in the command register, the CPSM enters the Boot state, and when:
  – BOOTMODE = 0 the SDMMC_CMD line is driven low and when CMDTRANS bit is set and the DTDIR = receive, the CPSM DataEnable signal is issued to the DPSM. This enables normal boot operation. This state is left at the end of the boot procedure by clearing the register bit BOOTEN, which cause the SDMMC_CMD line to be driven high and the CPSM Abort signal is issued to the DPSM, before moving to the Idle state. The CMDSENT flag is generated 56 cycles after SDMMC_CMD line is high.
  – BOOTMODE = 1, move to the Send state. This enables sending of the CMD0 (boot). Clearing BOOTEN has no effect.

Note: The CPSM remains in the Idle state for at least eight SDMMC_CK periods to meet the N_{CC} and N_{RC} timing constraints. N_{CC} is the minimum delay between two host commands, and N_{RC} is the minimum delay between the host command and the card response.

Note: The response timeout has a fixed value of 64 SDMMC_CK clock periods.

A command is a token that starts an operation. Commands are sent from the host to either a single card (addressed command) or all connected cards (broadcast command are available for *e*•MMC V3.31 or previous). Commands are transferred serially on the SDMMC_CMD line. All commands have a fixed length of 48 bits. The general format for a command token for SD-Memory cards, SDIO cards, and *e*•MMC cards is shown in *Table 478.*

The command token data is taken from 2 registers, one containing a 32-bits argument and the other containing the 6-bits command index (six bits sent to a card).

Table 478. Command token format

Bit position	Width	Value	Description
47	1	0	Start bit
46	1	1	Transmission bit
[45:40]	6	x	Command index
[39:8]	32	x	Argument
[7:1]	7	x	CRC7
0	1	1	End bit

Next to the command data there are command type (WAITRESP) bits controlling the command path state machine (CPSM). These bits also determine whether the command requires a response, and whether the response is short (48 bit) or long (136 bits) long, and if a CRC is present or not.

A response is a token that is sent from an addressed card or synchronously from all connected cards to the host as an answer to a previous received command. All responses are sent via the command line SDMMC_CMD. The response transmission always starts with the left bit of the bit string corresponding to the response code word. The code length depends on the response type. Response tokens R1, R2, R3, R4, R5, and R6 have various

coding schemes, depending on their content. The general formats for the response tokens for SD-Memory cards, SDIO cards, and *e*•MMC cards are shown in *Table 479*, *Table 480* and *Table 481*.

A response always starts with a start bit (always 0), followed by the bit indicating the direction of transmission (card = 0). A value denoted by x in the tables below indicates a variable entry. Most responses, except some, are protected by a CRC. Every command code word is terminated by the end bit (always 1).

The response token data is stored in 5 registers, four containing the 32-bits card status, OCR register, argument or 127-bits CID or CSD register including internal CRC, and one register containing the 6-bits command index.

Table 479. Short response with CRC token format

Bit position	Width	Value	Description
47	1	0	Start bit
46	1	0	Transmission bit
[45:40]	6	x	Command index (or reserved 111111)
[39:8]	32	x	Argument
[7:1]	7	x	CRC7
0	1	1	End bit

Table 480. Short response without CRC token format

Bit position	Width	Value	Description
47	1	0	Start bit
46	1	0	Transmission bit
[45:40]	6	x	Command index (or reserved 111111)
[39:8]	32	x	Argument
[7:1]	7	1111111	(reserved 1111111)
0	1	1	End bit

Table 481. Long response with CRC token format

Bit position	Width	Value	Description
135	1	0	Start bit
134	1	0	Transmission bit
[133:128]	6	111111	Reserved
[127:1]	127:8	x	CID or CSD slices
	7:1	x	CRC7 (included in CID or CSD)
0	1	1	End bit

The command/response path operates in a half-duplex mode, so that either commands can be sent or responses can be received. If the CPSM is not in the Send state, the

SDMMC_CMD output is in the Hi-Z state. Data sent on SDMMC_CMD are synchronous with the SDMMC_CK according the NEGEDGE register bit see *Figure 735*.

The command and short response with CRC, the CRC generator calculates the CRC checksum for all 40 bits before the CRC code. This includes the start bit, transmission bit, command index, and command argument (or card status).

For the long response the CRC checksum is calculated only over the 120 bits of R2 CID or CSD. Note that the start bit, transmission bit and the six reserved bits are not used in the CRC calculation.

The CRC checksum is a 7-bit value:

CRC[6:0] = remainder [(M(x) * x^7) / G(x)]

G(x) = $x^7 + x^3 + 1$

M(x) = (first bit) * x^n + (second bit) * x^{n-1}+... + (last bit before CRC) * x^0

Where n = 39 or 119.

The CPSM can send a number of specific commands to handle various operating modes when CPSMEN is set, see *Table 482*.

Table 482. Specific Commands overview

VSWITCH	BOOTEN	BOOTMOD	CMDTRAN	WAITPEND	CMDSTOP	WAITINT	Description
1	x	x	x	x	x	x	Start Voltage Switch Sequence
0	1	x	x	x	x	x	Start normal boot
0	1	1	x	x	x	x	Start alternative boot
0	0	1	x	x	x	x	Stop alternative boot.
0	0	0	1	x	x	x	Send command with associated data transfer.
0	0	0	0	1	1	x	*e*•MMC stream data transfer, command (STOP_TRANSMISSION) pending until end of data transfer.
0	0	0	0	1	0	x	*e*•MMC stream data transfer, command different from (STOP_TRANSMISSION) pending until end of data transfer.
0	0	0	0	0	1	x	Send command (STOP_TRANSMISSION), stopping any ongoing data transmission.
0	0	0	0	0	0	1	Enter *e*•MMC wait interrupt (Wait-IRQ) mode.
0	0	0	0	0	0	0	Any other none specific command

The command/response path implements the status flags and associated clear bits shown in *Table 483*:

Table 483. Command path status flags

Flag	Description
CMDSENT	Set at the end of the command without response. (CPSM moves from Send to Idle)
CMDREND	Set at the end of the command response when the CRC is OK. (CPSM moves from Receive to Idle)
CCRCFAIL	Set at the end of the command response when the CRC is FAIL. (CPSM moves from Receive to Idle)
CTIMEOUT	Set after the command when no response start bit received before the timeout. (CPSM moves from Wait to Idle)
CKSTOP	Set after the voltage switch (VSWITCHEN = 1) command response when the CRC is OK and the SDMMC_CK is stopped. (no impact on CPSM)
VSWEND	Set after the voltage switch (VSWITCH = 1) timeout of 5 ms + 1 ms. (no impact on CPSM)
CPSMACT	Command transfer in progress. (CPSM not in Idle state)

The command path error handling is shown in *Table 484*:

Table 484. Command path error handling

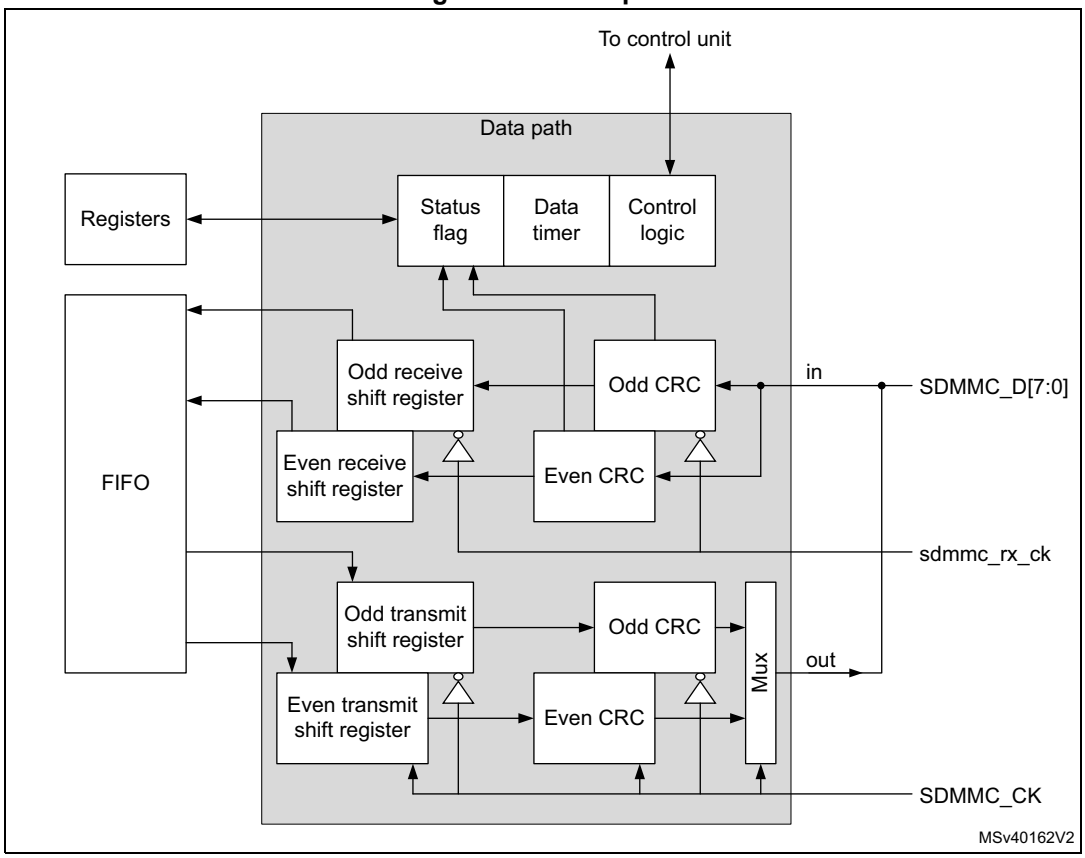
Error	CPSM state	Cause	Card action	Host action	CPSM action
Timeout	Wait	No start bit in time	Unknown	Reset or cycle power card(1)	Move to Idle
CRC status	Receive	Negative status	Command ignored	Resend command(1)	Move to Idle
		Transmission error	Command accepted	Resend command(1)	

1. When CMDTRANS is set, also a stop_transmission command must be send to move the DPSM to Idle.

Data path

The data path subunit transfers data on the SDMMC_D[7:0] lines to and from cards. The data transmit path is clocked on the SDMMC_CK and sends data to the card. The data receive path is clocked on the sdmmc_rx_ck and receives data from the card. *Figure 739* shows the data path block diagram.

Figure 739. Data path



The card data bus width can be programmed in the clock control register bits WIDBUS. The supported data bus width modes are:

- If the wide bus mode is not enabled, only one bit is transferred over SDMMC_D0.
- If the 4-bit wide bus mode is enabled, data is transferred at four bits over SDMMC_D[3:0].
- If the 8-bit wide bus mode is enabled, data is transferred at eight bits over SDMMC_D[7:0].

Next to the data bus width the data sampling mode can be programmed in the clock control register bit DDR. The supported data sampling modes are:

- Single data rate signaling (SDR), data is clocked on the rising edge of the clock.
- Double data rate signaling (DDR), data is clocked on the both edges of the clock. DDR mode is only supported in wide bus mode (4-bit wide and 8-bit wide).

Note: The data sampling mode only applies to the SDMMC_D[7:0] lines. (not applicable to the SDMMC_CMD line.)

In DDR mode, data is sampled on both edges of the SDMMC_CK according the following rules, see also *Figure 740* and *Figure 741*:

- On the rising edge of the clock odd bytes are sampled.
- On the falling edge of the clock even bytes are sampled.
- Data payload size is always a multiple of 2 Bytes.
- Two CRC16 are computed per data line
  - Odd bits CRC16 clocked on the falling edge of the clock.
  - Even bits CRC16 clocked on the rising edge of the clock.
- Start, end bits and idle conditions are full cycle.
- CRC status / boot acknowledgment and busy signaling are full cycle and are only sampled on the rising edge of the clock.

In DDR mode the SDMMC_CK clock division must be >= 2.

Figure 740. DDR mode data packet clocking

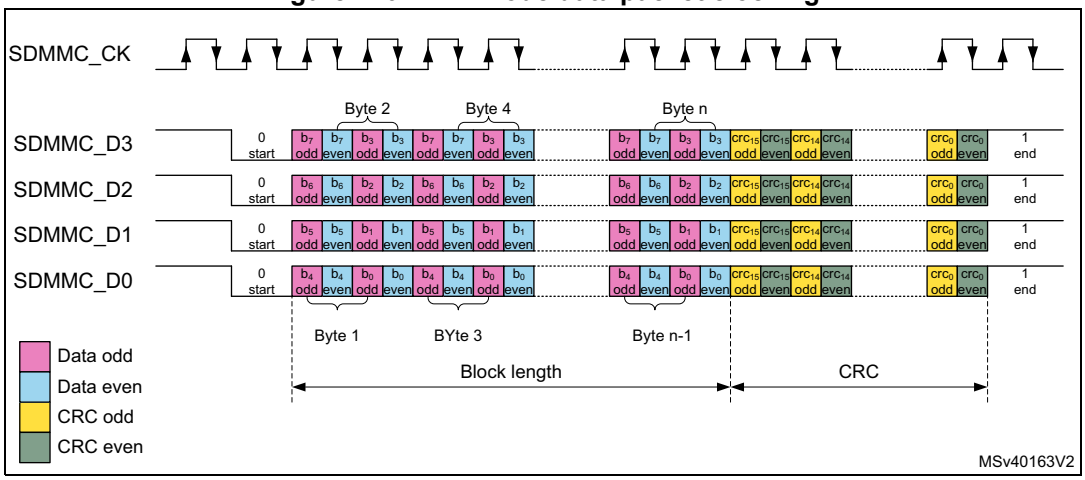
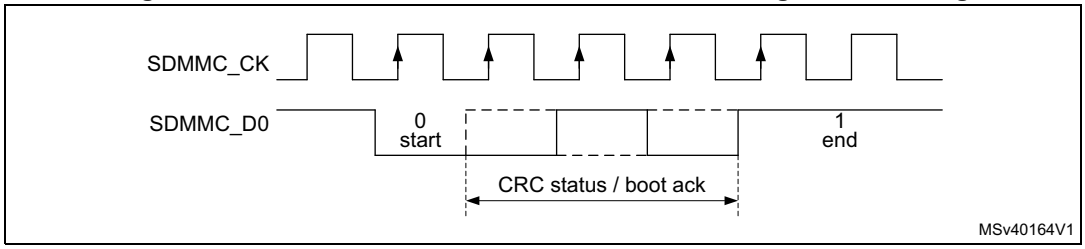


Figure 741. DDR mode CRC status / boot acknowledgment clocking



Data path state machine (DPSM)

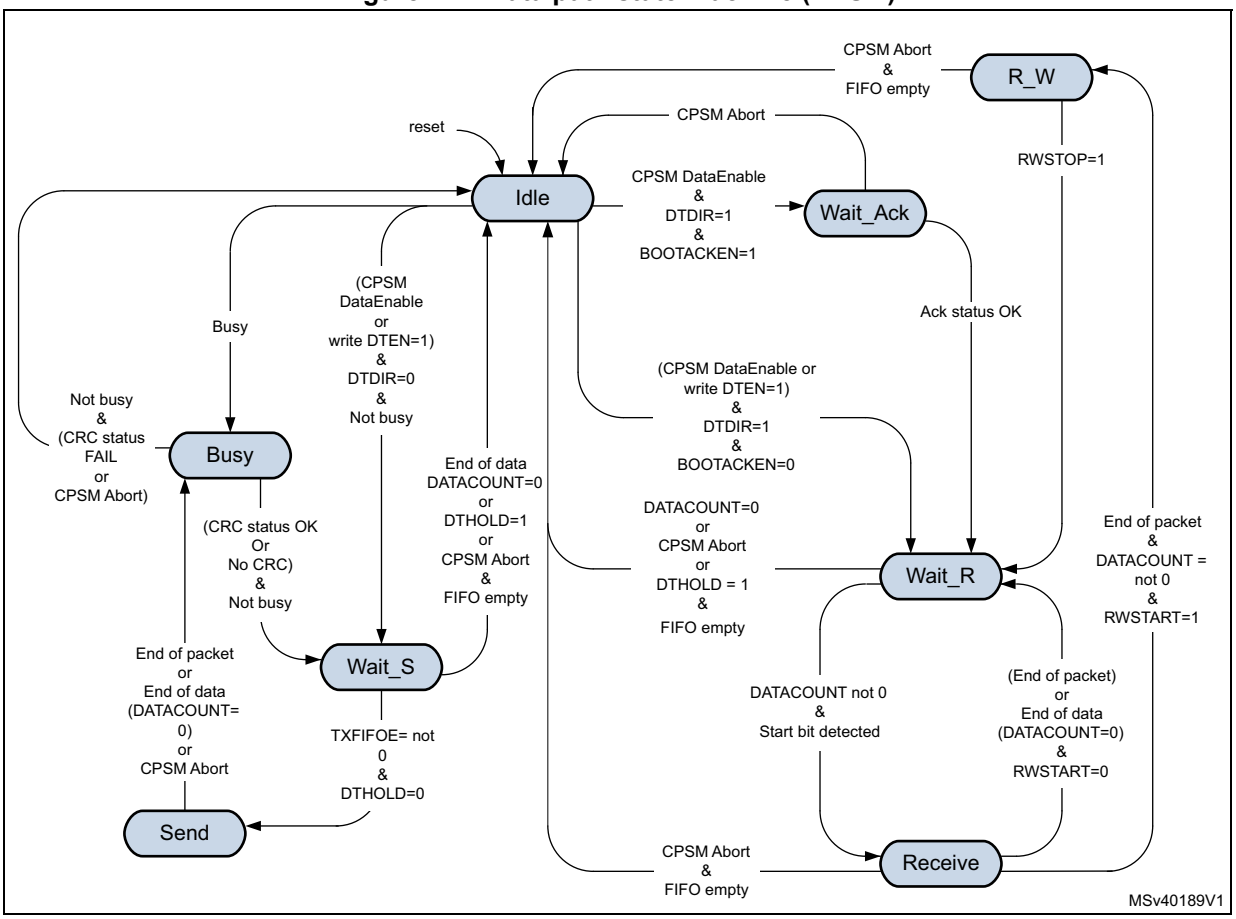
Depending on the transfer direction (send or receive), the data path state machine (DPSM) moves to the Wait_S or Wait_R state when it is enabled:

- Send: the DPSM moves to the Wait_S state. If there is data in the transmit FIFO, the DPSM moves to the Send state, and the data path subunit starts sending data to a card.
- Receive: the DPSM moves to the Wait_R state and waits for a start bit. When it receives a start bit, the DPSM moves to the Receive state, and the data path subunit starts receiving data from a card.

For boot operation with acknowledgment the DPSM moves to the Wait_Ack state and waits for the boot acknowledgment before moving to the Wait_R state.

The DPSM operates at SDMMC_CK. The DPSM has the following states, as shown in *Figure 742*. When ever the DPSM is active, i.e. not in the Idle state, the DPSMACT bit is set.

Figure 742. Data path state machine (DPSM)



- **Idle** state: the data path is inactive, and the SDMMC_D[7:0] outputs are according the PWRCTRL setting. The DPSM is activated either by sending a command with CMDTRANS bit set or by setting the DTEN bit, or by detecting Busy on SDMMC_D0 (that is, after a command with R1b response).

  When not busy, the DPSM activates the SDMMC_CK clock (when stopped due to power save PWRSAV bit), loads the data counter with a new (DATALENGTH) value and:

  – When the data direction bit (DTDIR) indicates send, moves to the Wait_S.

  – When the data direction bit (DTDIR) indicates receive, moves to the
  - Wait_R when BOOTACKEN register bit is clear.
  - Wait_Ack when BOOTACKEN register bit is set and start the acknowledgment timeout.

  When busy the DPSM keeps the SDMMC_CK clock active and move to the Busy state.

Note: DTEN must not be used to start data transfer with SD, SDIO and e•MMC cards.

- **Wait_Ack** state: the data path waits for the boot acknowledgment token.
  - The DPSM moves to the Wait_R state if it receives an error free acknowledgment before a timeout.
  - When a pattern different from the acknowledgment is received an acknowledgment status error is generated, and the ack fail status flag (ACKFAIL) is set. The DPSM stays in Wait_Ack.
  - If it reaches a timeout (ACKTIME) before it detects a start bit, it sets the timeout status flag (ACKTIMEOUT). The DPSM stays in Wait_Ack.
  - When the CPSM Abort signal is set it moves to the Idle state and sets the DABORT flag.
- **Wait_R** state: the data path, if the data counter is not zero and data is not hold, waits for a start bit on SDMMC_D[n:0]. If the data counter is zero or data is hold, wait for the FIFO to be empty.
  - In block mode, if a start bit is received before a timeout the DPSM moves to the Receive state and loads the data block counter with DBLOCKSIZE.
  - In SDIO multibyte mode, if a start bit is received before a timeout the DPSM moves to the Receive state and loads the data block counter with DATALENGTH.
  - In stream mode, if a start bit is received before a timeout the DPSM moves to the Receive state and loads the data counter with DATALENGTH.
  - if the data counter (DATACOUNT) equals zero (end of data) the DPSM moves to the Idle state when the receive FIFO is empty and the DATAEND flag is set.
  - If it reaches a timeout (DATATIME) before it detects a start bit, it sets the timeout status flag (DTIMEOUT) and the DPSM stays in the Wait_R state.
  - If the CPSM Abort signal is set:
    If DATACOUNT > 0, the DPSM moves to the Idle state when the FIFO is empty and when IDMAEN = 0 reset with FIFORST, and sets the DABORT flag.
    If DATACOUNT is zero normal operation is continued, there is no DABORT flag since the transfer has completed normally.
  - if the DTHOLD bit is set:
    - When DATACOUNT > 0, the DPSM moves to the Idle state when the receive FIFO is empty and when IDMAEN = 0 reset with FIFORST, and issues the DHOLD flag. When holding the timeout is disabled. When an CPSM Abort signal is received during holding, the transfer is aborted.

- When DATACOUNT = 0, the transfer is completed normally and there is no DHOLD flag.

– When DPSM has been started with DTEN, after an error (DTIMEOUT) the DPSM moves to the Idle state when the FIFO is empty and when IDMAEN = 0 reset with FIFORST.

- **R_W** state: the data path Read Wait the bus.
  – The DPSM moves to the Wait_R state when the Read Wait stop bit (RWSTOP) is set, and start the receive timeout.
  – If the CPSM Abort signal is set, wait for the FIFO to be empty and when IDMAEN = 0 reset with FIFORST, then moves to the Idle state and sets the DABORT flag.
- **Receive** state: the data path receives serial data from a card. Pack the data in bytes and written it to the data FIFO. Depending on the transfer mode selected in the data control register (DTMODE), the data transfer mode can be either block or stream:
  – In block mode, when the data block size (DBLOCKSIZE) number of data bytes are received, the DPSM waits until it receives the CRC code.
  – In SDIO multibyte mode, when the data block size (DATALENGTH) number of data bytes are received, the DPSM waits until it receives the CRC code.
  a) If the received CRC code matches the internally generated CRC code, the DPSM moves to the
  - R_W state when RWSTART = 1 and DATACOUNT > zero, the DBCKEND flag is set.
  - Wait_R state otherwise.
  b) If the received CRC code fails the internally generated CRC code any further data reception is prevented.
  - When not all data has been received (DATACOUNT > 0), the CRC fail status flag (DCRCFAIL) is set and the DPSM stays in the Receive state.
  - When all data has been received (DATACOUNT = 0), wait for the FIFO to be empty after which the CRC fail status flag (DCRCFAIL) is set and the DPSM moves to the Idle state.
  – In stream mode, the DPSM receives data while the data counter DATACOUNT > 0. When the counter is zero, the remaining data in the shift register is written to the data FIFO, and the DPSM moves to the Wait_R state.
  – When a FIFO overrun error occurs, the DPSM sets the FIFO overrun error flag (RXOVERR) and any further data reception is prevented. The DPSM stays in the Receive state.
  – When an CPSM Abort signal is received:
  - If the CPSM Abort signal is received before the 2 last bits of the data with DATACOUNT = 0, the transfer is aborted. The remaining data in the shift register is written to the data FIFO, wait for the FIFO to be empty and when IDMAEN = 0 reset with FIFORST, then the DPSM moves to the Idle state and the DABORT flag is set.
  - If the CPSM Abort signal is received during or after the 2 last bits of the transfer with DATACOUNT=0, the transfer is completed normally. The DPSM stays in the Receive state no DABORT flag is generated.
  – When DPSM has been started with DTEN, after an error (DCRCFAIL when DATACOUNT > 0, or RXOVERR) the DPSM moves to the Idle state when the FIFO is empty and when IDMAEN = 0 reset with FIFORST.

- **Wait_S** state: the data path waits for data to be available from the FIFO.
  - If the data counter DATACOUNT > 0, waits until the data FIFO empty flag (TXFIFOE) is de-asserted and DTHOLD is not set, and moves to the Send state.
  - If the data counter (DATACOUNT) = 0 the DPSM moves to the Idle state.
    - When DTHOLD is disabled, the DATAEND flag is set.
    - When DTHOLD is enabled, the DHOLD flag is set.
  - When DTHOLD is set and the DATACOUNT > 0
    - When IDMA is enabled, the DBCKEND flag is set and subsequently the FIFO is flushed, furthermore the DPSM moves to the Idle state and the DHOLD flag is set.
    - When IDMA is disabled the DBCKEND flag is set. Wait for the FIFO to be reset by software with FIFORST, then DPSM moves to the Idle state and issues the DHOLD flag.
  - When DTHOLD is set and DATACOUNT = 0 the transfer is completed normally.
  - When receiving the CPSM Abort signal
    - If the CPSM Abort signal is received before the 2 last bits of the data with DATACOUNT = 0, the transfer is aborted, wait for the FIFO to be empty and when IDMAEN = 0 reset with FIFORST, then the DPSM moves to the Idle state and sets the DABORT flag.
    - If the CPSM Abort signal is received during or after the 2 last bits of the transfer with DATACOUNT=0, normal operation is continued, there is no DABORT flag since the transfer has completed normally.

Note: The DPSM remains in the Wait_S state for at least two clock periods to meet the N_{WR} timing requirements, where N_{WR} is the number of clock cycles between the reception of the card response and the start of the data transfer from the host.

- **Send** state: the DPSM starts sending data to a card. Depending on the transfer mode bit in the data control register, the data transfer mode can be either block, SDIO multibyte or stream:
  - In block mode, when the data block size (DBLOCKSIZE) number of data bytes are send, the DPSM sends an internally generated CRC code and end bit, and moves to the Busy state and start the transmit timeout.
  - In SDIO multibyte mode, when the data block size (DATALENGTH) number of data bytes are send, the DPSM sends an internally generated CRC code and end bit, and moves to the Busy state and start the transmit timeout.
  - In stream mode, the DPSM sends data to a card while the data counter DATACOUNT > 0. When the data counter reaches zero moves to the Busy state and start the transmit timeout.
    Before sending the last stream Byte according to DATACOUNT, the DPSM issues a trigger on the send CMD signal. This signal is used by the CPSM to sent any pending command. (i.e. CMD12 Stop Transmission command)
  - If a FIFO underrun error occurs, the DPSM sets the FIFO underrun error flag (TXUNDERR). The DPSM stays in the Send state.
  - When receiving the CPSM Abort signal
    - If the CPSM Abort signal is received before the 2 last bits of the transfer with DATACOUNT=0, the transfer is aborted. The DPSM sends a last data bit followed by an end bit. The FIFO is disabled/flushed, and the DPSM moves to the Busy state to wait for not busy before setting the DABORT flag.
    - If the CPSM Abort signal is received during or after the 2 last bits of the transfer

with DATACOUNT=0, the transfer is completed normally, there is no DABORT flag.

- **Busy** state: the DPSM waits for the CRC status token when expected, and wait for a not busy signal:
  - If a CRC status token is expected and indicate “non-erroneous transmission” or when there is no CRC expected:
    - it moves to the Wait_S state when SDMMC_D0 is not low (the card is not busy).
    - When the card is busy SDMMC_D0 is low it remains in the Busy state.
  - If a CRC status token is expected and indicates “erroneous transmission”.
    - When not all data has been send (DATACOUNT > 0). The DPSM waits for not busy after which the CRC fail status flag (DCRCFAIL) is set. The FIFO is disabled/flushed and the DPSM stays in the Busy state.
    - When all data has been send (DATACOUNT = 0). The DPSM waits for not busy after which the CRC fail status flag (DCRCFAIL) is set and the DPSM moves to the Idle state.
  - If a CRC status (Ncrc) timeout occurs while the DPSM is in the Busy state, it sets the data timeout flag (DTIMEOUT) and stays in the Busy state.
  - If a busy timeout occurs while the DPSM is in the Busy state, it sets the data timeout flag (DTIMEOUT) and stays in the Busy state.
  - When receiving the CPSM Abort signal in the Busy state:
    - If the CPSM Abort signal is received before the 2 last bits of the CRC response with DATACOUNT > 0, the data transfer is aborted. The DPSM waits for not busy and the FIFO to be disabled/flushed before moving to the Idle state and the DABORT flag is set.
    - If the CPSM Abort signal is received during or after the 2 last bits of the CRC response when DATACOUNT=0 or when no CRC is expected and DATACOUNT = 0 and there has been no DTIMEOUT error, the DPSM stays in the Busy state no DABORT flag is generated, since the transfer may completed normally.
    - If the CPSM Abort signal is received when a DTIMEOUT error has occurred the DPSM waits for not busy and the FIFO to be disabled/flushed before moving to the Idle state and the DABORT flag is set.
  - When entering the Busy state due to an abort in the Send state, the DPSM waits for not busy before moving to the Idle state and the DABORT flag is set.
  - When DPSM has been started with DTEN, after an error (DCRCFAIL when DATACOUNT > 0, or DTIMEOUT) the DPSM moves to the Idle state when the FIFO is reset.
  - When the DPSM has been started due to Busy on SDMMC_D0, waits for not busy after which the Busy end status flag (BUSYD0END) is set and the DPSM moves to the Idle state.

The data timer (DATATIME) is enabled when the DPSM is in the Wait_R or Busy state 2 cycles after the data block end bit, or data read command end bit, or R1b response, and generates the data timeout error (DTIMEOUT):

- When transmitting data, the timeout occurs
  - when a CRC status is expected and no start bit is received withing 8 SDMMC_CK cycles, the DTIMEOUT flag is set.
  - when the Busy state takes longer than the programmed timeout period., the DTIMEOUT flag is set.
- When receiving data, the timeout occurs
  - when there is still data to be received DATACOUNT > 0 and no start bit is received before the programmed timeout period, the DTIMEOUT flag is set.
- After a R1b response, the timeout occurs
  - when the Busy state takes longer than the programmed timeout period., the DTIMEOUT flag is set.

When DATATIME = 0,

- In receive the start bit must be present 2 cycles after the data block end bit or data read command end bit.
- In transmit busy is timed out 2 cycles after the CRC token end bit or stream data end bit.
- After a R1b response busy is timed out 2 cycles after the response end bit.

Data can be transferred from the card to the host (transmit, send) or vice versa (receive). Data are transferred via the SDMMC_Dn data lines, they are stored in a FIFO.

Table 485. Data token format

Description	Start bit	Data(1)	CRC16	End bit	DTMODE
Block data	0	(DBLOCKSIZE, DATALENGTH)	yes	1	00
SDIO multibyte	0	(DATALENGTH)	yes	1	01
e•MMC stream	0	(DATALENGTH)	no	1	10

1. The total amount of data to transfer is given by DATALENGTH. Where for Block data the amount of data in each block is given by DBLOCKSIZE.

The data token format is selected with register bits DTMODE according.

The data path implements the status flags and associated clear bits shown in *Table 486*:

Table 486. Data path status flags and clear bits

Flag		Description
DATAEND	TX	Set at the end of the complete data transfer when the CRC is OK and busy has finished and both DTHOLD = 0 and DATACOUNT = 0. (DPSM moves from Wait_S to Idle)
	RX	Set at the end of the complete data transfer when the CRC is OK and all data has been read, (DATACOUNT = 0 and FIFO is empty). (DPSM moves from Wait_R to Idle)
	Boot	

Table 486. Data path status flags and clear bits (continued)

Flag		Description
DCRCFAIL	TX	Set at the end of the CRC when FAIL and busy has finished. (DPSM stay in Busy when there is still data to send and wait for CPSM Abort) (DPSM moves from Busy to Idle when all data has been sent) or DPSM has been started with DTEN
	RX	Set at the end of the CRC when FAIL and FIFO is empty. (DPSM stays in Receive when there is still data to be received and wait for CPSM Abort) (DPSM moves from Receive to Idle when all data has been received or DPSM has been started with DTEN)
	Boot	
ACKFAIL	Boot	Set at the end of the boot acknowledgment when fail. (DPSM stays in Wait_Ack and wait for CPSM Abort)
DTIMEOUT	CMD R1b	Set after the command response no end of busy received before the timeout. (DPSM stays in Busy and wait for CPSM Abort)
	TX	Set when no CRC token start bit received within Ncrc, or no end of busy received before the timeout. (DPSM stays in Busy and wait for CPSM Abort) (When DPSM has been started with DTEN move to Idle) Note: The DCRCFAIL flag may also be set when CRC failed before the busy timeout.
	RX	Set when no start bit received before the timeout. (DPSM stays in Wait_R and wait for CPSM Abort) (When DPSM has been started with DTEN move to Idle)
	Boot	
ACKTIMEOUT	Boot	Set when no start bit received before the timeout. (DPSM stays in Wait_Ack and wait for CPSM Abort)
DBCKEND	TX	When DTHOLD = 1 and IDMAEN = 0: Set at the end of data block transfer when the CRC is OK and busy has finished, when data transfer is not complete (DATACOUNT >0). (DPSM moves from Busy to Wait_S)
	RX	When RWSTART = 1: Set at the end of data block transfer when the CRC is OK, when data transfer is not complete (DATACOUNT > 0). (DPSM moves from Receive to R_W)
	Boot	
DHOLD	TX	When DTHOLD = 1: Set at the end of data block transfer when the CRC is OK and busy has finished. (DPSM moves from Wait_S to Idle)
	RX	When DTHOLD = 1: Set at the end of data block transfer when the CRC is OK and all data has been read (FIFO is empty), when data transfer is not complete (DATACOUNT >0). (DPSM moves from Wait_R to Idle)
DABORT	CMD R1b	When CPSM Abort event has been sent by the CPSM and busy has finished. (DPSM moves from Busy to Idle)
	TX	When CPSM Abort event has been sent by the CPSM before the 2 last bits of the transfer. (DPSM moves from any state to Idle)
	RX	
	Boot	
BUSYD0END	CMD R1b	Set after the command response when end of busy before the timeout. (DPSM moves from Busy to Idle)
DPSMACT		Data transfer in progress. (DPSM not in Idle state)

The data path error handling is shown in *Table 487*:

Table 487. Data path error handling

Error	DPSM state	Cause	Card action	Host action	DPSM action
Timeout	Wait_Ack	No Ack in time	unknown	Card cycle power	Stay in Wait_Ack (reset the SDMMC with the RCC.SDMMCxRST register bit)
	Wait_R	No start bit in time	unknown	Stop data reception Send stop transmission command	On CPSM Abort move to Idle
			unknown	Stop boot procedure	
	Busy	Busy too long (due to data transfer)	unknown	Stop data reception Send stop transmission command	
		Busy too long (due to R1b)	unknown	Send reset command	
CRC	Receive	transmission error	Send further data	Stop data reception Send stop transmission command	On CPSM Abort move to Idle
CRC status	Busy	Negative status	Ignore further data	Stop data transmission Send stop transmission command	On CPSM Abort move to Idle
		transmission error	wait for further data		
Ack status	Wait_Ack	transmission error	Send boot data	Stop boot procedure	On CPSM Abort move to Idle
Overrun	Receive	FIFO full	Send further data	Stop data reception Send stop transmission command	On CPSM Abort move to Idle
Underrun	Send	FIFO empty	Receive further data	Stop data transmission Send stop transmission command	On CPSM Abort move to Idle

Data FIFO

The data FIFO (first-in-first-out) subunit contains the transmit and receive data buffer. A single FIFO is used for either transmit or receive as selected by the DTDIR bit. The FIFO contain a 32-bit wide, 16-word deep data buffer and control logic. Because the data FIFO operates in the AHB clock domain (sdmmc_hclk), all signals from the subunits in the SDMMC clock domain (SDMMC_CK/sdmmc_rx_ck) are resynchronized.

The FIFO can be in one of the following states:

- The transmit FIFO refers to the transmit logic and data buffer when sending data out to the card. (DTDIR = 0)
- The receive FIFO refers to the receive logic and data buffer when receiving data in from the card. (DTDIR = 1)

The end of a correctly completed SDMMC data transfer from the FIFO is indicated by the DATAEND flags driven by the data path subunit. Any incorrect (aborted) SDMMC data transfer from the FIFO is indicated by one of the error flags (DCRCFAIL, DTIMEOUT, DABORT) driven by the data path subunit, or one of the FIFO error flags (TXUNDERR, RXOVERR) driven by the FIFO control.

The data FIFO can be accessed in the following ways, see *Table 488*.

Table 488. Data FIFO access

Data FIFO access	IDMAEN
From firmware via AHB slave interface	0
From IDMA via AHB master interface	1

Transmit FIFO:

Data can be written to the transmit FIFO when the DPSM has been activated (DPSMACT = 1).

When IDMAEN = 1 the FIFO is fully handled by the IDMA.

When IDMAEN = 0 the FIFO is controlled by firmware via the AHB slave interface. The transmit FIFO is accessible via sequential addresses. The transmit FIFO contains a data output register that holds the data word pointed to by the read pointer. When the data path subunit has loaded its shift register, it increments the read pointer and drives new data out. The transmit FIFO is handled in the following way:

1. Write the data length into DATALENGTH and the block length in DBLOCKSIZE.
   - For block data transfer (DTMODE = 0), DATALENGTH must be an integer multiple of DBLOCKSIZE.
2. Set the SDMMC in transmit mode (DTDIR = 0).
   - Configures the FIFO in transmit mode.
3. Enable the data transfer
   - either by sending a command from the CPSM with the CMDTRANS bit set
   - or by setting DTEN bit
4. When (DPSMACT = 1) write data to the FIFO.
   - The DPSM stays in the Wait_S state until FIFO is full (TXFIFOF = 1), or the number indicated by DATALENGTH.

- The SDMMC keeps sending data as long as FIFO is not empty, hardware flow control during data transfer is used to prevent FIFO underrun.

5. Write data to the FIFO.
   – When the FIFO is handled by software, wait until the FIFO is half empty (TXFIFOHE flag), write data to the FIFO until FIFO is full (TXFIFOF = 1), or last data has been written.
   – When the FIFO is handled by the IDMA, the IDMA transfers the FIFO date.
6. When last data has been written wait for end of data (DATAEND flag)
   – SDMMC has completely sent all data and the DPSM is disabled (DPSMACT = 0).

In case of a data transfer error or transfer hold when IDMAEN = 0, firmware must stop writing to the FIFO and flush and reset the FIFO with the FIFORST register bit.

The transmit FIFO status flags are listed in *Table 489*.

Table 489. Transmit FIFO status flags

Flag	Description
TXFIFOF	Set to high when all transmit FIFO words contain valid data.
TXFIFOE	Set to high when the transmit FIFO does not contain valid data.
TXFIFOHE	Set to high when half or more transmit FIFO words are empty.
TXUNDERR	Set to high when an underrun error occurs. This flag is cleared by writing to the SDMMC Clear register.

Receive FIFO:

Data can be read from the receive FIFO when the DPSM is activated (DPSMACT = 1).

When IDMAEN = 1 the FIFO is fully handled by the IDMA.

When IDMAEN = 0 the FIFO is controlled by firmware via the AHB slave interface.When the data path subunit receives a word of data, it drives the data on the write databus. The write pointer is incremented after the write operation completes. On the read side, the contents of the FIFO word pointed to by the current value of the read pointer is driven onto the read databus. The receive FIFO is accessible via sequential addresses.

The receive FIFO is handled in the following way:

1. Write the data length into DATALENGTH and the block length in DBLOCKSIZE.
   – For block data transfer (DTMODE = 0), DATALENGTH must be an integer multiple of DBLOCKSIZE.
2. Set the SDMMC in receive mode (DTDIR = 1).
   – Configures the FIFO in receive mode.
3. Enable the DPSM transfer
   – either by sending a command from the CPSM with the CMDTRANS bit set
   – or by setting DTEN bit.
4. When (DPSMACT = 1) the FIFO is ready to receive data.
   – The DPSM writes the received data to the FIFO.
   - The SDMMC keeps receiving data as long as FIFO is not full, hardware flow control during the data transfer is used to prevent FIFO overrun.
5. Read data from the FIFO.
   – When the FIFO is handled by software, wait until the FIFO is half full (RXFIFOHF flag), read data from the FIFO until FIFO is empty (RXFIFOE = 1).
   - When last data has been received end of data (DATAEND flag), read data from the FIFO until FIFO is empty (RXFIFOE = 1).
   – When the FIFO is handled by the IDMA, the IDMA transfers the FIFO date.
6. SDMMC has completely received all data and the DPSM is disabled (DPSMACT = 0).

In case of a data transfer hold when IDMAEN = 0, the firmware must read the remaining data until the FIFO is empty and reset the FIFO with the FIFORST register bit. This causes the DPSM to go to the Idle state (DPSMACT = 0).

In case of a data transfer error when IDMAEN = 0, the firmware must stop reading the FIFO and flush and reset the FIFO with the FIFORST register bit. This causes the DPSM to go to the Idle state (DPSMACT = 0).

The receive FIFO status flags are listed in *Table 490*.

Table 490. Receive FIFO status flags

Flag	Description
RXFIFOF	Set to high when all receive FIFO words contain valid data
RXFIFOE	Set to high when the receive FIFO does not contain valid data.
RXFIFOHF	Set to high when half or more receive FIFO words contain valid data.
RXOVERR	Set to high when an overrun error occurs. This flag is cleared by writing to the SDMMC Clear register.

CLKMUX unit

The CLKMUX selects the source for clock sdmmc_rx_ck to be used with the received data and command response. The receive data clock source can be selected by the clock control register bit SELCLKRX, between:

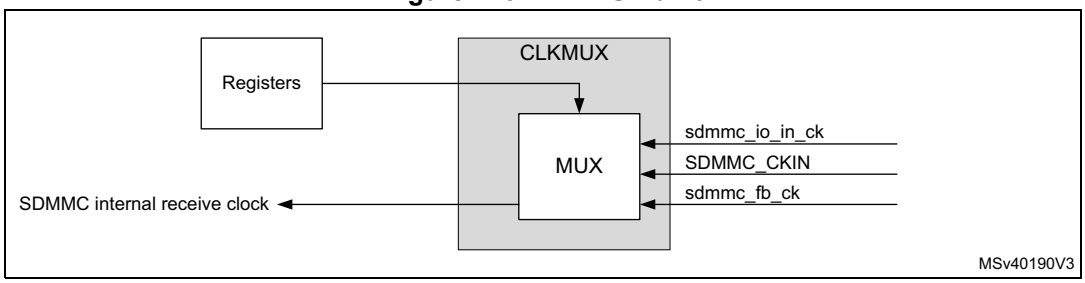
- sdmmc_io_in_ck bus master main feedback clock.
- SDMMC_CKIN external bus feedback clock.
- sdmmc_fb_ck bus tuned feedback clock.

The sdmmc_io_in_ck is selected when there is no external driver, with DS and HS.

The SDMMC_CKIN is selected when there is an external driver with SDR12, SDR25, SDR50 and DDR50.

The sdmmc_fb_ck clock input must be selected when the DLYB block on the device is used with SDR104, HS200 and optionally with SDR50 and DDR50 modes.

Figure 743. CLKMUX unit



The sdmmc_rx_ck source must be changed when the CPSM and DPSM are in the Idle state.

60.5.5 SDMMC AHB slave interface

The AHB slave interface generates the interrupt requests, and accesses the SDMMC adapter registers and the data FIFO. It consists of a data path, register decoder, and interrupt logic.

SDMMC FIFO

The FIFO access is restricted to word access only:

- In transmit FIFO mode
  - Data are written to the FIFO in words (32-bits) until all data according DATALENGTH has been transfered. When the DATALENGTH is not an integer multiple of 4, the last remaining data (1, 2 or 3 bytes) are written with a word transfer.
- In receive FIFO mode
  - Data are read from the FIFO in words (32-bits) until all data according DATALENGTH has been transfered. When the DATALENGTH is not an integer multiple of 4, the last remaining data (1, 2 or 3 bytes) are read with a word transfer padded with 0 value bytes.

When accessing the FIFO with half word or byte accesses an AHB bus fault is generated.

SDMMC interrupts

The interrupt logic generates an interrupt request signal that is asserted when at least one of the unmasked status flags is active. A mask register is provided to allow selection of the conditions that generate an interrupt. A status flag generates the interrupt request if a corresponding mask flag is set. Some status flags require an implicit clear in the clear register.

60.5.6 SDMMC AHB master interface

The AHB master interface is used to transfer the data between a memory and the FIFO using the SDMMC IDMA.

SDMMC IDMA

Direct memory access (DMA) is used to provide high-speed transfer between the SDMMC FIFO and the memory. The AHB master optimizes the bandwidth of the system bus. The SDMMC internal DMA (IDMA) provides one channel to be used either for transmit or receive.

The IDMA is enabled by the IDMAEN bit and supports burst transfers of 8 beats.

- In transmit burst transfer mode:
  - Data are fetched in burst from memory whenever the FIFO is empty for the number of burst transfers, until all data according DATALENGTH has been transfered. When the DATALENGTH is not an integer multiple of the burst size the remaining, smaller then burst size data is transfered using single transfer mode. When the DATALENGTH is not an integer multiple of 4, the last remaining data (1, 2 or 3 bytes) are fetched with a word transfer.
- In receive burst transfer mode:
  - Data are stored in burst in to memory whenever the FIFO contains the number of burst transfers, until all data according DATALENGTH has been transfered. When the DATALENGTH is not an integer multiple of the burst transfer the remaining, smaller then burst size data, is transfered using single transfer mode. When the DATALENGTH is not an integer multiple of 4, the last remaining data (1, 2 or 3 bytes) are stored with halfword and or byte transfers.

In addition the IDMA provides the following channel configurations selected by bit IDMABMODE:

- single buffered channel
- double buffered channel

Single buffered channel

In single buffer configuration the data at the memory side is accessed in a linear matter starting from the base address IDMABASE0. When the IDMA has finished transferring all data the and the DPSM has completed the transfer the DATAEND flag is set.

Double buffered channel

In double buffer configuration the data at the memory side is subsequently accessed from 2 buffers, one located from base address IDMABASE0 and a second located from base address IDMABASE1. This allows firmware to process one memory buffer while the IDMA is accessing the other memory buffer. The size of the memory buffers is defined by IDMABSIZE. The buffer size must be an integer multiple of the burst size. It is possible to update the base address of the buffers on-the-fly when the channel is enabled, the following rule apply:

- When IDMABACT bit is ‘0’ the IDMA hardware uses the IDMABASE0 to access memory. When attempting to write to this register by Firmware the write is discarded, IDMABASE0 data isl not changed. Firmware is authorized to write IDMABASE1.
- When IDMABACT bit is ‘1’ the IDMA hardware uses the IDMABASE1 to access memory. When attempting to write to this register by Firmware the write is discarded, IDMABASE1 data is not changed. Firmware is authorized to write IDMABASE0.

When the IDMA has finished transferring the data of one buffer the buffer transfer complete flag (IDMABTC) is set and the IDMABACT bit toggles where after the IDMA continues

transferring data from the other buffer. When the IDMA has finished transferring all data and the DPSM has completed the transfer the DATAEND flag is set.

The IDMABASEn address must be word aligned.

IDMA transfer error management

An IDMA transfer error can occur:

- When reading or writing a reserved address space.

On a IDMA transfer error subsequent IDMA transfers are disabled and an IDMATE flag is set. Depending when the IDMA transfer error occurs, it normally causes the generation of a TXUNDERR or RXOVERR error.

The behavior of the IDMATE flag depend on when the IDMA transfer error occurs during the SDMMC transfer:

- An IDMA transfer error is detected before any SDMMC transfer error (TXUNDERR, RXOVERR, DCRCFAIL, or DTIMEOUT):
  - The IDMATE flag is set at the same time as the SDMMC transfer error flag.
  - The TXUNDERR, RXOVERR, DCRCFAIL, or DTIMEOUT interrupt is generated.
- An IDMA transfer error is detected during a STOP_TRANSNMISSION command:
  - The IDMATE flag is set at the same time as the DABORT flag.
  - The DABORT interrupt is generated.
- An IDMA transfer error is detected at the end of the SDMMC transfer (DHOLD, or DATAEND).
  - The IDMATE flag is set at the end of the SDMMC transfer.
  - A SDMMC transfer end interrupt is generated and a DHOLD or DATAEND flag is set.

The IDMATE is generated on an other SDMMC transfer interrupt (TXUNDERR. RXOVERR, DCRCFAIL, DTIMEOUT, DABORT, DHOLD, or DATAEND).

60.5.7 MDMA request generation

The internal trigger lines from the SDMMC allow passing direct request to MDMA controller to enable successive transfers from/to different internal RAM addresses without CPU use.

When a data transfer from/to the card completes successfully, the DATAEND flag of the status register is set. The event is signaled to an MDMA request input through the sdmmc_dataend_trg output. It can trigger the clearance of the DATAEND and CMDREND flags and, eventually, a new transfer start, through MDMA direct access to the SDMMC control and configuration registers, thus without CPU intervention.

When a command response is received successfully, the CMDREND flag of the status register is set. When a busy state following an R1b response ends, the BUSYD0 flag of the status register falls down and the BUSYD0END flag rises. The sdmmc_cmdend_trg output connected to the MDMA is set when the sequence command response associated with an eventual busy signal ends. In this way, the MDMA can manage STOP_TRANSMISSION command (needed to support open mode transfers) by clearing CMDREND and BUSYD0END status flags.

When using LINUX operating system, data to be transferred through SDMMC bus are contained in separate 1- to 4-Kbyte blocks of the device internal memory at non-consecutive addresses. The double buffer mode allows changing the address targeted by the IDMA in

the internal memory. Each time a buffer transfer is completed, the IDMABTC flag of the status register is set. By signaling this event to MDMA through the sdmmc_buffend_trg output connected to an MDMA request input, the new buffer address base can alternatively fill the IDMABASE0 / IDMABASE1 fields without CPU intervention.

The actions to program in the MDMA according to the SDMMC requests are provided in the following table:

Table 491. SDMMC connections to MDMA

Trigger signal	Event signaled	Event occurrence condition	MDMA transfer configuration	MDMA action
sdmmc_ dataend_trg	End of successful data transfer	DATAEND = 1	single	Set DATAENDC
sdmmc_ cmdend_trg	End of command sequence	CMDSENT = 1, or (CMDREND = 1 and BUSYD0 = 0)	single	Set CMDSENTC Set CMDRENDC Set BUSYD0ENDC
sdmmc_ buffend_trg	End of buffer reached	IDMABTC = 1	link list	Set IDMABTCC Update IDMABASE0/1

60.5.8 AHB and SDMMC_CK clock relation

The AHB must at least have 3x more bandwidth than the SDMMC bus bandwidth i.e. for SDR50 4-bit mode (50 Mbyte/s) the minimum sdmmc_hclk frequency is 37.5 MHz (150 Mbyte/s).

Table 492. AHB and SDMMC_CK clock frequency relation

SDMMC bus mode	SDMMC bus width	Maximum SDMMC_CK [MHz]	Minimum AHB clock [MHz]
e•MMC DS	8	26	19.5
e•MMC HS	8	52	39
e•MMC DDR52	8	52	78
e•MMC HS200	8	200	150
SD DS / SDR12	4	25	9.4
SD HS / SDR25	4	50	18.8
SD DDR50	4	50	37.5
SD SDR50	4	100	37.5
SD SDR104	4	208	78

60.6 Card functional description

60.6.1 SD I/O mode

The following features are SDMMC specific operations:

- SDIO interrupts
- SDIO suspend/resume operation (write and read suspend)
- SDIO Read Wait operation by stopping the clock
- SDIO Read Wait operation by SDMMC_D2 signaling

Table 493. SDIO special operation control

Operation mode	SDIOEN	RWMOD	RWSTOP	RWSTART	DTDIR
Interrupt detection	1	X	X	X	X
Suspend/Resume operation	X	X	X	X	X
Read Wait SDMMC_CK clock stop (START)	X	1	0	1	1
Read Wait SDMMC_CK clock stop (STOP)	X	1	1	1	1
Read Wait SDMMC_D2 signaling (START)	X	0	0	1	1
Read Wait SDMMC_D2 signaling (STOP)	X	0	1	1	1

SD I/O interrupts

To allow the SD I/O card to interrupt the host, an interrupt function is available on pin 8 (shared with SDMMC_D1 in 4-bit mode) on the SD interface. The use of the interrupt is optional for each card or function within a card. The SD I/O interrupt is level-sensitive, which means that the interrupt line must be held active (low) until it is either recognized and acted upon by the host or deasserted due to the end of the interrupt period. After the host has serviced the interrupt, the interrupt status bit is cleared via an I/O write to the appropriate bit in the SD I/O card internal registers. The interrupt output of all SD I/O cards is active low and the application must provide external pull-up resistors on all data lines (SDMMC_D[3:0]).

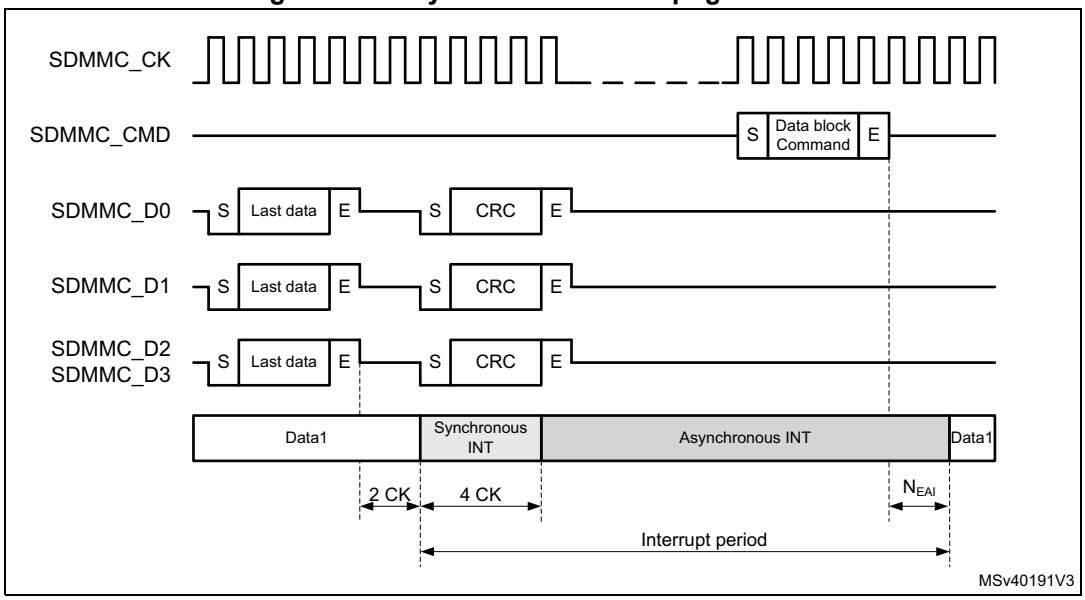
In SD 1-bit mode pin 8 is dedicated to the interrupt function (IRQ), and there are no timing constraints on interrupts.

In SD 4-bit mode the host samples the level of pin 8 (SDMMC_D1/IRQ) into the interrupt detector only during the interrupt period. At all other times, the host interrupt ignores this value. The interrupt period begins when interrupts are enabled at the card and SDIOEN bit is set see register settings in *Table 493*.

In 4-bit mode the card can generate a synchronous or asynchronous interrupt as indicated by the card CCCR register SAI and EAI bits.

- Synchronous interrupt, require the SDMMC_CK to be active.
- Asynchronous interrupt, can be generated when the SDMMC_CK is stopped, 4 cycles after the start of the card interrupt period following the last data block.

Figure 744. Asynchronous interrupt generation



The timing of the interrupt period is depended on the bus speed mode:

In DS, HS, SDR12, and SDR25 mode, selected by register bit BUSSPEED, the interrupt period is synchronous to the SD clock.

- The interrupt period ends at the next clock from the end bit of a command that transfers data block(s) (Command sent with the CMDTRANS bit is set), or when the DTEN bit is set.
- The interrupt period resumes 2 SDMMC_CK after the completion of the data block.
- At the data block gap the interrupt period is limited to 2 SDMMC_CK cycles.

Note: DTEN must not be used to start data transfer with SD and e•MMC cards.

Figure 745. Synchronous interrupt period data read

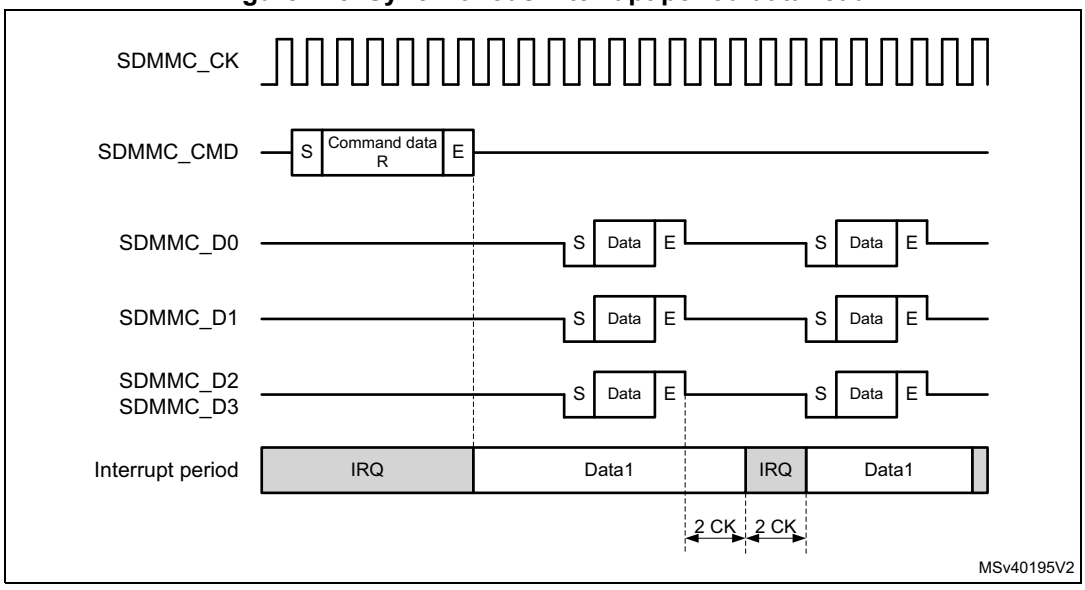
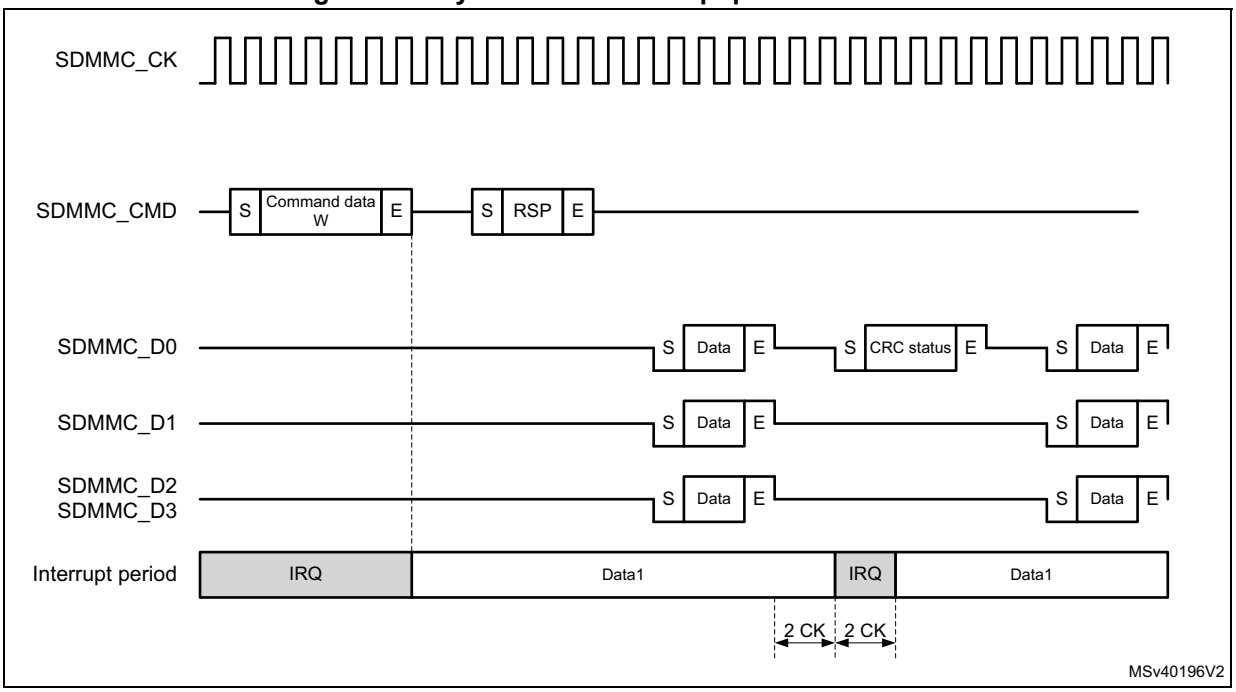


Figure 746. Synchronous interrupt period data write



In SDR50, SDR104, and DDR50, selected by register bit BUSSPEED, due to propagation delay from the card to host, the interrupt period is asynchronous.

- The card interrupt period ends after 0 to 2 SDMMC_CK cycles after the end bit of a command that transfers data block(s) (Command sent with the CMDTRANS bit is set), or when the DTEN bit is set. At the host the interrupt period ends after the end bit of a command that transfers data block(s). A card interrupt issued in the 1 to 2 cycles after the command end bit are not detected by the host during this interrupt period.
- The card interrupt period resumes 2 to 4 SDMMC_CK after the completion of the last data block. The host resumes the interrupt period always 2 cycles after the last data block.
- There is NO interrupt period at the data block gap.

Note: DTEN must not be used to start data transfer with SD and e•MMC cards.

Figure 747. Asynchronous interrupt period data read

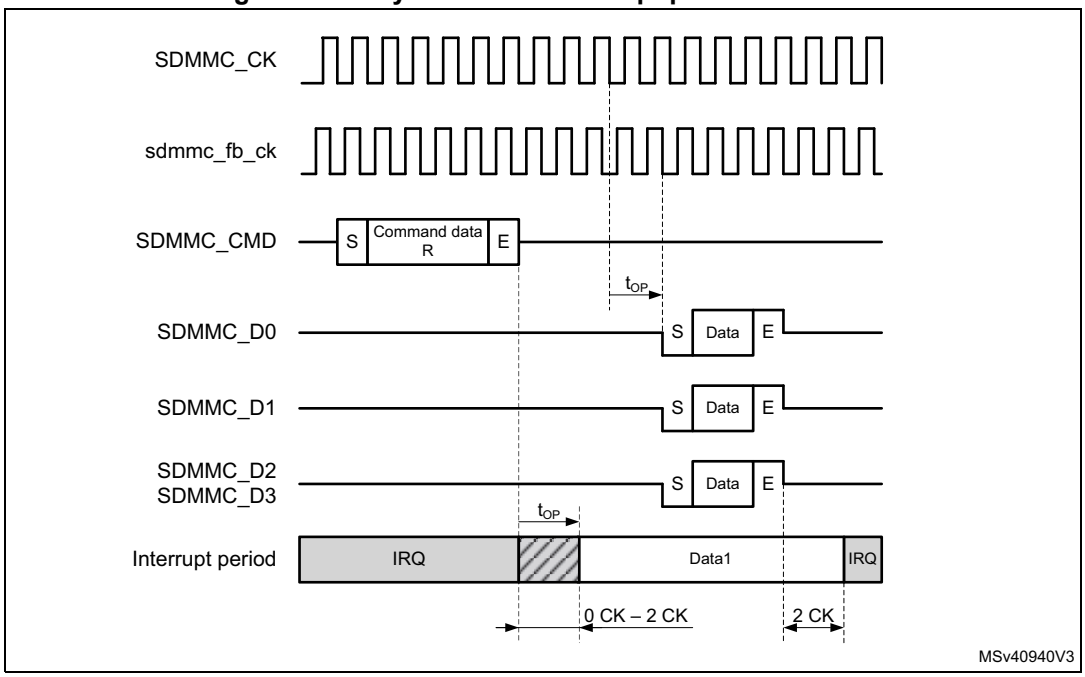
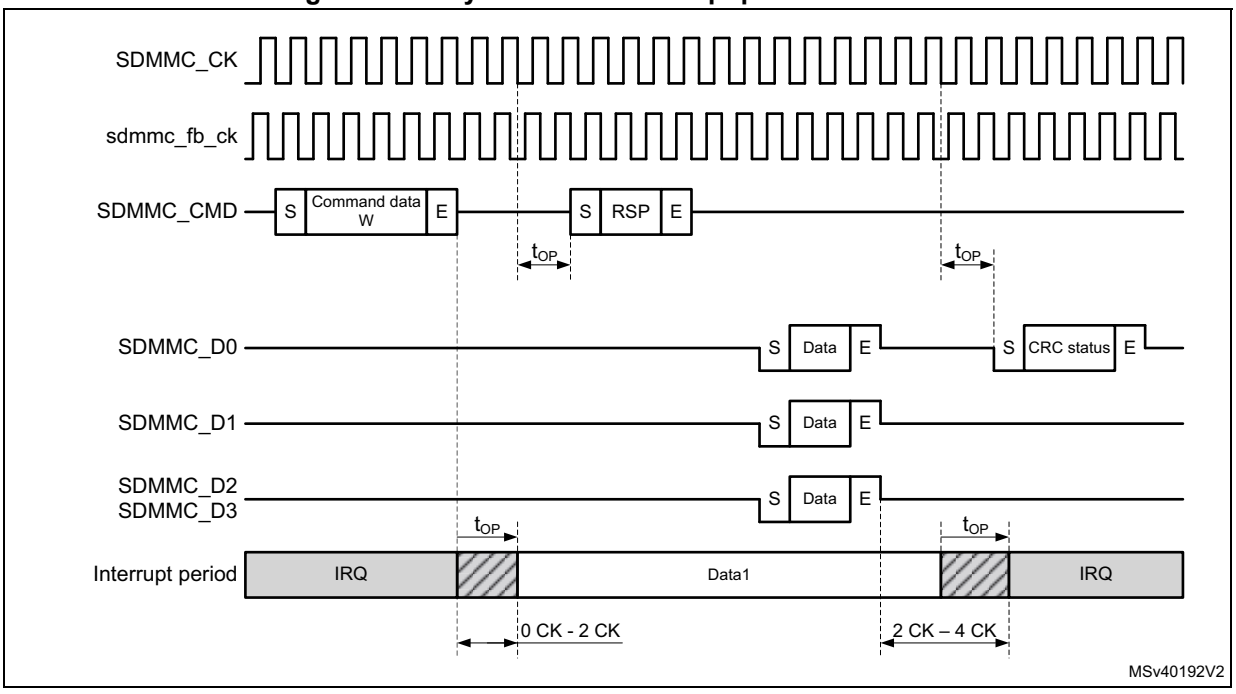


Figure 748. Asynchronous interrupt period data write



When transferring Open-ended multiple block data and using DTMODE “block data transfer ending with STOP_TRANSMISSION command”, the SDMMC masks the interrupt period after the last data block until the end of the CMD12 STOP_TRANSMISSION command.

The interrupt period is applicable for both memory and I/O operations.

In 4-bit mode interrupts can be differentiated from other signaling according *Table 494*.

Table 494. 4-bit mode Start, interrupt, and CRC-status Signaling detection

SDMMC data line	Start	Interrupt	CRC-status
SDMMC_D0	0	1 or CRC-status	0
SDMMC_D1	0	0	X
SDMMC_D2	0	1 or Read Wait	X
SDMMC_D3	0	1	X

SD I/O suspend and resume

This function is NOT supported in SDIO version 4.00 or later.

Within a multifunction SD I/O or a card with both I/O and memory functions, there are multiple devices (I/O and memory) that share access to the *e*•MMC/SD bus. To share access to the host among multiple devices, SD I/O and combo cards optionally implement the concept of suspend/resume. When a card supports suspend/resume, the host can temporarily halt (suspend) a data transfer operation to one function or memory to free the bus for a higher-priority transfer to a different function or memory. After this higher-priority transfer is complete, the original transfer is restarted (resume) where it left off.

To perform the suspend/resume operation on the bus, the host performs the following steps:

1. Determines the function currently using the SDMMC_D[3:0] line(s)
2. Requests the lower-priority or slower transaction to suspend
3. Waits for the transaction suspension to complete
4. Begins the higher-priority transaction
5. Waits for the completion of the higher priority transaction
6. Restores the suspended transaction

The card receiving a suspend command responds with its current bus status. Only when the bus has been suspended by the card the bus status indicates suspension completed.

There are different suspend cases conditions:

- Suspend request accepted prior to the start of data transfer.
- Suspend request not accepted, (due to data being transfered at the same time), the host keeps checking the request until it is accepted. (data transfer has suspended)
- Suspend request during write busy.
- Suspend request with write multiple.
- Suspend request during Read Wait.

For the host to know if the bus has been released it must check the status of the suspend request, suspension completed.

When the bus status of the suspend request response indicates suspension completed, the card has released the bus. At this time the state of the suspended operation must be saved where after an other operation can start.

The suspend command must be sent with the CMDSUSPEND bit set. This makes possible to start the interrupt period after the suspend command response when the bus is suspended (response bit BS = 0).

The hardware does not save the number of remaining data to be transfered when resuming the suspended operation. It is up to firmware to determine the data that has been transferred and resume with the correct remaining number of data bytes.

While receiving data from the card, the SDMMC can suspend the read operation after the read data block end (DPSM in Wait_R). After receiving the suspend acknowledgment response from the card the following steps must be taken by firmware:

1. The normal receive process must be stopped by setting DTHOLD bit.
   a) The remaining number of data bytes in the FIFO must be read until the receive FIFO is empty (RXFIFOE flag is set), and when IDMAEN = 0 the FIFO must be reset with FIFORST.
2. The confirmation that all data has been read from the FIFO, and that the suspend is completed is indicated by the DHOLD flag.
   a) The remaining number of data bytes (multiple of data blocks) still to be read when resuming the operation must be determined from the remaining number of bytes indicated by the DATACOUNT.

Note: When a DTIMEOUT flag occurs during the suspend procedure, this must be ignored.

To resume receiving data from the card, the following steps must be taken by firmware:

1. The remaining number of data bytes (multiple of data blocks) must be programmed in DATALENGTH.
2. The DPSM must be configured to receive data in the DTDIR bit.
3. The resume command must be sent from the CPSM, with the CMDTRANS bit set and the CMDSUSPEND bit set, which ends the interrupt period when data transfer is resumed (response bit DF = 1) and enabled the DPSM, after which the card resumes sending data.

While sending data to the card, the SDMMC can suspend the write operation after the write data block CRC status end (DPSM in Busy). Before sending the suspend command to the card the following steps must be taken by firmware:

1. Enable DHOLD flag (and DBCKEND flag when IDMAEN = 0)
2. The DPSM must be prevented from start sending a new data block by setting DTHOLD.
3. When IDMAEN = 0: When receiving the DBCKEND flag the data transfer is stopped. Firmware can stop filling the FIFO, after which the FIFO must be reset with FIFORST. Any bytes still in the FIFO need to be rewritten when resuming the operation.
4. When receiving the DHOLD flag the data transfer is stopped. The remaining number of data bytes still to be written when resuming must be determined from the remaining number of bytes indicated by the DATACOUNT.
5. To suspend the card the suspend command must be sent by the CPSM with the CMDSUSPEND bit set. This makes possible to start the interrupt period after the suspend command response when the bus is suspended (response bit BS = 0).

To resume sending data to the card, the following steps must be taken by firmware:

1. The remaining number of data bytes must be programmed in DATALENGTH.
2. The DPSM must be configured for transmission with DTDIR set and enabled by having the CPSM send the resume command with the CMDTRANS bit set and the CMDSUSPEND bit set. This ends the interrupt period and start the data transfer. The

DPSM either goes to the Wait_S state when SDMMC_D0 does not signal busy, or goes to the Busy state when busy is signaled.

3. When IDMAEN = 1: The IDMA needs to be reprogrammed for the remaining bytes to be transfered.
4. When IDMAEN = 0: Firmware must start filling the FIFO with the remaining data.

SD I/O Read Wait

There are 2 methods to pause the data transfer during the Block gap:

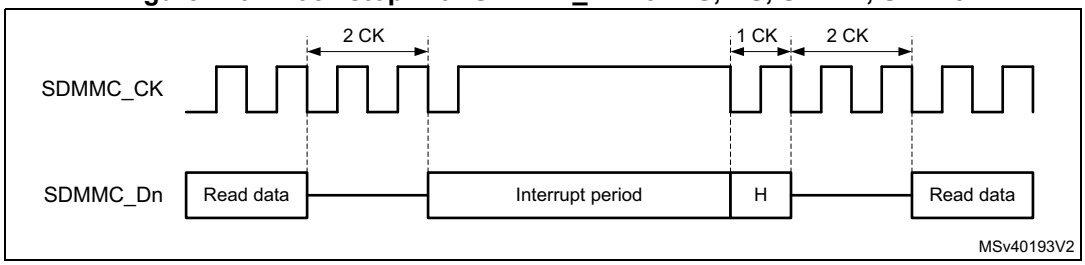
1. Stopping the SDMMC_CK.
2. Using Read Wait signaling on SDMMC_D2.

The SDMMC can perform a Read Wait with register settings according *Table 493*.

Depending the SDMMC operation mode (DS, HS, SDR12, SDR25) or (SDR50, SDR104, DDR) each method has a different characteristic.

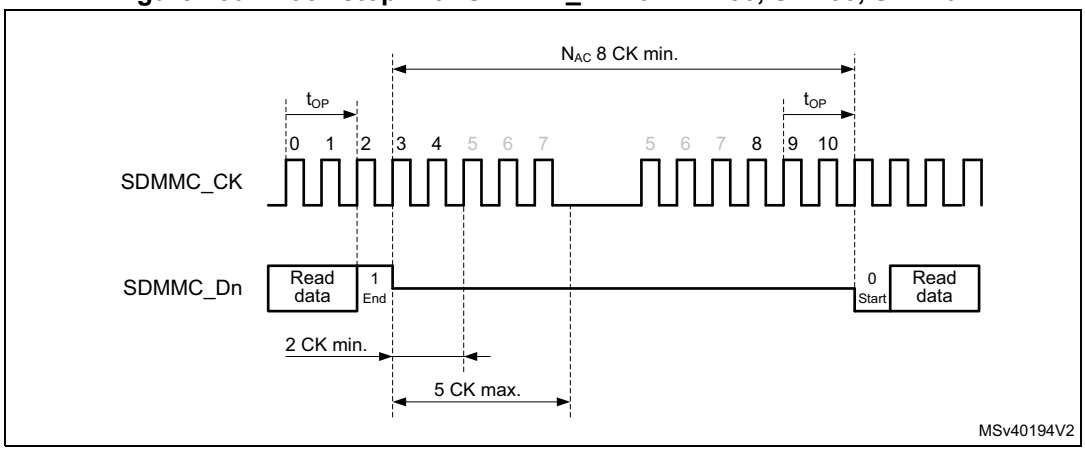
The timing for pause read operation by stopping the SDMMC_CK for DS, HS, SDR12, and SDR25, the SDMMC_CK may be stopped 2 SDMMC_CK cycles after the end bit. When ready the host resumes by restarting clock, see *Figure 749*.

Figure 749. Clock stop with SDMMC_CK for DS, HS, SDR12, SDR25



The timing for pause read operation by stopping the SDMMC_CK for SDR50, SDR104, and DDR50, the SDMMC_CK may be stopped minimum 2 SDMMC_CK cycles and maximum 5 SDMMC_CK cycles, after the end bit. When ready the host resumes by restarting clock, see *Figure 750*. (In DDR50 mode the SDMMC_CK must only be stopped after the falling edge, when the clock line is low.)

Figure 750. Clock stop with SDMMC_CK for DDR50, SDR50, SDR104



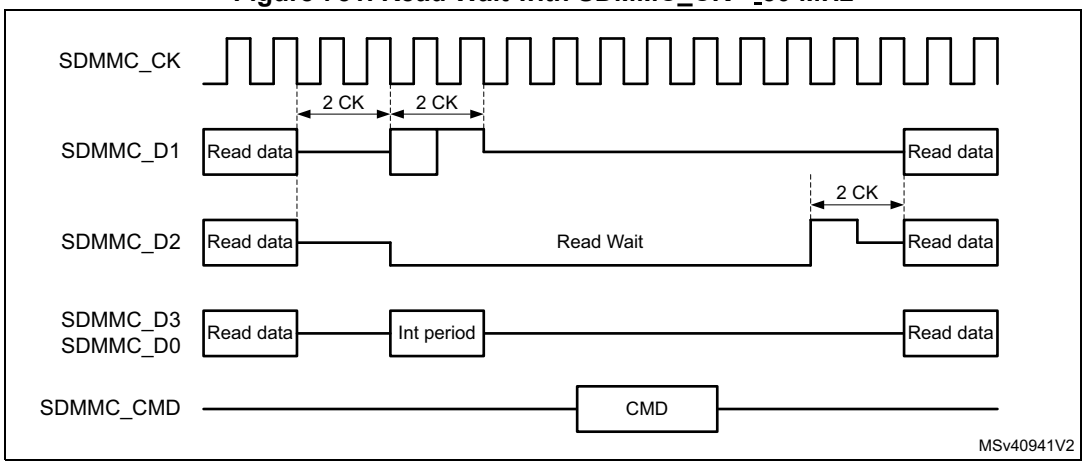
In Read Wait SDMMC_CK clock stopping, when RWSTART is set, the DSPM stops the clock after the end bit of the current received data block CRC. The clock start again after writing 1 to the RWSTOP bit, where after the DPSM waits for a start bit from the card.

As SDMMC_CK is stopped, no command can be issued to the card. During a Read Wait interval, the SDMMC can still detect SDIO interrupts on SDMMC_D1.

The optional Read Wait signaling on SDMMC_D2 (RW) operation is defined only for the SD 1-bit and 4-bit modes. The Read Wait operation enables the host to signal a card that is reading multiple registers (IO_RW_EXTENDED, CMD53) to temporarily stall the data transfer while allowing the host to send commands to any function within the SD I/O device. To determine when a card supports the Read Wait protocol, the host must test capability bits in the internal card registers.

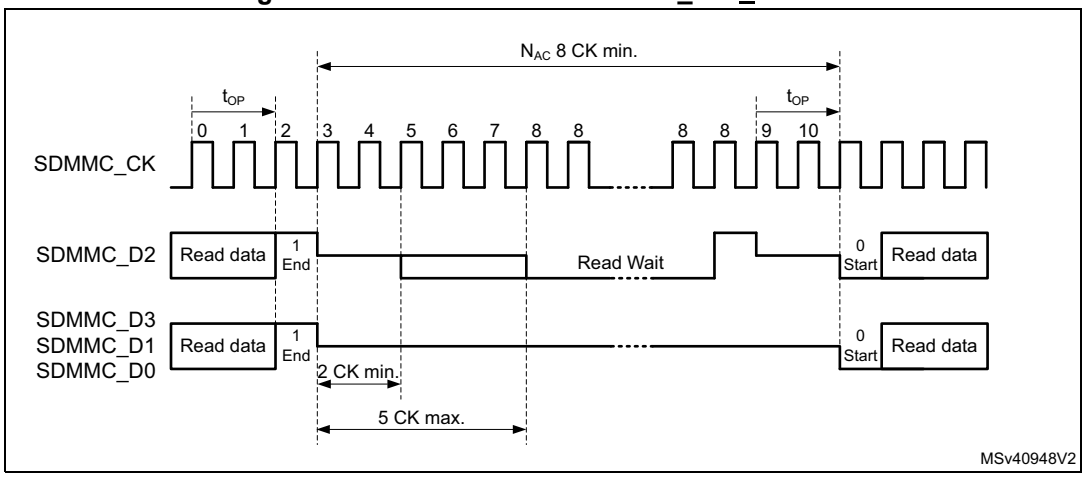
The timing for Read Wait with a SDMMC_CK less then 50MHz (DS, HS, SDR12, SDR25) is based on the interrupt period generated by the card on SDMMC_D1. The host by asserting SDMMC_D2 low during the interrupt period requests the card to enter Read Wait. To exit Read Wait the host must raise SDMMC_D2 high during one SDMMC_CK cycles before making it Hi-Z, see *Figure 751*.

Figure 751. Read Wait with SDMMC_CK <_50 MHz



For SDR50, SDR104 with a SDMMC_CK more than 50MHz, and DDR50, the card treats the Read Wait request on SDMMC_D2 as an asynchronous event. The host by asserting SDMMC_D2 low after minimum 2 SDMMC_CK cycles and maximum 5 SDMMC_CK cycles, request the card to enter Read Wait. To exit Read Wait the host must raise SDMMC_D2 high during one SDMMC_CK cycles before making it Hi-Z. The host must raise SDMMC_D2 on the SDMMC_CK clock (see *Figure 752*).

Figure 752. Read Wait with SDMMC_CK ≥ 50 MHz



In Read Wait SDMMC_D2 signaling, when RWSTART is set, the DPSM drives SDMMC_D2 after the end bit of the current received data block CRC. The Read Wait signaling on SDMMC_D2 is removed when writing 1 to the RWSTOP bit. The DPSM remains in R_W state for two more SDMMC_CK clock cycles to drive SDMMC_D2 to 1 for one clock cycle (in accordance with SDIO specification), where after the DPSM waits for a start bit from the card.

During the Read Wait signaling on SDMMC_D2 commands can be issued to the card. During the Read Wait interval, the SDMMC can detect SDIO interrupts on SDMMC_D1.

60.6.2 CMD12 send timing

CMD12 is used to stop/abort the data transfer, the card data transmission is terminated two clock cycles after the end bit of the Stop Transmission command.

Table 495. CMD12 use cases

Data operation	Stop Transmission command CMD12 Description
SDMMC stream write	The data transfer is stopped/aborted by sending the Stop Transmission command.
SDMMC open ended multiple block write	The data transfer is stopped/aborted by sending the Stop Transmission command. If the card detects an error, the host must abort the operation by sending the Stop Transmission command.
SDMMC block write with predefined block count	The Stop Transmission command is not required at the end of this type of multiple block write. (sending the Stop Transmission command after the card has received the last block is regarded as an illegal command.) If the card detects an error, the host must abort the operation by sending the Stop Transmission command.
SDMMC stream read	The data transfer is stopped/aborted by sending the Stop Transmission command.

Table 495. CMD12 use cases (continued)

Data operation	Stop Transmission command CMD12 Description
SDMMC open ended multiple block read	The data transfer is stopped/aborted by sending the Stop Transmission command. If the card detects an error, the host must abort the operation by sending the Stop Transmission command.
SDMMC block read with predefined block count	The Stop Transmission command is not required at the end of this type of multiple block read. (sending the Stop Transmission command after the card has transmitted the last block is regarded as an illegal command.) Transaction can be aborted by sending the Stop Transmission command. If the card detects an error, the host must abort the operation by sending the Stop Transmission command.

All data write and read commands can be aborted any time by a Stop Transmission command CMD12. The following data abort procedure applies during an ongoing data transfer:

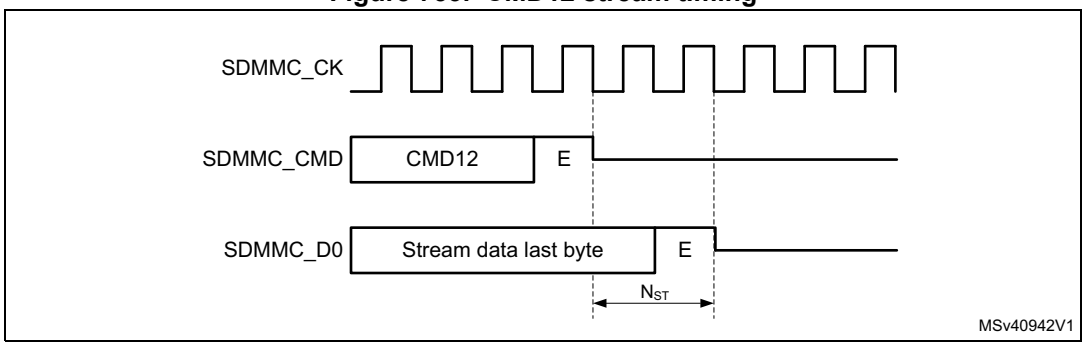
1. Load CMD12 Stop Transmission command in registers and set the CMDSTOP bit.
   a) This causes the CPSM Abort signal to be generated when the command is sent to the DPSM.
2. Configure the CPSM to send a command immediately (clear WAITPEND bit).
   a) The card, when sending data, stops data transfer 2 cycles after the Stop Transmission command end bit.
   The card when no data is being sent, does not start sending any new data.
   b) The host, when sending data, sends one last data bit followed by an end bit after the Stop Transmission command end bit.
   The host when not sending data, does not start sending any new data.
3. When IDMAEN = 0, the FIFO need to be reset with FIFORST.
   a) When writing data to the card. On the CMDREND flag, firmware must stop writing data to the FIFO. Subsequently the FIFO must be reset with FIFORST, this flushes the FIFO.
   b) When reading data from the card. On the CMDREND flag, firmware must read the remaining data from the FIFO. Subsequently the FIFO must be reset with FIFORST.
4. When IDMAEN = 1, hardware takes care of the FIFO.
   a) When writing data to the card. On the CPSM Abort signal, hardware stops the IDMA and subsequently the FIFO is flushed.
   b) When reading data from the card. On the CPSM Abort signal, hardware instructs the IDMA to transfer the remaining data from the FIFO to RAM.
5. When the FIFO is empty/reset the DABORT flag is generated.

Stream operation and CMD12

To stop the stream transfer after the last byte to be transfered, the CMD12 end bit timing must be sent aligned with the data stream end of last byte. The following write stream data procedure applies:

1. Initialize the stream data in the DPSM, DTMODE = MCC stream data transfer.
2. Send the WRITE_DATA_STREAM command from the CPSM with CMDTRANS = 1.
3. Preload CMD12 in command registers, with the CMDSTOP bit set.
4. Configure the CPSM to send a command only after a wait pending (WAITPEND = 1) end of last data (according DATALENGTH).
5. Enabling the CPSM to send the STOP_TRANSMISSION command, the stream data end bit and command end bit are aligned.
   a) When DATALENGTH > 5 bytes, Command CMD12 is waited in the CPSM to be aligned with the data transfer end bit.
   b) When DATALENGHT < 5 bytes, Command CMD12 is started before and the DPSM remains in the Wait_S state to align the data transfer end with the CMD12 end bit.
6. The write stream data can be aborted any time by clearing the WAITPEND bit. This causes the Preloaded CMD12 to be sent immediately and stop the write data stream.

Figure 753. CMD12 stream timing



To stop the read stream transfer after the last byte, the CMD12 end bit timing must occur after the last data stream byte. The following read stream data procedure applies:

1. Wait for all data to be received by the DPSM (DATAEND flag).
   a) The DPSM does not receive more data than indicated by DATALENGTH, even if the card is sending more data.
2. Send CMD12 by the CPSM.
   a) CMD12 stops the card sending data.

Note: The SDMMC does not receive any more data from the card when DATACOUNT = 0, even when the card continues sending data.

Block operation and CMD12

To stop block transfer at the end of the data, the CMD12 end bit must be sent after the last block end bit.

When writing data to the card the CMD12 end bit must be sent after the write data block CRC token end bit. This requires the CMD12 sending to be tied to the data block transmission timing. To stop an Open-ended Multiple block write, the following procedure applies:

1. Before starting the data transfer, set DTMODE to “block data transfer ending with STOP_TRANSMISSION command”.
2. Wait for all data to be sent by the DPSM and the CRC token to be received, (DATAEND flag).
   a) The DPSM does not send more data than indicated by DATALENGTH.
3. Send CMD12 by the CPSM.
   a) CMD12 sets the card to Idle mode.

When reading data from the card the CMD12 end bit must be sent earliest at the same time as the card read data block last data bit. This requires the CMD12 sending to be tied to the data block reception timing. The following stop Open-ended Multiple block read data block procedure applies:

1. Before starting the data transfer, set DTMODE to “block data transfer ending with STOP_TRANSMISSION command”.
2. Wait for all data to be received by the DPSM (DATAEND flag).
   a) The DPSM does not receive more data than indicated by DATALENGTH, even if the card is sending more data.
3. Send CMD12 with CMDSTOP bit set by the CPSM.
   a) CMD12 stops the Card sending more data and set the card to Idle mode. Any ongoing block transfer is aborted by the Card.

Note: The SDMMC does not receive any more data from the card when DATACOUNT = 0, even when the card continues sending data.

60.6.3 Sleep (CMD5)

The *e*•MMC card may be switched between a Sleep state and a Standby state by CMD5. In the Sleep state the power consumption of the card is minimized and the Vcc power supply may be switched off.

The CMD5 (SLEEP) is used to initiate the state transition from Standby state to Sleep state. The card indicates Busy, pulling down SDMMC_D0, during the transition phase. The Sleep state is reached when the card stops pulling down the SDMMC_DO line.

To set the card into Sleep state the following procedure applies:

1. Enable interrupt on BUSYD0END.
2. Send CMD5 (SLEEP).
3. On BUSYD0END interrupt, card is in Sleep state
4. Vcc power supply can be switched off

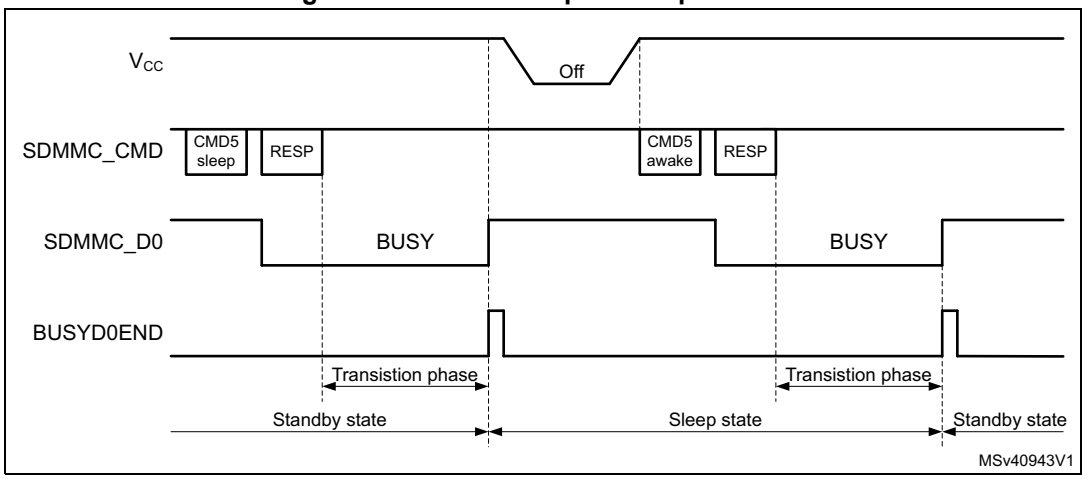
The CMD5 (AWAKE) is used to initiate the state transition from Sleep state to Standby state. The card indicates Busy, pulling down SDMMC_D0, during the transition phase. The Standby state is reached when the card stops pulling down the SDMMC_DO line.

To set the card into Sleep state the following procedure applies:

1. Switch on Vcc power supply and wait unit minimum operating level is reached.
2. Enable interrupt on BUSYD0END.
3. Send CMD5 (AWAKE).
4. On BUSYD0END interrupt card is in Standby state.

The Vcc power supply can be switched off only after the Sleep state has been reached. The Vcc supply must be reinstalled before CMD5 (AWAKE) is sent.

Figure 754. CMD5 Sleep Awake procedure



60.6.4 Interrupt mode (Wait-IRQ)

The host and card enter and exit interrupt mode (Wait-IRQ) simultaneously. In interrupt mode there is no data transfer. The only message allowed is an interrupt service request response from the card or the host. For the interrupt mode to work correctly the SDMMC_CK frequency must be set in accordance with the achievable SDMMC_CMD data rate in Open Drain mode, which depend on the capacitive load and pull-up resistor. The CLKDIV must be set >1, and the SETCLKRX must select either the sdmmc_io_in_ck or SDMMC_CLKin source.

The host must ensure that the card is in Standby state before issuing the CMD40 (GO_IRQ_STATE). While waiting for an interrupt response the SDMMC_CK clock signal must be kept active.

A card in interrupt mode (IRQ state):

- is waiting for an internal card interrupt event. Once the event occurs, the card starts to send the interrupt service request response. The response is sent in open-drain mode.
- while waiting for the internal card interrupt event, the card also monitors the SDMMC_CMD line for a start bit. Upon detection of a start bit the card aborts the interrupt mode and switch to Standby state.

The host in interrupt mode (CPSM Wait state waiting for interrupt):

- is waiting for a card interrupt service request response (start bit).
- while waiting for a card interrupt service request response the host may abort the interrupt mode (by clearing the WAITINT register bit), which causes the host to send a interrupt service request response R5 with RCA = 0x0000 in open-drain mode.

When sending the interrupt service request response, the sender bit-wise monitors the SDMMC_CMD bit stream. The sender whose interrupt service request response bit does not correspond to the bit on the SDMMC_CMD line stops sending. In the case of multiple senders only one successfully sends its full interrupt service request response. If the host sends simultaneously, it loses sending after the transmission bit.

To handle the interrupt mode, the following procedure applies:

1. Set the SDMMC_CK frequency in accordance with the achievable SDMMC_CMD data rate in Open-drain mode, CLKDIV must be set >1, and SETCLKRX must select the sdmmc_io_in_ck.
2. Load CMD40 (GO_IRQ_STATE) in the command registers.
3. Enable wait for interrupt by setting WAITINT register bit.
4. Configure the CPSM to send a command immediately.
   a) This causes the CMD40 to be sent and the CPSM to be halted in the Wait state, waiting for a interrupt service request response.
5. To exit the wait for interrupt state (CPSM Wait state):
   a) Upon the detection of an interrupt service request response start bit the CPSM moves to the Receive state where the response is received. The complete reception of the response is indicated by the CMDREND or the command CRC error flags.
   b) To abort the interrupt mode the host clears the WAITINT register bit, which causes the host to send an interrupt service request response by itself. This moves the CPSM to the Receive state. The complete reception of the response is indicated by the CMDREND or the command CRC error flags.

Note: On a simultaneous send interrupt service request response start bit collision the host loses the bus access after the transmission bit.

60.6.5 Boot operation

In boot operation mode the host can read boot data from the card by either one of the 2 boot operation functions:

1. Normal boot. (keeping CMD line low)
2. Alternative boot (sending CMD0 with argument 0xFFFFFFFA)

The boot data can be read according the following configuration options, depending on card register settings:

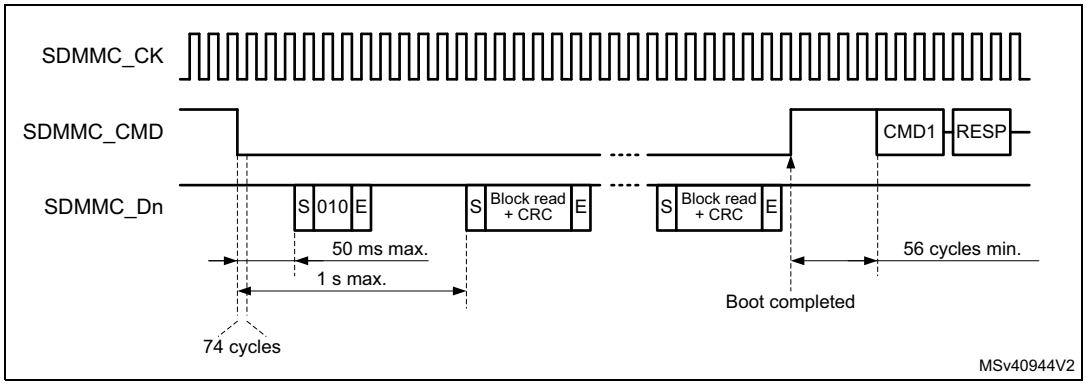
- The partition from which boot data is read (EXT_CSD Byte[179])
- The boot data size (EXT_CSD Byte[226])
- The bus configuration during boot (EXT_CSD Byte[177])
- Receiving boot acknowledgment from the card. (EXT_CSD Byte[179])

If boot acknowledgment is enabled the card send pattern 010 on SDMMC_D0 within 50ms after boot mode has been requested by either CMD line going low or after CMD0 with argument 0xFFFFFFFA. A boot acknowledgment timeout (ACKTIMEOUT) and acknowledgment status (ACKFAIL) is provided.

Normal boot operation

If the SDMMC_CMD line is held low for at least 74 clock cycles after card power-up or reset, before the first command is issued, the card recognizes that boot mode is being initiated. Within 1 second after the CMD line goes low, the card starts to sent the first boot code data on the SDMMC_Dn line(s). The host must keep the SDMMC_CMD line low until after all boot data has been read. The host can terminate boot mode by pulling the SDMMC_CMD line high.

Figure 755. Normal boot mode operation



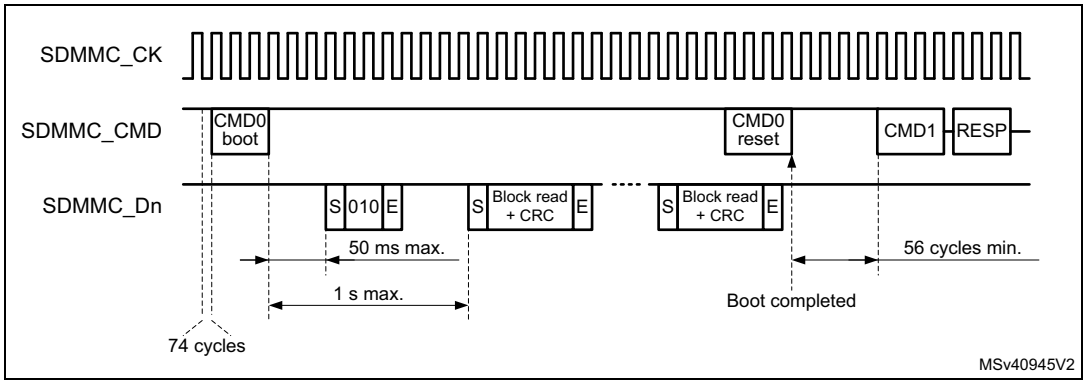
To perform the normal boot procedure the following steps needed:

1. Reset the card.
2. if a boot acknowledgment is requested enable the BOOTACKEN and set the ACKTIME and enable the ACKFAIL and ACKTIMEOUT interrupt.
3. enable the data reception by setting the DPSM in receive mode (DTDIR) and the number of data bytes to be received in DATALENGTH.
4. Enable the DTIMEOUT, DATAEND, and CMDSENT interrupts for end of boot command confirmation.
5. Select the normal boot operation mode in BOOTMODE, and enable boot in BOOTEN. The boot procedure is started by enabling the CPSM with CPSMEN.This causes:
   - the SDMMC_CMD to be driven low. (BOOTMODE = normal boot).
   - the ACK timeout to start.
   - DPSM to be enabled.
6. The incorrect reception of the boot acknowledgment can be detected with ACKFAIL flag or ACKTIMEOUT flag when enabled.
   - when an incorrect boot acknowledgment is received the ACKFAIL flag occurs.
   - when the boot acknowledgment is not received in time the ACKTIMEOUT flag occurs.
7. when all boot data has been received the DATAEND flag occurs.
   - when data CRC fails the DCRCFAIL flag is also generated.
   - when the data timeout occurs the DTIMEOUT flag is also generated.
8. When last data has been received, read data from the FIFO until FIFO is empty (RXFIFOE = 1) after which end of data DATAEND flag is generated.
   - SDMMC has completely received all data and the DPSM is disabled.
9. The boot procedure is terminated by firmware clearing BOOTEN, which causes the SDMMC_CMD line to go high. The CMDSENT flag is generated 56 cycles later to indicate that a new command can be sent.
   a) If the boot procedure is aborted by firmware before all data has been received the CPSM Abort signal stops data reception and disables the DPSM which triggers an DABORT flag when enabled.
10. The CMDSENT flag signals the end of the boot procedure and the card is ready to receive a new command.

Alternative boot operation

After card power-up or reset, if the host send CMD0 with the argument 0xFFFFFFFA after 74 clock cycles before CMD0 is issued, the card recognizes that boot mode is being initiated. Within 1 second after the CMD0 with argument 0xFFFFFFFA has been sent, the card starts to send the first boot code data on the SDMMC_Dn line(s). The master terminates boot operation by sending CMD0 (Reset).

Figure 756. Alternative boot mode operation



To perform the alternative boot procedure the following steps needed:

1. Move the SDMMC to power-off state, and reset the card
2. Move the SDMMC to power-on state. This guarantees the 74 SCDMMC_CK cycles to be clocked before any command.
3. if a boot acknowledgment is requested enable the BOOTACKEN and set the ACKTIME and enable the ACKTIMEOUT flag.
4. enable the data reception by setting the DPSM in receive mode (DTDIR) and the number of data to be received in DATALENGTH. Enable the DTIMEOUT and DATAEND flags.
5. Select the alternative boot operation mode in BOOTMODE, load the CMD0 with the 0xFFFFFFFA argument in the command registers. Enable CMDSENT flag for end of

boot command confirmation, and enable boot in BOOTEN. The boot procedure is started by enabling the CPSM with CPSMEN. This causes:

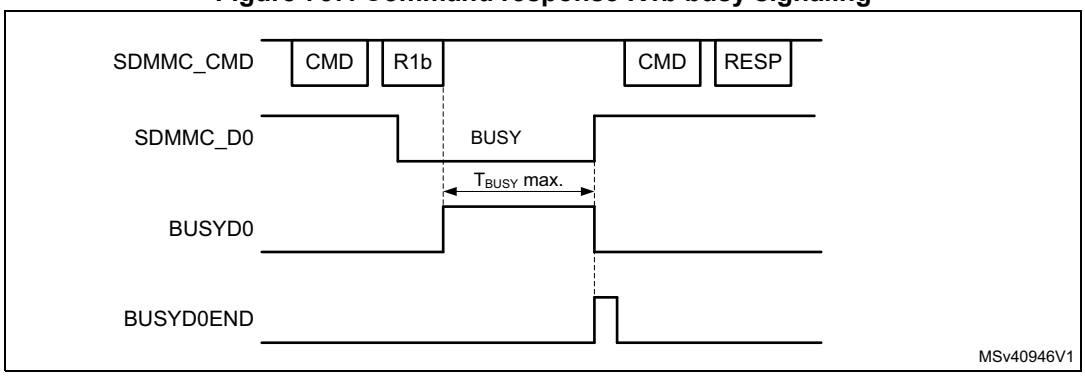
- the loaded command and argument to be sent out. (BOOTMODE = alternative boot).
- the ACK timeout to start.
- DPSM to be enabled.

6. When the command has been sent the CMDSENT flag is generated, at which time the BOOTEN bit must be cleared.
7. the reception of the boot acknowledgment can be detected with ACKFAIL flag when enabled.
   - when the boot acknowledgment is not received in time the ACKTIMEOUT flag occurs.
8. when all boot data has been received the DATAEND flag occurs.
   - when data CRC fails the DCRCFAIL flag is also generated.
   - when the data timeout occurs the DTIMEOUT flag is also generated.
9. When last data has been received, read data from the FIFO until FIFO is empty (RXFIFOE = 1) after which end of data DATAEND flag is generated.
   - SDMMC has completely received all data and the DPSM is disabled.
10. The BOOTEN bit must be cleared, before terminating the boot procedure by sending CMD0 (Reset) with BOOTMODE = alternative boot. This causes the CMDSENT flag to occur 56 cycles after the Command.
    - if the boot procedure is aborted by firmware before all data has been received the CPSM Abort signal stops the data transfer and disable the DPSM which triggers an DABORT flag when enabled.
11. The CMDSENT flag signals the end of the boot procedure and the card is ready to receive a new command. When the RESET command has been sent successfully, the BOOTMODE control bit has to be cleared to terminate the boot operation.

60.6.6 Response R1b handling

When sending commands which have a R1b response the busy signaling is reflected in the BUSYD0 register bit and the release of busy with the BUSYD0END flag. The SDMMC_D0 line is sampled at the end of the R1b response and signaled in the BUSYD0 register bit. The BUSYD0 register bit is reset to not busy when the SDMMC_D0 line release busy, at the same time the BUSYD0END flag is generated.

Figure 757. Command response R1b busy signaling



The expected maximum busy time must be set in the DATATIME register before sending the command. When enabled, the DTIMEOUT flag is set when after the R1b response busy stays active longer then the programmed time.

To detect the SDMMC_D0 busy signaling when sending a Command with R1b response the following procedure applies:

- Enable CMDREND flag
- Send Command through CPSM.
- On the CMDREND flag check the BUSYD0 register bit.
  - If BUSYD0 signals not busy, signal busy release to the Firmware
  - If BUSYD0 signals busy, wait for BUSYD0END flag
- On BUSYD0END flag signal busy released to the firmware.
- On DTIMEOUT flag busy is active longer then programmed time.

60.6.7 Reset and card cycle power

Reset

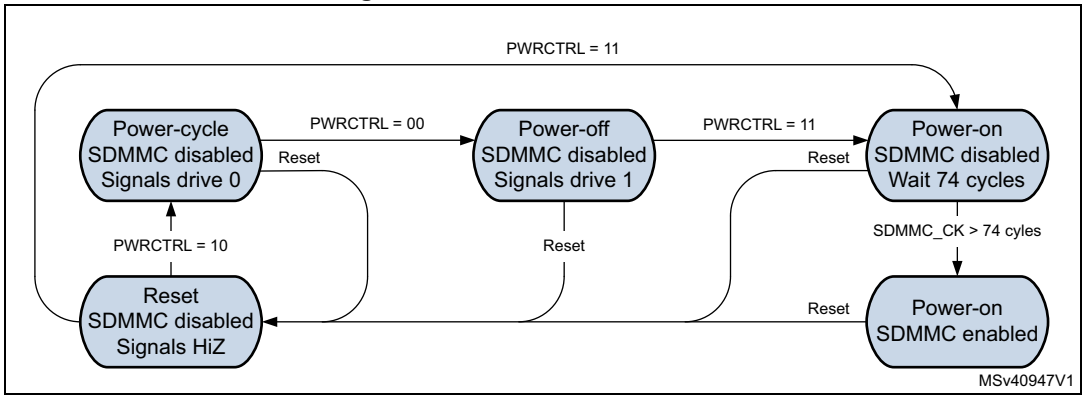
Following reset the SDMMC is in the reset state. In this state the SDMMC is disabled and no command nor data can be transfered. The SDMMC_D[7:0], and SDMMC_CMD are in HiZ and the SDMMC_CK is driven low.

Before moving to the power-on state the SDMMC must be configured.

In the power-on state the SDMMC_CK clock is running. First 74 SDMMC_CK cycles are clocked after which the SDMMC is enabled and command and data can be transfered.

The SDMMC states are controlled by Firmware with the PWRCTL register bits according *Figure 758.*.

Figure 758. SDMMC state control

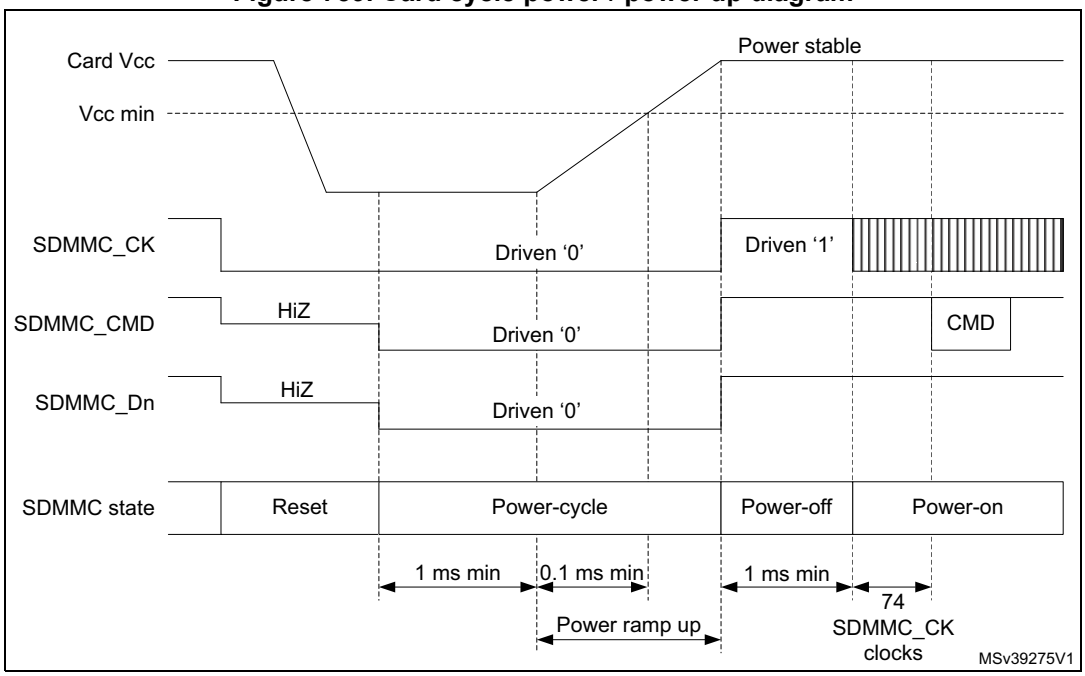


Card cycle power

To perform a card cycle power the following procedure applies:

1. Reset the SDMMC with the RCC.SDMMCxRST register bit. This resets the SDMMC to the reset state and the CPSM and DPSM to the Idle state.
2. Disable the Vcc power to the card.
3. Set the SDMMC in power-cycle state. This makes that the SDMMC_D[7:0], SDMMC_CMD and SDMMC_CK are driven low, to prevent the card from being supplied through the signal lines.
4. After minimum 1 ms enable the Vcc power to the card.
5. After the power ramp period set the SDMMC to the power-off state for minimum 1 ms. The SDMMC_D[7:0], SDMMC_CMD and SDMMC_CK are set to drive “1”.
6. After the 1 ms delay set the SDMMC to power-on state in which the SDMMC_CK clock is enabled.
7. After 74 SDMMC_CK cycles the first command can be sent to the card.

Figure 759. Card cycle power / power up diagram



60.7 Hardware flow control

The hardware flow control during data transfer functionality is used to avoid FIFO underrun (TX mode) and overrun (RX mode) errors.

The behavior is to stop SDMMC_CK during data transfer and freeze the SDMMC state machines. The data transfer is stalled when the FIFO is unable to transmit or receive data. The data transfer remains stalled until the transmit FIFO is half full or all data according DATALENGHT has been stored, or until the receive FIFO is half empty. Only state machines clocked by SDMMC_CK are frozen, the AHB interfaces are still alive. The FIFO can thus be filled or emptied even if flow control is activated.

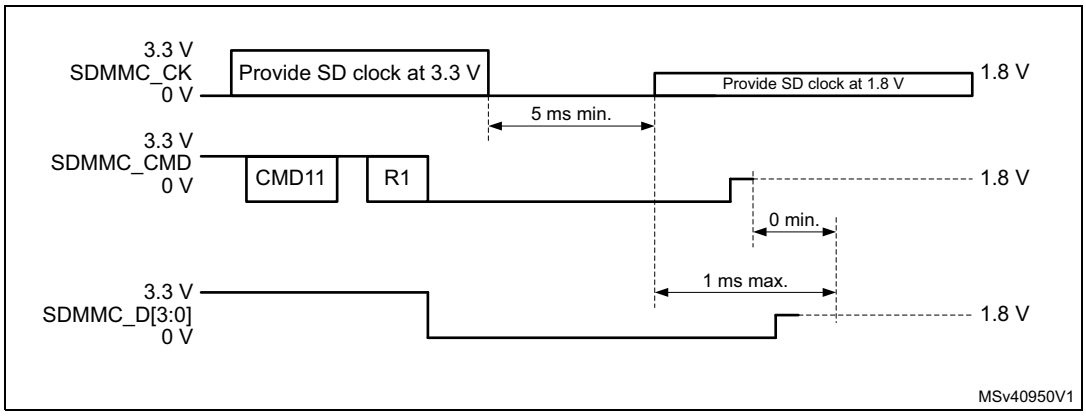
To enable hardware flow control during data transfer, the HWFC_EN register bit must be set to 1. After reset hardware flow control is disabled.

Hardware flow control shall only be used when the SDMMC_Dn data is cycle-aligned with the SDMMC_CK. Whenever the sdmmc_fb_ck from the DLYB delay block is used, i.e in the case of SDR104 mode with a t_{OP} and Dt_{OP} delay > 1 cycle, hardware flow control can not be used.

60.8 Ultra-high-speed phase I (UHS-I) voltage switch

UHS-I mode (SDR12, SDR25, SDR50, SDR104, and DDR50) requires the support for 1.8V signaling. After power up the card starts in 3.3V mode. CMD11 invokes the voltage switch sequence to the 1.8V mode. When the voltage sequence is completed successfully the card enters UHS-I mode with default SDR12 and card input and output timings are changed.

Figure 760. CMD11 signal voltage switch sequence



To perform the signal voltage switch sequence the following steps are needed:

1. Before starting the Voltage Switch procedure, the SDMMC_CK frequency must be set in the range 100 kHz - 400 kHz.
2. The host starts the Voltage Switch procedure by setting the VSWITCHEN bit before sending the CMD11.
3. The card returns an R1 response.
   - if the response CRC is pass, the Voltage Switch procedure continues the host does no longer drive the CMD and SDMMC_D[3:0] signals until completion of the voltage switch sequence. Some cycles after the response the SDMMC_CK is stopped and the CKSTOP flag is set.
   - if the response CRC is fail (CCRCFAIL flag) or no response is received before the timeout (CTIMEOUT flag), the Voltage Switch procedure is stopped.
4. The card drives CMD and SDMMC_D[3:0] to low at the next clock after the R1 response.
5. The host, after having received the R1 response, may monitor the SDMMC_D0 line using the BUSYD0 register bit. The SDMMC_D0 line is sampled two SDMMC_CK clock cycles after the Response. The Firmware may read the BUSYD0 register bit following the CKSTOP flag.
   - When the BUSYD0 is detected low the host firmware switches the Voltage regulator to 1.8V, after which it instructs the SDMMC to start the timing critical

section of the Voltage Switch sequence by setting register bit VSWITCH. The hardware continues to stop the SDMMC_CK by holding it low for at least 5 ms.

– When the BUSYD0 is detected high the host aborts the Voltage Switch sequence and cycle power the card.

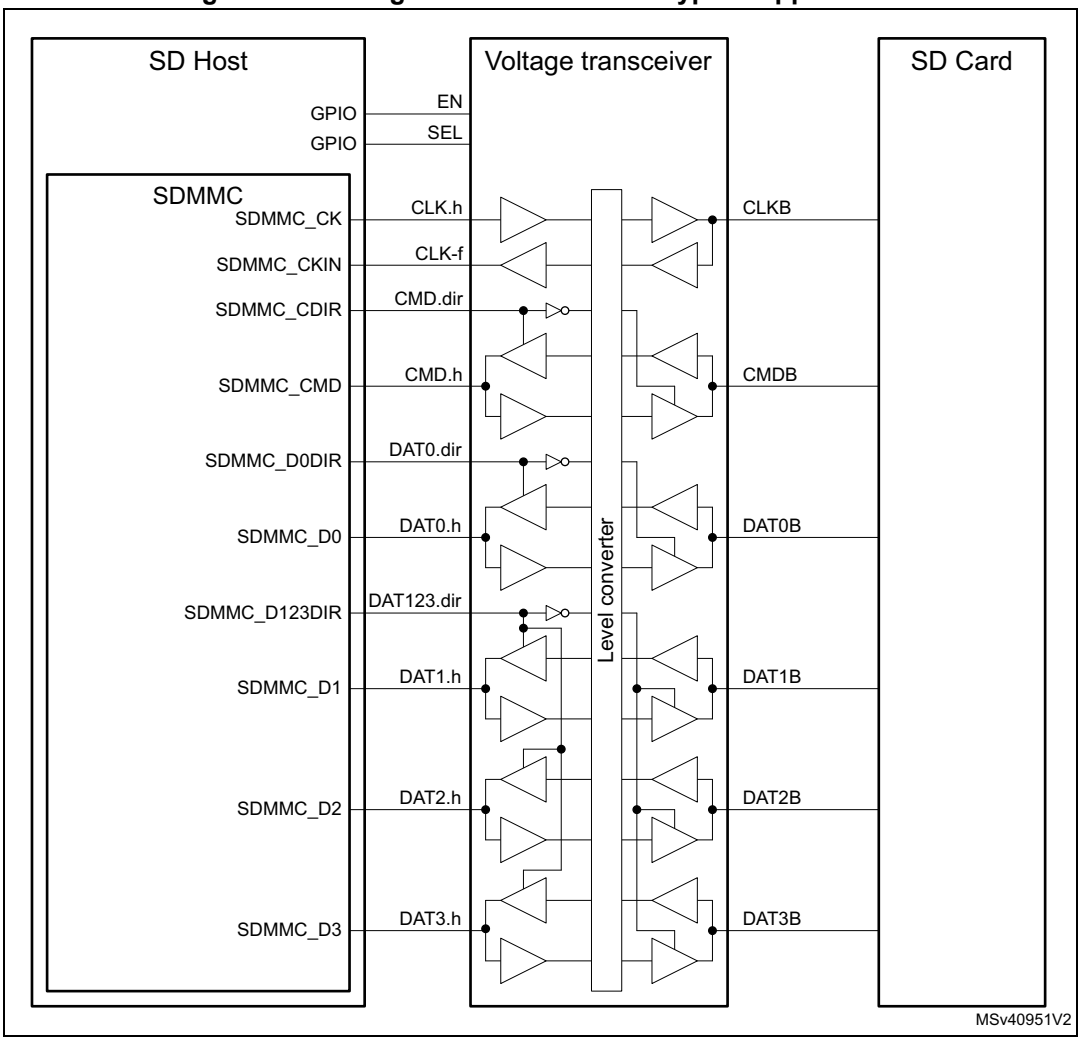
6. The card after detecting SDMMC_CK low begins switching signaling voltage to 1.8 V.
7. The host SDMMC hardware after at least 5 ms restarts the SDMMC_CK.
8. The card within 1 ms from detecting SDMMC_CK transition drives CMD and DAT[3:0] high for at least 1 SDMMC_CK cycle and then stop driving CMD and DAT[3:0].
9. The host SDMMC hardware, 1 ms after the SDMMC_CK has been restarted, the SDMMC_D0 is sampled into BUSYD0 and the VSWEND flag is set.
10. The host, on the VSWEND flag, checks SDMMC_D0 line using the BUSYD0 register bit, to confirm completion of voltage switch sequence:
    – When BUSYD0 is detected high, Voltage Switch has been completed successfully.
    – When BUSYD0 is detected low, Voltage Switch has failed, the host cycles the card power.

The minimum 5 ms time to stop the SDMMC_CK is derived from the internal un-gated SDMMC_CK clock, which has a maximum frequency of 25 MHz (SD mode), as set by the clock divider CLKDIV. The >5 ms time is counted by 2^{12} cycles (10.24 ms @ 400 kHz). If a lower SDMMC_CK frequency is selected by the clock divider CLKDIV the time for the SDMMC_CK clock to be stopped is longer.

The maximum 1 ms time for the card to drive the SDMMC_Dn and SDMMC_CMD lines high is derived from the internal ungated SDMMC_CK which has a maximum frequency of 25 MHz (SD mode), as set by the clock divider CLKDIV. The SDMMC checks the lines after >1 ms time which is counted by 2^9 cycles (1.28 ms @ 25 MHz). If a lower SDMMC_CK frequency is selected by the clock divider CLKDIV the time to check the lines is longer.

The signal voltage level is supported through an external voltage translation transceiver like STMicroelectronics ST6G3244ME.

Figure 761. Voltage switch transceiver typical application



To interface with an external driver (a voltage switch transceiver), next to the standard signals the SDMMC uses the following signals:

SDMMC_CKIN feedback input clock

SDMMC_CDIR I/O direction control for the CMD signal.

SDMMC_D0DIR I/O direction control for the SDMMC_D0 signal.

SDMMC_D123DIR I/O direction control for the SDMMC_D1, SDMMC_D2 and SDMMC_D3 signals.

The voltage transceiver signals **EN** and **SEL** are to be handled through general-purpose I/O.

The polarity of the SDMMC_CDIR, SDMMC_D0DIR and SDMMC_D123DIR signals can be selected through SDMMC_POWER.DIRPOL control bit.

60.9 SDMMC interrupts

Table 496. SDMMC interrupts

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit from Sleep mode
SDMMC	Command response CRC fail	CCRCFAIL	CCRCFAILIE	CCRCFAILC	Yes
SDMMC	Data block CRC fail	DCRCFAIL	DCRCFAILIE	DCRCFAILC	Yes
SDMMC	Command response timeout	CTIMEOUT	CTIMEOUTIE	CTIMEOUTC	Yes
SDMMC	Data timeout	DTIMEOUT	DTIMEOUTIE	DTIMEOUTC	Yes
SDMMC	Transmit FIFO underrun	TXUNDERR	TXUNDERRIE	TXUNDERRC	Yes
SDMMC	Receive FIFO overrun	RXOVERR	RXOVERRIE	RXOVERRC	Yes
SDMMC	Command reponse received	CMDREND	CMDRENDIE	CMDRENDC	Yes
SDMMC	Comand sent	CMDSENT	CMDSENTIE	CMDSENTC	Yes
SDMMC	Data transfer ended	DATAEND	DATAENDIE	DATAENDC	Yes
SDMMC	Data transfer hold	DHOLD	DHOLDIE	DHOLDC	Yes
SDMMC	Data block sent or received	DBCKEND	DBCKENDIE	DBCKENDC	Yes
SDMMC	Data transfer aborted	DABORT	DABORTIE	DABORTC	Yes
SDMMC	Transmit FIFO half empty	TXFIFOHE	TXFIFOHEIE	n.a.	Yes
SDMMC	Receive FIFO half full	RXFIFOHF	RXFIFOHFIE	n.a.	Yes
SDMMC	Transmit FIFO full	TXFIFOF	n.a.	n.a.	Yes
SDMMC	Receive FIFO full	RXFIFOF	RXFIFOFIE	n.a.	Yes
SDMMC	Transmit FIFO empty	TXFIFOE	TXFIFOEIE	n.a.	Yes
SDMMC	Receive FIFO empty	RXFIFOE	n.a.	n.a.	Yes

Table 496. SDMMC interrupts (continued)

Interrupt acronym	Interrupt event	Event flag	Enable control bit	Interrupt clear method	Exit from Sleep mode
SDMMC	Command response end of busy	BUSYD0END	BUSYD0ENDIE	BUSYD0ENDC	Yes
SDMMC	SDIO interrupt	SDIOIT	SDIOITIE	SDIOITC	Yes
SDMMC	Boot acknowledgment fail	ACKFAIL	ACKFAILIE	ACKFAILC	Yes
SDMMC	Boot acknowledgment timeout	ACKTIMEOUT	ACKTIMEOUTIE	ACKTIMEOUTC	Yes
SDMMC	Voltage switch timing	VSWEND	VSWENDIE	VSWENDC	Yes
SDMMC	SDMM_CK stopped in voltage switch	CKSTOP	CKSTOPIE	CKSTOPC	Yes
SDMMC	IDMA transfer error	IDMATE	IDMATEIE	IDMATEC	Yes
SDMMC	IDMA buffer transfer complete	IDMABTC	IDMABTCIE	IDMABTCC	Yes

60.10 SDMMC registers

The device communicates to the system via 32-bit control registers accessible via AHB slave interface.

The peripheral registers have to be accessed by words (32-bit). Byte (8-bit) and halfword (16-bit) accesses trigger an AHB bus error.

60.10.1 SDMMC power control register (SDMMC_POWER)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIR POL	VSWI TCHEN	VSWI TCH	PWRCTRL[1:0]	
											rw	rw	rw	rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **DIRPOL**: Data and command direction signals polarity selection

This bit can only be written when the SDMMC is in the power-off state (PWRCTRL = 00).

0: Voltage transceiver IOs driven as output when direction signal is low.

1: Voltage transceiver IOs driven as output when direction signal is high.

Bit 3 **VSWITCHEN**: Voltage switch procedure enable

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).

This bit is used to stop the SDMMC_CK after the voltage switch command response:

0: SDMMC_CK clock kept unchanged after successfully received command response.

1: SDMMC_CK clock stopped after successfully received command response.

Bit 2 **VSWITCH**: Voltage switch sequence start

This bit is used to start the timing critical section of the voltage switch sequence:

0: Voltage switch sequence not started and not active.

1: Voltage switch sequence started or active.

Bits 1:0 **PWRCTRL[1:0]**: SDMMC state control bits

These bits can only be written when the SDMMC is not in the power-on state (PWRCTRL ≠ 11).

These bits are used to define the functional state of the SDMMC signals:

00: After reset, Reset: the SDMMC is disabled and the clock to the Card is stopped, SDMMC_D[7:0], and SDMMC_CMD are HiZ and SDMMC_CK is driven low. When written 00, power-off: the SDMMC is disabled and the clock to the card is stopped, SDMMC_D[7:0], SDMMC_CMD and SDMMC_CK are driven high.

01: Reserved. (When written 01, PWRCTRL value does not change)

10: Power-cycle, the SDMMC is disabled and the clock to the card is stopped, SDMMC_D[7:0], SDMMC_CMD and SDMMC_CK are driven low.

11: Power-on: the card is clocked, The first 74 SDMMC_CK cycles the SDMMC is still disabled. After the 74 cycles the SDMMC is enabled and the SDMMC_D[7:0], SDMMC_CMD and SDMMC_CK are controlled according the SDMMC operation.

Any further write is ignored, PWRCTRL value keeps 11.

60.10.2 SDMMC clock control register (SDMMC_CLKCR)

Address offset: 0x004

Reset value: 0x0000 0000

The SDMMC_CLKCR register controls the SDMMC_CK output clock, the sdmmc_rx_ck receive clock, and the bus width.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SELCLKRX[1:0]		BUS SPEED	DDR	HWFC_EN	NEG EDGE
										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WID BUS[1:0]		Res.	PWR SAV	Res.	Res.	CLKDIV[9:0]									
rw	rw		rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:20 **SELCLKRX[1:0]**: Receive clock selection

These bits can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0)

00: sdmmc_io_in_ck selected as receive clock

01: SDMMC_CKIN feedback clock selected as receive clock

10: sdmmc_fb_ck tuned feedback clock selected as receive clock.

11: Reserved (select sdmmc_io_in_ck)

Bit 19 **BUSSPEED**: Bus speed for selection of SDMMC operating modes

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0)

0: DS, HS, SDR12, SDR25, Legacy compatible, High speed SDR, High speed DDR bus speed mode selected

1: SDR50, DDR50, SDR104, HS200 bus speed mode selected.

Bit 18 **DDR**: Data rate signaling selection

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0)

DDR rate must only be selected with 4-bit or 8-bit wide bus mode. (WIDBUS > 00). DDR = 1 has no effect when WIDBUS = 00 (1-bit wide bus).

DDR rate must only be selected with clock division >1. (CLKDIV > 0)

0: SDR Single data rate signaling

1: DDR double data rate signaling

Bit 17 **HWFC_EN**: Hardware flow control enable

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0)

0: Hardware flow control is disabled

1: Hardware flow control is enabled

When Hardware flow control is enabled, the meaning of the TXFIFOE and RXFIFOF flags change, please see SDMMC status register definition in *Section 60.10.11*.

Bit 16 **NEGEDGE**: SDMMC_CK dephasing selection bit for data and command

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0).

When clock division = 1 (CLKDIV = 0), this bit has no effect. Data and Command change on SDMMC_CK falling edge.

0: When clock division >1 (CLKDIV > 0) & DDR = 0:

- Command and data changed on the sdmmc_ker_ck falling edge succeeding the rising edge of SDMMC_CK.
- SDMMC_CK edge occurs on sdmmc_ker_ck rising edge.

When clock division >1 (CLKDIV > 0) & DDR = 1:

- Command changed on the sdmmc_ker_ck falling edge succeeding the rising edge of SDMMC_CK.
- Data changed on the sdmmc_ker_ck falling edge succeeding a SDMMC_CK edge.
- SDMMC_CK edge occurs on sdmmc_ker_ck rising edge.

1: When clock division >1 (CLKDIV > 0) & DDR = 0:

- Command and data changed on the same sdmmc_ker_ck rising edge generating the SDMMC_CK falling edge.

When clock division >1 (CLKDIV > 0) & DDR = 1:

- Command changed on the same sdmmc_ker_ck rising edge generating the SDMMC_CK falling edge.
- Data changed on the SDMMC_CK falling edge succeeding a SDMMC_CK edge.
- SDMMC_CK edge occurs on sdmmc_ker_ck rising edge.

Bits 15:14 **WIDBUS[1:0]**: Wide bus mode enable bit

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0)

00: Default 1-bit wide bus mode: SDMMC_D0 used (Does not support DDR)

01: 4-bit wide bus mode: SDMMC_D[3:0] used

10: 8-bit wide bus mode: SDMMC_D[7:0] used

Bit 13 Reserved, must be kept at reset value.

Bit 12 **PWRSAV**: Power saving configuration bit

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0)

For power saving, the SDMMC_CK clock output can be disabled when the bus is idle by setting PWRSAV:

0: SDMMC_CK clock is always enabled

1: SDMMC_CK is only enabled when the bus is active

Bits 11:10 Reserved, must be kept at reset value.

Bits 9:0 **CLKDIV[9:0]**: Clock divide factor

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0).

This field defines the divide factor between the input clock (sdmmc_ker_ck) and the output clock (SDMMC_CK): SDMMC_CK frequency = sdmmc_ker_ck / [2 * CLKDIV].

0x000: SDMMC_CK frequency = sdmmc_ker_ck / 1 (Does not support DDR)

0x001: SDMMC_CK frequency = sdmmc_ker_ck / 2

0x002: SDMMC_CK frequency = sdmmc_ker_ck / 4

0x0XX: etc..

0x080: SDMMC_CK frequency = sdmmc_ker_ck / 256

0xXXX: etc..

0x3FF: SDMMC_CK frequency = sdmmc_ker_ck / 2046

Note: 1 While the SD/SDIO card or e•MMC is in identification mode, the SDMMC_CK frequency must be less than 400 kHz.

2 The clock frequency can be changed to the maximum card bus frequency when relative card addresses are assigned to all cards.

3 At least seven sdmmc_hclk clock periods are needed between two write accesses to this register. SDMMC_CK can also be stopped during the Read Wait interval for SD I/O cards: in this case the SDMMC_CLKCR register does not control SDMMC_CK.

60.10.3 SDMMC argument register (SDMMC_ARGR)

Address offset: 0x008

Reset value: 0x0000 0000

The SDMMC_ARGR register contains a 32-bit command argument, which is sent to a card as part of a command message.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CMDARG[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CMDARG[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CMDARG[31:0]**: Command argument

These bits can only be written by firmware when CPSM is disabled (CPSMEN = 0). Command argument sent to a card as part of a command message. If a command contains an argument, it must be loaded into this register before writing a command to the command register.

60.10.4 SDMMC command register (SDMMC_CMDR)

Address offset: 0x00C

Reset value: 0x0000 0000

The SDMMC_CMDR register contains the command index and command type bits. The command index is sent to a card as part of a command message. The command type bits control the command path state machine (CPSM).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMD SUS PEND
															rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BOOT EN	BOOT MODE	DT HOLD	CPSM EN	WAITP END	WAIT INT	WAITRESP[1:0]		CMD STOP	CMD TRANS	CMDINDEX[5:0]					
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **CMDSUSPEND**: The CPSM treats the command as a Suspend or Resume command and signals interrupt period start/end

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).
CMDSUSPEND = 1 and CMDTRANS = 0 Suspend command, start interrupt period when response bit BS=0.
CMDSUSPEND = 1 and CMDTRANS = 1 Resume command with data, end interrupt period when response bit DF=1.

Bit 15 **BOOTEN**: Enable boot mode procedure

0: Boot mode procedure disabled
1: Boot mode procedure enabled

Bit 14 **BOOTMODE**: Select the boot mode procedure to be used

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0)
0: Normal boot mode procedure selected
1: Alternative boot mode procedure selected.

Bit 13 **DTHOLD**: Hold new data block transmission and reception in the DPSM

If this bit is set, the DPSM does not move from the Wait_S state to the Send state or from the Wait_R state to the Receive state.

Bit 12 **CPSMEN**: Command path state machine (CPSM) enable bit

This bit is written 1 by firmware, and cleared by hardware when the CPSM enters the Idle state.
If this bit is set, the CPSM is enabled.
When DTEN = 1, no command is transfered nor boot procedure is started. CPSMEN is cleared to 0.
During Read Wait with SDMMC_CK stopped no command is sent and CPSMEN is kept 0.

Bit 11 **WAITPEND**: CPSM waits for end of data transfer (CmdPend internal signal) from DPSM

This bit when set, the CPSM waits for the end of data transfer trigger before it starts sending a command.
WAITPEND is only taken into account when DTMODE = *e*•MMC stream data transfer, WIDBUS = 1-bit wide bus mode, DPSMACT = 1 and DTDIR = from host to card.

Bit 10 **WAITINT**: CPSM waits for interrupt request

If this bit is set, the CPSM disables command timeout and waits for an card interrupt request (Response).
If this bit is cleared in the CPSM Wait state, it causes the abort of the interrupt mode.

Bits 9:8 **WAITRESP[1:0]**: Wait for response bits

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).
They are used to configure whether the CPSM is to wait for a response, and if yes, which kind of response.
00: No response, expect CMDSENT flag
01: Short response, expect CMDREND or CCRCFAIL flag
10: Short response, expect CMDREND flag (No CRC)
11: Long response, expect CMDREND or CCRCFAIL flag

Bit 7 **CMDSTOP**: The CPSM treats the command as a Stop Transmission command and signals abort to the DPSM

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).

If this bit is set, the CPSM issues the abort signal to the DPSM when the command is sent.

Bit 6 **CMDTRANS**: The CPSM treats the command as a data transfer command, stops the interrupt period, and signals DataEnable to the DPSM

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).

If this bit is set, the CPSM issues an end of interrupt period and issues DataEnable signal to the DPSM when the command is sent.

Bits 5:0 **CMDINDEX[5:0]**: Command index

This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).

The command index is sent to the card as part of a command message.

Note: 1 At least seven sdmmc_hclk clock periods are needed between two write accesses to this register.

2 MultiMediaCard can send two kinds of response: short responses, 48 bits, or long responses,136 bits. SD card and SD I/O card can send only short responses, the argument can vary according to the type of response: the software distinguishes the type of response according to the send command.

60.10.5 SDMMC command response register (SDMMC_RESPCMDR)

Address offset: 0x010

Reset value: 0x0000 0000

The SDMMC_RESPCMDR register contains the command index field of the last command response received. If the command response transmission does not contain the command index field (long or OCR response), the RESPCMD field is unknown, although it must contain 111111b (the value of the reserved field from the response).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RESPCMD[5:0]					
										r	r	r	r	r	r

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:0 **RESPCMD[5:0]**: Response command index

Read-only bit field. Contains the command index of the last command response received.

60.10.6 SDMMC response x register (SDMMC_RESPxR)

Address offset: 0x010 + 0x004 * x, (x = 1 to 4)

Reset value: 0x0000 0000

The SDMMC_RESP1/2/3/4R registers contain the status of a card, which is part of the received response.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CARDSTATUS[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CARDSTATUS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **CARDSTATUS[31:0]**: Card status according table below
See *Table 497*.

The card status size is 32 or 128 bits, depending on the response type.

Table 497. Response type and SDMMC_RESPxR registers

Register(1)	Short response	Long response
SDMMC_RESP1R	Card status[31:0]	Card status [127:96]
SDMMC_RESP2R	all 0	Card status [95:64]
SDMMC_RESP3R	all 0	Card status [63:32]
SDMMC_RESP4R	all 0	Card status [31:0](2)

1. The most significant bit of the card status is received first.
2. The SDMMC_RESP4R register LSB is always 0.

60.10.7 SDMMC data timer register (SDMMC_DTIMER)

Address offset: 0x024

Reset value: 0x0000 0000

The SDMMC_DTIMER register contains the data timeout period, in card bus clock periods.

A counter loads the value from the SDMMC_DTIMER register, and starts decrementing when the data path state machine (DPSM) enters the Wait_R or Busy state. If the timer reaches 0 while the DPSM is in either of these states, the timeout status flag is set.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DATATIME[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATATIME[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DATATIME[31:0]**: Data and R1b busy timeout period

This bit can only be written when the CPSM and DPSM are not active (CPSMACT = 0 and DPSMACT = 0).

Data and R1b busy timeout period expressed in card bus clock periods.

Note: A data transfer must be written to the data timer register and the data length register before being written to the data control register.

60.10.8 SDMMC data length register (SDMMC_DLENR)

Address offset: 0x028

Reset value: 0x0000 0000

The SDMMC_DLENR register contains the number of data bytes to be transferred. The value is loaded into the data counter when data transfer starts.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATALENGTH[24:16]								
							rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATALENGTH[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 24:0 **DATALENGTH[24:0]**: Data length value

This register can only be written by firmware when DPSM is inactive (DPSMACT = 0).

Number of data bytes to be transferred.

When DDR = 1 DATALENGTH is truncated to a multiple of 2. (The last odd byte is not transfered)

When DATALENGTH = 0 no data are transfered, when requested by a CPSMEN and CMDTRANS = 1 also no command is transfered. DTEN and CPSMEN are cleared to 0.

Note: For a block data transfer, the value in the data length register must be a multiple of the block size (see SDMMC_DCTRL). A data transfer must be written to the data timer register and the data length register before being written to the data control register.

For an SDMMC multibyte transfer the value in the data length register must be between 1 and 512.

60.10.9 SDMMC data control register (SDMMC_DCTRL)

Address offset: 0x02C

Reset value: 0x0000 0000

The SDMMC_DCTRL register control the data path state machine (DPSM).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	FIFO RST	BOOT ACK EN	SDIO EN	RW MOD	RW STOP	RW START	DBLOCKSIZE[3:0]				DTMODE[1:0]		DTDIR	DTEN
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **FIFORST**: FIFO reset, flushes any remaining data

This bit can only be written by firmware when IDMAEN= 0 and DPSM is active (DPSMACT = 1). This bit only takes effect when a transfer error or transfer hold occurs.

0: FIFO not affected.

1: Flush any remaining data and reset the FIFO pointers. This bit is automatically cleared to 0 by hardware when DPSM gets inactive (DPSMACT = 0).

Bit 12 **BOOTACKEN**: Enable the reception of the boot acknowledgment

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).

0: Boot acknowledgment disabled, not expected to be received

1: Boot acknowledgment enabled, expected to be received

Bit 11 **SDIOEN**: SD I/O interrupt enable functions

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).

If this bit is set, the DPSM enables the SD I/O card specific interrupt operation.

Bit 10 **RWMOD**: Read Wait mode

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).

0: Read Wait control using SDMMC_D2

1: Read Wait control stopping SDMMC_CK

Bit 9 **RWSTOP**: Read Wait stop

This bit is written by firmware and auto cleared by hardware when the DPSM moves from the R_W state to the Wait_R or Idle state.

0: No Read Wait stop.

1: Enable for Read Wait stop when DPSM is in the R_W state.

Bit 8 **RWSTART**: Read Wait start

If this bit is set, Read Wait operation starts.

Bits 7:4 **DBLOCKSIZE[3:0]**: Data block size

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).
Define the data block length when the block data transfer mode is selected:
0000: Block length = 2^0 = 1 byte
0001: Block length = 2^1 = 2 bytes
0010: Block length = 2^2 = 4 bytes
0011: Block length = 2^3 = 8 bytes
0100: Block length = 2^4 = 16 bytes
0101: Block length = 2^5 = 32 bytes
0110: Block length = 2^6 = 64 bytes
0111: Block length = 2^7 = 128 bytes
1000: Block length = 2^8 = 256 bytes
1001: Block length = 2^9 = 512 bytes
1010: Block length = 2^{10} = 1024 bytes
1011: Block length = 2^{11} = 2048 bytes
1100: Block length = 2^{12} = 4096 bytes
1101: Block length = 2^{13} = 8192 bytes
1110: Block length = 2^{14} = 16384 bytes
1111: Reserved
When DATALENGTH is not a multiple of DBLOCKSIZE, the transfered data is truncated at a multiple of DBLOCKSIZE. (None of the remaining data are transfered.)
When DDR = 1, DBLOCKSIZE = 0000 must not be used. (No data are transfered)

Bits 3:2 **DTMODE[1:0]**: Data transfer mode selection

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).
00: Block data transfer ending on block count.
01: SDIO multibyte data transfer.
10: *e*•MMC Stream data transfer. (WIDBUS must select 1-bit wide bus mode)
11: Block data transfer ending with STOP_TRANSMISSION command (not to be used with DTEN initiated data transfers).

Bit 1 **DTDIR**: Data transfer direction selection

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).
0: From host to card.
1: From card to host.

Bit 0 **DTEN**: Data transfer enable bit

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0). This bit is cleared by Hardware when data transfer completes.
This bit must only be used to transfer data when no associated data transfer command is used, i.e. must not be used with SD or *e*•MMC cards.
0: Do not start data transfer without CPSM data transfer command.
1: Start data transfer without CPSM data transfer command.

60.10.10 SDMMC data counter register (SDMMC_DCNTR)

Address offset: 0x030

Reset value: 0x0000 0000

The SDMMC_DCNTR register loads the value from the data length register (see SDMMC_DLENR) when the DPSM moves from the Idle state to the Wait_R or Wait_S state. As data is transferred, the counter decrements the value until it reaches 0. The DPSM then

moves to the Idle state and when there has been no error, and no transmit data transfer hold, the data status end flag (DATAEND) is set.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATACOUNT[24:16]								
							r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATACOUNT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:25 Reserved, must be kept at reset value.

Bits 24:0 **DATACOUNT[24:0]**: Data count value

When read, the number of remaining data bytes to be transferred is returned. Write has no effect.

Note: This register should be read only after the data transfer is complete, or hold. When reading after an error event the read data count value may be different from the real number of data bytes transfered.

60.10.11 SDMMC status register (SDMMC_STAR)

Address offset: 0x034

Reset value: 0x0000 0000

The SDMMC_STAR register is a read-only register. It contains two types of flag:

- Static flags (bits [28, 21, 11:0]): these bits remain asserted until they are cleared by writing to the SDMMC interrupt Clear register (see SDMMC_ICR)
- Dynamic flags (bits [20:12]): these bits change state depending on the state of the underlying logic (for example, FIFO full and empty flags are asserted and deasserted as data while written to the FIFO)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	IDMA BTC	IDMA TE	CK STOP	VSW END	ACK TIME OUT	ACK FAIL	SDIOIT	BUSY D0END	BUSY D0	RX FIFOE	TX FIFOE	RX FIFOF	TX FIFOF
			r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RX FIFO HF	TX FIFO HE	CPSM ACT	DPSM ACT	DA BORT	DBCK END	DHOLD	DATA END	CMD SENT	CMDR END	RX OVERR	TX UNDER R	D TIME OUT	C TIME OUT	DCRC FAIL	CCRC FAIL
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **IDMABTC**: IDMA buffer transfer complete

The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 27 **IDMATE**: IDMA transfer error

The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 26 **CKSTOP**: SDMMC_CK stopped in Voltage switch procedure

The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 25 **VSWEND**: Voltage switch critical timing section completion
The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 24 **ACKTIMEOUT**: Boot acknowledgment timeout
The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 23 **ACKFAIL**: Boot acknowledgment received (boot acknowledgment check fail)
The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 22 **SDIOIT**: SDIO interrupt received
The interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 21 **BUSYD0END**: end of SDMMC_D0 Busy following a CMD response detected
This indicates only end of busy following a CMD response. This bit does not signal busy due to data transfer. Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.
0: card SDMMC_D0 signal does NOT signal change from busy to not busy.
1: card SDMMC_D0 signal changed from busy to NOT busy.

Bit 20 **BUSYD0**: Inverted value of SDMMC_D0 line (Busy), sampled at the end of a CMD response and a second time 2 SDMMC_CK cycles after the CMD response
This bit is reset to not busy when the SDMMCD0 line changes from busy to not busy. This bit does not signal busy due to data transfer. This is a hardware status flag only, it does not generate an interrupt.
0: card signals not busy on SDMMC_D0.
1: card signals busy on SDMMC_D0.

Bit 19 **RXFIFOE**: Receive FIFO empty
This is a hardware status flag only, does not generate an interrupt. This bit is cleared when one FIFO location becomes full.

Bit 18 **TXFIFOE**: Transmit FIFO empty
This bit is cleared when one FIFO location becomes full.

Bit 17 **RXFIFOF**: Receive FIFO full
This bit is cleared when one FIFO location becomes empty.

Bit 16 **TXFIFOF**: Transmit FIFO full
This is a hardware status flag only, does not generate an interrupt. This bit is cleared when one FIFO location becomes empty.

Bit 15 **RXFIFOHF**: Receive FIFO half full
There are at least half the number of words in the FIFO. This bit is cleared when the FIFO becomes half+1 empty.

Bit 14 **TXFIFOHE**: Transmit FIFO half empty
At least half the number of words can be written into the FIFO. This bit is cleared when the FIFO becomes half+1 full.

Bit 13 **CPSMACT**: Command path state machine active, i.e. not in Idle state
This is a hardware status flag only, does not generate an interrupt.

Bit 12 **DPSMACT**: Data path state machine active, i.e. not in Idle state
This is a hardware status flag only, does not generate an interrupt.

Bit 11 **DABORT**: Data transfer aborted by CMD12
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 10 **DBCKEND**: Data block sent/received
DBCKEND is set when:
- CRC check passed and DPSM moves to the R_W state
or
- IDMAEN = 0 and transmit data transfer hold and DATACOUNT >0 and DPSM moves to Wait_S.
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 9 **DHOLD**: Data transfer Hold
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 8 **DATAEND**: Data transfer ended correctly
DATAEND is set if data counter DATACOUNT is zero and no errors occur, and no transmit data transfer hold.
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 7 **CMDSENT**: Command sent (no response required)
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 6 **CMDREND**: Command response received (CRC check passed, or no CRC)
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 5 **RXOVERR**: Received FIFO overrun error
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 4 **TXUNDERR**: Transmit FIFO underrun error
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 3 **DTIMEOUT**: Data timeout
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 2 **CTIMEOUT**: Command response timeout
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.
The Command Timeout period has a fixed value of 64 SDMMC_CK clock periods.

Bit 1 **DCRCFAIL**: Data block sent/received (CRC check failed)
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Bit 0 **CCRCFAIL**: Command response received (CRC check failed)
Interrupt flag is cleared by writing corresponding interrupt clear bit in SDMMC_ICR.

Note: FIFO interrupt flags must be masked in SDMMC_MASKR when using IDMA mode.

60.10.12 SDMMC interrupt clear register (SDMMC_ICR)

Address offset: 0x038

Reset value: 0x0000 0000

The SDMMC_ICR register is a write-only register. Writing a bit with 1 clears the corresponding bit in the SDMMC_STAR status register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	IDMA BTCC	IDMA TEC	CK STOPC	VSW ENDC	ACK TIME OUTC	ACK FAILC	SDIO ITC	BUSY D0 ENDC	Res.	Res.	Res.	Res.	Res.
			rw	rw	rw	rw	rw	rw	rw	rw					
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	D ABORT C	DBCK ENDC	DHOLD C	DATA ENDC	CMD SENTC	CMDR ENDC	RX OVERR C	TX UNDER RC	D TIME OUTC	C TIME OUTC	DCRC FAILC	CCRC FAILC
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **IDMABTCC**: IDMA buffer transfer complete clear bit
Set by software to clear the IDMABTC flag.
0: IDMABTC not cleared
1: IDMABTC cleared

Bit 27 **IDMATEC**: IDMA transfer error clear bit
Set by software to clear the IDMATE flag.
0: IDMATE not cleared
1: IDMATE cleared

Bit 26 **CKSTOPC**: CKSTOP flag clear bit
Set by software to clear the CKSTOP flag.
0: CKSTOP not cleared
1: CKSTOP cleared

Bit 25 **VSWENDC**: VSWEND flag clear bit
Set by software to clear the VSWEND flag.
0: VSWEND not cleared
1: VSWEND cleared

Bit 24 **ACKTIMEOUTC**: ACKTIMEOUT flag clear bit
Set by software to clear the ACKTIMEOUT flag.
0: ACKTIMEOUT not cleared
1: ACKTIMEOUT cleared

Bit 23 **ACKFAILC**: ACKFAIL flag clear bit
Set by software to clear the ACKFAIL flag.
0: ACKFAIL not cleared
1: ACKFAIL cleared

Bit 22 **SDIOITC**: SDIOIT flag clear bit
Set by software to clear the SDIOIT flag.
0: SDIOIT not cleared
1: SDIOIT cleared

Bit 21 **BUSYD0ENDC**: BUSYD0END flag clear bit
Set by software to clear the BUSYD0END flag.
0: BUSYD0END not cleared
1: BUSYD0END cleared

Bits 20:12 Reserved, must be kept at reset value.

Bit 11 **DABORTC**: DABORT flag clear bit
Set by software to clear the DABORT flag.
0: DABORT not cleared
1: DABORT cleared

Bit 10 **DBCKENDC**: DBCKEND flag clear bit
Set by software to clear the DBCKEND flag.
0: DBCKEND not cleared
1: DBCKEND cleared

Bit 9 **DHOLDC**: DHOLD flag clear bit
Set by software to clear the DHOLD flag.
0: DHOLD not cleared
1: DHOLD cleared

Bit 8 **DATAENDC**: DATAEND flag clear bit
Set by software to clear the DATAEND flag.
0: DATAEND not cleared
1: DATAEND cleared

Bit 7 **CMDSENTC**: CMDSENT flag clear bit
Set by software to clear the CMDSENT flag.
0: CMDSENT not cleared
1: CMDSENT cleared

Bit 6 **CMDRENDC**: CMDREND flag clear bit
Set by software to clear the CMDREND flag.
0: CMDREND not cleared
1: CMDREND cleared

Bit 5 **RXOVERRC**: RXOVERR flag clear bit
Set by software to clear the RXOVERR flag.
0: RXOVERR not cleared
1: RXOVERR cleared

Bit 4 **TXUNDERRC**: TXUNDERR flag clear bit
Set by software to clear TXUNDERR flag.
0: TXUNDERR not cleared
1: TXUNDERR cleared

Bit 3 **DTIMEOUTC**: DTIMEOUT flag clear bit
Set by software to clear the DTIMEOUT flag.
0: DTIMEOUT not cleared
1: DTIMEOUT cleared

Bit 2 **CTIMEOUTC**: CTIMEOUT flag clear bit
Set by software to clear the CTIMEOUT flag.
0: CTIMEOUT not cleared
1: CTIMEOUT cleared

Bit 1 **DCRCFAILC**: DCRCFAIL flag clear bit
Set by software to clear the DCRCFAIL flag.
0: DCRCFAIL not cleared
1: DCRCFAIL cleared

Bit 0 **CCRCFAILC**: CCRCFAIL flag clear bit
Set by software to clear the CCRCFAIL flag.
0: CCRCFAIL not cleared
1: CCRCFAIL cleared

60.10.13 SDMMC mask register (SDMMC_MASKR)

Address offset: 0x03C

Reset value: 0x0000 0000

The interrupt mask register determines which status flags generate an interrupt request by setting the corresponding bit to 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	IDMA BTCIE	Res.	CK STOP IE	VSW ENDIE	ACK TIME OUTIE	ACK FAILIE	SDIO ITIE	BUSY D0 ENDIE	Res.	Res.	TX FIFO EIE	RX FIFO FIE	Res.
			rw		rw	rw	rw	rw	rw	rw			rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RX FIFO HFIE	TX FIFO HEIE	Res.	Res.	DA BORT IE	DBCK ENDIE	DHOLD IE	DATA ENDIE	CMD SENT IE	CMDR ENDIE	RX OVER RIE	TX UNDER RIE	D TIME OUTIE	C TIME OUTIE	DCRC FAILIE	CCRC FAILIE
rw	rw			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **IDMABTCIE**: IDMA buffer transfer complete interrupt enable
Set and cleared by software to enable/disable the interrupt generated when the IDMA has transferred all data belonging to a memory buffer.
0: IDMA buffer transfer complete interrupt disabled
1: IDMA buffer transfer complete interrupt enabled

Bit 27 Reserved, must be kept at reset value.

Bit 26 **CKSTOPIE**: Voltage Switch clock stopped interrupt enable
Set and cleared by software to enable/disable interrupt caused by Voltage Switch clock stopped.
0: Voltage Switch clock stopped interrupt disabled
1: Voltage Switch clock stopped interrupt enabled

Bit 25 **VSWENDIE**: Voltage switch critical timing section completion interrupt enable
Set and cleared by software to enable/disable the interrupt generated when voltage switch critical timing section completion.
0: Voltage switch critical timing section completion interrupt disabled
1: Voltage switch critical timing section completion interrupt enabled

Bit 24 **ACKTIMEOUTIE**: Acknowledgment timeout interrupt enable
Set and cleared by software to enable/disable interrupt caused by acknowledgment timeout.
0: Acknowledgment timeout interrupt disabled
1: Acknowledgment timeout interrupt enabled

Bit 23 **ACKFAILIE**: Acknowledgment Fail interrupt enable
Set and cleared by software to enable/disable interrupt caused by acknowledgment Fail.
0: Acknowledgment Fail interrupt disabled
1: Acknowledgment Fail interrupt enabled

Bit 22 **SDIOITIE**: SDIO mode interrupt received interrupt enable
Set and cleared by software to enable/disable the interrupt generated when receiving the SDIO mode interrupt.
0: SDIO Mode interrupt received interrupt disabled
1: SDIO Mode interrupt received interrupt enabled

Bit 21 **BUSYD0ENDIE**: BUSYD0END interrupt enable
Set and cleared by software to enable/disable the interrupt generated when SDMMC_D0 signal changes from busy to NOT busy following a CMD response.
0: BUSYD0END interrupt disabled
1: BUSYD0END interrupt enabled

Bits 20:19 Reserved, must be kept at reset value.

Bit 18 **TXFIFOEIE**: Tx FIFO empty interrupt enable
Set and cleared by software to enable/disable interrupt caused by Tx FIFO empty.
0: Tx FIFO empty interrupt disabled
1: Tx FIFO empty interrupt enabled

Bit 17 **RXFIFOFIE**: Rx FIFO full interrupt enable
Set and cleared by software to enable/disable interrupt caused by Rx FIFO full.
0: Rx FIFO full interrupt disabled
1: Rx FIFO full interrupt enabled

Bit 16 Reserved, must be kept at reset value.

Bit 15 **RXFIFOHFIE**: Rx FIFO half full interrupt enable
Set and cleared by software to enable/disable interrupt caused by Rx FIFO half full.
0: Rx FIFO half full interrupt disabled
1: Rx FIFO half full interrupt enabled

Bit 14 **TXFIFOHEIE**: Tx FIFO half empty interrupt enable
Set and cleared by software to enable/disable interrupt caused by Tx FIFO half empty.
0: Tx FIFO half empty interrupt disabled
1: Tx FIFO half empty interrupt enabled

Bits 13:12 Reserved, must be kept at reset value.

Bit 11 **DABORTIE**: Data transfer aborted interrupt enable
Set and cleared by software to enable/disable interrupt caused by a data transfer being aborted.
0: Data transfer abort interrupt disabled
1: Data transfer abort interrupt enabled

Bit 10 **DBCKENDIE**: Data block end interrupt enable
Set and cleared by software to enable/disable interrupt caused by data block end.
0: Data block end interrupt disabled
1: Data block end interrupt enabled

Bit 9 **DHOLDIE**: Data hold interrupt enable
Set and cleared by software to enable/disable the interrupt generated when sending new data is hold in the DPSM Wait_S state.
0: Data hold interrupt disabled
1: Data hold interrupt enabled

Bit 8 **DATAENDIE**: Data end interrupt enable
Set and cleared by software to enable/disable interrupt caused by data end.
0: Data end interrupt disabled
1: Data end interrupt enabled

Bit 7 **CMDSENTIE**: Command sent interrupt enable
Set and cleared by software to enable/disable interrupt caused by sending command.
0: Command sent interrupt disabled
1: Command sent interrupt enabled

Bit 6 **CMDRENDIE**: Command response received interrupt enable
Set and cleared by software to enable/disable interrupt caused by receiving command response.
0: Command response received interrupt disabled
1: command Response received interrupt enabled

Bit 5 **RXOVERRIE**: Rx FIFO overrun error interrupt enable
Set and cleared by software to enable/disable interrupt caused by Rx FIFO overrun error.
0: Rx FIFO overrun error interrupt disabled
1: Rx FIFO overrun error interrupt enabled

Bit 4 **TXUNDERRIE**: Tx FIFO underrun error interrupt enable
Set and cleared by software to enable/disable interrupt caused by Tx FIFO underrun error.
0: Tx FIFO underrun error interrupt disabled
1: Tx FIFO underrun error interrupt enabled

Bit 3 **DTIMEOUTIE**: Data timeout interrupt enable
Set and cleared by software to enable/disable interrupt caused by data timeout.
0: Data timeout interrupt disabled
1: Data timeout interrupt enabled

Bit 2 **CTIMEOUTIE**: Command timeout interrupt enable
Set and cleared by software to enable/disable interrupt caused by command timeout.
0: Command timeout interrupt disabled
1: Command timeout interrupt enabled

Bit 1 **DCRCFAILIE**: Data CRC fail interrupt enable
Set and cleared by software to enable/disable interrupt caused by data CRC failure.
0: Data CRC fail interrupt disabled
1: Data CRC fail interrupt enabled

Bit 0 **CCRCFAILIE**: Command CRC fail interrupt enable
Set and cleared by software to enable/disable interrupt caused by command CRC failure.
0: Command CRC fail interrupt disabled
1: Command CRC fail interrupt enabled

60.10.14 SDMMC acknowledgment timer register (SDMMC_ACKTIMER)

Address offset: 0x040

Reset value: 0x0000 0000

The SDMMC_ACKTIMER register contains the acknowledgment timeout period, in SDMMC_CK bus clock periods.

A counter loads the value from the SDMMC_ACKTIMER register, and starts decrementing when the data path state machine (DPSM) enters the Wait_Ack state. If the timer reaches 0 while the DPSM is in this states, the acknowledgment timeout status flag is set.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	ACKTIME[24:16]								
							rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACKTIME[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bits 24:0 **ACKTIME[24:0]**: Boot acknowledgment timeout period
This bit can only be written by firmware when CPSM is disabled (CPSMEN = 0).
Boot acknowledgment timeout period expressed in card bus clock periods.

Note: The data transfer must be written to the acknowledgment timer register before being written to the data control register.

60.10.15 SDMMC data FIFO registers x (SDMMC_FIFORx)

Address offset: 0x080 + 0x004 * x, (x =0 to 15)

Reset value: 0x0000 0000

The receive and transmit FIFOs can be only read or written as word (32-bit) wide registers. The FIFOs contain 16 entries on sequential addresses. This enables the CPU to use its load and store multiple operands to read from/write to the FIFO. The FIFO register interface takes care of correct data alignment inside the FIFO, the FIFO register address used by the CPU does matter.

When accessing SDMMC_FIFOR with half word or byte access an AHB bus fault is generated.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FIFODATA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FIFODATA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **FIFODATA[31:0]**: Receive and transmit FIFO data

This register can only be read or written by firmware when the DPSM is active (DPSMACT = 1).

The FIFO data occupies 16 entries of 32-bit words.

60.10.16 SDMMC DMA control register (SDMMC_IDMACTRLR)

Address offset: 0x050

Reset value: 0x0000 0000

The receive and transmit FIFOs can be read or written as 32-bit wide registers. The FIFOs contain 32 entries on 32 sequential addresses. This enables the CPU to use its load and store multiple operands to read from/write to the FIFO.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IDMABACT	IDMABMODE	IDMAEN
													rw	rw	rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **IDMABACT**: Double buffer mode active buffer indication

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0). When IDMA is enabled this bit is toggled by hardware.

0: When IDMA is enabled, uses buffer0 and firmware write access to IDMABASE0 is prohibited.

1: When IDMA is enabled, uses buffer1 and firmware write access to IDMABASE1 is prohibited.

Bit 1 **IDMABMODE**: Buffer mode selection

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).

0: Single buffer mode.

1: Double buffer mode.

Bit 0 **IDMAEN**: IDMA enable

This bit can only be written by firmware when DPSM is inactive (DPSMACT = 0).

0: IDMA disabled

1: IDMA enabled

60.10.17 SDMMC IDMA buffer size register (SDMMC_IDMABSIZER)

Address offset: 0x054

Reset value: 0x0000 0000

The SDMMC_IDMABSIZER register contains the buffers size when in double buffer configuration.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	IDMABNDT[7:0]								Res.	Res.	Res.	Res.	Res.
			rw	rw	rw	rw	rw	rw	rw	rw					

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:5 **IDMABNDT[7:0]**: Number of bytes per buffer

This 8-bit value must be multiplied by 8 to get the size of the buffer in 32-bit words and by 32 to get the size of the buffer in bytes.

Example: IDMABNDT = 0x01: buffer size = 8 words = 32 bytes.

Example: IDMABNDT = 0x80: buffer size = 1024 words = 4 Kbytes

These bits can only be written by firmware when DPSM is inactive (DPSMACT = 0).

Bits 4:0 Reserved, must be kept at reset value.

60.10.18 SDMMC IDMA buffer 0 base address register (SDMMC_IDMABASE0R)

Address offset: 0x058

Reset value: 0x0000 0000

The SDMMC_IDMABASE0R register contains the memory buffer base address in single buffer configuration and the buffer 0 base address in double buffer configuration.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IDMABASE0[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IDMABASE0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r

Bits 31:0 **IDMABASE0[31:0]**: Buffer 0 memory base address bits [31:2], must be word aligned (bit [1:0] are always 0 and read only)

This register can be written by firmware when DPSM is inactive (DPSMACT = 0), and can dynamically be written by firmware when DPSM active (DPSMACT = 1) and memory buffer 0 is inactive (IDMABACT = ‘1’).

60.10.19 SDMMC IDMA buffer 1 base address register (SDMMC_IDMABASE1R)

Address offset: 0x05C

Reset value: 0x0000 0000

The SDMMC_IDMABASE1R register contains the double buffer configuration second buffer memory base address.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IDMABASE1[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IDMABASE1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r

Bits 31:0 **IDMABASE1[31:0]**: Buffer 1 memory base address, must be word aligned (bit [1:0] are always 0 and read only)

This register can be written by firmware when DPSM is inactive (DPSMACT = 0), and can dynamically be written by firmware when DPSM active (DPSMACT = 1) and memory buffer 1 is inactive (IDMABACT = ‘0’).

60.10.20 SDMMC register map

The following table summarizes the SDMMC registers.

Table 498. SDMMC register map

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	**SDMMC_ POWER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIRPOL	VSWITCHEN	VSWITCH	PWRCTRL[1:0]	
	Reset value																												0	0	0	0	0
0x004	**SDMMC_ CLKCR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SELCLKRX[1:0]		BUSSPEED	DDR	HWFC_EN	NEGEDGE	WIDBUS[1:0]		Res.	PWRSAV	Res.	Res.	CLKDIV[9:0]									
	Reset value											0	0	0	0	0	0	0	0		0			0	0	0	0	0	0	0	0	0	0
0x008	**SDMMC_ ARGR**	CMDARG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00C	**SDMMC_ CMDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CMDSUSPEND	BOOTEN	BOOTMODE	DTHOLD	CPSMEN	WAITPEND	WAITINT	WAITRESP[1:0]		CMDSTOP	CMDTRANS	CMDINDEX[5:0]					
	Reset value																																
0x010	**SDMMC_ RESPCMDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RESPCMD[5:0]					
	Reset value																											0	0	0	0	0	0
0x014	**SDMMC_ RESP1R**	CARDSTATUS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x018	**SDMMC_ RESP2R**	CARDSTATUS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x01C	**SDMMC_ RESP3R**	CARDSTATUS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	**SDMMC_ RESP4R**	CARDSTATUS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	**SDMMC_ DTIMER**	DATATIME[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x028	**SDMMC_ DLENR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATALENGTH[24:0]																								
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 498. SDMMC register map (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x02C	**SDMMC_ DCTRLR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FIFORST	BOOTACKEN	SDIOEN	RWMOD	RWSTOP	RWSTART	DBLOCK SIZE[3:0]				DTMODE[1:0]		DTDIR	DTEN
	Reset value																			0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x030	**SDMMC_ DCNTR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DATACOUNT[24:0]																								
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x034	**SDMMC_ STAR**	Res.	Res.	Res.	IDMABTC	IDMATE	CKSTOP	VSWEND	ACKTIMEOUT	ACKFAIL	SDIOIT	BUSYD0END	BUSYD0	RXFIFOE	TXFIFOE	RXFIFOF	TXFIFOF	RXFIFOHF	TXFIFOHE	CPSMACT	DPSMACT	DABORT	DBCKEND	DHOLD	DATAEND	CMDSENT	CMDREND	RXOVERR	TXUNDERR	DTIMEOUT	CTIMEOUT	DCRCFAIL	CCRCFAIL
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x038	**SDMMC_ ICR**	Res.	Res.	Res.	IDMABTCC	IDMATEC	CKSTOPC	VSWENDC	ACKTIMEOUTC	ACKFAILC	SDIOITC	BUSYD0ENDC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DABORTC	DBCKENDC	DHOLDC	DATAENDC	CMDSENTC	CMDRENDC	RXOVERRC	TXUNDERRC	DTIMEOUTC	CTIMEOUTC	DCRCFAILC	CCRCFAILC
	Reset value				0	0	0	0	0	0	0	0										0	0	0	0	0	0	0	0	0	0	0	0
0x03C	**SDMMC_ MASKR**	Res.	Res.	Res.	IDMABTCIE	Res.	CKSTOPIE	VSWENDIE	ACKTIMEOUTIE	ACKFAILIE	SDIOITIE	BUSYD0ENDIE	Res.	Res.	TXFIFOEIE	RXFIFOFIE	Res.	RXFIFOHFIE	TXFIFOHEIE	Res.	Res.	DABORTIE	DBCKENDIE	DHOLDIE	DATAENDIE	CMDSENTIE	CMDRENDIE	RXOVERRIE	TXUNDERRIE	DTIMEOUTIE	CTIMEOUTIE	DCRCFAILIE	CCRCFAILIE
	Reset value				0		0	0	0	0	0	0			0	0		0	0			0	0	0	0	0	0	0	0	0	0	0	0
0x040	**SDMMC_ ACKTIMER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ACKTIME[24:0]																								
	Reset value								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x044 - 0x04C	**Reserved**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x050	**SDMMC_ IDMACTRLR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IDMABACT	IDMABMODE	IDMAEN
	Reset value																														0	0	0
0x054	**SDMMC_ IDMABSIZER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IDMABNDT[7:0]								Res.	Res.	Res.	Res.	Res.
	Reset value																				0	0	0	0	0	0	0	0					
0x058	**SDMMC_ IDMABASE0R**	IDMABASE0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x05C	**SDMMC_ IDMABASE1R**	IDMABASE1[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x060 - 0x07C	**Reserved**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
0x080 + 0x04 * x, (x=0..15)	**SDMMC_ FIFOR**	FIFODATA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

61 Controller area network with flexible data rate (FDCAN)

61.1 Introduction

The controller area network (CAN) subsystem (see *Figure 762*) consists of three CAN modules, a shared message RAM and a clock calibration unit. Refer to the product memory organization for the base address of each of them.

FDCAN modules are compliant with ISO 11898-1: 2015 (CAN protocol specification version 2.0 part A, B) and CAN FD protocol specification version 1.0.

In addition, the first CAN module FDCAN1 supports time triggered CAN (TTCAN), specified in ISO 11898-4, including event synchronized time-triggered communication, global system time, and clock drift compensation. The FDCAN1 contains additional registers, specific to the time triggered feature. The CAN FD option can be used together with event-triggered and time-triggered CAN communication.

A 10 Kbyte message RAM implements filters, receive FIFOs, receive buffers, transmit event FIFOs, transmit buffers (and triggers for TTCAN). This message RAM is shared between the FDCAN modules.

The common clock calibration unit is optional. It can be used to generate a calibrated clock for each FDCAN from the HSI internal RC oscillator and the PLL, by evaluating CAN messages received by the FDCAN1.

The CAN subsystem I/O signals and pins are detailed, respectively, in *Table 499* and *Table 501*.

Table 499. CAN subsystem I/O signals

Name	Type	Description
fdcan_ker_ck	Digital input	CAN subsystem kernel clock input
fdcan_pclk		CAN subsystem APB interface clock input
fdcan_cal_it	Digital output	FDCAN calibration interrupt
fdcan1_intr0_it	Digital output	FDCAN1 interrupt0
fdcan1_intr1_it		FDCAN1 interrupt1
fdcan2_intr0_it	Digital output	FDCAN2 interrupt0
fdcan2_intr1_it		FDCAN2 interrupt1
fdcan3_intr0_it	Digital output	FDCAN3 interrupt0
fdcan3_intr1_it		FDCAN3 interrupt1
fdcan1_swt[0:3]	Digital input	Stop watch trigger input
fdcan1_evt[0:3]		Event trigger input
fdcan1_ts[0:15]		External timestamp vector
fdcan1_soc	Digital output	Start of cycle pulse
fdcan1_rtp		Register time mark pulse
fdcan1_tmp		Trigger time mark pulse

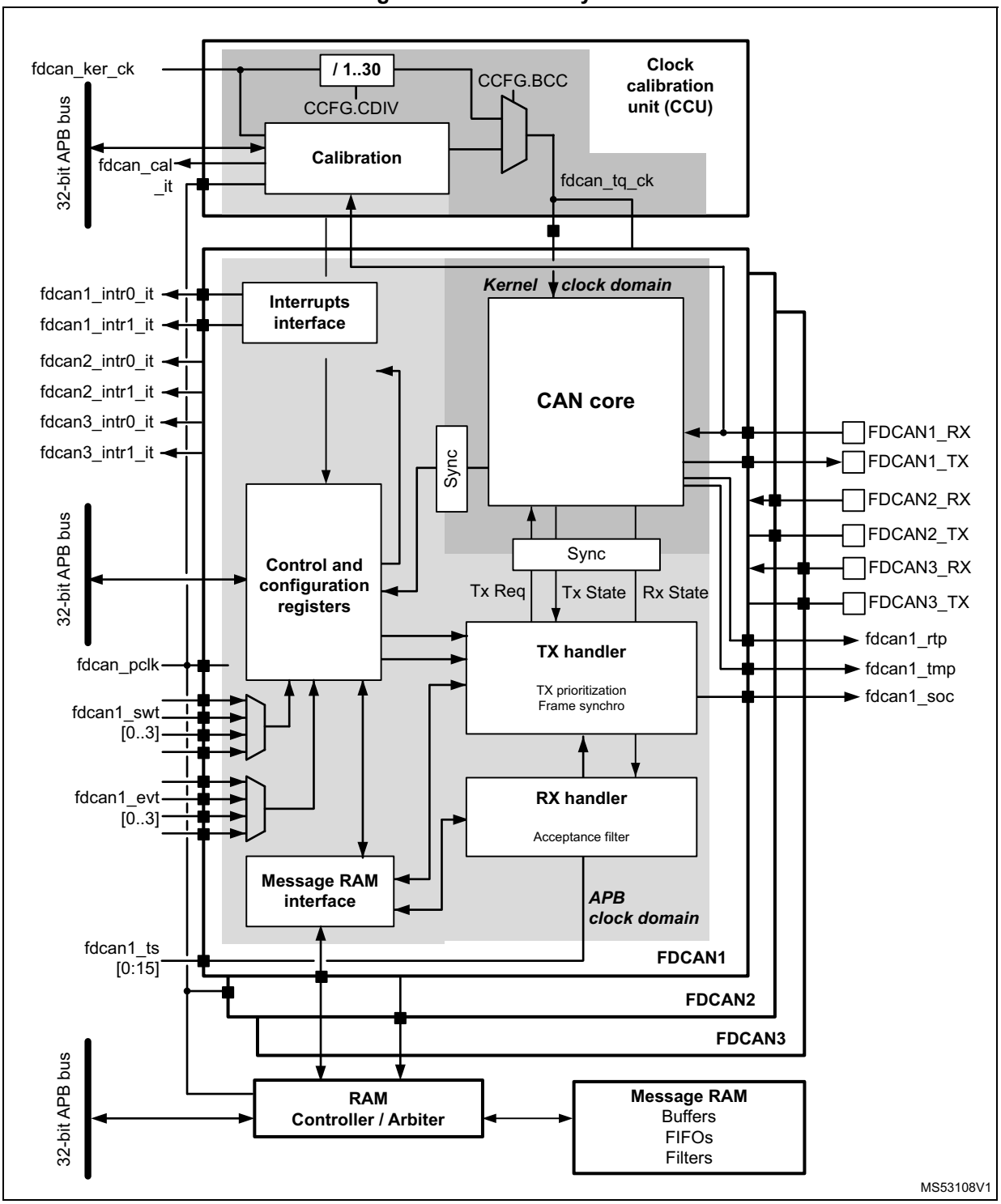
Table 500. CAN triggers

Type	ID	Source	Destination
Internal	SWT0	TIM2_TRGO	-
	SWT1	TIM3_TRGO	-
	SWT2	ETH_PPS	-
	SWT3	-	-
	EVT0	TIM2_TRGO	-
	EVT1	TIM3_TRGO	-
	EVT2	ETH_PPS	-
	EVT3	-	-
External	fdcan_tt_soc	-	TIM5_ITR6, TIM24_TI1_3
	fdcan_tt_tmp	-	TIM5_TI1_1, TIM24_TI1_1, ETH_PTP3
	fdcan_tt_rtp	-	TIM5_TI1_2, TIM24_TI1_2

Table 501. CAN subsystem I/O pins

Name	Type	Description
FDCAN1_RX	Digital input	FDCAN1 receive pin
FDCAN1_TX	Digital output	FDCAN1 transmit pin
FDCAN2_RX	Digital input	FDCAN2 receive pin
FDCAN2_TX	Digital output	FDCAN2 transmit pin
FDCAN3_RX	Digital input	FDCAN3 receive pin
FDCAN3_TX	Digital output	FDCAN3 transmit pin

Figure 762. CAN subsystem



61.2 FDCAN main features

- Conform with CAN protocol version 2.0 part A, B and ISO 11898-1: 2015, -4
- CAN FD with max. 64 data bytes supported
- TTCAN protocol level 1 and level 2 completely in hardware (FDCAN1 only)
- Event synchronized time-triggered communication supported (FDCAN1 only)
- CAN error logging
- AUTOSAR and J1939 support
- Improved acceptance filtering
- Two configurable receive FIFOs
- Separate signaling on reception of high priority messages
- Up to 64 dedicated receive buffers
- Up to 32 dedicated transmit buffers
- Configurable transmit FIFO / queue
- Configurable transmit event FIFO
- FDCAN modules share the same message RAM
- Programmable loop-back test mode
- Maskable module interrupts
- Two clock domains: APB bus interface and CAN core kernel clock
- Power-down support

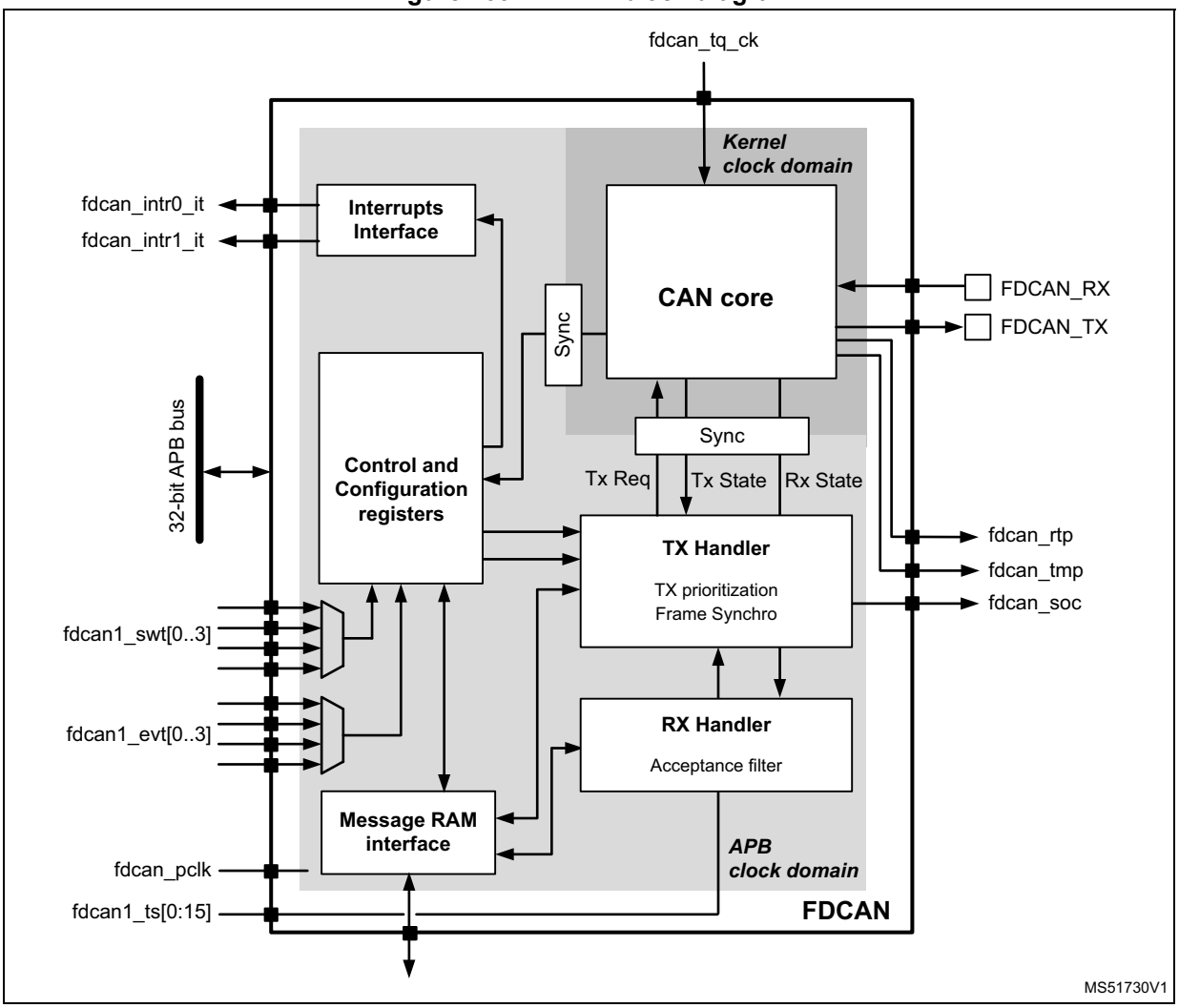
61.3 FDCAN implementation

Table 502. Main features

Module	FDCAN1	FDCAN2	FDCAN3
TTCAN	X	-	-

61.4 FDCAN functional description

Figure 763. FDCAN block diagram



Dual interrupt lines

The FDCAN peripheral provides two interrupt lines fdcan_intr0_it and fdcan_intr1_it. By programming EINT0 and EINT1 bits in FDCAN_ILE register, the interrupt lines can be enabled or disabled separately.

CAN core

The CAN core contains the protocol controller and receive/transmit shift registers. It handles all ISO 11898-1: 2015 protocol functions and supports both 11-bit and 29-bit identifiers.

Sync

The sync block synchronizes signals from the APB clock domain to the CAN kernel clock domain and vice versa.

Tx handler

Controls the message transfer from the message RAM to the CAN core. A maximum of 32 Tx buffers can be configured for transmission. Tx buffers can be used as dedicated Tx buffers, as Tx FIFO, part of a Tx queue, or as a combination of them. A Tx event FIFO stores Tx timestamps together with the corresponding message ID. Transmit cancellation is also supported.

On FDCAN1, the Tx handler also implements the frame synchronization entity (FSE) which controls time-triggered communication according to ISO11898-4. It synchronizes itself with the reference messages on the CAN bus, controls cycle time and global time, and handles transmissions according to the predefined message schedule, the system matrix. It also handles the time marks of the system matrix that are linked to the messages in the message RAM. Stop watch trigger, event trigger, and time mark interrupt are synchronization interfaces.

Rx handler

Controls the transfer of received messages from the CAN core to the external message RAM. The Rx handler supports two receive FIFOs, each of configurable size, and up to 64 dedicated Rx buffers for storage of all messages that have passed acceptance filtering. A dedicated Rx buffer, in contrast to a receive FIFO, is used to store only messages with a specific identifier. An Rx timestamp is stored together with each message. Up to 128 filters can be defined for 11-bit IDs and up to 64 filters for 29-bit IDs.

APB Interface

Connects the FDCAN to the APB bus.

Message RAM Interface

Connects the FDCAN access to an external 10 Kbytes message RAM through a RAM controller/arbiter.

61.4.1 Operating modes

Software initialization

Software initialization is started by setting INIT bit in FDCAN_CCCR register, either by software or by a hardware reset, or by going Bus_Off. While INIT bit in FDCAN_CCCR register is set, message transfer from and to the CAN bus is stopped, the status of the CAN bus output FDCAN_TX is recessive (high). The counters of the error management logic (EML) are unchanged. Setting INIT bit in FDCAN_CCCR does not change any configuration register. Clearing INIT bit in FDCAN_CCCR finishes the software initialization. Afterwards the bit stream processor (BSP) synchronizes itself to the data transfer on the CAN bus by waiting for the occurrence of a sequence of 11 consecutive recessive bits (Bus_Idle) before it can take part in bus activities and start the message transfer.

Access to the FDCAN configuration registers is only enabled when both INIT bit in FDCAN_CCCR register and CCE bit in FDCAN_CCCR register are set.

CCE bit in FDCAN_CCCR register can only be set/cleared while INIT bit in FDCAN_CCCR is set. CCE bit in FDCAN_CCCR register is automatically cleared when INIT bit in FDCAN_CCCR is cleared.

The following registers are reset when CCE bit in FDCAN_CCCR register is set:

- FDCAN_HPMS - high priority message status
- FDCAN_ RXF0S - Rx FIFO 0 status
- FDCAN_RXF1S - Rx FIFO 1 status
- FDCAN_TXFQS - Tx FIFO/queue status
- FDCAN_TXBRP - Tx buffer request pending
- FDCAN_TXBTO - Tx buffer transmission occurred
- FDCAN_TXBCF - Tx buffer cancellation finished
- FDCAN_TXEFS - Tx event FIFO status
- FDCAN_TTOST - TT (time trigger) operation status (FDCAN1 only)
- FDCAN_TTLGT - TT local and global time, only global time FDCAN_TTLGT.GT is reset (FDCAN1 only)
- FDCAN_TTCTC - TT cycle time and count (FDCAN1 only)
- FDCAN_TTCSM - TT cycle sync mark (FDCAN1 only)

The timeout counter value TOC bit in FDCAN_TOCV register is preset to the value configured by TOP bit in FDCAN_TOCC register when CCE bit in FDCAN_CCCR is set.

In addition the state machines of the Tx handler and Rx handler are held in idle state while CCE bit in FDCAN_CCCR is set.

The following registers can be written only when CCE bit in FDCAN_CCCR register is cleared:

- FDCAN_TXBAR - Tx buffer add request
- FDCAN_TXBCR - Tx buffer cancellation request

TEST bit in FDCAN_CCCR and MON bit in FDCAN_CCCR can only be set by software while both INIT bit and CCE bit in FDCAN_CCCR register are set. Both bits may be reset at any time. DAR bit in FDCAN_CCCR can only be set/cleared while both INIT bit in FDCAN_CCCR and CCE bit in FDCAN_CCCR are set.

Normal operation

The FDCAN1 default operating mode after hardware reset is event-driven CAN communication without time triggers (FDCAN_TTOCF.OM = 00). It is required that both INIT bit and CCE bit in FDCAN_CCCR register are set before the TT operation mode can be changed.

Once the FDCAN is initialized and INIT bit in FDCAN_CCCR register is cleared, the FDCAN synchronizes itself to the CAN bus and is ready for communication.

After passing the acceptance filtering, received messages including message ID and DLC are stored into a dedicated Rx buffer or into the Rx FIFO 0 or Rx FIFO 1.

For messages to be transmitted dedicated Tx buffers and/or a Tx FIFO or a Tx queue can be initialized or updated. Automated transmission on reception of remote frames is not supported.

CAN FD operation

There are two variants in the CAN FD protocol, first the long frame mode (LFM) where the data field of a CAN frame may be longer that eight bytes. The second variant is the fast frame mode (FFM) where control field, data field, and CRC field of a CAN frame are

transmitted with a higher bitrate than the beginning and the end of the frame. Fast frame mode can be used in combination with long frame mode.

The previously reserved bit in CAN frames with 11-bit identifiers and the first previously reserved bit in CAN frames with 29-bit identifiers are now decoded as FDF bit. FDF recessive signifies a CAN FD frame, while FDF dominant signifies a classic CAN frame. In a CAN FD frame, the two bits following FDF, res and BRS, decide whether the bitrate inside this CAN FD frame is switched. A CAN FD bitrate switch is signified by res dominant and BRS recessive. The coding of res recessive is reserved for future expansion of the protocol. If the FDCAN receives a frame with FDF recessive and res recessive, it signals a protocol exception event by setting bit FDCAN_PSR.PXE. When protocol exception handling is enabled (FDCAN_CCCR.PXHD = 0), this causes the operation state to change from receiver (FDCAN_PSR.ACT = 10) to Integrating (FDCAN_PSR.ACT = 00) at the next sample point. In case protocol exception handling is disabled (FDCAN_CCCR.PXHD = 1), the FDCAN treats a recessive res bit as a form error and responds with an error frame.

CAN FD operation is enabled by programming FDCAN_CCCR.FDOE. If FDCAN_CCCR.FDOE = 1, transmission and reception of CAN FD frames is enabled. Transmission and reception of classic CAN frames is always possible. Whether a CAN FD frame or a classic CAN frame is transmitted can be configured via bit FDF in the respective Tx buffer element. With FDCAN_CCCR.FDOE = 0, received frames are interpreted as classic CAN frames, which leads to the transmission of an error frame when receiving a CAN FD frame. When CAN FD operation is disabled, no CAN FD frames are transmitted, even if bit FDF of a Tx buffer element is set. FDCAN_CCCR.FDOE and FDCAN_CCCR.BRSE can only be changed while FDCAN_CCCR.INIT and FDCAN_CCCR.CCE are both set.

With FDCAN_CCCR.FDOE = 0, the setting of bits FDF and BRS is ignored and frames are transmitted in classic CAN format. With FDCAN_CCCR.FDOE = 1 and FDCAN_CCCR.BRSE = 0, only bit FDF of a Tx buffer element is evaluated. With FDCAN_CCCR.FDOE = 1 and FDCAN_CCCR.BRSE = 1, transmission of CAN FD frames with bitrate switching is enabled. All Tx buffer elements with bits FDF and BRS set are transmitted in CAN FD format with bitrate switching.

A mode change during CAN operation is only recommended under the following conditions:

- The failure rate in the CAN FD data phase is significant higher than in the CAN FD arbitration phase. In this case disable the CAN FD bitrate switching option for transmissions.
- During system startup all nodes are transmitting classic CAN messages until it is verified that they are able to communicate in CAN FD format. If this is true, all nodes switch to CAN FD operation.
- Wake-up messages in CAN partial networking have to be transmitted in classic CAN format.
- End-of-line programming in case not all nodes are CAN FD capable. Non CAN FD nodes are held in Silent mode until programming has completed. Then all nodes switch back to classic CAN communication.

In the CAN FD format, the coding of the DLC differs from the standard CAN format. DLC codes 0 to 8 have the same coding as in standard CAN, codes 9 to 15 (that in standard CAN all code a data field of 8 bytes) are coded according to *Table 503*.

Table 503. DLC coding in FDCAN

DLC	9	10	11	12	13	14	15
Number of data bytes	12	16	20	24	32	48	64

In CAN FD fast frames, the bit timing is switched inside the frame, after the BRS (bitrate Switch) bit, if this bit is recessive. Before the BRS bit, in the CAN FD arbitration phase, the nominal CAN bit timing is used as defined by the bit timing and prescaler register FDCAN_NBTP. In the following CAN FD data phase, the fast CAN bit timing is used as defined by the fast bit timing and prescaler register FDCAN_DBTP. The bit timing is switched back from the fast timing at the CRC delimiter or when an error is detected, whichever occurs first.

The maximum configurable bitrate in the CAN FD data phase depends on the FDCAN kernel clock frequency. For example, with a FDCAN kernel clock frequency of 20 MHz and the shortest configurable bit time of four time quanta (tq), the bitrate in the data phase is 5 Mbit/s.

In both data frame formats, CAN FD long frames and CAN FD fast frames, the value of the bit ESI (error status indicator) is determined by the transmitter error state at the start of the transmission. If the transmitter is error passive, ESI is transmitted recessive, else it is transmitted dominant. In CAN FD remote frames the ESI bit is always transmitted dominant, independent of the transmitter error state. The data length code of CAN FD remote frames is transmitted as 0.

In case a FDCAN Tx buffer is configured for CAN FD transmission with DLC > 8, the first eight bytes are transmitted as configured in the Tx buffer while the remaining part of the data field is padded with 0xCC. When the FDCAN receives a FDCAN frame with DLC > 8, the first eight bytes of that frame are stored into the matching Rx buffer or Rx FIFO. The remaining bytes are discarded.

Transceiver delay compensation

During the data phase of a CAN FD transmission only one node is transmitting, all others are receivers. The length of the bus line has no impact. When transmitting via pin FDCAN_TX the protocol controller receives the transmitted data from its local CAN transceiver via pin FDCAN_RX. The received data is delayed by the CAN transceiver loop delay. In case this delay is greater than TSEG1 (time segment before sample point), a bit error is detected. Without transceiver delay compensation, the bitrate in the data phase of a CAN FD frame is limited by the transceivers loop delay.

The FDCAN implements a delay compensation mechanism to compensate the CAN transceiver loop delay, thereby enabling transmission with higher bitrates during the CAN FD data phase independent of the delay of a specific CAN transceiver.

To check for bit errors during the data phase of transmitting nodes, the delayed transmit data is compared against the received data at the Secondary Sample Point SSP. If a bit error is detected, the transmitter reacts on this bit error at the next following regular sample point. During arbitration phase the delay compensation is always disabled.

The transmitter delay compensation enables configurations where the data bit time is shorter than the transmitter delay, it is described in detail in the new ISO11898-1. It is enabled by setting bit FDCAN_DBTP.TDC.

The received bit is compared against the transmitted bit at the SSP. The SSP position is defined as the sum of the measured delay from the FDCAN transmit output pin FDCAN_TX through the transceiver to the receive input pin FDCAN_RX plus the transmitter delay compensation offset as configured by FDCAN_TDCR.TDCO. The transmitter delay compensation offset is used to adjust the position of the SSP inside the received bit (e.g. half of the bit time in the data phase). The position of the secondary sample point is rounded down to the next integer number of mtq (minimum time quantum, that is one period of fdcan_tq_ck clock).

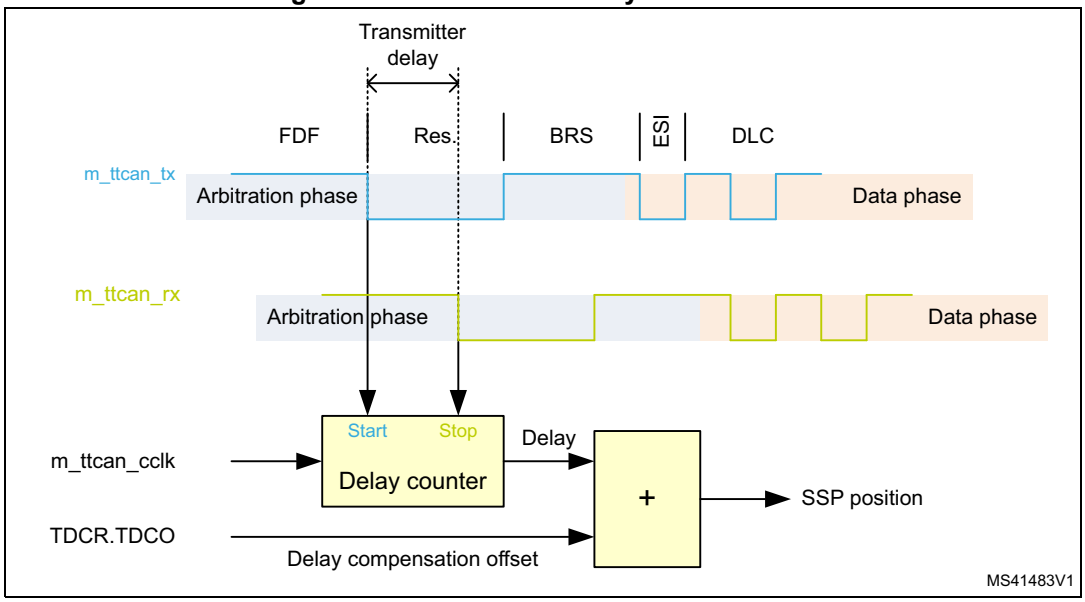
FDCAN_PSR.TDCV shows the actual transmitter delay compensation value, it is cleared when FDCAN_CCCR.INIT is set and is updated at each transmission of an FD frame while FDCAN_DBTP.TDC is set.

The following boundary conditions have to be considered for the transmitter delay compensation implemented in the FDCAN:

- The sum of the measured delay from FDCANx_TX to FDCANx_RX and the configured transmitter delay compensation offset FDCAN_TDCR.TDCO has to be less than six bit times in the data phase.
- The sum of the measured delay from FDCANx_TX to FDCANx_RX and the configured transmitter delay compensation offset FDCAN_TDCR.TDCO has to be less than or equal to 127 mtq. If this sum exceeds 127 mtq, the maximum value (127 mtq) is used for transmitter delay compensation.
- The data phase ends at the sample point of the CRC delimiter, that stops checking received bits at the SSPs

If transmitter delay compensation is enabled by programming FDCAN_DBTP.TDC = 1, the measurement is started within each transmitted CAN FD frame at the falling edge of bit FDF to bit res. The measurement is stopped when this edge is seen at the receive input pin FDCAN_TX of the transmitter. The resolution of this measurement is one mtq.

Figure 764. Transceiver delay measurement



To avoid that a dominant glitch inside the received FDF bit ends the delay compensation measurement before the falling edge of the received res bit (resulting in a to early SSP position) the use of a transmitter delay compensation filter window can be enabled by

programming FDCAN_TDCR.TDCF. This defines a minimum value for the SSP position. Dominant edges on FDCANx_RX, that would result in an earlier SSP position are ignored for transmitter delay measurement. The measurement is stopped when the SSP position is at least FDCAN_TDCR.TDCF and FDCAN_RX is low.

Restricted operation mode

In restricted operation mode the node is able to receive data and remote frames and to give acknowledge to valid frames, but it does not send data frames, remote frames, active error frames, or overload frames. In case of an error condition or overload condition, it does not send dominant bits, instead it waits for the occurrence of bus idle condition to resynchronize itself to the CAN communication. The error counters (FDCAN_ECR.REC, FDCAN_ECR.TEC) are frozen while error logging (FDCAN_ECR.CEL) is active. The software can set the FDCAN into restricted operation mode by setting bit FDCAN_CCCR.ASM. The bit can only be set by software when both FDCAN_CCCR.CCE and FDCAN_CCCR.INIT are set to 1. The bit can be cleared by software at any time.

Restricted operation mode is automatically entered when the Tx handler was not able to read data from the message RAM in time. To leave restricted operation mode, the software has to reset FDCAN_CCCR.ASM.

The restricted operation mode can be used in applications that adapt themselves to different CAN bitrates. In this case the application tests different bitrates and leaves the restricted operation mode after it has received a valid frame.

FDCAN_CCCR.ASM is also controlled by the clock calibration unit. Wen the clock calibration process is enabled, the restricted operation mode is entered and the FDCAN_CCR.ASM bit is set. Once the calibration is completed, FDCAN_CCR.ASM bit is cleared.

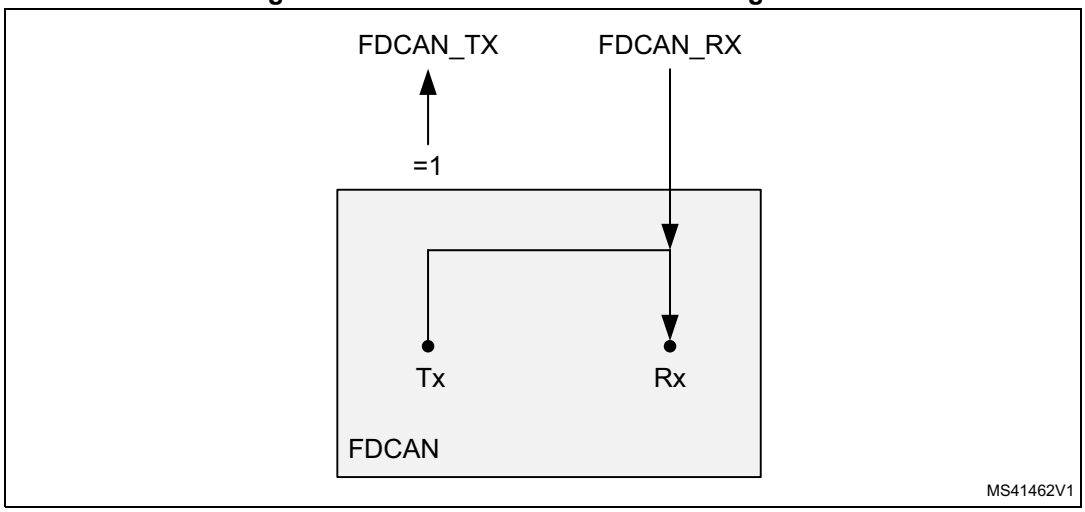
Note: The restricted operation mode must not be combined with the loop back mode (internal or external).

Bus monitoring mode

The FDCAN is set in bus monitoring mode by setting FDCAN_CCCR.MON bit or when error level S3 (FDCAN_TTOST.EL = 11) is entered. In bus monitoring mode (For more details please refer to ISO11898-1, 10.12 bus monitoring), the FDCAN is able to receive valid data frames and valid remote frames, but cannot start a transmission. In this mode, it sends only recessive bits on the CAN bus, if the FDCAN is required to send a dominant bit (ACK bit, overload flag, active error flag), the bit is rerouted internally so that the FDCAN monitors this dominant bit, although the CAN bus may remain in recessive state. In bus monitoring mode register FDCAN_TXBRP is held in reset state.

The bus monitoring mode can be used to analyze the traffic on a CAN bus without affecting it by the transmission of dominant bits. *Figure 765* shows the connection of FDCAN_TX and FDCAN_RX signals to the FDCAN in bus monitoring mode.

Figure 765. Pin control in bus monitoring mode



Disabled automatic retransmission (DAR) mode

According to the CAN Specification (see ISO11898-1, 6.3.3 recovery management), the FDCAN provides means for automatic retransmission of frames that have lost arbitration or that have been disturbed by errors during transmission. By default automatic retransmission is enabled.

To support time-triggered communication as described in ISO 11898-1: 2015, chapter 9.2, the automatic retransmission may be disabled via FDCAN_CCCR.DAR.

Frame transmission in disabled automatic retransmission (DAR) mode

In DAR mode all transmissions are automatically canceled after they started on the CAN bus. A Tx buffer Tx request pending bit FDCAN_TXBRP.TRPx is reset after successful transmission, when a transmission has not yet been started at the point of cancellation, has been aborted due to lost arbitration, or when an error occurred during frame transmission.

- Successful transmission:
  - Corresponding Tx buffer transmission occurred bit FDCAN_TXBTO.TOx set
  - Corresponding Tx buffer cancellation finished bit FDCAN_TXBCF.CFx not set
- Successful transmission in spite of cancellation:
  - Corresponding Tx buffer transmission occurred bit FDCAN_TXBTO.TOx set
  - Corresponding Tx buffer cancellation finished bit FDCAN_TXBCF.CFx set
- Arbitration loss or frame transmission disturbed:
  - Corresponding Tx buffer transmission occurred bit FDCAN_TXBTO.TOx not set
  - Corresponding Tx buffer cancellation finished bit FDCAN_TXBCF.CFx set

In case of a successful frame transmission, and if storage of Tx events is enabled, a Tx event FIFO element is written with event type ET = 10 (transmission in spite of cancellation).

Power down (Sleep mode)

The FDCAN can be set into power down mode controlled by clock stop request input via register FDCAN_CCCR.CSR. As long as the clock stop request is active, bit FDCAN_CCCR.CSR is read as 1.

When all pending transmission requests have completed, the FDCAN waits until bus idle state is detected. Then the FDCAN sets FDCAN_CCCR.INIT to 1 to prevent any further CAN transfers. Now the FDCAN acknowledges that it is ready for power down by setting FDCAN_CCCR.CSA to 1. In this state, before the clocks are switched off, further register accesses can be made. A write access to FDCAN_CCCR.INIT has no effect. Now the module clock inputs may be switched off.

To leave power down mode, the application has to turn on the module clocks before resetting CC control register flag FDCAN_CCCR.CSR. The FDCAN acknowledges this by resetting FDCAN_CCCR.CSA. Afterwards, the application can restart CAN communication by resetting bit FDCAN_CCCR.INIT.

Test modes

To enable write access to FDCAN test register (see *Section 61.5.4*), bit FDCAN_CCCR.TEST has to be set to 1, thus enabling the configuration of test modes and functions.

Four output functions are available for the CAN transmit pin FDCAN_TX by programming FDCAN_TEST.TX. Additionally to its default function – the serial data output – it can drive the CAN Sample Point signal to monitor the FDCAN bit timing and it can drive constant dominant or recessive values. The actual value at pin FDCAN_RX can be read from FDCAN_TEST.RX. Both functions can be used to check the CAN bus physical layer.

Due to the synchronization mechanism between CAN kernel clock and APB clock domain, there may be a delay of several APB clock periods between writing to FDCAN_TEST.TX until the new configuration is visible at FDCAN_TX output pin. This applies also when reading FDCAN_RX input pin via FDCAN_TEST.RX.

Note: Test modes should be used for production tests or self test only. The software control for FDCAN_TX pin interferes with all CAN protocol functions. It is not recommended to use test modes for application.

External loop back mode

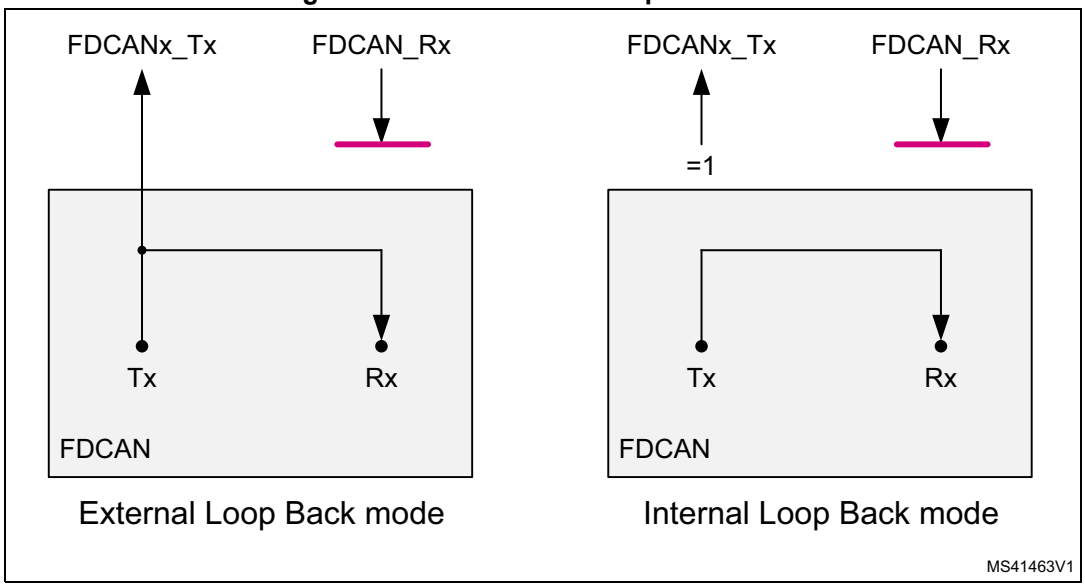
The FDCAN can be set in external loop back mode by programming FDCAN_TEST.LBCK to 1. In loop back mode, the FDCAN treats its own transmitted messages as received messages and stores them (if they pass acceptance filtering) into Rx FIFOs. *Figure 766* (left side) shows the connection of transmit and receive signals FDCAN_TX and FDCAN_RX to the FDCAN in external loop back mode.

This mode is provided for hardware self-test. To be independent from external stimulation, the FDCAN ignores acknowledge errors (recessive bit sampled in the acknowledge slot of a data/remote frame) in loop back mode. In this mode the FDCAN performs an internal feedback from its transmit output to its receive input. The actual value of the FDCAN_RX input pin is disregarded by the FDCAN. The transmitted messages can be monitored at the FDCAN_TX transmit pin.

Internal loop back mode

Internal loop back mode is entered by programming bits FDCAN_TEST.LBCK and FDCAN_CCCR.MON to 1. This mode can be used for a “Hot Selftest”, meaning the FDCAN can be tested without affecting a running CAN system connected to the FDCAN_TX and FDCAN_RX pins. In this mode, FDCAN_RX pin is disconnected from the FDCAN and FDCAN_TX pin is held recessive. *Figure 766* (right side) shows the connection of FDCAN_TX and FDCAN_RX pins to the FDCAN in case of internal loop back mode.

Figure 766. Pin control in loop back mode



Application watchdog (FDCAN1 only)

The application watchdog is served by reading register FDCAN_TTOST. When the application watchdog is not served in time, bit FDCAN_TTOST.AWE is set, all TTCAN communication is stopped, and the FDCAN1 is set into bus monitoring mode.

The TT application watchdog can be disabled by programming the application watchdog limit FDCAN_TTOCF.AWL to 0x00. The TT application watchdog should not be disabled in a TTCAN application program

Timestamp generation

For timestamp generation the FDCAN supplies a 16-bit wraparound counter. A prescaler FDCAN_TSCC.TCP can be configured to clock the counter in multiples of CAN bit times (1 … 16). The counter is readable via FDCAN_TSCV.TCV. A write access to register FDCAN_TSCV resets the counter to 0. When the timestamp counter wraps around interrupt flag FDCAN_IR.TSW is set.

On start of frame reception/transmission the counter value is captured and stored into the timestamp section of a Rx buffer/Rx FIFO (RXTS[15:0]) or Tx event FIFO (TXTS[15:0]) element.

By programming bit FDCAN_TSCC.TSS, a 16-bit timestamp can be used.

Timeout counter

To signal timeout conditions for Rx FIFO 0, Rx FIFO 1, and the Tx event FIFO the FDCAN supplies a 16-bit timeout counter. It operates as down-counter and uses the same prescaler controlled by FDCAN_TSCC.TCP as the timestamp counter. The timeout counter is configured via register FDCAN_TOCC. The actual counter value can be read from FDCAN_TOCV.TOC. The timeout counter can only be started while FDCAN_CCCR.INIT = 0. It is stopped when FDCAN_CCCR.INIT = 1, e.g. when the FDCAN enters Bus_Off state.

The operation mode is selected by FDCAN_TOCC.TOS. When operating in Continuous mode, the counter starts when FDCAN_CCCR.INIT is reset. A write to FDCAN_TOCV

presets the counter to the value configured by FDCAN_TOCC.TOP and continues down-counting.

When the timeout counter is controlled by one of the FIFOs, an empty FIFO presets the counter to the value configured by FDCAN_TOCC.TOP. Down-counting is started when the first FIFO element is stored. Writing to FDCAN_TOCV has no effect.

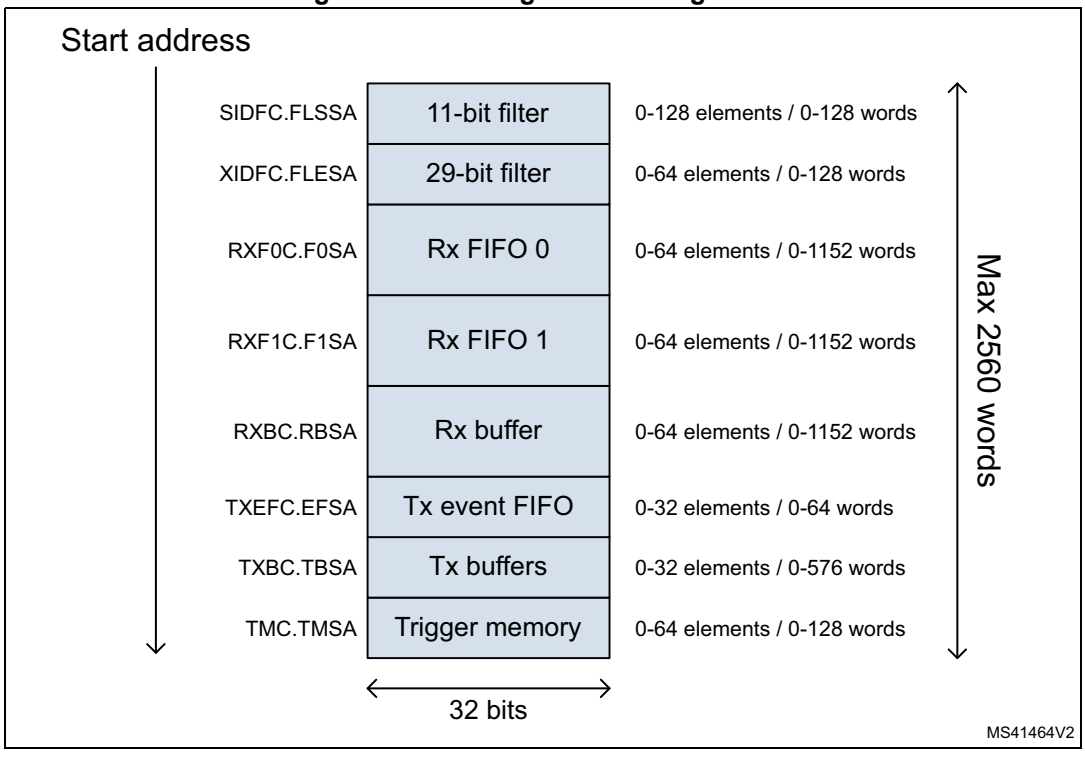
When the counter reaches 0, interrupt flag FDCAN_IR.TOO is set. In Continuous mode, the counter is immediately restarted at FDCAN_TOCC.TOP.

Note: The clock signal for the timeout counter is derived from the CAN core sample point signal. Therefore the point in time where the timeout counter is decremented may vary due to the synchronization/re-synchronization mechanism of the CAN core. If the baudrate switch feature in FDCAN is used, the timeout counter is clocked differently in arbitration and data fields.

61.4.2 Message RAM

The message RAM has a width of 32 bits. The FDCAN module can be configured to allocate up to 2560 words in the message RAM. It is not necessary to configure each of the sections listed in *Figure 767*, nor is there any restriction with respect to the sequence of the sections.

Figure 767. Message RAM configuration



When the FDCAN addresses the message RAM it addresses 32-bit words, not single bytes. The configured start addresses are 32-bit word addresses, i.e. only bits 15 to 2 are evaluated, the two least significant bits are ignored.

Note: The FDCAN does not check for erroneous configuration of the message RAM. Especially the configuration of the start addresses of the different sections and the number of elements of each section has to be done carefully to avoid falsification or loss of data.

Rx handling

The Rx handler controls the acceptance filtering, the transfer of received messages to Rx buffers or to 1 of the two Rx FIFOs, as well as the Rx FIFO put and get Indices.

Acceptance filter

The FDCAN offers the possibility to configure two sets of acceptance filters, one for standard identifiers and one for extended identifiers. These filters can be assigned to Rx buffer, Rx FIFO 0 or Rx FIFO 1. For acceptance filtering each list of filters is executed from element #0 until the first matching element. Acceptance filtering stops at the first matching element. The following filter elements are not evaluated for this message.

The main features are:

- Each filter element can be configured as
  - range filter (from 0 to 128 elements for the 11-bit filter and from 0 to 64 for the 29-bit filter)
  - filter for one or two dedicated IDs
  - classic bit mask filter
- Each filter element is configurable for acceptance or rejection filtering
- Each filter element can be enabled/disabled individually
- Filters are checked sequentially, execution stops with the first matching filter element

Related configuration registers are:

- Global filter configuration (FDCAN_GFC)
- Standard ID filter configuration (FDCAN_SIDFC)
- Extended ID filter configuration (FDCAN_XIDFC)
- Extended ID AND Mask (FDCAN_XIDAM)

Depending on the configuration of the filter element (SFEC / EFEC) a match triggers one of the following actions:

- Store received frame in FIFO 0 or FIFO 1
- Store received frame in Rx buffer
- Store received frame in Rx buffer and generate pulse at filter event pin
- Reject received frame
- Set high priority message interrupt flag FDCAN_IR.HPM
- Set high priority message interrupt flag FDCAN_IR.HPM and store received frame in FIFO 0 or FIFO 1
- Set high priority message interrupt flag FDCAN_IR.HPM and store received frame in FIFO 0 or FIFO 1

Acceptance filtering is started after the complete identifier has been received. After acceptance filtering has completed, and if a matching Rx buffer or Rx FIFO has been found, the message handler starts writing the received message data in portions of 32 bit to the

matching Rx buffer or Rx FIFO. If the CAN protocol controller has detected an error condition (e.g. CRC error), this message is discarded with the following impact:

- **Rx buffer**
  New data flag of matching Rx buffer is not set, but Rx buffer (partly) overwritten with received data. For error type see FDCAN_PSR.LEC and FDCAN_PSR.DLEC.
- **Rx FIFO**
  Put index of matching Rx FIFO is not updated, but related Rx FIFO element (partly) overwritten with received data. For error type see FDCAN_PSR.LEC and FDCAN_PSR.DLEC. In case the matching Rx FIFO is operated in overwrite mode, the boundary conditions described in *Rx FIFO overwrite mode* have to be considered.

Note: When an accepted message is written to one of the two Rx FIFOs, or into an Rx buffer, the unmodified received identifier is stored independent of the filter(s) used. The result of the acceptance filter process is strongly depending on the sequence of configured filter elements.

Range filter

The filter matches for all received frames with message IDs in the range defined by SF1ID / SF2ID and EF1ID / EF2ID.

There are two possibilities when range filtering is used together with extended frames:

- EFT = 00: The message ID of received frames is AND-ed with the extended ID AND Mask (FDCAN_XIDAM) before the range filter is applied
- EFT = 11: The extended ID AND Mask (FDCAN_XIDAM) is not used for range filtering

Filter for dedicated IDs

A filter element can be configured to filter for one or two specific message IDs. To filter for one specific message ID, the filter element has to be configured with SF1ID = SF2ID and EF1ID = EF2ID.

Classic bit mask filter

Classic bit mask filtering is intended to filter groups of message IDs by masking single bits of a received message ID. With classic bit mask filtering SF1ID / EF1ID is used as message ID filter, while SF2ID / EF2ID is used as filter mask.

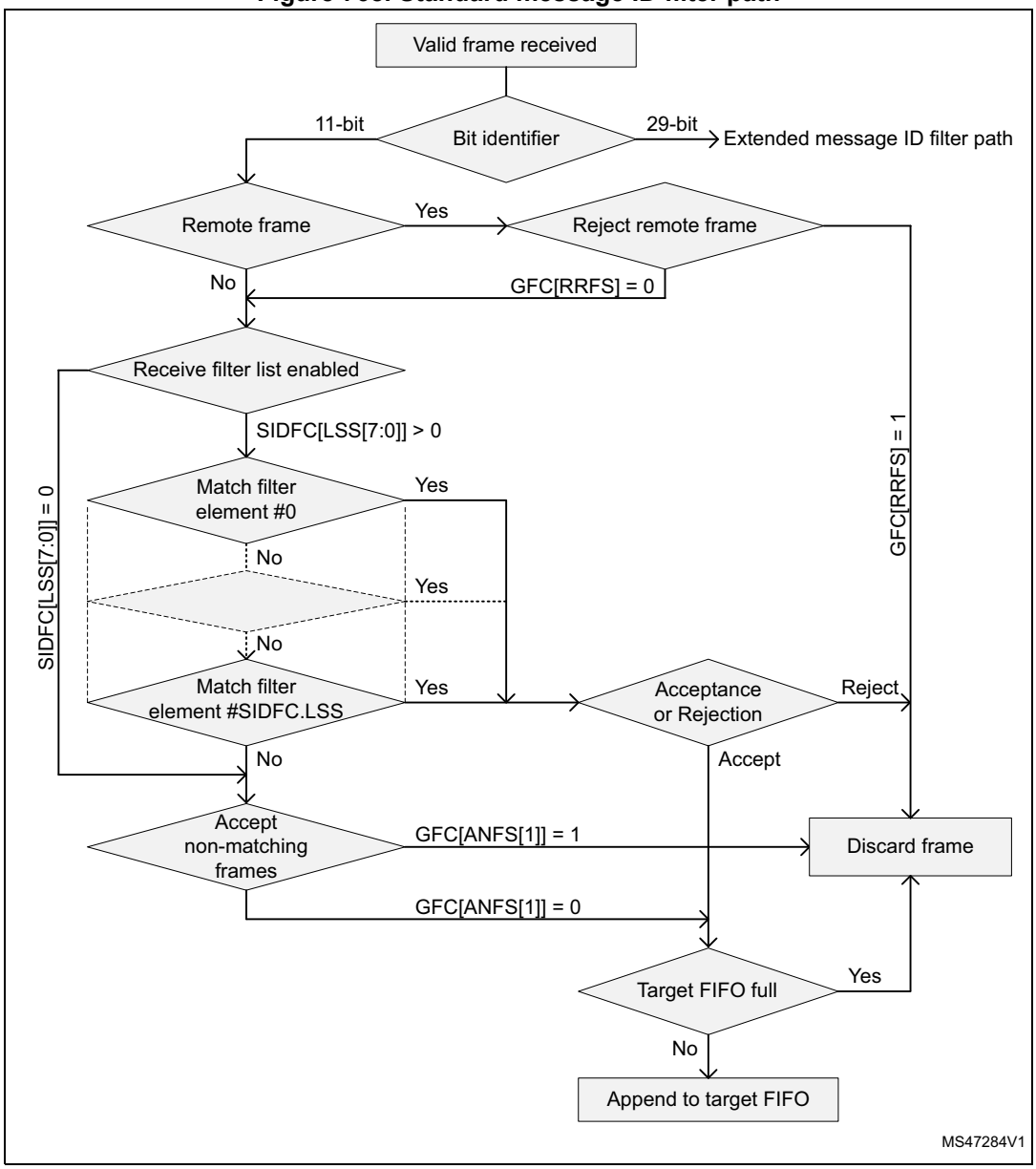
A 0 bit at the filter mask masks out the corresponding bit position of the configured ID filter, e.g. the value of the received message ID at that bit position is not relevant for acceptance filtering. Only those bits of the received message ID where the corresponding mask bits are one are relevant for acceptance filtering.

In case all mask bits are one, a match occurs only when the received message ID and the message ID filter are identical. If all mask bits are 0, all message IDs match.

Standard message ID filtering

Figure 768 shows the flow for standard message ID (11-bit Identifier) filtering. The standard message ID filter element is described in *Section 61.4.21*.

Figure 768. Standard message ID filter path

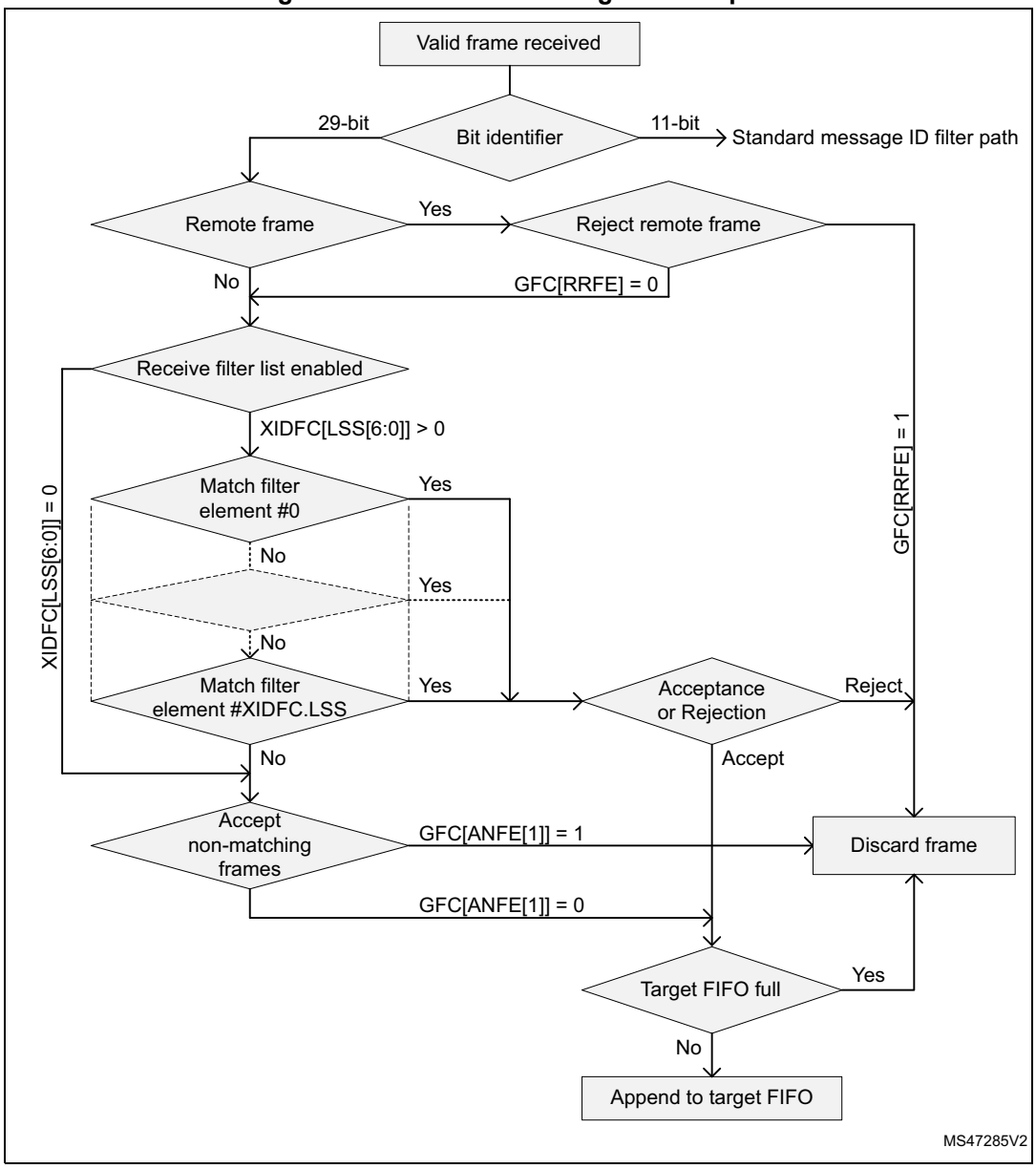


Controlled by the global filter configuration (FDCAN_GFC) and the standard ID filter configuration (FDCAN_SIDFC) message ID, remote transmission request bit (RTR), and the Identifier Extension bit (IDE) of received frames are compared against the list of configured filter elements.

Extended message ID filtering

Figure 769 shows the flow for extended message ID (29-bit Identifier) filtering. The extended message ID filter element is described in *Section 61.4.22*.

Figure 769. Extended message ID filter path



Controlled by the global filter configuration FDCAN_GFC and the extended ID filter configuration FDCAN_XIDFC message ID, remote transmission request bit (RTR), and the Identifier Extension bit (IDE) of received frames are compared against the list of configured filter elements.

The extended ID AND Mask (FDCAN_XIDAM) is AND-ed with the received identifier before the filter list is executed.

Rx FIFOs

Rx FIFO 0 and Rx FIFO 1 can be configured to hold up to 64 elements each. Configuration of the two Rx FIFOs is done via registers FDCAN_RXF0C and FDCAN_RXF1C.

Received messages that passed acceptance filtering are transferred to the Rx FIFO as configured by the matching filter element. For a description of the filter mechanisms available for Rx FIFO 0 and Rx FIFO 1, see *Acceptance filter*. The Rx buffer and FIFO element is described in *Section 61.4.18*.

When an Rx FIFO full condition is signaled by FDCAN_IR.RFnF, no further messages are written to the corresponding Rx FIFO until at least one message has been read out and the Rx FIFO get index has been incremented. In case a message is received while the corresponding Rx FIFO is full, this message is discarded and interrupt flag FDCAN_IR.RFnL is set.

To avoid an Rx FIFO overflow, the Rx FIFO watermark can be used. When the Rx FIFO fill level reaches the Rx FIFO watermark configured by FDCAN_RXFnC.FnWM, interrupt flag FDCAN_IR.RFnW is set.

When reading from an Rx FIFO, Rx FIFO get index RXFnS[FnGI] + FIFO element size has to be added to the corresponding Rx FIFO start address RXFnC[FnSA].

Rx FIFO blocking mode

The Rx FIFO blocking mode is configured by RXFnC.FnOM = 0. This is the default operation mode for the Rx FIFOs.

When an Rx FIFO full condition is reached (RXFnS.FnPI = RXFnS.FnGI), no further messages are written to the corresponding Rx FIFO until at least one message has been read out and the Rx FIFO get index has been incremented. An Rx FIFO full condition is signaled by RXFnS.FnF = 1. In addition interrupt flag FDCAN_IR.RFnF is set.

In case a message is received while the corresponding Rx FIFO is full, this message is discarded and the message lost condition is signaled by RXFnS.RFnL = 1. In addition interrupt flag FDCAN_IR.RFnL is set.

Rx FIFO overwrite mode

The Rx FIFO overwrite mode is configured by RXFnC.FnOM = 1.

When an Rx FIFO full condition (RXFnS.FnPI = RXFnS.FnGI) is signaled by RXFnS.FnF = 1, the next message accepted for the FIFO overwrites the oldest FIFO message. Put and get index are both incremented by one.

When an Rx FIFO is operated in overwrite mode and an Rx FIFO full condition is signaled, reading of the Rx FIFO elements should start at least at get index + 1. The reason for that is that it can happen that a received message is written to the message RAM (put index) while the CPU is reading from the message RAM (get index). In this case inconsistent data may be read from the respective Rx FIFO element. Adding an offset to the get index when reading from the Rx FIFO avoids this problem. The offset depends on how fast the CPU accesses the Rx FIFO. *Figure 771* shows an offset of two with respect to the get index when reading the Rx FIFO. In this case the two messages stored in elements 1 and 2 are lost.

After reading from the Rx FIFO, the number of the last element read has to be written to the Rx FIFO acknowledge index RXFnA.FnA. This increments the get index to that element number. In case the put index has not been incremented to this Rx FIFO element, the Rx FIFO full condition is reset (RXFnS.FnF = 0).

Dedicated Rx buffers

The FDCAN supports up to 64 dedicated Rx buffers. The start address of the dedicated Rx buffer section is configured via FDCAN_RXBC.RBSA.

For each Rx buffer a standard or extended message ID filter element with SFEC / EFEC=111 and SFID2 / EFID2[10:9] = 00 has to be configured (see *Section 61.4.21* and *Section 61.4.22*).

After a received message has been accepted by a filter element, the message is stored into the Rx buffer in the message RAM referenced by the filter element. The format is the same as for an Rx FIFO element. In addition the flag FDCAN_IR.DRX (message stored in dedicated Rx buffer) in the interrupt register is set.

Table 504. Example of filter configuration for Rx buffers

Filter element	SFID1[10:0] EFID1[28:0]	SFID2[10:9] EFID2[10:9]	SFID2[5:0] EFID2[5:0]
0	ID message 1	00	00 0000
1	ID message 2	00	00 0001
2	ID message 3	00	00 0010

After the last word of a matching received message has been written to the message RAM, the respective New data flag in register NDAT1,2 is set. As long as the New data flag is set, the respective Rx buffer is locked against updates from received matching frames. The New data flags have to be reset by the user by writing a 1 to the respective bit position.

While an Rx buffer New data flag is set, a message ID filter element referencing this specific Rx buffer is not matched, causing the acceptance filtering to continue. The following message ID filter elements may cause the received message to be stored into another Rx buffer, or into an Rx FIFO, or the message may be rejected, depending on filter configuration.

Rx buffer handling

- Reset interrupt flag FDCAN_IR.DRX
- Read New data registers
- Read messages from message RAM
- Reset New data flags of processed messages

Filtering for Debug messages

Filtering for debug messages is done by configuring one standard/extended message ID filter element for each of the three debug messages. To enable a filter element to filter for debug messages SFEC/EFEC has to be programmed to 111. In this case fields SFID1 / SFID2 and EFID1 / EFID2 have a different meaning. While SFID2 / EFID2[10:9] controls the debug message handling state machine, SFID2 / EFID2[5:0] controls the location for storage of a received debug message.

When a debug message is stored, neither the respective New data flag nor FDCAN_IR.DRX are set. The reception of debug messages can be monitored via FDCAN_RXF1S.DMS.

Table 505. Example of filter configuration for Debug messages

Filter element	SFID1[10:0] EFID1[28:0]	SFID2[10:9] EFID2[10:9]	SFID2[5:0] EFID2[5:0]
0	ID debug message A	01	11 1101
1	ID debug message B	10	11 1110
2	ID debug message C	11	11 1111

Tx handling

The Tx handler handles transmission requests for the dedicated Tx buffers, the Tx FIFO, and the Tx queue. It controls the transfer of transmit messages to the CAN core, the put and get Indices, and the Tx event FIFO.Up to 32 Tx buffers can be set up for message transmission (see *Dedicated Tx buffers*). Depending on the configuration of the element size (FDCAN_RXESC), between two and sixteen 32-bit words (Rn = 3 ... 17) are used for storage of a CAN message data field.

Table 506. Possible configurations for frame transmission

FDCAN_CCCR		Tx buffer element		Frame transmission
BRSE	FDOE	FDF	BRS	
Ignored	0	Ignored	Ignored	Classic CAN
0	1	0	Ignored	Classic CAN
0	1	1	Ignored	FD without bitrate switching
1	1	0	Ignored	Classic CAN
1	1	1	0	FD without bitrate switching
1	1	1	1	FD with bitrate switching

Note: AUTOSAR requires at least three Tx queue buffers and support of transmit cancellation.

The Tx handler starts a Tx scan to check for the highest priority pending Tx request (Tx buffer with lowest message ID) when the Tx buffer request pending register FDCAN_TXBRP is updated, or when a transmission has been started.

Transmit pause

This feature is intended for use in CAN systems where the CAN message identifiers are (permanently) specified to specific values and cannot easily be changed. These message identifiers may have a higher CAN arbitration priority than other defined messages, while in a specific application their relative arbitration priority should be inverse. This may lead to a case where one ECU sends a burst of CAN messages that cause another ECU CAN messages to be delayed because that other messages have a lower CAN arbitration priority.

If, as an example, CAN ECU-1 has the feature enabled and is requested by its application software to transmit four messages, it will, after the first successful message transmission, wait for two CAN bit times of bus idle before it is allowed to start the next requested message. If there are other ECUs with pending messages, those messages are started in the idle time, they would not need to arbitrate with the next message of ECU-1. After having

received a message, ECU-1 is allowed to start its next transmission as soon as the received message releases the CAN bus.

The feature is controlled by TXP bit in FDCAN_CCCR register. If the bit is set, the FDCAN will, each time it has successfully transmitted a message, pause for two CAN bit times before starting the next transmission. This enables other CAN nodes in the network to transmit messages even if their messages have lower prior identifiers. Default is disabled (FDCAN_CCCR.TXP = 0).

This feature looses up burst transmissions coming from a single node and it protects against "babbling idiot" scenarios where the application program erroneously requests too many transmissions.

Dedicated Tx buffers

Dedicated Tx buffers are intended for message transmission under complete control of the CPU. Each dedicated Tx buffer is configured with a specific message ID. In case that multiple Tx buffers are configured with the same message ID, the Tx buffer with the lowest buffer number is transmitted first.

If the data section has been updated, a transmission is requested by an add request via FDCAN_TXBAR.ARn. The requested messages arbitrate internally with messages from an optional Tx FIFO or Tx queue and externally with messages on the CAN bus, and are sent out according to their message ID.

A dedicated Tx buffer allocates four 32-bit words in the message RAM. Therefore the start address of a dedicated Tx buffer in the message RAM is calculated by adding four times the transmit buffer index (0 … 31) to the Tx buffer start address FDCAN_TXBC.TBSA.

Table 507. Tx buffer/FIFO - queue element size

FDCAN_TXESC.TBDS[2;0]	Data field (bytes)	Element size (RAM words)
000	8	4
001	12	5
010	16	6
011	20	7
100	24	8
101	32	10
110	48	14
111	64	18

Tx FIFO

Tx FIFO operation is configured by programming FDCAN_TXBC.TFQM to 0. Messages stored in the Tx FIFO are transmitted starting with the message referenced by the get index FDCAN_TXFQS.TFGI. After each transmission the get index is incremented cyclically until the Tx FIFO is empty. The Tx FIFO enables transmission of messages with the same message ID from different Tx buffers in the order these messages have been written to the Tx FIFO. The FDCAN calculates the Tx FIFO free level FDCAN_TXFQS.TFFL as difference between get and put index. It indicates the number of available (free) Tx FIFO elements.

New transmit messages have to be written to the Tx FIFO starting with the Tx buffer referenced by the put index FDCAN_TXFQS.TFQPI. An add request increments the put index to the next free Tx FIFO element. When the put index reaches the get index, Tx FIFO full (FDCAN_TXFQS.TFQF = 1) is signaled. In this case no further messages should be written to the Tx FIFO until the next message has been transmitted and the get index has been incremented.

When a single message is added to the Tx FIFO, the transmission is requested by writing a 1 to the FDCAN_TXBAR bit related to the Tx buffer referenced by the Tx FIFO put index.

When multiple (n) messages are added to the Tx FIFO, they are written to n consecutive Tx buffers starting with the put index. The transmissions are then requested via FDCAN_TXBAR. The put index is then cyclically incremented by n. The number of requested Tx buffers should not exceed the number of free Tx buffers as indicated by the Tx FIFO free level.

When a transmission request for the Tx buffer referenced by the get index is canceled, the get index is incremented to the next Tx buffer with pending transmission request and the Tx FIFO free level is recalculated. When transmission cancellation is applied to any other Tx buffer, the get index and the FIFO free level remain unchanged.

A Tx FIFO element allocates four 32-bit words in the message RAM. Therefore the start address of the next available (free) Tx FIFO buffer is calculated by adding four times the put index FDCAN_TXFQS.TFQPI (0 … 31) to the Tx buffer start address FDCAN_TXBC.TBSA.

Tx queue

Tx queue operation is configured by programming FDCAN_TXBC.TFQM to 1. Messages stored in the Tx queue are transmitted starting with the message with the lowest message ID (highest priority). In case that multiple queue buffers are configured with the same message ID, the queue buffer with the lowest buffer number is transmitted first.

New messages have to be written to the Tx buffer referenced by the put index FDCAN_TXFQS.TFQPI. An add request cyclically increments the put index to the next free Tx buffer. In case that the Tx queue is full (FDCAN_TXFQS.TFQF = 1), the put index is not valid and no further message should be written to the Tx queue until at least one of the requested messages has been sent out or a pending transmission request has been canceled.

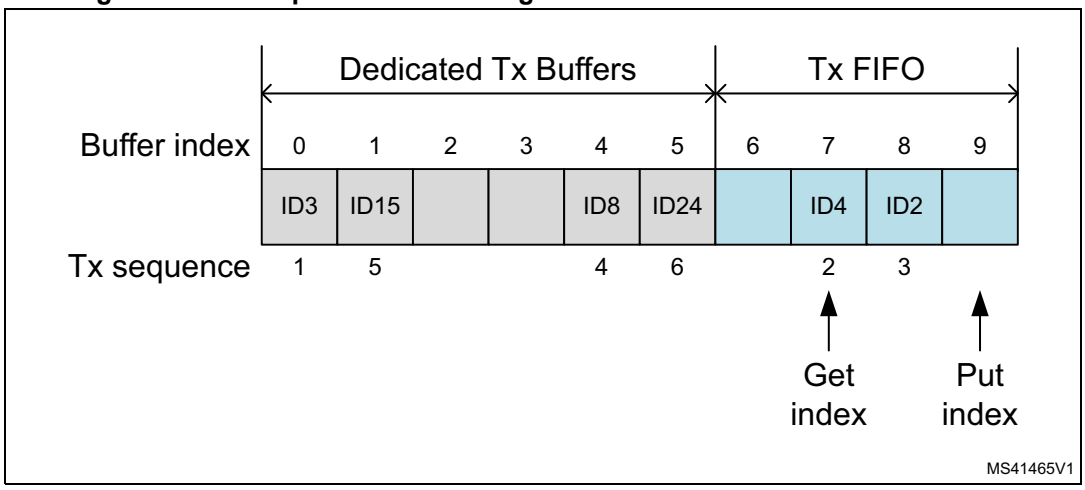
The application may use register FDCAN_TXBRP instead of the put index and may place messages to any Tx buffer without pending transmission request.

A Tx queue buffer allocates four 32-bit words in the message RAM. Therefore the start address of the next available (free) Tx queue buffer is calculated by adding four times the Tx queue put index FDCAN_TXFQS.TFQPI (0 … 31) to the Tx buffer start address FDCAN_TXBC.TBSA.

Mixed dedicated Tx buffers / Tx FIFO

In this case the Tx buffers section in the message RAM is subdivided into a set of dedicated Tx buffers and a Tx FIFO. The number of dedicated Tx buffers is configured by FDCAN_TXBC.NDTB. The number of Tx buffers assigned to the Tx FIFO is configured by FDCAN_TXBC.TFQS. In case, FDCAN_TXBC.TFQS is programmed to 0, only dedicated Tx buffers are used.

Figure 770. Example of mixed configuration dedicated Tx buffers / Tx FIFO



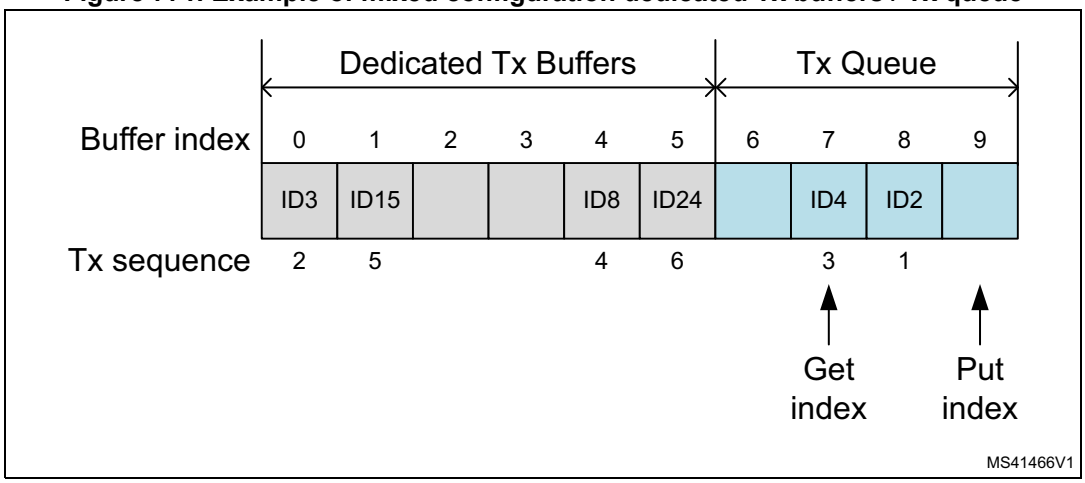
Tx prioritization:

- Scan dedicated Tx buffers and oldest pending Tx FIFO buffer (referenced by FDCAN_TXFS.TFGI)
- Buffer with lowest message ID gets highest priority and is transmitted next

Mixed dedicated Tx buffers / Tx queue

In this case the Tx buffers section in the message RAM is subdivided into a set of dedicated Tx buffers and a Tx queue. The number of dedicated Tx buffers is configured by FDCAN_TXBC.NDTB. The number of Tx queue buffers is configured by FDCAN_TXBC.TFQS. If FDCAN_TXBC.TFQS is programmed to 0, only dedicated Tx buffers are used.

Figure 771. Example of mixed configuration dedicated Tx buffers / Tx queue



Tx priority setting:

- Scan all Tx buffers with activated transmission request
- Tx buffer with lowest message ID gets highest priority and is transmitted next

Transmit cancellation

The FDCAN supports transmit cancellation. To cancel a requested transmission from a dedicated Tx buffer or a Tx queue buffer the user has to write a 1 to the corresponding bit position (= number of Tx buffer) of register FDCAN_TXBCR. Transmit cancellation is not intended for Tx FIFO operation.

Successful cancellation is signaled by setting the corresponding bit of register FDCAN_TXBCF to 1.

In case a transmit cancellation is requested while a transmission from a Tx buffer is already ongoing, the corresponding FDCAN_TXBRP bit remains set as long as the transmission is in progress. If the transmission was successful, the corresponding FDCAN_TXBTO and FDCAN_TXBCF bits are set. If the transmission was not successful, it is not repeated and only the corresponding FDCAN_TXBCF bit is set.

Note: In case a pending transmission is canceled immediately before this transmission could have been started, there follows a short time window where no transmission is stared even if another message is pending in this node. This may enable another node to transmit a message that may have a priority lower than that of the second message in this node.

Tx event handling

To support Tx event handling the FDCAN has implemented a Tx event FIFO. After the FDCAN has transmitted a message on the CAN bus, message ID and timestamp are stored in a Tx event FIFO element. To link a Tx event to a Tx event FIFO element, the message marker from the transmitted Tx buffer is copied into the Tx event FIFO element.

The Tx event FIFO can be configured to a maximum of 32 elements. The Tx event FIFO element is described in *Tx FIFO*. Depending on the configuration of the element size (FDCAN_TXESC), between two and sixteen 32-bit words (Tn = 3 ..17) are used for storage of a CAN message data field.

The purpose of the Tx event FIFO is to decouple handling transmit status information from transmit message handling i.e. a Tx buffer holds only the message to be transmitted, while the transmit status is stored separately in the Tx event FIFO. This has the advantage, especially when operating a dynamically managed transmit queue, that a Tx buffer can be used for a new message immediately after successful transmission. There is no need to save transmit status information from a Tx buffer before overwriting that Tx buffer.

When a Tx event FIFO full condition is signaled by FDCAN_IR.TEFF, no further elements are written to the Tx event FIFO until at least one element has been read out and the Tx event FIFO get index has been incremented. In case a Tx event occurs while the Tx event FIFO is full, this event is discarded and interrupt flag FDCAN_IR.TEFL is set.

To avoid a Tx event FIFO overflow, the Tx event FIFO watermark can be used. When the Tx event FIFO fill level reaches the Tx event FIFO watermark configured by FDCAN_TXEFC.EFWM, interrupt flag FDCAN_IR.TEFW is set.

When reading from the Tx event FIFO, two times the Tx event FIFO get index FDCAN_TXEFS.EFGI has to be added to the Tx event FIFO start address FDCAN_TXEFC.EFSA.

61.4.3 FIFO acknowledge handling

The get indices of Rx FIFO 0, Rx FIFO 1, and the Tx event FIFO are controlled by writing to the corresponding FIFO acknowledge index, see *FDCAN Rx FIFO 0 acknowledge register*

(FDCAN_RXF0A), *FDCAN Rx FIFO 1 acknowledge register (FDCAN_RXF1A)*, and *FDCAN Tx event FIFO configuration register (FDCAN_TXEFC)*. Writing to the FIFO acknowledge index sets the FIFO get index to the FIFO acknowledge index plus one and thereby updates the FIFO fill level. There are two use cases:

- When only a single element has been read from the FIFO (the one being pointed to by the get index), this get index value is written to the FIFO acknowledge index.
- When a sequence of elements has been read from the FIFO, it is sufficient to write the FIFO acknowledge index only once at the end of that read sequence (value: index of the last element read), to update the FIFO get index.

Due to the fact that the CPU has free access to the FDCAN message RAM, special care has to be taken when reading FIFO elements in an arbitrary order (get index not considered). This might be useful when reading a high priority message from one of the two Rx FIFOs. In this case the FIFO acknowledge index should not be written because this would set the get index to a wrong position and also alters the FIFO fill level. In this case some of the older FIFO elements would be lost.

Note: The application has to ensure that a valid value is written to the FIFO acknowledge index. The FDCAN does not check for erroneous values.

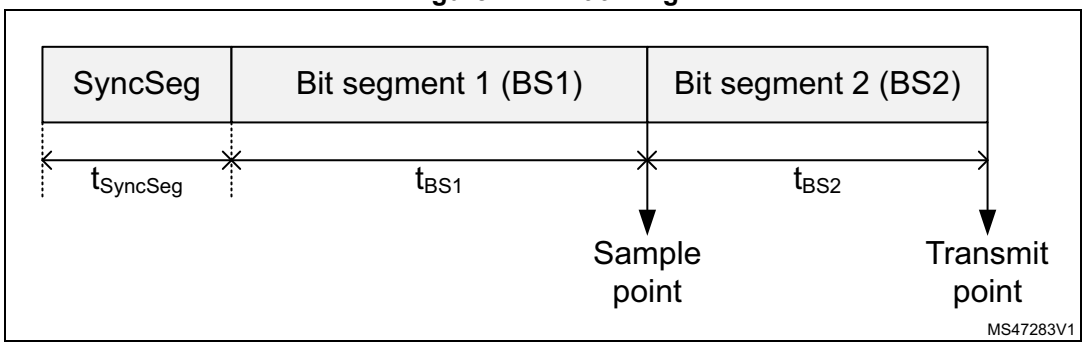
61.4.4 Bit timing

The bit timing logic monitors the serial bus-line and performs sampling and adjustment of the sample point by synchronizing on the start-bit edge and resynchronizing on the following edges.

As shown in *Figure 772*, its operation may be explained simply by splitting the bit time in three segments, as follows:

- Synchronization segment (SYNC_SEG): a bit change is expected to occur within this time segment, that has a fixed length of one time quantum (1 x tq).
- Bit segment 1 (BS1): defines the location of the sample point. It includes the PROP_SEG and PHASE_SEG1 of the CAN standard, its duration is programmable between 1 and 16 time quanta, but may be automatically lengthened to compensate for positive phase drifts due to differences in the frequency of the various nodes of the network.
- Bit segment 2 (BS2): defines the location of the transmit point. It represents the PHASE_SEG2 of the CAN standard, its duration is programmable between one and eight time quanta, but may also be automatically shortened to compensate for negative phase drifts.

Figure 772. Bit timing



The baudrate is the inverse of bit time (baudrate = 1 / bit time), which, in turn, is the sum of three components. *Figure 772* indicates that bit time = $t_{SyncSeg} + t_{BS1} + t_{BS2}$, where:

- for the nominal bit time
  - tq = (FDCAN_NBTP.NBRP[8:0] + 1) * $t_{fdcan\_tq\_ck}$
  - $t_{SyncSeg}$ = 1 tq
  - t_{BS1} = tq * (FDCAN_NBTP.NTSEG1[7:0] + 1)
  - t_{BS2} = tq * (FDCAN_NBTP.NTSEG2[6:0] + 1)
- for the data bit time
  - tq = (FDCAN_DBTP.DBRP[4:0] + 1) * $t_{fdcan\_tq\_ck}$
  - $t_{SyncSeg}$ = 1 tq
  - t_{BS1} = tq * (FDCAN_DBTP.DTSEG1[4:0] + 1)
  - t_{BS2} = tq * (FDCAN_DBTP.DTSEG2[3:0] + 1)

The (re)synchronization jump width (SJW) defines an upper bound for the amount of lengthening or shortening of the bit segments. It is programmable between one and four time quanta.

A valid edge is defined as the first transition in a bit time from dominant to recessive bus level, provided the controller itself does not send a recessive bit.

If a valid edge is detected in BS1 instead of SYNC_SEG, BS1 is extended by up to SJW so that the sample point is delayed.

Conversely, if a valid edge is detected in BS2 instead of SYNC_SEG, BS2 is shortened by up to SJW so that the transmit point is moved earlier.

As a safeguard against programming errors, the configuration of the bit timing register is only possible while the device is in Standby mode. Registers FDCAN_DBTP and FDCAN_NBTP (dedicated, respectively, to data and nominal bit timing) are only accessible when FDCAN_CCCR.CCE and FDCAN_CCCR.INIT are set.

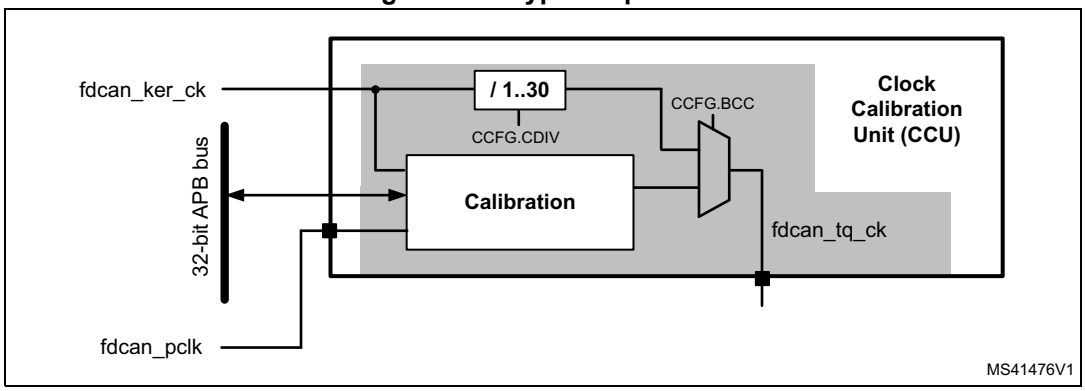
Note: For a detailed description of the CAN bit timing and resynchronization mechanism, refer to the ISO 11898-1 standard.

61.4.5 Clock calibration on CAN

After device reset the clock calibration unit (CCU) does not provide a valid clock signal to the FDCAN(s). The CCU has to be initialized via FDCAN_CCFG register. The FDCAN_CCFG register can be written only when FDCAN1 has both FDCAN_CCCR.CCE and FDCAN_CCCR.INIT bits set. In consequence the CCU and the FDCAN1 initialization needs to be completed before any FDCAN module can operate.

Clock calibration is bypassed when FDCAN_CCFG.BCC = 1 (see *Figure 773*).

Figure 773. Bypass operation



Operating conditions

The clock calibration on CAN unit is designed to operate under the following conditions:

- a CAN kernel clock frequency fdcan_ker_ck up of at least 80 MHz
- FDCAN bitrates:
  - Nominal bitrate: up to 1 Mbit/s
  - Data bitrate: between nominal bitrate and 8 Mbit/s

The clock calibration on FDCAN unit generates a calibrated time quanta clock fdcan_tq_ck in the range from 0.5 to 25 MHz.

Note: The FDCAN requires that the CAN time quanta clock is always below or equal to the APB clock (fdcan_tq_ck < fdcan_pclk). This has to be considered when the clock calibration on CAN unit is bypassed (FDCAN_CCFG.BCC = 1).

Calibration accuracy

The calibration accuracy in state Precision_Calibrated depends upon the factors listed below.

- Dynamic clock tolerance at the CAN kernel clock input fdcan_ker_ck
- Measurement error. For each bit sequence used for calibration measurement, there is a maximum error of one fdcan_pclk period. The number of bits used for measurement of the bit time is 32 or 64-bit, depending on configuration of FDCAN_CCFG.CFL.
- Tolerable error in calibration mechanism

The distance between two calibration messages has to be chosen to fit the clock tolerance requirements of the FDCAN1 module.

Note: Dynamic clock tolerance is the clock frequency variation between two calibration messages e.g. caused by change of temperature or operating voltage.

Functional description

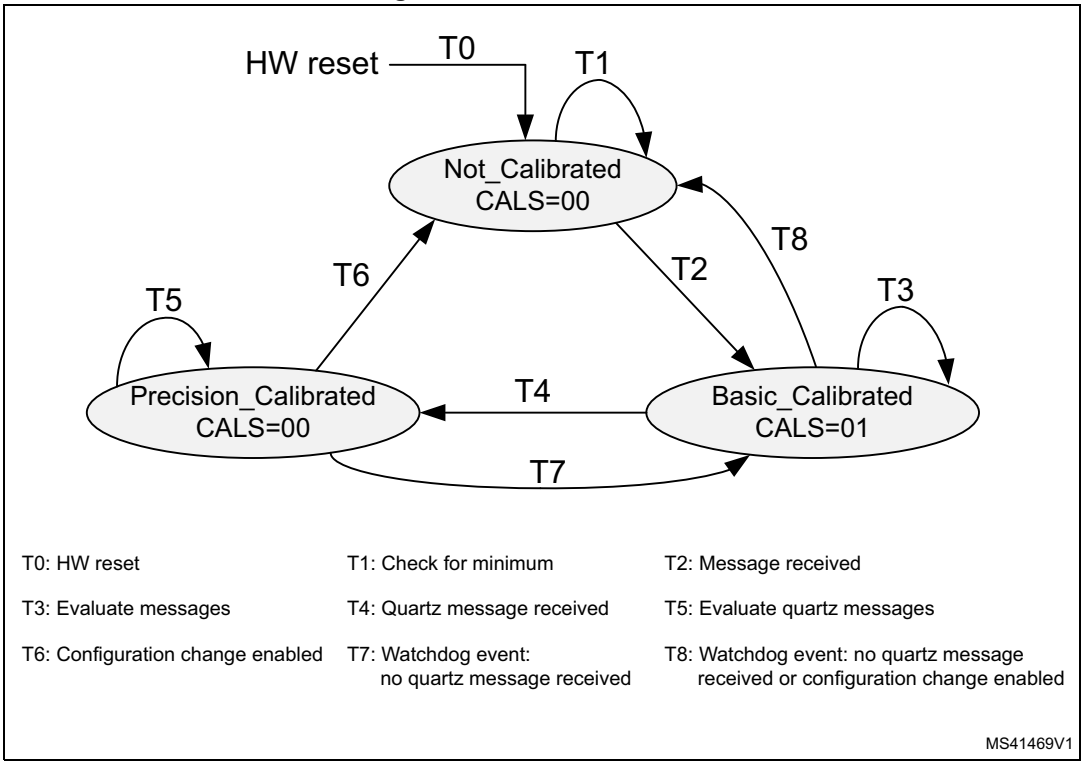
Calibration of the time quanta clock fdcan_tq_ck via CAN messages is performed by adapting a clock divider that generates the CAN protocol time quantum tq from the clock fdcan_ker_ck.

1. First step: basic calibration
   The minimum distance between two consecutive falling edges from recessive to dominant is measured, this time to be assumed two CAN bit times, counted in PLL clock periods. The clock divider (FDCAN_CCFG.CDIV) is updated each time a new

measurement finds a smaller distance between edges. Basic calibration is achieved when the CAN protocol controller detects a valid CAN message.

2. Second step: Precision calibration
The calibration state machine measures the length of a longer bit sequence inside a CAN frame by counting the number of fdcan_ker_ck periods. The length of this bit sequence can be configured to 32 or 64 bits via FDCAN_CCFG.CLF. For a calibration field length of 32/64 bit a calibration message with at least 2/6-byte data field is required. Precision calibration is based on the new clock divider value calculated from the measurement of the longer bit sequence.

Figure 774. FSM calibration



A change in the calibration state sets interupt flag FDCAN_CCU_IR.CSC, if enabled by the interupt enable FDCAN_CCU_IE.CSCE. it remains set until cleared by writing 1 in FDCAN_CCU_IR.CSC.

Until precision calibration is achieved, FDCANs operate in a restricted mode (no frame transmission, no error or overload flag transmission, no error counting). In case calibration of the fdcan_ker_clk is done by software by evaluating the calibration status from register FDCAN_CCU_CSTAT, FDCANs have to be set to restricted operation mode (FDCAN_CCCR.ASM = 1) until the calibration on CAN unit is in state Precision_Calibrated (see *Application*).

Precision calibration may be performed only on valid CAN frames transmitted by a node with a stable, quartz-controlled clock. calibration frames are detected by the FDCAN1 acceptance filtering A filter element and a Rx buffer have to be configured in the FDCAN1 to identify and store calibration messages. After reception of a calibration message the Rx buffer new data flag has to be reset to enable signaling of the next calibration message.

In case there is only one CAN transmitter with a quartz clock in the network, this node has to transmit its first message after startup with at least one 1010 binary sequence in the data field or in the identifier. This assures that the non-quartz nodes can enter state Basic_Calibrated and then acknowledge the quartz node messages.

Precision calibration must be repeated in predefined maximum intervals supervised by the calibration watchdog.

Note: When the clock calibration on CAN unit transits from state Precision_Calibrated back to Basic_Calibrated, the calibration OK signal is deasserted, the FDCAN1 complete ongoing transmissions, and then enter restricted operation (no frame transmission, no error or overload flag transmission, no error counting).

Configuration

The clock calibration on CAN unit is configured via register FDCAN_CCFG, i.e. when FDCAN1 has FDCAN_CCCR.CCE and FDCAN_CCCR.INIT bits set.

For basic calibration the minimum number of oscillator periods between two consecutive falling edges at pin FDCAN1_RX is measured. The number of clock periods depends on the clock frequency applied at input fdcan_ker_ck. In case the measured number of clock periods is below the minimum configured by FDCAN_CCFG.OCPM (as an example, because of a glitch on FDCAN1_RX) the value is discarded and measurement continues.

It is recommended to configure FDCAN_CCFG.OCPM slightly below two CAN bit times:

FDCAN_CCFG.OCPM < ((2 x CAN bit time) / fdcan_ker_ck period) / 32

The length of the bit field used for precision calibration can be configured to 32 or 64 bits via FDCAN_CCFG.CFL. The number of bits used for precision calibration has an impact on calibration accuracy and the maximum distance between two calibration messages.

The number of time quanta per bit time configured by FDCAN_CCFG.TQBT is used together with the measured number of oscillator clock periods FDCAN_CCU_CSTAT.OCPC to define the number of oscillator clocks per bit time.

When the clock calibration is bypassed by configuring FDCAN_CCFG.BCC = 1, the internal clock divider has to be configured via FDCAN_CCFG.CDIV to fulfill the condition fdcan_tq_ck < fdcan_pclk.

Note: When clock calibration on CAN is active (FDCAN_CCFG.BCC = 0), the baudrate prescalers of FDCAN modules have to be configured to inactive.

Status signaling

The status of the clock calibration on CAN unit can be monitored by reading register FDCAN_CCU_CSTAT. When in state Precision_Calibrated the oscillator clock period counter FDCAN_CCU_CSTAT.OCPC signals the number of oscillator clock periods in the calibration field while FDCAN_CCU_CSTAT.TQC signals the number of time quanta in the calibration field.

The calibration state is monitored by FDCAN_CCU_CSTAT.CALS. A change in the calibration state sets interupt flag FDCAN_CCU_IR.CSC, if enabled by the interrupt enable FDCAN_CCU_IE.CSCE it remains set until cleared by writing 1 in FDCAN_CCU_IR.CSC.

A calibration watchdog event also sets interrupt flag FDCAN_CCU_IR.CWE, if enabled by FDCAN_CCU_IE.CWEE (set to high) it remains active until reset by FDCAN_CCU_IE.CWE.

61.4.6 Application

Clock calibration bypassed

The CCU internal clock divider is configured for division by one (FDCAN_CCFG.CDIV = 0x0000). In this operation mode the input clock fdcan_ker_ck is directly routed to the clock output fdcan_tq_ck. In this case fdcan_tq_ck is independent from the configuration and status of FDCAN1and FDCAN2 connected to the CCU. CAN FD operation is possible with a fdcan_ker_ck above 80 MHz.

Software calibration

The clock calibration on CAN unit also supports software calibration of fdcan_ker_ck by trimming of an on-chip oscillator. For calculation of the trimming values the user has to read the CCU state from FDCAN_CCU_CSTAT. The clock from fdcan_ker_ck is routed to output fdcan_tq_ck (FDCAN_CCFG.BCC = 1).

The input clock fdcan_ker_ck must be at least 80 MHz. The clock divider of CCU has to be configured via FDCAN_CCFG.CDIV to bring fdcan_tq_ck to a valid range. All other configuration parameters have to be set via FDCAN_CCFG. For correct operation of tFDCAN1and FDCAN2, the APB clock fdcan_pclk needs to be equal to or higher than the time quanta clock (fdcan_tq_ck). CAN FD operation is not possible.

For startup FDCAN modules have to be both configured for restricted operation (FDCAN_CCCR.ASM = 1) before FDCAN_CCCR.INIT is reset. The input clock fdcan_ker_ck has to be adjusted until the clock calibration on CAN unit has reached state Precision_Calibrated. Now the software can reset FDCAN_CCCR.ASM and the CANFD1 and CANFD2 can start normal operation.

During operation the software has to check regularly whether the clock calibration on CAN unit is still in state Precision_Calibrated. In case the clock calibration on CAN unit has left state Precision_Calibrated due to drift of fdcan_ker_ck, FDCAN modules have to be set into restricted operation mode by programming FDCAN_CCCR.INIT, FDCAN_CCCR.CCE, and FDCAN_CCCR.ASM to 1. After fdcan_ker_ck has been adjusted successfully (clock calibration on CAN unit is in state Precision_Calibrated), FDCAN modules can resume normal operation.

Note: Trimming accuracy must be to sufficient to meet the CAN clock tolerance requirements for the configured bitrate.

Clock calibration active

This operation mode is entered by resetting FDCAN_CCFG.BCC to 0. In this operation mode the fdcan_ker_ck is controlled by the CCU.

The generation of CCU output signal fdcan_tq_ck depends upon the state of the FDCAN1. Input clock fdcan_ker_ck must be above 80 MHz. Configuration of the CCU and FDCAN1 is required. CAN FD operation is not possible.

If FDCAN1 turns to Bus_Off or when its INIT bit is set by the user command (FDCAN_CCCR.INIT = 1), the CCU enters state Not_Calibrated. CANFD1 and CANFD2 enter restricted operation mode.

Note: This is the default operation mode after reset in case the reset value of FDCAN_CCFG.BCC is configured to 0.

61.4.7 TTCAN operations (FDCAN1 only)

Reference message

A reference message is a data frame characterized by a specific CAN identifier. It is received and accepted by all nodes except the time master (sender of the reference message).

For level 1 the data length must be at least one; for level 0, 2 the data length must be at least four; otherwise, the message is not accepted as reference message. The reference message may be extended by other data up to the sum of eight CAN data bytes. All bits of the identifier except the three LSBs characterize the message as a reference message. The last three bits specify the priorities of up to eight potential time masters. Reserved bits are transmitted as logical 0 and are ignored by the receivers. The reference message is configured via register FDCAN_TTRMC.

The time master transmits the reference message. If the reference message is disturbed by an error, it is retransmitted immediately. In case of a retransmission, the transmitted Master_Ref_Mark is updated. The reference message is sent periodically, but is allowed to stop the periodic transmission (Next_is_Gap bit) and to initiate transmission event-synchronized at the start of the next basic cycle by the current time master or by one of the other potential time masters.

The node transmitting the reference message is the current time master. The time master is allowed to transmit other messages. If the current time master fails, its function is replicated by the potential time master with the highest priority. Nodes that are neither time master nor potential time master are time-receiving nodes.

Level 1

Level 1 operation is configured via FDCAN_TTOCF.OM = 01 and FDCAN_TTOCF.GEN. external clock synchronization is not available in level 1. The information related to the reference message is stored in the first data byte as shown in *Table 508*. Cycle_Count is optional.

Table 508. First byte of level 1 reference message

Bits	0	1	2	3	4	5	6	7
First byte	Next_is_Gap	Reserved	Cycle_Count[5;0]					

Level 2

Level 2 operation is configured via FDCAN_TTOCF.OM = 10 and FDCAN_TTOCF.GEN. The information related to the reference message is stored in the first four data bytes as shown in *Table 509*. Cycle_Count and the lower four bits of FDCAN_NTU_Res are optional. The TTCAN does not evaluate NTU_Res[3:0] from received reference messages, it always transmits these bits as 0.

Table 509. First four bytes of level 2 reference message

Bits	0	1	2	3	4	5	6	7
First byte	Next_is_Gap	Reserved	Cycle_Count[5;0]					
Second byte	NTU_Res[6:4]			NTU_Res[3:0]				Disc_Bit
Third byte	Master_Ref_Mark[7:0]							
Fourth byte	Master_Ref_Mark[15:8]							

Level 0

Level 0 operation is configured via FDCAN_TTOCF.OM = 11. External event-synchronized time-triggered operation is not available in level 0. The information related to the reference message is stored in the first four data bytes as shown in the table below. In level 0 Next_is_Gap is always 0. Cycle_Count and the lower four bits of NTU_Res are optional. The TTCAN does not evaluate NTU_Res[3:0] from received reference messages, it always transmits these bits as 0.

Table 510. First four bytes of level 0 reference message

Bits	0	1	2	3	4	5	6	7
First byte	Next_is_Gap	Reserved	Cycle_Count[5;0]					
Second byte	NTU_Res[6:4]			NTU_Res[3:0]				Disc_Bit
Third byte	Master_Ref_Mark[7:0]							
Fourth byte	Master_Ref_Mark[15:8]							

61.4.8 TTCAN configuration

TTCAN timing

The network time unit (NTU) is the unit in which all times are measured. The NTU is a constant of the whole network and is defined as a priority by the network system designer. In TTCAN level 1 the NTU is the nominal CAN bit time. In TTCAN level 0 and level 2 the NTU is a fraction of the physical second.

The NTU is the time base for the local time. The integer part of the local time (16-bit value) is incremented once each NTU. Cycle time and global time are both derived from local time. The fractional part (3-bit value) of local time, cycle time, and global time is not readable.

In TTCAN level 0 and level 2 the length of the NTU is defined by the time unit Ratio TUR. The TUR is in general a non-integer number, given by
TUR = FDCAN_TURNA.NAV / FDCAN_TURCF.DC. The NTU length is given by
NTU = CAN clock period x TUR.

The TUR numerator configuration NC is an 18-bit number, FDCAN_TURCF[NCL[15:0]] can be programmed in the range 0x0000–0xFFFF. FDCAN_TURCF[NCH[17:16]] is hard wired to 0b01. When 0xnnnn is written to FDCAN_TURCF[NCL[15:0]], FDCAN_TURNA.NAV starts with the value 0x10000 + 0x0nnnn = 0x1nnnn. The TUR denominator configuration FDCAN_TURCF.DC is a 14-bit number. FDCAN_TURCF.DC may be programmed in the range 0x0001 - 0x3FFF (0x0000 is an illegal value).

In level 1, NC must be equal to or higher than 4 x FDCAN_TURCF.DC. In level 0 and level 2 NC must be equal to or higher than 8 x FDCAN_TURCF.DC to get the 3-bit resolution for the internal fractional part of the NTU.

A hardware reset presets FDCAN_TURCF.DC to 0x1000 and FDCAN_TURCF.NCL to 0x10000, resulting in an NTU consisting of sixteen CAN clock periods. Local time and application watchdog are not started before either the FDCAN_CCCR.INIT is reset, or FDCAN_TURCF.ELT is set. FDCAN_TURCF.ELT may not be set before the NTU is configured. Setting FDCAN_TURCF.ELT to 1 also locks the write access to register FDCAN_TURCF.

At startup FDCAN_TURNA.NAV is updated from NC (= FDCAN_TURCF.NCL + 0x10000) when FDCAN_TURCF.ELT is set. In TTCAN level 1 there is no drift compensation. FDCAN_TURNA.NAV does not change during operation, it is always equal to NC.

In TTCAN level 0 and level 2 there are two possibilities for FDCAN_TURNA.NAV to change. When operating as time slave or backup time master, and when FDCAN_TTOCF.ECC is set, FDCAN_TURNA.NAV is updated automatically to the value calculated from the monitored global time speed, as long as the TTCAN is in synchronization state In_Schedule or In_Gap. When it loses synchronization, it returns to NC. When operating as the actual time master, and when FDCAN_TTOCF.EECS is set, the user may update FDCAN_TURCF.NCL. When the user sets FDCAN_TTOCN.ECS, FDCAN_TURNA.NAV is updated from the new value of NC at the next reference message. The status flag FDCAN_TTOST.WECS as is set when FDCAN_TTOCN.ECS is set and is cleared when FDCAN_TURNA.NAV is updated. FDCAN_TURCF.NCL is write locked while FDCAN_TTOST.WECS is set.

In TTCAN level 0 and level 2 the clock calibration process adapts FDCAN_TURNA.NAV in the range of the synchronization deviation limit SDL of NC ± 2(FDCAN_TTOCF.LDSDL + 5). FDCAN_TURCF.NCL should be programmed to the largest applicable numerical value in order to achieve the best accuracy in the calculation of FDCAN_TURNA.NAV.

The synchronization deviation SD is the difference between NC and FDCAN_TURNA.NAV (SD = | NC - FDCAN_TURNA.NAV |). It is limited by the synchronization deviation limit SDL, which is configured by its dual logarithm FDCAN_TTOCF.LDSDL (SDL = 2 (FDCAN_TTOCF.LDSDL + 5)) and should not exceed the clock tolerance given by the CAN bit timing configuration. SD is calculated at each new basic cycle. When the calculated TURNA[NAV deviates by more than SDL from NC, or if the Disc_Bit in the reference message is set, the drift compensation is suspended and FDCAN_TTIR.GTE is set and FDCAN_TTOSC.QCS is reset, or in case of the Disc_Bit = 1, FDCAN_TTIR.GTD is set.

Table 511. TUR configuration example

TUR	8	10	24	50	510	125000	32.5	100/12	529/17
NC	0x1FFF8	0x1FFFE	0x1FFF8	0x1FFEA	0x1FFFE	0x1E848	0x1FFE0	0x19000	0x10880
FDCAN _TURCF.DC	0x3FFF	0x3333	0x1555	0x0A3D	0x0101	0x0001	0x0FC0	0x3000	0x0880

FDCAN_TTOCN.ECS schedules NC for activation by the next reference message. FDCAN_TTOCN.SGT schedules FDCAN_TTGTP.TP for activation by the next reference message. Setting FDCAN_TTOCN.ECS and FDCAN_TTOCN.SGT requires FDCAN_TTOCF.EECS to be set (external clock synchronization enabled) while the FDCAN is actual time master.

The TTCAN module provides an application watchdog to verity the function of the application program. The user has to serve this watchdog regularly, else all CAN bus activity is stopped. The application watchdog limit FDCAN_TTOCF.AWL specifies the number of NTUs between two times the watchdog has to be served. The maximum number of NTUs is 256. The application watchdog is served by reading register FDCAN_TTOST. FDCAN_TTOST.AWE indicates whether the watchdog has been served in time. In case the application failed to serve the application watchdog, interrupt flag FDCAN_TTIR.AW is set. For software development, the application watchdog may be disabled by programming FDCAN_TTOCF.AWL to 0x00, see *Section 61.6.3*.

Timing of interface signals

The timing events that cause a pulse at output FDCAN trigger time mark interrupt pulse fdcan1_tmp for more than one instance and fdcan_tmp if only one instance; FDCAN register time mark interrupt pulse fdcan1_rtp for more than one instance and fdcan_rtp if only one instance are generated in the CAN clock domain.

There is a clock domain crossing delay to be considered before the same event is visible in the APB clock domain (when FDCAN_TTIR.TTMI is set or FDCAN_TTIR.RTMI is set). As an example, the signals can be connected to the timing input(s) of another FDCAN node (fdcan_swt/fdcan_evt), in order to automatically synchronize two TTCAN networks.

Output FDCAN start of cycle_fdcan1_soc for more than one instance and cycle_fdcan1_soc if only one instance gets active whenever a reference message is completed (either transmitted or received). The output is controlled in the APB clock domain.

61.4.9 Message scheduling

FDCAN_TTOCF.TM controls whether the TTCAN operates as potential time master or as a time slave. If it is a potential time master, the three LSBs of the reference message identifier FDCAN_TTRMC.RID define the master priority, 0 giving the highest and 7 giving the lowest. There cannot be two nodes in the network using the same master priority. FDCAN_TTRMC.RID is used for recognition of reference messages. FDCAN_TTRMC.RMPS is not relevant for time slaves.

The initial reference trigger offset FDCAN_TTOCF.IRTO is a 7-bit-value that defines (in NTUs) how long a backup time master waits before it starts the transmission of a reference message when a reference message is expected but the bus remains idle. The recommended value for FDCAN_TTOCF.IRTO is the master priority multiplied with a factor depending on the expected clock drift between the potential time masters in the network. The sequential order of the backup time masters, when one of them starts the reference message in case the current time master fails, should correspond to their master priority, even with maximum clock drift.

FDCAN_TTOCF.OM decides whether the node operates in TTCAN level 0, level 1, or level 2. In one network, all potential time masters have to operate on the same level. Time slaves may operate on level 1 in a level 2 network, but not vice versa. The configuration of the TTCAN operation mode via FDCAN_TTOCF.OM is the last step in the setup. With FDCAN_TTOCF.OM = 00 (event-driven CAN communication), the FDCAN operates

according to ISO 11898-1: 2015, without time triggers.With FDCAN_TTOCF.OM = 01 (level 1), the FDCAN operates according to ISO 11898-4, but without the possibility to synchronize the basic cycles to external events, the Next_is_Gap bit in the reference message is ignored. With FDCAN_TTOCF.OM = 10 (level 2), the TTCAN operates according to ISO 11898-4, including the event-synchronized start of a basic cycle. With FDCAN_TTOCF.OM = 11 (level 0), the FDCAN operates as event-driven CAN but maintains a calibrated global time base as in level 2.

FDCAN_TTOCF.EECS enables the external clock synchronization, allowing the application program of the current time master to update the TUR configuration during time-triggered operation, to adapt the clock speed and (in levels 0 and level 2 only) the global clock phase to an external reference.

FDCAN_TTMLM.ENTT in the TT matrix limits register specifies the number of expected Tx_Triggers in the system matrix. This is the sum of Tx_Triggers for exclusive, single arbitrating and merged arbitrating windows, excluding the Tx_Ref_Triggers. Note that this is usually not the number of Tx_Trigger memory elements; the number of basic cycles in the system matrix and the trigger repeat factors have to be taken into account.

An inaccurate configuration of FDCAN_TTMLM.ENTT results either in a TxCount Underflow (FDCAN_TTIR.TXU = 1 and FDCAN_TTOST.EL = 01, severity 1), or in a Tx count Overflow (FDCAN_TTIR.TXO = 1 and FDCAN_TTOST.EL = 10, severity 2).

Note: In case the first reference message seen by a node does not have Cycle_Count 0, this node may finish its first matrix cycle with its Tx count resulting in a Tx count underflow condition. As long as a node is in state Synchronizing, its Tx_Triggers do not lead to transmissions.

FDCAN_TTMLM.CCM specifies the number of the last basic cycle in the system matrix. The counting of basic cycles starts at 0. In a system matrix consisting of eight basic cycles FDCAN_TTMLM.CCM would be 7. FDCAN_TTMLM.CCM is ignored by time slaves, a receiver of a reference message considers the received cycle count as the valid cycle count for the actual basic cycle.

FDCAN_TTMLM.TXEW specifies the length of the Tx enable window in NTUs. The Tx enable window is that period of time at the beginning of a time window where a transmission may be started. If a transmission of a message cannot be started inside the Tx enable window because of for example, a slight overlap from the previous time window message, the transmission cannot be started in that time window at all. FDCAN_TTMLM.TXEW has to be chosen with respect to the network synchronization quality and with respect to the relation between the length of the time windows and the length of the messages.

Trigger memory

The trigger memory is part of the external message RAM to which the TTCAN is connected to (see *Section 61.5.26*). It stores up to 64 trigger elements. A trigger memory element consists of time mark TM, cycle code CC, trigger type TYPE, filter type FTYPE, message number MNR, message status count MSC, time mark event internal TMIN, time mark event external TMEX (see *Section 61.4.23*).

The time mark defines at which cycle time a trigger becomes active. The triggers in the trigger memory have to be sorted by their time marks. The trigger element with the lowest time mark is written to the first trigger memory word. Message number and cycle code are ignored for triggers of type Tx_Ref_Trigger, Tx_Ref_Trigger_Gap, Watch_Trigger, Watch_Trigger_Gap, and End_of_List.

When the cycle time reaches the time mark of the actual trigger, the FSE switches to the next trigger and starts to read the following trigger from the trigger memory. In case of a

transmit trigger, the Tx handler starts to read the message from the message RAM as soon as the FSE switches to its trigger. The RAM access speed defines the minimum time step between a transmit trigger and its preceding trigger, the Tx handler has to be able to prepare the transmission before the transmit trigger time mark is reached. The RAM access speed also limits the number of non-matching (with regard to their cycle code) triggers between two matching triggers, the next matching trigger must be read before its time mar k is reached. If the reference message is n NTU long, a trigger with a time mark lower than n never becomes active and is treated as a configuration error.

Starting point of the cycle time is the sample point of the reference message start of frame bit. The next reference message is requested when cycle time reaches the Tx_Ref_Trigger time mark. The FDCAN reacts on the transmission request at the next sample point. A new Sync_Mark is captured at the start of frame bit, but the cycle time is incremented until the reference message is successfully transmitted (or received) and the Sync_Mark is taken as the new Ref_Mark. At that point in time, cycle time is restarted. As a consequence, cycle time can never (with the exception of initialization) be seen at a value lower than n, with n being the length of the reference message measured in NTU.

Length of a basic cycle: Tx_Ref_Trigger time mark + 1 NTU + 1 CAN bit time.

The trigger list is different for all nodes in the CAN FD network. Each node knows only the Tx_Triggers for its own transmit messages, the Rx_Triggers for those receive messages that are processed by this node, and the triggers concerning the reference messages.

Trigger types

Tx_Ref_Trigger (TYPE = 0000) and Tx_Ref_Trigger_Gap (TYPE = 0001) cause the transmission of a reference message by a time master. A configuration error (FDCAN_TTOST.EL = 11, severity 3) is detected when a time slave encounters a Tx_Ref_Trigger(_Gap) in its trigger memory. Tx_Ref_Trigger_Gap is only used in external event-synchronized
time-triggered operation mode. In that mode, Tx_Ref_Trigger is ignored when the FDCAN synchronization state is In_Gap (FDCAN_TTOST.SYS = 10).

Tx_Trigger_Single (TYPE = 0010), Tx_Trigger_Continuous (TYPE = 0011), Tx_Trigger_Arbitration (TYPE = 0100), and Tx_Trigger_Merged (TYPE = 0101) cause the start of a transmission. They define the start of a time window.

Tx_Trigger_Single starts a single transmission in an exclusive time window when the message buffer transmission request pending bit is set. After successful transmission the transmission request pending bit is reset.

Tx_Trigger_Continuous starts a transmission in an exclusive time window when the message buffer transmission request pending bit is set. After successful transmission the transmission request pending bit remains set, and the message buffer is transmitted again in the next matching time window.

Tx_Trigger_Arbitration starts an arbitrating time window, Tx_Trigger_Merged a merged arbitrating time window. The last Tx_Trigger of a merged arbitrating time window must be of type Tx_Trigger_Arbitration. A configuration error (FDCAN_TTOST.EL = 11, severity 3) is detected when a trigger of type Tx_Trigger_Merged is followed by any other Tx_Trigger than one of type Tx_Trigger_Merged or Tx_Trigger_Arbitration. Several Tx_Triggers may be defined for the same Tx message buffer. Depending on their cycle code, they may be ignored in some basic cycles. The cycle code has to be considered when the expected number of Tx_Triggers (FDCAN_TTMLM.ENTT) is calculated.

Watch_Trigger (TYPE = 0110) and Watch_Trigger_Gap (TYPE = 0111) check for missing reference messages. They are used by both time masters and time slaves. Watch_Trigger_Gap is only used in external event-synchronized time-triggered operation mode. In that mode, a Watch_Trigger is ignored when the FDCAN synchronization state is In_Gap (FDCAN_TTOST.SYS = 10).

Rx_Trigger (TYPE = 1000) is used to check for the reception of periodic messages in exclusive time windows. Rx_Triggers are not active until state In_Schedule or In_Gap is reached. The time mark of an Rx_Trigger shall be placed after the end of that message transmission, independent of time window boundaries. Depending on their cycle code, Rx_Triggers may be ignored in some basic cycles. At the time mark of the Rx_Trigger, it is checked whether the last received message before this time mark and after start of cycle or previous Rx_Trigger had matched the acceptance filter element referenced by MNR. Accepted messages are stored in one of the two receive FIFOs, according to the acceptance filtering, independent of the Rx_Trigger. Acceptance filter elements referenced by Rx_Triggers should be placed at the beginning of the filter list to ensure that the filtering is finished before the Rx_Trigger time mark is reached.

Time_Base_Trigger (TYPE = 1001) are used to generate internal/external events depending on the configuration of TMIN and TMEX.

End_of_List (TYPE = 1010 … 1111) is an illegal trigger type, a configuration error (FDCAN_TTOST.EL = 11, severity 3) is detected when an End_of_List trigger is encountered in the trigger memory before the Watch_Trigger and Watch_Trigger_Gap.

Restrictions for the node trigger list

There may not be two triggers that are active at the same cycle time and cycle count, but triggers that are active in different basic cycles (different cycle code) may share the same time mark.

Rx_Triggers and Time_Base_Triggers may not be placed inside the Tx enable windows of Tx_Trigger_Single/Continuous/Arbitration, but they may be placed after Tx_Trigger_Merged.

Triggers that are placed after the Watch_Trigger (or the Watch_Trigger_Gap when FDCAN_TTOST.SYS = 10) never become active. The watch triggers themselves do not become active when the reference messages are transmitted on time.

All unused trigger memory words (after the Watch_Trigger or after the Watch_Trigger_Gap when FDCAN_TTOST.SYS = 10) must be set to trigger type End_of_List.

A typical trigger list for a potential time master begins with a number of Tx_Triggers and Rx_Triggers followed by the Tx_Ref_Trigger and the Watch_Trigger. For networks with external event- synchronized time-triggered communication, this is followed by the Tx_Ref_Trigger_Gap and the Watch_Trigger_Gap. The trigger list for a time slave is the same but without the Tx_Ref_Trigger and the Tx_Ref_Trigger_Gap.

At the beginning of each basic cycle, that is at each reception or transmission of a reference message, the trigger list is processed starting with the first trigger memory element. The FSE looks for the first trigger with a cycle code that matches the current cycle count. The FSE waits until cycle time reaches the trigger time mark and activates the trigger. Afterwards the FSE looks for the next trigger in the list with a cycle code that matches the current cycle count.

Special consideration is needed for the time around Tx_Ref_Trigger and Tx_Ref_Trigger_Gap. In a time master competing for master ship, the effective time mark of

a Tx_Ref_Trigger may be decremented in order to be the first node to start a reference message. In backup time masters the effective time mark of a Tx_Ref_Trigger or Tx_Ref_Trigger_Gap is the sum of its configured time mark and the reference trigger offset FDCAN_TTOCF.IRTO. In case error level 2 is reached (FDCAN_TTOST.EL = 10), the effective time mark is the sum of its time mark and 0x127. No other trigger elements should be placed in this range otherwise it may happen that the time marks appear out of order and are flagged as a configuration error. Trigger elements which are coming after Tx_Ref_Trigger may never become active as long as the reference messages come in time.

There are interdependencies between the following parameters:

- APB clock frequency
- Speed and waiting time for trigger RAM accesses
- Length of the acceptance filter list
- Number of trigger elements
- Complexity of cycle code filtering in the trigger elements
- Offset between time marks of the trigger elements

Example for trigger handling

The example shows how the trigger list is derived from a node system matrix. Assumption is that node A is first time master and has knowledge of the section of the system matrix shown in *Table 512*.

Table 512. System matrix, Node A

Cycle count	Time mark						
	1	2	3	4	5	6	7
0	Tx7	-	-	-	-	TxRef	Error
1	Rx3	-	Tx2, Tx4		-	TxRef	Error
2	-	-	-	-	-	TxRef	Error
3	Tx7	-	Rx5	-	-	TxRef	Error
4	Tx7	-	-	Rx6	-	TxRef	Error

The cycle count starts with 0 and runs until 0, 1, 3, 7, 15, 31, 63 (the corresponding number of basic cycles in the system matrix is, respectively, 1, 2, 4, 8, 16, 32, 64). The maximum cycle count is configured by FDCAN_TTMLM.CCM. The cycle code CC is composed of repeat factor (= value of most significant 1) and the number of the first basic cycle in the system matrix (= bit field after most significant 1).

As an example, with a cycle code of 0b0010011 (repeat factor = 16, first basic cycle = 3) and a maximum cycle count of FDCAN_TTMLM.CCM = 0x3F matches occur at cycle counts 3, 19, 35 and 51.

A trigger element consists of time mark TM, cycle code CC, trigger type TYPE, and message number MNR. For transmission MNR references the Tx buffer number (0 ... 31). For reception MNR references the number of the filter element (0 ... 127) that matched during acceptance filtering. Depending on the configuration of the filter type FTYPE, the 11-bit or 29-bit message ID filter list is referenced.

In addition a trigger element can be configured for generation of time mark event internal TMIN, and time mark event external TMEX. The message status count MSC holds the counter value (0 ... 7) for scheduling errors for periodic messages in exclusive time windows at the point in time when the time mark of the trigger element became active.

Table 513. Trigger list, Node A

Trigger	Time mark TM[15:0]	Cycle code CC [6:0]	Trigger type TYPE [3:0]	Mess No. MNR [6:0]
0	Mark1	0b0000100	Tx_Trigger_Single	7
1	Mark 1	0b1000000	Rx_Trigger	3
2	Mark 1	0b1000011	Tx_Trigger_Single	7
3	Mark 3	0b1000001	Tx_Trigger_Merged	2
4	Mark 3	0b1000011	Rx_Trigger	5
5	Mark 4	0b1000001	Tx_Trigger_Arbitration	4
6	Mark 4	0b1000100	Rx_Trigger	6
7	Mark 6	N/A	Tx_Ref_Trigger	0 (Ref)
8	Mark 7	N/A	Watch_Trigger	N/A
9	N/A	N/A	End_of_List	N/A

Tx_Trigger_Single, Tx_Trigger_Continuous, Tx_Trigger_Merged, Tx_Trigger_Arbitration, Rx_Trigger, and Time_Base_Trigger are only valid for the specified cycle code. For all other trigger types the cycle code is ignored.

The FSE starts the basic cycle with scanning the trigger list starting from 0 until a trigger with time mark higher than cycle time and with its cycle code CC matching the actual cycle count is reached, or a trigger of type Tx_Ref_Trigger, Tx_Ref_Trigger_Gap, Watch_Trigger, or Watch_Trigger_Gap is encountered.

When the cycle time reached the time mark TM, the action defined by trigger type TYPE and message number MNR is started. There is an error in the configuration when End_of_List is reached.

At mark 6 the reference message (always TxRef) is transmitted. After transmission of the reference message the FSE returns to the beginning of the trigger list. When the watch trigger at mark 7 is reached, the node was not able to transmit the reference message; error treatment is started.

Detection of configuration errors

A configuration error is signaled via FDCAN_TTOST.EL = 11 (severity 3) when:

- The FSE comes to a trigger in the list with a cycle code that matches the current cycle count but with a time mark that is less than the cycle time.
- The previous active trigger was a Tx_Trigger_Merged and the FSE comes to a trigger in the list with a cycle code that matches the current cycle count but that is neither a

Tx_Trigger_Merged nor a Tx_Trigger_Arbitration nor a Time_Base_Trigger nor an Rx_Trigger.

- The FSE of a node with FDCAN_TTOCF.TM=0 (time slave) encounters a Tx_Ref_Trigger or a Tx_Ref_Trigger_Gap.
- Any time mark placed inside the Tx enable window (defined by FDCAN_TTMLM.TXEW) of a Tx_Trigger with a matching cycle code.
- A time mark is placed near the time mark of a Tx_Ref_Trigger and the reference trigger offset FDCAN_TTOST.RTO causes a reversal of their sequential order measured in cycle time.

TTCAN schedule initialization

The synchronization to the TTCAN message schedule starts when FDCAN_CCCR.INIT is reset. The TTCAN can operate strictly time-triggered (FDCAN_TTOCF.GEN = 0) or external event-synchronized time-triggered (FDCAN_TTOCF.GEN = 1). All nodes start with cycle time 0 at the beginning of their trigger list with FDCAN_TTOST.SYS = 00 (out of synchronization), no transmission is enabled with the exception of the reference message. Nodes in external event-synchronized time-triggered operation mode will ignore Tx_Ref_Trigger and Watch_Trigger and will use instead Tx_Ref_Trigger_Gap and Watch_Trigger_Gap until the first reference message decides whether a Gap is active.

Time slaves

After configuration, a time slave will ignore its Watch_Trigger and Watch_Trigger_Gap when it did not receive any message before reaching the Watch_Triggers. When it reaches Init_Watch_Trigger, interrupt flag FDCAN_TTIR.IWT is set, the FSE is frozen, and the cycle time becomes invalid, but the node is still able to take part in CAN bus communication (to acknowledge or to send error flags). The first received reference message restarts the FSE and the cycle time.

Note: Init_Watch_Trigger is not part of the trigger list. It is implemented as an internal counter that counts up to 0xFFFF = maximum cycle time.

When a time slave has received any message but the reference message before reaching the Watch_Triggers, it will assume a fatal error (FDCAN_TTOST.EL = 11, severity 3), set interrupt flag FDCAN_TTIR.WT, switch off its CAN bus output, and enter the bus monitoring mode (FDCAN_CCCR.MON set to 1). In the bus monitoring mode it is still able to receive messages, but it cannot send any dominant bits and therefore cannot give acknowledge.

Note: To leave the fatal error state, the user has to set FDCAN_CCCR.INIT = 1. After reset of FDCAN_CCCR.INIT, the node restarts TTCAN communication.

When no error is encountered during synchronization, the first reference message sets FDCAN_TTOST.SYS = 01 (Synchronizing), the second sets the FDCAN synchronization state (depending on its Next_is_Gap bit) to FDCAN_TTOST.SYS = 11 (In_Schedule) or FDCAN_TTOST.SYS = 10 (In_Gap), enabling all Tx_Triggers and Rx_Triggers.

Potential time masters

After configuration, a potential time master will start the transmission of a reference message when it reaches its Tx_Ref_Trigger (or its Tx_Ref_Trigger_Gap when in external event-synchronized time-triggered operation). It will ignore its Watch_Trigger and Watch_Trigger_Gap when it did not receive any message or transmit the reference message successfully before reaching the Watch_Triggers (assumed reason: all other nodes still in reset or configuration, giving no acknowledge). When it reaches

Init_Watch_Trigger, the attempted transmission is aborted, interrupt flag FDCAN_TTIR.IWT is set, the FSE is frozen, and the cycle time will become invalid, but the node will still be able to take part in CAN bus communication (to give acknowledge or to send error flags). Resetting FDCAN_TTIR.IWT will re-enable the transmission of reference messages until next time the Init_Watch_Trigger condition is met, or another CAN message is received. The FSE will not be restarted by the reception of a reference message.

When a potential time master reaches the Watch_Triggers after it has received any message but the reference message, it will assume a fatal error (FDCAN_TTOST.EL = 11, severity 3), set interrupt flag FDCAN_TTIR.WT, switch off its CAN bus output, and enter the bus monitoring mode (FDCAN_CCCR.MON set to 1). In bus monitoring mode, it is still able to receive messages, but cannot send any dominant bits and therefore cannot give acknowledge.

When no error is detected during initialization, the first reference message sets FDCAN_TTOST.SYS = 01 (synchronizing), the second sets the FDCAN synchronization state (depending on its Next_is_Gap bit) to FDCAN_TTOST.SYS = 11 (In_Schedule) or FDCAN_TTOST.SYS = 10 (In_Gap), enabling all Tx_Triggers and Rx_Triggers.

A potential time master is current time master (FDCAN_TTOST.MS = 11) when it was the transmitter of the last reference message, else it is backup time master (FDCAN_TTOST.MS = 10).

When all potential time masters have finished configuration, the node with the highest time master priority in the network will become the current time master.

61.4.10 TTCAN gap control

All functions related to gap control apply only when the FDCAN is operated in external event synchronized time-triggered mode (FDCAN_TTOCF.GEN = 1). In this operation mode the FDCAN message schedule may be interrupted by inserting gaps between the basic cycles of the system matrix. All nodes connected to the CAN network have to be configured for external event- synchronized time-triggered operation.

During a gap, all transmissions are stopped and the CAN bus remains idle. A gap is finished when the next reference message starts a new basic cycle. A gap starts at the end of a basic cycle that itself was started by a reference message with bit Next_is_Gap = 1 e.g. gaps are initiated by the current time master.

The current time master has two options to initiate a gap. A gap can be initiated under software control when the application program writes FDCAN_TTOCN.NIG = 1. The Next_is_Gap bit is transmitted as 1 with the next reference message. A gap can also be initiated under hardware control when the application program enables the event trigger input pin fdcan_evt by writing FDCAN_TTOCN.GCS = 1. When a reference message is started and FDCAN_TTOCN.GCS is set, a HIGH level at event trigger pin fdcan_evt will set Next_is_Gap = 1.

As soon as that reference message is completed, the FDCAN_TTOST.WFE bit will announce the gap to the time master as well as to the time slaves. The current basic cycle will continue until its last time window. The time after the last time window is the gap time.

For the actual time master and the potential time masters, FDCAN_TTOST.GSI is set when the last basic cycle has finished and the gap time starts. In nodes that are time slaves, bit FDCAN_TTOST.GSI will remain at 0.

When a potential time master is in synchronization state In_Gap (FDCAN_TTOST.SYS = 10), it has four options to intentionally finish a gap:

1. Under software control by writing FDCAN_TTOCN.FGP = 1.
2. Under hardware control (FDCAN_TTOCN.GCS = 1) an edge from HIGH to LOW at the event-trigger input pin fdcan_evt sets FDCAN_TTOCN.FGP and restarts the schedule.
3. The third option is a time-triggered restart. When FDCAN_TTOCN.TMG = 1, the next register time mark interrupt (FDCAN_TTIR.RTMI = 1) will set FDCAN_TTOCN.FGP and start the reference message.
4. Finally any potential time master will finish a gap when it reaches its Tx_Ref_Trigger_Gap, assuming that the event to synchronize on did not occur in time.

None of these options can cause a basic cycle to be interrupted with a reference message.

Setting of FDCAN_TTOCN.FGP after the gap time begins starts the transmission of a reference message immediately and thereby synchronizes the message schedule. When FDCAN_TTOCN.FGP is set before the gap time has started (while the basic cycle is still in progress), the next reference message is started at the end of the basic cycle, at the Tx_Ref_Trigger – there is no gap time in the message schedule.

In strictly time-triggered operation, bit Next_is_Gap = 1 in the reference message is ignored, as well as the event-trigger input pin fdcan_evt and the bits FDCAN_TTOCN.NIG, FDCAN_TTOCN.FGP, and FDCAN_TTOCN.TMG.

61.4.11 Stop watch

The stop watch function enables capturing of FDCAN internal time values (local time, cycle time, or global time) triggered by an external event.

To enable the stop watch function, the application program first has to define local time, cycle time, or global time as stop watch source via FDCAN_TTOCN.SWS. When FDCAN_TTOCN.SWS is different from 00 and TT interrupt register flag FDCAN_TTIR.SWE is 0, the actual value of the time selected by FDCAN_TTTOCN.SWS is copied into FDCAN_TTCPT.SWV on the next rising / falling edge (as configured via FDCAN_TTOCN.SWP) on stop watch trigger pin fdcan_swt. This will set interrupt flag FDCAN_TTIR.SWE. After the application program has read FDCAN_TTCPT.SWV, it may enable the next stop watch event by resetting FDCAN_TTIR.SWE to 0.

61.4.12 Local time, cycle time, global time, and external clock synchronization

There are two possible levels in time-triggered CAN:

1. Level 1 only provides time-triggered operation using cycle time.
2. Level 2 additionally provides increased synchronization quality, global time and external clock synchronization. In both levels, all timing features are based on a local time base - the local time.

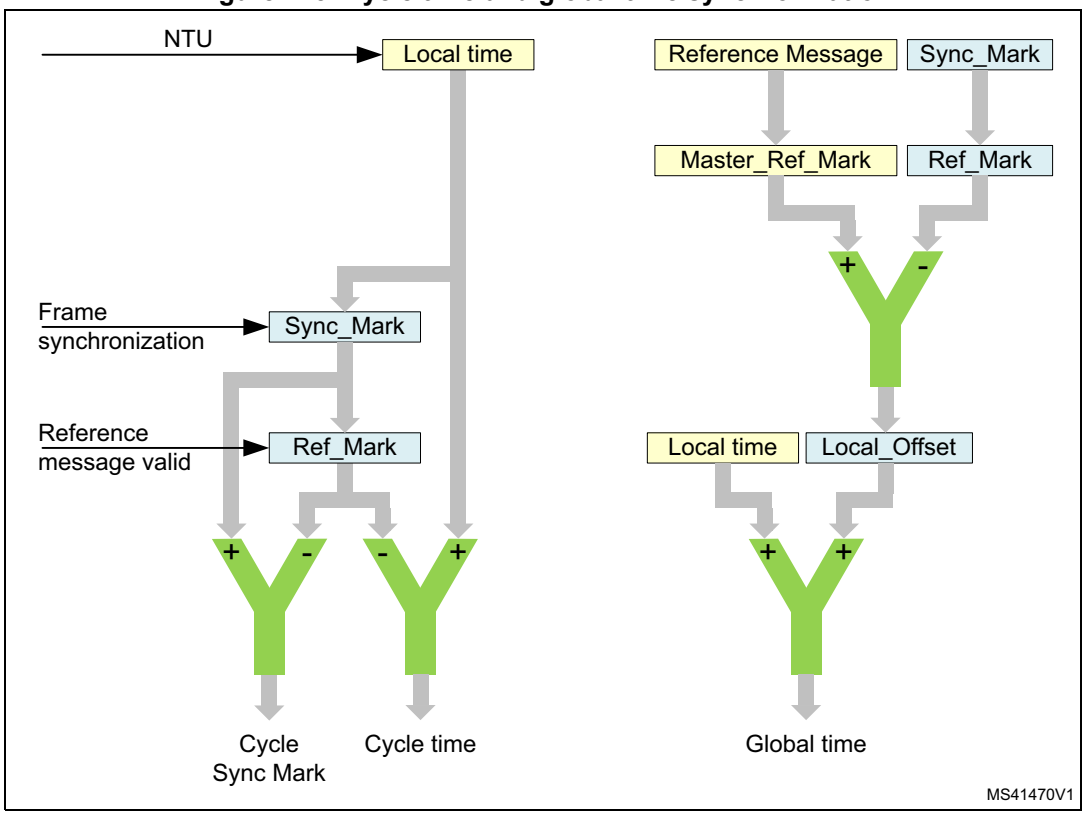
The local time is a 16-bit cyclic counter, it is incremented once each NTU. Internally the NTU is represented by a 3-bit counter which can be regarded as a fractional part (three binary digits) of the local time. Generally, the 3-bit NTU counter is incremented eight times each NTU. If the length of the NTU is shorter than eight CAN clock periods (as may be configured in level 1, or as a result of clock calibration in level 2), the length of the NTU fraction is adapted, and the NTU counter is incremented only four times each NTU.

Figure 775 describes the synchronization of the cycle time and global time, performed in the same manner by all FDCAN nodes, including the time master. Any message received or transmitted invokes a capture of the local time taken at the message is frame

synchronization event. This frame synchronization event occurs at the sample point of each start of frame (SoF) bit and causes the local time to be stored as Sync_Mark. Sync_Marks and Ref_Marks are captured including the 3-bit fractional part.

Whenever a valid reference message is transmitted or received, the internal Ref_Mark is updated from the Sync_Mark. The difference between Ref_Mark and Sync_Mark is the cycle sync mark (cycle sync mark = Sync_Mark - Ref_Mark) stored in register FDCAN_TTCSM. The most significant 16 bits of the difference between Ref_Mark and the actual value of the local time is the cycle time (cycle time = local time - Ref_Mark).

Figure 775. Cycle time and global time synchronization



The cycle time that can be read from FDCAN_TTCTC.CT is the difference of the node local time and Ref_Mark, both synchronized into the APB clock domain and truncated to 16 bit.

The global time exists for TTCAN level 0 and level 2 only, in level 1 it is invalid. The node view of the global time is the local image of the global time in (local) NTUs. After configuration, a potential time master will use its own local time as global time. The time master establishes its own local time as global time by transmitting its own Ref_Marks as Master_Ref_Marks in the reference message (bytes 3 and 4). The global time that can be read from FDCAN_TTLGT.GT is the sum of the node local time and its local offset, both synchronized into the APB clock domain and truncated to 16 bit. The fractional part is used for clock synchronization only.

A node that receives a reference message calculates its local offset to the global time by comparing its local Ref_Mark with the received Master_Ref_Mark (see *Figure 776*). The node view of the global time is local time plus local offset. In a potential time master that has never received another time master reference message, Local_Offset is 0. When a node becomes the current time master after first having received other reference messages,

Local_Offset is frozen at its last value. In the time receiving nodes, Local_Offset may be subject to small adjustments, due to clock drift, when another node becomes time master, or when there is a global time discontinuity, signaled by Disc_Bit in the reference message. With the exception of global time discontinuity, the global time provided to the application program by register FDCAN_TTLGT is smoothed by a low-pass filtering to have a continuous monotonic value.

Figure 776. TTCAN level 0 and level 2 drift compensation

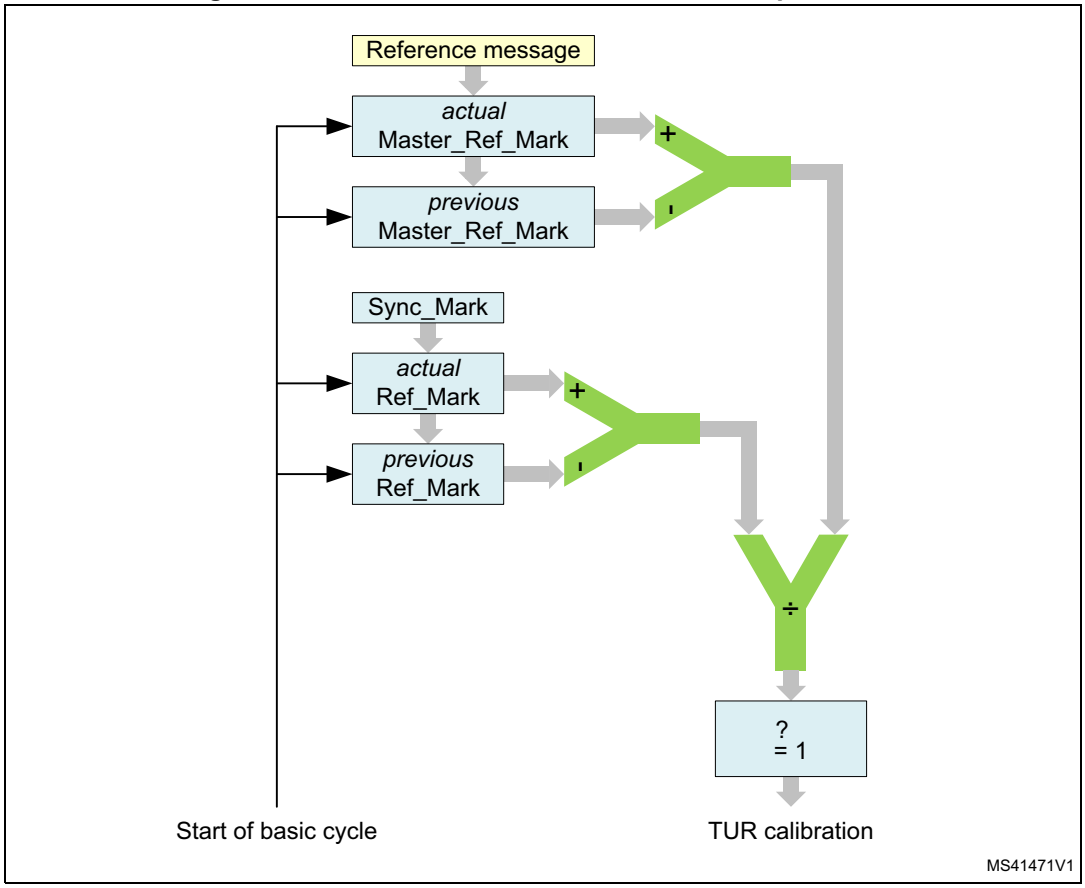


Figure 776 describes how in TTCAN levels 0 and 2 each time receiving node compensates the drift between its own local clock and the time master clock by comparing the length of a basic cycle in local time and in global time. If there is a difference between the two values and the Disc_Bit in the reference message is not set, a new value for FDCAN_TURNA.NAV is calculated. If the synchronization deviation SD = | NC - FDCAN_TURNA.NAV | ≤ SDL (synchronization deviation limit), the new value for FDCAN_TURNA.NAV takes effect. Else the automatic drift compensation is suspended.

In TTCAN level 0 and level 2, FDCAN_TTOST.QCS indicates whether the automatic drift compensation is active or suspended. In TTCAN level 1, FDCAN_TOST.QCS is always 1.

The current time master may synchronize its local clock speed and the global time phase to an external clock source. This is enabled by bit FDCAN_TTOCF.EECS.

The stop watch function (see *Section 61.4.11*) may be used to measure the difference in clock speed between the local clock and the external clock. The local clock speed is adjusted by first writing the newly calculated numerator configuration low to

FDCAN_TURCF.NCL (FDCAN_TURCF.DC cannot be updated during operation). The new value takes effect by writing FDCAN_TTOCN.ECS to 1.

The global time phase is adjusted by first writing the phase offset into the TT global time Preset register FDCAN_TTGTP. The new value takes effect by writing FDCAN_TTOCN.SGT to 1. The first reference message transmitted after the global time phase adjustment will have the Disc_Bit set to 1.

FDCAN_TTOST.QGTP shows whether the node global time is in phase with the time master global time. FDCAN_TTOST.QGTP is permanently 0 in TTCAN level 1 and when the synchronization deviation limit is exceeded in TTCAN level 0, 2 (FDCAN_TTOST.QCS = 0). It is temporarily 0 while the global time is low-pass filtered to supply the application with a continuous monotonic value. There is no low-pass filtering when the last reference message contained a Disc_Bit = 1 or when FDCAN_TTOST.QCS = 0.

61.4.13 TTCAN error level

The ISO 11898-4 specifies four levels of error severity:

1. S0 - No error
2. S1 - Warning - Only notification of application, reaction application-specific.
3. S2 error - Notification of application. All transmissions in exclusive or arbitrating time windows are disabled (i.e. no data or remote frames may be started). Potential time masters still transmit reference messages with the reference trigger offset FDCAN_TTOST.RTO set to the maximum value of 127.
4. S3 - Severe error - Notification of application. All CAN bus operations are stopped, i.e. transmission of dominant bits is not allowed, and FDCAN_CCCR.MON is set. The S3 error condition remains active until the application updates the configuration (set FDCAN_CCCR.CCE).

If several errors are detected at the same time, the highest severity prevails. When an error is detected, the application is notified by FDCAN_TTIR.ELC. The error level is monitored by FDCAN_TTOST.EL.

The TTCAN signals the following error conditions as required by ISO 11898-4:

- Config_error (S3)
  - Sets error level FDCAN_TTOST.EL to 11 when a merged arbitrating time window is not properly closed or when there is a Tx_Trigger with a time mark beyond the Tx_Ref_Trigger.
- Watch_Trigger_Reached (S3)
  - Sets error level FDCAN_TTOST.EL to 11 when a watch trigger was reached because the reference message is missing.
- Application_Watchdog (S3)
  - Sets error level FDCAN_TTOST.EL to 11 when the application failed to serve the application watchdog.The application watchdog is configured via FDCAN_TTOCF.AWL. It is served by reading register FDCAN_TTOST. When the watchdog is not served in time, bit FDCAN_TTOST.AWE and interrupt flag

FDCAN_TTIR.AW are set, all FDCAN communication is stopped, and the FDCAN is set into bus monitoring mode (FDCAN_CCCR.MON set to 1).

- CAN_Bus_Off (S3)
  - Entering CAN_Bus_Off state sets error level FDCAN_TTOST.EL to 11. CAN_Bus_Off state is signaled by FDCAN_PSR.BO = 1 and FDCAN_CCCR.INIT = 1.
- Scheduling_Error_2 (S2)
  - Sets error level FDCAN_TTOST.EL to 10 if the MSC of one Tx_Trigger has reached 7. In addition interrupt flag FDCAN_TTIR.SE2 is set. The error level FDCAN_TTOST.EL is reset to 00 at the beginning of a matrix cycle when no Tx_Trigger has an MSC of 7 in the preceding matrix cycle.
- Tx_Overflow (S2)
  - Sets error level FDCAN_TTOST.EL to 10 when the Tx count is equal to or higher than the expected number of Tx_T riggers FDCAN_TTMLM.ENTT and a Tx_Trigger event occurs. In addition interrupt flag FDCAN_TTIR.TXO is set. The error level FDCAN_TTOST.EL is reset to 00 when the Tx count is no more than FDCAN_TTMLM.ENTT at the start of a new matrix cycle.
- Scheduling_Error_1 (S1)
  - Sets error level FDCAN_TTOST.EL to 01 if within one matrix cycle the difference between the maximum MSC and the minimum MSC for all trigger memory elements (of exclusive time windows) is larger than two, or if one of the MSCs of an exclusive Rx_Trigger has reached seven. In addition interrupt flag FDCAN_TTIR.SE1 is set. If within one matrix cycle none of these conditions is valid, the error level FDCAN_TTOST.EL is reset to 00.
- Tx_Underflow (S1)
  - Sets error level FDCAN_TTOST.EL to 01 when the Tx count is less than the expected number of Tx_Triggers FDCAN_TTMLM.ENTT at the start of a new matrix cycle. In addition interrupt flag FDCAN_TTIR.TXU is set. The error level FDCAN_TTOST.EL is reset to 00 when the Tx count is at least FDCAN_TTMLM.ENTT at the start of a new matrix cycle.

61.4.14 TTCAN message handling

Reference message

For potential time masters the identifier of the reference message is configured via FDCAN_TTRMC.RID. No dedicated Tx buffer is required for transmission of the reference message. When a reference message is transmitted, the first data byte for TTCAN level 1 (that is, the first four data bytes for TTCAN level 0 and the first four data bytes for TTCAN level 2) is provided by the FSE.

In case the reference message Payload select FDCAN_TTRMC.RMPS is set, the rest of the reference message payload (level 1: bytes 2-8, level 0, 2: bytes 5-6) is taken from Tx buffer 0. In this case the data length DLC code from message buffer 0 is used.

Table 514. Number of data bytes transmitted with a reference message

FDCAN_TTRMC.RMPS	FDCAN_TXBRP.TRP0	Level 0	Level 1	Level 2
0	0	4	1	4
0	1	4	1	4

Table 514. Number of data bytes transmitted with a reference message (continued)

FDCAN_TTRMC.RMPS	FDCAN_TXBRP.TRP0	Level 0	Level 1	Level 2
1	0	4	1	4
1	1	4 + MBO	1 + MBO	4 + MBO

To send additional payload with the reference message in level 1 a DLC > 1 has to be configured, for level 0 and level 2 a DLC > 4 is required. In addition the transmission request pending bit FDCAN_TXBRP.TRP0 of message buffer 0 must be set (see *Table 514*). In case bit FDCAN_TXBRP.TRP0 is not set when a reference message is started, the reference message is transmitted with the data bytes supplied by the FSE only.

For acceptance filtering of reference messages the reference identifier FDCAN_TTRMC.RID is used.

Message reception

Message reception is done via the two Rx FIFOs in the same way as for event-driven CAN communication (see *Rx handler*).

The message status count MSC is part of the corresponding trigger memory element and has to be initialized to 0 during configuration. It is updated while the TTCAN is in synchronization states In_Gap or In_Schedule. The update happens at the message Rx_Trigger. At this point in time it is checked at which acceptance filter element the latest message received in this basic cycle had matched. The matching filter number is stored as the acceptance filter result. If this is the same the filter number as defined in this trigger memory element, the MSC is decremented by one. If the acceptance filter result is not the same filter number as defined for this filter element, or if the acceptance filter result is cleared, the MSC is incremented by one. At each Rx_Trigger and at each start of cycle, the last acceptance filter result is cleared.

The time mark of an Rx_Trigger should be set to a value where it is ensured that reception and acceptance filtering for the targeted message has completed. This has to take into consideration the RAM access time and the order of the filter list. It is recommended, that filters which are used for Rx_Triggers are placed at the beginning of the filter list. It is not recommended to use an Rx_Trigger for the reference message.

Message transmission

For time-triggered message transmission the TTCAN supplies 32 dedicated Tx buffers (see *Transmit pause*). A Tx FIFO or Tx queue is not available when the FDCAN is configured for time-triggered operation (FDCAN_TTOCF.OM = 01 or 10).

Each Tx_Trigger in the trigger memory points to a particular Tx buffer containing a specific message. There may be more than one Tx_Trigger for a given Tx buffer if that Tx buffer contains a message that is to be transmitted more than once in a basic cycle or matrix cycle.

The application program has to update the data regularly and on time, synchronized to the cycle time. The user is responsible that no partially updated messages are transmitted. To assure this the user has to proceed in the following way:

Tx_Trigger_Single / Tx_Trigger_Merged / Tx_Trigger_Arbitration

- Check whether the previous transmission has completed by reading FDCAN_TXBTO
- Update the Tx buffer configuration and/or payload
- Issue an add request to set the Tx buffer request pending bit

Tx_Trigger_Continous

- Issue a cancellation request to reset the Tx buffer request pending bit
- Check whether the cancellation has finished by reading FDCAN_TXBCF
- Update Tx buffer configuration and/or payload
- Issue an add request to set the Tx buffer request pending bit

The message MSC stored with the corresponding Tx_Trigger provides information on the success of the transmission.

The MSC is incremented by one when the transmission could not be started because the CAN bus was not idle within the corresponding transmit enable window or when the message was started and could not be completed successfully. The MSC is decremented by one when the message was transmitted successfully or when the message could have been started within its transmit enable window but was not started because transmission was disabled (TTCAN in error level S2 or user has disabled this particular message).

The Tx buffers may be managed dynamically, i.e. several messages with different identifiers may share the same Tx buffer element. In this case the user must ensure that no transmission request is pending for the Tx buffer element to be reconfigured by checking FDCAN_TXBRP.

If a Tx buffer with pending transmission request should be updated, the user must first issue a cancellation request and check whether the cancellation has completed by reading FDCAN_TXBCF before it starts updating.

The Tx handler will transfer a message from the message RAM to its intermediate output buffer at the trigger element which becomes active immediately before the Tx_Trigger element which defines the beginning of the transmit window. During and after the transfer time the transmit message may not be updated and its FDCAN_TXBRP bit may not be changed. To control this transfer time, an additional trigger element may be placed before the Tx_Trigger. This may be example of a Time_Base_Trigger which need not cause any other action. The difference in time marks between the Tx_Trigger and the preceding trigger has to be large enough to guarantee that the Tx handler can read four words from the message RAM even at high RAM access load from other modules.

Transmission in exclusive time windows

A transmission is started time-triggered when the cycle time reaches the time mark of a Tx_Trigger_Single or Tx_Trigger_Continuous. There is no arbitration on the bus with messages from other nodes. The MSC is updated according the result of the transmission attempt. After successful transmission started by a Tx_Trigger_Single the respective Tx buffer request pending bit is reset. After successful transmission started by a Tx_Trigger_Continuous the respective Tx buffer request pending remains set. When the transmission was not successful due to disturbances, it is repeated next time (one of) its Tx_Trigger(s) become(s) active.

Transmission in arbitrating time windows

A transmission is started time-triggered when the cycle time reaches the time mark of a Tx_Trigger_Arbitration. Several nodes may start to transmit at the same time. In this case the message has to arbitrate with the messages from other nodes. The MSC is not updated. When the transmission was not successful (lost arbitration or disturbance), it is repeated next time (one of) its Tx_Trigger(s) become(s) active.

Transmission in merged arbitrating time windows

The purpose of a merged arbitrating time window is, to enable multiple nodes to send a limited number of frames which are transmitted in immediate sequence, the order given by CAN arbitration. It is not intended for burst transmission by a node. Since the node does not have exclusive access within this time window, it may happen that not all requested transmissions are successful.

Messages which have lost arbitration or were disturbed by an error, may be re-transmitted inside the same merged arbitrating time window. The re-transmission will not be started if the corresponding transmission request pending flag was reset by a successful Tx cancellation.

In single transmit windows, the Tx handler transmits the message indicated by the message number of the trigger element. In merged arbitrating time windows, it can handle up to three message numbers from the trigger list. Their transmission is attempted in the sequence defined by the trigger list. If the time mark of a fourth message is reached before the first is transmitted (or canceled by the user), the fourth request is ignored.

The transmission inside a merged arbitrating time window is not time-triggered. The transmission of a message may start before its time mark, or after the time mark if the bus was not idle.

The messages transmitted by a specific node inside a merged arbitrating time window are started in the order of their Tx_Triggers, so a message with low CAN priority may prevent the successful transmission of a following message with higher priority, if their is compelling bus traffic. This has to be considered for the configuration of the trigger list. Time_Base_Triggers may be placed between consecutive Tx_Triggers to define the time until the data of the corresponding Tx buffer needs to be updated.

61.4.15 TTCAN interrupt and error handling

The TT interrupt register FDCAN_TTIR consists of four segments. Each interrupt can be enabled separately by the corresponding bit in the TT interrupt enable register FDCAN_TTIE. The flags remain set until the user clears them. A flag is cleared by writing a 1 to the corresponding bit position.

The first segment consists of flags CER, AW, WT, and IWT. Each flag indicates a fatal error condition where the CAN communication is stopped. With the exception of IWT, these error conditions require a re-configuration of the FDCAN module before the communication can be restarted.

The second segment consists of flags ELC, SE1, SE2, TXO, TXU, and GTE. Each flag indicates an error condition where the CAN communication is disturbed. If they are caused by a transient failure, e.g. by disturbances on the CAN bus, they are handled by the FDCAN protocol failure handling and do not require intervention by the application program.

The third segment consists of flags GTD, GTW, SWE, TTMI, and RTMI. The first two flags are controlled by global time events (level 0, 2 only) that require a reaction by the application

program. With a stop watch event triggered by a rising edge on pin fdcan_swt internal time values are captured. The trigger time mark interrupt notifies the application that a specific Time_Base_Trigger is reached. The register time mark interrupt signals that the time referenced by FDCAN_TTOCN.TMC (cycle, local, or global) is equal to the time mark FDCAN_TTTMK.TM. It can also be used to finish a gap.

The fourth segment consists of flags SOG, CSM, SMC, and SBC. These flags provide a means to synchronize the application program to the communication schedule.

61.4.16 Level 0

TTCAN level 0 is not part of ISO11898-4. This operation mode makes the hardware, that in TTCAN level 2 maintains the calibrated global time base, also available for event-driven CAN according to ISO11898-1.

Level 0 operation is configured via FDCAN_TTOCF.OM = 11. In this mode the FDCAN operates in event driven CAN communication, there is no fixed schedule, the configuration of FDCAN_TTOCF.GEN is ignored. External event-synchronized operation is not available in level 0. A synchronized time base is maintained by transmission of reference messages.

In level 0 the trigger memory is not active and therefore needs not to be configured. The time mark interrupt flag (FDCAN_TTIR.TTMI) is set when the cycle time has reached FDCAN_TTOCF.IRTO ´ 0x200, it reminds the user to set a transmission request for message buffer 0. The Watch_Trigger interrupt flag (FDCAN_TTIR.WT) is set when the cycle time has reached 0xFF00. These values were chosen to have enough margin for a stable clock calibration. There are no further TT-error-checks.

Register time mark interrupts (FDCAN_TTIR.RTMI) are also possible.

The reference message is configured as for level 2 operation. Received reference messages are recognized by the identifier configured in register FDCAN_TTRMC. For the transmission of reference messages only message buffer 0 may be used. The node transmits reference messages any time the user sets a transmission request for message buffer 0, there is no reference trigger offset.

Level 0 operation is configured via:

- FDCAN_TTRMC
- FDCAN_TTOCF except EVTP, AWL, GEN
- FDCAN_TTMLM except ENTT, TXEW
- FDCAN_TURCF

Level 0 operation is controlled via:

- FDCAN_TTOCN except NIG, TMG, FGP, GCS, TTMIE
- FDCAN_TTGTP
- FDCAN_TTTMK
- FDCAN_TTIR excluding bits CER, AW, IWT SE2, SE1, TXO, TXU, SOG (no function)
- FDCAN_TTIR the following bits have changed function
  - TTMI not defined by trigger memory - activated at cycle time FDCAN_TTOCF.IRTO 0x200
  - WT not defined by trigger memory - activated at cycle time 0xFF00

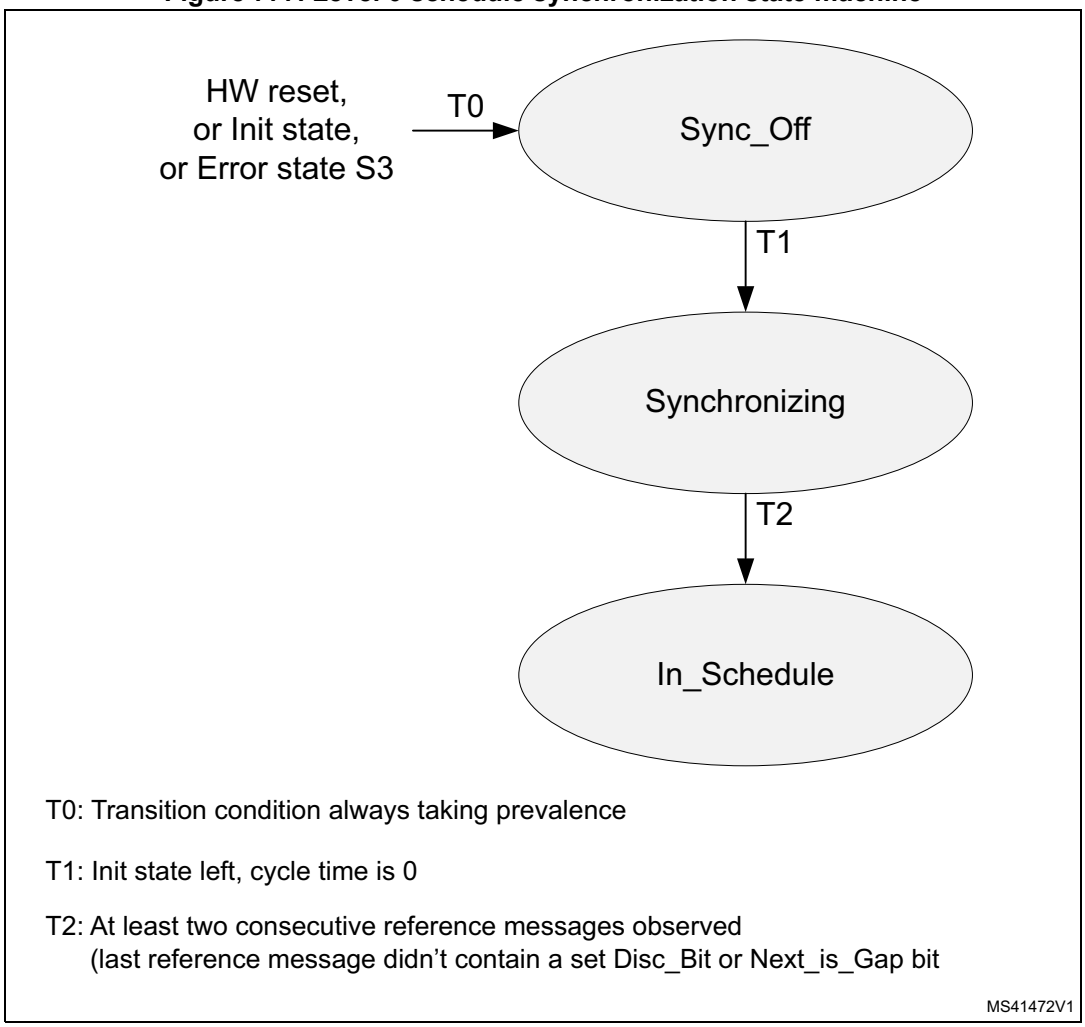
Level 0 operation is signaled via:

- TTOST excluding bits AWE, WFE, GSI, GFI, RTO (no function)

Synchronizing

Figure 777 describes the states and the state transitions in TTCAN level 0 operation. level 0 has no In_Gap state.

Figure 777. Level 0 schedule synchronization state machine



Handling of error levels

During level 0 operation only the following error conditions may occur:

- Watch_Trigger_Reached (S3), reached cycle time 0xFF00
- CAN_Bus_Off (S3)

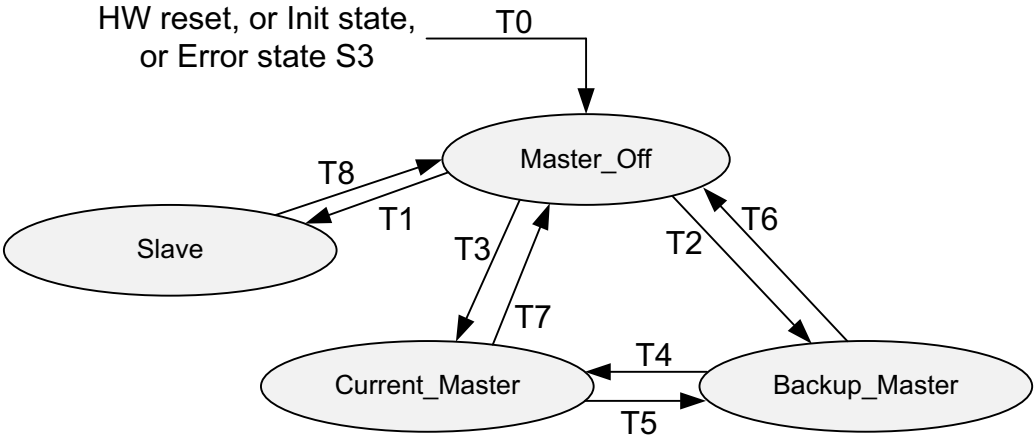
Since no S1 and S2 errors are possible, the error level can only switch between S0 (No error) and S3 (Severe error). In TTCAN level 0 an S3 error is handled differently. When error level S3 is reached, both FDCAN_TTOST.SYS and FDCAN_TTOST.MS are reset, and interrupt flags FDCAN_TTIR.GTE and FDCAN_TTIR.GTD are set.

When error level S3 (FDCAN_TTOST.EL = 11) is entered, bus monitoring mode is (contrary to TTCAN level 1 and level 2) not entered. S3 error level is left automatically after transmission (time master) or reception (time slave) of the next reference message.

Master slave relation

Figure 778 describes the master slave relation in TTCAN level 0. In case of an S3 error the FDCAN returns to state Master_Off.

Figure 778. Level 0 master to slave relation



T0: Transition condition, always taking prevalence

T1: Reference message observed when not potential time master

T2: Reference message observed with master priority different from own master priority, Error state ≠ S3

T3: Reference message observed with master priority equal to own master priority, Error state ≠ S3

T4: Reference message observed with own master priority

T5: Reference message observed with master priority higher than own master priority

T6: Error state S3

T7: Error state S3

T8: Error state S3

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61.4.17 Synchronization to external time schedule

This feature can be used to synchronize the phase of the FDCAN schedule to an external schedule (e.g. that of a second TTCAN network or FlexRay network). It is applicable only when the FDCAN is current time master (FDCAN_TTOST.MS = 11).

External synchronization is controlled by event trigger input pin fdcan_evt. If bit FDCAN_TTOCN.ESCN is set, a rising edge at event trigger pin fdcan_evt the FDCAN compares its actual cycle time with the target phase value configured by FDCAN_TTGTP.CTP.

Before setting FDCAN_TTOCN.ESCN the user has to adapt the phases of the two time schedules e.g. by using the FDCAN gap control (see *Section 61.4.10*). When the user sets FDCAN_TTOCN.ESCN, FDCAN_TTOSTSPL is set.

If the difference between the cycle time and the target phase value FDCAN_TTGTP.CTP at the rising edge at event trigger pin fdcan_evt is greater than 9 NTU, the phase lock bit FDCAN_TTOST.SPL is reset, and interrupt flag FDCAN_TTIR.CSM is set.

FDCAN_TTOST.SPL is also reset (and FDCAN_TTIR.CSM is set), when another node becomes time master.

If both FDCAN_TTOST.SPL and FDCAN_TTOCN.ESCN are set, and if the difference between the cycle time and the target phase value FDCAN_TTGTP.CTP at the rising edge at event trigger pin fdcan_evt is lower or equal to nine NTU, the phase lock bit FDCAN_TTOST.SPL remains set, and the measured difference is used as reference trigger offset value to adjust the phase at the next transmitted reference message.

Note: The rising edge detection at event trigger pin fdcan_evt is enabled with the start of each basic cycle. The first rising edge triggers the compare of the actual cycle time with FDCAN_*TTGTP.CTP. All further edges until the beginning of the next basic cycle are ignored.*

61.4.18 FDCAN Rx buffer and FIFO element

Up to 64 Rx buffers and two Rx FIFOs can be configured in the message RAM. Each Rx FIFO section can be configured to store up to 64 received messages. The structure of a Rx buffer / FIFO element is shown in *Table 515*, the description is provided in *Table 516*.

Table 515. Rx buffer and FIFO element

Bit	31			24	23			16	15	8	7	0
R0	ESI	XTD	RTR	ID[28:0]								
R1	ANMF	FIDX[6:0]			Res.	FDF	BRS	DLC[3:0]	RXTS[15:0]			
R2	DB3[7:0]				DB2[7:0]				DB1[7:0]		DB0[7:0]	
R3	DB7[7:0]				DB6[7:0]				DB5[7:0]		DB4[7:0]	
⋮	⋮				⋮				⋮			
Rn	DBm[7:0]				DBm-1[7:0]				DBm-2[7:0]		DBm-3[7:0]	

The element size can be configured for storage of CAN FD messages with up to 64 bytes data field via register FDCAN_RXESC.

Table 516. Rx buffer and FIFO element description

Field	Description
R0 bit 31 ESI	Error state indicator 0: Transmitting node is error active 1: Transmitting node is error passive
R0 bit 30 XTD	Extended identifier Signals to the user whether the received frame has a standard or extended identifier. 0: 11-bit standard identifier 1: 29-bit extended identifier
R0 bit 29 RTR	Remote transmission request Signals to the user whether the received frame is a data frame or a remote frame. 0: Received frame is a data frame 1: Received frame is a remote frame

Table 516. Rx buffer and FIFO element description (continued)

Field	Description
R0 bits 28:0 ID[28:0]	Identifier Standard or extended identifier depending on bit XTD. A standard identifier is stored into ID[28:18].
R1 bit 31 ANMF	Accepted non-matching frame Acceptance of non-matching frames may be enabled via FDCAN_GFC.ANFS and FDCAN_GFC.ANFE. 0: Received frame matching filter index FIDX 1: Received frame did not match any Rx filter element
R1 bits 30:24 FIDX[6:0]	Filter index 0-127 = index of matching Rx acceptance filter element (invalid if ANMF = 1). Range is 0 to FDCAN_SIDFC.LSS. - 1 or FDCAN_XIDFC.LSE. - 1.
R1 bit 21 FDF	FD Format 0: Standard frame format 1: FDCAN frame format (new DLC-coding and CRC)
R1 bit 20 BRS	Bitrate Switch 0: Frame received without bitrate switching 1: Frame received with bitrate switching
R1 bits 19:16 DLC[3:0]	Data length code 0-8: Classic CAN + CAN FD: received frame has 0-8 data bytes 9-15: Classic CAN: received frame has 8 data bytes 9-15: CAN FD: received frame has 12/16/20/24/32/48/64 data bytes
R1 bits 15:0 RXTS[15:0]	Rx timestamp Timestamp counter value captured on start of frame reception. Resolution depending on configuration of the timestamp counter prescaler FDCAN_TSCC.TCP.
R2 bits 31:24 DB3[7:0]	Data Byte 3
R2 bits 23:16 DB2[7:0]	Data Byte 2
R2 bits 15:8 DB1[7:0]	Data Byte 1
R2 bits 7:0 DB0[7:0]	Data Byte 0
R3 bits 31:24 DB7[7:0]	Data Byte 7
R3 bits 23:16 DB6[7:0]	Data Byte 6
R3 bits 15:8 DB5[7:0]	Data Byte 5
R3 bits 7:0 DB4[7:0]	Data Byte 4
⋮	⋮

Table 516. Rx buffer and FIFO element description (continued)

Field	Description
Rn bits 31:24 DBm[7:0]	Data Byte m
Rn bits 23:16 DBm-1[7:0]	Data Byte m-1
Rn bits 15:8 DBm-2[7:0]	Data Byte m-2
Rn bits 7:0 DBm-3[7:0]	Data Byte m-3

61.4.19 FDCAN Tx buffer element

The Tx buffers section can be configured to hold dedicated Tx buffers as well as a Tx FIFO / Tx queue. In case that the Tx buffers section is shared by dedicated Tx buffers and a Tx FIFO / Tx queue, the dedicated Tx buffers start at the beginning of the Tx buffers section followed by the buffers assigned to the Tx FIFO or Tx queue. The Tx handler distinguishes between dedicated Tx buffers and Tx FIFO / Tx queue by evaluating the Tx buffer configuration FDCAN_TXBC.TFQS and FDCAN_TXBC.NDTB. The element size can be configured for storage of CAN FD messages with up to 64 bytes data field via register FDCAN_TXESC.

Table 517. Tx buffer and FIFO element

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
T0	ESI	XTD	RTR	ID[28:0]																												
T1	MM[7:0]								EFC	Res.	FDF	BPS	DLC[3:0]				Reserved															
T2	DB3[7:0]								DB2[7:0]								DB1[7:0]								DB0[7:0]							
T3	DB7[7:0]								DB6[7:0]								DB5[7:0]								DB4[7:0]							
⋮	⋮								⋮								⋮															
Tn	DBm[7:0]								DBm-1[7:0]								DBm-2[7:0]								DBm-3[7:0]							

Table 518. Tx buffer element description

Field	Description
T0 bit 31 ESI(1)	Error state indicator 0: ESI bit in CAN FD format depends only on error passive flag 1: ESI bit in CAN FD format transmitted recessive
T0 bit 30 XTD	Extended identifier 0: 11-bit standard identifier 1: 29-bit extended identifier
T0 bit 29 RTR(2)	Remote transmission request 0: Transmit data frame 1: Transmit remote frame

Table 518. Tx buffer element description (continued)

Field	Description
T0 bits 28:0 ID[28:0]	Identifier Standard or extended identifier depending on bit XTD. A standard identifier has to be written to ID[28:18].
T1 bits 31:24 MM[7:0]	Message marker Written by CPU during Tx buffer configuration. Copied into Tx event FIFO element for identification of Tx message status.
T1 bit 23 EFC	Event FIFO control 0: Don’t store Tx events 1: Store Tx events
T1 bit 21 FDF	FD Format 0: Frame transmitted in classic CAN format 1: Frame transmitted in CAN FD format
T1 bit 20 BRS(3)	Bitrate switching 0: CAN FD frames transmitted without bitrate switching 1: CAN FD frames transmitted with bitrate switching
T1 bits 19:16 DLC[3:0]	Data length code 0 - 8: Classic CAN + CAN FD: received frame has 0-8 data bytes 9-15: Classic CAN: received frame has 8 data bytes 9 - 15: CAN FD: received frame has 12/16/20/24/32/48/64 data bytes
T2 bits 31:24 DB3[7:0]	Data Byte 3
T2 bits 23:16 DB2[7:0]	Data Byte 2
T2 bits 15:8 DB1[7:0]	Data Byte 1
T2 bits 7:0 DB0[7:0]	Data Byte 0
T3 bits 31:24 DB7[7:0]	Data Byte 7
T3 bits 23:16 DB6[7:0]	Data Byte 6
T3 bits 15:8 DB5[7:0]	Data Byte 5
T3 bits 7:0 DB4[7:0]	Data Byte 4
⋮	⋮
Tn bits 31:24 DBm[7:0]	Data Byte m
Tn bits 23:16 DBm-1[7:0]	Data Byte m-1

Table 518. Tx buffer element description (continued)

Field	Description
Tn bits 15:8 DBm-2[7:0]	Data Byte m-2
Tn bits 7:0 DBm-3[7:0]	Data Byte m-3

1. The ESI bit of the transmit buffer is OR-ed with the error passive flag to decide the value of the ESI bit in the transmitted FD frame. As required by the CAN FD protocol specification, an error active node may optionally transmit the ESI bit recessive, but an error passive node will always transmit the ESI bit recessive.
2. When RTR = 1, the FDCAN transmits a remote frame according to ISO11898-1, even if FDCAN_CCCR.FDOE enables the transmission in CAN FD format.
3. Bits ESI, FDF, and BRS are only evaluated when CAN FD operation is enabled FDCAN_CCCR.FDOE = 1. Bit BRS is only evaluated when in addition FDCAN_CCCR.BRSE = 1.

61.4.20 FDCAN Tx event FIFO element

Each element stores information about transmitted messages. By reading the Tx event FIFO the user gets this information in the order the messages were transmitted. Status information about the Tx event FIFO can be obtained from register FDCAN_TXEFS.

Table 519. Tx Event FIFO element

Bit	31			24	23					16	15	8	7	0
E0	ESI	XTD	RTR		ID[28:0]									
E1	MM[7:0]				ET[1:0]		EDL	BRS	DLC[3:0]		TXTS[15:0]			

Table 520. Tx Event FIFO element description

Field	Description
E0 bit 31 ESI	Error state indicator – 0: Transmitting node is error active – 1: Transmitting node is error passive
E0 bit 30 XTD	Extended Identifier – 0: 11-bit standard identifier – 1: 29-bit extended identifier
E0 bit 29 RTR	Remote transmission request – 0: Transmit data frame – 1: Transmit remote frame
E0 bits 28:0 ID[28:0]	Identifier Standard or extended identifier depending on bit XTD. A standard identifier has to be written to ID[28:18].
E1 bits 31:24 MM[7:0]	Message marker Copied from Tx buffer into Tx event FIFO element for identification of Tx message status.

Table 520. Tx Event FIFO element description (continued)

Field	Description
E1 bits 23:22 EFC	Event type – 00: Reserved – 01: Tx event – 10: Transmission in spite of cancellation (always set for transmissions in DAR mode) – 11: Reserved
E1 bit 21 EDL	Extended data length – 0: Standard frame format – 1: FDCAN frame format (new DLC-coding and CRC)
E1 bit 20 BRS	Bitrate switching – 0: Frame transmitted without bitrate switching – 1: Frame transmitted with bitrate switching
T1 bits 19:16 DLC[3:0]	Data length code – 0 - 8: Frame with 0-8 data bytes transmitted – 9 - 15: Frame with eight data bytes transmitted
E1 bits 15:0 TXTS[15:0]	Tx timestamp Timestamp counter value captured on start of frame transmission. Resolution depending on configuration of the timestamp counter prescaler FDCAN_TSCC.TCP.

61.4.21 FDCAN standard message ID filter element

Up to 128 filter elements can be configured for 11-bit standard IDs. When accessing a standard message ID filter element, its address is the filter list standard start address FDCAN_SIDFC.FLSSA plus the index of the filter element (0 … 127).

Table 521. Standard message ID filter element

Bit	31		24	23	16	15	8	7	0
S0	SFT[1:0]	SFEC[2:0]		SFID1[10:0]		Res.		SFID2[10:0]	

Table 522. Standard message ID filter element field description

Field		Description
Bit 31:30 SFT[1:0](1)		Standard filter type – 00: Range filter from SFID1 to SFID2 – 01: Dual ID filter for SFID1 or SFID2 – 10: Classic filter: SFID1 = filter, SFID2 = mask – 11: Filter element disabled
Bit 29:27 SFEC[2:0]		Standard filter element configuration All enabled filter elements are used for acceptance filtering of standard frames. Acceptance filtering stops at the first matching enabled filter element or when the end of the filter list is reached. If SFEC = “100”, “101”, or “110” a match sets interrupt flag FDCAN_IR.HPM and, if enabled, an interrupt is generated. In this case register FDCAN_HPMS is updated with the status of the priority match. – 000: Disable filter element – 001: Store in Rx FIFO 0 if filter matches – 010: Store in Rx FIFO 1 if filter matches – 011: Reject ID if filter matches – 100: Set priority if filter matches – 101: Set priority and store in FIFO 0 if filter matches – 110: Set priority and store in FIFO 1 if filter matches – 111: Store into Rx buffer or as debug message, configuration of FDCAN_SFT[1:0] ignored
Bits 26:16 SFID1[10:0]		Standard filter ID 1 First ID of standard ID filter element. When filtering for Rx buffers or for debug messages this field defines the ID of a standard message to be stored. The received identifiers must match exactly, no masking mechanism is used.
Bits 15:0	SFID2[15:10]	Standard filter ID 2 This bit field has a different meaning depending on the configuration of SFEC: – SFEC = 001 ... 110 Second ID of standard ID filter element – SFEC = 111 Filter for Rx buffers or for debug messages
	SFID2[10:9]	Decides whether the received message is stored into an Rx buffer or treated as message A, B, or C of the debug message sequence. – 00: Store message into an Rx buffer – 01: Debug message A – 10: Debug message B – 11: Debug message C
	SFID2[8:6]	Is used to control the filter event pins at the Extension Interface. A 1 at the respective bit position enables generation of a pulse at the related filter event pin with the duration of one fdcan_pclk period in case the filter matches. SFID2[8] is used by the calibration unit.
	SFID2[5:0]	Defines the offset to the Rx buffer start address FDCAN_RXBC.RBSA for storage of a matching message.

1. With SFT = “11” the filter element is disabled and the acceptance filtering continues (same behavior as with SFEC = “000”).

Note: In case a reserved value is configured, the filter element is considered disabled.

61.4.22 FDCAN extended message ID filter element

Up to 64 filter elements can be configured for 29-bit extended IDs. When accessing an Extended message ID filter element, its address is the filter list extended start address FDCAN_XIDFC.FLESA plus two times the index of the filter element (0 … 63).

Table 523. Extended message ID filter element

Bit	31	30	29	28	0
F0	EFEC[2:0]			EFID1[28:0]	
F1	EFTI[1:0]		Reserved	EFID2[28:0]	

Table 524. Extended message ID filter element field description

Field	Description
F0 bits 31:29 EFEC[2:0]	Extended filter element configuration All enabled filter elements are used for acceptance filtering of extended frames. Acceptance filtering stops at the first matching enabled filter element or when the end of the filter list is reached. If EFEC = 100, 101, or 110 a match sets interrupt flag FDCAN_IR.HPM and, if enabled, an interrupt is generated. In this case register FDCAN_HPMS is updated with the status of the priority match. – 000: Disable filter element – 001: Store in Rx FIFO 0 if filter matches – 010: Store in Rx FIFO 1 if filter matches – 011: Reject ID if filter matches – 100: Set priority if filter matches – 101: Set priority and store in FIFO 0 if filter matches – 110: Set priority and store in FIFO 1 if filter matches – 111: Store into Rx buffer, configuration of EFT[1:0] ignored
F0 bits 28:0 EFID1[28:0]	Extended filter ID 1 First ID of extended ID filter element. When filtering for Rx buffers or for debug messages this field defines the ID of an extended message to be stored. The received identifiers must match exactly, only FDCAN_XIDAM masking mechanism.
F1 bits 31:30 EFT[1:0]	Extended filter type – 00: Range filter from EF1ID to EF2ID (EF2ID ≥ EF1ID) – 01: Dual ID filter for EF1ID or EF2ID – 10: Classic filter: EF1ID = filter, EF2ID = mask – 11: Range filter from EF1ID to EF2ID (EF2ID ≥ EF1ID), FDCAN_XIDAM mask not applied

Table 524. Extended message ID filter element field description (continued)

Field		Description
F1 bits 28:0	EFID2[10:0]	Extended filter ID 2 This bit field has a different meaning depending on the configuration of EFEC: – SFEC = 001 ... 110 Second ID of extended ID filter element – SFEC = 111 Filter for Rx buffers or for debug messages
	EFID2[10:9]	Decides whether the received message is stored into an Rx buffer or treated as message A, B, or C of the debug message sequence. – 00: Store message into an Rx buffer – 01: Debug message A – 10: Debug message B – 11: Debug message C
	EFID2[8:6]	Is used to control the filter event pins at the Extension Interface. A 1 at the respective bit position enables generation of a pulse at the related filter event pin with the duration of one fdcan_pclk period in case the filter matches. EFID2[8] interface is used by the calibration unit.
	EFID2[5:0]	Defines the offset to the Rx buffer start address FDCAN_RXBC.RBSA for storage of a matching message.

61.4.23 FDCAN trigger memory element

Up to 64 trigger memory elements can be configured. When accessing a trigger memory element, its address is the trigger memory start address FDCAN_TTTMC.TMSA plus the index of the trigger memory element (0 … 63).

Table 525. Trigger memory element

Bit	31 24	23 16	15 8	7 0
T0	TM[15:0]	Res. CC[6:0]	Res. TMIN TMEX	TYPE[3:0]
T1	Res.	FTYPE MNR[6:0]	Res.	MSC[2:0]

Table 526. Trigger memory element description

Field	Description
T0 bits 31:16 TM[15:0]	Time mark Cycle time for which the trigger becomes active.
T0 bit 14:8 CC[6:0]	Cycle code Cycle count for which the trigger is valid. Ignored for trigger types Tx_Ref_Trigger, Tx_Ref_Trigger_Gap, Watch_Trigger, Watch_Trigger_Gap, End_of_List. – 0b000000x valid for all cycles – 0b000001c valid every 2^{nd} cycle at cycle count mod2 = c – 0b00001cc valid every 4^{th} cycle at cycle count mod4 = cc – 0b0001ccc valid every 8^{th} cycle at cycle count mod8 = ccc – 0b001cccc valid every 16^{th} cycle at cycle count mod16 = cccc – 0b01ccccc valid every 32^{nd} cycle at cycle count mod32 = ccccc – 0b1cccccc valid every 64^{th} cycle at cycle count mod64 = cccccc

Table 526. Trigger memory element description (continued)

Field	Description
T0 bit 5 TMIN	Time mark event internal – 0: No action – 1: FDCAN_TTIR.TTMI is set when trigger memory element becomes active
T0 bit 4 TMEX	Time mark event external – 0: No action – 1: Pulse at output fdcan1_tmp for more than one instance and fdcan_tmp if only one instance with the length of one period is generated when the time arc of the trigger memory element becomes active and FDCAN_TTOCN.TTMIE = 1
T0 bit 3:0 TYPE[3:0]	Trigger type – 0000 Tx_Ref_Trigger - valid when not in gap – 0001 Tx_Ref_Trigger_Gap - valid when in gap – 0010 Tx_Trigger_Single - starts a single transmission in an exclusive time window – 0011 Tx_Trigger_Continuous - starts continuous transmission in an exclusive time window – 0100 Tx_Trigger_Arbitration - starts a transmission in an arbitrating time window – 0101 Tx_Trigger_Merged - starts a merged arbitration window – 0110 Watch_Trigger - valid when not in gap – 0111 Watch_Trigger_Gap - valid when in gap – 1000 Rx_Trigger - check for reception – 1001 Time_Base_Trigger - only control TMIN, TMEX – 1010 … 1111=End_of_List - illegal type, causes configuration error
T1 bit 23FTYPE	Filter type – 0: 11-bit standard message ID – 1: 29-bit extended message ID
T1 bit 22:16 MNR[6:0](1)	Message number – Transmission: trigger is valid for configured Tx buffer number. Valid values are 0 to 31. – Reception: trigger is valid for standard/extended message ID filter element number. Valid values are, respectively 0 to 63 and 0 to 127.
T1 bits 2:0 MSC[2:0]	Message status count Counts scheduling errors for periodic messages in exclusive time windows. It has no function for arbitrating messages and in event-driven CAN communication (ISO11898-1). – 0-7= Actual status

1. The trigger memory elements have to be written when the FDCAN is in INIT state. Write access to the trigger memory elements outside INIT state is not allowed. There is an exception for TMIN and TMEX when they are defined as part of a trigger memory element of TYPE Tx_Ref_Trigger. In this case they become active at the time mark modified by the actual reference trigger offset (TTOST[RTO]).

61.5 FDCAN registers

61.5.1 FDCAN core release register (FDCAN_CREL)

Address offset: 0x0000

Reset value: 0x3214 1218

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REL[3:0]				STEP[3:0]				SUBSTEP[3:0]				YEAR[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MON[7:0]								DAY[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 **REL[3:0]**: Core release = 3

Bits 27:24 **STEP[3:0]**: Step of core release = 2

Bits 23:20 **SUBSTEP[3:0]**: Sub-step of core release = 1

Bits 19:16 **YEAR[3:0]**: Timestamp Year = 4

Bits 15:8 **MON[7:0]**: Timestamp Month = 12

Bits 7:0 **DAY[7:0]**: Timestamp Day =18

61.5.2 FDCAN Endian register (FDCAN_ENDN)

Address offset: 0x0004

Reset value: 0x8765 4321

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ETV[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ETV[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **ETV[31:0]**: Endiannes Test value
The endianness test value is 0x8765 4321.

61.5.3 FDCAN data bit timing and prescaler register (FDCAN_DBTP)

Address offset: 0x000C

Reset value: 0x0000 0A33

This register is dedicated to data bit timing phase and only writable if bits FDCAN_CCCR.CCE and FDCAN_CCCR.INIT are set. The CAN time quantum may be programmed in the range from 1 to 32 FDCAN clock periods. tq = (DBRP + 1) FDCAN clock periods.

DTSEG1 is the sum of Prop_Seg and Phase_Seg1. DTSEG2 is Phase_Seg2. Therefore the length of the bit time is (DTSEG1 + DTSEG2 + 3) tq for programmed values, or (Sync_Seg + Prop_Seg + Phase_Seg1 + Phase_Seg2) tq for functional values.

The information processing time (IPT) is zero, meaning the data for the next bit is available at the first clock edge after the sample point.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDC	Res.	Res.	DBRP[4:0]				
								rw			rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	DTSEG1[4:0]					DTSEG2[3:0]				DSJW[3:0]			
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **TDC**: Transceiver delay compensation
0: Transceiver delay compensation disabled
1: Transceiver delay compensation enabled

Bits 22:21 Reserved, must be kept at reset value.

Bits 20:16 **DBRP[4:0]**: Data bitrate prescaler
The value by which the oscillator frequency is divided to generate the bit time quanta. The bit time is built up from a multiple of these quanta. Valid values for the baudrate prescaler are 0 to 31. The hardware interpreters this value as the programmed value plus 1.

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **DTSEG1[4:0]**: Data time segment before sample point
Valid values are 0 to 31. The value used by the hardware is the one programmed, incremented by 1, i.e. t_{BS1} = (DTSEG1 + 1) x tq.

Bits 7:4 **DTSEG2[3:0]**: Data time segment after sample point
Valid values are 0 to 15. The value used by the hardware is the one programmed, incremented by 1, i.e. t_{BS2} = (DTSEG2 + 1) x tq.

Bits 3:0 **DSJW[3:0]**: Synchronization jump width
Should always be smaller than DTSEG2, valid values are 0 to 15. The value used by the hardware is the one programmed, incremented by 1, i.e. t_{SJW} = (DSJW + 1) x tq.

Note: With a FDCAN clock of 8 MHz, the reset value 0x00000A33 configures the FDCAN for a fast bitrate of 500 kbit/s.

61.5.4 FDCAN test register (FDCAN_TEST)

Write access to this register has to be enabled by setting bit FDCAN_CCCR.TEST to 1. All register functions are set to their reset values when bit FDCAN_CCCR.TEST is reset.

Loop back mode and software control of Tx pin FDCANx_TX are hardware test modes. Programming TX differently from 00 may disturb the message transfer on the CAN bus.

Address offset: 0x0010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RX	TX[1:0]		LBCK	Res.	Res.	Res.	Res.
								r	rw	rw	rw				

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **RX**: Receive pin
Monitors the actual value of transmit pin FDCANx_RX
0: The CAN bus is dominant (FDCANx_RX = 0)
1: The CAN bus is recessive (FDCANx_RX = 1)

Bits 6:5 **TX[1:0]**: Control of transmit pin
00: Reset value , FDCANx_TX TX is controlled by the CAN core, updated at the end of the CAN bit time
01: Sample point can be monitored at pin FDCANx_TX
10: Dominant (0) level at pin FDCANx_TX
11: Recessive (1) at pin FDCANx_TX

Bit 4 **LBCK**: Loop back mode
0: Reset value, loop back mode is disabled
1: Loop back mode is enabled (see *Test modes*)

Bits 3:0 Reserved, must be kept at reset value.

61.5.5 FDCAN RAM watchdog register (FDCAN_RWD)

The RAM watchdog monitors the READY output of the message RAM. A message RAM access starts the message RAM watchdog counter with the value configured by the FDCAN_RWD.WDC bits.

The counter is reloaded with FDCAN_RWD.WDC bits when the message RAM signals successful completion by activating its READY output. In case there is no response from the message RAM until the counter has counted down to 0, the counter stops and interrupt flag FDCAN_IR.WDI bit is set. The RAM watchdog counter is clocked by the fdcan_pclk clock.

Address offset: 0x0014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WDV[7:0]								WDC[7:0]							
r	r	r	r	r	r	r	r	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **WDV[7:0]**: Watchdog value
Actual message RAM watchdog counter value.

Bits 7:0 **WDC[7:0]**: Watchdog configuration
Start value of the message RAM watchdog counter. With the reset value of 00 the counter is disabled.
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

61.5.6 FDCAN CC control register (FDCAN_CCCR)

Address offset: 0x0018

Reset value: 0x0000 0001

For details about setting and resetting of single bits see *Software initialization*.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NISO	TXP	EFBI	PXHD	Res.	Res.	BRSE	FDOE	TEST	DAR	MON	CSR	CSA	ASM	CCE	INIT
rw	rw	rw	rw			rw	rw	rw	rw	rw	rw	r	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **NISO**: Non ISO operation
If this bit is set, the FDCAN uses the CAN FD frame format as specified by the Bosch CAN FD Specification V1.0.
0: CAN FD frame format according to ISO11898-1
1: CAN FD frame format according to Bosch CAN FD Specification V1.0

Bit 14 **TXP**:
If this bit is set, the FDCAN pauses for two CAN bit times before starting the next transmission after successfully transmitting a frame.
0: Disabled
1: Enabled

Bit 13 **EFBI**: Edge filtering during bus integration
0: Edge filtering disabled
1: Two consecutive dominant tq required to detect an edge for hard synchronization

Bit 12 **PXHD**: Protocol exception handling disable
0: Protocol exception handling enabled
1: Protocol exception handling disabled

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **BRSE**: FDCAN bitrate switching
0: Bitrate switching for transmissions disabled
1: Bitrate switching for transmissions enabled

Bit 8 **FDOE**: FD operation enable
0: FD operation disabled
1: FD operation enabled

Bit 7 **TEST**: Test mode enable
0: Normal operation, register TEST holds reset values
1: Test mode, write access to register TEST enabled

Bit 6 **DAR**: Disable automatic retransmission
0: Automatic retransmission of messages not transmitted successfully enabled
1: Automatic retransmission disabled

Bit 5 **MON**: Bus monitoring mode
Bit MON can only be set by software when both CCE and INIT are set to 1. The bit can be reset by the user at any time.
0: Bus monitoring mode is disabled
1: Bus monitoring mode is enabled

Bit 4 **CSR**: Clock stop request
0: No clock stop is requested
1: Clock stop requested. When clock stop is requested, first INIT and then CSA is set after all pending transfer requests have been completed and the CAN bus reached idle.

Bit 3 **CSA**: Clock stop acknowledge
0: No clock stop acknowledged
1: FDCAN may be set in power down by stopping APB clock and kernel clock

Bit 2 **ASM**: ASM restricted operation mode
The restricted operation mode is intended for applications that adapt themselves to different CAN bitrates. The application tests different bitrates and leaves the restricted operation mode after it has received a valid frame. In the optional restricted operation mode the node is able to transmit and receive data and remote frames and it gives acknowledge to valid frames, but it does not send active error frames or overload frames. In case of an error condition or overload condition, it does not send dominant bits, instead it waits for the occurrence of bus idle condition to resynchronize itself to the CAN communication. The error counters are not incremented. Bit ASM can only be set by software when both CCE and INIT are set to 1. The bit can be reset by the software at any time. This bit is set automatically set to 1 when the Tx handler was not able to read data from the message RAM in time.
If the FDCAN is connected to a clock calibration on CAN unit, ASM bit is set by hardware as long as the calibration is not completed.
0: Normal CAN operation
1: Restricted operation mode active

Bit 1 **CCE**: Configuration change enable
0: The CPU has no write access to the protected configuration registers
1: The CPU has write access to the protected configuration registers (while FDCAN_CCCR.INIT = 1 CCE bit is automatically cleared when INIT bit is cleared)

Bit 0 **INIT**: Initialization
0: Normal operation
1: Initialization is started (while FDCAN_CCCR.INIT = 1 CCE bit is automatically cleared when INIT bit is cleared)

Note: Due to the synchronization mechanism between the two clock domains, there may be a delay until the value written to INIT can be read back. Therefore the programmer has to

assure that the previous value written to INIT has been accepted by reading INIT before setting INIT to a new value.

61.5.7 FDCAN nominal bit timing and prescaler register (FDCAN_NBTP)

Address offset: 0x001C

Reset value: 0x0600 0A03

This register is dedicated to the nominal bit timing used during the arbitration phase, and is only writable if bits FDCAN_CCCR.CCE and FDCAN_CCCR.INIT are set. The CAN bit time may be programed in the range of 4 to 81 tq. The CAN time quantum may be programmed in the range of [1 … 1024] FDCAN kernel clock periods.

tq = (BRP + 1) FDCAN clock period fdcan_tq_ck

NTSEG1 is the sum of Prop_Seg and Phase_Seg1. NTSEG2 is Phase_Seg2. Therefore the length of the bit time is (programmed values) [NTSEG1 + NTSEG2 + 3] tq or (functional values) [Sync_Seg + Prop_Seg + Phase_Seg1 + Phase_Seg2] tq.

The information processing time (IPT) is zero, meaning the data for the next bit is available at the first clock edge after the sample point.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NSJW[6:0]							NBRP[8:0]								
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NTSEG1[7:0]								Res.	NTSEG2[6:0]						
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:25 **NSJW[6:0]**: Nominal (re)synchronization jump width

Should be smaller than NTSEG2, valid values are 0 to 127. The value used by the hardware is the one programmed, incremented by 1, i.e. t_{SJW} = (NSJW + 1) x tq.

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 24:16 **NBRP[8:0]**: Bitrate prescaler

Value by which the oscillator frequency is divided for generating the bit time quanta. The bit time is built up from a multiple of this quanta. Valid values are 0 to 511. The value used by the hardware is the one programmed, incremented by 1.

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 15:8 **NTSEG1[7:0]**: Nominal time segment before sample point

Valid values are 0 to 255. The value used by the hardware is the one programmed, incremented by 1, i.e. t_{BS1} = (NTSEG1 + 1) x tq.

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 7 Reserved, must be kept at reset value.

Bits 6:0 **NTSEG2[6:0]**: Nominal time segment after sample point

Valid values are 0 to 127. The value used by the hardware is the one programmed, incremented by 1, i.e. t_{BS2} = (NTSEG2 + 1) x tq.

Note: With a CAN kernel clock of 8 MHz, the reset value of 0x00000A33 configures the FDCAN for a bitrate of 125 kbit/s.

61.5.8 FDCAN timestamp counter configuration register (FDCAN_TSCC)

Address offset: 0x0020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCP[3:0]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSS[1:0]	
														rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:16 **TCP[3:0]**: Timestamp counter prescaler

Configures the timestamp and timeout counters time unit in multiples of CAN bit times [1 … 16].

The actual interpretation by the hardware of this value is such that one more than the value programmed here is used.

In CAN FD mode the internal timestamp counter TCP does not provide a constant time base due to the different CAN bit times between arbitration phase and data phase. Thus CAN FD requires an external counter for timestamp generation (TSS = 10).

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 15:2 Reserved, must be kept at reset value.

Bits 1:0 **TSS[1:0]**: Timestamp select

00: Timestamp counter value always 0x0000

01: Timestamp counter value incremented according to TCP

10: External timestamp counter from TIM3 value used (tim3_cnt[0:15])

11: Same as 00.

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

61.5.9 FDCAN timestamp counter value register (FDCAN_TSCV)

Address offset: 0x0024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSC[15:0]															
rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **TSC[15:0]**: Timestamp counter

The internal/external timestamp counter value is captured on start of frame (both Rx and Tx). When FDCAN_TSCC.TSS = 01, the timestamp counter is incremented in multiples of CAN bit times [1 … 16] depending on the configuration of FDCAN_TSCC.TCP. A wrap around sets interrupt flag FDCAN_IR.TSW. Write access resets the counter to 0. When FDCAN_TSCC.TSS = 10, TSC reflects the external timestamp counter value. A write access has no impact.

Note: A "wrap around" is a change of the timestamp counter value from non-0 to 0 not caused by write access to FDCAN_TSCV.

61.5.10 FDCAN timeout counter configuration register (FDCAN_TOCC)

Address offset: 0x0028

Reset value: 0xFFFF 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TOP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TOS[1:0]		ETOC
													rw	rw	rw

Bits 31:16 **TOP[15:0]**: Timeout period

Start value of the timeout counter (down-counter). Configures the timeout period.

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 15:3 Reserved, must be kept at reset value.

Bits 2:1 **TOS[1:0]**: Timeout select

When operating in Continuous mode, a write to FDCAN_TOCV presets the counter to the value configured by FDCAN_TOCC.TOP and continues down-counting. When the timeout counter is controlled by one of the FIFOs, an empty FIFO presets the counter to the value configured by FDCAN_TOCC.TOP. Down-counting is started when the first FIFO element is stored.

00: Continuous operation

01: Timeout controlled by Tx event FIFO

10: Timeout controlled by Rx FIFO 0

11: Timeout controlled by Rx FIFO 1

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 0 **ETOC**: Enable timeout counter

0: Timeout counter disabled

1: Timeout counter enabled

This is a write-protected bit, write access is possible only when the bit 1 (CCE) and bit 0 (INIT) of FDCAN_CCCR register are set to 1.

For more details see *Timeout counter*.

61.5.11 FDCAN timeout counter value register (FDCAN_TOCV)

Address offset: 0x002C

Reset value: 0x0000 FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TOC[15:0]															
rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **TOC[15:0]**: Timeout counter

The timeout counter is decremented in multiples of CAN bit times [1 … 16] depending on the configuration of FDCAN_TSCC.TCP. When decremented to 0, interrupt flag FDCAN_IR.TOO is set and the timeout counter is stopped. Start and reset/restart conditions are configured via FDCAN_TOCC.TOS.

61.5.12 FDCAN error counter register (FDCAN_ECR)

Address offset: 0x0040

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CEL[7:0]							
								rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RP	REC[6:0]							TEC[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **CEL[7:0]**: CAN error logging

The counter is incremented each time when a CAN protocol error causes the transmit error counter or the receive error counter to be incremented. It is reset by read access to CEL. The counter stops at 0xFF; the next increment of TEC or REC sets interrupt flag FDCAN_IR.ELO.

Bit 15 **RP**: Receive error passive

0: The receive error counter is below the error passive level of 128

1: The receive error counter has reached the error passive level of 128

Bits 14:8 **REC[6:0]:** Receive error counter

Actual state of the receive error counter, values between 0 and 127.

Bits 7:0 **TEC[7:0]**: Transmit error counter

Actual state of the transmit error counter, values between 0 and 255.

When FDCAN_CCCR.ASM is set, the CAN protocol controller does not increment TEC and REC when a CAN protocol error is detected, but CEL is still incremented.

61.5.13 FDCAN protocol status register (FDCAN_PSR)

Address offset: 0x0044

Reset value: 0x0000 0707

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDCV[6:0]						
									r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	PXE	REDL	RBRS	RESI	DLEC[2:0]			BO	EW	EP	ACT[1:0]		LEC[2:0]		
	rc_r	rc_r	rc_r	rc_r	rs_r	rs_r	rs_r	r	r	r	r	r	rs_r	rs_r	rs_r

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:16 **TDCV[6:0]**: Transmitter delay compensation value

Position of the secondary sample point, defined by the sum of the measured delay from FDCAN_TX to FDCAN_RX and FDCAN_TDCR.TDCO. The SSP position is, in the data phase, the number of minimum time quanta (mtq) between the start of the transmitted bit and the secondary sample point. Valid values are 0 to 127 mtq.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **PXE**: Protocol exception event
0: No protocol exception event occurred since last read access
1: Protocol exception event occurred

Bit 13 **REDL**: Received FDCAN message
This bit is set independent of acceptance filtering.
0: Since this bit was reset by the CPU, no FDCAN message has been received
1: Message in FDCAN format with EDL flag set has been received
Access type is RX: reset on read.

Bit 12 **RBRS:** BRS flag of last received FDCAN message
This bit is set together with REDL, independent of acceptance filtering.
0: Last received FDCAN message did not have its BRS flag set
1: Last received FDCAN message had its BRS flag set
Access type is RX: reset on read.

Bit 11 **RESI**: ESI flag of last received FDCAN message
This bit is set together with REDL, independent of acceptance filtering.
0: Last received FDCAN message did not ha ve its ESI flag set
1: Last received FDCAN message had its ESI flag set
Access type is RX: reset on read.

Bits 10:8 **DLEC[2:0]**: Data last error code
Type of last error that occurred in the data phase of a FDCAN format frame with its BRS flag set. Coding is the same as for LEC. This field is cleared to 0 when a FDCAN format frame with its BRS flag set has been transferred (reception or transmission) without error.
Access type is RS: set on read.

Bit 7 **BO**: Bus_Off status
0: The FDCAN is not Bus_Off
1: The FDCAN is in Bus_Off state

Bit 6 **EW**: Warning status
0: Both error counters are below the Error_Warning limit of 96
1: At least one of error counter has reached the Error_Warning limit of 96

Bit 5 **EP**: Error passive
0: The FDCAN is in the Error_Active state. It normally takes part in bus communication and sends an active error flag when an error has been detected
1: The FDCAN is in the Error_Passive state

Bits 4:3 **ACT[1:0]**: Activity
Monitors the module CAN communication state.
00: Synchronizing: node is synchronizing on CAN communication
01: Idle: node is neither receiver nor transmitter
10: Receiver: node is operating as receiver
11: Transmitter: node is operating as transmitter

Bits 2:0 **LEC[2:0]:** Last error code

The LEC indicates the type of the last error to occur on the CAN bus. This field is cleared to 0 when a message has been transferred (reception or transmission) without error.

000: No error: No error occurred since LEC has been reset by successful reception or transmission.

001: Stuff error: More than 5 equal bits in a sequence have occurred in a part of a received message where this is not allowed.

010: Form error: A fixed format part of a received frame has the wrong format.

011: AckError: The message transmitted by the FDCAN was not acknowledged by another node.

100: Bit1Error: During the transmission of a message (with the exception of the arbitration field), the device wanted to send a recessive level (bit of logical value 1), but the monitored bus value was dominant.

101: Bit0Error: During the transmission of a message (or acknowledge bit, or active error flag, or overload flag), the device wanted to send a dominant level (data or identifier bit logical value 0), but the monitored bus value was recessive. During Bus_Off recovery this status is set each time a sequence of 11 recessive bits has been monitored. This enables the CPU to monitor the proceeding of the Bus_Off recovery sequence (indicating the bus is not stuck at dominant or continuously disturbed).

110: CRCError: The CRC check sum of a received message was incorrect. The CRC of an incoming message does not match with the CRC calculated from the received data.

111: NoChange: Any read access to the protocol status register re-initializes the LEC to ‘7. When the LEC shows the value 7, no CAN bus event was detected since the last CPU read access to the protocol status register.

Access type is RS: set on read.

Note: When a frame in FDCAN format has reached the data phase with BRS flag set, the next CAN event (error or valid frame) is shown in FLEC instead of LEC. An error in a fixed stuff bit of a FDCAN CRC sequence is shown as a Form error, not Stuff error

Note: The Bus_Off recovery sequence (see CAN Specification Rev. 2.0 or ISO11898-1) cannot be shortened by setting or resetting FDCAN_CCCR.INIT. If the device goes Bus_Off, it will set FDCAN_CCCR.INIT of its own, stopping all bus activities. Once FDCAN_CCCR.INIT has been cleared by the CPU, the device will then wait for 129 occurrences of bus Idle (129 × 11 consecutive recessive bits) before resuming normal operation. At the end of the Bus_Off recovery sequence, the error management counters are reset. During the waiting time after the reset of FDCAN_CCCR.INIT, each time a sequence of 11 recessive bits has been monitored, a Bit0 error code is written to FDCAN_PSR.LEC, enabling the CPU to readily check up whether the CAN bus is stuck at dominant or continuously disturbed and to monitor the Bus_Off recovery sequence. FDCAN_ECR.REC is used to count these sequences.

61.5.14 FDCAN transmitter delay compensation register (FDCAN_TDCR)

Address offset: 0x0048

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TDCO[6:0]							Res.	TDCF[6:0]						
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:15 Reserved, must be kept at reset value.

Bits 14:8 **TDCO[6:0]**: Transmitter delay compensation offset

Offset value defining the distance between the measured delay from FDCAN_TX to FDCAN_RX and the secondary sample point. Valid values are 0 to 127 mtq.

These are write-protected bits, which means that write access by the bits is possible only when the bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 7 Reserved, must be kept at reset value.

Bits 6:0 **TDCF[6:0]**: Transmitter delay compensation filter window length

Defines the minimum value for the SSP position, dominant edges on FDCAN_RX that would result in an earlier SSP position are ignored for transmitter delay measurements.

These are write-protected bits, which means that write access by the bits is possible only when the bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

61.5.15 FDCAN interrupt register (FDCAN_IR)

The flags are set when one of the listed conditions is detected (edge-sensitive). The flags remain set until the user clears them. A flag is cleared by writing a 1 to the corresponding bit position.

Writing a 0 has no effect. A hard reset will clear the register. The configuration of IE controls whether an interrupt is generated. The configuration of ILS controls on which interrupt line an interrupt is signaled.

Address offset: 0x0050

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	ARA	PED	PEA	WDI	BO	EW	EP	ELO	Res.	Res.	DRX	TOO	MRAF	TSW
		rw	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TEFL	TEFF	TEFW	TEFN	TFE	TCF	TC	HPM	RF1L	RF1F	RF1W	RF1N	RF0L	RF0F	RF0W	RF0N
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **ARA**: Access to reserved address

0: No access to reserved address occurred

1: Access to reserved address occurred

Bit 28 **PED**: Protocol error in data phase (data bit time is used)

0: No protocol error in data phase

1: Protocol error in data phase detected (PSR.DLEC different from 0,7)

Bit 27 **PEA**: Protocol error in arbitration phase (nominal bit time is used)
0: No protocol error in arbitration phase
1: Protocol error in arbitration phase detected (PSR.LEC different from 0,7)

Bit 26 **WDI**: Watchdog interrupt
0: No message RAM watchdog event occurred
1: Message RAM watchdog event due to missing READY

Bit 25 **BO**: Bus_Off status
0: Bus_Off status unchanged
1: Bus_Off status changed

Bit 24 **EW**: Warning status
0: Error_Warning status unchanged
1: Error_Warning status changed

Bit 23 **EP**: Error passive
0: Error_Passive status unchanged
1: Error_Passive status changed

Bit 22 **ELO**: Error logging overflow
0: CAN error logging counter did not overflow
1: Overflow of CAN error logging counter occurred

Bits 21:20 Reserved, must be kept at reset value.

Bit 19 **DRX**: Message stored to dedicated Rx buffer
The flag is set whenever a received message has been stored into a dedicated Rx buffer.
0: No Rx buffer updated
1: At least one received message stored into a Rx buffer

Bit 18 **TOO**: Timeout occurred
0: No timeout
1: Timeout reached

Bit 17 **MRAF**: Message RAM Access Failure
The flag is set when the Rx handler
- Has not completed acceptance filtering or storage of an accepted message until the arbitration field of the following message has been received. In this case acceptance filtering or message storage is aborted and the Rx handler starts processing of the following message.
- Was unable to write a message to the message RAM. In this case message storage is aborted.

In both cases the FIFO put index is not updated or the New data flag for a dedicated Rx buffer is not set. The partly stored message is overwritten when the next message is stored to this location.

The flag is also set when the Tx handler was not able to read a message from the message RAM in time. In this case message transmission is aborted. In case of a Tx handler access failure the FDCAN is switched into restricted operation mode (see *Restricted operation mode*). To leave restricted operation mode, the user has to reset FDCAN_CCCR.ASM.

0: No message RAM access failure occurred
1: Message RAM access failure occurred

Bit 16 **TSW**: Timestamp wraparound
0: No timestamp counter wraparound
1: Timestamp counter wraparound

Bit 15 **TEFL**: Tx event FIFO element lost
0: No Tx event FIFO element lost
1: Tx event FIFO element lost, also set after write attempt to Tx event FIFO of size 0

Bit 14 **TEFF**: Tx event FIFO full
0: Tx event FIFO not full
1: Tx event FIFO full

Bit 13 **TEFW**: Tx event FIFO watermark reached
0: Tx event FIFO fill level below watermark
1: Tx event FIFO fill level reached watermark

Bit 12 **TEFN**: Tx event FIFO new entry
0: Tx event FIFO unchanged
1: Tx handler wrote Tx event FIFO element

Bit 11 **TFE**: Tx FIFO empty
0: Tx FIFO non-empty
1: Tx FIFO empty

Bit 10 **TCF**: Transmission cancellation finished
0: No transmission cancellation finished
1: Transmission cancellation finished

Bit 9 **TC**: Transmission completed
0: No transmission completed
1: Transmission completed

Bit 8 **HPM**: High priority message
0: No high priority message received
1: High priority message received

Bit 7 **RF1L**: Rx FIFO 1 message lost
0: No Rx FIFO 1 message lost
1: Rx FIFO 1 message lost, also set after write attempt to Rx FIFO 1 of size 0

Bit 6 **RF1F**: Rx FIFO 1 full
0: Rx FIFO 1 not full
1: Rx FIFO 1 full

Bit 5 **RF1W**: Rx FIFO 1 watermark reached
0: Rx FIFO 1 fill level below watermark
1: Rx FIFO 1 fill level reached watermark

Bit 4 **RF1N**: Rx FIFO 1 new message
0: No new message written to Rx FIFO 1
1: New message written to Rx FIFO 1

Bit 3 **RF0L**: Rx FIFO 0 message lost
0: No Rx FIFO 0 message lost
1: Rx FIFO 0 message lost, also set after write attempt to Rx FIFO 0 of size 0

Bit 2 **RF0F**: Rx FIFO 0 full
0: Rx FIFO 0 not full
1: Rx FIFO 0 full

Bit 1 **RF0W**: Rx FIFO 0 watermark reached
0: Rx FIFO 0 fill level below watermark
1: Rx FIFO 0 fill level reached watermark

Bit 0 **RF0N**: Rx FIFO 0 New message
0: No new message written to Rx FIFO 0
1: New message written to Rx FIFO 0

61.5.16 FDCAN interrupt enable register (FDCAN_IE)

The settings in the interrupt enable register determine which status changes in the interrupt register is signaled on an interrupt line.

Address offset: 0x0054

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	ARAE	PEDE	PEAE	WDIE	BOE	EWE	EPE	ELOE	Res.	Res.	DRXE	TOOE	MRAFE	TSWE
		rw	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TEFLE	TEFFE	TEFWE	TEFNE	TFEE	TCFE	TCE	HPME	RF1LE	RF1FE	RF1WE	RF1NE	RF0LE	RF0FE	RF0WE	RF0NE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **ARAE**: Access to Reserved address enable

Bit 28 **PEDE**: Protocol error in data phase enable

Bit 27 **PEAE**: Protocol error in Arbitration phase enable

Bit 26 **WDIE**: Watchdog interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 25 **BOE**: Bus_Off status
0: Interrupt disabled
1: Interrupt enabled

Bit 24 **EWE**: Warning status interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 23 **EPE**: Error passive interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 22 **ELOE**: Error logging overflow interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bits 21:20 Reserved, must be kept at reset value.

Bit 19 **DRXE**: Message stored to dedicated Rx buffer interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 18 **TOOE**: Timeout occurred interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 17 **MRAFE:** Message RAM access failure interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 16 **TSWE**: Timestamp wraparound interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 15 **TEFLE**: Tx event FIFO element lost interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 14 **TEFFE**: Tx event FIFO full interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 13 **TEFWE**: Tx event FIFO watermark reached interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 12 **TEFNE**: Tx event FIFO new entry interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 11 **TFEE**: Tx FIFO empty interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 10 **TCFE**: Transmission cancellation finished interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 9 **TCE**: Transmission completed interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 8 **HPME**: High priority message interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 7 **RF1LE**: Rx FIFO 1 message lost interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 6 **RF1FE**: Rx FIFO 1 full interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 5 **RF1WE**: Rx FIFO 1 watermark reached interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 4 **RF1NE**: Rx FIFO 1 new message interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 3 **RF0LE**: Rx FIFO 0 message lost interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 2 **RF0FE**: Rx FIFO 0 full interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 1 **RF0WE**: Rx FIFO 0 watermark reached interrupt enable
0: Interrupt disabled
1: Interrupt enabled

Bit 0 **RF0NE**: Rx FIFO 0 new message interrupt enable
0: Interrupt disabled
1: Interrupt enabled

61.5.17 FDCAN interrupt line select register (FDCAN_ILS)

This register assigns an interrupt generated by a specific interrupt flag from the interrupt register to one of the two module interrupt lines. For interrupt generation the respective interrupt line has to be enabled via FDCAN_ILE.EINT0 and FDCAN_ILE.EINT1.

Address offset: 0x0058

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	ARAL	PEDL	PEAL	WDIL	BOL	EWL	EPL	ELOL	Res.	Res.	DRXL	TOOL	MRAFL	TSWL
		rw	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TEFLL	TEFFL	TEFWL	TEFNL	TFEL	TCFL	TCL	HPML	RF1LL	RF1FL	RF1WL	RF1NL	RF0LL	RF0FL	RF0WL	RF0NL
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **ARAL**: Access to reserved address line

Bit 28 **PEDL**: Protocol error in data phase line

Bit 27 **PEAL**: Protocol error in arbitration phase line

Bit 26 **WDIL**: Watchdog interrupt Line

Bit 25 **BOL**: Bus_Off status

Bit 24 **EWL**: Warning status interrupt Line

Bit 23 **EPL**: Error passive interrupt line

Bit 22 **ELOL**: Error logging overflow interrupt line

Bits 21:20 Reserved, must be kept at reset value.

Bit 19 **DRXL**: Message stored to dedicated Rx buffer interrupt line

Bit 18 **TOOL**: Timeout occurred interrupt Line

Bit 17 **MRAFL**: Message RAM access failure interrupt line

Bit 16 **TSWL**: Timestamp wraparound interrupt line

Bit 15 **TEFLL**: Tx event FIFO element Lost interrupt line

Bit 14 **TEFFL**: Tx event FIFO full interrupt line

Bit 13 **TEFWL**: Tx event FIFO watermark reached interrupt line

Bit 12 **TEFNL**: Tx event FIFO new entry interrupt line

Bit 11 **TFEL**: Tx FIFO empty interrupt Line

Bit 10 **TCFL**: Transmission cancellation finished interrupt line

Bit 9 **TCL**: Transmission completed interrupt line

Bit 8 **HPML**: High priority message interrupt line

Bit 7 **RF1LL**: Rx FIFO 1 message lost interrupt line

Bit 6 **RF1FL**: Rx FIFO 1 full interrupt line

Bit 5 **RF1WL**: Rx FIFO 1 watermark reached interrupt line

Bit 4 **RF1NL**: Rx FIFO 1 new message interrupt line

Bit 3 **RF0LL**: Rx FIFO 0 message lost interrupt line

Bit 2 **RF0FL**: Rx FIFO 0 full interrupt line

Bit 1 **RF0WL**: Rx FIFO 0 watermark reached interrupt line

Bit 0 **RF0NL**: Rx FIFO 0 new message interrupt line

61.5.18 FDCAN interrupt line enable register (FDCAN_ILE)

Each of the two interrupt lines to the CPU can be enabled/disabled separately by programming bits EINT0 and EINT1.

Address offset: 0x005C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EINT1	EINT0
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **EINT1**: Enable interrupt Line 1
0: Interrupt line fdcan_intr1_it disabled
1: Interrupt line fdcan_intr1_it enabled

Bit 0 **EINT0**: Enable interrupt Line 0
0: Interrupt line fdcan_intr0_it disabled
1: Interrupt line fdcan_intr0_it enabled

61.5.19 FDCAN global filter configuration register (FDCAN_GFC)

Global settings for message ID filtering. The global filter configuration register controls the filter path for standard and extended messages as described in *Figure 768: Standard message ID filter path* and *Figure 769: Extended message ID filter path*.

Address offset: 0x0080

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ANFS[1:0]		ANFE[1:0]		RRFS	RRFE
										rw	rw	rw	rw	rw	rw

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:4 **ANFS[1:0]**: Accept non-matching frames standard
Defines how received messages with 11-bit ID that do not match any element of the filter list are treated.
00: Accept in Rx FIFO 0
01: Accept in Rx FIFO 1
10: Reject
11: Reject
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 3:2 **ANFE[1:0]**: Accept non-matching frames extended
Defines how received messages with 29-bit ID that do not match any element of the filter list are treated.
00: Accept in Rx FIFO 0
01: Accept in Rx FIFO 1
10: Reject
11: Reject
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 1 **RRFS**: Reject remote frames standard
0: Filter remote frames with 11-bit standard ID
1: Reject all remote frames with 11-bit standard ID
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 0 **RRFE**: Reject remote frames extended
0: Filter remote frames with 29-bit standard ID
1: Reject all remote frames with 29-bit standard ID
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

61.5.20 FDCAN standard ID filter configuration register (FDCAN_SIDFC)

Settings for 11-bit standard message ID filtering.The standard ID filter configuration register controls the filter path for standard messages as described in *Figure 768*.

Address offset: 0x0084

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LSS[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FLSSA[13:0]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **LSS[7:0]**: List size standard
0: No standard message ID filter
1-128: Number of standard message ID filter elements
>128: Values greater than 128 are interpreted as 128.
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 15:2 **FLSSA[13:0]**: Filter list standard start address
Start address of standard message ID filter list (32-bit word address, see *Table 521: Standard message ID filter element*).These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 1:0 Reserved, must be kept at reset value.

61.5.21 FDCAN extended ID filter configuration register (FDCAN_XIDFC)

Settings for 29-bit extended message ID filtering. The FDCAN extended ID filter configuration register controls the filter path for standard messages as described in *Figure 769: Extended message ID filter path*.

Address offset: 0x0088

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LSE[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FLESA[13:0]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **LSE[7:0]**: List size extended

0: No extended message ID filter

1-128: Number of extended ID filter elements

>128: Values greater than 128 are interpreted as 128.

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 15:2 **FLESA[13:0]**: Filter list extended start address

Start address of extended message ID filter list (32-bit word address, see *Table 523: Extended message ID filter element*).

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 1:0 Reserved, must be kept at reset value.

61.5.22 FDCAN extended ID and mask register (FDCAN_XIDAM)

Address offset: 0x0090

Reset value: 0x1FFF FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	EIDM[28:16]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EIDM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:0 **EIDM[28:0]**: Extended ID Mask

For acceptance filtering of extended frames the extended ID AND Mask is AND-ed with the message ID of a received frame. Intended for masking of 29-bit IDs in SAE J1939. With the reset value of all bits set to 1 the mask is not active.

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

61.5.23 FDCAN high priority message status register (FDCAN_HPMS)

This register is updated every time a message ID filter element configured to generate a priority event match. This can be used to monitor the status of incoming high priority messages and to enable fast access to these messages.

Address offset: 0x0094

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FLST	FIDX[6:0]							MSI[1:0]		BIDX[5:0]					
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **FLST**: Filter list
Indicates the filter list of the matching filter element.
0: Standard filter list
1: Extended filter list

Bits 14:8 **FIDX[6:0]**: Filter index
Index of matching filter element. Range is 0 to FDCAN_SIDFC[LSS] - 1 or FDCAN_XIDFC[LSE] - 1.

Bits 7:6 **MSI[1:0]**: Message storage indicator
00: No FIFO selected
01: FIFO overrun
10: Message stored in FIFO 0
11: Message stored in FIFO 1

Bits 5:0 **BIDX[5:0]**: Buffer index
Index of Rx FIFO element to which the message was stored. Only valid when MSI[1] = 1.

61.5.24 FDCAN new data 1 register (FDCAN_NDAT1)

Address offset: 0x0098

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ND31	ND30	ND29	ND28	ND27	ND26	ND25	ND24	ND23	ND22	ND21	ND20	ND19	ND18	ND17	ND16
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ND15	ND14	ND13	ND12	ND11	ND10	ND9	ND8	ND7	ND6	ND5	ND4	ND3	ND2	ND1	ND0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ND[31:0]**: New data[31:0]

The register holds the New data flags of Rx buffers 0 to 31. The flags are set when the respective Rx buffer has been updated from a received frame. The flags remain set until the user clears them. A flag is cleared by writing a 1 to the corresponding bit position. Writing a 0 has no effect. A hard reset will clear the register.

0: Rx buffer not updated

1: Rx buffer updated from new message

61.5.25 FDCAN new data 2 register (FDCAN_NDAT2)

Address offset: 0x009C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ND63	ND62	ND61	ND60	ND59	ND58	ND57	ND56	ND55	ND54	ND53	ND52	ND51	ND50	ND49	ND48
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ND47	ND46	ND45	ND44	ND43	ND42	ND41	ND40	ND39	ND38	ND37	ND36	ND35	ND34	ND33	ND32
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ND[63:32]**: New data[63:32]

The register holds the New data flags of Rx buffers 32 to 63. The flags are set when the respective Rx buffer has been updated from a received frame. The flags remain set until the user clears them. A flag is cleared by writing a 1 to the corresponding bit position. Writing a 0 has no effect. A hard reset will clear the register.

0: Rx buffer not updated

1: Rx buffer updated from new message

61.5.26 FDCAN Rx FIFO 0 configuration register (FDCAN_RXF0C)

Address offset: 0x00A0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
F0OM	F0WM[6:0]							Res.	F0S[6:0]						
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
F0SA[13:0]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bit 31 **F0OM**: FIFO 0 operation mode

FIFO 0 can be operated in blocking or in overwrite mode.

0: FIFO 0 blocking mode

1: FIFO 0 overwrite mode

Bits 30:24 **F0WM[6:0]**: FIFO 0 watermark
0: Watermark interrupt disabled
1-64: Level for Rx FIFO 0 watermark interrupt (FDCAN_IR.RF0W)
>64: Watermark interrupt disabled
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 23 Reserved, must be kept at reset value.

Bits 22:16 **F0S[6:0]**: Rx FIFO 0 size
0: No Rx FIFO 0
1-64: Number of Rx FIFO 0 elements
>64: Values greater than 64 are interpreted as 64
The Rx FIFO 0 elements are indexed from 0 to F0S-1.

Bits 15:2 **F0SA[13:0]**: Rx FIFO 0 start address
Start address of Rx FIFO 0 in message RAM (32-bit word address, see *Figure 767*).

Bits 1:0 Reserved, must be kept at reset value.

61.5.27 FDCAN Rx FIFO 0 status register (FDCAN_RXF0S)

Address offset: 0x00A4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	RF0L	F0F	Res.	Res.	F0PI[5:0]					
						rw	rw			rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	F0GI[5:0]						Res.	F0FL[6:0]						
		rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **RF0L**: Rx FIFO 0 message lost
This bit is a copy of interrupt flag FDCAN_IR.RF0L. When FDCAN_IR.RF0L is reset, this bit is also reset.
0: No Rx FIFO 0 message lost
1: Rx FIFO 0 message lost, also set after write attempt to Rx FIFO 0 of size 0

Bit 24 **F0F**: Rx FIFO 0 full
0: Rx FIFO 0 not full
1: Rx FIFO 0 full

Bits 23:22 Reserved, must be kept at reset value.

Bits 21:16 **F0PI[5:0]**: Rx FIFO 0 put index
Rx FIFO 0 write index pointer, range 0 to 63.

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:8 **F0GI[5:0]**: Rx FIFO 0 get index
Rx FIFO 0 read index pointer, range 0 to 63.

Bit 7 Reserved, must be kept at reset value.

Bits 6:0 **F0FL**[6:0]: Rx FIFO 0 fill level
Number of elements stored in Rx FIFO 0, range 0 to 64.

61.5.28 FDCAN Rx FIFO 0 acknowledge register (FDCAN_RXF0A)

Address offset: 0x00A8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	F0AI[5:0]					
										rw	rw	rw	rw	rw	rw

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:0 **F0AI[5:0]**: Rx FIFO 0 acknowledge index
After the user has read a message or a sequence of messages from Rx FIFO 0 it has to write the buffer index of the last element read from Rx FIFO 0 to F0AI. This will set the Rx FIFO 0 get index FDCAN_RXF0S.F0GI to F0AI + 1 and update the FIFO 0 fill level FDCAN_RXF0S.F0FL.

61.5.29 FDCAN Rx buffer configuration register (FDCAN_RXBC)

Address offset: 0x00AC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RBSA[13:0]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:2 **RBSA[13:0]**: Rx buffer start address
Configures the start address of the Rx buffers section in the message RAM (32-bit word address). Also used to reference debug messages A, B, C.
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 1:0 Reserved, must be kept at reset value.

61.5.30 FDCAN Rx FIFO 1 configuration register (FDCAN_RXF1C)

Address offset: 0x00B0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
F1OM	F1WM[6:0]							Res.	F1S[6:0]						
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
F1SA[13:0]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bit 31 **F1OM**: FIFO 1Operation mode
FIFO 1 can be operated in blocking or in overwrite mode.
0: FIFO 1 blocking mode
1: FIFO 1 overwrite mode

Bits 30:24 **F1WM[6:0]**: Rx FIFO 1 watermark
0: Watermark interrupt disabled
1-64: Level for Rx FIFO 1 watermark interrupt (FDCAN_IR.RF1W)
>64: Watermark interrupt disabled.
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 23 Reserved, must be kept at reset value.

Bits 22:16 **F1S[6:0]**: Rx FIFO 1 size
0: No Rx FIFO 1
1-64: Number of Rx FIFO 1 elements
>64: Values greater than 64 are interpreted as 64
The Rx FIFO 1 elements are indexed from 0 to F1S - 1.
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 15:2 **F1SA[13:0]**: Rx FIFO 1 start address
start address of Rx FIFO 1 in message RAM (32-bit word address, see *Figure 767: Message RAM configuration*).
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 1:0 Reserved, must be kept at reset value.

61.5.31 FDCAN Rx FIFO 1 status register (FDCAN_RXF1S)

Address offset: 0x00B4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMS[1:0]		Res.	Res.	Res.	Res.	RF1L	F1F	Res.	Res.	F1PI[5:0]					
r	r					r	r			r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	F1GI[5:0]						Res.	F1FL[6:0]						
		r	r	r	r	r	r		r	r	r	r	r	r	r

Bits 31:30 **DMS[1:0]**: Debug message status
00: Idle state, wait for reception of debug messages
01: Debug message A received
10: Debug messages A, B received
11: Debug messages A, B, C received

Bits 29:26 Reserved, must be kept at reset value.

Bit 25 **RF1L**: Rx FIFO 1 message lost
This bit is a copy of interrupt flag FDCAN_IR.RF1L. When FDCAN_IR.RF1L is reset, this bit is also reset.
0: No Rx FIFO 1 message lost
1: Rx FIFO 1 message lost, also set after write attempt to Rx FIFO 1 of size 0.

Bit 24 **F1F**: Rx FIFO 1 full
0: Rx FIFO 1 not full
1: Rx FIFO 1 full

Bits 23:22 Reserved, must be kept at reset value.

Bits 21:16 **F1PI[5:0]**: Rx FIFO 1 put index
Rx FIFO 1 write index pointer, range 0 to 63.

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:8 **F1GI[5:0]**: Rx FIFO 1 get index
Rx FIFO 1 read index pointer, range 0 to 63.

Bit 7 Reserved, must be kept at reset value.

Bits 6:0 **F1FL[6:0]**: Rx FIFO 1 fill level
Number of elements stored in Rx FIFO 1, range 0 to 64

61.5.32 FDCAN Rx FIFO 1 acknowledge register (FDCAN_RXF1A)

Address offset: 0x00B8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	F1AI[5:0]					
										rw	rw	rw	rw	rw	rw

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:0 **F1AI[5:0]**: Rx FIFO 1 acknowledge index
After the user has read a message or a sequence of messages from Rx FIFO 1 it has to write the buffer index of the last element read from Rx FIFO 1 to F1AI. This will set the Rx FIFO 1 get index FDCAN_RXF1S.F1GI. to F1AI + 1 and update the FIFO 1 fill level FDCAN_RXF1S.F1FL.

61.5.33 FDCAN Rx buffer element size configuration register (FDCAN_RXESC)

Configures the number of data bytes belonging to an Rx buffer / Rx FIFO element. Data field sizes higher than 8 bytes are intended for CAN FD operation only.

Address offset: 0x00BC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	RBDS[2:0]			Res.	F1DS[2:0]			Res.	F0DS[2:0]		
					r	r	r		r	r	r		r	r	r

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:8 **RBDS[2:0]**: Rx buffer data Field size:
000: 8-byte data field
001: 12-byte data field
010: 16-byte data field
011: 20-byte data field
100: 24-byte data field
101: 32-byte data field
110: 48-byte data field
111: 64-byte data field

Bit 7 Reserved, must be kept at reset value.

Bits 6:4 **F1DS[2:0]**: Rx FIFO 0 data Field size:
000: 8-byte data field
001: 12-byte data field
010: 16-byte data field
011: 20-byte data field
100: 24-byte data field
101: 32-byte data field
110: 48-byte data field
111: 64-byte data field

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **F0DS[2:0]**: Rx FIFO 1 data Field size:
000: 8-byte data field
001: 12-byte data field
010: 16-byte data field
011: 20-byte data field
100: 24-byte data field
101: 32-byte data field
110: 48-byte data field
111: 64-byte data field

61.5.34 FDCAN Tx buffer configuration register (FDCAN_TXBC)

Address offset: 0x00C0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	TFQM	TFQS[5:0]						Res.	Res.	NDTB[5:0]					
	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TBSA[13:0]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bit 31 Reserved, must be kept at reset value.

Bit 30 **TFQM**: Tx FIFO/queue mode.
0: Tx FIFO operation
1: Tx queue operation.
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 29:24 **TFQS[5:0]**: Transmit FIFO/queue size.
0: No Tx FIFO/queue
1-32: Number of Tx buffers used for Tx FIFO/queue
>32: Values greater than 32 are interpreted as 32.
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 23:22 Reserved, must be kept at reset value.

Bits 21:16 **NDTB[5:0]**: Number of dedicated transmit buffers.
0: No dedicated Tx buffers
1-32: Number of dedicated Tx buffers
>32: Values greater than 32 are interpreted as 32.
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 15:2 **TBSA[13:0]**: Tx buffers start address.
Start address of Tx buffers section in message RAM (32-bit word address, see *Figure 767*).
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 1:0 Reserved, must be kept at reset value.

Note: The sum of TFQS and NDTB cannot be larger than 32. There is no check for erroneous configurations. The Tx buffers section in the message RAM starts with the dedicated Tx buffers.

61.5.35 FDCAN Tx FIFO/queue status register (FDCAN_TXFQS)

The Tx FIFO/queue status is related to the pending Tx requests listed in register FDCAN_TXBRP. Therefore the effect of add/cancellation requests may be delayed due to a running Tx scan (FDCAN_TXBRP not yet updated).

Address offset: 0x00C4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TFQF	TFQPI[4:0]				
										r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	TFGI[4:0]					Res.	Res.	TFFL[5:0]					
			r	r	r	r	r			r	r	r	r	r	r

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **TFQF**: Tx FIFO/queue full
0 Tx FIFO/queue not full
1 Tx FIFO/queue full

Bits 20:16 **TFQPI[4:0]**: Tx FIFO/queue put index
Tx FIFO/queue write index pointer, range 0 to 31

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **TFGI[4:0]**:
Tx FIFO get index.
Tx FIFO read index pointer, range 0 to 31. Read as 0 when Tx queue operation is configured (FDCAN_TXBC.TFQM = 1)

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:0 **TFFL[5:0]**: Tx FIFO free level
Number of consecutive free Tx FIFO elements starting from TFGI, range 0 to 32. Read as 0 when Tx queue operation is configured (FDCAN_TXBC.TFQM = 1).

Note: In case of mixed configurations where dedicated Tx buffers are combined with a Tx FIFO or a Tx queue, the put and get index indicate the number of the Tx buffer starting with the first dedicated Tx buffers. For example: For a configuration of 12 dedicated Tx buffers and a Tx FIFO of 20 buffers a put index of 15 points to the fourth buffer of the Tx FIFO.

61.5.36 FDCAN Tx buffer element size configuration register (FDCAN_TXESC)

Configures the number of data bytes belonging to a Tx buffer element. Data field sizes >8 bytes are intended for CAN FD operation only.

Address offset: 0x00C8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TBDS[2:0]		
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bits 2:0 **TBDS[2:0]**: Tx buffer data Field size:
000: 8-byte data field
001: 12-byte data field
010: 16-byte data field
011: 20-byte data field
100: 24-byte data field
101: 32-byte data field
110: 48-byte data field
111: 64-byte data field

61.5.37 FDCAN Tx buffer request pending register (FDCAN_TXBRP)

Address offset: 0x00CC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TRP[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRP[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TRP[31:0]**:Transmission request pending.

Each Tx buffer has its own transmission request pending bit. The bits are set via register FDCAN_TXBAR. The bits are reset after a requested transmission has completed or has been canceled via register FDCAN_TXBCR.

FDCAN_TXBRP bits are set only for those Tx buffers configured via FDCAN_TXBC. After a FDCAN_TXBRP bit has been set, a Tx scan (see *Filtering for Debug messages*) is started to check for the pending Tx request with the highest priority (Tx buffer with lowest message ID).

A cancellation request resets the corresponding transmission request pending bit of register FDCAN_TXBRP. In case a transmission has already been started when a cancellation is requested, this is done at the end of the transmission, regardless whether the transmission was successful or not. The cancellation request bits are reset directly after the corresponding FDCAN_TXBRP bit has been reset.

After a cancellation has been requested, a finished cancellation is signaled via FDCAN_TXBCF

– after successful transmission together with the corresponding FDCAN_TXBTO bit
– when the transmission has not yet been started at the point of cancellation
– when the transmission has been aborted due to lost arbitration
– when an error occurred during frame transmission

In DAR mode all transmissions are automatically canceled if they are not successful. The corresponding FDCAN_TXBCF bit is set for all unsuccessful transmissions.

0: No transmission request pending

1: Transmission request pending

Note: FDCAN_TXBRP bits set while a Tx scan is in progress are not considered during this particular Tx scan. In case a cancellation is requested for such a Tx buffer, this add request is canceled immediately, the corresponding FDCAN_TXBRP bit is reset.

61.5.38 FDCAN Tx buffer add request register (FDCAN_TXBAR)

Address offset: 0x00D0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **AR[31:0]**:Add request

Each Tx buffer has its own add request bit. Writing a 1 will set the corresponding add request bit; writing a 0 has no impact. This enables the user to set transmission requests for multiple Tx buffers with one write to FDCAN_TXBAR. FDCAN_TXBAR bits are set only for those Tx buffers configured via FDCAN_TXBC. When no Tx scan is running, the bits are reset immediately, else the bits remain set until the Tx scan process has completed.

0: No transmission request added

1: Transmission requested added.

Note: If an add request is applied for a Tx buffer with pending transmission request (corresponding FDCAN_TXBRP bit already set), the request is ignored.

61.5.39 FDCAN Tx buffer cancellation request register (FDCAN_TXBCR)

Address offset: 0x00D4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CR[31:0]**: Cancellation request

Each Tx buffer has its own cancellation request bit. Writing a 1 will set the corresponding cancellation request bit; writing a 0 has no impact.

This enables the user to set cancellation requests for multiple Tx buffers with one write to FDCAN_TXBCR. FDCAN_TXBCR bits are set only for those Tx buffers configured via FDCAN_TXBC. The bits remain set until the corresponding FDCAN_TXBRP bit is reset.

0: No cancellation pending

1: Cancellation pending

61.5.40 FDCAN Tx buffer transmission occurred register (FDCAN_TXBTO)

Address offset: 0x00D8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TO[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TO[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TO[31:0]**: Transmission occurred.

Each Tx buffer has its own transmission occurred bit. The bits are set when the corresponding FDCAN_TXBRP bit is cleared after a successful transmission. The bits are reset when a new transmission is requested by writing a 1 to the corresponding bit of register FDCAN_TXBAR.

0: No transmission occurred

1: Transmission occurred

61.5.41 FDCAN Tx buffer cancellation finished register (FDCAN_TXBCF)

Address offset: 0x00DC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CF[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CF[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **CF[31:0]**: Cancellation finished

Each Tx buffer has its own cancellation finished bit. The bits are set when the corresponding FDCAN_TXBRP bit is cleared after a cancellation was requested via FDCAN_TXBCR. In case the corresponding FDCAN_TXBRP bit was not set at the point of cancellation, CF is set immediately. The bits are reset when a new transmission is requested by writing a 1 to the corresponding bit of register FDCAN_TXBAR.

0: No transmit buffer cancellation

1: Transmit buffer cancellation finished

61.5.42 FDCAN Tx buffer transmission interrupt enable register (FDCAN_TXBTIE)

Address offset: 0x00E0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TIE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TIE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TIE[31:0]**: Transmission interrupt enable

Each Tx buffer has its own transmission interrupt enable bit.

0: Transmission interrupt disabled

1: Transmission interrupt enable

61.5.43 FDCAN Tx buffer cancellation finished interrupt enable register (FDCAN_TXBCIE)

Address offset: 0x00E4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CFIE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CFIE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CFIE[31:0]**: Cancellation finished interrupt enable.
Each Tx buffer has its own cancellation finished interrupt enable bit.
0: Cancellation finished interrupt disabled
1: Cancellation finished interrupt enabled

61.5.44 FDCAN Tx event FIFO configuration register (FDCAN_TXEFC)

Address offset: 0x00F0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	EFWM[5:0]						Res.	Res.	EFS[5:0]					
		rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EFSA[13:0]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:24 **EFWM[5:0]**: Event FIFO watermark
0: Watermark interrupt disabled
1-32: Level for Tx event FIFO watermark interrupt (FDCAN_IR.TEFW)
>32: Watermark interrupt disabled
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 23:22 Reserved, must be kept at reset value.

Bits 21:16 **EFS[5:0]**: Event FIFO size.
0: Tx event FIFO disabled
1-32: Number of Tx event FIFO elements
>32: Values greater than 32 are interpreted as 32
The Tx event FIFO elements are indexed from 0 to EFS-1.
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 15:2 **EFSA[13:0]**: Event FIFO start address
Start address of Tx event FIFO in message RAM (32-bit word address, see *Figure 767: Message RAM configuration*).
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 1:0 Reserved, must be kept at reset value.

61.5.45 FDCAN Tx event FIFO status register (FDCAN_TXEFS)

Address offset: 0x00F4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	TEFL	EFF	Res.	Res.	Res.	EFPI[4:0]				
						r	r				r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	EFGI[4:0]					Res.	Res.	EFFL[5:0]					
			r	r	r	r	r			r	r	r	r	r	r

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **TEFL**: Tx event FIFO element Lost.
This bit is a copy of interrupt flag FDCAN_IR.TEFL. When FDCAN_IR.TEFL is reset, this bit is also reset.
0 No Tx event FIFO element lost
1 Tx event FIFO element lost, also set after write attempt to Tx event FIFO of size 0.

Bit 24 **EFF**: Event FIFO full.
0: Tx event FIFO not full
1: Tx event FIFO full

Bits 23:21 Reserved, must be kept at reset value.

Bits 20:16 **EFPI[4:0]**: Event FIFO put index.
Tx event FIFO write index pointer, range 0 to 31.

Bits 15:13 Reserved, must be kept at reset value.

Bits 12:8 **EFGI[4:0]**: Event FIFO get index.
Tx event FIFO read index pointer, range 0 to 31.

Bits 7:6 Reserved, must be kept at reset value.

Bits 5:0 **EFFL[5:0]**: Event FIFO fill level.
Number of elements stored in Tx event FIFO, range 0 to 31.

61.5.46 FDCAN Tx event FIFO acknowledge register (FDCAN_TXEFA)

Address offset: 0x00F8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EFAI[4:0]				
											rw	rw	rw	rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bits 4:0 **EFAI[4:0]**: Event FIFO acknowledge index.

After the user has read an element or a sequence of elements from the Tx event FIFO, it has to write the index of the last element read from Tx event FIFO to EFAI. This will set the Tx event FIFO get index FDCAN_TXEFS.EFGI to EFAI + 1 and update the FIFO 0 fill level FDCAN_TXEFS.EFFL.

61.5.47 FDCAN register map and reset values

Table 527. FDCAN register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0000	FDCAN_CREL	REL [3:0]				STEP [3:0]				SUBSTEP [3:0]				YEAR [3:0]				MON [7:0]								DAY [7:0]							
	Reset value	0	0	1	1	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	0
0x0004	FDCAN_ENDN	ETV[31:0]																															
	Reset value	1	0	0	0	0	1	1	1	0	1	1	0	0	1	1	1	0	1	0	0	0	0	1	1	0	0	1	0	0	0	0	1
0x0008	Reserved	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x000C	FDCAN_DBTP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDC	Res.	Res.	DBRP[4:0]					Res.	Res.	Res.	DTSEG1[4:0]					DTSEG2[3:0]				DSJW[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	0	0	1	1
0x0010	FDCAN_TEST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RX	TX [1:0]		LBCK	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0x0014	FDCAN_RWD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDV[7:0]								WDC[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0018	FDCAN _CCCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NISO	TXP	EFBI	PXHD	Res.	Res.	BRSE	FDOE	TEST	DAR	MON	CSR	CSA	ASM	CCE	INIT
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x001C	FDCAN_NBTP	NSJW[6:0]							NBRP[8:0]									NTSEG1[7:0]								Res.	NTSEG2[6:0]						
	Reset value	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	1
0x0020	FDCAN_TSCC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCP[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSS [1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0024	FDCAN_TSCV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSC[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0028	FDCAN_TOCC	TOP[15:0]																Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TOS [1:0]		ETOC
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x002C	FDCAN_TOCV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TOC[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x00D0	FDCAN _TXBAR	AR31	AR30	AR29	AR28	AR27	AR26	AR25	AR24	AR23	AR22	AR21	AR20	AR19	AR18	AR17	AR16	AR15	AR14	AR13	AR12	AR11	AR10	AR9	AR8	AR7	AR6	AR5	AR4	AR3	AR2	AR1	AR0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00D4	FDCAN _TXBCR	CR31	CR30	CR29	CR28	CR27	CR26	CR25	CR24	CR23	CR22	CR21	CR20	CR19	CR18	CR17	CR16	CR15	CR14	CR13	CR12	CR11	CR10	CR9	CR8	CR7	CR6	CR5	CR4	CR3	CR2	CR1	CR0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00D8	FDCAN _TXBTO	TO31	TO30	TO29	TO28	TO27	TO26	TO25	TO24	TO23	TO22	TO21	TO20	TO19	TO18	TO17	TO16	TO15	TO14	TO13	TO12	TO11	TO10	TO9	TO8	TO7	TO6	TO5	TO4	TO3	TO2	TO1	TO0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 527. FDCAN register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00DC	FDCAN_TXBCF	CF31	CF30	CF29	CF28	CF27	CF26	CF25	CF24	CF23	CF22	CF21	CF20	CF19	CF18	CF17	CF16	CF15	CF14	CF13	CF12	CF11	CF10	CF9	CF8	CF7	CF6	CF5	CF4	CF3	CF2	CF1	CF0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00E0	FDCAN_TXBTIE	TIE31	TIE30	TIE29	TIE28	TIE27	TIE26	TIE25	TIE24	TIE23	TIE22	TIE21	TIE20	TIE19	TIE18	TIE17	TIE16	TIE15	TIE14	TIE13	TIE12	TIE11	TIE10	TIE9	TIE8	TIE7	TIE6	TIE5	TIE4	TIE3	TIE2	TIE1	TIE0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00E4	FDCAN_TXBCIE	CFIE31	CFIE30	CFIE29	CFIE28	CFIE27	CFIE26	CFIE25	CFIE24	CFIE23	CFIE22	CFIE21	CFIE20	CFIE19	CFIE18	CFIE17	CFIE16	CFIE15	CFIE14	CFIE13	CFIE12	CFIE11	CFIE10	CFIE9	CFIE8	CFIE7	CFIE6	CFIE5	CFIE4	CFIE3	CFIE2	CFIE1	CFIE0
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00F0	FDCAN_TXEFC	Res.	Res.	EFWM[5:0]						Res.	Res.	EFS[5:0]						EFSA[15:2]														Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00F4	FDCAN_TXEFS	Res.	Res.	Res.	Res.	Res.	Res.	TEF	EFF	Res.	Res.	Res.	EFPI[4:0]					Res.	Res.	Res.	EFGI[4:0]					Res.	Res.	EFFL[5:0]					
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00F8	FDCAN_TXEFA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EFAI[4:0]				
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

61.6 TTCAN registers

These registers are available only for FDCAN1.

61.6.1 FDCAN TT trigger memory configuration register (FDCAN_TTTMC)

Address offset: 0x100

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TME[6:0]						
									rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TMSA[13:0]														Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:16 **TME[6:0]**: Trigger memory elements

0: No trigger memory

1-64: Number of trigger memory elements

>64: Values greater than 64 are interpreted as 64

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 15:2 **TMSA[13:0]**: Trigger memory start address.

Start address of trigger memory in message RAM (32-bit word address, see *Figure 767: Message RAM configuration*).

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 1:0 Reserved, must be kept at reset value.

61.6.2 FDCAN TT reference message configuration register (FDCAN_TTRMC)

Address offset: 0x0104

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RMPS	XTD	Res.	RID[28:16]												
rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RID[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **RMPS**: Reference message Payload select
Ignored in case of time slaves.
0: Reference message has no additional payload
1: The following elements are taken from Tx buffer 0:
– Message marker MM,
– Event FIFO control EFC,
– Data length code DLC,
– Data Bytes DB (level 1: bytes 2-8, level 0, 2: bytes 5-8)
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 30 **XTD**: Extended identifier
0: 11-bit standard identifier
1: 29-bit extended identifier
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 29 Reserved, must be kept at reset value.

Bits 28:0 **RID[28:0]**: Reference identifier.
Identifier transmitted with reference message and used for reference message filtering. Standard or extended reference identifier depending on bit XTD. A standard identifier has to be written to ID[28:18].
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

61.6.3 FDCAN TT operation configuration register (FDCAN_TTOCF)

Address offset: 0x0108

Reset value: 0x0001 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	EVTP	ECC	EGTF	AWL[7:0]							
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EECS	IRTO[6:0]							LDSDL[2:0]			TM	GEN	Res.	OM[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bit 26 **EVTP**: Event trigger polarity.
0: Rising edge trigger
1: Falling edge trigger
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 25 **ECC**: Enable clock calibration.
0: Automatic clock calibration in FDCAN level 0, 2 is disabled
1: Automatic clock calibration in FDCAN level 0, 2 is enabled
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 24 **EGTF**: Enable global time Filtering.
0: Global time filtering in FDCAN level 0, 2 is disabled
1: Global time filtering in FDCAN level 0, 2 is enabled
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 23:16 **AWL[7:0]**: Application watchdog limit.
The application watchdog can be disabled by programming AWL to 0x00.
0x00–FF: Maximum time after which the application has to serve the application watchdog. The application watchdog is incremented once each 256 NTUs.
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 15 **EECS**: Enable external clock synchronization
If enabled, TUR configuration (FDCAN_TURCF.NCL only) may be updated during FDCAN operation.
0: External clock synchronization in FDCAN level 0, 2 disabled
1: External clock synchronization in FDCAN level 0, 2 enabled
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 14:8 **IRTO[6:0]**: Initial reference trigger offset.
0x00–7F Positive offset, range from 0 to 127
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 7:5 **LDSDL[2:0]**: LD of synchronization deviation limit.
The synchronization deviation limit SDL is configured by its dual logarithm LDSDL with SDL = 2 * (LDSDL + 5). SDL is comprised between 32 and 4096. It should not exceed the clock tolerance given by the CAN bit timing configuration.
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 4 **TM**: Time master.
0: Time master function disabled
1: Potential time master
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 3 **GEN**: Gap enable.
0: Strictly time-triggered operation
1: External event-synchronized time-triggered operation
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bit 2 Reserved, must be kept at reset value.

Bits 1:0 **OM[1:0]**: Operation mode.
00: Event-driven CAN communication, default
01: TTCAN level 1
10: TTCAN level 2
11: TTCAN level 0
These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

61.6.4 FDCAN TT matrix limits register (FDCAN_TTMLM)

Address offset: 0x010C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	ENTT[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TXEW[3:0]				CSS[1:0]		CCM[5:0]					
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bits 27:16 **ENTT[11:0]**: Expected number of Tx triggers

0x000–FFF Expected number of Tx triggers in one matrix cycle.

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:8 **TXEW[3:0]**: Tx enable window

0x0–F Length of Tx enable window, 1-16 NTU cycles

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 7:6 **CSS[1:0]**: Cycle start synchronization

Enables sync pulse output.

00: No sync pulse

01: Sync pulse at start of basic cycle

10: Sync pulse at start of matrix cycle

11: Reserved

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 5:0 **CCM[5:0]:** Cycle count Max

0x00: 1 basic cycle per matrix cycle

0x01: 2 basic cycles per matrix cycle

0x03: 4 basic cycles per matrix cycle

0x07: 8 basic cycles per matrix cycle

0x0F: 16 basic cycles per matrix cycle

0x1F: 32 basic cycles per matrix cycle

0x3F: 64 basic cycles per matrix cycle

Others: Reserved

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Note: ISO 11898-4, Section 5.2.1 requires that only the listed cycle count values are configured. Other values are possible, but may lead to inconsistent matrix cycles.

61.6.5 FDCAN TUR configuration register (FDCAN_TURCF)

The length of the NTU is given by: NTU = CAN clock period x NC/DC.

NC is an 18-bit value. Its high part, NCH[17:16] is hard wired to 0b01. Therefore the range of NC extends from 0x10000 to 0x1FFFF. The value configured by NCL is the initial value for FDCAN_TURNA.NAV[15:0]. DC is set to 0x1000 by hardware reset and it may not be written to 0x0000.

- Level 1: NC 4 × DC and NTU = CAN bit time
- Levels 0 and 2: NC 8 × DC

The actual value of FDCAN_TUR may be changed by the clock drift compensation function of TTCAN level 0 and level 2 in order to adjust the node local view of the NTU to the time master view of the NTU. DC will not be changed by the automatic drift compensation, FDCAN_TURNA.NAV may be adjusted around NC in the range of the synchronization deviation limit given by FDCAN_TTOCF.LDSDL. NC and DC should be programmed to the largest suitable values in achieve the best computational accuracy for the drift compensation process.

Address offset: 0x0110

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ELT	Res.	DC[13:0]													
rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NCL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **ELT**: Enable local time.

0: Local time is stopped, default

1: Local time is enabled

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Note: The local time is started by setting ELT. It remains active until ELT is reset or until the next hardware reset. FDCAN_TURCF.DC is locked when FDCAN_TURCF.ELT = 1. If ELT is written to 0, the readable value will stay at 1 until the new value has been synchronized into the CAN clock domain. During this time write access to the other bits of the register remains locked.

Bit 30 Reserved, must be kept at reset value.

Bits 29:16 **DC[13:0]**: Denominator configuration.

0x0000: Illegal value

0x0001 to 0x3FFF: Denominator configuration

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Bits 15:0 **NCL[15:0]**: Numerator configuration low.

Write access to the TUR numerator configuration low is only possible during configuration with FDCAN_TURCF.ELT = 0 or if FDCAN_TTOCF.EECS (external clock synchronization enabled) is set. When a new value for NCL is written outside TT configuration mode, the new value takes effect when FDCAN_TTOST.WECS is cleared to 0. NCL is locked FDCAN_TTOST.WECS is 1.

0x0000–FFFF Numerator configuration low

These are write-protected bits, write access is possible only when bit CCE and bit INIT of FDCAN_CCCR register are set to 1.

Note: If NC < 7 × DC in TTCAN level 1, it is required that subsequent time marks in the trigger memory must differ by at least two NTUs.

61.6.6 FDCAN TT operation control register (FDCAN_TTOCN)

Address offset: 0x0114

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LCKC	Res.	ESCN	NIG	TMG	FGP	GCS	TTIE	TMC[1:0]		RTIE	SWS[1:0]		SWP	ECS	SGT
r		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **LCKC**: TT operation control register locked.

Set by a write access to register FDCAN_TTOCN. Reset when the updated configuration has been

synchronized into the CAN clock domain.

0: Write access to FDCAN_TTOCN enabled

1: Write access to FDCAN_TTOCN locked

Bit 14 Reserved, must be kept at reset value.

Bit 13 **ESCN**: External synchronization control

If enabled the FDCAN synchronizes its cycle time phase to an external event signaled by a rising edge at event trigger pin (see *Section 61.4.17: Synchronization to external time schedule*).

0: External synchronization disabled

1: External synchronization enabled

Bit 12 **NIG**: Next is gap.
This bit can only be set when the FDCAN is the actual time master and when it is configured for external event-synchronized time-triggered operation (FDCAN_TTOCF.GEN = 1)
0: No action, reset by reception of any reference message
1: Transmit next reference message with Next_is_Gap = 1

Bit 11 **TMG**: Time mark gap.
0: Reset by each reference message
1: Next reference message started when register time mark interrupt FDCAN_TTIR.RTMI is activated

Bit 10 **FGP**: Finish gap.
Set by the CPU, reset by each reference message
0: No reference message requested
1: Application requested start of reference message

Bit 9 **GCS**: Gap control select
0: Gap control independent from event trigger
1: Gap control by input event trigger pin

Bit 8 **TTIE**: Trigger time mark interrupt pulse enable
External time mark events are configured by trigger memory element TMEX. A trigger time mark interrupt pulse is generated when the trigger memory element becomes active, and the FDCAN is in synchronization state In_Schedule or In_Gap.
0: Trigger time mark interrupt output fdcan1_tmp for more than one instance and fdcan_tmp if only one instance disabled
1: Trigger time mark interrupt output fdcan1_tmp for more than one instance and fdcan_tmp if only one instance enabled

Bits 7:6 **TMC[1:0]**: Register time mark compare.
00: No Register time mark interrupt generated
01: Register time mark interrupt if time mark = cycle time
10: Register time mark interrupt if time mark = local time
11: Register time mark interrupt if time mark = global time
Note: When changing the time mark reference (cycle, local, global time), it is recommended to first write TMC = 00, then reconfigure FDCAN_TTTMK, and finally set FDCAN_TMC to the intended time reference.

Bit 5 **RTIE**: Register time mark interrupt pulse enable.
Register time mark interrupts are configured by register FDCAN_TTTMK. A register time mark interrupt pulse with the length of one fdcan_tq_ck period is generated when time referenced by FDCAN_TTOCN.TMC (cycle, local, or global) is equal to FDCAN_TTTMK.TM, independently from the synchronization state.
0: Register time mark interrupt output disabled
1: Register time mark interrupt output enabled

Bits 4:3 **SWS[1:0]**: Stop watch source.
00: Stop watch disabled
01: Actual value of cycle time is copied to FDCAN_TTCPT.SWV
10: Actual value of local time is copied to FDCAN_TTCPT.SWV
11: Actual value of global time is copied to FDCAN_TTCPT.SWV

Bit 2 **SWP**: Stop watch polarity.
0: Rising edge trigger
1: Falling edge trigger

Bit 1 **ECS**: External clock synchronization.
Writing a 1 to ECS sets FDCAN_TTOST.WECS if the node is the actual time master. ECS is reset after one APB clock period. The external clock synchronization takes effect at the start of the next basic cycle.

Bit 0 **SGT**: Set global time.
Writing a 1 to SGT sets FDCAN_TTOST.WGDT if the node is the actual time master. SGT is reset after one APB clock period. The global time preset takes effect when the node transmits the next reference message with the Master_Ref_Mark modified by the preset value written to FDCAN_TTGTP.

61.6.7 FDCAN TT global time preset register (FDCAN_TTGTP)

If TTOST.WGDT is set, the next reference message is transmitted with the Master_Ref_Mark modified by the preset value and with Disc_Bit = 1, presetting the global time in all nodes simultaneously.

TP is reset to 0x0000 each time a reference message with Disc_Bit = 1 becomes valid or if the node is not the current time master. TP is locked while FDCAN_TTOST.WGTD = 1 after setting FDCAN_TTOCN.SGT until the reference message with Disc_Bit = 1 becomes valid or until the node is no longer the current time master.

Address offset: 0x0118

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CTP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **CTP[15:0]**: Cycle time target phase
CTP is write-protected while FDCAN_TTOCN.ESCN or FDCAN_TTOST.SPL are set (see *Section 61.4.17: Synchronization to external time schedule*).
0x0000–FFFF Defines the target value of cycle time when a rising edge of event trigger is expected

Bits 15:0 **TP[15:0]**: Time Preset.
TP is write-protected while FDCAN_TTOST.WGTD is set.
0x0000–7FFF next master reference mark = master reference mark + TP
0x8000 reserved
0x8001–FFFF Next master reference mark = master reference mark - (0x10000 - TP).

61.6.8 FDCAN TT time mark register (FDCAN_TTTMK)

A time mark interrupt (FDCAN_TTIR.TMI = 1) is generated when the time base indicated by FDCAN_TTOCN.TMC (cycle time, local time, or global time) has the same value as TM.

Address offset: 0x011C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LCKM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TICC[6:0]						
r									rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **LCKM**: TT time mark register Locked.
Always set by a write access to registers FDCAN_TTOCN. Set by write access to register FDCAN_TTTMK when FDCAN_TTOCN.TMC 00. Reset when the registers have been synchronized into the CAN clock domain.
0: Write access to FDCAN_TTTMK enabled
1: Write access to FDCAN_TTTMK locked

Bits 30:23 Reserved, must be kept at reset value.

Bits 22:16 **TICC[6:0]**: Time mark cycle code.
Cycle count for which the time mark is valid.
0b000000x valid for all cycles
0b000001c valid every second cycle at cycle count mod2 = c
0b00001cc valid every fourth cycle at cycle count mod4 = cc
0b0001ccc valid every eighth cycle at cycle count mod8 = ccc
0b001cccc valid every sixteenth cycle at cycle count mod16 = cccc
0b01ccccc valid every thirty-second cycle at cycle count mod32 = ccccc
0b1cccccc valid every sixty-fourth cycle at cycle count mod64 = cccccc

Bits 15:0 **TM[15:0]**: Time mark.
0x0000–FFFF time mark

Note: When using byte access to register FDCAN_TTTMK it is recommended to first disable the time mark compare function (FDCAN_TTOCN.TMC = 00) to avoid comparisons on inconsistent register values.

61.6.9 FDCAN TT interrupt register (FDCAN_TTIR)

The flags are set when one of the listed conditions is detected (edge-sensitive). The flags remain set until the user clears them. A flag is cleared by writing a 1 to the corresponding bit position. Writing a 0 has no effect. A hard reset clears the register.

Address offset: 0x0120

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CER	AW	WT
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IWTG	ELC	SE2	SE1	TXO	TXU	GTE	GTD	GTW	SWE	TTMI	RTMI	SOG	CSM	SMC	SBC
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **CER**: Configuration error.
Trigger out of order.
0: No error found in trigger list
1: Error found in trigger list

Bit 17 **AW**: Application watchdog.
0: Application watchdog served in time
1: Application watchdog not served in time

Bit 16 **WT**: Watch trigger.
0: No missing reference message
1: Missing reference message (level 0: cycle time 0xFF00)

Bit 15 **IWTG**: Initialization watch trigger.
The initialization is restarted by resetting IWT.
0 No missing reference message during system startup
1 No system startup due to missing reference message

Bit 14 **ELC**: Error level Changed.
Not set when error level changed during initialization.
0: No change in error level
1: Error level changed

Bit 13 **SE2**: Scheduling error 2.
0: No scheduling error 2
1: Scheduling error 2 occurred

Bit 12 **SE1**: Scheduling error 1.
0: No scheduling error 1
1: Scheduling error 1 occurred

Bit 11 **TXO**: Tx count overflow.
0: Number of Tx trigger as expected
1: More Tx trigger than expected in one cycle

Bit 10 **TXU**: Tx count underflow.
0: Number of Tx trigger as expected
1: Less Tx trigger than expected in one cycle

Bit 9 **GTE**: Global time error.
Synchronization deviation SD exceeds limit specified by FDCAN_TTOCF.LDSDL, TTCAN level 0, 2 only.
0: Synchronization deviation within limit
1: Synchronization deviation exceeded limit

Bit 8 **GTD**: Global time discontinuity.
0: No discontinuity of global time
1: Discontinuity of global time

Bit 7 **GTW**: Global time wrap
0: No global time wrap occurred
1: Global time wrap from 0xFFFF to 0x0000 occurred

Bit 6 **SWE**: Stop watch event
0: No rising/falling edge at stop watch trigger pin detected
1 :Rising/falling edge at stop watch trigger pin detected

Bit 5 **TTMI:** Trigger time mark event internal
Internal time mark events are configured by trigger memory element TMIN (see *Section 61.4.23: FDCAN trigger memory element*). Set when the trigger memory element becomes active, and the FDCAN is in synchronization state In_Gap or In_Schedule.
0: Time mark not reached
1: Time mark reached (level 0: cycle time FDCAN_TTOCF.RTO x 0x200)

Bit 4 **RTMI**: Register time mark interrupt.
Set when time referenced by TTOCN.TMC (cycle, local, or global) is equal to FDCAN_TTTMK.TM, independently from the synchronization state.
0: Time mark not reached
1: Time mark reached

Bit 3 **SOG**: Start of gap
0 No reference message seen with Next_is_Gap bit set
1 Reference message with Next_is_Gap bit set becomes valid

Bit 2 **CSM**: Change of synchronization mode.
0: No change in master to slave relation or schedule synchronization
1: Master to slave relation or schedule synchronization changed,
also set when FDCAN_TTOST.SPL is reset

Bit 1 **SMC**: Start of matrix cycle.
0: No matrix cycle started since bit has been reset
1: Matrix cycle started

Bit 0 **SBC**: Start of basic cycle.
0: No basic cycle started since bit has been reset
1: Basic cycle started

61.6.10 FDCAN TT interrupt enable register (FDCAN_TTIE)

The settings in the TT interrupt enable register determine which status changes in the TT interrupt register will result in an interrupt.

Address offset: 0x0124

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CERE	AWE	WTE
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IWTE	ELCE	SE2E	SE1E	TXOE	TXUE	GTEE	GTDE	GTWE	SWEE	TTMIE	RTMIE	SOGE	CSME	SMCE	SBCE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **CERE**: Configuration error interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 17 **AWE**: Application watchdog interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 16 **WTE**: Watch trigger interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 15 **IWTE**: Initialization watch trigger interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 14 **ELCE**: Change error level interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 13 **SE2E**: Scheduling error 2 interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 12 **SE1E**: Scheduling error 1 interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 11 **TXOE**: Tx count overflow interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 10 **TXUE**: Tx count underflow interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 9 **GTEE**: Global time error interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 8 **GTDE**: Global time discontinuity interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 7 **GTWE**: Global time wrap interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 6 **SWEE**: Stop watch event interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 5 **TTMIE:** Trigger time mark event internal interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 4 **RTMIE**: Register time mark interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 3 **SOGE**: Start of gap interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 2 **CSME**: Change of synchronization mode interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 1 **SMCE**: Start of matrix cycle interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

Bit 0 **SBCE**: Start of basic cycle interrupt enable
0: TT interrupt disabled
1: TT interrupt enabled

61.6.11 FDCAN TT interrupt line select register (FDCAN_TTILS)

The TT interrupt Line select register assigns an interrupt generated by a specific interrupt flag from the TT interrupt register to one of the two module interrupt lines. For interrupt generation the respective interrupt line has to be enabled via FDCAN_ILE.EINT0 and FDCAN_ILE.EINT1.

Address offset: 0x0128

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CERL	AWL	WTL
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IWTL	ELCL	SE2L	SE1L	TXOL	TXUL	GTEL	GTDL	GTWL	SWEL	TTMIL	RTMIL	SOGL	CSML	SMCL	SBCL
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **CERL**: Configuration error interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 17 **AWL**: Application watchdog interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 16 **WTL:** Watch trigger interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 15 **IWTL:** Initialization watch trigger interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 14 **ELCL:** Change error level interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 13 **SE2L:** Scheduling error 2 interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 12 **SE1L:** Scheduling error 1 interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 11 **TXOL:** Tx count overflow interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 10 **TXUL:** Tx count underflow interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 9 **GTEL:** Global time error interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 8 **GTDL:** Global time discontinuity interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 7 **GTWL:** Global time wrap interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 6 **SWEL:** Stop watch event interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 5 **TTMIL:** Trigger time mark event internal interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 4 **RTMIL:** Register time mark interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 3 **SOGL:** Start of gap interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 2 **CSML:** Change of synchronization mode interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 1 **SMCL:** Start of matrix cycle interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

Bit 0 **SBCL:** Start of basic cycle interrupt Line
0: TT interrupt assigned to interrupt line 0
1: TT interrupt assigned to interrupt line 1

61.6.12 FDCAN TT operation status register (FDCAN_TTOST)

Address offset: 0x012C

Reset value: 0x0000 0080

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SPL	WECS	AWE	WFE	GSI	TMP[2:0]			GFI	WGTD	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r	r	r	r	r	r	r						
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RTO[7:0]								QCS	QGTP	SYS[1:0]		MS[1:0]		EL[1:0]	
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 **SPL**: Schedule phase lock.
The bit is valid only when external synchronization is enabled (FDCAN_TTOCN.ESCN = 1). In this case it signals that the difference between cycle time configured by FDCAN_TTGTP.CTP and the cycle time at the rising edge at event trigger pin is less than or equal to 9 NTU (see *Section 61.4.17: Synchronization to external time schedule*).
0: Phase outside range
1: Phase inside range

Bit 30 **WECS**: Wait for external clock synchronization.
0: No external clock synchronization pending
1: Node waits for external clock synchronization to take effect. The bit is reset at the start of the next basic cycle.

Bit 29 **AWE**: Application watchdog event.
The application watchdog is served by reading FDCAN_TTOST. When the watchdog is not served in time, bit AWE is set, all FDCAN communication is stopped, and the FDCAN is set into bus monitoring mode.
0: Application watchdog served in time
1: Failed to serve application watchdog in time

Bit 28 **WFE**: Wait for event.
0: No gap announced, reset by a reference message with Next_is_Gap = 0
1: Reference message with Next_is_Gap = 1 received

Bit 27 **GSI**: Gap started indicator.
0: No gap in schedule, reset by each reference message and for all time slaves
1: Gap time after basic cycle has started

Bits 26:24 **TMP[2:0]**: Time master priority.
0x0-7 Priority of actual time master

Bit 23 **GFI**: Gap finished indicator.
Set when the CPU writes FDCAN_TTOCN.FGP, or by a time mark interrupt if TMG = 1, or via input pin (event trigger) if FDCAN_TTOCN.GCS = 1. Not set by Ref_Trigger_Gap or when Gap is finished by another node sending a reference message.
0: Reset at the end of each reference message
1: Gap finished by FDCAN

Bit 22 **WGTD**: Wait for global time discontinuity.
0: No global time preset pending
1: Node waits for the global time preset to take effect. The bit is reset when the node has transmitted a reference message with Disc_Bit = 1 or after it received a reference message.

Bits 21:16 Reserved, must be kept at reset value.

Bits 15:8 **RTO[7:0]**: Reference trigger offset.
The reference trigger offset value is a signed integer with a range from -127 (0x81) to 127 (0x7F). There is no notification when the lower limit of-127 is reached. In case the FDCAN becomes time master (MS[1:0] = 11), the reset of RTO is delayed due to synchronization between user and CAN clock domain. For time slaves the value configured by FDCAN_TTOCF.IRTO is read.
0x00-FF Actual reference trigger offset value

Bit 7 **QCS**: Quality of clock Speed.
Only relevant in TTCAN level 0 and level 2, otherwise fixed to 1.
0: Local clock speed not synchronized to time master clock speed
1: Synchronization deviation ≤ SDL

Bit 6 **QGTP**: Quality of global time phase.
Only relevant in TTCAN level 0 and level 2, otherwise fixed to 0.
0: Global time not valid
1: Global time in phase with time master

Bits 5:4 **SYS[1:0]**: Synchronization state
00: Out of Synchronization
01: Synchronizing to FDCAN communication
10: Schedule suspended by gap (In_Gap)
11: Synchronized to schedule (In_Schedule)

Bits 3:2 **MS[1:0]**: Master state.
00: Master_Off, no master properties relevant
01: Operating as time Slave
10: Operating as backup time master
11: Operating as current time master

Bits 1:0 **EL[1:0]**: Error level.
00: Severity 0 - No error
01: Severity 1 - Warning
10: Severity 2 - error
11: Severity 3 - Severe error

61.6.13 FDCAN TUR numerator actual register (FDCAN_TURNA)

There is no drift compensation in TTCAN level 1 (NAV = NC). In TTCAN level 0 and level 2, the drift between the node local clock and the time master local clock is calculated. The drift is compensated when the synchronization deviation (difference between NC and the calculated NAV) is lower than 2 * (FDCAN_TTOCF.LDSDL + 5). With FDCAN_TTOCF.LDSDL < 7, this results in a maximum range for NAV of (NC - 0x1000) ≤ NAV ≤ (NC + 0x1000).

Address offset: 0x0130

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAV[17:16]	
														r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NAV[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:0 **NAV[17:0]**: Numerator actual value.
0x0EFFF Illegal value
0x0F000–20FFF Actual numerator value
0x21000 Illegal value

61.6.14 FDCAN TT local and global time register (FDCAN_TTLGT)

Address offset: 0x0134

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
GT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **GT[15:0]**: Global time.
Non-fractional part of the sum of the node local time and its local offset (see *Section 61.4.12: Local time, cycle time, global time, and external clock synchronization*).
0x0000–FFFF Global time value of FDCAN network

Bits 15:0 **LT[15:0]**: Local time.
Non-fractional part of local time, incremented once each local NTU (see *Section 61.4.12: Local time, cycle time, global time, and external clock synchronization*).
0x0000–FFFF Local time value of FDCAN node

61.6.15 FDCAN TT cycle time and count register (FDCAN_TTCTC)

Address offset: 0x0138

Reset value: 0x003F 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC[5:0]					
										r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:16 **CC[5:0]**: Cycle count.
0x00–3F Number of actual basic cycle in the system matrix

Bits 15:0 **CT[15:0]**: Cycle time
Non-fractional part of the difference of the node local time and Ref_Mark (see *Section 61.4.12: Local time, cycle time, global time, and external clock synchronization*).
0x0000–FFFF Cycle time value of FDCAN basic cycle

61.6.16 FDCAN TT capture time register (FDCAN_TTCPT)

Address offset: 0x013C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SWV[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCV[5:0]					
										r	r	r	r	r	r

Bits 31:16 **SWV[15:0]**: Stop watch value.
On a rising / falling edge (as configured via FDCAN_TTOCN.SWP) at the stop watch trigger pin, when FDCAN_TTOCN.SWS] is different from 00 and FDCAN_TTIR.SWE is 0, the actual time value as selected by FDCAN_TTOCN.SWS (cycle, local, global) is copied to SWV and TFDCAN_TIR.SWE is set to 1.Capturing of the next stop watch value is enabled by resetting FDCAN_TTIR.SWE.
0x0000–FFFF Captured stop watch value

Bits 15:6 Reserved, must be kept at reset value.

Bits 5:0 **CCV[5:0]**: Cycle count value
Cycle count value captured together with SWV.
0x00–3F Captured cycle count value

61.6.17 FDCAN TT cycle sync mark register (FDCAN_TTCSM)

Address offset: 0x0140

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CSM[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **CSM[15:0]**: Cycle sync mark.
The cycle sync mark is measured in cycle time. It is updated when the reference message becomes valid and retains its value until the next reference message becomes valid.
0x0000–FFFF Captured cycle time

61.6.18 FDCAN TT trigger select register (FDCAN_TTTS)

The settings in the FDCAN_TTTS register select the input to be used as event trigger and stop watch trigger.

Address offset: 0x0300

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EVTSEL[1:0]		Res.	Res.	SWTDEL[1:0]	
										rw	rw			rw	rw

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:4 **EVTSEL[1:0]**: Event trigger input selection
These bits are used to select the input to be used as event trigger
00: fdcan1_evt0
01: fdcan1_evt1
10: fdcan1_evt2
11: fdcan1_evt3

Bits 3:2 Reserved, must be kept at reset value.

Bits 1:0 **SWTDEL[1:0]**: Stop watch trigger input selection
These bits are used to select the input to be used as stop watch trigger
00: fdcan1_swt0
01: fdcan1_swt1
10: fdcan1_swt2
11: fdcan1_swt3

61.6.19 FDCAN TT register map and reset values

Table 528. FDCAN TT register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0100	FDCAN_TTTMC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TME[6:0]							TMSA[13:0]														Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0104	FDCAN_TTRMC	RMPS	XTD	Res.	RID[28:0]																												
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0108	FDCAN_TTOCF	Res.	Res.	Res.	Res.	Res.	EVTP	ECC	EGTF	AWL[7:0]								EECS	IRTO[6:0]							LDSDL [2:0]			TM	GEN	Res.	OM [1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x010C	FDCAN_TTMLM	Res.	Res.	Res.	Res.	ENTT[11:0]												Res.	Res.	Res.	Res.	TXEW[3:0]				CSS[1:0]	CCM[5:0]						
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0110	FDCAN_TURCF	ELT	Res.	DC[13:0]														NCL[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0114	FDCAN_TTOCN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LCKC	Res.	ESCN	NIG	TMG	FGP	GCS	TTIE	TMC[1:0]		RTIE	SWS[1:0]		SWP	ECS	SGT
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0118	FDCAN_TTGTP	CTP[15:0]																TP[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x011C	FDCAN_TTTMK	LCKM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TICC[6:0]							TM[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0120	FDCAN_TTIR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CER	AW	WT	IWTG	ELC	SE2	SE1	TXO	TXU	GTE	GTD	GTW	SWE	TTMI	RTMI	SOG	CSM	SMC	SBC
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0124	FDCAN_TTIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CERE	AWE	WTE	IWTE	ELCE	SE2E	SE1E	TXOE	TXUE	GTEE	GTDE	GTWE	SWEE	TTMIE	RTMIE	SOGE	CSME	SMCE	SBCE
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0128	FDCAN_TTILS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CERL	AWL	WTL	IWTL	ELCL	SE2L	SE1L	TXOL	TXUL	GTEL	GTDL	GTWL	SWEL	TTMIL	RTMIL	SOGL	CSML	SMCL	SBCL
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x012C	FDCAN_TTOST	SPL	WECS	AWE	WFE	GSI	TMP[2:0]			GFI	WGTD	Res.	Res.	Res.	Res.	Res.	Res.	RTO[7:0]								QCS	QGTP	SYS[1:0]		MS[1:0]		EL[1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
0x0130	FDCAN_TURNA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAV[17:0]																	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 528. FDCAN TT register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0134	FDCAN_TTLGT	GT[15:0]																LT[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0138	FDCAN_TTCTC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CC[5:0]						CT[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x013C	FDCAN_TTCPT	SWV[15:0]																Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CCV[5:0]					
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0140	FDCAN_TTCSM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSM[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0144 to 0x01FC	Reserved																																
	Reset value																																
0x0300	FDCAN_TTTS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EVTSEL[1:0]		Res.	Res.	SWTSEL[1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

61.7 CCU registers

61.7.1 Clock calibration unit core release register (FDCAN_CCU_CREL)

Address offset: 0x0000

Reset value: 0x1114 1218

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REL[3:0]				STEP[3:0]				SUBSTEP[3:0]				YEAR[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MON[7:0]								DAY[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 **REL[3:0]**: Core release = 1

Bits 27:24 **STEP[3:0]**: Step of core release = 1

Bits 23:20 **SUBSTEP[3:0]**: Sub-step of core release = 1

Bits 19:16 **YEAR[3:0]**: Timestamp year =

Bits 15:8 **MON[7:0]**: Timestamp month = 12

Bits 7:0 **DAY[7:0]**: Timestamp day = 18

61.7.2 Calibration configuration register (FDCAN_CCU_CCFG)

Address offset: 0x0004

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SWR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CDIV[3:0]			
rw												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OCPM[7:0]								CFL	BCC	Res.	TQBT[4:0]				
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw

Bit 31 **SWR**: Software reset

Writing a 1 to this bit resets the calibration FSM to state Not_Calibrated (FDCAN_CCU_CSTAT.CALS = 00). The calibration watchdog value CWD.WDV is also reset. Registers FDCAN_CCFG, FDCAN_CCU_CSTAT and the calibration watchdog configuration CWD.WDC are unchanged. The bit remains set until reset is completed.

Write access by the user to registers/bits marked with “P = Protected Write” is possible only when FDCAN control bits FDCAN_CCCR.CCE = 1 AND FDCAN_CCCR.INIT = 1.

Bits 30:20 Reserved, must be kept at reset value.

Bits 19:16 **CDIV[3:0]**: Clock divider

The clock divider has to be configured when the clock calibration is bypassed (BCC = 1) to ensure that the FDCAN requirement is fulfilled.

0000: Divide by 1
0001: Divide by 2
0010: Divide by 4
0011: Divide by 6
0100: Divide by 8
0101: Divide by 10
0110: Divide by 12
0111: Divide by 14
1000: Divide by 16
1001: Divide by 18
1010: Divide by 20
1011: Divide by 22
1100: Divide by 24
1101: Divide by 26
1110: Divide by 28
1111: Divide by 30

Write access by the user to registers/bits marked with “P = Protected Write” is possible only when FDCAN control bits FDCAN_CCCR.CCE = 1 AND FDCAN_CCCR.INIT = 1.

Bits 15:8 **OCPM[7:0]**: Oscillator clock periods minimum

Configures the minimum number of periods in two CAN bit times. OCPM is used in basic calibration to avoid false measurements in case of glitches on the bus line. The configured number of periods is OCPM × 32. The configuration depends on the frequency and the bitrate configured in FDCAN modules (from 125 kbit/s up to 1 Mbit/s). It is recommended to configure a value slightly below two CAN bit times. The reset value is 1.6 bit times at 80 MHz fdcan_ker_ck and 1 Mbit/s CAN bitrate.

Write access by the user to registers/bits marked with “P = Protected Write” is possible only when FDCAN control bits FDCAN_CCCR.CCE = 1 AND FDCAN_CCCR.INIT = 1.

Bit 7 **CFL**: Calibration field length

0: Calibration field length is 32 bits

1: Calibration field length is 64 bits

Write access by the user to registers/bits marked with “P = Protected Write” is possible only when FDCAN control bits FDCAN_CCCR.CCE = 1 AND FDCAN_CCCR.INIT = 1.

Bit 6 **BCC**: Bypass clock calibration

If this bit is set, the clock input fdcan_ker_ck is routed to the time quanta clock through a clock divider configurable via CDIV. In this case the baudrate prescaler of the connected FDCANs has to be configured to generate the FDCAN internal time quanta clock.

0: Clock calibration unit generates time quanta clock

1: Clock calibration unit bypassed (default configuration)

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **TQBT[4:0]**: Time quanta per bit time

Configures the number of time quanta per bit time. Same value as configured in FDCAN modules. The range of the resulting time quanta clock fdcan_tq_ck is from 0.5 MHz (bitrate of 125 kbit/s with 4 tq per bit time) to 25 MHz (bitrate of 1 Mbit/s with 25 tq per bit time). Valid values are 4 to 25. Configured values below 4 are interpreted as 4, values above 25 are interpreted as 25.

Write access by the user to registers/bits marked with “P = Protected Write” is possible only when FDCAN control bits FDCAN_CCCR.CCE = 1 AND FDCAN_CCCR.INIT = 1.

61.7.3 Calibration status register (FDCAN_CCU_CSTAT)

Address offset: 0x0008

Reset value: 0x0203 FFFF

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CALS[1:0]		Res.	TQC[10:0]											OCPC[17:16]	
r	r		r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OCPC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:30 **CALS[1:0]**: Calibration state

00: Not_Calibrated

01: Basic_Calibrated

10: Precision_Calibrated

11: Reserved

Bit 29 Reserved, must be kept at reset value.

Bits 28:18 **TQC[10:0]**: Time quanta counter

Captured number of time quanta in calibration field (32 or 64 bits). Only valid when the clock calibration unit is in state Precision_Calibrated.

Bits 17:0 **OCPC[17:0]**: Oscillator clock period counter

Captured number of oscillator clock periods in calibration field (32 or 64 bits). Only valid when the clock calibration unit is in state Precision_Calibrated.

61.7.4 Calibration watchdog register (FDCAN_CCU_CWD)

Address offset: 0x000C

Reset value: 0x0000 0000

The calibration watchdog is started after the first falling edge when the calibration FSM is in state Not_Calibrated (FDCAN_CCU_CSTAT.CALS = 00). In this state the calibration watchdog monitors the message received. In case no message was received until the calibration watchdog has counted down to 0, the calibration FSM stays in state Not_Calibrated (FDCAN_CCU_CSTAT.CALS = 00), the counter is reloaded with FDCAN_RWD.WDC and basic calibration is restarted after the next falling edge.

When in state Basic_Calibrated (FDCAN_CCU_CSTAT.CALS = 01), the calibration watchdog is restarted with each received message . In case no message was received until the calibration watchdog has counted down to 0, the calibration FSM returns to state Not_Calibrated (FDCAN_CCU_CSTAT.CALS = 00), the counter is reloaded with FDCAN_RWD.WDC and basic calibration is restarted after the next falling edge.

When a quartz message is received, state Precision_Calibrated (FDCAN_CCU_CSTAT.CALS = 10) is entered and the calibration watchdog is restarted. In this state the calibration watchdog monitors the quartz message received input. In case no message from a quartz controlled node is received by the attached TTCAN until the calibration watchdog has counted down to 0, the calibration FSM transits back to state Basic_Calibrated (FDCAN_CCU_CSTAT.CALS = 01). The signal is active when the CAN protocol engine on the attached TTCAN is started i.e. when the INIT bit is reset.

A calibration watchdog event also sets interrupt flag FDCAN_CCU_IR.CWE. If enabled by FDCAN_CCU_IE.CWEE, interrupt line is activated (set to high). Interrupt line remains active until interrupt flag FDCAN_CCU_IR.CWE is reset.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WDV[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
WDC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **WDV[15:0]**: Watchdog value
Actual calibration watchdog counter value.

Bits 15:0 **WDC[15:0]**: WDC
Watchdog configuration
Start value of the calibration watchdog counter. With the reset value of 00 the counter is disabled.
Write access by the user to registers/bits marked with “P = Protected Write” is possible only when FDCAN control bits FDCAN_CCCR.CCE = 1 AND FDCAN_CCCR.INIT = 1.

61.7.5 Clock calibration unit interrupt register (FDCAN_CCU_IR)

The flags are set when one of the listed conditions is detected (edge-sensitive). The flags remain set until the user clears them. A flag is cleared by writing a 1 to the corresponding bit position. Writing a 0 has no effect. A hard reset clears the register. The configuration of FDCAN_CCU_IE controls whether an interrupt is generated or not.

Address offset: 0x0010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSC	CWE
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **CSC**: Calibration state changed
0: Calibration state unchanged
1: Calibration state has changed

Bit 0 **CWE**: Calibration watchdog event
0: No calibration watchdog event
1: Calibration watchdog event occurred

61.7.6 Clock calibration unit interrupt enable register (FDCAN_CCU_IE)

Address offset: 0x0014

Reset value: 0x0000 0000

The settings in the CU interrupt enable register determine whether a status change in the CU interrupt register is signaled on an interrupt line.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSCE	CWEE
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **CSCE**: Calibration state changed enable
0: Interrupt disabled
1: Interrupt enabled

Bit 0 **CWEE**: Calibration watchdog event enable
0: Interrupt disabled
1: Interrupt enabled

61.7.7 CCU register map and reset value table

Table 529. CCU register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0000	FDCAN_CCU_CREL	REL[3:0]				STEP[3:0]				SUBSTEP [3:0]				YEAR[3:0]				MON[7:0]								DAY[7:0]							
	Reset value	0	0	0	1	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	0
0x0004	FDCAN_CCU_CCFG	SWR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CDIV[3:0]				OCPM[7:0]								CFL	BCC	Res.	TQBT[4:0]				
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0008	FDCAN_CCU_CSTAT	CALS [1:0]		Res.	TQC[10:0]											OCPC[17:0]																	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x000C	FDCAN_CCU_CWD	WDV[15:0]																WDC[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0010	FDCAN_CCU_IR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSC	CWE
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0014	FDCAN_CCU_IE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CSCE	CWEE
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

62 USB on-the-go high-speed (OTG_HS)

62.1 Introduction

This section presents the architecture and the programming model of the OTG_HS controller.

The following acronyms are used throughout the section:

FS	Full-speed
LS	Low-speed
HS	High-speed
MAC	Media access controller
OTG	On-the-go
PFC	Packet FIFO controller
PHY	Physical layer
USB	Universal serial bus
UTMI	USB 2.0 Transceiver Macrocell interface (UTMI)
ULPI	UTMI+ Low Pin Interface
LPM	Link power management
BCD	Battery charging detector
HNP	Host negotiation protocol
SRP	Session request protocol

References are made to the following documents:

- USB On-The-Go Supplement, Revision 2.0
- Universal Serial Bus Revision 2.0 Specification
- USB 2.0 Link Power Management Addendum Engineering Change Notice to the USB 2.0 specification, July 16, 2007
- Errata for USB 2.0 ECN: Link Power Management (LPM) - 7/2007
- Battery Charging Specification, Revision 1.2

The USB OTG is a dual-role device (DRD) controller that supports both device and host functions and is fully compliant with the *On-The-Go Supplement to the USB 2.0 Specification*. It can also be configured as a host-only or device-only controller, fully compliant with the *USB 2.0 Specification.* OTG_HS supports the speeds defined in the *Table 530: OTG_HS speeds supported* below.The USB OTG supports both HNP and SRP. The only external device required is a charge pump for V_{BUS} in OTG mode.

Table 530. OTG_HS speeds supported

-	HS (480 Mb/s)	FS (12 Mb/s)	LS (1.5 Mb/s)
Host mode	X	X	X
Device mode	X	X	-

62.2 OTG_HS main features

The main features can be divided into three categories: general, host-mode and device-mode features.

62.2.1 General features

The OTG_HS interface general features are the following:

- It is USB-IF certified to the Universal Serial Bus Specification Rev 2.0
- OTG_HS supports the following PHY interfaces:
  - An on-chip full-speed PHY
  - A ULPI interface for external high-speed PHY
- It includes full support (PHY) for the optional On-The-Go (OTG) protocol detailed in the On-The-Go Supplement Rev 2.0 specification
  - Integrated support for A-B device identification (ID line)
  - Integrated support for host Negotiation protocol (HNP) and session request protocol (SRP)
  - It allows host to turn V_{BUS} off to conserve battery power in OTG applications
  - It supports OTG monitoring of V_{BUS} levels with internal comparators
  - It supports dynamic host-peripheral switch of role
- It is software-configurable to operate as:
  - SRP capable USB HS Peripheral (B-device)
  - SRP capable USB HS/LS host (A-device)
  - USB On-The-Go Full-Speed Dual Role device
- It supports HS SOF and LS Keep-alives with
  - SOF pulse PAD connectivity
  - SOF pulse internal connection to timer (TIMx)
  - Configurable framing period
  - Configurable end of frame interrupt
- OTG_HS embeds an internal DMA with thresholding support and software selectable AHB burst type in DMA mode.
- It supports Descriptor-Based Scatter/Gather DMA controller for device and host mode. (Descriptor-Based Congruent-Sequential DMA is not supported). Scatter/Gather DMA operation is supported in both device and host mode. This feature will improve performance for device mode isochronous endpoints. Note that hubs (split transfers)

are not supported in host scatter/gather DMA mode of operation. Split transfers are supported only in host buffer DMA (internal DMA) mode of operation.

- It includes power saving features such as system stop during USB suspend, switch-off of clock domains internal to the digital core, PHY and DFIFO power management.
- It features a dedicated RAM of 4 Kbytes with advanced FIFO control:
  - Configurable partitioning of RAM space into different FIFOs for flexible and efficient use of RAM
  - Each FIFO can hold multiple packets
  - Dynamic memory allocation
  - Configurable FIFO sizes that are not powers of 2 to allow the use of contiguous memory locations
- It guarantees max USB bandwidth for up to one frame (1 ms) without system intervention.
- It supports charging port detection as described in Battery Charging Specification Revision 1.2 on the FS PHY transceiver only.

62.2.2 Host-mode features

The OTG_HS interface main features and requirements in host-mode are the following:

- External charge pump for V_{BUS} voltage generation.
- Up to 16 host channels (pipes): each channel is dynamically reconfigurable to allocate any type of USB transfer.
- Built-in hardware scheduler holding:
  - Up to 16 interrupt plus isochronous transfer requests in the periodic hardware queue
  - Up to 16 control plus bulk transfer requests in the non-periodic hardware queue
- Management of a shared Rx FIFO, a periodic Tx FIFO and a nonperiodic Tx FIFO for efficient usage of the USB data RAM.

62.2.3 Peripheral-mode features

The OTG_HS interface main features in peripheral-mode are the following:

- 1 bidirectional control endpoint0
- 8 IN endpoints (EPs) configurable to support bulk, interrupt or isochronous transfers
- 8 OUT endpoints configurable to support bulk, interrupt or isochronous transfers
- Management of a shared Rx FIFO and a Tx-OUT FIFO for efficient usage of the USB data RAM
- Management of up to 9 dedicated Tx-IN FIFOs (one for each active IN EP) to put less load on the application
- Support for the soft disconnect feature.

62.3 OTG_HS implementation

Table 531. OTG_HS implementation(1)

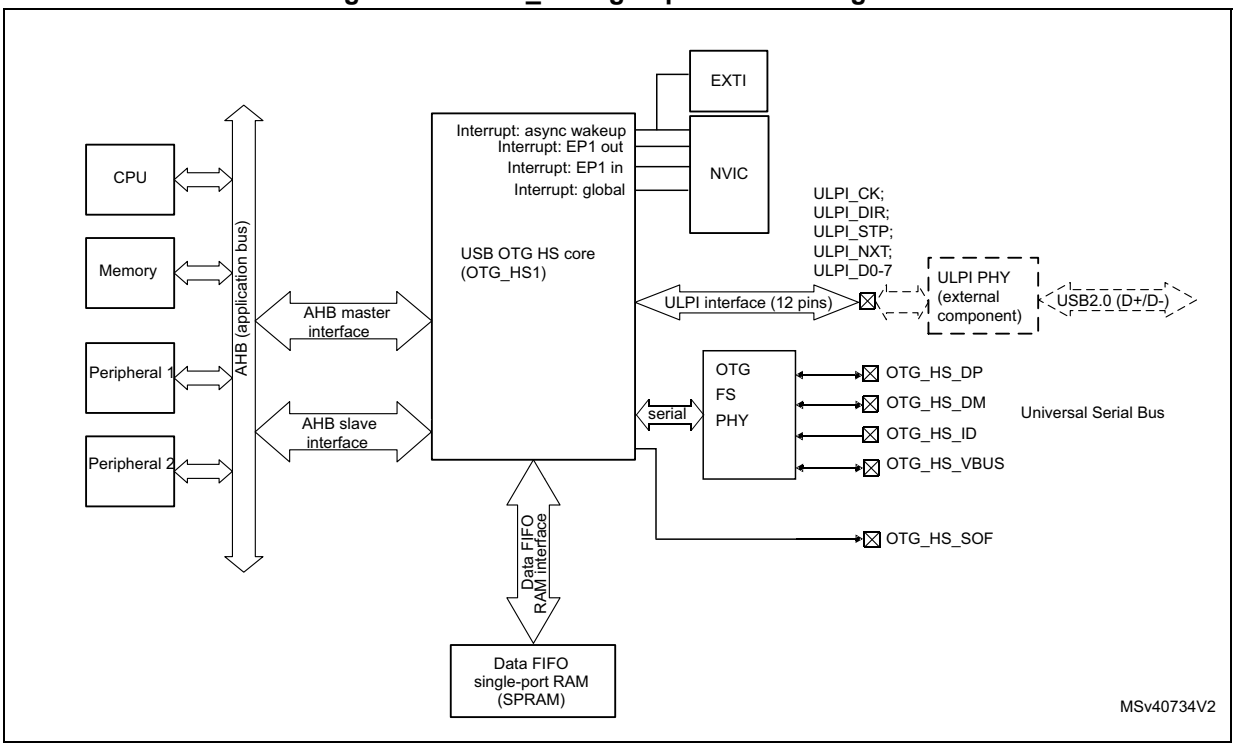
USB features	OTG_HS1
Device bidirectional endpoints (including EP0)	9
Host mode channels	16
Size of dedicated SRAM	4 Kbytes
USB 2.0 link power management (LPM) support	X
OTG revision supported	2.0
Attach detection protocol (ADP) support	-
Battery charging detection (BCD) support	X
ULPI available to primary IOs via, muxing	X
Integrated PHY	FS
Scatter/gather DMA	X

1. “X” = supported, “-” = not supported.

62.4 OTG_HS functional description

62.4.1 OTG_HS block diagram

Figure 779. OTG_HS high-speed block diagram



62.4.2 OTG_HS pin and internal signals

Table 532. OTG_HS input/output pins

Signal name	Signal type	Description
OTG_HS_DP	Digital input/output	USB OTG D+ line
OTG_HS_DM	Digital input/output	USB OTG D- line
OTG_HS_ID	Digital input	USB OTG ID
OTG_HS_VBUS	Analog input	USB OTG VBUS
OTG_HS_SOF	Digital output	USB OTG Start Of Frame (visibility)
OTG_HS_ULPI_CK	Digital input	USB OTG ULPI clock
OTG_HS_ULPI_DIR	Digital input	USB OTG ULPI data bus direction control
OTG_HS_ULPI_STP	Digital output	USB OTG ULPI data stream stop
OTG_HS_ULPI_NXT	Digital input	USB OTG ULPI next data stream request
OTG_HS_ULPI_D[0..7]	Digital input/output	USB OTG ULPI 8-bit bi-directional data bus

Table 533. OTG_HS input/output signals

Signal name	Signal type	Description
usb_sof	Digital output	USB OTG start-of-frame event for on chip peripherals
usb_wkup	Digital output	USB OTG wakeup event output
usb_gbl_it	Digital output	USB OTG global interrupt
usb_ep1_in_it	Digital output	USB OTG endpoint 1 in interrupt
usb_ep1_out_it	Digital output	USB OTG endpoint 1 out interrupt

62.4.3 OTG_HS core

The USB OTG_HS receives the 48 MHz clock from the reset and clock controller (RCC). This clock is used for driving the 48 MHz domain at full-speed (12 Mbit/s) and must be enabled prior to configuring the OTG core.

The CPU reads and writes from/to the OTG core registers through the AHB peripheral bus. It is informed of USB events through the single USB OTG interrupt line described in *Section 62.12: OTG_HS interrupts*.

The CPU submits data over the USB by writing 32-bit words to dedicated OTG locations (push registers). The data are then automatically stored into Tx-data FIFOs configured within the USB data RAM. There is one Tx FIFO push register for each in-endpoint (peripheral mode) or out-channel (host mode).

The CPU receives the data from the USB by reading 32-bit words from dedicated OTG addresses (pop registers). The data are then automatically retrieved from a shared Rx FIFO configured within the 4-Kbyte USB data RAM. There is one Rx FIFO pop register for each out-endpoint or in-channel.

The USB protocol layer is driven by the serial interface engine (SIE) and serialized over the USB by the transceiver module within the on-chip physical layer (PHY) or external HS PHY.

Caution: To guarantee a correct operation for the USB OTG_HS peripheral, the AHB frequency should be higher than 30 MHz.

62.4.4 Embedded full-speed OTG PHY connected to OTG_HS

The embedded full-speed OTG PHY is controlled by the OTG_HS core and conveys USB control & data signals through the full-speed subset of the UTMI+ Bus (UTMIFS). It provides the physical support to USB connectivity.
The full-speed OTG PHY includes the following components:

- FS/LS transceiver module used by both host and device. It directly drives transmission and reception on the single-ended USB lines.
- DP/DM integrated pull-up and pull-down resistors controlled by the OTG_HS core depending on the current role of the device. As a peripheral, it enables the DP pull-up resistor to signal full-speed peripheral connections as soon as V_{BUS} is sensed to be at a valid level (B-session valid). In host mode, pull-down resistors are enabled on both DP/DM. Pull-up and pull-down resistors are dynamically switched when the peripheral role is changed via the host negotiation protocol (HNP).
- Pull-up/pull-down resistor ECN circuit. The DP pull-up consists of 2 resistors controlled separately from the OTG_HS as per the resistor Engineering Change Notice applied to USB Rev2.0. The dynamic trimming of the DP pull-up strength allows to achieve a better noise rejection and Tx/Rx signal quality.

62.4.5 OTG detections

Additionally the OTG_HS uses the following functions:

- integrated ID pull-up resistor used to sample the ID line for A/B device identification.
- V_{BUS} sensing comparators with hysteresis used to detect V_{BUS} valid, A-B session valid and session-end voltage thresholds. They are used to drive the session request protocol (SRP), detect valid startup and end-of-session conditions, and constantly monitor the V_{BUS} supply during USB operations.

62.4.6 High-speed OTG PHY connected to OTG_HS

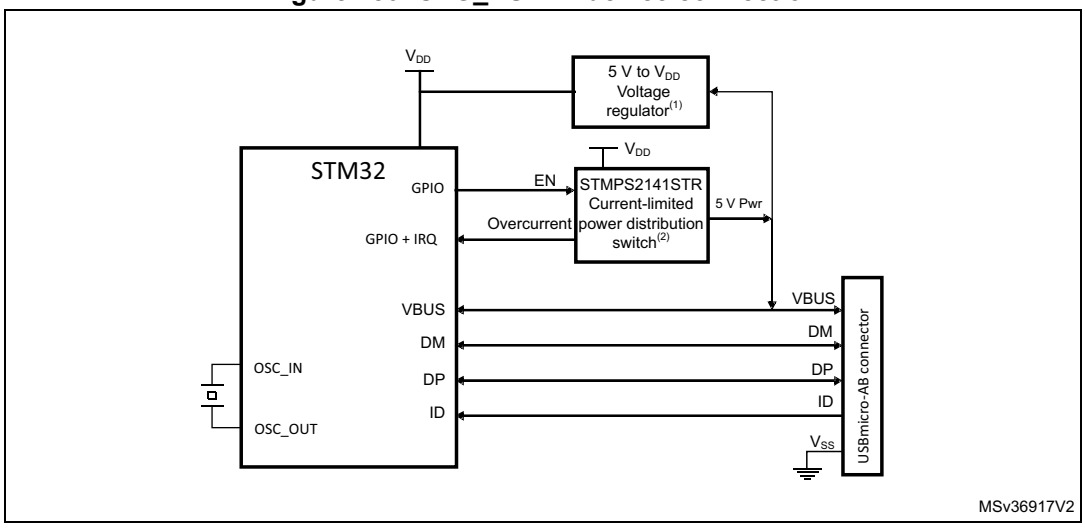
Note: Refer to implementation table to determine if an HS PHY is embedded.

The USB OTG_HS core includes an ULPI interface to connect an external HS PHY.

Note: In case of multiple OTG_HS instances, ULPI may not be available on each one. Refer to implementation table.

62.5 OTG_HS dual role device (DRD)

Figure 780. OTG_HS A-B device connection



1. External voltage regulator only needed when building a VBUS powered device.
2. STMPS2141STR needed only if the application has to support a VBUS powered device. A basic power switch can be used if 5 V are available on the application board.

62.5.1 ID line detection

The host or peripheral (the default) role is assumed depending on the ID input pin. The ID line status is determined on plugging in the USB cable, depending on whether a MicroA or MicroB plug is connected to the micro-AB receptacle.

- If the B-side of the USB cable is connected with a floating ID wire, the integrated pull-up resistor detects a high ID level and the default peripheral role is confirmed. In this configuration the OTG_HS complies with the standard FSM described in section 4.2.4: ID pin of the On-the-Go specification Rev2.0, supplement to the USB2.0.
- If the A-side of the USB cable is connected with a grounded ID, the OTG_HS issues an ID line status change interrupt (CIDSCHG bit in OTG_GINTSTS) for host software initialization, and automatically switches to the host role. In this configuration the OTG_HS complies with the standard FSM described by section 4.2.4: ID pin of the On-the-Go specification Rev2.0, supplement to the USB2.0.

62.5.2 HNP dual role device

The HNP capable bit in the Global USB configuration register (HNPCAP bit in OTG_ GUSBCFG) enables the OTG_HS core to dynamically change its role from A-host to A-peripheral and vice-versa, or from B-Peripheral to B-host and vice-versa according to the host negotiation protocol (HNP). The current device status can be read by the combined values of the connector ID status bit in the Global OTG control and status register (CIDSTS bit in OTG_GOTGCTL) and the current mode of operation bit in the global interrupt and status register (CMOD bit in OTG_GINTSTS).

The HNP program model is described in detail in *Section 62.15: OTG_HS programming model*.

62.5.3 SRP dual role device

The SRP capable bit in the global USB configuration register (SRPCAP bit in OTG_GUSBCFG) enables the OTG_HS core to switch off the generation of V_{BUS} for the A-device to save power. Note that the A-device is always in charge of driving V_{BUS} regardless of the host or peripheral role of the OTG_HS.

The SRP A/B-device program model is described in detail in *Section 62.15: OTG_HS programming model*.

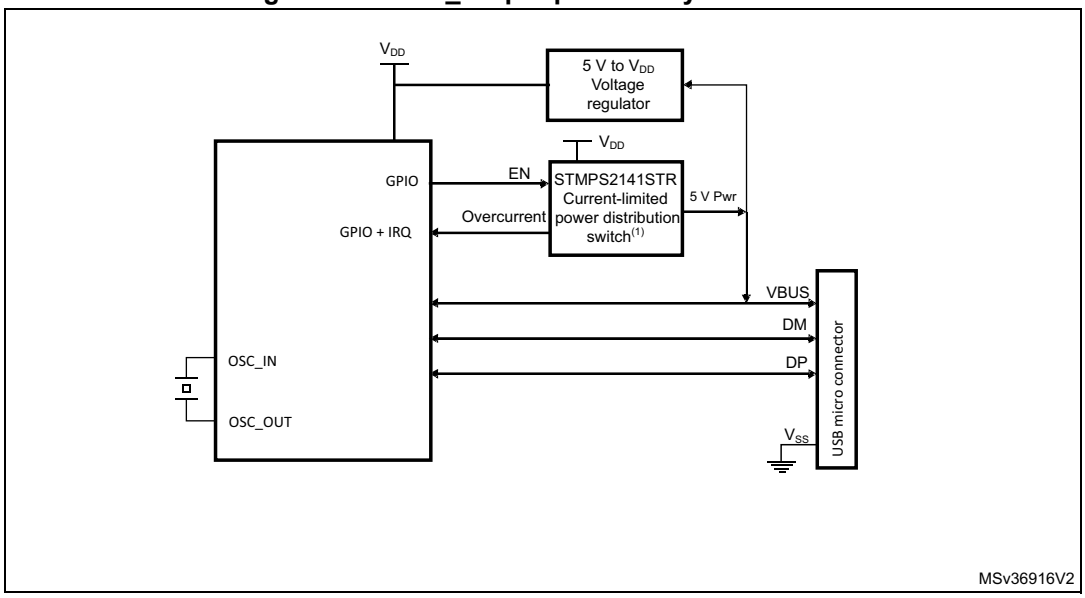
62.6 OTG_HS as a USB peripheral

This section gives the functional description of the OTG_HS in the USB peripheral mode. The OTG_HS works as an USB peripheral in the following circumstances:

- OTG B-Peripheral
  - OTG B-device default state if B-side of USB cable is plugged in
- OTG A-Peripheral
  - OTG A-device state after the HNP switches the OTG_HS to its peripheral role
- B-device
  - If the ID line is present, functional and connected to the B-side of the USB cable, and the HNP-capable bit in the Global USB Configuration register (HNPCAP bit in OTG_GUSBCFG) is cleared.
- Peripheral only
  - The force device mode bit (FDMOD) in the *Section 62.14.4: OTG USB configuration register (OTG_GUSBCFG)* is set to 1, forcing the OTG_HS core to work as an USB peripheral-only. In this case, the ID line is ignored even if it is present on the USB connector.

Note: To build a bus-powered device implementation in case of the B-device or peripheral-only configuration, an external regulator has to be added, that generates the necessary power-supply from V_{BUS}.

Figure 781. OTG_HS peripheral-only connection



1. Use a regulator to build a bus-powered device.

62.6.1 SRP-capable peripheral

The SRP capable bit in the Global USB configuration register (SRPCAP bit in OTG_GUSBCFG) enables the OTG_HS to support the session request protocol (SRP). In this way, it allows the remote A-device to save power by switching off V_{BUS} while the USB session is suspended.

The SRP peripheral mode program model is described in detail in the *B-device session request protocol* section.

62.6.2 Peripheral states

Powered state

The V_{BUS} input detects the B-session valid voltage by which the USB peripheral is allowed to enter the powered state (see USB2.0 section 9.1). The OTG_HS then automatically connects the DP pull-up resistor to signal full-speed device connection to the host and generates the session request interrupt (SRQINT bit in OTG_GINTSTS) to notify the powered state.

The V_{BUS} input also ensures that valid V_{BUS} levels are supplied by the host during USB operations. If a drop in V_{BUS} below B-session valid happens to be detected (for instance because of a power disturbance or if the host port has been switched off), the OTG_HS automatically disconnects and the session end detected (SEDET bit in OTG_GOTGINT) interrupt is generated to notify that the OTG_HS has exited the powered state.

In the powered state, the OTG_HS expects to receive some reset signaling from the host. No other USB operation is possible. When a reset signaling is received the reset detected interrupt (USBRST in OTG_GINTSTS) is generated. When the reset signaling is complete, the enumeration done interrupt (ENUMDNE bit in OTG_GINTSTS) is generated and the OTG_HS enters the Default state.

Soft disconnect

The powered state can be exited by software with the soft disconnect feature. The DP pull-up resistor is removed by setting the soft disconnect bit in the device control register (SDIS bit in OTG_DCTL), causing a device disconnect detection interrupt on the host side even though the USB cable was not really removed from the host port.

Default state

In the Default state the OTG_HS expects to receive a SET_ADDRESS command from the host. No other USB operation is possible. When a valid SET_ADDRESS command is decoded on the USB, the application writes the corresponding number into the device address field in the device configuration register (DAD bit in OTG_DCFG). The OTG_HS then enters the address state and is ready to answer host transactions at the configured USB address.

Suspended state

The OTG_HS peripheral constantly monitors the USB activity. After counting 3 ms of USB idleness, the early suspend interrupt (ESUSP bit in OTG_GINTSTS) is issued, and confirmed 3 ms later, if appropriate, by the suspend interrupt (USBSUSP bit in OTG_GINTSTS). The device suspend bit is then automatically set in the device status register (SUSPSTS bit in OTG_DSTS) and the OTG_HS enters the suspended state.

The suspended state may optionally be exited by the device itself. In this case the application sets the remote wakeup signaling bit in the device control register (RWUSIG bit in OTG_DCTL) and clears it after 1 to 15 ms.

When a resume signaling is detected from the host, the resume interrupt (WKUPINT bit in OTG_GINTSTS) is generated and the device suspend bit is automatically cleared.

62.6.3 Peripheral endpoints

The OTG_HS core instantiates the following USB endpoints:

- Control endpoint 0:
  - Bidirectional and handles control messages only
  - Separate set of registers to handle in and out transactions
  - Proper control (OTG_DIEPCTL0/OTG_DOEPCTL0), transfer configuration (OTG_DIEPTSIZ0/OTG_DOEPTSIZ0), and status-interrupt (OTG_DIEPINT0/)OTG_DOEPINT0) registers. The available set of bits inside the control and transfer size registers slightly differs from that of other endpoints
- 8 IN endpoints
  - Each of them can be configured to support the isochronous, bulk or interrupt transfer type
  - Each of them has proper control (OTG_DIEPCTL*x*), transfer configuration (OTG_DIEPTSIZ*x*), and status-interrupt (OTG_DIEPINT*x*) registers
  - The device IN endpoints common interrupt mask register (OTG_DIEPMSK) is available to enable/disable a single kind of endpoint interrupt source on all of the IN endpoints (EP0 included)
  - Support for incomplete isochronous IN transfer interrupt (IISOIXFR bit in OTG_GINTSTS), asserted when there is at least one isochronous IN endpoint on

which the transfer is not completed in the current frame. This interrupt is asserted along with the end of periodic frame interrupt (OTG_GINTSTS/EOPF).

- 8 OUT endpoints
  - Each of them can be configured to support the isochronous, bulk or interrupt transfer type
  - Each of them has a proper control (OTG_DOEPCTL*x*), transfer configuration (OTG_DOEPTSIZ*x*) and status-interrupt (OTG_DOEPINT*x*) register
  - Device OUT endpoints common interrupt mask register (OTG_DOEPMSK) is available to enable/disable a single kind of endpoint interrupt source on all of the OUT endpoints (EP0 included)
  - Support for incomplete isochronous OUT transfer interrupt (INCOMPISOOUT bit in OTG_GINTSTS), asserted when there is at least one isochronous OUT endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the end of periodic frame interrupt (OTG_GINTSTS/EOPF).

Endpoint control

- The following endpoint controls are available to the application through the device endpoint-*x* IN/OUT control register (OTG_DIEPCTL*x*/OTG_DOEPCTL*x*):
  - Endpoint enable/disable
  - Endpoint activate in current configuration
  - Program USB transfer type (isochronous, bulk, interrupt)
  - Program supported packet size
  - Program Tx FIFO number associated with the IN endpoint
  - Program the expected or transmitted data0/data1 PID (bulk/interrupt only)
  - Program the even/odd frame during which the transaction is received or transmitted (isochronous only)
  - Optionally program the NAK bit to always negative-acknowledge the host regardless of the FIFO status
  - Optionally program the STALL bit to always stall host tokens to that endpoint
  - Optionally program the SNOOP mode for OUT endpoint not to check the CRC field of received data

Endpoint transfer

The device endpoint-*x* transfer size registers (OTG_DIEPTSIZ*x*/OTG_DOEPTSIZ*x*) allow the application to program the transfer size parameters and read the transfer status. Programming must be done before setting the endpoint enable bit in the endpoint control register. Once the endpoint is enabled, these fields are read-only as the OTG_HS core updates them with the current transfer status.

The following transfer parameters can be programmed:

- Transfer size in bytes
- Number of packets that constitute the overall transfer size

Endpoint status/interrupt

The device endpoint-*x* interrupt registers (OTG_DIEPINT*x*/OTG_DOPEPINT*x)* indicate the status of an endpoint with respect to USB- and AHB-related events. The application must read these registers when the OUT endpoint interrupt bit or the IN endpoint interrupt bit in

the core interrupt register (OEPINT bit in OTG_GINTSTS or IEPINT bit in OTG_GINTSTS, respectively) is set. Before the application can read these registers, it must first read the device all endpoints interrupt (OTG_DAINT) register to get the exact endpoint number for the device endpoint-*x* interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_DAINT and OTG_GINTSTS registers

The peripheral core provides the following status checks and interrupt generation:

- Transfer completed interrupt, indicating that data transfer was completed on both the application (AHB) and USB sides
- Setup stage has been done (control-out only)
- Associated transmit FIFO is half or completely empty (in endpoints)
- NAK acknowledge has been transmitted to the host (isochronous-in only)
- IN token received when Tx FIFO was empty (bulk-in/interrupt-in only)
- Out token received when endpoint was not yet enabled
- Babble error condition has been detected
- Endpoint disable by application is effective
- Endpoint NAK by application is effective (isochronous-in only)
- More than 3 back-to-back setup packets were received (control-out only)
- Timeout condition detected (control-in only)
- Isochronous out packet has been dropped, without generating an interrupt

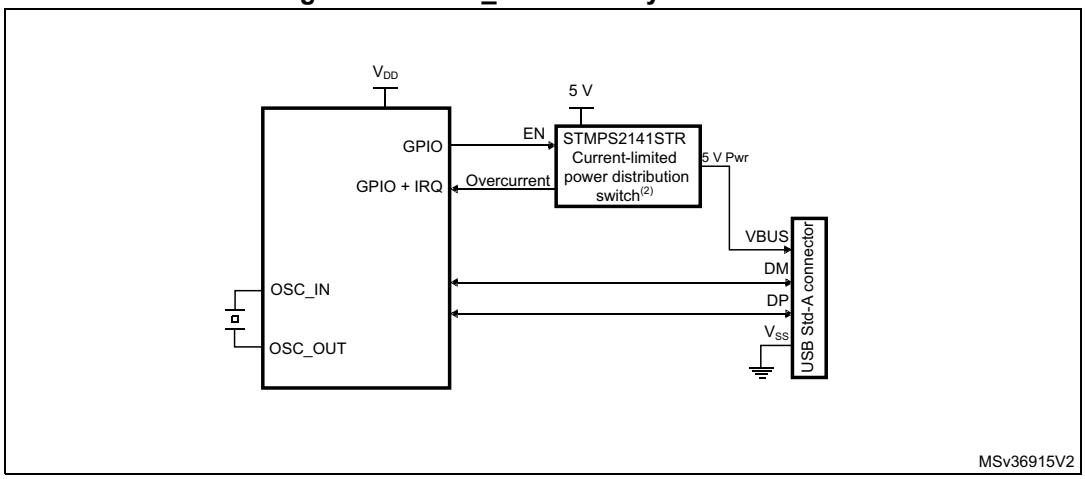
62.7 OTG_HS as a USB host

This section gives the functional description of the OTG_HS in the USB host mode. The OTG_HS works as a USB host in the following circumstances:

- OTG A-host
  - OTG A-device default state when the A-side of the USB cable is plugged in
- OTG B-host
  - OTG B-device after HNP switching to the host role
- A-device
  - If the ID line is present, functional and connected to the A-side of the USB cable, and the HNP-capable bit is cleared in the Global USB Configuration register (HNPCAP bit in OTG_GUSBCFG). Integrated pull-down resistors are automatically set on the DP/DM lines.
- Host only
  - The force host mode bit (FHMOD) in the *OTG USB configuration register (OTG_GUSBCFG)* forces the OTG_HS core to work as a USB host-only. In this case, the ID line is ignored even if present on the USB connector. Integrated pull-down resistors are automatically set on the DP/DM lines.

Note: On-chip 5 V V_{BUS} generation is not supported. For this reason, a charge pump or, if 5 V are available on the application board, a basic power switch must be added externally to drive the 5 V V_{BUS} line. The external charge pump can be driven by any GPIO output. This is required for the OTG A-host, A-device and host-only configurations.

Figure 782. OTG_HS host-only connection



1. V_{DD} range is between 2 V and 3.6 V.

62.7.1 SRP-capable host

SRP support is available through the SRP capable bit in the global USB configuration register (SRPCAP bit in OTG_GUSBCFG). With the SRP feature enabled, the host can save power by switching off the V_{BUS} power while the USB session is suspended.

The SRP host mode program model is described in detail in the *A-device session request protocol*) section.

62.7.2 USB host states

Host port power

On-chip 5 V V_{BUS} generation is not supported. For this reason, a charge pump or, if 5 V are available on the application board, a basic power switch, must be added externally to drive the 5 V V_{BUS} line. The external charge pump can be driven by any GPIO output or via an I^2C interface connected to an external PMIC (power management IC). When the application decides to power on V_{BUS}, it must also set the port power bit in the host port control and status register (PPWR bit in OTG_HPRT).

V_{BUS} valid

When HNP or SRP is enabled the VBUS sensing pin should be connected to V_{BUS}. The V_{BUS} input ensures that valid V_{BUS} levels are supplied by the charge pump during USB operations. Any unforeseen V_{BUS} voltage drop below the V_{BUS} valid threshold (4.4 V) leads to an OTG interrupt triggered by the session end detected bit (SEDET bit in OTG_GOTGINT). The application is then required to remove the V_{BUS} power and clear the port power bit.

When HNP and SRP are both disabled, the VBUS sensing pin does not need to be connected to V_{BUS}.

The charge pump overcurrent flag can also be used to prevent electrical damage. Connect the overcurrent flag output from the charge pump to any GPIO input and configure it to generate a port interrupt on the active level. The overcurrent ISR must promptly disable the V_{BUS} generation and clear the port power bit.

Host detection of a peripheral connection

If SRP or HNP are enabled, even if USB peripherals or B-devices can be attached at any time, the OTG_HS does not detect any bus connection until V_{BUS} is no longer sensed at a valid level (5 V). When V_{BUS} is at a valid level and a remote B-device is attached, the OTG_HS core issues a host port interrupt triggered by the device connected bit in the host port control and status register (PCDET bit in OTG_HPRT).

When HNP and SRP are both disabled, USB peripherals or B-device are detected as soon as they are connected. The OTG_HS core issues a host port interrupt triggered by the device connected bit in the host port control and status (PCDET bit in OTG_HPRT).

Host detection of peripheral a disconnection

The peripheral disconnection event triggers the disconnect detected interrupt (DISCINT bit in OTG_GINTSTS).

Host enumeration

After detecting a peripheral connection the host must start the enumeration process by sending USB reset and configuration commands to the new peripheral.

Before starting to drive a USB reset, the application waits for the OTG interrupt triggered by the debounce done bit (DBCDNE bit in OTG_GOTGINT), which indicates that the bus is stable again after the electrical debounce caused by the attachment of a pull-up resistor on DP (FS) or DM (LS).

The application drives a USB reset signaling (single-ended zero) over the USB by keeping the port reset bit set in the host port control and status register (PRST bit in OTG_HPRT) for a minimum of 10 ms and a maximum of 20 ms. The application takes care of the timing count and then of clearing the port reset bit.

Once the USB reset sequence has completed, the host port interrupt is triggered by the port enable/disable change bit (PENCHNG bit in OTG_HPRT). This informs the application that the speed of the enumerated peripheral can be read from the port speed field in the host port control and status register (PSPD bit in OTG_HPRT) and that the host is starting to drive SOFs (FS) or Keep alives (LS). The host is now ready to complete the peripheral enumeration by sending peripheral configuration commands.

Host suspend

The application decides to suspend the USB activity by setting the port suspend bit in the host port control and status register (PSUSP bit in OTG_HPRT). The OTG_HS core stops sending SOFs and enters the suspended state.

The suspended state can be optionally exited on the remote device's initiative (remote wakeup). In this case the remote wakeup interrupt (WKUPINT bit in OTG_GINTSTS) is generated upon detection of a remote wakeup signaling, the port resume bit in the host port control and status register (PRES bit in OTG_HPRT) self-sets, and resume signaling is automatically driven over the USB. The application must time the resume window and then clear the port resume bit to exit the suspended state and restart the SOF.

If the suspended state is exited on the host initiative, the application must set the port resume bit to start resume signaling on the host port, time the resume window and finally clear the port resume bit.

62.7.3 Host channels

The OTG_HS core instantiates 16 host channels. Each host channel supports an USB host transfer (USB pipe). The host is not able to support more than 16 transfer requests at the same time. If more than 16 transfer requests are pending from the application, the host controller driver (HCD) must re-allocate channels when they become available from previous duty, that is, after receiving the transfer completed and channel halted interrupts.

Each host channel can be configured to support in/out and any type of periodic/nonperiodic transaction. Each host channel makes us of proper control (OTG_HCCHAR*x*), transfer configuration (OTG_HCTSIZ*x*) and status/interrupt (OTG_HCINT*x*) registers with associated mask (OTG_HCINTMSK*x*) registers.

Host channel control

- The following host channel controls are available to the application through the host channel-*x* characteristics register (OTG_HCCHAR*x*):
  - Channel enable/disable
  - Program the HS/FS/LS speed of target USB peripheral
  - Program the address of target USB peripheral
  - Program the endpoint number of target USB peripheral
  - Program the transfer IN/OUT direction
  - Program the USB transfer type (control, bulk, interrupt, isochronous)
  - Program the maximum packet size (MPS)
  - Program the periodic transfer to be executed during odd/even frames

Host channel transfer

The host channel transfer size registers (OTG_HCTSIZ*x*) allow the application to program the transfer size parameters, and read the transfer status. Programming must be done before setting the channel enable bit in the host channel characteristics register. Once the endpoint is enabled the packet count field is read-only as the OTG_HS core updates it according to the current transfer status.

- The following transfer parameters can be programmed:
  - transfer size in bytes
  - number of packets making up the overall transfer size
  - initial data PID

Host channel status/interrupt

The host channel-*x* interrupt register (OTG_HCINT*x*) indicates the status of an endpoint with respect to USB- and AHB-related events. The application must read these register when the host channels interrupt bit in the core interrupt register (HCINT bit in OTG_GINTSTS) is set. Before the application can read these registers, it must first read the host all channels interrupt (OTG_HAINT) register to get the exact channel number for the host channel-x interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_HAINT and OTG_GINTSTS registers.

The mask bits for each interrupt source of each channel are also available in the OTG_HCINTMSKx register.

- The host core provides the following status checks and interrupt generation:
  - Transfer completed interrupt, indicating that the data transfer is complete on both the application (AHB) and USB sides
  - Channel has stopped due to transfer completed, USB transaction error or disable command from the application
  - Associated transmit FIFO is half or completely empty (IN endpoints)
  - ACK response received
  - NAK response received
  - STALL response received
  - USB transaction error due to CRC failure, timeout, bit stuff error, false EOP
  - Babble error
  - frame overrun
  - data toggle error

62.7.4 Host scheduler

The host core features a built-in hardware scheduler which is able to autonomously re-order and manage the USB transaction requests posted by the application. At the beginning of each frame the host executes the periodic (isochronous and interrupt) transactions first, followed by the nonperiodic (control and bulk) transactions to achieve the higher level of priority granted to the isochronous and interrupt transfer types by the USB specification.

The host processes the USB transactions through request queues (one for periodic and one for nonperiodic). Each request queue can hold up to 8 entries. Each entry represents a pending transaction request from the application, and holds the IN or OUT channel number along with other information to perform a transaction on the USB. The order in which the requests are written to the queue determines the sequence of the transactions on the USB interface.

At the beginning of each frame, the host processes the periodic request queue first, followed by the nonperiodic request queue. The host issues an incomplete periodic transfer interrupt (IPXFR bit in OTG_GINTSTS) if an isochronous or interrupt transaction scheduled for the current frame is still pending at the end of the current frame. The OTG_HS core is fully responsible for the management of the periodic and nonperiodic request queues.The periodic transmit FIFO and queue status register (OTG_HPTXSTS) and nonperiodic transmit FIFO and queue status register (OTG_HNPTXSTS) are read-only registers which can be used by the application to read the status of each request queue. They contain:

- The number of free entries currently available in the periodic (nonperiodic) request queue (8 max)
- Free space currently available in the periodic (nonperiodic) Tx FIFO (out-transactions)
- IN/OUT token, host channel number and other status information.

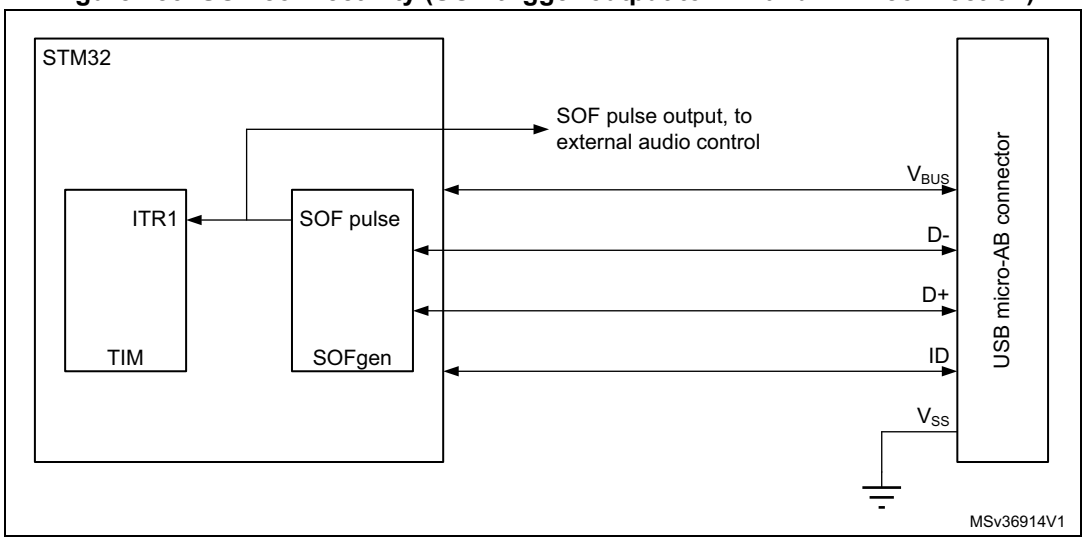
As request queues can hold a maximum of 8 entries each, the application can push to schedule host transactions in advance with respect to the moment they physically reach the SB for a maximum of 8 pending periodic transactions plus 8 pending non-periodic transactions.

To post a transaction request to the host scheduler (queue) the application must check that there is at least 1 entry available in the periodic (nonperiodic) request queue by reading the

PTXQSAV bits in the OTG_HNPTXSTS register or NPTQXSAV bits in the OTG_HNPTXSTS register.

62.8 OTG_HS SOF trigger

Figure 783. SOF connectivity (SOF trigger output to TIM and ITR1 connection)



The OTG_HS core provides means to monitor, track and configure SOF framing in the host and peripheral, as well as an SOF pulse output connectivity feature.

Such utilities are especially useful for adaptive audio clock generation techniques, where the audio peripheral needs to synchronize to the isochronous stream provided by the PC, or the host needs to trim its framing rate according to the requirements of the audio peripheral.

62.8.1 Host SOFs

In host mode the number of PHY clocks occurring between the generation of two consecutive SOF (HS/FS) or Keep-alive (LS) tokens is programmable in the host frame interval register (HFIR), thus providing application control over the SOF framing period. An interrupt is generated at any start of frame (SOF bit in OTG_GINTSTS). The current frame number and the time remaining until the next SOF are tracked in the host frame number register (HFNUM).

A SOF pulse signal, is generated at any SOF starting token and with a width of 20 HCLK cycles. The SOF pulse is also internally connected to the input trigger of the timer, so that the input capture feature, the output compare feature and the timer can be triggered by the SOF pulse.

62.8.2 Peripheral SOFs

In device mode, the start of frame interrupt is generated each time an SOF token is received on the USB (SOF bit in OTG_GINTSTS). The corresponding frame number can be read from the device status register (FNSOF bit in OTG_DSTS). A SOF pulse signal with a width of 20 HCLK cycles is also generated.The SOF pulse signal is also internally connected to the TIM input trigger, so that the input capture feature, the output compare feature and the timer can be triggered by the SOF pulse.

The end of periodic frame interrupt (OTG_GINTSTS/EOPF) is used to notify the application when 80%, 85%, 90% or 95% of the time frame interval elapsed depending on the periodic frame interval field in the device configuration register (PFIVL bit in OTG_DCFG). This feature can be used to determine if all of the isochronous traffic for that frame is complete.

62.9 OTG_HS low-power modes

Table 534 below defines the STM32 low power modes and their compatibility with the OTG.

Table 534. Compatibility of STM32 low power modes with the OTG

Mode	Description	USB compatibility
Run	MCU fully active	Required when USB not in suspend state.
Sleep	USB suspend exit causes the device to exit Sleep mode. Peripheral registers content is kept.	Available while USB is in suspend state.
Stop	USB suspend exit causes the device to exit Stop mode. Peripheral registers content is kept(1).	Available while USB is in suspend state.
Standby	Powered-down. The peripheral must be reinitialized after exiting Standby mode.	Not compatible with USB applications.

1. Within Stop mode there are different possible settings. Some restrictions may also exist, please refer to *Section 6: Power control (PWR)* to understand which (if any) restrictions apply when using OTG.

The following bits and procedures reduce power consumption.

The power consumption of the OTG PHY is controlled by two or three bits in the general core configuration register, depending on OTG revision supported.

- PHY power down (OTG_GCCFG/PWRDWN)

  It switches on/off the full-speed transceiver module of the PHY. It must be preliminarily set to allow any USB operation
- V_{BUS} detection enable (OTG_GCCFG/VBDEN)

  It switches on/off the V_{BUS} sensing comparators associated with OTG operations

Power reduction techniques are available while in the USB suspended state, when the USB session is not yet valid or the device is disconnected.

- Stop PHY clock (STPPCLK bit in OTG_PCGCCTL)

  When setting the stop PHY clock bit in the clock gating control register, most of the 48 MHz clock domain internal to the OTG core is switched off by clock gating. The dynamic power consumption due to the USB clock switching activity is cut even if the 48 MHz clock input is kept running by the application

  Most of the transceiver is also disabled, and only the part in charge of detecting the asynchronous resume or remote wakeup event is kept alive.
- Gate HCLK (GATEHCLK bit in OTG_PCGCCTL)

  When setting the Gate HCLK bit in the clock gating control register, most of the system clock domain internal to the OTG_HS core is switched off by clock gating. Only the register read and write interface is kept alive. The dynamic power consumption due to

the USB clock switching activity is cut even if the system clock is kept running by the application for other purposes.

- USB system stop

  When the OTG_HS is in the USB suspended state, the application may decide to drastically reduce the overall power consumption by a complete shut down of all the clock sources in the system. USB System Stop is activated by first setting the Stop PHY clock bit and then configuring the system deep sleep mode in the power control system module (PWR).

  The OTG_HS core automatically reactivates both system and USB clocks by asynchronous detection of remote wakeup (as an host) or resume (as a device) signaling on the USB.

To save dynamic power, the USB data FIFO is clocked only when accessed by the OTG_HS core.

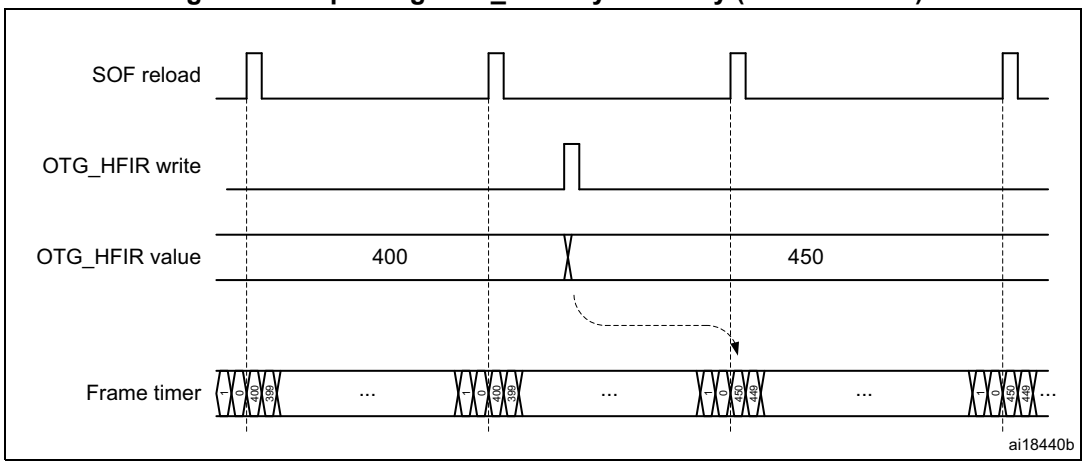
62.10 OTG_HS Dynamic update of the OTG_HFIR register

The USB core embeds a dynamic trimming capability of micro-SOF framing period in host mode allowing to synchronize an external device with the micro-SOF frames.

When the OTG_HFIR register is changed within a current micro-SOF frame, the SOF period correction is applied in the next frame as described in *Figure 784*.

For a dynamic update, it is required to set RLDCTRL=1.

Figure 784. Updating OTG_HFIR dynamically (RLDCTRL = 1)

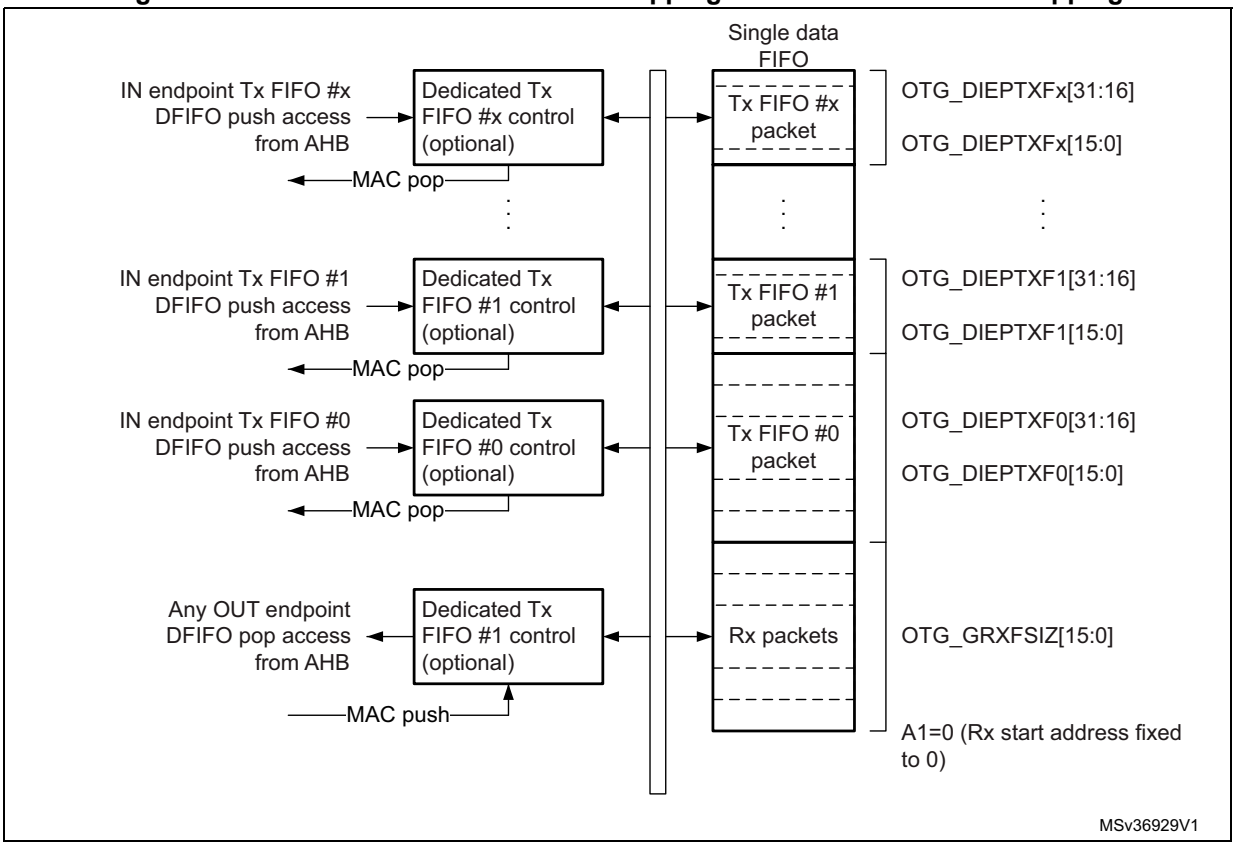


62.11 OTG_HS data FIFOs

The USB system features 4 Kbytes of dedicated RAM with a sophisticated FIFO control mechanism. The packet FIFO controller module in the OTG_HS core organizes RAM space into Tx FIFOs into which the application pushes the data to be temporarily stored before the USB transmission, and into a single Rx FIFO where the data received from the USB are temporarily stored before retrieval (popped) by the application. The number of instructed FIFOs and how these are organized inside the RAM depends on the device's role. In peripheral mode an additional Tx FIFO is instructed for each active IN endpoint. Any FIFO size is software configured to better meet the application requirements.

62.11.1 Peripheral FIFO architecture

Figure 785. Device-mode FIFO address mapping and AHB FIFO access mapping



Peripheral Rx FIFO

The OTG peripheral uses a single receive FIFO that receives the data directed to all OUT endpoints. Received packets are stacked back-to-back until free space is available in the Rx FIFO. The status of the received packet (which contains the OUT endpoint destination number, the byte count, the data PID and the validity of the received data) is also stored by the core on top of the data payload. When no more space is available, host transactions are NACKed and an interrupt is received on the addressed endpoint. The size of the receive FIFO is configured in the receive FIFO size register (OTG_GRXFSIZ).

The single receive FIFO architecture makes it more efficient for the USB peripheral to fill in the receive RAM buffer:

- All OUT endpoints share the same RAM buffer (shared FIFO)
- The OTG_HS core can fill in the receive FIFO up to the limit for any host sequence of OUT tokens

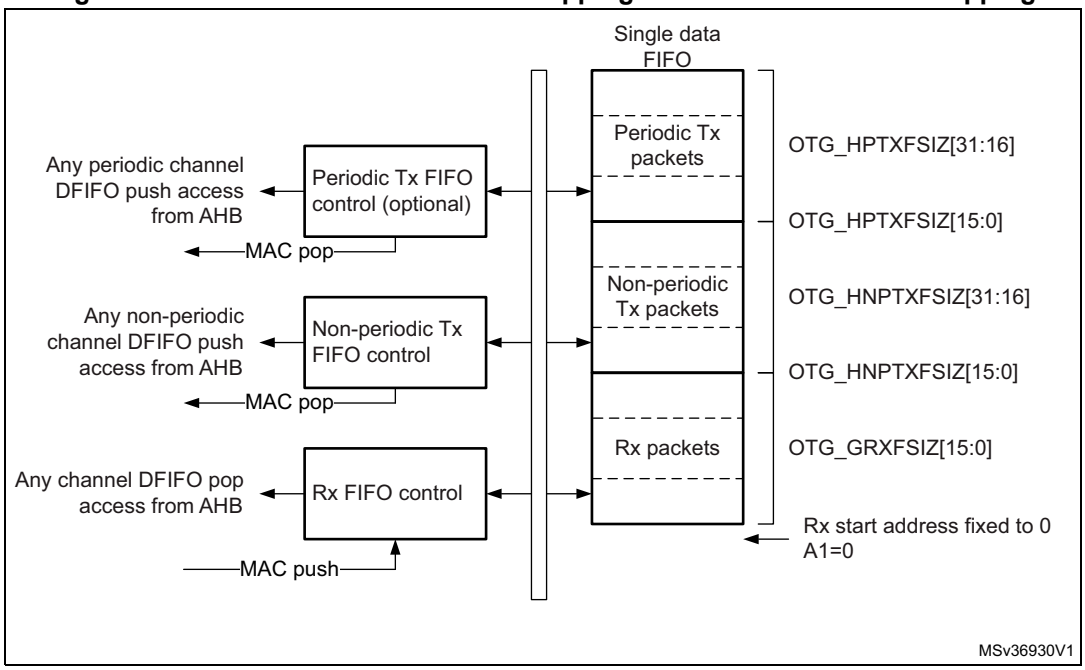
The application keeps receiving the Rx FIFO non-empty interrupt (RXFLVL bit in OTG_GINTSTS) as long as there is at least one packet available for download. It reads the packet information from the receive status read and pop register (OTG_GRXSTSP) and finally pops data off the receive FIFO by reading from the endpoint-related pop address.

Peripheral Tx FIFOs

The core has a dedicated FIFO for each IN endpoint. The application configures FIFO sizes by writing the endpoint 0 transmit FIFO size register (OTG_DIEPTXF0) for IN endpoint0 and the device IN endpoint transmit FIFOx registers (OTG_DIEPTXFx) for IN endpoint-x.

62.11.2 Host FIFO architecture

Figure 786. Host-mode FIFO address mapping and AHB FIFO access mapping



Host Rx FIFO

The host uses one receiver FIFO for all periodic and nonperiodic transactions. The FIFO is used as a receive buffer to hold the received data (payload of the received packet) from the USB until it is transferred to the system memory. Packets received from any remote IN endpoint are stacked back-to-back until free space is available. The status of each received packet with the host channel destination, byte count, data PID and validity of the received data are also stored into the FIFO. The size of the receive FIFO is configured in the receive FIFO size register (OTG_GRXFSIZ).

The single receive FIFO architecture makes it highly efficient for the USB host to fill in the receive data buffer:

- All IN configured host channels share the same RAM buffer (shared FIFO)
- The OTG_HS core can fill in the receive FIFO up to the limit for any sequence of IN tokens driven by the host software

The application receives the Rx FIFO not-empty interrupt as long as there is at least one packet available for download. It reads the packet information from the receive status read and pop register and finally pops the data off the receive FIFO.

Host Tx FIFOs

The host uses one transmit FIFO for all non-periodic (control and bulk) OUT transactions and one transmit FIFO for all periodic (isochronous and interrupt) OUT transactions. FIFOs are used as transmit buffers to hold the data (payload of the transmit packet) to be transmitted over the USB. The size of the periodic (nonperiodic) Tx FIFO is configured in the host periodic (nonperiodic) transmit FIFO size OTG_HPTXFSIZ / OTG_HNPTXFSIZ) register.

The two Tx FIFO implementation derives from the higher priority granted to the periodic type of traffic over the USB frame. At the beginning of each frame, the built-in host scheduler processes the periodic request queue first, followed by the nonperiodic request queue.

The two transmit FIFO architecture provides the USB host with separate optimization for periodic and nonperiodic transmit data buffer management:

- All host channels configured to support periodic (nonperiodic) transactions in the OUT direction share the same RAM buffer (shared FIFOs)
- The OTG_HS core can fill in the periodic (nonperiodic) transmit FIFO up to the limit for any sequence of OUT tokens driven by the host software

The OTG_HS core issues the periodic Tx FIFO empty interrupt (PTXFE bit in OTG_GINTSTS) as long as the periodic Tx FIFO is half or completely empty, depending on the value of the periodic Tx FIFO empty level bit in the AHB configuration register (PTXFELVL bit in OTG_GAHBCFG). The application can push the transmission data in advance as long as free space is available in both the periodic Tx FIFO and the periodic request queue. The host periodic transmit FIFO and queue status register (OTG_HPTXSTS) can be read to know how much space is available in both.

OTG_HS core issues the non periodic Tx FIFO empty interrupt (NPTXFE bit in OTG_GINTSTS) as long as the nonperiodic Tx FIFO is half or completely empty depending on the non periodic Tx FIFO empty level bit in the AHB configuration register (TXFELVL bit in OTG_GAHBCFG). The application can push the transmission data as long as free space is available in both the nonperiodic Tx FIFO and nonperiodic request queue. The host nonperiodic transmit FIFO and queue status register (OTG_HNPTXSTS) can be read to know how much space is available in both.

62.11.3 FIFO RAM allocation

Device mode

Receive FIFO RAM allocation: the application should allocate RAM for SETUP packets:

- 10 locations must be reserved in the receive FIFO to receive SETUP packets on control endpoint. The core does not use these locations, which are reserved for SETUP packets, to write any other data.
- One location is to be allocated for Global OUT NAK.
- Status information is written to the FIFO along with each received packet. Therefore, a minimum space of (largest packet size / 4) + 1 must be allocated to receive packets. If multiple isochronous endpoints are enabled, then at least two (largest packet size / 4) + 1 spaces must be allocated to receive back-to-back packets. Typically, two (largest packet size / 4) + 1 spaces are recommended so that when the previous packet is being transferred to the CPU, the USB can receive the subsequent packet.
- Along with the last packet for each endpoint, transfer complete status information is also pushed to the FIFO. One location for each OUT endpoint is recommended.

Device RxFIFO =

(5 * number of control endpoints + 8) + ((largest USB packet used / 4) + 1 for status information) + (2 * number of OUT endpoints) + 1 for Global NAK

Example: The MPS is 1,024 bytes for a periodic USB packet and 512 bytes for a non-periodic USB packet. There are three OUT endpoints, three IN endpoints, one control endpoint, and three host channels.

Device RxFIFO = (5 * 1 + 8) + ((1,024 / 4) +1) + (2 * 4) + 1 = 279

Transmit FIFO RAM allocation: the minimum RAM space required for each IN endpoint Transmit FIFO is the maximum packet size for that particular IN endpoint.

Note: More space allocated in the transmit IN endpoint FIFO results in better performance on the USB.

Host mode

Receive FIFO RAM allocation:

Status information is written to the FIFO along with each received packet. Therefore, a minimum space of (largest packet size / 4) + 1 must be allocated to receive packets. If multiple isochronous channels are enabled, then at least two (largest packet size / 4) + 1 spaces must be allocated to receive back-to-back packets. Typically, two (largest packet size / 4) + 1 spaces are recommended so that when the previous packet is being transferred to the CPU, the USB can receive the subsequent packet.

Along with the last packet in the host channel, transfer complete status information is also pushed to the FIFO. So one location must be allocated for this.

Host RxFIFO = (largest USB packet used / 4) + 1 for status information + 1 transfer complete

Example: Host RxFIFO = ((1,024 / 4) + 1) + 1 = 258

Transmit FIFO RAM allocation:

The minimum amount of RAM required for the host Non-periodic Transmit FIFO is the largest maximum packet size among all supported non-periodic OUT channels.

Typically, two largest packet sizes worth of space is recommended, so that when the current packet is under transfer to the USB, the CPU can get the next packet.

Non-Periodic TxFIFO = largest non-periodic USB packet used / 4

Example: Non-Periodic TxFIFO = (512 / 4) = 128

The minimum amount of RAM required for host periodic Transmit FIFO is the largest maximum packet size out of all the supported periodic OUT channels. If there is at least one isochronous OUT endpoint, then the space must be at least two times the maximum packet size of that channel.

Host Periodic TxFIFO = largest periodic USB packet used / 4

Example: Host Periodic TxFIFO = (1,024 / 4) = 256

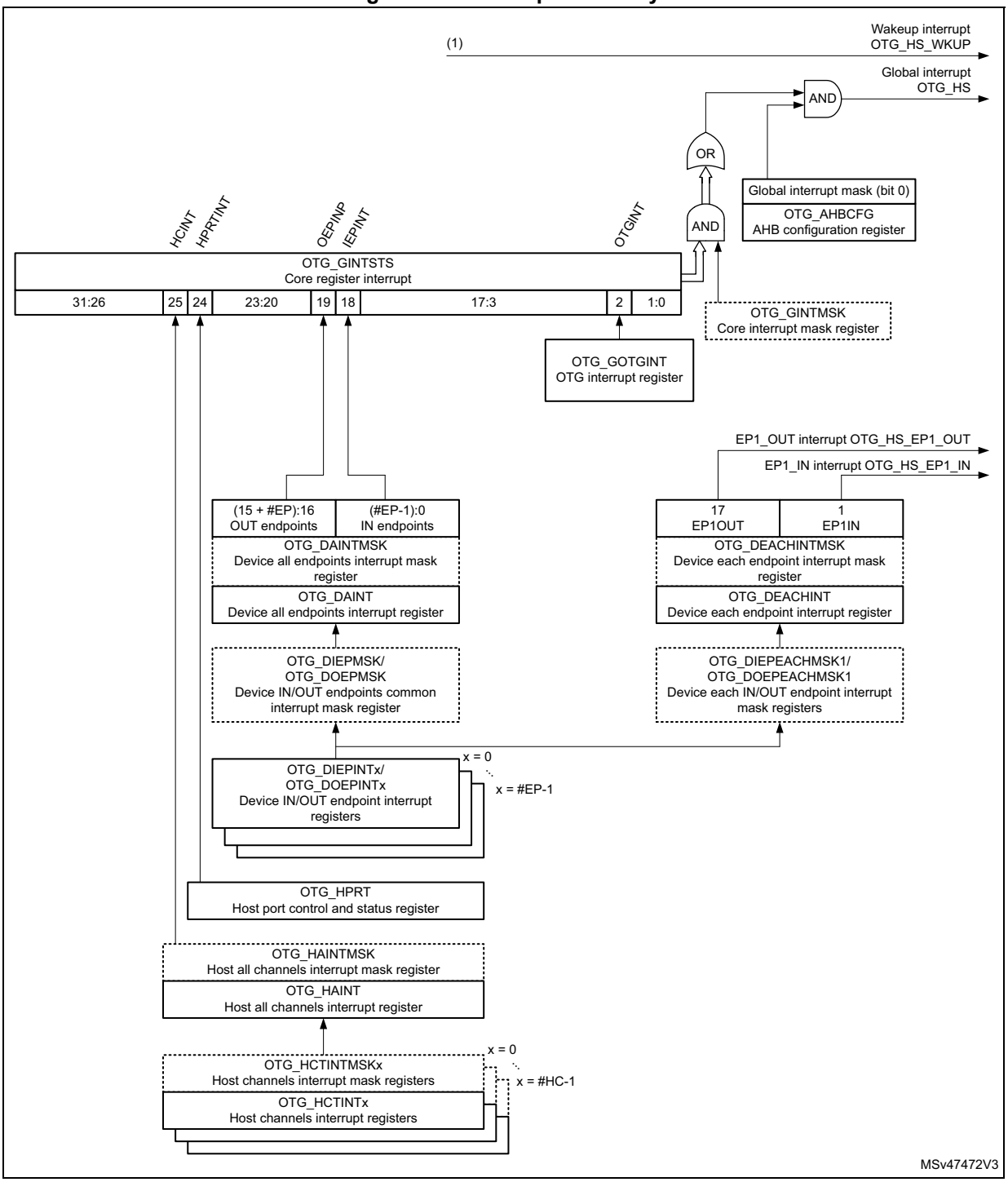
Note: More space allocated in the Transmit Non-periodic FIFO results in better performance on the USB.

62.12 OTG_HS interrupts

When the OTG_HS controller is operating in one mode, either device or host, the application must not access registers from the other mode. If an illegal access occurs, a mode mismatch interrupt is generated and reflected in the core interrupt register (MMIS bit in the OTG_GINTSTS register). When the core switches from one mode to the other, the registers in the new mode of operation must be reprogrammed as they would be after a power-on reset.

Figure 787 shows the interrupt hierarchy.

Figure 787. Interrupt hierarchy



1. OTG_HS_WKUP becomes active (high state) when resume condition occurs during L1 SLEEP or L2 SUSPEND states.

62.13 OTG_HS control and status registers

By reading from and writing to the control and status registers (CSRs) through the AHB slave interface, the application controls the OTG_HS controller. These registers are 32 bits wide, and the addresses are 32-bit block aligned. The OTG_HS registers must be accessed by words (32 bits).

CSRs are classified as follows:

- Core global registers
- Host-mode registers
- Host global registers
- Host port CSRs
- Host channel-specific registers
- Device-mode registers
- Device global registers
- Device endpoint-specific registers
- Power and clock-gating registers
- Data FIFO (DFIFO) access registers

Only the core global, power and clock-gating, data FIFO access, and host port control and status registers can be accessed in both host and device modes. When the OTG_HS controller is operating in one mode, either device or host, the application must not access registers from the other mode. If an illegal access occurs, a mode mismatch interrupt is generated and reflected in the core interrupt register (MMIS bit in the OTG_GINTSTS register). When the core switches from one mode to the other, the registers in the new mode of operation must be reprogrammed as they would be after a power-on reset.

62.13.1 CSR memory map

The host and device mode registers occupy different addresses. All registers are implemented in the AHB clock domain.

Global CSR map

These registers are available in both host and device modes.

Table 535. Core global control and status registers (CSRs)

Acronym	Address offset	Register name
OTG_GOTGCTL	0x000	*Section 62.14.1: OTG control and status register (OTG_GOTGCTL)*
OTG_GOTGINT	0x004	*Section 62.14.2: OTG interrupt register (OTG_GOTGINT)*
OTG_GAHBCFG	0x008	*Section 62.14.3: OTG AHB configuration register (OTG_GAHBCFG)*
OTG_GUSBCFG	0x00C	*Section 62.14.4: OTG USB configuration register (OTG_GUSBCFG)*
OTG_GRSTCTL	0x010	*Section 62.14.5: OTG reset register (OTG_GRSTCTL)*
OTG_GINTSTS	0x014	*Section 62.14.6: OTG core interrupt register (OTG_GINTSTS)*
OTG_GINTMSK	0x018	*Section 62.14.7: OTG interrupt mask register (OTG_GINTMSK)*

Table 535. Core global control and status registers (CSRs) (continued)

Acronym	Address offset	Register name
OTG_GRXSTSR	0x01C	*Section 62.14.8: OTG receive status debug read register (OTG_GRXSTSR)*
		Section 62.14.9: OTG receive status debug read [alternate] (OTG_GRXSTSR)
OTG_GRXSTSP	0x020	*Section 62.14.10: OTG status read and pop registers (OTG_GRXSTSP)*
		Section 62.14.11: OTG status read and pop registers [alternate] (OTG_GRXSTSP)
OTG_GRXFSIZ	0x024	*Section 62.14.12: OTG receive FIFO size register (OTG_GRXFSIZ)*
OTG_HNPTXFSIZ/ OTG_DIEPTXF0(1)	0x028	*Section 62.14.13: OTG host non-periodic transmit FIFO size register (OTG_HNPTXFSIZ)/Endpoint 0 Transmit FIFO size (OTG_DIEPTXF0)*
OTG_HNPTXSTS	0x02C	*Section 62.14.14: OTG non-periodic transmit FIFO/queue status register (OTG_HNPTXSTS)*
OTG_GCCFG	0x038	*Section 62.14.15: OTG general core configuration register (OTG_GCCFG)*
OTG_CID	0x03C	*Section 62.14.16: OTG core ID register (OTG_CID)*
OTG_GLPMCFG	0x54	*Section 62.14.17: OTG core LPM configuration register (OTG_GLPMCFG)*
OTG_HPTXFSIZ	0x100	*Section 62.14.18: OTG host periodic transmit FIFO size register (OTG_HPTXFSIZ)*
OTG_DIEPTXFx	0x104 0x108 ... 0x120	*Section 62.14.19: OTG device IN endpoint transmit FIFO x size register (OTG_DIEPTXFx)*

1. The general rule is to use OTG_HNPTXFSIZ for host mode and OTG_DIEPTXF0 for device mode.

Host-mode CSR map

These registers must be programmed every time the core changes to host mode.

Table 536. Host-mode control and status registers (CSRs)

Acronym	Offset address	Register name
OTG_HCFG	0x400	*Section 62.14.21: OTG host configuration register (OTG_HCFG)*
OTG_HFIR	0x404	*Section 62.14.22: OTG host frame interval register (OTG_HFIR)*
OTG_HFNUM	0x408	*Section 62.14.23: OTG host frame number/frame time remaining register (OTG_HFNUM)*
OTG_HPTXSTS	0x410	*Section 62.14.24: OTG_Host periodic transmit FIFO/queue status register (OTG_HPTXSTS)*
OTG_HAINT	0x414	*Section 62.14.25: OTG host all channels interrupt register (OTG_HAINT)*
OTG_HAINTMSK	0x418	*Section 62.14.26: OTG host all channels interrupt mask register (OTG_HAINTMSK)*

Table 536. Host-mode control and status registers (CSRs) (continued)

Acronym	Offset address	Register name
OTG_HFLBADDR	0x41C	*Section 62.14.27: OTG host frame list base address register (OTG_HFLBADDR)*
OTG_HPRT	0x440	*Section 62.14.28: OTG host port control and status register (OTG_HPRT)*
OTG_HCCHARx	0x500 0x520 ... 0x6E0	*Section 62.14.29: OTG host channel x characteristics register (OTG_HCCHARx)*
OTG_HCSPLTx	0x504 0x524 .... 0x6E4	*Section 62.14.30: OTG host channel x split control register (OTG_HCSPLTx)*
OTG_HCINTx	0x508 0x528 .... 0x6E8	*Section 62.14.31: OTG host channel x interrupt register (OTG_HCINTx)*
OTG_HCINTMSKx	0x50C 0x52C 0x6EC	*Section 62.14.32: OTG host channel x interrupt mask register (OTG_HCINTMSKx)*
OTG_HCTSIZx	0x510 0x530 .... 0x6F0	*Section 62.14.33: OTG host channel x transfer size register (OTG_HCTSIZx)*
OTG_HCTSIZSGx	0x510 0x530 .... 0x6F0	*Section 62.14.34: OTG host channel x transfer size register (OTG_HCTSIZSGx)*
OTG_HCDMAx	0x514 0x534 .... 0x6F4	*Section 62.14.35: OTG host channel x DMA address register in buffer DMA [alternate] (OTG_HCDMAx)*
OTG_HCDMASGx	0x514 0x534 .... 0x6F4	*Section 62.14.36: OTG host channel x DMA address register in scatter/gather DMA [alternate] (OTG_HCDMASGx)*
OTG_HCDMABx	0x51C 0x53C 0x6FC	*Section 62.14.37: OTG host channel-n DMA address buffer register (OTG_HCDMABx)*

Device-mode CSR map

These registers must be programmed every time the core changes to device mode.

Table 537. Device-mode control and status registers

Acronym	Offset address	Register name
OTG_DCFG	0x800	*Section 62.14.39: OTG device configuration register (OTG_DCFG)*
OTG_DCTL	0x804	*Section 62.14.40: OTG device control register (OTG_DCTL)*
OTG_DSTS	0x808	*Section 62.14.41: OTG device status register (OTG_DSTS)*
OTG_DIEPMSK	0x810	*Section 62.14.42: OTG device IN endpoint common interrupt mask register (OTG_DIEPMSK)*
OTG_DOEPMSK	0x814	*Section 62.14.43: OTG device OUT endpoint common interrupt mask register (OTG_DOEPMSK)*
OTG_DAINT	0x818	*Section 62.14.44: OTG device all endpoints interrupt register (OTG_DAINT)*
OTG_DAINTMSK	0x81C	*Section 62.14.45: OTG all endpoints interrupt mask register (OTG_DAINTMSK)*
OTG_DVBUSDIS	0x828	*Section 62.14.46: OTG device V_{BUS} discharge time register (OTG_DVBUSDIS)*
OTG_DVBUSPULSE	0x82C	*Section 62.14.47: OTG device V_{BUS} pulsing time register (OTG_DVBUSPULSE)*
OTG_DTHRCTL	0x830	*Section 62.14.48: OTG device threshold control register (OTG_DTHRCTL)*
OTG_DIEPEMPMSK	0x834	*Section 62.14.49: OTG device IN endpoint FIFO empty interrupt mask register (OTG_DIEPEMPMSK)*
OTG_DEACHINT	0x838	*Section 62.14.50: OTG device each endpoint interrupt register (OTG_DEACHINT)*
OTG_DEACHINTMSK	0x83C	*Section 62.14.51: OTG device each endpoint interrupt mask register (OTG_DEACHINTMSK)*
OTG_HS_DIEPEACHMSK1	0x844	*Section 62.14.52: OTG device each IN endpoint-1 interrupt mask register (OTG_HS_DIEPEACHMSK1)*
OTG_HS_DOEPEACHMSK1	0x884	*Section 62.14.53: OTG device each OUT endpoint-1 interrupt mask register (OTG_HS_DOEPEACHMSK1)*
OTG_DIEPCTLx	0x900 0x920 ... 0xA00	*Section 62.14.54: OTG device IN endpoint x control register (OTG_DIEPCTLx)*
OTG_DIEPINTx	0x908 0x928 ... 0x9E8	*Section 62.14.55: OTG device IN endpoint x interrupt register (OTG_DIEPINTx)*

Table 537. Device-mode control and status registers (continued)

Acronym	Offset address	Register name
OTG_DIEPTSIZ0	0x910	*Section 62.14.56: OTG device IN endpoint 0 transfer size register (OTG_DIEPTSIZ0)*
OTG_DIEPDMAx	0x914 0x934 ... 0x9F4	*Section 62.14.57: OTG device IN endpoint x DMA address register (OTG_DIEPDMAx)*
OTG_DTXFSTSx	0x918 0x938 ..... 0x9F8	*Section 62.14.58: OTG device IN endpoint transmit FIFO status register (OTG_DTXFSTSx)*
OTG_DIEPTSIZx	0x930 0x950 ... 0x9F0	*Section 62.14.59: OTG device IN endpoint x transfer size register (OTG_DIEPTSIZx)*
OTG_DOEPCTL0	0xB00	*Section 62.14.60: OTG device control OUT endpoint 0 control register (OTG_DOEPCTL0)*
OTG_DOEPINTx	0xB08 0XB28 ... 0xC08	*Section 62.14.61: OTG device OUT endpoint x interrupt register (OTG_DOEPINTx)*
OTG_DOEPTSIZ0	0xB10	*Section 62.14.62: OTG device OUT endpoint 0 transfer size register (OTG_DOEPTSIZ0)*
OTG_DOEPDMAx	0xB14 0xB34 ... 0xC14	*Section 62.14.63: OTG device OUT endpoint x DMA address register (OTG_DOEPDMAx)*
OTG_DOEPCTLx	0xB20 0xB40 ... 0xC00	*Section 62.14.64: OTG device OUT endpoint x control register (OTG_DOEPCTLx)*
OTG_DOEPTSIZx	0xB30 0xB50 .. 0xBF0	*Section 62.14.65: OTG device OUT endpoint x transfer size register (OTG_DOEPTSIZx)*

Data FIFO (DFIFO) access register map

These registers, available in both host and device modes, are used to read or write the FIFO space for a specific endpoint or a channel, in a given direction. If a host channel is of type IN, the FIFO can only be read on the channel. Similarly, if a host channel is of type OUT, the FIFO can only be written on the channel.

Table 538. Data FIFO (DFIFO) access register map

FIFO access register section	Offset address	Access
Device IN endpoint 0/Host OUT Channel 0: DFIFO write access Device OUT endpoint 0/Host IN Channel 0: DFIFO read access	0x1000–0x1FFC	w r
Device IN endpoint 1/Host OUT Channel 1: DFIFO write access Device OUT endpoint 1/Host IN Channel 1: DFIFO read access	0x2000–0x2FFC	w r
...	...	...
Device IN endpoint x(1)/Host OUT Channel x(1): DFIFO write access Device OUT endpoint x(1)/Host IN Channel x(1): DFIFO read access	0xX000–0xXFFC	w r

1. Where x is 8in device mode and 15 in host mode.

Power and clock gating CSR map

There is a single register for power and clock gating. It is available in both host and device modes.

Table 539. Power and clock gating control and status registers

Acronym	Offset address	Register name
OTG_PCGCCTL	0xE00–0xE04	*Section 62.14.66: OTG power and clock gating control register (OTG_PCGCCTL)*

62.14 OTG_HS registers

These registers are available in both host and device modes, and do not need to be reprogrammed when switching between these modes.

Bit values in the register descriptions are expressed in binary unless otherwise specified.

62.14.1 OTG control and status register (OTG_GOTGCTL)

Address offset: 0x000

Reset value: 0x0001 0000

The OTG_GOTGCTL register controls the behavior and reflects the status of the OTG function of the core.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CUR MOD	OTG VER	BSVLD	ASVLD	DBCT	CID STS
										r	rw	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	EHEN	DHNP EN	HSHNP EN	HNP RQ	HNG SCS	BVALO VAL	BVALO EN	AVALO VAL	AVALO EN	VBVAL OVAL	VBVAL OEN	SRQ	SRQ SCS
			rw	rw	rw	rw	r	rw	rw	rw	rw	rw	rw	rw	r

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **CURMOD:** Current mode of operation

Indicates the current mode (host or device).

0: Device mode

1: Host mode

Bit 20 **OTGVER:** OTG version

Selects the OTG revision.

0:OTG Version 1.3. OTG1.3 is obsolete for new product development.

1:OTG Version 2.0. In this version the core supports only data line pulsing for SRP.

Bit 19 **BSVLD:** B-session valid

Indicates the device mode transceiver status.

0: B-session is not valid.

1: B-session is valid.

In OTG mode, the user can use this bit to determine if the device is connected or disconnected.

Note: Only accessible in device mode.

Bit 18 **ASVLD:** A-session valid

Indicates the host mode transceiver status.

0: A-session is not valid

1: A-session is valid

Note: Only accessible in host mode.

Bit 17 **DBCT:** Long/short debounce time

Indicates the debounce time of a detected connection.

0: Long debounce time, used for physical connections (100 ms + 2.5 µs)

1: Short debounce time, used for soft connections (2.5 µs)

Note: Only accessible in host mode.

Bit 16 **CIDSTS:** Connector ID status

Indicates the connector ID status on a connect event.

0: The OTG_HS controller is in A-device mode

1: The OTG_HS controller is in B-device mode

Note: Accessible in both device and host modes.

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **EHEN:** Embedded host enable

It is used to select between OTG A device state machine and embedded host state machine.

0: OTG A device state machine is selected

1: Embedded host state machine is selected

Bit 11 **DHNPEN:** Device HNP enabled

The application sets this bit when it successfully receives a SetFeature.SetHNPEnable command from the connected USB host.

0: HNP is not enabled in the application

1: HNP is enabled in the application

Note: Only accessible in device mode.

Bit 10 **HSHNPEN:** host set HNP enable

The application sets this bit when it has successfully enabled HNP (using the SetFeature.SetHNPEnable command) on the connected device.

0: Host Set HNP is not enabled

1: Host Set HNP is enabled

Note: Only accessible in host mode.

Bit 9 **HNPRQ:** HNP request

The application sets this bit to initiate an HNP request to the connected USB host. The application can clear this bit by writing a 0 when the host negotiation success status change bit in the OTG_GOTGINT register (HNSSCHG bit in OTG_GOTGINT) is set. The core clears this bit when the HNSSCHG bit is cleared.

0: No HNP request

1: HNP request

Note: Only accessible in device mode.

Bit 8 **HNGSCS:** Host negotiation success

The core sets this bit when host negotiation is successful. The core clears this bit when the HNP request (HNPRQ) bit in this register is set.

0: Host negotiation failure

1: Host negotiation success

Note: Only accessible in device mode.

Bit 7 **BVALOVAL:** B-peripheral session valid override value.

This bit is used to set override value for Bvalid signal when BVALOEN bit is set.

0: Bvalid value is '0' when BVALOEN = 1

1: Bvalid value is '1' when BVALOEN = 1

Note: Only accessible in device mode.

Bit 6 **BVALOEN:** B-peripheral session valid override enable.

This bit is used to enable/disable the software to override the Bvalid signal using the BVALOVAL bit.

0:Override is disabled and Bvalid signal from the respective PHY selected is used internally by the core

1:Internally Bvalid received from the PHY is overridden with BVALOVAL bit value

Note: Only accessible in device mode.

Bit 5 **AVALOVAL:** A-peripheral session valid override value.

This bit is used to set override value for Avalid signal when AVALOEN bit is set.

0: Avalid value is '0' when AVALOEN = 1

1: Avalid value is '1' when AVALOEN = 1

Note: Only accessible in host mode.

Bit 4 **AVALOEN:** A-peripheral session valid override enable.

This bit is used to enable/disable the software to override the Avalid signal using the AVALOVAL bit.

0:Override is disabled and Avalid signal from the respective PHY selected is used internally by the core

1:Internally Avalid received from the PHY is overridden with AVALOVAL bit value

Note: Only accessible in host mode.

Bit 3 **VBVALOVAL:** V_{BUS} valid override value.

This bit is used to set override value for vbusvalid signal when VBVALOEN bit is set.

0: vbusvalid value is '0' when VBVALOEN = 1

1: vbusvalid value is '1' when VBVALOEN = 1

Note: Only accessible in host mode.

Bit 2 **VBVALOEN:** V_{BUS} valid override enable.

This bit is used to enable/disable the software to override the vbusvalid signal using the VBVALOVAL bit.

0: Override is disabled and vbusvalid signal from the respective PHY selected is used internally by the core

1: Internally vbusvalid received from the PHY is overridden with VBVALOVAL bit value

Note: Only accessible in host mode.

Bit 1 **SRQ:** Session request

The application sets this bit to initiate a session request on the USB. The application can clear this bit by writing a 0 when the host negotiation success status change bit in the OTG_GOTGINT register (HNSSCHG bit in OTG_GOTGINT) is set. The core clears this bit when the HNSSCHG bit is cleared.

If the user uses the USB 1.1 full-speed serial transceiver interface to initiate the session request, the application must wait until V_{BUS} discharges to 0.2 V, after the B-session valid bit in this register (BSVLD bit in OTG_GOTGCTL) is cleared.

0: No session request

1: Session request

Note: Only accessible in device mode.

Bit 0 **SRQSCS:** Session request success

The core sets this bit when a session request initiation is successful.

0: Session request failure

1: Session request success

Note: Only accessible in device mode.

62.14.2 OTG interrupt register (OTG_GOTGINT)

Address offset: 0x04

Reset value: 0x0000 0000

The application reads this register whenever there is an OTG interrupt and clears the bits in this register to clear the OTG interrupt.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBC DNE	ADTO CHG	HNG DET	Res.
												rc_w1	rc_w1	rc_w1	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	HNSS CHG	SRSS CHG	Res.	Res.	Res.	Res.	Res.	SEDET	Res.	Res.
						rc_w1	rc_w1						rc_w1		

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **DBCDNE:** Debounce done

The core sets this bit when the debounce is completed after the device connect. The application can start driving USB reset after seeing this interrupt. This bit is only valid when the HNP Capable or SRP Capable bit is set in the OTG_GUSBCFG register (HNPCAP bit or SRPCAP bit in OTG_GUSBCFG, respectively).

Note: Only accessible in host mode.

Bit 18 **ADTOCHG:** A-device timeout change

The core sets this bit to indicate that the A-device has timed out while waiting for the B-device to connect.

Note: Accessible in both device and host modes.

Bit 17 **HNGDET:** Host negotiation detected

The core sets this bit when it detects a host negotiation request on the USB.

Note: Accessible in both device and host modes.

Bits 16:10 Reserved, must be kept at reset value.

Bit 9 **HNSSCHG:** Host negotiation success status change

The core sets this bit on the success or failure of a USB host negotiation request. The application must read the host negotiation success bit of the OTG_GOTGCTL register (HNGSCS bit in OTG_GOTGCTL) to check for success or failure.

Note: Accessible in both device and host modes.

Bits 7:3 Reserved, must be kept at reset value.

Bit 8 **SRSSCHG:** Session request success status change

The core sets this bit on the success or failure of a session request. The application must read the session request success bit in the OTG_GOTGCTL register (SRQSCS bit in OTG_GOTGCTL) to check for success or failure.

Note: Accessible in both device and host modes.

Bit 2 **SEDET:** Session end detected

The core sets this bit to indicate that the level of the voltage on V_{BUS} is no longer valid for a B-Peripheral session when $V_{BUS} < 0.8$ V.

Note: Accessible in both device and host modes.

Bits 1:0 Reserved, must be kept at reset value.

62.14.3 OTG AHB configuration register (OTG_GAHBCFG)

Address offset: 0x008

Reset value: 0x0000 0000

This register can be used to configure the core after power-on or a change in mode. This register mainly contains AHB system-related configuration parameters. Do not change this register after the initial programming. The application must program this register before starting any transactions on either the AHB or the USB.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	PTXFE LVL	TXFE LVL	Res.	DMAEN	HBSTLEN[3:0]				GINT MSK
							rw	rw		rw	rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **PTXFELVL:** Periodic Tx FIFO empty level

Indicates when the periodic Tx FIFO empty interrupt bit in the OTG_GINTSTS register (PTXFE bit in OTG_GINTSTS) is triggered.

0: PTXFE (in OTG_GINTSTS) interrupt indicates that the Periodic Tx FIFO is half empty

1: PTXFE (in OTG_GINTSTS) interrupt indicates that the Periodic Tx FIFO is completely empty

Note: Only accessible in host mode.

Bit 7 **TXFELVL:** Tx FIFO empty level

In device mode, this bit indicates when IN endpoint Transmit FIFO empty interrupt (TXFE in OTG_DIEPINTx) is triggered:

0:The TXFE (in OTG_DIEPINTx) interrupt indicates that the IN endpoint Tx FIFO is half empty

1:The TXFE (in OTG_DIEPINTx) interrupt indicates that the IN endpoint Tx FIFO is completely empty

In host mode, this bit indicates when the nonperiodic Tx FIFO empty interrupt (NPTXFE bit in OTG_GINTSTS) is triggered:

0:The NPTXFE (in OTG_GINTSTS) interrupt indicates that the nonperiodic Tx FIFO is half empty

1:The NPTXFE (in OTG_GINTSTS) interrupt indicates that the nonperiodic Tx FIFO is completely empty

Bit 6 Reserved, must be kept at reset value.

Bit 5 **DMAEN:** DMA enabled
0: The core operates in slave mode
1: The core operates in DMA mode

Bits 4:1 **HBSTLEN[3:0]:** Burst length/type
0000 Single: Bus transactions use single 32 bit accesses (not recommended)
0001 INCR: Bus transactions use unspecified length accesses (not recommended, uses the INCR AHB bus command)
0011 INCR4: Bus transactions target 4x 32 bit accesses
0101 INCR8: Bus transactions target 8x 32 bit accesses

0111 INCR16: Bus transactions based on 16x 32 bit accesses
Others: Reserved

Bit 0 **GINTMSK:** Global interrupt mask
The application uses this bit to mask or unmask the interrupt line assertion to itself. Irrespective of this bit's setting, the interrupt status registers are updated by the core.
0: Mask the interrupt assertion to the application.
1: Unmask the interrupt assertion to the application.

Note: Accessible in both device and host modes.

62.14.4 OTG USB configuration register (OTG_GUSBCFG)

Address offset: 0x00C

Reset value: 0x0000 1400

This register can be used to configure the core after power-on or a changing to host mode or device mode. It contains USB and USB-PHY related configuration parameters. The application must program this register before starting any transactions on either the AHB or the USB. Do not make changes to this register after the initial programming.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	FD MOD	FH MOD	Res.	Res.	Res.	ULPI IPD	PTCI	PCCI	TSDPS	ULPIE VBUSI	ULPIE VBUSD	ULPI CSM	ULPI AR	ULPI FSL	Res.
	rw	rw				rw	rw	rw	rw	rw	rw	rw	rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PHYL PC	Res.	TRDT[3:0]				HNP CAP	SRP CAP	Res.	PHY SEL	Res.	Res.	Res.	TOCAL[2:0]		
rw		rw	rw	rw	rw	rw	rw		rw				rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **FDMOD:** Force device mode

Writing a 1 to this bit, forces the core to device mode irrespective of the OTG_ID input pin.
0: Normal mode
1: Force device mode
After setting the force bit, the application must wait at least 25 ms before the change takes effect.

Note: Accessible in both device and host modes.

Bit 29 **FHMOD:** Force host mode

Writing a 1 to this bit, forces the core to host mode irrespective of the OTG_ID input pin.
0: Normal mode
1: Force host mode
After setting the force bit, the application must wait at least 25 ms before the change takes effect.

Note: Accessible in both device and host modes.

Bits 28:26 Reserved, must be kept at reset value.

Bit 25 **ULPIIPD:** ULPI interface protect disable

This bit controls the circuitry built in the PHY to protect the ULPI interface when the link tri-states stp and data. Any pull-up or pull-down resistors employed by this feature can be disabled. Refer to the ULPI specification for more details.
0: Enables the interface protection circuit
1: Disables the interface protection circuit

Bit 24 **PTCI:** Indicator pass through

This bit controls whether the complement output is qualified with the internal V_{BUS} valid comparator before being used in the V_{BUS} state in the RX CMD. Refer to the ULPI specification for more details.
0: Complement Output signal is qualified with the Internal V_{BUS} valid comparator
1: Complement Output signal is not qualified with the Internal V_{BUS} valid comparator

Bit 23 **PCCI:** Indicator complement

This bit controls the PHY to invert the ExternalVbusIndicator input signal, and generate the complement output. Refer to the ULPI specification for more details.
0: PHY does not invert the ExternalVbusIndicator signal
1: PHY inverts ExternalVbusIndicator signal

Bit 22 **TSDPS**: TermSel DLine pulsing selection

This bit selects utmi_termselect to drive the data line pulse during SRP (session request protocol).
0: Data line pulsing using utmi_txvalid (default)
1: Data line pulsing using utmi_termsel

Bit 21 **ULPIEVBUSI:** ULPI external V_{BUS} indicator

This bit indicates to the ULPI PHY to use an external V_{BUS} overcurrent indicator.
0: PHY uses an internal V_{BUS} valid comparator
1: PHY uses an external V_{BUS} valid comparator

Bit 20 **ULPIEVBUSD:** ULPI External V_{BUS} Drive

This bit selects between internal or external supply to drive 5 V on V_{BUS}, in the ULPI PHY.
0: PHY drives V_{BUS} using internal charge pump (default)
1: PHY drives V_{BUS} using external supply.

Bit 19 **ULPICSM:** ULPI clock SuspendM

This bit sets the ClockSuspendM bit in the interface control register on the ULPI PHY. This bit applies only in the serial and carkit modes.

0: PHY powers down the internal clock during suspend

1: PHY does not power down the internal clock

Bit 18 **ULPIAR:** ULPI Auto-resume

This bit sets the AutoResume bit in the interface control register on the ULPI PHY.

0: PHY does not use AutoResume feature

1: PHY uses AutoResume feature

Bit 17 **ULPIFSLS:** ULPI FS/LS select

The application uses this bit to select the FS/LS serial interface for the ULPI PHY. This bit is valid only when the FS serial transceiver is selected on the ULPI PHY.

0: ULPI interface

1: ULPI FS/LS serial interface

Bit 16 Reserved, must be kept at reset value.

Bit 15 **PHYLPC:** PHY Low-power clock select

This bit selects either 480 MHz or 48 MHz (low-power) PHY mode. In FS and LS modes, the PHY can usually operate on a 48 MHz clock to save power.

0: 480 MHz internal PLL clock

1: 48 MHz external clock

In 480 MHz mode, the UTMI interface operates at either 60 or 30 MHz, depending on whether the 8- or 16-bit data width is selected. In 48 MHz mode, the UTMI interface operates at 48 MHz in FS and LS modes.

Bit 14 Reserved, must be kept at reset value.

Bits 13:10 **TRDT[3:0]:** USB turnaround time

These bits allows to set the turnaround time in PHY clocks. They must be configured according to *Table 540: TRDT values*, depending on the application AHB frequency. Higher TRDT values allow stretching the USB response time to IN tokens in order to compensate for longer AHB read access latency to the data FIFO.

Note: Only accessible in device mode.

Bit 9 **HNPCAP:** HNP-capable

The application uses this bit to control the OTG_HS controller's HNP capabilities.

0: HNP capability is not enabled.

1: HNP capability is enabled.

Note: Accessible in both device and host modes.

Bit 8 **SRPCAP:** SRP-capable

The application uses this bit to control the OTG_HS controller's SRP capabilities. If the core operates as a non-SRP-capable
B-device, it cannot request the connected A-device (host) to activate V_{BUS} and start a session.

0: SRP capability is not enabled.

1: SRP capability is enabled.

Note: Accessible in both device and host modes.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **PHYSEL:** Full speed serial transceiver mode select

0: USB 2.0 external ULPI high-speed PHY.

1: USB 1.1 full-speed serial mode.

Bit 5 Reserved, must be kept at reset value.

Bit 4 Reserved, must be kept at reset value.

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **TOCAL[2:0]:** FS timeout calibration

The number of PHY clocks that the application programs in this field is added to the full-speed interpacket timeout duration in the core to account for any additional delays introduced by the PHY. This can be required, because the delay introduced by the PHY in generating the line state condition can vary from one PHY to another.

The USB standard timeout value for full-speed operation is 16 to 18 (inclusive) bit times. The application must program this field based on the speed of enumeration. The number of bit times added per PHY clock is 0.25 bit times.

Table 540. TRDT values

AHB frequency range (MHz)		TRDT minimum value
Min	Max	
30	-	0x9

62.14.5 OTG reset register (OTG_GRSTCTL)

Address offset: 0x10

Reset value: 0x8000 0000

The application uses this register to reset various hardware features inside the core.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AHB IDL	DMAR EQ	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r														
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	TXFNUM[4:0]					TXF FLSH	RXF FLSH	Res.	FCRST	PSRST	CSRST
					rw	rw	rw	rw	rw	rs	rs		rs	rs	rs

Bit 31 **AHBIDL:** AHB master idle

Indicates that the AHB master state machine is in the Idle condition.

Note: Accessible in both device and host modes.

Bit 30 **DMAREQ:** DMA request signal enabled

This bit indicates that the DMA request is in progress. Used for debug.

Bits 29:11 Reserved, must be kept at reset value.

Bits 10:6 **TXFNUM[4:0]:** Tx FIFO number

This is the FIFO number that must be flushed using the Tx FIFO Flush bit. This field must not be changed until the core clears the Tx FIFO Flush bit.

00000:

- Non-periodic Tx FIFO flush in host mode
- Tx FIFO 0 flush in device mode

00001:

- Periodic Tx FIFO flush in host mode
- Tx FIFO 1 flush in device mode

00010: Tx FIFO 2 flush in device mode

...

01111: Tx FIFO 15 flush in device mode

10000: Flush all the transmit FIFOs in device or host mode.

Note: Accessible in both device and host modes.

Bit 5 **TXFFLSH:** Tx FIFO flush

This bit selectively flushes a single or all transmit FIFOs, but cannot do so if the core is in the midst of a transaction.

The application must write this bit only after checking that the core is neither writing to the Tx FIFO nor reading from the Tx FIFO. Verify using these registers:

Read—NAK Effective interrupt ensures the core is not reading from the FIFO

Write—AHBIDL bit in OTG_GRSTCTL ensures the core is not writing anything to the FIFO.

Flushing is normally recommended when FIFOs are reconfigured. FIFO flushing is also recommended during device endpoint disable. The application must wait until the core clears this bit before performing any operations. This bit takes eight clocks to clear, using the slower clock of phy_clk or hclk.

Note: Accessible in both device and host modes.

Bit 4 **RXFFLSH:** Rx FIFO flush

The application can flush the entire Rx FIFO using this bit, but must first ensure that the core is not in the middle of a transaction.

The application must only write to this bit after checking that the core is neither reading from the Rx FIFO nor writing to the Rx FIFO.

The application must wait until the bit is cleared before performing any other operations. This bit requires 8 clocks (slowest of PHY or AHB clock) to clear.

Note: Accessible in both device and host modes.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **FCRST:** Host frame counter reset

The application writes this bit to reset the (micro-)frame number counter inside the core. When the (micro-)frame counter is reset, the subsequent SOF sent out by the core has a frame number of 0.

When application writes '1' to the bit, it might not be able to read back the value as it gets cleared by the core in a few clock cycles.

Note: Only accessible in host mode.

Bit 1 **PSRST:** Partial soft reset

Resets the internal state machines but keeps the enumeration info. Could be used to recover some specific PHY errors.

Note: Accessible in both device and host modes.

Bit 0 **CSRST:** Core soft reset

Resets the HCLK and PHY clock domains as follows:

Clears the interrupts and all the CSR register bits except for the following bits:

– GATEHCLK bit in OTG_PCGCCTL
– STPPCLK bit in OTG_PCGCCTL
– FSLSPCS bits in OTG_HCFG
– DSPD bit in OTG_DCFG
– SDIS bit in OTG_DCTL
– OTG_GCCFG register

All module state machines (except for the AHB slave unit) are reset to the Idle state, and all the transmit FIFOs and the receive FIFO are flushed.

Any transactions on the AHB Master are terminated as soon as possible, after completing the last data phase of an AHB transfer. Any transactions on the USB are terminated immediately.

The application can write to this bit any time it wants to reset the core. This is a self-clearing bit and the core clears this bit after all the necessary logic is reset in the core, which can take several clocks, depending on the current state of the core. Once this bit has been cleared, the software must wait at least 3 PHY clocks before accessing the PHY domain (synchronization delay). The software must also check that bit 31 in this register is set to 1 (AHB Master is Idle) before starting any operation.

Typically, the software reset is used during software development and also when the user dynamically changes the PHY selection bits in the above listed USB configuration registers. When the user changes the PHY, the corresponding clock for the PHY is selected and used in the PHY domain. Once a new clock is selected, the PHY domain has to be reset for proper operation.

Note: Accessible in both device and host modes.

62.14.6 OTG core interrupt register (OTG_GINTSTS)

Address offset: 0x014

Reset value: 0x0400 0020

This register interrupts the application for system-level events in the current mode (device mode or host mode).

Some of the bits in this register are valid only in host mode, while others are valid in device mode only. This register also indicates the current mode. To clear the interrupt status bits of the rc_w1 type, the application must write 1 into the bit.

The FIFO status interrupts are read-only; once software reads from or writes to the FIFO while servicing these interrupts, FIFO interrupt conditions are cleared automatically.

The application must clear the OTG_GINTSTS register at initialization before unmasking the interrupt bit to avoid any interrupts generated prior to initialization.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WKUP INT	SRQ INT	DISC INT	CIDS CHG	LPM INT	PTXFE	HCINT	HPRT INT	RST DET	DATAF SUSP	IPXFR/ IN COMP ISO OUT	IISOI XFR	OEP INT	IEPINT	Res.	Res.
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	r	r	r	rc_w1	rc_w1	rc_w1	rc_w1	r	r		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EOPF	ISOO DRP	ENUM DNE	USB RST	USB SUSP	ESUSP	Res.	Res.	GO NAK EFF	GI NAK EFF	NPTXF E	RXF LVL	SOF	OTG INT	MMIS	CMOD
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1			r	r	r	r	rc_w1	r	rc_w1	r

Bit 31 **WKUPINT:** Resume/remote wakeup detected interrupt

Wakeup interrupt during suspend(L2) or LPM(L1) state.

– During suspend(L2):

In device mode, this interrupt is asserted when a resume is detected on the USB. In host mode, this interrupt is asserted when a remote wakeup is detected on the USB.

– During LPM(L1):

This interrupt is asserted for either host initiated resume or device initiated remote wakeup on USB.

Note: Accessible in both device and host modes.

Bit 30 **SRQINT:** Session request/new session detected interrupt

In host mode, this interrupt is asserted when a session request is detected from the device. In device mode, this interrupt is asserted when V_{BUS} is in the valid range for a B-peripheral device. Accessible in both device and host modes.

Bit 29 **DISCINT:** Disconnect detected interrupt

Asserted when a device disconnect is detected.

Note: Only accessible in host mode.

Bit 28 **CIDSCHG:** Connector ID status change

The core sets this bit when there is a change in connector ID status.

Note: Accessible in both device and host modes.

Bit 27 **LPMINT:** LPM interrupt

In device mode, this interrupt is asserted when the device receives an LPM transaction and responds with a non-ERRORed response.

In host mode, this interrupt is asserted when the device responds to an LPM transaction with a non-ERRORed response or when the host core has completed LPM transactions for the programmed number of times (RETRYCNT bit in OTG_GLPMCFG).

This field is valid only if the LPMEN bit in OTG_GLPMCFG is set to 1.

Bit 26 **PTXFE:** Periodic Tx FIFO empty

Asserted when the periodic transmit FIFO is either half or completely empty and there is space for at least one entry to be written in the periodic request queue. The half or completely empty status is determined by the periodic Tx FIFO empty level bit in the OTG_GAHBCFG register (PTXFELVL bit in OTG_GAHBCFG).

Note: Only accessible in host mode.

Bit 25 **HCINT:** Host channels interrupt

The core sets this bit to indicate that an interrupt is pending on one of the channels of the core (in host mode). The application must read the OTG_HAINT register to determine the exact number of the channel on which the interrupt occurred, and then read the corresponding OTG_HCINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the OTG_HCINTx register to clear this bit.

Note: Only accessible in host mode.

Bit 24 **HPRTINT:** Host port interrupt

The core sets this bit to indicate a change in port status of one of the OTG_HS controller ports in host mode. The application must read the OTG_HPRT register to determine the exact event that caused this interrupt. The application must clear the appropriate status bit in the OTG_HPRT register to clear this bit.

Note: Only accessible in host mode.

Bit 23 **RSTDET:** Reset detected interrupt

In device mode, this interrupt is asserted when a reset is detected on the USB in partial power-down mode when the device is in suspend.

Note: Only accessible in device mode.

Bit 22 **DATAFSUSP:** Data fetch suspended

This interrupt is valid only in DMA mode. This interrupt indicates that the core has stopped fetching data for IN endpoints due to the unavailability of TxFIFO space or request queue space. This interrupt is used by the application for an endpoint mismatch algorithm. For example, after detecting an endpoint mismatch, the application:

- Sets a global nonperiodic IN NAK handshake
- Disables IN endpoints
- Flushes the FIFO
- Determines the token sequence from the IN token sequence learning queue
- Re-enables the endpoints

Clears the global nonperiodic IN NAK handshake If the global nonperiodic IN NAK is cleared, the core has not yet fetched data for the IN endpoint, and the IN token is received: the core generates an “IN token received when FIFO empty” interrupt. The OTG then sends a NAK response to the host. To avoid this scenario, the application can check the FetSusp interrupt in OTG_GINTSTS, which ensures that the FIFO is full before clearing a global NAK handshake. Alternatively, the application can mask the “IN token received when FIFO empty” interrupt when clearing a global IN NAK handshake.

Bit 21 **IPXFR:** Incomplete periodic transfer

In host mode, the core sets this interrupt bit when there are incomplete periodic transactions still pending, which are scheduled for the current frame.

INCOMPISOOUT: Incomplete isochronous OUT transfer

In device mode, the core sets this interrupt to indicate that there is at least one isochronous OUT endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the End of periodic frame interrupt (EOPF) bit in this register.

Bit 20 **IISOIXFR:** Incomplete isochronous IN transfer

The core sets this interrupt to indicate that there is at least one isochronous IN endpoint on which the transfer is not completed in the current frame. This interrupt is asserted along with the End of periodic frame interrupt (EOPF) bit in this register.

Note: Only accessible in device mode.

Bit 19 **OEPINT:** OUT endpoint interrupt

The core sets this bit to indicate that an interrupt is pending on one of the OUT endpoints of the core (in device mode). The application must read the OTG_DAINT register to determine the exact number of the OUT endpoint on which the interrupt occurred, and then read the corresponding OTG_DOEPINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the corresponding OTG_DOEPINTx register to clear this bit.

Note: Only accessible in device mode.

Bit 18 **IEPINT:** IN endpoint interrupt

The core sets this bit to indicate that an interrupt is pending on one of the IN endpoints of the core (in device mode). The application must read the OTG_DAINT register to determine the exact number of the IN endpoint on which the interrupt occurred, and then read the corresponding OTG_DIEPINTx register to determine the exact cause of the interrupt. The application must clear the appropriate status bit in the corresponding OTG_DIEPINTx register to clear this bit.

Note: Only accessible in device mode.

Bits 17:16 Reserved, must be kept at reset value.

Bit 15 **EOPF:** End of periodic frame interrupt

Indicates that the period specified in the periodic frame interval field of the OTG_DCFG register (PFIVL bit in OTG_DCFG) has been reached in the current frame.

Note: Only accessible in device mode.

Bit 14 **ISOODRP:** Isochronous OUT packet dropped interrupt

The core sets this bit when it fails to write an isochronous OUT packet into the Rx FIFO because the Rx FIFO does not have enough space to accommodate a maximum size packet for the isochronous OUT endpoint.

Note: Only accessible in device mode.

Bit 13 **ENUMDNE:** Enumeration done

The core sets this bit to indicate that speed enumeration is complete. The application must read the OTG_DSTS register to obtain the enumerated speed.

Note: Only accessible in device mode.

Bit 12 **USBRST:** USB reset

The core sets this bit to indicate that a reset is detected on the USB.

Note: Only accessible in device mode.

Bit 11 **USBSUSP:** USB suspend

The core sets this bit to indicate that a suspend was detected on the USB. The core enters the suspended state when there is no activity on the data lines for an extended period of time.

Note: Only accessible in device mode.

Bit 10 **ESUSP:** Early suspend

The core sets this bit to indicate that an Idle state has been detected on the USB for 3 ms.

Note: Only accessible in device mode.

Bits 9:8 Reserved, must be kept at reset value.

Bit 7 **GONAKEFF:** Global OUT NAK effective

Indicates that the Set global OUT NAK bit in the OTG_DCTL register (SGONAK bit in OTG_DCTL), set by the application, has taken effect in the core. This bit can be cleared by writing the Clear global OUT NAK bit in the OTG_DCTL register (CGONAK bit in OTG_DCTL).

Note: Only accessible in device mode.

Bit 6 **GINAKEFF:** Global IN non-periodic NAK effective

Indicates that the Set global non-periodic IN NAK bit in the OTG_DCTL register (SGINAK bit in OTG_DCTL), set by the application, has taken effect in the core. That is, the core has sampled the Global IN NAK bit set by the application. This bit can be cleared by clearing the Clear global non-periodic IN NAK bit in the OTG_DCTL register (CGINAK bit in OTG_DCTL).

This interrupt does not necessarily mean that a NAK handshake is sent out on the USB. The STALL bit takes precedence over the NAK bit.

Note: Only accessible in device mode.

Bit 5 **NPTXFE:** Non-periodic Tx FIFO empty

This interrupt is asserted when the non-periodic Tx FIFO is either half or completely empty, and there is space for at least one entry to be written to the non-periodic transmit request queue. The half or completely empty status is determined by the non-periodic Tx FIFO empty level bit in the OTG_GAHBCFG register (TXFELVL bit in OTG_GAHBCFG).

Note: Accessible in host mode only.

Bit 4 **RXFLVL:** Rx FIFO non-empty

Indicates that there is at least one packet pending to be read from the Rx FIFO.

Note: Accessible in both host and device modes.

Bit 3 **SOF:** Start of frame

In host mode, the core sets this bit to indicate that an SOF (FS), or Keep-Alive (LS) is transmitted on the USB. The application must write a 1 to this bit to clear the interrupt.

In device mode, in the core sets this bit to indicate that an SOF token has been received on the USB. The application can read the OTG_DSTS register to get the current frame number. This interrupt is seen only when the core is operating in FS.

Note: This register may return '1' if read immediately after power on reset. If the register bit reads '1' immediately after power on reset it does not indicate that an SOF has been sent (in case of host mode) or SOF has been received (in case of device mode). The read value of this interrupt is valid only after a valid connection between host and device is established. If the bit is set after power on reset the application can clear the bit.

Note: Accessible in both host and device modes.

Bit 2 **OTGINT:** OTG interrupt

The core sets this bit to indicate an OTG protocol event. The application must read the OTG interrupt status (OTG_GOTGINT) register to determine the exact event that caused this interrupt. The application must clear the appropriate status bit in the OTG_GOTGINT register to clear this bit.

Note: Accessible in both host and device modes.

Bit 1 **MMIS:** Mode mismatch interrupt

The core sets this bit when the application is trying to access:

– A host mode register, when the core is operating in device mode

– A device mode register, when the core is operating in host mode

The register access is completed on the AHB with an OKAY response, but is ignored by the core internally and does not affect the operation of the core.

Note: Accessible in both host and device modes.

Bit 0 **CMOD:** Current mode of operation

Indicates the current mode.

0: Device mode

1: Host mode

Note: Accessible in both host and device modes.

62.14.7 OTG interrupt mask register (OTG_GINTMSK)

Address offset: 0x018

Reset value: 0x0000 0000

This register works with the core interrupt register to interrupt the application. When an interrupt bit is masked, the interrupt associated with that bit is not generated. However, the core interrupt (OTG_GINTSTS) register bit corresponding to that interrupt is still set.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
WUIM	SRQIM	DISCINT	CIDSCHGM	LPMINTM	PTXFEM	HCIM	PRTIM	RSTDETM	FSUSPM	IPXFRM/IISOOXFRM	IISOIXFRM	OEPINT	IEPINT	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	r	rw	rw	rw	rw	rw	rw		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EOPFM	ISOODRPM	ENUMDNEM	USBRST	USBSUSPM	ESUSPM	Res.	Res.	GONAKEFFM	GINAKEFFM	NPTXFEM	RXFLVLM	SOFM	OTGINT	MMISM	Res.
rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw	rw	

Bit 31 **WUIM:** Resume/remote wakeup detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Accessible in both host and device modes.

Bit 30 **SRQIM:** Session request/new session detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Accessible in both host and device modes.

Bit 29 **DISCINT:** Disconnect detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in host mode.

Bit 28 **CIDSCHGM:** Connector ID status change mask
0: Masked interrupt
1: Unmasked interrupt
Note: Accessible in both host and device modes.

Bit 27 **LPMINTM:** LPM interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Accessible in both host and device modes.

Bit 26 **PTXFEM:** Periodic Tx FIFO empty mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in host mode.

Bit 25 **HCIM:** Host channels interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in host mode.

Bit 24 **PRTIM:** Host port interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in host mode.

Bit 23 **RSTDETM:** Reset detected interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in device mode.

Bit 22 **FSUSPM:** Data fetch suspended mask
0: Masked interrupt
1: Unmasked interrupt
Only accessible in peripheral mode.

Bit 21 **IPXFRM:** Incomplete periodic transfer mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in host mode.
IISOOXFRM: Incomplete isochronous OUT transfer mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in device mode.

Bit 20 **IISOIXFRM:** Incomplete isochronous IN transfer mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in device mode.

Bit 19 **OEPINT:** OUT endpoints interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in device mode.

Bit 18 **IEPINT:** IN endpoints interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in device mode.

Bits 17:16 Reserved, must be kept at reset value.

Bit 15 **EOPFM:** End of periodic frame interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in device mode.

Bit 14 **ISOODRPM:** Isochronous OUT packet dropped interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in device mode.

Bit 13 **ENUMDNEM:** Enumeration done mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in device mode.

Bit 12 **USBRST:** USB reset mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in device mode.

Bit 11 **USBSUSPM:** USB suspend mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in device mode.

Bit 10 **ESUSPM:** Early suspend mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in device mode.

Bits 9:8 Reserved, must be kept at reset value.

Bit 7 **GONAKEFFM:** Global OUT NAK effective mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in device mode.

Bit 6 **GINAKEFFM:** Global non-periodic IN NAK effective mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in device mode.

Bit 5 **NPTXFEM:** Non-periodic Tx FIFO empty mask
0: Masked interrupt
1: Unmasked interrupt
Note: Only accessible in host mode.

Bit 4 **RXFLVLM:** Receive FIFO non-empty mask
0: Masked interrupt
1: Unmasked interrupt
Note: Accessible in both device and host modes.

Bit 3 **SOFM:** Start of frame mask
0: Masked interrupt
1: Unmasked interrupt
Note: Accessible in both device and host modes.

Bit 2 **OTGINT:** OTG interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Accessible in both device and host modes.

Bit 1 **MMISM:** Mode mismatch interrupt mask
0: Masked interrupt
1: Unmasked interrupt
Note: Accessible in both device and host modes.

Bit 0 Reserved, must be kept at reset value.

62.14.8 OTG receive status debug read register (OTG_GRXSTSR)

Address offset for read: 0x01C

Reset value: 0x0000 0000

This description is for register OTG_GRXSTSR in Device mode.

A read to the receive status debug read register returns the contents of the top of the receive FIFO.

The core ignores the receive status read when the receive FIFO is empty and returns a value of 0x0000 0000.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	STSPHST	Res.	Res.	FRMNUM[3:0]				PKTSTS[3:0]				DPID[1]
				r			r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DPID[0]	BCNT[10:0]											EPNUM[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **STSPHST:** Status phase start

Indicates the start of the status phase for a control write transfer. This bit is set along with the OUT transfer completed PKTSTS pattern.

Bits 26:25 Reserved, must be kept at reset value.

Bits 24:21 **FRMNUM[3:0]:** Frame number

This is the least significant 4 bits of the frame number in which the packet is received on the USB. This field is supported only when isochronous OUT endpoints are supported.

Bits 20:17 **PKTSTS[3:0]:** Packet status

Indicates the status of the received packet
0001: Global OUT NAK (triggers an interrupt)
0010: OUT data packet received
0011: OUT transfer completed (triggers an interrupt)
0100: SETUP transaction completed (triggers an interrupt)
0110: SETUP data packet received
Others: Reserved

Bits 16:15 **DPID[1:0]:** Data PID

Indicates the data PID of the received OUT data packet
00: DATA0
10: DATA1
01: DATA2
11: MDATA

Bits 14:4 **BCNT[10:0]:** Byte count

Indicates the byte count of the received data packet.

Bits 3:0 **EPNUM[3:0]:** Endpoint number

Indicates the endpoint number to which the current received packet belongs.

62.14.9 OTG receive status debug read [alternate] (OTG_GRXSTSR)

Address offset for read: 0x01C

Reset value: 0x0000 0000

This description is for register OTG_GRXSTSR in Host mode.

A read to the receive status debug read register returns the contents of the top of the receive FIFO.

The core ignores the receive status read when the receive FIFO is empty and returns a value of 0x0000 0000.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTSTS[3:0]				DPID
											r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DPID	BCNT[10:0]											CHNUM[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:17 **PKTSTS[3:0]:** Packet status
Indicates the status of the received packet
0010: IN data packet received
0011: IN transfer completed (triggers an interrupt)
0101: Data toggle error (triggers an interrupt)
0111: Channel halted (triggers an interrupt)
Others: Reserved

Bits 16:15 **DPID[1:0]:** Data PID
Indicates the data PID of the received packet
00: DATA0
10: DATA1
01: DATA2
11: MDATA

Bits 14:4 **BCNT[10:0]:** Byte count
Indicates the byte count of the received IN data packet.

Bits 3:0 **CHNUM[3:0]:** Channel number
Indicates the channel number to which the current received packet belongs.

62.14.10 OTG status read and pop registers (OTG_GRXSTSP)

Address offset for pop: 0x020

Reset value: 0x0000 0000

This description is for register OTG_GRXSTSP in Device mode.

Similarly to OTG_GRXSTSR (receive status debug read register) where a read returns the contents of the top of the receive FIFO, a read to OTG_GRXSTSP (receive status read and pop register) additionally pops the top data entry out of the Rx FIFO.

The core ignores the receive status pop/read when the receive FIFO is empty and returns a value of 0x0000 0000. The application must only pop the receive status FIFO when the receive FIFO non-empty bit of the core interrupt register (RXFLVL bit in OTG_GINTSTS) is asserted.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	STSPHST	Res.	Res.	FRMNUM[3:0]				PKTSTS[3:0]				DPID[1]
				r			r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DPID[0]	BCNT[10:0]											EPNUM[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **STSPHST:** Status phase start

Indicates the start of the status phase for a control write transfer. This bit is set along with the OUT transfer completed PKTSTS pattern.

Bits 26:25 Reserved, must be kept at reset value.

Bits 24:21 **FRMNUM[3:0]:** Frame number

This is the least significant 4 bits of the frame number in which the packet is received on the USB. This field is supported only when isochronous OUT endpoints are supported.

Bits 20:17 **PKTSTS[3:0]:** Packet status

Indicates the status of the received packet
0001: Global OUT NAK (triggers an interrupt)
0010: OUT data packet received
0011: OUT transfer completed (triggers an interrupt)
0100: SETUP transaction completed (triggers an interrupt)
0110: SETUP data packet received
Others: Reserved

Bits 16:15 **DPID[1:0]:** Data PID
Indicates the data PID of the received OUT data packet
00: DATA0
10: DATA1
01: DATA2
11: MDATA

Bits 14:4 **BCNT[10:0]:** Byte count
Indicates the byte count of the received data packet.

Bits 3:0 **EPNUM[3:0]:** Endpoint number
Indicates the endpoint number to which the current received packet belongs.

62.14.11 OTG status read and pop registers [alternate] (OTG_GRXSTSP)

Address offset for pop: 0x020

Reset value: 0x0000 0000

This description is for register OTG_GRXSTSP in Host mode.

Similarly to OTG_GRXSTSR (receive status debug read register) where a read returns the contents of the top of the receive FIFO, a read to OTG_GRXSTSP (receive status read and pop register) additionally pops the top data entry out of the Rx FIFO.

The core ignores the receive status pop/read when the receive FIFO is empty and returns a value of 0x0000 0000. The application must only pop the receive status FIFO when the receive FIFO non-empty bit of the core interrupt register (RXFLVL bit in OTG_GINTSTS) is asserted.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTSTS[3:0]				DPID
											r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DPID	BCNT[10:0]											CHNUM[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:17 **PKTSTS[3:0]:** Packet status
Indicates the status of the received packet
0010: IN data packet received
0011: IN transfer completed (triggers an interrupt)
0101: Data toggle error (triggers an interrupt)
0111: Channel halted (triggers an interrupt)
Others: Reserved

Bits 16:15 **DPID[1:0]:** Data PID
Indicates the data PID of the received packet
00: DATA0
10: DATA1
01: DATA2
11: MDATA

Bits 14:4 **BCNT[10:0]:** Byte count
Indicates the byte count of the received IN data packet.

Bits 3:0 **CHNUM[3:0]:** Channel number
Indicates the channel number to which the current received packet belongs.

62.14.12 OTG receive FIFO size register (OTG_GRXFSIZ)

Address offset: 0x024

Reset value: 0x0000 0400

The application can program the RAM size that must be allocated to the Rx FIFO.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXFD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **RXFD[15:0]:** Rx FIFO depth
This value is in terms of 32-bit words.
Maximum value is 1024
Programmed values must respect the available FIFO memory allocation and must not exceed the power-on value.

62.14.13 OTG host non-periodic transmit FIFO size register (OTG_HNPTXFSIZ)/Endpoint 0 Transmit FIFO size (OTG_DIEPTXF0)

Address offset: 0x028

Reset value: 0x0200 0200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NPTXFD/TX0FD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NPTXFSA/TX0FSA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Host mode

Bits 31:16 **NPTXFD[15:0]:** Non-periodic Tx FIFO depth
This value is in terms of 32-bit words.
Minimum value is 16
Programmed values must respect the available FIFO memory allocation and must not exceed the power-on value.

Bits 15:0 **NPTXFSA[15:0]:** Non-periodic transmit RAM start address
This field configures the memory start address for non-periodic transmit FIFO RAM.

Device mode

Bits 31:16 **TX0FD:** Endpoint 0 Tx FIFO depth
This value is in terms of 32-bit words.
Minimum value is 16
Programmed values must respect the available FIFO memory allocation and must not exceed the power-on value.

Bits 15:0 **TX0FSA:** Endpoint 0 transmit RAM start address
This field configures the memory start address for the endpoint 0 transmit FIFO RAM.

62.14.14 OTG non-periodic transmit FIFO/queue status register (OTG_HNPTXSTS)

Address offset: 0x02C

Reset value: 0x0008 0400

Note: In device mode, this register is not valid.

This read-only register contains the free space information for the non-periodic Tx FIFO and the non-periodic transmit request queue.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	NPTXQTOP[6:0]							NPTQXSAV[7:0]							
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NPTXFSAV[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:24 **NPTXQTOP[6:0]:** Top of the non-periodic transmit request queue
Entry in the non-periodic Tx request queue that is currently being processed by the MAC.
Bits 30:27: Channel/endpoint number
Bits 26:25:
00: IN/OUT token
01: Zero-length transmit packet (device IN/host OUT)
11: Channel halt command
Bit 24: Terminate (last entry for selected channel/endpoint)

Bits 23:16 **NPTQXSAV[7:0]:** Non-periodic transmit request queue space available
Indicates the amount of free space available in the non-periodic transmit request queue. This queue holds both IN and OUT requests.
0: Non-periodic transmit request queue is full
1: 1 location available
2: locations available
n: n locations available (0 ≤ n ≤ 8)
Others: Reserved

Bits 15:0 **NPTXFSAV[15:0]:** Non-periodic Tx FIFO space available
Indicates the amount of free space available in the non-periodic Tx FIFO.
Values are in terms of 32-bit words.
0: Non-periodic Tx FIFO is full
1: 1 word available
2: 2 words available
n: n words available (where 0 ≤ n ≤ 512)
Others: Reserved

62.14.15 OTG general core configuration register (OTG_GCCFG)

Address offset: 0x038

Reset value: 0x0000 XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VBDEN	SDEN	PDEN	DCD EN	BCDEN	PWR DWN
										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PS2 DET	SDET	PDET	DCDET
												r	r	r	r

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **VBDEN:** USB V_{BUS} detection enable

Enables V_{BUS} sensing comparators to detect V_{BUS} valid levels on the V_{BUS} PAD for USB host and device operation. If HNP and/or SRP support is enabled, V_{BUS} comparators are automatically enabled independently of VBDEN value.

0 = V_{BUS} detection disabled

1 = V_{BUS} detection enabled

Bit 20 **SDEN:** Secondary detection (SD) mode enable

This bit is set by the software to put the BCD into SD mode. Only one detection mode (DCD, PD, SD or OFF) should be selected to work correctly

Bit 19 **PDEN:** Primary detection (PD) mode enable

This bit is set by the software to put the BCD into PD mode. Only one detection mode (DCD, PD, SD or OFF) should be selected to work correctly.

Bit 18 **DCDEN:** Data contact detection (DCD) mode enable

This bit is set by the software to put the BCD into DCD mode. Only one detection mode (DCD, PD, SD or OFF) should be selected to work correctly.

Bit 17 **BCDEN:** Battery charging detector (BCD) enable

This bit is set by the software to enable the BCD support within the USB device. When enabled, the USB PHY is fully controlled by BCD and cannot be used for normal communication. Once the BCD discovery is finished, the BCD should be placed in OFF mode by clearing this bit to ‘0’ in order to allow the normal USB operation.

Bit 16 **PWRDWN:** Power down control of FS PHY

Used to activate the FS PHY in transmission/reception. When reset, the PHY is kept in power-down. When set, the BCD function must be off (BCDEN=0).

0 = USB FS PHY disabled

1 = USB FS PHY enabled

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **PS2DET:** DM pull-up detection status

This bit is active only during PD and gives the result of comparison between DM voltage level and VLGC threshold. In normal situation, the DM level should be below this threshold. If it is above, it means that the DM is externally pulled high. This can be caused by connection to a PS2 port (which pulls-up both DP and DM lines) or to some proprietary charger not following the BCD specification.

0: Normal port detected (connected to SDP, CDP or DCP)

1: PS2 port or proprietary charger detected

Bit 2 **SDET:** Secondary detection (SD) status

This bit gives the result of SD.

0: CDP detected

1: DCP detected

Bit 1 **PDET:** Primary detection (PD) status

This bit gives the result of PD.

0: no BCD support detected (connected to SDP or proprietary device).

1: BCD support detected (connected to CDP or DCP).

Bit 0 **DCDET:** Data contact detection (DCD) status

This bit gives the result of DCD.

0: data lines contact not detected

1: data lines contact detected

62.14.16 OTG core ID register (OTG_CID)

Address offset: 0x03C

Reset value: 0x0000 2300

This is a register containing the Product ID as reset value.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PRODUCT_ID[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRODUCT_ID[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PRODUCT_ID[31:0]:** Product ID field
Application-programmable ID field.

62.14.17 OTG core LPM configuration register (OTG_GLPMCFG)

Address offset: 0x54

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	EN BESL	LPMRCNTSTS[2:0]			SND LPM	LPMRCNT[2:0]			LPMCHIDX[3:0]				L1RSM OK
			rw	r	r	r	rs	rw	rw	rw	rw	rw	rw	rw	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SLP STS	LPMRSP[1:0]		L1DS EN	BESLTHRS[3:0]				L1SS EN	REM WAKE	BESL[3:0]				LPM ACK	LPM EN
r	r	r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **ENBESL:** Enable best effort service latency
This bit enables the BESL feature as defined in the LPM errata:
0:The core works as described in the following document:
USB 2.0 Link Power Management Addendum Engineering Change Notice to the USB 2.0 specification, July 16, 2007
1:The core works as described in the LPM Errata:
Errata for USB 2.0 ECN: Link Power Management (LPM) - 7/2007
Note: Only the updated behavior (described in LPM Errata) is considered in this document and so the ENBESL bit should be set to '1' by application SW.

Bits 27:25 **LPMRCNTSTS[2:0]:** LPM retry count status
Number of LPM host retries still remaining to be transmitted for the current LPM sequence.
Note: Accessible only in host mode.

Bit 24 **SNDLPM:** Send LPM transaction

When the application software sets this bit, an LPM transaction containing two tokens, EXT and LPM is sent. The hardware clears this bit once a valid response (STALL, NYET, or ACK) is received from the device or the core has finished transmitting the programmed number of LPM retries.

Note: This bit must be set only when the host is connected to a local port.

Note: Accessible only in host mode.

Bits 23:21 **LPMRCNT[2:0]:** LPM retry count

When the device gives an ERROR response, this is the number of additional LPM retries that the host performs until a valid device response (STALL, NYET, or ACK) is received.

Note: Accessible only in host mode.

Bits 20:17 **LPMCHIDX[3:0]:** LPM Channel Index

The channel number on which the LPM transaction has to be applied while sending an LPM transaction to the local device. Based on the LPM channel index, the core automatically inserts the device address and endpoint number programmed in the corresponding channel into the LPM transaction.

Note: Accessible only in host mode.

Bit 16 **L1RSMOK:** Sleep state resume OK

Indicates that the device or host can start resume from Sleep state. This bit is valid in LPM sleep (L1) state. It is set in sleep mode after a delay of 50 µs ($T_{L1Residency}$).

This bit is reset when SLPSTS is 0.

1: The application or host can start resume from Sleep state

0: The application or host cannot start resume from Sleep state

Bit 15 **SLPSTS:** Port sleep status

Device mode:

This bit is set as long as a Sleep condition is present on the USB bus. The core enters the Sleep state when an ACK response is sent to an LPM transaction and the $T_{L1TokenRetry}$ timer has expired. To stop the PHY clock, the application must set the STPPCLK bit in OTG_PCGCCTL, which asserts the PHY suspend input signal.

The application must rely on SLPSTS and not ACK in LPMRSP to confirm transition into sleep.

The core comes out of sleep:

– When there is any activity on the USB linestate

– When the application writes to the RWUSIG bit in OTG_DCTL or when the application resets or soft-disconnects the device.

Host mode:

The host transitions to Sleep (L1) state as a side-effect of a successful LPM transaction by the core to the local port with ACK response from the device. The read value of this bit reflects the current Sleep status of the port.

The core clears this bit after:

– The core detects a remote L1 wakeup signal,

– The application sets the PRST bit or the PRES bit in the OTG_HPRT register, or

– The application sets the L1Resume/ remote wakeup detected interrupt bit or disconnect detected interrupt bit in the core interrupt register (WKUPINT or DISCINT bit in OTG_GINTSTS, respectively).

0: Core not in L1

1: Core in L1

Bits 14:13 **LPMRSP[1:0]:** LPM response

Device mode:

The response of the core to LPM transaction received is reflected in these two bits.

Host mode:

Handshake response received from local device for LPM transaction

11: ACK

10: NYET

01: STALL

00: ERROR (No handshake response)

Bit 12 **L1DSEN:** L1 deep sleep enable

Enables suspending the PHY in L1 Sleep mode. For maximum power saving during L1 Sleep mode, this bit should be set to '1' by application SW in all the cases.

Bits 11:8 **BESLTHRS[3:0]:** BESL threshold

Device mode:

The core puts the PHY into deep low power mode in L1 when BESL value is greater than or equal to the value defined in this field BESL_Thres[3:0].

Host mode:

The core puts the PHY into deep low power mode in L1. BESLTHRS[3:0] specifies the time for which resume signaling is to be reflected by host ($T_{L1HubDrvResume2}$) on the USB bus when it detects device initiated resume.

BESLTHRS must not be programmed with a value greater than 1100b in host mode, because this exceeds maximum $T_{L1HubDrvResume2}$.

Thres[3:0] host mode resume signaling time (µs):

0000: 75

0001: 100

0010: 150

0011: 250

0100: 350

0101: 450

0110: 950

All other values: reserved

Bit 7 **L1SSEN:** L1 Shallow Sleep enable

Enables suspending the PHY in L1 Sleep mode. For maximum power saving during L1 Sleep mode, this bit should be set to '1' by application SW in all the cases.

Bit 6 **REMWAKE:** bRemoteWake value

Host mode:

The value of remote wake up to be sent in the wIndex field of LPM transaction.

Device mode (read-only):

This field is updated with the received LPM token bRemoteWake bmAttribute when an ACK, NYET, or STALL response is sent to an LPM transaction.

Bits 5:2 **BESL[3:0]:** Best effort service latency

Host mode:

The value of BESL to be sent in an LPM transaction. This value is also used to initiate resume for a duration $T_{L1HubDrvResume1}$ for host initiated resume.

Device mode (read-only):

This field is updated with the received LPM token BESL bmAttribute when an ACK, NYET, or STALL response is sent to an LPM transaction.

BESL[3:0]T_{BESL} (µs)

0000: 125
0001: 150
0010: 200
0011: 300
0100: 400
0101: 500
0110: 1000
0111: 2000
1000: 3000
1001: 4000
1010: 5000
1011: 6000
1100: 7000
1101: 8000
1110: 9000
1111: 10000

Bit 1 **LPMACK:** LPM token acknowledge enable

Handshake response to LPM token preprogrammed by device application software.

1: ACK

Even though ACK is preprogrammed, the core device responds with ACK only on successful LPM transaction. The LPM transaction is successful if:

– No PID/CRC5 errors in either EXT token or LPM token (else ERROR)
– Valid bLinkState = 0001B (L1) received in LPM transaction (else STALL)
– No data pending in transmit queue (else NYET).

0: NYET

The preprogrammed software bit is over-ridden for response to LPM token when:

– The received bLinkState is not L1 (STALL response), or
– An error is detected in either of the LPM token packets because of corruption (ERROR response).

Note: Accessible only in device mode.

Bit 0 **LPMEN:** LPM support enable

The application uses this bit to control the OTG_HS core LPM capabilities.

If the core operates as a non-LPM-capable host, it cannot request the connected device or hub to activate LPM mode.

If the core operates as a non-LPM-capable device, it cannot respond to any LPM transactions.

0: LPM capability is not enabled
1: LPM capability is enabled

62.14.18 OTG host periodic transmit FIFO size register (OTG_HPTXFSIZ)

Address offset: 0x100

Reset value: 0x0400 0800

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PTXFSIZ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PTXSA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **PTXFSIZ[15:0]:** Host periodic Tx FIFO depth
This value is in terms of 32-bit words.
Minimum value is 16

Bits 15:0 **PTXSA[15:0]:** Host periodic Tx FIFO start address
This field configures the memory start address for periodic transmit FIFO RAM.

62.14.19 OTG device IN endpoint transmit FIFO x size register (OTG_DIEPTXFx)

Address offset: 0x104 + 0x04 * (x - 1), (x = 1 to 8)

Reset value: Block 1: 0x0200 0400

Reset value: Block 2: 0x0200 0600

Reset value: Block 3: 0x0200 0800

Reset value: Block 4: 0x0200 0A00

Reset value: Block 5: 0x0200 0C00

Reset value: Block 6: 0x0200 0E00

Reset value: Block 7: 0x0200 1000

Reset value: Block 8: 0x0200 1200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
INEPTXFD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INEPTXSA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **INEPTXFD[15:0]:** IN endpoint Tx FIFO depth
This value is in terms of 32-bit words.
Minimum value is 16

Bits 15:0 **INEPTXSA[15:0]:** IN endpoint FIFOx transmit RAM start address
This field contains the memory start address for IN endpoint transmit FIFOx. The address must be aligned with a 32-bit memory location.

62.14.20 Host-mode registers

Bit values in the register descriptions are expressed in binary unless otherwise specified.

Host-mode registers affect the operation of the core in the host mode. Host mode registers must not be accessed in device mode, as the results are undefined. Host mode registers can be categorized as follows:

62.14.21 OTG host configuration register (OTG_HCFG)

Address offset: 0x400

Reset value: 0x0000 0000

This register configures the core after power-on. Do not make changes to this register after initializing the host.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	PERSSCHEDENA	FRLSTEN[1:0]		DESCDMA	Res.	Res.	Res.	Res.	Res.	Res.	Res.
					rw	rw	rw	rw							

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSLSS	FSLSPCS[1:0]	
													r	rw	rw

Bits 31:27 Reserved, must be kept at reset value.

Bit 26 **PERSSCHEDENA**: Enable periodic scheduling
Applicable in host scatter/gather DMA mode only. Enables periodic scheduling within the core. Initially, the bit is res and the core does not process any periodic channels. As soon as this bit is set, the core gets ready to start scheduling periodic channels and sets OTG_HCFG.PERSCHEDSTAT. The setting of PERSCHEDSTAT indicates the core has enabled periodic scheduling. Once PERSSCHEDENA is set, the application is not supposed to reset the bit unless PERSCHEDSTAT is set. As soon as this bit is reset, the core gets ready to stop scheduling periodic channels and resets HCFG. PerSchedStat. In non-Scatter/Gather DMA mode, this bit is reserved.

Bits 25:24 **FRLSTEN[1:0]**: Frame list entries
The value in the register specifies the number of entries in the Frame list. This field is valid only in Scatter/Gather DMA mode.
2'b00: Reserved
2'b01: 8 Entries
2'b10: 16 Entries
2'b11: 32 Entries In non-Scatter/Gather

Bit 23 **DESCDMA**: Enable scatter/gather DMA in host mode

The application can set this bit during initialization to enable the Scatter/Gather DMA operation. This bit must be modified only once after a reset. The following combinations are available for programming:
OTG_GAHBCFG.DMAEN=0,OTG_HCFG.DESCDMA=0 => Slave mode
OTG_GAHBCFG.DMAEN=0,OTG_HCFG.DESCDMA=1 => Invalid
OTG_GAHBCFG.DMAEN=1,OTG_HCFG.DESCDMA=0 => Buffered DMA mode
OTG_GAHBCFG.DMAEN=1,OTG_HCFG.DESCDMA=1 => Scatter/Gather DMA mode

Bits 22:3 Reserved, must be kept at reset value.

Bit 2 **FSLSS:** FS- and LS-only support

The application uses this bit to control the core's enumeration speed. Using this bit, the application can make the core enumerate as an FS host, even if the connected device supports HS traffic. Do not make changes to this field after initial programming.

Bits 1:0 **FSLSPCS[1:0]:** FS/LS PHY clock select

When the core is in FS host mode
01: PHY clock is running at 48 MHz
Others: Reserved
When the core is in LS host mode
00: Reserved
01: Select 48 MHz PHY clock frequency
10: Select 6 MHz PHY clock frequency
11: Reserved

Note: The FSLSPCS must be set on a connection event according to the speed of the connected device (after changing this bit, a software reset must be performed).

62.14.22 OTG host frame interval register (OTG_HFIR)

Address offset: 0x404

Reset value: 0x0000 EA60

This register stores the frame interval information for the current speed to which the OTG_HS controller has enumerated.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RLD CTRL
															rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FRIVL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:17 Reserved, must be kept at reset value.

Bit 16 **RLDCTRL:** Reload control

This bit allows dynamic reloading of the HFIR register during run time.

0: The HFIR cannot be reloaded dynamically

1: The HFIR can be dynamically reloaded during run time.

This bit needs to be programmed during initial configuration and its value must not be changed during run time.

Caution: RLDCTRL = 0 is not recommended.

Bits 15:0 **FRIVL[15:0]:** Frame interval

The value that the application programs to this field, specifies the interval between two consecutive micro-SOFs (HS) or Keep-Alive tokens (LS). This field contains the number of PHY clocks that constitute the required frame interval. The application can write a value to this register only after the port enable bit of the host port control and status register (PENA bit in OTG_HPRT) has been set. If no value is programmed, the core calculates the value based on the PHY clock specified in the FS/LS PHY clock select field of the host configuration register (FSLSPCS in OTG_HCFG). Do not change the value of this field after the initial configuration, unless the RLDCTRL bit is set. In such case, the FRIVL is reloaded with each SOF event.

– Frame interval = 125 µs × (FRIVL - 1) in high speed operation

– Frame interval = 1 ms × (FRIVL - 1) in low/full speed operation

62.14.23 OTG host frame number/frame time remaining register (OTG_HFNUM)

Address offset: 0x408

Reset value: 0x0000 3FFF

This register indicates the current frame number. It also indicates the time remaining (in terms of the number of PHY clocks) in the current frame.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
FTREM[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FRNUM[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **FTREM[15:0]:** Frame time remaining

Indicates the amount of time remaining in the current frame, in terms of PHY clocks. This field decrements on each PHY clock. When it reaches zero, this field is reloaded with the value in the Frame interval register and a new SOF is transmitted on the USB.

Bits 15:0 **FRNUM[15:0]:** Frame number

This field increments when a new SOF is transmitted on the USB, and is cleared to 0 when it reaches 0x3FFF.

62.14.24 OTG_Host periodic transmit FIFO/queue status register (OTG_HPTXSTS)

Address offset: 0x410

Reset value: 0x0008 0100

This read-only register contains the free space information for the periodic Tx FIFO and the periodic transmit request queue.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PTXQTOP[7:0]								PTXQSAV[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PTXFSAVL[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 **PTXQTOP[7:0]:** Top of the periodic transmit request queue

This indicates the entry in the periodic Tx request queue that is currently being processed by the MAC.

This register is used for debugging.

Bit 31: Odd/Even frame

0: send in even frame

1: send in odd frame

Bits 30:27: Channel/endpoint number

Bits 26:25: Type

00: IN/OUT

01: Zero-length packet

11: Disable channel command

Bit 24: Terminate (last entry for the selected channel/endpoint)

Bits 23:16 **PTXQSAV[7:0]:** Periodic transmit request queue space available

Indicates the number of free locations available to be written in the periodic transmit request queue. This queue holds both IN and OUT requests.

00: Periodic transmit request queue is full

01: 1 location available

10: 2 locations available

bxn: n locations available (0 ≤ n ≤ 8)

Others: Reserved

Bits 15:0 **PTXFSAVL[15:0]:** Periodic transmit data FIFO space available

Indicates the number of free locations available to be written to in the periodic Tx FIFO.

Values are in terms of 32-bit words

0000: Periodic Tx FIFO is full

0001: 1 word available

0010: 2 words available

bxn: n words available (where 0 ≤ n ≤ PTXFD)

Others: Reserved

62.14.25 OTG host all channels interrupt register (OTG_HAINT)

Address offset: 0x414

Reset value: 0x0000 0000

When a significant event occurs on a channel, the host all channels interrupt register interrupts the application using the host channels interrupt bit of the core interrupt register (HCINT bit in OTG_GINTSTS). This is shown in *Figure 787*. There is one interrupt bit per channel, up to a maximum of 16 bits. Bits in this register are set and cleared when the application sets and clears bits in the corresponding host channel-x interrupt register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HAINT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **HAINT[15:0]:** Channel interrupts
One bit per channel: Bit 0 for Channel 0, bit 15 for Channel 15

62.14.26 OTG host all channels interrupt mask register (OTG_HAINTMSK)

Address offset: 0x418

Reset value: 0x0000 0000

The host all channel interrupt mask register works with the host all channel interrupt register to interrupt the application when an event occurs on a channel. There is one interrupt mask bit per channel, up to a maximum of 16 bits.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HAINTM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **HAINTM[15:0]:** Channel interrupt mask
0: Masked interrupt
1: Unmasked interrupt
One bit per channel: Bit 0 for channel 0, bit 15 for channel 15

62.14.27 OTG host frame list base address register (OTG_HFLBADDR)

Address offset: 0x41C

Reset value: 0x0000 0000

This register holds the starting address of the frame list information (scatter/gather mode).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HFLBADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HFLBADDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **HFLBADDR[31:0]**: The starting address of the frame list (scatter/gather mode).
This register is used only for isochronous and interrupt channels.

62.14.28 OTG host port control and status register (OTG_HPRT)

Address offset: 0x440

Reset value: 0x0000 0000

This register is available only in host mode. Currently, the OTG host supports only one port.

A single register holds USB port-related information such as USB reset, enable, suspend, resume, connect status, and test mode for each port. It is shown in *Figure 787*. The rc_w1 bits in this register can trigger an interrupt to the application through the host port interrupt bit of the core interrupt register (HPRTINT bit in OTG_GINTSTS). On a port interrupt, the application must read this register and clear the bit that caused the interrupt. For the rc_w1 bits, the application must write a 1 to the bit to clear the interrupt.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSPD[1:0]		PTCTL[3]
													r	r	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PTCTL[2:0]			PPWR	PLSTS[1:0]		Res.	PRST	PSUSP	PRES	POC CHNG	POCA	PEN CHNG	PENA	PCDET	PCSTS
rw	rw	rw	rw	r	r		rw	rs	rw	rc_w1	r	rc_w1	rc_w1	rc_w1	r

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:17 **PSPD[1:0]:** Port speed

Indicates the speed of the device attached to this port.
01: Full speed
10: Low speed
11: Reserved
00: High speed

Bits 16:13 **PTCTL[3:0]:** Port test control

The application writes a nonzero value to this field to put the port into a Test mode, and the corresponding pattern is signaled on the port.
0000: Test mode disabled
0001: Test_J mode
0010: Test_K mode
0011: Test_SE0_NAK mode
0100: Test_Packet mode
0101: Test_Force_Enable
Others: Reserved

Bit 12 **PPWR:** Port power

The application uses this field to control power to this port, and the core clears this bit on an overcurrent condition.
0: Power off
1: Power on

Bits 11:10 **PLSTS[1:0]:** Port line status

Indicates the current logic level USB data lines
Bit 10: Logic level of OTG_DP
Bit 11: Logic level of OTG_DM

Bit 9 Reserved, must be kept at reset value.

Bit 8 **PRST:** Port reset

When the application sets this bit, a reset sequence is started on this port. The application must time the reset period and clear this bit after the reset sequence is complete.
0: Port not in reset
1: Port in reset
The application must leave this bit set for a minimum duration of at least 10 ms to start a reset on the port. The application can leave it set for another 10 ms in addition to the required minimum duration, before clearing the bit, even though there is no maximum limit set by the USB standard.
High speed: 50 ms
Full speed/Low speed: 10 ms

Bit 7 **PSUSP:** Port suspend

The application sets this bit to put this port in suspend mode. The core only stops sending SOFs when this is set. To stop the PHY clock, the application must set the port clock stop bit, which asserts the suspend input pin of the PHY.
The read value of this bit reflects the current suspend status of the port. This bit is cleared by the core after a remote wakeup signal is detected or the application sets the port reset bit or port resume bit in this register or the resume/remote wakeup detected interrupt bit or disconnect detected interrupt bit in the core interrupt register (WKUPINT or DISCINT in OTG_GINTSTS, respectively).
0: Port not in suspend mode
1: Port in suspend mode

Bit 6 **PRES:** Port resume

The application sets this bit to drive resume signaling on the port. The core continues to drive the resume signal until the application clears this bit.

If the core detects a USB remote wakeup sequence, as indicated by the port resume/remote wakeup detected interrupt bit of the core interrupt register (WKUPINT bit in OTG_GINTSTS), the core starts driving resume signaling without application intervention and clears this bit when it detects a disconnect condition. The read value of this bit indicates whether the core is currently driving resume signaling.

0: No resume driven

1: Resume driven

When LPM is enabled and the core is in L1 state, the behavior of this bit is as follow:

1. The application sets this bit to drive resume signaling on the port.

2. The core continues to drive the resume signal until a predetermined time specified in BESLTHRS[3:0] field of OTG_GLPMCFG register.

3. If the core detects a USB remote wakeup sequence, as indicated by the port L1Resume/Remote L1Wakeup detected interrupt bit of the core interrupt register (WKUPINT in OTG_GINTSTS), the core starts driving resume signaling without application intervention and clears this bit at the end of resume.This bit can be set or cleared by both the core and the application. This bit is cleared by the core even if there is no device connected to the host.

Bit 5 **POCCHNG:** Port overcurrent change

The core sets this bit when the status of the port overcurrent active bit (bit 4) in this register changes.

Bit 4 **POCA:** Port overcurrent active

Indicates the overcurrent condition of the port.

0: No overcurrent condition

1: Overcurrent condition

Bit 3 **PENCHNG:** Port enable/disable change

The core sets this bit when the status of the port enable bit 2 in this register changes.

Bit 2 **PENA:** Port enable

A port is enabled only by the core after a reset sequence, and is disabled by an overcurrent condition, a disconnect condition, or by the application clearing this bit. The application cannot set this bit by a register write. It can only clear it to disable the port. This bit does not trigger any interrupt to the application.

0: Port disabled

1: Port enabled

Bit 1 **PCDET:** Port connect detected

The core sets this bit when a device connection is detected to trigger an interrupt to the application using the host port interrupt bit in the core interrupt register (HPRTINT bit in OTG_GINTSTS). The application must write a 1 to this bit to clear the interrupt.

Bit 0 **PCSTS:** Port connect status

0: No device is attached to the port

1: A device is attached to the port

62.14.29 OTG host channel x characteristics register (OTG_HCCHARx)

Address offset: 0x500 + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CHENA	CHDIS	ODD FRM	DAD[6:0]							MCNT[1:0]		EPTYP[1:0]		LSDEV	Res.
rs	rs	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EPDIR	EPNUM[3:0]				MPSIZ[10:0]										
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **CHENA:** Channel enable

When Scatter/Gather mode is enabled:

1'b0: Indicates that the descriptor structure is not yet ready

1'b1: Indicates that the descriptor structure and data buffer with data is setup and this channel can access the descriptor

When Scatter/Gather mode is disabled: This field is set by the application and cleared by the OTG host.

0: Channel disabled
1: Channel enabled

Bit 30 **CHDIS:** Channel disable

The application sets this bit to stop transmitting/receiving data on a channel, even before the transfer for that channel is complete. The application must wait for the Channel disabled interrupt before treating the channel as disabled.

Bit 29 **ODDFRM:** Odd frame

This field is set (reset) by the application to indicate that the OTG host must perform a transfer in an odd frame. This field is applicable for only periodic (isochronous and interrupt) transactions.

0: Even frame
1: Odd frame

Bits 28:22 **DAD[6:0]:** Device address

This field selects the specific device serving as the data source or sink.

Bits 21:20 **MCNT[1:0]:** Multicount

This field indicates to the host the number of transactions that must be executed per frame for this periodic endpoint. For non-periodic transfers, this field is not used

00: Reserved. This field yields undefined results
01: 1 transaction
10: 2 transactions per frame to be issued for this endpoint
11: 3 transactions per frame to be issued for this endpoint

Note: This field must be set to at least 01.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

Indicates the transfer type selected.

00: Control
01: Isochronous
10: Bulk
11: Interrupt

Bit 17 **LSDEV:** Low-speed device
This field is set by the application to indicate that this channel is communicating to a low-speed device.

Bit 16 Reserved, must be kept at reset value.

Bit 15 **EPDIR:** Endpoint direction
Indicates whether the transaction is IN or OUT.
0: OUT
1: IN

Bits 14:11 **EPNUM[3:0]:** Endpoint number
Indicates the endpoint number on the device serving as the data source or sink.

Bits 10:0 **MPSIZ[10:0]:** Maximum packet size
Indicates the maximum packet size of the associated endpoint.

62.14.30 OTG host channel x split control register (OTG_HCSPLTx)

Address offset: 0x504 + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SPLIT EN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COMP LSPLT
rw															rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
XACTPOS[1:0]		HUBADDR[6:0]							PRTADDR[6:0]						
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **SPLITEN:** Split enable
The application sets this bit to indicate that this channel is enabled to perform split transactions.

Bits 30:17 Reserved, must be kept at reset value.

Bit 16 **COMPLSPLT:** Do complete split
The application sets this bit to request the OTG host to perform a complete split transaction.

Bits 15:14 **XACTPOS[1:0]:** Transaction position
This field is used to determine whether to send all, first, middle, or last payloads with each OUT transaction.
11: All. This is the entire data payload of this transaction (which is less than or equal to 188 bytes)
10: Begin. This is the first data payload of this transaction (which is larger than 188 bytes)
00: Mid. This is the middle payload of this transaction (which is larger than 188 bytes)
01: End. This is the last payload of this transaction (which is larger than 188 bytes)

Bits 13:7 **HUBADDR[6:0]:** Hub address
This field holds the device address of the transaction translator's hub.

Bits 6:0 **PRTADDR[6:0]:** Port address
This field is the port number of the recipient transaction translator.

62.14.31 OTG host channel x interrupt register (OTG_HCINTx)

Address offset: 0x508 + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

This register indicates the status of a channel with respect to USB- and AHB-related events. It is shown in *Figure 787*. The application must read this register when the host channels interrupt bit in the core interrupt register (HCINT bit in OTG_GINTSTS) is set. Before the application can read this register, it must first read the host all channels interrupt (OTG_HAINT) register to get the exact channel number for the host channel-x interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_HAINT and OTG_GINTSTS registers.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	DESCLSTROLL	XCSXACTERR	BNA	DTERR	FRMOR	BBERR	TXERR	NYET	ACK	NAK	STALL	AHBERR	CHH	XFRC
		rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **DESCLSTROLL:** Descriptor rollover interrupt.
This bit is valid only when Scatter/Gather DMA mode is enabled. The core sets this bit when the corresponding channel descriptor list rolls over. For non Scatter/Gather DMA mode, this bit is reserved.

Bit 12 **XCSXACTERR:** Excessive transaction error.
This bit is valid only when Scatter/Gather DMA mode is enabled. The core sets this bit when 3 consecutive transaction errors occurred on the USB bus. XCS_XACT_ERR is not generated for isochronous channels. For non Scatter/Gather DMA mode, this bit is reserved.

Bit 11 **BNA:** Buffer not available interrupt.
This bit is valid only when Scatter/Gather DMA mode is enabled. The core generates this interrupt when the descriptor accessed is not ready for the core to process. BNA interrupt is not generated for isochronous channels. For non Scatter/Gather DMA mode, this bit is reserved.

Bit 10 **DTERR:** Data toggle error. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.

Bit 9 **FRMOR:** Frame overrun. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.

Bit 8 **BBERR:** Babble error. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.

Bit 7 **TXERR:** Transaction error. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.
Indicates one of the following errors occurred on the USB.
CRC check failure
Timeout
Bit stuff error
False EOP

Bit 6 **NYET:** Not yet ready response received interrupt. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.

Bit 5 **ACK:** ACK response received/transmitted interrupt. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.

Bit 4 **NAK:** NAK response received interrupt. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.

Bit 3 **STALL:** STALL response received interrupt. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.

Bit 2 **AHBERR:** AHB error

This error is generated only in Internal DMA mode when an AHB error occurs during an AHB read/write operation. The application can read the corresponding DMA channel address register to get the error address.

Bit 1 **CHH:** Channel halted.

In non scatter/gather DMA mode indicates the transfer completed abnormally either because of any USB transaction error or in response to disable request by the application. In scatter/gather DMA mode, this indicates that transfer completed due to any of the following:

– EOL being set in descriptor
– AHB error
– Excessive transaction errors
– In response to disable request by the application
– Babble
– Stall

Bit 0 **XFRC:** Transfer completed.

Transfer completed normally without any errors.

62.14.32 OTG host channel x interrupt mask register (OTG_HCINTMSKx)

Address offset: 0x50C + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

This register reflects the mask for each channel status described in the previous section.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	DESCLSTROLLMSK	Res.	BNAMSK	DTERRM	FRMORM	BBERRM	TXERRM	NYET	ACKM	NAKM	STALLM	AHBERRM	CHHM	XFRCM
		rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **DESCLSTROLLMSK:** Descriptor rollover interrupt mask register.
This bit is valid only when Scatter/Gather DMA mode is enabled.
In non Scatter/Gather DMA mode, this bit is reserved.

Bit 12 Reserved, must be kept at reset value.

Bit 11 **BNAMSK:** Buffer not available interrupt mask register.
This bit is valid only when Scatter/Gather DMA mode is enabled.
In non Scatter/Gather DMA mode, this bit is reserved

Bit 10 **DTERRM:** Data toggle error mask. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.
0: Masked interrupt
1: Unmasked interrupt

Bit 9 **FRMORM:** Frame overrun mask. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.
0: Masked interrupt
1: Unmasked interrupt

Bit 8 **BBERRM:** Babble error mask. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.
0: Masked interrupt
1: Unmasked interrupt

Bit 7 **TXERRM:** Transaction error mask. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.
0: Masked interrupt
1: Unmasked interrupt

Bit 6 **NYET:** response received interrupt mask. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.
0: Masked interrupt
1: Unmasked interrupt

Bit 5 **ACKM:** ACK response received/transmitted interrupt mask. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.
0: Masked interrupt
1: Unmasked interrupt

Bit 4 **NAKM:** NAK response received interrupt mask. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **STALLM:** STALL response received interrupt mask. In Scatter/Gather DMA mode, the interrupt due to this bit is masked.
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **AHBERRM:** AHB error. In scatter/gather DMA mode for host, interrupts will not be generated due to the corresponding bits set in OTG_HCINTx.
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **CHHM:** Channel halted mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed mask
0: Masked interrupt
1: Unmasked interrupt

62.14.33 OTG host channel x transfer size register (OTG_HCTSIZx)

Address offset: 0x510 + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DO PNG	DPID[1:0]		PKTCNT[9:0]										XFRSIZ[18:16]		
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
XFRSIZ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **DOPNG:** Do Ping
This bit is used only for OUT transfers. Setting this field to 1 directs the host to do PING protocol.
Note: Do not set this bit for IN transfers. If this bit is set for IN transfers, it disables the channel.

Bits 30:29 **DPID[1:0]:** Data PID
The application programs this field with the type of PID to use for the initial transaction. The host maintains this field for the rest of the transfer.
00: DATA0
01: DATA2
10: DATA1
11: SETUP (control) / MDATA (non-control)

Bits 28:19 **PKTCNT[9:0]:** Packet count
This field is programmed by the application with the expected number of packets to be transmitted (OUT) or received (IN).
The host decrements this count on every successful transmission or reception of an OUT/IN packet. Once this count reaches zero, the application is interrupted to indicate normal completion.

Bits 18:0 **XFRSIZ[18:0]:** Transfer size
For an OUT, this field is the number of data bytes the host sends during the transfer.
For an IN, this field is the buffer size that the application has reserved for the transfer. The application is expected to program this field as an integer multiple of the maximum packet size for IN transactions (periodic and non-periodic).

62.14.34 OTG host channel x transfer size register (OTG_HCTSIZSGx)

Address offset: 0x510 + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DO PNG	PID[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw													
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NTD[7:0]								SCHED_INFO[7:0]							
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **DOPNG:** Do Ping

This bit is used only for OUT transfers. Setting this field to 1 directs the host to do PING protocol.

Note: Do not set this bit for IN transfers. If this bit is set for IN transfers, it disables the channel.

Bits 30:29 **PID[1:0]:** Pid

The application programs this field with the type of PID to use for the initial transaction. The host maintains this field for the rest of the transfer.

00: DATA0

01: DATA2

10: DATA1

11: MDATA (non-control) / SETUP (control)

Bits 28:16 Reserved, must be kept at reset value.

Bits 15:8 **NTD[7:0]:** Number of transfer descriptors

Non isochronous: this value is in terms of number of descriptors. The maximum number of descriptor that can be present in the list is 64. The values can be from 0 to 63.
0: 1 descriptor
1: 2 descriptors
...
63: 64 descriptors
Others: Reserved
This field indicates the total number of descriptors present in that list. The core will wrap around after servicing NTD number of descriptors for that list.

Isochronous: this field indicates the number of descriptors present in that list.
The possible values for FS are:
1: 2 descriptors
3: 4 descriptors
7: 8 descriptors
15: 16 descriptors
31: 32 descriptors
63: 64: descriptors
Others: Reserved
The possible values for HS are:
7: 8 descriptors
15: 16 descriptors
31: 32 descriptors
63: 64 descriptors
127: 128 descriptors
255: 256 descriptors
Others: Reserved

Bits 7:0 **SCHED_INFO[7:0]**: Schedule information
Every bit in this 8 bit register indicates scheduling for that microframe. Bit 0 indicates scheduling for 1st microframe and bit 7 indicates scheduling for 8th microframe in that frame. A value of 0b11111111 indicates that the corresponding interrupt channel is scheduled to issue a token every microframe in that frame. A value of 0b10101010 indicates that the corresponding interrupt channel is scheduled to issue a token every alternate microframe starting with second microframe. Note that this field is applicable only for periodic (isochronous and interrupt) channels.

62.14.35 OTG host channel x DMA address register in buffer DMA [alternate] (OTG_HCDMAx)

Address offset: 0x514 + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMAADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAADDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DMAADDR[31:0]:** DMA address

This field holds the start address in the external memory from which the data for the endpoint must be fetched or to which it must be stored. This register is incremented on every AHB transaction.

62.14.36 OTG host channel x DMA address register in scatter/gather DMA [alternate] (OTG_HCDMASGx)

Address offset: 0x514 + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMASG[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMASG[15:3]													Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw			

Bits 31:3 **DMASG[31:3]:** DMA scatter/gather information

The DMASG information is composed of two parts DMASG_ADDR = DMASG[31:N] and DMASG_CTD = DAMSG[N-1:3].

Non-isochronous case (N = 9):

The DAMSG_ADDR field holds the start address of the 512 bytes page. The first descriptor in the list should be located in this address. The first descriptor may be or may not be ready. The core starts processing the list from the CTD value.

The DMASG_CTD field holds a value in terms of number of descriptors. The values can be from 0 (1 descriptor) to 63 (64 descriptors). This field indicates the current descriptor processed in the list. This field is updated both by application and the core. For example, if the application enables the channel after programming CTD = 5, then the core will start processing the 6th descriptor. The address is obtained by adding a value of 8 * 5 = 40 bytes (decimal) to DMAAddr.

Isochronous case (N=4 to 11):

The DAMSG_ADDR field holds the address of the 2*(NTD+1) bytes of locations in which the isochronous descriptors are present where N is based on NTD as per the following table:

HS ISOC; NTD = 7: N = 6
HS ISOC; NTD = 15: N = 7
HS ISOC; NTD = 31: N = 8
HS ISOC; NTD = 63: N = 9
HS ISOC; NTD = 127: N = 10
HS ISOC; NTD = 255: N = 11
FS ISOC; NTD = 1: N = 4
FS ISOC; NTD = 3: N = 5
FS ISOC; NTD = 7: N = 6
FS ISOC; NTD = 15: N = 7
FS ISOC; NTD = 31: N = 8
FS ISOC; NTD = 63: N = 9

The DMASG_CTD field is based on the current frame/(micro)frame value. Need to be set to zero by application.

Bits 2:0 Reserved, must be kept at reset value.

62.14.37 OTG host channel-n DMA address buffer register (OTG_HCDMABx)

Address offset: 0x51C + 0x20 * x, (x = 0 to 15)

Reset value: 0x0000 0000 (0x0000 0000)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HCDMAB[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HCDMAB[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **HCDMAB[31:0]:** DMA address

This register holds the current buffer address (scatter/gather mode).

62.14.38 Device-mode registers

These registers must be programmed every time the core changes to device mode

62.14.39 OTG device configuration register (OTG_DCFG)

Address offset: 0x800

Reset value: 0x0220 0000

This register configures the core in device mode after power-on or after certain control commands or enumeration. Do not make changes to this register after initial programming.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	PERSCHIVL[1:0]		DESCDMA	Res.	Res.	Res.	Res.	Res.	Res.	Res.
						rw	rw	rw							

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ERRATIM	XCVRDLY	Res.	PFIVL[1:0]		DAD[6:0]							Res.	NZLSOHSK	DSPD[1:0]	
rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:24 **PERSCHIVL[1:0]:** Periodic schedule interval

This field specifies the amount of time the Internal DMA engine must allocate for fetching periodic IN endpoint data. Based on the number of periodic endpoints, this value must be specified as 25, 50 or 75% of the (micro) frame.

- When any periodic endpoints are active, the internal DMA engine allocates the specified amount of time in fetching periodic IN endpoint data
- When no periodic endpoint is active, then the internal DMA engine services nonperiodic endpoints, ignoring this field
- After the specified time within a (micro) frame, the DMA switches to fetching nonperiodic endpoints

00: 25% of (micro)frame
01: 50% of (micro)frame
10: 75% of (micro)frame
11: Reserved

Note: Periodic Scheduling Interval (PERSCHIVL) must be programmed for Scatter/Gather DMA mode.

Bit 23 **DESCDMA:** Enable scatter/gather DMA in device mode

The application can set this bit during initialization to enable the Scatter/Gather DMA operation. This bit must be modified only once after a reset. The following combinations are available for programming:
OTG_GAHBCFG.DMAEN=0,OTG_DCFG.DESCDMA=0 => Slave mode
OTG_GAHBCFG.DMAEN=0,OTG_DCFG.DESCDMA=1 => Invalid
OTG_GAHBCFG.DMAEN=1,OTG_DCFG.DESCDMA=0 => Buffer DMA mode
OTG_GAHBCFG.DMAEN=1,OTG_DCFG.DESCDMA=1 => Scatter/Gather DMA mode

Bits 22:16 Reserved, must be kept at reset value.

Bit 15 **ERRATIM:** Erratic error interrupt mask
1: Mask early suspend interrupt on erratic error
0: Early suspend interrupt is generated on erratic error

Bit 14 **XCVRDLY:** Transceiver delay
Enables or disables delay in ULPI timing during device chirp.
0: Disable delay (use default timing)
1: Enable delay to default timing, necessary for some ULPI PHYs

Bit 13 Reserved, must be kept at reset value.

Bits 12:11 **PFIVL[1:0]:** Periodic frame interval
Indicates the time within a frame at which the application must be notified using the end of periodic frame interrupt. This can be used to determine if all the isochronous traffic for that frame is complete.
00: 80% of the frame interval
01: 85% of the frame interval
10: 90% of the frame interval
11: 95% of the frame interval

Bits 10:4 **DAD[6:0]:** Device address
The application must program this field after every SetAddress control command.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **NZLSOHSK:** Non-zero-length status OUT handshake
The application can use this field to select the handshake the core sends on receiving a nonzero-length data packet during the OUT transaction of a control transfer's status stage.
1:Send a STALL handshake on a nonzero-length status OUT transaction and do not send the received OUT packet to the application.
0:Send the received OUT packet to the application (zero-length or nonzero-length) and send a handshake based on the NAK and STALL bits for the endpoint in the device endpoint control register.

Bits 1:0 **DSPD[1:0]:** Device speed
Indicates the speed at which the application requires the core to enumerate, or the maximum speed the application can support. However, the actual bus speed is determined only after the chirp sequence is completed, and is based on the speed of the USB host to which the core is connected.
00: High speed
01: Full speed using HS
10: Reserved
11: Full speed using internal FS PHY

62.14.40 OTG device control register (OTG_DCTL)

Address offset: 0x804

Reset value: 0x0000 0002

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DSBESLRJCT	ENCONTONBNA	Res.
													rw	rw	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	POPRGDNE	CGONAK	SGONAK	CGINAK	SGINAK	TCTL[2:0]			GONSTS	GINSTS	SDIS	RWUSIG
				rw	w	w	w	w	rw	rw	rw	r	r	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **DSBESLRJCT:** Deep sleep BESL reject

Core rejects LPM request with BESL value greater than BESL threshold programmed. NYET response is sent for LPM tokens with BESL value greater than BESL threshold. By default, the deep sleep BESL reject feature is disabled.

Bit 17 ENCONTONBNA: Enable continue on BNA

This bit enables the core to continue on BNA for Bulk OUT and INTR OUT endpoints. With this feature enabled, when a Bulk OUT or INTR OUT endpoint receives a BNA interrupt the core starts processing the descriptor that caused the BNA interrupt after the endpoint re-enables the endpoint.

0: After receiving BNA interrupt, the core disables the endpoint. When the endpoint is re-enabled by the application, the core starts processing from the DOEPDMA descriptor.

1: After receiving BNA interrupt, the core disables the endpoint. When the endpoint is re-enabled by the application, the core starts processing from the descriptor that received the BNA interrupt. It is a one-time programmable after reset bit like any other OTG_DCTL register bit.

Bits 16:12 Reserved, must be kept at reset value.

Bit 11 **POPRGDNE:** Power-on programming done

The application uses this bit to indicate that register programming is completed after a wakeup from power down mode.

Bit 10 **CGONAK:** Clear global OUT NAK

Writing 1 to this field clears the Global OUT NAK.

Bit 9 **SGONAK:** Set global OUT NAK

Writing 1 to this field sets the Global OUT NAK.
The application uses this bit to send a NAK handshake on all OUT endpoints.
The application must set the this bit only after making sure that the Global OUT NAK effective bit in the core interrupt register (GONAKEFF bit in OTG_GINTSTS) is cleared.

Bit 8 **CGINAK:** Clear global IN NAK

Writing 1 to this field clears the Global IN NAK.

Bit 7 **SGINAK:** Set global IN NAK

Writing 1 to this field sets the Global non-periodic IN NAK.The application uses this bit to send a NAK handshake on all non-periodic IN endpoints.
The application must set this bit only after making sure that the Global IN NAK effective bit in the core interrupt register (GINAKEFF bit in OTG_GINTSTS) is cleared.

Bits 6:4 **TCTL[2:0]:** Test control
000: Test mode disabled
001: Test_J mode
010: Test_K mode
011: Test_SE0_NAK mode
100: Test_Packet mode
101: Test_Force_Enable
Others: Reserved

Bit 3 **GONSTS:** Global OUT NAK status
0:A handshake is sent based on the FIFO status and the NAK and STALL bit settings.
1:No data is written to the Rx FIFO, irrespective of space availability. Sends a NAK handshake on all packets, except on SETUP transactions. All isochronous OUT packets are dropped.

Bit 2 **GINSTS:** Global IN NAK status
0:A handshake is sent out based on the data availability in the transmit FIFO.
1:A NAK handshake is sent out on all non-periodic IN endpoints, irrespective of the data availability in the transmit FIFO.

Bit 1 **SDIS:** Soft disconnect
The application uses this bit to signal the USB OTG core to perform a soft disconnect. As long as this bit is set, the host does not see that the device is connected, and the device does not receive signals on the USB. The core stays in the disconnected state until the application clears this bit.
0:Normal operation. When this bit is cleared after a soft disconnect, the core generates a device connect event to the USB host. When the device is reconnected, the USB host restarts device enumeration.
1:The core generates a device disconnect event to the USB host.

Bit 0 **RWUSIG:** Remote wakeup signaling
When the application sets this bit, the core initiates remote signaling to wake up the USB host. The application must set this bit to instruct the core to exit the suspend state. As specified in the USB 2.0 specification, the application must clear this bit 1 ms to 15 ms after setting it.
If LPM is enabled and the core is in the L1 (sleep) state, when the application sets this bit, the core initiates L1 remote signaling to wake up the USB host. The application must set this bit to instruct the core to exit the sleep state. As specified in the LPM specification, the hardware automatically clears this bit 50 µs ($T_{L1DevDrvResume}$) after being set by the application. The application must not set this bit when bRemoteWake from the previous LPM transaction is zero (refer to REMWAKE bit in GLPMCFG register).

Table 541 contains the minimum duration (according to device state) for which the Soft disconnect (SDIS) bit must be set for the USB host to detect a device disconnect. To accommodate clock jitter, it is recommended that the application add some extra delay to the specified minimum duration.

Table 541. Minimum duration for soft disconnect

Operating speed	Device state	Minimum duration
Full speed	Suspended	1 ms + 2.5 µs
Full speed	Idle	2.5 µs
Full speed	Not Idle or suspended (Performing transactions)	2.5 µs
High speed	Not Idle or suspended (Performing transactions)	125 µs

62.14.41 OTG device status register (OTG_DSTS)

Address offset: 0x808

Reset value: 0x0000 0010

This register indicates the status of the core with respect to USB-related events. It must be read on interrupts from the device all interrupts (OTG_DAINT) register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEVLNSTS[1:0]		FNSOF[13:8]					
								r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FNSOF[7:0]								Res.	Res.	Res.	Res.	EERR	ENUMSPD[1:0]		SUSP STS
r	r	r	r	r	r	r	r					r	r	r	r

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:22 **DEVLNSTS[1:0]:** Device line status

Indicates the current logic level USB data lines.
Bit [23]: Logic level of D+
Bit [22]: Logic level of D-

Bits 21:8 **FNSOF[13:0]:** Frame number of the received SOF

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **EERR:** Erratic error

The core sets this bit to report any erratic errors.
Due to erratic errors, the OTG_HS controller goes into suspended state and an interrupt is generated to the application with Early suspend bit of the OTG_GINTSTS register (ESUSP bit in OTG_GINTSTS). If the early suspend is asserted due to an erratic error, the application can only perform a soft disconnect recover.

Bits 2:1 **ENUMSPD[1:0]:** Enumerated speed

Indicates the speed at which the OTG_HS controller has come up after speed detection through a chirp sequence.
00: High Speed using HS PHY
01: Full Speed using HS PHY
11: Full speed using embedded FS PHY
Others: reserved

Bit 0 **SUSPSTS:** Suspend status

In device mode, this bit is set as long as a suspend condition is detected on the USB. The core enters the suspended state when there is no activity on the USB data lines for a period of 3 ms. The core comes out of the suspend:

– When there is an activity on the USB data lines
– When the application writes to the remote wakeup signaling bit in the OTG_DCTL register (RWUSIG bit in OTG_DCTL).

62.14.42 OTG device IN endpoint common interrupt mask register (OTG_DIEPMSK)

Address offset: 0x810

Reset value: 0x0000 0000

This register works with each of the OTG_DIEPINTx registers for all endpoints to generate an interrupt per IN endpoint. The IN endpoint interrupt for a specific status in the OTG_DIEPINTx register can be masked by writing to the corresponding bit in this register. Status bits are masked by default.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	NAKM	Res.	Res.	Res.	BNAM	TXFURM	Res.	INEPNEM	INEPNMM	ITTXFEMSK	TOM	AHBERRM	EPDM	XFRCM
		rw				rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **NAKM:** NAK interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 12:10 Reserved, must be kept at reset value.

Bit 9 **BNAM:** BNA interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 8 **TXFURM:** FIFO underrun mask
0: Masked interrupt
1: Unmasked interrupt

Bit 7 Reserved, must be kept at reset value.

Bit 6 **INEPNEM:** IN endpoint NAK effective mask
0: Masked interrupt
1: Unmasked interrupt

Bit 5 **INEPNMM:** IN token received with EP mismatch mask
0: Masked interrupt
1: Unmasked interrupt

Bit 4 **ITTXFEMSK:** IN token received when Tx FIFO empty mask
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **TOM:** Timeout condition mask (Non-isochronous endpoints)
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **AHBERRM:** AHB error mask
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **EPDM:** Endpoint disabled interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed interrupt mask
0: Masked interrupt
1: Unmasked interrupt

62.14.43 OTG device OUT endpoint common interrupt mask register (OTG_DOEPMSK)

Address offset: 0x814

Reset value: 0x0000 0000

This register works with each of the OTG_DOEPINTx registers for all endpoints to generate an interrupt per OUT endpoint. The OUT endpoint interrupt for a specific status in the OTG_DOEPINTx register can be masked by writing into the corresponding bit in this register. Status bits are masked by default.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	NYET MSK	NAK MSK	BERR M	Res.	Res.	BNAM	OUT PKT ERRM	Res.	B2B STUPM	STS PHSR XM	OTEPD M	STUPM	AHB ERRM	EPDM	XFRC M
	rw	rw	rw			rw	rw		rw	rw	rw	rw	rw	rw	rw

Bits 31:15 Reserved, must be kept at reset value.

Bit 14 **NYETMSK:** NYET interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 13 **NAKMSK:** NAK interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 12 **BERRM**: Babble error interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **BNAM:** BNA interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 8 **OUTPKTERRM:** Out packet error mask
0: Masked interrupt
1: Unmasked interrupt

Bit 7 Reserved, must be kept at reset value.

Bit 6 **B2BSTUPM:** Back-to-back SETUP packets received mask
Applies to control OUT endpoints only.
0: Masked interrupt
1: Unmasked interrupt

Bit 5 **STSPHSRXM**: Status phase received for control write mask
0: Masked interrupt
1: Unmasked interrupt

Bit 4 **OTEPDM:** OUT token received when endpoint disabled mask. Applies to control OUT endpoints only.
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **STUPM:** STUPM: SETUP phase done mask. Applies to control endpoints only.
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **AHBERRM:** AHB error mask
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **EPDM:** Endpoint disabled interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed interrupt mask
0: Masked interrupt
1: Unmasked interrupt

62.14.44 OTG device all endpoints interrupt register (OTG_DAINT)

Address offset: 0x818

Reset value: 0x0000 0000

When a significant event occurs on an endpoint, a OTG_DAINT register interrupts the application using the device OUT endpoints interrupt bit or device IN endpoints interrupt bit of the OTG_GINTSTS register (OEPINT or IEPINT in OTG_GINTSTS, respectively). There is one interrupt bit per endpoint, up to a maximum of 16 bits for OUT endpoints and 16 bits for IN endpoints. For a bidirectional endpoint, the corresponding IN and OUT interrupt bits are used. Bits in this register are set and cleared when the application sets and clears bits in the corresponding device endpoint-x interrupt register (OTG_DIEPINTx/OTG_DOEPINTx).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OEPINT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IEPINT[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **OEPINT[15:0]:** OUT endpoint interrupt bits
One bit per OUT endpoint:
Bit 16 for OUT endpoint 0, bit 19 for OUT endpoint 3.

Bits 15:0 **IEPINT[15:0]:** IN endpoint interrupt bits
One bit per IN endpoint:
Bit 0 for IN endpoint 0, bit 3 for endpoint 3.

62.14.45 OTG all endpoints interrupt mask register (OTG_DAINTMSK)

Address offset: 0x81C

Reset value: 0x0000 0000

The OTG_DAINTMSK register works with the device endpoint interrupt register to interrupt the application when an event occurs on a device endpoint. However, the OTG_DAINT register bit corresponding to that interrupt is still set.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OEPM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IEPM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **OEPM[15:0]:** OUT EP interrupt mask bits
One per OUT endpoint:
Bit 16 for OUT EP 0, bit 19 for OUT EP 3
0: Masked interrupt
1: Unmasked interrupt

Bits 15:0 **IEPM[15:0]:** IN EP interrupt mask bits
One bit per IN endpoint:
Bit 0 for IN EP 0, bit 3 for IN EP 3
0: Masked interrupt
1: Unmasked interrupt

62.14.46 OTG device V_{BUS} discharge time register (OTG_DVBUSDIS)

Address offset: 0x0828

Reset value: 0x0000 17D7

This register specifies the V_{BUS} discharge time after V_{BUS} pulsing during SRP.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VBUSDT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **VBUSDT[15:0]:** Device V_{BUS} discharge time
Specifies the V_{BUS} discharge time after V_{BUS} pulsing during SRP. This value equals:
V_{BUS} discharge time in PHY clocks / 1 024
Depending on V_{BUS} load, this value may need adjusting.

62.14.47 OTG device V_{BUS} pulsing time register (OTG_DVBUSPULSE)

Address offset: 0x082C

Reset value: 0x0000 05B8

This register specifies the V_{BUS} pulsing time during SRP.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DVBUSP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **DVBUSP[15:0]:** Device V_{BUS} pulsing time. This feature is only relevant to OTG1.3.
Specifies the V_{BUS} pulsing time during SRP. This value equals:
V_{BUS} pulsing time in PHY clocks / 1 024

62.14.48 OTG device threshold control register (OTG_DTHRCTL)

Address offset: 0x0830

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	ARPEN	Res.	RXTHRLEN[8:0]									RXTHREN
				rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	TXTHRLEN[8:0]									ISOTHREN	NONISOTHREN
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **ARPEN:** Arbiter parking enable

This bit controls internal DMA arbiter parking for IN endpoints. When thresholding is enabled and this bit is set to one, then the arbiter parks on the IN endpoint for which there is a token received on the USB. This is done to avoid getting into underrun conditions. By default parking is enabled.

Bit 26 Reserved, must be kept at reset value.

Bits 25:17 **RXTHRLEN[8:0]:** Receive threshold length

This field specifies the receive thresholding size in 32-bit words. This field also specifies the amount of data received on the USB before the core can start transmitting on the AHB. The threshold length has to be at least eight 32-bit words. The recommended value for RXTHRLEN is to be the same as the programmed AHB burst length (HBSTLEN bit in OTG_GAHBCFG).

Bit 16 **RXTHREN:** Receive threshold enable

When this bit is set, the core enables thresholding in the receive direction.

Bits 15:11 Reserved, must be kept at reset value.

Bits 10:2 **TXTHRLEN[8:0]:** Transmit threshold length

This field specifies the transmit thresholding size in 32-bit words. This field specifies the amount of data in bytes to be in the corresponding endpoint transmit FIFO, before the core can start transmitting on the USB. The threshold length has to be at least eight 32-bit words. This field controls both isochronous and nonisochronous IN endpoint thresholds. The recommended value for TXTHRLEN is to be the same as the programmed AHB burst length (HBSTLEN bit in OTG_GAHBCFG).

Bit 1 **ISOTHREN:** ISO IN endpoint threshold enable

When this bit is set, the core enables thresholding for isochronous IN endpoints.

Bit 0 **NONISOTHREN:** Nonisochronous IN endpoints threshold enable

When this bit is set, the core enables thresholding for nonisochronous IN endpoints.

62.14.49 OTG device IN endpoint FIFO empty interrupt mask register (OTG_DIEPEMPMSK)

Address offset: 0x834

Reset value: 0x0000 0000

This register is used to control the IN endpoint FIFO empty interrupt generation (TXFE_OTG_DIEPINTx).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INEPTXFEM[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **INEPTXFEM[15:0]:** IN EP Tx FIFO empty interrupt mask bits
These bits act as mask bits for OTG_DIEPINTx.
TXFE interrupt one bit per IN endpoint:
Bit 0 for IN endpoint 0, bit 3 for IN endpoint 3
0: Masked interrupt
1: Unmasked interrupt

62.14.50 OTG device each endpoint interrupt register (OTG_DEACHINT)

Address offset: 0x0838

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OEP1 INT	Res.
														r	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IEP1 INT	Res.
														r	

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **OEP1INT:** OUT endpoint 1 interrupt bit

Bits 16:2 Reserved, must be kept at reset value.

Bit 1 **IEP1INT:** IN endpoint 1interrupt bit

Bit 0 Reserved, must be kept at reset value.

62.14.51 OTG device each endpoint interrupt mask register (OTG_DEACHINTMSK)

Address offset: 0x083C

Reset value: 0x0000 0000

There is one interrupt bit for endpoint 1 IN and one interrupt bit for endpoint 1 OUT.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OEP1INTM	Res.
														rw	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IEP1INTM	Res.
														rw	

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **OEP1INTM:** OUT endpoint 1 interrupt mask bit

Bits 16:2 Reserved, must be kept at reset value.

Bit 1 **IEP1INTM:** IN endpoint 1 interrupt mask bit

Bit 0 Reserved, must be kept at reset value.

62.14.52 OTG device each IN endpoint-1 interrupt mask register (OTG_HS_DIEPEACHMSK1)

Address offset: 0x844

Reset value: 0x0000 0000

This register works with the OTG_DIEPINT1 register to generate a dedicated interrupt OTG_HS_EP1_IN for endpoint #1. The IN endpoint interrupt for a specific status in the OTG_DOEPINT1 register can be masked by writing into the corresponding bit in this register. Status bits are masked by default.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	NAKM	Res.	Res.	Res.	BNAM	TXFURM	Res.	INEPNEM	Res.	ITTXFEMSK	TOM	AHBERRM	EPDM	XFRCM
		rw				rw	rw		rw		rw	rw	rw	rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **NAKM:** NAK interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 12:10 Reserved, must be kept at reset value.

Bit 9 **BNAM:** BNA interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 8 **TXFURM:** FIFO underrun mask
0: Masked interrupt
1: Unmasked interrupt

Bit 7 Reserved, must be kept at reset value.

Bit 6 **INEPNEM:** IN endpoint NAK effective mask
0: Masked interrupt
1: Unmasked interrupt

Bit 5 Reserved, must be kept at reset value.

Bit 4 **ITTXFEMSK:** IN token received when Tx FIFO empty mask
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **TOM:** Timeout condition mask (Non-isochronous endpoints)
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **AHBERRM:** AHB error mask
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **EPDM:** Endpoint disabled interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed interrupt mask
0: Masked interrupt
1: Unmasked interrupt

62.14.53 OTG device each OUT endpoint-1 interrupt mask register (OTG_HS_DOEPEACHMSK1)

Address offset: 0x884

Reset value: 0x0000 0000

This register works with the OTG_DOEPINT1 register to generate a dedicated interrupt OTG_HS_EP1_OUT for endpoint #1. The OUT endpoint interrupt for a specific status in the OTG_DOEPINT1 register can be masked by writing into the corresponding bit in this register. Status bits are masked by default.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	NYET MSK	NAK MSK	BERR M	Res.	Res.	BNAM	OUT PKT ERRM	Res.	B2B STUPM	Res.	OTEPD M	STUPM	AHB ERRM	EPDM	XFRC M
	rw	rw	rw			rw	rw		rw		rw	rw	rw	rw	rw

Bits 31:15 Reserved, must be kept at reset value.

Bit 14 **NYETMSK:** NYET interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 13 **NAKMSK:** NAK interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 12 **BERRM**: Babble error interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **BNAM:** BNA interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 8 **OUTPKTERRM:** Out packet error mask
0: Masked interrupt
1: Unmasked interrupt

Bit 7 Reserved, must be kept at reset value.

Bit 6 **B2BSTUPM:** Back-to-back SETUP packets received mask
Applies to control OUT endpoints only.
0: Masked interrupt
1: Unmasked interrupt

Bit 5 Reserved, must be kept at reset value.

Bit 4 **OTEPDM:** OUT token received when endpoint disabled mask
Applies to control OUT endpoints only.
0: Masked interrupt
1: Unmasked interrupt

Bit 3 **STUPM:** STUPM: SETUP phase done mask
Applies to control endpoints only.
0: Masked interrupt
1: Unmasked interrupt

Bit 2 **AHBERRM:** AHB error mask
0: Masked interrupt
1: Unmasked interrupt

Bit 1 **EPDM:** Endpoint disabled interrupt mask
0: Masked interrupt
1: Unmasked interrupt

Bit 0 **XFRCM:** Transfer completed interrupt mask
0: Masked interrupt
1: Unmasked interrupt

62.14.54 OTG device IN endpoint x control register (OTG_DIEPCTLx)

Address offset: 0x900 + 0x20 * x, (x = 0 to 8)

Reset value: 0x0000 0000

The application uses this register to control the behavior of each logical endpoint other than endpoint 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	SODD FRM	SD0 PID/ SEVN FRM	SNAK	CNAK	TXFNUM[3:0]				STALL	Res.	EPTYP[1:0]		NAK STS	EO NUM/ DPID
rs	rs	w	w	w	w	rw	rw	rw	rw	rw		rw	rw	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBA EP	Res.	Res.	Res.	Res.	MPSIZ[10:0]										
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **EPENA:** Endpoint enable

The application sets this bit to start transmitting data on an endpoint.

The core clears this bit before setting any of the following interrupts on this endpoint:

– SETUP phase done

– Endpoint disabled

– Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application sets this bit to stop transmitting/receiving data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the endpoint disabled interrupt. The application must set this bit only if endpoint enable is already set for this endpoint.

Bit 29 **SODDFRM:** Set odd frame

Applies to isochronous IN and OUT endpoints only.

Writing to this field sets the Even/Odd frame (EONUM) field to odd frame.

Bit 28 **SD0PID:** Set DATA0 PID

Applies to interrupt/bulk IN endpoints only.

Writing to this field sets the endpoint data PID (DPID) field in this register to DATA0.

SEVNFRM: Set even frame

Applies to isochronous IN endpoints only.

Writing to this field sets the Even/Odd frame (EONUM) field to even frame.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.

Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for OUT endpoints on a transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 **TXFNUM[3:0]:** Tx FIFO number

These bits specify the FIFO number associated with this endpoint. Each active IN endpoint must be programmed to a separate FIFO number.
This field is valid only for IN endpoints.

Bit 21 **STALL:** STALL handshake

Applies to non-control, non-isochronous IN endpoints only (access type is rw).
The application sets this bit to stall all tokens from the USB host to this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Only the application can clear this bit, never the core.

Bit 20 Reserved, must be kept at reset value.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

This is the transfer type supported by this logical endpoint.
00: Control
01: Isochronous
10: Bulk
11: Interrupt

Bit 17 **NAKSTS:** NAK status

It indicates the following:
0: The core is transmitting non-NAK handshakes based on the FIFO status.
1: The core is transmitting NAK handshakes on this endpoint.
When either the application or the core sets this bit:
For non-isochronous IN endpoints: The core stops transmitting any data on an IN endpoint, even if there are data available in the Tx FIFO.
For isochronous IN endpoints: The core sends out a zero-length data packet, even if there are data available in the Tx FIFO.
Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 **EONUM:** Even/odd frame

Applies to isochronous IN endpoints only.
Indicates the frame number in which the core transmits/receives isochronous data for this endpoint. The application must program the even/odd frame number in which it intends to transmit/receive isochronous data for this endpoint using the SEVNFRM and SODDFRM fields in this register.
0: Even frame
1: Odd frame

DPID: Endpoint data PID

Applies to interrupt/bulk IN endpoints only.
Contains the PID of the packet to be received or transmitted on this endpoint. The application must program the PID of the first packet to be received or transmitted on this endpoint, after the endpoint is activated. The application uses the SD0PID register field to program either DATA0 or DATA1 PID.
0: DATA0
1: DATA1

Bit 15 **USBAEP:** USB active endpoint

Indicates whether this endpoint is active in the current configuration and interface. The core clears this bit for all endpoints (other than EP 0) after detecting a USB reset. After receiving the SetConfiguration and SetInterface commands, the application must program endpoint registers accordingly and set this bit.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:0 **MPSIZ[10:0]:** Maximum packet size

The application must program this field with the maximum packet size for the current logical endpoint. This value is in bytes.

62.14.55 OTG device IN endpoint x interrupt register (OTG_DIEPINTx)

Address offset: 0x908 + 0x20 * x, (x = 0 to 8)

Reset value: 0x0000 0080

This register indicates the status of an endpoint with respect to USB- and AHB-related events. It is shown in *Figure 787*. The application must read this register when the IN endpoints interrupt bit of the core interrupt register (IEPINT in OTG_GINTSTS) is set. Before the application can read this register, it must first read the device all endpoints interrupt (OTG_DAINT) register to get the exact endpoint number for the device endpoint-x interrupt register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_DAINT and OTG_GINTSTS registers.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	NAK	Res.	PKTDRPSTS	Res.	BNA	TXFIFOUDRN	TXFE	INEPNE	INEPNM	ITTXFE	TOC	AHBERR	EPDISD	XFRC
		rc_w1		rc_w1		rc_w1	rc_w1	r	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **NAK:** NAK input

The core generates this interrupt when a NAK is transmitted or received by the device. In case of isochronous IN endpoints the interrupt gets generated when a zero length packet is transmitted due to unavailability of data in the Tx FIFO.

Bit 12 Reserved, must be kept at reset value.

Bit 11 **PKTDRPSTS:** Packet dropped status

This bit indicates to the application that an ISOC OUT packet has been dropped. This bit does not have an associated mask bit and does not generate an interrupt.

Bit 10 Reserved, must be kept at reset value.

Bit 9 **BNA:** Buffer not available interrupt

The core generates this interrupt when the descriptor accessed is not ready for the core to process, such as host busy or DMA done.

This bit is only valid when Scatter/Gather DMA mode is enabled.

Bit 8 **TXFIFOUDRN:** Transmit Fifo Underrun (TxfifoUndrn)

The core generates this interrupt when it detects a transmit FIFO underrun condition for this endpoint. Dependency: This interrupt is valid only when Thresholding is enabled

Bit 7 **TXFE:** Transmit FIFO empty

This interrupt is asserted when the Tx FIFO for this endpoint is either half or completely empty. The half or completely empty status is determined by the Tx FIFO Empty Level bit in the OTG_GAHBCFG register (TXFELVL bit in OTG_GAHBCFG).

Bit 6 **INEPNE:** IN endpoint NAK effective

This bit can be cleared when the application clears the IN endpoint NAK by writing to the CNAK bit in OTG_DIEPCTLx.

This interrupt indicates that the core has sampled the NAK bit set (either by the application or by the core). The interrupt indicates that the IN endpoint NAK bit set by the application has taken effect in the core.

This interrupt does not guarantee that a NAK handshake is sent on the USB. A STALL bit takes priority over a NAK bit.

Bit 5 **INEPNM**: IN token received with EP mismatch

Indicates that the data in the top of the non-periodic TxFIFO belongs to an endpoint other than the one for which the IN token was received. This interrupt is asserted on the endpoint for which the IN token was received.

Bit 4 **ITTXFE:** IN token received when Tx FIFO is empty

Indicates that an IN token was received when the associated Tx FIFO (periodic/non-periodic) was empty. This interrupt is asserted on the endpoint for which the IN token was received.

Bit 3 **TOC:** Timeout condition

Indicates that the core has detected a timeout condition on the USB for the last IN token on this endpoint.

Bit 2 **AHBERR**: AHB error

This is generated only in internal DMA mode when there is an AHB error during an AHB read/write. The application can read the corresponding endpoint DMA address register to get the error address.

Bit 1 **EPDISD:** Endpoint disabled interrupt

This bit indicates that the endpoint is disabled per the application’s request.

Bit 0 **XFRC:** Transfer completed interrupt

This field indicates that the programmed transfer is complete on the AHB as well as on the USB, for this endpoint.

62.14.56 OTG device IN endpoint 0 transfer size register (OTG_DIEPTSIZ0)

Address offset: 0x910

Reset value: 0x0000 0000

The application must modify this register before enabling endpoint 0. Once endpoint 0 is enabled using the endpoint enable bit in the device control endpoint 0 control registers (EPENA in OTG_DIEPCTL0), the core modifies this register. The application can only read this register once the core has cleared the endpoint enable bit.

Nonzero endpoints use the registers for endpoints 1–3.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTCNT[1:0]		Res.	Res.	Res.
											rw	rw			

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XFRSIZ[6:0]						
									rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:19 **PKTCNT[1:0]:** Packet count

Indicates the total number of USB packets that constitute the transfer size amount of data for endpoint 0.

This field is decremented every time a packet (maximum size or short packet) is read from the Tx FIFO.

Bits 18:7 Reserved, must be kept at reset value.

Bits 6:0 **XFRSIZ[6:0]:** Transfer size

Indicates the transfer size in bytes for endpoint 0. The core interrupts the application only after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.

The core decrements this field every time a packet from the external memory is written to the Tx FIFO.

62.14.57 OTG device IN endpoint x DMA address register (OTG_DIEPDMAx)

Address offset: 0x914 + 0x20 * x, (x = 0 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMAADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAADDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DMAADDR[31:0]:** DMA Address

This field holds the start address in the external memory from which the data for the endpoint must be fetched. This register is incremented on every AHB transaction.

62.14.58 OTG device IN endpoint transmit FIFO status register (OTG_DTXFSTSx)

Address offset: 0x918 + 0x20 * x, (x = 0 to 8)

Reset value: 0x0000 0200

This read-only register contains the free space information for the device IN endpoint Tx FIFO.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INEPTFSAV[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **INEPTFSAV[15:0]:** IN endpoint Tx FIFO space available

Indicates the amount of free space available in the endpoint Tx FIFO.
Values are in terms of 32-bit words:
0x0: Endpoint Tx FIFO is full
0x1: 1 word available
0x2: 2 words available
0xn: n words available
Others: Reserved

62.14.59 OTG device IN endpoint x transfer size register (OTG_DIEPTSIZx)

Address offset: 0x910 + 0x20 * x, (x = 1 to 8)

Reset value: 0x0000 0000

The application must modify this register before enabling the endpoint. Once the endpoint is enabled using the endpoint enable bit in the OTG_DIEPCTLx registers (EPENA bit in OTG_DIEPCTLx), the core modifies this register. The application can only read this register once the core has cleared the endpoint enable bit.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	MCNT[1:0]		PKTCNT[9:0]										XFRSIZ[18:16]		
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
XFRSIZ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:29 **MCNT[1:0]:** Multi count

For periodic IN endpoints, this field indicates the number of packets that must be transmitted per frame on the USB. The core uses this field to calculate the data PID for isochronous IN endpoints.

01: 1 packet

10: 2 packets

11: 3 packets

Bits 28:19 **PKTCNT[9:0]:** Packet count

Indicates the total number of USB packets that constitute the transfer size amount of data for this endpoint.

This field is decremented every time a packet (maximum size or short packet) is read from the Tx FIFO.

Bits 18:0 **XFRSIZ[18:0]:** Transfer size

This field contains the transfer size in bytes for the current endpoint. The core only interrupts the application after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.

The core decrements this field every time a packet from the external memory is written to the Tx FIFO.

62.14.60 OTG device control OUT endpoint 0 control register (OTG_DOEPCTL0)

Address offset: 0xB00

Reset value: 0x0000 8000

This section describes the OTG_DOEPCTL0 register. Nonzero control endpoints use registers for endpoints 1–3.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	Res.	Res.	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EPTYP[1:0]		NAK STS	Res.
w	r			w	w					rs	rw	r	r	r	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBAEP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MPSIZ[1:0]	
r														r	r

Bit 31 **EPENA:** Endpoint enable

The application sets this bit to start transmitting data on endpoint 0.

The core clears this bit before setting any of the following interrupts on this endpoint:

– SETUP phase done

– Endpoint disabled

– Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application cannot disable control OUT endpoint 0.

Bits 29:28 Reserved, must be kept at reset value.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.

Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit on a transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **STALL:** STALL handshake

The application can only set this bit, and the core clears it, when a SETUP token is received for this endpoint. If a NAK bit or Global OUT NAK is set along with this bit, the STALL bit takes priority. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 20 **SNPM:** Snoop mode

This bit configures the endpoint to Snoop mode. In Snoop mode, the core does not check the correctness of OUT packets before transferring them to application memory.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

Hardcoded to 2'b00 for control.

Bit 17 **NAKSTS:** NAK status

Indicates the following:

0: The core is transmitting non-NAK handshakes based on the FIFO status.

1: The core is transmitting NAK handshakes on this endpoint.

When either the application or the core sets this bit, the core stops receiving data, even if there is space in the Rx FIFO to accommodate the incoming packet. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 Reserved, must be kept at reset value.

Bit 15 **USBAEP:** USB active endpoint

This bit is always set to 1, indicating that a control endpoint 0 is always active in all configurations and interfaces.

Bits 14:2 Reserved, must be kept at reset value.

Bits 1:0 **MPSIZ[1:0]:** Maximum packet size

The maximum packet size for control OUT endpoint 0 is the same as what is programmed in control IN endpoint 0.

00: 64 bytes

01: 32 bytes

10: 16 bytes

11: 8 bytes

62.14.61 OTG device OUT endpoint x interrupt register (OTG_DOEPINTx)

Address offset: 0xB08 + 0x20 * x, (x = 0 to 8)

Reset value: 0x0000 0080

This register indicates the status of an endpoint with respect to USB- and AHB-related events. It is shown in *Figure 787*. The application must read this register when the OUT endpoints interrupt bit of the OTG_GINTSTS register (OEPINT bit in OTG_GINTSTS) is set. Before the application can read this register, it must first read the OTG_DAINT register to get the exact endpoint number for the OTG_DOEPINTx register. The application must clear the appropriate bit in this register to clear the corresponding bits in the OTG_DAINT and OTG_GINTSTS registers.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STPK TRX	NYET	NAK	BERR	Res.	Res.	BNA	OUT PKT ERR	Res.	B2B STUP	STSPH SRX	OTEP DIS	STUP	AHB ERR	EP DISD	XFRC
rc_w1	rc_w1	rc_w1	rc_w1			rc_w1	rc_w1		rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **STPKTRX:** Setup packet received

Applicable for control OUT endpoints in only in the Buffer DMA Mode. Set by the OTG_HS, this bit indicates that this buffer holds 8 bytes of setup data. There is only one setup packet per buffer. On receiving a setup packet, the OTG_HS closes the buffer and disables the corresponding endpoint after SETUP_COMPLETE status is seen in the Rx FIFO. OTG_HS puts a SETUP_COMPLETE status into the Rx FIFO when it sees the first IN or OUT token after the SETUP packet for that particular endpoint. The application must then re-enable the endpoint to receive any OUT data for the control transfer and reprogram the buffer start address. Because of the above behavior, OTG_HS can receive any number of back to back setup packets and one buffer for every setup packet is used.

Bit 14 **NYET:** NYET interrupt

This interrupt is generated when a NYET response is transmitted for a non isochronous OUT endpoint.

Bit 13 **NAK:** NAK input

The core generates this interrupt when a NAK is transmitted or received by the device. In case of isochronous IN endpoints the interrupt gets generated when a zero length packet is transmitted due to unavailability of data in the Tx FIFO.

Bit 12 **BERR:** Babble error interrupt

The core generates this interrupt when babble is received for the endpoint.

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **BNA:** Buffer not available interrupt

The core generates this interrupt when the descriptor accessed is not ready for the core to process, such as host busy or DMA done.

This bit is only valid when Scatter/Gather DMA mode is enabled.

Bit 8 **OUTPKTERR**: OUT packet error

This interrupt is asserted when the core detects an overflow or a CRC error for an OUT packet. This interrupt is valid only when thresholding is enabled.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **B2BSTUP:** Back-to-back SETUP packets received

Applies to control OUT endpoint only.
This bit indicates that the core has received more than three back-to-back SETUP packets for this particular endpoint.

Bit 5 **STSPHSRX**: Status phase received for control write

This interrupt is valid only for control OUT endpoints. This interrupt is generated only after OTG_HS has transferred all the data that the host has sent during the data phase of a control write transfer, to the system memory buffer. The interrupt indicates to the application that the host has switched from data phase to the status phase of a control write transfer. The application can use this interrupt to ACK or STALL the status phase, after it has decoded the data phase.

Bit 4 **OTEPDIS:** OUT token received when endpoint disabled

Applies only to control OUT endpoints.
Indicates that an OUT token was received when the endpoint was not yet enabled. This interrupt is asserted on the endpoint for which the OUT token was received.

Bit 3 **STUP:** SETUP phase done

Applies to control OUT endpoint only.Indicates that the SETUP phase for the control endpoint is complete and no more back-to-back SETUP packets were received for the current control transfer. On this interrupt, the application can decode the received SETUP data packet.

Bit 2 **AHBERR**: AHB error

This is generated only in internal DMA mode when there is an AHB error during an AHB read/write. The application can read the corresponding endpoint DMA address register to get the error address.

Bit 1 **EPDISD:** Endpoint disabled interrupt

This bit indicates that the endpoint is disabled per the application’s request.

Bit 0 **XFRC:** Transfer completed interrupt

This field indicates that the programmed transfer is complete on the AHB as well as on the USB, for this endpoint.

62.14.62 OTG device OUT endpoint 0 transfer size register (OTG_DOEPTSIZ0)

Address offset: 0xB10

Reset value: 0x0000 0000

The application must modify this register before enabling endpoint 0. Once endpoint 0 is enabled using the endpoint enable bit in the OTG_DOEPCTL0 registers (EPENA bit in OTG_DOEPCTL0), the core modifies this register. The application can only read this register once the core has cleared the endpoint enable bit.

Nonzero endpoints use the registers for endpoints 1–8.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	STUPCNT[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTCNT	Res.	Res.	Res.
	rw	rw										rw			

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XFRSIZ[6:0]						
									rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:29 **STUPCNT[1:0]:** SETUP packet count

This field specifies the number of back-to-back SETUP data packets the endpoint can receive.
01: 1 packet
10: 2 packets
11: 3 packets

Bits 28:20 Reserved, must be kept at reset value.

Bit 19 **PKTCNT:** Packet count

This field is decremented to zero after a packet is written into the Rx FIFO.

Bits 18:7 Reserved, must be kept at reset value.

Bits 6:0 **XFRSIZ[6:0]:** Transfer size

Indicates the transfer size in bytes for endpoint 0. The core interrupts the application only after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.
The core decrements this field every time a packet is read from the Rx FIFO and written to the external memory.

62.14.63 OTG device OUT endpoint x DMA address register (OTG_DOEPDMAx)

Address offset: 0xB14 + 0x20 * x, (x = 0 to 8)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DMAADDR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DMAADDR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **DMAADDR[31:0]:** DMA Address

This field holds the start address in the external memory from which the data for the endpoint must be fetched. This register is incremented on every AHB transaction.

62.14.64 OTG device OUT endpoint x control register (OTG_DOEPCTLx)

Address offset: 0xB00 + 0x20 * x, (x = 1 to 8)

Reset value: 0x0000 0000

The application uses this register to control the behavior of each logical endpoint other than endpoint 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EPENA	EPDIS	SD1 PID/ SODD FRM	SD0 PID/ SEVN FRM	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EPTYP[1:0]		NAK STS	EO NUM/ DPID
rs	rs	w	w	w	w					rw	rw	rw	rw	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USBA EP	Res.	Res.	Res.	Res.	MPSIZ[10:0]										
rw					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **EPENA:** Endpoint enable

Applies to IN and OUT endpoints.

The application sets this bit to start transmitting data on an endpoint.

The core clears this bit before setting any of the following interrupts on this endpoint:

– SETUP phase done

– Endpoint disabled

– Transfer completed

Bit 30 **EPDIS:** Endpoint disable

The application sets this bit to stop transmitting/receiving data on an endpoint, even before the transfer for that endpoint is complete. The application must wait for the endpoint disabled interrupt before treating the endpoint as disabled. The core clears this bit before setting the endpoint disabled interrupt. The application must set this bit only if endpoint enable is already set for this endpoint.

Bit 29 **SD1PID:** Set DATA1 PID

Applies to interrupt/bulk IN and OUT endpoints only. Writing to this field sets the endpoint data PID (DPID) field in this register to DATA1.

SODDFRM: Set odd frame

Applies to isochronous IN and OUT endpoints only. Writing to this field sets the Even/Odd frame (EONUM) field to odd frame.

Bit 28 **SD0PID:** Set DATA0 PID

Applies to interrupt/bulk OUT endpoints only.

Writing to this field sets the endpoint data PID (DPID) field in this register to DATA0.

SEVNFRM: Set even frame

Applies to isochronous OUT endpoints only.

Writing to this field sets the Even/Odd frame (EONUM) field to even frame.

Bit 27 **SNAK:** Set NAK

A write to this bit sets the NAK bit for the endpoint.

Using this bit, the application can control the transmission of NAK handshakes on an endpoint. The core can also set this bit for OUT endpoints on a transfer completed interrupt, or after a SETUP is received on the endpoint.

Bit 26 **CNAK:** Clear NAK

A write to this bit clears the NAK bit for the endpoint.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **STALL:** STALL handshake

Applies to non-control, non-isochronous OUT endpoints only (access type is rw).

The application sets this bit to stall all tokens from the USB host to this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Only the application can clear this bit, never the core.

Applies to control endpoints only (access type is rs).

The application can only set this bit, and the core clears it, when a SETUP token is received for this endpoint. If a NAK bit, Global IN NAK, or Global OUT NAK is set along with this bit, the STALL bit takes priority. Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 20 **SNPM:** Snoop mode

This bit configures the endpoint to Snoop mode. In Snoop mode, the core does not check the correctness of OUT packets before transferring them to application memory.

Bits 19:18 **EPTYP[1:0]:** Endpoint type

This is the transfer type supported by this logical endpoint.
00: Control
01: Isochronous
10: Bulk
11: Interrupt

Bit 17 **NAKSTS:** NAK status

Indicates the following:
0: The core is transmitting non-NAK handshakes based on the FIFO status.
1: The core is transmitting NAK handshakes on this endpoint.
When either the application or the core sets this bit:
The core stops receiving any data on an OUT endpoint, even if there is space in the Rx FIFO to accommodate the incoming packet.
Irrespective of this bit's setting, the core always responds to SETUP data packets with an ACK handshake.

Bit 16 **EONUM:** Even/odd frame

Applies to isochronous IN and OUT endpoints only.
Indicates the frame number in which the core transmits/receives isochronous data for this endpoint. The application must program the even/odd frame number in which it intends to transmit/receive isochronous data for this endpoint using the SEVNFRM and SODDFRM fields in this register.
0: Even frame
1: Odd frame

DPID: Endpoint data PID

Applies to interrupt/bulk OUT endpoints only.
Contains the PID of the packet to be received or transmitted on this endpoint. The application must program the PID of the first packet to be received or transmitted on this endpoint, after the endpoint is activated. The application uses the SD0PID register field to program either DATA0 or DATA1 PID.
0: DATA0
1: DATA1

Bit 15 **USBAEP:** USB active endpoint

Indicates whether this endpoint is active in the current configuration and interface. The core clears this bit for all endpoints (other than EP 0) after detecting a USB reset. After receiving the SetConfiguration and SetInterface commands, the application must program endpoint registers accordingly and set this bit.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:0 **MPSIZ[10:0]:** Maximum packet size

The application must program this field with the maximum packet size for the current logical endpoint. This value is in bytes.

62.14.65 OTG device OUT endpoint x transfer size register (OTG_DOEPTSIZx)

Address offset: 0xB10 + 0x20 * x, (x = 1 to 8)

Reset value: 0x0000 0000

The application must modify this register before enabling the endpoint. Once the endpoint is enabled using endpoint enable bit of the OTG_DOEPCTLx registers (EPENA bit in OTG_DOEPCTLx), the core modifies this register. The application can only read this register once the core has cleared the endpoint enable bit.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	RXDPID/ STUPCNT[1:0]		PKTCNT[9:0]										XFRSIZ[18:16]		
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
XFRSIZ[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bits 30:29 **RXDPID[1:0]:** Received data PID

Applies to isochronous OUT endpoints only.

This is the data PID received in the last packet for this endpoint.

00: DATA0

01: DATA2

10: DATA1

11: MDATA

STUPCNT[1:0]: SETUP packet count

Applies to control OUT endpoints only.

This field specifies the number of back-to-back SETUP data packets the endpoint can receive.

01: 1 packet

10: 2 packets

11: 3 packets

Bits 28:19 **PKTCNT[9:0]:** Packet count

Indicates the total number of USB packets that constitute the transfer size amount of data for this endpoint.

This field is decremented every time a packet (maximum size or short packet) is written to the Rx FIFO.

Bits 18:0 **XFRSIZ[18:0]:** Transfer size

This field contains the transfer size in bytes for the current endpoint. The core only interrupts the application after it has exhausted the transfer size amount of data. The transfer size can be set to the maximum packet size of the endpoint, to be interrupted at the end of each packet.

The core decrements this field every time a packet is read from the Rx FIFO and written to the external memory.

62.14.66 OTG power and clock gating control register (OTG_PCGCCTL)

Address offset: 0xE00

Reset value: 0x200B 8000

This register is available in host and device modes.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUSP	PHY SLEEP	ENL1 GTG	PHY SUSP	Res.	Res.	GATE HCLK	STPP CLK
								r	r	rw	r			rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **SUSP:** Deep Sleep

This bit indicates that the PHY is in Deep Sleep when in L1 state.

Bit 6 **PHYSLEEP:** PHY in Sleep

This bit indicates that the PHY is in the Sleep state.

Bit 5 **ENL1GTG:** Enable sleep clock gating

When this bit is set, core internal clock gating is enabled in Sleep state if the core cannot assert utmi_l1_suspend_n. When this bit is not set, the PHY clock is not gated in Sleep state.

Bit 4 **PHYSUSP:** PHY suspended

Indicates that the PHY has been suspended. This bit is updated once the PHY is suspended after the application has set the STPPCLK bit.

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **GATEHCLK:** Gate HCLK

The application sets this bit to gate HCLK to modules other than the AHB Slave and Master and wakeup logic when the USB is suspended or the session is not valid. The application clears this bit when the USB is resumed or a new session starts.

Bit 0 **STPPCLK:** Stop PHY clock

The application sets this bit to stop the PHY clock when the USB is suspended, the session is not valid, or the device is disconnected. The application clears this bit when the USB is resumed or a new session starts.

62.14.67 OTG_HS register map

The table below gives the USB OTG register map and reset values.

Table 542. OTG_HS register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	OTG_ GOTGCTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CURMOD	OTGVER	BSVLD	ASVLD	DBCT	CIDSTS	Res.	Res.	Res.	EHEN	DHNPEN	HSHNPEN	HNPRQ	HNGSCS	BVALOVAL	BVALOEN	AVALOVAL	AVALOEN	VBVALOVA	VBVALOEN	SRQ	SRQSCS
	Reset value											0	0	0	0	0	1				0	0	0	0	0	0	0	0	0	0	0	0	0
0x004	OTG_ GOTGINT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBCDNE	ADTOCHG	HNGDET	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HNSSCHG	SRSSCHG	Res.	Res.	Res.	Res.	Res.	SEDET	Res.	Res.
	Reset value													0	0	0							-	0	0						0		
0x008	OTG_ GAHBCFG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PTXFELVL	TXFELVL	Res.	DMAEN	HBSTLEN				GINTMSK
	Reset value																								0	0		0	0	0	0	0	0
0x00C	OTG_ GUSBCFG	Res.	FDMOD	FHMOD	Res.	Res.	Res.	ULPIIPD	PTCI	PCCI	TSDPS	ULPIEVBUSI	ULPIEVBUSD	ULPICSM	ULPIAR	ULPIFSL	Res.	PHYLPC	Res.	TRDT				HNPCAP	SRPCAP	Res.	PHYSEL	Res.	Res.	Res.	TOCAL		
	Reset value		0	0				0	0	0	0	0	0	0	0	0		0		0	1	0	1	0	0		1				0	0	0
0x010	OTG_ GRSTCTL	AHBIDL	DMAREQ	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXFNUM					TXFFLSH	RXFFLSH	Res.	FCRST	PSRST	CSRST
	Reset value	1	0																				0	0	0	0	0	0	0		0	0	0
0x014	OTG_ GINTSTS	WKUPINT	SRQINT	DISCINT	CIDSCHG	LPMINT	PTXFE	HCINT	HPRTINT	RSTDET	DATAFSUSP	IPXFR/INCOMPISOOUT	IISOIXFR	OEPINT	IEPINT	Res.	Res.	EOPF	ISOODRP	ENUMDNE	USBRST	USBSUSP	ESUSP	Res.	Res.	GONAKEFF	GINAKEFF	NPTXFE	RXFLVL	SOF	OTGINT	MMIS	CMOD
	Reset value	0	0	0	0	0	1	0	0	0	0	0	0	0	0			0	0	0	0	0	0			0	0	1	0	0	0	0	0
0x018	OTG_ GINTMSK	WUIM	SRQIM	DISCINT	CIDSCHGM	LPMINTM	PTXFEM	HCIM	PRTIM	RSTDETM	FSUSPM	IPXFRM/IISOOXFRM	IISOIXFRM	OEPINT	IEPINT	Res.	Res.	EOPFM	ISOODRPM	ENUMDNEM	USBRST	USBSUSPM	ESUSPM	Res.	Res.	GONAKEFFM	GINAKEFFM	NPTXFEM	RXFLVLM	SOFM	OTGINT	MMISM	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0	0	0			0	0	0	0	0	0	0	

Table 542. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x01C	**OTG_ GRXSTSR (Device mode)**	Res.	Res.	Res.	Res.	STSPHST	Res.	Res.	FRMNUM				PKTSTS				DPID		BCNT											EPNUM			
	Reset value					0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OTG_ GRXSTSR (Host mode)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTSTS				DPID		BCNT											CHNUM			
	Reset value												0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	**OTG_ GRXSTSP (Device mode)**	Res.	Res.	Res.	Res.	STSPHST	Res.	Res.	FRMNUM				PKTSTS				DPID		BCNT											EPNUM			
	Reset value					0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OTG_ GRXSTSP (Host mode)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTSTS				DPID		BCNT											CHNUM			
	Reset value												0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	**OTG_ GRXFSIZ**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXFD															
	Reset value																	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x028	**OTG_ HNPTXFSIZ/ OTG_ DIEPTXF0**	NPTXFD/TX0FD																NPTXFSA/TX0FSA															
	Reset value	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x02C	**OTG_ HNPTXSTS**	Res.	NPTXQTOP							NPTQXSAV								NPTXFSAV															
	Reset value		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x038	**OTG_ GCCFG**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VBDEN	SDEN	PDEN	DCDEN	BCDEN	PWRDWN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PS2DET	SDET	PDET	DCDET
	Reset value											0	0	0	0	0	0													X	X	X	X
0x03C	**OTG_CID**	PRODUCT_ID																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0
0x054	**OTG_ GLPMCFG**	Res.	Res.	Res.	ENBESL	LPMR CNTSTS			SNDLPM	LPM RCNT			LPMCHIDX				L1RSMOK	SLPSTS	LPM RSP		L1DSEN	BESLTHRS				L1SSEN	REMWAKE	BESL			LPMACK	LPMEN	
	Reset value				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x100	**OTG_ HPTXFSIZ**	PTXFSIZ																PTXSA															
	Reset value	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
0x104	**OTG_ DIEPTXF1**	INEPTXFD																INEPTXSA															
	Reset value	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0x108	**OTG_ DIEPTXF2**	INEPTXFD																INEPTXSA															
	Reset value	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0

Table 542. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
. . . .	. . . .	. . . .																															
. . . .	. . . .	. . . .																															
0x120	**OTG_ DIEPTXF7**	INEPTXFD																INEPTXSA															
	Reset value	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
0x400	**OTG_ HCFG**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FSLSS	FSLS PCS	
	Reset value																														0	0	0
0x404	**OTG_ HFIR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RLDCTRL	FRIVL															
	Reset value																0	1	1	1	0	1	0	1	0	0	1	1	0	0	0	0	0
0x408	**OTG_ HFNUM**	FTREM																FRNUM															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x410	**OTG_ HPTXSTS**	PTXQTOP								PTXQSAV								PTXFSAVL															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0x414	**OTG_ HAINT**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	HAINT															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x418	**OTG_ HAINTMSK**	Res	Res.	Res.	Res	Res	Res	Res.	Res	Res	Res	Res	Res	Res.	Res	Res	Res.	HAINTM															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x41C	**OTG_ HFLBADDR**	HFLBADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x440	**OTG_ HPRT**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSPD	PTCTL					PPWR	PLSTS		Res.	PRST	PSUSP	PRES	POCCHNG	POCA	PENCHNG	PENA	PCDET	PCSTS
	Reset value														0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0
0x500	**OTG_ HCCHAR0**	CHENA	CHDIS	ODDFRM	DAD							MCNT		EPTYP	LSDEV	Res.	EPDIR	EPNUM				MPSIZ											
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x504	**OTG_ HCSPLT0**	SPLITEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COMPLSPLT	XACTPOS		HUBADDR							PRTADDR						
	Reset value	0															0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 542. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x508	**OTG_ HCINT0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERR	FRMOR	BBERR	TXERR	Res.	ACK	NAK	STALL	Res.	CHH	XFRC
	Reset value																						0	0	0	0		0	0	0		0	0
0x508	**OTG_ HCINT0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERR	FRMOR	BBERR	TXERR	NYET	ACK	NAK	STALL	AHBERR	CHH	XFRC
	Reset value																						0	0	0	0	0	0	0	0	0	0	0
0x50C	**OTG_ HCINTMSK0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERRM	FRMORM	BBERRM	TXERRM	NYET	ACKM	NAKM	STALLM	Res.	CHHM	XFRCM
	Reset value																						0	0	0	0	0	0	0	0		0	0
0x510	**OTG_ HCTSIZ0**	DOPNG	DPID		PKTCNT										XFRSIZ																		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x510	**OTG_ HCTSIZSG0**	DOPNG	PID		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NTD								SCHED_INFO							
	Reset value	0	0	0														0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x514	**OTG_ HCDMA0**	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x514	**OTG_ HCDMASG0**	DMASG[31:3]																													Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0x51C	**OTG_ HCDMAB0**	HCDMAB																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x520	**OTG_ HCCHAR1**	CHENA	CHDIS	ODDFRM	DAD							MCNT		EPTYP		LSDEV	Res.	EPDIR	EPNUM				MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x524	**OTG_ HCSPLT1**	SPLITEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COMPLSPLT	XACTPOS		HUBADDR							PRTADDR						
	Reset value	0															0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x528	**OTG_ HCINT1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERR	FRMOR	BBERR	TXERR	Res.	ACK	NAK	STALL	Res.	CHH	XFRC
	Reset value																						0	0	0	0		0	0	0		0	0
0x528	**OTG_ HCINT1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERR	FRMOR	BBERR	TXERR	NYET	ACK	NAK	STALL	AHBERR	CHH	XFRC
	Reset value																						0	0	0	0	0	0	0	0	0	0	0

Table 542. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x52C	**OTG_ HCINTMSK1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERRM	FRMORM	BBERRM	TXERRM	NYET	ACKM	NAKM	STALLM	Res.	CHHM	XFRCM
	Reset value																						0	0	0	0	0	0	0	0		0	0
0x530	**OTG_ HCTSIZ1**	DOPNG	DPID		PKTCNT										XFRSIZ																		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x530	**OTG_ HCTSIZSG1**	DOPNG	PID		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NTD							SCHED_INFO								
	Reset value	0	0	0														0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x534	**OTG_ HCDMA1**	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x534	**OTG_ HCDMASG1**	DMASG[31:3]																													Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-
0x53C	**OTG_ HCDMAB1**	HCDMAB																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
. . . .	. . . .	. . . .																															
0x660	**OTG_ HCCHAR11**	CHENA	CHDIS	ODDFRM	DAD							MCNT		EPTYP	LSDEV	Res.	EPDIR	EPNUM					MPSIZ											
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x664	**OTG_ HCSPLT11**	SPLITEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COMPLSPLT	XACTPOS		HUBADDR							PRTADDR							
	Reset value	0															0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x668	**OTG_ HCINT11**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERR	FRMOR	BBERR	TXERR	Res.	ACK	NAK	STALL	Res.	CHH	XFRC
	Reset value																						0	0	0	0		0	0	0		0	0
0x66C	**OTG_ HCINTMSK11**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERRM	FRMORM	BBERRM	TXERRM	NYET	ACKM	NAKM	STALLM	Res.	CHHM	XFRCM
	Reset value																						0	0	0	0	0	0	0	0		0	0
0x670	**OTG_ HCTSIZ11**	DOPNG	DPID		PKTCNT										XFRSIZ																		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 542. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x670	**OTG_ HCTSIZSG11**	DOPNG	PID		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NTD								SCHED_INFO							
	Reset value	0	0	0														0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x674	**OTG_ HCDMA11**	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x674	**OTG_ HCDMASG11**	DMASG[31:3]																													Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-
0x67C	**OTG_ HCDMAB11**	HCDMAB																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
. . . .	. . . .	. . . .																															
0x6E0	**OTG_ HCCHAR15**	CHENA	CHDIS	ODDFRM	DAD							MCNT		EPTYP		LSDEV	Res.	EPDIR	EPNUM				MPSIZ											
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x6E4	**OTG_ HCSPLT15**	SPLITEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	COMPLSPLT	XACTPOS		HUBADDR							PRTADDR							
	Reset value	0															0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x6E8	**OTG_ HCINT15**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERR	FRMOR	BBERR	TXERR	Res.	ACK	NAK	STALL	Res.	CHH	XFRC
	Reset value																						0	0	0	0		0	0	0		0	0
0x6EC	**OTG_ HCINTMSK15**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DTERRM	FRMORM	BBERRM	TXERRM	NYET	ACKM	NAKM	STALLM	Res.	CHHM	XFRCM
	Reset value																						0	0	0	0	0	0	0	0		0	0
0x6F0	**OTG_ HCTSIZ15**	DOPNG	DPID		PKTCNT											XFRSIZ																	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x6F0	**OTG_ HCTSIZSG15**	DOPNG	PID		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NTD								SCHED_INFO							
	Reset value	0	0	0														0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x6F4	**OTG_ HCDMA15**	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 542. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x6F4	OTG_ HCDMASG15	DMASG[31:3]																													Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-
0x6FC	OTG_ HCDMAB15	HCDMAB																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x800	OTG_ DCFG	Res.	Res.	Res.	Res.	Res.	Res.	PERSCHIVL		DESCDMA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ERRATIM	XCVRDLY	Res.	PFIVL		DAD							Res.	NZLSOHSK	DSPD	
	Reset value							0	0	0								0	0		0	0	0	0	0	0	0	0	0		0	0	0
0x804	OTG_ DCTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DSBESLRJCT	ENCONTONBN	Res.	Res.	Res.	Res.	Res.	POPRGDNE	CGONAK	SGONAK	CGINAK	SGINAK	TCTL			GONSTS	GINSTS	SDIS	RWUSIG
	Reset value														0	0						0	0	0	0	0	0	0	0	0	0	1	0
0x808	OTG_ DSTS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEVLNSTS		FNSOF										Res.	Res.	Res.	Res.	EERR	ENUMSPD		SUSPSTS				
	Reset value									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x810	OTG_ DIEPMSK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAKM	Res.	Res.	Res.	BNAM	TXFURM	Res.	INEPNEM	INEPNMM	ITTXFEMSK	TOM	AHBERRM	EPDM	XFRCM
	Reset value																			0				0	0		0	0	0	0	0	0	0
0x814	OTG_ DOEPMSK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NYETMSK	NAKMSK	BERRM	Res.	Res.	BNAM	OUTPKTERRM	Res.	B2BSTUPM	Res.	OTEPDM	STUPM	AHBERRM	EPDM	XFRCM
	Reset value																		0	0	0			0	0		0		0	0	0	0	0
0x818	OTG_ DAINT	OEPINT																IEPINT															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x81C	OTG_ DAINTMSK	OEPM																IEPM															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x828	OTG_ DVBUSDIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VBUSDT															
	Reset value																	0	0	0	1	0	1	1	1	1	1	0	1	0	1	1	1
0x82C	OTG_DVB USPULSE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DVBUSP															
	Reset value																	0	0	0	0	0	1	0	1	1	0	1	1	1	0	0	0

Table 542. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x830	OTG_ DTHRCTL	Res.	Res.	Res.	Res.	ARPEN	Res.	RXTHRLEN									RXTHREN	Res.	Res.	Res.	Res.	TXTHRLEN										ISOTHREN	NONISOTHREN
	Reset value					0											0					0	0	0	0	0	0	0	0	0	0	0	0
0x834	OTG_DIE PEMPMSK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INEPTXFEM															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x838	OTG_ DEACHINT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OEP1INT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IEP1INT	Res.
	Reset value															0																0	
0x83C	OTG_DEACHI NTMSK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OEP1INTM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IEP1INTM	Res.
	Reset value															0																0	
0x844	OTG_HS_ DIEPEACH MSK1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAKM	Res.	Res.	Res.	BNAM	TXFURM	Res.	INEPNEM	Res.	ITTXFEMSK	TOM	AHBERRM	EPDM	XFRCM
	Reset value																			0				0	0	-	0		0	0	0	0	0
0x884	OTG_HS_ DOEPEACH MSK1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NYETMSK	NAKMSK	BERRM	Res.	Res.	BNAM	OUTPKTERRM	Res.	B2BSTUPM	Res.	OTEPDM	STUPM	AHBERRM	EPDM	XFRCM
	Reset value																		0	0	0			0	0		0		0	0	0	0	0
0x900	OTG_ DIEPCTL0	EPENA	EPDIS	SODDFRM/SD1PID	SD0PID/SEVNFRM	SNAK	CNAK	TXFNUM				STALL	Res.	EPTYP		NAKSTS	EONUM/DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
0x908	OTG_ DIEPINT0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAK	Res.	PKTDRPSTS	Res.	BNA	TXFIFOUDRN	TXFE	INEPNE	INEPNM	ITTXFE	TOC	AHBERR	EPDISD	XFRC
	Reset value																			0		0		0	0	1	0	0	0	0	0	0	0
0x910	OTG_ DIEPTSIZ0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKT CNT		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XFRSIZ						
	Reset value												0	0													0	0	0	0	0	0	0
0x914	OTG_ DIEPDMA	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 542. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x918	**OTG_ DTXFSTS0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INEPTFSAV															
	Reset value																	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x920	**OTG_ DIEPCTL1**	EPENA	EPDIS	SODDFRM/SD1PID	SD0PID/SEVNFRM	SNAK	CNAK	TXFNUM				STALL	Res.	EPTYP		NAKSTS	EONUM/DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
0x928	**OTG_ DIEPINT1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAK	Res.	PKTDRPSTS	Res.	BNA	TXFIFOUDRN	TXFE	INEPNE	INEPNM	ITTXFE	TOC	AHBERR	EPDISD	XFRC
	Reset value																			0		0		0	0	1	0	0	0	0	0	0	0
0x930	**OTG_ DIEPTSIZ1**	Res.	MCNT		PKTCNT										XFRSIZ																		
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x938	**OTG_ DTXFSTS1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INEPTFSAV															
	Reset value																	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x940	**OTG_ DIEPCTL2**	EPENA	EPDIS	SODDFRM	SD0PID/SEVNFRM	SNAK	CNAK	TXFNUM				STALL	Res.	EPTYP		NAKSTS	EONUM/DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
. . . .	. . . .	.																															
. . . .	. . . .	.																															
. . . .	. . . .	.																															
. . . .	. . . .	.																															

Table 542. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x9E0	**OTG_ DIEPCTL7**	EPENA	EPDIS	SODDFRM	SD0PID/SEVNFRM	SNAK	CNAK	TXFNUM				STALL	Res.	EPTYP		NAKSTS	EONUM/DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
. . . .	. . . .	. . . .																															
0x9E8	**OTG_ DIEPINT7**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NAK	Res.	PKTDRPSTS	Res.	BNA	TXFIFOUDRN	TXFE	INEPNE	INEPNM	ITTXFE	TOC	AHBERR	EPDISD	XFRC
	Reset value																			0		0		0	0	1	0	0	0	0	0	0	0
. . . .	. . . .	. . . .																															
0x9F0	**OTG_ DIEPTSIZ7**	Res.	MCNT		PKTCNT											XFRSIZ																	
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
. . . .	. . . .	. . . .																															
0x9F8	**OTG_ DTXFSTS7**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INEPTFSAV															
	Reset value																	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0xB00	**OTG_ DOEPCTL0**	EPENA	EPDIS	Res.	Res.	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EPTYP		NAKSTS	Res.	USBAEP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MPSIZ	
	Reset value	0	0			0	0					0	0	0	0	0		1													0	0
0xB08	**OTG_ DOEPINT0**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STPKTRX	NYET	NAK	BERR	Res.	Res.	BNA	OUTPKTERR	Res.	B2BSTUP	STSPHSRX	OTEPDIS	STUP	AHBERR	EPDISD	XFRC
	Reset value																	0	0	0	0			0	0		0	0	0	0	0	0	0
0xB10	**OTG_ DOEPTSIZ0**	Res.	STUPCNT		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PKTCNT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	XFRSIZ						
	Reset value		0	0										0													0	0	0	0	0	0	0
0xB14	**OTG_ DOEPDMA0**	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 542. OTG_HS register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xB20	**OTG_ DOEPCTL1**	EPENA	EPDIS	SODDFRM	SD0PID/SEVNFRM	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EP TYP		NAKSTS	EONUM/DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0					0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
0xB28	**OTG_ DOEPINT1**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STPKTRX	NYET	NAK	BERR	Res.	Res.	BNA	OUTPKTERR	Res.	B2BSTUP	STSPHSRX	OTEPDIS	STUP	AHBERR	EPDISD	XFRC
	Reset value																	0	0	0	0			0	0		0	0	0	0	0	0	0
0xB30	**OTG_ DOEPTSIZ1**	Res.	RXDPID/ STUPCNT		PKTCNT											XFRSIZ																	
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xB34	**OTG_ DOEPDMA1**	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
. . . .	. . . .	.																															
0xC00	**OTG_ DOEPCTL8**	EPENA	EPDIS	SODDFRM	SD0PID/SEVNFRM	SNAK	CNAK	Res.	Res.	Res.	Res.	STALL	SNPM	EPTYP		NAKSTS	EONUM/DPID	USBAEP	Res.	Res.	Res.	Res.	MPSIZ										
	Reset value	0	0	0	0	0	0					0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0
0xC08	**OTG_ DOEPINT8**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STPKTRX	NYET	NAK	BERR	Res.	Res.	BNA	OUTPKTERR	Res.	B2BSTUP	STSPHSRX	OTEPDIS	STUP	AHBERR	EPDISD	XFRC
	Reset value																	0	0	0	0		-	0	0		0	0	0	0	0	0	0
0xC10	**OTG_ DOEPTSIZ8**	Res.	RXDPID/ STUPCNT		PKTCNT											XFRSIZ																	
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xC14	**OTG_ DOEPDMA8**	DMAADDR																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xE00	**OTG_ PCGCCTL**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUSP	PHYSLEEP	ENL1GTG	PHYSUSP	Res.	Res.	GATEHCLK	STPPCLK
	Reset value																									0	0	0	0			0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

62.15 OTG_HS programming model

62.15.1 Core initialization

The application must perform the core initialization sequence. If the cable is connected during power-up, the current mode of operation bit in the OTG_GINTSTS (CMOD bit in OTG_GINTSTS) reflects the mode. The OTG_HS controller enters host mode when an “A” plug is connected or device mode when a “B” plug is connected.

This section explains the initialization of the OTG_HS controller after power-on. The application must follow the initialization sequence irrespective of host or device mode operation. All core global registers are initialized according to the core’s configuration:

1. Program the following fields in the OTG_GAHBCFG register:
   - Global interrupt mask bit GINTMSK = 1
   - Rx FIFO non-empty (RXFLVL bit in OTG_GINTSTS)
   - Periodic Tx FIFO empty level
2. Program the following fields in the OTG_GUSBCFG register:
   - HNP capable bit
   - SRP capable bit
   - OTG_HS timeout calibration field
   - USB turnaround time field
3. The software must unmask the following bits in the OTG_GINTMSK register:

   OTG interrupt mask

   Mode mismatch interrupt mask
4. The software can read the CMOD bit in OTG_GINTSTS to determine whether the OTG_HS controller is operating in host or device mode.

62.15.2 Host initialization

To initialize the core as host, the application must perform the following steps:

1. Program the HPRTINT in the OTG_GINTMSK register to unmask
2. Program the OTG_HCFG register to select full-speed host
3. Program the PPWR bit in OTG_HPRT to 1. This drives V_{BUS} on the USB.
4. Wait for the PCDET interrupt in OTG_HPRT0. This indicates that a device is connecting to the port.
5. Program the PRST bit in OTG_HPRT to 1. This starts the reset process.
6. Wait at least 10 ms for the reset process to complete.
7. Program the PRST bit in OTG_HPRT to 0.
8. Wait for the PENCHNG interrupt in OTG_HPRT.
9. Read the PSPD bit in OTG_HPRT to get the enumerated speed.
10. Program the HFIR register with a value corresponding to the selected PHY clock 1
11. Program the FSLSPCS field in the OTG_HCFG register following the speed of the device detected in step 9. If FSLSPCS has been changed a port reset must be performed.
12. Program the OTG_GRXFSIZ register to select the size of the receive FIFO.
13. Program the OTG_HNPTXFSIZ register to select the size and the start address of the Non-periodic transmit FIFO for non-periodic transactions.
14. Program the OTG_HPTXFSIZ register to select the size and start address of the periodic transmit FIFO for periodic transactions.

To communicate with devices, the system software must initialize and enable at least one channel.

62.15.3 Device initialization

The application must perform the following steps to initialize the core as a device on power-up or after a mode change from host to device.

1. Program the following fields in the OTG_DCFG register:
   – DESCDMA
   – Device speed
   – Non-zero-length status OUT handshake
   – Periodic Frame Interval
2. Program the Device threshold control register. This is required only if you are using DMA mode and you are planning to enable thresholding.
3. Clear the DCTL.SDIS bit. The core issues a connect after this bit is cleared.
4. Program the OTG_GINTMSK register to unmask the following interrupts:
   – USB reset
   – Enumeration done
   – Early suspend
   – USB suspend
   – SOF
5. Wait for the USBRST interrupt in OTG_GINTSTS. It indicates that a reset has been detected on the USB that lasts for about 10 ms on receiving this interrupt.
6. Wait for the ENUMDNE interrupt in OTG_GINTSTS. This interrupt indicates the end of reset on the USB. On receiving this interrupt, the application must read the OTG_DSTS register to determine the enumeration speed and perform the steps listed in *Endpoint initialization on enumeration completion on page 2793*.

At this point, the device is ready to accept SOF packets and perform control transfers on control endpoint 0.

62.15.4 DMA mode

The OTG host uses the AHB master interface to fetch the transmit packet data (AHB to USB) and receive the data update (USB to AHB). The AHB master uses the programmed DMA address (OTG_HCDMAx register in host mode and OTG_DIEPDMAx/OTG_DOEPDMAx register in peripheral mode) to access the data buffers.

Scatter/Gather DMA mode

In Scatter/Gather DMA mode, the core implements a true scatter/gather memory distribution in which data buffers are scattered over the system memory. However, the descriptors themselves are continuous. Each channel memory structure is implemented as a contiguous list of descriptors; each descriptor points to a data buffer of predefined size. In addition to the buffer pointer (a 32-bit word), the descriptor also has a status quadlet (32-bit word). When the list is implemented as a ring buffer, the list processor switches to the first element of the list when it encounters last bit. All channels (control, bulk, interrupt, and isochronous) implement these structures in memory. When Scatter/Gather DMA is enabled in device mode, OTG_DIEPDMAx and OTG_DOEPDMAx registers are used to access the base descriptor.

62.15.5 Host programming model

Channel initialization

The application must initialize one or more channels before it can communicate with connected devices. To initialize and enable a channel, the application must perform the following steps:

1. Program the OTG_GINTMSK register to unmask the following:
2. Channel interrupt
   - Non-periodic transmit FIFO empty for OUT transactions (applicable when operating in pipelined transaction-level with the packet count field programmed with more than one).
   - Non-periodic transmit FIFO half-empty for OUT transactions (applicable when operating in pipelined transaction-level with the packet count field programmed with more than one).
3. Program the OTG_HAINTMSK register to unmask the selected channels' interrupts.
4. Program the OTG_HCINTMSK register to unmask the transaction-related interrupts of interest given in the host channel interrupt register.
5. Program the selected channel's OTG_HCTSIZx register with the total transfer size, in bytes, and the expected number of packets, including short packets. The application must program the PID field with the initial data PID (to be used on the first OUT transaction or to be expected from the first IN transaction).
6. Program the OTG_HCCHARx register of the selected channel with the device's endpoint characteristics, such as type, speed, direction, and so forth. (The channel can be enabled by setting the channel enable bit to 1 only when the application is ready to transmit or receive any packet).
7. Program the selected channels in the OTG_HCSPLTx register(s) with the hub and port addresses (split transactions only).
8. Program the selected channels in the OTG_HCDMAx register(s) with the buffer start address (DMA transactions only).

Halting a channel

The application can disable any channel by programming the OTG_HCCHARx register with the CHDIS and CHENA bits set to 1. This enables the OTG_HS host to flush the posted requests (if any) and generates a channel halted interrupt. The application must wait for the CHH interrupt in OTG_HCINTx before reallocating the channel for other transactions. The OTG_HS host does not interrupt the transaction that has already been started on the USB.

To disable a channel in DMA mode operation, the application does not need to check for space in the request queue. The OTG_HS host checks for space to write the disable

request on the disabled channel's turn during arbitration. Meanwhile, all posted requests are dropped from the request queue when the CHDIS bit in OTG_HCCHARx is set to 1.

Before disabling a channel, the application must ensure that there is at least one free space available in the non-periodic request queue (when disabling a non-periodic channel) or the periodic request queue (when disabling a periodic channel). The application can simply flush the posted requests when the request queue is full (before disabling the channel), by programming the OTG_HCCHARx register with the CHDIS bit set to 1 which automatically clears the CHENA bit to 0.

The application is expected to disable a channel on any of the following conditions:

1. When an STALL, TXERR, BBERR or DTERR interrupt in OTG_HCINTx is received for an IN or OUT channel. The application must be able to receive other interrupts (DTERR, Nak, data, TXERR) for the same channel before receiving the halt.
2. When an XFRC interrupt in OTG_HCINTx is received during a non periodic IN transfer or high-bandwidth interrupt IN transfer
3. When a DISCINT (disconnect device) interrupt in OTG_GINTSTS is received. (The application is expected to disable all enabled channels).
4. When the application aborts a transfer before normal completion.

Ping protocol

When the OTG_HS host operates in high speed, the application must initiate the ping protocol when communicating with high-speed bulk or control (data and status stage) OUT endpoints. The application must initiate the ping protocol when it receives a NAK/NYET/TXERR interrupt. When the OTG_HS host receives one of the above responses, it does not continue any transaction for a specific endpoint, drops all posted or fetched OUT requests (from the request queue), and flushes the corresponding data (from the transmit FIFO).This is valid in slave mode only. In Slave mode, the application can send a ping token either by setting the DOPING bit in OTG_HCTSIZx before enabling the channel or by just writing the OTG_HCTSIZx register with the DOPING bit set when the channel is already enabled. This enables the OTG_HS host to write a ping request entry to the request queue. The application must wait for the response to the ping token (a NAK, ACK, or TXERR interrupt) before continuing the transaction or sending another ping token. The application can continue the data transaction only after receiving an ACK from the OUT endpoint for the requested ping. In DMA mode operation, the application does not need to set the DOPING bit in OTG_HCTSIZx for a NAK/NYET response in case of bulk/control OUT. The OTG_HS host automatically sets the DOPING bit in OTG_HCTSIZx, and issues the ping tokens for bulk/control OUT. The OTG_HS host continues sending ping tokens until it receives an ACK, and then switches automatically to the data transaction.

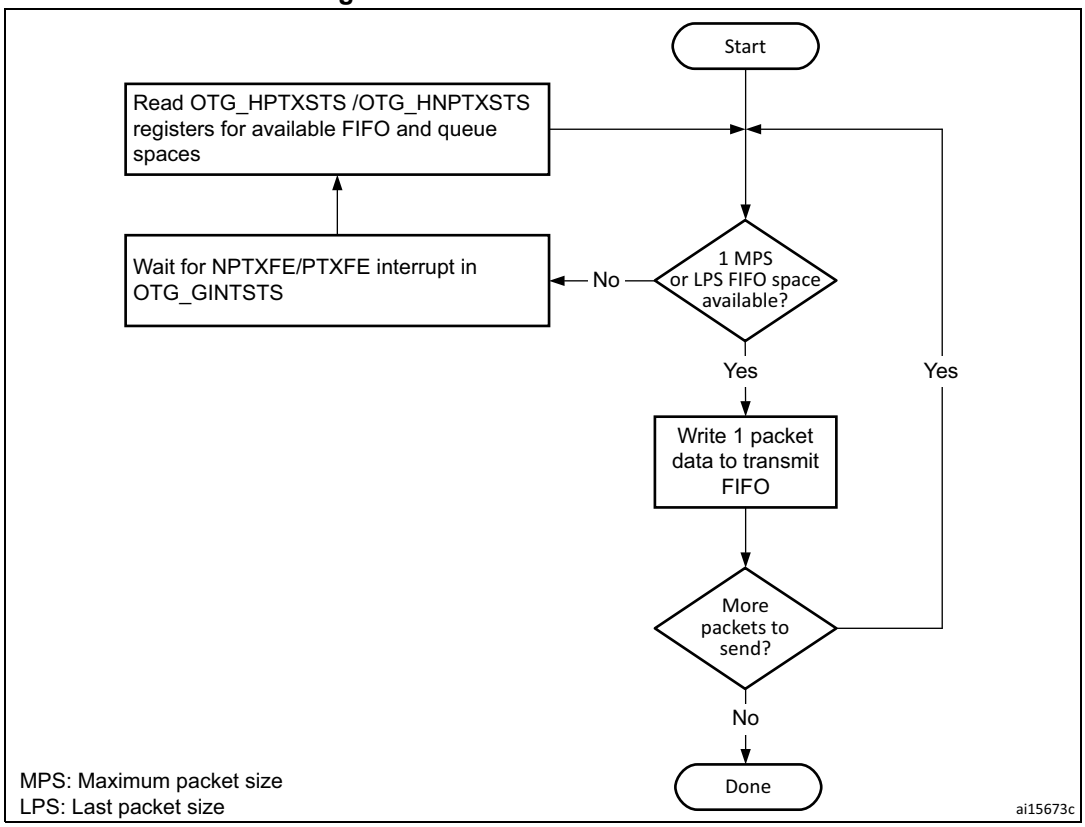
Operational model

The application must initialize a channel before communicating to the connected device. This section explains the sequence of operation to be performed for different types of USB transactions.

- **Writing the transmit FIFO**

  The OTG_HS host automatically writes an entry (OUT request) to the periodic/non-periodic request queue, along with the last 32-bit word write of a packet. The application must ensure that at least one free space is available in the periodic/non-periodic request queue before starting to write to the transmit FIFO. The application must always write to the transmit FIFO in 32-bit words. If the packet size is non-32-bit word aligned, the application must use padding. The OTG_HS host determines the actual packet size based on the programmed maximum packet size and transfer size.

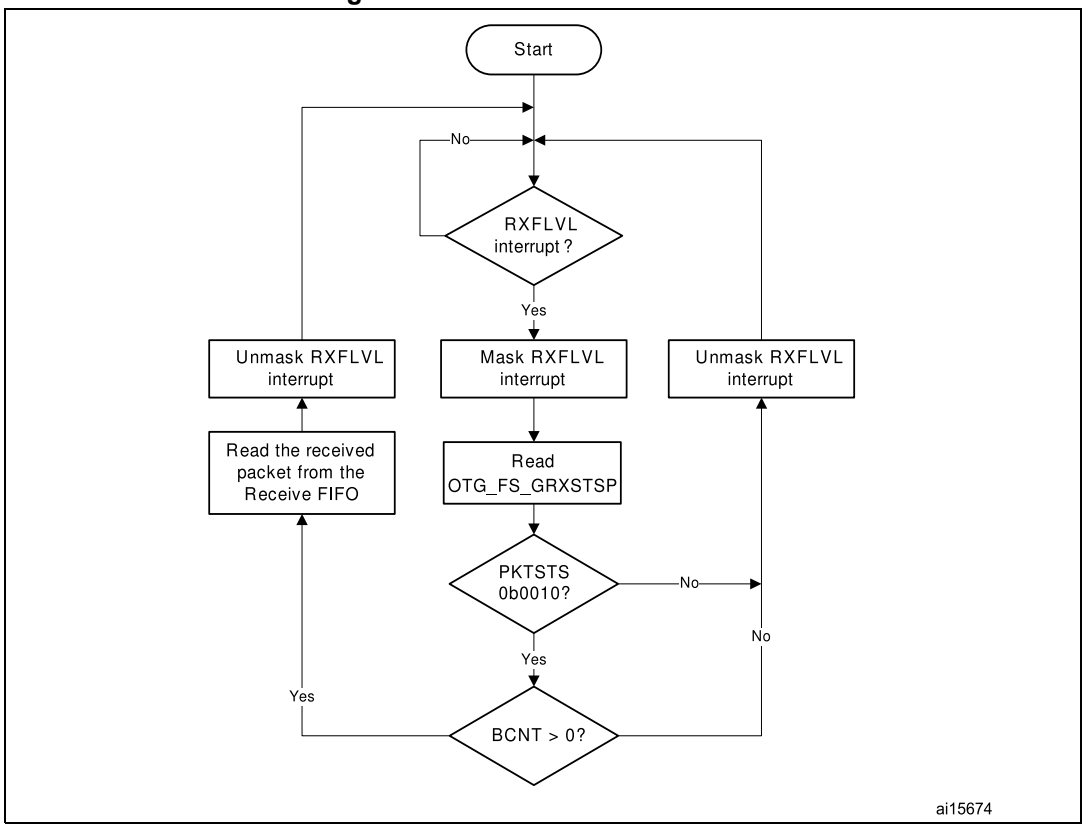
Figure 788. Transmit FIFO write task



- **Reading the receive FIFO**

  The application must ignore all packet statuses other than IN data packet (bx0010).

Figure 789. Receive FIFO read task



- **Bulk and control OUT/SETUP transactions**

  A typical bulk or control OUT/SETUP pipelined transaction-level operation is shown in *Figure 790*. See channel 1 (ch_1). Two bulk OUT packets are transmitted. A control SETUP transaction operates in the same way but has only one packet. The assumptions are:

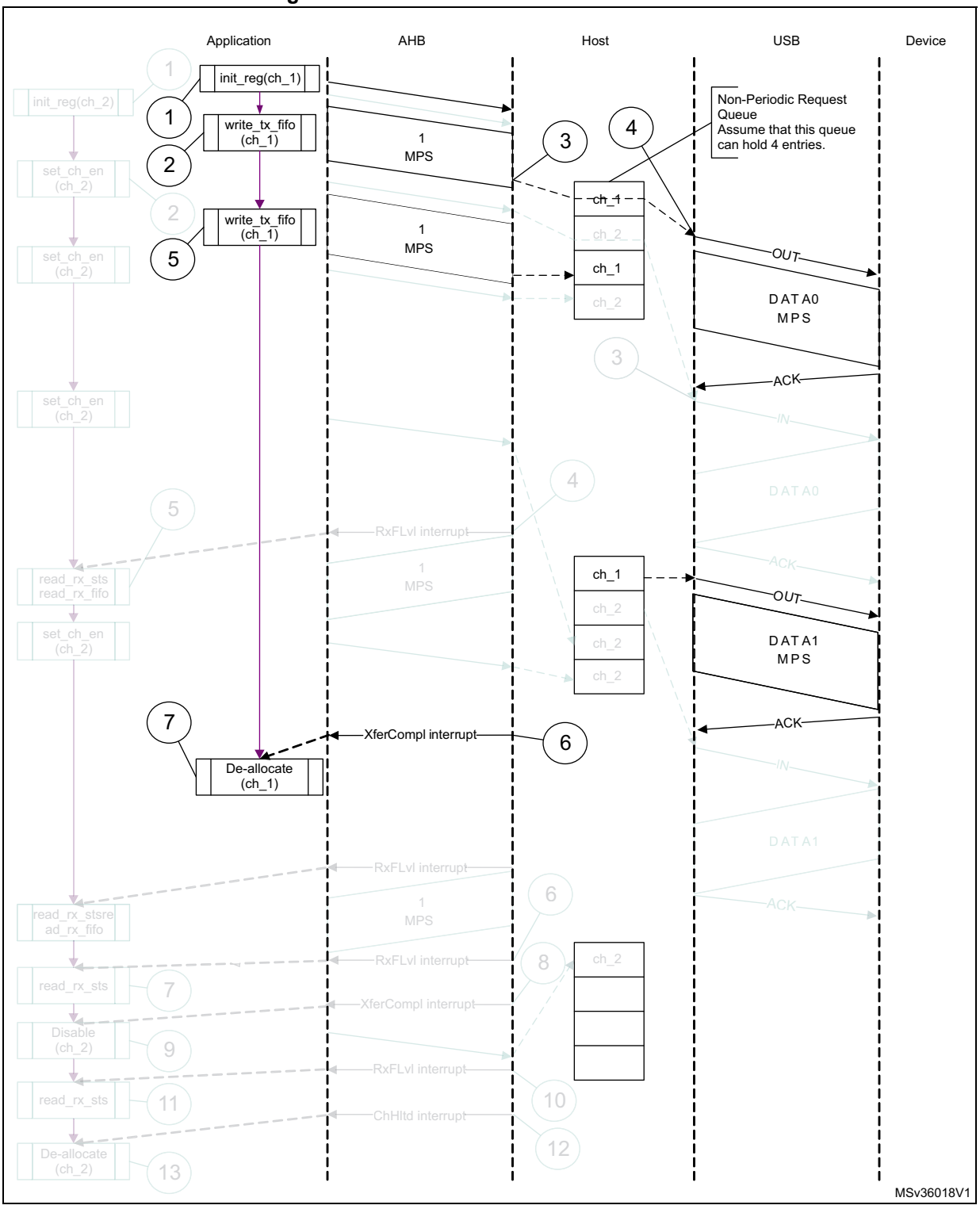
  – The application is attempting to send two maximum-packet-size packets (transfer size = 1, 024 bytes).
  – The non-periodic transmit FIFO can hold two packets (1 Kbyte for HS).
  – The non-periodic request queue depth = 4.

- **Normal bulk and control OUT/SETUP operations**

  The sequence of operations in (channel 1) is as follows:

1. Initialize channel 1
2. Write the first packet for channel 1
3. Along with the last word write, the core writes an entry to the non-periodic request queue
4. As soon as the non-periodic queue becomes non-empty, the core attempts to send an OUT token in the current frame
5. Write the second (last) packet for channel 1
6. The core generates the XFRC interrupt as soon as the last transaction is completed successfully
7. In response to the XFRC interrupt, de-allocate the channel for other transfers
8. Handling non-ACK responses

Figure 790. Normal bulk/control OUT/SETUP



1. The grayed elements are not relevant in the context of this figure.

The channel-specific interrupt service routine for bulk and control OUT/SETUP transactions is shown in the following code samples.

- **Interrupt service routine for bulk/control OUT/SETUP and bulk/control IN transactions**

  a) Bulk/control OUT/SETUP

```
Unmask (NAK/TXERR/STALL/XFRC)
if (XFRC)
   {
   Reset Error Count
   Mask ACK
   De-allocate Channel
   }
else if (STALL)
   {
   Transfer Done = 1
   Unmask CHH
   Disable Channel
   }
else if (NAK or TXERR )
   {
   Rewind Buffer Pointers
   Unmask CHH
   Disable Channel
   if (TXERR)
      {
      Increment Error Count
      Unmask ACK
      }
   else
      {
      Reset Error Count
      }
      }
else if (CHH)
   {
   Mask CHH
   if (Transfer Done or (Error_count == 3))
      {
      De-allocate Channel
      }
   else
      {
      Re-initialize Channel
      }
   }
```

```
   else if (ACK)
      {
      Reset Error Count
      Mask ACK
      }
```

The application is expected to write the data packets into the transmit FIFO when the space is available in the transmit FIFO and the request queue. The application can make use of the NPTXFE interrupt in OTG_GINTSTS to find the transmit FIFO space.

b) Bulk/control IN

```
Unmask (TXERR/XFRC/BBERR/STALL/DTERR)
if (XFRC)
   {
   Reset Error Count
   Unmask CHH
   Disable Channel
   Reset Error Count
   Mask ACK
   }
else if (TXERR or BBERR or STALL)
   {
   Unmask CHH
   Disable Channel
   if (TXERR)
      {
      Increment Error Count
      Unmask ACK
      }
   }
else if (CHH)
   {
   Mask CHH
   if (Transfer Done or (Error_count == 3))
      {
      De-allocate Channel
      }
   else
      {
      Re-initialize Channel
      }
   }
else if (ACK)
   {
   Reset Error Count
   Mask ACK
   }
```

```
else if (DTERR)
   {
   Reset Error Count
   }
```

The application is expected to write the requests as and when the request queue space is available and until the XFRC interrupt is received.

- **Bulk and control IN transactions**

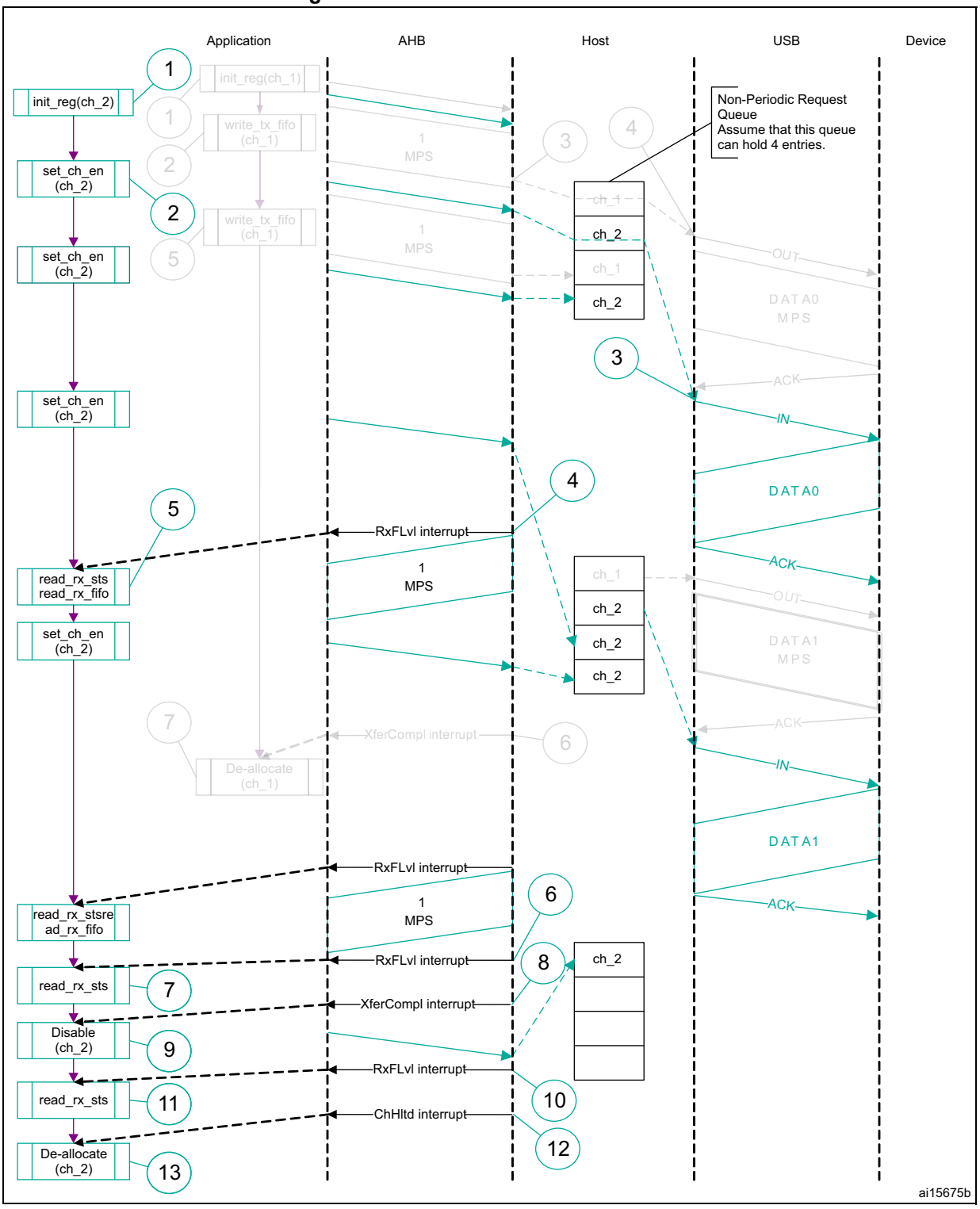
  A typical bulk or control IN pipelined transaction-level operation is shown in *Figure 791*. See channel 2 (ch_2). The assumptions are:

  – The application is attempting to receive two maximum-packet-size packets (transfer size = 1 024 bytes).

  – The receive FIFO can contain at least one maximum-packet-size packet and two status words per packet (520 bytes for HS).

  – The non-periodic request queue depth = 4.

Figure 791. Bulk/control IN transactions



1. The grayed elements are not relevant in the context of this figure.

The sequence of operations is as follows:

1. Initialize channel 2.
2. Set the CHENA bit in OTG_HCCHAR2 to write an IN request to the non-periodic request queue.
3. The core attempts to send an IN token after completing the current OUT transaction.
4. The core generates an RXFLVL interrupt as soon as the received packet is written to the receive FIFO.
5. In response to the RXFLVL interrupt, mask the RXFLVL interrupt and read the received packet status to determine the number of bytes received, then read the receive FIFO accordingly. Following this, unmask the RXFLVL interrupt.
6. The core generates the RXFLVL interrupt for the transfer completion status entry in the receive FIFO.
7. The application must read and ignore the receive packet status when the receive packet status is not an IN data packet (PKTSTS in OTG_GRXSTSR ≠ 0b0010).
8. The core generates the XFRC interrupt as soon as the receive packet status is read.
9. In response to the XFRC interrupt, disable the channel and stop writing the OTG_HCCHAR2 register for further requests. The core writes a channel disable request to the non-periodic request queue as soon as the OTG_HCCHAR2 register is written.
10. The core generates the RXFLVL interrupt as soon as the halt status is written to the receive FIFO.
11. Read and ignore the receive packet status.
12. The core generates a CHH interrupt as soon as the halt status is popped from the receive FIFO.
13. In response to the CHH interrupt, de-allocate the channel for other transfers.
14. Handling non-ACK responses

- **Control transactions**

  Setup, data, and status stages of a control transfer must be performed as three separate transfers. setup-, data- or status-stage OUT transactions are performed similarly to the bulk OUT transactions explained previously. Data- or status-stage IN transactions are performed similarly to the bulk IN transactions explained previously. For all three stages, the application is expected to set the EPTYP field in

OTG_HCCHAR1 to control. During the setup stage, the application is expected to set the PID field in OTG_HCTSIZ1 to SETUP.

- **Interrupt OUT transactions**

  A typical interrupt OUT operation is shown in *Figure 792*. The assumptions are:

  – The application is attempting to send one packet in every frame (up to 1 maximum packet size), starting with the odd frame (transfer size = 1 024 bytes)

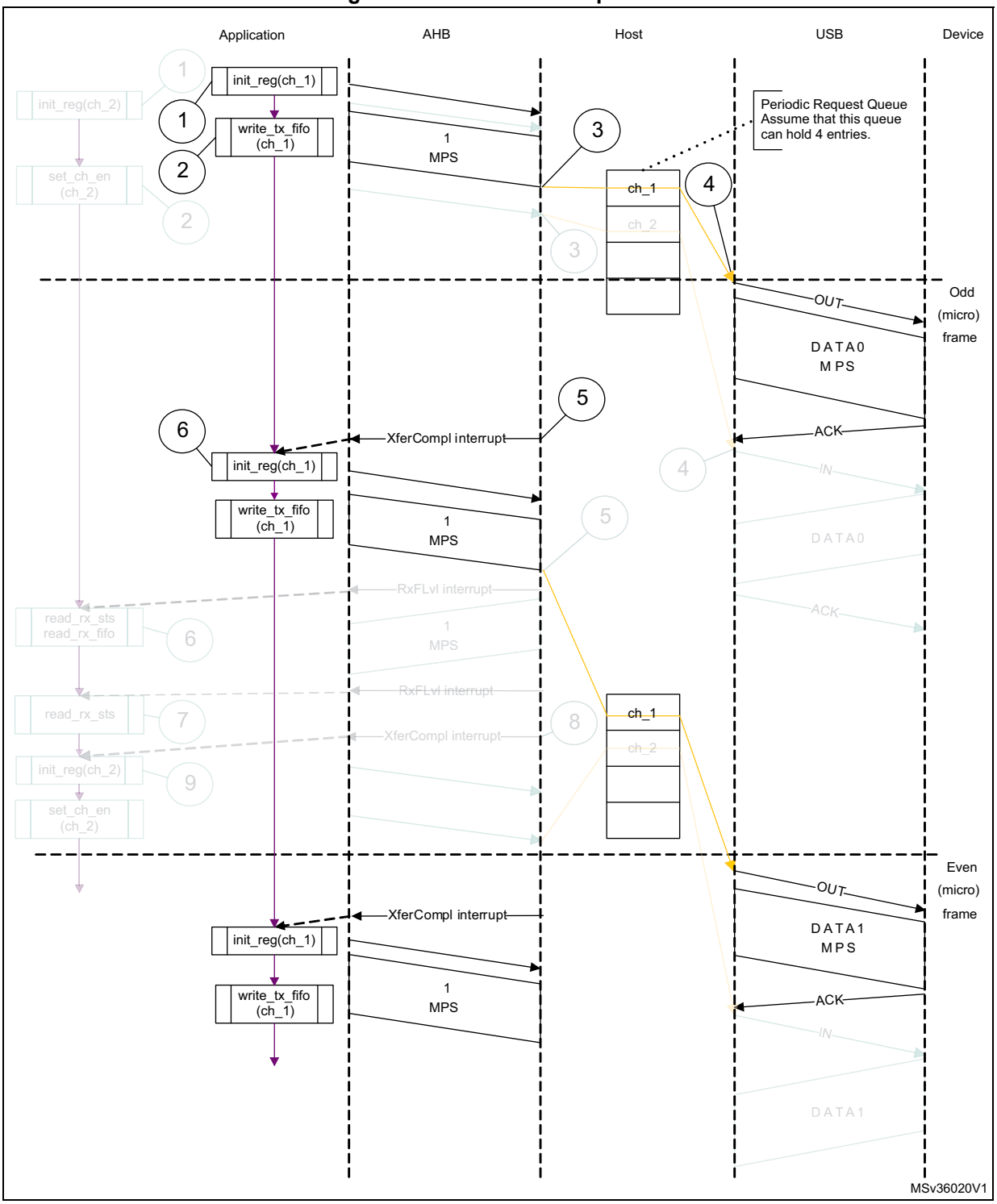
  – The periodic transmit FIFO can hold one packet (1 Kbyte)

  – Periodic request queue depth = 4

  The sequence of operations is as follows:

1. Initialize and enable channel 1. The application must set the ODDFRM bit in OTG_HCCHAR1.
2. Write the first packet for channel 1.
3. Along with the last word write of each packet, the OTG_HS host writes an entry to the periodic request queue.
4. The OTG_HS host attempts to send an OUT token in the next (odd) frame.
5. The OTG_HS host generates an XFRC interrupt as soon as the last packet is transmitted successfully.
6. In response to the XFRC interrupt, reinitialize the channel for the next transfer.

Figure 792. Normal interrupt OUT



1. The grayed elements are not relevant in the context of this figure.

- **Interrupt service routine for interrupt OUT/IN transactions**

  a) Interrupt OUT

`Unmask (NAK/TXERR/STALL/XFRC/FRMOR)`

```
if (XFRC)
   {
   Reset Error Count
   Mask ACK
   De-allocate Channel
   }
else
   if (STALL or FRMOR)
      {
      Mask ACK
      Unmask CHH
      Disable Channel
      if (STALL)
         {
         Transfer Done = 1
         }
      }
   else
      if (NAK or TXERR)
         {
         Rewind Buffer Pointers
         Reset Error Count
         Mask ACK
         Unmask CHH
         Disable Channel
         }
      else
         if (CHH)
         {
         Mask CHH
         if (Transfer Done or (Error_count == 3))
            {
            De-allocate Channel
            }
         else
            {
            Re-initialize Channel (in next b_interval - 1 Frame)
            }
         }
      else
         if (ACK)
         {
         Reset Error Count
         Mask ACK
         }
```

```
The application uses the NPTXFE interrupt in OTG_GINTSTS to find the
transmit FIFO space.
Interrupt IN
Unmask (NAK/TXERR/XFRC/BBERR/STALL/FRMOR/DTERR)
if (XFRC)
   {
   Reset Error Count
   Mask ACK
   if (OTG_HCTSIZx.PKTCNT == 0)
      {
      De-allocate Channel
      }
   else
      {
      Transfer Done = 1
      Unmask CHH
      Disable Channel
      }
   }
else
   if (STALL or FRMOR or NAK or DTERR or BBERR)
      {
      Mask ACK
      Unmask CHH
      Disable Channel
      if (STALL or BBERR)
         {
         Reset Error Count
         Transfer Done = 1
         }
      else
         if (!FRMOR)
         {
         Reset Error Count
         }
      }
else
   if (TXERR)
      {
      Increment Error Count
      Unmask ACK
      Unmask CHH
      Disable Channel
      }
else
```

```
   if (CHH)
      {
      Mask CHH
      if (Transfer Done or (Error_count == 3))
         {
         De-allocate Channel
         }
      else
         Re-initialize Channel (in next b_interval - 1 /Frame)
      }
   }
else
   if (ACK)
      {
      Reset Error Count
      Mask ACK
      }
```

- **Interrupt IN transactions**

  The assumptions are:

  – The application is attempting to receive one packet (up to 1 maximum packet size) in every frame, starting with odd (transfer size = 1 024 bytes).

  – The receive FIFO can hold at least one maximum-packet-size packet and two status words per packet (1 031 bytes).

  – Periodic request queue depth = 4.

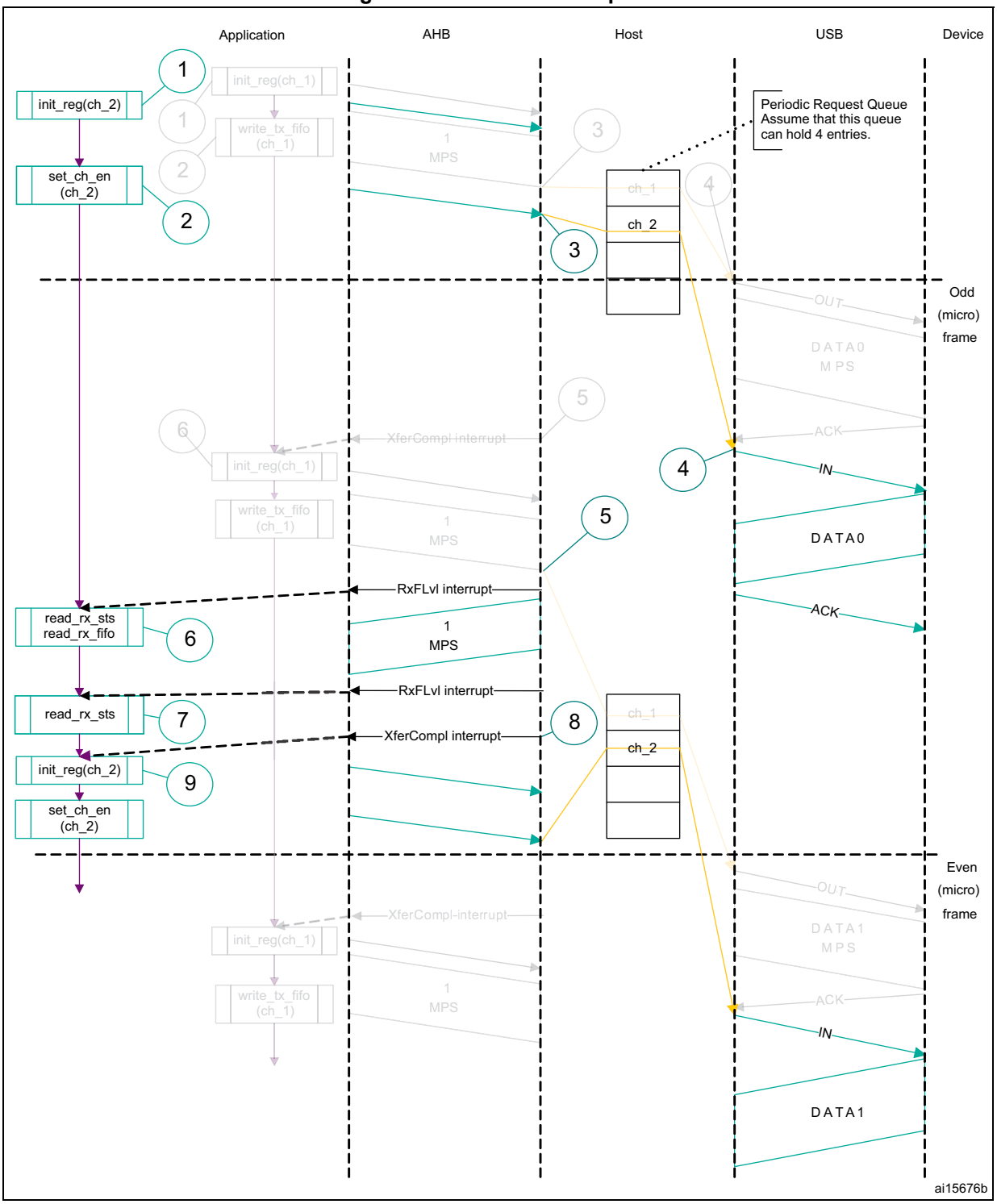
- **Normal interrupt IN operation**

  The sequence of operations is as follows:

1. Initialize channel 2. The application must set the ODDFRM bit in OTG_HCCHAR2.
2. Set the CHENA bit in OTG_HCCHAR2 to write an IN request to the periodic request queue.
3. The OTG_HS host writes an IN request to the periodic request queue for each OTG_HCCHAR2 register write with the CHENA bit set.
4. The OTG_HS host attempts to send an IN token in the next (odd) frame.
5. As soon as the IN packet is received and written to the receive FIFO, the OTG_HS host generates an RXFLVL interrupt.
6. In response to the RXFLVL interrupt, read the received packet status to determine the number of bytes received, then read the receive FIFO accordingly. The application must mask the RXFLVL interrupt before reading the receive FIFO, and unmask after reading the entire packet.
7. The core generates the RXFLVL interrupt for the transfer completion status entry in the receive FIFO. The application must read and ignore the receive packet status when the receive packet status is not an IN data packet (PKTSTS in GRXSTSR ≠ 0b0010).
8. The core generates an XFRC interrupt as soon as the receive packet status is read.
9. In response to the XFRC interrupt, read the PKTCNT field in OTG_HCTSIZ2. If the PKTCNT bit in OTG_HCTSIZ2 is not equal to 0, disable the channel before re-

initializing the channel for the next transfer, if any). If PKTCNT bit in OTG_HCTSIZ2 = 0, reinitialize the channel for the next transfer. This time, the application must reset the ODDFRM bit in OTG_HCCHAR2.

Figure 793. Normal interrupt IN



1. The grayed elements are not relevant in the context of this figure.

- **Isochronous OUT transactions**

  A typical isochronous OUT operation is shown in *Figure 794*. The assumptions are:

  – The application is attempting to send one packet every frame (up to 1 maximum

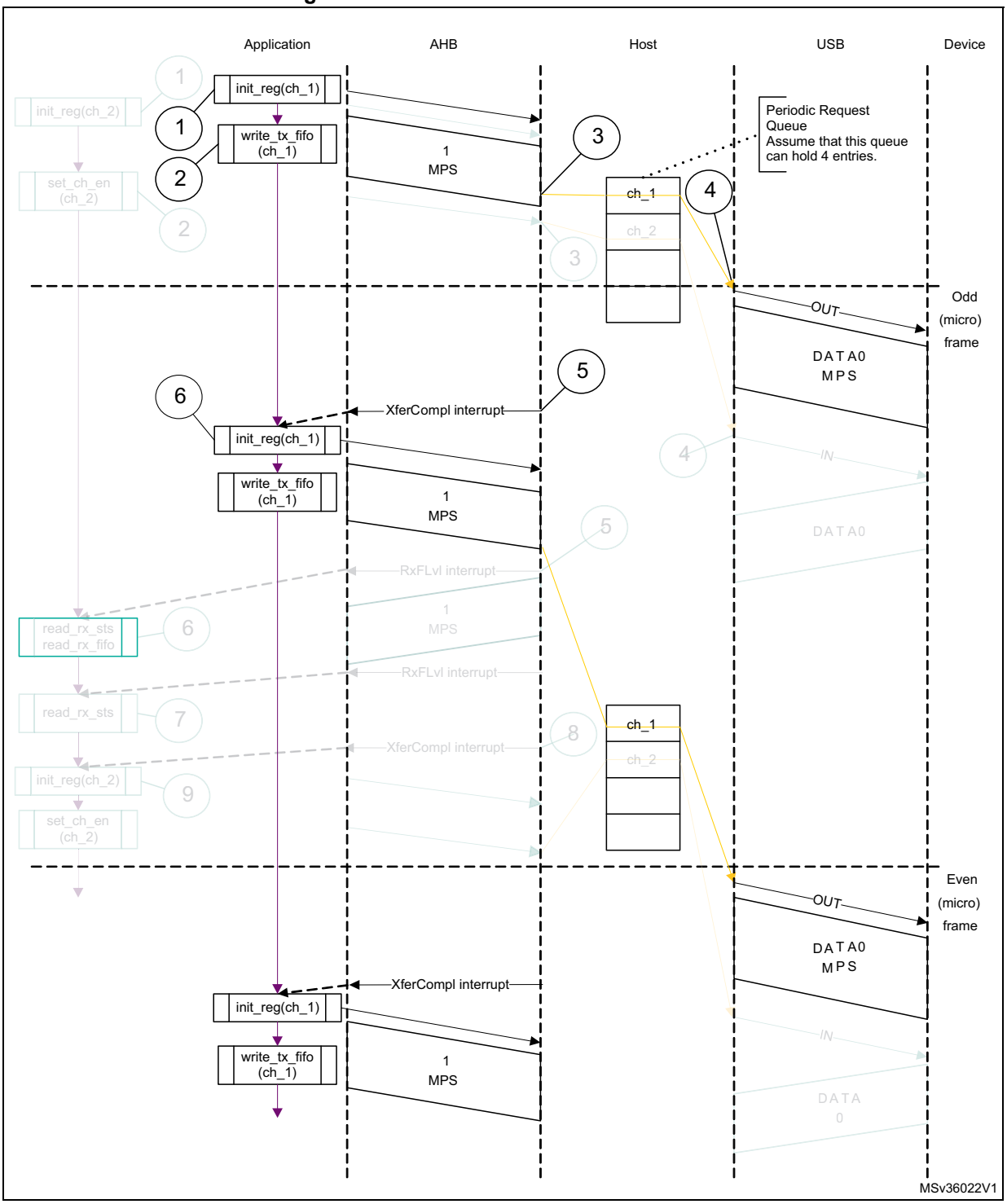
packet size), starting with an odd frame. (transfer size = 1 024 bytes).

– The periodic transmit FIFO can hold one packet (1 Kbyte).
– Periodic request queue depth = 4.

The sequence of operations is as follows:

1. Initialize and enable channel 1. The application must set the ODDFRM bit in OTG_HCCHAR1.
2. Write the first packet for channel 1.
3. Along with the last word write of each packet, the OTG_HS host writes an entry to the periodic request queue.
4. The OTG_HS host attempts to send the OUT token in the next frame (odd).
5. The OTG_HS host generates the XFRC interrupt as soon as the last packet is transmitted successfully.
6. In response to the XFRC interrupt, reinitialize the channel for the next transfer.
7. Handling non-ACK responses

Figure 794. Isochronous OUT transactions



1. The grayed elements are not relevant in the context of this figure.

- **Interrupt service routine for isochronous OUT/IN transactions**

  Code sample: isochronous OUT

```
Unmask (FRMOR/XFRC)
if (XFRC)
```

```
   {
   De-allocate Channel
   }
else
   if (FRMOR)
      {
      Unmask CHH
      Disable Channel
      }
   else
   if (CHH)
      {
      Mask CHH
      De-allocate Channel
      }
Code sample: Isochronous IN
Unmask (TXERR/XFRC/FRMOR/BBERR)
if (XFRC or FRMOR)
   {
   if (XFRC and (OTG_HCTSIZx.PKTCNT == 0))
      {
      Reset Error Count
      De-allocate Channel
      }
   else
      {
      Unmask CHH
      Disable Channel
      }
   }
   else
      if (TXERR or BBERR)
         {
         Increment Error Count
         Unmask CHH
         Disable Channel
         }
      else
         if (CHH)
            {
            Mask CHH
            if (Transfer Done or (Error_count == 3))
               {
               De-allocate Channel
               }
```

```
else
   {
   Re-initialize Channel
   }
}
```

- **Isochronous IN transactions**

  The assumptions are:

  – The application is attempting to receive one packet (up to 1 maximum packet size) in every frame starting with the next odd frame (transfer size = 1 024 bytes).

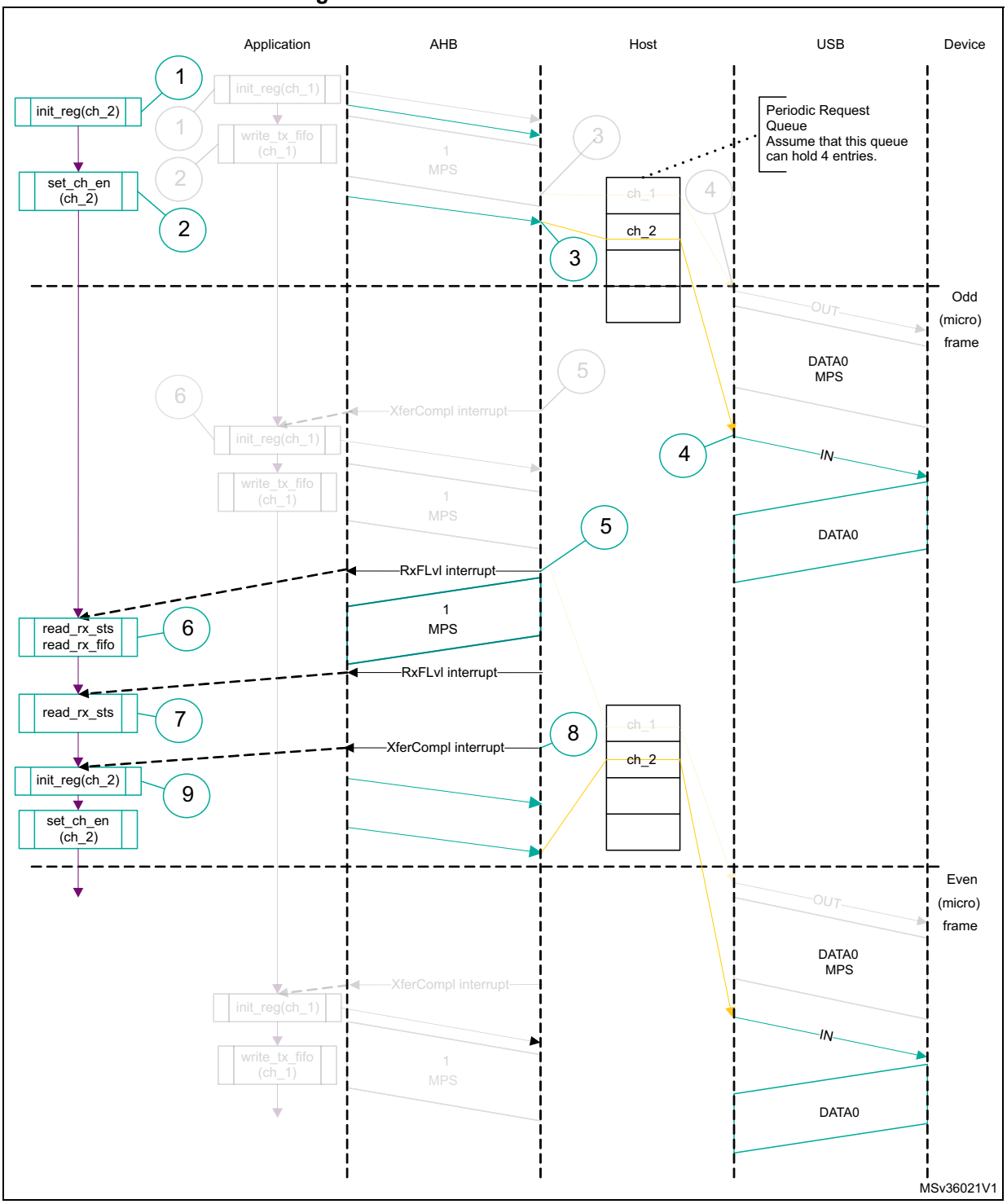
  – The receive FIFO can hold at least one maximum-packet-size packet and two status word per packet (1 031 bytes).

  – Periodic request queue depth = 4.

  The sequence of operations is as follows:

1. Initialize channel 2. The application must set the ODDFRM bit in OTG_HCCHAR2.
2. Set the CHENA bit in OTG_HCCHAR2 to write an IN request to the periodic request queue.
3. The OTG_HS host writes an IN request to the periodic request queue for each OTG_HCCHAR2 register write with the CHENA bit set.
4. The OTG_HS host attempts to send an IN token in the next odd frame.
5. As soon as the IN packet is received and written to the receive FIFO, the OTG_HS host generates an RXFLVL interrupt.
6. In response to the RXFLVL interrupt, read the received packet status to determine the number of bytes received, then read the receive FIFO accordingly. The application must mask the RXFLVL interrupt before reading the receive FIFO, and unmask it after reading the entire packet.
7. The core generates an RXFLVL interrupt for the transfer completion status entry in the receive FIFO. This time, the application must read and ignore the receive packet status when the receive packet status is not an IN data packet (PKTSTS bit in OTG_GRXSTSR ≠ 0b0010).
8. The core generates an XFRC interrupt as soon as the receive packet status is read.
9. In response to the XFRC interrupt, read the PKTCNT field in OTG_HCTSIZ2. If PKTCNT ≠ 0 in OTG_HCTSIZ2, disable the channel before re-initializing the channel for the next transfer, if any. If PKTCNT = 0 in OTG_HCTSIZ2, reinitialize the channel for the next transfer. This time, the application must reset the ODDFRM bit in OTG_HCCHAR2.

Figure 795. Isochronous IN transactions



1. The grayed elements are not relevant in the context of this figure.

- **Selecting the queue depth**

  Choose the periodic and non-periodic request queue depths carefully to match the number of periodic/non-periodic endpoints accessed.

  The non-periodic request queue depth affects the performance of non-periodic

transfers. The deeper the queue (along with sufficient FIFO size), the more often the core is able to pipeline non-periodic transfers. If the queue size is small, the core is able to put in new requests only when the queue space is freed up.

The core's periodic request queue depth is critical to perform periodic transfers as scheduled. Select the periodic queue depth, based on the number of periodic transfers scheduled in a microframe. If the periodic request queue depth is smaller than the periodic transfers scheduled in a microframe, a frame overrun condition occurs.

- **Handling babble conditions**

  OTG_HS controller handles two cases of babble: packet babble and port babble. Packet babble occurs if the device sends more data than the maximum packet size for the channel. Port babble occurs if the core continues to receive data from the device at EOF2 (the end of frame 2, which is very close to SOF).

  When OTG_HS controller detects a packet babble, it stops writing data into the Rx buffer and waits for the end of packet (EOP). When it detects an EOP, it flushes already written data in the Rx buffer and generates a Babble interrupt to the application.

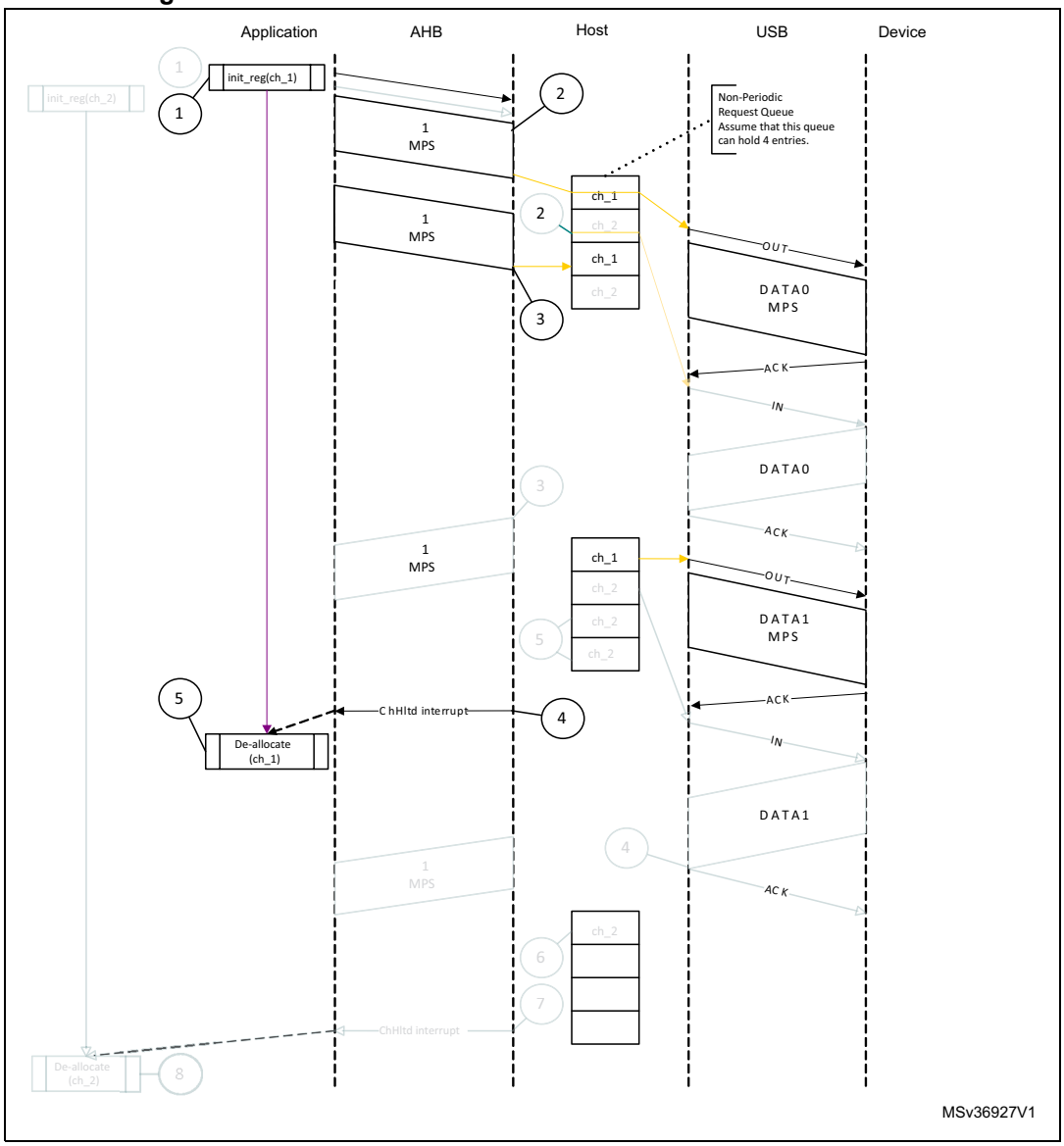
  When OTG_HS controller detects a port babble, it flushes the Rx FIFO and disables the port. The core then generates a port disabled interrupt (HPRTINT in OTG_GINTSTS, PENCHNG in OTG_HPRT). On receiving this interrupt, the application must determine that this is not due to an overcurrent condition (another cause of the port disabled interrupt) by checking POCA in OTG_HPRT, then perform a soft reset. The core does not send any more tokens after it has detected a port babble condition.

- **Bulk and control OUT/SETUP transactions in DMA mode**

  The sequence of operations is as follows:

1. Initialize and enable channel 1 as explained in *Section : Channel initialization*.
2. The OTG_HS host starts fetching the first packet as soon as the channel is enabled. For internal DMA mode, the OTG_HS host uses the programmed DMA address to fetch the packet.
3. After fetching the last 32-bit word of the second (last) packet, the OTG_HS host masks channel 1 internally for further arbitration.
4. The OTG_HS host generates a CHH interrupt as soon as the last packet is sent.
5. In response to the CHH interrupt, de-allocate the channel for other transfers.

Figure 796. Normal bulk/control OUT/SETUP transactions - DMA



- **NAK and NYET handling with internal DMA:**

1. The OTG_HS host sends a bulk OUT transaction.
2. The device responds with NAK or NYET.
3. If the application has unmasked NAK or NYET, the core generates the corresponding interrupt(s) to the application. The application is not required to service these interrupts, since the core takes care of rewinding the buffer pointers and re-initializing the Channel without application intervention.
4. The core automatically issues a ping token.
5. When the device returns an ACK, the core continues with the transfer. Optionally, the application can utilize these interrupts, in which case the NAK or NYET interrupt is masked by the application.

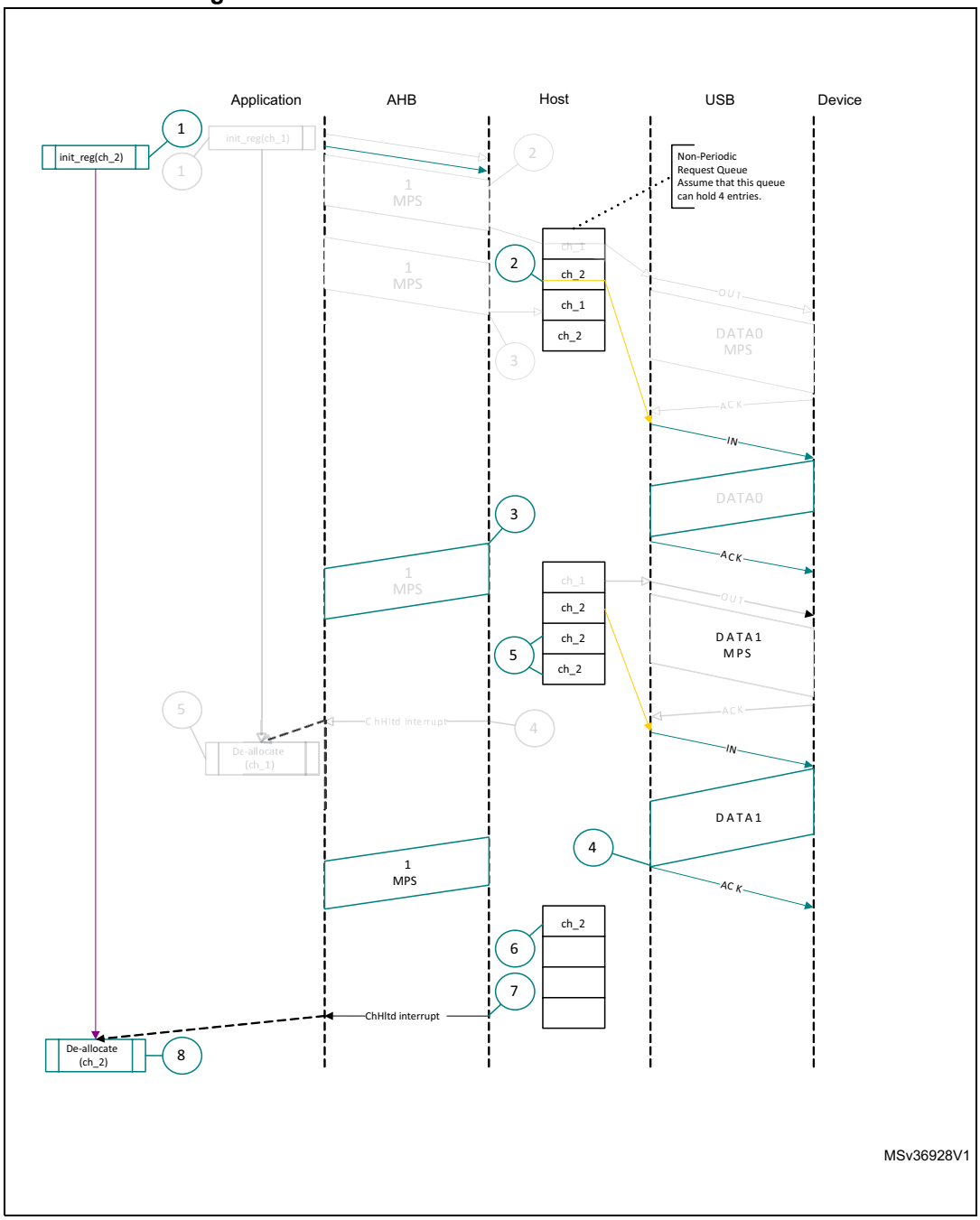
The core does not generate a separate interrupt when NAK or NYET is received by the host functionality.

- **Bulk and control IN transactions in DMA mode**

  The sequence of operations is as follows:

1. Initialize and enable the used channel (channel x) as explained in *Section : Channel initialization*.
2. The OTG_HS host writes an IN request to the request queue as soon as the channel receives the grant from the arbiter (arbitration is performed in a round-robin fashion).
3. The OTG_HS host starts writing the received data to the system memory as soon as the last byte is received with no errors.
4. When the last packet is received, the OTG_HS host sets an internal flag to remove any extra IN requests from the request queue.
5. The OTG_HS host flushes the extra requests.
6. The final request to disable channel x is written to the request queue. At this point, channel 2 is internally masked for further arbitration.
7. The OTG_HS host generates the CHH interrupt as soon as the disable request comes to the top of the queue.
8. In response to the CHH interrupt, de-allocate the channel for other transfers.

Figure 797. Normal bulk/control IN transaction - DMA

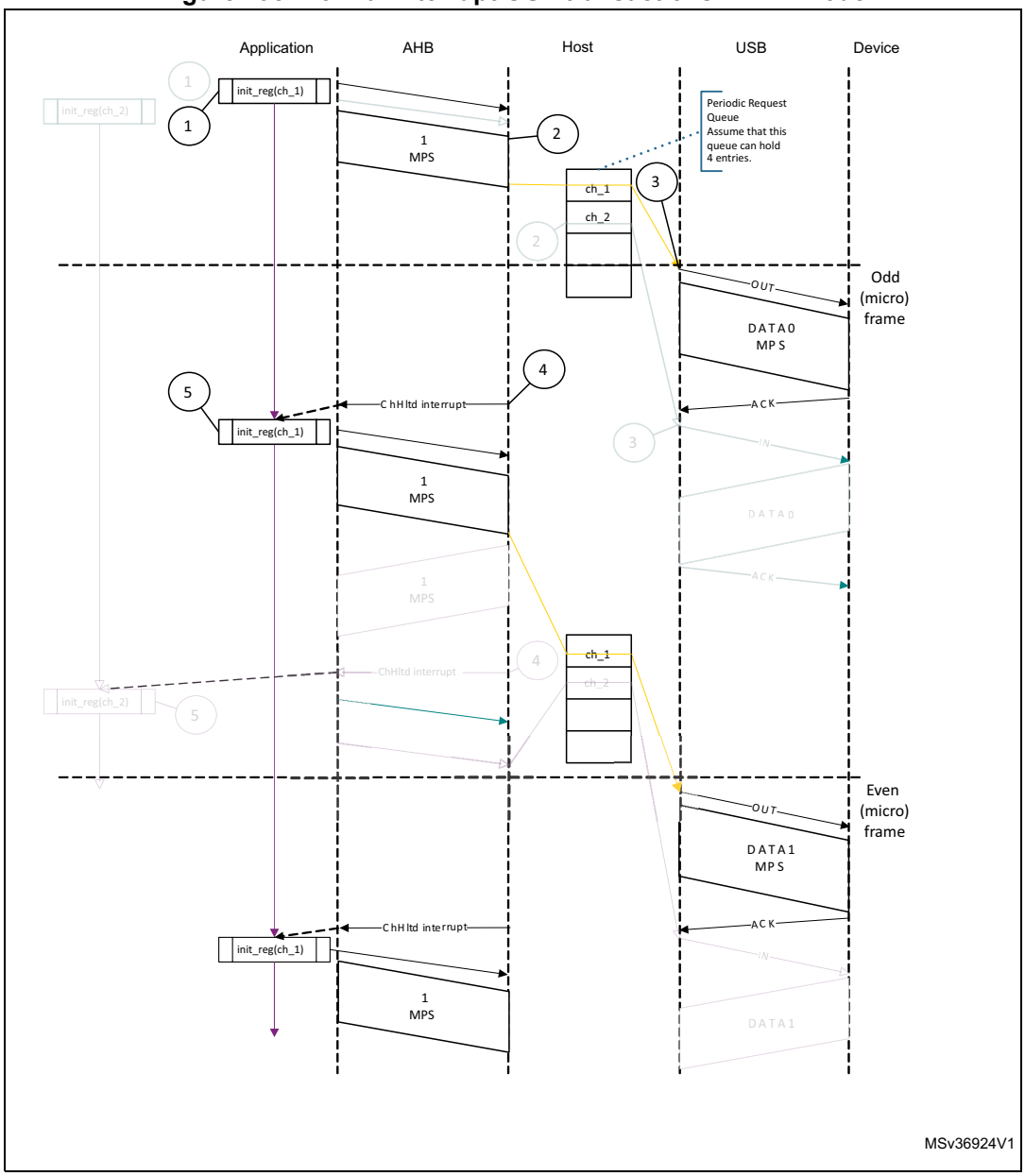


- **Interrupt OUT transactions in DMA mode**

1. Initialize and enable channel x as explained in *Section : Channel initialization*.
2. The OTG_HS host starts fetching the first packet as soon the channel is enabled and writes the OUT request along with the last 32-bit word fetch. In high-bandwidth transfers, the OTG_HS host continues fetching the next packet (up to the value specified in the MC field) before switching to the next channel.
3. The OTG_HS host attempts to send the OUT token at the beginning of the next odd frame/micro-frame.

4. After successfully transmitting the packet, the OTG_HS host generates a CHH interrupt.
5. In response to the CHH interrupt, reinitialize the channel for the next transfer.

Figure 798. Normal interrupt OUT transactions - DMA mode



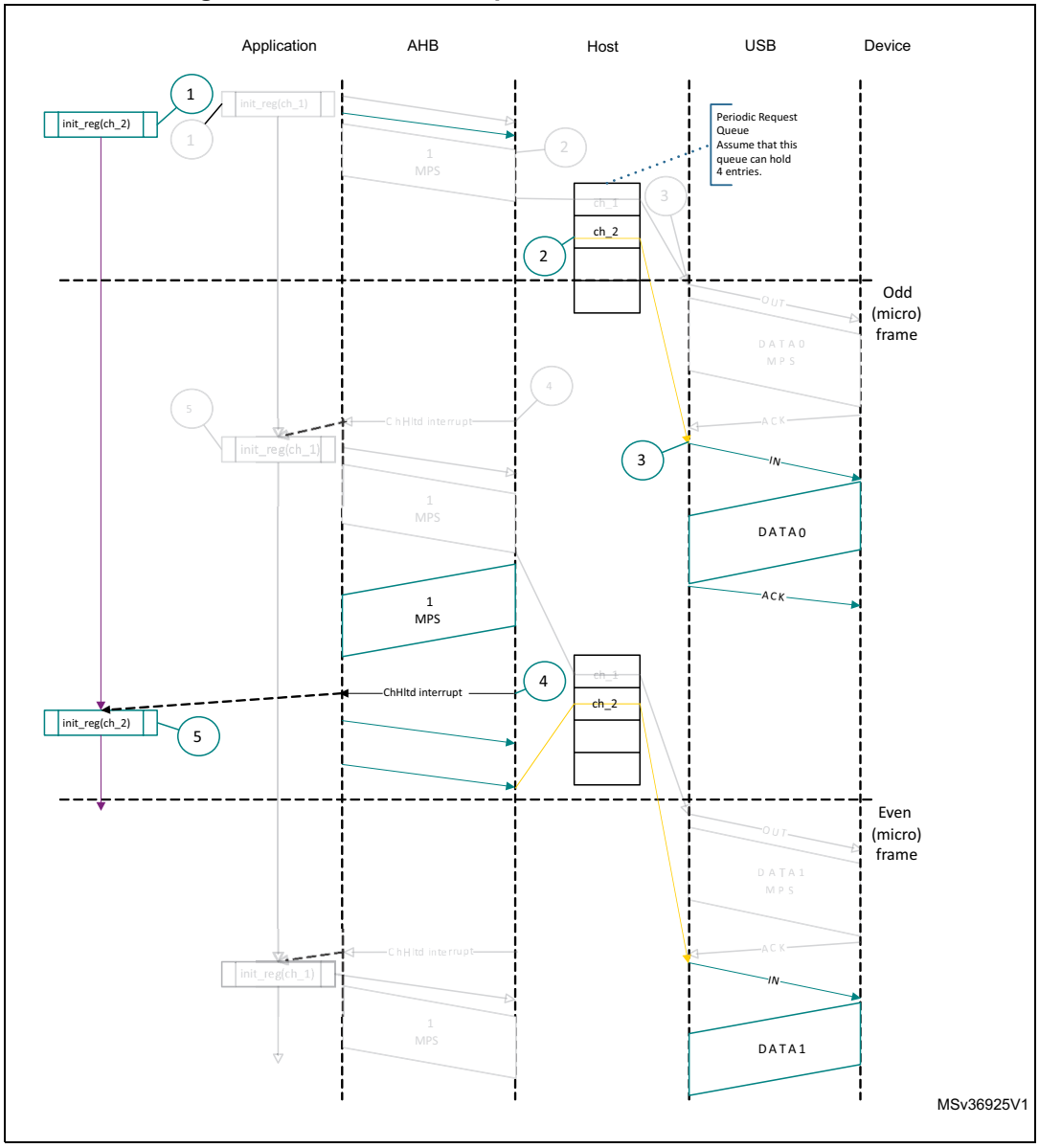
- **Interrupt IN transactions in DMA mode**

  The sequence of operations (channelx) is as follows:

1. Initialize and enable channel x as explained in *Section : Channel initialization*.
2. The OTG_HS host writes an IN request to the request queue as soon as the channel x gets the grant from the arbiter (round-robin with fairness). In high-bandwidth transfers, the OTG_HS host writes consecutive writes up to MC times.

3. The OTG_HS host attempts to send an IN token at the beginning of the next (odd) frame/micro-frame.
4. As soon the packet is received and written to the receive FIFO, the OTG_HS host generates a CHH interrupt.
5. In response to the CHH interrupt, reinitialize the channel for the next transfer.

Figure 799. Normal interrupt IN transactions - DMA mode



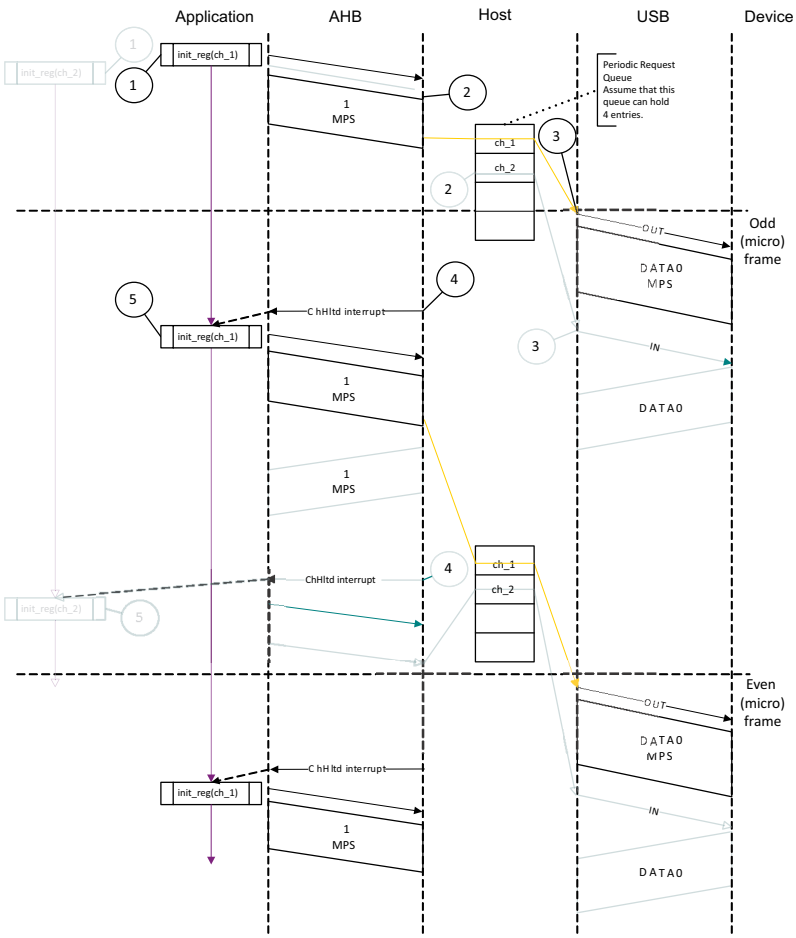
- **Isochronous OUT transactions in DMA mode**

1. Initialize and enable channel x as explained in *Section : Channel initialization*.
2. The OTG_HS host starts fetching the first packet as soon as the channel is enabled, and writes the OUT request along with the last 32-bit word fetch. In high-bandwidth

transfers, the OTG_HS host continues fetching the next packet (up to the value specified in the MC field) before switching to the next channel.

3. The OTG_HS host attempts to send an OUT token at the beginning of the next (odd) frame/micro-frame.
4. After successfully transmitting the packet, the OTG_HS host generates a CHH interrupt.
5. In response to the CHH interrupt, reinitialize the channel for the next transfer.

Figure 800. Normal isochronous OUT transaction - DMA mode



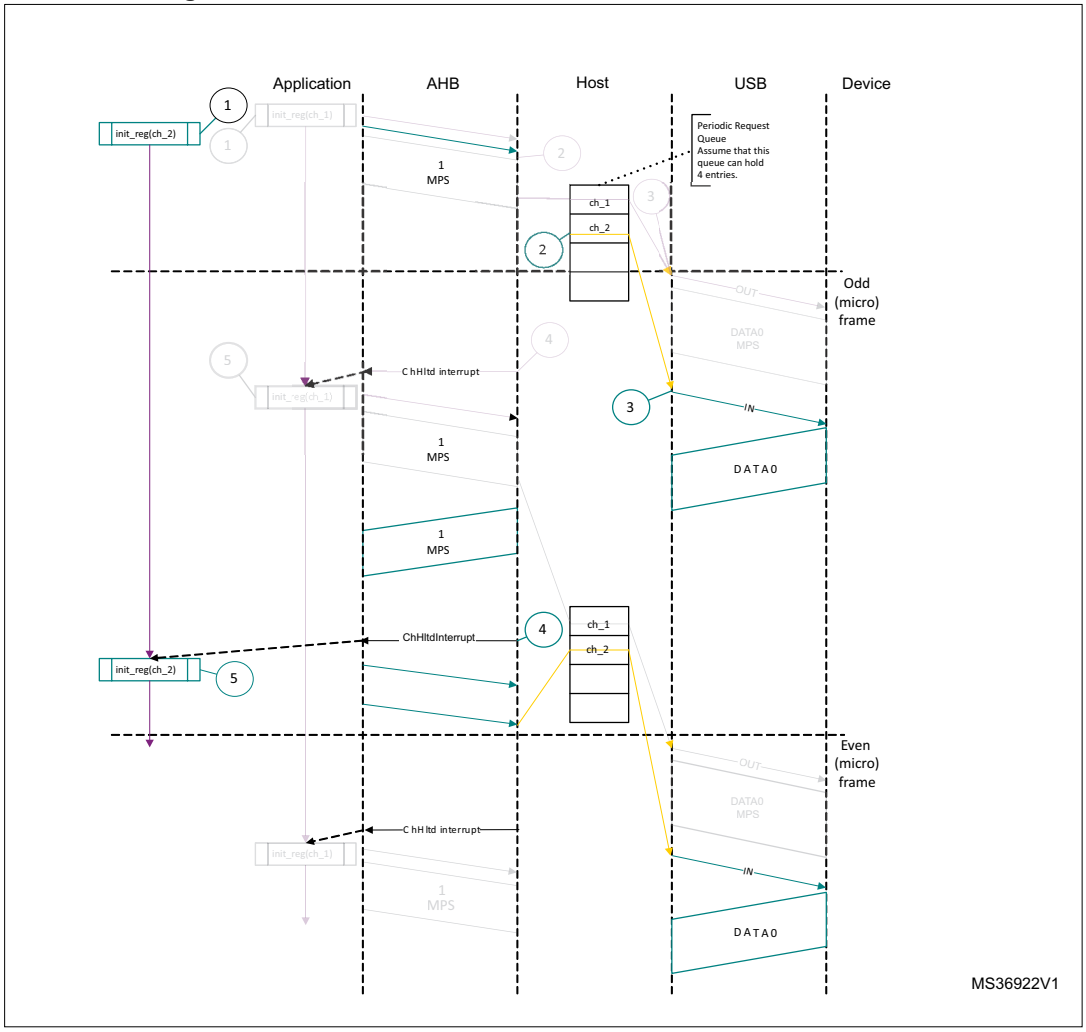
- **Isochronous IN transactions in DMA mode**

The sequence of operations ((channel x) is as follows:

1. Initialize and enable channel x as explained in *Section : Channel initialization*.
2. The OTG_HS host writes an IN request to the request queue as soon as the channel x gets the grant from the arbiter (round-robin with fairness). In high-bandwidth transfers, the OTG_HS host performs consecutive write operations up to MC times.

3. The OTG_HS host attempts to send an IN token at the beginning of the next (odd) frame/micro-frame.
4. As soon the packet is received and written to the receive FIFO, the OTG_HS host generates a CHH interrupt.
5. In response to the CHH interrupt, reinitialize the channel for the next transfer.

Figure 801. Normal isochronous IN transactions - DMA mode



- **Bulk and control OUT/SETUP split transactions in DMA mode**

  The sequence of operations in (channel x) is as follows:

1. Initialize and enable channel x for start split as explained in *Section : Channel initialization*.
2. The OTG_HS host starts fetching the first packet as soon the channel is enabled and writes the OUT request along with the last 32-bit word fetch.
3. After successfully transmitting start split, the OTG_HS host generates the CHH interrupt.
4. In response to the CHH interrupt, set the COMPLSPLT bit in OTG_HCSPLT1 to send the complete split.

5. After successfully transmitting complete split, the OTG_HS host generates the CHH interrupt.
6. In response to the CHH interrupt, de-allocate the channel.

- **Bulk/control IN split transactions in DMA mode**

The sequence of operations (channel x) is as follows:

1. Initialize and enable channel x as explained in *Section : Channel initialization*.
2. The OTG_HS host writes the start split request to the nonperiodic request after getting the grant from the arbiter. The OTG_HS host masks the channel x internally for the arbitration after writing the request.
3. As soon as the IN token is transmitted, the OTG_HS host generates the CHH interrupt.
4. In response to the CHH interrupt, set the COMPLSPLT bit in OTG_HCSPLT2 and re-enable the channel to send the complete split token. This unmasks channel x for arbitration.
5. The OTG_HS host writes the complete split request to the nonperiodic request after receiving the grant from the arbiter.
6. The OTG_HS host starts writing the packet to the system memory after receiving the packet successfully.
7. As soon as the received packet is written to the system memory, the OTG_HS host generates a CHH interrupt.
8. In response to the CHH interrupt, de-allocate the channel.

- **Interrupt OUT split transactions in DMA mode**

The sequence of operations in (channel x) is as follows:

1. Initialize and enable channel 1 for start split as explained in *Section : Channel initialization*. The application must set the ODDFRM bit in OTG_HCCHAR1.
2. The OTG_HS host starts reading the packet.
3. The OTG_HS host attempts to send the start split transaction.
4. After successfully transmitting the start split, the OTG_HS host generates the CHH interrupt.
5. In response to the CHH interrupt, set the COMPLSPLT bit in OTG_HCSPLT1 to send the complete split.
6. After successfully completing the complete split transaction, the OTG_HS host generates the CHH interrupt.
7. In response to CHH interrupt, de-allocate the channel.

- **Interrupt IN split transactions in DMA mode**

The sequence of operations in (channel x) is as follows:

1. Initialize and enable channel x for start split as explained in *Section : Channel initialization*.
2. The OTG_HS host writes an IN request to the request queue as soon as channel x receives the grant from the arbiter.
3. The OTG_HS host attempts to send the start split IN token at the beginning of the next odd micro-frame.
4. The OTG_HS host generates the CHH interrupt after successfully transmitting the start split IN token.
5. In response to the CHH interrupt, set the COMPLSPLT bit in OTG_HCSPLT2 to send the complete split.

6. As soon as the packet is received successfully, the OTG_HS host starts writing the data to the system memory.
7. The OTG_HS host generates the CHH interrupt after transferring the received data to the system memory.
8. In response to the CHH interrupt, de-allocate or reinitialize the channel for the next start split.

- **Isochronous OUT split transactions in DMA mode**

The sequence of operations (channel x) is as follows:

1. Initialize and enable channel x for start split (begin) as explained in *Section : Channel initialization*. The application must set the ODDFRM bit in OTG_HCCHAR1. Program the MPS field.
2. The OTG_HS host starts reading the packet.
3. After successfully transmitting the start split (begin), the OTG_HS host generates the CHH interrupt.
4. In response to the CHH interrupt, reinitialize the registers to send the start split (end).
5. After successfully transmitting the start split (end), the OTG_HS host generates a CHH interrupt.
6. In response to the CHH interrupt, de-allocate the channel.

- **Isochronous IN split transactions in DMA mode**

The sequence of operations (channel x) is as follows:

1. Initialize and enable channel x for start split as explained in *Section : Channel initialization*.
2. The OTG_HS host writes an IN request to the request queue as soon as channel x receives the grant from the arbiter.
3. The OTG_HS host attempts to send the start split IN token at the beginning of the next odd micro-frame.
4. The OTG_HS host generates the CHH interrupt after successfully transmitting the start split IN token.
5. In response to the CHH interrupt, set the COMPLSPLT bit in OTG_HCSPLT2 to send the complete split.
6. As soon as the packet is received successfully, the OTG_HS host starts writing the data to the system memory.

   The OTG_HS host generates the CHH interrupt after transferring the received data to the system memory. In response to the CHH interrupt, de-allocate the channel or reinitialize the channel for the next start split.

62.15.6 Device programming model

Endpoint initialization on USB reset

1. Set the NAK bit for all OUT endpoints
   – SNAK = 1 in OTG_DOEPCTLx (for all OUT endpoints)
2. Unmask the following interrupt bits
   – INEP0 = 1 in OTG_DAINTMSK (control 0 IN endpoint)
   – OUTEP0 = 1 in OTG_DAINTMSK (control 0 OUT endpoint)
   – STUPM = 1 in OTG_DOEPMSK
   – XFRCM = 1 in OTG_DOEPMSK
   – XFRCM = 1 in OTG_DIEPMSK
   – TOM = 1 in OTG_DIEPMSK
3. Set up the data FIFO RAM for each of the FIFOs
   – Program the OTG_GRXFSIZ register, to be able to receive control OUT data and setup data. If thresholding is not enabled, at a minimum, this must be equal to 1 max packet size of control endpoint 0 + 2 words (for the status of the control OUT data packet) + 10 words (for setup packets).
   – Program the OTG_DIEPTXF0 register (depending on the FIFO number chosen) to be able to transmit control IN data. At a minimum, this must be equal to 1 max packet size of control endpoint 0.
4. Program the following fields in the endpoint-specific registers for control OUT endpoint 0 to receive a SETUP packet
   – STUPCNT = 3 in OTG_DOEPTSIZ0 (to receive up to 3 back-to-back SETUP packets)
5. For USB OTG_HS in DMA mode, the OTG_DOEPDMA0 register should have a valid memory address to store any SETUP packets received.

At this point, all initialization required to receive SETUP packets is done.

Endpoint initialization on enumeration completion

1. On the Enumeration Done interrupt (ENUMDNE in OTG_GINTSTS), read the OTG_DSTS register to determine the enumeration speed.
2. Program the MPSIZ field in OTG_DIEPCTL0 to set the maximum packet size. This step configures control endpoint 0. The maximum packet size for a control endpoint depends on the enumeration speed.
3. For USB OTG_HS in DMA mode, program the OTG_DOEPCTL0 register to enable control OUT endpoint 0, to receive a SETUP packet.

At this point, the device is ready to receive SOF packets and is configured to perform control transfers on control endpoint 0.

Endpoint initialization on SetAddress command

This section describes what the application must do when it receives a SetAddress command in a SETUP packet.

1. Program the OTG_DCFG register with the device address received in the SetAddress command
2. Program the core to send out a status IN packet

Endpoint initialization on SetConfiguration/SetInterface command

This section describes what the application must do when it receives a SetConfiguration or SetInterface command in a SETUP packet.

1. When a SetConfiguration command is received, the application must program the endpoint registers to configure them with the characteristics of the valid endpoints in the new configuration.
2. When a SetInterface command is received, the application must program the endpoint registers of the endpoints affected by this command.
3. Some endpoints that were active in the prior configuration or alternate setting are not valid in the new configuration or alternate setting. These invalid endpoints must be deactivated.
4. Unmask the interrupt for each active endpoint and mask the interrupts for all inactive endpoints in the OTG_DAINTMSK register.
5. Set up the data FIFO RAM for each FIFO.
6. After all required endpoints are configured; the application must program the core to send a status IN packet.

At this point, the device core is configured to receive and transmit any type of data packet.

Endpoint activation

This section describes the steps required to activate a device endpoint or to configure an existing device endpoint to a new type.

1. Program the characteristics of the required endpoint into the following fields of the OTG_DIEPCTLx register (for IN or bidirectional endpoints) or the OTG_DOEPCTLx register (for OUT or bidirectional endpoints).
   - Maximum packet size
   - USB active endpoint = 1
   - Endpoint start data toggle (for interrupt and bulk endpoints)
   - Endpoint type
   - Tx FIFO number
2. Once the endpoint is activated, the core starts decoding the tokens addressed to that endpoint and sends out a valid handshake for each valid token received for the endpoint.

Endpoint deactivation

This section describes the steps required to deactivate an existing endpoint.

1. In the endpoint to be deactivated, clear the USB active endpoint bit in the OTG_DIEPCTLx register (for IN or bidirectional endpoints) or the OTG_DOEPCTLx register (for OUT or bidirectional endpoints).
2. Once the endpoint is deactivated, the core ignores tokens addressed to that endpoint, which results in a timeout on the USB.

Note: The application must meet the following conditions to set up the device core to handle traffic:
NPTXFEM and RXFLVLM in the OTG_GINTMSK register must be cleared.

Operational model

SETUP and OUT data transfers:

This section describes the internal data flow and application-level operations during data OUT transfers and SETUP transactions.

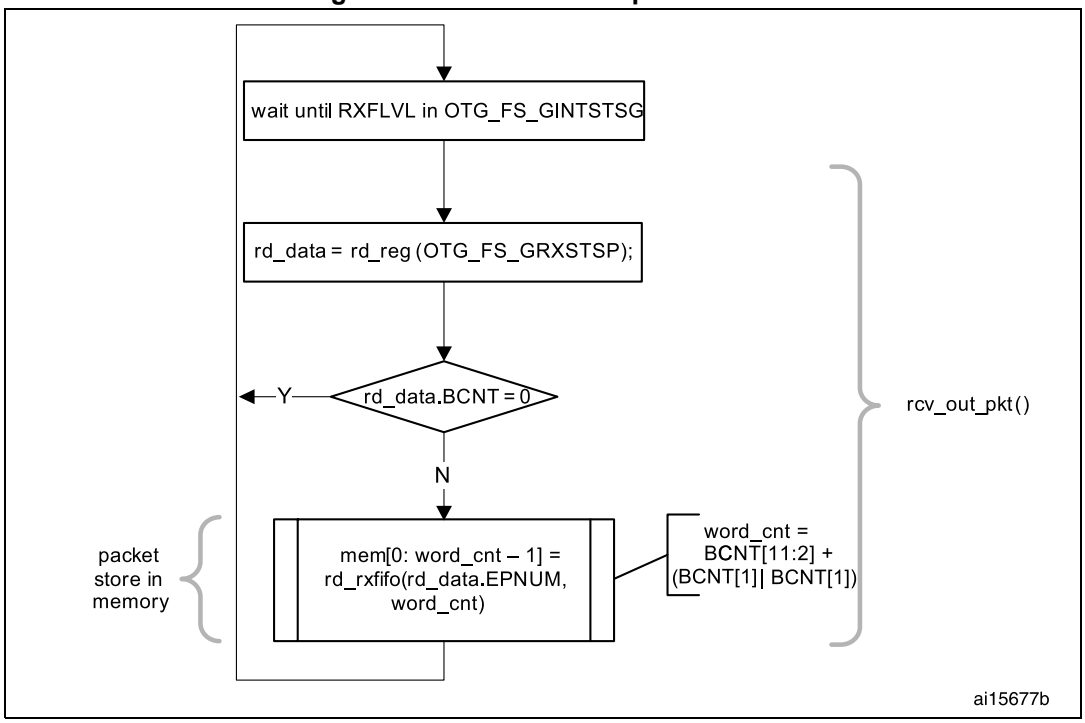
- **Packet read**

This section describes how to read packets (OUT data and SETUP packets) from the receive FIFO.

1. On catching an RXFLVL interrupt (OTG_GINTSTS register), the application must read the receive status pop register (OTG_GRXSTSP).
2. The application can mask the RXFLVL interrupt (in OTG_GINTSTS) by writing to RXFLVLM = 0 (in OTG_GINTMSK), until it has read the packet from the receive FIFO.
3. If the received packet's byte count is not 0, the byte count amount of data is popped from the receive data FIFO and stored in memory. If the received packet byte count is 0, no data is popped from the receive data FIFO.
4. The receive status readout of the packet of FIFO indicates one of the following:
   a) Global OUT NAK pattern:
   PKTSTS = Global OUT NAK, BCNT = 0x000, EPNUM = (0x0),
   DPID = (0b00).
   These data indicate that the global OUT NAK bit has taken effect.
   b) SETUP packet pattern:
   PKTSTS = SETUP, BCNT = 0x008, EPNUM = Control EP Num,
   DPID = DATA0. These data indicate that a SETUP packet for the specified endpoint is now available for reading from the receive FIFO.
   c) Setup stage done pattern:
   PKTSTS = Setup Stage Done, BCNT = 0x0, EPNUM = Control EP Num,
   DPID = (0b00).
   These data indicate that the setup stage for the specified endpoint has completed and the data stage has started. After this entry is popped from the receive FIFO, the core asserts a setup interrupt on the specified control OUT endpoint.
   d) Data OUT packet pattern:
   PKTSTS = DataOUT, BCNT = size of the received data OUT packet (0 ≤ BCNT ≤ 1 024), EPNUM = EPNUM on which the packet was received, DPID = Actual Data PID.
   e) Data transfer completed pattern:
   PKTSTS = Data OUT transfer done, BCNT = 0x0, EPNUM = OUT EP Num on which the data transfer is complete, DPID = (0b00).
   These data indicate that an OUT data transfer for the specified OUT endpoint has completed. After this entry is popped from the receive FIFO, the core asserts a transfer completed interrupt on the specified OUT endpoint.
5. After the data payload is popped from the receive FIFO, the RXFLVL interrupt (OTG_GINTSTS) must be unmasked.
6. Steps 1–5 are repeated every time the application detects assertion of the interrupt line due to RXFLVL in OTG_GINTSTS. Reading an empty receive FIFO can result in undefined core behavior.

Figure 802 provides a flowchart of the above procedure.

Figure 802. Receive FIFO packet read



SETUP transactions

This section describes how the core handles SETUP packets and the application's sequence for handling SETUP transactions.

- **Application requirements**

1. To receive a SETUP packet, the STUPCNT field (OTG_DOEPTSIZx) in a control OUT endpoint must be programmed to a non-zero value. When the application programs the STUPCNT field to a non-zero value, the core receives SETUP packets and writes them to the receive FIFO, irrespective of the NAK status and EPENA bit setting in OTG_DOEPCTLx. The STUPCNT field is decremented every time the control endpoint receives a SETUP packet. If the STUPCNT field is not programmed to a proper value before receiving a SETUP packet, the core still receives the SETUP packet and decrements the STUPCNT field, but the application may not be able to determine the correct number of SETUP packets received in the setup stage of a control transfer.
   – STUPCNT = 3 in OTG_DOEPTSIZx
2. The application must always allocate some extra space in the receive data FIFO, to be able to receive up to three SETUP packets on a control endpoint.
   – The space to be reserved is 10 words. Three words are required for the first SETUP packet, 1 word is required for the setup stage done word and 6 words are required to store two extra SETUP packets among all control endpoints.
   – 3 words per SETUP packet are required to store 8 bytes of SETUP data and 4 bytes of SETUP status (setup packet pattern). The core reserves this space in the

receive data FIFO to write SETUP data only, and never uses this space for data packets.

3. The application must read the 2 words of the SETUP packet from the receive FIFO.
4. The application must read and discard the setup stage done word from the receive FIFO.

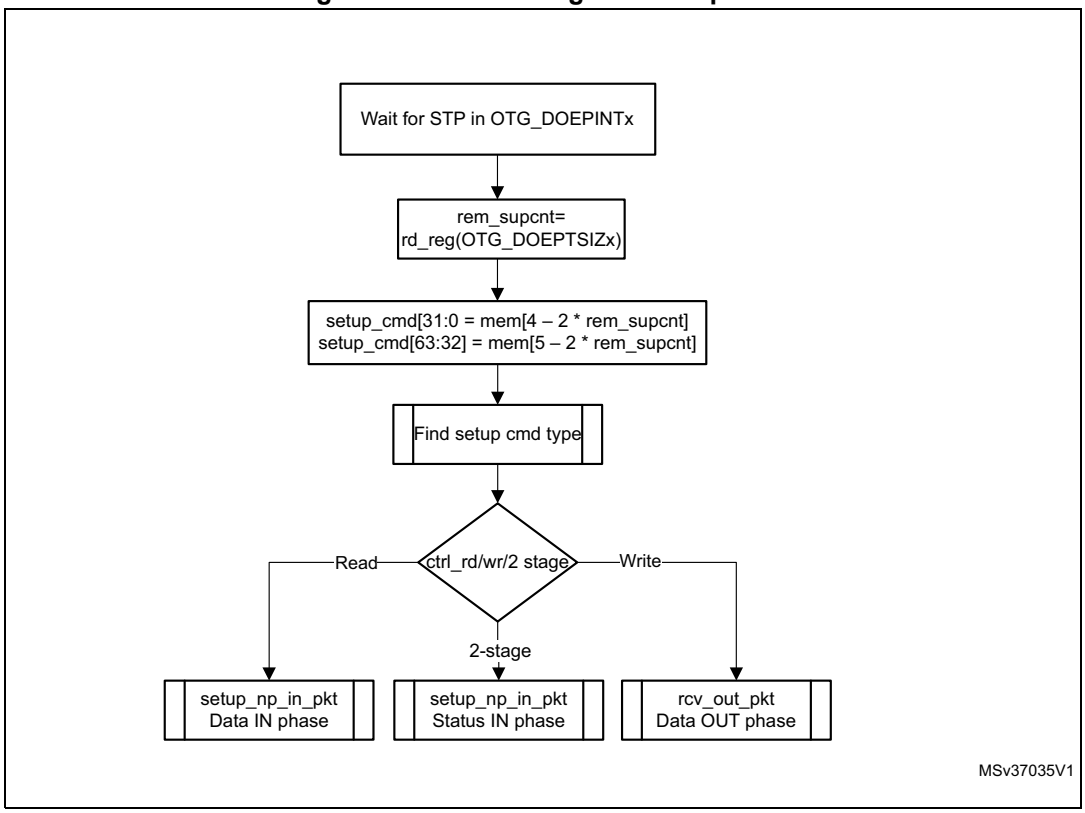
- **Internal data flow**

1. When a SETUP packet is received, the core writes the received data to the receive FIFO, without checking for available space in the receive FIFO and irrespective of the endpoint's NAK and STALL bit settings.
   – The core internally sets the IN NAK and OUT NAK bits for the control IN/OUT endpoints on which the SETUP packet was received.
2. For every SETUP packet received on the USB, 3 words of data are written to the receive FIFO, and the STUPCNT field is decremented by 1.
   – The first word contains control information used internally by the core
   – The second word contains the first 4 bytes of the SETUP command
   – The third word contains the last 4 bytes of the SETUP command
3. When the setup stage changes to a data IN/OUT stage, the core writes an entry (setup stage done word) to the receive FIFO, indicating the completion of the setup stage.
4. On the AHB side, SETUP packets are emptied by the application.
5. When the application pops the setup stage done word from the receive FIFO, the core interrupts the application with an STUP interrupt (OTG_DOEPINTx), indicating it can process the received SETUP packet.
6. The core clears the endpoint enable bit for control OUT endpoints.

- **Application programming sequence**

1. Program the OTG_DOEPTSIZx register.
   – STUPCNT = 3
2. Wait for the RXFLVL interrupt (OTG_GINTSTS) and empty the data packets from the receive FIFO.
3. Assertion of the STUP interrupt (OTG_DOEPINTx) marks a successful completion of the SETUP data transfer.
   – On this interrupt, the application must read the OTG_DOEPTSIZx register to determine the number of SETUP packets received and process the last received SETUP packet.

Figure 803. Processing a SETUP packet



- **Handling more than three back-to-back SETUP packets**

Per the USB 2.0 specification, normally, during a SETUP packet error, a host does not send more than three back-to-back SETUP packets to the same endpoint. However, the USB 2.0 specification does not limit the number of back-to-back SETUP packets a host can send to the same endpoint. When this condition occurs, the OTG_HS controller generates an interrupt (B2BSTUP in OTG_DOEPINTx).

- **Setting the global OUT NAK**

Internal data flow:

1. When the application sets the Global OUT NAK (SGONAK bit in OTG_DCTL), the core stops writing data, except SETUP packets, to the receive FIFO. Irrespective of the space availability in the receive FIFO, non-isochronous OUT tokens receive a NAK handshake response, and the core ignores isochronous OUT data packets
2. The core writes the Global OUT NAK pattern to the receive FIFO. The application must reserve enough receive FIFO space to write this data pattern.
3. When the application pops the Global OUT NAK pattern word from the receive FIFO, the core sets the GONAKEFF interrupt (OTG_GINTSTS).
4. Once the application detects this interrupt, it can assume that the core is in Global OUT NAK mode. The application can clear this interrupt by clearing the SGONAK bit in OTG_DCTL.

Application programming sequence:

1. To stop receiving any kind of data in the receive FIFO, the application must set the Global OUT NAK bit by programming the following field:
   – SGONAK = 1 in OTG_DCTL
2. Wait for the assertion of the GONAKEFF interrupt in OTG_GINTSTS. When asserted, this interrupt indicates that the core has stopped receiving any type of data except SETUP packets.
3. The application can receive valid OUT packets after it has set SGONAK in OTG_DCTL and before the core asserts the GONAKEFF interrupt (OTG_GINTSTS).
4. The application can temporarily mask this interrupt by writing to the GONAKEFFM bit in the OTG_GINTMSK register.
   – GONAKEFFM = 0 in the OTG_GINTMSK register
5. Whenever the application is ready to exit the Global OUT NAK mode, it must clear the SGONAK bit in OTG_DCTL. This also clears the GONAKEFF interrupt (OTG_GINTSTS).
   – CGONAK = 1 in OTG_DCTL
6. If the application has masked this interrupt earlier, it must be unmasked as follows:
   – GONAKEFFM = 1 in OTG_GINTMSK

- **Disabling an OUT endpoint**

The application must use this sequence to disable an OUT endpoint that it has enabled.

Application programming sequence:

1. Before disabling any OUT endpoint, the application must enable Global OUT NAK mode in the core.
   – SGONAK = 1 in OTG_DCTL
2. Wait for the GONAKEFF interrupt (OTG_GINTSTS)
3. Disable the required OUT endpoint by programming the following fields:
   – EPDIS = 1 in OTG_DOEPCTLx
   – SNAK = 1 in OTG_DOEPCTLx
4. Wait for the EPDISD interrupt (OTG_DOEPINTx), which indicates that the OUT endpoint is completely disabled. When the EPDISD interrupt is asserted, the core also clears the following bits:
   – EPDIS = 0 in OTG_DOEPCTLx
   – EPENA = 0 in OTG_DOEPCTLx
5. The application must clear the Global OUT NAK bit to start receiving data from other non-disabled OUT endpoints.
   – SGONAK = 0 in OTG_DCTL

- **Transfer Stop Programming for OUT endpoints**

The application must use the following programing sequence to stop any transfers (because of an interrupt from the host, typically a reset).

Sequence of operations:

1. Enable all OUT endpoints by setting
   – EPENA = 1 in all OTG_HS_DOEPCTLx registers.
2. Flush the RxFIFO as follows
   – Poll OTG_HS_GRSTCTL.AHBIDL until it is 1. This indicates that AHB master is idle.
   – Perform read modify write operation on OTG_HS_GRSTCTL.RXFFLSH =1
   – Poll OTG_HS_GRSTCTL.RXFFLSH until it is 0, but also using a timeout of less than 10 milli-seconds (corresponds to minimum reset signaling duration). If 0 is seen before the timeout, then the RxFIFO flush is successful. If at the moment the timeout occurs, there is still a 1, (this may be due to a packet on EP0 coming from the host) then go back (once only) to the previous step (“Perform read modify write operation”).
3. Before disabling any OUT endpoint, the application must enable Global OUT NAK mode in the core, according to the instructions in “*Setting the global OUT NAK on page 2798*”. This ensures that data in the RxFIFO is sent to the application successfully. Set SGONAK = 1 in OTG_HS_DCTL
4. Wait for the GONAKEFF interrupt (OTG_HS_GINTSTS)
5. Disable all active OUT endpoints by programming the following register bits:
   – EPDIS = 1 in registers OTG_HS_DOEPCTLx
   – SNAK = 1 in registers OTG_HS_DOEPCTLx
6. Wait for the EPDIS interrupt in OTG_HS_DOEPINTx for each OUT endpoint programmed in the previous step. The EPDIS interrupt in OTG_HS_DOEPINTx indicates that the corresponding OUT endpoint is completely disabled. When the EPDIS interrupt is asserted, the following bits are cleared:
   – EPENA = 0 in registers OTG_HS_DOEPCTLx
   – EPDIS = 0 in registers OTG_HS_DOEPCTLx
   – SNAK = 0 in registers OTG_HS_DOEPCTLx

- **Generic non-isochronous OUT data transfers**

This section describes a regular non-isochronous OUT data transfer (control, bulk, or interrupt).

Application requirements:

1. Before setting up an OUT transfer, the application must allocate a buffer in the memory to accommodate all data to be received as part of the OUT transfer.
2. For OUT transfers, the transfer size field in the endpoint's transfer size register must be a multiple of the maximum packet size of the endpoint, adjusted to the word boundary.
   – transfer size[EPNUM] = *n* × (MPSIZ[EPNUM] + 4 – (MPSIZ[EPNUM] mod 4))
   – packet count[EPNUM] = *n*
   – *n* > 0
3. On any OUT endpoint interrupt, the application must read the endpoint's transfer size register to calculate the size of the payload in the memory. The received payload size can be less than the programmed transfer size.
   – Payload size in memory = application programmed initial transfer size – core updated final transfer size
   – Number of USB packets in which this payload was received = application programmed initial packet count – core updated final packet count

Internal data flow:

1. The application must set the transfer size and packet count fields in the endpoint-specific registers, clear the NAK bit, and enable the endpoint to receive the data.
2. Once the NAK bit is cleared, the core starts receiving data and writes it to the receive FIFO, as long as there is space in the receive FIFO. For every data packet received on the USB, the data packet and its status are written to the receive FIFO. Every packet (maximum packet size or short packet) written to the receive FIFO decrements the packet count field for that endpoint by 1.
   – OUT data packets received with bad data CRC are flushed from the receive FIFO automatically.
   – After sending an ACK for the packet on the USB, the core discards non-isochronous OUT data packets that the host, which cannot detect the ACK, re-sends. The application does not detect multiple back-to-back data OUT packets on the same endpoint with the same data PID. In this case the packet count is not decremented.
   – If there is no space in the receive FIFO, isochronous or non-isochronous data packets are ignored and not written to the receive FIFO. Additionally, non-isochronous OUT tokens receive a NAK handshake reply.
   – In all the above three cases, the packet count is not decremented because no data are written to the receive FIFO.
3. When the packet count becomes 0 or when a short packet is received on the endpoint, the NAK bit for that endpoint is set. Once the NAK bit is set, the isochronous or non-isochronous data packets are ignored and not written to the receive FIFO, and non-isochronous OUT tokens receive a NAK handshake reply.
4. After the data are written to the receive FIFO, the application reads the data from the receive FIFO and writes it to external memory, one packet at a time per endpoint.
5. At the end of every packet write on the AHB to external memory, the transfer size for the endpoint is decremented by the size of the written packet.
6. The OUT data transfer completed pattern for an OUT endpoint is written to the receive FIFO on one of the following conditions:
   – The transfer size is 0 and the packet count is 0
   – The last OUT data packet written to the receive FIFO is a short packet (0 ≤ packet size < maximum packet size)

7. When either the application pops this entry (OUT data transfer completed), a transfer completed interrupt is generated for the endpoint and the endpoint enable is cleared.

Application programming sequence:

1. Program the OTG_DOEPTSIZx register for the transfer size and the corresponding packet count.
2. Program the OTG_DOEPCTLx register with the endpoint characteristics, and set the EPENA and CNAK bits.
   – EPENA = 1 in OTG_DOEPCTLx
   – CNAK = 1 in OTG_DOEPCTLx
3. Wait for the RXFLVL interrupt (in OTG_GINTSTS) and empty the data packets from the receive FIFO.
   – This step can be repeated many times, depending on the transfer size.
4. Asserting the XFRC interrupt (OTG_DOEPINTx) marks a successful completion of the non-isochronous OUT data transfer.
5. Read the OTG_DOEPTSIZx register to determine the size of the received data payload.

- **Generic isochronous OUT data transfer**

This section describes a regular isochronous OUT data transfer.

Application requirements:

1. All the application requirements for non-isochronous OUT data transfers also apply to isochronous OUT data transfers.
2. For isochronous OUT data transfers, the transfer size and packet count fields must always be set to the number of maximum-packet-size packets that can be received in a single frame and no more. Isochronous OUT data transfers cannot span more than 1 frame.
3. The application must read all isochronous OUT data packets from the receive FIFO (data and status) before the end of the periodic frame (EOPF interrupt in OTG_GINTSTS).
4. To receive data in the following frame, an isochronous OUT endpoint must be enabled after the EOPF (OTG_GINTSTS) and before the SOF (OTG_GINTSTS).

Internal data flow:

1. The internal data flow for isochronous OUT endpoints is the same as that for non-isochronous OUT endpoints, but for a few differences.
2. When an isochronous OUT endpoint is enabled by setting the endpoint enable and clearing the NAK bits, the Even/Odd frame bit must also be set appropriately. The core receives data on an isochronous OUT endpoint in a particular frame only if the following condition is met:
   – EONUM (in OTG_DOEPCTLx) = FNSOF[0] (in OTG_DSTS)
3. When the application completely reads an isochronous OUT data packet (data and status) from the receive FIFO, the core updates the RXDPID field in OTG_DOEPTSIZx with the data PID of the last isochronous OUT data packet read from the receive FIFO.

Application programming sequence:

1. Program the OTG_DOEPTSIZx register for the transfer size and the corresponding packet count
2. Program the OTG_DOEPCTLx register with the endpoint characteristics and set the endpoint enable, ClearNAK, and Even/Odd frame bits.
   – EPENA = 1
   – CNAK = 1
   – EONUM = (0: Even/1: Odd)
3. Wait for the RXFLVL interrupt (in OTG_GINTSTS) and empty the data packets from the receive FIFO
   – This step can be repeated many times, depending on the transfer size.
4. The assertion of the XFRC interrupt (in OTG_DOEPINTx) marks the completion of the isochronous OUT data transfer. This interrupt does not necessarily mean that the data in memory are good.
5. This interrupt cannot always be detected for isochronous OUT transfers. Instead, the application can detect the INCOMPISOOUT interrupt in OTG_GINTSTS.
6. Read the OTG_DOEPTSIZx register to determine the size of the received transfer and to determine the validity of the data received in the frame. The application must treat the data received in memory as valid only if one of the following conditions is met:
   – RXDPID = DATA0 (in OTG_DOEPTSIZx) and the number of USB packets in which this payload was received = 1
   – RXDPID = DATA1 (in OTG_DOEPTSIZx) and the number of USB packets in which this payload was received = 2

     RXDPID = D2 (in OTG_DOEPTSIZx) and the number of USB packets in which this payload was received = 3The number of USB packets in which this payload was received =
     Application programmed initial packet count – core updated final packet count

   The application can discard invalid data packets.

- **Incomplete isochronous OUT data transfers**

This section describes the application programming sequence when isochronous OUT data packets are dropped inside the core.

Internal data flow:

1. For isochronous OUT endpoints, the XFRC interrupt (in OTG_DOEPINTx) may not always be asserted. If the core drops isochronous OUT data packets, the application could fail to detect the XFRC interrupt (OTG_DOEPINTx) under the following circumstances:
   – When the receive FIFO cannot accommodate the complete ISO OUT data packet, the core drops the received ISO OUT data
   – When the isochronous OUT data packet is received with CRC errors
   – When the isochronous OUT token received by the core is corrupted
   – When the application is very slow in reading the data from the receive FIFO
2. When the core detects an end of periodic frame before transfer completion to all isochronous OUT endpoints, it asserts the incomplete isochronous OUT data interrupt (INCOMPISOOUT in OTG_GINTSTS), indicating that an XFRC interrupt (in OTG_DOEPINTx) is not asserted on at least one of the isochronous OUT endpoints. At

this point, the endpoint with the incomplete transfer remains enabled, but no active transfers remain in progress on this endpoint on the USB.

Application programming sequence:

1. Asserting the INCOMPISOOUT interrupt (OTG_GINTSTS) indicates that in the current frame, at least one isochronous OUT endpoint has an incomplete transfer.
2. If this occurs because isochronous OUT data is not completely emptied from the endpoint, the application must ensure that the application empties all isochronous OUT data (data and status) from the receive FIFO before proceeding.
   – When all data are emptied from the receive FIFO, the application can detect the XFRC interrupt (OTG_DOEPINTx). In this case, the application must re-enable the endpoint to receive isochronous OUT data in the next frame.
3. When it receives an INCOMPISOOUT interrupt (in OTG_GINTSTS), the application must read the control registers of all isochronous OUT endpoints (OTG_DOEPCTLx) to determine which endpoints had an incomplete transfer in the current microframe. An endpoint transfer is incomplete if both the following conditions are met:
   – EONUM bit (in OTG_DOEPCTLx) = FNSOF[0] (in OTG_DSTS)
   – EPENA = 1 (in OTG_DOEPCTLx)
4. The previous step must be performed before the SOF interrupt (in OTG_GINTSTS) is detected, to ensure that the current frame number is not changed.
5. For isochronous OUT endpoints with incomplete transfers, the application must discard the data in the memory and disable the endpoint by setting the EPDIS bit in OTG_DOEPCTLx.
6. Wait for the EPDISD interrupt (in OTG_DOEPINTx) and enable the endpoint to receive new data in the next frame.
   – Because the core can take some time to disable the endpoint, the application may not be able to receive the data in the next frame after receiving bad isochronous data.

- **Stalling a non-isochronous OUT endpoint**

This section describes how the application can stall a non-isochronous endpoint.

1. Put the core in the Global OUT NAK mode.
2. Disable the required endpoint
   – When disabling the endpoint, instead of setting the SNAK bit in OTG_DOEPCTL, set STALL = 1 (in OTG_DOEPCTL).

   The STALL bit always takes precedence over the NAK bit.
3. When the application is ready to end the STALL handshake for the endpoint, the STALL bit (in OTG_DOEPCTLx) must be cleared.
4. If the application is setting or clearing a STALL for an endpoint due to a SetFeature.Endpoint Halt or ClearFeature.Endpoint Halt command, the STALL bit must be set or cleared before the application sets up the status stage transfer on the control endpoint.

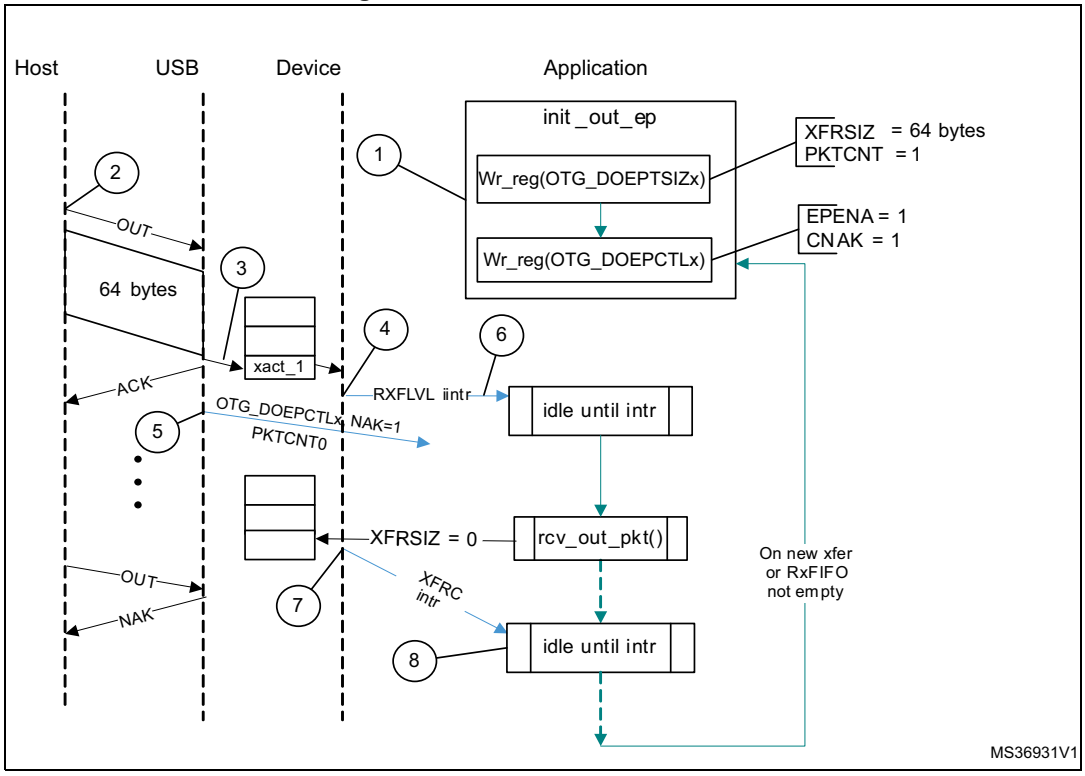
Examples

This section describes and depicts some fundamental transfer types and scenarios.

- Bulk OUT transaction

Figure 804 depicts the reception of a single Bulk OUT data packet from the USB to the AHB and describes the events involved in the process.

Figure 804. Bulk OUT transaction



After a SetConfiguration/SetInterface command, the application initializes all OUT endpoints by setting CNAK = 1 and EPENA = 1 (in OTG_DOEPCTLx), and setting a suitable XFRSIZ and PKTCNT in the OTG_DOEPTSIZx register.

1. host attempts to send data (OUT token) to an endpoint.
2. When the core receives the OUT token on the USB, it stores the packet in the Rx FIFO because space is available there.
3. After writing the complete packet in the Rx FIFO, the core then asserts the RXFLVL interrupt (in OTG_GINTSTS).
4. On receiving the PKTCNT number of USB packets, the core internally sets the NAK bit for this endpoint to prevent it from receiving any more packets.
5. The application processes the interrupt and reads the data from the Rx FIFO.
6. When the application has read all the data (equivalent to XFRSIZ), the core generates an XFRC interrupt (in OTG_DOEPINTx).
7. The application processes the interrupt and uses the setting of the XFRC interrupt bit (in OTG_DOEPINTx) to determine that the intended transfer is complete.

IN data transfers

- **Packet write**

This section describes how the application writes data packets to the endpoint FIFO when dedicated transmit FIFOs are enabled.

1. The application can either choose the polling or the interrupt mode.
   – In polling mode, the application monitors the status of the endpoint transmit data FIFO by reading the OTG_DTXFSTSx register, to determine if there is enough space in the data FIFO.
   – In interrupt mode, the application waits for the TXFE interrupt (in OTG_DIEPINTx) and then reads the OTG_DTXFSTSx register, to determine if there is enough space in the data FIFO.
   – To write a single non-zero length data packet, there must be space to write the entire packet in the data FIFO.
   – To write zero length packet, the application must not look at the FIFO space.
2. Using one of the above mentioned methods, when the application determines that there is enough space to write a transmit packet, the application must first write into the endpoint control register, before writing the data into the data FIFO. Typically, the application, must do a read modify write on the OTG_DIEPCTLx register to avoid modifying the contents of the register, except for setting the endpoint enable bit.

The application can write multiple packets for the same endpoint into the transmit FIFO, if space is available. For periodic IN endpoints, the application must write packets only for one microframe. It can write packets for the next periodic transaction only after getting transfer complete for the previous transaction.

- **Setting IN endpoint NAK**

Internal data flow:

1. When the application sets the IN NAK for a particular endpoint, the core stops transmitting data on the endpoint, irrespective of data availability in the endpoint's transmit FIFO.
2. Non-isochronous IN tokens receive a NAK handshake reply
   – Isochronous IN tokens receive a zero-data-length packet reply
3. The core asserts the INEPNE (IN endpoint NAK effective) interrupt in OTG_DIEPINTx in response to the SNAK bit in OTG_DIEPCTLx.
4. Once this interrupt is seen by the application, the application can assume that the endpoint is in IN NAK mode. This interrupt can be cleared by the application by setting the CNAK bit in OTG_DIEPCTLx.

Application programming sequence:

1. To stop transmitting any data on a particular IN endpoint, the application must set the IN NAK bit. To set this bit, the following field must be programmed.
   – SNAK = 1 in OTG_DIEPCTLx
2. Wait for assertion of the INEPNE interrupt in OTG_DIEPINTx. This interrupt indicates that the core has stopped transmitting data on the endpoint.
3. The core can transmit valid IN data on the endpoint after the application has set the NAK bit, but before the assertion of the NAK Effective interrupt.
4. The application can mask this interrupt temporarily by writing to the INEPNEM bit in OTG_DIEPMSK.
   – INEPNEM = 0 in OTG_DIEPMSK
5. To exit endpoint NAK mode, the application must clear the NAK status bit (NAKSTS) in OTG_DIEPCTLx. This also clears the INEPNE interrupt (in OTG_DIEPINTx).

– CNAK = 1 in OTG_DIEPCTLx

6. If the application masked this interrupt earlier, it must be unmasked as follows:
   – INEPNEM = 1 in OTG_DIEPMSK

- **IN endpoint disable**

Use the following sequence to disable a specific IN endpoint that has been previously enabled.

Application programming sequence:

1. The application must stop writing data on the AHB for the IN endpoint to be disabled.
2. The application must set the endpoint in NAK mode.
   – SNAK = 1 in OTG_DIEPCTLx
3. Wait for the INEPNE interrupt in OTG_DIEPINTx.
4. Set the following bits in the OTG_DIEPCTLx register for the endpoint that must be disabled.
   – EPDIS = 1 in OTG_DIEPCTLx
   – SNAK = 1 in OTG_DIEPCTLx
5. Assertion of the EPDISD interrupt in OTG_DIEPINTx indicates that the core has completely disabled the specified endpoint. Along with the assertion of the interrupt, the core also clears the following bits:
   – EPENA = 0 in OTG_DIEPCTLx
   – EPDIS = 0 in OTG_DIEPCTLx
6. The application must read the OTG_DIEPTSIZx register for the periodic IN EP, to calculate how much data on the endpoint were transmitted on the USB.
7. The application must flush the data in the endpoint transmit FIFO, by setting the following fields in the OTG_GRSTCTL register:
   – TXFNUM (in OTG_GRSTCTL) = Endpoint transmit FIFO number
   – TXFFLSH in (OTG_GRSTCTL) = 1

The application must poll the OTG_GRSTCTL register, until the TXFFLSH bit is cleared by the core, which indicates the end of flush operation. To transmit new data on this endpoint, the application can re-enable the endpoint at a later point.

- **Transfer Stop Programming for IN endpoints**

The application must use the following programing sequence to stop any transfers (because of an interrupt from the host, typically a reset).

Sequence of operations:

1. Disable the IN endpoint by setting:
   – EPDIS = 1 in all OTG_HS_DIEPCTLx registers
2. Wait for the EPDIS interrupt in OTG_HS_DIEPINTx, which indicates that the IN endpoint is completely disabled. When the EPDIS interrupt is asserted the following bits are cleared:
   – EPDIS = 0 in OTG_HS_DIEPCTLx
   – EPENA = 0 in OTG_HS_DIEPCTLx
3. Flush the TxFIFO by programming the following bits:
   – TXFFLSH = 1 in OTG_HS_GRSTCTL
   – TXFNUM = “FIFO number specific to endpoint” in OTG_HS_GRSTCTL
4. The application can start polling till TXFFLSH in OTG_HS_GRSTCTL is cleared. When this bit is cleared, it ensures that there is no data left in the Tx FIFO.

- **Generic non-periodic IN data transfers**

Application requirements:

1. Before setting up an IN transfer, the application must ensure that all data to be transmitted as part of the IN transfer are part of a single buffer.
2. For IN transfers, the transfer size field in the endpoint transfer size register denotes a payload that constitutes multiple maximum-packet-size packets and a single short packet. This short packet is transmitted at the end of the transfer.
   – To transmit a few maximum-packet-size packets and a short packet at the end of the transfer:
     Transfer size[EPNUM] = *x* × MPSIZ[EPNUM] + sp
     If (sp > 0), then packet count[EPNUM] = x + 1.
     Otherwise, packet count[EPNUM] = *x*
   – To transmit a single zero-length data packet:
     Transfer size[EPNUM] = 0
     Packet count[EPNUM] = 1
   – To transmit a few maximum-packet-size packets and a zero-length data packet at the end of the transfer, the application must split the transfer into two parts. The first sends maximum-packet-size data packets and the second sends the zero-length data packet alone.
     First transfer: transfer size[EPNUM] = *x* × MPSIZ[epnum]; packet count = *n*;
     Second transfer: transfer size[EPNUM] = 0; packet count = 1;
3. Once an endpoint is enabled for data transfers, the core updates the transfer size register. At the end of the IN transfer, the application must read the transfer size register to determine how much data posted in the transmit FIFO have already been sent on the USB.
4. Data fetched into transmit FIFO = Application-programmed initial transfer size – core-updated final transfer size
   – Data transmitted on USB = (application-programmed initial packet count – core updated final packet count) × MPSIZ[EPNUM]
   – Data yet to be transmitted on USB = (Application-programmed initial transfer size – data transmitted on USB)

Internal data flow:

1. The application must set the transfer size and packet count fields in the endpoint-specific registers and enable the endpoint to transmit the data.
2. The application must also write the required data to the transmit FIFO for the endpoint.
3. Every time a packet is written into the transmit FIFO by the application, the transfer size for that endpoint is decremented by the packet size. The data is fetched from the memory by the application, until the transfer size for the endpoint becomes 0. After writing the data into the FIFO, the “number of packets in FIFO” count is incremented (this is a 3-bit count, internally maintained by the core for each IN endpoint transmit FIFO. The maximum number of packets maintained by the core at any time in an IN endpoint FIFO is eight). For zero-length packets, a separate flag is set for each FIFO, without any data in the FIFO.
4. Once the data are written to the transmit FIFO, the core reads them out upon receiving an IN token. For every non-isochronous IN data packet transmitted with an ACK handshake, the packet count for the endpoint is decremented by one, until the packet count is zero. The packet count is not decremented on a timeout.
5. For zero length packets (indicated by an internal zero length flag), the core sends out a zero-length packet for the IN token and decrements the packet count field.
6. If there are no data in the FIFO for a received IN token and the packet count field for that endpoint is zero, the core generates an “IN token received when Tx FIFO is empty” (ITTXFE) interrupt for the endpoint, provided that the endpoint NAK bit is not set. The core responds with a NAK handshake for non-isochronous endpoints on the USB.
7. The core internally rewinds the FIFO pointers and no timeout interrupt is generated.
8. When the transfer size is 0 and the packet count is 0, the transfer complete (XFRC) interrupt for the endpoint is generated and the endpoint enable is cleared.

Application programming sequence:

1. Program the OTG_DIEPTSIZx register with the transfer size and corresponding packet count.
2. Program the OTG_DIEPCTLx register with the endpoint characteristics and set the CNAK and EPENA (endpoint enable) bits.
3. When transmitting non-zero length data packet, the application must poll the OTG_DTXFSTSx register (where x is the FIFO number associated with that endpoint) to determine whether there is enough space in the data FIFO. The application can optionally use TXFE (in OTG_DIEPINTx) before writing the data.

- **Generic periodic IN data transfers**

This section describes a typical periodic IN data transfer.

Application requirements:

1. Application requirements 1, 2, 3, and 4 of *Generic non-periodic IN data transfers on page 2808* also apply to periodic IN data transfers, except for a slight modification of requirement 2.
   – The application can only transmit multiples of maximum-packet-size data packets or multiples of maximum-packet-size packets, plus a short packet at the end. To

transmit a few maximum-packet-size packets and a short packet at the end of the transfer, the following conditions must be met:

transfer size[EPNUM] = x × MPSIZ[EPNUM] + sp
(where *x* is an integer ≥ 0, and 0 ≤ sp < MPSIZ[EPNUM])

If (sp > 0), packet count[EPNUM] = *x* + 1
Otherwise, packet count[EPNUM] = *x*;

MCNT[EPNUM] = packet count[EPNUM]

– The application cannot transmit a zero-length data packet at the end of a transfer. It can transmit a single zero-length data packet by itself. To transmit a single zero-length data packet:
– transfer size[EPNUM] = 0

packet count[EPNUM] = 1

MCNT[EPNUM] = packet count[EPNUM]

2. The application can only schedule data transfers one frame at a time.
   – (MCNT – 1) × MPSIZ ≤ XFERSIZ ≤ MCNT × MPSIZ
   – PKTCNT = MCNT (in OTG_DIEPTSIZx)
   – If XFERSIZ < MCNT × MPSIZ, the last data packet of the transfer is a short packet.
   – Note that: MCNT is in OTG_DIEPTSIZx, MPSIZ is in OTG_DIEPCTLx, PKTCNT is in OTG_DIEPTSIZx and XFERSIZ is in OTG_DIEPTSIZx
3. The complete data to be transmitted in the frame must be written into the transmit FIFO by the application, before the IN token is received. Even when 1 word of the data to be transmitted per frame is missing in the transmit FIFO when the IN token is received, the core behaves as when the FIFO is empty. When the transmit FIFO is empty:
   – A zero data length packet would be transmitted on the USB for isochronous IN endpoints
   – A NAK handshake would be transmitted on the USB for interrupt IN endpoints

Internal data flow:

1. The application must set the transfer size and packet count fields in the endpoint-specific registers and enable the endpoint to transmit the data.
2. The application must also write the required data to the associated transmit FIFO for the endpoint.
3. Every time the application writes a packet to the transmit FIFO, the transfer size for that endpoint is decremented by the packet size. The data are fetched from application memory until the transfer size for the endpoint becomes 0.
4. When an IN token is received for a periodic endpoint, the core transmits the data in the FIFO, if available. If the complete data payload (complete packet, in dedicated FIFO

mode) for the frame is not present in the FIFO, then the core generates an IN token received when Tx FIFO empty interrupt for the endpoint.
   – A zero-length data packet is transmitted on the USB for isochronous IN endpoints
   – A NAK handshake is transmitted on the USB for interrupt IN endpoints
5. The packet count for the endpoint is decremented by 1 under the following conditions:
   – For isochronous endpoints, when a zero- or non-zero-length data packet is transmitted
   – For interrupt endpoints, when an ACK handshake is transmitted
   – When the transfer size and packet count are both 0, the transfer completed interrupt for the endpoint is generated and the endpoint enable is cleared.
6. At the “Periodic frame Interval” (controlled by PFIVL in OTG_DCFG), when the core finds non-empty any of the isochronous IN endpoint FIFOs scheduled for the current frame non-empty, the core generates an IISOIXFR interrupt in OTG_GINTSTS.

Application programming sequence:

1. Program the OTG_DIEPCTLx register with the endpoint characteristics and set the CNAK and EPENA bits.
2. Write the data to be transmitted in the next frame to the transmit FIFO.
3. Asserting the ITTXFE interrupt (in OTG_DIEPINTx) indicates that the application has not yet written all data to be transmitted to the transmit FIFO.
4. If the interrupt endpoint is already enabled when this interrupt is detected, ignore the interrupt. If it is not enabled, enable the endpoint so that the data can be transmitted on the next IN token attempt.
5. Asserting the XFRC interrupt (in OTG_DIEPINTx) with no ITTXFE interrupt in OTG_DIEPINTx indicates the successful completion of an isochronous IN transfer. A read to the OTG_DIEPTSIZx register must give transfer size = 0 and packet count = 0, indicating all data were transmitted on the USB.
6. Asserting the XFRC interrupt (in OTG_DIEPINTx), with or without the ITTXFE interrupt (in OTG_DIEPINTx), indicates the successful completion of an interrupt IN transfer. A read to the OTG_DIEPTSIZx register must give transfer size = 0 and packet count = 0, indicating all data were transmitted on the USB.
7. Asserting the incomplete isochronous IN transfer (IISOIXFR) interrupt in OTG_GINTSTS with none of the aforementioned interrupts indicates the core did not receive at least 1 periodic IN token in the current frame.

- **Incomplete isochronous IN data transfers**

This section describes what the application must do on an incomplete isochronous IN data transfer.

Internal data flow:

1. An isochronous IN transfer is treated as incomplete in one of the following conditions:
   a) The core receives a corrupted isochronous IN token on at least one isochronous IN endpoint. In this case, the application detects an incomplete isochronous IN transfer interrupt (IISOIXFR in OTG_GINTSTS).
   b) The application is slow to write the complete data payload to the transmit FIFO and an IN token is received before the complete data payload is written to the FIFO. In this case, the application detects an IN token received when Tx FIFO empty interrupt in OTG_DIEPINTx. The application can ignore this interrupt, as it

eventually results in an incomplete isochronous IN transfer interrupt (IISOIXFR in OTG_GINTSTS) at the end of periodic frame.

The core transmits a zero-length data packet on the USB in response to the received IN token.

2. The application must stop writing the data payload to the transmit FIFO as soon as possible.
3. The application must set the NAK bit and the disable bit for the endpoint.
4. The core disables the endpoint, clears the disable bit, and asserts the endpoint disable interrupt for the endpoint.

Application programming sequence:

1. The application can ignore the IN token received when Tx FIFO empty interrupt in OTG_DIEPINTx on any isochronous IN endpoint, as it eventually results in an incomplete isochronous IN transfer interrupt (in OTG_GINTSTS).
2. Assertion of the incomplete isochronous IN transfer interrupt (in OTG_GINTSTS) indicates an incomplete isochronous IN transfer on at least one of the isochronous IN endpoints.
3. The application must read the endpoint control register for all isochronous IN endpoints to detect endpoints with incomplete IN data transfers.
4. The application must stop writing data to the Periodic Transmit FIFOs associated with these endpoints on the AHB.
5. Program the following fields in the OTG_DIEPCTLx register to disable the endpoint:
   – SNAK = 1 in OTG_DIEPCTLx
   – EPDIS = 1 in OTG_DIEPCTLx
6. The assertion of the endpoint disabled interrupt in OTG_DIEPINTx indicates that the core has disabled the endpoint.
   – At this point, the application must flush the data in the associated transmit FIFO or overwrite the existing data in the FIFO by enabling the endpoint for a new transfer in the next microframe. To flush the data, the application must use the OTG_GRSTCTL register.

- **Stalling non-isochronous IN endpoints**

This section describes how the application can stall a non-isochronous endpoint.

Application programming sequence:

1. Disable the IN endpoint to be stalled. Set the STALL bit as well.
2. EPDIS = 1 in OTG_DIEPCTLx, when the endpoint is already enabled
   – STALL = 1 in OTG_DIEPCTLx
   – The STALL bit always takes precedence over the NAK bit
3. Assertion of the endpoint disabled interrupt (in OTG_DIEPINTx) indicates to the application that the core has disabled the specified endpoint.
4. The application must flush the non-periodic or periodic transmit FIFO, depending on the endpoint type. In case of a non-periodic endpoint, the application must re-enable the other non-periodic endpoints that do not need to be stalled, to transmit data.
5. Whenever the application is ready to end the STALL handshake for the endpoint, the STALL bit must be cleared in OTG_DIEPCTLx.
6. If the application sets or clears a STALL bit for an endpoint due to a SetFeature.Endpoint Halt command or ClearFeature.Endpoint Halt command, the STALL bit must be set or cleared before the application sets up the status stage transfer on the control endpoint.

Special case: stalling the control OUT endpoint

The core must stall IN/OUT tokens if, during the data stage of a control transfer, the host sends more IN/OUT tokens than are specified in the SETUP packet. In this case, the application must enable the ITTXFE interrupt in OTG_DIEPINTx and the OTEPDIS interrupt in OTG_DOEPINTx during the data stage of the control transfer, after the core has transferred the amount of data specified in the SETUP packet. Then, when the application receives this interrupt, it must set the STALL bit in the corresponding endpoint control register, and clear this interrupt.

62.15.7 Worst case response time

When the OTG_HS controller acts as a device, there is a worst case response time for any tokens that follow an isochronous OUT. This worst case response time depends on the AHB clock frequency.

The core registers are in the AHB domain, and the core does not accept another token before updating these register values. The worst case is for any token following an isochronous OUT, because for an isochronous transaction, there is no handshake and the next token could come sooner. This worst case value is 7 PHY clocks when the AHB clock is the same as the PHY clock. When the AHB clock is faster, this value is smaller.

If this worst case condition occurs, the core responds to bulk/interrupt tokens with a NAK and drops isochronous and SETUP tokens. The host interprets this as a timeout condition for SETUP and retries the SETUP packet. For isochronous transfers, the Incomplete isochronous IN transfer interrupt (IISOIXFR) and Incomplete isochronous OUT transfer interrupt (IISOOXFR) inform the application that isochronous IN/OUT packets were dropped.

Choosing the value of TRDT in OTG_GUSBCFG

The value in TRDT (OTG_GUSBCFG) is the time it takes for the MAC, in terms of PHY clocks after it has received an IN token, to get the FIFO status, and thus the first data from the PFC block. This time involves the synchronization delay between the PHY and AHB clocks. The worst case delay for this is when the AHB clock is the same as the PHY clock. In this case, the delay is 5 clocks.

Once the MAC receives an IN token, this information (token received) is synchronized to the AHB clock by the PFC (the PFC runs on the AHB clock). The PFC then reads the data from the SPRAM and writes them into the dual clock source buffer. The MAC then reads the data out of the source buffer (4 deep).

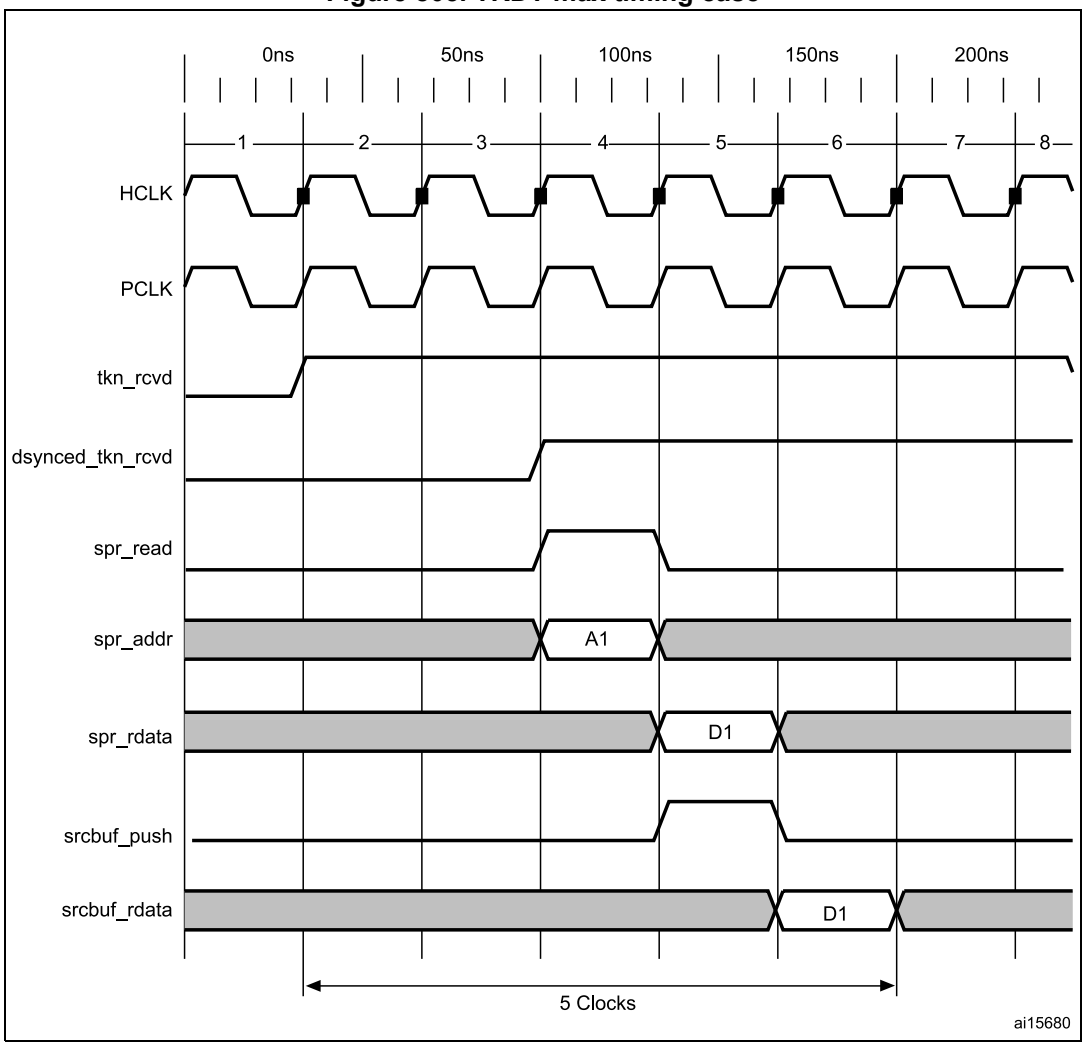
If the AHB is running at a higher frequency than the PHY, the application can use a smaller value for TRDT (in OTG_GUSBCFG).

Figure 805 has the following signals:

- tkn_rcvd: Token received information from MAC to PFC
- dynced_tkn_rcvd: Doubled sync tkn_rcvd, from PCLK to HCLK domain
- spr_read: Read to SPRAM
- spr_addr: Address to SPRAM
- spr_rdata: Read data from SPRAM
- srcbuf_push: Push to the source buffer
- srcbuf_rdata: Read data from the source buffer. Data seen by MAC

To calculate the value of TRDT, refer to *Table 540: TRDT values*.

Figure 805. TRDT max timing case



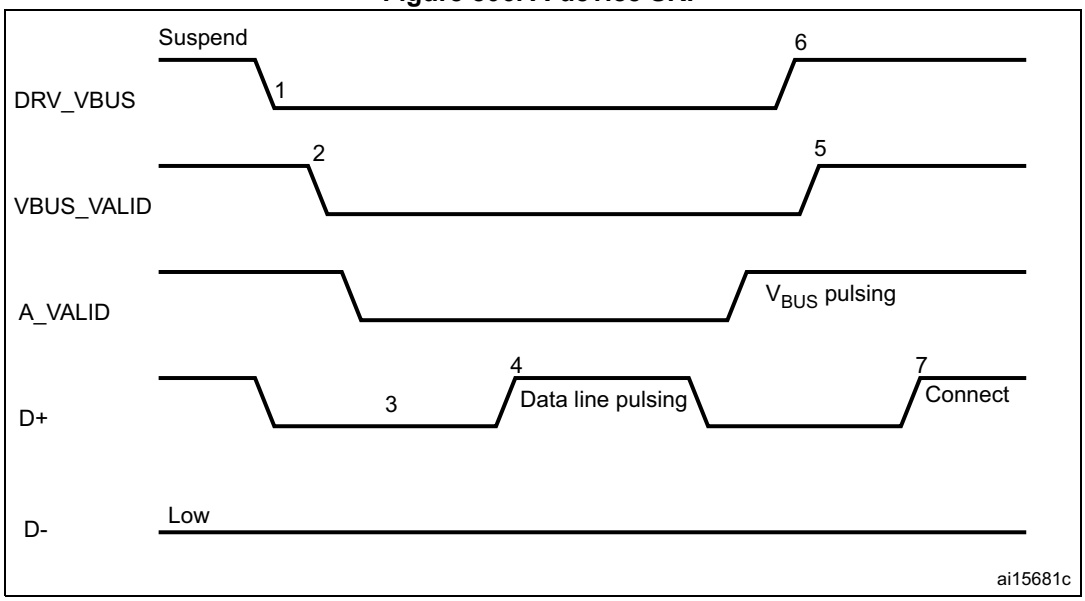
62.15.8 OTG programming model

The OTG_HS controller is an OTG device supporting HNP and SRP. When the core is connected to an “A” plug, it is referred to as an A-device. When the core is connected to a “B” plug it is referred to as a B-device. In host mode, the OTG_HS controller turns off V_{BUS} to conserve power. SRP is a method by which the B-device signals the A-device to turn on V_{BUS} power. A device must perform both data-line pulsing and V_{BUS} pulsing, but a host can detect either data-line pulsing or V_{BUS} pulsing for SRP. HNP is a method by which the B-device negotiates and switches to host role. In Negotiated mode after HNP, the B-device suspends the bus and reverts to the device role.

A-device session request protocol

The application must set the SRP-capable bit in the core USB configuration register. This enables the OTG_HS controller to detect SRP as an A-device.

Figure 806. A-device SRP



1. DRV_VBUS = V_{BUS} drive signal to the PHY
   VBUS_VALID = V_{BUS} valid signal from PHY
   A_VALID = A-peripheral V_{BUS} level signal to PHY
   D+ = Data plus line
   D- = Data minus line

The following points refer and describe the signal numeration shown in the *Figure 806*:

1. To save power, the application suspends and turns off port power when the bus is idle by writing the port suspend and port power bits in the host port control and status register.
2. PHY indicates port power off by deasserting the VBUS_VALID signal.
3. The device must detect SE0 for at least 2 ms to start SRP when V_{BUS} power is off.
4. To initiate SRP, the device turns on its data line pull-up resistor for 5 to 10 ms. The OTG_HS controller detects data-line pulsing.
5. The device drives V_{BUS} above the A-device session valid (2.0 V minimum) for V_{BUS} pulsing.
   The OTG_HS controller interrupts the application on detecting SRP. The session

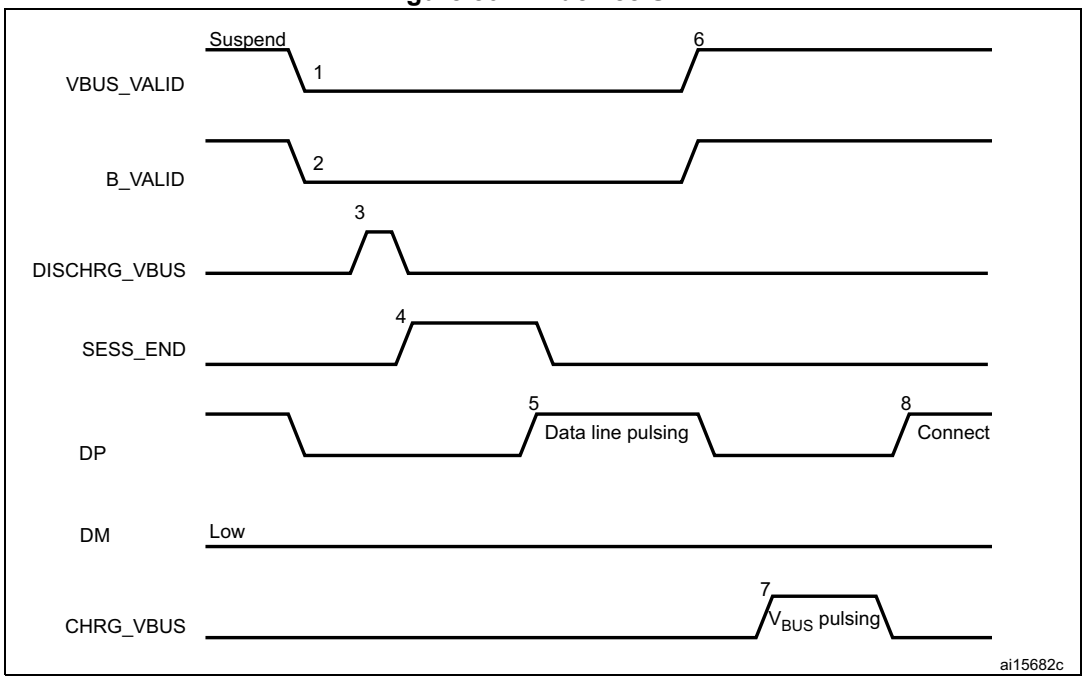
request detected bit is set in Global interrupt status register (SRQINT set in OTG_GINTSTS).

6. The application must service the session request detected interrupt and turn on the port power bit by writing the port power bit in the host port control and status register. The PHY indicates port power-on by asserting the VBUS_VALID signal.
7. When the USB is powered, the device connects, completing the SRP process.

B-device session request protocol

The application must set the SRP-capable bit in the core USB configuration register. This enables the OTG_HS controller to initiate SRP as a B-device. SRP is a means by which the OTG_HS controller can request a new session from the host.

Figure 807. B-device SRP



1. VBUS_VALID = V_{BUS} valid signal from PHY
B_VALID = B-peripheral valid session to PHY
DISCHRG_VBUS = discharge signal to PHY
SESS_END = session end signal to PHY
CHRG_VBUS = charge V_{BUS} signal to PHY
DP = Data plus line
DM = Data minus line

The following points refer and describe the signal numeration shown in the *Figure 807*:

1. To save power, the host suspends and turns off port power when the bus is idle.
The OTG_HS controller sets the early suspend bit in the core interrupt register after 3 ms of bus idleness. Following this, the OTG_HS controller sets the USB suspend bit in the core interrupt register.
The OTG_HS controller informs the PHY to discharge V_{BUS}.
2. The PHY indicates the session's end to the device. This is the initial condition for SRP.
The OTG_HS controller requires 2 ms of SE0 before initiating SRP.
For a USB 1.1 full-speed serial transceiver, the application must wait until V_{BUS} discharges to 0.2 V after BSVLD (in OTG_GOTGCTL) is deasserted. This discharge

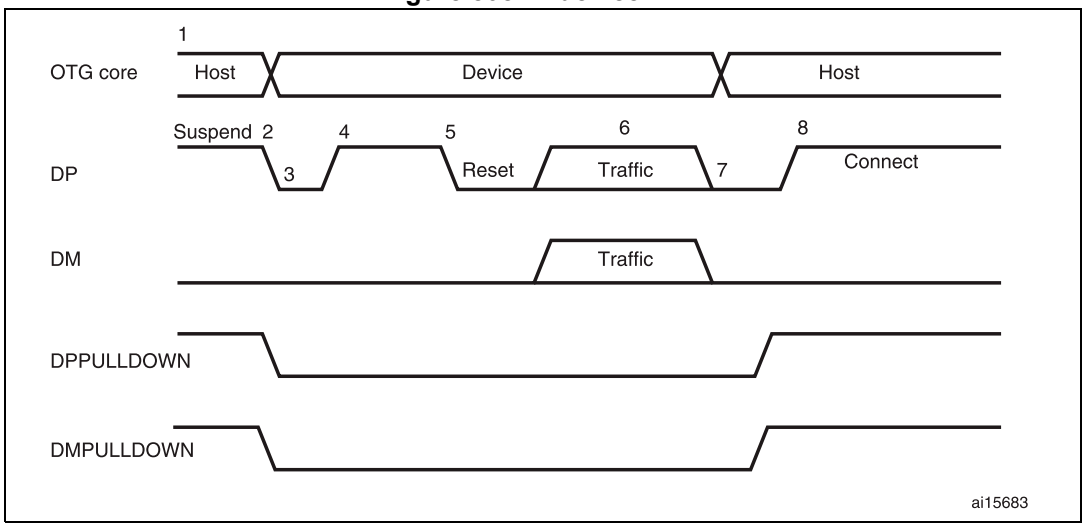
time can be obtained from the transceiver vendor and varies from one transceiver to another.

3. The OTG_HS core informs the PHY to speed up V_{BUS} discharge.
4. The application initiates SRP by writing the session request bit in the OTG control and status register. The OTG_HS controller perform data-line pulsing followed by V_{BUS} pulsing.
5. The host detects SRP from either the data-line or V_{BUS} pulsing, and turns on V_{BUS}. The PHY indicates V_{BUS} power-on to the device.
6. The OTG_HS controller performs V_{BUS} pulsing.
   The host starts a new session by turning on V_{BUS}, indicating SRP success. The OTG_HS controller interrupts the application by setting the session request success status change bit in the OTG interrupt status register. The application reads the session request success bit in the OTG control and status register.
7. When the USB is powered, the OTG_HS controller connects, completing the SRP process.

A-device host negotiation protocol

HNP switches the USB host role from the A-device to the B-device. The application must set the HNP-capable bit in the core USB configuration register to enable the OTG_HS controller to perform HNP as an A-device.

Figure 808. A-device HNP



1. DPPULLDOWN = signal from core to PHY to enable/disable the pull-down on the DP line inside the PHY.
   DMPULLDOWN = signal from core to PHY to enable/disable the pull-down on the DM line inside the PHY.

The following points refer and describe the signal numeration shown in the *Figure 808*:

1. The OTG_HS controller sends the B-device a SetFeature b_hnp_enable descriptor to enable HNP support. The B-device's ACK response indicates that the B-device supports HNP. The application must set host Set HNP enable bit in the OTG control

and status register to indicate to the OTG_HS controller that the B-device supports HNP.

2. When it has finished using the bus, the application suspends by writing the port suspend bit in the host port control and status register.
3. When the B-device observes a USB suspend, it disconnects, indicating the initial condition for HNP. The B-device initiates HNP only when it must switch to the host role; otherwise, the bus continues to be suspended.

   The OTG_HS controller sets the host negotiation detected interrupt in the OTG interrupt status register, indicating the start of HNP.

   The OTG_HS controller deasserts the DM pull down and DM pull down in the PHY to indicate a device role. The PHY enables the OTG_DP pull-up resistor to indicate a connect for B-device.

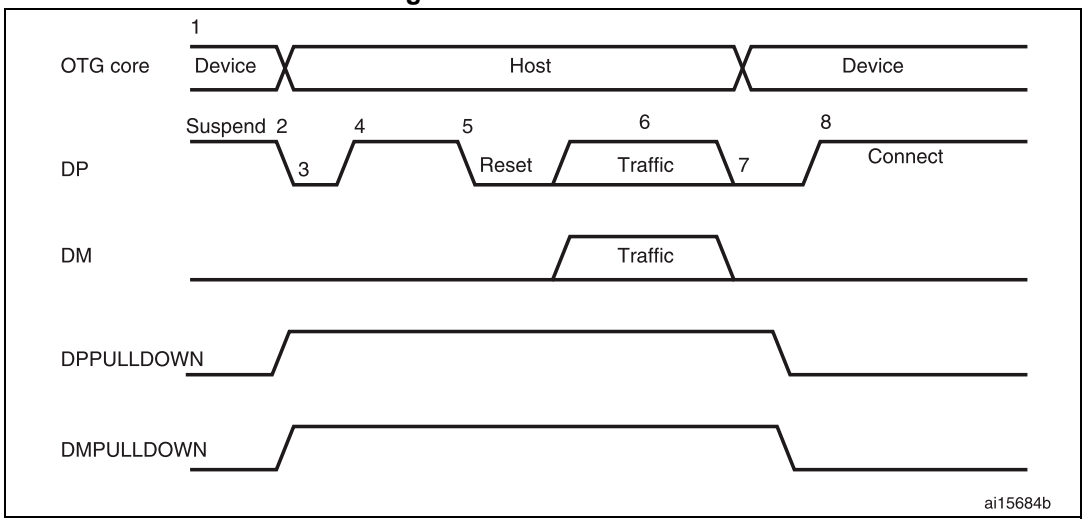
   The application must read the current mode bit in the OTG control and status register to determine device mode operation.
4. The B-device detects the connection, issues a USB reset, and enumerates the OTG_HS controller for data traffic.
5. The B-device continues the host role, initiating traffic, and suspends the bus when done.

   The OTG_HS controller sets the early suspend bit in the core interrupt register after 3 ms of bus idleness. Following this, the OTG_HS controller sets the USB suspend bit in the core interrupt register.
6. In Negotiated mode, the OTG_HS controller detects the suspend, disconnects, and switches back to the host role. The OTG_HS controller asserts the DM pull down and DM pull down in the PHY to indicate its assumption of the host role.
7. The OTG_HS controller sets the connector ID status change interrupt in the OTG interrupt status register. The application must read the connector ID status in the OTG control and status register to determine the OTG_HS controller operation as an A-device. This indicates the completion of HNP to the application. The application must read the Current mode bit in the OTG control and status register to determine host mode operation.
8. The B-device connects, completing the HNP process.

B-device host negotiation protocol

HNP switches the USB host role from B-device to A-device. The application must set the HNP-capable bit in the core USB configuration register to enable the OTG_HS controller to perform HNP as a B-device.

Figure 809. B-device HNP



1. DPPULLDOWN = signal from core to PHY to enable/disable the pull-down on the DP line inside the PHY. DMPULLDOWN = signal from core to PHY to enable/disable the pull-down on the DM line inside the PHY.

The following points refer and describe the signal numeration shown in the *Figure 809*:

1. The A-device sends the SetFeature b_hnp_enable descriptor to enable HNP support. The OTG_HS controller's ACK response indicates that it supports HNP. The application must set the device HNP enable bit in the OTG control and status register to indicate HNP support.

   The application sets the HNP request bit in the OTG control and status register to indicate to the OTG_HS controller to initiate HNP.

2. When it has finished using the bus, the A-device suspends by writing the port suspend bit in the host port control and status register.

   The OTG_HS controller sets the Early suspend bit in the core interrupt register after 3 ms of bus idleness. Following this, the OTG_HS controller sets the USB suspend bit in the core interrupt register.

   The OTG_HS controller disconnects and the A-device detects SE0 on the bus, indicating HNP. The OTG_HS controller asserts the DP pull down and DM pull down in the PHY to indicate its assumption of the host role.

   The A-device responds by activating its OTG_DP pull-up resistor within 3 ms of detecting SE0. The OTG_HS controller detects this as a connect.

   The OTG_HS controller sets the host negotiation success status change interrupt in the OTG interrupt status register, indicating the HNP status. The application must read the host negotiation success bit in the OTG control and status register to determine

host negotiation success. The application must read the current Mode bit in the core interrupt register (OTG_GINTSTS) to determine host mode operation.

3. The application sets the reset bit (PRST in OTG_HPRT) and the OTG_HS controller issues a USB reset and enumerates the A-device for data traffic.
4. The OTG_HS controller continues the host role of initiating traffic, and when done, suspends the bus by writing the port suspend bit in the host port control and status register.
5. In Negotiated mode, when the A-device detects a suspend, it disconnects and switches back to the host role. The OTG_HS controller deasserts the DP pull down and DM pull down in the PHY to indicate the assumption of the device role.
6. The application must read the current mode bit in the core interrupt (OTG_GINTSTS) register to determine the host mode operation.
7. The OTG_HS controller connects, completing the HNP process.

63 Ethernet (ETH): media access control (MAC) with DMA controller

63.1 Ethernet introduction

The Ethernet peripheral enables the devices to transmit and receive data over Ethernet in compliance with the IEEE 802.3-2002 standard.

The Ethernet provides a configurable, flexible peripheral to meet the needs of various applications and customers. It supports two industry standard interfaces to the external physical layer (PHY): the default media independent interface (MII) defined in the IEEE 802.3 specifications and the reduced media independent interface (RMII). It can be used in number of applications such as switches and network interface cards.

In addition to the default interfaces defined in the IEEE 802.3 specifications, the Ethernet peripheral supports several industry standard interfaces to the PHY. It is compliant with the following standards:

- IEEE 802.3-2008 for Ethernet MAC and media independent interface (MII)
- IEEE 1588-2008 for precision networked clock synchronization (PTP)
- IEEE 802.3az-2010 for Energy Efficient Ethernet (EEE)
- AMBA 2.0 for AHB master and AHB slave ports
- RMII specification version 1.2 from RMII consortium

63.2 Ethernet main features

Ethernet peripheral embeds a dedicated DMA for direct memory interface, a media access controller (MAC) and a PHY interface block supporting several formats.

63.2.1 MAC core features

Interfaces

- Separate transmission, reception, and control interfaces to the application
- 32-bit data transfer interface on the application side
- 10, 100 Mbps data transfer rates with the following PHY interfaces:
  - IEEE 802.3-compliant MII interface to communicate with an external Fast Ethernet PHY
  - RMII interface to communicate with an external Fast Ethernet PHY
- MDIO (Clause 22 and Clause 45) master interface for PHY device configuration and management
- Supports mandatory network statistics with RMON counters (RFC2819/RFC2665)

Main operations

- Support of both full-duplex and half-duplex operations:
  - CSMA/CD protocol for half-duplex operation
  - IEEE 802.3x flow control for full-duplex operation
  - Optional forwarding of received pause control frames to the user application in full-duplex operation
  - Back-pressure in half-duplex operation
  - Automatic transmission of zero-quanta pause frame on deassertion of flow control input in full-duplex operation
- Full-duplex flow control operations (IEEE 802.3x Pause packets and Priority flow control)
- Preamble and start-of-frame data (SFD) insertion in Transmit mode, and deletion in Receive paths
- Automatic CRC and pad generation controllable on a per-frame basis
- Programmable packet length to support Standard or up to 16 Kbyte Jumbo Ethernet packets
- Programmable Inter Packet Gap
- Layer 3/Layer 4 checksum offload for received packets
- Calculation and insertion of IPv4 header checksum and TCP, UDP, or ICMP checksum in frames transmitted in Store-and-Forward mode
- Two sets of FIFOs: a 2048-byte Transmit FIFO with programmable threshold capability, and a 2048-byte Receive FIFO with a configurable threshold
- Store-and-Forward mechanism or threshold mode (cut-through) for transmission to the MAC
- Programmable Rx queue threshold (or cut-through) mode
- Internal loopback from Tx to Rx on MII for debugging.

VLAN management

- Source Address field insertion or replacement, as well as VLAN insertion, replacement, and deletion in transmitted packets with per-packet or static-global control
- Insertion, replacement or deletion of up to two VLAN tags
- IEEE 802.1Q VLAN tag detection and possibility to delete the VLAN tags in received packets
- Stripping of up to two VLAN tags and providing the tags in the status.

Packet filtering

- Flexible address filtering modes:
  - 3 additional 48-bit perfect destination address (DA) filters with masks for each byte
  - 3 additional 48-bit source address (SA) comparison check with masks for each byte
  - 64 bit Hash filter for multicast and unicast (DA) addresses
  - Option to pass all multicast addressed packets
  - Promiscuous mode to pass all packets without any filtering for network monitoring
  - Pass all incoming packets (as per filter) with a status report
- Additional packet filtering:
  - VLAN tag-based: perfect match and Hash-based filtering with filtering based either on the outer or inner VLAN tag
  - Layer 3 and Layer 4-based: TCP or UDP over IPv4 or IPv6

IEEE 1588-2008/PTPv2

- Ethernet packet time-stamping as described in IEEE 1588-2002 and IEEE 1588-2008 specifications (64-bit timestamps given in the Tx or Rx status of PTP packet). Both one-step and two-step timestamping is supported in Tx direction.
- Flexibility to control the pulse-per-second (PPS) output signal (eth_ptp_pps_out)

Low-power modes

- Standard IEEE 802.3az-2010 for Energy Efficient Ethernet in MII PHYs.
- Module to detect remote wakeup packets and AMD Magic packets

63.2.2 DMA features

The DMA block exchanges data between the peripheral and the system memory. DMA transfers are driven by software descriptors structure. The application can use a set of registers (see *Section 63.11.2: Ethernet DMA registers*) to control the DMA operations. The DMA block supports the following features:

- 32-bit data transfers
- Separate DMA in Transmit path and receive paths
- Optimization for packet-oriented DMA transfers with packet delimiters
- Byte-aligned addressing for data buffer support
- Dual-buffer (ring) descriptor support
- Descriptor architecture allowing large blocks of data transfer with minimum CPU intervention (each descriptor can transfer up to 32 Kbytes of data)
- Comprehensive status reporting normal operation and transfer errors
- Individual programmable burst length for Tx DMA and Rx DMA engines for optimal host bus utilization
- Programmable interrupt options for different operational conditions
- Per-packet Transmit or Receive Complete Interrupt control
- Round-robin or fixed-priority arbitration between the Receive and Transmit engines
- Start and Stop modes
- Separate ports for host control (AHB) access and host data interface

- Tx DMA channel with TCP Segmentation Offload (TSO) feature enabled

63.2.3 Bus interface features

AHB master interface

The AHB master interface features as the following:

- Interfaces with the application through AHB
- Little-endian mode
- 32-bit data on the AHB master port
- Split, Retry, and Error AHB responses
- AHB 1K boundary burst splitting
- Software-selected type of AHB burst (fixed burst, indefinite burst, or mix of both)

The AHB master interface does not generate the following:

- Wrap burst
- Locked or protected transfers

AHB slave interface

The AHB slave interface supports the following features:

- Interfaces with the application through AHB
- Little-endian mode
- AHB slave interface (32-bit) for CSR access
- All AHB burst types

The AHB slave interface does not generate the following responses:

- Split
- Retry
- Error

63.3 Ethernet pins and internal signals

Table 543 lists the Ethernet inputs and output signals connected to package pins or balls. Active pins depend on the PHY type selected (MII or RMII) and on the device configuration.

Table 544 shows the internal Ethernet signals.

Table 543. Ethernet peripheral pins

Port name	Digital port type	Description
ETH_COL	Input	Collision detection signal, MII only.
ETH_CRS	input	Carrier sense signal, MII only
ETH_REF_CLK	Input	RMII reference clock
ETH_RX_CLK	Input	MII timing reference for Rx data transfers
ETH_RXD[3:0]	Input	Receive data. 4 pins for MII, 2 for RMII.

Table 543. Ethernet peripheral pins (continued)

Port name	Digital port type	Description
ETH_RX_DV	Input	Receive data valid
ETH_CRS_DV	Input	RMII: Carrier Sense (CRS) and RX_Data Valid (RX_DV) multiplexed on alternate clock cycles. In 10 Mbit/s mode, it alternates every 10 clock cycles.
ETH_RX_ER	Input	Receive error
ETH_TX_CLK	Input	MII timing reference for Tx data transfers
ETH_TXD[3:0]	Output	Transmit data. 4 pins for MII, 2 for RMII.
ETH_TX_EN	Output	Transmit data enable
ETH_TX_ER	Output	Transmit error
ETH_MDC	Output	Management data clock
ETH_MDIO	Input/output	Management data
ETH_PHY_INTN	Input	PHY interrupt
ETH_PPS_OUT	Output	PTP pulse-per-second output

Table 544. Ethernet internal input/output signals

Signal name	Signal type	Description
eth_hclk	Digital input	AHB clock
eth_sbd_intr_it	Digital output	Main Ethernet interrupt
lpi_intr_o	Digital output	Sideband signal generated when the transmitter or receiver enters or exits the LPI state.
pmt_intr_o	Digital output	Sideband signal generated when a valid remote wakeup packet is received
eth_mii_tx_clk	Digital input	MII Tx kernel clock
eth_mii_rx_clk	Digital input	MII Rx kernel clock
eth_rmii_ref_clk	Digital input	RMII reference kernel clock
eth_ptp_pps_out	Digital output	PTP pulse-per-second signal
mac_speed_o[1:0]	Digital output	MAC speed information used by the RCC
clk_ptp_ref_i	Digital input	PTP reference clock input. This input is connected to eth_hclk clock.
eth_ptp_trig[4:1]	Digital input	Trigger input for auxiliary snapshots of the PTP system time

63.4 Ethernet architecture

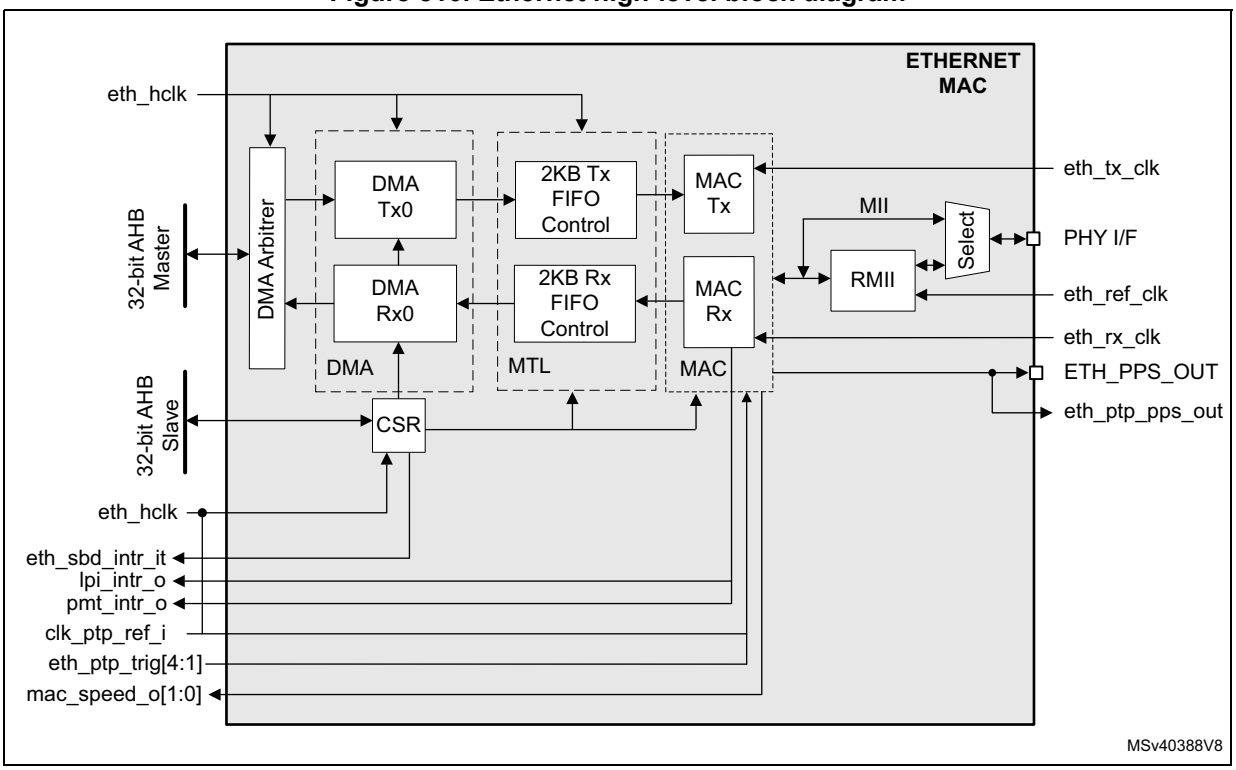
The Ethernet peripheral is composed of 4 main functional modules:

- **The control and status register module (CSR)** that controls the registers access through AHB 32-bit slave interface
- The direct memory access interface (DMA)

  This is the logical DMA module with one physical channel for reception and 1 for transmission. It controls the data transfers between MAC and system memory through the AMBA AHB 32-bit master interface.
- **The media access control module (MAC)** in charge of implementing the Ethernet protocol
- **The MAC transaction layer (MTL)** in charge of controlling the data flow between application and MAC.

A protocol adaption module is added to support the RMII PHY Media Independent Interfaces.

Figure 810. Ethernet high-level block diagram



1. For a definition of the internal signals, refer to *Table 544*.
2. Refer to RCC chapter "Clock distribution for Ethernet" for a detailed description of the Ethernet clock architecture.

63.4.1 DMA controller

The DMA has independent Transmit (Tx) and Receive (Rx) engines. The Tx engine transfers data from the system memory to the MAC Transaction Layer (MTL), whereas the Rx engine transfers data from the device port (PHY) to the system memory.

The controller uses descriptors to efficiently move data from source to destination with minimal application CPU intervention. The DMA is designed for packet-oriented data transfers such as packets in Ethernet. The controller can be programmed to interrupt the application CPU for situations such as Packet Transmit and Receive Transfer completion, and other normal or error conditions.

DMA data structures

The DMA and the application communicate through the following two data structures:

- Control and Status registers (CSR)
- Descriptor lists and data buffers

The DMA transfers the data packets received by the MAC to the Rx buffer in system memory and Tx data packets from the Tx buffer in the system memory. The descriptors that reside in the system memory contain the pointers to these buffers.

The base address of each list is written to the respective Tx and Rx registers: *Channel Tx descriptor list address register (ETH_DMACTXDLAR)*) and *Channel Rx descriptor list address register (ETH_DMACRXDLAR)*.

The descriptor list is forward linked and the next descriptor is always considered at a fixed offset to the current one. The number of descriptors in the list is programmed in the respective Tx/Rx, *Channel Tx descriptor ring length register (ETH_DMACTXRLR)* and *Channel Rx descriptor ring length register (ETH_DMACRXRLR)*.

Once the DMA processes the last descriptor in the list, it automatically jumps back to the descriptor in the List address register to create a descriptor ring. The descriptor lists reside in the physical memory address space of the application. Each descriptor can point to a maximum of two buffers. This enables two buffers to be used and physically addressed, rather than contiguous buffers in memory.

A data buffer resides in the application physical memory space and consists of an entire packet or part of a packet, but cannot exceed a single packet. Buffers contain only data. The buffer status is saved in the descriptor. Data chaining refers to packets that span multiple data buffers. However, a single descriptor cannot span multiple packets. The DMA skips to the data buffer of next packet when EOP is detected.

Descriptors are specified in *Section 63.10: Descriptors*.

DMA arbitration

The DMA module incorporates an arbiter that performs the arbitration between the Tx and Rx channels accesses from the AHB master interface. The following two types of arbitrations are supported and can be selected through *DMA mode register (ETH_DMAMR)*:

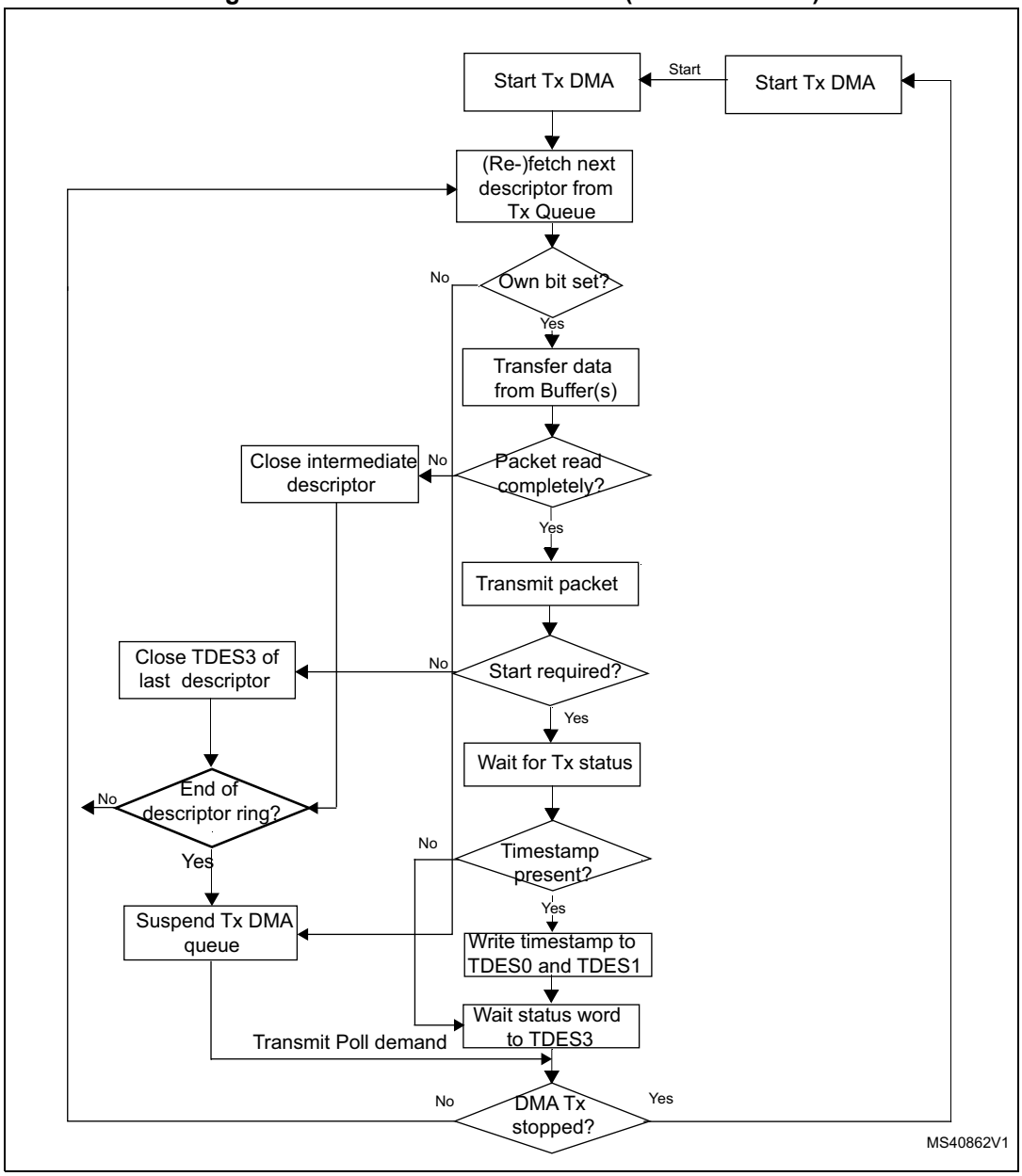
- Round-robin arbitration**:** the arbiter allocates the data bus between Rx and Tx in ratio set by Bits [14:12] of ETH_DMAMR.
- Fixed-priority arbitration**:** by default Rx DMA always gets priority over Tx DMA for data access. Setting bit 11 of ETH_DMAMR register gives priority to the Tx DMA.

DMA transmission in default mode

The Tx DMA engine in default mode proceeds as follows:

1. The application sets up the Transmit descriptor (TDES0–TDES3) and sets the Own bit (TDES0[31]) after setting up the corresponding data buffer(s) with Ethernet Packet data.
2. The application shifts the Descriptor tail pointer offset value of the Transmit channel.
3. The DMA fetches the descriptor from the application memory.
4. If the DMA detects one of the following conditions, the transmission from that channel is suspended, bit 2 and 16 of the corresponding DMA channel Status register are set, and the Tx engine proceeds to step 11:
   – The descriptor is flagged as owned by the application (TDES3 [31] = 0).
   – The descriptor tail pointer is equal to the current descriptor pointer in Ring Descriptor list mode.
   – An error condition occurs.
5. If the acquired descriptor is flagged as owned by the DMA (TDES3[31] = 1), the DMA decodes the Transmit Data Buffer address from the acquired descriptor.
6. The DMA fetches the Transmit data from the system memory and transfers the data to the MTL for transmission.
7. If an Ethernet packet is stored over data buffers in multiple descriptors, the DMA closes the intermediate descriptor and fetches the next descriptor. Steps 3 through 7 are repeated until the end-of-Ethernet-packet data is transferred to the MTL.
8. When packet transmission is complete, if IEEE 1588 timestamp feature was enabled for the packet (as indicated in the Tx status), the timestamp value obtained from MTL is written to the Tx descriptor (TDES0 and TDES1) that contains the EOP buffer. The status information is written to this Tx descriptor (TDES3). The application now owns this descriptor because the Own bit is cleared during this step. If the timestamp feature is disabled for this packet, the DMA does not alter TDES0 and TDES1 contents.
9. Bit 0 of *Channel status register (ETH_DMACSR)*) is set after completing transmission of a packet that has Interrupt on Completion (TDES2[31]) set in its Last Descriptor. The DMA engine returns to step 3.
10. In the Suspend state, the DMA tries to acquire the descriptor again (and thereby return to step 3). A poll demand command is triggered by writing any value to the *Channel Tx descriptor tail pointer register (ETH_DMACTXDTPR)* when it receives a Transmit Poll demand and the Underflow Interrupt Status bit is cleared. If the application stopped the DMA by clearing Bit 0 of Transmit control register of corresponding DMA channel, the DMA enters the Stop state.

Figure 811. DMA transmission flow (standard mode)



DMA transmission in OSP (Operate on Second Packet) mode

In Run state, if bit 4 is set in the *Channel transmit control register (ETH_DMACTXCR)*), the Transmit process can simultaneously acquire two packets without closing the Status descriptor of the first packet. While the Transmit process completes the first packet transfer, it immediately polls the Transmit descriptor list for the second packet. If the second packet is valid, the Transmit process transfers this packet before writing the status information of the first packet.

In OSP mode, DMA transmission in the Run state operates as described in the following sequence:

1. The DMA executes steps 1 to 7 of the DMA transmission sequence in default mode (see *Section : DMA transmission in default mode*).
2. The DMA fetches the next descriptor without closing previous packet last descriptor.
3. If the DMA owns the acquired descriptor, the DMA decodes the transmit buffer address in this descriptor. If the DMA does not own the descriptor, the DMA goes into Suspend mode and jumps to step 7.
4. The DMA fetches the Transmit packet from the system memory and transfers the packet to the MTL until the EOP data is transferred, closing the intermediate descriptors if this packet is split across multiple descriptors.
5. The DMA waits for the packet transmission status and timestamp of previous packet. When the status is available, the DMA writes the timestamp to TDES0 and TDES1 if such timestamp was captured (as indicated by a status bit). The DMA writes the status, with a cleared Own bit, to the corresponding TDES3, thus closing the descriptor. If Timestamp feature is not enabled for the previous packet, the DMA does not alter the contents of TDES2 and TDES3.
6. The Transmit interrupt is set (if enabled). The DMA fetches the next descriptor and proceeds to step 3 (when Status is normal). If the previous transmission status shows an underflow error, the DMA goes into Suspend mode (step 7).
7. In Suspend mode, if a pending status and timestamp are received from the MTL, the DMA performs the following operations:

   a) The DMA writes the timestamp (if enabled for the current packet) to TDES2 and TDES3.

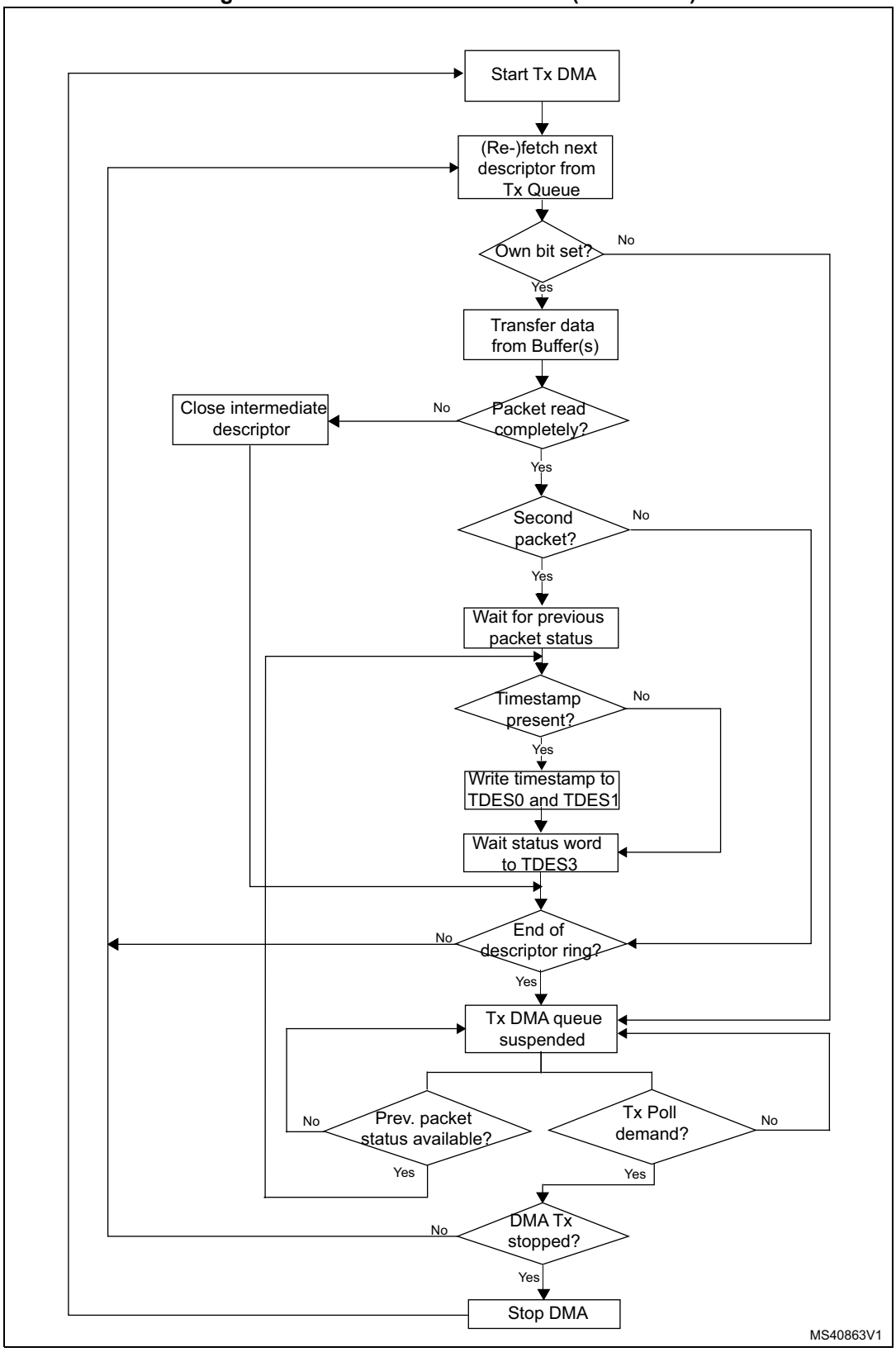
   a) The DMA writes the status to the corresponding TDES3.

   a) The DMA sets the relevant interrupts and returns to Suspend mode.

   If no status is pending and the application stopped the DMA by clearing bit 0 of Transmit Control Register of corresponding DMA channel, the DMA enters the Stop state.
8. The DMA can exit Suspend mode and enter the Run state (it goes either to step 1 or to step 2 depending on pending status) only after receiving a Transmit Poll demand in Transmit Descriptor Tail Pointer register of corresponding channel.

A description of the basic DMA transmission flow in OSP mode in given in *Figure 813: Receive DMA flow*.

Figure 812. DMA transmission flow (OSP mode)



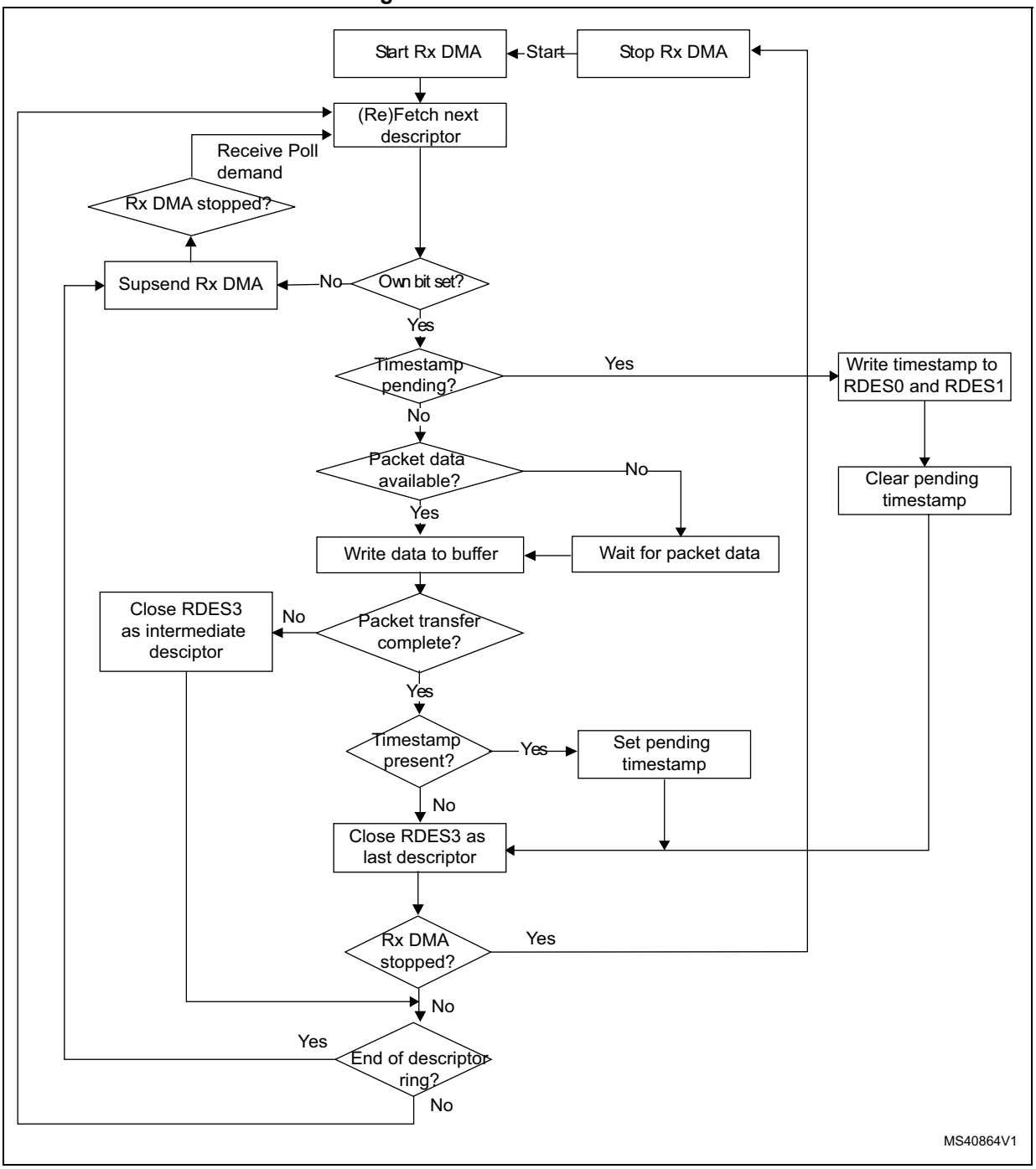
DMA reception

In the Receive path, the DMA reads a packet from the MTL receive queue and writes it to the packet data buffers of the corresponding DMA channel.

The reception sequence for Rx DMA engine is as follows (see also *Figure 813: Receive DMA flow*):

1. The application sets up the Rx descriptors (RDES0-RDES3) and the Own bit (RDES3[31]). The application must set the correct value in the Receive descriptor tail pointer register of corresponding DMA channel.
2. When bit 0 of *Channel receive control register (ETH_DMACRXCR)*) is set, the DMA enters the Run state. The DMA looks for free descriptors based on the Rx Current Descriptor and Descriptor tail pointer register values. If there are no free descriptors, the DMA channel enters the Suspend state and goes to step 11.
3. The DMA fetches the next available descriptor in the ring and decodes the receive data buffer address from acquired descriptors.
4. If IEEE 1588 timestamping is enabled and the timestamp is available for the previous packet, the DMA writes the timestamp (if available) to the RDES0 and RDES1 of current descriptor and sets the CTXT field (RDES3[30]).
5. The DMA processes the incoming packets and stores them in the data buffers of acquired descriptor.
6. If the current packet transfer is not complete, the DMA closes the current descriptor as intermediate and goes to step 10.
7. The DMA retrieves the status of the Receive frame from the MTL and writes the status word to current descriptor with the Own bit cleared and the Last descriptor bit set.
8. The DMA writes the Frame Length to RDES3 and the VLAN tag to RDES0. The DMA also writes the MAC control frame opcode, OAM control frame code, and extended status information (if available) to RDES1 of the last descriptor.
9. The DMA stores the timestamp (if available). The DMA writes the context descriptor after the last descriptor for the current packet (in the next available descriptor).
10. If more descriptors are available in the Rx DMA descriptor ring, go to step 3, otherwise go to the Suspend state (step 11).
11. The Receive DMA exits the Suspend state when a Receive Poll demand is given and the application increments the channel Receive tail pointer register. The engine proceeds to step 2 and fetches again the next descriptor.

Figure 813. Receive DMA flow



63.4.2 MTL

The MAC Transaction Layer (MTL) provides the FIFO memory interface to buffer and regulate the packets between the application system memory and the MAC. It also enables the data to be transferred between the application clock and MAC clock domains. The MTL layer features two 32-bit wide data paths: the Transmit path and the Receive Path.

- Transmit path

The application or internal DMA pushes the Ethernet packets read from the application or system memory into the Tx FIFO. The packet is then popped out and transferred to the MAC when the queue threshold is reached (threshold mode) or complete packet is in the queue (store-and-forward mode). When EOP is transferred, the status of the transmission is taken from the MAC and transferred back to the application or internal DMA. The Tx queue size is 2048 bytes.

- Receive path

  The MTL Rx module receives the packets from the MAC and pushes them into the Rx queue. The status (fill level) of the queue is indicated to the application or to DMA when it crosses the configured Receive threshold (RTC bits[1:0] defined in *Rx queue operating mode register (ETH_MTLRXQOMR)*), or when the complete packet was received. The MTL also indicates the queue fill level so that the DMA can initiate preconfigured burst transfers towards the master interface. The Rx queue size is 2048 bytes.

63.4.3 MAC

The MAC is responsible of the Ethernet protocol processing.In Transmission mode, it receives data from MTL before transferring it to the PHY interface. In Reception mode, the MAC receives data from the PHY interface before transferring them to the Rx FIFO of the MTL module.

This section briefly describes transmission and reception sequences.

MAC transmission

The transmission sequence is as follows:

1. Transmission is initiated when the MTL application pushes in data with the SOP (Start of packet) signal asserted.
2. When the SOP signal is detected, the MAC accepts the data and begins the transmission to the MII.
3. When the EOP (End of packet) is transferred to the MAC, the MAC does one of the following:
   - The MAC completes the normal transmission and provides the transmission status to the MTL.
   - If a normal collision (in Half-duplex mode) occurs during transmission, the MAC provides the Transmit status to the MTL, with the Retry bit set. The MAC provides the Retry request till one of the following is true:

     the packet was successfully transmitted;

     the maximum number of Retry requests expires. In this case, the MAC aborts the packet transmission with Excessive Collision Transmit status. The MAC accepts and drops all further data until the next SOP is received. The MTL block should retransmit the same packet from SOP when a Retry request (in the Status) is observed from the MAC.
   - If any one of the following event happens, the MAC aborts the packet transmission:

     no carrier (Half-duplex mode)

     loss of carrier (Half-duplex mode)

     excessive deferral (Half-duplex mode)

     late collisions (Half-duplex mode)

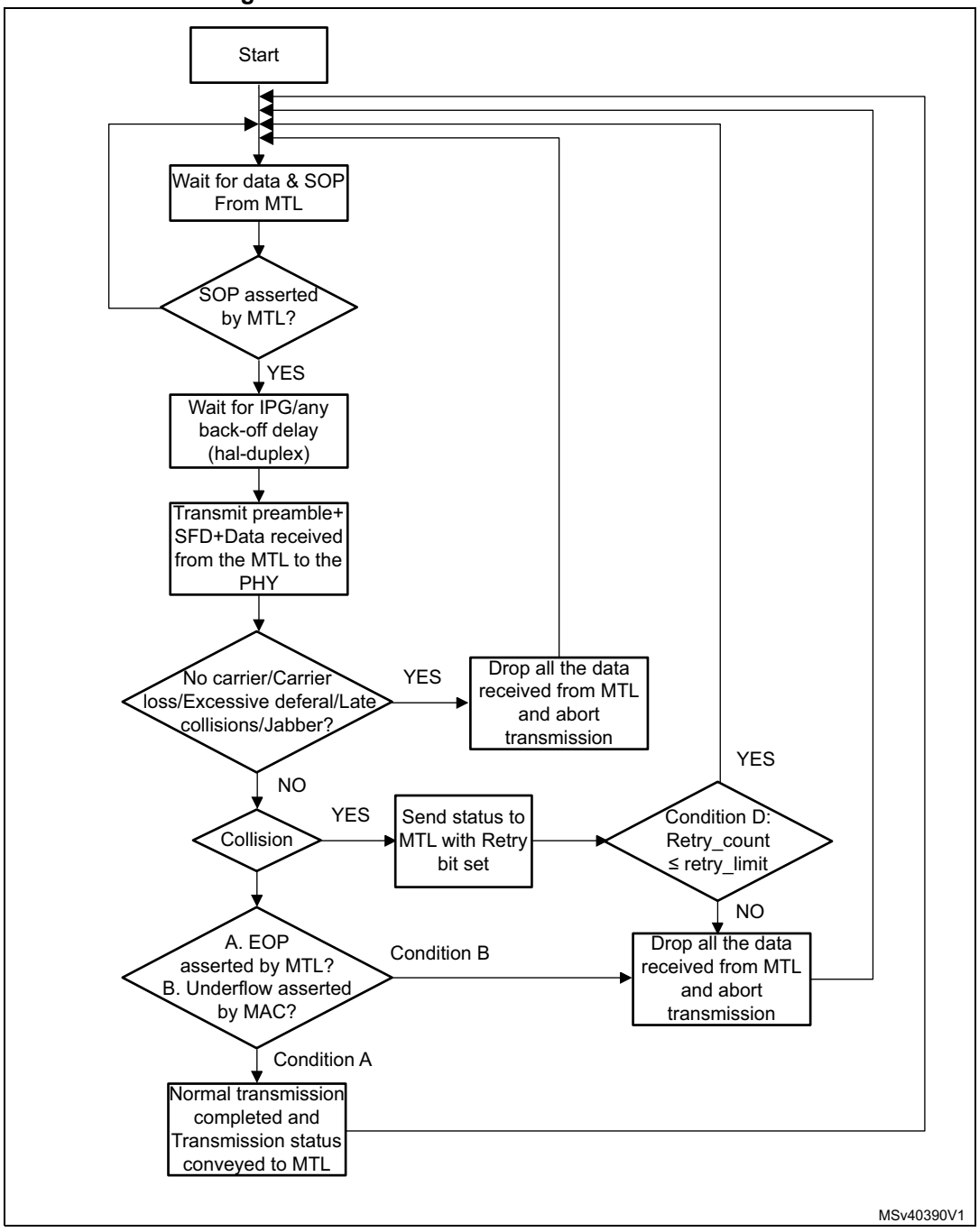
jabber

the MAC accepts and drops all further data until the next SOP is received.

4. The MAC issues an underflow status if the MTL is not able to provide the data continuously during the transmission. The MAC accepts and drops all further data until the next SOP is received.
5. During the normal transfer of a packet from MTL, if the MAC receives a SOP without getting an EOP for the previous packet, it ignores the SOP and considers the new packet as continuation of the previous packet.

Figure 814: Overview of MAC transmission flow illustrates the MAC transmission process flow.

Figure 814. Overview of MAC transmission flow



MAC reception

A receive operation is initiated when the MAC detects an SFD on MII. The MAC strips the preamble and SFD before proceeding to process the packet. The header fields are checked for filtering and the FCS field used to verify the CRC for the packet. The received packet is stored in a shallow buffer until the address filtering is performed. The packet is dropped in the MAC if it fails the address filter.

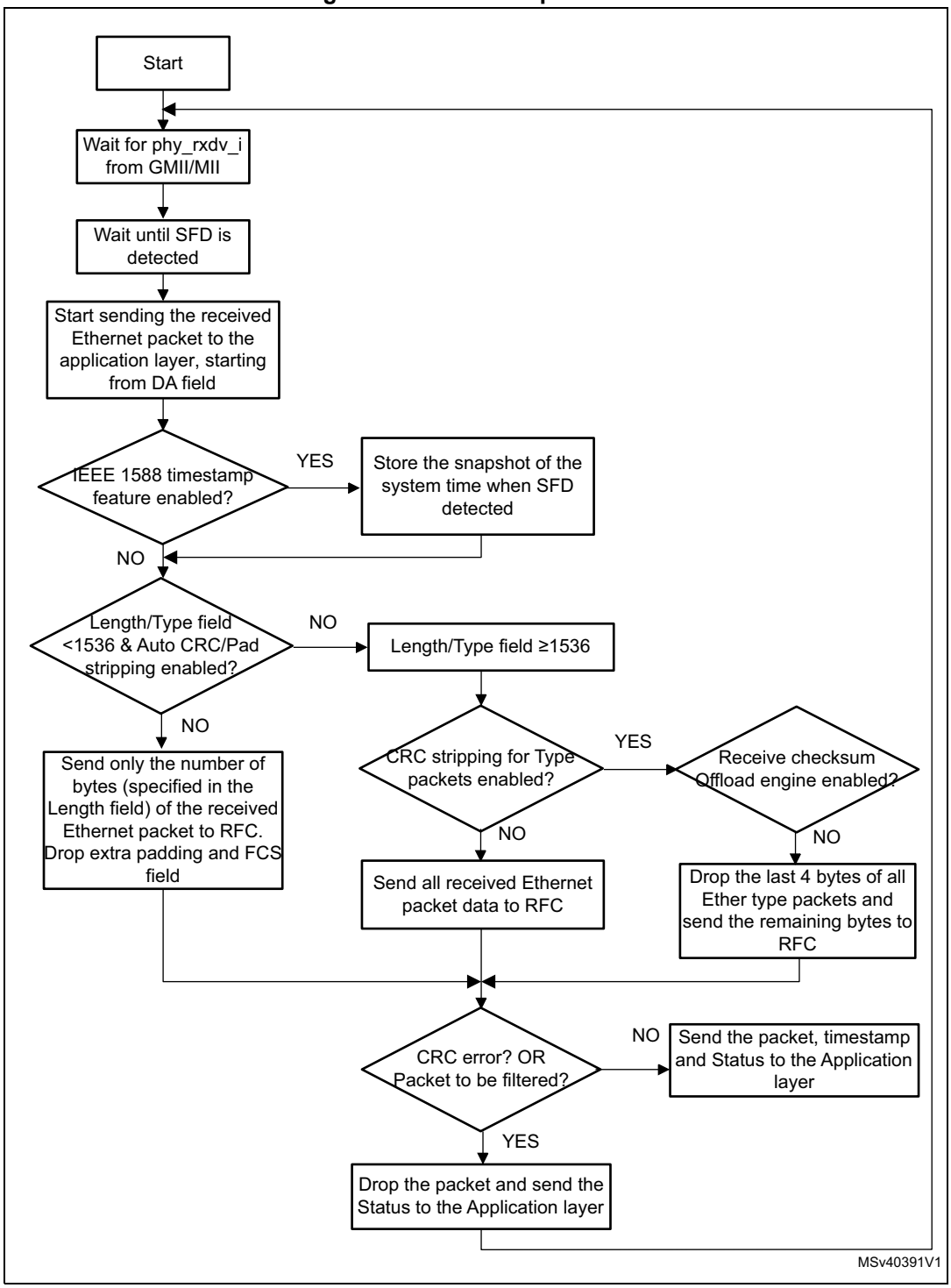
The reception sequence is as follows:

1. When the receive data valid signal (RxDV) of MII becomes active, the Receive State Machine (RSM) starts looking for the SFD field (0xD nibble).

   The state machine drops received packets until it detects SFD.
2. When SFD is detected, the state machine starts sending the data of Ethernet packet to the RPC module, beginning with the first byte following the SFD (destination address).
3. If IEEE 1588 timestamp feature is enabled, the MAC takes a snapshot of the system time at which SFD of any packet is detected on MII. If this packet is not dropped during MAC filtering, the timestamp is passed to the application. The MAC converts the received nibble data into bytes and forwards the valid packet data to the RFC module.
4. The Receive State Machine decodes the Length/Type field of the Ethernet packet being received.

   If the Length/Type field is less than 1,536 and if the MAC is programmed for the Auto CRC/Pad Stripping (bit 20 of the *Operating mode configuration register (ETH_MACCR)*), the state machine sends the packet data up to the count specified in the Length/Type field and starts dropping bytes (including the FCS field). The state machine decodes the Length/Type field and checks for the Length interpretation.
5. If the Length/Type field is greater than or equal to 1,536, the RPE module sends all received Ethernet packet data to the RFC module if you have not enabled the CRC stripping for Type packet in Bit 21 of the *Operating mode configuration register (ETH_MACCR)*. However, if the CRC stripping has been enabled for Type packets and not enabled the Receive Checksum Offload Engine, the MAC strips and drops the last 4 bytes of all packets of ether type before forwarding the packets to the application.
6. By default, the MAC is programmed for watchdog timer to be enabled, that is, packets above 2,048 (10,240 if Jumbo Packet is enabled) bytes (DA + SA + LT + DATA + PAD + FCS) are cut off at the RPE module. In addition, you can use a programmable watchdog timer (bit 16 of *Watchdog timeout register (ETH_MACWTR)*) to override the fixed timeout of 2,048 or 10,240 bytes. You can disable the watchdog timer by programming bit 19 of *Operating mode configuration register (ETH_MACCR)*. However, even if the watchdog timer is disabled, a packet greater than 32 Kbytes is cut off and a watchdog timeout status is given.

Figure 815. MAC reception flow



63.5 Ethernet functional description: MAC

63.5.1 Double VLAN processing

The Ethernet peripheral supports the double VLAN (Virtual LAN) tagging feature in which the MAC can process up to two VLAN tags (inner and outer).

The MAC supports the following:

- Insertion, replacement, or deletion of up to two VLAN tags in the Transmit path
- Packet filtering and stripping based on any one of the two VLAN Tags in the Receive path. Stripping and providing up to two VLAN Tags in the Receive path as a part of the Receive status

Transmit path

Table 545: Double VLAN processing features in Tx path describes the features supported by the MAC on the Transmit side.

Table 545. Double VLAN processing features in Tx path

Feature	Description
Support for C-VLAN and S-VLAN Tag types	The inner or outer VLAN tag can be of C-VLAN and S-VLAN type. The VLAN type is specified through the CSVL bit of *VLAN inclusion register (ETH_MACVIR)* and *Inner VLAN inclusion register (ETH_MACIVIR)*, respectively. The Ethernet peripheral supports processing of any sequence of outer and inner VLAN tags. However, it does not support the C-VLAN S-VLAN sequence. The MAC does not check whether the packet provided by the application has a valid sequence of the VLAN Tag types or the insertion or replacement operation results in invalid sequence of VLAN Tag type. Therefore, the application must provide correct sequence of VLAN Tag types and program the MAC in such a way that it results in correct sequence of VLAN Tag types in the transmitted packet. The application must ensure the following: – The inner tag should not be S-VLAN when outer C-VLAN Tag insertion is enabled. – The outer tag should not be C-VLAN when inner S-VLAN Tag insertion is enabled. – The inner tag should not be S-VLAN when outer tag should be replaced with C-VLAN. – The outer tag should not be C-VLAN when inner tag should be replaced with S-VLAN.
VLAN Tag deletion	VLAN tag deletion can be enabled for outer or inner tag through VLC field in the *VLAN inclusion register (ETH_MACVIR)* or *Inner VLAN inclusion register (ETH_MACIVIR)*, respectively. When VLAN deletion is enabled, the MAC deletes the tag present at the corresponding position. When a packet has only one tag, it is considered as the outer tag. If inner tag deletion is enabled and the packet has only one tag, the MAC does not delete the tag.
VLAN Tag Insertion or Replacement	VLAN tag insertion or replacement can be enabled for outer or inner tag through VLC field in the *VLAN inclusion register (ETH_MACVIR)* or *Inner VLAN inclusion register (ETH_MACIVIR)*, respectively. When VLAN tag insertion or replacement is enabled, the VLTI bit in the previous register is used to determine whether the VLAN tag should be taken from the register or the Control Word.

Receive path

Table 546: Double VLAN processing in Rx path describes the features supported by the MAC on the Receive side and the corresponding bits in the *VLAN tag register (ETH_MACVTR)*.

Table 546. Double VLAN processing in Rx path

Feature	Description
Outer or inner VLAN tag-based filtering	The MAC can filter packets based on the outer or inner VLAN tag through the ERIVLT bit.
C-VLAN or S-VLAN tag-based filtering	The MAC can filter packets based on the C-VLAN or S-VLAN type based on the ERSVLM bit.
Outer and Inner VLAN Tag stripping	The MAC can strip the outer and inner VLAN Tags from received frame based on the EVLS and EIVLS bits.
16-bit outer and inner VLAN Tag and Type in Rx status	The MAC can provide the 16-bit outer and inner VLAN Tag and Type in the Rx status based on the EVLRXS and EIVLRXS bits, respectively.
Disabling or skipping checking of outer VLAN Tag type	The MAC can disable or skip checking of outer VLAN Tag type to match C-VLAN or S-VLAN based on the DOVLTC bit.

63.5.2 Source Address and VLAN insertion, replacement, or deletion

Source address insertion or replacement

The software can use the SA (source address) insertion or replacement feature to instruct the MAC to do the following for Tx packets:

- Insert the content of the MAC Address registers in the SA field
- Replace the content of the SA field with the content of the MAC Address registers

When SA insertion is enabled, the application must ensure that the packets sent to the MAC do not have the SA field. The MAC does not check whether the SA field is present in the Transmit packet and it inserts the content of MAC Address Registers in the SA field. Similarly, when SA replacement is enabled, the application must ensure that the SA field is present in the packets sent to the MAC. The MAC replaces the six bytes following the Destination Address field in the Transmit packet with the content of the MAC Address Registers.

SA insertion or replacement feature can be enabled for all Transmit packets or selective packets:

- Enabling SA insertion or replacement for all packets

  To enable this feature for all packets, program the SARC field of the *Operating mode configuration register (ETH_MACCR)*.
- Enabling SA insertion or replacement for selective packets

  To enable this feature for selective packets, use the following program the SA Insertion Control field (bits[25:23] of Transmit Descriptor Word 3/TDES3, refer to *Section 63.10.3: Transmit descriptor*) in the first Transmit descriptor of the packet. When Bit 25 of TDES3 is set, the SA Insertion Control field indicates insertion or replacement by MAC Address1 registers. When bit 25 of TDES3 is reset, it indicates insertion or replacement by MAC Address 0 registers.

If MAC Address1 registers are not enabled, the MAC Address0 registers are used for insertion or replacement whatever of the value of the most-significant bit of the SA Insertion Control field.

VLAN insertion, replacement, or deletion

The software can use the VLAN insertion, replacement, or deletion feature to instruct the MAC to do the following for Tx packets:

- Delete the VLAN Type and VLAN Tag fields
- Insert or replace the VLAN Type and VLAN Tag fields

  Insertion or replacement is performed based on the setting of VLTI bit in the *VLAN inclusion register (ETH_MACVIR)* as described in *Table 547: VLAN insertion or replacement based on VLTI bit*.

Table 547. VLAN insertion or replacement based on VLTI bit

Condition	Description
VLTI bit is set	The MAC inserts or replaces the following: VLAN Type field (C-VLAN or S-VLAN as indicated by the CSVL bit of *VLAN inclusion register (ETH_MACVIR)*) VLAN Tag field with VT field of Transmit context descriptor of the packet
VLTI bit is reset	The MAC inserts or replaces the following: VLAN Type field (C-VLAN or S-VLAN as indicated by the CSVL bit of *VLAN inclusion register (ETH_MACVIR)*) VLAN Tag field with the VLT field of *VLAN inclusion register (ETH_MACVIR)*

When VLAN replacement or deletion is enabled, the MAC checks if the VLAN Type field (0x8100 or 0x88A8) is present after the DA and SA fields in the Transmit packet. The replace or delete operation does not occur if the VLAN Type field is not detected in two bytes following the DA and SA fields. However, when VLAN insertion is enabled, the MAC does not check the presence of VLAN Type field in the Transmit packet and just inserts the VLAN Type and VLAN Tag fields.

You can enable the VLAN insertion, replacement, or deletion feature for all Tx packets or selective packets:

- To enable this feature for all packets, program the VLC and VLP fields of *VLAN inclusion register (ETH_MACVIR)*.
- To enable this feature for selective packets, program the VTIR field of TDES2 Normal Descriptor (see *Table 580: TDES2 normal descriptor (read format)*).

  In addition, the VLP (VLAN Priority control) bit must be reset in *VLAN inclusion register (ETH_MACVIR)* (for outer VLAN) and *Inner VLAN inclusion register (ETH_MACIVIR)* (in inner VLAN) for the MAC to take the control inputs from the host, depending on the configuration.

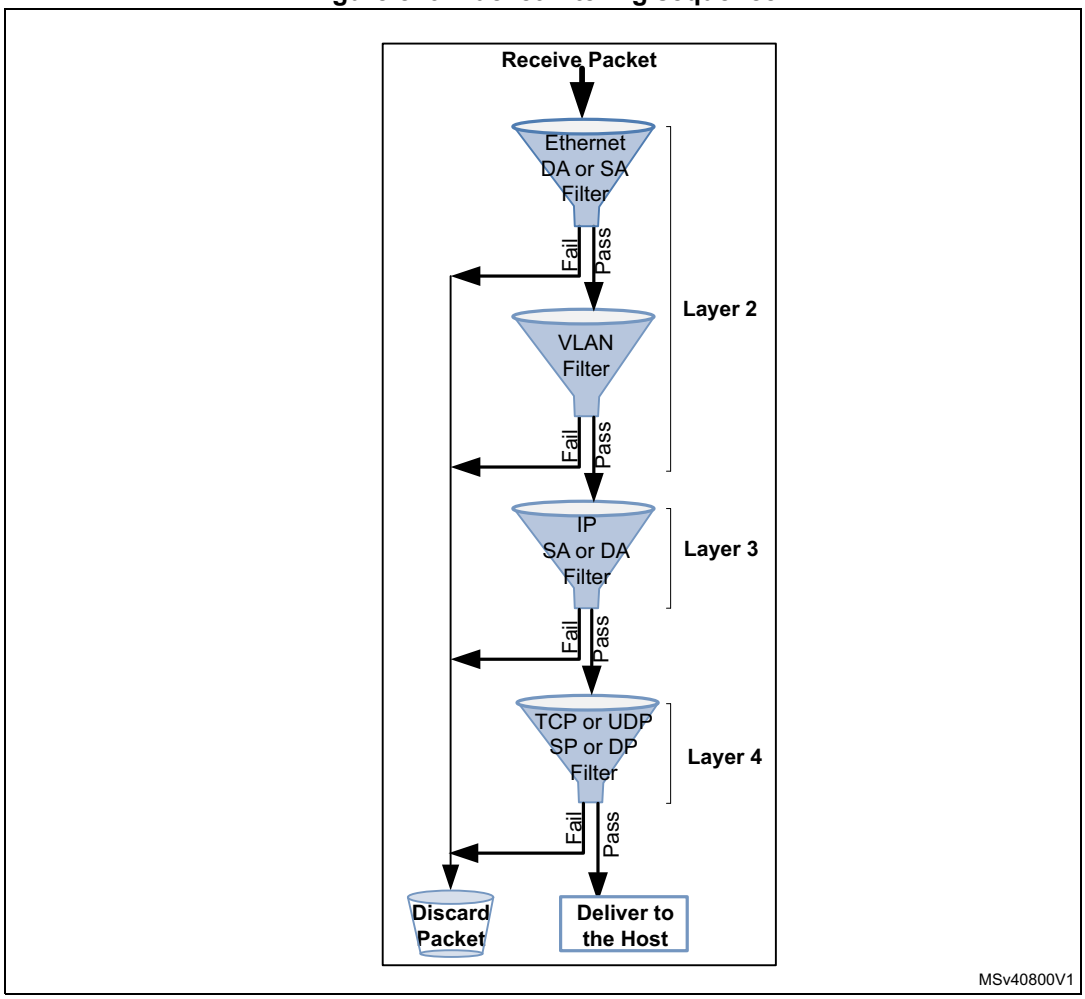
63.5.3 Packet filtering

The MAC supports the following types of filtering for Rx packets:

- *MAC source or destination address filtering*: the Address Filtering Module (AFM) checks the source address and destination address fields of each incoming packet.
- *VLAN filtering*: the MAC supports the VLAN tag-based and VLAN Hash filtering.
- *Layer 3 and Layer 4 filtering*: Layer 3 filtering refers to IP source address and destination address filtering. Layer 4 filtering refers to source port and destination port filtering.

The three filter types can be cascaded. *Figure 816* shows the filtering sequence for Rx packets.

Figure 816. Packet filtering sequence



The sequence shown in *Figure 816* is valid when all the filters (L2, VLAN, L3, L4) are active. If any of the Layer filters are not enabled, that filter is bypassed and the subsequent filter is applied. A packet that fails any of the filters is discarded. However, the discarded packet can be forwarded to the host based on the register control.

For example, when RA bit of *Packet filtering control register (ETH_MACPFR)* is set to 1, all the discarded packets are forwarded to the host but with their packet status indicating the

specific filter failure. If RA bit is cleared to 0, VTFE and IPFE bits of *Packet filtering control register (ETH_MACPFR)* control if the packets that fail the VLAN filter and Layer 3-4 filter should be discarded or forwarded to the host.

MAC source or destination address filtering

The MAC address filtering module checks the source address (SA) and destination address (DA) fields of each incoming packet.

Unicast destination address filtering

The MAC supports 4 MAC addresses for unicast perfect filtering. If perfect filtering is selected (HUC bit of *Packet filtering control register (ETH_MACPFR)* is reset), the MAC compares all 48 bits of received unicast address with the programmed MAC address for any match. The default MacAddr0 is always enabled.

The MacAddr1 to MacAddr3 addresses are selected with an individual enable bit. You can mask each byte during comparison with corresponding received DA byte by setting the corresponding Mask Byte Control bit in *MAC Address x high register (ETH_MACAxHR)*. This enables group address filtering for the DA.

In Hash filtering mode (when HUC bit is set), the MAC performs imperfect filtering for unicast addresses using a 64-bit Hash table. For Hash filtering, the MAC uses the upper 6 bits CRC of the received destination address to index the content of the Hash table. A value of 00000 selects bit 0 of selected register, and a value of 11111 selects bit 63 of Hash Table register. If the corresponding bit (indicated by the 6-bit CRC) is set to 1, the unicast packet is considered to have passed the Hash filter; otherwise, the packet is considered to have failed the Hash filter.

Multicast destination address filtering

To program the MAC to pass all multicast packets, set the PM bit in *Packet filtering control register (ETH_MACPFR)*. If the PM bit is reset, the MAC performs the filtering for multicast addresses based on the HMC bit of the *Packet filtering control register (ETH_MACPFR)*.

In Perfect filtering mode, the multicast address is compared with the programmed MAC destination address registers. Group address filtering is also supported.

In Hash filtering mode, the MAC performs imperfect filtering using a 64-bit Hash table. The MAC uses the upper 6-bits CRC of received multicast address to index the content of the Hash table. A value of 000000 selects bit 0 of selected register and a value of 111111 selects bit 63 of the Hash Table register. If the corresponding bit is set to 1, the multicast packet is considered to have passed the Hash filter. Otherwise, the packet is considered to have failed the Hash filter.

Hash or Perfect address filtering

To configure the DA filter to pass a packet when its DA matches either the Hash filter or the Perfect filter, set the HPF bit and the corresponding HUC or HMC bits in *Packet filtering control register (ETH_MACPFR)*. This is applicable to both unicast and multicast packets. If the HPF bit is reset, only one of the filters (Hash or Perfect) is applied to receive packet.

Broadcast address filtering

The MAC does not filter any broadcast packets by default. To program the MAC to reject all broadcast packets, set the DBF bit in *Packet filtering control register (ETH_MACPFR)*.

Unicast source address filtering

The MAC can perform perfect filtering based on the source address field of received packets. By default, the MAC compares the SA field with the values programmed in the SA registers. You can configure the MAC Address registers to use SA instead of DA for comparison by setting bit 30 of *MAC Address x high register (ETH_MACAxHR)*.

The MAC also supports group filtering with SA. You can filter a group of addresses by masking one or more bytes of the address. The MAC drops the packets that fail the SA filter if the SAF bit is set in *Packet filtering control register (ETH_MACPFR)*. Otherwise, the result of the SA filter is given as a status bit in the Receive Status word (see *Table 549*). When the SAF bit is set, the SA filter and DA filter result is ANDed to decide whether the packet needs to be forwarded. This means that the packet is dropped if either filter fails. The packet is forwarded to the application only if the packet passes both filters in-order.

Inverse filtering

For DA and SA filtering, you can invert the filter-match result at the final output by setting the DAIF and SAIF bits of *Packet filtering control register (ETH_MACPFR)*. The DAIF bit is applicable for both Unicast and Multicast DA packets. The result of the unicast or multicast destination address filter is inverted in this mode. Similarly, when the SAIF bit is set, the result of unicast SA filter is reversed.

Table 548 and *Table 549* summarize the DA and SA filtering based on the type of packets received.

Note: When the RA bit of Packet filtering control register (ETH_MACPFR) is set, all packets are forwarded to the system along with the correct result of the address filtering in the Rx status.

Table 548. Destination address filtering

Packet type	PR	HPF	HUC	DAIF	HMC	PM	DBF	DA filter operation
Broadcast	1	X	X	X	X	X	X	Pass
	0	X	X	X	X	X	0	Pass
	0	X	X	X	X	X	1	Fail
Unicast	1	X	X	X	X	X	X	Pass all packets
	0	X	0	0	X	X	X	Pass on Perfect/Group filter match
	0	X	0	1	X	X	X	Fail on Perfect/Group filter match
	0	0	1	0	X	X	X	Pass on Hash filter match
	0	0	1	1	X	X	X	Fail on Hash filter match
	0	1	1	0	X	X	X	Pass on Hash or Perfect/Group filter match
	0	1	1	1	X	X	X	Fail on Hash or Perfect/Group filter match
Multicast	1	X	X	X	X	X	X	Pass all packets
	X	X	X	X	X	1	X	Pass all packets
	0	X	X	0	0	0	X	Pass on Perfect/Group filter match and drop Pause packets if PCF = 0x
	0	0	X	0	1	0	X	Pass on Hash filter match and drop Pause packets if PCF = 0x
	0	1	X	0	1	0	X	Pass on Hash or Perfect/Group filter match and drop Pause packets if PCF = 0x

Table 548. Destination address filtering (continued)

Packet type	PR	HPF	HUC	DAIF	HMC	PM	DBF	DA filter operation
Multicast	0	X	X	1	0	0	X	Fail on Perfect/Group filter match and drop Pause packets if PCF = 0x
	0	0	X	1	1	0	X	Fail on Hash filter match and drop Pause packets if PCF = 0x
	0	1	X	1	1	0	X	Fail on Hash or Perfect/Group filter match and drop Pause packets if PCF = 0x

Table 549. Source address filtering

Packet type	PR	SAIF	SAF	SA filter operation
Unicast	1	X	X	Pass all packets.
	0	0	0	Pass status on Perfect or Group filter match but do not drop packets that fail
	0	1	0	Fail status on Perfect or Group filter match but do not drop packet
	0	0	1	Pass on Perfect or Group filter match and drop packets that fail
	0	1	1	Fail on Perfect or Group filter match and drop packets that fail

VLAN filtering

The MAC supports Perfect and Hash VLAN filtering. Refer to *Section 63.9.14: Programming guidelines to perform VLAN filtering on the receive* for detailed programming steps.

VLAN tag Perfect filtering

In VLAN tag Perfect filtering, the MAC compares the VLAN tag of received packet and provides the VLAN packet status to the application. Based on the programmed mode, the MAC compares the lower 12 bits or all 16 bits of received VLAN tag to determine the perfect match.

If VLAN tag Perfect filtering is enabled, the MAC forwards the VLAN-tagged packets along with VLAN tag match status and drops the VLAN packets that do not match. You can also enable the inverse matching for VLAN packets by setting the VTIM bit of *VLAN tag register (ETH_MACVTR)*. In addition, you can enable matching of S-VLAN tagged packets along with the default C-VLAN tagged packets by setting the ESVL bit of *VLAN tag register (ETH_MACVTR)*. The VLAN packet status bit(bit 10 of RDES0) indicates the VLAN tag match status for the matched packets.

Note: The source or destination address (if enabled) has precedence over the VLAN tag filters. This means that a packet that fails the source or destination address filter is dropped irrespective of the VLAN tag filter results.

VLAN tag Hash filtering

The 16-bit VLAN Hash Table is used for group address filtering based on the VLAN tag. The VLAN tag Hash filtering feature can be enabled using the VTHM (VLAN tag Hash Table match enable) bit of the *VLAN tag register (ETH_MACVTR)*. If the VTHM bit is set, the most significant four bits of CRC-32 of VLAN tag are used to index the content of the VLAN Hash Table register. A value of 1 in the VLAN Hash Table register, corresponding to the index, indicates that the VLAN tag of the packet matched and the packet should be forwarded. A value of 0 indicates that VLAN-tagged packet should be dropped.

Note: The 16 or 12 bits of VLAN Tag are considered for CRC-32 computation based on ETV bit in ETH_MACVTR register.

When ETV bit is reset, most significant four bits of CRC-32 of VLAN Tag are inverted and used to index the content of VLAN Hash table register (ETH_MACVHTR).

When ETV bit is set, most significant four bits of CRC-32 of VLAN Tag are directly used to index the content of VLAN tag register (ETH_MACVTR).

The MAC also supports the inverse matching for VLAN packets. In the inverse matching mode, when the VLAN tag of a packet matches the Perfect or Hash filter, the packet should be dropped. If the VLAN perfect and VLAN Hash match are enabled, a packet is considered as matched if either the VLAN Hash or the VLAN perfect filter matches. When inverse match is set, a packet is forwarded only when both perfect and Hash filters indicate mismatch.

Table 550 shows the different possibilities for VLAN matching and the final VLAN match status. When the RA bit of *Packet filtering control register (ETH_MACPFR)* is set, all packets are received and the VLAN match status is indicated in the VF bit of *RDES2 normal descriptor (write-back format)*. When the RA bit is not set and the VTFE bit is set in *Packet filtering control register (ETH_MACPFR)*, the packet is dropped if the final VLAN match status is Fail. In *Table 550*, value *X* means that this column can have any value.

When VLAN VID is programmed to 0 in the VL field of *VLAN tag register (ETH_MACVTR)*, all VLAN-tagged packets are considered as perfect matched but the status of the VLAN Hash match depends on the VTHM and VTIM bits in *VLAN tag register (ETH_MACVTR)*.

Table 550. VLAN match status(1)

VID	VLAN perfect filter match result	VTHM Bit	VLAN Hash filter match result	VTIM bit	Final VLAN match status
VID = 0	Pass	0	X	X	Pass
	Pass	1	X	0	Pass
	Pass	1	Fail	1	Pass
	Pass	1	Pass	1	Fail
VID!= 0	Pass	X	X	0	Pass
	Fail	0	X	0	Fail
	Fail	1	Fail	0	Fail
	Fail	1	Pass	0	Pass
	Fail	0	X	1	Pass
	Pass	X	X	1	Fail
	Fail	1	Pass	1	Fail
	Fail	1	Fail	1	Pass

1. In this table, 'X' represents any value.

Layer 3 and Layer 4 filtering

The MAC supports Layer 3 and Layer 4 based packet filtering. The Layer 3 filtering refers to the IP Source or Destination Address filtering in the IPv4 or IPv6 packets whereas Layer 4 filtering refers to the Source or Destination Port number filtering in TCP or UDP.

The Layer 3 and Layer 4 packet filtering feature automatically enables the IPC Full Checksum Offload Engine on the Receive side. For Layer 3 or Layer 4 filtering operation, you must set the IPC bit of the *Operating mode configuration register (ETH_MACCR)* to enable the Rx Checksum Offload engine.

When Layer 3 and Layer 4 filtering is enabled, the packets are filtered in the following way:

- Matched packets

  The MAC forwards the packets that match all enabled fields to the application along with the status. The MAC gives the matched field status only if the IPC bit of *Operating mode configuration register (ETH_MACCR)* is set and one of the following conditions is true:

  – All enabled Layer 3 and Layer 4 fields match.

  – At least one of the enabled field matches and other fields are bypassed or disabled

    When multiple Layer 3 and Layer 4 filters are enabled, any filter match is considered as a match. If more than one filter matches, the MAC provides the status of the lowest filter where Filter 0 is the lowest filter and Filter 3 is the highest filter. For example, if Filter 0 and Filter 1 match, the MAC gives the status corresponding to filter 0.

Note: The source or destination address and VLAN tag filters (if enabled) have precedence over Layer 3 and Layer 4 filter. This means that a packet which fails the source or destination address or VLAN tag filter is dropped irrespective of the Layer 3 and Layer 4 filter results.

- Unmatched packets

  The MAC drops the packets that do not match any of the enabled fields. You can use the inverse match feature to block or drop a packet with specific TCP or UDP over IP fields and forward all other packets.The aborted or partial packets are dropped in the MTL Rx FIFO. If the Rx FIFO operates in the Threshold (cut-through) mode and the threshold is programmed to a small value. Such packet transfer to the application starts before the failed Layer 3 and Layer 4 filter results are available, the application may receive a partial packet with appropriate abort status.

- Non-TCP or UDP IP Packets

  By default, all non-TCP or UDP IP packets are bypassed from the Layer 3 and Layer 4 filters. You can optionally program the MAC to drop all non-TCP or UDP over IP packets.

Layer 3 filtering

The MAC supports perfect matching or inverse matching for IP Source Address and Destination Address. In addition, you can match the complete IP address or mask the lower bits matching, that is, compare all bits of the address except the specified lower mask bits.

For IPv6 packets filtering, you can enable the last four data registers of a register set to contain the 128-bit IP Source Address or IP Destination Address. The IP Source Address or Destination Address should be programmed in the order defined in the IPv6 specification, that is, the first byte of the IP Source Address or Destination Address in the received packet is in the higher byte of the register and the subsequent registers follow the same order.

For IPv4 packet filtering, you can enable the second and third data registers of a register set to contain the 32-bit IP Source Address and IP Destination Address. The remaining two data registers are reserved. The IP Source Address or Destination Address should be programmed in the order defined in the IPv4 specification, that is, the first byte of IP Source Address and Destination Address in the received packet in the higher byte of the respective register.

Layer 4 filtering

The MAC supports perfect matching or inverse matching for TCP or UDP Source and Destination Port numbers. However, you can program only one type (TCP or UDP) at a time. The first data register contains the 16-bit Source and Destination Port numbers of TCP or UDP, that is, the lower 16 bits for Source Port number and higher 16 bits for Destination Port number.

The TCP or UDP Source and Destination Port numbers should be programmed in the order defined in the TCP or UDP specification, that is, the first byte of TCP or UDP Source and Destination Port number in the received packet is in the higher byte of the register.

Layer 3 and Layer 4 filters register set

The MAC implements two sets of registers for Layer 3 and Layer 4 based packet filtering. In a register set, there is a control register, such as *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, to control the packet filtering. In addition, there are five address registers to program the Layer 3 and Layer 4 fields to be matched, such as:

- *Layer4 Address filter 0 register (ETH_MACL4A0R)*
- *Layer3 Address 0 filter 0 register (ETH_MACL3A00R)*
- *Layer3 Address 1 filter 0 register (ETH_MACL3A10R)*
- *Layer3 Address 2 filter 0 register (ETH_MACL3A20R)*
- *Layer3 Address 3 filter 0 register (ETH_MACL3A30R)*

The second, and independent set of registers are: *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, *Layer 4 address filter 1 register (ETH_MACL4A1R)*, *Layer3 address 0 filter 1 Register (ETH_MACL3A01R)*, *Layer3 address 1 filter 1 register (ETH_MACL3A11R)*, *Layer3 address 2 filter 1 Register (ETH_MACL3A21R)* and *Layer3 address 3 filter 1 register (ETH_MACL3A31R)*.

63.5.4 IEEE 1588 timestamp support

The IEEE 1588 standard defines a precision time protocol (PTP) which allows precise synchronization of clocks in measurement and control systems implemented with technologies such as network communication, local computing, and distributed objects. The PTP applies to systems communicating by local area networks supporting multicast messaging, including (but not limited to) Ethernet. This protocol enables heterogeneous systems that include clocks of varying inherent precision, resolution, and stability to synchronize. The protocol supports system-wide synchronization accuracy in the submicrosecond range with minimal network and local clock computing resources.

This chapter contains the following sections:

- *IEEE 1588 timestamp support*
- *IEEE 1588 system time source*
- *IEEE 1588 auxiliary snapshots*
- *Flexible pulse-per-second output*

- *PTP timestamp offload function*
- *One-step timestamp*"

IEEE 1588 timestamp support

The Ethernet peripheral supports the IEEE 1588-2002 (version 1) and IEEE 1588-2008 (version 2). The IEEE 1588-2002 supports PTP transported over UDP/IP. The IEEE 1588 2008 supports PTP transported over Ethernet. The peripheral provides programmable support for both standards. It supports the following features:

- Support of both timestamp formats
- Optional snapshot of all packets or only PTP type packets
- Optional snapshot of only event messages
- Optional snapshot based on the clock type: ordinary, boundary, end-to-end transparent, and peer-to-peer transparent
- Optional selection of the node to act as master or slave for ordinary and boundary clock
- Identification of the PTP message type, version, and PTP payload in packets sent directly over Ethernet and sends the status
- Optional measurement subsecond time in digital or binary format

Clock types

The MAC supports the following clock types defined in the IEEE 1588-2008 specifications:

- Ordinary clock

  The ordinary clock of a domain supports a single copy of the protocol. It has a single PTP state and a single physical port. In typical industrial automation applications, an ordinary clock is associated with an application device such as a sensor or an actuator. In telecom applications, the ordinary clock can be associated with a timing demarcation device.

  The ordinary clock can be a grandmaster or a slave clock. It supports the following features:

  – Transmission and reception of PTP messages. The timestamp snapshot can be controlled as described in *Timestamp control Register (ETH_MACTSCR)*.

  – Maintenance of the data sets such as timestamp values.

  The table below shows the messages for which you can take the timestamp snapshot on the receive side for master and slave nodes.

Table 551. Ordinary clock: PTP messages for snapshot

Master	Slave
Delay_Req	SYNC

  For an ordinary clock, you can take the snapshot of either of the following PTP message types: version 1 or version 2. You cannot take the snapshots for both PTP message types. You can take the snapshot by setting the TSVER2ENA bit and selecting the snapshot mode in *Timestamp control Register (ETH_MACTSCR)*.

- Boundary clock

  The boundary clock typically has several physical ports which communicate with the network. The messages related to synchronization, master-slave hierarchy, and

signaling end in the protocol engine of the boundary clock. Such messages are not forwarded. The PTP message type status given by the MAC helps to identify the type of message and take appropriate action.

The boundary clock is similar to the ordinary clock except for the following features:

– The clock data sets are common to all ports of the boundary clock.

– The local clock is common to all ports of the boundary clock.

- End-to-end transparent clock

  The end-to-end transparent clock supports the end-to-end delay measurement mechanism between the slave clocks and the master clock. The end-to-end transparent clock forwards all messages like normal bridge, router, or repeater. The residence time of a PTP packet is the time taken by the PTP packet from the Ingress port to the Egress port.

  The residence time of a SYNC packet inside the end-to-end transparent clock is updated in the correction field of the associated Follow_Up PTP packet before it is transmitted. Similarly, the residence time of a Delay_Req packet, inside the end-to-end transparent clock, is updated in the correction field of the associated Delay_Resp PTP packet before it is transmitted. Therefore, the snapshot needs to be taken at both Ingress and Egress ports only for the messages mentioned in *Table 552*. You can take the snapshot by setting the SNAPTYPSEL bits to 10 in the *Timestamp control Register (ETH_MACTSCR)*.

Table 552. End-to-end transparent clock: PTP messages for snapshot

PTP messages
SYNC
Delay_Req

- Peer-to-peer transparent clock

  In the peer-to-peer transparent clock, the computation of the link delay is based on an exchange of Pdelay_Req, Pdelay_Resp, and Pdelay_Resp_Follow_Up messages with the link peer.

  The peer-to-peer transparent clock differs from the end-to-end transparent clock in the way it corrects and handles the PTP timing messages. In all other aspects, it is identical to the end-to-end transparent clock.

  The residence time of the Pdelay_Req and the associated Pdelay_Resp packets is added and inserted into the correction field of the associated Pdely_Resp_Followup packet. Therefore, support for taking snapshot for the event messages related to Pdelay is added as shown in *Table 560*.

Table 553. Peer-to-peer transparent clock: PTP messages for snapshot

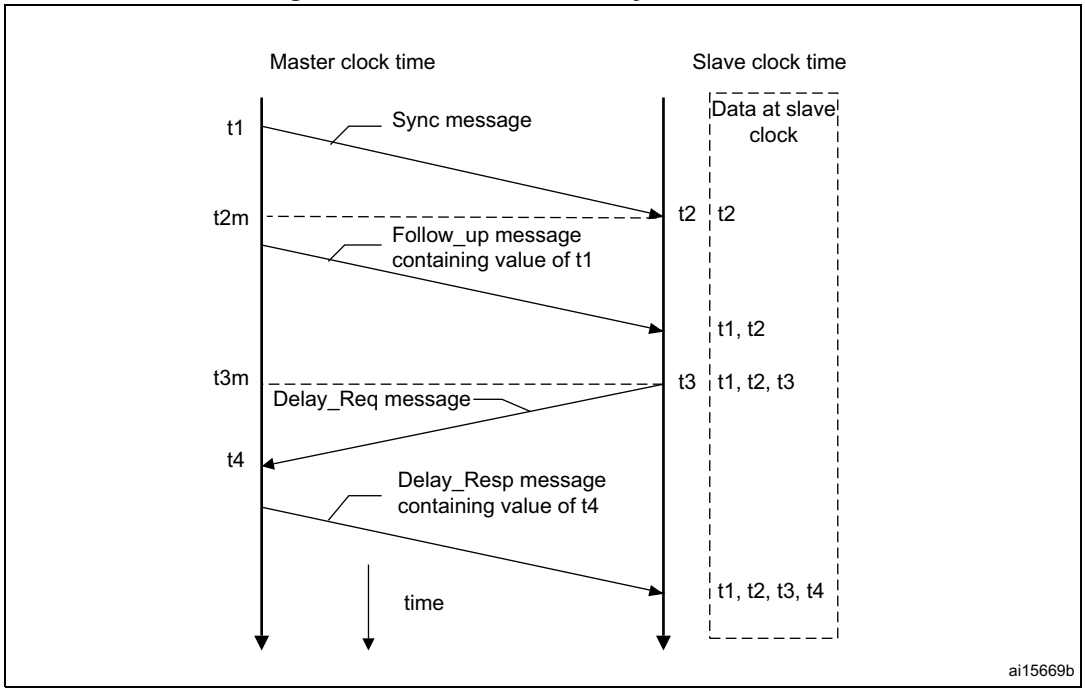
PTP messages
SYNC
Pdelay_Req
Pdelay_Resp

You can take the snapshot by setting the SNAPTYPESEL bit to 11 in *Timestamp control Register (ETH_MACTSCR)*.

Delay request-response mechanism

The system or network is classified into the master and slave nodes for distributing the timing and clock information. *Figure 817* shows the process that PTP uses for synchronizing a slave node with a master node by exchanging PTP messages.

Figure 817. Networked time synchronization



As shown in *Figure 817*, the PTP uses the following process:

1. The master broadcasts the PTP Sync messages to all its nodes. The Sync message contains the reference time information of the master. This message leaves the system of the master at t_1. This time must be captured for Ethernet ports at MII.
2. The slave receives the SYNC message and also captures the exact time, t_2, using its timing reference.
3. The master sends a Follow_up message to the slave, which contains t_1 information for later use.
4. The slave sends a Delay_Req message to the master and notes the exact time, t_3, at which this packet leaves the MII interface.

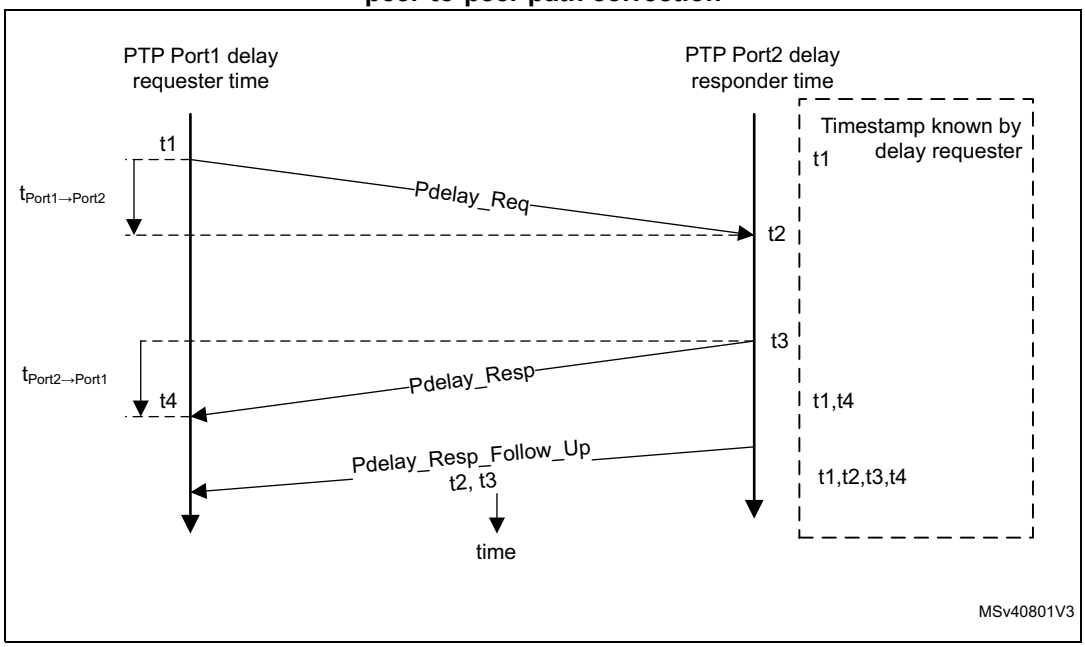
5. The master receives the message, capturing the exact time t_4, at which the message enters its system.
6. The master sends the t_4 information to the slave in the Delay_Resp message.
7. The slave uses the four values of t_1, t_2, t_3, and t_4 to synchronize its local timing reference with the timing reference of the master.

Most of the PTP implementation is done in the software above the UDP layer. However, the hardware support is required to capture the exact time when specific PTP packets enter or leave the Ethernet port at the MII interface. This timing information must be captured and returned to the software for proper implementation of PTP with high accuracy.

Peer-to-peer PTP transparent clock (P2P TC) message support

The IEEE 1588-2008 standard supports peer-to-peer PTP (Pdelay) message in addition to the Sync, Delay Request, Follow-up, and Delay Response messages. *Figure 818* shows the method to calculate the propagation delay in clocks supporting peer-to-peer path correction.

Figure 818. Propagation delay calculation in clocks supporting peer-to-peer path correction



As shown in *Figure 818*, the propagation delay is calculated as follows:

1. Port 1 issues a Pdelay_Req message and generates a timestamp (t_1) for the Pdelay_Req message.
2. Port 2 receives the Pdelay_Req message and generates a timestamp (t_2) for this message.

3. Port 2 returns a Pdelay_Resp message and generates a timestamp (t_3) for this message.

   To minimize errors caused by frequency offset between the two ports, Port 2 returns the Pdelay_Resp message as quickly as possible after the receipt of the Pdelay_Req message. Port 2 returns any one of the following:

   – Difference between the timestamps t_2 and t_3 in the Pdelay_Resp message
   – Difference between the timestamps t_2 and t_3 in the Pdelay_Resp_Follow_Up message
   – Timestamps t_2 and t_3 in the Pdelay_Resp and Pdelay_Resp_Follow_Up messages, respectively

4. Port 1 generates a timestamp (t_4) on receiving the Pdelay_Resp message.
5. Port 1 uses all four timestamps to compute the mean link delay.

Timestamp correction

According to the IEEE 1588 specifications, a timestamp must be captured when the message timestamp point (leading edge of the first bit of the octet immediately following the Start Frame Delimiter octet) crosses the boundary between the node and the network.

As the MAC takes the timestamp at an internal point far from the actual boundary of the node and network, this captured timestamp is corrected/updated for the ingress/egress path latency (including the delay in the PHY layers). Further correction is done for the inaccuracies/errors introduced due to the clock (MII Tx, Rx clock) being different at the capture point as compared to the PTP clock (clk_ptp_ref_i) that is used to generate the time. The resultant CDC (clock domain crossing) circuits add an error the depends on the clock period of the MII and PTP clocks.

Ingress correction

In the Receive side, the timestamp captured at the internal snapshot point is delayed (later in time) as compared to the time at which that packet SFD bit is received at the port boundary. Therefore, the captured timestamp must be reduced by the ingress latency and the errors in CDC sampling. This correction value must be determined/calculated by the software and written into the *Timestamp Ingress correction nanosecond register (ETH_MACTSICNR)*.

The correction value consists of the following three components:

1. External latency in the PHY layer between boundary point and the input of the core

   If the PHY is compliant with the IEEE 802.3 Clause 45 MMD registers, it has registers indicating the maximum and minimum ingress latency. The software can read these registers and determine the average ingress latency in the PHY. Alternatively (if the PHY does not support these registers), the ingress latency must be determined from the PHY datasheet or timing characteristics.

2. Internal latency from the input of the core to the internal capture point

   The latency differs based on the active PHY interface (such as MII or RMII) and the operating speed, as shown in *Table 554*.

3. CDC synchronization

   The CDC synchronization error is almost equal to twice the clock-period of the PTP clock (clk_ptp_ref_i).

The values determined from these three components should be added by the software and must be written into the TSIC field of the *Timestamp Ingress correction nanosecond register (ETH_MACTSICNR)*.

Note: The value written to the register must be negative (two's complement), because it has to be subtracted from the captured timestamp. The MAC receiver adds the value in this register to the captured timestamp and then gives the resultant value as the timestamp of the received packet.

When TSCTRLSSR bit in *Timestamp control Register (ETH_MACTSCR)* is set, the nanoseconds field of the captured timestamp is in decimal format with a granularity of 1 ns. So bit 31 of TSIC must be set to 1 (for negative value) and bits 30 to 0 must be programmed with "10^9 – total ingress_correction_value[nanosecond part]" represented in binary. For example, if the required correction value is –5 ns, then the value is 0xBB9A C9FB.

When TSCTRLSSR bit in *Timestamp control Register (ETH_MACTSCR)* is reset, the nanoseconds field of the captured timestamp is in binary format with a granularity of ~0.466 ns. Therefore, bits[30:0] must be written with "2^{31} – total ingress_correction_value" represented in binary with bit[31] = 1.

Egress correction

In the Transmit side, the timestamp captured at the internal snapshot point is earlier (advanced in time) as compared to the time at which that packet SFD bit is output at the port boundary. Therefore, the captured timestamp must be compensated by the egress latency and the errors in CDC sampling. This correction value must be determined/calculated by the software and written into the *Timestamp Egress correction nanosecond register (ETH_MACTSECNR)*.

The correction value consists of the following three components:

1. External latency in the PHY layer between the output of the core and the boundary of the port and the network

   If the PHY is compliant with the IEEE 802.3 Clause 45 MMD registers, it has registers indicating the maximum and minimum egress latency. The software can read these registers and determine the average egress latency in the PHY. Alternatively (if the PHY does not support these registers), the egress latency must be determined from the PHY datasheet or timing characteristics.
2. Internal latency from the internal capture point and the output of the core

   The latency differs based on the active PHY interface (RMII, MII, etc.) and the operating speed as shown in *Table 554*.
3. CDC synchronization error

   The timestamp correction because of synchronization is compensated by adding

$$\text{EGRESS\_SYNC\_CORR} = (1 \times \text{PTP\_CLK\_PER} + 4 \times \text{TX\_CLK\_PER})$$

Table 554 lists the Egress and Ingress latency values for various PHY interfaces:

Table 554. Egress and ingress latency for PHY interfaces

PHY interface		Egress latency	Ingress latency
RGMII	1 Gbps	12	12
RGMII	100 Mbps	40	40
RGMII	10 Mbps	400	400

Table 554. Egress and ingress latency for PHY interfaces (continued)

PHY interface		Egress latency	Ingress latency
RMII	100 Mbps	40	120
RMII	10 Mbps	400	800

Frequency range of reference timing clock

The timestamp information are transferred across asynchronous clock domains, from the MAC clock domain to the application clock domain. Therefore, a minimum delay is required between two consecutive timestamp captures. This delay is four clock cycles of MII and three clock cycles of PTP clocks. If the delay between two timestamp captures is less than this delay, the MAC does not take a timestamp snapshot for the second packet.

The PTP clock frequency limitations are the following:

- Maximum PTP clock frequency

  The maximum PTP clock frequency is limited by the maximum resolution of the reference time (10 ns at 100 MHz). In addition, the resolution or granularity of the reference time source determines the accuracy of the synchronization. Therefore, a higher PTP clock frequency gives better system performance.
- Minimum PTP clock frequency

  The minimum PTP clock frequency depends on the time required between two consecutive SFD bytes and the time taken for synchronizing the time with the MII clock domain. This relationship is given by the following equation:

  3 * PTP clock period + 4 * MII clock period ≤ Minimum gap between two SFDs

  The MII clock frequency is fixed by IEEE specifications. Therefore, the minimum PTP clock frequency required for proper operation depends on the operating mode and operating speed of the MAC as shown in *Table 555*.

Table 555. Minimum PTP clock frequency example

Mode	Minimum gap between two SFDs	Minimum PTP frequency with internal timestamp
10 Mbps full-duplex	168 MII clocks (128 clocks for a 64-byte packet + 24 clocks of min IFG + 16 clocks of preamble)	5 MHz
10 Mbps half-duplex	48 MII clocks (8 clocks for a JAM pattern sent just after SFD because of collision + 24 IFG + 16 preamble)	5 MHz
100 Mbps full duplex	168 MII clocks (128 clocks for a 64-byte packet + 24 clocks of min IFG + 16 clocks of preamble)	5 MHz
100 Mbps half-duplex	48 MII clocks (8 clocks for a JAM pattern sent just after SFD because of collision + 24 IFG + 16 preamble)	5 MHz

PTP processing and control

Table 556 shows the common message header for the PTP messages. This format is taken from the IEEE 1588-2008 specifications.

Table 556. Message format defined in IEEE 1588-2008

Bits								Octet	Offset
7	6	5	4	3	2	1	0		
transportSpecific				messageType				1	0
Reserved				versionPTP				1	1
messageLength								2	2
domainNumber								1	4
Reserved								1	5
flagField								2	6
correctionField								8	8
Reserved								4	16
sourcePortIdentity								10	20
sequenceId								2	30
controlField(1)								1	32
logMessageInterval								1	33

1. The controlField is used in version 1. In version 2, the messageType field is used for detecting different message types.

Some fields of the Ethernet payload can be used to detect the PTP packet type and control the snapshot to be taken. These fields are different for the following PTP packets:

- PTP packets over IPv4
- PTP frames over IPv6
- PTP packets over Ethernet

PTP packets over IPv4

Table 557 provides information about the fields that are matched to control the snapshot for the PTP packets sent over UDP over IPv4 for IEEE 1588 version 1 and 2. The octet positions for the tagged packets are offset by 4. This is based on the IEEE 1588-2008, Annex D and the message format defined in *Table 556*.

Table 557. Message format defined in IEEE 1588-2008

Matched field	Octet position	Matched value	Description
MAC packet type	12, 13	0x0800	IPv4 datagram
IP version and header length	14	0x45	IP version is IPv4
Layer 4 protocol	23	0x11	UDP

Table 557. Message format defined in IEEE 1588-2008 (continued)

Matched field	Octet position	Matched value	Description
IP multicast address (IEEE 1588 version 1)	30, 31, 32, 33	0xE0, 0x00, 0x01, 0x81 (or 0x82 or 0x83 or 0x84)	Multicast IPv4 addresses allowed: 224.0.1.129 224.0.1.130 224.0.1.131 224.0.1.132
IP multicast address (IEEE 1588 version 2)	30, 31, 32, 33	0xE0, 0x00, 0x01, 0x81 (Hex) 0xE0, 0x00, 0x00, 0x6B (Hex)	PTP Primary multicast address: 224.0.1.129 PTP Pdelay multicast address: 224.0.0.107
UDP destination port	36, 37	0x013F, 0x0140	0x013F: PTP event messages(1) 0x0140: PTP general messages
PTP control field (IEEE 1588 version 1)	74	0x00, 0x01, 0x02, 0x03, 0x04	0x00: SYNC 0x01: Delay_Req 0x02: Follow_Up 0x03: Delay_Resp 0x04: Management
PTP message type field (IEEE 1588 version 2)	42 (nibble)	0x0, 0x1, 0x2, 0x3, 0x8, 0x9, 0xB, 0xC, 0xD	0x0: SYNC 0x1: Delay_Req 0x2: Pdelay_Req 0x3: Pdelay_Resp 0x8: Follow_Up 0x9: Delay_Resp 0xA: Pdelay_Resp_Follow_Up 0xB: Announce 0xC: Signaling 0xD: Management
PTP version	43 (nibble)	0x1 or 0x2	0x1: Supports PTP version 1 0x2: Supports PTP version 2

1. PTP event messages are SYNC, Delay_Req (IEEE 1588 version 1 and 2) or Pdelay_Req, Pdelay_Resp (IEEE 1588 version 2 only)

PTP frames over IPv6

Table 558 provides information about the fields that are matched to control the snapshots for the PTP packets sent over UDP over IPv6 for IEEE 1588 version 1 and 2. The octet positions for the tagged packets are offset by 4. This is based on the IEEE 1588-2008, Annex D and the message format defined in *Table 556*.

Table 558. IPv6-UDP PTP packet fields required for control and status

Matched field	Octet position	Matched value	Description
MAC packet type	12, 13	0x86DD	IP datagram
IP version	14 (bits [7:4])	0x6	IP version is IPv6
Layer 4 protocol	20(1)	0x11	UDP

Table 558. IPv6-UDP PTP packet fields required for control and status (continued)

Matched field	Octet position	Matched value	Description
PTP multicast address	38 – 53	FF0x:0:0:0:0:0:0:181 (Hex) FF02:0:0:0:0:0:0:6B (Hex)	PTP primary multicast address: FF0x:0:0:0:0:0:0:0:181 (Hex) PTP Pdelay multicast address: FF02:0:0:0:0:0:0:0:6B (Hex)
UDP destination port	56, 57a	0x013F, 0x140	0x013F: PTP event message 0x0140: PTP general messages
PTP control field (IEEE 1588 version 1)	94a	0x00, 0x01, 0x02, 0x03, or 0x04	0x00: SYNC 0x01: Delay_Req 0x02: Follow_Up 0x03: Delay_Resp 0x04: Management (version1)
PTP message type field (IEEE 1588 version 2)	62a (nibble)	0x0, 0x1, 0x2, 0x3, 0x8, 0x9, 0xB, 0xC, or 0xD	0x0: SYNC 0x1: Delay_Req 0x2: Pdelay_Req 0x3: Pdelay_Resp 0x8: Follow_Up 0x9: Delay_Resp 0xA: Pdelay_Resp_Follow_Up 0xB: Announce 0xC: Signaling 0xD: Management
PTP Version	63 (nibble)	0x1 or 0x2	0x1: Supports PTP version 1 0x2: Supports PTP version 2

1. The Extension header is not defined for PTP packets.

PTP packets over Ethernet

Table 559 provides information about the fields that are matched to control the snapshots for the PTP packets sent over Ethernet for IEEE 1588 version 1 and 2. The octet positions for the tagged packets are offset by 4. This is based on the IEEE 1588-2008, Annex D and the message format.

Table 559. Ethernet PTP packet fields required for control and status

Matched field	Octet position	Matched value	Description
MAC destination multicast address(1)	0–5	01-1B-19-00-00-00 01-80-C2-00-00-0E	All PTP messages can use any of the following multicast addresses(2): 01-1B-19-00-00-00 01-80-C2-00-00-0E(3)
MAC packet type	12, 13	0x88F7	PTP Ethernet packet

Table 559. Ethernet PTP packet fields required for control and status (continued)

Matched field	Octet position	Matched value	Description
PTP control field (IEEE 1588 version 1)	46	0x00, 0x01, 0x02, 0x03, or 0x04	0x00: SYNC 0x01: Delay_Req 0x02: Follow_Up 0x03: Delay_Resp 0x04: Management
PTP message type field (IEEE 1588 version 2)	14 (nibble)	0x0, 0x1, 0x2, 0x3, 0x8, 0x9, 0xB, 0xC, or 0xD	0x0: SYNC 0x1: Delay_Req 0x2: Pdelay_Req 0x3: Pdelay_Resp 0x8: Follow_Up 0x9: Delay_Resp 0xA: Pdelay_Resp_Follow_Up 0xB: Announce 0xC: Signaling 0xD: Management
PTP version	15 (nibble)	0x1 or 0x2	0x1: Supports PTP version 1 0x2: Supports PTP version 2

1. The unicast address match of destination addresses (DA), programmed in MAC address 0 to 31, is used if the TSENMACADDR bit of *Timestamp control Register (ETH_MACTSCR)* is set.
2. IEEE 1588-2008, Annex F
3. The MAC does not consider the PTP version 1 messages with Peer delay multicast address (01-80-C2-00-00-0E) as valid PTP messages.

Transmit path functions

The MAC captures a timestamp when the start packet delimiter (SFD) of a packet is sent on the MII interface. The packets, for which a timestamp has to be captured, can be controlled on per-packet basis. Each Transmit packet can be marked to indicate whether a timestamp should be captured for it.

The MAC does not process the transmitted packets to identify the PTP packets. The packets for which a timestamp has to be captured must be specified. The packets can be defined by using the control bits in the Transmit Descriptor (see *Section 63.10.3: Transmit descriptor*). The MAC returns the timestamp to the software inside the corresponding Transmit descriptor, thus automatically connecting the timestamp to the specific PTP packet.

The 64-bit timestamp information is written to the TDES0 and TDES1 fields. The TDES0 field holds the 32 least significant bits of the timestamp.

Receive path functions

The MAC can be programmed to capture the timestamp of all packets received on the MII interface or to process packets to identify the valid PTP messages. The snapshot of the time to be sent to the application can be controlled by using the following options of the *Timestamp control Register (ETH_MACTSCR)*:

- Enable snapshot for all packets
- Enable snapshot for IEEE 1588 version 1 or version 2 timestamp

- Enable snapshot for PTP packets transmitted directly over Ethernet or UDP-IP-Ethernet
- Enable timestamp snapshot for the received packet for IPv4 or IPv6
- Enable timestamp snapshot only for EVENT messages (SYNC, DELAY_REQ, PDELAY_REQ, or PDELAY_RESP)
- Enable the node to be a master or slave and select the snapshot type

  This feature controls the type of messages for which snapshots are taken.

Note: The peripheral also supports the PTP messages over VLAN packets.

Table 560 indicates the PTP messages for which a snapshot is taken depending on the SNAPTYPSEL field in *Timestamp control Register (ETH_MACTSCR)*.

Table 560. Timestamp snapshot dependency on ETH_MACTSCR bits

SNAPTYPSEL	TSMSTRENA	TSEVNTENA	PTP messages
00	X	0	SYNC, Follow_Up, Delay_Req, Delay_Resp
00	0	1	SYNC
00	1	1	Delay_Req
01	X	0	SYNC, Follow_Up, Delay_Req, Delay_Resp, Pdelay_Req, Pdelay_Resp, Pdelay_Resp_Follow_Up
01	0	1	SYNC, Pdelay_Req, Pdelay_Resp
01	1	1	Delay_Req, Pdelay_Req, Pdelay_Resp
10	X	X	SYNC, Delay_Req
11	X	X	Pdelay_Req, Pdelay_Resp

The DMA returns the timestamp to the software application inside the corresponding Receive descriptor. The extended status, containing the timestamp message status and the IPC status, is written in the RDES1 normal descriptor and the snapshot of the timestamp is written in RDES0 and RDES1 fields of the context descriptor. The RDES0 field holds the 32 least significant bits of the timestamp.

Programming guidelines for IEEE 1588 timestamping (system time correction)

See *Section : System time correction* in *Section 63.9.9: Programming guidelines for IEEE 1588 timestamping*.

IEEE 1588 system time source

To get a snapshot of the time, the MAC requires a reference time in 64-bit format as defined in the IEEE 1588-2002 (80-bit format as defined in the IEEE 1588-2008).

Description of IEEE 1588 system time source

The peripheral uses the reference clock input and uses it to internally generate the Reference time (also called the system time) and capture timestamps.

The timestamp has the following fields:

- UInteger48 seconds field

The seconds field is the integer portion of the timestamp in units of seconds. It is 48-bit wide. For example, 2.000000001 seconds are represented as seconds Field = 0x0000 0000 0002.

- UInteger32 nanosecondsField

  The nanoseconds field is the fractional portion of the timestamp in units of nanoseconds. For example, 2.000000001 seconds are represented as nanoSeconds = 0x0000 0001.

  The nanoseconds field supports the following two modes:

  – **Digital rollover mode**: In this mode, the maximum value in the nanoseconds field is 0x3B9A C9FF, that is, (10e9-1) nanoseconds.

  – **Binary rollover mode**: In this mode, the nanoseconds field rolls over and increments the seconds field after value 0x7FFF FFFF. Accuracy is ~0.466 ns per bit.

  These modes can be set through TSCTRLSSR bit in *Timestamp control Register (ETH_MACTSCR)*.

System time register module

The 64-bit PTP time is updated using the PTP input reference clock, clk_ptp_ref_i. This PTP time is used as a source to take snapshots (timestamps) of the Ethernet frames being transmitted or received at the MII.

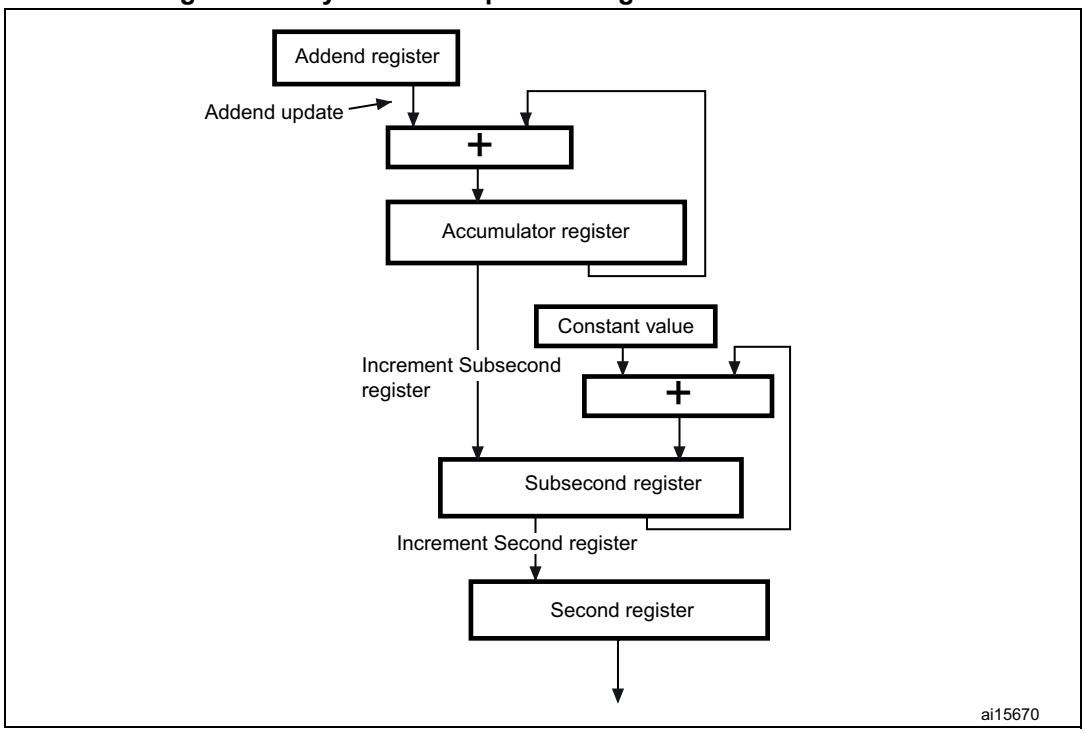
The system time counter can be initialized or corrected using either the coarse or the fine correction method.

In the coarse correction method, the initial value or the offset value is written to the timestamp update register. For initialization, the system time counter is programmed with the value in the timestamp update registers, whereas for system time correction the offset value (timestamp update register) is added to or subtracted from the system time.

In the fine correction method, the slave clock (reference clock) frequency drift with respect to the master clock (as defined in IEEE 1588-2002 specifications) is corrected over a period of time, unlike in the coarse correction method where it is corrected in a single clock cycle. The longer correction time helps maintain linear time and does not introduce drastic changes (or a large jitter) in the reference time between PTP Sync message intervals. In this method, an accumulator sums up the contents of the Addend register as shown in *Figure 819*. The arithmetic carry that the accumulator generates is used as a pulse to increment the system time counter. The accumulator and the addend are 32-bit registers. The accumulator acts as a high-precision frequency multiplier or divider.

This system time update algorithm is shown in *Figure 819*.

Figure 819. System time update using fine correction method



The system time update logic requires a 50 MHz clock frequency to achieve 20 ns accuracy. The frequency division is the ratio of the reference clock frequency to the required clock frequency. For example, if the reference clock (clk_ptp_ref_i) is 66 MHz, this ratio is calculated as 66 MHz/50 MHz = 1.32. Therefore, the default addend value to be set in the register is 2^{32} / 1.32, 0xC1F07C1F.

If the reference clock drifts lower, for example, to 65 MHz, the ratio is 65 / 50, that is 1.3 and the value to set in the addend register is 2^{32} / 1.30, or 0xC4EC 4EC4.

If the clock drifts higher, for example to 67 MHz, the addend register must be set to 0xBF0B 7672. When there is not clock drift, the default addend value of 0xC1F0 7C1F (2^{32} / 1.32) must be programmed.

In *Figure 819*, the constant value used to accumulate the subsecond register is decimal 43, which achieves a system time accuracy of 20 ns (in other words, it is incremented in 20 ns steps).

The software must calculate the drift in frequency based on the SYNC messages and accordingly update the Addend register.

Initially, the slave clock is set with FreqCompensationValue0 in the Addend register. This value is as follows:

$$\text{FreqCompensationValue}_0 = 2^{32} / \text{FreqDivisionRatio}$$

If MasterToSlaveDelay is initially assumed to be the same for consecutive Sync messages, the algorithm given in this section must be applied. After a few Sync cycles, frequency lock occurs. The slave clock can then determine a precise MasterToSlaveDelay value and re-synchronize with the master using the new value.

The algorithm is as follows:

1. At time $MasterSyncTime_n$ the master sends the slave clock a SYNC message. The slave receives this message when its local clock is $SlaveClockTime_n$ and computes $MasterClockTime_n$ as follows:

$$MasterClockTime_n = MasterSyncTime_n + MasterToSlaveDelay_n$$

2. The master clock counts for current Sync cycle, $MasterClockCount_n$ is

$$MasterClockCount_n = MasterClockTime_n - MasterClockTime_{n-1}$$

(assuming that MasterToSlaveDelay is the same for Sync cycles n and n – 1)

3. The slave clock count for current Sync cycle, $SlaveClockCount_n$ is

$$SlaveClockCount_n = SlaveClockTime_n - SlaveClockTime_{n-1}$$

4. The difference between master and slave clock counts for current Sync cycle, $ClockDiffCount_n$ is

$$ClockDiffCount_n = MasterClockTime_n - SlaveClockTime_n$$

5. The frequency-scaling factor for slave clock, $FreqScaleFactor_n$ is

$$FreqScaleFactor_n = (MasterClockCount_n + ClockDiffCount_n)/SlaveClockCount_n$$

6. The frequency compensation value for Addend register, $FreqCompensationValue_n$ is

$$FreqCompensationValue_n = FreqScaleFactor_n \times FreqCompensationValue_{n-1}$$

In theory, this algorithm achieves the lock in one Sync cycle. However, it may take several cycles, because of changing network propagation delays and operating conditions. This algorithm is self-correcting. If the slave clock is initially set to an incorrect value by the master, the algorithm corrects it at the cost of additional Sync cycles.

Refer to *Section 63.9.9: Programming guidelines for IEEE 1588 timestamping* for detailed programming steps.

IEEE 1588 auxiliary snapshots

The auxiliary snapshot feature enables to store a snapshot of the system time based on an external event. The event is considered to be the rising edge of the eth_ptp_trgx (where x = 1 to 4) sideband signal.

Up to four auxiliary snapshot inputs can be configured and up to four snapshots can be stored. A FIFO is accessible through registers: *Auxiliary timestamp seconds register (ETH_MACATSSR)* and *Auxiliary timestamp nanoseconds register (ETH_MACATSNR)*.

The snapshots taken for any input are stored in a common FIFO; only 64 bits are kept. The application can read the *Timestamp status register (ETH_MACTSSR)* to know the timestamp of which input is available for reading at the top of this FIFO.

When a snapshot is stored, the MAC indicates this to the application with an interrupt. The value of the snapshot is read through a FIFO register access. If the FIFO becomes full and an external trigger to take the snapshot is asserted, a snapshot trigger-missed status (ATSSTM) is set in the *Timestamp status register (ETH_MACTSSR)*. This indicates that the latest auxiliary snapshot of the timestamp is not stored in the FIFO. The latest snapshot is not written to the FIFO when it is full.

When an application reads the 64-bit timestamp from the FIFO, the space becomes available to store the next snapshot. You can clear a FIFO by setting the ATSFC bit in *Auxiliary control register (ETH_MACACR)*. When multiple snapshots are present in the FIFO, the count is indicated in bits[27:25] of *Timestamp status register (ETH_MACTSSR)*.

Flexible pulse-per-second output

The MAC supports either a fixed pulse-per-second output mode (also called fixed mode) or a flexible pulse-per-second output mode for the eth_ptp_pps_out outputs:

- Fixed pulse-per-second output

  In this mode, only the frequency of the PPS output can be changed by setting the PPSCTRL0 field in the *PPS control register (ETH_MACPPSCR)*.
- Flexible pulse-per-second output

  In this mode, the software has the flexibility to program the start or stop time, width, and interval of the pulse generated on the eth_ptp_pps_out output:

  The start and stop times are programmed through *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*.

  The PPS width and interval are programmed in terms of granularity of system time (number of the units of subsecond increment value) through *PPS width register (ETH_MACPPSWR)* and *PPS interval register (ETH_MACPPSIR)*, respectively.

Note: By default, the peripheral is in Fixed mode and indicates one second interval. When Fixed mode is selected by clearing PPSEN0 to 0 in the PPS control register (ETH_MACPPSCR):

- *the output on all PPS outputs is controlled by the value programmed in the PPSCTRL_PPSCMD field. Independent control of individual PPS output is not supported in Fixed mode.*
- *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR) are used only for generating target time reached interrupt; they are not used for PPS output generation.*
- *TRGTMODSEL0/1/2/3 must be programmed to 0.*
- *the frequency of the PPS output can be changed by setting the PPSCTRL0 field in the PPS control register (ETH_MACPPSCR).*

Description of flexible pulse-per-second (PPS) output

The peripheral supports the following features with the flexible PPS outputs:

- Programming the start or stop time in terms of system time.
- Programming the start point of the single pulse and start and stop points of the pulse train in terms of 64-bit system time. The Target Time registers are used to program the start and stop time.
- Programming the stop time in advance, that is, the stop time can be programmed before the actual start time has elapsed.
- Programming the width between the rising edge and corresponding falling edge of PPS signal output in terms of number of units of subsecond increment value programmed in the *Subsecond increment register (ETH_MACSSIR)*. The pulse width can be programmed from 1 to 232–1 units of subsecond increment value.
- Programming the interval, between the rising edges of PPS signal, in terms of number of units of subsecond increment value. You can program the interval between pulses from 1 to 232–1 units of subsecond increment value.
- Option to cancel the programmed PPS start or stop request.
- Error if the start or stop time being programmed has already elapsed.

Note: The PTP reference clock mentioned in the following sections is the clock at which the system time is updated. When the TSCFUPDT bit of Timestamp control Register (ETH_MACTSCR) is set to 0, this clock is similar to the clk_ptp_ref_i clock. In Fine correction mode, this is the clock tick at which the system time is updated (using Subsecond increment register (ETH_MACSSIR) (as shown in Figure 819).

Refer to *Section 63.9.12: Programming guidelines for flexible pulse-per-second (PPS) output* for further details on how configuring flexible pulse output.

PPS start and stop times

The initial start time can be programmed in the Target Time registers.

If required, the start or stop time can be programmed again. However, this can be done only after the earlier programmed value is synchronized with the PTP clock domain. Bit 31 of *PPS target time nanoseconds register (ETH_MACPPSTTNR)* indicates that the synchronization is complete. This enables to program the start or stop time in advance even before the earlier stop or start time has elapsed.

To ensure proper PPS signal output, it is recommended to program advanced system time for the start or stop time. If the application programs a start or stop time that has already elapsed, the MAC sets an error status bit indicating the programming error. If enabled, the MAC also sets the Target Time Reached interrupt event. The application can cancel the start or stop request only if the corresponding start or stop time has not elapsed. If the time has elapsed, the cancel command has no effect.

PPS width and interval

The PPS width and interval are programmed in terms of granularity of system time, that is, number of the units of subsecond increment value. For example, to obtain a PPS pulse width of 40 ns and an interval of 100 ns with a PTP reference clock of 50 MHz, program the width and interval to values 2 and 5, respectively. Smaller granularity can be achieved by using a faster PTP reference clock.

Before giving the command to trigger a pulse or pulse train on the PPS output, program or update the interval and width of the PPS signal output.

PTP timestamp offload function

This feature enables the automatic generation of specific PTP packets to be performed, when the MAC operates as a specific node in the PTP network.

These packets can be generated periodically or triggered by the host software. In other modes, this feature can parse the incoming PTP packets on the receiver, and automatically generate and respond to the required PTP packets. It helps to offload certain PTP node functions with better accuracy and lower response latency.

The PTP offload feature is selected through *PTP Offload control register (ETH_MACPOCR)*. 80-bit PTP node identity is configured through the following three registers: *PTP Source Port Identity 0 Register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)*.

Description of PTP offload function

Depending on the programmed mode, the MAC generates PTP Ethernet messages periodically or from the application, or based on reception of a particular PTP message. *Table 561* indicates the PTP message generation criteria.

Table 561. PTP message generation criteria

Programming			Mode	Criteria for generation of PTP messages	PTP message type generated
SNAPTYPSEL	TSMSTRENA	TSEVNTENA			
00	0	1	Ordinary or Boundary Slave	SYNC message reception	Delay_Req
00	1	1	Ordinary or Boundary Master	Periodic or on trigger from application	SYNC
				Delay_Req message reception	Delay_Resp
01	0	1	Transparent Slave	Periodic or on trigger from application	Pdelay_Req
				Pdelay_Req message reception	Pdelay_Resp
				SYNC message reception	Delay_Req

Table 561. PTP message generation criteria (continued)

Programming			Mode	Criteria for generation of PTP messages	PTP message type generated
SNAPTYPSEL	TSMSTRENA	TSEVNTENA			
01	1	1	Transparent Master	Periodic or on trigger from application	Pdelay_Req
				Pdelay_Req message reception	Pdelay_Resp
				Periodic or on trigger from application	SYNC
				Delay_Req message reception	Delay_Resp
11	X	X	Peer-to-Peer Transparent	Periodic or on trigger from application	Pdelay_Req
				Pdelay_Req message reception	Pdelay_Resp
All other programming combinations are invalid for PTP Offload feature.					

Note: Clocks supporting peer delay mechanism must not generate delay request/delay response messages, according to IEEE 1588-2008 specifications. However, the peripheral controller supports this for flexibility, with a programmable control bit (DRRDIS) in the PTP Offload control register (ETH_MACPOCR).

The DRRDIS bit can be used to control the response generation for delay request/delay response message. For example, in transparent slave mode, delay request is generated in response to received SYNC *only when the bit is reset.*

When the MAC is set as an Ordinary or Boundary Slave clock in the PTP network, it can respond to the reception of SYNC messages with an automatic generation and transmission of the corresponding Delay_Req message. Similarly, various other modes of operation are explained in *Table 561*.

The MAC supports the multicast communication model for the generation of SYNC and Pdelay_Req PTP messages. For instance, the Destination Address field of the generated PTP over Ethernet packet is the defined special multicast addresses (0x011B 1900 0000 for all except peer delay mechanism messages and 0x0180 C200 000E for peer delay mechanism messages).

When the MAC responds to received SYNC, Delay_Req and Pdelay_Req PTP messages with special multicast destination address, it also uses the corresponding special multicast address in the DA field of the automatically generated Delay_Req, Delay_Resp, and Pdelay_Resp PTP messages, respectively.

When the MAC responds to received SYNC, Delay_Req and Pdelay_Req PTP messages with unicast destination address, it takes the SA field of the received packets and makes

them as the DA field of the automatically generated Delay_Req, Delay_Resp, and Pdelay_Resp PTP messages, respectively.

At the same time, all the received PTP messages are forwarded to the application along with Rx status, indicating whether the response was generated by the MAC, if it satisfies the packet filtering logic of the MAC receiver

When the MAC automatically generates a PdelayReq or responds with a Delay_Req, the egress timestamp of these two PTP messages are provided in the Tx TS status (Tx Timestamp Status register and interrupt generated).

In addition to messageType and versionPTP fields match for basic PTP over Ethernet message detection, the following additional fields are matched to qualify the received PTP message type:

1. The domainNumber field is checked for a match against the value programmed in the CSR.
2. The twoStepFlag in flagField field is checked for one-step indication (0b0).
3. The transportSpecific field is checked for Default PTP over Ethernet (0b0000) or 802.1AS mode (0b1111) when enabled.

PTP packet generation

This section explains the format and content of the automatically generated PTP packets by the MAC when this mode is enabled. It provides the template of the common PTP message header, as well as the detailed description of the fields of the specific PTP packets generated.

Table 562. Common PTP message header fields

Bits								Octets	Offset
7	6	5	4	3	2	1	0		
transportSpecific				messageType				1	0
Reserved				versionPTP				1	1
messageLength								2	2
domainNumber								1	4
Reserved								1	5
flagField								2	6
correctionField								8	8
Reserved								4	16
sourcePortIdentity								10	20
sequenceId								2	30
sequenceId								2	30
controlField								1	32
logMessageInterval								1	33

PTP message header fields

- **messageType**

  The following encoded values are used for PTP message types:
  - SYNC: 0000
  - Delay_Req: 0001
  - Pdelay_Req: 0010
  - Pdelay_Resp: 0011
  - Delay_Resp: 1001
- **transportSpecific**

  The following transport protocol encoding is used:
  - Default PTP over Ethernet: 0000
  - 802.1AS mode: 0001
- **versionPTP**

  It is always set to 2 because PTP version 2 is supported.
- **domainNumber**

  This field contains the value from the *PTP Offload control register (ETH_MACPOCR)*.
- **flagField**

  The following values are used:
  - alternateMasterFlag (Octet 0 bit 0): 0 for SYNC and Delay_Resp
  - twoStepFlag (Octet 0 bit 1): 0 for SYNC and Pdelay_Resp
  - unicastFlag (Octet 0 bit 2): 0 for Multicast Address, 1 for Unicast Address
- **correctionField**

  For more information, see *Table 563*.
- **sourcePortIdentity**

  This field takes the value programmed in the *PTP Source Port Identity 0 Register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)*.
- **sequenceId**

  Pdelay_Resp and Delay_Resp use the same sequenceId field from received Pdelay_Req and Delay_Req PTP messages. For SYNC/Delay_Req, Pdelay_Req, a separate sequenceId counter is maintained. These sequenceId counters get incremented by 1 every time the corresponding message is generated and transmitted.
- **controlField**

  The following encoded values are used for controlField:
  - SYNC: 0000 0000
  - Delay_Req: 0000 0001
  - Pdelay_Req: 0000 0010
  - Pdelay_Resp: 0000 0101
  - Delay_Resp: 0000 0011
- **logMessageInterval**
  - SYNC:

    This field contains logSyncInterval from the corresponding MAC_Log_Message_Interval register.

– Delay_Resp:

This field contains the sum of DRSYNCR and logSyncInterval value taken from the *Log message interval register (ETH_MACLMIR)* for a multicast PTP message and 0111 1111 for unicast PTP message.

– Delay_Req, Pdelay_Req and Pdelay_Resp: 0111 1111

where logSyncInterval = log2 (Mean Value of Interval in seconds)

The MAC supports values of –15 to 15 for logSyncInterval fields, which translates to a range from 32.768 micro second (2–15) to 215 second. For a given value of log sync interval (N), the time interval between two SYNC packets is given by the following:

- $2^{(30+N)}$ ns, when N is negative (–1 to –15)
- 2^{N} seconds, when N is positive (0 to 15)

For example:

- When logSyncInterval is programmed to 1, the interval is 2^{1}; therefore, the SYNC message is sent once every 2 seconds.
- When logSyncInterval is programmed to -1, the interval is 2^{-1} = 0.536 seconds; therefore, the SYNC message is sent once every 536 milliseconds. The value is 0.536 seconds, because 2^{-30} = 1 ns.
- When logSyncInterval is programmed to –-5, the interval is 2^{-5} = 33.55 ms; therefore, the SYNC message is sent once every 33.55 ms.

Note: The MAC uses the PTP system time to generate the intervals for periodic packet transmission. For negative values of log message interval programmed, the generated period may deviate from the value given by the equation $2^{(30+N)}$, because of the non-binary nature of the nanoseconds field of the system time.

PTP message-specific fields

The message-specific fields are the following:

- **messageLength**

  There is no suffix supported, so this field contains the length of the PTP message that includes 34-byte PTP common header and the body specific to the message type.

  For SYNC and Delay_Req packets, this field contains 44, whereas for Delay_Resp, Pdelay_Req and Pdelay_Resp, it contains 54.

- **originTimestamp**

  This field is the captured egress timestamp for SYNC, Delay_Req, and Pdelay_Req PTP messages.

- **receiveTimestamp**

  For Delay_Resp PTP message, this is the ingress timestamp of the corresponding received Delay_Req PTP message.

- **requestingPortIdentity**

  For Delay_Resp and Pdelay_Resp PTP messages, this is the sourcePortIdentity field taken from the corresponding received Delay_Req and Pdelay_Req PTP messages.

- **requestReceiptTimestamp**

  For the Pdelay_Resp PTP message, this field is set to 0.

One-step timestamp

The MAC supports the one-step timestamp feature that enables to identify the offset in the packet and inserts the timestamp received from the application at that offset.

MAC Transmit PTP mode for one-step timestamp

Depending upon the type of message and its mode, the MAC updates the following fields of Transmit PTP packets:

- correctionField in the PTP header of messages
- originTimestamp in SYNC, Delay_Req, and Pdelay_Req messages

Table 563 shows how the PTP mode is selected based on the settings of SNAPTYPSEL, TSMSTRENA, and TSEVNTENA bits of the *Timestamp control Register (ETH_MACTSCR)* and the fields that are updated for the incoming PTP packets based on the message type in that mode, during the one-step timestamping operation.

Table 563. MAC Transmit PTP mode and one-step timestamping operation

Programming			Mode	Per packet control(1)			Messages processed on transmission
SNAPTYPSEL	TSMSTRENA	TSEVNTENA		TTSE (2)	OSTC (3)	TTS(4)	
X	X	X	N/A	1	X	X	Timestamp is captured and returned to application
X	X	X	N/A	X	0	X	OST operation is not performed (PTP packet is not modified)
00	X	0	End-to-end transparent	0	1	Ingress TS	Sync (correction field for residence time and Ingress asymmetric correction)
							Delay_Req (correction field for residence time and Egress asymmetric correction)
00	0	1	Ordinary or Boundary Slave	1	1	X	Delay_Req (originTimestamp field) Delay_Req (correction field for Egress asymmetric correction)
00	1	1	Ordinary or Boundary Master	0	1	X	Sync (originTimestamp field) Sync (correction field for subnanosecond correction)
01	X	0	End-to-end Transparent with support for peer delay mechanism	0	1	Ingress TS	Sync (correction field for residence time and Ingress asymmetric correction)
						Ingress TS	Pdelay_Req (correction field for residence time and Egress asymmetric correction)
						Ingress TS	Pdelay_Resp (correction field for residence time and Ingress asymmetric correction)

Table 563. MAC Transmit PTP mode and one-step timestamping operation (continued)

Programming			Mode	Per packet control[1]			Messages processed on transmission
SNAPTYPSEL	TSMSTRENA	TSEVNTENA		TTSE[2]	OSTC[3]	TTS[4]	
01	0	1	Ordinary or Boundary Slave with support for peer delay mechanism or Peer-to-peer transparent	0	1	Ingress TS	Sync (correction field for residence time and Ingress asymmetric correction) (applicable only for Peer to Peer transparent clock operation)
				1	1	X	Delay_Req (originTimestamp field) Delay_Req (correction field for Egress asymmetric correction)
				1	1	X	Pdelay_Req (originTimestamp field) Pdelay_Req (correction field for Egress asymmetric correction)
				0	1	Ingress TS for Pdelay_Req	Pdelay_Resp (correction field for turnaround time and Ingress asymmetric correction)
01	1	1	Ordinary or Boundary Master with support for peer delay mechanism	0	1	X	Sync (originTimestamp field) Sync (correction field for subnanosecond correction)
				1	1	X	Pdelay_Req (originTimestamp field) Pdelay_Req (correction field for Egress asymmetric correction)
				0	1	Ingress TS for Pdelay_Req	Pdelay_Resp (correction field for turnaround time and Ingress asymmetric correction)
10	X	X	End-to-end transparent	0	1	Ingress TS	Sync (correction field for residence time and Ingress asymmetric correction)
						Ingress TS	Delay_Req (correction field for residence time and Egress asymmetric correction)

Table 563. MAC Transmit PTP mode and one-step timestamping operation (continued)

Programming			Mode	Per packet control(1)			Messages processed on transmission
SNAPTYPSEL	TSMSTRENA	TSEVNTENA		TTSE (2)	OSTC (3)	TTS(4)	
11	X	X	Peer-to-peer transparent	0	1	Ingress TS	Sync (correction field for residence time and Ingress asymmetric correction)
				1	1	X	Pdelay_Req (originTimestamp field) Pdelay_Req (correction field for Egress asymmetric correction)
				0	1	Ingress TS for Pdelay_Req	Pdelay_Resp (correction field for turnaround time and Ingress asymmetric correction)

1. The per-packet control values provided here are the recommended settings used by devices in typical PTP operation and for the programmed mode.
2. TTSE represents TTSE bit of TDES2 transmit normal descriptor. The TTSE function is independent from the OST function and the programmed operation mode for OST. The MAC captures and returns the timestamp when the TTSE bit is set.
3. OSTC represents OSTC bit of TDES3 transmit context descriptor
4. TTS represents the timestamp value provided in the TTSH, TTSL fields of TDES0 and TDES1 transmit normal descriptor (write-back format).

Note: Residence time/ turnaround time is calculated as the difference between the captured timestamp (egress timestamp) and the ingress timestamp. Clocks supporting peer delay mechanism do not use delay request or response, but it is included in OST for flexibility.

Enabling one-step timestamp

The one-step timestamp feature can be enabled for a given packet by setting bit 20 (OSTC) in TDES3 context descriptor. To update the correction field in certain PTP packets, the ingress timestamp must be given in the TSSL and TSSH fields.

The one-step timestamp feature is supported only for the PTP over Ethernet packets. It is not supported for PTP over IPv4/IPv6 packets.

63.5.5 Checksum offload engine

Communication protocols such as TCP and UDP implement checksum fields, which help determine the integrity of data transmitted over a network. The most widespread use of Ethernet is to encapsulate TCP and UDP over IP datagrams. The MAC has a Checksum Offload Engine (COE) to support checksum calculation and insertion in the Transmit path, as well as error detection in the Receive path.

Transmit checksum offload engine

In the transmit path, the MAC calculates the checksum and inserts it in the Tx packet. This feature helps reducing the load on the software and can improve the overall system throughput.

The COE module supports two types of checksum calculation and insertion. The checksum engine can be controlled for each packet by setting the CIC bits (TDES3 bits[17:16]).

Note: The checksum for TCP, UDP, or ICMP is calculated over a complete packet, and then inserted into its corresponding header field. Because of this requirement, the Tx FIFO automatically operates in the Store-and-forward mode even if the MAC is configured in Threshold (cut-through) mode.

Make sure that the Tx FIFO is deep enough to store a complete packet before that packet is transferred to the MAC transmitter, the reason being that when space is not available to accept the programmed burst length of data, then the MTL Tx FIFO starts reading to avoid deadlock. In such a case, the COE fails as the start of the packet header is read out before the payload checksum can be calculated and inserted. Therefore, the checksum insertion must be enabled only in the packets that are less than the number of bytes, given by the following equation:

$$\text{Packet size} < \text{TxQSize} - (\text{PBL} + 7) \times 4$$

where

TxQSize corresponds to the TQS bitfield of *Tx queue operating mode Register (ETH_MTLTXQOMR)*

PBL corresponds to the TxPBL bitfield of *Channel transmit control register (ETH_DMACTXCR)*

Refer to IETF specifications RFC 791, RFC 793, RFC 768, RFC 792, RFC 2460, and RFC 4443 for IPv4, TCP, UDP, ICMP, IPv6, and ICMPv6 packet header specifications, respectively.

IP header checksum engine

In IPv4 datagrams, the integrity of the header fields is indicated by the 16-bit Header Checksum field (the eleventh and twelfth bytes of the IPv4 datagram). The COE detects an IPv4 datagram when the Type field of Ethernet packet has the value 0x0800 and the Version field of IP datagram has the value 0x4. The checksum field of the input packet is ignored during calculation and replaced with the calculated value.

Note: IPv6 headers do not have a checksum field. Therefore, the COE does not modify the IPv6 header fields.

The result of this IP header checksum calculation is indicated by the IP Header Error status it in the Transmit status (bit 0 in *Table 585: TDES3 normal descriptor (write-back format)*).

This status bit is set whenever the values of the Ethernet Type field and the Version field of IP header are not consistent, or when the Ethernet packet does not have enough data, as

indicated by the IP header Length field. In other words, this bit is set when an IP header error is asserted under the following circumstances:

- For IPv4 datagrams:
  - The received Ethernet type is 0x0800, but the Version field of IP header is not equal to 0x4.
  - The IPv4 Header Length field indicates a value less than 0x5 (20 bytes).
  - The total packet length is less than the value given in the IPv4 Header Length field.
- For IPv6 datagrams:
  - The Ethernet type is 0x86DD but the IP header Version field is not equal to 0x6.
  - The packet ends before the IPv6 header (40 bytes) or extension header (as given in the corresponding Header Length field in an extension header) is completely received.

TCP/UDP/ICMP checksum engine

The TCP/UDP/ICMP Checksum Engine processes the IPv4 or IPv6 header (including extension headers) and determines whether the encapsulated payload is TCP, UDP, or ICMP. The checksum is calculated for the TCP, UDP, or ICMP payload and inserted into its corresponding field in the header. The Tx COE can work in the following two modes:

- The TCP, UDP, or ICMPv6 pseudo-header is not included in the checksum calculation and is assumed to be present in the Checksum field of the input packet. This engine includes the Checksum field in the checksum calculation, and then replaces the Checksum field with the final calculated checksum.
- The engine ignores the Checksum field, includes the TCP, UDP, or ICMPv6 pseudo-header data into the checksum calculation, and overwrites the checksum field with the final calculated value.

Note: For ICMP-over-IPv4 packets, the Checksum field in the ICMP packet must always be 0x0000 in both modes, because pseudo-headers are not defined for such packets. If it does not equal 0x0000, an incorrect checksum may be inserted into the packet.

The result of this operation is indicated by the Payload Checksum Error status bit in the Transmit Status vector (bit 12 in *Table 585: TDES3 normal descriptor (write-back format)*). This engine sets the Payload Checksum Error status bit when it detects that the packet has been forwarded to the MAC Transmitter engine in the store-and-forward mode without the end of packet (EOP) being written to the FIFO, or when the packet ends before the number of bytes indicated by the Payload Length field in the IP Header is received. When the packet is longer than the indicated payload length, the COE ignores them as stuff bytes, and no error is reported. When this engine detects the first type of error, it does not modify the TCP, UDP, or ICMP header. For the second error type, it still inserts the calculated checksum into the corresponding header field.

Table 564 describes the functions supported by Transmit Checksum Offload engine based on the packet type. When the MAC does not insert the checksum, it is indicated as “No” in the table.

Note: Do not enable checksum insertion for IPv4 or IPv6 packets that are greater than the frame size constraint specified in Section : Transmit checksum offload engine because it might result in incorrect checksum insertion or unexpected behavior.

Table 564. Transmit checksum offload engine functions for different packet types

Packet type	Hardware IP header checksum insertion	Hardware TCP/UDP checksum insertion
Non-IPv4 or IPv6 packet	No	No
IPv4 packet is greater than 1,522 bytes (2,000 bytes when IEEE 802.3ad support for 2K packets is enabled in the MAC) but less than or equal to the frame size constraint specified in *Section : Transmit checksum offload engine*.	Yes	Yes
IPv6 packet is greater than 1,522 bytes (2,000 bytes when IEEE 802.3ad support for 2K packets is enabled in MAC) but less than or equal to the frame size constraint specified in *Section : Transmit checksum offload engine*.	Not applicable	Yes
IPv4 with TCP, UDP, or ICMP	Yes	Yes
IPv4 packet has IP options (IP header is longer than 20 bytes)	Yes	Yes
Packet is an IPv4 fragment	Yes	No
IPv6 packet with the following next header fields in main or extension headers: – Hop-by-hop options (in IPv6 main header) – Hop-by-hop options (in IPv6 extension header) – Destinations options – Routing (with segment left 0) – Routing (with segment left > 0) – TCP, UDP, or ICMP – Authentication – Any other next header field in main or extension headers	 – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable	 – Yes – No – Yes – No – No – Yes – No – No
IPv4 packet has TCP header with Options fields	Yes	Yes
IPv4 Tunnels: – IPv4 packet in an IPv4 tunnel – IPv6 packet in an IPv4 tunnel	 – Yes (IPv4 tunnel header) – Yes (IPv4 tunnel header)	 – No – No
IPv6 Tunnels: – IPv4 packet in an IPv6 tunnel – IPv6 packet in an IPv6 tunnel	 – Not applicable – Not applicable	 – No – No
IPv4 packet has 802.3ac tag (with C-VLAN tag or S-VLAN Tag when enabled).	Yes	Yes
IPv6 packet has 802.3ac tag (with C-VLAN tag or S-VLAN Tag when enabled).	Not applicable	Yes
IPv4 frames with security features (such as encapsulated security payload)	Yes	No
IPv6 frames with security features (such as encapsulated security payload)	Not applicable	No

Receive checksum offload engine

The Receive Checksum Offload engine is used to detect errors in IP packets by calculating the header checksum and further matching it with the received header checksum. This engine also identifies a TCP, UDP, or ICMP payload in received IP packets and calculates the checksum of such payloads appropriately.

The Receive Checksum Offload Engine (Rx COE) can be enabled by setting the IPC bit of *Operating mode configuration register (ETH_MACCR)*. When this bit is set, both IPv4 and IPv6 packet in the received Ethernet packets are detected and processed for data integrity. The MAC receiver identifies IPv4 or IPv6 packets by checking for value 0x0800 or 0x86DD, respectively, in the Type field of the received Ethernet packet. This identification is applicable to single VLAN-tagged packets. It is also applicable to double VLAN-tagged packets when the EDVLP bit of the *VLAN tag register (ETH_MACVTR)* is set.

The Rx COE calculates the IPv4 header checksums and checks that they match the received IPv4 header checksums. The result of this operation (pass or fail) is given to the RFC module for insertion into the receive status word. The IP Header Error bit is set for any mismatch between the indicated payload type (Ethernet Type field) and the IP header version, or when the received packet does not have enough bytes, as indicated by the Length field of the IPv4 header (or when fewer than 20 bytes are available in an IPv4 or IPv6 header).

Packets with TCP/IP errors (header or payload) are dropped in MTL when DIS_TCP_EF bit of the *Rx queue operating mode register (ETH_MTLRXQOMR)* is reset and FEP bit is set.

This engine also identifies a TCP, UDP, or ICMP payload in the received IP datagrams (IPv4 or IPv6) and calculates the checksum of such payloads properly, as defined in the TCP, UDP, or ICMP specifications. This engine includes the TCP, UDP, or ICMPv6 pseudo-header bytes for checksum calculation and checks whether the received checksum field matches the calculated value. The result of this operation is given as a Payload Checksum Error bit in the receive status word. This status bit is also set if the length of the TCP, UDP, or ICMP payload does not match the expected payload length given in the IP header.

Table 565: Receive checksum offload engine functions for different packet types describes the functions supported by the Rx COE based on the packet type. When the payload of an IP packet is not processed (indicated as "No" in the table), the information (whether the checksum engine is bypassed or not) is given in the receive status.

Note: The MAC does not append any payload checksum bytes to the received Ethernet packets.

Table 565. Receive checksum offload engine functions for different packet types

Packet type	Hardware IP header checksum checking	Hardware TCP/UDP/ICMP checksum checking
Non-IPv4 or IPv6	No	No
IPv4 packet is greater than 1,522 bytes (2,000 bytes when IEEE 802.3ad support for 2K packets is enabled in the MAC)	Yes	Yes
IPv6 packet is greater than 1,522 bytes (2,000 bytes when IEEE 802.3ad Support for 2K packets is enabled in the MAC)	Not applicable	Yes
IPv4 with TCP, UDP, or ICMP	Yes	Yes
IPv4 header's protocol field contains a protocol other than TCP, UDP, or ICMP	Yes	No
IPv4 packet has IP options (IP header is longer than 20 bytes)	Yes	Yes
Packet is an IPv4 fragment	Yes	No
IPv6 packet with the following next header fields in main or extension headers: – Hop-by-hop options (in IPv6 main header) – Hop-by-hop options (in IPv6 extension header) – Destinations options – Routing (with segment left 0) – Routing (with segment left > 0) – TCP, UDP, or ICMP – Any other next header field in main or extension headers	 – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable – Not applicable	 – Yes – No – Yes – Yes – No – Yes – No
IPv4 packet has TCP header with Options fields	Yes	Yes
IPv4 Tunnels: – IPv4 packet in an IPv4 tunnel – IPv6 packet in an IPv4 tunnel	 – Yes (IPv4 tunnel header) – Yes (IPv4 tunnel header)	 – No – No
IPv6 Tunnels: – IPv4 packet in an IPv6 tunnel – IPv6 packet in an IPv6 tunnel	 – Not applicable – Not applicable	 – No – No
IPv4 packet has 802.3ac tag (with C-VLAN Tag or S-VLAN Tag when enabled).	Yes	Yes
IPv6 packet has 802.3ac tag (with C-VLAN Tag or S-VLAN Tag when enabled).	Not applicable	Yes
IPv4 frames with security features (such as encapsulated security payload)	Yes	No
IPv6 frames with security features (such as encapsulated security payload)	Not applicable	No

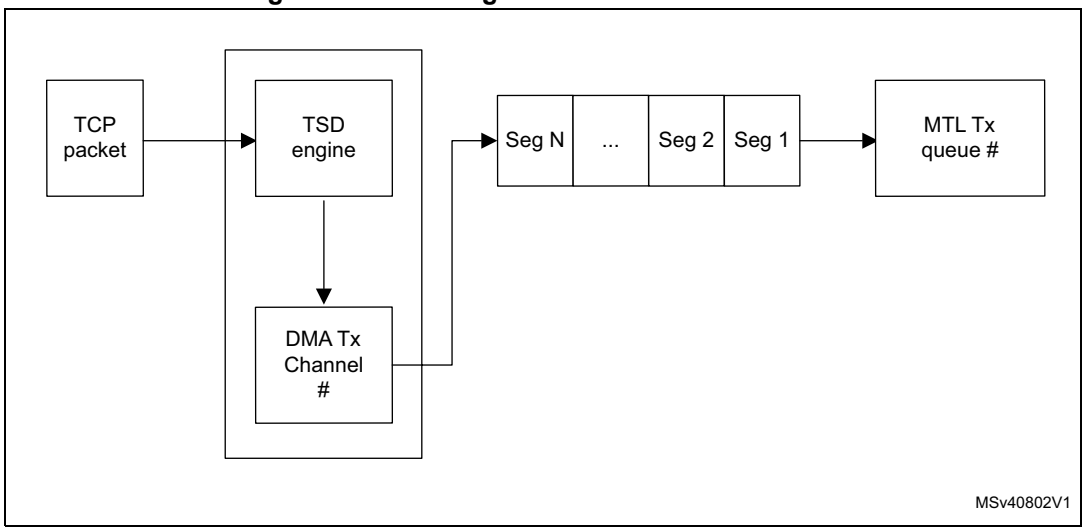
63.5.6 TCP segmentation offload

The MAC supports the TCP segmentation offload (TSO) feature in which the DMA splits a large TCP packet into multiple small packets and passes these packets to the MTL as shown in *Figure 820*.

This feature is enabled by programming the TSE bit of corresponding ETH_DMACCR register (see *Channel transmit control register (ETH_DMACTXCR)*). It is only supported when the MAC operates in Full-duplex mode.

For detailed programming steps, refer to *Section 63.9.13: Programming guidelines for TSO*.

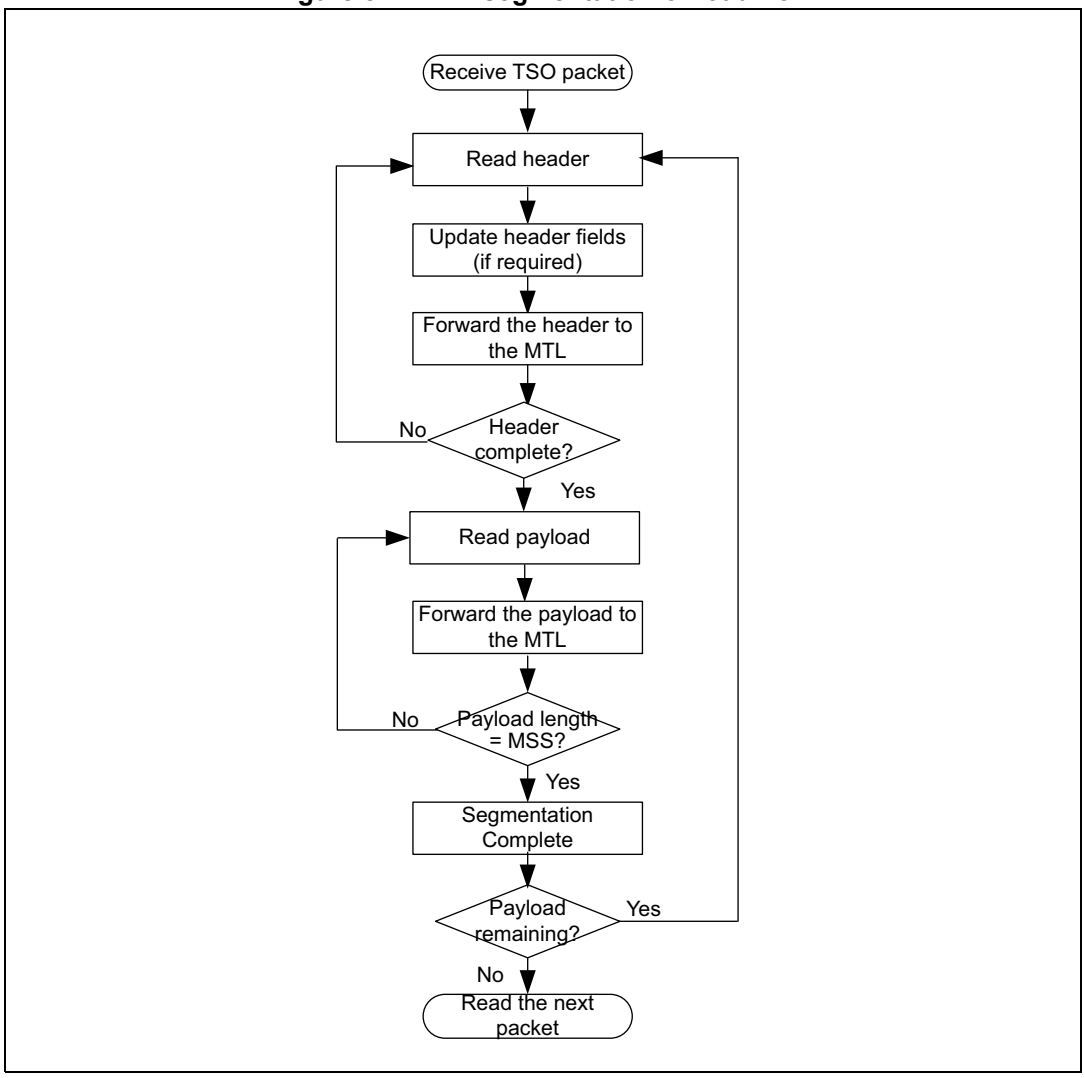
Figure 820. TCP segmentation offload overview



DMA operation with TSO feature

Figure 821 shows the TSO flow.

Figure 821. TCP segmentation offload flow



For the TSO feature, the Tx DMA operation is as follows:

1. The application sets up the Transmit descriptor (TDES0-TDES3) and sets the Own bit (TDES3[31]) after setting up the corresponding data buffer(s) with Ethernet packet data.
2. The application increases the offset value of the Descriptor tail pointer of the DMA Tx channel.
3. While in the Run state, the DMA fetches the next available descriptor and performs one of the following actions:
   – If the descriptor is a context descriptor and the context is not between the first and last descriptors of a packet, the DMA stores the context values.

- If the descriptor is a context descriptor and the context is between the first and last descriptors of a packet, the DMA closes the context descriptor indicating a Context Descriptor Error (TDES3[23]) and fetches the next descriptor.
- If the descriptor is a normal descriptor, the DMA checks the TSE bit. If the TSE bit is not set, the DMA continues with the default mode of operation or OSF operation (if enabled).

4. The DMA calculates the number of segments from the TCP payload length (TDES3[17:0]) and the MSS value.
5. The DMA goes through channel arbitration to fetch the data buffers. The DMA fetches the header and payload separately.
6. For the first segment, the DMA fetches the header from the system memory and stores it in the TSO memory (if present and when the length of header is not greater than the TSO memory size). If the current segmented packet is not the first segment, it fetches again the header buffer in system memory, as done for the first segment. In such cases, the DMA does not close the first descriptor containing the header buffer until the header for last segment is fetched.
7. The required fields in the header bytes are modified/updated as per the segmentation requirements and written into the corresponding MTL Tx queue.
8. The DMA then takes the payload buffer pointer, fetches the MSS number of payload bytes from the system memory, and directly pushes it into the MTL Tx queue. If the buffer(s) in the descriptor do(es) not have enough data for the MSS payload (except for the last segment), the DMA closes this descriptor.
9. The DMA jumps to Step 3 and repeats the process until the last segment is written into the Tx queue.
10. The DMA closes the last descriptor and the first descriptor (containing the header buffer when it is not stored in TSO memory), and then moves on to the next packet transfer.

The DMA repeats all these steps if more descriptors are available. When no more descriptor are available, the DMA enters the suspend state.

Note: The TSO engine determines whether to perform TSO or USO operation based on the THL field (TCP Header Length) in TDES3 of first Normal Tx descriptor for the packet. The value of 2 indicates USO and any value greater than or equal to 5 indicates TSO.

TCP/IP header fields

While segmenting a TCP packet, the DMA automatically updates the TCP/IP header fields. *Table 566* describes how the TCP and IP headers are updated.

Table 566. TSO: TCP and IP header fields

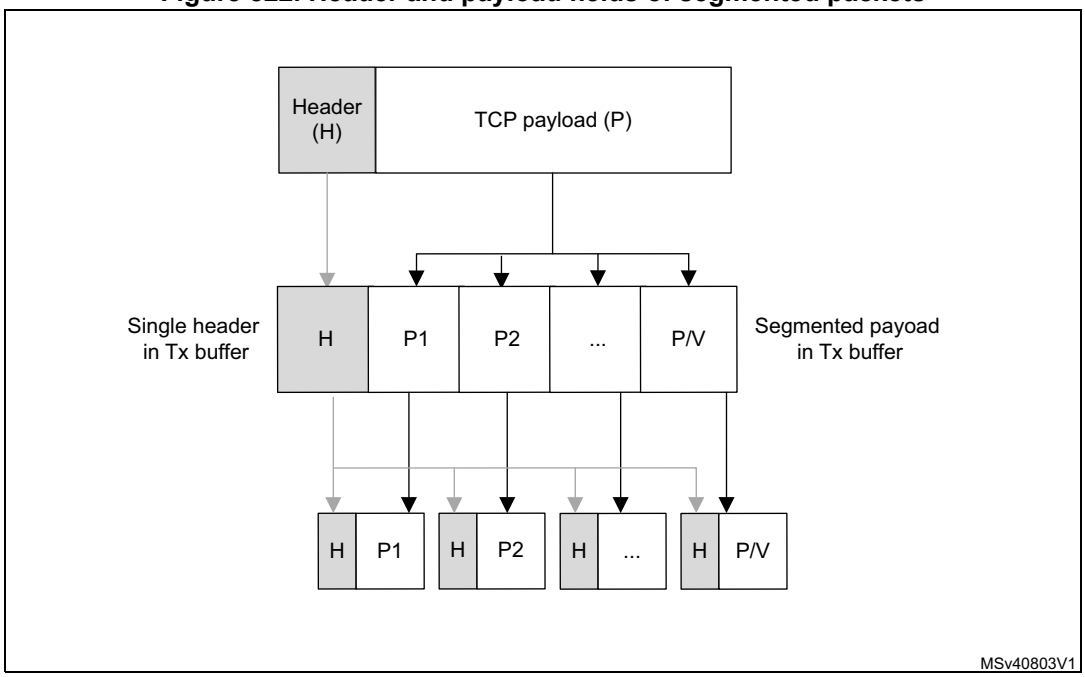
Packet sequence	TCP header	IP header
First packet	1. The sequence number is not updated. The value provided in the header is used. 2. If set, the FIN and PSH flags are cleared. 3. The TCP checksum is calculated again.	IPv4 Header – Total Length = MSS + TCP Header Length + IP Header Length – Identification field is not modified. It is sent as per the header provided by the software. – IPv4 Header Checksum is recalculated. IPv6 Header – Payload Length = MSS + TCP Header Length + IP Extension Header Length
Subsequent packets	1. The sequence number is updated. The MSS value is added to the sequence number value of previous segment. 2. If set, the FIN and PSH flags are cleared. 3. The TCP checksum is calculated again.	IPv4 Header – Total Length = MSS + TCP Header Length + IP Header Length – Identification field = Previous Identification Field + 1 – IPv4 Header Checksum is recalculated IPv6 Header – Payload Length = MSS + TCP Header Length + IP Extension Header Length
Last packet	1. The sequence number is updated. The MSS value is added to the sequence number value of previous segment. 2. If FIN and PSH flags were set in original header, these flags are set. 3. The TCP checksum is calculated again.	IPv4 Header – Total Length = Remaining Payload + TCP Header Length + IP Header Length – Identification Field = Previous Identification Field + 1 – IPv4 header Checksum is recalculated IPv6 Header – Payload Length = Remaining Payload Length + TCP Header Length + IP Extension Header Length

Header and payload fields of segmented packets

After segmentation, the split packets use the same header as the parent TCP packet for header fields other than the ones described in *Table 566: TSO: TCP and IP header fields*. *Figure 822: Header and payload fields of segmented packets* shows how same header is used for the header fields of segmented packets.

The application must create the header in Buffer 1 of the first descriptor of the packet to be segmented and provide the header length in TDES2 of the first descriptor (FD = 1). When the FD bit is set, the DMA reads the header from the header buffer to which the TDES0 is pointing. Buffer 2 of the first descriptor can be used for payload and TDES0 and TDES1 of subsequent descriptors. For subsequent descriptors (FD = 0), the address to which the TDES0 and TDES1 are pointing is treated as payload buffer address of the same packet.

Figure 822. Header and payload fields of segmented packets



Context descriptor sequence

The context descriptor can provide the maximum segment size (MSS) value for segmentation. The application must provide the context descriptor before the normal descriptor to be used for the corresponding TCP packet. If the application needs to provide a new MSS, it must create the context descriptor in the descriptor list before the first normal descriptor of the packet to be segmented with the new MSS value. The MSS value in the context descriptor is valid only if the TCMSSV bit of TDES3 in context descriptor is set and the OSTC bit is reset (refer to *Section 63.10.3: Transmit descriptor*).

When the application provides a context descriptor with a valid MSS value, the DMA internally stores the MSS value and uses this value for all subsequent packets for which the TSO is enabled through the TSE bit of TDES3 normal descriptor.

If the application places a context descriptor in the middle of a packet (between the first and last descriptors of a packet), the DMA does the following:

1. The DMA ignores the context and closes the descriptor.
2. The DMA indicates the error in descriptor status.
3. The DMA generates an interrupt if the CDEE bit is set in the Interrupt enable register corresponding to a DMA channel (see *Channel interrupt enable register (ETH_DMACIER)*).

The application can read the interrupt status through CDE bit of Status register corresponding to a DMA channel (see *Channel status register (ETH_DMACSR)*).

Building the Descriptor and the packet for the TSO feature

To enable segmentation for a packet, the application must set the TSE bit of TDES3 of first normal descriptor (see *Section 63.10.3: Transmit descriptor*). If the TSE bit is set in TDES3 for a non TCP/IP packet, the DMA behavior is unpredictable.

The application must program the length of the TCP packet payload in TDES3[17:0] and the TCP header in TDES3[22:19]. The maximum length of TCP packet payload that can be segmented is 256 Kbytes.

The header of the packet including Ethernet header, L3 header and L4 header should be provided in Buffer1 of the first normal descriptor of the TSO packet. Only buffer 1 of the first normal descriptor of a packet enabled for TSO is taken as the buffer containing the header.

The TCP payload can begin from buffer 2 of the first normal descriptor and continue to buffer1 and buffer 2 of second normal descriptor and subsequent descriptors.

The TCP payload may span across multiple buffers and multiple descriptors. The size of buffers containing the TCP payload should add up to be equal to the TCP payload length provided in TDES3[17:0] of the first normal descriptor.

The MAC always calculates and appends CRC and inserts Padding (if required) for all packets segmented by the DMA. If the TSE bit of TDES3 is enabled, the CRC PAD Control (CPC) field of TDES3 is reserved. To determine the size of a TCP packet after segmentation, the DMA uses the Maximum Segment Size (MSS) provided by the application through context descriptor. The DMA segments only those packets which have payload size greater than MSS. The application must provide the MSS by either programming the MSS value in ETH_DMACCR (see *Channel control register (ETH_DMACCR)*) or by providing a context descriptor. The DMA uses the last programmed value of MSS or the last MSS value provided through context (whichever is provided later).

The header length plus the MSS size (which is equal to the size of each TCP segment) should not exceed 16383 bytes otherwise the MAC transmitter truncates the packet after 16383 bytes causing a CRC error.

The header length plus MSS size plus programmed PBL value in ETH_DMACTXCR register (see *Channel transmit control register (ETH_DMACTXCR)*) should be lesser than the Tx queue size programmed in TQS field of ETH_MTLTXQOMR register (see *Tx queue operating mode Register (ETH_MTLTXQOMR)*). A MSS plus header equal to half the programmed Tx queue size is recommended.

The DMA also supports segmentation of VLAN-tagged TCP/IP frames. If the TCP packet has a VLAN tag, then the same tag is used for all the segments irrespective of the VLAN tag type provided (C-VLAN or S-VLAN). The VLAN tag insert/replace control bits are used for all segments.

If the Double VLAN feature is selected, then the DMA passes both tags for all segments irrespective of the VLAN tag types provided (C-VLAN or S-VLAN). The VLAN tag Insert/Replace control bits for both tags is applicable to all segments. If the Double VLAN feature is not selected, then the application must not set the TSE bit in TDES3 for a TCP/IP packet with two tags. The DMA behavior in this scenario is unpredictable.

If the TSE bit is set in TDES3 for the packet and TCP header length provided is less than 5 (meaning this is an invalid TCP header because it is less than 20 bytes), the DMA does not perform segmentation, instead it transmits the entire packet as a single packet. In this scenario, the CRC pad control bits are forced by DMA to 00 (MAC does CRC and padding) and checksum insertion control bits are forced to 11 (hardware does the checksum calculation for both header and payload).

63.5.7 IPv4 ARP offload

The MAC supports the Address Recognition Protocol (ARP) Offload for IPv4 packets. This feature allows to process the IPv4 ARP request packet in the receive path and to generate the corresponding ARP response packet in the transmit path.

The MAC generates the ARP reply packets for appropriate ARP request packets**.** ARP packets for IPv4 are L2 layer packets with Length/Type of 0x0806.

The ARP offloading sequence is as follows:

1. The MAC receiver gets an ARP request if the request Target Protocol Address matches the IPv4 address programmed in the MAC L3 register.
2. The MAC generates an ARP reply packet.
3. The MAC copies the Sender Hardware Address field in the ARP request to the following fields:
   – DA field of the Ethernet packet header
   – Target Hardware Address field of the ARP reply packet
4. The MAC copies the Sender Protocol Address field in the ARP request to the Target Protocol Address field in the ARP reply packet.
5. The MAC places its MAC address in the following fields:
   – SA field of the Ethernet packet header
   – Sender Hardware Address field of the ARP reply packet
6. The MAC copies the Target Protocol Address field in the ARP request to the Sender Protocol Address field in the ARP reply packet.
7. The MAC sets the opcode field in ARP reply packet to 2 indicating ARP reply.
8. The MAC recalculates the CRC and performs padding for the generated ARP reply packet.
9. The MAC transmitter sends the ARP reply

The MAC processes only one ARP request at a time. It does not store the fields of multiple ARP requests. If the MAC receives an ARP request when it is already processing an earlier ARP request, the MAC does not generate the ARP reply for new ARP request. The MAC forwards the new ARP request packet to the application with ARP Reply Not Generated status bit set (bit 34). However, in power-down mode, if the MAC receives an ARP request when it is already processing an earlier ARP request, the MAC drops the new ARP request. If the Disable CRC check (DCRCC) bit of the *Extended operating mode configuration register (ETH_MACECR)* is set, then the MAC does not check for valid CRC of a ARP

request packet. It can generate an ARP response packet if the other conditions are valid. The ARP request packet must always have a valid CRC.

Note: When the received ARP request is less than the 64-byte packet length, the MAC does not send an ARP response. It is treated as a normal packet and forwarded to the application based on the MAC filter settings.

63.5.8 Loopback

The MAC supports loopback of transmitted packets to its receiver.

Guidelines for using Loopback mode

Below some guidelines for using the Loopback mode:

- Enable loopback only with the Full-duplex mode. In Half-duplex mode, the carrier sense signal or collision signal inputs get sampled which may result into issues such as packet dropping.
- If the Loopback mode is enabled without connecting a PHY chip, externally generate the Tx and Rx clocks and provide these clocks to the MAC.
- Do not loop back big packets since they may get corrupted in the loopback FIFO.

The Transmit and Receive clocks can have an asynchronous timing relationship. Therefore, an asynchronous FIFO is used to make the loopback path of the transmitted data to the Receive path. The FIFO is free-running to write on the write clock (eth_mii_tx_clk) and read on every read clock (eth_mii_rx_clk). At the start of each packet read from the FIFO, the write and read pointers are reinitialized to have an offset of four (in 10/100 Mbps mode). This avoids overflow or underflow during a packet transfer, and ensures that the overflow or underflow occurs only during the IPG period between the packets. The FIFO depth of five or nine is sufficient to prevent data corruption for packet sizes up to 9,022 bytes with a difference of 200 ppm between MII Transmit and Receive clock frequencies.

Therefore, bigger packets should not be looped back because they may get corrupted in this loopback FIFO.

At the end of every received packet, the Receive Protocol Engine module generates received packet status and sends it to the Receive Packet Controller module. The control, missed packet, and filter fail status are added to the Receive status in the Receive Packet Controller module. The MAC does not process ARP or PMT packets that are looped back.

Enabling Loopback mode

To enable this feature, program the LM bit of the *Operating mode configuration register (ETH_MACCR)*. Loopback can be enabled for all PHY interfaces. The data is always looped back through internal asynchronous FIFO on to the internal Receive MII interface, irrespective of which PHY interface is selected.

The loopback data is also passed through the corresponding transmit PHY interface block, onto the Ethernet line.

Note: During loopback, the data/packet is reflected on mii_txd signal.

Preemption is not supported in Loopback mode.

63.5.9 Flow control

The transmit flow control involves transmitting Pause packets in Full-duplex mode and back-pressure in Half-duplex mode to control the flow of packets from the remote end. This section describes the flow control for transmit and receive paths.

Flow control in Full-duplex mode

In Full-duplex mode, the MAC uses IEEE 802.3x Pause packets for flow control. *Table 567* describes the fields of a Pause packet.

Table 567. Pause packet fields

Field	Description
DA	Contains the special multicast address
SA	Contains the MAC address 0
Type	Contains 8808
MAC Control opcode	Contains 0001 for IEEE 802.3x Pause Control packets
PT	Contains Pause time specified in the PT field of the *Tx Queue flow control register (ETH_MACQTXFCR)*

When the FCB bit is set, the MAC generates and transmits a single Pause packet. If the FCB bit is set again after the Pause packet transmission is complete, the MAC sends another Pause packet irrespective of whether the pause time is complete or not. To extend the pause or terminate the pause prior to the time specified in the previously-transmitted Pause packet, the application should program the Pause Time register with appropriate value and then again set the FCB bit.

Flow control in Half-duplex mode

In Half-duplex mode, the MAC uses the deferral mechanism for the flow control (backpressure). When the application requests to stop receiving packets, the MAC sends a JAM pattern of 32 bytes when it senses a packet reception, provided the transmit flow control is enabled. This results in a collision and the remote station backs off. If the application requests a packet to be transmitted, it is scheduled and transmitted even when the backpressure is activated. If the backpressure is kept activated for a long time (and more than 16 consecutive collision events occur), the remote stations abort the transmission because of excessive collisions.

Table 568 describes the flow control in the Tx path based on the setting of the following bits:

- TFE bit of *Tx Queue flow control register (ETH_MACQTXFCR)*
- DM bit of *Operating mode configuration register (ETH_MACCR)*

Flow control is similar for all queues.

Table 568. Tx MAC flow control

TFE	DM	Description
0	X	The MAC transmitter does not perform the flow control or backpressure operation.
1	0	The MAC transmitter performs backpressure when Bit 0 of *Tx Queue flow control register (ETH_MACQTXFCR)* is set.
1	1	The MAC transmitter sends the Pause packet when Bit 0 of *Tx Queue flow control register (ETH_MACQTXFCR)* is set.

Transmit flow control

The transmit flow control is enabled when TFE bit is set in *Tx Queue flow control register (ETH_MACQTXFCR)*.

Flow control trigger

The application can request the MAC to send a Pause packet or initiate back-pressure by setting the FCB bit in the corresponding *Tx Queue flow control register (ETH_MACQTX-FCR)*.

Receive flow control

In the Receive path, the flow control is functional only in Full-duplex mode. If any Pause packet is received in Half-duplex mode, the packet is considered as a normal control packet.

Description of receive flow control

Table 569 describes the flow control in the Rx path based on the setting of the following bits:

- RFE bit of *Rx flow control register (ETH_MACRXFCR)*
- DM bit of *Operating mode configuration register (ETH_MACCR)*

Table 569. Rx MAC flow control

RFE	DM	Description
0	x	The MAC receiver does not detect the received Pause packets.
1	0	The MAC receiver does not detect the received Pause packets but recognizes such packets as Control packets.
1	1	The MAC receiver detects or processes the Pause packets and responds to such packets by stopping the MAC transmitter.

The following sequence describes the Rx flow control:

1. The MAC checks the destination address (DA) of the received Pause packet for either of the following:
   - Multicast destination address: the DA matches the unique multicast address specified for the control packet (0x0180 C200 0001).
   - Unicast destination address: the DA matches the content of the MAC Address 0 registers (*MAC Address 0 high register (ETH_MACA0HR)* and *MAC Address x*

low register (ETH_MACAxLR)) and the UP bit of *Rx flow control register (ETH_MACRXFCR)* is set.

If the UP bit is set, the MAC processes Pause packets with unicast destination address in addition to the unique multicast address.

2. The MAC decodes the following fields of the received packet:
   - Type field: this field is checked for 0x8808.
   - Opcode field: this field is checked for 0x0001 (Pause packet).
   - Pause time: the Pause time (for Pause packet) is captured to determine the time for which the transmitter needs to be blocked.
3. If the byte count of the status indicates 64 bytes and there is no CRC error, the MAC transmitter pauses the transmission of any data packet for the duration of the decoded Pause Time value multiplied by the slot time (64 byte times).

If subsequent Pause packets are received before the earlier Pause Time expires, the MAC updates the Pause Timer with new value.

Enabling receive flow control

Set the RFE bit in the *Rx flow control register (ETH_MACRXFCR)* to enable the Pause flow control.

63.5.10 MAC management counters

The peripheral supports storing the statistics about the received and transmitted packets in registers that are accessible through the application.

The counters in the MAC management counters (MMC) module can be viewed as an extension of the register address space of the CSR module. The MMC module maintains a set of registers for gathering statistics on the received and transmitted packets. The register set includes a control register for controlling the behavior of the registers, two 32-bit registers containing interrupts generated (receive and transmit), and two 32-bit registers containing masks for the Interrupt register (receive and transmit). These registers are accessible from the Application through the AHB slave interface in the same way the CSR registers are accessed. The organization of these registers is shown in *Section 63.11.4: Ethernet MAC and MMC registers*.

The MMC counters are free running. There is no separate enable for the counters to start. A particular MMC counter starts counting when corresponding packet is received or transmitted.

The Receive MMC counters are updated for packets that are passed by the Address Filter (AFM) block. The statistics of packets dropped by the AFM module, are not updated unless they are runt packets of less than 6 bytes (DA bytes are not received fully). To get statistics of all packets, set bit 0 in the *Packet filtering control register (ETH_MACPFR)*. The MMC module gathers statistics on encapsulated IPv4, IPv6, TCP, UDP, or ICMP payloads in received Ethernet packets.

In addition to control registers, two sets of registers are implemented:

- 6 registers used for collision, error and good packets counters:
  - Tx single collision good packets register (*Tx single collision good packets register (ETH_TX_SINGLE_COLLISION_GOOD_PACKETS)*
  - Tx multiple collision good packets register (*Tx multiple collision good packets register (ETH_TX_MULTIPLE_COLLISION_GOOD_PACKETS)*
  - Tx packet count good register (*Tx packet count good register (ETH_TX_PACKET_COUNT_GOOD)*
  - Rx CRC error packets register (*Rx CRC error packets register (ETH_RX_CRC_ERROR_PACKETS)*
  - Rx alignment error packets register (*Rx alignment error packets register (ETH_RX_ALIGNMENT_ERROR_PACKETS)*
  - Rx unicast packets good register (*Rx unicast packets good register (ETH_RX_UNICAST_PACKETS_GOOD)*
- 4 registers to record LPI mode transition:
  - Tx LPI microsecond timer register (*Tx LPI microsecond timer register (ETH_TX_LPI_USEC_CNTR)*
  - Tx LPI transition counter register (*Tx LPI transition counter register (ETH_TX_LPI_TRAN_CNTR)*
  - Rx LPI microsecond counter register (*Rx LPI microsecond counter register (ETH_RX_LPI_USEC_CNTR)*
  - Rx LPI transition counter register (*Rx LPI transition counter register (ETH_RX_LPI_TRAN_CNTR)*

Definitions

The following terminology is used in MMC register descriptions:

- Transmitted packets are considered “good” if transmitted successfully. In other words, a transmitted packet is good if the packets transmission is not aborted because of any of the following errors:
  - Jabber timeout
  - No carrier or loss of carrier
  - Late collision
  - Packet underflow
  - Excessive deferral
  - Excessive collision
- Received packets are considered “good” if none of the following errors exists:
  - CRC error
  - Runt packet (shorter than 64 bytes)
  - Alignment error (in 10/100 Mbps only)
  - Length error (non-Type packet only)
  - Out of range (non-Type packet only, longer than 1518 bytes)
- The maximum transmit frame size depends on the frame type, as follows:
  - Untagged frame maxsize = 1,518
  - VLAN frame maxsize = 1,522
  - Jumbo frame maxsize = 9,018
  - JumboVLAN frame maxsize = 9,022
- The maximum receive packet size depends on the packet type and control bits (JE, S2KP, GPSLCE and EDVLP), as shown in the *Table 570*.

Table 570. Size of the maximum receive packet

JE	S2KP	GPSLCE	EDVLP	Untagged frame maximum size in bytes	Single VLAN frame maximum size in bytes	Double VLAN Frame maximum size in bytes
1	X	X	1	9018	9022	9026
0	1	X	X	2000	2000	2000
0	0	1	1	GPSL	GPSL+4	GPSL+8
0	0	0	1	1518	1522	1526
1	X	X	0	9018	9022	9022
0	0	1	0	GPSL	GPSL+4	GPSL+4
0	0	0	0	1518	1522	1522

63.5.11 Interrupts generated by the MAC

Interrupts can be generated from the MAC as a result of various events. These interrupt events are combined with the events in the DMA on the eth_sbd_intr_it signal. The MAC interrupts are of level type, that is, the interrupt remains asserted (high) until it is cleared by the application or software.

The *Interrupt status register (ETH_MACISR)* describes the events that can cause an interrupt from the MAC. The MAC interrupts are enabled by default. Each event can be prevented from asserting the interrupt on the eth_sbd_intr_it signals by setting the corresponding mask bits in the *Interrupt enable register (ETH_MACIER)*.

The interrupt register bits only indicate the block from which the event is reported. You must read the corresponding status registers and other registers to clear the interrupt.

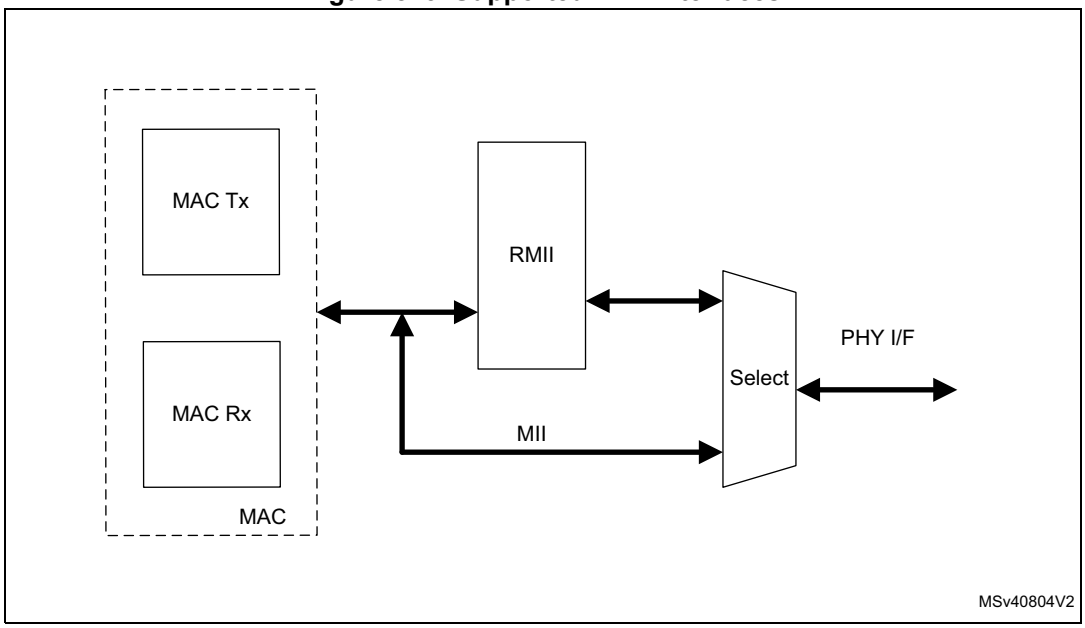
63.5.12 MAC and MMC register descriptions

Refer to *Section 63.11.4: Ethernet MAC and MMC registers*.

63.6 Ethernet functional description: PHY interfaces

The Ethernet peripheral support several PHY interfaces. The root interface is the MII one. All other interfaces are derived from it as shown in *Figure 823*.

Figure 823. Supported PHY interfaces



This section describes the SMA module used for PHY control and different PHY interfaces. It contains the following sections:

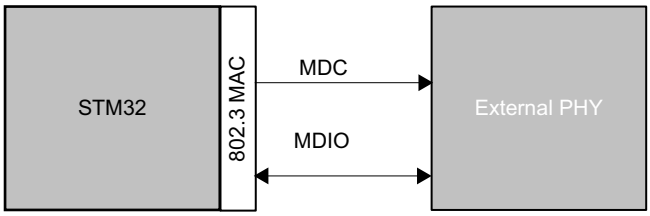
- *Station management agent (SMA)*
- *Media independent interface (MII)*
- *Reduced media independent interface (RMII)*

63.6.1 Station management agent (SMA)

The application can access the PHY registers through the station management agent (SMA) module. The SMA includes a two-wire station management interface (MIM).

The SMA module supports accessing up to 32 PHYs. The application can address one of the 32 registers from any 32 PHYs. Only one register in one PHY can be addressed at a time. The application sends the control data to the PHY and receives status information from the PHY through the SMA module, as shown in *Figure 824*.

Figure 824. SMA Interface block



SMA functional overview

The MAC initiates the management write or read operation with respect to the MDC clock. The MDC clock is derived from the CSR clock (eth_hclk). The maximum operating frequency of the ETH_MDC pin is 2.5 MHz, as specified in IEEE 802.3 specifications. However, a different divider can be selected if the system supports higher clock frequencies. The division factor depends on the clock range setting through CR[3:0] in the *MDIO address register (ETH_MACMDIOAR)* register. The MDC clock is selected as follows:

Table 571. MCD clock selection

Selection	eth_hclk	MDC clock
0000	60–100 MHz	CSR clock/42
0001	100–150 MHz	CSR clock/62
0010	20–35 MHz	CSR clock/16
0011	35–60 MHz	CSR clock/26
0100	150–250 MHz	CSR clock/102
0101	250–300 MHz	CSR clock/124
0110, 0111	Reserved	-

The data exchange between the MAC and the PHY is performed through a three-state buffer and brought out as ETH_MDIO line connected to the PHY.

Figure 825 shows the structure of a Clause 45 MDIO packet, while *Table 572* provides a detailed description of the packet fields.

Figure 825. MDIO packet structure (Clause 45)

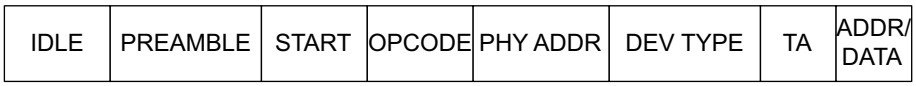


Table 572. MDIO Clause 45 frame structure

Field	Description
IDLE	The ETH_MDIO line is three-state; there is no clock on ETH_MDC.
PREAMBLE	32 continuous bits of value 1
START	Start of packet is 0b00
OPCODE	– 0b00: Address – 0b01: Write – 0b10: Read+ Address – 0b11: Read
PHY ADDR	5-bit address select for one of 32 PHYs
DEV TYPE	5-bit device type
TA	Turnaround – 0bZ0: Read and post-read increment address – 0b10: Write and address MDIO accesses where Z is the tri-state level
DATA	16-bit value: for an address cycle (OPCODE = 0b00), this frame contains the address of the register to be accessed on the next cycle. For the data cycle of a write frame, this field contains the data to be written to the register. For read or post-read increment address frames, this field contains the contents of the register read from the PHY. – In address and data write cycles, the peripheral drives the ETH_MDIO line during the transfer of these 16 bits. – In read and post-read increment address cycles, the PHY drives the ETH_MDIO line during the transfer of these 16 bits.

The frame structure for Clause 22 frames is also supported. The C45E bit in *MDIO address register (ETH_MACMDIOAR)* can be programmed to enable Clause 22 or Clause 45 mode of operation. *Figure 826* shows the structure of a Clause 22 MDIO packet, while *Table 573* provides a detailed description of the packet fields.

Figure 826. MDIO packet structure (Clause 22)

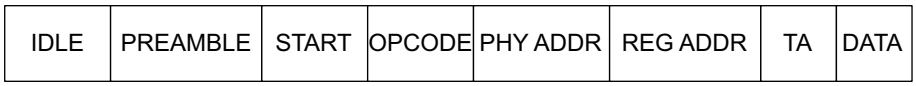


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Table 573. MDIO Clause 22 frame structure

Field	Description
IDLE	The ETH_MDIO line is three-state; there is no clock on ETH_MDC.
PREAMBLE	32 continuous bits of value 1
START	Start of packet is 0b01
OPCODE	0b10 for Read and 0b01 for Write
PHY ADDR	5-bit address select for one of 32 PHYs
REG ADDR	Register address in the selected PHY
TA	Turnaround – 0bZ0: Read and post-read increment address – 0b10: Write and address MDIO accesses where Z is the tri-state level
DATA	Any 16-bit value. In a Write operation, the MAC drives ETH_MDIO. In a Read operation, the PHY drives it.

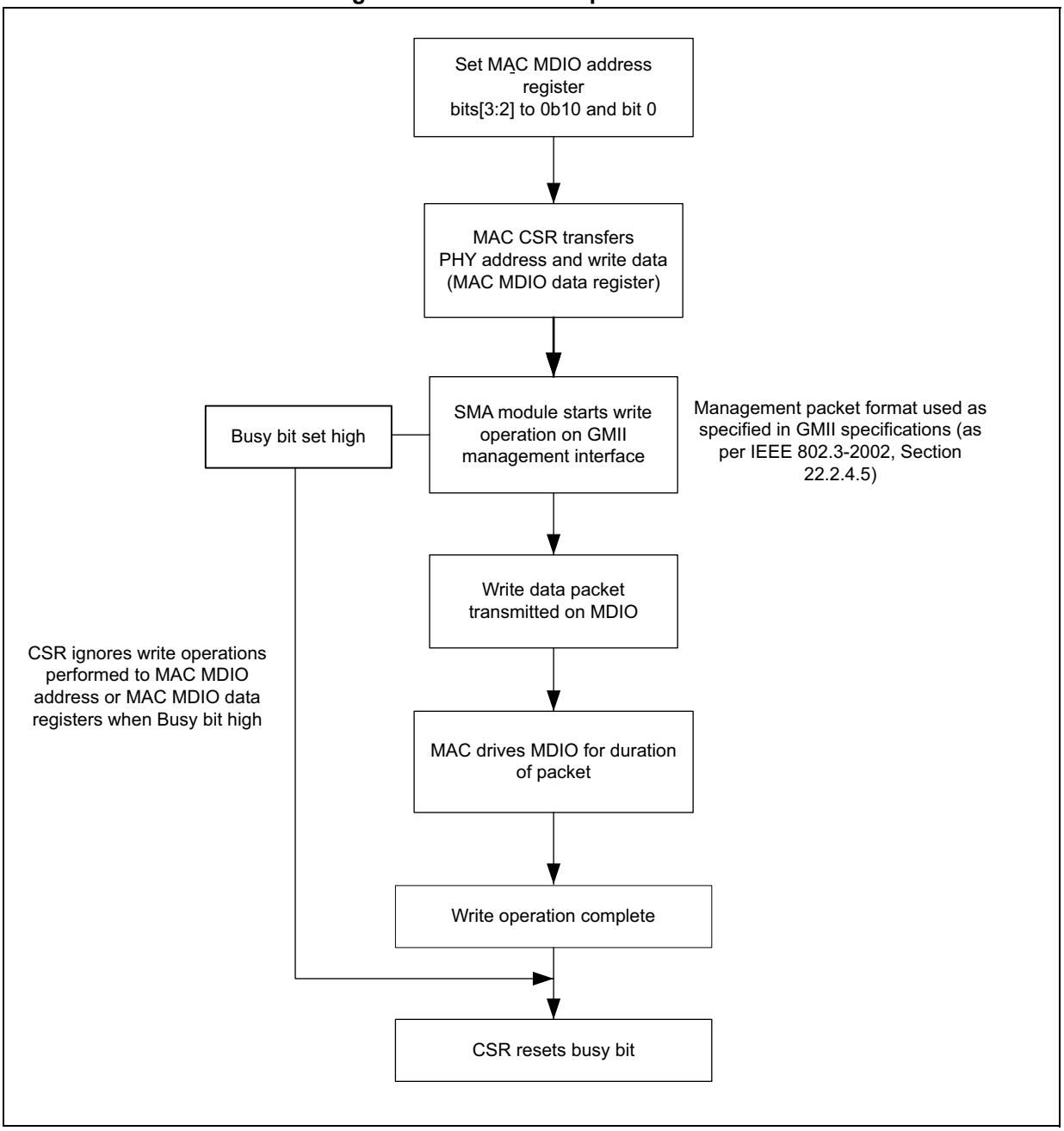
In addition to normal read and write operations, the SMA also supports post-read increment address while operating in Clause 45 mode.

MII management write operations

After the station management agent receives the PHY address and the write data from the MAC CSR module, the SMA starts a write operation to the PHY registers.

Figure 827 illustrates the flow for a write operation from the SMA module to the PHY registers.

Figure 827. SMA write operation flow



When bits[3:2] are set to 01 and bit 0 to 1 in the *MDIO address register (ETH_MACMDIOAR)*, the MAC CSR module transfers the PHY address, the register address in PHY, and the write data (*MDIO data register (ETH_MACMDIODR)*) to the SMA to initiate a Write operation into the PHY registers. At this point, the SMA module starts a Write operation on the MII management Interface using the management packet format specified in the MII specifications (as per IEEE 802.3-2002 specifications, *Section 22.2.4.5*).

When the SMA module starts a Write operation, the write data packet is transmitted on the MDIO line. The MAC drives the MDIO line for complete duration of the packet. The Busy bit is set high until the write operation is complete. The CSR ignores the Write operations performed to the *MDIO address register (ETH_MACMDIOAR)* or the *MDIO data register*

(ETH_MACMDIODR) during this period (the Busy bit is high). When the Write operation is complete, the SMA module indicates this to the CSR, and the CSR resets the Busy bit. The packet format for the Write operation is as follows:

Figure 828. Write data packet

IDLE	PREAMBLE	START	OPCODE	PHY ADDR	REG ADDR	TA	DATA	IDLE
Z	1111..11	01	01	AAAAA	RRRRR	10	DDD...DDD	Z

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MII management read operation

When bits[3:2] are set to 11 and bit 0 to 1 in the *MDIO address register (ETH_MACMDIOAR)*, the MAC CSR module transfers the PHY address and the register address in PHY to the SMA to initiate a Read operation in the PHY registers. At this point, the SMA module starts a Read operation on the MII management interface using the management packet format specified in the MII specifications (as per IEEE 802.3-2002 specifications, *Section 22.2.4.5*).

When the SMA module starts a Read operation on the MDIO, the CSR ignores the Write operations to the *MDIO address register (ETH_MACMDIOAR)* or *MDIO data register (ETH_MACMDIODR)* register during this period (the Busy bit is high) and the transaction is completed without any error on the MCI interface. When the Read operation is complete, the SMA indicates this to the CSR. The CSR resets the Busy bit and updates the *MDIO data register (ETH_MACMDIODR)* with the data read from the PHY. The MAC drives the MDIO line for the complete duration of the frame except during the Data fields when the PHY is driving the MDIO line. For more information about the communication from the application to the PHYs, see the Reconciliation Sublayer and Media Independent Interface Specifications sections of the IEEE 802.3z, 1000BASE Ethernet.

The packet format for the Read operation is as follows:

Figure 829. Read data packet

IDLE	PREAMBLE	START	OPCODE	PHY ADDR	REG ADDR	TA	DATA	IDLE
Z	1111..11	01	10	AAAAA	RRRRR	Z0	DDD...DDD	Z

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Preamble suppression

The IEEE standard specifies 32-bit preamble (all-ones) for the MDIO frames. The peripheral provides controls to support preamble suppression. It transmits MDIO frames with only 1 preamble bit. The preamble suppression can be enabled by setting the PSE bit in *MDIO address register (ETH_MACMDIOAR)*.

Trailing clocks and back-to-back transactions

The peripheral drives the ETH_MDC clock for the duration of the MDIO frame. There is no clock driven during the idle period. The trailing clock feature can be used if the PHY needs the ETH_MDC clock to be active for some cycles after the MDIO frame. The NTC[2:0] bitfield in *MDIO address register (ETH_MACMDIOAR)* allows the programming of trailing clocks from 0 to 7.

The peripheral supports back-to-back transactions which allow starting the next MDIO frame even before the trailing clocks are complete for previous MDIO frame. This feature can be enabled by setting BTB bit in *MDIO address register (ETH_MACMDIOAR)* when the trailing clock feature is also enabled. When back-to-back transactions are enabled, the GMII busy bit (GB) is cleared immediately after MDIO frame completion. This allows the software to issue the next command, which is executed by the peripheral while trailing clocks are still on for the previous MDIO frame. When (GB) transactions are not enabled, the GMII busy bit is cleared after the trailing clocks are complete for the MDIO frame.

Interrupt for MDIO transaction completion

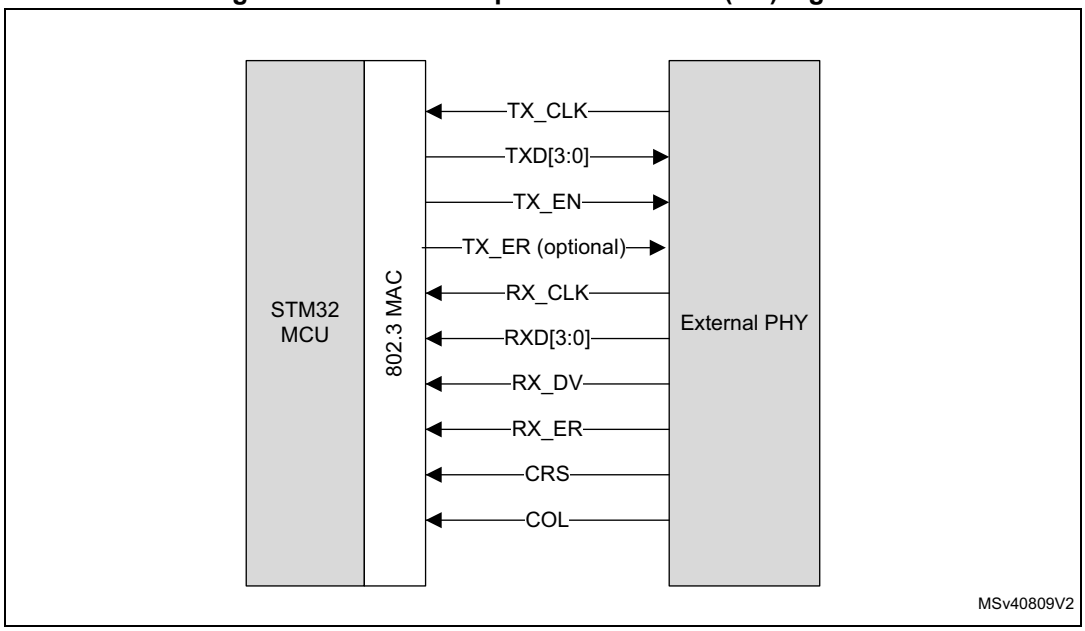
The peripheral can generate an interrupt on completion of MDIO read or write transactions. Therefore, the application need not poll the GMII busy bit of the *MDIO address register (ETH_MACMDIOAR)* to know the completion of MDIO commands.

63.6.2 Media independent interface (MII)

The media-independent interface (MII) defines the interconnection between the MAC sublayer and the PHY for data transfer at 10 Mbit/s and 100 Mbit/s.

MII signals are given in *Figure 830: Media independent interface (MII) signals*.

Figure 830. Media independent interface (MII) signals



- TX_CLK: continuous clock that provides the timing reference for Tx data transfers. The nominal frequency is 2.5 MHz at 10 Mbit/s and 25 MHz at 100 Mbit/s.
- TXD[3:0]: transmit data.

  TXD is a bundle of 4 data signals driven synchronously by the MAC sublayer and qualified (valid data) on the assertion of the TX_EN signal. TXD[0] is the least significant bit, TXD[3] is the most significant bit. While TX_EN is deasserted, the transmit data must have no effect upon the PHY.
- TX_EN: transmission enable signal indicating that the MAC is presenting nibbles on the MII for transmission. It must be asserted synchronously (TX_CLK) with the first nibble of the preamble and must remain asserted while all nibbles to be transmitted are presented to the MII.
- TX_ER (optional): required only for Energy Efficient Ethernet (EEE). The transmit error is indicated by inverting the CRC. The remote station can detect the Transmit error through incorrect CRC.
- RX_CLK: continuous clock that provides the timing reference for Rx data transfers. The nominal frequency is 2.5 MHz at 10 Mbit/s, 25 MHz at 100 Mbit/s.
- RXD[3:0]: receive data

  RXD is a bundle of 4 data signals driven synchronously by the PHY and qualified (valid data) on the assertion of the RX_DV signal. RXD[0] is the least significant bit, RXD[3] is

the most significant bit. While RX_EN is deasserted and RX_ER is asserted, a specific RXD[3:0] value is used to transfer specific information from the PHY.

- RX_DV: receive data valid

  This signal indicates that the PHY is presenting recovered and decoded nibbles on the MII for reception. It must be asserted synchronously (RX_CLK) with the first recovered nibble of the frame and must remain asserted through the final recovered nibble. It must be deasserted prior to the first clock cycle that follows the final nibble. In order to receive the frame correctly, the RX_DV signal must encompass the frame, starting no later than the SFD field.

- RX_ER: receive error

  This signal must be asserted for one or more clock periods (RX_CLK) to indicate to the MAC sublayer that an error was detected somewhere in the frame. This error condition must be qualified by RX_DV assertion.

- CRS: carrier sense.

  This signal is asserted by the PHY when either the transmit or receive medium is non idle. It shall be deasserted by the PHY when both transmit and receive media are idle. The PHY must ensure that the CS signal remains asserted throughout the duration of a collision condition. This signal is not required to transition synchronously with respect to the Tx and Rx clocks. In Full-duplex mode the state of this signal is don't care for the MAC sublayer.

- COL: collision detection signal

  This signal must be asserted by the PHY upon detection of a collision on the medium and must remain asserted while the collision condition persists. This signal is not required to transition synchronously with respect to the Tx and Rx clocks. In Full-duplex mode, the state of this signal is don't care for the MAC sublayer.

63.6.3 Reduced media independent interface (RMII)

The reduced media independent interface (RMII) specification reduces the pin count between Ethernet PHYs and STM32 MCU. According to the IEEE 802.3u, an MII contains 16 pins for data and control. RMII specification reduces the pin count to 7.

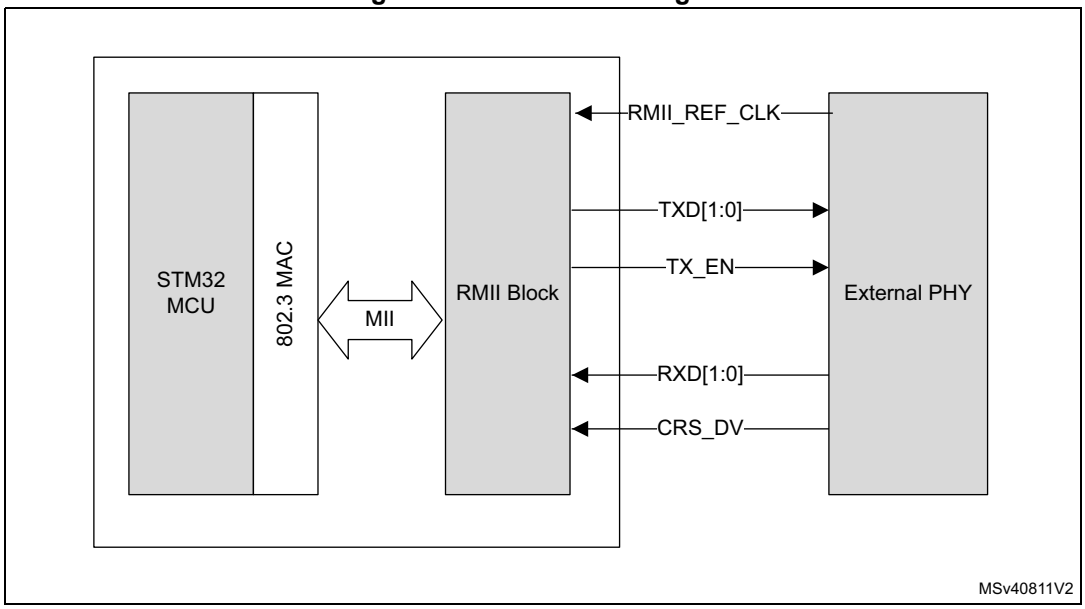
Part of the Ethernet peripheral, the RMII module is instantiated at the MAC output. This helps in translating the MII of the MAC into the RMII. The RMII block has the following characteristics:

- Supports 10 Mbps and 100 Mbps operating rates. It does not support the 1000 Mbps operation.
- Provides independent 2-bits wide Transmit and Receive paths by sourcing two clock references externally.

RMII block diagram

Figure 831: RMII block diagram shows the position of the RMII block relative to the MAC and RMII PHY. The RMII block is placed in front of the MAC to translate the MII signals to RMII signals.

Figure 831. RMII block diagram

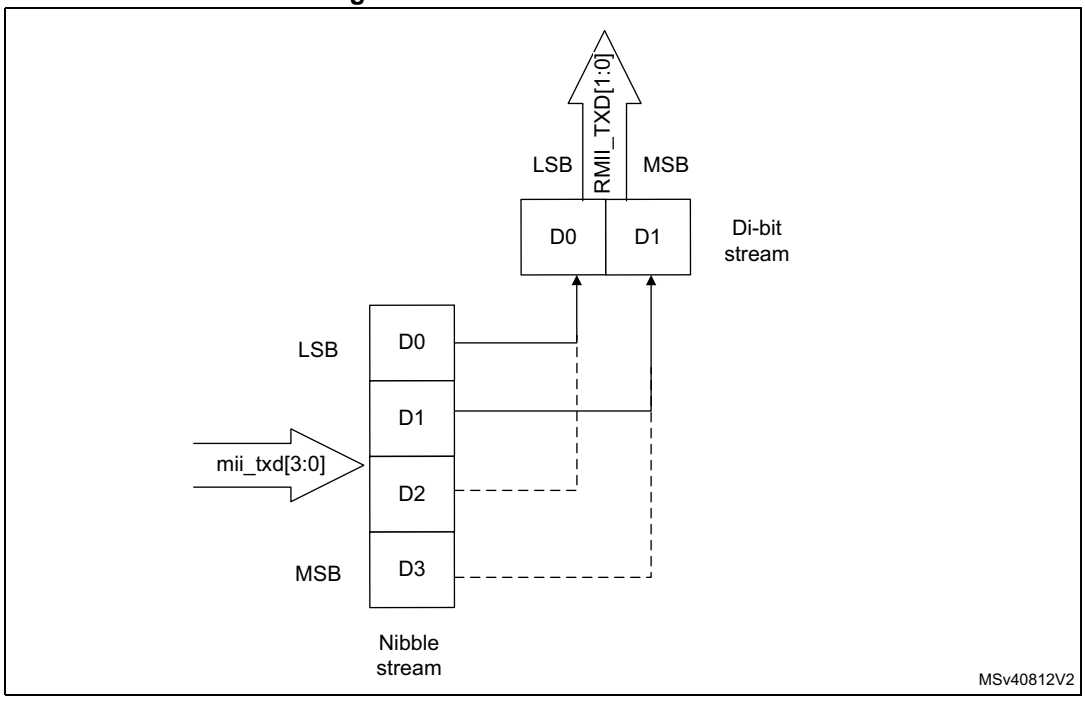


- RMII_REF_CLK: continuous 50 MHz reference clock input
- TXD[1:0]: transmit data
- TX_EN: transmit data enable.
  When high, this bit indicates that valid data are being transmitted on TXD[1:0].
- RXD[1:0]: receive data
- CRS_DV: carrier Sense (CRS) and RX_Data Valid (RX_DV) multiplexed on alternate clock cycles. In 10 Mbit/s mode, it alternates every 10 clock cycles.

Transmit bit order

Each nibble from the MII interface must be transmitted on the RMII interface di-bit at a time with the order of di-bit transmission shown in *Figure 832: Transmission bit order*. The lower order bits (D1 and D0) are transmitted first followed by higher order bits (D2 and D3).

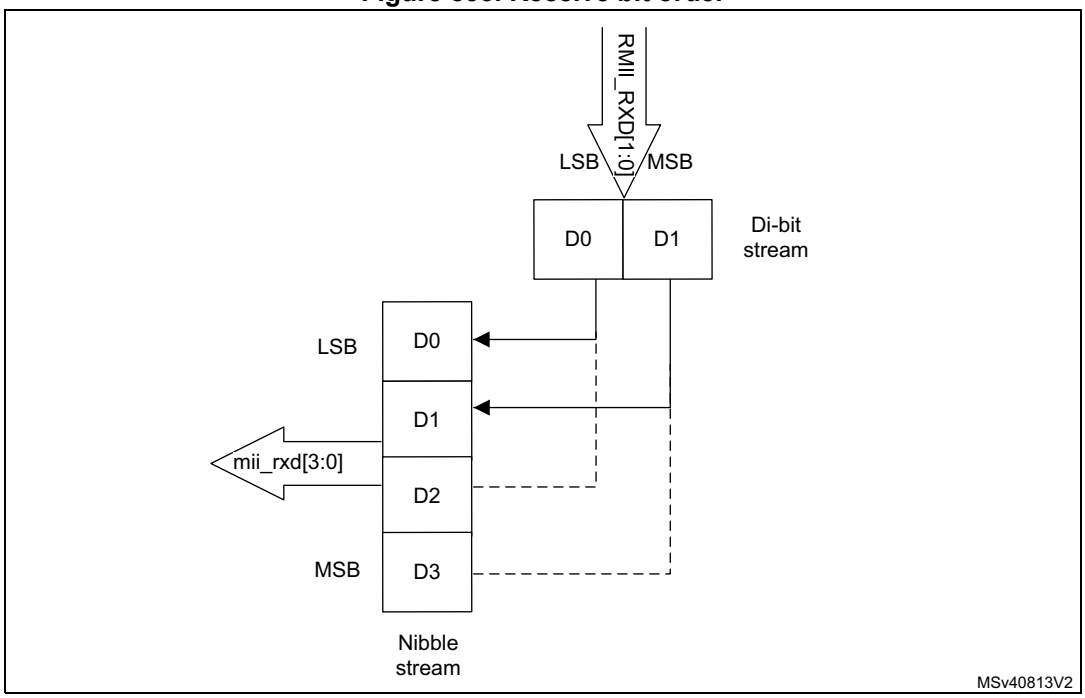
Figure 832. Transmission bit order



Receive bit order

Each nibble is transmitted to the MII interface from the di-bit received from the RMII interface in the nibble transmission order shown in *Figure 833: Receive bit order*. The lower order bits (D0 and D1) are received first, followed by the higher order bits (D2 and D3).

Figure 833. Receive bit order



63.7 Ethernet low-power modes

63.7.1 Low-power management

The Ethernet peripheral supports the following techniques to save power:

- Magic packet
- Remote wakeup

The magic packet and remove wakeup techniques are used to save power in the host system when it is idle (Sleep mode) and has to be woken up only at the reception of specific packets from the Ethernet network. In Sleep mode, the power to the host logic along with the majority of the peripheral (except the MAC receiver logic), can be shut down. On receiving the specific packets from the network, the MAC provides the trigger to restore the power to the host system and come back to normal state.

The Energy Efficient Ethernet (EEE) mode is compliant with the IEEE 802.3az-2010 standard. It is primarily targeted to save power in the Ethernet port when there is no traffic on the line. In this mode, the host indicates to the far-end that it does not have any packets to transmit in the near future and puts the transmitter port (MAC controller, PCS and PHY layers) in low-power mode. Similarly, the receiver port can also be put in low-power mode when the far-end host indicates that it does not have any traffic to transfer. This allows significant saving of power in the Ethernet port (mainly in the PHY) with intermittent and bursty traffic profile. The triggering of entry and exit out of the EEE mode is controlled by the MAC and is supported within the peripheral.

Simultaneous operation of the EEE mode along with any or both the other power saving modes is also supported.

Description of magic packet mode

This section describes how to save power through magic packet detection.

Note: The magic packet feature is based on the magic packet technology white paper from Advanced Micro Device (AMD).

The watchdog timeout limit for a magic packet is 2,048 bytes irrespective of the value programmed in WD bit in Operating mode configuration register (ETH_MACCR) and PWE bit in Watchdog timeout register (ETH_MACWTR).

In the magic-packet-based power saving mode, the reception of a valid magic packet by the MAC receiver triggers an exit from low-power mode. The MAC enters power saving mode when PWRDWN bit of *PMT control status register (ETH_MACPCSR)* is programmed to 1. Exit from the magic-packet-based power saving mode is enabled by setting the MGKPKTEN bit of *PMT control status register (ETH_MACPCSR)* to 1.

The magic packet contains a unique pattern at any offset after the Destination address, Source address, and Length/Type fields. In addition to the unique pattern matching, the MAC receiver also checks for the following, to detect the received packet as a valid magic packet:

- The packet must be addressed to it (Destination Address of the received packet should perfect match the *MAC Address 0 high register (ETH_MACA0HR)* and *MAC Address 0 low register (ETH_MACA0LR)*) or with multicast/broadcast address.
- The packet must not have any length error, FCS error, dribble bit error, GMII error, and collision.

- The packet must not be runt (length including Ethernet header and FCS is at least 64 bytes).

Magic packet data format

The content of the unique pattern in magic packets is described as follows:

- Six bytes of all-ones (0xFF FF FF FF FF FF) called synchronization stream. There can be more than six bytes of 0xFF, but only the last six are considered.
- The synchronization stream is immediately followed by 16 repetitions of the Destination address field of the packet (*MAC Address 0 high register (ETH_MACA0HR)* and the *MAC Address 0 low register (ETH_MACA0LR)*) or multicast/broadcast address.
- No break or interruption between synchronization stream and first repetition of Destination address field or within its 16 repetitions.

If the MAC address of a node is 0x00 11 22 33 44 55, the MAC scans for the following data sequence:

Destination Address Source Address Length/Type…… FF FF FF FF FF FF
00 11 22 33 44 55 00 11 22 33 44 55 00 11 22 33 44 55
00 11 22 33 44 55 00 11 22 33 44 55 00 11 22 33 44 55
00 11 22 33 44 55 00 11 22 33 44 55 00 11 22 33 44 55
00 11 22 33 44 55 00 11 22 33 44 55 00 11 22 33 44 55
…CRC

Description of remote wakeup packet mode

This section describes the power saving mode based on remote wakeup packet.

Note: The remote wakeup packet feature implementation is based on the Device Class Power Management Reference Specification and various implementation-specific white papers.

The watchdog timeout limit for a magic packet is 2,048 bytes irrespective of the value programmed in WD bit in Operating mode configuration register (ETH_MACCR) and PWE bit in Watchdog timeout register (ETH_MACWTR).

In the remote-wakeup-magic-packet-based power saving mode, the reception of expected remote wakeup packet by the MAC receiver triggers the exit from low-power mode. The MAC enters power saving mode when PWRDWN bit in *PMT control status register (ETH_MACPCSR)* is programmed to 1. Exit from the remote-wakeup-magic-packet-based power saving mode is enabled by programming RWKPKTEN bit of *PMT control status register (ETH_MACPCSR)* to 1.

The MAC implements a filter lookup table (programmed through *Remote wakeup packet filter register (ETH_MACRWKPFR)* in which CRC, offset, and byte mask of the pattern embedded in remote wakeup packet and the filter operation commands are programmed.

The pattern embedded in the remote wakeup packet is located at any offset after the Destination address and Source address fields. In addition to the CRC match for the pattern, the MAC receiver also checks the following, to detect the received packet as a valid remote wakeup packet:

- The packet must be addressed to it (Destination Address of the received packet should perfect match the *MAC Address 0 high register (ETH_MACA0HR)* and *MAC Address 0 low register (ETH_MACA0LR)*) or with multicast/broadcast address.
- The packet must not have any length error, FCS error, dribble bit error, GMII error, and collision.

- The packet must not be runt (length including Ethernet header and FCS is at least 64 bytes).

When a valid remote wakeup packet is received, the MAC receiver sets the RWKPRCVD bit in *PMT control status register (ETH_MACPCSR)* and triggers the interrupt on pmt_intr_o output port. The PMTIS bit in *Interrupt status register (ETH_MACISR)* is set when power-gating is not enabled in low-power mode. An interrupt is triggered to the application on the sbd_intr_o output port when interrupt is enabled (PMTIE bit in *Interrupt enable register (ETH_MACIER)* is set) and CSR clock is not gated off in low-power mode.

Remote wakeup packet filters

When the remote-wakeup-based power saving mode is enabled, four remote wakeup filters can be selected. The structure of the remote wakeup filters is shown in *Table 574: Remote wakeup packet filter register*.

Table 574. Remote wakeup packet filter register

ETH_MACRWKPFR value	Field							
0	Filter 0 byte mask							
1	Filter 1 byte mask							
2	Filter 2 byte mask							
3	Filter 3 byte mask							
4	Reserved	Filter 3 command	Reserved	Filter 2 command	Reserved	Filter 1 command	Reserved	Filter 0 command
5	Filter 3 offset		Filter 2 offset		Filter 1 offset		Filter 0 offset	
6	Filter 1 CRC - 16				Filter 0 CRC - 16			
7	Filter 3 CRC - 16				Filter 2 CRC - 16			

The remote wakeup filter fields are described in *Table 575: Description of the remote wakeup filter fields*.

Table 575. Description of the remote wakeup filter fields

Register	Description
Filter *i* Byte mask	The filter *i* byte mask register defines the bytes of the packet that are examined by filter *i* (0, 1, 2 or 3) to determine whether or not a packet is a wakeup packet. – The MSB (31st bit) must be zero. – Bit j[30:0] is the byte mask. – If Bit j (byte number) of the byte mask is set, the CRC block processes the Filter *i* Offset + j of the incoming packet; otherwise Filter *i* Offset + j is ignored.
Filter *i* Command	The 4-bit filter *i* command controls the filter *i* operation. – Bit 3 specifies the address type, defining the destination address type of the pattern. When the bit is set, the pattern applies to only multicast packets; when the bit is reset, the pattern applies only to unicast packet. – Bit 2 (Inverse mode), when set, reverses the logic of the CRC16 Hash function signal, to reject a packet with matching CRC_16 value. Bit 2, along with Bit 1, allows a MAC to reject a subset of remote wakeup packets by creating filter logic such as "Pattern 1 AND NOT Pattern 2". – Bit 1 (And_Previous) implements the Boolean logic(1). When set, the result of the current entry is logically ANDed with the result of the previous filter. This AND logic allows a filter pattern longer than 32 bytes by splitting the mask among two, three, or four filters. This depends on the number of filters that have the And_Previous bit set. – Bit 0 is the enable for filter *i*. If Bit 0 is not set, filter *i* is disabled.
Filter *i* Offset	This filter *i* offset register defines the offset (within the packet) from which the filter *i* examines the packets. – This 8-bit pattern-offset is the offset for the filter *i* first byte to be examined. – The minimum allowed offset is 12, which refers to the 13th byte of the packet. – The offset value 0 refers to the first byte of the packet.
Filter *i* CRC-16	This filter *i* CRC-16 register contains the CRC_16 value calculated from the pattern and also the byte mask programmed to the wakeup filter register block. – The 16-bit CRC calculation uses the following polynomial: G(x) = x^16 + x^15 + x^2 + 1 Each mask, used in the Hash function calculation, is compared with a 16-bit value associated with that mask. Each filter has the following: – 32-bit Mask: Each bit in this mask corresponds to one byte in the detected packet. If the bit is 1', the corresponding byte is taken into the CRC16 calculation. – 8-bit Offset Pointer: Specifies the byte to start the CRC16 computation. The pointer and the mask are used together to locate the bytes to be used in the CRC16 calculations.

1. The And_Previous bit setting is applicable within a set of four filters.
Setting And_Previous bit of a filter that is not enabled has no effect, that is setting And_Previous bit of lowest number filter in the set of four filters has no effect. For example, setting And_Previous bit of Filter 0 has no effect.
If And_Previous bit is set for a given filter to form an AND chained filter, the AND chain breaks when it finds a disabled filter. For example: If Filter 2 And_Previous bit is set (bit 1 in Filter 2 command is set) but Filter 1 is not enabled (bit 0 in Filter 1 command is reset), then only Filter 2 result is considered. If Filter 2 And_Previous bit is set (bit 1 in Filter 2 command is set), Filter 3 And_Previous bit is set (bit 1 in Filter 3 command is set), but Filter 1 is not enabled (bit 0 in Filter 1 command is reset), then only Filter 2 result ANDed with Filter 3 result is considered. If Filter 2 And_Previous bit is set (bit 1 in Filter 2 command is set), Filter 3 And_Previous bit is set (bit 1 in Filter 3 command is set), but Filter 2 is not enabled (bit 0 in Filter 2 command is reset), then since setting Filter 2 And_Previous bit has no effect, only Filter 1 result ORed with Filter 3 result is considered.
If filters chained by And_Previous bit setting have complementary programming, then a frame may never pass the AND chained filter. For example, if Filter 2 And_Previous bit is set (bit 1 in Filter 2 command is set), Filter 1 Address_Type bit is set (bit 3 in Filter 1 command is set) indicating multicast detection and Filter 2 Address_Type bit is reset (bit 3 in Filter 2 command is reset) indicating unicast detection or vice versa, then a remote wakeup frame does not pass the AND chained filter as a remote wakeup frame cannot be of both unicast and multicast address types.

The remote wakeup filter registers are implemented as eight indirect access registers (wkuppktfilter_reg#i) for four remote wakeup filters, and accessed by the application through *Remote wakeup packet filter register (ETH_MACRWKPFR)*. The entire set of wkuppktfilter_reg registers must be written to program the remote wakeup filters. The wkuppktfilter_reg register is programmed by sequentially writing the eight register values in *Remote wakeup packet filter register (ETH_MACRWKPFR)* for wkuppktfilter_reg0 to wkuppktfilter_reg3, respectively. The wkuppktfilter_reg register is read in a similar way. The MAC updates the wkuppktfilter_reg register current pointer value in RWKPTR field of *PMT control status register (ETH_MACPCSR)*.

Note: If the Remote wakeup packet filter register (ETH_MACRWKPFR) is accessed in byte or half-word mode, the internal counter to access the appropriate wkuppktfilter_reg is incremented when the CPU accesses Lane 3.

When Remote wakeup packet filter register (ETH_MACRWKPFR) is written, the content is transferred from CSR clock domain to PHY receive clock domain after the write operation. There should not be any further write to the Remote wakeup packet filter register (ETH_MACRWKPFR) until the first write is updated in PHY receive clock domain. Otherwise, the second write operation does not get updated to the PHY receive clock domain. Therefore, the delay between two write operations to the Remote wakeup packet filter register (ETH_MACRWKPFR) should be at least 4 cycles of the PHY receive clock.

PMT interrupt

The PMT interrupt signal is asserted when a valid remote wakeup packet is received.

Table 576 lists the remote wakeup scenarios in which PMT interrupt is generated.

Table 576. Remote wakeup packet and PMT interrupt generation(1)

Filter i Command			Frame Type and CRC Status		Interrupt Generation
CAST	INV	EN	Received Frame Cast Type	CRC Status	RWK INTR
0	0	1	Unicast	MATCH	Remote Wakeup packet is detected and PMT interrupt is generated
0	1	1	Unicast	MISMATCH	Remote Wakeup packet is detected and PMT interrupt is generated
1	0	1	Multicast	MATCH	Remote Wakeup packet is detected and PMT interrupt is generated
1	1	1	Multicast	MISMATCH	Remote Wakeup packet is detected and PMT interrupt is generated

1. In all other combinations, the Remote Wakeup packet is not detected and PMT interrupt is not generated.

In addition to sbd_intr_o signal, the pmt_intr_o (synchronous to Rx clock) signal is asserted. The pmt_intr_o signal, synchronous to the Rx clock domain, is provided so that the application clock can be stopped by software when the MAC is in the power-down mode. It is ORed with lpi_intr_o signal (see *Section : LPI interrupt*) and tied to the EXTI peripheral (line 86).

As the pmt_intr_o signal is generated in the PHY Rx clock domain, it is not cleared immediately when the *PMT control status register (ETH_MACPCSR)* is read. This is

because the resultant clear signal has to cross to the PHY Rx clock domain, and then clear the interrupt source. This delay is at least 4 clock cycles of Rx clock and can be significant when the peripheral is operating in the 10 Mbps mode. When the application clears the PWRDWN bit in *Remote wakeup packet filter register (ETH_MACRWKPFR)*, the MAC comes out of the power-down mode, but this event does not generate the PMT interrupt.

Power-down sequence

The software must perform the following tasks to initiate the power-down sequence:

- Disable the Transmit DMA (if applicable) by clearing the ST bit of the *Channel transmit control register (ETH_DMACTXCR)*.
- Wait for any previous frame transmissions to complete. You can check this by reading TFCSTS[1:0] and TPESTS bits in *Debug register (ETH_MACDR)* and TXQSTS bit in *Tx queue debug Register (ETH_MTLTXQDR)* of all MTL Tx Queues.
- Disable the MAC transmitter and MAC receiver by clearing TE and RE bits in *Operating mode configuration register (ETH_MACCR)*.
- Wait till the Receive DMA empties all frames from the Rx FIFO. You can check this by reading PRXQ[13:0] in *Rx queue debug register (ETH_MTLRXQDR)* of all Rx Queues. If these bits are zero, it indicates that the Rx FIFO is empty.
- Configure the magic packet (MGKPKTEN) and/or remote wake-up (RWKPKTEN) detection in the *PMT control status register (ETH_MACPCSR)*.
- Set bit 31 (ARPEN) in the *Operating mode configuration register (ETH_MACCR)*.
- Enable the MAC Receiver by setting RE bit and then set PWRDWN bit in the *PMT control status register (ETH_MACPCSR)* to initiate the power-down sequence in MAC.

Note: If the feature is enabled and the MAC Transmitter is in the LPI mode when it is put into the power-down mode, then the MII interface gets clamped to assert the LPI pattern. If the MAC Transmitter is not in the LPI mode when it is put into the power-down mode, the GMII or MII interface gets clamped to all-zero.

Power-up sequence

The MAC wakes up on receiving the magic packet or remote wake-up frame. The power-up sequence is as follows:

- The MAC asserts pmt_intr_o. When only clock-gating is employed in low-power mode, the pmt_intr_o signal can be used to start the clocks that were gated-off after entering low-power mode.
- The software performs the following tasks:
  - De-assert the pmt_intr_o by reading the *PMT control status register (ETH_MACPCSR)*.
  - Perform a write operation (with reset values) to the *PMT control status register (ETH_MACPCSR)* and the *Remote wakeup packet filter register (ETH_MACRWKPFR)* so that the corresponding values in the always-on block gets synchronized. Otherwise, the values of these registers are different.
  - Perform write operations to the *Operating mode configuration register (ETH_MACCR)*, *MAC Address 0 high register (ETH_MACA0HR)* and *MAC Address 0 low register (ETH_MACA0LR)* to synchronize the values in the CSR module and the respective bits in the always-on block. Otherwise, the MAC receiver is on even though the Receive Enable bit is set to 0.

After completing these steps, the software must initialize all registers, enable the transmitter, and program the DMA (in DMA configurations) to resume the normal operation.

63.7.2 Energy Efficient Ethernet (EEE)

EEE is an operational mode that enables the IEEE 802.3 Media Access Control (MAC) sub layer along with a family of physical layers to operate in the Low-Power Idle (LPI) mode. The EEE operational mode supports the IEEE 802.3 MAC operation at 100 Mbps. The peripheral supports the IEEE 802.3az-2010 for EEE.

The LPI mode allows saving power by switching off the parts of the communication device functionality when there is no data to be transmitted and received. The systems on both sides of the link can disable some functionalities to save power during the periods of low-link utilization. The MAC controls whether the system should enter or exit the LPI mode and communicates this to the PHY.

The EEE specifies the capabilities negotiation methods that the link partners can use to determine whether EEE is supported, and then select the set of parameters that are common to both devices.

Transmit path functions

The transmit path functions include tasks that the MAC must perform to make the PHY enter the LPI state.

In the transmit path, the software must set the LPIEN bit of the *LPI control and status register (ETH_MACLCSR)* to indicate to the MAC to stop transmission and initiate the LPI protocol. The MAC completes the transmission in progress, generates its transmission status, and starts transmitting the LPI pattern instead of the IDLE pattern if the link status has been up continuously for a period specified in the LPI LS TIMER LST[9:0] bitfield of *LPI timers control register (ETH_MACLTCR)*. The PHY Link Status PLS bit of the *LPI control and status register (ETH_MACLCSR)* indicates the link status of the PHY.

Note: The EEE feature is not supported when the MAC is configured to use the RMII.

According to the standard (IEEE 802.3az-2010), the PHY must not stop the TxCLK clock during the LPI state in the MII (10 or 100) mode.

To make the PHY enter the LPI state, the MAC performs the following tasks:

1. De-asserts TX_EN.
2. Asserts TX_ER.
3. Sets TXD[3:0] to 0x1 (for 100 Mbps)
4. Updates the status (TLPIEN bit of *LPI control and status register (ETH_MACLCSR)*) and generates an interrupt.

Note: The MAC maintains the same state of the TX_EN, TX_ER, and TXD signals for the entire duration during which the PHY remains in the LPI state.

To bring the PHY out of the LPI state, that is when the software resets the LPIEN bit, the MAC performs the following tasks:

1. Stops transmitting the LPI pattern and starts transmitting the IDLE pattern.
2. Starts the LPI TW TIMER:

   The MAC cannot start the transmission until the wakeup time specified for the PHY expires. The auto-negotiated wake-up interval is programmed in the TWT field of the *LPI timers control register (ETH_MACLTCR)*.
3. Updates the LPI exit status (TLPIEX bit of the *LPI control and status register (ETH_MACLCSR)*) and generates an interrupt.

Figure 834 shows the behavior of TX_EN, TX_ER, and TXD[3:0] signals during the LPI mode transitions.

Note: The MAC does not stop the TX_CLK clock. The application can stop this clock (as shown in Figure 834) if the PHY supports it and when the MAC sets the sbd_tx_clk_gating_ctrl_o signal to 1. The sbd_tx_clk_gating_ctrl_o signal is asserted after nine Tx Clock Cycles, one Pulse Synchronizer delay, and one CSR clock cycle. The assertion of the sbd_tx_clk_gating_ctrl_o signal depends on the LPITCSE bit of the LPI control and status register (ETH_MACLCSR) and can be done automatically as shown on Figure 835.

If RGMII Interface is selected, the Tx clock is required for transmitting the LPI pattern and so the Tx Clock cannot be gated.

If the MAC is in the Tx LPI mode and the Tx clock is stopped, the application should not write to CSR registers that are synchronized to Tx clock domain.

If the MAC is in the LPI mode and the application issues a soft reset or hard reset, the MAC transmitter comes out of the LPI mode.

Figure 834. LPI transitions (Transmit, 100 Mbds)

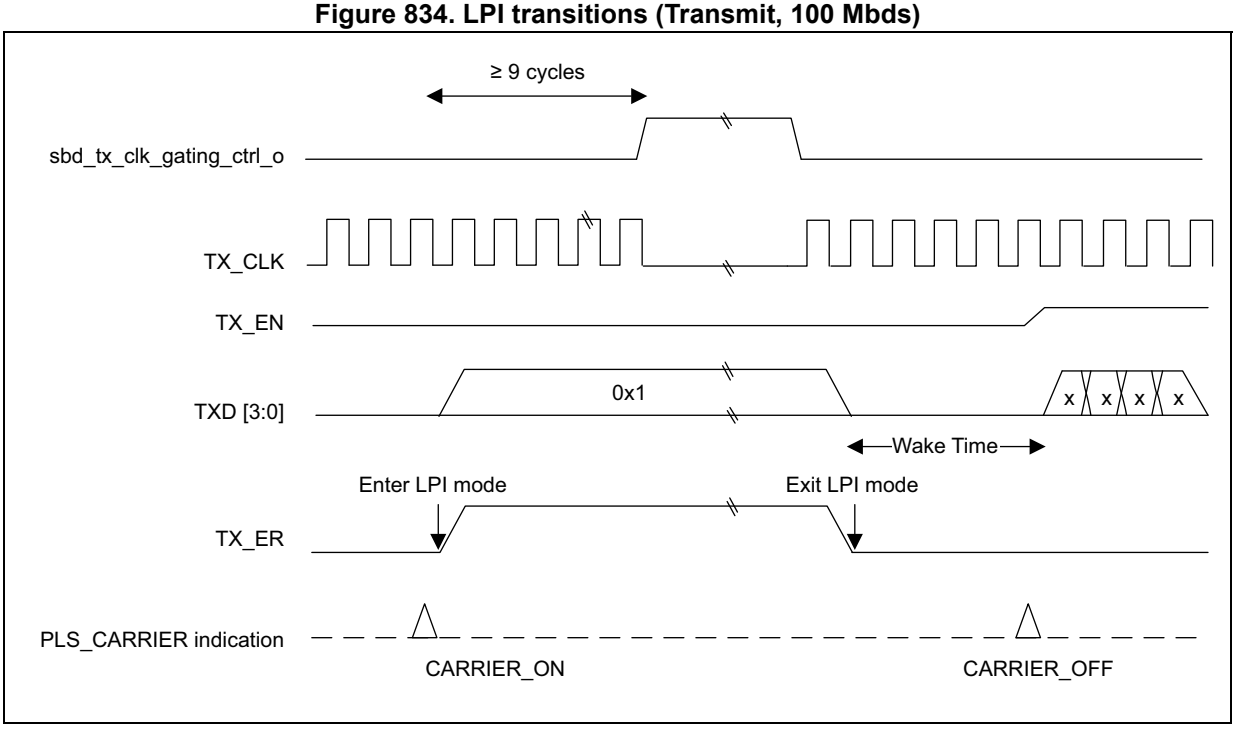
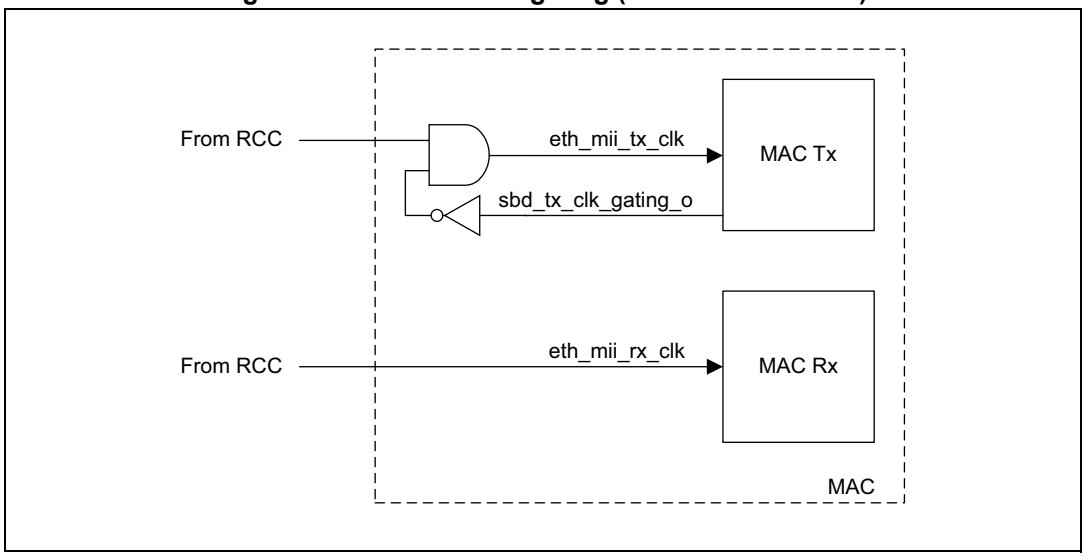


Figure 835. LPI Tx clock gating (when LPITCSE = 1)



Automated entry/exit from LPI mode in transmit path

The MAC transmitter can be programmed to enter and exit LPI Idle mode automatically based on whether it is Idle for a specific period of time or has a packet to transfer. These modes are enabled and controlled by the *LPI control and status register (ETH_MACLCSR)*.

When LPITXA and LPIEN of *LPI control and status register (ETH_MACLCSR)* are set, the MAC transmitter enters LPI Idle state when the MAC transmit path (including the MTL layers and DMA layers) are idle. The MAC transmitter exits the LPI Idle state and clears the LPITXEN bit as soon as any of functions in the TX path (DMA, MTL or MAC) becomes non-idle due to initiation of a packet transfer.

In addition, when LPITE is also set, the MAC transmitter enters LPI Idle state only if the Transmit path remains in idle state (no activity) for the time period indicated by the value in *LPI entry timer register (ETH_MACLETR)*. In this mode also, the MAC transmitter exits the LPI Idle state as soon as any of the functions becomes non-idle. However, the LPIEN bit is not cleared but remains active so that reentry to LPI Idle state is possible without any software intervention when the MAC becomes idle again.

When both LPITE and LPITXA bits are cleared, the application can directly control the entry and exit of LPI Idle state by programming the LPIEN bit.

Receive path Functions

The receive path functions include the tasks that the PHY and MAC must perform when the PHY receives signals from the link partner to exit the LPI state.

In the receive path, when the PHY receives the signals from the link partner to enter into the LPI state, the PHY and MAC perform the following tasks:

1. The PHY asserts RX_ER.
2. The PHY sets RXD[3:0] to 0x1 (for 100 Mbps).
3. The PHY de-asserts RX_DV.
4. The MAC updates the RLPIEN bit of the *LPI control and status register (ETH_MACLCSR)* and immediately generates an interrupt.

Note: The PHY maintains the same state of the RX_ER, RXD, and RX_DV signals for the entire duration during which it remains in the LPI state.

If the LPI pattern is detected for a very short duration (that is, less than two cycles of Rx clock), the MAC does not enter the Rx LPI mode.

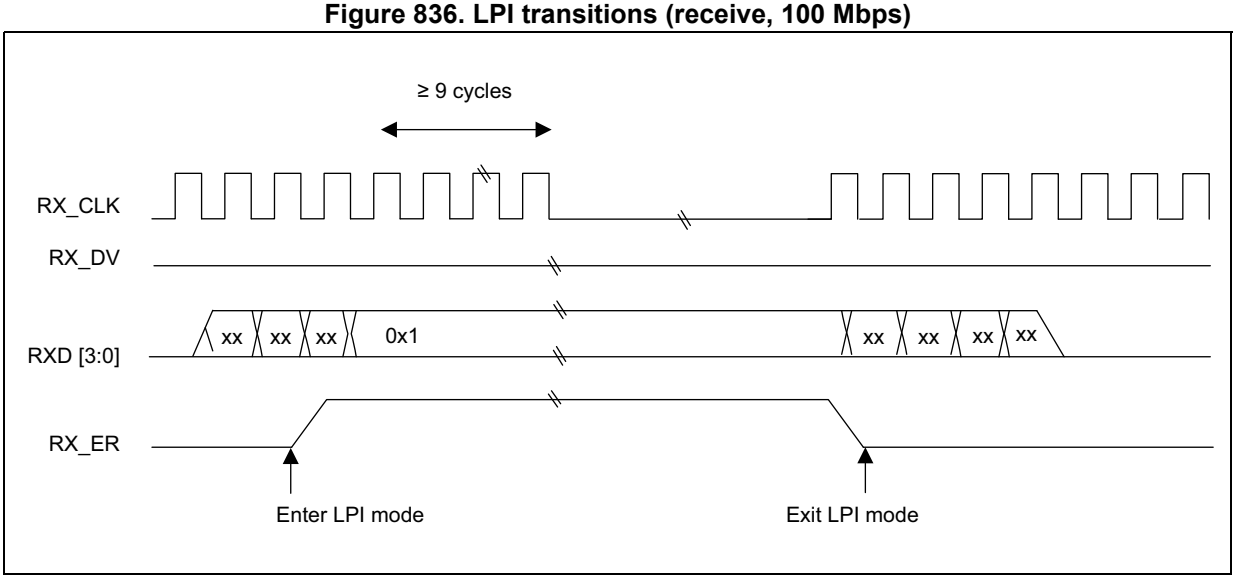
If the duration between the end of the current Rx LPI pattern and the start of the next Rx LPI pattern is very short (that is, less than two Rx clock cycles), then the MAC exits and enters again the Rx LPI mode. The MAC does not trigger the Rx LPI Exit and Entry interrupts.

When the PHY receives signals from the link partner to exit the LPI state, the PHY and MAC perform the following tasks:

1. The PHY de-asserts RX_ER and returns to a normal inter-packet state.
2. The MAC updates the RLPIEX bit of the *LPI control and status register (ETH_MACLCSR)* and generates an interrupt immediately. The sideband signal lpi_intr_o (synchronous to Rx clock) is also asserted.

Figure 836 shows the behavior of RX_ER, RX_DV, and RXD[3:0] signals during the LPI mode transitions.

Figure 836. LPI transitions (receive, 100 Mbps)



Note: If the RX_CLK_stoppable bit (in the PHY register written through MDIO) is asserted when the PHY is indicating LPI to the MAC, the PHY may halt the RX_CLK at any time more than nine clock cycles after the start of the LPI state as shown in Figure 836.

If the MAC is in LPI mode and the application issues a soft reset or hard reset, the MAC receiver exits from LPI mode during reset. If the LPI pattern is still received after the reset is de-asserted, the MAC receiver enters again the LPI state.

If the RX clock is stopped in the RX LPI mode, the application should not write to the CSR registers that are being synchronized to the RX clock domain.

When the PHY sends the LPI pattern, if EEE feature is enabled, the MAC automatically enters the LPI state. There is no software control to prevent the MAC from entering the LPI state.

LPI timers

The transmitter maintains the LPI LS TIMER, LPI TW TIMER, and LPI AUTO ENTRY TIMER timers.

The following LPI timers are loaded with the respective values from the *LPI timers control register (ETH_MACLTCR)* and *LPI entry timer register (ETH_MACLETR)*:

- LPI LS TIMER

  The LPI LS TIMER counts, in milliseconds, the time expired since the link status is up.

  This timer is cleared every time the link goes down. It starts to increment when the link is up again and continues to increment until the value of the timer becomes equal to the terminal count. Once the terminal count is reached, the timer remains at the same value as long as the link is up. The terminal count is the value programmed in the LST[9:0] bitfield in the *LPI timers control register (ETH_MACLTCR)*. The LPI LS TIMER is 10-bit wide. The software can program up to 1023 milliseconds.
- LPI TW TIMER

  The LPI TW TIMER counts, in microseconds, the time expired since the de-assertion of LPI. The terminal count should be programmed in Bit[15:0] of *LPI timers control register (ETH_MACLTCR)*. The terminal count of the timer is the value of resolved Transmit TW that is the auto-negotiated time after which the MAC can resume the normal transmit operation. After exiting the LPI mode, the MAC resumes its normal operation after the TW timer reaches the terminal count.

  The MAC supports the LPI TW TIMER in units of microsecond. The LPI TW TIMER is 16-bit wide. Therefore, the software can program up to 65535 micro seconds.
- LPI AUTO ENTRY TIMER

  This timer counts in steps of eight microseconds, the time for which the MAC transmit path has to remain in idle state (no activity), before the MAC Transmitter enters the LPI IDLE state and starts transmitting the LPI pattern. This timer is enabled when LPITE bit in *LPI control and status register (ETH_MACLCSR)* is set.

LPI interrupt

The MAC generates the LPI interrupt when the Tx or Rx side enters or exits the LPI state. The interrupt sbd_intr_o is asserted when the LPI interrupt status is set. The LPI interrupt can be cleared by reading the *LPI control and status register (ETH_MACLCSR)*.

When the MAC exits the Rx LPI state, then in addition to the sbd_intr_o, the sideband signal lpi_intr_o (synchronous to Rx clock) is asserted. The lpi_intr_o signal can be used to trigger the external clock-gating circuitry to restore the application clock to the MAC. The lpi_intr_o signal, synchronous to the Rx clock domain, is provided so that the application clock can be stopped by software when the MAC is in the LPI state. It is ORed with pmt_intr_o signal (see *Section : PMT interrupt*) and tied to the EXTI peripheral (line 86).

The lpi_intr_o signal is generated in the Rx clock domain. It may not be cleared immediately after the *LPI control and status register (ETH_MACLCSR)* is read. This is because the clear signal, generated in CSR clock domain, has to cross the Rx clock domain, and then clear the interrupt source. This delay is at least four clock cycles of Rx clock and can be significant when the peripheral is operating in the 10 Mbps mode.

Programming guidelines for Energy Efficient Ethernet

For detailed guidelines on the programming guidelines, see *Section 63.9.11: Programming guidelines for Energy Efficient Ethernet (EEE)*.

63.8 Ethernet interrupts

The Ethernet peripheral generates a single interrupt signal (eth_sbd_intr_it). This signal can be raised as a result of various events. These events are captured in status registers and interrupt enables are provided for each source of interrupt such that the interrupt signal is asserted for an event only when the corresponding interrupt enable is set.

The interrupt status and corresponding enable registers are organized in a hierarchical manner so that it is easier for software to traverse and identify the source of interrupt event quickly. When interrupt is asserted, the *Interrupt status register (ETH_DMAISR)* register is first level that indicates the major blocks for the interrupt event source. This register is read-only, and it contains bits corresponding to each DMA channel (TX & RX pair), the MTL, and the MAC. The software application must then read one (or more) of the following registers corresponding to the bits that are set:

- ETH_DMACSR: Channel Status (see *Channel status register (ETH_DMACSR)*))
- ETH_MTLISR: Interrupt Status (see *Interrupt status Register (ETH_MTLISR)*)
- ETH_MACISR: Interrupt Status (see *Interrupt status register (ETH_MACISR)*)

63.8.1 DMA interrupts

Interrupt registers description

The ETH_DMACSR: Channel Status register (see *Channel status register (ETH_DMACSR)*) captures all the interrupt events of that TxDMA and RxDMA channel. The ETH_DMACIER: Channel Interrupt Enable register (see *Channel interrupt enable register (ETH_DMACIER)*) contains the corresponding enable bits for each of the interrupt event.

There are two groups of interrupts in the DMA channel namely Normal and Abnormal interrupts.They are indicated by Bits[15:14] of ETH_DMACSR register respectively. The normal group is for events that happen during the normal transfer of packets (TI: transmit interrupt, RI: receive interrupt, TBU: Transmit buffer unavailable) while the abnormal interrupt events are for error events.

Interrupts are not queued. If the same interrupt event occurs again before the driver responds to the previous one, no additional interrupts are generated. An interrupt is generated only once for multiple events. The driver must scan the *Interrupt status register (ETH_DMAISR)* for the cause of the interrupt and clear the source in the respective Status register. The interrupt is cleared only when all the bits of *Interrupt status register (ETH_DMAISR)* are cleared.

Periodic scheduling of Transmit and Receive Interrupt

It is not preferable to generate interrupts for every packet transferred by DMA (RI and TI) for system throughput performance reasons. The Ethernet peripheral gives the flexibility to schedule the interrupt at regular intervals using two methods:

1. Set Interrupt on Completion bit in Transmit descriptor (TDES2[31] in *Table 580: TDES2 normal descriptor (read format)*) once for every “required” number of packets to be transmitted.
2. Similarly, set the IOC (RDES3[30] in*Table 593: RDES3 normal descriptor (read format)*) bit only at some specific intervals of Receive descriptors. This way, whenever a received packet transfer to system memory is complete and any of the descriptors used for that packet transfer has the IOC bit set, only then the RI event is generated.

In addition to above, an interrupt timer (ETH_DMACRXIWTR: Channel Rx Interrupt Watchdog Timer) is given for flexible control and periodic scheduling of Receive Interrupt. When this interrupt timer is programmed with a nonzero value, it gets activated as soon as the Rx DMA completes a transfer of a received packet to system memory without asserting the Receive Interrupt because the corresponding interrupt of completion IOC bit (RDES3[30] in *Table 593: RDES3 normal descriptor (read format)*) is not set. When this timer runs out as per the programmed value, RI bit is set and the interrupt is asserted if the corresponding RIE is enabled in ETH_DMACIER register (see *Channel interrupt enable register (ETH_DMACIER)*). The timer is stopped and cleared before it expires, if the RI is set for a packet transfer whose descriptor's IOC was set. The timer is reactivated automatically after the next packet transfer is complete without the RI event being generated.

Channel transfer complete interrupt

The Transmit Transfer complete interrupt (TI) and Receive Transfer complete interrupt (RI) is reflected in the Channel Status register (*Channel status register (ETH_DMACSR)*). The TI bit is set whenever the Tx DMA channel closes the descriptor in which the IOC bit is set (Interrupt On Completion - TDES2[31]). Similarly, the RI bit is set whenever the Rx DMA channel closes the descriptor with the LD bit set and, in any of the descriptors used for transferring that packet, IOC bit is set (Interrupt Enable on completion - RDES3[30])).

The interrupt signal is asserted for the Transfer complete interrupts only when the corresponding interrupts are enabled in the channel interrupt enable register (*Channel interrupt enable register (ETH_DMACIER)*).

The behavior of the RI/TI interrupts changes depending on the settings of INTM field (bits[17:16]) in the ETH_DMAMR register (*DMA mode register (ETH_DMAMR)*). *Table 577* explains the behavior of the Transfer Complete interrupt.

Table 577. Transfer complete interrupt behavior

Interrupt Mode	Behavior of TI/RI and interrupt signal
INTM=0	The TI/RI status signals are set whenever the Transfer complete event is detected. These bits are cleared whenever the software driver writes 1 to these bits. The interrupt signal is asserted whenever the corresponding interrupts are also enabled in ETH_DMACIER register.
INTM=1	The TI/RI is set as explained above. However, the interrupt is not asserted for any RI/TI event.
INTM=2	The RI/TI status bits are set whenever the Transfer Complete event is detected and are reset whenever software driver clears them by writing 1. However, if another Transfer complete event is detected before it is cleared (serviced) by the software, then these status bits are automatically set again. However, the interrupt is not generated based on TI/RI.

63.8.2 MTL interrupts

MTL interrupt events are combined with the events in the DMA to generate the interrupt signal.

The register *Interrupt status Register (ETH_MTLISR)* report the queue number responsible for the event. ETH_MTLQICSR: Queue Interrupt Control Status shall be read for event description.

The MTL interrupts are enabled by default. Each event can be prevented from asserting the interrupt by setting the corresponding mask bits in the *Interrupt status Register (ETH_MTLISR)* register.

MTL interrupt signal is driven by one of these events:

- Receive Queue Overflow Interrupt
- Transmit Queue Underflow

63.8.3 MAC Interrupts

MAC interrupt events are combined with the events in the DMA to generate the interrupt signal.

The MAC interrupts are of level type, that is, the interrupt remains asserted (high) until it is cleared by the application or software.

The *Interrupt status register (ETH_MACISR)* describes the events that can cause an interrupt from the MAC. The MAC interrupts are enabled by default. Each event can be prevented from asserting the interrupt by setting the corresponding mask bits in the *Interrupt status register (ETH_MACISR)*.

The interrupt register bits only indicate the block from which the event is reported. You must read the corresponding status registers and other registers to clear the interrupt.

MAC interrupt signal is driven by one of these events:

- Receive Status Interrupt
- Transmit Status Interrupt
- Timestamp Interrupt Status
- MMC Interrupt Status
  - MMC Receive Checksum Offload Interrupt Status
  - MMC Transmit Interrupt Status
  - MMC Receive Interrupt Status
- LPI Interrupt Status
- PMT Interrupt Status
- PHY Interrupt

Note: Two sidebands signals are generated together with LPI and PMT interrupts: lpi_intr_o and pmt_intr_o. They are used for wakeup event detection at EXTI level.

63.9 Ethernet programming model

This chapter provides the instructions for initializing the DMA or MAC registers in the proper sequence. It contains the following sections:

- DMA initialization (see *Section 63.9.1*)
- MTL initialization (see *Section 63.9.2*)
- MAC initialization (see *Section 63.9.3*)
- Performing Normal Receive and Transmit Operation (see *Section 63.9.4*)
- Stopping and Starting Transmission (see *Section 63.9.5*)
- Programming Guidelines for MII Link State Transitions (see *Section 63.9.8*)
- Programming Guidelines for IEEE 1588 Timestamping (see *Section 63.9.9*)
- Programming Guidelines for Energy Efficient Ethernet (see *Section 63.9.11*)
- Programming Guidelines for flexible pulse-per-second (PPS) output (see *Section 63.9.12*)
- Programming Guidelines for TSO (see *Section 63.9.13*)
- Programming Guidelines for VLAN filtering on Receive (see *Section 63.9.14*)

63.9.1 DMA initialization

Complete the following steps to initialize the DMA:

1. Provide a software reset to reset all MAC internal registers and logic (bit 0 of *DMA mode register (ETH_DMAMR)*).
2. Wait for the completion of the reset process (poll bit 0 of the *DMA mode register (ETH_DMAMR)*, which is cleared when the reset operation is completed).
3. Program the following fields to initialize the *System bus mode register (ETH_DMASBMR)*:
   a) AAL
   b) Fixed burst or undefined burst
   c) Burst mode values in case of AHB bus interface.
4. Create a transmit and a receive descriptor list. In addition, ensure that the receive descriptors are owned by the DMA (set bit 31 of TDES3/RDES3 descriptor). For more information on descriptors, refer to *Section 63.10: Descriptors*.

Note: Descriptor address from start to end of the ring should not cross the 4GB boundary.

5. Program ETH_DMACTXRLR and ETH_DMACRXRLR registers (see *Channel Tx descriptor ring length register (ETH_DMACTXRLR)* and *Channel Rx descriptor ring length register (ETH_DMACRXRLR)*). The programmed ring length must be at least 4.
6. Initialize receive and transmit descriptor list address with the base address of transmit and receive descriptor (*Channel Tx descriptor list address register (ETH_DMACTXDLAR)*, *Channel Rx descriptor list address register (ETH_DMACRXDLAR)*). In addition, program the transmit and receive tail pointer registers that inform the DMA about the available descriptors (see *Channel Tx descriptor tail pointer register (ETH_DMACTXDTPR)* and *Channel Rx descriptor tail pointer register (ETH_DMACRXDTPR)*).
7. Program ETH_DMACCR, ETH_DMACTXCR and ETH_DMACRXCR registers (see *Channel control register (ETH_DMACCR)*, *Channel transmit control register (ETH_DMACTXCR)* and *Channel receive control register (ETH_DMACRXCR)*) to

configure the parameters such as the maximum burst-length (PBL) initiated by the DMA, descriptor skip lengths, OSP for TxDMA, RBSZ[13:0] for RxDMA, and so on.

8. Enable the interrupts by programming the ETH_DMACIER register (see *Channel interrupt enable register (ETH_DMACIER)*).
9. Start the Receive and Transmit DMAs by setting SR (bit 0) of *Channel receive control register (ETH_DMACRXCR)* and ST (bit 0) of the ETH_DMACTXCR (see *Channel transmit control register (ETH_DMACTXCR)*).

63.9.2 MTL initialization

Complete the following steps to initialize the MTL registers:

1. Program the following fields to initialize the operating mode in *Tx queue operating mode Register (ETH_MTLTXQOMR)*.
   a) Transmit Store And Forward (TSF) or Transmit Threshold Control (TTC) if the Threshold mode is used.
   b) Transmit Queue Enable (TXQEN) to value 2‘b10 to enable Transmit Queue 0.
   c) Transmit Queue Size (TQS).
2. Program the following fields to initialize the operating mode in the ETH_MTLRXQOMR register (see *Rx queue operating mode register (ETH_MTLRXQOMR)*):
   a) Receive Store and Forward (RSF) or RTC if Threshold mode is used.
   b) Flow Control Activation and De-activation thresholds for MTL Receive FIFO (RFA and RFD).
   c) Error Packet and undersized good Packet forwarding enable (FEP and FUP).
   d) Receive Queue Size (RQS).

63.9.3 MAC initialization

The MAC configuration registers establish the operating mode of the MAC. If possible, these registers must be initialized before initializing the DMA. The following MAC Initialization operations can also be performed after DMA initialization. If the MAC initialization is complete before the DMA is configured, enable the MAC receiver (last step in the following sequence) only after the DMA is active. Otherwise, received frames fill the Rx FIFO and overflow.

1. Provide the MAC address registers: *MAC Address x low register (ETH_MACAxLR)*, *MAC Address 0 high register (ETH_MACA0HR)* and *MAC Address x high register (ETH_MACAxHR)*.
2. Program the following fields to set the appropriate filters for the incoming frames in the *Packet filtering control register (ETH_MACPFR)*:
   a) Receive All.
   b) Promiscuous mode.
   c) Hash or Perfect Filter.
   d) Unicast, multicast, broadcast, and control frames filter settings.
3. Program the following fields for proper flow control in the *Tx Queue flow control register (ETH_MACQTXFCR)*:
   a) Pause time and other Pause frame control bits.
   b) Transmit Flow control bits.
   c) Flow Control Busy.

4. Program the *Interrupt enable register (ETH_MACIER)* as required, if it is applicable for your configuration.
5. Program the appropriate fields in the *Operating mode configuration register (ETH_MACCR)* register. For example, Inter-packet gap while transmission and jabber disable.
6. Set bit 0 and 1 in *Operating mode configuration register (ETH_MACCR)* register to start the MAC transmitter and receiver.

To support Jumbo Transmit/Receive packets, follow these steps:

- In the *Operating mode configuration register (ETH_MACCR)*
  a) Set JE bit to 1.
  b) Set JD and WD bits to 0 to avoid giant packet error reporting.
  c) Set GPSLCE bit to 1
  d) Set GPSL bitfield of the *Extended operating mode configuration register (ETH_MACECR)* to a value > 9026

To support Transmit/Receive packets, up to 16K, follow these steps:

- In the *Operating mode configuration register (ETH_MACCR)*
  a) Set JD and WD bits to 1 to avoid giant packet error reporting.
  b) Set GPSLCE bit to 1.
  c) Set GPSL bitfield of the *Extended operating mode configuration register (ETH_MACECR)* to 16383.

63.9.4 Performing normal receive and transmit operation

For normal operation, complete the following steps:

1. For normal transmit and receive interrupts, read the interrupt status. Then, poll the descriptor by reading the status of the descriptor owned by the Host (either transmit or receive).
2. Set the descriptors to appropriate values. Make sure that transmit and receive descriptors are owned by the DMA to resume the transmission and reception of data.
3. If the descriptors are not owned by the DMA (or no descriptor is available), the DMA goes into Suspend state. The transmission or reception can be resumed by freeing the descriptors and writing the ETH_DMACTXDTPR (see *Channel Tx descriptor tail pointer register (ETH_DMACTXDTPR)* and ETH_DMACRXDTPR (see *Channel Rx descriptor tail pointer register (ETH_DMACRXDTPR)*).
4. In debug mode, the values of the current host transmitter or receiver descriptor address pointer can be read in ETH_DMACCATXDR and ETH_DMACCARXDR registers (see *Channel current application transmit descriptor register (ETH_DMACCATXDR)* and *Channel current application receive descriptor register (ETH_DMACCARXDR)*).
5. In debug mode, the values of the current host transmit buffer address pointer and receive buffer address pointer can be read in ETH_DMACCATXDR and ETH_DMACCARXDR registers (see *Channel current application transmit descriptor register (ETH_DMACCATXDR)* and *Channel current application receive descriptor register (ETH_DMACCARXDR)*).

63.9.5 Stopping and starting transmission

Complete the following steps to pause the transmission for some time:

1. Disable the Transmit DMA (if applicable) by clearing Bit 0 (ST) of ETH_DMACTXCR register (see *Channel transmit control register (ETH_DMACTXCR)*).
2. Wait for any previous frame transmissions to complete. You can check this by reading the appropriate bits of *Tx queue debug Register (ETH_MTLTXQDR)* (TRCSTS[1:0] is not 01 and TXQSTS = 0).
3. Disable the MAC transmitter and MAC receiver by clearing RE and TE bits of the *Operating mode configuration register (ETH_MACCR)* Register.
4. Disable the Receive DMA (if applicable), after making sure that the data in the Rx FIFO is transferred to the system memory (by reading the appropriate bits of *Tx queue debug Register (ETH_MTLTXQDR)*, PRXQ=0 and RXQSTS[1:0] = 00).
5. Make sure that both Tx queue and Rx queue are empty (TXQSTS is 0 in *Tx queue debug Register (ETH_MTLTXQDR)* and RXQSTS[1:0] is set to 00.
6. To restart the operation, first start the DMAs, and then enable the MAC Transmitter and Receiver.

Note: Do not change the configuration (such as duplex mode, speed, port, or loopback) when the MAC is actively transmitting or receiving. These parameters are changed by software only when the MAC transmitter and receiver are not active.

Similarly, do not change the DMA-related configuration when Transmit and Receive DMA are active.

63.9.6 Programming guidelines for switching to new descriptor list in RxDMA

Switching to a new descriptor list is different in the Rx DMA compared to the Tx DMA. Switching to a new descriptor list is permitted when the RxDMA is in Suspend state, as explained below:

- Generally, RxDMA prepares the descriptors in advance.
- If the RxDMA goes to Suspend state due to descriptors not being available, a major failure occurs (software is not able to free the filled-up descriptors/buffers). If this issue is not rectified immediately, frames are lost because of an RxFIFO overflow. Therefore, the software is allowed to create a new descriptor list and program the RxDMA to start using it immediately, without going into Stop state.

63.9.7 Programming guidelines for switching the AHB clock frequency

To dynamically change the AHB clock frequency (without applying soft reset or hard reset), follow these steps:

1. Disable the Transmit DMA (if applicable) and wait for any previous frame transmissions to complete. When the frame transmissions is complete, the Tx FIFO becomes empty and the Tx DMA enters Stop state. The Tx FIFO status is given in the *Tx queue debug*

Register (ETH_MTLTXQDR) and the status of DMA is given in *Debug status register (ETH_DMADSR)*.

2. Disable the MAC transmitter and the MAC receiver by clearing the appropriate bits in *Operating mode configuration register (ETH_MACCR)*.
3. Disable the Receive DMA (if applicable) after making sure that the data in the Rx FIFO is transferred to the system memory. The Rx FIFO empty status is given in *Rx queue debug register (ETH_MTLRXQDR)*.
4. Ensure that the application does not perform any register read or write operation.
5. Change the frequency of the AHB clock.
6. Enable the MAC Transmitter or the MAC Receiver and the Transmit or Receive DMA. These steps ensure that no valid data is present in the Tx FIFO or Rx FIFO at the time of clock frequency switching and prevent any data corruption.

63.9.8 Programming guidelines for MII link state transitions

Transmit and Receive clocks are running when the link is down

Complete the following steps when the link is down while the Transmit and Receive clocks are running:

1. Disable the Transmit DMA (if applicable) by clearing bit 0 (ST) of *Channel control register (ETH_DMACCR)*.
2. Disable the MAC receiver by clearing RE bit of *Operating mode configuration register (ETH_MACCR)*.
3. Wait for any previous frame transmissions to complete. You can check this by reading the appropriate bits of *Tx queue debug Register (ETH_MTLTXQDR)* (TRCSTS[1:0] is not 01).

   or

   Flush the Tx FIFO for faster empty operation.
4. Disable the MAC transmitter by clearing TE bit of the *Operating mode configuration register (ETH_MACCR)* Register.
5. Make sure that both Tx and Rx queues are empty (TXQSTS is set to 0 in *Tx queue debug Register (ETH_MTLTXQDR)* and RXQSTS[1:0] to 00 in *Rx queue debug register (ETH_MTLRXQDR)*).
6. After the link is up, read the PHY registers to identify the latest configuration and program the MAC registers accordingly.
7. Restart the operation by starting the Tx DMA. Then enable the MAC Transmitter and Receiver.

   The Rx DMA does not need to be enabled: since the Receiver is disabled, there are no data in the Rx FIFO.

Transmit and Receive clocks are stopped when the link is down

Complete the following steps when the link is down and the Transmit and Receive clocks are stopped:

1. Disable the MAC Transmitter and Receiver by clearing RE and TE bits in the *Operating mode configuration register (ETH_MACCR)*. This will not take immediate effect as the clocks are absent.
2. Wait till the link is up and the clocks are restored.
3. Wait until the transfer of any partial frame is complete if any was ongoing when the Transmit/Receive clock is stopped. This can be checked by reading the *Debug register (ETH_MACDR)* (all bits should be set to 0). Some old packets may still remain in the TXFIFO as the MAC Transmitter is stopped.
4. Read the PHY registers to identify the latest operating mode and program the MAC registers accordingly.
5. Restart the MAC Transmitter and Receiver by setting RE and TE bits.

63.9.9 Programming guidelines for IEEE 1588 timestamping

Initializing the System time generation

The timestamp feature can be enabled by setting bit 0 of the *Timestamp control Register (ETH_MACTSCR)*. However, it is essential that the timestamp counter is initialized after this bit is set. Complete the following steps to perform the peripheral initialization:

1. Mask the Timestamp Trigger interrupt by clearing bit 12 of *Interrupt enable register (ETH_MACIER)*.
2. Set bit 0 of *Timestamp control Register (ETH_MACTSCR)* to enable timestamping.
3. Program *Subsecond increment register (ETH_MACSSIR)* based on the PTP clock frequency.
4. If you use the Fine Correction method, program *Timestamp addend register (ETH_MACTSAR)* and set bit 5 of *Timestamp control Register (ETH_MACTSCR)*.
5. Poll the *Timestamp control Register (ETH_MACTSCR)* until bit 5 is cleared.
6. Program bit 1 of *Timestamp control Register (ETH_MACTSCR)* to select the Fine Update method (if required).
7. Program *System time seconds update register (ETH_MACSTSUR)* and *System time nanoseconds update register (ETH_MACSTNUR)* with the appropriate time value.
8. Set bit 2 in *Timestamp control Register (ETH_MACTSCR)*.

   The timestamp counter starts as soon as it is initialized with the value written in the timestamp update registers. If one-step timestamping is required:

   a) Enable one-step timestamping by programming bit 27 of the TDES3 Context Descriptor.

   b) Program *Timestamp Ingress asymmetric correction register (ETH_MACTSIACR)* to update the correction field in PDelay_Req PTP messages.
9. Enable the MAC receiver and transmitter for proper timestamping.

Note: If timestamp operation is disabled by clearing bit 0 of Timestamp control Register (ETH_MACTSCR), repeat all these steps to restart the timestamp operation.

System time correction

To synchronize or update the system time in one shot (coarse correction method), complete the following steps:

1. Set the offset (positive or negative) in the timestamp update registers (*System time seconds update register (ETH_MACSTSUR)* and *System time nanoseconds update register (ETH_MACSTNUR)*).
2. Set bit 3 (TSUPDT) of the *Timestamp control Register (ETH_MACTSCR)*.

   The value in the timestamp update registers is added to or subtracted from the system time when the TSUPDT bit is cleared.

To synchronize or update the system time to reduce system-time jitter (fine correction method), complete the following steps:

1. With the help of the algorithm described in *Section : System time register module*, calculate at which rate you intend to increment or decrement the system time.
2. Update the *Timestamp addend register (ETH_MACTSAR)* with the new value and set bit 5 of the *Timestamp control Register (ETH_MACTSCR)* Register.
3. Wait for the time during which you want the new value of the Addend register to be active. This can be done by enabling the Timestamp Trigger interrupt after the system time reaches the target value.
4. Program the required target time in *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*.
5. Enable the Timestamp interrupt in bit 12 of *Interrupt enable register (ETH_MACIER)*.
6. Set bit 4 in Register *Timestamp control Register (ETH_MACTSCR)*.
7. When this trigger generates an interrupt, read *Interrupt status register (ETH_MACISR)*.
8. Reprogram *Timestamp addend register (ETH_MACTSAR)* with the old value and set bit 5 again.

63.9.10 Programming guidelines for PTP offload feature

Programming guidelines to enable automatic periodic generation of PTP sync messages

Follow these steps to enable automatic periodic generation of PTP sync messages:

1. Program SNAPTYPSEL, TSMSTRENA, and TSEVNTENA fields of *Timestamp control Register (ETH_MACTSCR)* to 0, 1, and 1 respectively, to configure the node as Ordinary or Boundary Master (1, 1, and 1 for Transparent Master).
2. Program the PTOEN bit and DN field of *PTP Offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain number to send in egress PTP Sync message.
3. Program the ASYNCEN bit of *PTP Offload control register (ETH_MACPOCR)* to enable periodic generation of PTP Sync messages.
4. Program the 80-bit Source Port Identity in *PTP Source Port Identity 0 Register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP*

Source port identity 2 register (ETH_MACSPI2R) to send in egress PTP Sync message.

5. Program the LSI field of *Log message interval register (ETH_MACLMIR)* to program the periodicity of the PTP Sync messages.

   For example, a value of 1 corresponds to 2^1 which translates to PTP Sync message every 2 seconds, and a value of 0xFF (twos complement of -1) corresponds to 2^{-1} which translates to PTP Sync message every 0.536 seconds.
6. Program the TSIE bit of *Interrupt enable register (ETH_MACIER)* to enable generation of Timestamp interrupt.
7. Wait for sbd_intr_o interrupt generated by setting TXTSSIS bit in *Timestamp status register (ETH_MACTSSR)*. It indicates that the timestamp for PTP Sync message is captured in *Tx timestamp status seconds register (ETH_MACTXTSSSR)* and *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)*.

Programming guidelines to enable periodic generation of PTP Pdelay_Req messages

Follow these steps to enable automatic periodic generation of PTP Pdelay_Req messages

1. Program SNAPTYPSEL, TSMSTRENA and TSEVNTENA fields of *Timestamp control Register (ETH_MACTSCR)* to 1, 0, and 1 respectively to configure the node as Transparent Slave (1, 1, and 1 for Transparent Master OR 3, X, and X for Peer-to-Peer Transparent).
2. Program the PTOEN bit and DN field of *PTP Offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain number to send in egress PTP Pdelay_Req message.
3. Program the APDREQEN bit of *PTP Offload control register (ETH_MACPOCR)* to enable periodic generation of PTP Pdelay_Req messages.
4. Program the 80-bit Source Port Identity in *PTP Source Port Identity 0 Register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)* to send in egress PTP Pdelay_Req message.
5. Program the LMPDRI field of *Log message interval register (ETH_MACLMIR)* to program the periodicity of the PTP Pdelay_Req messages.

   For example, a value of 1 corresponds to 2^1 which translates to PTP Pdelay_Req message every 2 seconds, and a value of 0xFF (twos complement of -1) corresponds to 2^{-1} which translates to PTP Pdelay_Req message every 0.536 seconds.
6. Program the TSIE bit of *Interrupt enable register (ETH_MACIER)* to enable generation of Timestamp interrupt.
7. Wait for sbd_intr_o interrupt generated by setting TXTSSIS bit in *Timestamp status register (ETH_MACTSSR)*. It indicates that the timestamp for PTP Sync message is captured in *Tx timestamp status seconds register (ETH_MACTXTSSSR)* and *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)*.

Programming guidelines to enable the generation of PTP response messages for Ordinary or Boundary Master mode

Follow these steps to enable the generation of PTP response messages for Ordinary or Boundary Master mode (Periodic PTP Sync messages generated and PTP Delay_Resp message generated in response to PTP Delay_Req message):

1. Program SNAPTYPSEL, TSMSTRENA and TSEVNTENA fields of *Timestamp control Register (ETH_MACTSCR)* to 0, 1, and 1 respectively.
2. Program the PTOEN bit and DN field of *PTP Offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain number to match with ingress PTP Delay_Req message and send in egress PTP Delay_Resp message.
3. Program the 80-bit Source Port Identity in *PTP Source Port Identity 0 Register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)* to match with ingress PTP Delay_Req message and send in egress PTP Delay_Resp message.
4. Program the DRSYNCR and LSI fields in *Log message interval register (ETH_MACLMIR)*. The sum of both fields is updated in logMinDelayReqInterval field of PTP Delay_Resp message.

Programming guidelines to enable the generation of PTP response messages for Ordinary or Boundary Slave mode

Follow these steps to enable generation of PTP response messages for Ordinary or Boundary Slave mode (PTP Delay_Req message generated in response to PTP Sync message):

1. Program SNAPTYPSEL, TSMSTRENA and TSEVNTENA fields of *Timestamp control Register (ETH_MACTSCR)* to 0, 0, and 1 respectively.
2. Program the PTOEN bit and DN field of *PTP Offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain Number to match with ingress PTP Sync message and send in egress PTP Delay_Req message.
3. Program the 80-bit Source Port Identity in *PTP Source Port Identity 0 Register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)* to match with ingress PTP Sync message and send in egress PTP Delay_Req message.
4. Program the DRSYNCR field in *Log message interval register (ETH_MACLMIR)* to indicate one PTP Delay_Req message is generated in response to how many received PTP Sync messages.

Programming guidelines to enable the generation of PTP response messages for Transparent Slave mode

Follow these steps to enable generation of PTP response messages for Transparent Slave mode (PTP Delay_Req message generated in response to PTP Sync message, PTP Pdelay_Resp message generated in response to PTP Pdelay_Req message and Periodic PTP Pdelay_Req messages generated)

1. Program SNAPTYPSEL, TSMSTRENA and TSEVNTENA fields of *Timestamp control Register (ETH_MACTSCR)* to 1, 0, and 1 respectively.
2. Program the PTOEN bit and DN field of *PTP Offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain Number to match with ingress PTP Sync or Pdelay_Req message and send in egress PTP Delay_Req or Pdelay_Resp or Pdelay_Req message.
3. Program the 80-bit Source Port Identity in *PTP Source Port Identity 0 Register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)* to match with ingress PTP Sync or

Pdelay_Req message and send in egress PTP Delay_Req or Pdelay_Resp or Pdelay_Req message.

4. Program the DRSYNCR and LMPDRI fields in *Log message interval register (ETH_MACLMIR)* to indicate one PTP Delay_Req message is generated in response to how many received PTP Sync messages and periodicity of the PTP Pdelay_Req messages.
5. Program the TSIE bit of *Interrupt enable register (ETH_MACIER)* to enable generation of Timestamp interrupt.
6. Wait for sbd_intr_o interrupt generated by setting TXTSSIS bit in *Timestamp status register (ETH_MACTSSR)*. It indicates that the timestamp for PTP Sync message is captured in *Tx timestamp status seconds register (ETH_MACTXTSSSR)* and *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* for egress PTP Pdelay_Req and Pdelay_Resp messages.

Programming guidelines to enable the generation of PTP response messages for Transparent Master mode

Follow these steps to enable generation of PTP response messages for Transparent Master mode (PTP Delay_Resp message generated in response to PTP Delay_Req message, PTP Pdelay_Resp message generated in response to PTP Pdelay_Req message and Periodic PTP Pdelay_Req or Sync messages generated):

1. Program SNAPTYPSEL, TSMSTRENA and TSEVNTENA fields of *Timestamp control Register (ETH_MACTSCR)* to 1, 1, and 1 respectively.
2. Program the PTOEN bit and DN field of *PTP Offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain number to match with ingress PTP Delay_Req or Pdelay_Req message and send in egress PTP Delay_Resp or Pdelay_Resp or Pdelay_Req or Sync message.
3. Program the 80-bit Source Port Identity in *PTP Source Port Identity 0 Register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)* to match with ingress PTP Delay_Req or Pdelay_Req message and send in egress PTP Delay_Resp or Pdelay_Resp or Pdelay_Req or Sync message.
4. Program the DRSYNCR, LSI and LMPDRI fields in *Log message interval register (ETH_MACLMIR)*, the sum of DRSYNCR and LSI is updated in logMinDelayReqInterval field of PTP Delay_Resp message and periodicity of the PTP Sync or Pdelay_Req messages.
5. Program the TSIE bit of *Interrupt enable register (ETH_MACIER)* to enable generation of Timestamp interrupt.
6. Wait for sbd_intr_o interrupt generated by setting TXTSSIS bit in *Timestamp status register (ETH_MACTSSR)*. It indicates that the timestamp for PTP Sync message is captured in *Tx timestamp status seconds register (ETH_MACTXTSSSR)* and *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* for egress PTP Sync, Pdelay_Req and Pdelay_Resp messages.

Programming guidelines to enable the generation of PTP response messages for Peer-to-Peer Transparent mode

Follow these steps to enable generation of PTP response messages for Peer-to-Peer Transparent mode (PTP Pdelay_Resp message generated in response to PTP Pdelay_Req message and Periodic PTP Pdelay_Req messages generated):

1. Program the SNAPTYPSEL, TSMSTRENA and TSEVNTENA fields of *Timestamp control Register (ETH_MACTSCR)* to 3, X, and X respectively.
2. Program the PTOEN bit and DN field of *PTP Offload control register (ETH_MACPOCR)* to enable PTP Offload feature and domain Number to match with ingress PTP Pdelay_Req message and send in egress PTP Pdelay_Resp message.
3. Program the 80-bit Source Port Identity in *PTP Source Port Identity 0 Register (ETH_MACSPI0R)*, *PTP Source port identity 1 register (ETH_MACSPI1R)* and *PTP Source port identity 2 register (ETH_MACSPI2R)* to match with ingress PTP Pdelay_Req message and send in egress PTP Pdelay_Resp message.
4. Program the LMPDRI field in *Log message interval register (ETH_MACLMIR)* to indicate periodicity of the PTP Pdelay_Req messages
5. Program the TSIE bit of *Interrupt enable register (ETH_MACIER)* to enable generation of Timestamp interrupt
6. Wait for sbd_intr_o interrupt generated by setting TXTSSIS bit in *Timestamp status register (ETH_MACTSSR)*. It indicates that the timestamp for PTP Sync message is captured in *Tx timestamp status seconds register (ETH_MACTXTSSSR)* and *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* for egress PTP Pdelay_Req and Pdelay_Resp messages.

63.9.11 Programming guidelines for Energy Efficient Ethernet (EEE)

Entering and exiting Tx LPI mode

EEE enables the IEEE 802.3 Media Access Control (MAC) sublayer along with a family of physical layers to operate in the Low-power idle (LPI) mode. In the Transmit path, the software must set the LPIEN bit of the *LPI control and status register (ETH_MACLCSR)* to indicate to the MAC to stop transmission and initiate the LPI protocol.

Complete the following steps during MAC initialization:

1. Read the PHY register through the MDIO interface and check if the remote end has the EEE capability. Then negotiate the timer values.
2. Program the PHY registers through the MDIO interface (including the RX_CLK_stoppable bit that indicates to the PHY whether to stop Rx clock in LPI mode or not).
3. Program bits 25 to 16 and bits 15 to 0 in *LPI timers control register (ETH_MACLTCR)*.
4. Read the PHY link status by using the MDIO interface and update bit 17 of *LPI control and status register (ETH_MACLCSR)*.

   Update *LPI control and status register (ETH_MACLCSR)* accordingly. This update should be done whenever the link status in the PHY chip changes.
5. Program *One-microsecond-tick counter register (ETH_MAC1USTCR)* as per the frequency of the clock used for accessing the CSR slave port.
6. Program the LPIET bit in the *LPI entry timer register (ETH_MACLETR)* with the IDLE time for which the MAC should wait before entering the LPI state on its own.

7. Set LPITE and LPITXA (bits 20 to 19) of *LPI control and status register (ETH_MACLCSR)* to enable LPI auto-entry and MAC auto-exit from LPI state.
8. Set bit 16 of *LPI control and status register (ETH_MACLCSR)* to put the MAC transmitter in LPI state.

   The MAC enters the LPI state when all scheduled packets are completed. It remains IDLE for the time indicated by LPIET bits. It sets the TLPIEN (bit 0) after entering LPI state.
9. When a packet transmission is scheduled (when the TxDMA exits IDLE state or when a packet is presented at ATI or MTI interface), the MAC Transmitter automatically exits LPI state. It waits for TWT time before setting the TLPIEX interrupt status bit and then resume the packet transmission.
10. The MAC Transmitter enters again LPI state if it remains IDLE for LPIET time. It then sets the TLPIEN bit and the entry-exit cycle continues.
11. Reset LPIEN bit if the application needs to override the auto-entry/exit modes and directly exit the MAC Transmitter from LPI state.

Note: To make sure the MAC enters the LPI state only after the transmission of all the queued frames in the Tx FIFO is complete, set LPITXA bit in LPI control and status register (ETH_MACLCSR).

To switch off the CSR clock or power to the rest of the system during the LPI state, wait for the TLPIEN interrupt of LPI control and status register (ETH_MACLCSR) to be generated. Restore the clocks before performing step 6 when you want to come out of the LPI state.

Gating Off the CSR Clock in the LPI mode

You can gate off the CSR clock to save the power when the MAC is in the Low-Power Idle (LPI) mode.

Gating off the CSR clock in the Rx LPI mode

The following operations are performed when the MAC receives the LPI pattern from the PHY:

1. The MAC RX enters the LPI mode and the Rx LPI entry interrupt status (RLPIEN interrupt of *LPI control and status register (ETH_MACLCSR)*) is set.
2. The interrupt pin (sbd_intr_o) is asserted. The sbd_intr_o interrupt is cleared when the host reads the *LPI control and status register (ETH_MACLCSR)*.

After the sbd_intr_o interrupt is asserted and the MAC Tx is also in the LPI mode, the CSR clock can be gated off. If the MAC TX is not in LPI mode when the CSR clock is gated off, the events on the MAC transmitter do not get reported or updated in the CSR. To restore the CSR clock, wait for the LPI exit indication from the PHY after which the MAC asserts the LPI exit interrupt on lpi_intr_o (synchronous to clk_rx_i). The lpi_intr_o interrupt is cleared when *LPI control and status register (ETH_MACLCSR)* is read.

Gating off the CSR clock in the Tx LPI mode

The following operations are performed when bit 16 (LPIEN) of *LPI control and status register (ETH_MACLCSR)* is set:

1. The Transmit LPI Entry interrupt (TLPIEN bit of *LPI control and status register (ETH_MACLCSR)*) is set.
2. The interrupt pin (sbd_intr_o) is asserted. The sbd_intr_o interrupt is cleared when the host reads the *LPI control and status register (ETH_MACLCSR)*.

After the sbd_intr_o interrupt is asserted and the MAC RX is also in the LPI mode, the CSR clock can be gated off. If the MAC RX is not in LPI mode when the CSR clock is gated off, the events on the MAC receiver do not get reported or updated in the CSR. To restore the CSR clock, switch on the CSR clock when the MAC has exited TX LPI mode. After the CSR clock is resumed, reset bit 16 (LPIEN) of *LPI control and status register (ETH_MACLCSR)* to exit the MAC from LPI mode.

63.9.12 Programming guidelines for flexible pulse-per-second (PPS) output

Generating a single pulse on PPS

To generate a single pulse on PPS:

1. Program TRGTMODSEL[1:0] bit to 11 or 10 (for interrupt) in *PPS control register (ETH_MACPPSCR)*. This instructs the MAC to use the Target Time registers (*PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*) as start time of PPS signal output.
2. Program the start time value in the Target Time registers (register *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*).
3. Program the width of the PPS signal output in *PPS width register (ETH_MACPPSWR)* Register.
4. Program PPSCMD[3:0] of *PPS control register (ETH_MACPPSCR)* to 0001. This instructs the MAC to generate a single pulse on the PPS signal output at the time programmed in the Target Time registers.

Generating next pulse on PPS

When the PPSCMD is executed (PPSCMD bits = 0), you can cancel the pulse generation by giving the Cancel Start Command (PPSCMD=0011) before the programmed start time has elapsed. You can also program the behavior of the next pulse in advance. To program the next pulse:

1. Program the start time for the next pulse in the Target Time registers. This time should be higher than the time at which the falling edge occurs for the previous pulse.
2. Program the width of the next PPS signal output in *PPS width register (ETH_MACPPSWR)*.
3. Program PPSCMD[3:0] bits of *PPS control register (ETH_MACPPSCR)* to generate a single pulse after the previous pulse is deasserted. This instructs the MAC to generate a single pulse on the PPS signal output at the time programmed in Target Time registers.

   If this command is given before the previous pulse becomes low, then the new command overwrites the previous command and the peripheral may generate only 1 extended pulse.

Generating a pulse train on PPS

To generate a pulse train on PPS:

1. Program TRGTMODSEL[1:0] bits to 11 or 10 (for interrupt) in *PPS control register (ETH_MACPPSCR)*. This instructs the MAC to use the Target Time registers (*PPS*

target time seconds register (ETH_MACPPSTTSR) and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*) for start time of the PPS signal output.

2. Program the start time value in the Target Time registers (register *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*).
3. Program the interval value between the train of pulses on the PPS signal output in *PPS interval register (ETH_MACPPSIR)*.
4. Program the width of the PPS signal output in *PPS width register (ETH_MACPPSWR)*.
5. Program PPSCMD[3:0] bits in *PPS control register (ETH_MACPPSCR)* to 0010. This instructs the MAC to generate a train of pulses on the PPS signal output at the start time programmed in Target Time registers.

   By default, the PPS pulse train is free-running unless it is stopped by issuing a 'STOP Pulse train at time' or 'STOP Pulse Train immediately' commands.
6. Program the stop value in the Target Time registers. Ensure that TSTRBUSY bit in *PPS target time nanoseconds register (ETH_MACPPSTTNR)* is reset before programming the Target Time registers again.
7. Program the PPSCMD[3:0] bits in *PPS control register (ETH_MACPPSCR)* to 0100 to stop the train of pulses on PPS signal output after the programmed stop time specified at step 6 has elapsed.

The pulse train can be stopped at any time by programming 0101 in the PPSCMD[3:0] field.

Similarly, the Stop Pulse train command (given in Step 7) can be canceled by programming PPSCMD[3:0] bits to 0110 before the time (programmed at step 6) has elapsed.

The pulse train generation can be stopped by programming PPSCMD[3:0] to 0011 before the start time programmed at step 2) has elapsed.

Generating an interrupt without affecting the PPS

TRGTMODSEL[1:0] bits in *PPS control register (ETH_MACPPSCR)* enable you to program the Target Time registers (*PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*) to do any one of the following:

- Generate only interrupts.
- Generate interrupts and the PPS start and stop time.
- Generate only PPS start and stop time.

To program the Target Time registers to generate only interrupt event:

1. Program TRGTMODSEL[1:0] bits of *PPS control register (ETH_MACPPSCR)* to 00 (for interrupt). This instructs the MAC to use the Target Time registers for target time interrupt.
2. Program a target time value in the Target Time registers. This instructs the MAC to generate an interrupt when the target time elapses.

   If TRGTMODSEL[1:0] bits are changed (for example, to control the PPS), then the interrupt generation is overwritten with the new mode and new programmed Target Time register value.

Note: The TSTRGTERR0 bit in Timestamp status register (ETH_MACTSSR) is set when the programmed target time is smaller (that is corresponds to a time in the past) compared to

the system time in the System time seconds register (ETH_MACSTSR) and System time nanoseconds register (ETH_MACSTNR).

An interrupt is generated (sbd_intr_o) if the TSIE bit in the Interrupt enable register (ETH_MACIER) is set.

Therefore, to avoid unwanted interrupt, the correct writing order is as follow:

1. *PPS target time nanoseconds register (ETH_MACPPSTTNR).*
2. *PPS target time seconds register (ETH_MACPPSTTSR).*
3. *PPS interval register (ETH_MACPPSIR).*
4. *PPS width register (ETH_MACPPSWR).*
5. *PPSCTRL[3:0] and PPSCTRL[3:0] and PPSEN0 bitfields of PPS control register (ETH_MACPPSCR).*

63.9.13 Programming guidelines for TSO

The TCP Segmentation Offload (TSO) engine is used to offload the TCP segmentation functions to the hardware. To program the TSO, set the TSE bit to enable TCP packet segmentation, and program descriptor fields to enable TSO for the current packet.

Follow the steps below to program TSO:

1. Program TSE bit of the corresponding *Channel transmit control register (ETH_DMACTXCR)* to enable TCP packet segmentation in that DMA.
2. In addition to the normal transfer descriptor setting, the following descriptor fields must be programmed to enable TSO for the current packet:
   a) Enable TSE of TDES3 (bit 18).
   b) Program the length of the unsegmented TCP/IP packet payload in bits 17 to 0 of TDES3, and the TCP header in bits 22 to 19 of TDES3.
   c) Program the maximum size of the segment in:
   – MSS[13:0] of *Channel control register (ETH_DMACCR)*
   – or MSS in the context descriptor

   If MSS[13:0] field is programmed in both *Channel control register (ETH_DMACCR)* and in the context descriptor, the latest software programmed sequence is considered.
3. The unsegmented TCP/IP packet header should be stored in Buffer 1 of the first descriptor. This buffer must not hold any payload bytes. The payload is allocated to Buffer 2 and the buffers of the subsequent descriptors.

Caution: If TSE is enabled in TDES3 for a non-TCP-IP packet, the result is unpredictable.

63.9.14 Programming guidelines to perform VLAN filtering on the receive

Follow the sequence below to perform VLAN filtering on the receiver:

1. Program *VLAN tag register (ETH_MACVTR)* for the following bit to select the filtering method:
   - ETV: Enable 12-bit VLAN Tag Comparison or 16-bit VLAN Tag comparison.
   - VTHM: VLAN Tag Hash Table Match Enable.
   - ERIVLT: Enable inner VLAN Tag or outer VLAN Tag (to enable the inner or outer VLAN Tag filtering, Double VLAN Processing should enabled by setting EDVLP)
   - ERSVLM: Enable Receive S-VLAN Match or C-VLAN match (for S-VLAN processing to be enabled, set ESVL)
   - DOVLTC: Ignores VLAN Type for Tag Match
   - VTIM: to enable VLAN Tag Inverse Match instead of the normal VLAN Tag matching
2. Program VL bit in *VLAN tag register (ETH_MACVTR)* for the 12-bit or 16-bit VLAN tag.
3. If VLAN tag Hash filtering is enabled, program *VLAN Hash table register (ETH_MACVHTR)*.
   - When the ETV bit is reset, the upper 4 bits of the calculated CRC-32 of VLAN tag are inverted and used to index the content of the *VLAN Hash table register (ETH_MACVHTR)*.
   - When ETV bit is set, the upper 4 bits of the calculated CRC-32 of VLAN tag are used to index the content of *VLAN Hash table register (ETH_MACVHTR)*.

   For example, when ETV bit is set, a hash value of 0b1000 selects bit 8 of the VLAN Hash table. When ETV bit is reset, a hash value of 0b1000 selects bit 7 of the VLAN Hash table.

63.10 Descriptors

63.10.1 Descriptor overview

In the Ethernet peripheral, the DMA transfers data based on a linked list of descriptors. The application creates the descriptors in the system memory (SRAM). The following two types of descriptors are supported:

- **Normal descriptors**

  The normal descriptors are used for packet data and to provide control information applicable to the packets to be transmitted.
- **Context descriptors**

  The context descriptors are used to provide control information applicable to the packet to be transmitted.

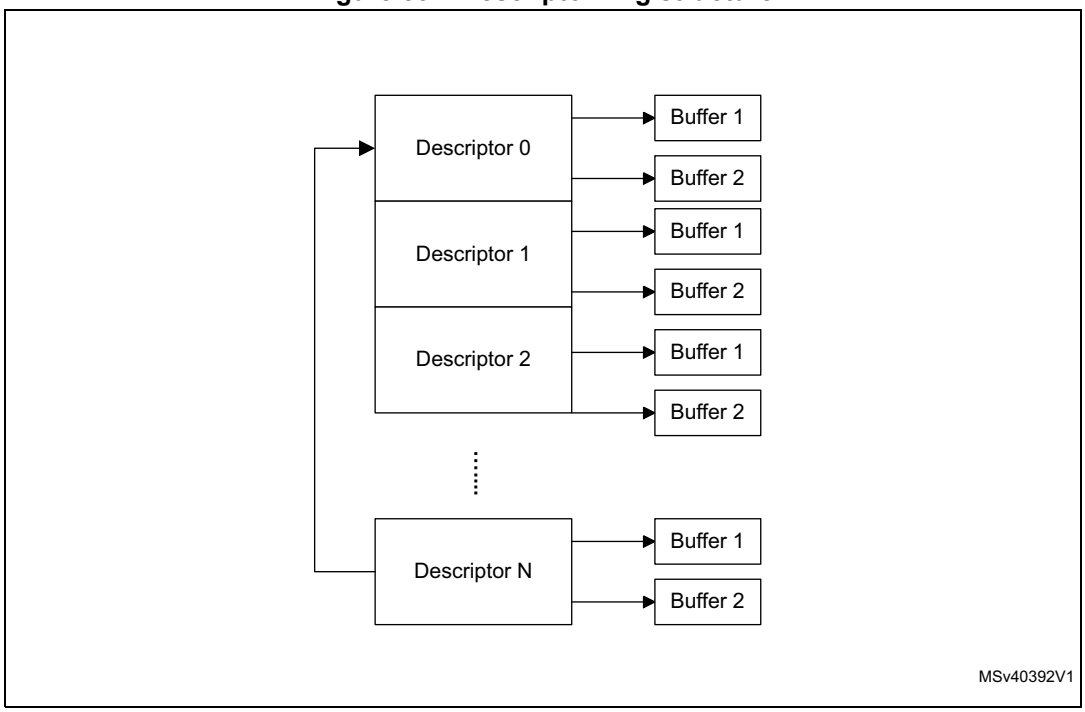
Each normal descriptor contains two buffers and two address pointers. These buffers enable the adapter port to be compatible with various types of memory management schemes.

There is no limit to the number of descriptors that can be used for a single packet.

63.10.2 Descriptor structure

The Ethernet peripheral supports the ring structure for DMA descriptors.

Figure 837. Descriptor ring structure



In a ring structure, descriptors are separated by the 32-bit word number programmed in the DSL field of the *Channel control register (ETH_DMACCR)*). The application needs to program the total ring length, that is the total number of descriptors in ring span, in the following registers of a DMA channel:

- *Channel Tx descriptor ring length register (ETH_DMACTXRLR)*)
- *Channel Rx descriptor ring length register (ETH_DMACRXRLR)*)

The *Channel Tx descriptor tail pointer register (ETH_DMACTXDTPR)* or *Channel Rx descriptor tail pointer register (ETH_DMACRXDTPR)* contains the pointer to the descriptor address (*N*). The base address and the current descriptor pointer decide the address of the current descriptor that the DMA can process. The descriptors up to one location less than the one indicated by the descriptor tail pointer (*N* – 1) are owned by the DMA. The DMA continues to process the descriptors until the following condition occurs:

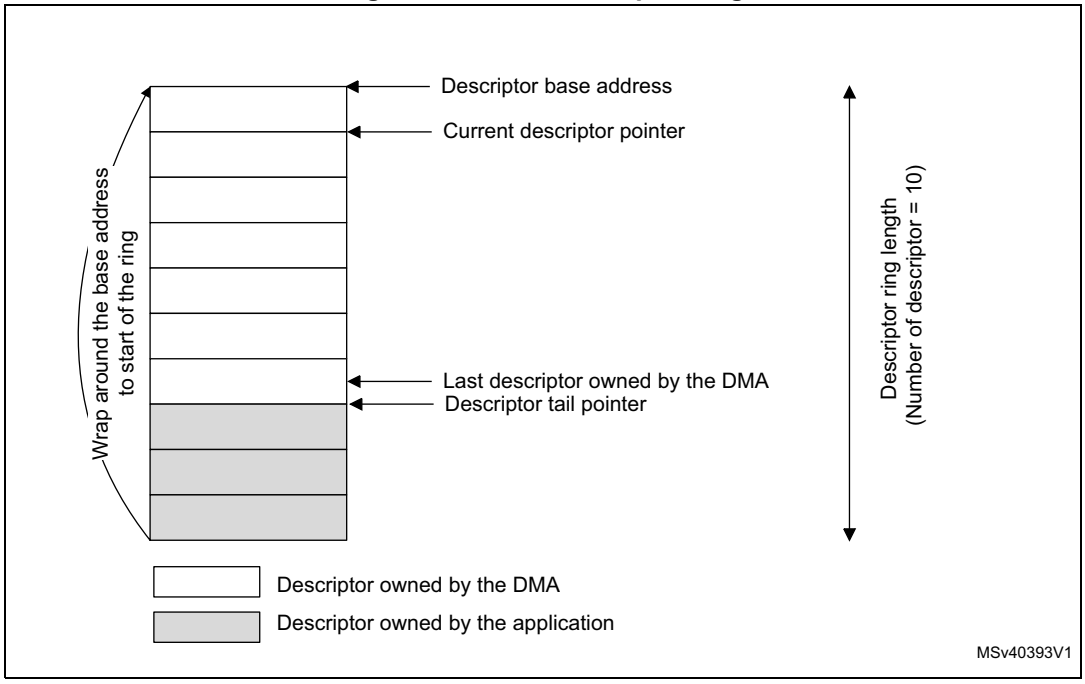
```
Current Descriptor Pointer == Descriptor Tail Pointer;
```

The DMA enters the Suspend state when this condition occurs. The application must perform a write operation to the Descriptor tail pointer register and update the tail pointer so that the following condition is met:

```
Current Descriptor Pointer < Descriptor Tail Pointer;
```

The DMA automatically wraps around the base address when the end of ring is reached, as shown in *Figure 838: DMA descriptor ring*.

Figure 838. DMA descriptor ring



For descriptors owned by the application, the OWN bit of DES3 is reset to 0.

For descriptors owned by the DMA, the OWN bit is set to 1.

At the beginning, if the application has only one descriptor, it sets the last descriptor address (tail pointer) to Descriptor Base Address + 1. The DMA then processes the first descriptor and waits for the application to increment the tail pointer.

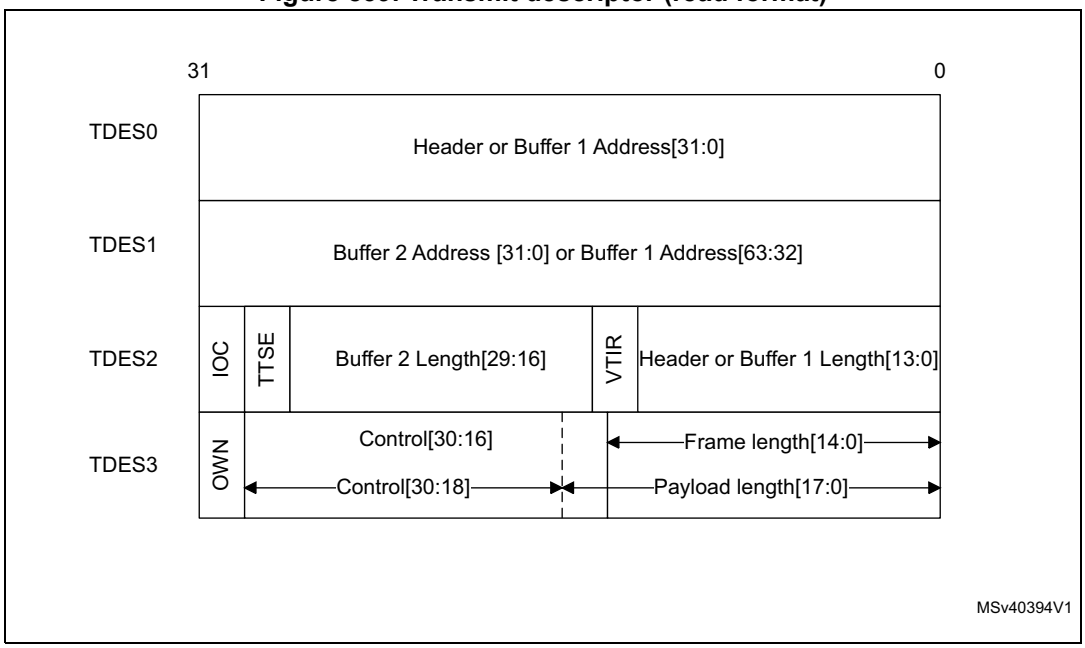
63.10.3 Transmit descriptor

The Ethernet peripheral DMA requires at least one descriptor for a transmit packet. In addition to two buffers, two byte-count buffers, and two address pointers, the transmit descriptor features control fields which can be used to manage the MAC operation on per-transmit packet basis. The Transmit normal descriptor has the following two formats: Read format and Write-back format

Transmit normal descriptor (read format)

Figure 839 shows the Read format for Transmit normal descriptor. *Table 578* to *Table 581* provide a detailed description of all Transmit normal descriptors (read format).

Figure 839. Transmit descriptor (read format)



- TDES0 normal descriptor (read format)

Table 578. TDES0 normal descriptor (read format)

Bit	Name	Description
31:0	BUF1AP	**Buffer 1 Address Pointer or TSO Header Address Pointer** These bits indicate either the physical address of Buffer 1 or the TSO Header Address pointer when the following bits are set: – TSE bit of TDES3 – FD bit of TDES3

- TDES1 normal descriptor (read format)

Table 579. TDES1 normal descriptor (read format)

Bit	Name	Description
31:0	BUF2AP	**Buffer 2 or Buffer 1 Address Pointer:** These bits indicate the physical address of Buffer 2 when a descriptor ring structure is used. There is no limitation to the buffer address alignment.

- TDES2 normal descriptor (read format)

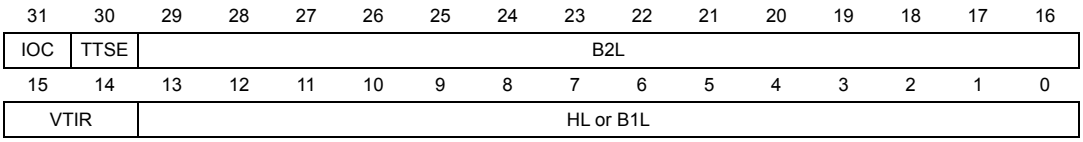


Table 580. TDES2 normal descriptor (read format)

Bits	Name	Description
31	IOC	**Interrupt on completion:** This bit sets the TI bit in the *Channel status register (ETH_DMACSR)*) when the present packet transmission is complete.
30	TTSE	**Transmit Timestamp Enable** This bit enables the IEEE1588 timestamping for Transmit packet referenced by the descriptor.
29:16	B2L	**Buffer 2 Length** The driver sets this field. When set, this field indicates Buffer 2 length.
15:14	VTIR	**VLAN Tag Insertion or Replacement:** These bits request the MAC to perform VLAN tagging or untagging before transmitting the packets. The application must set the CRC Pad Control bits appropriately when VLAN tag insertion, replacement, or deletion is enabled for the packet. The values of these bits are as follows: 00: Do not add a VLAN tag. 01: Remove the VLAN tag from the packets before transmission. This option should be used only with the VLAN packets. 10: Insert a VLAN tag with the tag value programmed in the *VLAN inclusion register (ETH_MACVIR)* or context descriptor. 11: Replace the VLAN tag in packets with the tag value programmed in the *VLAN inclusion register (ETH_MACVIR)* or context descriptor. This option should be used only with the VLAN packets.

Table 580. TDES2 normal descriptor (read format) (continued)

Bits	Name	Description
13:0	HL or B1L	**Header length or buffer 1 length** For Header length, only bits [9:0] are taken into account. Bits 13 to 0 are applicable only to buffer 1 length. If the TCP Segmentation Offload feature is enabled through the TSE bit of TDES3, this field is equal to the header length. When the TSE bit is set in TDES3, the header length includes the length (expressed in bytes) from Ethernet Source address till the end of the TCP header. The maximum header length supported for TSO feature is 1023 bytes. If the TCP Segmentation Offload feature is not enabled, this field is equal to Buffer 1 length.

- TDES3 normal descriptor (read format)

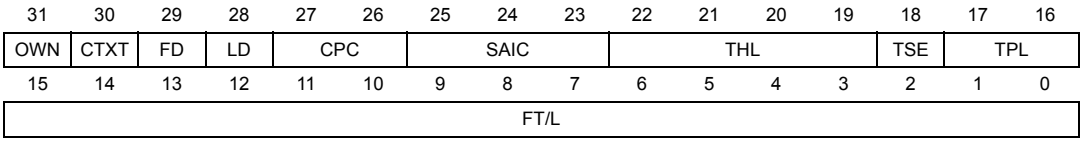


Table 581. TDES3 normal descriptor (read format)

Bits	Name	Description
31	OWN	**Own bit** 1: the DMA owns the descriptor. 0: the application owns the descriptor. The DMA clears this bit after it completes the transfer of data given in the associated buffer(s).
30	CTXT	**Context Type** This bit should be set to 0 for normal descriptor.
29	FD	**First Descriptor** When this bit is set, it indicates that the buffer contains the first segment of a packet.
28	LD	**Last Descriptor** When this bit is set, it indicates that the buffer contains the last segment of the packet. B1L or B2L field should have a non-zero value.

Table 581. TDES3 normal descriptor (read format) (continued)

Bits	Name	Description
27:26	CPC	**CRC Pad Control** This field controls the CRC and Pad Insertion for Tx packet. It is valid only when the first descriptor bit (TDES3[29]) is set. The values of bits[27:26] are the following: 00: CRC and Pad Insertion The MAC appends the cyclic redundancy check (CRC) at the end of the transmitted packets whose length greater than or equal to 60 bytes. The MAC automatically appends padding and CRC to a packet with length less than 60 bytes. 01: CRC Insertion (Disable Pad Insertion) The MAC appends the CRC at the end of the transmitted packet but it does not append padding. The application should ensure that the padding bytes are present in the packet being transferred from the Transmit buffer, that is, the packet being transferred from the Transmit Buffer is of length greater than or equal to 60 bytes. 10: Disable CRC Insertion The MAC does not append the CRC at the end of the transmitted packet. The application should ensure that the padding and CRC bytes are present in the packet being transferred from the Transmit Buffer. 11: CRC Replacement The MAC replaces the last four bytes of the transmitted packet with recalculated CRC bytes. The application should ensure that the padding and CRC bytes are present in the packet being transferred from the Transmit Buffer. When the TSE bit is set, the MAC ignores this field because the CRC and pad insertion is always done for segmentation.
25:23	SAIC	**SA Insertion Control** These bits request the MAC to add or replace the Source Address field in the Ethernet packet with the value given in the MAC Address 0 register. The application must appropriately set the CRC Pad Control bits when SA Insertion Control is enabled for the packet. Bit 25 specifies the MAC Address Register (1 or 0) value that is used for Source Address insertion or replacement. The following list describes the values of Bits[24:23]: 00: Do not include the source address 01: Include or insert the source address. For reliable transmission, the application must provide frames without source addresses. 10: Replace the source address. For reliable transmission, the application must provide frames with source addresses. 11: Reserved These bits are valid when the First Segment control bit (TDES3 [29]) is set.
22:19	THL	**THL**: TCP Header Length If the TSE bit is set, this field contains the length of the TCP/UDP header. The minimum value of this field must be 5 for TCP header. THL value must be equal to 2 for UDP header. This field is valid only for the first descriptor.
18	TSE	**TCP Segmentation Enable** When this bit is set, the DMA performs the TCP/UDP segmentation for a packet. This bit is valid only if the FD bit is set.

Table 581. TDES3 normal descriptor (read format) (continued)

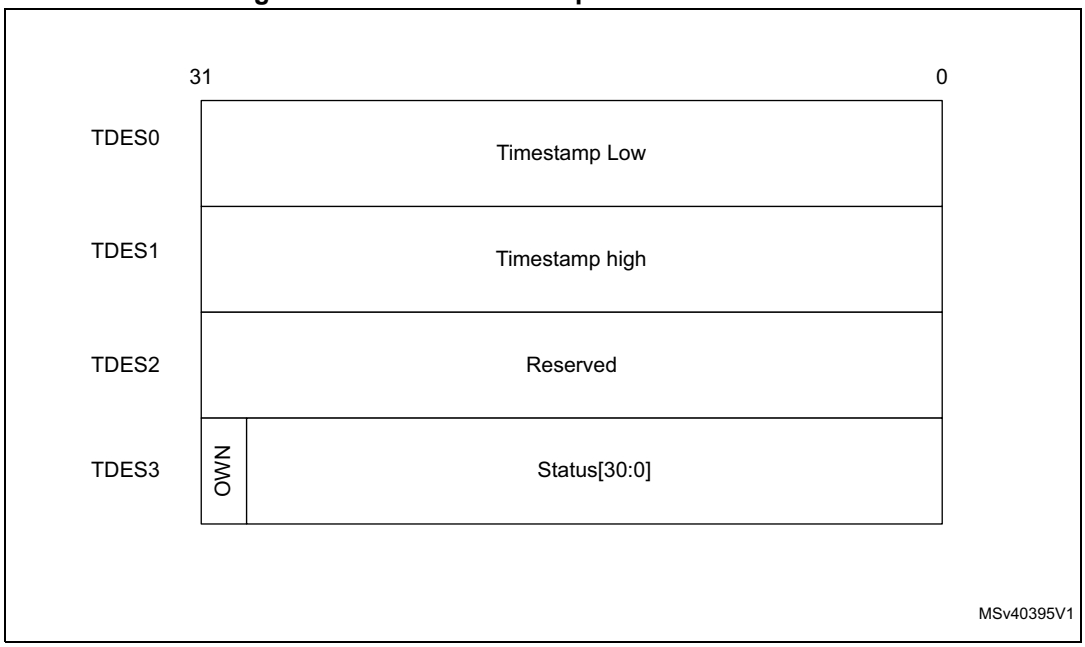
Bits	Name	Description
17:16	CIC/TPL	**Checksum Insertion Control or TCP Payload Length** These bits control the checksum calculation and insertion. They can take the following values: 00: Checksum insertion disabled. 01: Only IP header checksum calculation and insertion are enabled. 10: IP header checksum and payload checksum calculation and insertion are enabled, but pseudo-header checksum is not calculated in hardware. 11: IP header checksum and payload checksum calculation and insertion are enabled, and pseudo-header checksum is calculated in hardware. This field is valid when the TSE bit is reset.When the TSE bit is set, it contains the upper bits [17:16] of the TCP Payload length. This allows the TCP packet length field to be spanned across TDES3[17:0] to provide 256 Kbyte packet length support.
15	TPL	**Reserved or TCP Payload Length** When the TSE bit is reset, this bit is reserved. When the TSE bit is set, this is bit 15 of the TCP payload length [17:0].
14:0	FL/TPL	**Reserved or TCP Payload Length** When the TSE bit is set, this field is equal to the lower 15 bits of the TCP payload length. This length does not include Ethernet header or TCP/UDP/IP header length. When the TSE bit is reset, this bit is reserved.

Transmit normal descriptor (write-back format)

The write-back format is applicable only for the last descriptor of the corresponding packet. The LD bit (TDES3[28]) is set in the descriptor where the DMA writes back the status and timestamp information for the corresponding Transmit packet.

Figure 840 shows the write-back format for Transmit normal descriptors. *Table 582* to *Table 585* provide a detailed description of all Transmit Normal descriptors (Write-Back Format).

Figure 840. Transmit descriptor write-back format



- TDES0 normal descriptor (write-back format)

Table 582. TDES0 normal descriptor (write-back format)(1)

Bit	Name	Description
31:0	TTSL	**Transmit Packet Timestamp Low** The DMA updates this field with least significant 32 bits of the timestamp captured for the corresponding Transmit packet. The DMA writes the timestamp only if TTSE bit of TDES2 is set in the first descriptor of the packet. This field holds the timestamp only if the Last Segment bit (LS) in the descriptor is set and the Timestamp status (TTSS) bit is set.

1. This format is only applicable to the last descriptor of a packet.

- TDES1 normal descriptor (write-back format)

Table 583. TDES1 normal descriptor (write-back format)(1)

Bit	Name	Description
31:0	TTSH	**Transmit Packet Timestamp High** The DMA updates this field with the most significant 32 bits of the timestamp captured for corresponding Receive packet. The DMA writes the timestamp only if the TTSE bit of TDES2 is set in the first descriptor of the packet. This field has the timestamp only if the Last Segment bit (LS) in the descriptor is set and Timestamp status (TTSS) bit is set.

1. This format is only applicable to the last descriptor of a packet.

- TDES2 normal descriptor (write-back format)

Table 584. TDES2 normal descriptor (write-back format)(1)

Bit	Description
31:0	Reserved

1. This format is only applicable to the last descriptor of a packet.

- TDES3 normal descriptor (write-back format)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OWN	CTXT	FD	LD	Reserved										TTSS	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ES	JT	FF	PCE	LoC	NC	LC	EC	CC				ED	UF	DB	IHE

Table 585. TDES3 normal descriptor (write-back format)(1)

Bit	Name	Description
31	OWN	**Own bit** When this bit is set, it indicates that the DMA owns the descriptor. The DMA clears this bit when it completes the packet transmission. After the write-back is complete, this bit is set to 0.
30	CTXT	**Context Type** This bit should be set to 0 for normal descriptors.
29	FD	**First Descriptor** This bit indicates that the buffer contains the first segment of a packet.
28	LD	**Last Descriptor** This bit is set 1 for last descriptor of a packet. The DMA writes the status fields only in the last descriptor of the packet.
27:18	Reserved	
17	TTSS	**Tx Timestamp Status** This status bit indicates that a timestamp has been captured for the corresponding transmit packet. When this bit is set, TDES0 and TDES1 have timestamp values that were captured for the Transmit packet. This field is valid only when the Last Segment control bit (TDES3 [28]) in a descriptor is set.
16	Reserved	
15	ES	**Error Summary** This bit indicates the logical OR of the following bits: TDES3[0]: IP Header Error TDES3[14]: Jabber Timeout TDES3[13]: Packet Flush TDES3[12]: Payload Checksum Error TDES3[11]: Loss of Carrier TDES3[10]: No Carrier TDES3[9]: Late Collision TDES3[8]: Excessive Collision TDES3[3]: Excessive Deferral TDES3[2]: Underflow Error

Table 585. TDES3 normal descriptor (write-back format)(1) (continued)

Bit	Name	Description
14	JT	**Jabber Timeout** This bit indicates that the MAC transmitter has experienced a jabber timeout. This bit is set only when the JD bit of the *Operating mode configuration register (ETH_MACCR)* is not set.
13	FF	**Packet Flushed** This bit indicates that the DMA or MTL flushed the packet because of a software flush command given by the CPU.
12	PCE	**Payload Checksum Error** This bit indicates that the Checksum Offload engine had a failure and did not insert any checksum into the encapsulated TCP, UDP, or ICMP payload. This failure can be either caused by insufficient bytes, as indicated by the Payload Length field of the IP Header, or by the MTL starting to forward the packet to the MAC transmitter in Store-and-Forward mode without the checksum having been calculated yet. This second error condition only occurs when the Transmit FIFO depth is less than the length of the Ethernet packet being transmitted to avoid deadlock, the MTL starts forwarding the packet when the FIFO is full, even in the store-and-forward mode. This error can also occur when a Bus error is detected during packet transfer.
11	LoC	**Loss of Carrier** This bit indicates that Loss of Carrier occurred during packet transmission (that is, the ETH_CRS signal was inactive for one or more transmit clock periods during packet transmission). This is valid only for the packets transmitted without collision and when the MAC operates in the Half-duplex mode.
10	NC	**No Carrier** This bit indicates that the carrier sense signal form the PHY was not asserted during transmission.
9	LC	**Late Collision** This bit indicates that packet transmission was aborted because a collision occurred after the collision window (64 byte times including Preamble in MII mode). This bit is not valid if Underflow Error is set.
8	EC	**Excessive Collision** This bit indicates that the transmission was aborted after 16 successive collisions while attempting to transmit the current packet. If the DR bit is set in the *Operating mode configuration register (ETH_MACCR)*, this bit is set after first collision and the transmission of the packet is aborted.
7:4	CC	**Collision Count** This 4-bit counter value indicates the number of collisions occurred before the packet was transmitted. The count is not valid when the EC bit is set.
3	ED	**Excessive Deferral** This bit indicates that the transmission ended because of excessive deferral of over 24,288 bit times if DC bit is set in the *Operating mode configuration register (ETH_MACCR)*.

Table 585. TDES3 normal descriptor (write-back format)(1) (continued)

Bit	Name	Description
2	UF	**Underflow Error** This bit indicates that the MAC aborted the packet because the data arrived late from the system memory. The underflow error can occur because of either of the following conditions: The DMA encountered an empty Transmit Buffer while transmitting the packet The application filled the MTL Tx FIFO slower than the MAC transmit rate The transmission process enters the Suspend state and sets the underflow bit corresponding to a queue in the ETH_MTLISR register.
1	DB	**Deferred Bit** This bit indicates that the MAC deferred before transmitting because of presence of carrier. This bit is valid only in the Half-duplex mode.
0	IHE	**IP Header Error** When IP Header Error is set, this bit indicates that the Checksum Offload engine detected an IP header error. If COE detects an IP header error, it still inserts an IPv4 header checksum if the Ethernet Type field indicates an IPv4 payload.

1. This format is only applicable to the last descriptor of a packet.

Transmit context descriptor

The Transmit context descriptor can be provided any time before a packet descriptor. The context is valid for the current packet and subsequent packets. The context descriptor is used to provide the timestamps for one-step timestamp correction, and VLAN Tag ID for VLAN insertion feature. Write-back is only done on a context descriptor to reset the OWN bit.

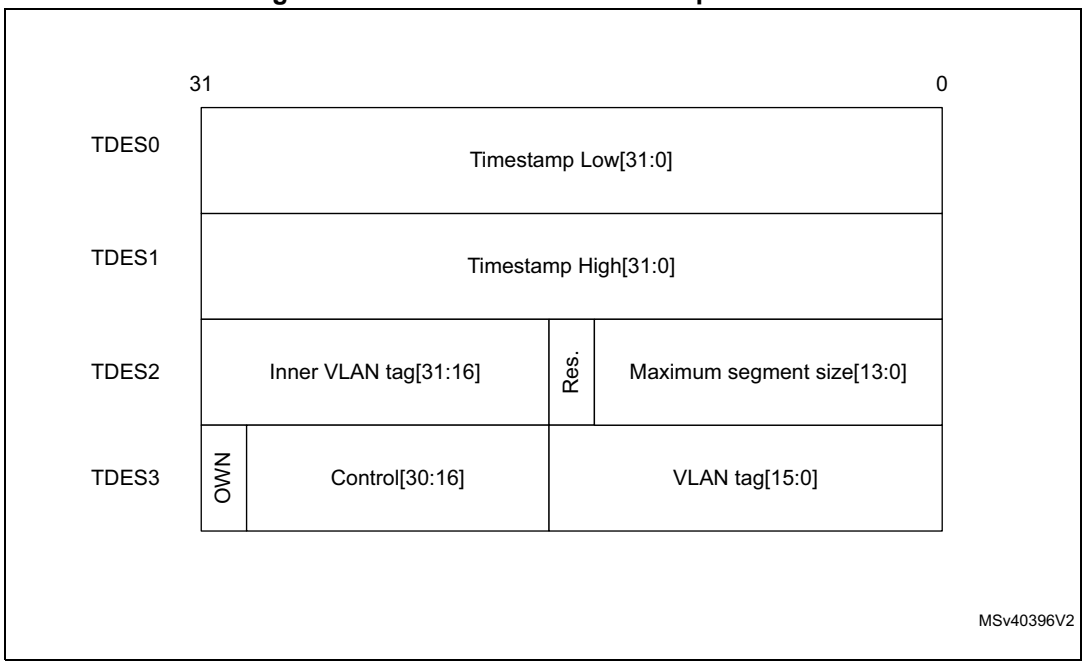
Note: The VLAN tag IDs and MSS values, which are provided by the application in a context descriptor with their corresponding Valid bits set, are stored internally by the DMA.

When the outer or inner VLAN tag is provided with the Valid bit set, the DMA always passes the last valid VLAN tag to the MTL. The application cannot invalidate the valid VLAN tag stored by the DMA. The VLAN tag is inserted or replaced based on the control inputs provided for the packet.

The Inner VLAN Tag Control input is used only for the packet that immediately follows the context descriptor. The application must provide a context descriptor before the normal descriptor of each packet for which the DMA should use the inner VLAN Tag control input.

Figure 841 shows the format for Transmit context descriptors. *Table 586* to *Table 589* provide a detailed description of all Transmit context descriptors.

Figure 841. Transmit context descriptor format



- TDES0 context descriptor (read format)

Table 586. TDES0 context descriptor

Bit	Name	Description
31:0	TTSL	**Transmit Packet Timestamp Low** For one-step correction, the driver can provide the lower 32 bits of timestamp in this descriptor word. The DMA uses this value as the low word for doing one-step timestamp correction. This field is valid only if the OSTC and TCMSSV bits of TDES3 context descriptor are set.

- TDES1 context descriptor (read format)

Table 587. TDES1 context descriptor

Bit	Name	Description
31:0	TTSH	**Transmit Packet Timestamp High** For one-step correction, the driver can provide the upper 32 bits of timestamp in this descriptor. The DMA uses this value as the high word for doing one-step timestamp correction. This field is valid only if the OSTC and TCMSSV bits of TDES3 context descriptor are set.

- TDES2 context descriptor (read format)

Table 588. TDES2 context descriptor

Bit	Name	Description
31:16	IVT	**Inner VLAN Tag** When the IVLTV bit of TDES3 context descriptor is set and the TCMSSV and OSTC bits of TDES3 context descriptor are reset, TDES2[31:16] contains the inner VLAN Tag to be inserted in the subsequent Transmit packets.
15:14	Reserved	
13:0	MSS	**Maximum Segment Size** This segment size is used while segmenting the TCP/IP payload. This field is valid only if the TCMSSV bit of TDES3 context descriptor is set and the OSTC bit of the TDES3 context descriptor is reset.

- TDES3 context descriptor (read format)

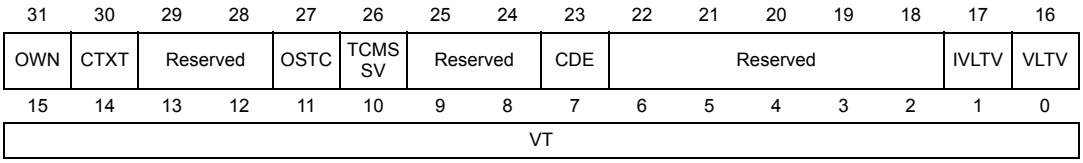


Table 589. TDES3 context descriptor

Bit	Name	Description
31	OWN	**Own bit** 1: the DMA owns the descriptor. 0: the application owns the descriptor. The DMA clears this bit immediately after a read operation.
30	CTXT	**Context Type** This bit should be set to 1 for context descriptor.
29:28	Reserved	
27	OSTC	**One-Step Timestamp Correction Enable** When this bit is set, the DMA performs a one-step timestamp correction with reference to the timestamp values provided in TDES0 and TDES1.
26	TCMSSV	**One-Step Timestamp Correction Input or MSS Valid** When this bit and the OSTC bit are set, it indicates that the Timestamp Correction input provided in TDES0 and TDES1 is valid. When the OSTC bit is reset and this bit and the TSE bit of TDES3 are set in subsequent normal descriptor, it indicates that the MSS input in TDES2 is valid.
25:24	Reserved	

Table 589. TDES3 context descriptor (continued)

Bit	Name	Description
23	CDE	**Context Descriptor Error** When this bit is set, it indicates that the context descriptor is incorrect. The DMA sets this bit during write-back while closing the context descriptor. The Context Descriptor errors can be: – Incorrect sequence from the context descriptor. For example, a location before the first descriptor for a packet. – All 1s. – CD, LD, and FD bits set to 1. *Note: When a Context Descriptor error occurs due to All 1s or CTXT, LD, and FD bits set to 1, the Transmit DMA closes the transmit descriptor with DE and LD bits set to 1. When IOC bit in TDES2 of corresponding first descriptor is set to 1, Transmit DMA sets the TI bit in the Channel status register (ETH_DMACSR).* *Based on CTXT, LD, and FD bits of the transmit descriptor, the subsequent descriptor might be considered as the First Descriptor (even if FD bit is not set) and partial packet is sent.* *This error is categorized as an abnormal event; recovery is only by issuing a software reset (DMA stopping-reconfiguring-restarting recovery mechanism is not supported)*
22:20	Reserved	
19:18	IVTIR	Inner VLAN Tag Insert or Replace When these bits are set, they request the MAC to perform Inner VLAN tagging or untagging before transmitting the packets. If the packet is modified for VLAN tags, the MAC automatically recalculates and replaces the CRC bytes. This bitfield has the following values: 00: Do not add the inner VLAN tag. 01: Remove the inner VLAN tag from the packets before transmission. This option should be used only with the VLAN frames. 10: Insert an inner VLAN tag with the tag value programmed in the *Inner VLAN inclusion register (ETH_MACIVIR)* or context descriptor. 11: Replace the inner VLAN tag in packets with the tag value programmed in the *Inner VLAN inclusion register (ETH_MACIVIR)* or context descriptor. This option should be used only with the VLAN frames.
17	IVLTV	Inner VLAN Tag Valid When this bit is set, it indicates that the IVT field of TDES2 is valid.
16	VLTV	VLAN Tag Valid When this bit is set, it indicates that the VT field of TDES3 is valid.
15:0	VT	VLAN Tag This field contains the VLAN Tag to be inserted or replaced in the packet. This field is used as VLAN Tag only when the VLTI bit of the *VLAN inclusion register (ETH_MACVIR)* is reset.

63.10.4 Receive descriptor

The DMA in the Ethernet peripheral attempts to read a descriptor only if the Tail pointer is different from the Base pointer or current pointer. It is recommended to have a descriptor ring with a length that can accommodate at least two complete packets received by the MAC; otherwise, the performance of the DMA is greatly impacted because of the unavailability of the descriptors. In such a situation, the MTL RxFIFO becomes full and starts dropping packets.

The following Receive descriptors are present:

- Normal descriptors with read and write-back formats
- Context descriptors

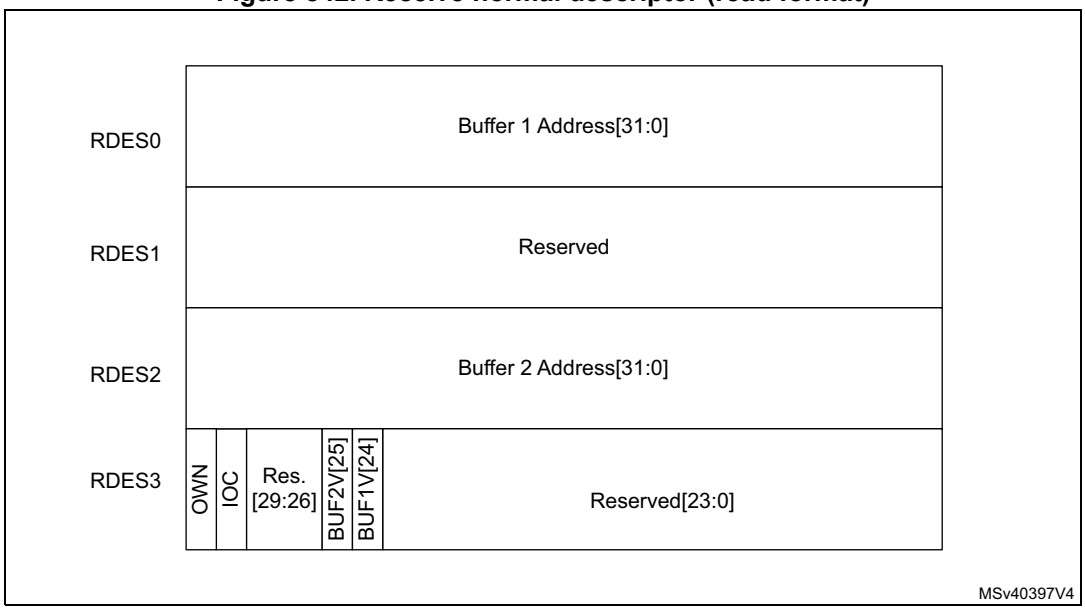
All received descriptors are prepared by the software and given to the DMA as “normal” descriptors (see *Figure 842: Receive normal descriptor (read format)* for a description of their content). The DMA reads this descriptor and, after transferring a received packet (or part of it) to the buffers indicated by the descriptor, the Rx DMA closes the descriptor with the corresponding packet status. The status format is given in *Figure 843: Receive normal descriptor (write-back format)*.

For some packets, the normal descriptor bits are not sufficient to write the complete status. For such packets, the Rx DMA will write the extended status to the next descriptor (without processing or using the Buffers pointers embedded in that descriptor). The format and content of this write-back descriptor is described in *Figure 844: Receive context descriptor*.

Receive normal descriptor (read format)

Figure 842 shows the read format for Receive normal descriptors. *Table 590* to *Table 593* provide a detailed description of all Receive normal descriptors (read format).

Figure 842. Receive normal descriptor (read format)



Note: In the Receive descriptor (read format), if the Buffer Address field contains only 0s, the MAC does not transfer data to this buffer and skips to the next buffer or next descriptor.

- RDES0 normal descriptor (read format)

Table 590. RDES0 normal descriptor (read format)

Bit	Name	Description
31:0	BUF1AP	**Buffer 1 Address Pointer** These bits indicate the physical address of Buffer 1. The application can program a byte-aligned address for this buffer, which means that the LS bits of this field can be non-zero. However, while transferring the start of packet, the DMA performs a write operation with RDES2[1:0]=0 in case of 64-/128-bit configuration) as zero. However, the packet data is shifted by the actual offset as given in the buffer address pointer. If the address pointer points to a buffer where the middle or last part of the packet is stored, the DMA ignores the offset address and writes to the full location as indicated by the data-width.

- RDES1 normal descriptor (read format)

Table 591. RDES1 normal descriptor (read format)

Bit	Name	Description
31:0	Reserved	Field reserved.

- RDES2 normal descriptor (read format)

Table 592. RDES2 normal descriptor (read format)

Bit	Name	Description
31:0	BUF2AP	**Buffer 2 Address Pointer** These bits indicate Buffer 2 physical address. The RxDMA uses the LS bits of the pointer address only while transferring the start bytes of a packet. If the BUF2AP is giving the address of a buffer in which the middle or last part of a packet is stored, the DMA ignores RDES2[1:0]=0 and writes to the complete location.

- RDES3 normal descriptor (read format)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OWN	IOC	Reserved				BUF2V	BUF1V	Reserved							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															

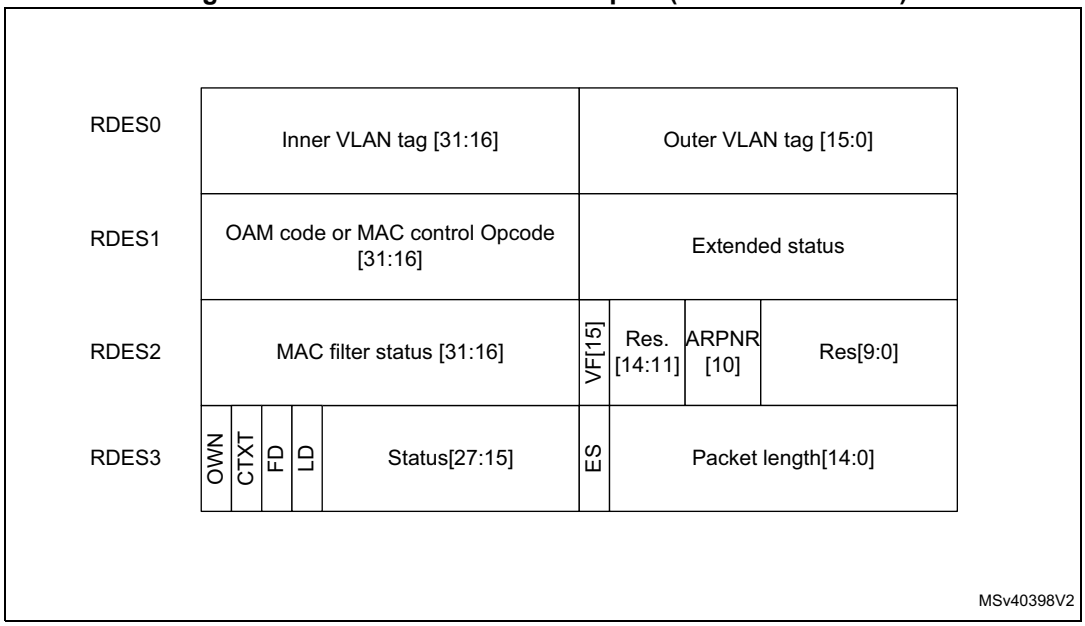
Table 593. RDES3 normal descriptor (read format)

Bit	Name	Description
31	OWN	**Own bit** When this bit is set, it indicates that the DMA owns the descriptor. When this bit is reset, it indicates that the application owns the descriptor. The DMA clears this bit when either of the following conditions is true: – The DMA completes the packet reception – The buffers associated with the descriptor are full
30	IOC	**Interrupt Enabled on Completion** When this bit is set, an interrupt is issued to the application when the DMA closes this descriptor.
29:26	Reserved	
25	BUF2V	**Buffer 2 Address Valid** When this bit is set, it indicates to the DMA that the buffer 2 address specified in RDES2 is valid. The application must set this bit so that the DMA can use the address to which the Buffer 2 address in RDES0 is pointing, to write received packet data.
24	BUF1V	**Buffer 1 Address Valid** When set, this indicates to the DMA that the buffer 1 address specified in RDES0 is valid. The application must set this value if the address to which Buffer 1 address points in RDES0, can be used by the DMA to write received packet data.
23:0	Reserved	

Receive normal descriptor (write-back format)

Figure 843 shows the write-back format for Receive normal descriptors. *Table 594* to *Table 597* provide a detailed description of all Receive normal descriptors (write-back format).

Figure 843. Receive normal descriptor (write-back format)



- RDES0 normal descriptor (write-back format)

Table 594. RDES0 normal descriptor (write-back format)

Bit	Name	Description
31:16	IVT	**Inner VLAN Tag** This field contains the Inner VLAN tag of the received packet if the RS0V bit of RDES3 is set. This is valid only when Double VLAN tag processing and VLAN tag stripping are enabled.
15:0	OVT	**Outer VLAN Tag** This field contains the Outer VLAN tag of the received packet if the RS0V bit of RDES3 is set.

- RDES1 normal descriptor (write-back format)

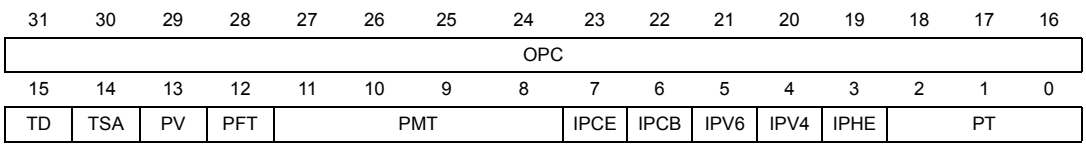


Table 595. RDES1 normal descriptor (write-back format)(1)

Bit	Name	Description
31:16	OPC	**OAM Subtype Code, or MAC Control Packet opcode** OAM Subtype Code If bits[18:16] of RDES3 are set to 111, this field contains the OAM subtype and code fields. MAC Control Packet opcode If bits[18:16] of RDES3 are set to 110, this field contains the MAC Control packet opcode field.
15	TD	**Timestamp Dropped** This bit indicates that the timestamp was captured for this packet but got dropped in the MTL Rx FIFO because of overflow.
14	TSA	**Timestamp Available** When Timestamp is present, this bit indicates that the timestamp value is available in a context descriptor word 2 (RDES2) and word 1(RDES1). This is valid only when the Last Descriptor bit (RDES3 [28]) is set. The context descriptor is written in the next descriptor just after the last normal descriptor for a packet.
13	PV	**PTP Version** 1: Received PTP message in IEEE 1588 version 2 format 0: Received PTP message in IEEE 1588 version 1 format
12	PFT	**PTP Packet Type** This bit indicates that the PTP message is sent directly over Ethernet.
11:8	PMT	**PTP Message Type** These bits are encoded to give the type of the message received: 0000: No PTP message received 0001: SYNC (all clock types) 0010: Follow_Up (all clock types) 0011: Delay_Req (all clock types) 0100: Delay_Resp (all clock types) 0101: Pdelay_Req (in peer-to-peer transparent clock) 0110: Pdelay_Resp (in peer-to-peer transparent clock) 0111: Pdelay_Resp_Follow_Up (in peer-to-peer transparent clock) 1000: Announce 1001: Management 1010: Signaling 1011–1110: Reserved 1111: PTP packet with Reserved message type
7	IPCE	**IP Payload Error** When this bit is set, it indicates either of the following: – The 16-bit IP payload checksum (that is, the TCP, UDP, or ICMP checksum) calculated by the MAC does not match the corresponding checksum field in the received segment. – The TCP, UDP, or ICMP segment length does not match the payload length value in the IP Header field. – The TCP, UDP, or ICMP segment length is less than minimum allowed segment length for TCP, UDP, or ICMP. Bit 15 (ES) of RDES3 is not set when this bit is set.

Table 595. RDES1 normal descriptor (write-back format)(1) (continued)

Bit	Name	Description
6	IPCB	**IP Checksum Bypassed** This bit indicates that the checksum offload engine is bypassed.
5	IPV6	**IPv6 header Present** This bit indicates that an IPV6 header is detected.
4	IPV4	**IPV4 Header Present** This bit indicates that an IPV4 header is detected.
3	IPHE	**IP Header Error** – When this bit is set, it indicates either of the following: – The 16-bit IPv4 header checksum calculated by the MAC does not match the received checksum bytes. – The IP datagram version is not consistent with the Ethernet Type value. – Ethernet packet does not have the expected number of IP header bytes. This bit is valid when either bit 5 or bit 4 is set.
2:0	PT	**Payload Type** These bits indicate the type of payload encapsulated in the IP datagram processed by the Receive Checksum Offload Engine (COE): 000: Unknown type or IP/AV payload not processed 001: UDP 010: TCP 011: ICMP 100: IGMP if IPV4 Header Present bit is set Others: reserved. If the COE does not process the payload of an IP datagram because there is an IP header error or fragmented IP, it sets these bits to 3'b000.

1. The Status fields in write-back format are valid only for the last descriptor (RDES3[28] is set).

- RDES2 normal descriptor (write-back format)

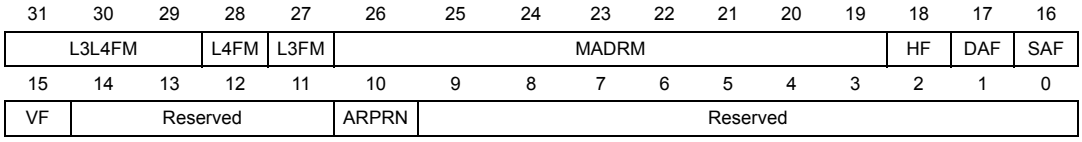


Table 596. RDES2 normal descriptor (write-back format)

Bit	Name	Description
31:29	L3L4FM	**Layer 3 and Layer 4 Filter Number Matched** These bits indicate the number of the Layer 3 and Layer 4 Filter that matched the received packet: – 000: Filter 0 – 001: Filter 1 – 010: Filter 2 – 011: Filter 3 – 100: Filter 4 – 101: Filter 5 – 110: Filter 6 – 111: Filter 7 This field is valid only when bit 28 or bit 27 is set high. When more than one filter matches, these bits give the number of lowest filter.
28	L4FM	**Layer 4 Filter Match** When this bit is set, it indicates that the received packet matches one of the enabled Layer 4 Port Number fields. This status is given only when one of the following conditions is true: – Layer 3 fields are not enabled and all enabled Layer 4 fields match – All enabled Layer 3 and Layer 4 filter fields match When more than one filter matches, this bit gives the layer 4 filter status of filter indicated by bits[31:29].
27	L3FM	**Layer 3 Filter Match** When this bit is set, it indicates that the received packet matches one of the enabled Layer 3 IP Address fields. This status is given only when one of the following conditions is true: – All enabled Layer 3 fields match and all enabled Layer 4 fields are bypassed – All enabled filter fields match When more than one filter matches, this bit gives the layer 3 filter status of filter indicated by bits[31:29].
26:19	MADRM	**MAC Address Match or Hash Value** When the HF bit is reset, this field contains the MAC address register number that matched the Destination address of the received packet. This field is valid only if the DAF bit is reset. When the HF bit is set, this field contains the Hash value computed by the MAC. A packet passes the Hash filter when the bit corresponding to the Hash value is set in the Hash filter register.
18	HF	**Hash Filter Status** When this bit is set, it indicates that the packet passed the MAC address Hash filter. its[26:19] indicate the Hash value.
17	DAF	**Destination Address Filter Fail** When this bit is set, it indicates that the packet failed the DA Filter in the MAC.
16	SAF	**SA Address Filter Fail** When this bit is set, it indicates that the packet failed the SA Filter in the MAC.

Table 596. RDES2 normal descriptor (write-back format) (continued)

Bit	Name	Description
15	VF	**VLAN Filter Status** When this bit is set, it indicates that the VLAN Tag of received packet passed the VLAN filter.
14:11	Reserved	
10	ARPNR	**ARP Reply Not Generated** When this bit is set, it indicates that the MAC did not generate the ARP Reply for received ARP Request packet. This bit is set when the MAC is busy transmitting ARP reply to earlier ARP request (only one ARP request is processed at a time).
9:0	Reserved	

- RDES3 normal descriptor (write-back format)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OWN	CTXT	FD	LD	RS2V	RS1V	RS0V	CE	GP	RWT	OE	RE	DE	LT		
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ES	PL														

Table 597. RDES3 normal descriptor (write-back format)

Bit	Name	Description
31	OWN	**Own bit** 1: The DMA owns the descriptor. 0: The application owns the descriptor. The DMA clears this bit when either of the following conditions is true: The DMA completes the packet reception The buffers associated with the descriptor are full
30	CTXT	**Receive Context Descriptor** When this bit is set, it indicates that the current descriptor is a context type descriptor. The DMA writes 0 to this bit for normal receive descriptor. When CTXT and FD bits are used together, {CTXT, FD} possible values are: 00: Intermediate Descriptor 01: First Descriptor 10: Reserved 11: Descriptor error (due to all 1s) *Note: When a Descriptor error occurs, the Receive DMA closes the receive descriptor indicating a Descriptor error. This receive descriptor is skipped and the buffer addresses are not used to write the packet data. The receive DMA sets the CDE field of the Channel status register (ETH_DMACSR) but does not set the RI field, even when IOC field is set, as this is not marked as last receive descriptor for the packet. The subsequent valid receive descriptor is used to write the packet data.*

Table 597. RDES3 normal descriptor (write-back format) (continued)

Bit	Name	Description
29	FD	**First Descriptor** When this bit is set, it indicates that this descriptor contains the first buffer of the packet. If the size of the first buffer is 0, the second buffer contains the beginning of the packet. If the size of the second buffer is also 0, the next descriptor contains the beginning of the packet. Refer to the CTXT bit description for details on how to use the CTXT bit and FD bit together.
28	LD	**Last Descriptor** When this bit is set, it indicates that the buffers to which this descriptor is pointing are the last buffers of the packet.
27	RS2V	**Receive Status RDES2 Valid** When this bit is set, it indicates that the status in RDES2 is valid and it is written by the DMA. This bit is valid only when the LD bit of RDES3 is set.
26	RS1V	**Receive Status RDES1 Valid** When this bit is set, it indicates that the status in RDES1 is valid and it is written by the DMA. This bit is valid only when the LD bit of RDES3 is set.
25	RS0V	R**eceive Status RDES0 Valid** When this bit is set, it indicates that the status in RDES0 is valid and it is written by the DMA. This bit is valid only when the LD bit of RDES3 is set.
24	CE	**CRC Error** When this bit is set, it indicates that a Cyclic Redundancy Check (CRC) Error occurred on the received packet. This field is valid only when the LD bit of RDES3 is set.
23	GP	**Giant Packet** When this bit is set, it indicates that the packet length exceeds the specified maximum Ethernet size of 1518, 1522, or 2000 bytes (9018 or 9022 bytes if jumbo packet enable is set). Giant packet indicates only the packet length. It does not cause any packet truncation.
22	RWT	**Receive Watchdog Timeout** When this bit is set, it indicates that the Receive Watchdog Timer has expired while receiving the current packet. The current packet is truncated after watchdog timeout.
21	OE	**Overflow Error** When this bit is set, it indicates that the received packet is damaged because of buffer overflow in Rx FIFO. This bit is set only when the DMA transfers a partial packet to the application. This happens only when the Rx FIFO is operating in the threshold mode. In the store-and-forward mode, all partial packets are dropped completely in Rx FIFO.
20	RE	**Receive Error** When this bit is set, it indicates that the ETH_RX_ER signal is asserted while the ETH_RX_DV signal is asserted during packet reception.

Table 597. RDES3 normal descriptor (write-back format) (continued)

Bit	Name	Description
19	DE	**Dribble Bit Error** When this bit is set, it indicates that the received packet has a non-integer multiple of bytes (odd nibbles). This bit is valid only in the MII Mode.
18:16	LT	**Length/Type Field** This field indicates if the packet received is a length packet or a type packet. The encoding of the 3 bits is as follows: 000: The packet is a length packet 001: The packet is a type packet. 011: The packet is a ARP Request packet type 100: The packet is a type packet with VLAN Tag 101: The packet is a type packet with Double VLAN tag 110: The packet is a MAC Control packet type 111: The packet is a OAM packet type 010: Reserved
15	ES	**Error Summary** When this bit is set, it indicates the logical OR of the following bits: RDES3[19]: Dribble Error RDES3[20]: Receive Error RDES3[21]: Overflow Error RDES3[22]: Watchdog Timeout RDES3[23]: Giant Packet RDES3[24]: CRC Error This field is valid only when the LD bit of RDES3 is set.
14:0	PL	**Packet Length** These bits indicate the byte length of the received packet that was transferred to system memory (including CRC). This field is valid when both the LD bit of RDES3 is set and the Overflow Error bit is reset. The packet length also includes the two bytes appended to the Ethernet packet when IP checksum calculation is enabled and the received packet is not a MAC control packet. When LD bit of RDES3 is reset, this field contains the accumulated number of bytes (partial) that have been transferred for the current packet.

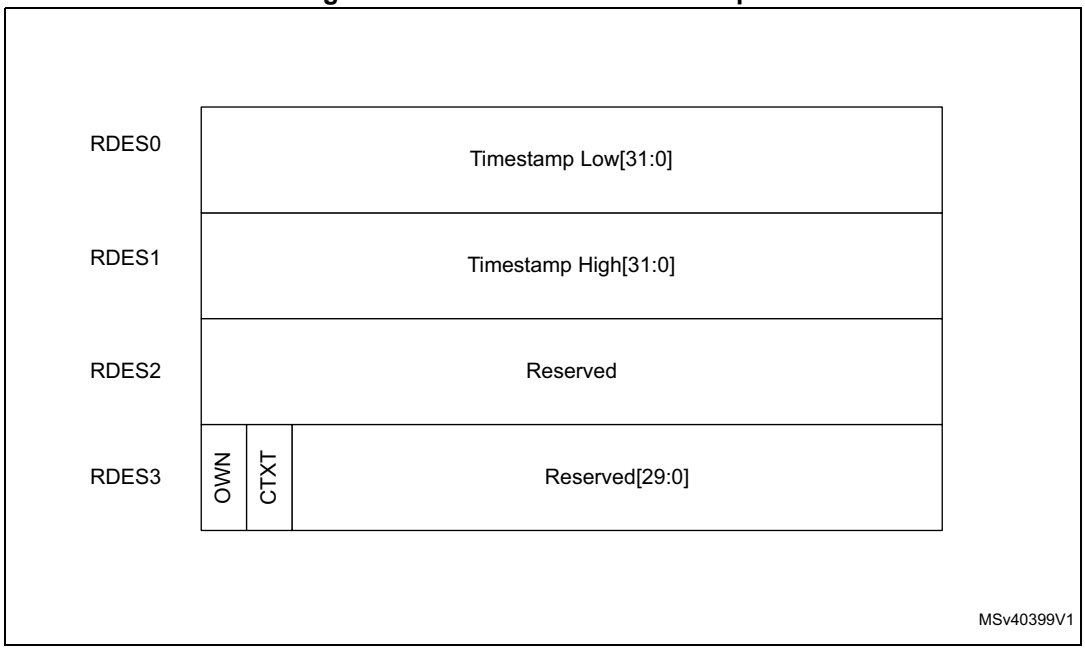
Receive context descriptor

This descriptor is read-only for the application. This descriptor can be written only by the DMA.

The context descriptor provides information about the extended status related to the last received packet. Bit 30 of RDES3 indicates the context type descriptor.

Figure 844 shows the format for Receive context descriptors. *Table 598* to *Table 601* provide a detailed description of all Receive context descriptors.

Figure 844. Receive context descriptor



- RDES0 context descriptor

Table 598. RDES0 context descriptor

Bit	Name	Description
31:0	RTSL	**Receive Packet Timestamp Low** The DMA updates this field with least significant 32 bits of the timestamp captured for corresponding Receive packet. When this field and the RTSH field of RDES1 show all-ones value, the timestamp must be considered as corrupt.

- RDES1 context descriptor

Table 599. RDES1 context descriptor

Bit	Field	Description
31:0	RTSH	**Receive Packet Timestamp High** The DMA updates this field with most significant 32 bits of the timestamp captured for corresponding receive packet. When this field and the RTSL field of RDES0 show all-ones value, the timestamp must be considered as corrupt.

- RDES2 context descriptor

Table 600. RDES2 context descriptor

Bit	Description
31:0	Reserved

- RDES3 context descriptor

Table 601. RDES3 context descriptor

Bit	Name	Description
31	OWN	**Own Bit** 1: The DMA owns the descriptor 0: The application owns the descriptor. The DMA clears this bit when either of the following conditions is true: The DMA completes the packet reception The buffers associated with the descriptor are full
30	CTXT	**Receive Context Descriptor** When this bit is set, it indicates that the current descriptor is a context descriptor. The DMA writes 1'b1 to this bit for context descriptor.
29:0	Reserved	

63.11 Ethernet registers

63.11.1 Ethernet registers maps

This section provides the following register maps:

- DMA registers (see *Section 63.11.2: Ethernet DMA registers*)
- MTL registers (see *Section 63.11.3: Ethernet MTL registers*)
- MAC registers including MMC register (see *Section 63.11.4: Ethernet MAC and MMC registers*)

63.11.2 Ethernet DMA registers

DMA mode register (ETH_DMAMR)

Address offset: 0x1000

Reset value: 0x0000 0000

The DMA mode register establishes the bus operating modes for the DMA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INTM[1:0]	
														rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	PR[2:0]			TXPR	Res.	Res.	Res.	Res.	Res.	Res.	Res.			DA	SWR
	rw	rw	rw	rw										rw	rw

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:16 **INTM[1:0]**: Interrupt Mode

This field defines the interrupt mode of the Ethernet peripheral.
The behavior of the interrupt signal and of the RI/TI bits in the ETH_DMACSR register changes depending on the INTM value (refer to *Table 577: Transfer complete interrupt behavior*).

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **PR[2:0]**: Priority ratio

These bits control the priority ratio in weighted round-robin arbitration between the Rx DMA and Tx DMA. These bits are valid only when the DA bit is reset. The priority ratio is Rx:Tx or Tx:Rx depending on whether the TXPR bit is reset or set.
000: The priority ratio is 1:1
001: The priority ratio is 2:1
010: The priority ratio is 3:1
011: The priority ratio is 4:1
100: The priority ratio is 5:1
101: The priority ratio is 6:1
110: The priority ratio is 7:1
111: The priority ratio is 8:1

Bit 11 **TXPR**: Transmit priority

When set, this bit indicates that the Tx DMA has higher priority than the Rx DMA during arbitration for the system-side bus.

Bits 10:2 Reserved, must be kept at reset value.

Bit 1 **DA**: DMA Tx or Rx Arbitration Scheme

This bit specifies the arbitration scheme between the Transmit and Receive paths of all channels:

0: Weighted Round-Robin with Rx:Tx or Tx:Rx

The priority between the paths is according to the priority specified in Bits[14:12] and the priority weight is specified in the TXPR bit.

1: Fixed priority

The Tx path has priority over the Rx path when the TXPR bit is set. Otherwise, the Rx path has priority over the Tx path.

Bit 0 **SWR**: Software Reset

When this bit is set, the MAC and the DMA controller reset the logic and all internal registers of the DMA, MTL, and MAC. This bit is automatically cleared after the reset operation is complete in all clock domains. Before reprogramming any register, a value of zero should be read in this bit.

Note: The reset operation is complete only when all resets in all active clock domains are deasserted. Therefore, it is essential that all PHY inputs clocks (applicable for the selected PHY interface) are present for software reset completion. The time to complete the software reset operation depends on the frequency of the slowest active clock.

System bus mode register (ETH_DMASBMR)

Address offset: 0x1004

Reset value: 0x0000 0000

The System bus mode register controls the behavior of the AHB master. It mainly controls burst splitting and number of outstanding requests.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RB	MB	Res.	AAL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FB
r	r		rw												rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **RB**: Rebuild INCRx Burst

When this bit is set high and the AHB master gets SPLIT, RETRY, or Early Burst Termination (EBT) response, the AHB master interface rebuilds the pending beats of any initiated burst transfer with INCRx and SINGLE transfers. By default, the AHB master interface rebuilds pending beats of an EBT with an unspecified (INCR) burst.

Bit 14 **MB**: Mixed Burst

When this bit is set high and the FB bit is low, the AHB master performs undefined bursts transfers (INCR) for burst length of 16 or more. For burst length of 16 or less, the AHB master performs fixed burst transfers (INCRx and SINGLE).

Bit 13 Reserved, must be kept at reset value.

Bit 12 **AAL**: Address-Aligned Beats

When this bit is set to 1, the master performs address-aligned burst transfers on Read and Write channels.

Bits 11:1 Reserved, must be kept at reset value.

Bit 0 **FB**: Fixed Burst Length

When this bit is set to 1, the AHB master will initiate burst transfers of specified length (INCRx or SINGLE).

When this bit is set to 0, the AHB master will initiate transfers of unspecified length (INCR) or SINGLE transfers.

Interrupt status register (ETH_DMAISR)

Address offset: 0x1008

Reset value: 0x0000 0000

The application reads this Interrupt Status register during interrupt service routine or polling to determine the interrupt status of DMA channels, MTL queues, and the MAC.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MACIS	MTLIS
														r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DC0IS
															r

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **MACIS**: MAC Interrupt Status

This bit indicates an interrupt event in the MAC. To reset this bit to 1'b0, the software must read the corresponding register in the MAC to get the exact cause of the interrupt and clear its source.

Bit 16 **MTLIS**: MTL Interrupt Status

This bit indicates an interrupt event in the MTL. To reset this bit to 1'b0, the software must read the corresponding register in the MTL to get the exact cause of the interrupt and clear its source.

Bits 15:1 Reserved, must be kept at reset value.

Bit 0 **DC0IS**: DMA Channel Interrupt Status

This bit indicates an interrupt event in DMA Channel. To reset this bit to 0, the software must read the corresponding register in DMA Channel to get the exact cause of the interrupt and clear its source.

Debug status register (ETH_DMADSR)

Address offset: 0x100C

Reset value: 0x0000 0000

The Debug status register gives the Receive and Transmit process status for DMA Channel for debugging purpose.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TPS0[3:0]				RPS0[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	AXWHSTS
r	r	r	r	r	r	r	r								r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:12 **TPS0[3:0]**: DMA Channel Transmit Process State
This field indicates the Tx DMA FSM state for Channel:
000: Stopped (Reset or Stop Transmit Command issued)
001: Running (Fetching Tx Transfer Descriptor)
010: Running (Waiting for status)
011: Running (Reading Data from system memory buffer and queuing it to the Tx buffer (Tx FIFO))
100: Timestamp write state
101: Reserved for future use
110: Suspended (Tx Descriptor Unavailable or Tx Buffer Underflow)
111: Running (Closing Tx Descriptor)
The MSB of this field always returns 0. This field does not generate an interrupt.

Bits 11:8 **RPS0[3:0]**: DMA Channel Receive Process State
This field indicates the Rx DMA FSM state for Channel:
000: Stopped (Reset or Stop Receive Command issued)
001: Running (Fetching Rx Transfer Descriptor)
010: Reserved for future use
011: Running (Waiting for Rx packet)
100: Suspended (Rx Descriptor Unavailable)
101: Running (Closing the Rx Descriptor)
110: Timestamp write state
111: Running (Transferring the received packet data from the Rx buffer to the system memory)
The MSB of this field always returns 0. This field does not generate an interrupt.

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **AXWHSTS**: AHB Master Write Channel
When high, this bit indicates that the write channel of the AHB master FMSs are in non-idle state.

Channel control register (ETH_DMACCR)

Address offset: 0x1100

Reset value: 0x0000 0000

The DMA Channel control register specifies the MSS value for segmentation, length to skip between two descriptors, and also the features such as header splitting and 8xPBL mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DSL[2:0]			Res.	PBLX8
											rw	rw	rw		rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	MSS[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bits 20:18 **DSL[2:0]**: Descriptor Skip Length

This bit specifies the 32-bit word number to skip between two unchained descriptors. The address skipping starts from the end of the current descriptor to the start of the next descriptor.

When the DSL value is equal to zero, the DMA takes the descriptor table as contiguous.

Bit 17 Reserved, must be kept at reset value.

Bit 16 **PBLX8**: 8xPBL mode

When this bit is set, the PBL value programmed in Bits[21:16] in *Channel transmit control register (ETH_DMACTXCR)* is multiplied eight times. Therefore, the DMA transfers the data in 8, 16, 32, 64, 128, and 256 beats depending on the PBL value.

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:0 **MSS[13:0]**: Maximum Segment Size

This field specifies the maximum segment size that should be used while segmenting the packet. This field is valid only if the TSE bit of *Channel transmit control register (ETH_DMACTXCR)* is set.

The value programmed in this field must be more than the configured Data width in bytes. It is recommended to use a MSS value of 64 bytes or more.

Channel transmit control register (ETH_DMACTXCR)

Address offset: 0x1104

Reset value: 0x0000 0000

The DMA Channel Transmit Control register controls the Tx features such as PBL, TCP segmentation, and Tx Channel weights.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXPBL[5:0]					
										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	TSE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OSF	Res.	Res.	Res.	ST
			rw								rw				rw

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:16 **TXPBL[5:0]**: Transmit Programmable Burst Length

These bits indicate the maximum number of beats to be transferred in one DMA data transfer. This is the maximum value that is used in a single block Read or Write. The DMA always attempts to burst as specified in PBL each time it starts a burst transfer on the application bus. You can program PBL with any of the following values: 1, 2, 4, 8, 16, or 32. Any other value results in undefined behavior.

To transfer more than 32 beats, perform the following steps:

a) Set the PBLx8 mode in ETH_DMACCR.

b) Set the TXPBL[5:0].

Note: The maximum value of TXPBL must be less than or equal to half the Tx Queue size (TQS field of *Tx queue operating mode Register (ETH_MTLTXQOMR)*) in terms of beats. This is required so that the Tx Queue has space to store at least another Tx PBL worth of data while the MTL Tx Queue Controller is transferring data to MAC. The total locations in Tx Queue of size 2048 bytes is 512, TXPBL and 8xPBL needs to be programmed to less than or equal to 512/2.

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **TSE**: TCP Segmentation Enabled

When this bit is set, the DMA performs the TCP segmentation for packets in Channel i. The TCP segmentation is done only for those packets for which the TSE bit (TDES0[19]) is set in the Tx Normal descriptor. When this bit is set, the TxPBL value must be greater than or equal to 4.

Bits 11:5 Reserved, must be kept at reset value.

Bit 4 **OSF**: Operate on Second Packet

When this bit is set, it instructs the DMA to process the second packet of the Transmit data even before the status for the first packet is obtained.

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **ST**: Start or Stop Transmission Command

When this bit is set, transmission is placed in the Running state. The DMA checks the Transmit list at the current position for a packet to be transmitted.

The DMA tries to acquire descriptor from either of the following positions:

– The current position in the list: this is the base address of the Transmit list set by the ETH_DMACTXDLAR register.

– The position at which the transmission was previously stopped

If the DMA does not own the current descriptor, the transmission enters the Suspended state and the TBU bit of the ETH_DMACSR is set. The Start Transmission command is effective only when the transmission is stopped. If the command is issued before setting the ETH_DMACTXDLAR register, the DMA behavior is unpredictable.

When this bit is reset, the transmission process is placed in the Stopped state after completing the transmission of the current packet. The Next Descriptor position in the Transmit list is saved, and it becomes the current position when the transmission is restarted. To change the list address, you need to program ETH_DMACTXDLAR register with a new value when this bit is reset. The new value is considered when this bit is set again. The stop transmission command is effective only when the transmission of the current packet is complete or the transmission is in the Suspended state.

Channel receive control register (ETH_DMACRXCR)

Address offset: 0x1108

Reset value: 0x0000 0000

The DMA Channel Receive Control register controls the Rx features such as PBL, buffer size, and extended status.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RPF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXPBL[5:0]					
rw										rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	RBSZ[13:0]														SR
	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **RPF**: DMA Rx Channel Packet Flush

When this bit is set to 1, the Ethernet peripheral will automatically flush the packet from the Rx queues destined to DMA Rx Channel when the DMA Rx Channel is stopped after a system bus error has occurred. When this bit remains set and the DMA is re-started by the software driver, the packets residing in the Rx Queues that were received when this RxDMA was stopped, are flushed out. The packets that are received by the MAC after the RxDMA is re-started are routed to the RxDMA. The flushing happens on the Read side of the Rx queue.

When this bit is set to 0 the Ethernet peripheral does not flush the packet in the Rx queue destined to DMA Rx Channel after the DMA is stopped due to a system bus error.

This might cause head-of-line blocking in the corresponding RxQueue.

Note: The stopping of packet flow from a Rx DMA Channel to the application by setting RPF works only when there is one-to-one mapping of Rx Queue to Rx DMA channels. In Dynamic mapping mode, setting RPF bit in ETH_DMACRXCR register might flush packets from unintended Rx Queues which are destined to the stopped Rx DMA Channel.

Bits 30:22 Reserved, must be kept at reset value.

Bits 21:16 **RXPBL[5:0]**: Receive Programmable Burst Length

These bits indicate the maximum number of beats to be transferred in one DMA data transfer. This is the maximum value that is used in a single block Read or Write. The DMA always attempts to burst as specified in PBL each time it starts a burst transfer on the application bus. You can program PBL with any of the following values: 1, 2, 4, 8, 16, or 32. Any other value results in undefined behavior.

To transfer more than 32 beats, perform the following steps:

a) Set the PBLx8 mode in the ETH_DMACCR.

b) Set the RXPBL[5:0].

Note: The maximum value of RXPBL must be less than or equal to half the Rx Queue size (RQS field of Rx queue operating mode register (ETH_MTLRXQOMR)) in terms of beats. This is required so that the Rx Queue has space to store at least another Rx PBL worth of data while the MTL Rx Queue Controller is transferring data to MAC.The total locations in Rx Queue of size 2048 bytes is 512, RXPBL and 8xPBL needs to be programmed to less than or equal to 512/2.

Bit 15 Reserved, must be kept at reset value.

Bits 14:1 **RBSZ[13:0]**: Receive Buffer size

This field indicates the size of the Rx buffers specified in bytes. The maximum buffer size is limited to 16 Kbytes.

Note: The buffer size must be a multiple of 4. This is required even if the value of buffer address pointer is not aligned to bus width. If the buffer size is not a multiple of 4, it may result into an undefined behavior.

The LSB bits (1:0) are ignored and the DMA internally takes the LSB bits as all-zero. Therefore, these LSB bits are read-only (RO).

Bit 0 **SR**: Start or Stop Receive

When this bit is set, the DMA tries to acquire the descriptor from the Receive list and processes the incoming packets.

The DMA tries to acquire descriptor from either of the following positions:

– The current position in the list: this is the address set by the *Channel Rx descriptor list address register (ETH_DMACRXDLAR)*.

– The position at which the Rx process was previously stopped

If the DMA does not own the current descriptor, the reception is suspended and the RBU bit of the ETH_DMACSR is set. The Start Receive command is effective only when the reception is stopped. If the command is issued before setting the *Channel Rx descriptor list address register (ETH_DMACRXDLAR)*, the DMA behavior is unpredictable.

When this bit is reset, the Rx DMA operation is stopped after the transfer of the current packet. The next descriptor position in the Receive list is saved, and it becomes the current position after the Rx process is restarted. The Stop Receive command is effective only when the Rx process is in the Running (waiting for Rx packet) or Suspended state.

Channel Tx descriptor list address register (ETH_DMACTXDLAR)

Address offset: 0x1114

Reset value: 0x0000 0000

Channel Tx Descriptor List Address register points the DMA to the start of Transmit descriptor list. The descriptor lists reside in the physical memory space of the application and must be word-aligned. The DMA internally converts it to bus width aligned address by making the corresponding LSB to low.

You can write to this register only when the Tx DMA has stopped, that is, the ST bit is set to zero in ETH_DMACiTXCR register. When stopped, this register can be written with a new descriptor list address. When you set ST bit to 1, the DMA takes the newly-programmed descriptor base address. If this register is not changed when ST bit is set to 0, the DMA takes the descriptor address where it was stopped earlier.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TDESLA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TDESLA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r

Bits 31:0 **TDESLA[31:0]**: Start of Transmit List

This field contains the base address of the first descriptor in the Transmit descriptor list. The DMA ignores the LSB bits (1:0) for 32-bit bus width and internally takes these bits as all-zero. Therefore, these LSB bits are read-only (RO).

Channel Rx descriptor list address register (ETH_DMACRXDLAR)

Address offset: 0x111C

Reset value: 0x0000 0000

The Channel Rx Descriptor List Address register points the DMA to the start of Receive descriptor list.

This register points to the start of the Receive Descriptor List. The descriptor lists reside in the physical memory space of the application and must be word-aligned. The DMA internally converts it to bus width aligned address by making the corresponding LS bits low. Writing to this register is permitted only when reception is stopped. When stopped, this register must be written to before the receive Start command is given. You can write to this register only when Rx DMA has stopped, that is, SR bit is set to zero in *ETH_DMACRXCR* register. When stopped, this register can be written with a new descriptor list address.

When you set the SR bit to 1, the DMA takes the newly programmed descriptor base address.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RDESLA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDESLA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r

Bits 31:0 **RDESLA[31:0]**: Start of Receive List

This field contains the base address of the first descriptor in the Rx Descriptor list. The DMA ignores the LSB bits (1:0) for 32-bit bus width and internally takes these bits as all-zero. Therefore, these LSB bits are read-only (RO).

Channel Tx descriptor tail pointer register (ETH_DMACTXDTPR)

Address offset: 0x1120

Reset value: 0x0000 0000

The Channel Tx Descriptor Tail Pointer register points to an offset from the base and indicates the location of the last valid descriptor.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TDT[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TDT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r

Bits 31:0 **TDT[31:0]**: Transmit Descriptor Tail Pointer

This field contains the tail pointer for the Tx descriptor ring. The software writes the tail pointer to add more descriptors to the Tx channel. The hardware tries to transmit all packets referenced by the descriptors between the head and the tail pointer registers.

Channel Rx descriptor tail pointer register (ETH_DMACRXDTPR)

Address offset: 0x1128

Reset value: 0x0000 0000

The Channel Rx Descriptor Tail Pointer Points to an offset from the base and indicates the location of the last valid descriptor.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RDT[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r

Bits 31:0 **RDT[31:0]**: Receive Descriptor Tail Pointer

This field contains the tail pointer for the Rx descriptor ring. The software writes the tail pointer to add more descriptors to the Rx channel. The hardware tries to write all received packets to the descriptors referenced between the head and the tail pointer registers.

Channel Tx descriptor ring length register (ETH_DMACTXRLR)

Address offset: 0x112C

Reset value: 0x0000 0000

The Tx Descriptor Ring Length register contains the length of the Transmit descriptor ring.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	TDRL[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:0 **TDRL[9:0]**: Transmit Descriptor Ring Length

This field sets the maximum number of Tx descriptors in the circular descriptor ring. The maximum number of descriptors is limited to 1K descriptors. It is recommended to put a minimum ring descriptor length of 4.

For example, you can program any value up to 0x3FF in this field. This field is 10 bits wide, if you program 0x3FF, you can have 1024 descriptors. If you want to have 10 descriptors, program it to a value of 0x9.

Channel Rx descriptor ring length register (ETH_DMACRXRLR)

Address offset: 0x1130

Reset value: 0x0000 0000

The Channel Rx Descriptor Ring Length register contains the length of the Receive descriptor circular ring.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARBS[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	RDRL[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **ARBS[7:0]**: Alternate Receive Buffer Size

Indicates size in bytes for Buffer 1 when ARBS[7:0] is programmed to a non-zero value. When ARBS[7:0] = 0, Rx Buffer1 and Rx Buffer2 sizes are based on RBSZ[13:0] field of *Channel receive control register (ETH_DMACRXCR)*.

Bits 15:10 Reserved, must be kept at reset value.

Bits 9:0 **RDRL[9:0]**: Receive Descriptor Ring Length

This register sets the maximum number of Rx descriptors in the circular descriptor ring. The maximum number of descriptors is limited to 1K descriptors.

For example, you can program any value up to 0x3FF in this field. This field is 10-bit wide. If you program 0x3FF, you can have 1024 descriptors. If you want to have 10 descriptors, program it to a value of 0x9.

Channel interrupt enable register (ETH_DMACIER)

Address offset: 0x1134

Reset value: 0x0000 0000

The Channel Interrupt Enable register enables the interrupts reported by the Status register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NIE	AIE	CDEE	FBEE	ERIE	ETIE	RWTE	RSE	RBUE	RIE	Res.	Res.	Res.	TBUE	TXSE	TIE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw				rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **NIE**: Normal Interrupt Summary Enable

When this bit is set, the normal interrupt summary is enabled. This bit enables the following interrupts in the *Channel status register (ETH_DMACSR)*:
Bit 0: Transmit Interrupt
Bit 2: Transmit Buffer Unavailable
Bit 6: Receive Interrupt
Bit 11: Early Receive Interrupt
When this bit is reset, the normal interrupt summary is disabled.

Bit 14 **AIE**: Abnormal Interrupt Summary Enable

When this bit is set, the abnormal interrupt summary is enabled. This bit enables the following interrupts in the *Channel status register (ETH_DMACSR)*:
Bit 1: Transmit Process Stopped
Bit 7: Rx Buffer Unavailable
Bit 8: Receive Process Stopped
Bit 9: Receive Watchdog Timeout
Bit 10: Early Transmit Interrupt
Bit 12: Fatal Bus Error
When this bit is reset, the abnormal interrupt summary is disabled.

Bit 13 **CDEE**: Context Descriptor Error Enable

When this bit is set along with the AIE bit, the Context Descriptor error interrupt is enabled. When this bit is reset, the Context Descriptor error interrupt is disabled.

Bit 12 **FBEE**: Fatal Bus Error Enable

When this bit is set along with the AIE bit, the Fatal Bus error interrupt is enabled. When this bit is reset, the Fatal Bus Error error interrupt is disabled.

Bit 11 **ERIE**: Early Receive Interrupt Enable

When this bit is set along with the NIE bit, the Early Receive interrupt is enabled. When this bit is reset, the Early Receive interrupt is disabled.

Bit 10 **ETIE**: Early Transmit Interrupt Enable

When this bit is set along with the AIE bit, the Early Transmit interrupt is enabled. When this bit is reset, the Early Transmit interrupt is disabled.

Bit 9 **RWTE**: Receive Watchdog Timeout Enable

When this bit is set along with the AIE bit, the Receive Watchdog Timeout interrupt is enabled. When this bit is reset, the Receive Watchdog Timeout interrupt is disabled.

Bit 8 **RSE**: Receive Stopped Enable

When this bit is set along with the AIE bit, the Receive Stopped Interrupt is enabled. When this bit is reset, the Receive Stopped interrupt is disabled.

Bit 7 **RBUE**: Receive Buffer Unavailable Enable

When this bit is set along with the AIE bit, the Receive Buffer Unavailable interrupt is enabled. When this bit is reset, the Receive Buffer Unavailable interrupt is disabled.

Bit 6 **RIE**: Receive Interrupt Enable

When this bit is set along with the NIE bit, the Receive Interrupt is enabled. When this bit is reset, the Receive Interrupt is disabled.

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **TBUE**: Transmit Buffer Unavailable Enable

When this bit is set along with the NIE bit, the Transmit Buffer Unavailable interrupt is enabled. When this bit is reset, the Transmit Buffer Unavailable interrupt is disabled.

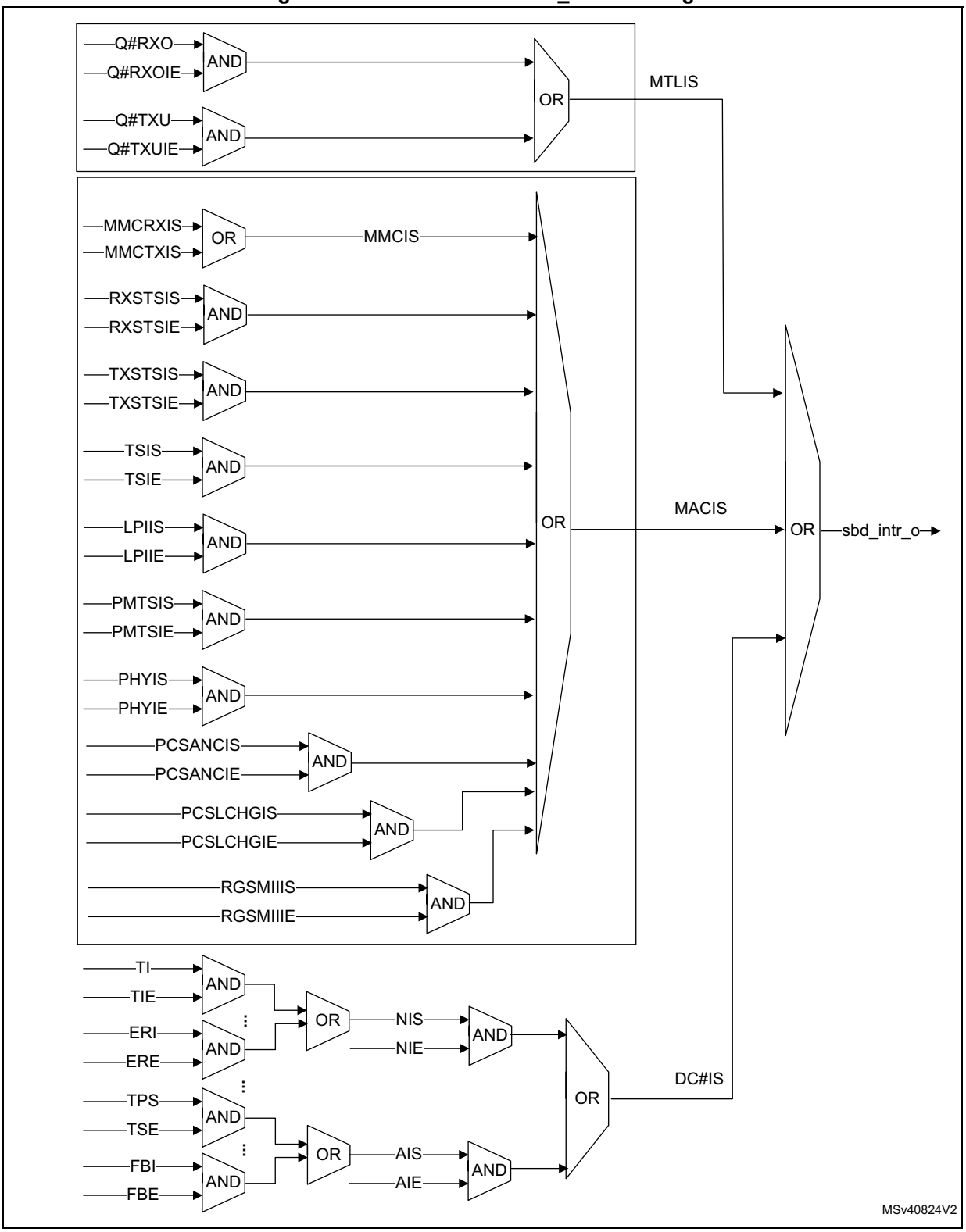
Bit 1 **TXSE**: Transmit Stopped Enable

When this bit is set along with the AIE bit, the Transmission Stopped interrupt is enabled. When this bit is reset, the Transmission Stopped interrupt is disabled.

Bit 0 **TIE**: Transmit Interrupt Enable

When this bit is set along with the NIE bit, the Transmit Interrupt is enabled. When this bit is reset, the Transmit Interrupt is disabled.

Figure 845. Generation of ETH_DMAISR flags



Channel Rx interrupt watchdog timer register (ETH_DMACRXIWTR)

Address offset: 0x1138

Reset value: 0x0000 0000

The Receive Interrupt Watchdog Timer register indicates the watchdog timeout for Receive Interrupt (RI) from the DMA. When this register is written with a non-zero value, it enables the watchdog timer for the RI bit of the *Channel status register (ETH_DMACSR)*.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RWTU[1:0]	
														rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RWT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:18 Reserved, must be kept at reset value.

Bits 17:16 **RWTU[1:0]**: Receive Interrupt Watchdog Timer Count Units

This field indicates the number of system clock cycles corresponding to one unit in RWT[7:0] field.
00: 256
01: 512
10: 1024
11: 2048
For example, when RWT[7:0] = 2 and RWTU[1:0] = 1, the watchdog timer is set for 2 * 512 = 1024 system clock cycles.

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **RWT[7:0]**: Receive Interrupt Watchdog Timer Count

This field indicates the number of system clock cycles, multiplied by factor indicated in RWTU field, for which the watchdog timer is set.
The watchdog timer is triggered with the programmed value after the Rx DMA completes the transfer of a packet for which the RI bit is not set in the ETH_DMACSR, because of the setting of Interrupt Enable bit in the corresponding descriptor RDES3[30].
When the watchdog timer runs out, the RI bit is set and the timer is stopped. The watchdog timer is reset when the RI bit is set high because of automatic setting of RI as per the Interrupt Enable bit RDES3[30] of any received packet.

Channel current application transmit descriptor register (ETH_DMACCATXDR)

Address offset: 0x1144

Reset value: 0x0000 0000

The Channel Current Application Transmit Descriptor register points to the current Transmit descriptor read by the DMA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CURTDESAPTR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CURTDESAPTR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **CURTDESAPTR[31:0]**: Application Transmit Descriptor Address Pointer
The DMA updates this pointer during Tx operation. This pointer is cleared on reset.

Channel current application receive descriptor register (ETH_DMACCARXDR)

Address offset: 0x114C

Reset value: 0x0000 0000

The Channel Current Application Receive Descriptor register points to the current Receive descriptor read by the DMA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CURRDESAPTR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CURRDESAPTR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **CURRDESAPTR[31:0]**: Application Receive Descriptor Address Pointer
The DMA updates this pointer during Rx operation. This pointer is cleared on reset.

Channel current application transmit buffer register (ETH_DMACCATXBR)

Address offset: 0x1154

Reset value: 0x0000 0000

The Channel Current Application Transmit Buffer Address register points to the current Tx buffer address read by the DMA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CURTBUFAPTR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CURTBUFAPTR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **CURTBUFAPTR[31:0]**: Application Transmit Buffer Address Pointer
The DMA updates this pointer during Tx operation. This pointer is cleared on reset.

Channel current application receive buffer register (ETH_DMACCARXBR)

Address offset: 0x115C

Reset value: 0x0000 0000

The Channel Current Application Receive Buffer Address register points to the current Rx buffer address read by the DMA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CURRBUFAPTR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CURRBUFAPTR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **CURRBUFAPTR[31:0]**: Application Receive Buffer Address Pointer
The DMA updates this pointer during Rx operation. This pointer is cleared on reset.

Channel status register (ETH_DMACSR)

Address offset: 0x1160

Reset value: 0x0000 0000

The software driver (application) reads the Status register during interrupt service routine or polling to determine the status of the DMA.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REB[2:0]			TEB[2:0]		
										r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NIS	AIS	CDE	FBE	ERI	ETI	RWT	RPS	RBU	RI	Res.	Res.	Res.	TBU	TPS	TI
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rw	rc_w1	rc_w1	rc_w1				rc_w1	rc_w1	rc_w1

Bits 31:22 Reserved, must be kept at reset value.

Bits 21:19 **REB[2:0]**: Rx DMA Error Bits

This field indicates the type of error that caused a Bus Error. For example, error response on the AHB interface.
Bit [2]: Error during data transfer by Rx DMA when 1, no Error during data transfer by Rx DMA when 0.
Bit[1]: Error during descriptor access when 1, Error during data buffer access when 0
Bit[0]: Error during read transfer when 1, Error during write transfer when 0
This field is valid only when the FBE bit is set. This field does not generate an interrupt.

Bits 18:16 **TEB[2:0]**: Tx DMA Error Bits

This field indicates the type of error that caused a Bus Error. For example, error response on the AHB interface.
Bit[2]: Error during data transfer by Tx DMA when 1, no Error during data transfer by Tx DMA when 0
Bit[1]: Error during descriptor access when 1, Error during data buffer access when 0
Bit[0]: Error during read transfer when 1, Error during write transfer when 0
This field is valid only when the FBE bit is set. This field does not generate an interrupt.

Bit 15 **NIS**: Normal Interrupt Summary

Normal Interrupt Summary bit value is the logical OR of the following bits when the corresponding interrupt bits are enabled in the ETH_DMACIER register:
Bit 0: Transmit Interrupt
Bit 2: Transmit Buffer Unavailable
Bit 6: Receive Interrupt
Bit 11: Early Receive Interrupt
Only unmasked bits (interrupts for which interrupt enable is set in ETH_DMACIER register) affect the Normal Interrupt Summary bit.
This is a sticky bit. You must clear this bit (by writing 1 to this bit) each time a corresponding bit which causes NIS to be set is cleared.

Bit 14 **AIS**: Abnormal Interrupt Summary

Abnormal Interrupt Summary bit value is the logical OR of the following when the corresponding interrupt bits are enabled in the ETH_DMACIER register:
Bit 1: Transmit Process Stopped
Bit 7: Receive Buffer Unavailable
Bit 8: Receive Process Stopped
Bit 10: Early Transmit Interrupt
Bit 12: Fatal Bus Error
Bit 13: Context Descriptor Error
Only unmasked bits affect the Abnormal Interrupt Summary bit.
This is a sticky bit. You must clear this bit (by writing 1 to this bit) each time a corresponding bit, which causes AIS to be set, is cleared.

Bit 13 **CDE**: Context Descriptor Error

This bit indicates that the DMA Tx/Rx engine received a descriptor error, which indicates invalid context in the middle of packet flow (intermediate descriptor) or all one‘s descriptor in Tx case and on Rx side it indicates DMA has read a descriptor with either of the buffer address as ones which is considered to be invalid.

Bit 12 **FBE**: Fatal Bus Error

This bit indicates that a bus error occurred (as described in the EB field). When this bit is set, the corresponding DMA channel engine disables all bus accesses.

Bit 11 **ERI**: Early Receive Interrupt

This bit indicates that the DMA filled the first data buffer of the packet.The RI bit of this register automatically clears this bit.

Bit 10 **ETI**: Early Transmit Interrupt

This bit indicates that the packet to be transmitted is fully transferred to the MTL Tx FIFO.

Bit 9 **RWT**: Receive Watchdog Timeout

This bit is asserted when a packet with length greater than 2,048 bytes (10,240 bytes when Jumbo Packet mode is enabled) is received.

Bit 8 **RPS**: Receive Process Stopped

This bit is asserted when the Rx process enters the Stopped state.

Bit 7 **RBU**: Receive Buffer Unavailable

This bit indicates that the application owns the next descriptor in the Receive list, and the DMA cannot acquire it. The Rx process is suspended. To resume processing Rx descriptors, the application should change the ownership of the descriptor and issue a Receive Poll Demand command. If this command is not issued, the Rx process resumes when the next recognized incoming packet is received. In ring mode, the application should advance the Receive Descriptor Tail Pointer register of a channel. This bit is set only when the DMA owns the previous Rx descriptor.

Bit 6 **RI**: Receive Interrupt

This bit indicates that the packet reception is complete. When packet reception is complete, Bit 31 of RDES1 is reset in the last descriptor, and the specific packet status information is updated in the descriptor.

The reception remains in the Running state.

Bits 5:3 Reserved, must be kept at reset value.

Bit 2 **TBU**: Transmit Buffer Unavailable

This bit indicates that the application owns the next descriptor in the Transmit list, and the DMA cannot acquire it. Transmission is suspended. The TPSi field of the *Debug status register (ETH_DMADSR)* register explains the Transmit Process state transitions.

To resume processing the Transmit descriptors, the application should do the following:

1. Change the ownership of the descriptor by setting Bit 31 of TDES3.
2. Issue a Transmit Poll Demand command.

For ring mode, the application should advance the Transmit Descriptor Tail Pointer register of a channel.

Bit 1 **TPS**: Transmit Process Stopped

This bit is set when the transmission is stopped.

Bit 0 **TI**: Transmit Interrupt

This bit indicates that the packet transmission is complete. When transmission is complete, Bit 31 of TDES3 is reset in the last descriptor, and the specific packet status information is updated in the descriptor.

Channel missed frame count register (ETH_DMACMFCR)

Address offset: 0x116C

Reset value: 0x0000 0000

This register has the number of packet counter that got dropped by the DMA either due to Bus Error or due to programing RPF field in *Channel receive control register (ETH_DMACRXCR)* register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MFCO	Res.	Res.	Res.	Res.	MFC[10:0]										
rc_r					rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **MFCO**: Overflow status of the MFC Counter

When this bit is set then the MFC counter does not get incremented further. The bit gets cleared when this register is read.

Bits 14:11 Reserved, must be kept at reset value.

Bits 10:0 **MFC[10:0]**: Dropped Packet Counters

This counter indicates the number of packet counters that are dropped by the DMA either because of bus error or because of programing RPF field in *Channel receive control register (ETH_DMACRXCR)*. The counter gets cleared when this register is read.

Ethernet DMA register map and reset values

Table 602. ETH_DMA common register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x1000	ETH_DMAMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INTM[1:0]		Res.	PR[2:0]			TXPR	Res.	Res.	Res.	Res.	Res.	Res.	Res.			DA	SWR
	Reset value															0	0		0	0	0	0										0	0
0x1004	ETH_DMASBMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RB	MB	Res.	AAL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FB
	Reset value																	0	0		0												0
0x1008	ETH_DMAISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MACIS	MTLIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DC0IS
	Reset value															0	0																0
0x100C	ETH_DMADSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TPS0[3:0]				RPS0[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	AXWHSTS
	Reset value																	0	0	0	0	0	0	0	0								0

Table 603. ETH_DMA_CH register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x1100	ETH_DMACCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DSL[2:0]			Res.	PBLX8	Res.	Res.	MSS[13:0]													
	Reset value												0	0	0		0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1104	ETH_DMACTXCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXPBL[5:0]						Res.	Res.	Res.	TSE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OSF	Res.			ST
	Reset value											0	0	0	0	0	0				0								0				0
0x1108	ETH_DMACRXCR	RPF	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXPBL[5:0]						Res.	RBSZ[13:0]											Res.	Res.	Res.	SR
	Reset value	0										0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0				0
0x110C - 01110	Reserved																																
0x1114	ETH_DMACTXDLAR	TDESLA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1118	Reserved																																
0x111C	ETH_DMACRXDLAR	RDESLA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1120	ETH_DMACTXDTPR	TDT[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 603. ETH_DMA_CH register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x1124	Reserved																																
0x1128	ETH_DMACRXDTPR	RDT[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x112C	ETH_DMACTXRLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TDRL[9:0]									
	Reset value																							0	0	0	0	0	0	0	0	0	0
0x1130	ETH_DMACRXRLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ARBS[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	RDRL[9:0]									
	Reset value									0	0	0	0	0	0	0	0							0	0	0	0	0	0	0	0	0	0
0x1134	ETH_DMACIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NIE	AIE	CDEE	FBEE	ERIE	ETIE	RWTE	RSE	RBUE	RIE	Res.	Res.	Res.	TBUE	TXSE	TIE
	Reset value																	0	0	0	0	0	0	0	0	0	0				0	0	0
0x1138	ETH_DMACRXIWTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RWTU[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RWT[7:0]							
	Reset value															0	0									0	0	0	0	0	0	0	0
0x113C-0x1140	Reserved																																
0x1144	ETH_DMACCATXDR	CURTDESAPTR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1148	Reserved																																
0x0114C	ETH_DMACCARXDR	CURRDESAPTR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1150	Reserved																																
0x1154	ETH_DMACCATXBR	CURTBUFAPTR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1158	Reserved																																
0x115C	ETH_DMACCARXBR	CURRBUFAPTR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x1160	ETH_DMACSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REB[2:0]			TEB[2:0]			NIS	AIS	CDE	FBE	ERI	ETI	RWT	RPS	RBU	RI	Res.	Res.	Res.	TBU	TPS	TI
	Reset value											0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
0x1164 - 0x1168	Reserved																																

Table 603. ETH_DMA_CH register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x116C	ETH_DMACMFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MFCO	Res.	Res.	Res.	Res.	MFC[10:0]										
	Reset value																	0					0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

63.11.3 Ethernet MTL registers

Operating mode Register (ETH_MTLOMR)

Address offset: 0x0C00

Reset value: 0x0000 0000

The Operating Mode register establishes the Transmit and Receive operating modes and commands.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	CNT CLR	CNT PRST	Res.	Res.	Res.	Res.	Res.	Res.	DTX STS	Res.
						rw	rw							rw	

Bits 31:10 Reserved, must be kept at reset value.

Bit 9 **CNTCLR**: Counters Reset

When this bit is set, all counters are reset. This bit is cleared automatically after 1 clock cycle. If this bit is set along with CNTPRST bit, CNTPRST has precedence.

Bit 8 **CNTPRST**: Counters Preset

When this bit is set:

- *Tx queue underflow register (ETH_MTLTXQUR)* is initialized/preset to 0x7F0.
- Missed Packet and Overflow Packet counters in *Rx queue missed packet and overflow counter register (ETH_MTLRXQMPOCR)* is initialized/preset to 0x7F0

This bit is cleared automatically.

Bit 7 Reserved, must be kept at reset value.

Bits 6:2 Reserved, must be kept at reset value.

Bit 1 **DTXSTS**: Drop Transmit Status

When this bit is set, the Tx packet status received from the MAC is dropped in the MTL. When this bit is reset, the Tx packet status received from the MAC is forwarded to the application.

Bit 0 Reserved, must be kept at reset value.

Interrupt status Register (ETH_MTLISR)

Address offset: 0x0C20

Reset value: 0x0000 0000

The software driver (application) reads this register during interrupt service routine or polling to determine the interrupt status of MTL queues and the MAC.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Q0IS
															r

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **Q0IS**: Queue interrupt status

This bit indicates that an interrupt has been generated by Queue. To reset this bit, read ETH_MTLQICSR register to identify the interrupt cause and clear the source.

Tx queue operating mode Register (ETH_MTLTXQOMR)

Address offset: 0x0D00

Reset value: 0x0007 0008

The Queue Transmit Operating Mode register establishes the Transmit queue operating modes and commands.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TQS[2:0]		
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TTC[2:0]			TXQEN[1:0]		TSF	FTQ
									rw	rw	rw	r	r	rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:16 **TQS[2:0]**: Transmit queue size

This field indicates the size of the allocated transmit queues in blocks of 256 bytes.

Queue size range from 256 bytes (TQS=0b000) to 2048 bytes (TQS=0b111).

Bits 15:7 Reserved, must be kept at reset value.

Bits 6:4 **TTC[2:0]**: Transmit Threshold Control

These bits control the threshold level of the MTL Tx queue. The transmission starts when the packet size within the MTL Tx queue is larger than the threshold. In addition, full packets with length less than the threshold are also transmitted. These bits are used only when the TSF bit is reset.

000: 32
001: 64
010: 96
011: 128
100: 192
101: 256
110: 384
111: 512

Bits 3:2 **TXQEN[1:0]**: Transmit Queue Enable

This field is used to enable/disable the transmit queue .

00: Not enabled
10: Enabled
Others: Reserved, must not be used.

Note: In multiple Tx queues configuration, all the queues are disabled by default. Enable the Tx queue by programming this field.

Bit 1 **TSF**: Transmit Store and Forward

When this bit is set, the transmission starts when a full packet resides in the MTL Tx queue. When this bit is set, the TTC values specified in Bits[6:4] of this register are ignored. This bit should be changed only when the transmission is stopped.

Bit 0 **FTQ**: Flush Transmit Queue

When this bit is set, the Tx queue controller logic is reset to its default values. Therefore, all the data in the Tx queue is lost or flushed. This bit is internally reset when the flushing operation is complete. Until this bit is reset, you should not write to the ETH_MTLTXQOMR register. The data which is already accepted by the MAC transmitter is not flushed. It is scheduled for transmission and results in underflow and runt packet transmission.

Note: The flush operation is complete only when the Tx queue is empty and the application has accepted the pending Tx Status of all transmitted packets. To complete this flush operation, the PHY Tx clock (eth_mii_tx_clk) should be active.

Tx queue underflow register (ETH_MTLTXQUR)

Address offset: 0x0D04

Reset value: 0x0000 0000

The Queue Underflow Counter register contains the counter for packets aborted because of Transmit queue underflow and packets missed because of Receive queue packet flush

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	UFCNT OVF	UFFRMCNT[10:0]										
				rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **UFCNTOVF**: Overflow Bit for Underflow Packet Counter

This bit is set every time the Tx queue Underflow Packet Counter field overflows, that is, it has crossed the maximum count. In such a scenario, the overflow packet counter is reset to all-zeros and this bit indicates that the rollover happened.

Bits 10:0 **UFFRMCNT[10:0]**: Underflow Packet Counter

This field indicates the number of packets aborted by the controller because of Tx queue Underflow. This counter is incremented each time the MAC aborts outgoing packet because of underflow. The counter is cleared when this register is read.

Tx queue debug Register (ETH_MTLTXQDR)

Address offset: 0x0D08

Reset value: 0x0000 0000

The Queue Transmit Debug register gives the debug status of various blocks related to the Transmit queue.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STXSTSF[2:0]			Res.	PTXQ[2:0]		
									r	r	r		r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXSTSFSTS	TXQSTS	TWCSTS	TRCSTS[1:0]		TXQPAUSED
										r	r	r	r	r	r

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:20 **STXSTSF[2:0]**: Number of Status Words in Tx Status FIFO of Queue

This field indicates the current number of status in the Tx Status FIFO of this queue.
When the DTXSTS bit of ETH_MTLOMR register is set to 1, this field does not reflect the number of status words in Tx Status FIFO.

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **PTXQ[2:0]**: Number of Packets in the Transmit Queue

This field indicates the current number of packets in the Tx queue.
When the DTXSTS bit of *Operating mode Register (ETH_MTLOMR)* register is set to 1, this field does not reflect the number of packets in the Transmit queue.

Bits 15:6 Reserved, must be kept at reset value.

Bit 5 **TXSTSFSTS**: MTL Tx Status FIFO Full Status

When high, this bit indicates that the MTL Tx Status FIFO is full. Therefore, the MTL cannot accept any more packets for transmission.

Bit 4 **TXQSTS**: MTL Tx Queue Not Empty Status

When this bit is high, it indicates that the MTL Tx queue is not empty and some data is left for transmission.

Bit 3 **TWCSTS**: MTL Tx Queue Write Controller Status
When high, this bit indicates that the MTL Tx queue Write Controller is active, and it is transferring the data to the Tx queue.

Bits 2:1 **TRCSTS[1:0]**: MTL Tx Queue Read Controller Status
This field indicates the state of the Tx Queue Read Controller:
00: Idle state
01: Read state (transferring data to the MAC transmitter)
10: Waiting for pending Tx Status from the MAC transmitter
11: Flushing the Tx queue because of the Packet Abort request from the MAC

Bit 0 **TXQPAUSED**: Transmit Queue in Pause
When this bit is high and the Rx flow control is enabled, it indicates that the Tx queue is in the Pause condition (in the Full-duplex only mode) because of the following:
– Reception of the PFC packet for the priorities assigned to the Tx queue when PFC is enabled
– Reception of 802.3x Pause packet when PFC is disabled

Queue interrupt control status Register (ETH_MTLQICSR)

Address offset: 0x0D2C

Reset value: 0x0000 0000

This register contains the interrupt enable and status bits for the queue interrupts.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXOIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXOVFIS
							rw								rc_w1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXUIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXUNFIS
							rw								rc_w1

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **RXOIE**: Receive Queue Overflow Interrupt Enable
When this bit is set, the Receive Queue Overflow interrupt is enabled. When this bit is reset, the Receive Queue Overflow interrupt is disabled.

Bits 23:17 Reserved, must be kept at reset value.

Bit 16 **RXOVFIS**: Receive Queue Overflow Interrupt Status
This bit indicates that the Receive Queue had an overflow while receiving the packet. If a partial packet is transferred to the application, the overflow status is set in RDES3[21]. This bit is cleared when the application writes 1 to this bit.

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **TXUIE**: Transmit Queue Underflow Interrupt Enable

When this bit is set, the Transmit Queue Underflow interrupt is enabled. When this bit is reset, the Transmit Queue Underflow interrupt is disabled.

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **TXUNFIS**: Transmit Queue Underflow Interrupt Status

This bit indicates that the Transmit Queue had an underflow while transmitting the packet. Transmission is suspended and an Underflow Error TDES3[2] is set. This bit is cleared when the application writes 1 to this bit.

Rx queue operating mode register (ETH_MTLRXQOMR)

Address offset: 0x0D30

Reset value: 0x0070 0000

The Queue Receive operating Mode register establishes the Receive queue operating modes and command.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RQS[2:0]			Res.	Res.	Res.	Res.
									r	r	r				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIS_ TCP_EF	RSF	FEP	FUP	Res.	RTC[1:0]	
									rw	rw	rw	rw		rw	rw

Bits 31:23 Reserved, must be kept at reset value.

Bits 22:20 **RQS[2:0]**: Receive Queue Size

This field is read-only and the configured Rx FIFO size in blocks of 256 bytes is reflected in the reset value. The size of the Queue is (RQS + 1) * 256 bytes.

Bits 19:7 Reserved, must be kept at reset value.

Bit 6 **DIS_TCP_EF**: Disable Dropping of TCP/IP Checksum Error Packets

When this bit is set, the MAC does not drop the packets which only have the errors detected by the Receive Checksum Offload engine. Such packets have errors only in the encapsulated payload. There are no errors (including FCS error) in the Ethernet packet received by the MAC.

When this bit is reset, all error packets are dropped if the FEP bit is reset.

Bit 5 **RSF**: Receive Queue Store and Forward

When this bit is set, the Ethernet peripheral reads a packet from the Rx queue only after the complete packet has been written to it, ignoring the RTC field of this register. When this bit is reset, the Rx queue operates in the Threshold (cut-through) mode, subject to the threshold specified by the RTC field of this register.

Bit 4 **FEP**: Forward Error Packets

When this bit is reset, the Rx queue drops packets with error status (CRC error, receive error, watchdog timeout, or overflow). However, if the start byte (write) pointer of a packet is already transferred to the read controller side (in Threshold mode), the packet is not dropped.

When this bit is set, all packets except the runt error packets are forwarded to the application or DMA. If the RSF bit is set and the Rx queue overflows when a partial packet is written, the packet is dropped irrespective of the setting of this bit. However, if the RSF bit is reset and the Rx queue overflows when a partial packet is written, a partial packet may be forwarded to the application or DMA.

Bit 3 **FUP**: Forward Undersized Good Packets

When this bit is set, the Rx queue forwards the undersized good packets (packets with no error and length less than 64 bytes), including pad-bytes and CRC. When this bit is reset, the Rx queue drops all packets of less than 64 bytes, unless a packet is already transferred because of the lower value of Rx Threshold, for example, RTC = 01.

Bit 2 Reserved, must be kept at reset value.

Bits 1:0 **RTC[1:0]**: Receive Queue Threshold Control

These bits control the threshold level of the MTL Rx queue (in bytes):

00: 64

01: 32

10: 96

11: 128

The received packet is transferred to the application or DMA when the packet size within the MTL Rx queue is larger than the threshold. In addition, full packets with length less than the threshold are automatically transferred.

This field is valid only when the RSF bit is zero. This field is ignored when the RSF bit is set to 1.

Rx queue missed packet and overflow counter register (ETH_MTLRXQMPOCR)

Address offset: 0x0D34

Reset value: 0x0000 0000

The Queue missed packet and overflow counter registers contain the counter for packets missed because of Receive queue packet flush and packets discarded because of Receive queue overflow.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	MISCNTOVF	MISPKTCNT[10:0]										
				rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	OVFCNTOVF	OVFPKTCNT[10:0]										
				rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **MISCNTOVF**: Missed Packet Counter Overflow Bit

When set, this bit indicates that the Rx Queue Missed Packet Counter crossed the maximum limit.

Bits 26:16 **MISPKTCNT[10:0]**: Missed Packet Counter

This field indicates the number of packets missed by the Ethernet peripheral because the application requested to flush the packets for this queue. This counter is reset when this register is read.

This counter is incremented by 1 when the DMA discards the packet because of buffer unavailability.

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **OVFCNTOVF**: Overflow Counter Overflow Bit

When set, this bit indicates that the Rx Queue Overflow Packet Counter field crossed the maximum limit.

Bits 10:0 **OVFPKTCNT[10:0]**: Overflow Packet Counter

This field indicates the number of packets discarded by the Ethernet peripheral because of Receive queue overflow. This counter is incremented each time the Ethernet peripheral discards an incoming packet because of overflow. This counter is reset when this register is read.

Rx queue debug register (ETH_MTLRXQDR)

Address offset: 0x0D38

Reset value: 0x0000 0000

The Queue Receive Debug register gives the debug status of various blocks related to the Receive queue.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	PRXQ[13:0]													
		r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXQSTS[1:0]		Res.	RRCSTS[1:0]		RWCSTS
										r	r		r	r	r

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:16 **PRXQ[13:0]**: Number of Packets in Receive Queue

This field indicates the current number of packets in the Rx queue. The theoretical maximum value for this field is 256Kbyte/16bytes = 16K Packets, that is, Max_Queue_Size/Min_Packet_Size.

Bits 15:6 Reserved, must be kept at reset value.

Bits 5:4 **RXQSTS[1:0]**: MTL Rx Queue Fill-Level Status

This field gives the status of the fill-level of the Rx queue:
00: Rx queue empty
01: Rx queue fill-level below flow-control deactivate threshold
10: Rx queue fill-level above flow-control activate threshold
11: Rx queue full

Bit 3 Reserved, must be kept at reset value.

Bits 2:1 **RRCSTS[1:0]**: MTL Rx Queue Read Controller State

This field gives the state of the Rx queue Read controller:
00: Idle state
01: Reading packet data
10: Reading packet status (or timestamp)
11: Flushing the packet data and status

Bit 0 **RWCSTS**: MTL Rx Queue Write Controller Active Status

When high, this bit indicates that the MTL Rx queue Write controller is active, and it is transferring a received packet to the Rx queue.

Ethernet MTL register map and reset values

Table 604. ETH_MTL register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0C00	ETH_MTLOMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CNTCLR	CNTPRST	Res.	Res.	Res.	Res.	Res.	Res.	DTXSTS	Res.
	Reset value																							0	0							0	
0x0C04 - 0x0C1C	Reserved																																
0x0C20	ETH_MTLISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Q0IS
	Reset value																																0
0x0C24 - 0x0CFC	Reserved																																
0x0D00	ETH_ MTLTXQOMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TQS[2:0]							Res.	Res.	Res.	Res.	Res.	TTC[2:0]			TXQEN[1:0]		TSF	FTQ
	Reset value														1	1	1										0	0	0	1	0	0	0
0x0D04	ETH_MTLTXQUR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UFCNTOVF	UFFRMCNT[10:0]										
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x0D08	ETH_MTLTXQDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STXSTSF[2:0]			Res.	PTXQ[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXSTSFSTS	TXQSTS	TWCSTS	TRCSTS[1:0]		TXQPAUSED
	Reset value										0	0	0		0	0	0											0	0	0	0	0	0
0x0D0C - 0x0D28	Reserved																																
0x0D2C	ETH_MTLQICSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXOIE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXOVFIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXUIE	Res.	Res.	Res.	Res.	Res.	Res.	TXUNFIS
	Reset value								0								0								0								0
0x0D30	ETH_ MTLRXQOMR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RQS[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DIS_TCP_EF	RSF	FEP	FUP	Res.	RTC[1:0]	
	Reset value										1	1	1														0	0	0	0		0	0

Table 604. ETH_MTL register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0D34	ETH_ MTLRXQMPOCR	Res.	Res.	Res.	Res.	MISCNTOVF	MISPKTCNT[10:0]											Res.	Res.	Res.	Res.	OVFCNTOVF	OVFPKTCNT[10:0]										
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
0x0D38	ETH_ MTLRXQDR	Res.	Res.	PRXQ[13:0]														Res.	Res.	Res.	Res	Res	Res.	Res.	Res.	Res		RXQSTS[1:0]		Res.	RRCSTS[1:0]		RWCSTS
	Reset value			0	0	0	0	0	0	0	0	0	0	0	0	0	0											0	0		0	0	0
0xD3C-0xD58	Reserved																																

Refer to *Section 2.3 on page 131* for the register boundary addresses.

63.11.4 Ethernet MAC and MMC registers

Operating mode configuration register (ETH_MACCR)

Address offset: 0x0000

Reset value: 0x0000 0000

The MAC Configuration Register establishes the operating mode of the MAC.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ARPEN	SARC[2:0]			IPC	IPG[2:0]			GPSLCE	S2KP	CST	ACS	WD	Res.	JD	JE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	FES	DM	LM	ECRSFD	DO	DCRS	DR	Res.	BL[1:0]		DC	PRELEN[1:0]		TE	RE
	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

Bit 31 **ARPEN**: ARP Offload Enable

When this bit is set, the MAC can recognize an incoming ARP request packet and schedules the ARP packet for transmission. It will forward the ARP packet to the application and also indicate the events in the RxStatus.

When this bit is reset, the MAC receiver does not recognize any ARP packet and indicates them as Type frame in the RxStatus.

Bits 30:28 **SARC[2:0]**: Source Address Insertion or Replacement Control

This field controls the source address insertion or replacement for all transmitted packets. Bit 30 specifies which MAC Address register (0 or 1) is used for source address insertion or replacement based on the values of Bits[29:28]:

010:the MAC inserts the content of the MAC Address 0 registers (*MAC Address 0 high register (ETH_MACA0HR)* and *MAC Address x low register (ETH_MACAxLR)*) in the SA field of all transmitted packets.

011: the MAC replaces the content of the MAC Address 0 registers (*MAC Address 0 high register (ETH_MACA0HR)* and *MAC Address x low register (ETH_MACAxLR)*) in the SA field of all transmitted packets.

110: the MAC inserts the content of the MAC Address 1 registers (*MAC Address x high register (ETH_MACAxHR)* and *MAC Address x low register (ETH_MACAxLR)*) in the SA field of all transmitted packets

111: the MAC replaces the content of the MAC Address 1 registers (*MAC Address x high register (ETH_MACAxHR)* and *MAC Address x low register (ETH_MACAxLR)*) in the SA field of all transmitted packets.

Others: Reserved, must not be used.

Note: Changes to this field take effect only on the start of a packet. If you write to this register field when a packet is being transmitted, only the subsequent packet can use the updated value, that is, the current packet does not use the updated value.

Bit 27 **IPC**: Checksum Offload

When set, this bit enables the IPv4 header checksum checking and IPv4 or IPv6 TCP, UDP, or ICMP payload checksum checking. When this bit is reset, the COE function in the receiver is disabled.

The Layer 3 and Layer 4 Packet Filter feature automatically selects the IPC Full Checksum Offload Engine on the Receive side. When this feature is enabled, you must set the IPC bit.

Bits 26:24 **IPG[2:0]**: Inter-Packet Gap

These bits control the minimum IPG between packets during transmission.

000: 96 bit times

001: 88 bit times

010: 80 bit times

...

111: 40 bit times

This range of minimum IPG is valid in Full-duplex mode.

In the Half-duplex mode, the minimum IPG can be configured only for 64-bit times (IPG = 100). Lower values are not considered.

When a JAM pattern is being transmitted because of backpressure activation, the MAC does not consider the minimum IPG.

The above function (IPG less than 96 bit times) is valid only when EIPGEN bit in ETH_MACECR register is reset. When EIPGEN is set, then the minimum IPG (greater than 96 bit times) is controlled as per the description given in EIPG field in ETH_MACECR register.

Bit 23 **GPSLCE**: Giant Packet Size Limit Control Enable

When this bit is set, the MAC considers the value in GPSL field in ETH_MACECR register to declare a received packet as Giant packet. This field must be programmed to more than 1,518 bytes. Otherwise, the MAC considers 1,518 bytes as giant packet limit.

When this bit is reset, the MAC considers a received packet as Giant packet when its size is greater than 1,518 bytes (1522 bytes for tagged packet).

The watchdog timeout limit, Jumbo Packet Enable and 2K Packet Enable have higher precedence over this bit, that is the MAC considers a received packet as Giant packet when its size is greater than 9,018 bytes (9,022 bytes for tagged packet) with Jumbo Packet Enabled and greater than 2,000 bytes with 2K Packet Enabled. The watchdog timeout, if enabled, terminates the received packet when watchdog limit is reached. Therefore, the programmed giant packet limit should be less than the watchdog limit to get the giant packet status.

Bit 22 **S2KP**: IEEE 802.3as Support for 2K Packets

When this bit is set, the MAC considers all packets with up to 2,000 bytes length as normal packets. When the JE bit is not set, the MAC considers all received packets of size more than 2K bytes as Giant packets.

When this bit is reset and the JE bit is not set, the MAC considers all received packets of size more than 1,518 bytes (1,522 bytes for tagged) as giant packets. For more information about how the setting of this bit and the JE bit impact the Giant packet status, see *Table 605: Giant Packet Status based on S2KP and JE Bits*.

Note: When the JE bit is set, setting this bit has no effect on the giant packet status.

Bit 21 **CST**: CRC stripping for Type packets

When this bit is set, the last four bytes (FCS) of all packets of Ether type (type field greater than 1,536) are stripped and dropped before forwarding the packet to the application. This function is not valid when the IP Checksum Engine (Type 1) is enabled in the MAC receiver. This function is valid when Type 2 Checksum Offload Engine is enabled.

Note: For information about how the settings of the ACS bit and this bit impact the packet length, see Table 606: Packet Length based on the CST and ACS bits.

Bit 20 **ACS**: Automatic Pad or CRC Stripping

When this bit is set, the MAC strips the Pad or FCS field on the incoming packets only if the value of the length field is less than 1,536 bytes. All received packets with length field greater than or equal to 1,536 bytes are passed to the application without stripping the Pad or FCS field.

When this bit is reset, the MAC passes all incoming packets to the application, without any modification.

Note: For information about how the settings of CST bit and this bit impact the packet length, see Table 606: Packet Length based on the CST and ACS bits.

Bit 19 **WD**: Watchdog Disable

When this bit is set, the MAC disables the watchdog timer on the receiver. The MAC can receive packets of up to 16,383 bytes.

When this bit is reset, the MAC does not allow more than 2,048 bytes (10,240 if JE is set high) of the packet being received. The MAC cuts off any bytes received after 2,048 bytes.

Bit 18 Reserved, must be kept at reset value.

Bit 17 **JD**: Jabber Disable

When this bit is set, the MAC disables the jabber timer on the transmitter. The MAC can transfer packets of up to 16,383 bytes.

When this bit is reset, if the application sends more than 2,048 bytes of data (10,240 if JE is set high) during transmission, the MAC does not send rest of the bytes in that packet.

Bit 16 **JE**: Jumbo Packet Enable

When this bit is set, the MAC allows jumbo packets of 9,018 bytes (9,022 bytes for VLAN tagged packets) without reporting a giant packet error in the Rx packet status.

For more information about how the setting of this bit and the JE bit impact the Giant packet status, see *Table 605: Giant Packet Status based on S2KP and JE Bits*.

Bit 15 Reserved, must be kept at reset value.

Bit 14 **FES**: MAC Speed

This bit selects the speed in the 10/100 Mbps mode:

0: 10 Mbps

1: 100 Mbps

Bit 13 **DM**: Duplex Mode

When this bit is set, the MAC operates in the Full-duplex mode in which it can transmit and receive simultaneously.

Bit 12 **LM**: Loopback Mode

When this bit is set, the MAC operates in the loopback mode at MII. The MII Rx clock input (eth_mii_rx_clk) is required for the loopback to work properly. This is because the Tx clock is not internally looped back.

Bit 11 **ECRSFD**: Enable Carrier Sense Before Transmission in Full-duplex mode

When this bit is set, the MAC transmitter checks the CRS signal before packet transmission in the Full-duplex mode. The MAC starts the transmission only when the CRS signal is low.

When this bit is reset, the MAC transmitter ignores the status of the CRS signal.

Bit 10 **DO**: Disable Receive Own

When this bit is set, the MAC disables the reception of packets when the ETH_TX_EN is asserted in the Half-duplex mode. When this bit is reset, the MAC receives all packets given by the PHY.

This bit is not applicable in the Full-duplex mode. This bit is reserved and read-only (RO) with default value in the full-duplex-only configurations.

Bit 9 **DCRS**: Disable Carrier Sense During Transmission

When this bit is set, the MAC transmitter ignores the MII CRS signal during packet transmission in the Half-duplex mode. As a result, no errors are generated because of Loss of Carrier or No Carrier during transmission.

When this bit is reset, the MAC transmitter generates errors because of Carrier Sense. The MAC can even abort the transmission.

Bit 8 **DR**: Disable Retry

When this bit is set, the MAC attempts only one transmission. When a collision occurs on the MII interface, the MAC ignores the current packet transmission and reports a Packet Abort with excessive collision error in the Tx packet status.

When this bit is reset, the MAC retries based on the settings of the BL field. This bit is applicable only in the Half-duplex mode.

Bit 7 Reserved, must be kept at reset value.

Bits 6:5 **BL[1:0]**: Back-Off Limit

The back-off limit determines the random integer number (r) of slot time delays (512 bit times for 10/100 Mbps) for which the MAC waits before rescheduling a transmission attempt during retries after a collision:

00: k= min (n, 10)

01: k = min (n, 8)

10: k = min (n, 4)

11: k = min (n, 1)

where n = retransmission attempt

The random integer r takes the value in the range 0 <= r < 2^k.

This bit is applicable only in the Half-duplex mode.

Bit 4 **DC**: Deferral Check

When this bit is set, the deferral check function is enabled in the MAC. The MAC issues a Packet Abort status, along with the excessive deferral error bit set in the Tx packet status, when the Tx state machine is deferred for more than 24,288 bit times in 10 or 100 Mbps mode.

Deferral begins when the transmitter is ready to transmit, but it is prevented because of an active carrier sense signal (CRS) on MII.

The defer time is not cumulative. For example, if the transmitter defers for 10,000 bit times because the CRS signal is active and the CRS signal becomes inactive, the transmitter transmits and collision happens. Because of collision, the transmitter needs to back off and then defer again after back off completion. In such a scenario, the deferral timer is reset to 0, and it is restarted.

When this bit is reset, the deferral check function is disabled and the MAC defers until the CRS signal goes inactive.

This bit is applicable only in the Half-duplex mode.

Bits 3:2 **PRELEN[1:0]**: Preamble Length for Transmit packets

These bits control the number of preamble bytes that are added to the beginning of every Tx packet. The preamble reduction occurs only when the MAC is operating in the Full-duplex mode.

00: 7 bytes of preamble

01: 5 bytes of preamble

10: 3 bytes of preamble

11: Reserved, must not be used

Bit 1 **TE**: Transmitter Enable

When this bit is set, the Tx state machine of the MAC is enabled for transmission on the MII interface. When this bit is reset, the MAC Tx state machine is disabled after it completes the transmission of the current packet. The Tx state machine does not transmit any more packets.

Bit 0 **RE**: Receiver Enable

When this bit is set, the Rx state machine of the MAC is enabled for receiving packets from the MII interface. When this bit is reset, the MAC Rx state machine is disabled after it completes the reception of the current packet. The Rx state machine does not receive any more packets from the MII interface.

Table 605 shows how the settings of S2KP and JE bits of the ETH_MACCR register impact the giant packet status.

Table 605. Giant Packet Status based on S2KP and JE Bits(1)

Length/Type Field	Received Packet Length	S2KP	JE	Giant Packet Status
Untagged packet	> 1,518	0	0	1
	> 2,000	1	0	1
	> 9,018	x	1	1
VLAN tagged packet	> 1,522	0	0	1
	> 2,000	1	0	1
	> 9,022	x	1	1

1. For all other combinations, the Giant Packet status is 0.

Table 606 shows how the settings of the CST and ACS bits of the ETH_MACCR register impact whether CRC length is included in the packet length.

Table 606. Packet Length based on the CST and ACS bits

Received Packet Length	CST	ACS	FCS Stripping Done
< 1,536	x	0	No
	x	1	Yes (for Ethernet packets)
≥ 1,536	0	x	No
	1	x	Yes (for Type packets)

Extended operating mode configuration register (ETH_MACECR)

Address offset: 0x0004

Reset value: 0x0000 0000

The MAC Extended Configuration Register establishes the operating mode of the MAC.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	EIPG[4:0]					EIPGEN	Res.	Res.	Res.	Res.	Res.	USP	SPEN	DCRCC
		rw	rw	rw	rw	rw	rw						rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	GPSL[13:0]													
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:25 **EIPG[4:0]**: Extended Inter-Packet Gap

The value in this field is applicable when the EIPGEN bit is set. This field (as Most Significant bits) along with IPG field in *Operating mode configuration register (ETH_MACCR)*, gives the minimum IPG greater than 96 bit times in steps of 8 bit times. For example:

- EIPG = 0 and IPG = 0 give 104 bit times
- EIPG = 0 and IPG = 1 give 112 bit times
- EIPG = 0 and IPG = 2 give 120 bit times
- ..
- EIPG = 7 and IPG = 31 give 2144 bit times

Bit 24 **EIPGEN**: Extended Inter-Packet Gap Enable

When this bit is set, the MAC interprets EIPG field and IPG field in *Operating mode configuration register (ETH_MACCR)* together as minimum IPG greater than 96 bit times in steps of 8 bit times.

When this bit is reset, the MAC ignores EIPG field and interprets IPG field in *Operating mode configuration register (ETH_MACCR)* as minimum IPG less than or equal to 96 bit times in steps of 8 bit times.

Note: The extended Inter-Packet Gap feature must be enabled when operating in Full-duplex mode only. There may be undesirable effects on back-pressure function and frame transmission if it is enabled in Half-duplex mode.

Bits 23:19 Reserved, must be kept at reset value.

Bit 18 **USP**: Unicast Slow Protocol Packet Detect

When this bit is set, the MAC detects the Slow Protocol packets with unicast address of the station specified in the *MAC Address 0 high register (ETH_MACA0HR)* and MAC Address 0 low register *MAC Address x low register (ETH_MACAxLR)*. The MAC also detects the Slow Protocol packets with the Slow Protocols multicast address (01-80-C2-00-00-02).

When this bit is reset, the MAC detects only Slow Protocol packets with the Slow Protocol multicast address specified in the IEEE 802.3-2008, Section 5.

Bit 17 **SPEN**: Slow Protocol Detection Enable

When this bit is set, MAC processes the Slow Protocol packets (Ether Type 0x8809) and provides the Rx status. The MAC discards the Slow Protocol packets with invalid subtypes.
When this bit is reset, the MAC forwards all error-free Slow Protocol packets to the application. The MAC considers such packets as normal Type packets.

Bit 16 **DCRCC**: Disable CRC Checking for Received Packets

When this bit is set, the MAC receiver does not check the CRC field in the received packets.
When this bit is reset, the MAC receiver always checks the CRC field in the received packets.

Bits 15:14 Reserved, must be kept at reset value.

Bits 13:0 **GPSL[13:0]**: Giant Packet Size Limit

If the received packet size is greater than the value programmed in this field in units of bytes, the MAC declares the received packet as Giant packet. The value programmed in this field must be greater than or equal to 1,518 bytes. Any other programmed value is considered as 1,518 bytes.
For VLAN tagged packets, the MAC adds 4 bytes to the programmed value. For double VLAN tagged packets, the MAC adds 8 bytes to the programmed value. The value in this field is applicable when the GPSLCE bit is set in ETH_MACCR register.

Packet filtering control register (ETH_MACPFR)

Address offset: 0x0008

Reset value: 0x0000 0000

The MAC Packet Filter register contains the filter controls for receiving packets. Some of the controls from this register go to the address check block of the MAC which performs the first level of address filtering. The second level of filtering is performed on the incoming packet based on other controls such as Pass Bad Packets and Pass Control Packets.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DNTU	IPFE	Res.	Res.	Res.	VTFE
rw										rw	rw				rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	HPF	SAF	SAIF	PCF[1:0]		DBF	PM	DAIF	HMC	HUC	PR
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **RA**: Receive All

When this bit is set, the MAC Receiver module passes all received packets to the application, irrespective of whether they pass the address filter or not. The result of the SA or DA filtering is updated (pass or fail) in the corresponding bit in the Rx Status Word.
When this bit is reset, the Receiver module passes only those packets to the application that pass the SA or DA address filter.

Bits 30:22 Reserved, must be kept at reset value.

Bit 21 **DNTU**: Drop Non-TCP/UDP over IP Packets

When this bit is set, the MAC drops the non-TCP or UDP over IP packets. The MAC forward only those packets that are processed by the Layer 4 filter. When this bit is reset, the MAC forwards all non-TCP or UDP over IP packets.

Bit 20 **IPFE**: Layer 3 and Layer 4 Filter Enable

When this bit is set, the MAC drops packets that do not match the enabled Layer 3 and Layer 4 filters. If Layer 3 or Layer 4 filters are not enabled for matching, this bit does not have any effect.

When this bit is reset, the MAC forwards all packets irrespective of the match status of the Layer 3 and Layer 4 fields.

Bits 19:17 Reserved, must be kept at reset value.

Bit 16 **VTFE**: VLAN Tag Filter Enable

When this bit is set, the MAC drops the VLAN tagged packets that do not match the VLAN Tag. When this bit is reset, the MAC forwards all packets irrespective of the match status of the VLAN Tag.

Bits 15:11 Reserved, must be kept at reset value.

Bit 10 **HPF**: Hash or Perfect Filter

When this bit is set, the address filter passes a packet if it matches either the perfect filtering or Hash filtering as set by the HMC or HUC bit.

When this bit is reset and the HUC or HMC bit is set, the packet is passed only if it matches the Hash filter.

Bit 9 **SAF**: Source Address Filter Enable

When this bit is set, the MAC compares the SA field of the received packets with the values programmed in the enabled SA registers. If the comparison fails, the MAC drops the packet.

When this bit is reset, the MAC forwards the received packet to the application with updated SAF bit of the Rx Status depending on the SA address comparison.

Note: According to the IEEE specification, Bit 47 of the SA is reserved. However, the MAC compares all 48 bits. The software driver should take this into consideration while programming the MAC address registers for SA.

Bit 8 **SAIF**: SA Inverse Filtering

When this bit is set, the Address Check block operates in the inverse filtering mode for SA address comparison. If the SA of a packet matches the values programmed in the SA registers, it is marked as failing the SA Address filter.

When this bit is reset, if the SA of a packet does not match the values programmed in the SA registers, it is marked as failing the SA Address filter.

Bits 7:6 **PCF[1:0]**: Pass Control Packets

These bits control the forwarding of all control packets (including unicast and multicast Pause packets).

00: The MAC filters all control packets from reaching the application.

01: The MAC forwards all control packets except Pause packets to the application even if they fail the Address filter.

10: The MAC forwards all control packets to the application even if they fail the Address filter.

11: The MAC forwards the control packets that pass the Address filter.

Bit 5 **DBF**: Disable Broadcast Packets

When this bit is set, the AFM module blocks all incoming broadcast packets. In addition, it overrides all other filter settings.

When this bit is reset, the AFM module passes all received broadcast packets.

Bit 4 **PM**: Pass All Multicast

When this bit is set, it indicates that all received packets with a multicast destination address (first bit in the destination address field is '1') are passed. When this bit is reset, filtering of multicast packet depends on HMC bit.

Bit 3 **DAIF**: DA Inverse Filtering

When this bit is set, the Address Check block operates in inverse filtering mode for the DA address comparison for both unicast and multicast packets. When this bit is reset, normal filtering of packets is performed.

Bit 2 **HMC**: Hash Multicast

When this bit is set, the MAC performs the destination address filtering of received multicast packets according to the Hash table.

When this bit is reset, the MAC performs the perfect destination address filtering for multicast packets, that is, it compares the DA field with the values programmed in DA registers.

Bit 1 **HUC**: Hash Unicast

When this bit is set, the MAC performs the destination address filtering of unicast packets according to the Hash table.

When this bit is reset, the MAC performs a perfect destination address filtering for unicast packets, that is, it compares the DA field with the values programmed in DA registers.

Bit 0 **PR**: Promiscuous Mode

When this bit is set, the Address Filtering module passes all incoming packets irrespective of the destination or source address. The SA or DA Filter Fails status bits of the Rx Status Word are always cleared when PR is set.

Watchdog timeout register (ETH_MACWTR)

Address offset: 0x000C

Reset value: 0x0000 0000

The Watchdog Timeout register controls the watchdog timeout for received packets.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	PWE	Res.	Res.	Res.	Res.	WTO[3:0]			
							rw					rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **PWE**: Programmable Watchdog Enable

When this bit is set and the WD bit of the *Operating mode configuration register (ETH_MACCR)* register is reset, the WTO field is used as watchdog timeout for a received packet. When this bit is cleared, the watchdog timeout for a received packet is controlled by setting of WD and JE bits in *Operating mode configuration register (ETH_MACCR)* register.

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:0 **WTO[3:0]**: Watchdog Timeout

When the PWE bit is set and the WD bit of the *Operating mode configuration register (ETH_MACCR)* register is reset, this field is used as watchdog timeout for a received packet. If the length of a received packet exceeds the value of this field, such packet is terminated and declared as an error packet.

Encoding is as follows:

0x0: 2 Kbytes

0x1: 3 Kbytes

0x2: 4 Kbytes

0x3: 5 Kbytes

..

0xC: 14 Kbytes

0xD: 15 Kbytes

0xE: 16383 Bytes

0xF: Reserved, must not be used

Note: When the PWE bit is set, the value in this field should be more than 1,522 (0x05F2). Otherwise, the IEEE 802.3-specified valid tagged packets are declared as error packets and then dropped.

Hash Table 0 register (ETH_MACHT0R)

Address offset: 0x0010

Reset value: 0x0000 0000

The Hash Table Register 0 contains the first lower 32 bits of the Hash table (64 bits).

The Hash table is used for group address filtering.

For Hash filtering, the content of the destination address in the incoming packet is passed through the CRC logic and the upper six bits of the CRC register are used to index the content of the Hash table. The most significant bits determines the register to be used (Hash Table Register 0 or 1) and the least significant five bits determine the bit within the register. For example, a hash value of 0b100000 selects Bit 0 of the Hash Table Register 1.

The Hash value of the destination address is calculated in the following way:

1. Calculate the 32-bit CRC for the DA (See IEEE 802.3, Section 3.2.8 for the steps to calculate CRC32).
2. Perform bitwise reversal for the value obtained in Step 1.
3. Take the upper 7 or 8 bits from the value obtained in Step 2.

If the corresponding bit value of the register is 1, the packet is accepted. Otherwise, it is rejected. If the PM bit is set in ETH_MACPFR, all multicast packets are accepted regardless of the multicast Hash values.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HT31T0[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HT31T0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **HT31T0[31:0]**: MAC Hash Table First 32 Bits
This field contains the first 32 Bits [31:0] of the Hash table.

Hash Table 1 register (ETH_MACHT1R)

Address offset: 0x0014

Reset value: 0x0000 0000

The Hash Table 1 register contains the upper 32 bits of the Hash table (64 bits).

The Hash table is used for group address filtering.

For Hash filtering, the content of the destination address in the incoming packet is passed through the CRC logic and the upper six bits of the CRC register are used to index the content of the Hash table. The most significant bits determines the register to be used (Hash Table Register 0 or 1) and the least significant five bits determine the bit within the register. For example, a hash value of 6'b100000 selects Bit 0 of the Hash Table Register 1.

The Hash value of the destination address is calculated in the following way:

1. Calculate the 32-bit CRC for the DA (See IEEE 802.3, Section 3.2.8 for the steps to calculate CRC32).
2. Perform bitwise reversal for the value obtained in Step 1.
3. Take the upper 7 or 8 bits from the value obtained in Step 2.

If the corresponding bit value of the register is 1, the packet is accepted. Otherwise, it is rejected. If the PM bit is set in ETH_MACPFR, all multicast packets are accepted regardless of the multicast Hash values.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
HT63T32[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
HT63T32[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **HT63T32[31:0]**: MAC Hash Table Second 32 Bits
This field contains the second 32 Bits [63:32] of the Hash table.

VLAN tag register (ETH_MACVTR)

Address offset: 0x0050

Reset value: 0x0000 0000

The VLAN Tag register identifies the IEEE 802.1Q VLAN type packets.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EIVLRXS	Res.	EIVLS[1:0]		ERIVLT	EDVLP	VTHM	EVLRXS	Res.	EVLS[1:0]		DOVLTC	ERSVLM	ESVL	VTIM	ETV
rw		rw	rw	rw	rw	rw	rw		rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VL[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **EIVLRXS**: Enable Inner VLAN Tag in Rx Status

When this bit is set, the MAC provides the inner VLAN Tag in the Rx status. When this bit is reset, the MAC does not provide the inner VLAN Tag in Rx status.

Bit 30 Reserved, must be kept at reset value.

Bits 29:28 **EIVLS[1:0]**: Enable Inner VLAN Tag Stripping on Receive

This field indicates the stripping operation on inner VLAN Tag in received packet:
00: Do not strip
01: Strip if VLAN filter passes
10: Strip if VLAN filter fails
11: Always strip

Bit 27 **ERIVLT**: Enable Inner VLAN Tag

When this bit and the EDVLP field are set, the MAC receiver enables operation on the inner VLAN Tag (if present). When this bit is reset, the MAC receiver enables operation on the outer VLAN Tag (if present). The ERSVLM bit determines which VLAN type is enabled for filtering or matching.The ERSVLM bit and DOVLTC bit determines which VLAN type is enabled for filtering.

Bit 26 **EDVLP**: Enable Double VLAN Processing

When this bit is set, the MAC enables processing of up to two VLAN Tags on Tx and Rx (if present). When this bit is reset, the MAC enables processing of up to one VLAN Tag on Tx and Rx (if present).

Bit 25 **VTHM**: VLAN Tag Hash Table Match Enable

When this bit is set, the most significant four bits of CRC of VLAN Tag are used to index the content of the ETH_MACVLANHTR register. A value of 1 in the VLAN Hash Table register, corresponding to the index, indicates that the packet matched the VLAN Hash table.
When the ETV bit is set, the CRC of the 12-bit VLAN Identifier (VID) is used for comparison.
When the ETV bit is reset, the CRC of the 16-bit VLAN tag is used for comparison.
When this bit is reset, the VLAN Hash Match operation is not performed.

Bit 24 **EVLRXS**: Enable VLAN Tag in Rx status

When this bit is set, MAC provides the outer VLAN Tag in the Rx status. When this bit is reset, the MAC does not provide the outer VLAN Tag in Rx status.

Bit 23 Reserved, must be kept at reset value.

Bits 22:21 **EVLS[1:0]**: Enable VLAN Tag Stripping on Receive

This field indicates the stripping operation on the outer VLAN Tag in received packet:
00: Do not strip
01: Strip if VLAN filter passes
10: Strip if VLAN filter fails
11: Always strip

Bit 20 **DOVLTC**: Disable VLAN Type Check

When this bit is set, the MAC does not check whether the VLAN Tag specified by the ERIVLT bit is of type S-VLAN or C-VLAN.
When this bit is reset, the MAC filters or matches the VLAN Tag specified by the ERIVLT bit only when VLAN Tag type is similar to the one specified by the ERSVLM bit.

Bit 19 **ERSVLM**: Enable Receive S-VLAN Match

When this bit is set, the MAC receiver enables filtering or matching for S-VLAN (Type = 0x88A8) packets. When this bit is reset, the MAC receiver enables filtering or matching for C-VLAN (Type = 0x8100) packets.
The ERIVLT bit determines the VLAN tag position considered for filtering or matching.

Bit 18 **ESVL**: Enable S-VLAN

When this bit is set, the MAC transmitter and receiver consider the S-VLAN packets (Type = 0x88A8) as valid VLAN tagged packets.

Bit 17 **VTIM**: VLAN Tag Inverse Match Enable

When this bit is set, this bit enables the VLAN Tag inverse matching. The packets without matching VLAN Tag are marked as matched. When reset, this bit enables the VLAN Tag perfect matching. The packets with matched VLAN Tag are marked as matched.

Bit 16 **ETV**: Enable 12-Bit VLAN Tag Comparison

When this bit is set, a 12-bit VLAN identifier is used for comparing and filtering instead of the complete 16-bit VLAN tag. Bits[11:0] of VLAN tag are compared with the corresponding field in the received VLAN-tagged packet. Similarly, when enabled, only 12 bits of the VLAN tag in the received packet are used for Hash-based VLAN filtering.
When this bit is reset, all 16 bits of the 15th and 16th bytes of the received VLAN packet are used for comparison and VLAN Hash filtering.

Bits 15:0 **VL[15:0]**: VLAN Tag Identifier for Receive Packets

This field contains the 802.1Q VLAN tag to identify the VLAN packets. This VLAN tag identifier is compared to the 15th and 16th bytes of the packets being received for VLAN packets. The following list describes the bits of this field:
Bits[15:13]: User Priority
Bit 12: Canonical Format Indicator (CFI) or Drop Eligible Indicator (DEI)
Bits[11:0]: VLAN Identifier (VID) field of VLAN tag
When the ETV bit is set, only the VID is used for comparison.
If this field ([11:0] if ETV is set) is all zeros, the MAC does not check the 15th and 16th bytes for VLAN tag comparison and declares all packets with Type field value of 0x8100 or 0x88a8 as VLAN packets.

VLAN Hash table register (ETH_MACVHTR)

Address offset: 0x0058

Reset value: 0x0000 0000

When the VTHM bit of *VLAN tag register (ETH_MACVTR)* register is set, the 16-bit VLAN Hash Table register is used for group address filtering based on the VLAN tag. For Hash filtering, the content of the 16-bit VLAN tag or 12-bit VLAN ID (based on the ETV bit of *VLAN tag register (ETH_MACVTR)* register) in the incoming packet is passed through the CRC logic. The upper four bits of the calculated CRC are used to index the contents of the VLAN Hash table. For example, a Hash value of 1000 selects Bit 8 of the VLAN Hash table.

The Hash value of the destination address is calculated in the following way:

1. Calculate the 32-bit CRC for the VLAN tag or ID (For steps to calculate CRC32, see Section 3.2.8 of IEEE 802.3).
2. Perform bitwise reversal for the value obtained in step 1.
3. Take the upper four bits from the value obtained in step 2.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VLHT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **VLHT[15:0]**: VLAN Hash Table
This field contains the 16-bit VLAN Hash Table.

VLAN inclusion register (ETH_MACVIR)

Address offset: 0x0060

Reset value: 0x0000 0000

The VLAN Tag Inclusion or Replacement register contains the VLAN tag for insertion or replacement in the Transmit packets. It also contains the VLAN tag insertion controls.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VLTI	CSVL	VLP	VLC[1:0]	
											rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VLT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **VLTI**: VLAN Tag Input

When this bit is set, it indicates that the VLAN tag to be inserted or replaced in Tx packet should be taken from the Tx descriptor.

Bit 19 **CSVL**: C-VLAN or S-VLAN

When this bit is set, S-VLAN type (0x88A8) is inserted or replaced in the 13th and 14th bytes of transmitted packets. When this bit is reset, C-VLAN type (0x8100) is inserted or replaced in the 13th and 14th bytes of transmitted packets.

0: C-LAN

1: S-LAN

Bit 18 **VLP**: VLAN Priority Control

When this bit is set, the control bits[17:16] are used for VLAN deletion, insertion, or replacement. When this bit is reset, bits[17:16] are ignored.

Bits 17:16 **VLC[1:0]**: VLAN Tag Control in Transmit Packets

00: No VLAN tag deletion, insertion, or replacement

01: VLAN tag deletion. The MAC removes the VLAN type (bytes 13 and 14) and VLAN tag (bytes 15 and 16) of all transmitted packets with VLAN tags.

10: VLAN tag insertion. The MAC inserts VLT in bytes 15 and 16 of the packet after inserting the Type value (0x8100 or 0x88a8) in bytes 13 and 14. This operation is performed on all transmitted packets, irrespective of whether they already have a VLAN tag.

11: VLAN tag replacement. The MAC replaces VLT in bytes 15 and 16 of all VLAN-type transmitted packets (Bytes 13 and 14 are 0x8100 or 0x88a8).

Note: Changes to this field take effect only on the start of a packet. If you write this register field when a packet is being transmitted, only the subsequent packet can use the updated value, that is, the current packet does not use the updated value.

Bits 15:0 **VLT[15:0]**: VLAN Tag for Transmit Packets

This field contains the value of the VLAN tag to be inserted or replaced. The value must only be changed when the transmit lines are inactive or during the initialization phase.

The following list describes the bits of this field:

Bits[15:13]: User Priority

Bit 12: Canonical Format Indicator (CFI) or Drop Eligible Indicator (DEI)

Bits[11:0]: VLAN Identifier (VID) field of VLAN tag

Inner VLAN inclusion register (ETH_MACIVIR)

Address offset: 0x0064

Reset value: 0x0000 0000

The Inner VLAN Tag Inclusion or Replacement register contains the inner VLAN tag to be inserted or replaced in the Transmit packet. It also contains the inner VLAN tag insertion controls.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VLTI	CSVL	VLP	VLC[1:0]	
											rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VLT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **VLTI**: VLAN Tag Input

When this bit is set, it indicates that the VLAN tag to be inserted or replaced in Tx packet should be taken from the Tx descriptor

Bit 19 **CSVL**: C-VLAN or S-VLAN

When this bit is set, S-VLAN type (0x88A8) is inserted or replaced in the 13th and 14th bytes of transmitted packets. When this bit is reset, C-VLAN type (0x8100) is inserted or replaced in the 13th and 14th bytes of transmitted packets.

0: C-LAN

1: S-LAN

Bit 18 **VLP**: VLAN Priority Control

When this bit is set, the VLC field is used for VLAN deletion, insertion, or replacement. When this bit is reset, the VLC field is ignored.

Bits 17:16 **VLC[1:0]**: VLAN Tag Control in Transmit Packets

00: No VLAN tag deletion, insertion, or replacement

01: VLAN tag deletion

The MAC removes the VLAN type (bytes 17 and 18) and VLAN tag (bytes 19 and 20) of all transmitted packets with VLAN tags.

10: VLAN tag insertion

The MAC inserts VLT in bytes 19 and 20 of the packet after inserting the Type value (0x8100 or 0x88a8) in bytes 17 and 18. This operation is performed on all transmitted packets, irrespective of whether they already have a VLAN tag.

11: VLAN tag replacement

The MAC replaces VLT in bytes 19 and 20 of all VLAN-type transmitted packets (Bytes 17 and 18 are 0x8100 or 0x88a8).

Note: Changes to this field take effect only on the start of a packet. If you write to this register field when a packet is being transmitted, only the subsequent packet can use the updated value, that is, the current packet does not use the updated value.

Bits 15:0 **VLT[15:0]**: VLAN Tag for Transmit Packets

This field contains the value of the VLAN tag to be inserted or replaced. The value must only be changed when the transmit lines are inactive or during the initialization phase.
The following list describes the bits of this field:
Bits[15:13]: User Priority
Bit 12: Canonical Format Indicator (CFI) or Drop Eligible Indicator (DEI)
Bits[11:0]: VLAN Identifier (VID) field of VLAN tag

Tx Queue flow control register (ETH_MACQTXFCR)

Address offset: 0x0070

Reset value: 0x0000 0000

The Flow Control register controls the generation and reception of the Control (Pause Command) packets by the Flow control module of the MAC. A Write to a register with the Busy bit set to 1 triggers the Flow Control block to generate a Pause packet. The fields of the control packet are selected as specified in the 802.3x specification, and the Pause Time value from this register is used in the Pause Time field of the control packet. The Busy bit remains set until the control packet is transferred onto the cable. The application must make sure that the Busy bit is cleared before writing to the register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DZPQ	PLT[2:0]			Res.	Res.	TFE	FCB_BPA
								rw	rw	rw	rw			rw	rw

Bits 31:16 **PT[15:0]**: Pause Time

This field holds the value to be used in the Pause Time field in the Tx control packet. I

Bits 15:8 Reserved, must be kept at reset value.

Bit 7 **DZPQ**: Disable Zero-Quanta Pause

When this bit is set, it disables the automatic generation of the zero-quanta Pause packets.
When this bit is reset, normal operation with automatic zero-quanta Pause packet generation is enabled.

Bits 6:4 **PLT[2:0]**: Pause Low Threshold

This field configures the threshold of the Pause timer at which the input flow is checked for automatic retransmission of the Pause packet.

The threshold values should be always less than the Pause Time configured in Bits[31:16]. For example, if PT = 100H (256 slot times), and PLT = 001, a second Pause packet is automatically transmitted at 228 (256-28) slot times after the first Pause packet is transmitted.

The following list provides the threshold values for different values:

000: Pause Time minus 4 Slot Times (PT -4 slot times)

001: Pause Time minus 28 Slot Times (PT -28 slot times)

010: Pause Time minus 36 Slot Times (PT -36 slot times)

011: Pause Time minus 144 Slot Times (PT -144 slot times)

100: Pause Time minus 256 Slot Times (PT -256 slot times)

101: Pause Time minus 512 Slot Times (PT -512 slot times)

110 to 111: Reserved, must not be used

The slot time is defined as the time taken to transmit 512 bits (64 bytes) on the MII interface.

This (approximate) computation is based on the packet size (64, 1518, 2000, 9018, 16384, or 32768) + 2 Pause Packet Size + IPG in Slot Times.

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **TFE**: Transmit Flow Control Enable

Full-duplex mode: when this bit is set, the MAC enables the flow control operation to Tx Pause packets. When this bit is reset, the flow control operation in the MAC is disabled, and the MAC does not transmit any Pause packets.

Half-duplex mode: when this bit is set, the MAC enables the backpressure operation. When this bit is reset, the backpressure feature is disabled.

Bit 0 **FCB_BPA**: Flow Control Busy or Backpressure Activate

This bit initiates a Pause packet in the full-duplex mode and activates the backpressure function in the Half-duplex mode if the TFE bit is set.

Full-Duplex mode: this bit should be read as 0 before writing to this register. To initiate a Pause packet, the application must set this bit to 1. During Control packet transfer, this bit continues to be set to indicate that a packet transmission is in progress. When Pause packet transmission is complete, the MAC resets this bit to 0. You should not write to this register until this bit is cleared.

Half-duplex mode: When this bit is set (and TFE bit is set) in the Half-duplex mode, the MAC asserts the backpressure. During backpressure, when the MAC receives a new packet, the transmitter starts sending a JAM pattern resulting in a collision. When the MAC is configured for the Full-duplex mode, the BPA is automatically disabled.

Rx flow control register (ETH_MACRXFCR)

Address offset: 0x0090

Reset value: 0x0000 0000

The Receive Flow Control register controls the pausing of MAC Transmit based on the received Pause packet.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UP	RFE
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **UP**: Unicast Pause Packet Detect

A pause packet is processed when it has the unique multicast address specified in the IEEE 802.3. When this bit is set, the MAC can also detect Pause packets with unicast address of the station. This unicast address should be as specified in *MAC Address 0 high register (ETH_MACA0HR)* and MAC Address 0 low register *MAC Address x low register (ETH_MACAxLR)*.

When this bit is reset, the MAC only detects Pause packets with unique multicast address.

Note: The MAC does not process a Pause packet if the multicast address is different from the unique multicast address. This is also applicable to the received PFC packet when the Priority Flow Control (PFC) is enabled. The unique multicast address (0x01_80_C2_00_00_01) is as specified in IEEE 802.1 Qbb-2011.

Bit 0 **RFE**: Receive Flow Control Enable

When this bit is set and the MAC is operating in Full-duplex mode, the MAC decodes the received Pause packet and disables its transmitter for a specified (Pause) time. When this bit is reset or the MAC is operating in Half-duplex mode, the decode function of the Pause packet is disabled.

When PFC is enabled, flow control is enabled for PFC packets. The MAC decodes the received PFC packet and disables the Transmit queue, with matching priorities, for a duration of received Pause time.

Interrupt status register (ETH_MACISR)

Address offset: 0x00B0

Reset value: 0x0000 0000

The Interrupt Status register contains the status of interrupts.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	RXSTSIS	TXSTSIS	TSIS	Res.	MMCTXIS	MMCRXIS	MMCIS	Res.	Res.	LPIIS	PMTIS	PHYIS	Res.	Res.	Res.
	rc_r	rc_r	rc_r		r	r	r			r	r	r			

Bits 31:15 Reserved, must be kept at reset value.

Bit 14 **RXSTSIS**: Receive Status Interrupt

This bit indicates the status of received packets. This bit is set when the RWT bit is set in the *Rx Tx status register (ETH_MACRXTXSR)*. This bit is cleared when the corresponding interrupt source bit is read (or corresponding interrupt source bit is written to 1 when RCWE bit of *CSR software control register (ETH_MACCSRSWCR)* is set) in the ETH_MACISR register.

Bit 13 **TXSTSIS**: Transmit Status Interrupt

This bit indicates the status of transmitted packets. This bit is set when any of the following bits is set in the *Rx Tx status register (ETH_MACRXTXSR)*:

- Excessive Collision (EXCOL)
- Late Collision (LCOL)
- Excessive Deferral (EXDEF)
- Loss of Carrier (LCARR)
- No Carrier (NCARR)
- Jabber Timeout (TJT)

This bit is cleared when the corresponding interrupt source bit is read (or corresponding interrupt source bit is written to 1 when RCWE bit of *CSR software control register (ETH_MACCSRSWCR)* is set) in the ETH_MACISR register.

Bit 12 **TSIS**: Timestamp Interrupt Status

If the Timestamp feature is enabled, this bit is set when any of the following conditions is true:

– The system time value is equal to or exceeds the value specified in the Target Time High and Low registers.

– There is an overflow in the Seconds register.

– The Target Time Error occurred, that is, programmed target time already elapsed.

If the Auxiliary Snapshot feature is enabled, this bit is set when the auxiliary snapshot trigger is asserted.

When drop transmit status is enabled in MTL, this bit is set when the captured transmit timestamp is updated in the *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* and *Tx timestamp status seconds register (ETH_MACTXTSSSR)* registers.

When PTP offload feature is enabled, this bit is set when the captured transmit timestamp is updated in the *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* and *Tx timestamp status seconds register (ETH_MACTXTSSSR)* registers, for PTO generated Delay Request and Pdelay request packets.

This bit is cleared when the corresponding interrupt source bit is read (or corresponding interrupt source bit is written to 1 when RCWE bit of *CSR software control register (ETH_MACCSRSWCR)* is set) in the *Timestamp status register (ETH_MACTSSR)*.

Bit 11 Reserved, must be kept at reset value.

Bit 10 **MMCTXIS**: MMC Transmit Interrupt Status

This bit is set high when an interrupt is generated in the *MMC Tx interrupt register (ETH_MMC_TX_INTERRUPT)*. This bit is cleared when all bits in this interrupt register are cleared.

Bit 9 **MMCRXIS**: MMC Receive Interrupt Status

This bit is set high when an interrupt is generated in the *MMC Rx interrupt register (ETH_MMC_RX_INTERRUPT)*. This bit is cleared when all bits in this interrupt register are cleared.

Bit 8 **MMCIS**: MMC Interrupt Status

This bit is set high when MMCTXIS or MMCRXIS is set high. This bit is cleared only when all these bits are low.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **LPIIS**: LPI Interrupt Status

This bit is set for any LPI state entry or exit in the MAC Transmitter or Receiver. This bit is cleared when the TLPIEN bit of *LPI control and status register (ETH_MACLCSR)* is read.

Bit 4 **PMTIS**: PMT Interrupt Status

This bit is set when a Magic packet or Wake-on-LAN packet is received in the power-down mode (RWKPRCVD and MGKPRCVD bits in ETH_MACPCSR register). This bit is cleared when Bits[6:5] are cleared because of a Read operation to the *PMT control status register (ETH_MACPCSR)*.

Bit 3 **PHYIS**: PHY Interrupt

This bit is set when rising edge is detected on the ETH_PHY_INTN input. This bit is cleared when this register is read.

Bits 2:0 Reserved, must be kept at reset value.

Interrupt enable register (ETH_MACIER)

Address offset: 0x00B4

Reset value: 0x0000 0000

The Interrupt Enable register contains the masks for generating the interrupts.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	RXSTSIE	TXSTSIE	TSIE	Res.	Res.	Res.	Res.	Res.	Res.	LPIIE	PMTIE	PHYIE	Res.	Res.	Res.
	rw	rw	rw							rw	rw	rw			

Bits 31:15 Reserved, must be kept at reset value.

Bit 14 **RXSTSIE**: Receive Status Interrupt Enable

When this bit is set, it enables the assertion of the interrupt signal because of the setting of RXSTSIS bit in the *Interrupt status register (ETH_MACISR)*.

Bit 13 **TXSTSIE**: Transmit Status Interrupt Enable

When this bit is set, it enables the assertion of the interrupt signal because of the setting of TXSTSIS bit in the *Interrupt status register (ETH_MACISR)*.

Bit 12 **TSIE**: Timestamp Interrupt Enable

When this bit is set, it enables the assertion of the interrupt signal because of the setting of TSIS bit in *Interrupt status register (ETH_MACISR)*.

Bits 11:6 Reserved, must be kept at reset value.

Bit 5 **LPIIE**: LPI Interrupt Enable

When this bit is set, it enables the assertion of the interrupt signal because of the setting of LPIIS bit in *Interrupt status register (ETH_MACISR)*.

Bit 4 **PMTIE**: PMT Interrupt Enable

When this bit is set, it enables the assertion of the interrupt signal because of the setting of PMTIS bit in *Interrupt status register (ETH_MACISR)*.

Bit 3 **PHYIE**: PHY Interrupt Enable

When this bit is set, it enables the assertion of the interrupt signal because of the setting of PHYIS bit in *Interrupt status register (ETH_MACISR)*.

Bits 2:0 Reserved, must be kept at reset value.

Rx Tx status register (ETH_MACRXTXSR)

Address offset: 0x00B8

Reset value: 0x0000 0000

The Receive Transmit Status register contains the Receive and Transmit Error status.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	RWT	Res.	Res.	EXCOL	LCOL	EXDEF	LCARR	NCARR	TJT
							rc_r			rc_r	rc_r	rc_r	rc_r	rc_r	rc_r

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **RWT**: Receive Watchdog Timeout

This bit is set when a packet with length greater than 2,048 bytes is received (10, 240 bytes when Jumbo Packet mode is enabled) and the WD bit is reset in the *Operating mode configuration register (ETH_MACCR)*. This bit is set when a packet with length greater than 16,383 bytes is received and the WD bit is set in the *Operating mode configuration register (ETH_MACCR)*.

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **EXCOL**: Excessive Collisions

When the DTXSTS bit is set in the *Operating mode Register (ETH_MTLOMR)*, this bit indicates that the transmission aborted after 16 successive collisions while attempting to transmit the current packet. If the DR bit is set in the *Operating mode configuration register (ETH_MACCR)*, this bit is set after the first collision and the packet transmission is aborted.

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 4 **LCOL**: Late Collision

When the DTXSTS bit is set in the *Operating mode Register (ETH_MTLOMR)*, this bit indicates that the packet transmission aborted because a collision occurred after the collision window (64 bytes including Preamble in MII mode.

This bit is not valid if the Underflow error occurs.

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 3 **EXDEF**: Excessive Deferral

When the DTXSTS bit is set in the *Operating mode Register (ETH_MTLOMR)* and the DC bit is set in the *Operating mode configuration register (ETH_MACCR)*, this bit indicates that the transmission ended because of excessive deferral of over 24,288 bit times (155,680 when Jumbo packet is enabled).

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 2 **LCARR**: Loss of Carrier

When the DTXSTS bit is set in the *Operating mode Register (ETH_MTLOMR)*, this bit indicates that the loss of carrier occurred during packet transmission, that is, the ETH_CRS signal was inactive for one or more transmission clock periods during packet transmission. This bit is valid only for packets transmitted without collision.

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 1 **NCARR**: No Carrier

When the DTXSTS bit is set in the *Operating mode Register (ETH_MTLOMR)*, this bit indicates that the carrier signal from the PHY is not present at the end of preamble transmission.

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 0 **TJT**: Transmit Jabber Timeout

This bit indicates that the Transmit Jabber Timer expired which happens when the packet size exceeds 2,048 bytes (10,240 bytes when the Jumbo packet is enabled) and JD bit is reset in the *Operating mode configuration register (ETH_MACCR)*. This bit is set when the packet size exceeds 16,383 bytes and the JD bit is set in the *Operating mode configuration register (ETH_MACCR)*.

Cleared on read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

PMT control status register (ETH_MACPCSR)

Address offset: 0x00C0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RWKFILTRST	Res.	Res.	RWKPTR[4:0]					Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw			r	r	r	r	r								

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	RWKPFE	GLBLUCAST	Res.	Res.	RWKPRCVD	MGKPRCVD	Res.	Res.	RWKPKTEN	MGKPKTEN	PWRDWN
					rw	rw			r	rc_r			rw	rw	rw

Bit 31 **RWKFILTRST**: Remote wakeup Packet Filter Register Pointer Reset

When this bit is set, the remote wakeup packet filter register pointer is reset to 0. It is automatically cleared after 1 clock cycle.

Bits 30:29 Reserved, must be kept at reset value.

Bits 28:24 **RWKPTR[4:0]**: Remote wakeup FIFO Pointer

This field gives the current value (0 to 7) of the Remote wakeup Packet Filter register pointer. When the value of this pointer is equal to 7, the contents of the Remote wakeup Packet Filter Register are transferred to the eth_mii_rx_clk domain when a Write occurs to that register.

Bits 23:11 Reserved, must be kept at reset value.

Bit 10 **RWKPFE**: Remote wakeup Packet Forwarding Enable

When this bit is set along with RWKPKTEN, the MAC receiver drops all received frames until it receives the expected wakeup frame. All frames after that event including the received wakeup frame are forwarded to application. This bit is then self-cleared on receiving the wakeup packet.

The application can also clear this bit before the expected wakeup frame is received. In such cases, the MAC reverts to the default behavior where packets received are forwarded to the application. This bit must only be set when RWKPKTEN is set high and PWRDWN is set low. The setting of this bit has no effect when PWRDWN is set high.

Note: If Magic Packet Enable and wakeup Frame Enable are both set along with setting of this bit and Magic Packet is received prior to wakeup frame, this bit is self-cleared on receiving Magic Packet, the received Magic packet is dropped, and all frames after received Magic Packet are forwarded to application.

Bit 9 **GLBLUCAST**: Global Unicast

When this bit set, any unicast packet filtered by the MAC (DAF) address recognition is detected as a remote wakeup packet.

Bits 8:7 Reserved, must be kept at reset value.

Bit 6 **RWKPRCVD**: Remote wakeup Packet Received

When this bit is set, it indicates that the power management event is generated because of the reception of a remote wakeup packet. This bit is cleared when this register is read.

Bit 5 **MGKPRCVD**: Magic Packet Received

When this bit is set, it indicates that the power management event is generated because of the reception of a magic packet. This bit is cleared when this register is read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bits 4:3 Reserved, must be kept at reset value.

Bit 2 **RWKPKTEN**: Remote wakeup Packet Enable

When this bit is set, a power management event is generated when the MAC receives a remote wakeup packet.

Bit 1 **MGKPKTEN**: Magic Packet Enable

When this bit is set, a power management event is generated when the MAC receives a magic packet.

Bit 0 **PWRDWN**: Power Down

When this bit is set, the MAC receiver drops all received packets until it receives the expected magic packet or remote wakeup packet. This bit is then self-cleared and the power-down mode is disabled. The software can clear this bit before the expected magic packet or remote wakeup packet is received. The packets received by the MAC after this bit is cleared are forwarded to the application. This bit must only be set when the Magic Packet Enable, Global Unicast, or Remote wakeup Packet Enable bit is set high.

Note: You can gate-off the CSR clock during the power-down mode. However, when the CSR clock is gated-off, you cannot perform any read or write operations on this register. Therefore, the Software cannot clear this bit.

Remote wakeup packet filter register (ETH_MACRWKPFR)

Address offset: 0x00C4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MACRWKPFR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MACRWKPFR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **MACRWKPFR[31:0]**: Remote wakeup packet filter

Refer to *Table 574*, *Table 575* and *Table 576* for details on register content and programming sequence.

The ETH_MACRWKPFR register at address 0x00C4 loads the wakeup Packet Filter register.

To load values in a wakeup Packet Filter register, the entire register (ETH_MACRWKPFR) must be written. The ETH_MACRWKPFR register is loaded by sequentially loading the eight, sixteen or thirty two register values in address (0x00C4) for ETH_MACRWKPFR value 0 to 7, respectively. The ETH_MACRWKPFR register is read in a similar way. The Ethernet peripheral updates the ETH_MACRWKPFR register current pointer value in Bits[26:24] of ETH_MACPCSR register.

LPI control and status register (ETH_MACLCSR)

Address offset: 0x00D0

Reset value: 0x0000 0000

The LPI Control and Status Register controls the LPI functions and provides the LPI interrupt status. The status bits are cleared when this register is read.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LPITCSE	LPITE	LPITXA	Res.	PLS	LPIEN
										rw	rw	rw		rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	RLPIST	TLPIST	Res.	Res.	Res.	Res.	RLPIEX	RLPIEN	TLPIEX	TLPIEN
						r	r					r	r	r	r

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **LPITCSE**: LPI Tx Clock Stop Enable

When this bit is set, the MAC asserts sbd_tx_clk_gating_ctrl_o signal high after it enters Tx LPI mode to indicate that the Tx clock to MAC can be stopped. When this bit is reset, the MAC does not assert sbd_tx_clk_gating_ctrl_o signal high after it enters Tx LPI mode.
If RGMII Interface is selected, the Tx clock is required for transmitting the LPI pattern. The Tx Clock cannot be gated and so the LPITCSE bit cannot be programmed.

Bit 20 **LPITE**: LPI Timer Enable

This bit controls the automatic entry of the MAC Transmitter into and exit out of the LPI state. When LPITE, LPITXA and LPIEN bits are set, the MAC Transmitter enters LPI state only when the complete MAC TX data path is IDLE for a period indicated by the ETH_MACLETR register.
After entering LPI state, if the data path becomes non-IDLE (due to a new packet being accepted for transmission), the Transmitter exits LPI state but does not clear LPIEN bit. This enables the re-entry into LPI state when it is IDLE again.
When LPITE is 0, the LPI Auto timer is disabled and MAC Transmitter enters LPI state based on the settings of LPITXA and LPIEN bit descriptions.

Bit 19 **LPITXA**: LPI Tx Automate

This bit controls the behavior of the MAC when it is entering or coming out of the LPI mode on the Transmit side.
If the LPITXA and LPIEN bits are set to 1, the MAC enters the LPI mode only after all outstanding packets (in the core) and pending packets (in the application interface) have been transmitted. The MAC comes out of the LPI mode when the application sends any packet for transmission or the application issues a Tx FIFO Flush command. In addition, the MAC automatically clears the LPIEN bit when it exits the LPI state. If Tx FIFO Flush is set in the FTQ bit of ETH_MTLTxQOMR, when the MAC is in the LPI mode, it exits the LPI mode.
When this bit is 0, the LPIEN bit directly controls behavior of the MAC when it is entering or coming out of the LPI mode.

Bit 18 Reserved, must be kept at reset value.

Bit 17 **PLS**: PHY Link Status

This bit indicates the link status of the PHY. The MAC Transmitter asserts the LPI pattern only when the link status is up (OKAY) at least for the time indicated by the LPI LS TIMER.
When this bit is set, the link is considered to be okay (UP) and when this bit is reset, the link is considered to be down.

Bit 16 **LPIEN**: LPI Enable

When this bit is set, it instructs the MAC Transmitter to enter the LPI state. When this bit is reset, it instructs the MAC to exit the LPI state and resume normal transmission.
This bit is cleared when the LPITXA bit is set and the MAC exits the LPI state because of the arrival of a new packet for transmission.

Bits 15:10 Reserved, must be kept at reset value.

Bit 9 **RLPIST**: Receive LPI State

When this bit is set, it indicates that the MAC is receiving the LPI pattern on the MII interface.

Bit 8 **TLPIST**: Transmit LPI State

When this bit is set, it indicates that the MAC is transmitting the LPI pattern on the MII interface.

Bits 7:4 Reserved, must be kept at reset value.

Bit 3 **RLPIEX**: Receive LPI Exit

When this bit is set, it indicates that the MAC Receiver has stopped receiving the LPI pattern on the MII interface, exited the LPI state, and resumed the normal reception. This bit is cleared by a read into this register (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Note: This bit may not be set if the MAC stops receiving the LPI pattern for a very short duration, such as, less than three clock cycles of CSR clock.

Bit 2 **RLPIEN**: Receive LPI Entry

When this bit is set, it indicates that the MAC Receiver has received an LPI pattern and entered the LPI state. This bit is cleared by a read into this register (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Note: This bit may not be set if the MAC stops receiving the LPI pattern for a very short duration, such as, less than three clock cycles of CSR clock.

Bit 1 **TLPIEX**: Transmit LPI Exit

When this bit is set, it indicates that the MAC transmitter exited the LPI state after the application cleared the LPIEN bit and the LPI TW Timer has expired. This bit is cleared by a read into this register (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 0 **TLPIEN**: Transmit LPI Entry

When this bit is set, it indicates that the MAC Transmitter has entered the LPI state because of the setting of the LPIEN bit. This bit is cleared by a read into this register (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

LPI timers control register (ETH_MACLTCR)

Address offset: 0x00D4

Reset value: 0x03E8 0000

The LPI Timers Control register controls the timeout values in the LPI states. It specifies the time for which the MAC transmits the LPI pattern and also the time for which the MAC waits before resuming the normal transmission.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	LST[9:0]									
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TWT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bits 25:16 **LST[9:0]**: LPI LS Timer

This field specifies the minimum time (in milliseconds) for which the link status from the PHY should be up (OKAY) before the LPI pattern can be transmitted to the PHY. The MAC does not transmit the LPI pattern even when the LPIEN bit is set unless the LPI LS Timer reaches the programmed terminal count. The default value of the LPI LS Timer is 1000 (1 sec) as defined in the IEEE standard.

Bits 15:0 **TWT[15:0]**: LPI TW Timer

This field specifies the minimum time (in microseconds) for which the MAC waits after it stops transmitting the LPI pattern to the PHY and before it resumes the normal transmission. The TLPIEX status bit is set after the expiry of this timer.

LPI entry timer register (ETH_MACLETR)

Address offset: 0x00D8

Reset value: 0x0000 0000

This register controls the Tx LPI entry timer. This counter is enabled only when LPITE bit of *LPI control and status register (ETH_MACLCSR)* register is set to 1.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LPIET[19:16]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LPIET[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r	r

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:0 **LPIET[19:0]**: LPI Entry Timer

This field specifies the time in microseconds the MAC will wait to enter LPI mode, after it has transmitted all the frames. This field is valid and used only when LPITE and LPITXA are set to 1.

Bits [2:0] are read-only so that the granularity of this timer is in steps of 8 micro-seconds.

One-microsecond-tick counter register (ETH_MAC1USTCR)

Address offset: 0x00DC

Reset value: 0x0000 0000

This register controls the generation of the Reference time (one-microsecond tick) for all the LPI timers. This timer has to be programmed by the software initially.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TIC_1US_CNTR[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **TIC_1US_CNTR[11:0]**: 1 µs tick Counter

The application must program this counter so that the number of clock cycles of CSR clock is 1 µs (subtract 1 from the value before programming).
For example if the CSR clock is 100 MHz then this field needs to be programmed to 100 - 1 = 99 (which is 0x63).
This is required to generate the 1 µs events that are used to update some of the EEE related counters.

Version register (ETH_MACVR)

Address offset: 0x0110

Reset value: 0x0000 3142

The version register identifies the version of the Ethernet peripheral.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
USERVER[7:0]								SNPSVER[7:0]							
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **USERVER[7:0]**: ST-defined version

Bits 7:0 **SNPSVER[7:0]**: IP version

Debug register (ETH_MACDR)

Address offset: 0x0114

Reset value: 0x0000 0000

The Debug register provides the debug status of various MAC blocks.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TFCSTS[1:0]		TPESTS
													r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFCFCSTS[1:0]		RPESTS
													r	r	r

Bits 31:19 Reserved, must be kept at reset value.

Bits 18:17 **TFCSTS[1:0]**: MAC Transmit Packet Controller Status

This field indicates the state of the MAC Transmit Packet Controller module:

00: Idle state

01: Waiting for one of the following:

– Status of the previous packet

– IPG or backoff period to be over

10: Generating and transmitting a Pause control packet (in Full-duplex mode)

11: Transferring input packet for transmission

Bit 16 **TPESTS**: MAC MII Transmit Protocol Engine Status

When this bit is set, it indicates that the MAC MII transmit protocol engine is actively transmitting data, and it is not in the Idle state.

Bits 15:3 Reserved, must be kept at reset value.

Bits 2:1 **RFCFCSTS[1:0]**: MAC Receive Packet Controller FIFO Status

When this bit is set, this field indicates the active state of the small FIFO Read and Write controllers of the MAC Receive Packet Controller module.

Bit 0 **RPESTS**: MAC MII Receive Protocol Engine Status

When this bit is set, it indicates that the MAC MII receive protocol engine is actively receiving data, and it is not in the Idle state.

HW feature 0 register (ETH_MACHWF0R)

Address offset: 0x011C

Reset value: 0x0A0D 73F7

This register indicates the presence of first set of the optional features or functions of the Ethernet peripheral. The software driver can use this register to dynamically enable or disable the programs related to the optional blocks.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	ACTPHYSEL[2:0]			SAVLANINS	TSSTSSEL[1:0]		MACADR64SEL	MACADR32SEL	ADDMACADRSEL[4:0]					Res.	RXCOESEL
	r	r	r	r	r	r	r	r	r	r	r	r	r		r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	TXCOESEL	EEESEL	TSSEL	Res.	Res.	ARPOFFSEL	MMCSEL	MGKSEL	RWKSEL	SMASEL	VLHASH	PCSSEL	HDSEL	GMIISEL	MIISEL
	r	r	r			r	r	r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:28 **ACTPHYSEL[2:0]**: Active PHY Selected
When you have multiple PHY interfaces in your configuration, this field indicates the sampled value of phy_intf_sel_i during reset de-assertion:
000: GMII or MII
001: RGMII
010: SGMII
011: TBI
100: RMII
101: RTBI
110: SMII
Others: Reserved, must not be used

Bit 27 **SAVLANINS**: Source Address or VLAN Insertion Enable
This bit is set to 1 when the Enable SA and VLAN Insertion on Tx option is selected

Bits 26:25 **TSSTSSEL[1:0]**: Timestamp System Time Source
This bit indicates the source of the Timestamp system time:
01: Internal
10: External
11: Both
00: Reserved, must not be used
This bit is set to 1 when the Enable IEEE 1588 Timestamp Support option is selected

Bit 24 **MACADR64SEL**: MAC Addresses 64-127 Selected
This bit is set to 1 when the Enable Additional 64 MAC Address Registers (64-127) option is selected

Bit 23 **MACADR32SEL**: MAC Addresses 32-63 Selected
This bit is set to 1 when the Enable Additional 32 MAC Address Registers (32-63) option is selected

Bits 22:18 **ADDMACADRSEL[4:0]**: MAC Addresses 1-31 Selected
This bit is set to 1 when the Enable Additional 1-31 MAC Address Registers option is selected

Bit 17 Reserved, must be kept at reset value.

Bit 16 **RXCOESEL**: Receive Checksum Offload Enabled
This bit is set to 1 when the Enable Receive TCP/IP Checksum Check option is selected

Bit 15 Reserved, must be kept at reset value.

Bit 14 **TXCOESEL**: Transmit Checksum Offload Enabled
This bit is set to 1 when the Enable Transmit TCP/IP Checksum Insertion option is selected

Bit 13 **EEESEL**: Energy Efficient Ethernet Enabled
This bit is set to 1 when the Enable Energy Efficient Ethernet (EEE) option is selected

Bit 12 **TSSEL**: IEEE 1588-2008 Timestamp Enabled
This bit is set to 1 when the Enable IEEE 1588 Timestamp Support option is selected

Bits 11:10 Reserved, must be kept at reset value.

Bit 9 **ARPOFFSEL**: ARP Offload Enabled
This bit is set to 1 when the Enable IPv4 ARP Offload option is selected

Bit 8 **MMCSEL**: RMON Module Enable
This bit is set to 1 when the Enable MAC management counters (MMC) option is selected

Bit 7 **MGKSEL**: PMT Magic Packet Enable
This bit is set to 1 when the Enable Magic Packet Detection option is selected

Bit 6 **RWKSEL**: PMT Remote Wakeup Packet Enable
This bit is set to 1 when the Enable Remote wakeup Packet Detection option is selected

Bit 5 **SMASEL**: SMA (MDIO) Interface
This bit is set to 1 when the Enable Station Management (MDIO Interface) option is selected

Bit 4 **VLHASH**: VLAN Hash Filter Selected
This bit is set to 1 when the Enable VLAN Hash Table Based Filtering option is selected

Bit 3 **PCSSEL**: PCS Registers (TBI, SGMII, or RTBI PHY interface)
This bit is set to 1 when the TBI, SGMII, or RTBI PHY interface option is selected

Bit 2 **HDSEL**: Half-duplex Support
This bit is set to 1 when the Half-duplex mode is selected

Bit 1 **GMIISEL**: 1000 Mbps Support
This bit is set to 1 when 1000 Mbps is selected as operating mode.

Bit 0 **MIISEL**: 10 or 100 Mbps Support
This bit is set to 1 when 10/100 Mbps is selected as operating mode.

HW feature 1 register (ETH_MACHWF1R)

Address offset: 0x0120

Reset value: 0x1104 1904

This register indicates the presence of second set of the optional features or functions of the Ethernet peripheral. The software driver can use this register to dynamically enable or disable the programs related to the optional blocks.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	L3L4FNUM[3:0]				Res.	HASHTBLSZ[1:0]		POUOST	Res.	RAVSEL	AVSEL	DBGMEMA	TSOEN	SPHEN	DCBEN
	r	r	r	r		r	r	r		r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDR64[1:0]		ADVTHWORD	PTOEN	OSTEN	TXFIFOSIZE[4:0]					Res.	RXFIFOSIZE[4:0]				
r	r	r	r	r	r	r	r	r	r		r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:27 **L3L4FNUM[3:0]**: Total number of L3 or L4 Filters
This field indicates the total number of L3 or L4 filters:
0000: No L3 or L4 Filter
0001: 1 L3 or L4 Filter
0010: 2 L3 or L4 Filters
..
1000: 8 L3 or L4

Bit 26 Reserved, must be kept at reset value.

Bits 25:24 **HASHTBLSZ[1:0]**: Hash Table Size
This field indicates the size of the Hash table:
00: No Hash table
01: 64
10: 128
11: 256

Bit 23 **POUOST**: One Step for PTP over UDP/IP Feature Enable
This bit is set to 1 when the Enable one step timestamp for PTP over UDP/IP feature is selected.

Bit 22 Reserved, must be kept at reset value.

Bit 21 **RAVSEL**: Rx Side Only AV Feature Enable
This bit is set to 1 when the Enable Audio Video Bridging option on Rx Side Only is selected.

Bit 20 **AVSEL**: AV Feature Enable
This bit is set to 1 when the Enable Audio Video Bridging option is selected.

Bit 19 **DBGMEMA**: DMA Debug Registers Enable
This bit is set to 1 when the Debug Mode Enable option is selected

Bit 18 **TSOEN**: TCP Segmentation Offload Enable
This bit is set to 1 when the Enable TCP Segmentation Offloading for TCP/IP Packets option is selected

Bit 17 **SPHEN**: Split Header Feature Enable
This bit is set to 1 when the Enable Split Header Structure option is selected

Bit 16 **DCBEN**: DCB Feature Enable
This bit is set to 1 when the Enable Data Center Bridging option is selected

Bits 15:14 **ADDR64[1:0]**: Address width
This field indicates the configured address width.
00: 32 bits
Others: Reserved, must not be used

Bit 13 **ADVTHWORD**: IEEE 1588 High Word Register Enable
This bit is set to 1 when the Add IEEE 1588 Higher Word Register option is selected

Bit 12 **PTOEN**: PTP Offload Enable
This bit is set to 1 when the Enable PTP Timestamp Offload Feature is selected.

Bit 11 **OSTEN**: One-Step Timestamping Enable
This bit is set to 1 when the Enable One-Step Timestamp Feature is selected.

Bits 10:6 **TXFIFOSIZE[4:0]**: MTL Transmit FIFO Size
This field contains the configured value of MTL Tx FIFO in bytes expressed as Log to base 2 minus 7, that is, Log2(TXFIFO_SIZE) -7:
00000: 128 bytes
00001: 256 bytes
00010: 512 bytes
00011: 1,024 bytes
00100: 2,048 bytes
00101: 4,096 bytes
00110: 8,192 bytes
00111: 16,384 bytes
01000: 32 Kbytes
01001: 64 Kbytes
01010: 128 Kbytes
01011 to 11111: Reserved, must not be used

Bit 5 Reserved, must be kept at reset value.

Bits 4:0 **RXFIFOSIZE[4:0]**: MTL Receive FIFO Size
This field contains the configured value of MTL Rx FIFO in bytes expressed as Log to base 2 minus 7, that is, Log2(RXFIFO_SIZE) -7:
00000: 128 bytes
00001: 256 bytes
00010: 512 bytes
00011: 1,024 bytes
00100: 2,048 bytes
00101: 4,096 bytes
00110: 8,192 bytes
00111: 16,384 bytes
01000: 32 Kbytes
01001: 64 Kbytes
01010: 128 Kbytes
01011: 256 Kbytes
01100 to 11111: Reserved, must not be used

HW feature 2 register (ETH_MACHWF2R)

Address offset: 0x0124

Reset value: 0x4100 0000

This register indicates the presence of third set of the optional features or functions of the Ethernet peripheral. The software driver can use this register to dynamically enable or disable the programs related to the optional blocks.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	AUXSNAPNUM[2:0]			Res.	PPSOUTNUM[2:0]			TDCSZ[1:0]		TXCHCNT[3:0]				RDCSZ[1:0]	
	r	r	r		r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXCHCNT[3:0]				Res.	Res.	TXQCNT[3:0]				Res.	Res.	RXQCNT[3:0]			
r	r	r	r			r	r	r	r			r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:28 **AUXSNAPNUM[2:0]**: Number of Auxiliary Snapshot Inputs
This field indicates the number of auxiliary snapshot inputs:
000: No auxiliary input
001: 1 auxiliary input
010: 2 auxiliary inputs
011: 3 auxiliary inputs
100: 4 auxiliary inputs
101 to 111: Reserved, must not be used

Bit 27 Reserved, must be kept at reset value.

Bits 26:24 **PPSOUTNUM[2:0]**: Number of PPS Outputs
This field indicates the number of PPS outputs:
000: No PPS output
001: 1 PPS output
010: 2 PPS outputs
011: 3 PPS outputs
100: 4 PPS outputs
101 to 111: Reserved, must not be used

Bits 23:22 **TDCSZ[1:0]**: Tx DMA Descriptor Cache Size in terms of 16-byte descriptors
00: Cache not configured
01: Four 16-byte descriptors
10: Eight 16-byte descriptors
11: Sixteen 16-byte descriptors

Bits 21:18 **TXCHCNT[3:0]**: Number of DMA Transmit Channels
This field indicates the number of DMA Transmit channels:
0000: 1 DMA Tx Channel
0001: 2 DMA Tx Channels
..
0111: 8 DMA Tx

Bits 17:16 **RDCSZ[1:0]**: Rx DMA Descriptor Cache Size in terms of 16-byte descriptors
00: Cache not configured
01: Four 16-byte descriptors
10: Eight 16-byte descriptors
11: Sixteen 16-byte descriptors

Bits 15:12 **RXCHCNT[3:0]**: Number of DMA Receive Channels
This field indicates the number of DMA Receive channels:
0000: 1 DMA Rx Channel
0001: 2 DMA Rx Channels
..
0111: 8 DMA Rx

Bits 11:10 Reserved, must be kept at reset value.

Bits 9:6 **TXQCNT[3:0]**: Number of MTL Transmit Queues
This field indicates the number of MTL Transmit queues:
0000: 1 MTL Tx queue
0001: 2 MTL Tx queues
..
0111: 8 MTL Tx

Bits 5:4 Reserved, must be kept at reset value.

Bits 3:0 **RXQCNT[3:0]**: Number of MTL Receive Queues
This field indicates the number of MTL Receive queues:
0000: 1 MTL Rx queue
0001: 2 MTL Rx queues
..
0111: 8 MTL Rx

HW feature 3 register (ETH_MACHWF3R)

Address offset: 0x0128

Reset value: 0x0000 0020

This register indicates the presence of fourth set the optional features or functions of the Ethernet peripheral. The software driver can use this register to dynamically enable or disable the programs related to the optional blocks.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DVLAN	CBTISEL	Res.	NRVF[2:0]		
										r	r		r	r	r

Bits 31:6 Reserved, must be kept at reset value.

Bit 5 **DVLAN**: Double VLAN processing enable
This bit is set to 1 when Double VLAN processing is enabled.

Bit 4 **CBTISEL**: Queue/Channel based VLAN tag insertion on Tx enable
This bit is set to 1 when the Enable Queue/Channel based VLAN tag insertion on Tx feature is selected.

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **NRVF[2:0]**: Number of Extended VLAN Tag Filters Enabled
This field indicates the Number of Extended VLAN Tag Filters selected:
000: No Extended Rx VLAN Filters
001: 4 Extended Rx VLAN Filters
010: 8 Extended Rx VLAN Filters
011: 16 Extended Rx VLAN Filters
100: 24 Extended Rx VLAN Filters
101: 32 Extended Rx VLAN Filters
110 to 111: Reserved, must not be used

MDIO address register (ETH_MACMDIOAR)

Address offset: 0x0200

Reset value: 0x0000 0000

The MDIO Address register controls the management cycles to external PHY through a management interface.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	PSE	BTB	PA[4:0]					RDA[4:0]				
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	NTC[2:0]			CR[3:0]				Res.	Res.	Res.	SKAP	GOC[1:0]		C45E	MB
	rw	rw	rw	rw	rw	rw	rw				rw	rw	rw	rw	rw

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **PSE**: Preamble Suppression Enable

When this bit is set, the SMA will suppress the 32-bit preamble and transmit MDIO frames with only 1 preamble bit.

When this bit is 0, the MDIO frame always has 32 bits of preamble as defined in the IEEE specifications.

Bit 26 **BTB**: Back to Back transactions

When this bit is set and the NTC has value greater than 0, then the MAC will inform the completion of a read or write command at the end of frame transfer (before the trailing clocks are transmitted). The software can thus initiate the next command which will be executed immediately irrespective of the number trailing clocks generated for the previous frame.

When this bit is reset, then the read/write command completion (MII busy is cleared) only after the trailing clocks are generated. In this mode, it is ensured that the NTC is always generated after each frame.

This bit must not be set when NTC=0.

Bits 25:21 **PA[4:0]**: Physical Layer Address

This field indicates which Clause 22 PHY devices (out of 32 devices) the MAC is accessing.
This field indicates which Clause 45 capable PHYs (out of 32 PHYs) the MAC is accessing.

Bits 20:16 **RDA[4:0]**: Register/Device Address

These bits select the PHY register in selected Clause 22 PHY device. These bits select the Device (MMD) in selected Clause 45 capable PHY.

Bit 15 Reserved, must be kept at reset value.

Bits 14:12 **NTC[2:0]**: Number of Training Clocks

This field controls the number of trailing clock cycles generated on ETH_MDC after the end of transmission of MDIO frame. The valid values can be from 0 to 7. Programming the value to 011 indicates that there are additional three clock cycles on the MDC line after the end of MDIO frame transfer.

Bits 11:8 **CR[3:0]**: CSR Clock Range

The CSR Clock Range selection determines the frequency of the MDC clock according to the CSR clock frequency used in your design:
0000: CSR clock = 60-100 MHz; MDC clock = CSR clock/42
0001: CSR clock = 100-150 MHz; MDC clock = CSR clock/62
0010: CSR clock = 20-35 MHz; MDC clock = CSR clock/16
0011: CSR clock = 35-60 MHz; MDC clock = CSR clock/26
0100: CSR clock = 150-250 MHz; MDC clock = CSR clock/102
0101: CSR clock = 250-300 MHz; MDC clock = CSR clock/124
0110 to 0111: Reserved, must not be used
The suggested range of CSR clock frequency applicable for each value (when Bit 11 = 0) ensures that the MDC clock is approximately between 1.0 MHz to 2.5 MHz frequency range.
When Bit 11 is set, you can achieve a higher frequency of the MDC clock than the frequency limit of 2.5 MHz (specified in the IEEE 802.3) and program a clock divider of lower value. For example, when CSR clock is of 100 MHz frequency and you program these bits to 1010, the resultant MDC clock is of 12.5 MHz which is above the range specified in IEEE 802.3.
Program the following values only if the interfacing chips support faster MDC clocks:
1000: CSR clock/4
1001: CSR clock/6
1010: CSR clock/8
1011: CSR clock/10
1100: CSR clock/12
1101: CSR clock/14
1110: CSR clock/16
1111: CSR clock/18

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **SKAP**: Skip Address Packet

When this bit is set, the SMA does not send the address packets before read, write, or post-read increment address packets. This bit is valid only when C45E is set.

Bits 3:2 **GOC[1:0]**: MII Operation Command

This bit indicates the operation command to the PHY.
00: Reserved, must not be used
01: Write
10: Post Read Increment Address for Clause 45 PHY
11: Read
When Clause 22 PHY is enabled, only Write and Read commands are valid.

Bit 1 **C45E**: Clause 45 PHY Enable

When this bit is set, Clause 45 capable PHY is connected to MDIO. When this bit is reset, Clause 22 capable PHY is connected to MDIO.

Bit 0 **MB**: MII Busy

The application sets this bit to instruct the SMA to initiate a Read or Write access to the MDIOS. The MAC clears this bit after the MDIO frame transfer is completed. Hence the software must not write or change any of the fields in *MDIO address register (ETH_MACMDIOAR)* and *MDIO data register (ETH_MACMDIODR)* as long as this bit is set.
For write transfers, the application must first write 16-bit data in the MD field (and also RA field when C45E is set) in *MDIO data register (ETH_MACMDIODR)* register before setting this bit. When C45E is set, it should also write into the RA field of *MDIO data register (ETH_MACMDIODR)* before initiating a read transfer. When a read transfer is completed (MII busy=0), the data read from the PHY register is valid in the MD field of the *MDIO data register (ETH_MACMDIODR)*.

Note: Even if the addressed PHY is not present, there is no change in the functionality of this bit.

MDIO data register (ETH_MACMDIODR)

Address offset: 0x0204

Reset value: 0x0000 0000

The MDIO Data register stores the Write data to be written to the PHY register located at the address specified in *MDIO address register (ETH_MACMDIOAR)* This register also stores the Read data from the PHY register located at the address specified by MDIO Address register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MD[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **RA[15:0]**: Register Address

This field is valid only when C45E is set. It contains the Register Address in the PHY to which the MDIO frame is intended for.

Bits 15:0 **MD[15:0]**: MII Data

This field contains the 16-bit data value read from the PHY after a Management Read operation or the 16-bit data value to be written to the PHY before a Management Write operation.

ARP address register (ETH_MACARPAR)

Address offset: 0x0210

Reset value: 0x0000 0000

The ARP Address register contains the IPv4 Destination Address of the MAC.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ARPPA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARPPA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ARPPA[31:0]**: ARP Protocol Address

This field contains the IPv4 Destination Address of the MAC. This address is used for perfect match with the Protocol Address of Target field in the received ARP packet.

CSR software control register (ETH_MACCSRSWCR)

Address offset: 0x0230

Reset value: 0x0000 0000

This register contains software-programmable controls for changing the CSR access response and status bits clearing.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RCWE
							rw								rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **SEEN**: Slave Error Response Enable

When this bit is set, the MAC responds with a Slave Error for accesses to reserved registers in CSR space.

When this bit is reset, the MAC responds with an Okay response to any register accessed from CSR space.

Bits 7:1 Reserved, must be kept at reset value.

Bit 0 **RCWE**: Register Clear on Write 1 Enable

When this bit is set, the access mode to some register fields changes to rc_w1 (clear on write) meaning that the application needs to set that respective bit to 1 to clear it.

When this bit is reset, the access mode to these register fields remains rc_r (clear on read).

MAC Address 0 high register (ETH_MACA0HR)

Address offset: 0x0300

Reset value: 0x8000 FFFF

The MAC Address0 High register holds the upper 16 bits of the first 6-byte MAC address of the station. The first DA byte that is received on the MII interface corresponds to the LS byte (Bits [7:0]) of the MAC Address Low register. For example, if 0x112233445566 is received (0x11 in lane 0 of the first column) on the MII as the destination address, then the MacAddress0 Register [47:0] is compared with 0x665544332211.

If the MAC address registers are configured to be double-synchronized to the MII clock domains, then the synchronization is triggered only when Bits[31:24] (in little-endian mode) or Bits[7:0] (in big-endian mode) of the MAC Address0 Low Register are written. For proper synchronization updates, the consecutive writes to this Address Low Register should be performed after at least four clock cycles in the destination clock domain.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDRHI[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **AE**: Address Enable
This bit is always set to 1.

Bits 30:16 Reserved, must be kept at reset value.

Bits 15:0 **ADDRHI[15:0]**: MAC Address0[47:32]
This field contains the upper 16 bits [47:32] of the first 6-byte MAC address. The MAC uses this field for filtering the received packets and inserting the MAC address in the Transmit Flow Control (Pause) Packets.

MAC Address x low register (ETH_MACAxLR)

Address offset: 0x0304 + 0x8 * x, (x = 0 to 3)

Reset value: 0xFFFF FFFF

The MAC Address x Low register holds the lower 32 bits of the 6-byte first MAC address of the station.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADDRLO[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDRLO[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **ADDRLO[31:0]**: MAC Address x [31:0] (x = 0 to 3)

This field contains the lower 32 bits of the first 6-byte MAC address. The MAC uses this field for filtering the received packets and inserting the MAC address in the Transmit Flow Control (Pause) Packets.

MAC Address x high register (ETH_MACAxHR)

Address offset: 0x0308 + 0x8 * (x-1), (x = 1 to 3)

Reset value: 0x0000 FFFF

The MAC Address x High register holds the upper 16 bits of the second 6-byte MAC address of the station.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AE	SA	MBC[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADDRHI[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **AE**: Address Enable

When this bit is set, the address filter module uses the second MAC address for perfect filtering. When this bit is reset, the address filter module ignores the address for filtering.

Bit 30 **SA**: Source Address

When this bit is set, the MAC Addressx[47:0] is used to compare with the SA fields of the received packet. When this bit is reset, the MAC Address x[47:0] is used to compare with the DA fields of the received packet.

0: DA

1: SA

Bits 29:24 **MBC[5:0]**: Mask Byte Control

These bits are mask control bits for comparing each of the MAC Address bytes. When set high, the MAC does not compare the corresponding byte of received DA or SA with the contents of MAC Address1 registers. Each bit controls the masking of the bytes as follows:

Bit 29: ETH_MACAxHR[15:8]

Bit 28: ETH_MACAxHR[7:0]

Bit 27: ETH_MACAxLR[31:24]

Bit 26: ETH_MACAxLR[23:16]

Bit 25: ETH_MACAxLR[15:8]

Bit 24: ETH_MACAxLR[7:0]

You can filter a group of addresses (known as group address filtering) by masking one or more bytes of the address.

Bits 23:16 Reserved, must be kept at reset value.

Bits 15:0 **ADDRHI[15:0]**: MAC Address1 [47:32]

This field contains the upper 16 bits[47:32] of the second 6-byte MAC address.

MMC control register (ETH_MMC_CONTROL)

Address offset: 0x0700

Reset value: 0x0000 0000

This register configures the MMC operating mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	UCDBC	Res.	Res.	CNTPRSTLVL	CNTPRST	CNTFREEZ	RSTONRD	CNTSTOPRO	CNTRST
							rw			rw	rw	rw	rw	rw	rw

Bits 31:9 Reserved, must be kept at reset value.

Bit 8 **UCDBC**: Update MMC Counters for Dropped Broadcast Packets

The CNTRST bit has a higher priority than the CNTPRST bit. Therefore, when the software tries to set both bits in the same write cycle, all counters are cleared and the CNTPRST bit is not set.

When set, the MAC updates all related MMC Counters for Broadcast packets that are dropped because of the setting of the DBF bit of *Packet filtering control register (ETH_MACPFR)*.

When reset, the MMC Counters are not updated for dropped Broadcast packets.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **CNTPRSTLVL**: Full-Half Preset

When this bit is low and the CNTPRST bit is set, all MMC counters get preset to almost-half value. All octet counters get preset to 0x7FFF_F800 (Half 2Kbytes) and all packet-counters get preset to 0x7FFF_FFF0 (Half 16).

When this bit is high and the CNTPRST bit is set, all MMC counters get preset to almost-full value. All octet counters get preset to 0xFFFF_F800 (Full 2Kbytes) and all packet-counters get preset to 0xFFFF_FFF0 (Full 16).

For 16-bit counters, the almost-half preset values are 0x7800 and 0x7FF0 for the respective octet and packet counters. Similarly, the almost-full preset values for the 16-bit counters are 0xF800 and 0xFFF0.

Bit 4 **CNTPRST**: Counters Preset

When this bit is set, all counters are initialized or preset to almost full or almost half according to the CNTPRSTLVL bit. This bit is cleared automatically after 1 clock cycle.

This bit, along with the CNTPRSTLVL bit, is useful for debugging and testing the assertion of interrupts because of MMC counter becoming half-full or full.

Bit 3 **CNTFREEZ**: MMC Counter Freeze

When this bit is set, it freezes all MMC counters to their current value.

Until this bit is reset to 0, no MMC counter is updated because of any transmitted or received packet. If any MMC counter is read with the Reset on Read bit set, then that counter is also cleared in this mode.

Bit 2 **RSTONRD**: Reset on Read

When this bit is set, the MMC counters are reset to zero after Read (self-clearing after reset). The counters are cleared when the least significant byte lane (Bits[7:0]) is read.

Bit 1 **CNTSTOPRO**: Counter Stop Rollover

When this bit is set, the counter does not roll over to zero after reaching the maximum value.

Bit 0 **CNTRST**: Counters Reset

When this bit is set, all counters are reset. This bit is cleared automatically after 1 clock cycle.

MMC Rx interrupt register (ETH_MMC_RX_INTERRUPT)

Address offset: 0x0704

Reset value: 0x0000 0000

This register maintains the interrupts generated from all Receive statistics counters.

The MMC Receive Interrupt register maintains the interrupts that are generated when the following occur:

- Receive statistic counters reach half of their maximum values (0x8000_0000 for 32 bit counter and 0x8000 for 16 bit counter).
- Receive statistic counters cross their maximum values (0xFFFF_FFFF for 32 bit counter and 0xFFFF for 16 bit counter).

When the CNTSTOPRO is set in *MMC control register (ETH_MMC_CONTROL)*, interrupts are set but the counter remains at all-ones. The MMC Receive Interrupt register is a 32 bit register. An interrupt bit is cleared when the respective MMC counter that caused the interrupt is read. The least significant byte lane (Bits[7:0]) of the respective counter must be read to clear the interrupt bit.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	RXLPITRCIS	RXLPIUSCIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXUCGPIS	Res.
				rc_r	rc_r									rc_r	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXALGNERPIS	RXCRCERPIS	Res.	Res.	Res.	Res.	Res.
									rc_r	rc_r					

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **RXLPITRCIS**: MMC Receive LPI transition counter interrupt status

This bit is set when the *Rx LPI transition counter register (ETH_RX_LPI_TRAN_CNTR)* counter reaches half of the maximum value or the maximum value.

Bit 26 **RXLPIUSCIS**: MMC Receive LPI microsecond counter interrupt status

This bit is set when the *Rx LPI microsecond counter register (ETH_RX_LPI_USEC_CNTR)* counter reaches half of the maximum value or the maximum value.

Bits 25:18 Reserved, must be kept at reset value.

Bit 17 **RXUCGPIS**: MMC Receive Unicast Good Packet Counter Interrupt Status
This bit is set when the *Rx unicast packets good register (ETH_RX_UNICAST_PACKETS_GOOD)* counter reaches half of the maximum value or the maximum value.

Bits 16:7 Reserved, must be kept at reset value.

Bit 6 **RXALGNERPIS**: MMC Receive Alignment Error Packet Counter Interrupt Status
This bit is set when the *Rx alignment error packets register (ETH_RX_ALIGNMENT_ERROR_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bit 5 **RXCRCERPIS**: MMC Receive CRC Error Packet Counter Interrupt Status
This bit is set when the *Rx CRC error packets register (ETH_RX_CRC_ERROR_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bits 4:0 Reserved, must be kept at reset value.

MMC Tx interrupt register (ETH_MMC_TX_INTERRUPT)

Address offset: 0x0708

Reset value: 0x0000 0000

This register maintains the interrupts generated from all Transmit statistics counters.

The MMC Transmit Interrupt register maintains the interrupts generated when transmit statistic counters reach half their maximum values (0x8000_0000 for 32 bit counter and 0x8000 for 16 bit counter), and when they cross their maximum values (0xFFFF_FFFF for 32-bit counter and 0xFFFF for 16-bit counter).

When CNTSTOPRO is set in *MMC control register (ETH_MMC_CONTROL)*, the interrupts are set but the counter remains at all-ones.

The MMC Transmit Interrupt register is a 32 bit register. An interrupt bit is cleared when the respective MMC counter that caused the interrupt is read.

The least significant byte lane (Bits[7:0]) of the respective counter must be read to clear the interrupt bit.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TXLPITRCIS	TXLPIUSCIS	Res.	Res.	Res.	Res.	TXGPKTIS	Res.	Res.	Res.	Res.	Res.
				rc_r	rc_r					rc_r					

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXMCOLGPIS	TXSCOLGPIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rc_r	rc_r														

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **TXLPITRCIS**: MMC Transmit LPI transition counter interrupt status
This bit is set when the *Tx LPI transition counter register (ETH_TX_LPI_TRAN_CNTR)* counter reaches half of the maximum value or the maximum value.

Bit 26 **TXLPIUSCIS**: MMC Transmit LPI microsecond counter interrupt status
This bit is set when the *Tx LPI microsecond timer register (ETH_TX_LPI_USEC_CNTR)* counter reaches half of the maximum value or the maximum value.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **TXGPKTIS**: MMC Transmit Good Packet Counter Interrupt Status
This bit is set when the *Tx packet count good register (ETH_TX_PACKET_COUNT_GOOD)* counter reaches half of the maximum value or the maximum value.

Bits 20:16 Reserved, must be kept at reset value.

Bit 15 **TXMCOLGPIS**: MMC Transmit Multiple Collision Good Packet Counter Interrupt Status
This bit is set when the *Tx multiple collision good packets register (ETH_TX_MULTIPLE_COLLISION_GOOD_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bit 14 **TXSCOLGPIS**: MMC Transmit Single Collision Good Packet Counter Interrupt Status
This bit is set when the *Tx single collision good packets register (ETH_TX_SINGLE_COLLISION_GOOD_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bits 13:0 Reserved, must be kept at reset value.

MMC Rx interrupt mask register (ETH_MMC_RX_INTERRUPT_MASK)

Address offset: 0x070C

Reset value: 0x0000 0000

The MMC Receive Interrupt Mask register maintains the masks for the interrupts generated when receive statistic counters reach half of their maximum value or the maximum values.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	RXLPITRCIM	RXLPIUSCIM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXUCGPIM	Res.
				rw	rw									rw	

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXALGNERPIM	RXCRCERPIM	Res.	Res.	Res.	Res.	Res.
									rw	rw					

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **RXLPITRCIM**: MMC Receive LPI transition counter interrupt Mask
Setting this bit masks the interrupt when the *Rx LPI transition counter register (ETH_RX_LPI_TRAN_CNTR)* counter reaches half of the maximum value or the maximum value.

Bit 26 **RXLPIUSCIM**: MMC Receive LPI microsecond counter interrupt Mask
Setting this bit masks the interrupt when the *Rx LPI microsecond counter register (ETH_RX_LPI_USEC_CNTR)* counter reaches half of the maximum value or the maximum value.

Bits 25:18 Reserved, must be kept at reset value.

Bit 17 **RXUCGPIM**: MMC Receive Unicast Good Packet Counter Interrupt Mask
Setting this bit masks the interrupt when the *Rx unicast packets good register (ETH_RX_UNICAST_PACKETS_GOOD)* counter reaches half of the maximum value or the maximum value.

Bits 16:7 Reserved, must be kept at reset value.

Bit 6 **RXALGNERPIM**: MMC Receive Alignment Error Packet Counter Interrupt Mask
Setting this bit masks the interrupt when the *Rx alignment error packets register (ETH_RX_ALIGNMENT_ERROR_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bit 5 **RXCRCERPIM**: MMC Receive CRC Error Packet Counter Interrupt Mask
Setting this bit masks the interrupt when the *Rx CRC error packets register (ETH_RX_CRC_ERROR_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bits 4:0 Reserved, must be kept at reset value.

MMC Tx interrupt mask register (ETH_MMC_TX_INTERRUPT_MASK)

Address offset: 0x0710

Reset value: 0x0000 0000

The MMC Transmit Interrupt Mask register maintains the masks for the interrupts generated when the transmit statistic counters reach half of their maximum value or the maximum values. This register is 32 bit wide.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	TXLPITRCIM	TXLPIUSCIM	Res.	Res.	Res.	Res.	TXGPKTIM	Res.	Res.	Res.	Res.	Res.
				rw	rw					rw					

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXMCOLGPIM	TXSCOLGPIM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw														

Bits 31:28 Reserved, must be kept at reset value.

Bit 27 **TXLPITRCIM**: MMC Transmit LPI transition counter interrupt Mask
Setting this bit masks the interrupt when the *Tx LPI transition counter register (ETH_TX_LPI_TRAN_CNTR)* counter reaches half of the maximum value or the maximum value.

Bit 26 **TXLPIUSCIM**: MMC Transmit LPI microsecond counter interrupt Mask
Setting this bit masks the interrupt when the *Tx LPI microsecond timer register (ETH_TX_LPI_USEC_CNTR)* counter reaches half of the maximum value or the maximum value.

Bits 25:22 Reserved, must be kept at reset value.

Bit 21 **TXGPKTIM**: MMC Transmit Good Packet Counter Interrupt Mask
Setting this bit masks the interrupt when the *Tx packet count good register (ETH_TX_PACKET_COUNT_GOOD)* counter reaches half of the maximum value or the maximum value.

Bits 20:16 Reserved, must be kept at reset value.

Bit 15 **TXMCOLGPIM**: MMC Transmit Multiple Collision Good Packet Counter Interrupt Mask
Setting this bit masks the interrupt when the *Tx multiple collision good packets register (ETH_TX_MULTIPLE_COLLISION_GOOD_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bit 14 **TXSCOLGPIM**: MMC Transmit Single Collision Good Packet Counter Interrupt Mask
Setting this bit masks the interrupt when the *Tx single collision good packets register (ETH_TX_SINGLE_COLLISION_GOOD_PACKETS)* counter reaches half of the maximum value or the maximum value.

Bits 13:0 Reserved, must be kept at reset value.

Tx single collision good packets register (ETH_TX_SINGLE_COLLISION_GOOD_PACKETS)

Address offset: 0x074C

Reset value: 0x0000 0000

This register provides the number of successfully transmitted packets by Ethernet peripheral after a single collision in the Half-duplex mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXSNGLCOLG[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXSNGLCOLG[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXSNGLCOLG[31:0]**: Tx Single Collision Good Packets

This field indicates the number of successfully transmitted packets after a single collision in the Half-duplex mode.

Tx multiple collision good packets register (ETH_TX_MULTIPLE_COLLISION_GOOD_PACKETS)

Address offset: 0x0750

Reset value: 0x0000 0000

This register provides the number of successfully transmitted packets by Ethernet peripheral after multiple collisions in the Half-duplex mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXMULTCOLG[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXMULTCOLG[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXMULTCOLG[31:0]**: Tx Multiple Collision Good Packets

This field indicates the number of successfully transmitted packets after multiple collisions in the Half-duplex mode.

Tx packet count good register (ETH_TX_PACKET_COUNT_GOOD)

Address offset: 0x0768

Reset value: 0x0000 0000

This register provides the number of good packets transmitted by Ethernet peripheral.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXPKTG[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXPKTG[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXPKTG[31:0]**: Tx Packet Count Good

This field indicates the number of good packets transmitted.

Rx CRC error packets register (ETH_RX_CRC_ERROR_PACKETS)

Address offset: 0x0794

Reset value: 0x0000 0000

This register provides the number of packets received by Ethernet peripheral with CRC error.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXCRCERR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXCRCERR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXCRCERR[31:0]**: Rx CRC Error Packets

This field indicates the number of packets received with CRC error.

Rx alignment error packets register (ETH_RX_ALIGNMENT_ERROR_PACKETS)

Address offset: 0x0798

Reset value: 0x0000 0000

This register provides the number of packets received by Ethernet peripheral with alignment (dribble) error. It is valid only in 10/100 mode.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXALGNERR[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXALGNERR[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXALGNERR[31:0]**: Rx Alignment Error Packets

This field indicates the number of packets received with alignment (dribble) error. It is valid only in 10/100 mode.

Rx unicast packets good register (ETH_RX_UNICAST_PACKETS_GOOD)

Address offset: 0x07C4

Reset value: 0x0000 0000

This register provides the number of good unicast packets received by Ethernet peripheral.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXUCASTG[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXUCASTG[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXUCASTG[31:0]**: Rx Unicast Packets Good

This field indicates the number of good unicast packets received.

Tx LPI microsecond timer register (ETH_TX_LPI_USEC_CNTR)

Address offset: 0x07EC

Reset value: 0x0000 0000

This register provides the number of microseconds Tx LPI is asserted by Ethernet peripheral.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXLPIUSC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXLPIUSC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXLPIUSC[31:0]**: Tx LPI Microseconds Counter

This field indicates the number of microseconds Tx LPI is asserted. For every Tx LPI Entry and Exit, the Timer value can have an error of +/- 1 microsecond.

Tx LPI transition counter register (ETH_TX_LPI_TRAN_CNTR)

Address offset: 0x07F0

Reset value: 0x0000 0000

This register provides the number of times Ethernet peripheral has entered Tx LPI.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXLPITRC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXLPITRC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXLPITRC[31:0]**: Tx LPI Transition counter

This field indicates the number of times Tx LPI Entry has occurred. Even if Tx LPI Entry occurs in Automate mode (because of LPITXA bit set in the *LPI control and status register (ETH_MACLCSR)*), the counter will increment.

Rx LPI microsecond counter register (ETH_RX_LPI_USEC_CNTR)

Address offset: 0x07F4

Reset value: 0x0000 0000

This register provides the number of microseconds Rx LPI is sampled by Ethernet peripheral.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXLPIUSC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXLPIUSC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXLPIUSC[31:0]**: Rx LPI Microseconds Counter

This field indicates the number of microseconds Rx LPI is asserted. For every Rx LPI Entry and Exit, the Timer value can have an error of +/- 1 microsecond.

Rx LPI transition counter register (ETH_RX_LPI_TRAN_CNTR)

Address offset: 0x07F8

Reset value: 0x0000 0000

This register provides the number of times Ethernet peripheral has entered Rx LPI.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RXLPITRC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RXLPITRC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RXLPITRC[31:0]**: Rx LPI Transition counter

This field indicates the number of times Rx LPI Entry has occurred.

L3 and L4 control 0 register (ETH_MACL3L4C0R)

Address offset: 0x0900

Reset value: 0x0000 0000

The Layer 3 and Layer 4 Control register controls the operations of filter 0 of Layer 3 and Layer 4.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	L4DPIM0	L4DPM0	L4SPIM0	L4SPM0	Res.	L4PEN0
										rw	rw	rw	rw		rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3HDBM0[4:0]					L3HSBM0[4:0]					L3DAIM0	L3DAM0	L3SAIM0	L3SAM0	Res.	L3PEN0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **L4DPIM0**: Layer 4 Destination Port Inverse Match Enable

When this bit is set, the Layer 4 Destination Port number field is enabled for inverse matching. When this bit is reset, the Layer 4 Destination Port number field is enabled for perfect matching.

This bit is valid and applicable only when the L4DPM0 bit is set high.

Bit 20 **L4DPM0**: Layer 4 Destination Port Match Enable

When this bit is set, the Layer 4 Destination Port number field is enabled for matching. When this bit is reset, the MAC ignores the Layer 4 Destination Port number field for matching.

Bit 19 **L4SPIM0**: Layer 4 Source Port Inverse Match Enable

When this bit is set, the Layer 4 Source Port number field is enabled for inverse matching. When this bit is reset, the Layer 4 Source Port number field is enabled for perfect matching.

This bit is valid and applicable only when the L4SPM0 bit is set high.

Bit 18 **L4SPM0**: Layer 4 Source Port Match Enable

When this bit is set, the Layer 4 Source Port number field is enabled for matching. When this bit is reset, the MAC ignores the Layer 4 Source Port number field for matching.

Bit 17 Reserved, must be kept at reset value.

Bit 16 **L4PEN0**: Layer 4 Protocol Enable

When this bit is set, the Source and Destination Port number fields of UDP packets are used for matching. When this bit is reset, the Source and Destination Port number fields of TCP packets are used for matching.

The Layer 4 matching is done only when the L4SPM0 or L4DPM0 bit is set.

Bits 15:11 **L3HDBM0[4:0]**: Layer 3 IP DA higher bits match

Condition: IPv4 packets

This field contains the number of higher bits of IP Destination Address that are masked in the IPv4 packets:

0: No bits are masked.

1: LSb[0] is masked

2: Two LSbs [1:0] are masked

..

31: All bits except MSb are masked.

Condition: IPv6 packets

Bits[12:11] of this field correspond to Bits[6:5] of L3HSBM0 which indicate the number of lower bits of IP Source or Destination Address that are masked in the IPv6 packets. Number of bits masked is given by concatenated values of the L3HDBM0[1:0] and L3HSBM0 bits:

0: No bits are masked.

1: LSb[0] is masked

2: Two LSbs [1:0] are masked

..

31: All bits except MSb are masked.

This field is valid and applicable only when the L3DAM0 or L3SAM0 bit is set.

Bits 10:6 **L3HSBM0[4:0]**: Layer 3 IP SA higher bits match

Condition: IPv4 packets

This field contains the number of lower bits of IP source address that are masked for matching in the IPv4 packets. The following list describes the values of this field:

0: No bits are masked.

1: LSb[0] is masked

2: Two LSbs [1:0] are masked

..

31: All bits except MSb are masked.

Condition: IPv6 packets:

This field contains Bits[4:0] of L3HSBM0. These bits indicate the number of higher bits of IP source or destination address matched in the IPv6 packets. This field is valid and applicable only when the L3DAM0 or L3SAM0 bit is set high.

Bit 5 **L3DAIM0**: Layer 3 IP DA Inverse Match Enable

When this bit is set, the Layer 3 IP Destination Address field is enabled for inverse matching. When this bit is reset, the Layer 3 IP Destination Address field is enabled for perfect matching.

This bit is valid and applicable only when the L3DAM0 bit is set high.

Bit 4 **L3DAM0**: Layer 3 IP DA Match Enable

When this bit is set, the Layer 3 IP Destination Address field is enabled for matching. When this bit is reset, the MAC ignores the Layer 3 IP Destination Address field for matching.

Note: When the L3PEN0 bit is set, you should set either this bit or the L3SAM0 bit because either IPv6 DA or SA can be checked for filtering.

Bit 3 **L3SAIM0**: Layer 3 IP SA Inverse Match Enable

When this bit is set, the Layer 3 IP Source Address field is enabled for inverse matching. When this bit reset, the Layer 3 IP Source Address field is enabled for perfect matching.

This bit is valid and applicable only when the L3SAM0 bit is set.

Bit 2 **L3SAM0**: Layer 3 IP SA Match Enable

When this bit is set, the Layer 3 IP Source Address field is enabled for matching. When this bit is reset, the MAC ignores the Layer 3 IP Source Address field for matching.

Note: When the L3PEN0 bit is set, you should set either this bit or the L3DAM0 bit because either IPv6 SA or DA can be checked for filtering.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **L3PEN0**: Layer 3 Protocol Enable

When this bit is set, the Layer 3 IP Source or Destination Address matching is enabled for IPv6 packets. When this bit is reset, the Layer 3 IP Source or Destination Address matching is enabled for IPv4 packets.

The Layer 3 matching is done only when the L3SAM0 or L3DAM0 bit is set.

Layer4 Address filter 0 register (ETH_MACL4A0R)

Address offset: 0x0904

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L4DP0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L4SP0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **L4DP0[15:0]**: Layer 4 Destination Port Number Field

When the L4PEN0 bit is reset and the L4DPM0 bit is set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with the TCP Destination Port Number field in the IPv4 or IPv6 packets.

When the L4PEN0 and L4DPM0 bits are set in *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with the UDP Destination Port Number field in the IPv4 or IPv6 packets.

Bits 15:0 **L4SP0[15:0]**: Layer 4 Source Port Number Field

When the L4PEN0 bit is reset and the L4DPM0 bit is set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with the TCP Source Port Number field in the IPv4 or IPv6 packets.

When the L4PEN0 and L4DPM0 bits are set in *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with the UDP Source Port Number field in the IPv4 or IPv6 packets.

Layer3 Address 0 filter 0 register (ETH_MACL3A00R)

Address offset: 0x0910

Reset value: 0x0000 0000

For IPv4 packets, the Layer 3 Address 0 filter 0 register contains the 32-bit IP Source Address field. For IPv6 packets, it contains Bits[31:0] of the 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A00[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A00[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A00[31:0]**: Layer 3 Address 0 Field

When the L3PEN0 and L3SAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[31:0] of the IP Source Address field in the IPv6 packets.

When the L3PEN0 and L3DAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[31:0] of the IP Destination Address field in the IPv6 packets.

When the L3PEN0 bit is reset and the L3SAM0 bit is set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with the IP Source Address field in the IPv4 packets.

Layer3 Address 1 filter 0 register (ETH_MACL3A10R)

Address offset: 0x0914

Reset value: 0x0000 0000

For IPv4 packets, the Layer 3 Address 1 filter 0 register contains the 32-bit IP Destination Address field. For IPv6 packets, it contains Bits[63:32] of the 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A10[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A10[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A10[31:0]**: Layer 3 Address 1 Field

When the L3PEN0 and L3SAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[63:32] of the IP Source Address field in the IPv6 packets.

When the L3PEN0 and L3DAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[63:32] of the IP Destination Address field in the IPv6 packets.

When the L3PEN0 bit is reset and the L3SAM0 bit is set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with the IP Destination Address field in the IPv4 packets.

Layer3 Address 2 filter 0 register (ETH_MACL3A20R)

Address offset: 0x0918

Reset value: 0x0000 0000

The Layer 3 Address 2 filter 0 register is reserved for IPv4 packets. For IPv6 packets, it contains Bits[95:64] of 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A20[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A20[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A20[31:0]**: Layer 3 Address 2 Field

When the L3PEN0 and L3SAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[95:64] of the IP Source Address field in the IPv6 packets.

When the L3PEN0 and L3DAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[95:64] of the IP Destination Address field in the IPv6 packets.

When the L3PEN0 bit is reset in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field is not used.

Layer3 Address 3 filter 0 register (ETH_MACL3A30R)

Address offset: 0x091C

Reset value: 0x0000 0000

The Layer 3 Address 3 filter 0 register is reserved for IPv4 packets. For IPv6 packets, it contains Bits[127:96] of 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A30[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A30[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A30[31:0]**: Layer 3 Address 3 Field

When the L3PEN0 and L3SAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[127:96] of the IP Source Address field in the IPv6 packets.

When the L3PEN0 and L3DAM0 bits are set in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field contains the value to be matched with Bits[127:96] of the IP Destination Address field in the IPv6 packets.

When the L3PEN0 bit is reset in the *L3 and L4 control 0 register (ETH_MACL3L4C0R)*, this field is not used.

L3 and L4 control 1 register (ETH_MACL3L4C1R)

Address offset: 0x0930

Reset value: 0x0000 0000

The Layer 3 and Layer 4 Control register controls the operations of filter 0 of Layer 3 and Layer 4.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	L4DPIM1	L4DPM1	L4SPIM1	L4SPM1	Res.	L4PEN1
										rw	rw	rw	rw		rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3HDBM1[4:0]					L3HSBM1[4:0]					L3DAIM1	L3DAM1	L3SAIM1	L3SAM1	Res.	L3PEN1
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **L4DPIM1**: Layer 4 Destination Port Inverse Match Enable

When this bit is set, the Layer 4 Destination Port number field is enabled for inverse matching. When this bit is reset, the Layer 4 Destination Port number field is enabled for perfect matching.

This bit is valid and applicable only when the L4DPM1 bit is set high.

Bit 20 **L4DPM1**: Layer 4 Destination Port Match Enable

When this bit is set, the Layer 4 Destination Port number field is enabled for matching. When this bit is reset, the MAC ignores the Layer 4 Destination Port number field for matching.

Bit 19 **L4SPIM1**: Layer 4 Source Port Inverse Match Enable

When this bit is set, the Layer 4 Source Port number field is enabled for inverse matching. When this bit is reset, the Layer 4 Source Port number field is enabled for perfect matching.

This bit is valid and applicable only when the L4SPM1 bit is set high.

Bit 18 **L4SPM1**: Layer 4 Source Port Match Enable

When this bit is set, the Layer 4 Source Port number field is enabled for matching. When this bit is reset, the MAC ignores the Layer 4 Source Port number field for matching.

Bit 17 Reserved, must be kept at reset value.

Bit 16 **L4PEN1**: Layer 4 Protocol Enable

When this bit is set, the Source and Destination Port number fields of UDP packets are used for matching. When this bit is reset, the Source and Destination Port number fields of TCP packets are used for matching.

The Layer 4 matching is done only when the L4SPM1 or L4DPM1 bit is set.

Bits 15:11 **L3HDBM1[4:0]**: Layer 3 IP DA higher bits match

Condition: IPv4 packets

This field contains the number of lower bits of IP Destination Address that are masked for matching in the IPv4 packets. The following list describes the values of this field:

0: No bits are masked.

1: LSb[0] is masked

2: Two LSbs [1:0] are masked

..

31: All bits except MSb are masked.

Condition: IPv6 packets

Bits[12:11] of this field correspond to Bits[6:5] of L3HSBM1, which indicate the number of lower bits of IP Source or Destination Address that are masked in the IPv6 packets. The following list describes the concatenated values of the L3HDBM1[1:0] and L3HSBM1 bits:

0: No bits are masked

1: LSb[0] is masked

2: Two LSbs [1:0] are masked

..

127: All bits except MSb are masked

This field is valid and applicable only when the L3DAM1 or L3SAM1 bit is set.

Bits 10:6 **L3HSBM1[4:0]**: Layer 3 IP SA Higher Bits Match

Condition: IPv4 packets

This field contains the number of lower bits of IP Source Address that are masked for matching in the IPv4 packets. The following list describes the values of this field:

0: No bits are masked.

1: LSb[0] is masked

2: Two LSbs [1:0] are masked

..

31: All bits except MSb are masked.

Condition: IPv6 packets

This field contains Bits[4:0] of L3HSBM1. These bits indicate the number of higher bits of IP Source or Destination Address matched in the IPv6 packets. This field is valid and applicable only when the L3DAM1 or L3SAM1 bit is set high.

Bit 5 **L3DAIM1**: Layer 3 IP DA Inverse Match Enable

When this bit is set, the Layer 3 IP Destination Address field is enabled for inverse matching. When this bit is reset, the Layer 3 IP Destination Address field is enabled for perfect matching.

This bit is valid and applicable only when the L3DAM1 bit is set high.

Bit 4 **L3DAM1**: Layer 3 IP DA Match Enable

When this bit is set, the Layer 3 IP Destination Address field is enabled for matching. When this bit is reset, the MAC ignores the Layer 3 IP Destination Address field for matching.

Note: When the L3PEN1 bit is set, you should set either this bit or the L3SAM1 bit because either IPv6 DA or SA can be checked for filtering.

Bit 3 **L3SAIM1**: Layer 3 IP SA Inverse Match Enable

When this bit is set, the Layer 3 IP Source Address field is enabled for inverse matching. When this bit reset, the Layer 3 IP Source Address field is enabled for perfect matching.

This bit is valid and applicable only when the L3SAM1 bit is set.

Bit 2 **L3SAM1**: Layer 3 IP SA Match Enable

When this bit is set, the Layer 3 IP Source Address field is enabled for matching. When this bit is reset, the MAC ignores the Layer 3 IP Source Address field for matching.

Note: When the L3PEN01 bit is set, you should set either this bit or the L3DAM1 bit because either IPv6 SA or DA can be checked for filtering.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **L3PEN1**: Layer 3 Protocol Enable

When this bit is set, the Layer 3 IP Source or Destination Address matching is enabled for IPv6 packets. When this bit is reset, the Layer 3 IP Source or Destination Address matching is enabled for IPv4 packets.

The Layer 3 matching is done only when the L3SAM1 or L3DAM1 bit is set.

Layer 4 address filter 1 register (ETH_MACL4A1R)

Address offset: 0x0934

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L4DP1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L4SP1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 **L4DP1[15:0]**: Layer 4 Destination Port Number Field

When the L4PEN1 bit is reset and the L4DPM1 bit is set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with the TCP Destination Port Number field in the IPv4 or IPv6 packets.

When the L4PEN1 and L4DPM1 bits are set in *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with the UDP Destination Port Number field in the IPv4 or IPv6 packets.

Bits 15:0 **L4SP1[15:0]**: Layer 4 Source Port Number Field

When the L4PEN1 bit is reset and the L4DPM1 bit is set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with the TCP Source Port Number field in the IPv4 or IPv6 packets.

When the L4PEN1 and L4DPM1 bits are set in *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with the UDP Source Port Number field in the IPv4 or IPv6 packets.

Layer3 address 0 filter 1 Register (ETH_MACL3A01R)

Address offset: 0x0940

Reset value: 0x0000 0000

For IPv4 packets, the Layer 3 Address 0 filter 1 register contains the 32-bit IP Source Address field. For IPv6 packets, it contains Bits[31:0] of the 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A01[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A01[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A01[31:0]**: Layer 3 Address 0 Field

When the L3PEN1 and L3SAM1bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[31:0] of the IP Source Address field in the IPv6 packets.

When the L3PEN1 and L3DAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[31:0] of the IP Destination Address field in the IPv6 packets.

When the L3PEN1 bit is reset and the L3SAM1 bit is set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with the IP Source Address field in the IPv4 packets.

Layer3 address 1 filter 1 register (ETH_MACL3A11R)

Address offset: 0x0944

Reset value: 0x0000 0000

For IPv4 packets, the Layer 3 Address 1 filter 1 register contains the 32-bit IP Destination Address field. For IPv6 packets, it contains Bits[63:32] of the 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A11[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A11[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A11[31:0]**: Layer 3 Address 1 Field

When the L3PEN1 and L3SAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[63:32] of the IP Source Address field in the IPv6 packets.

When the L3PEN1 and L3DAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[63:32] of the IP Destination Address field in the IPv6 packets.

When the L3PEN1 bit is reset and the L3SAM1 bit is set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with the IP Destination Address field in the IPv4 packets.

Layer3 address 2 filter 1 Register (ETH_MACL3A21R)

Address offset: 0x0948

Reset value: 0x0000 0000

The Layer 3 Address 2 filter 1 register is reserved for IPv4 packets. For IPv6 packets, it contains Bits[95:64] of 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A21[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A21[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A21[31:0]**: Layer 3 Address 2 Field

When the L3PEN1 and L3SAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[95:64] of the IP Source Address field in the IPv6 packets.

When the L3PEN1 and L3DAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[95:64] of the IP Destination Address field in the IPv6 packets.

When the L3PEN1 bit is reset in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field is not used.

Layer3 address 3 filter 1 register (ETH_MACL3A31R)

Address offset: 0x94C

Reset value: 0x0000 0000

The Layer 3 Address 3 filter 1 register is reserved for IPv4 packets. For IPv6 packets, it contains Bits[127:96] of 128-bit IP Source Address or Destination Address field.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L3A31[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L3A31[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **L3A31[31:0]**: Layer 3 Address 3 Field

When the L3PEN1 and L3SAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[127:96] of the IP Source Address field in the IPv6 packets.

When the L3PEN1 and L3DAM1 bits are set in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field contains the value to be matched with Bits[127:96] of the IP Destination Address field in the IPv6 packets.

When the L3PEN1 bit is reset in the *L3 and L4 control 1 register (ETH_MACL3L4C1R)*, this field is not used.

Timestamp control Register (ETH_MACTSCR)

Address offset: 0x0B00

Reset value: 0x0000 2000

This register controls the operation of the System Time generator and processing of PTP packets for timestamping in the Receiver.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	AV8021ASMEN	Res.	Res.	Res.	TXTSSTSM	Res.	Res.	Res.	Res.	Res.	TSENMACADDR	SNAPTYPSEL[1:0]	
			rw				rw						rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSMSTRENA	TSEVNTENA	TSIPV4ENA	TSIPV6ENA	TSIPENA	TSVER2ENA	TSCTRLSSR	TSENALL	Res.	Res.	TSADDREG	Res.	TSUPDT	TSINIT	TSCFUPDT	TSENA
rw	rw	rw	rw	rw	rw	rw	rw			rw		rw	rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **AV8021ASMEN**: AV 802.1AS Mode Enable

When this bit is set, the MAC processes only untagged PTP over Ethernet packets for providing PTP status and capturing timestamp snapshots, that is, IEEE 802.1AS operating mode.

When PTP offload feature is enabled, for the purpose of PTP offload, the transport specific field in the PTP header is generated and checked based on the value of this bit.

Bits 27:25 Reserved, must be kept at reset value.

Bit 24 **TXTSSTSM**: Transmit Timestamp Status Mode

When this bit is set, the MAC overwrites the earlier transmit timestamp status even if it is not read by the software. The MAC indicates this by setting the TXTSSMIS bit of the *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* register.

When this bit is reset, the MAC ignores the timestamp status of current packet if the timestamp status of previous packet is not read by the software. The MAC indicates this by setting the TXTSSMIS bit of the *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)*.

Bits 23:19 Reserved, must be kept at reset value.

Bit 18 **TSENMACADDR**: Enable MAC Address for PTP Packet Filtering

When this bit is set, the DA MAC address (that matches any MAC Address register) is used to filter the PTP packets when PTP is directly sent over Ethernet.

When this bit is set, received PTP packets with DA containing a special multicast or unicast address that matches the one programmed in MAC address registers are considered for processing as indicated below, when PTP is directly sent over Ethernet.

For normal timestamping operation, MAC address registers 0 to 31 is considered for unicast destination address matching.

For PTP offload, only MAC address register 0 is considered for unicast destination address matching.

Bits 17:16 **SNAPTYPSEL[1:0]**: Select PTP packets for Taking Snapshots

These bits, along with Bits 15 and 14, define the set of PTP packet types for which snapshot needs to be taken. The encoding is given in *Table 560: Timestamp Snapshot Dependency on ETH_MACTSCR Bits*.

Bit 15 **TSMSTRENA**: Enable Snapshot for Messages Relevant to Master

When this bit is set, the snapshot is taken only for the messages that are relevant to the master node. Otherwise, the snapshot is taken for the messages relevant to the slave node.

Bit 14 **TSEVNTENA**: Enable Timestamp Snapshot for Event Messages

When this bit is set, the timestamp snapshot is taken only for event messages (SYNC, Delay_Req, Pdelay_Req, or Pdelay_Resp). When this bit is reset, the snapshot is taken for all messages except Announce, Management, and Signaling. For more information about the timestamp snapshots, see *Table 560: Timestamp Snapshot Dependency on ETH_MACTSCR Bits*.

Bit 13 **TSIPV4ENA**: Enable Processing of PTP Packets Sent over IPv4-UDP

When this bit is set, the MAC receiver processes the PTP packets encapsulated in IPv4-UDP packets. When this bit is reset, the MAC ignores the PTP transported over IPv4-UDP packets. This bit is set by default.

Bit 12 **TSIPV6ENA**: Enable Processing of PTP Packets Sent over IPv6-UDP

When this bit is set, the MAC receiver processes the PTP packets encapsulated in IPv6-UDP packets. When this bit is clear, the MAC ignores the PTP transported over IPv6-UDP packets.

Bit 11 **TSIPENA**: Enable Processing of PTP over Ethernet Packets

When this bit is set, the MAC receiver processes the PTP packets encapsulated directly in the Ethernet packets. When this bit is reset, the MAC ignores the PTP over Ethernet packets.

Bit 10 **TSVER2ENA**: Enable PTP Packet Processing for Version 2 Format

When this bit is set, the IEEE 1588 version 2 format is used to process the PTP packets. When this bit is reset, the IEEE 1588 version 1 format is used to process the PTP packets. The IEEE 1588 formats are described in 'PTP Processing and Control'.

Bit 9 **TSCTRLSSR**: Timestamp Digital or Binary Rollover Control

When this bit is set, the Timestamp Low register rolls over after 0x3B9A_C9FF value (that is, 1 nanosecond accuracy) and increments the timestamp (High) seconds. When this bit is reset, the rollover value of subsecond register is 0x7FFF_FFFF. The subsecond increment must be programmed correctly depending on the PTP reference clock frequency and the value of this bit.

Bit 8 **TSENALL**: Enable Timestamp for All Packets

When this bit is set, the timestamp snapshot is enabled for all packets received by the MAC.

Bits 7:6 Reserved, must be kept at reset value.

Bit 5 **TSADDREG**: Update Addend Register

When this bit is set, the content of the Timestamp Addend register is updated in the PTP block for fine correction. This bit is cleared when the update is complete. This bit should be zero before it is set.

Bit 4 Reserved, must be kept at reset value.

Bit 3 **TSUPDT**: Update Timestamp

When this bit is set, the system time is updated (added or subtracted) with the value specified in *System time seconds update register (ETH_MACSTSUR)* and *System time nanoseconds update register (ETH_MACSTNUR)*.
This bit should be zero before updating it. This bit is reset when the update is complete in hardware.

Bit 2 **TSINIT**: Initialize Timestamp

When this bit is set, the system time is initialized (overwritten) with the value specified in the *System time seconds update register (ETH_MACSTSUR)* and *System time nanoseconds update register (ETH_MACSTNUR)*.

This bit should be zero before it is updated. This bit is reset when the initialization is complete.

Bit 1 **TSCFUPDT**: Fine or Coarse Timestamp Update

When this bit is set, the Fine method is used to update system timestamp. When this bit is reset, Coarse method is used to update the system timestamp.

Bit 0 **TSENA**: Enable Timestamp

When this bit is set, the timestamp is added for Transmit and Receive packets. When disabled, timestamp is not added for transmit and receive packets and the Timestamp Generator is also suspended. You need to initialize the Timestamp (system time) after enabling this mode.
On the Receive side, the MAC processes the 1588 packets only if this bit is set.

Subsecond increment register (ETH_MACSSIR)

Address offset: 0x0B04

Reset value: 0x0000 0000

In Coarse Update mode (bit TSCFUPDT in *Timestamp control Register (ETH_MACTSCR)*), the value in this register is added to the system time every clock cycle of clk_ptp_ref_i. In Fine Update mode, the value in this register is added to the system time whenever the Accumulator gets an overflow.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SSINC[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **SSINC[7:0]**: Subsecond Increment Value

The value programmed in this field is accumulated every clock cycle (of clk_ptp_i) with the contents of the subsecond register. For example, when the PTP clock is 50 MHz (period is 20 ns), you should program 20 (0x14) when the System Time Nanoseconds register has an accuracy of 1 ns [TSCTRLSSR bit is set in *Timestamp control Register (ETH_MACTSCR)*]. When TSCTRLSSR is cleared, the Nanoseconds register has a resolution of ~0.465 ns. In this case, you should program a value of 43 (0x2B) which is derived by 20 ns/0.465.

Bits 15:0 Reserved, must be kept at reset value.

System time seconds register (ETH_MACSTSR)

Address offset: 0x0B08

Reset value: 0x0000 0000

The System Time Seconds register, along with System Time Nanoseconds register, indicates the current value of the system time maintained by the MAC. Though it is updated on a continuous basis, there is some delay from the actual time because of clock domain transfer latencies (from clk_ptp_ref_i to CSR clock).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TSS[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TSS[31:0]**: Timestamp Second

The value in this field indicates the current value in seconds of the System Time maintained by the MAC.

System time nanoseconds register (ETH_MACSTNR)

Address offset: 0x0B0C

Reset value: 0x0000 0000

The System Time Nanoseconds register, along with System Time Seconds register, indicates the current value of the system time maintained by the MAC.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	TSSS[30:16]														
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSSS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:0 **TSSS[30:0]**: Timestamp subseconds

The value in this field has the subsecond representation of time, with an accuracy of 0.46 ns. When TSCTRLSSR is set in *Timestamp control Register (ETH_MACTSCR)*, each bit represents 1 ns. The maximum value is 0x3B9A_C9FF after which it rolls-over to zero.

System time seconds update register (ETH_MACSTSUR)

Address offset: 0x0B10

Reset value: 0x0000 0000

The System Time Seconds Update register, along with the System Time Nanoseconds update register, initializes or updates the system time maintained by the MAC. You must write both registers before setting the TSINIT or TSUPDT bits in *Timestamp control Register (ETH_MACTSCR)*.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TSS[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSS[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TSS[31:0]**: Timestamp Seconds

The value in this field is the seconds part of the update.
When ADDSUB is reset, this field must be programmed with the seconds part of the update value.
When ADDSUB is set, this field must be programmed with the complement of the seconds part of the update value.
For example, to subtract 2.000000001 seconds from the system time, the TSS field in the ETH_MACSTSUR register must be 0xFFFF_FFFE (that is, 2^32 – 2).

Caution: When the ADDSUB bit is set, TSSS[30:0] field cannot be set to 0 in *System time nanoseconds update register (ETH_MACSTNUR)*. The TSSS bitfield must be programmed to 0x7FFF FFFF (resulting in –0.46 ns) even if 0 ns must be subtracted.
For example, to subtract 2.000000000 seconds from the system time, the TSS field in the *System time seconds update register (ETH_MACSTSUR)* must be 0xFFFF FFFE (that is, 2^32 – 1) and the *System time nanoseconds update register (ETH_MACSTNUR)* must be 0xFFFF FFFF (ADDSUB = 1 and TSSS[30:0] field = 0x7FFF_FFFF)

System time nanoseconds update register (ETH_MACSTNUR)

Address offset: 0x0B14

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADD SUB	TSSS[30:16]														
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSSS[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **ADDSUB**: Add or Subtract Time

When this bit is set, the time value is subtracted with the contents of the update register. When this bit is reset, the time value is added with the contents of the update register.

Bits 30:0 **TSSS[30:0]**: Timestamp subseconds

The value in this field is the subseconds part of the update.

– ADDSUB is 1: This field must be programmed with the complement of the subseconds part of the update value as described.

– ADDSUB is 0: This field must be programmed with the subseconds part of the update value, with an accuracy based on the TSCTRLSSR bit of the *Timestamp control Register (ETH_MACTSCR)*.

– TSCTRLSSR field in the *Timestamp control Register (ETH_MACTSCR)*is 1:
- The programmed value must be 10^9 – <subsecond value>.
- Each bit represents 1 ns and the programmed value should not exceed 0x3B9A_C9FF.

– TSCTRLSSR field in the *Timestamp control Register (ETH_MACTSCR)* is 0:
- The programmed value must be 2^31 - <subsecond_value>.
- Each bit represents an accuracy of 0.46 ns.

For example, to subtract 2.000000001 seconds from the system time, then the TSSS field in the ETH_MACSTNUR register must be 0x7FFF_FFFF (that is, 2^31 – 1), when TSCTRLSSR bit in *Timestamp control Register (ETH_MACTSCR)* is reset and 0x3B9A_C9FF (that is, 10^9 –1), when TSCTRLSSR bit in *Timestamp control Register (ETH_MACTSCR)* is set.

Caution: When the ADDSUB bit is set, TSSS[30:0] field cannot be set to 0. The TSSS bitfield must be programmed to 0x7FFF FFFF (resulting in –0.46 ns) even if 0 ns must be subtracted.
For example, to subtract 2.000000000 seconds from the system time, *System time nanoseconds update register (ETH_MACSTNUR)* must be 0xFFFF FFFF (ADDSUB = 1 and TSSS[30:0] = 0) and the TSS field in the *System time seconds update register (ETH_MACSTSUR)* must be 0xFFFF FFFE (that is, 2^32 – 1).

Timestamp addend register (ETH_MACTSAR)

Address offset: 0x0B18

Reset value: 0x0000 0000

This register value is used only when the system time is configured for Fine Update mode (TSCFUPDT bit in the *Timestamp control Register (ETH_MACTSCR)*). The content of this register is added to a 32-bit accumulator in every clock cycle of clk_ptp_ref_i and the system time is updated whenever the accumulator overflows.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TSAR[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSAR[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TSAR[31:0]**: Timestamp Addend Register

This field indicates the 32-bit time value to be added to the Accumulator register to achieve time synchronization.

Timestamp status register (ETH_MACTSSR)

Address offset: 0x0B20

Reset value: 0x0000 0000

All bits except Bits[27:25] gets cleared when the application reads this register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	ATSNS[4:0]					ATSSTM	Res.	Res.	Res.	Res.	ATSSTN[3:0]			
		r	r	r	r	r	rc_r					rc_r	rc_r	rc_r	rc_r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXTSSIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSTRGTERR0	AUXTSTRIG	TSTARGT0	TSSOVF
rc_r												rc_r	rc_r	rc_r	rc_r

Bits 31:30 Reserved, must be kept at reset value.

Bits 29:25 **ATSNS[4:0]**: Number of Auxiliary Timestamp Snapshots

This field indicates the number of Snapshots available in the FIFO. A value equal to the depth of FIFO (4) indicates that the Auxiliary Snapshot FIFO is full. These bits are cleared (to 00000) when the Auxiliary snapshot FIFO clear bit is set.

Bit 24 **ATSSTM**: Auxiliary Timestamp Snapshot Trigger Missed

This bit is set when the Auxiliary timestamp snapshot FIFO is full and external trigger was set. This indicates that the latest snapshot is not stored in the FIFO.

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **ATSSTN[3:0]**: Auxiliary Timestamp Snapshot Trigger Identifier

These bits identify the Auxiliary trigger inputs for which the timestamp available in the Auxiliary Snapshot Register is applicable. When more than one bit is set at the same time, it means that corresponding auxiliary triggers were sampled at the same clock. These bits are applicable only if the number of Auxiliary snapshots is more than one. One bit is assigned for each trigger as shown in the following list:

Bit 16: Auxiliary trigger 0

Bit 17: Auxiliary trigger 1

Bit 18: Auxiliary trigger 2

Bit 19: Auxiliary trigger 3

The software can read this register to find the triggers that are set when the timestamp is taken.

Bit 15 **TXTSSIS**: Tx Timestamp Status Interrupt Status

When drop transmit status is enabled in MTL, this bit is set when the captured transmit timestamp is updated in the *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* and *Tx timestamp status seconds register (ETH_MACTXTSSSR)*.

When PTP offload feature is enabled, this bit is set when the captured transmit timestamp is updated in the *Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)* and *Tx timestamp status seconds register (ETH_MACTXTSSSR)*, for PTO generated Delay Request and Pdelay request packets.

This bit is cleared when the *Tx timestamp status seconds register (ETH_MACTXTSSSR)* is read (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bits 14:4 Reserved, must be kept at reset value.

Bit 3 **TSTRGTERR0**: Timestamp Target Time Error

This bit is set when the latest target time programmed in the *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)* elapses. This bit is cleared when the application reads this bit (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 2 **AUXTSTRIG**: Auxiliary Timestamp Trigger Snapshot

This bit is set high when the auxiliary snapshot is written to the FIFO.

This bit is cleared when the application reads this bit (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set).

Bit 1 **TSTARGT0**: Timestamp Target Time Reached

When set, this bit indicates that the value of system time is greater than or equal to the value specified in the *PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*.

This bit is cleared when the application reads this bit (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set)

Bit 0 **TSSOVF**: Timestamp Seconds Overflow

When this bit is set, it indicates that the seconds value of the timestamp (when supporting version 2 format) has overflowed beyond 32'hFFFF_FFFF.

This bit is cleared when the application reads this bit (or write of 1 when RCWE bit in *CSR software control register (ETH_MACCSRSWCR)* is set)

Tx timestamp status nanoseconds register (ETH_MACTXTSSNR)

Address offset: 0x0B30

Reset value: 0x0000 0000

This register contains the nanosecond part of timestamp captured for Transmit packets when Tx status is disabled.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXTSSMIS	TXTSSLO[30:16]														
r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXTSSLO[15:0]															
rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r	rc_r

Bit 31 **TXTSSMIS**: Transmit Timestamp Status Missed

When this bit is set, it indicates one of the following:

– The timestamp of the current packet is ignored if TXTSSTSM bit of the *Timestamp control Register (ETH_MACTSCR)* is reset

– The timestamp of the previous packet is overwritten with timestamp of the current packet if TXTSSTSM bit of the *Timestamp control Register (ETH_MACTSCR)* is set.

Bits 30:0 **TXTSSLO[30:0]**: Transmit Timestamp Status Low

This field contains the 31 bits of the Nanoseconds field of the Transmit packet's captured timestamp.

Tx timestamp status seconds register (ETH_MACTXTSSSR)

Address offset: 0x0B34

Reset value: 0x0000 0000

The register contains the higher 32 bits of the timestamp (in seconds) captured when a PTP packet is transmitted.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TXTSSHI[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TXTSSHI[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **TXTSSHI[31:0]**: Transmit Timestamp Status High

This field contains the lower 32 bits of the Seconds field of Transmit packet's captured timestamp.

Auxiliary control register (ETH_MACACR)

Address offset: 0x0B40

Reset value: 0x0000 0000

The Auxiliary Timestamp Control register controls the Auxiliary Timestamp snapshot.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ATSEN3	ATSEN2	ATSEN1	ATSEN0	Res.	Res.	Res.	ATSFC
								rw	rw	rw	rw				rw

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **ATSEN3**: Auxiliary Snapshot 3 Enable

– This bit controls the capturing of Auxiliary Snapshot Trigger 3. When this bit is set, the auxiliary snapshot of the event on eth_ptp_trg3 input is enabled. When this bit is reset, the events on this input are ignored.

Bit 6 **ATSEN2**: Auxiliary Snapshot 2 Enable

– This bit controls the capturing of Auxiliary Snapshot Trigger 2. When this bit is set, the auxiliary snapshot of the event on eth_ptp_trg2 input is enabled. When this bit is reset, the events on this input are ignored.

Bit 5 **ATSEN1**: Auxiliary Snapshot 1 Enable

– This bit controls the capturing of Auxiliary Snapshot Trigger 1. When this bit is set, the auxiliary snapshot of the event on eth_ptp_trg1 input is enabled. When this bit is reset, the events on this input are ignored.

Bit 4 **ATSEN0**: Auxiliary Snapshot 0 Enable
This bit controls the capturing of Auxiliary Snapshot Trigger 0. When this bit is set, the auxiliary snapshot of the event on eth_ptp_trg0 input is enabled. When this bit is reset, the events on this input are ignored.

Bits 3:1 Reserved, must be kept at reset value.

Bit 0 **ATSFC**: Auxiliary Snapshot FIFO Clear
When set, this bit resets the pointers of the Auxiliary Snapshot FIFO. This bit is cleared when the pointers are reset and the FIFO is empty. When this bit is high, the auxiliary snapshots are stored in the FIFO.

Auxiliary timestamp nanoseconds register (ETH_MACATSNR)

Address offset: 0x0B48

Reset value: 0x0000 0000

The *Auxiliary timestamp nanoseconds register (ETH_MACATSNR)*, along with *Auxiliary timestamp seconds register (ETH_MACATSSR)*, gives the 64-bit timestamp stored as auxiliary snapshot. These two registers form the read port of a 64-bit wide FIFO with a depth of 4 words.

You can store multiple snapshots in this FIFO. Bits[29:25] in *Timestamp status register (ETH_MACTSSR)* indicate the fill-level of the FIFO. The top of the FIFO is removed only when *Auxiliary timestamp seconds register (ETH_MACATSSR)* is read.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	AUXTSLO[30:16]														
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AUXTSLO[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:0 **AUXTSLO[30:0]**: Auxiliary Timestamp
Contains the lower 31 bits (nanoseconds field) of the auxiliary timestamp.

Auxiliary timestamp seconds register (ETH_MACATSSR)

Address offset: 0x0B4C

Reset value: 0x0000 0000

The Auxiliary Timestamp Seconds register contains the lower 32 bits of the Seconds field of the auxiliary timestamp register.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
AUXTSHI[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AUXTSHI[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **AUXTSHI[31:0]**: Auxiliary Timestamp

Contains the lower 32 bits of the Seconds field of the auxiliary timestamp.

Timestamp Ingress asymmetric correction register (ETH_MACTSIACR)

Address offset: 0x0B50

Reset value: 0x0000 0000

The MAC Timestamp Ingress Asymmetry Correction register contains the Ingress Asymmetry Correction value to be used while updating correction field in PDelay_Resp PTP messages.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OSTIAC[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OSTIAC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **OSTIAC[31:0]**: One-Step Timestamp Ingress Asymmetry Correction

This field contains the ingress path asymmetry value to be added to correctionField of Pdelay_Resp PTP packet. The programmed value should be in units of nanoseconds and multiplied by 2^16. For example, 2.5 ns is represented as 0x00028000.

The value can also be negative, which is represented in 2's complement form with bit 31 representing the sign bit.

Timestamp Egress asymmetric correction register (ETH_MACTSEACR)

Address offset: 0x0B54

Reset value: 0x0000 0000

The MAC Timestamp Egress Asymmetry Correction register contains the Egress Asymmetry Correction value to be used while updating the correction field in PDelay_Req PTP messages.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OSTEAC[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OSTEAC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **OSTEAC[31:0]**: One-Step Timestamp Egress Asymmetry Correction

This field contains the egress path asymmetry value to be subtracted from correctionField of Pdelay_Resp PTP packet. The programmed value must be the negated value in units of nanoseconds multiplied by 2^16.

For example, if the required correction is +2.5 ns, the programmed value must be 0xFFFD_8000, which is the 2's complement of 0x0002_8000(2.5 * 2^16). Similarly, if the required correction is -3.3 ns, the programmed value is 0x0003_4CCC (3.3 *2^16).

Timestamp Ingress correction nanosecond register (ETH_MACTSICNR)

Address offset: 0x0B58

Reset value: 0x0000 0000

This register contains the correction value in nanoseconds to be used with the captured timestamp value in the ingress path.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TSIC[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSIC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TSIC[31:0]**: Timestamp Ingress Correction

This field contains the ingress path correction value as defined by the Ingress Correction expression.

Timestamp Egress correction nanosecond register (ETH_MACTSECNR)

Address offset: 0x0B5C

Reset value: 0x0000 0000

This register contains the correction value in nanoseconds to be used with the captured timestamp value in the egress path.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TSEC[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSEC[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TSEC[31:0]**: Timestamp Egress Correction

This field contains the nanoseconds part of the egress path correction value as defined by the Egress Correction expression.

PPS control register (ETH_MACPPSCR)

Address offset: 0x0B70

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRGTMODSEL0[1:0]		PPSEN0	PPSCTRL[3:0]			
									rw	rw	rw	rw	rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bits 6:5 **TRGTMODSEL0[1:0]**: Target Time Register Mode for PPS Output

This field indicates the Target Time registers (*PPS target time seconds register (ETH_MACPPSTTSR)* and *PPS target time nanoseconds register (ETH_MACPPSTTNR)*) mode for PPS output signal:

00: Target Time registers are programmed only for generating the interrupt event.

01: Reserved, must not be used

10: Target Time registers are programmed for generating the interrupt event and starting or stopping the PPS output signal generation.

11: Target Time registers are programmed only for starting or stopping the PPS output signal generation. No interrupt is asserted.

Bit 4 **PPSEN0**: Flexible PPS Output Mode Enable

When this bit is set, PPSCTRL[3:0] function as PPSCMD[3:0]. When this bit is reset, PPSCTRL[3:0] function as PPSCTRL (Fixed PPS mode).

Bits 3:0 **PPSCTRL[3:0]**: PPS Output Frequency Control

This field controls the frequency of the PPS output (eth_ptp_pps_out) signal. The default value of PPSCTRL is 0000, and the PPS output is 1 pulse (of width clk_ptp_i) every second. For other values of PPSCTRL, the PPS output becomes a generated clock of following frequencies:

0001: The binary rollover is 2 Hz, and the digital rollover is 1 Hz.

0010: The binary rollover is 4 Hz, and the digital rollover is 2 Hz.

0011: The binary rollover is 8 Hz, and the digital rollover is 4 Hz.

0100: The binary rollover is 16 Hz, and the digital rollover is 8 Hz.

..

1111: The binary rollover is 32.768 KHz and the digital rollover is 16.384 KHz.

Note: In the binary rollover mode, the PPS output (eth_ptp_pps_out) has a duty cycle of 50 percent with these frequencies. In the digital rollover mode, the PPS output frequency is an average number. The actual clock is of different frequency that gets synchronized every second. For example:

- *When PPSCTRL = 0001, the PPS (1 Hz) has a low period of 537 ms and a high period of 463 ms*
- *When PPSCTRL = 0010, the PPS (2 Hz) is a sequence of*
  One clock of 50 percent duty cycle and 537 ms period
  Second clock of 463 ms period (268 ms low and 195 ms high)
- *When PPSCTRL = 0011, the PPS (4 Hz) is a sequence of*
  Three clocks of 50 percent duty cycle and 268 ms period
  Fourth clock of 195 ms period (134 ms low and 61 ms high)

This behavior is because of the non-linear toggling of bits in the digital rollover mode in the ETH_MACSTNR register.

PPS control register [alternate] (ETH_MACPPSCR)

Address offset: 0x0B70

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRGTMODSEL0 [1:0]		PPSEN 0	PPSCMD[3:0]			
									rw	rw	rw	rw	rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bits 6:5 **TRGTMODSEL0[1:0]**: Target Time Register Mode for PPS Output

This field indicates the Target Time registers (MAC registers 96 and 97) mode for PPS output signal:

00: Target Time registers are programmed only for generating the interrupt event.

01: Reserved, must not be used

10: Target Time registers are programmed for generating the interrupt event and starting or stopping the PPS output signal generation.

11: Target Time registers are programmed only for starting or stopping the PPS output signal generation. No interrupt is asserted.

Bit 4 **PPSEN0**: Flexible PPS Output Mode Enable

When this bit is set, Bits[3:0] function as PPSCMD[3:0]. When this bit is reset, Bits[3:0] function as PPSCTRL (Fixed PPS mode).

Bits 3:0 **PPSCMD[3:0]:** Flexible PPS Output (eth_ptp_pps_out) Control

Programming these bits with a non-zero value instructs the MAC to initiate an event. When the command is transferred or synchronized to the PTP clock domain, these bits get cleared automatically. The software should ensure that these bits are programmed only when they are ‘all zero’. The following list describes the values of PPSCMD0:

0000: No Command

0001: START Single Pulse.

This command generates single pulse rising at the start point defined in Target Time Registers (register 455 and 456) and of a duration defined in the PPS Width Register.

0010: START Pulse Train.

This command generates the train of pulses rising at the start point defined in the Target Time Registers and of a duration defined in the PPS Width Register and repeated at interval defined in the PPS Interval Register. By default, the PPS pulse train is free-running unless stopped by the 'Stop Pulse train at time' or 'Stop Pulse Train immediately' commands.

0011: Cancel START.

This command cancels the START Single Pulse and START Pulse Train commands if the system time has not crossed the programmed start time.

0100: STOP Pulse Train at time.

This command stops the train of pulses initiated by the START Pulse Train command (PPSCMD[3:0] = 0010) after the time programmed in the Target Time registers elapses.

0101: STOP Pulse Train immediately.

This command immediately stops the train of pulses initiated by the START Pulse Train command (PPSCMD[3:0] = 0010).

0110: Cancel STOP Pulse train.

This command cancels the STOP pulse train at time command if the programmed stop time has not elapsed. The PPS pulse train becomes free-running on the successful execution of this command.

0111 to 1111: Reserved, must not be used

PPS target time seconds register (ETH_MACPPSTTSR)

Address offset: 0x0B80

Reset value: 0x0000 0000

The PPS Target Time Seconds register, along with *PPS target time nanoseconds register (ETH_MACPPSTTNR)*, is used to schedule an interrupt event [Bit TSSOVF of *Timestamp status register (ETH_MACTSSR)*] when the system time exceeds the value programmed in these registers.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TSTRH0[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSTRH0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **TSTRH0[31:0]**: PPS Target Time Seconds Register

This field stores the time in seconds. When the timestamp value matches or exceeds both Target Timestamp registers, the MAC starts or stops the PPS signal output and generates an interrupt (if enabled) based on Target Time mode selected for the corresponding PPS output in the *PPS control register (ETH_MACPPSCR)*.

PPS target time nanoseconds register (ETH_MACPPSTTNR)

Address offset: 0x0B84

Reset value: 0x0000 0000

The PPS Target Time Nanoseconds register is present only when more than one Flexible PPS output is selected.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TRGTBUSY0	TTSL0[30:16]														
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TTSL0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **TRGTBUSY0**: PPS Target Time Register Busy

The MAC sets this bit when the PPSCMD0 field in the *PPS control register (ETH_MACPPSCR)* is programmed to 010 or 011. Programming the PPSCMD0 field to 010 or 011 instructs the MAC to synchronize the Target Time Registers to the PTP clock domain. The MAC clears this bit after synchronizing the Target Time Registers with the PTP clock domain The application must not update the Target Time Registers when this bit is read as 1. Otherwise, the synchronization of the previous programmed time gets corrupted.

Bits 30:0 **TTSL0[30:0]**: Target Time Low for PPS Register

This register stores the time in (signed) nanoseconds. When the value of the timestamp matches the value in both Target Timestamp registers, the MAC starts or stops the PPS signal output and generates an interrupt (if enabled) based on the TRGTMODSEL0 field (Bits [6:5]) in *PPS control register (ETH_MACPPSCR)*.

When the TSCTRLSSR bit is set in the *Timestamp control Register (ETH_MACTSCR)*, this value should not exceed 0x3B9A_C9FF. The actual start or stop time of the PPS signal output may have an error margin up to one unit of subsecond increment value.

PPS interval register (ETH_MACPPSIR)

Address offset: 0x0B88

Reset value: 0x0000 0000

The PPS Interval register contains the number of units of subsecond increment value between the rising edges of PPS signal output (eth_ptp_pps_out).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PPSINT0[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PPSINT0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PPSINT0[31:0]**: PPS Output Signal Interval

These bits store the interval between the rising edges of PPS signal output. The interval is stored in terms of number of units of subsecond increment value.

You need to program one value less than the required interval. For example, if the PTP reference clock is 50 MHz (period of 20 ns), and desired interval between the rising edges of PPS signal output is 100 ns (that is, 5 units of subsecond increment value), you should program value 4 (5-1) in this register.

PPS width register (ETH_MACPPSWR)

Address offset: 0x0B8C

Reset value: 0x0000 0000

The PPS Width register contains the number of units of subsecond increment value between the rising and corresponding falling edges of PPS signal output (eth_ptp_pps_out).

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PPSWIDTH0[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PPSWIDTH0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PPSWIDTH0[31:0]**: PPS Output Signal Width

These bits store the width between the rising edge and corresponding falling edge of PPS signal output. The width is stored in terms of number of units of subsecond increment value. You need to program one value less than the required interval. For example, if PTP reference clock is 50 MHz (period of 20 ns), and width between the rising and corresponding falling edges of PPS signal output is 80 ns (that is, four units of subsecond increment value), you should program value 3 (4-1) in this register.

Note: The value programmed in this register must be lesser than the value programmed in PPS interval register (ETH_MACPPSIR).

PTP Offload control register (ETH_MACPOCR)

Address offset: 0x0BC0

Reset value: 0x0000 0000

This register controls the PTP Offload Engine operation.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DN[7:0]								Res.	DRRDIS	APDREQTRIG	ASYNCTRIG	Res.	APDREQEN	ASYNCEN	PTOEN
rw	rw	rw	rw	rw	rw	rw	rw		rw	rw	rw		rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:8 **DN[7:0]**: Domain Number

This field indicates the domain Number in which the PTP node is operating.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **DRRDIS**: Disable PTO Delay Request/Response response generation

When this bit is set, the Delay Request and Delay response will not be generated for received SYNC and Delay request packet respectively, as required by the programmed mode.

Bit 5 **APDREQTRIG**: Automatic PTP Pdelay_Req message Trigger

When this bit is set, one PTP Pdelay_Req message is transmitted. This bit is automatically cleared after the PTP Pdelay_Req message is transmitted. The application should set the APDREQEN bit for this operation.

Bit 4 **ASYNCTRIG**: Automatic PTP SYNC message Trigger

When this bit is set, one PTP SYNC message is transmitted. This bit is automatically cleared after the PTP SYNC message is transmitted. The application should set the ASYNCEN bit for this operation.

Bit 3 Reserved, must be kept at reset value.

Bit 2 **APDREQEN**: Automatic PTP Pdelay_Req message Enable

When this bit is set, PTP Pdelay_Req message is generated periodically based on interval programmed or trigger from application, when the MAC is programmed to be in Peer-to-Peer Transparent mode.

Bit 1 **ASYNCEN**: Automatic PTP SYNC message Enable

When this bit is set, PTP SYNC message is generated periodically based on interval programmed or trigger from application, when the MAC is programmed to be in Clock Master mode.

Bit 0 **PTOEN**: PTP Offload Enable

When this bit is set, the PTP Offload feature is enabled.

PTP Source Port Identity 0 Register (ETH_MACSPI0R)

Address offset: 0x0BC4

Reset value: 0x0000 0000

This register contains Bits[31:0] of the 80-bit Source Port Identity of the PTP node.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SPI0[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI0[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SPI0[31:0]**: Source Port Identity 0

This field indicates bits [31:0] of sourcePortIdentity of PTP node.

PTP Source port identity 1 register (ETH_MACSPI1R)

Address offset: 0x0BC8

Reset value: 0x0000 0000

This register contains Bits[63:32] of the 80-bit Source Port Identity of the PTP node.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SPI1[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI1[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **SPI1[31:0]**: Source Port Identity 1
This field indicates bits [63:32] of sourcePortIdentity of PTP node.

PTP Source port identity 2 register (ETH_MACSPI2R)

Address offset: 0x0BCC

Reset value: 0x0000 0000

This register contains Bits[79:64] of the 80-bit Source Port Identity of the PTP node.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SPI2[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **SPI2[15:0]**: Source Port Identity 2
This field indicates bits [79:64] of sourcePortIdentity of PTP node.

Log message interval register (ETH_MACLMIR)

Address offset: 0x0BD0

Reset value: 0x0000 0000

This register contains the periodic intervals for automatic PTP packet generation.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LMPDRI[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	DRSYNCR[2:0]			LSI[7:0]							
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 **LMPDRI[7:0]**: Log Min Pdelay_Req Interval

This field indicates logMinPdelayReqInterval of PTP node. This is used to schedule the periodic Pdelay request packet transmission. Allowed values are -15 to 15.Negative value must be represented in 2's-complement form. For example, if the required value is -1, the value programmed must be 0xFF.

Bits 23:11 Reserved, must be kept at reset value.

Bits 10:8 **DRSYNCR[2:0]**:

Delay_Req to SYNC Ratio

In Slave mode, it is used for controlling frequency of Delay_Req messages transmitted.

0: DelayReq generated for every received SYNC

1: DelayReq generated every alternate reception of SYNC

2: for every 4 SYNC messages

3: for every 8 SYNC messages

4: for every 16 SYNC messages

5: for every 32 SYNC messages

Others: Reserved, must not be used

The master sends this information (logMinDelayReqInterval) in the DelayResp PTP messages to the slave. The reception processes this value from the received DelayResp messages and updates this field accordingly. In the Slave mode, the host must not write/update this register unless it has to override the received value. In Master mode, the sum of this field and logSyncInterval (LSI) field is provided in the logMinDelayReqInterval field of the generated multicast Delay_Resp PTP message.

Bits 7:0 **LSI[7:0]**:

Log Sync Interval

This field indicates the periodicity of the automatically generated SYNC message when the PTP node is Master. Allowed values are -15 to 15. Negative value must be represented in 2's-complement form. For example, if the required value is -1, the value programmed must be 0xFF.

Ethernet MAC register map and reset values

Table 607. Ethernet MAC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0000	ETH_MACCR	ARPEN	SARC[2:0]			IPC	IPG[2:0]			GPSLCE	S2KP	CST	ACS	WD	Res.	JD	JE	Res.	FES	DM	LM	ECRSFD	DO	DCRS	DR	Res.	BL[1:0]		DC	PRELEN[1:0]		TE	RE
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
0x0004	ETH_MACECR	Res.	Res.	EIPG[4:0]					EIPGEN	Res.	Res.	Res.	Res.	Res.	USP	SPEN	DCRCC	Res.	Res.	GPSL[13:0]														
	Reset value			0	0	0	0	0	0						0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0008	ETH_MACPFR	RA	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DNTU	IPFE	Res.	Res.	Res.	VTFE	Res.	Res.	Res.	Res.	Res.	HPF	SAF	SAIF	PCF[1:0]		DBF	PM	DAIF	HMC	HUC	PR
	Reset value	0										0	0				0						0	0	0	0	0	0	0	0	0	0	0
0x000C	ETH_MACWTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PWE	Res.	Res.	Res.	Res.	WTO[3:0]			
	Reset value																								0					0	0	0	0
0x0010	ETH_MACHT0R	HT31T0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0014	ETH_MACHT1R	HT63T32[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0018 - 0x004C	Reserved																																
0x0050	ETH_MACVTR	EIVLRXS	Res.	EIVLS[1:0]		ERIVLT	EDVLP	VTHM	EVLRXS	Res.	EVLS[1:0]		DOVLTC	ERSVLM	ESVL	VTIM	ETV	VL[15:0]																
	Reset value	0		0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0054	Reserved																																
0x0058	ETH_MACVHTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VLHT[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x005C	Reserved																																
0x0060	ETH_MACVIR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VLTI	CSVL	VLP	VLC[1:0]		VLT[15:0]															
	Reset value												0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 607. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0064	ETH_MACiVIR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VLTI	CSVL	VLP	VLC[1:0]		VLT[15:0]															
	Reset value												0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0068 - 0x006C	Reserved																																
0x0070	ETH_ MACQTXFCR	PT[15:0]																Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DZPQ	PLT[2:0]			Res.	Res.	TFE	FCB_ BPA
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									0	0	0	0			0	0
0x0074 - 0x008C	Reserved																																
0x0090	ETH_MACRXFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UP	RFE
	Reset value																															0	0
0x0094- 0x00AC	Reserved																																
0x00B0	ETH_MACISR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXSTSIS	TXSTSIS	TSIS	Res.	MMCTXIS	MMCRXIS	MMCIS	Res.	Res.	LPIIS	PMTIS	PHYIS	Res.	Res.	Res.
	Reset value																		0	0	0		0	0	0			0	0	0			
0x00B4	ETH_MACIER	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXSTSIE	TXSTSIE	TSIE	Res.	Res.	Res.	Res.	Res.	Res.	LPIIE	PMTIE	PHYIE	Res.	Res.	Res
	Reset value																		0	0	0							0	0	0			
0x00B8	ETH_ MACRXTXSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RWT	Res.	Res.	EXCOL	LCOL	EXDEF	LCARR	NCARR	TJT
	Reset value																								0			0	0	0	0	0	0
0x00BC	Reserved																																
0x00C0	ETH_MACPCSR	RWKFILTRST	Res.	Res.	RWKPTR[4:0]					Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RWKPFE	GLBLUCAST	Res.	Res.	RWKPRCVD	MGKPRCVD	Res.	Res.	RWKPKTEN	MGKPKTEN	PWRDWN
	Reset value	0			0	0	0	0	0														0	0			0	0			0	0	0
0x00C4	ETH_ MACRWKPFR	MACRWKPFR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00C8 - 0x00CC	Reserved																																

Table 607. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00D0	ETH_MACLCSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LPITCSE	LPITE	LPITXA	Res.	PLS	LPIEN	Res.	Res.	Res.	Res.	Res.	Res.	RLPIST	TLPIST	Res.	Res.	Res.	Res.	RLPIEX	RLPIEN	TLPIEX	TLPIEN
	Reset value											0	0	0		0	0							0	0					0	0	0	0
0x00D4	ETH_MACLTCR	Res.	Res.	Res.	Res.	Res.	Res.	LST[9:0]										TWT[15:0]															
	Reset value							1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00D8	ETH_MACLETR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LPIET[19:0]																			
	Reset value													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00DC	ETH_ MAC1USTCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TIC_1US_CNTR[11:0]											
	Reset value																					0	0	0	0	0	0	0	0	0	0	0	0
0x00E0 - 0x010C	Reserved																																
0x0110	ETH_MACVR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	USERVER[7:0]								SNPSVER[7:0]							
	Reset value																	0	0	1	1	0	0	0	1	0	1	0	0	0	0	1	0
0x0114	ETH_MACDR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TFCSTS[1:0]		TPESTS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RFCFCSTS[1:0]		RPESTS	
	Reset value														0	0	0													0	0	0	
0x0118	Reserved																																
0x011C	ETH_MACHWF0R	Res.	ACTPHYSEL[2:0]			SAVLANINS	TSSTSSEL[1:0]		MACADR64SEL	MACADR32SEL	ADDMACADRSEL[4:0]					Res.	RXCOESEL	Res.	TXCOESEL	EEESEL	TSSEL	Res.	Res.	ARPOFFSEL	MMCSEL	MGKSEL	RWKSEL	SMASEL	VLHASH	PCSSEL	HDSEL	GMIISEL	MIISEL
	Reset value		0	0	0	1	0	1	0	0	0	0	0	1	1		1		1	1	1			1	1	1	1	1	1	0	1		1
0x0120	ETH_MACHWF1R	Res.	L3L4FNUM[3:0]			Res.	HASHTBLSZ[1:0]		POUOST	Res.	RAVSEL	AVSEL	DBGMEMA	TSOEN	SPHEN	DCBEN	ADDR64[1:0]		ADVTHWORD	PTOEN	OSTEN	TXFIFOSIZE[4:0]					Res.	RXFIFOSIZE[4:0]				
	Reset value		0	0	1	0		0	1	0		0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	0		0	0	1	0	0

Table 607. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0124	ETH_MACHWF2R	Res.	AUXSNAPNUM[2:0]			Res.	PPSOUTNUM[2:0]			TDCSZ[1:0]		TXCHCNT[3:0]				RDCSZ[1:0]		RXCHCNT[3:0]				Res.	Res.	TXQCNT[3:0]				Res.	Res.	RXQCNT[3:0]			
	Reset value		1	0	0		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0	0			0	0	0	0
0x0128	ETH_MACHWF3R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DVLAN	CBTISEL	Res.	NRVF[2:0]		
	Reset value																											1	0		0	0	0
0x012C - 0x01FC	Reserved																																
0x0200	ETH_ MACMDIOAR	Res.	Res.	Res.	Res.	PSE	BTB	PA[4:0]					RDA[4:0]					Res.	NTC[2:0]			CR[3:0]				Res.	Res.	Res.	SKAP	GOC[1:0]		C45E	MB
	Reset value					0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0				0	0	0	0	0
0x0204	ETH_ MACMDIODR	RA[15:0]																MD[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0208 - 0x020C	Reserved																																
0x0210	ETH_MACARPAR	ARPPA[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0214 - 0x022C	Reserved																																
0x0230	ETH_MACCSRSWCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SEEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RCWE
	Reset value																								0								0
0x0234 - 0x02FC	Reserved																																
0x0300	ETH_MACA0HR	AE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDRHI[15:0]															
	Reset value	1																1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0304	ETH_MACA0LR	ADDRLO[31:0]																															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 607. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0308	ETH_MACA1HR	AE	SA	MBC[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDRHI[15:0]															
	Reset value	0	0	0	0	0	0	0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x30C	ETH_MACA1LR	ADDRLO[31:0]																															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0310	ETH_MACA2HR	AE	SA	MBC[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDRHI[15:0]															
	Reset value	0	0	0	0	0	0	0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0314	ETH_MACA2LR	ADDRLO[31:0]																															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0318	ETH_MACA3HR	AE	SA	MBC[5:0]						Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ADDRHI[15:0]															
	Reset value	0	0	0	0	0	0	0	0									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x031C	ETH_MACA3LR	ADDRLO[31:0]																															
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x0320 - 0x06FC	Reserved																																
0x0700	ETH_MMC_ CONTROL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	UCDBC	Res.	Res.	CNTPRSTLVL	CNTPRST	CNTFREEZ	RSTONRD	CNTSTOPRO	CNTRST
	Reset value																								0			0	0	0	0	0	0
0x0704	ETH_MMC_RX_ INTERRUPT	Res.	Res.	Res.	Res.	RXLPITRCIS	RXLPIUSCIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXUCGPIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXALGNERPIS	RXCRCERPIS	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0									0											0	0					
0x0708	ETH_MMC_TX_ INTERRUPT	Res.	Res.	Res.	Res.	TXLPITRCIS	TXLPIUSCIS	Res.	Res.	Res.	Res.	TXGPKTIS	Res.	Res.	Res.	Res.	Res.	TXMCOLGPIS	TXSCOLGPIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0					0						0	0														

Table 607. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x070C	ETH_MMC_RX_INTERRUPT_MASK	Res.	Res.	Res.	Res.	RXLPITRCIM	RXLPIUSCIM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXUCGPIM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXALGNERPIM	RXCRCERPIM	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0									0											0	0					
0x0710	ETH_MMC_TX_INTERRUPT_MASK	Res.	Res.	Res.	Res.	TXLPITRCIM	TXLPIUSCIM	Res.	Res.	Res.	Res.	TXGPKTIM	Res.	Res.	Res.	Res.	Res.	TXMCOLGPIM	TXSCOLGPIM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value					0	0					0						0	0														
0x0714 - 0x0748	Reserved																																
0x074C	ETH_TX_SINGLE_COLLISION_GOOD_PACKETS	TXSNGLCOLG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0750	ETH_TX_MULTIPLE_COLLISION_GOOD_PACKETS	TXMULTCOLG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0754 - 0x0764	Reserved																																
0x0768	ETH_TX_PACKET_COUNT_GOOD	TXPKTG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x076C - 0x0790	Reserved																																
0x0794	ETH_RX_CRC_ERROR_PACKETS	RXCRCERR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0798	ETH_RX_ALIGNMENT_ERROR_PACKETS	RXALGNERR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x079C - 0x07C0	Reserved																																
0x07C4	ETH_RX_UNICAST_PACKETS_GOOD	RXUCASTG[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 607. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x07C8 - 0x07E8	Reserved																																
0x07EC	ETH_TX_LPI_USEC_CNTR	TXLPIUSC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x07F0	ETH_TX_LPI_TRAN_CNTR	TXLPITRC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x07F4	ETH_RX_LPI_USEC_CNTR	RXLPIUSC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x07F8	ETH_RX_LPI_TRAN_CNTR	RXLPITRC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x07FC - 0x08FC	Reserved																																
0x0900	ETH_MACL3L4C0R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	L4DPIM0	L4DPM0	L4SPIM0	L4SPM0	Res.	L4PEN0	L3HDBM0[4:0]						L3HSBM0[4:0]					L3DAIM0	L3DAM0	L3SAIM0	L3SAM0	Res.	L3PEN0
	Reset value											0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
0x0904	ETH_MACL4A0R	L4DP0[15:0]																L4SP0[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0908 - 0x090C	Reserved																																
0x0910	ETH_MACL3A00R	L3A00[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0914	ETH_MACL3A10R	L3A10[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0918	ETH_MACL3A20R	L3A20[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x091C	ETH_MACL3A30R	L3A30[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0920 - 0x092C	Reserved																																

Table 607. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0930	ETH_ MACL3L4C1R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	L4DPIM1	L4DPM1	L4SPIM1	L4SPM1	Res.	L4PEN1	L3HDBM1[4:0]					L3HSBM1[4:0]					L3DAIM1	L3DAM1	L3SAIM1	L3SAM1	Res.	L3PEN1
	Reset value											0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
0x0934	ETH_MACL4A1R	L4DP1[15:0]																L4SP1[15:0]															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0938 - 0x093C	Reserved																																
0x0940	ETH_MACL3A01R	L3A01[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0944	ETH_MACL3A11R	L3A11[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0948	ETH_MACL3A21R	L3A21[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x094C	ETH_MACL3A31R	L3A31[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0950 - 0x0AFC	Reserved																																
0x0B00	ETH_MACTSCR	Res.	Res.	Res.	AV8021ASMEN	Res.	Res.	Res.	TXTSSTSM	Res.	Res.	Res.	Res.	Res.	TSENMACADDR	SNAPTYPSEL[1:0]		TSMSTRENA	TSEVNTENA	TSIPV4ENA	TSIPV6ENA	TSIPENA	TSVER2ENA	TSCTRLSSR	TSENALL	Res.	Res.	TSADDREG	Res.	TSUPDT	TSINIT	TSCFUPDT	TSENA
	Reset value				0				0						0	0	0	0	0	1	0	0	0	0	0			0		0	0	0	0
0x0B04	ETH_MACSSIR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SSINC[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value									0	0	0	0	0	0	0	0																
0x0B08	ETH_MACSTSR	TSS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B0C	ETH_MACSTNR	Res.	TSSS[30:0]																														
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B10	ETH_MACSTSUR	TSS[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B14	ETH_MACSTNUR	ADDSUB	TSSS[30:0]																														
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 607. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0B18	ETH_MACTSAR	TSAR[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B1C	Reserved																																
0x0B20	ETH_MACTSSR	Res.	Res.	ATSNS[4:0]					ATSSTM	Res.	Res.	Res.	Res.	ATSSTN[3:0]				TXTSSIS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSTRGTERR0	AUXTSTRIG	TSTARGT0	TSSOVF
	Reset value			0	0	0	0	0	0					0	0	0	0	0												0	0	0	0
0x0B24 - 0x0B2C	Reserved																																
0x0B30	ETH_MACTXTSSNR	TXTSSMIS	TXTSSLO[30:0]																														
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B34	ETH_MACTXTSSSR	TXTSSHI[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B38 - 0x0B3C	Reserved																																
0x0B40	ETH_MACACR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ATSEN3	ATSEN2	ATSEN1	ATSEN0	Res.	Res.	Res.	ATSFC
	Reset value																									0	0	0	0				0
0x0B44	Reserved																																
0x0B48	ETH_MACATSNR	Res.	AUXTSLO[30:0]																														
	Reset value		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B4C	ETH_MACATSSR	AUXTSHI[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B50	ETH_MACTSIACR	OSTIAC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B54	ETH_MACTSEACR	OSTEAC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B58	ETH_ MACTSICNR	TSIC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 607. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0B5C	ETH_ MACTSECNR	TSEC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B60 - 0x0B6C	Reserved																																
0x0B70	ETH_MACPPSCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRGTMODSEL0[1:0]		PPSEN0	PPSCTRL[3:0]			
	Reset value																										0	0	0	0	0	0	0
0x0B70	ETH_MACPPSCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRGTMODSEL0[1:0]		PPSEN0	PPSCMD[3:0]			
	Reset value																										0	0	0	0	0	0	0
0x0B74 - 0x0B7C	Reserved																																
0x0B80	ETH_ MACPPSTTSR	TSTRH0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B84	ETH_ MACPPSTTNR	TRGTBUSY0	TTSL0[30:0]																														
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B88	ETH_MACPPSIR	PPSINT0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B8C	ETH_MACPPSWR	PPSWIDTH0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0B90 - 0x0BBC	Reserved																																
0x0BC0	ETH_MACPOCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DN[7:0]								Res.	DRRDIS	APDREQTRIG	ASYNCTRIG	Res.	APDREQEN	ASYNCEN	PTOEN
	Reset value																	0	0	0	0	0	0	0	0		0	0	0		0	0	0

Table 607. Ethernet MAC register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x0BC4	ETH_MACSPI0R	SPI0[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0BC8	ETH_MACSPI1R	SPI1[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0BCC	ETH_MACSPI2R	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SPI2[15:0]															
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x0BD0	ETH_MACLMIR	LMPDRI[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DRSYNCR[2:0]			LSI[7:0]							
	Reset value	0	0	0	0	0	0	0	0														0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3 on page 131* for the register boundary addresses.

64 HDMI-CEC controller (CEC)

64.1 Introduction

Consumer electronics control (CEC) is part of HDMI (high-definition multimedia interface) standard. It contains a protocol that provides high-level control functions between various audiovisual products. CEC operates at low speeds, with minimum processing and memory overhead.

The HDMI-CEC controller provides hardware support for this protocol.

64.2 HDMI-CEC controller main features

- Complies with HDMI-CEC v1.4 specification
- Independent 32 kHz CEC kernel (refer to *section RCC kernel clock distribution*)
- Works in Stop mode for ultra-low-power applications
- Configurable signal-free time before start of transmission
  - Automatic by hardware, according to CEC state and transmission history
  - Fixed by software (7 timing options)
- Configurable peripheral address (OAR)
- Supports Listen mode
  - Enables reception of CEC messages sent to destination address different from OAR without interfering with the CEC line
- Configurable Rx-tolerance margin
  - Standard tolerance
  - Extended tolerance
- Receive-error detection
  - Bit rising error (BRE), with optional stop of reception (BRESTP)
  - Short bit period error (SBPE)
  - Long bit period error (LBPE)
- Configurable error-bit generation
  - on BRE detection (BREGEN)
  - on LBPE detection (LBPEGEN)
  - always generated on SBPE detection
- Transmission error detection (TXERR)
- Arbitration lost detection (ARBLST)
  - with automatic transmission retry
- Transmission underrun detection (TXUDR)
- Reception overrun detection (RXOVR)

64.3 HDMI-CEC functional description

64.3.1 HDMI-CEC pin and internal signals

The CEC bus consists of a single bidirectional line that is used to transfer data in and out of the device. It is connected to a +3.3 V supply voltage via a 27 kΩ pull-up resistor. The output stage of the device must have an open-drain or open-collector to allow a wired-AND connection.

The HDMI-CEC controller manages the CEC bidirectional line as an alternate function of a standard GPIO, assuming that it is configured as alternate function open drain. The 27 kΩ pull-up must be added externally to the microcontroller.

To not interfere with the CEC bus when the application power is removed, it is mandatory to isolate the CEC pin from the bus in such conditions. This can be done by using a MOS transistor, as shown on *Figure 846*.

Table 609 lists the internal signals that are exchanged between the HDMI-CEC and other functional blocks (such as RCC and EXTI).

Table 608. HDMI pin

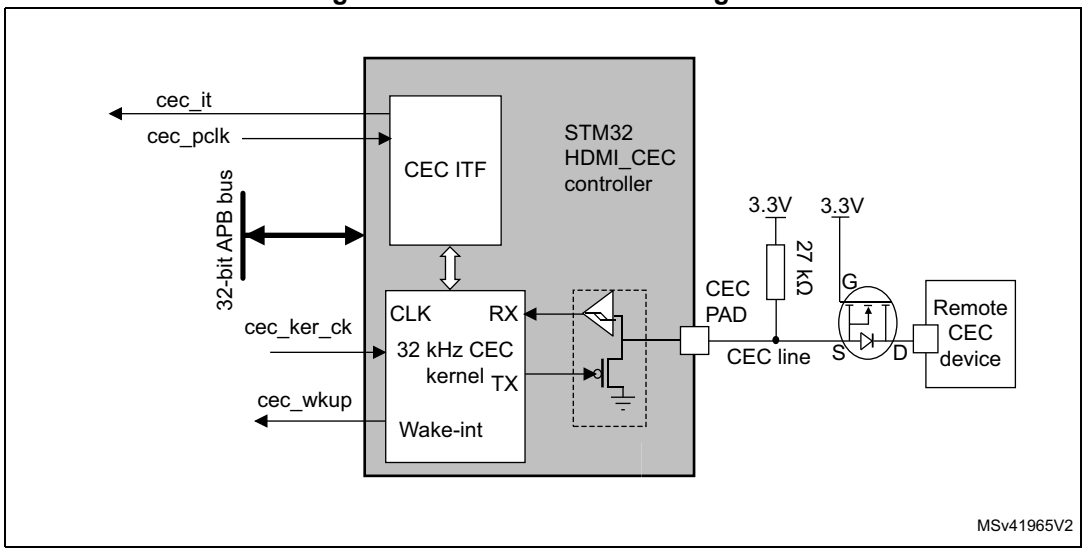
Name	Signal type	Remarks
CEC	Bidirectional	Two states: – 1 = high impedance – 0 = low impedance A 27 kΩ resistor must be added externally.

Table 609. HDMI-CEC internal input/output signals

Signal name	Signal type	Description
cec_wkup	Digital output	HDMI-CEC wakeup signal
cec_it	Digital output	HDMI-CEC interrupt signal
cec_pclk	Digital input	APB clock
cec_ker_ck	Digital input	HDMI-CEC kernel clock

64.3.2 HDMI-CEC block diagram

Figure 846. HDMI-CEC block diagram



64.3.3 Message description

All transactions on the CEC line consist of an initiator and one or more followers. The initiator is responsible for sending the message structure and the data. The follower is the recipient of any data and is responsible for setting any acknowledgment bits.

A message is conveyed in a single frame that consists of a start bit followed by a header block and optionally an opcode and a variable number of operand blocks.

All these blocks are made of a 8-bit payload - most significant bit is transmitted first - followed by an end of message (EOM) bit and an acknowledge (ACK) bit.

The EOM bit is set in the last block of a message and kept reset in all others. In case a message contains additional blocks after an EOM is indicated, those additional blocks must be ignored. The EOM bit may be set in the header block to ‘ping’ other devices, to make sure they are active.

The acknowledge bit is always set to high impedance by the initiator so that it can be driven low either by the follower that has read its own address in the header, or by the follower that needs to reject a broadcast message.

The header consists of the source logical address field, and the destination logical address field. Note that the special address 0xF is used for broadcast messages.

Figure 847. Message structure

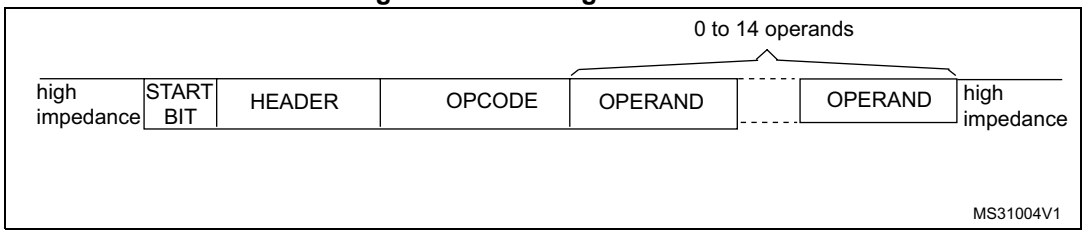
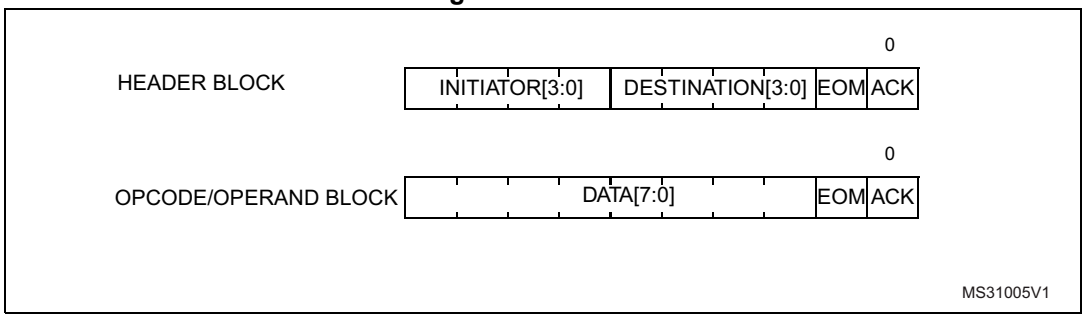


Figure 848. Blocks

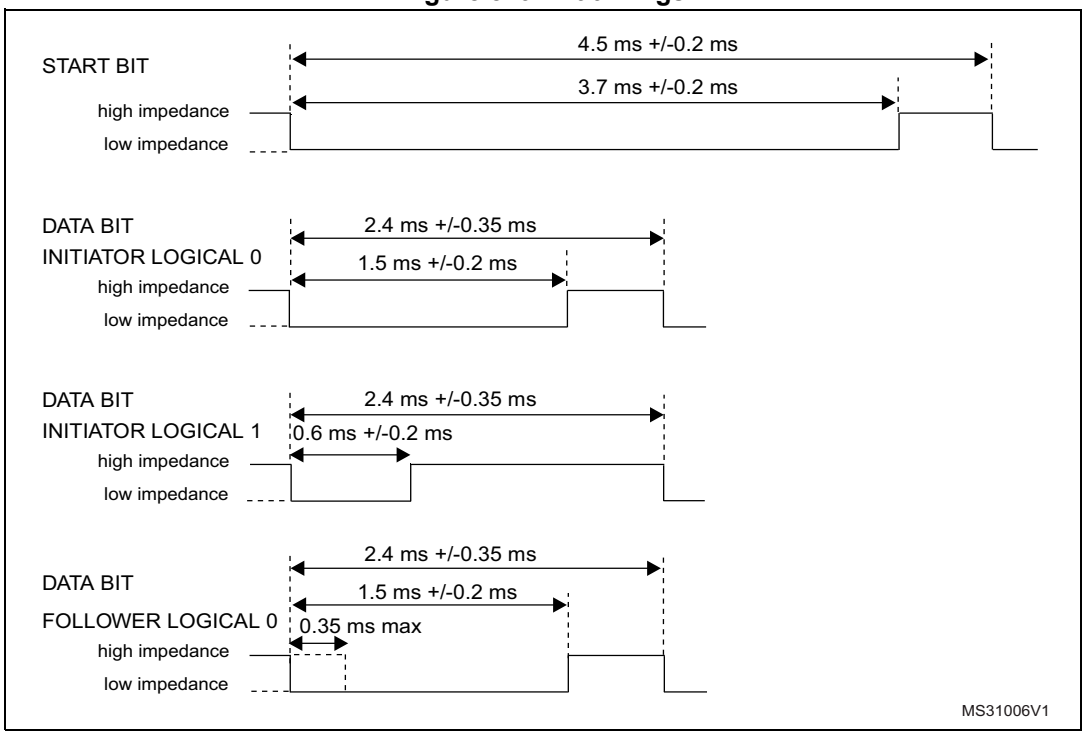


64.3.4 Bit timing

The format of the start bit is unique and identifies the start of a message. It must be validated by its low duration and its total duration.

All remaining data bits in the message, after the start bit, have consistent timing. The high-to-low transition at the end of the data bit is the start of the next data bit except for the final bit where the CEC line remains high.

Figure 849. Bit timings

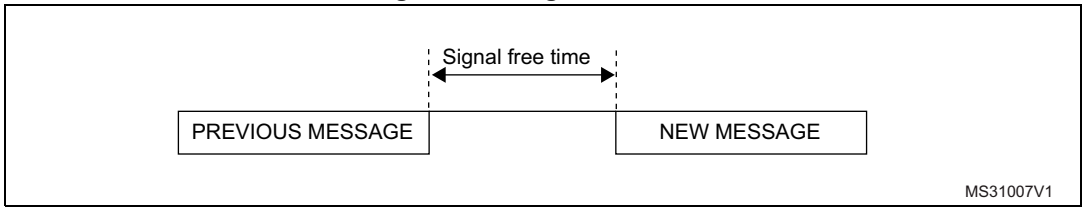


64.4 Arbitration

All devices transmitting - or retransmitting - a message onto the CEC line must ensure that it has been inactive for a number of bit periods. This signal-free time is defined as the time

starting from the final bit of the previous frame and depends on the initiating device and the current status as shown in the figure below.

Figure 850. Signal free time



Since only one initiator is allowed at any one time, an arbitration mechanism is provided to avoid conflict when more than one initiator begins transmitting at the same time.

CEC line arbitration starts with the leading edge of the start bit and continues until the end of the initiator address bits within the header block. During this period, the initiator must monitor the CEC line, if whilst driving the line to high impedance it reads it back to 0. Assuming then it has lost arbitration, it stops transmitting and becomes a follower.

Figure 851. Arbitration phase

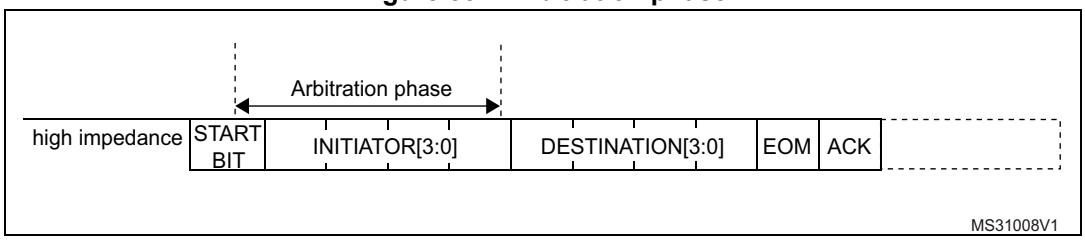
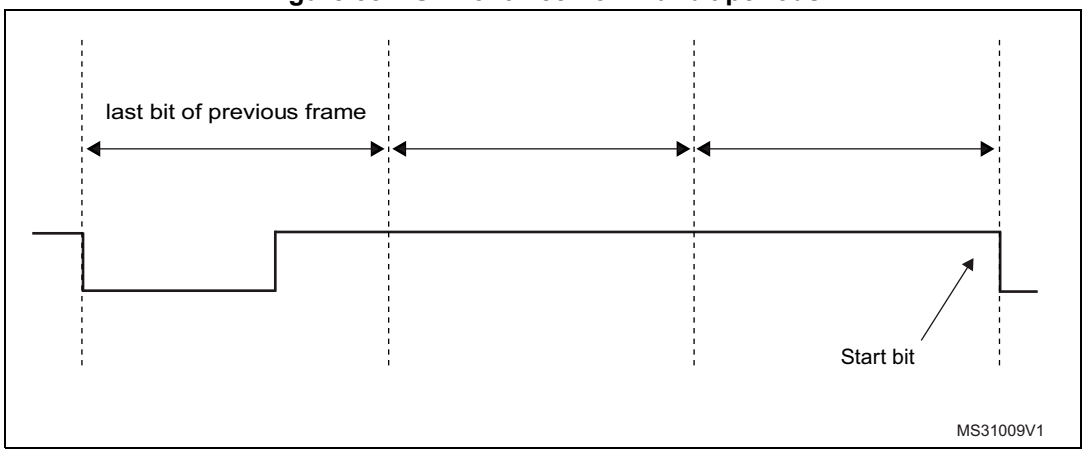


Figure 852 shows an example for a SFT of three nominal bit periods.

Figure 852. SFT of three nominal bit periods



A configurable time window is counted before starting the transmission.

In the SFT = 0 configuration, HDMI-CEC performs automatic SFT calculation ensuring compliance with the HDMI-CEC standard:

- 2.5 data bit periods if the CEC is the last bus initiator with unsuccessful transmission
- 4 data bit periods if the CEC is the new bus initiator
- 6 data bit periods if the CEC is the last bus initiator with successful transmission

This is done to guarantee the maximum priority to a failed transmission and the lowest one to the last initiator that completed successfully its transmission.

Otherwise there is the possibility to configure the SFT bits to count a fixed timing value. Possible values are 0.5, 1.5, 2.5, 3.5, 4.5, 5.5, 6.5 data bit periods.

64.4.1 SFT option bit

In case of SFTOPT = 0 configuration, SFT starts being counted when the start-of-transmission command is set by software (TXSOM = 1).

In case of SFTOPT = 1, SFT starts automatically being counted by the HDMI-CEC device when a bus-idle or line error condition is detected. If the SFT timer is completed at the time TXSOM command is set then transmission starts immediately without latency. If the SFT timer is still running instead, the system waits until the timer elapses before transmission can start.

In case of SFTOPT = 1 a bus-event condition starting the SFT timer is detected in the following cases:

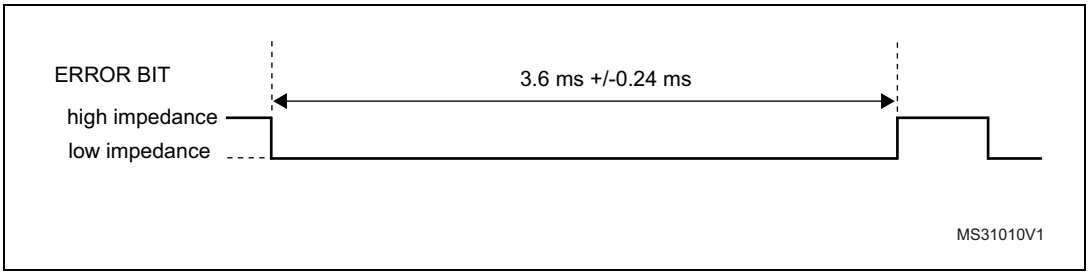
- In case of a regular end of transmission/reception, when TXEND/RXEND bits are set at the minimum nominal data bit duration of the last bit in the message (ACK bit).
- In case of a transmission error detection, SFT timer starts when the TXERR transmission error is detected (TXERR = 1).
- In case of a missing acknowledge from the CEC follower, the SFT timer starts when the TXACKE bit is set, that is at the nominal sampling time of the ACK bit.
- In case of a transmission underrun error, the SFT timer starts when the TXUDR bit is set at the end of the ACK bit.
- In case of a receive error detection implying reception abort, the SFT timer starts at the same time the error is detected. If an error bit is generated, then SFT starts being counted at the end of the error bit.
- In case of a wrong start bit or of any uncodified low impedance bus state from idle, the SFT timer is restarted as soon as the bus comes back to hi-impedance idleness.

64.5 Error handling

64.5.1 Bit error

If a data bit - excluding the start bit - is considered invalid, the follower is expected to notify such error by generating a low bit period on the CEC line of 1.4 to 1.6 times the nominal data bit period (3.6 ms nominally).

Figure 853. Error bit timing



64.5.2 Message error

A message is considered lost and therefore may be retransmitted under the following conditions:

- a message is not acknowledged in a directly addressed message
- a message is negatively acknowledged in a broadcast message
- a low impedance is detected on the CEC line while it is not expected (line error)

Three kinds of error flag can be detected when the CEC interface is receiving a data bit:

64.5.3 Bit rising error (BRE)

BRE (bit rising error) is set when a bit rising edge is detected outside the windows where it is expected (see *Figure 854*). BRE flag also generates a CEC interrupt if the BREIE = 1.

In the case of a BRE detection, the message reception can be stopped according to the BRESTP bit value and an error bit can be generated if BREGEN bit is set.

When BRE is detected in a broadcast message with BRESTP = 1 an error bit is generated even if BREGEN = 0 to enforce initiator's retry of the failed transmission. Error bit generation can be disabled by configuring BREGEN = 0, BRDNOGEN = 1.

64.5.4 Short bit period error (SBPE)

SBPE is set when a bit falling edge is detected earlier than expected (see *Figure 854*). SBPE flag also generates a CEC interrupt if the SBPEIE = 1.

An error bit is always generated on the line in case of a SBPE error detection. An error bit is not generated upon SBPE detection only when Listen mode is set (LSTN = 1) and the following conditions are met:

- A directly addressed message is received containing SBPE
- A broadcast message is received containing SBPE AND BRDNOGEN = 1

64.5.5 Long bit period error (LBPE)

LBPE is set when a bit falling edge is not detected in a valid window (see *Figure 854*). LBPE flag also generates a CEC interrupt if the LBPEIE = 1.

LBPE always stops the reception, an error bit is generated on the line when LBPEGEN bit is set.

When LBPE is detected in a broadcast message an error bit is generated even if LBPEGEN = 0 to enforce initiator's retry of the failed transmission. Error bit generation can be disabled by configuring LBPEGEN = 0, BRDNOGEN = 1.

Note: The BREGEN = 1, BRESTP = 0 configuration must be avoided.

Figure 854. Error handling

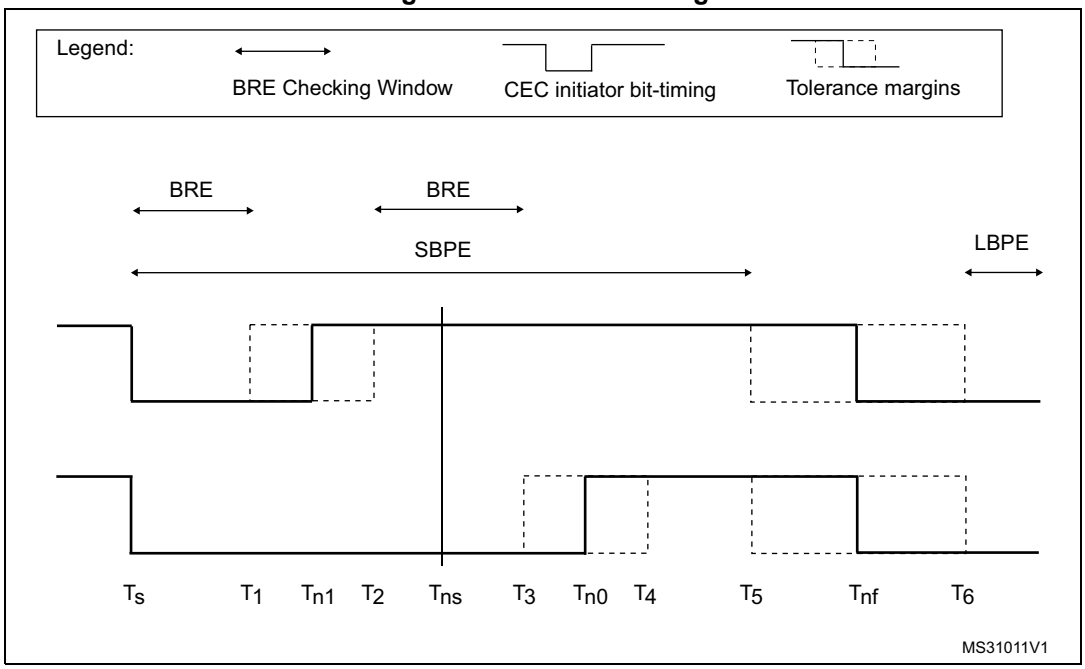


Table 610. Error handling timing parameters

Time	RXTOL	ms	Description
T_s	x	0	Bit start event.
T_1	1	0.3	The earliest time for a low - high transition when indicating a logical 1.
	0	0.4	
T_{n1}	x	0.6	The nominal time for a low - high transition when indicating a logical 1.
T_2	0	0.8	The latest time for a low - high transition when indicating a logical 1.
	1	0.9	
T_{ns}	x	1.05	Nominal sampling time.
T_3	1	1.2	The earliest time a device is permitted return to a high impedance state (logical 0).
	0	1.3	
T_{n0}	x	1.5	The nominal time a device is permitted return to a high impedance state (logical 0).
T_4	0	1.7	The latest time a device is permitted return to a high impedance state (logical 0).
	1	1.8	
T_5	1	1.85	The earliest time for the start of a following bit.
	0	2.05	
T_{nf}	x	2.4	The nominal data bit period.
T_6	0	2.75	The latest time for the start of a following bit.
	1	2.95	

64.5.6 Transmission error detection (TXERR)

The CEC initiator sets the TXERR flag if detecting low impedance on the CEC line when it is transmitting high impedance and is not expecting a follower asserted bit. TXERR flag also generates a CEC interrupt if the TXERRIE = 1.

TXERR assertion stops the message transmission. Application is in charge to retry the failed transmission up to five times.

TXERR checks are performed differently depending on the different states of the CEC line and on the RX tolerance configuration.

Figure 855. TXERR detection

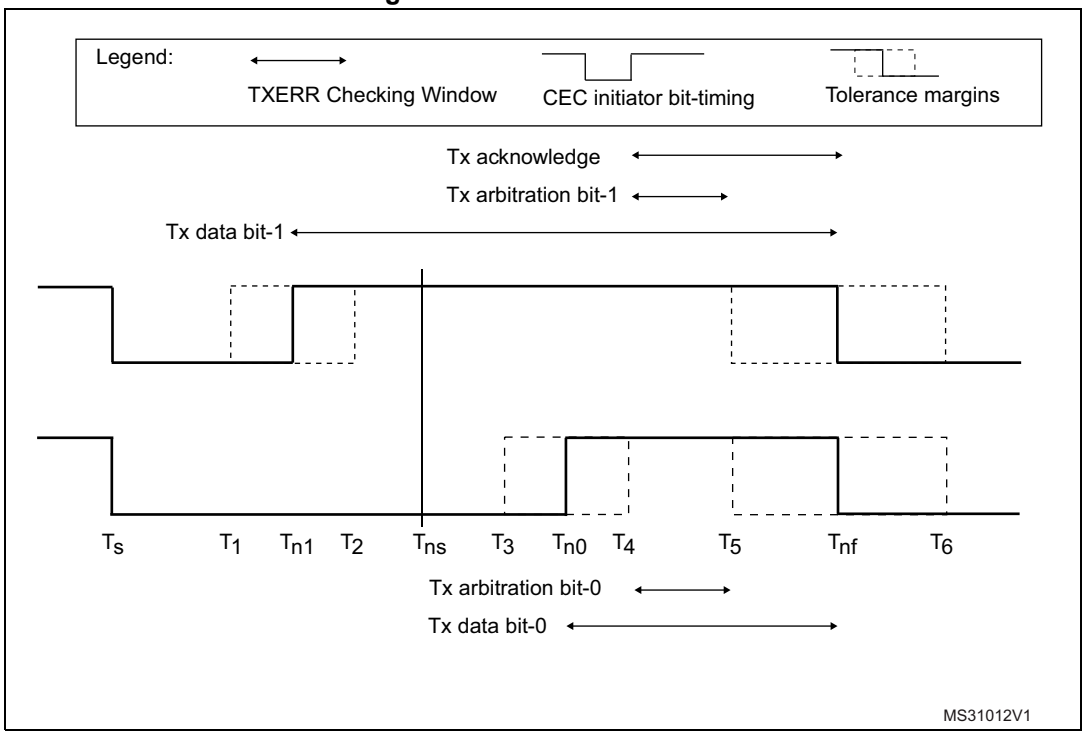


Table 611. TXERR timing parameters

Time	RXTOL	ms	Description
T_s	x	0	Bit start event.
T_1	1	0.3	The earliest time for a low - high transition when indicating a logical 1.
	0	0.4	
T_{n1}	x	0.6	The nominal time for a low - high transition when indicating a logical 1.
T_2	0	0.8	The latest time for a low - high transition when indicating a logical 1.
	1	0.9	
T_{ns}	x	1.05	Nominal sampling time.
T_3	1	1.2	The earliest time a device is permitted return to a high impedance state (logical 0).
	0	1.3	

Table 611. TXERR timing parameters (continued)

Time	RXTOL	ms	Description
T_{n0}	x	1.5	The nominal time a device is permitted return to a high impedance state (logical 0).
T_4	0	1.7	The latest time a device is permitted return to a high impedance state (logical 0).
	1	1.8	
T_5	1	1.85	The earliest time for the start of a following bit.
	0	2.05	
T_{nf}	x	2.4	The nominal data bit period.
T_6	0	2.75	The latest time for the start of a following bit.
	1	2.95	

64.6 HDMI-CEC interrupts

An interrupt can be produced:

- during reception if a receive block transfer is finished or if a receive error occurs.
- during transmission if a transmit block transfer is finished or if a transmit error occurs.

Table 612. HDMI-CEC interrupts

Interrupt event	Event flag	Enable control bit
Rx-byte received	RXBR	RXBRIE
End of reception	RXEND	RXENDIE
Rx-overrun	RXOVR	RXOVRIE
Rxbit rising error	BRE	BREIE
Rx-short bit period error	SBPE	SBPEIE
Rx-long bit period error	LBPE	LBPEIE
Rx-missing acknowledge error	RXACKE	RXACKEIE
Arbitration lost	ARBLST	ARBLSTIE
Tx-byte request	TXBR	TXBRIE
End of transmission	TXEND	TXENDIE
Tx-buffer underrun	TXUDR	TXUDRIE
Tx-error	TXERR	TXERRIE
Tx-missing acknowledge error	TXACKE	TXACKEIE

64.7 HDMI-CEC registers

Refer to *Section 1.2* for a list of abbreviations used in register descriptions. The registers have to be accessed by words (32 bits).

64.7.1 CEC control register (CEC_CR)

Address offset: 0x00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXEOM	TXSOM	CECEN
													rs	rs	rw

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **TXEOM***:* Tx end of message

The TXEOM bit is set by software to command transmission of the last byte of a CEC message.
TXEOM is cleared by hardware at the same time and under the same conditions as for TXSOM.
0: TXDR data byte is transmitted with EOM = 0
1: TXDR data byte is transmitted with EOM = 1

Note: TXEOM must be set when CECEN = 1.

TXEOM must be set before writing transmission data to TXDR.

If TXEOM is set when TXSOM = 0, transmitted message consists of 1 byte (HEADER) only (PING message).

Bit 1 **TXSOM**: Tx start of message

TXSOM is set by software to command transmission of the first byte of a CEC message. If the CEC message consists of only one byte, TXEOM must be set before of TXSOM.
Start-bit is effectively started on the CEC line after SFT is counted. If TXSOM is set while a message reception is ongoing, transmission starts after the end of reception.
TXSOM is cleared by hardware after the last byte of the message is sent with a positive acknowledge (TXEND = 1), in case of transmission underrun (TXUDR = 1), negative acknowledge (TXACKE = 1), and transmission error (TXERR = 1). It is also cleared by CECEN = 0. It is not cleared and transmission is automatically retried in case of arbitration lost (ARBLST = 1).
TXSOM can be also used as a status bit informing application whether any transmission request is pending or under execution. The application can abort a transmission request at any time by clearing the CECEN bit.
0: No CEC transmission is on-going
1: CEC transmission command

Note: TXSOM must be set when CECEN = 1.

TXSOM must be set when transmission data is available into TXDR.

HEADER first four bits containing own peripheral address are taken from TXDR[7:4], not from CEC_CFGR.OAR that is used only for reception.

Bit 0 **CECEN:** CEC enable

The CECEN bit is set and cleared by software. CECEN = 1 starts message reception and enables the TXSOM control. CECEN = 0 disables the CEC peripheral, clears all bits of CEC_CR register and aborts any on-going reception or transmission.

0: CEC peripheral is off.

1: CEC peripheral is on.

64.7.2 CEC configuration register (CEC_CFGR)

This register is used to configure the HDMI-CEC controller.

Address offset: 0x04

Reset value: 0x0000 0000

Caution: It is mandatory to write CEC_CFGR only when CECEN = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
LSTN	OAR[14:0]														
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	SFT OP	BRDN OGEN	LBPE GEN	BRE GEN	BRE STP	RX TOL	SFT[2:0]		
							rw	rw	rw	rw	rw	rw	rw	rw	rw

Bit 31 **LSTN:** Listen mode

LSTN bit is set and cleared by software.

0: CEC peripheral receives only message addressed to its own address (OAR). Messages addressed to different destination are ignored. Broadcast messages are always received.

1: CEC peripheral receives messages addressed to its own address (OAR) with positive acknowledge. Messages addressed to different destination are received, but without interfering with the CEC bus: no acknowledge sent.

Bits 30:16 **OAR[14:0]:** Own addresses configuration

The OAR bits are set by software to select which destination logical addresses has to be considered in receive mode. Each bit, when set, enables the CEC logical address identified by the given bit position.

At the end of HEADER reception, the received destination address is compared with the enabled addresses. In case of matching address, the incoming message is acknowledged and received. In case of non-matching address, the incoming message is received only in listen mode (LSTN = 1), but without acknowledge sent. Broadcast messages are always received.

Example:

OAR = 0b000 0000 0010 0001 means that CEC acknowledges addresses 0x0 and 0x5. Consequently, each message directed to one of these addresses is received.

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **SFTOP**: SFT option bit

The SFTOPT bit is set and cleared by software.

0: SFT timer starts when TXSOM is set by software.

1: SFT timer starts automatically at the end of message transmission/reception.

Bit 7 **BRDNOGEN:** Avoid error-bit generation in broadcast

The BRDNOGEN bit is set and cleared by software.

0: BRE detection with BRESTP = 1 and BREGEN = 0 on a broadcast message generates an error-bit on the CEC line. LBPE detection with LBPEGEN = 0 on a broadcast message generates an error-bit on the CEC line.

1: Error-bit is not generated in the same condition as above. An error-bit is not generated even in case of an SBPE detection in a broadcast message if listen mode is set.

Bit 6 **LBPEGEN:** Generate error-bit on long bit period error

The LBPEGEN bit is set and cleared by software.

0: LBPE detection does not generate an error-bit on the CEC line.

1: LBPE detection generates an error-bit on the CEC line.

Note: If BRDNOGEN = 0, an error-bit is generated upon LBPE detection in broadcast even if LBPEGEN = 0.

Bit 5 **BREGEN:** Generate error-bit on bit rising error

The BREGEN bit is set and cleared by software.

0: BRE detection does not generate an error-bit on the CEC line.

1: BRE detection generates an error-bit on the CEC line (if BRESTP is set).

Note: If BRDNOGEN = 0, an error-bit is generated upon BRE detection with BRESTP = 1 in broadcast even if BREGEN = 0.

Bit 4 **BRESTP**: Rx-stop on bit rising error

The BRESTP bit is set and cleared by software.

0: BRE detection does not stop reception of the CEC message. Data bit is sampled at 1.05 ms.

1: BRE detection stops message reception.

Bit 3 **RXTOL:** Rx-tolerance

The RXTOL bit is set and cleared by software.

0: Standard tolerance margin:

- Start-bit, +/- 200 µs rise, +/- 200 µs fall
- Data-bit: +/- 200 µs rise. +/- 350 µs fall

1: Extended tolerance

- Start-bit: +/- 400 µs rise, +/- 400 µs fall
- Data-bit: +/-300 µs rise, +/- 500 µs fall

Bits 2:0 **SFT[2:0]**: Signal free time

SFT bits are set by software. In the SFT = 0x0 configuration, the number of nominal data bit periods waited before transmission is ruled by hardware according to the transmission history. In all the other configurations the SFT number is determined by software.

0x0

- 2.5 data-bit periods if CEC is the last bus initiator with unsuccessful transmission (ARBLST = 1, TXERR = 1, TXUDR = 1 or TXACKE = 1)
- 4 data-bit periods if CEC is the new bus initiator
- 6 data-bit periods if CEC is the last bus initiator with successful transmission (TXEOM = 1)

0x1: 0.5 nominal data bit periods

0x2: 1.5 nominal data bit periods

0x3: 2.5 nominal data bit periods

0x4: 3.5 nominal data bit periods

0x5: 4.5 nominal data bit periods

0x6: 5.5 nominal data bit periods

0x7: 6.5 nominal data bit periods

64.7.3 CEC Tx data register (CEC_TXDR)

Address offset: 0x8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXD[7:0]							
								w	w	w	w	w	w	w	w

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **TXD[7:0]**: Tx data

TXD is a write-only register containing the data byte to be transmitted.

64.7.4 CEC Rx data register (CEC_RXDR)

Address offset: 0xC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXD[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **RXD[7:0]**: Rx data

RXD is read-only and contains the last data byte that has been received from the CEC line.

64.7.5 CEC interrupt and status register (CEC_ISR)

Address offset: 0x10

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	TX ACKE	TX ERR	TX UDR	TX END	TXBR	ARB LST	RX ACKE	LBPE	SBPE	BRE	RX OVR	RX END	RXBR
			rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:13 Reserved, must be kept at reset value.

Bit 12 **TXACKE:** Tx-missing acknowledge error

In transmission mode, TXACKE is set by hardware to inform application that no acknowledge was received. In case of broadcast transmission, TXACKE informs application that a negative acknowledge was received. TXACKE aborts message transmission and clears TXSOM and TXEOM controls.

TXACKE is cleared by software write at 1.

Bit 11 **TXERR:** Tx-error

In transmission mode, TXERR is set by hardware if the CEC initiator detects low impedance on the CEC line while it is released. TXERR aborts message transmission and clears TXSOM and TXEOM controls.

TXERR is cleared by software write at 1.

Bit 10 **TXUDR:** Tx-buffer underrun

In transmission mode, TXUDR is set by hardware if application was not in time to load TXDR before of next byte transmission. TXUDR aborts message transmission and clears TXSOM and TXEOM control bits.

TXUDR is cleared by software write at 1

Bit 9 **TXEND:** End of transmission

TXEND is set by hardware to inform application that the last byte of the CEC message has been successfully transmitted. TXEND clears the TXSOM and TXEOM control bits.

TXEND is cleared by software write at 1.

Bit 8 **TXBR:** Tx-byte request

TXBR is set by hardware to inform application that the next transmission data has to be written to TXDR. TXBR is set when the 4th bit of currently transmitted byte is sent. Application must write the next byte to TXDR within six nominal data-bit periods before transmission underrun error occurs (TXUDR).

TXBR is cleared by software write at 1.

Bit 7 **ARBLST:** Arbitration lost

ARBLST is set by hardware to inform application that CEC device is switching to reception due to arbitration lost event following the TXSOM command. ARBLST can be due either to a contending CEC device starting earlier or starting at the same time but with higher HEADER priority. After ARBLST assertion TXSOM bit keeps pending for next transmission attempt.

ARBLST is cleared by software write at 1.

Bit 6 **RXACKE:** Rx-missing acknowledge

In receive mode, RXACKE is set by hardware to inform application that no acknowledge was seen on the CEC line. RXACKE applies only for broadcast messages and in listen mode also for not directly addressed messages (destination address not enabled in OAR). RXACKE aborts message reception.

RXACKE is cleared by software write at 1.

Bit 5 **LBPE:** Rx-long bit period error

LBPE is set by hardware in case a data-bit waveform is detected with long bit period error. LBPE is set at the end of the maximum bit-extension tolerance allowed by RXTOL, in case falling edge is still longing. LBPE always stops reception of the CEC message. LBPE generates an error-bit on the CEC line if LBPEGEN = 1. In case of broadcast, error-bit is generated even in case of LBPEGEN = 0.

LBPE is cleared by software write at 1.

Bit 4 **SBPE:** Rx-short bit period error

SBPE is set by hardware in case a data-bit waveform is detected with short bit period error. SBPE is set at the time the anticipated falling edge occurs. SBPE generates an error-bit on the CEC line.
SBPE is cleared by software write at 1.

Bit 3 **BRE***:* Rx-bit rising error

BRE is set by hardware in case a data-bit waveform is detected with bit rising error. BRE is set either at the time the misplaced rising edge occurs, or at the end of the maximum BRE tolerance allowed by RXTOL, in case rising edge is still longing. BRE stops message reception if BRESTP = 1. BRE generates an error-bit on the CEC line if BREGEN = 1.
BRE is cleared by software write at 1.

Bit 2 **RXOVR***:* Rx-overrun

RXOVR is set by hardware if RXBR is not yet cleared at the time a new byte is received on the CEC line and stored into RXD. RXOVR assertion stops message reception so that no acknowledge is sent. In case of broadcast, a negative acknowledge is sent.
RXOVR is cleared by software write at 1.

Bit 1 **RXEND***:* End of reception

RXEND is set by hardware to inform application that the last byte of a CEC message is received from the CEC line and stored into the RXD buffer. RXEND is set at the same time of RXBR.
RXEND is cleared by software write at 1.

Bit 0 **RXBR***:* Rx-byte received

The RXBR bit is set by hardware to inform application that a new byte has been received from the CEC line and stored into the RXD buffer.
RXBR is cleared by software write at 1.

64.7.6 CEC interrupt enable register (CEC_IER)

Address offset: 0x14

Reset value: 0x0000 0000

Caution: It is mandatory to write CEC_IER only when CECEN = 0.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	TXACKIE	TXERRIE	TXUDRIE	TXENDIE	TXBRIE	ARBLSTIE	RXACKIE	LBPEIE	SBPEIE	BREIE	RXOVRIE	RXENDIE	RXBRIE
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bit 12 **TXACKIE***:* Tx-missing acknowledge error interrupt enable

The TXACKEIE bit is set and cleared by software.
0: TXACKE interrupt disabled
1: TXACKE interrupt enabled

Bit 11 **TXERRIE***:* Tx-error interrupt enable

The TXERRIE bit is set and cleared by software.
0: TXERR interrupt disabled
1: TXERR interrupt enabled

Bit 10 **TXUDRIE***:* Tx-underrun interrupt enable
The TXUDRIE bit is set and cleared by software.
0: TXUDR interrupt disabled
1: TXUDR interrupt enabled

Bit 9 **TXENDIE***:* Tx-end of message interrupt enable
The TXENDIE bit is set and cleared by software.
0: TXEND interrupt disabled
1: TXEND interrupt enabled

Bit 8 **TXBRIE***:* Tx-byte request interrupt enable
The TXBRIE bit is set and cleared by software.
0: TXBR interrupt disabled
1: TXBR interrupt enabled

Bit 7 **ARBLSTIE***:* Arbitration lost interrupt enable
The ARBLSTIE bit is set and cleared by software.
0: ARBLST interrupt disabled
1: ARBLST interrupt enabled

Bit 6 **RXACKIE***:* Rx-missing acknowledge error interrupt enable
The RXACKIE bit is set and cleared by software.
0: RXACKE interrupt disabled
1: RXACKE interrupt enabled

Bit 5 **LBPEIE***:* Long bit period error interrupt enable
The LBPEIE bit is set and cleared by software.
0: LBPE interrupt disabled
1: LBPE interrupt enabled

Bit 4 **SBPEIE***:* Short bit period error interrupt enable
The SBPEIE bit is set and cleared by software.
0: SBPE interrupt disabled
1: SBPE interrupt enabled

Bit 3 **BREIE***:* Bit rising error interrupt enable
The BREIE bit is set and cleared by software.
0: BRE interrupt disabled
1: BRE interrupt enabled

Bit 2 **RXOVRIE***:* Rx-buffer overrun interrupt enable
The RXOVRIE bit is set and cleared by software.
0: RXOVR interrupt disabled
1: RXOVR interrupt enabled

Bit 1 **RXENDIE***:* End of reception interrupt enable
The RXENDIE bit is set and cleared by software.
0: RXEND interrupt disabled
1: RXEND interrupt enabled

Bit 0 **RXBRIE***:* Rx-byte received interrupt enable
The RXBRIE bit is set and cleared by software.
0: RXBR interrupt disabled
1: RXBR interrupt enabled

64.7.7 HDMI-CEC register map

The following table summarizes the HDMI-CEC registers.

Table 613. HDMI-CEC register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**CEC_CR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXEOM	TXSOM	CECEN
	Reset value																														0	0	0
0x04	**CEC_CFGR**	LSTN	OAR[14:0]															Res.	Res.	Res.	Res.	Res.	Res.	Res.	SFTOPT	BRDNOGEN	LBPEGEN	BREGEN	BRESTP	RXTOL	SFT[2:0]		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								0	0	0	0	0	0	0	0	0
0x08	**CEC_TXDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXD[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x0C	**CEC_RXDR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RXD[7:0]							
	Reset value																									0	0	0	0	0	0	0	0
0x10	**CEC_ISR**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXACKE	TXERR	TXUDR	TXEND	TXBR	ARBLST	RXACKE	LBPE	SBPE	BRE	RXOVR	RXEND	RXBR
	Reset value																				0	0	0	0	0	0	0	0	0	0	0	0	0
0x14	**CEC_IER**	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TXACKIE	TXERRIE	TXUDRIE	TXENDIE	TXBRIE	ARBLSTIE	RXACKIE	LBPEIE	SBPEIE	BREIE	RXOVRIE	RXENDIE	RXBRIE
	Reset value																				0	0	0	0	0	0	0	0	0	0	0	0	0

Refer to *Section 2.3* for the register boundary addresses.

65 Debug infrastructure

65.1 Introduction

The debug infrastructure allows software designers to debug and trace their embedded software.

The debug features can be controlled via a JTAG/Serial-wire debug access port, using industry standard debugging tools. A trace port allows data to be captured for logging and analysis.

The trace and debug system is designed to support a variety of typical use cases:

- **Low cost trace**

  Limited trace capability is available over the single-wire debug output. This supports code instrumentation using “printf”, tracing of data and address watchpoints, interrupt detection and program counter sampling. Single-wire trace can be maintained even when the processor is switched off or clock-stopped.

- **Breakpoint debugging**

  The processor can be debugged using equipment connected to the JTAG/SWD debug port. This allows breakpoint and watchpoint setting, code stepping, memory access and so on.

- **Tracing code execution via the trace port**

  Trace information is combined into a single trace stream and output to a trace port analyzer in real time. An ID embedded in the trace allows the analyzer to identify the source of each information packet.

- **Continuous trace capturing in a circular buffer**

  Instead of streaming it off-chip, the combined trace information can be stored on-chip in a circular buffer. The trace storage can be started and stopped by different means such as a debugger command, a software command, an external trigger signal, an internal event, and so on.

- **Draining the buffer to the trace port**

  The stored trace can be dumped off-chip to the trace port analyzer. The buffer draining can be initiated by the debugger, software, external trigger, internal event and so on.

- **Reading the buffer with the debugger**

  The debugger can read the contents of the trace buffer via the debug port. This is slower than the trace port, but allows basic trace functionality on the debugger without the cost of a trace port analyzer.

- **Analyzing stored trace in software**

  The trace buffer can be read by the processor core, or transferred into system memory by DMA. This powerful feature allows built-in test software to monitor code execution in real time, analyze and identify faults, handle exceptions autonomously, and so on.

- **Uploading stored trace**

  The stored trace can also be uploaded to a host machine using one of the MCU’s many communication interfaces (USB, USART, SPI, I2C, Ethernet, CAN and so on). This is especially useful if the trace port is not accessible, for example remote monitoring and failure analysis of a deployed product.

65.2 Debug infrastructure features

A comprehensive set of trace and debug features is provided to support software development and system integration:

- Breakpoint debugging
- Code execution tracing
- Software instrumentation
- Cross-triggering
- JTAG debug port
- Serial-wire debug port
- Trigger input and output
- Serial-wire trace port
- Trace port
- Arm® CoreSight™ debug and trace components.

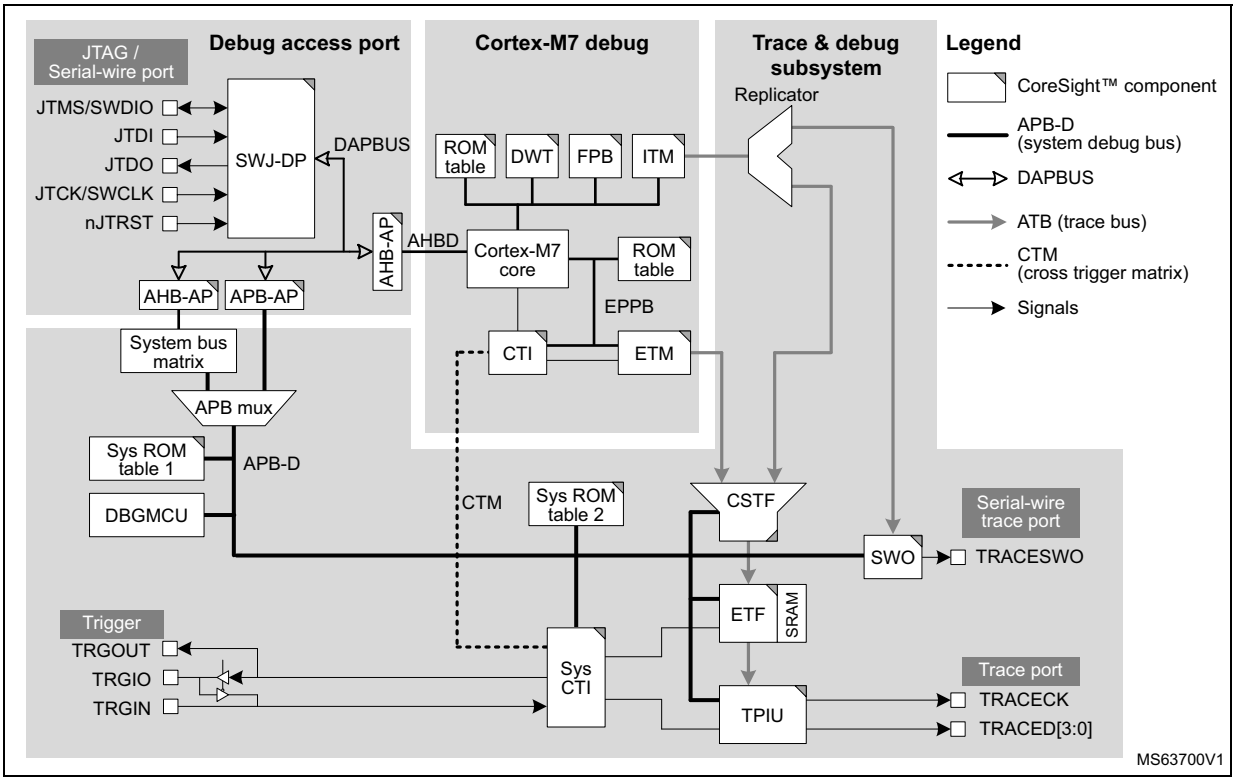
The CoreSight components are described at high level in this document. Detailed information is available in the Arm® documents referenced in *Section 65.7*.

65.3 Debug infrastructure functional description

65.3.1 Debug infrastructure block diagram

The block diagram shows the logical partitioning of the debug infrastructure.

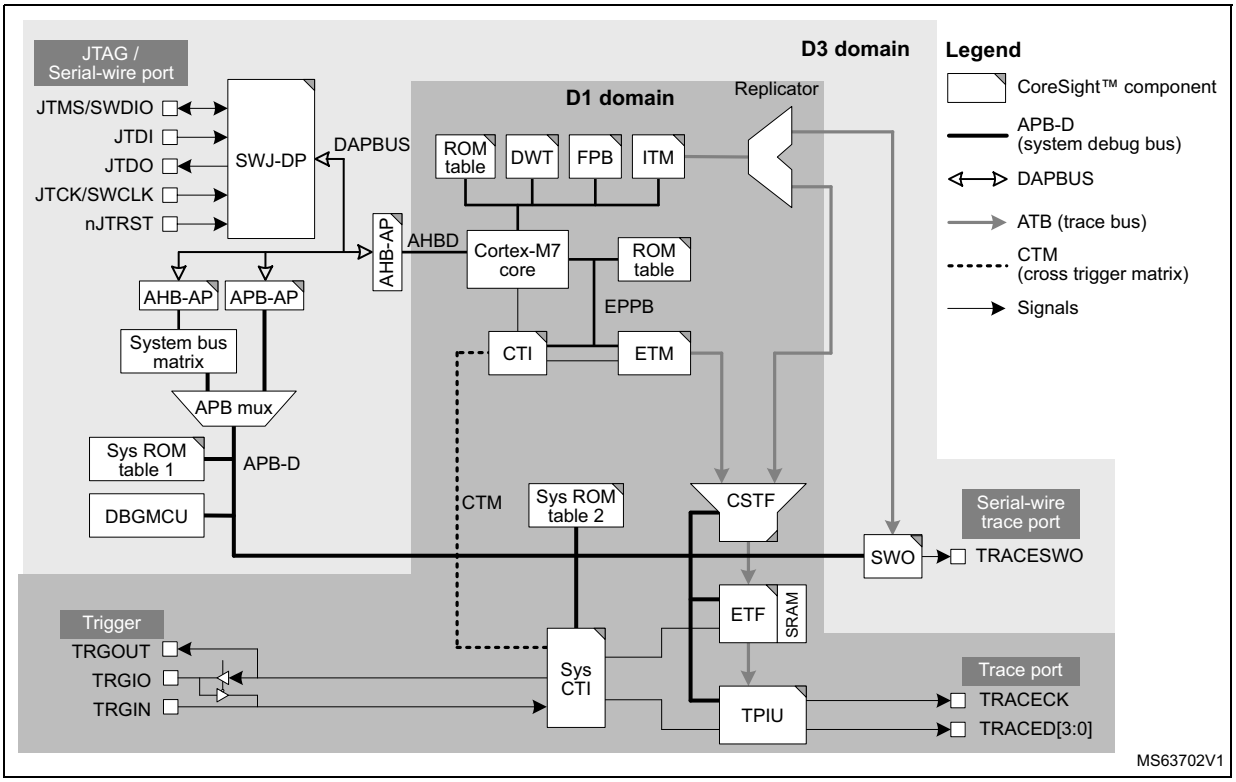
Figure 856. Block diagram of debug infrastructure



65.3.2 Debug infrastructure powering, clocking and reset

Power domains

Figure 857. Power domains of debug infrastructure

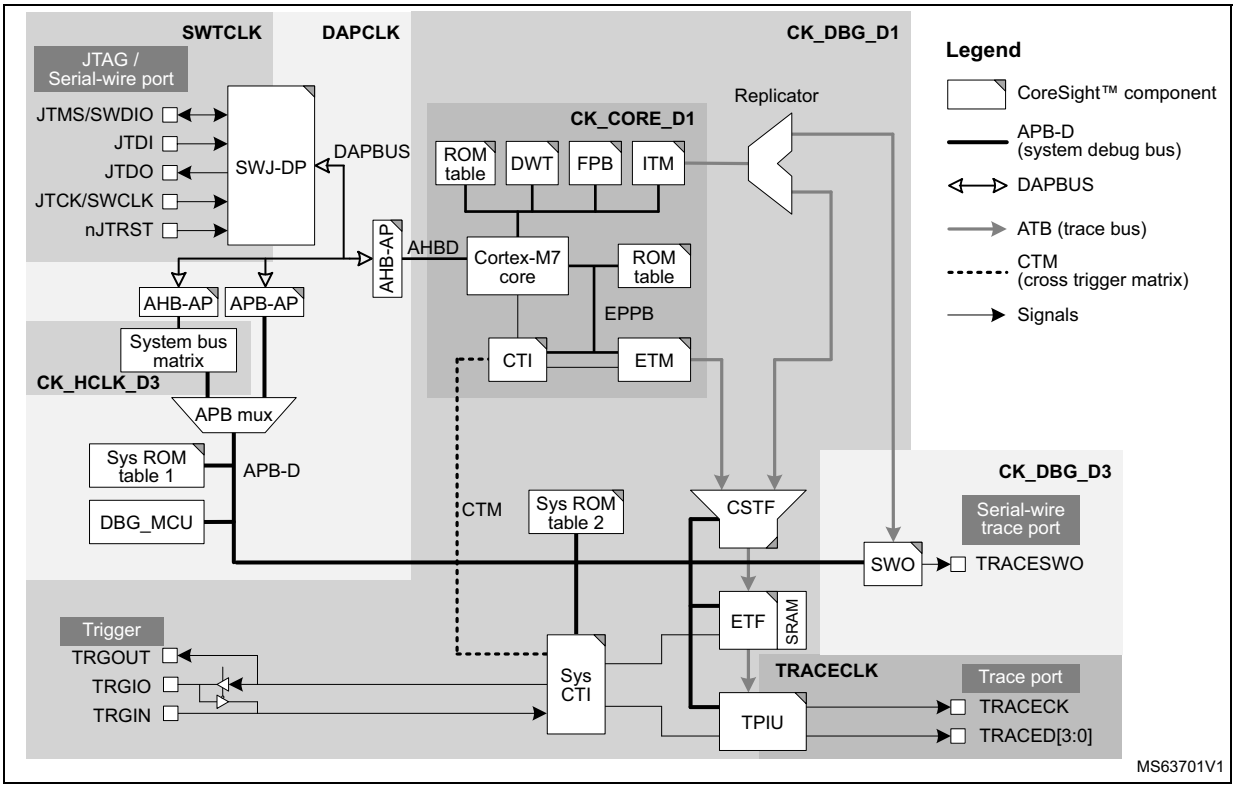


The debug components are distributed across the power domains D1 and D3. The D3 power domain is always considered on when the debugger is connected. It therefore contains the SWJ-DP, so that the debugger does not lose the connection with the SoC when the other power domain is switched off. In addition, it contains the DBGMCU and the serial wire trace features.

The D1 power domain contains the Cortex-M7 core and the associated debug and trace components. It also contains the system trace components located on the APB-D. This power domain therefore needs to be on whenever a debug access to the Cortex-M7 is required, or whenever a trace functionality is active on the processor.

Clock domains

Figure 858. Clock domains of debug infrastructure



The debugger supplies the clock for the debug port, SWTCLK, via the debug interface pin, JTCK/SWCLK. This clock is used to register the serial input data in both serial wire and JTAG mode, as well as to operate the state machines and internal logic of the debug port. It must therefore continue to toggle for several cycles after the end of an access, to ensure that the debug port returns to the idle state.

The SWJ-DP contains an asynchronous interface to the DAPCLK domain, which covers the rest of the SWJ-DP and the access ports. The DBGMCU and System ROM table 1 are also in the DAPCLK domain.

CK_DBG_D3 clocks the SWO.

Both DAPCLK and CK_DBG_D3 are gated versions of the D3 domain system clock (rcc_hclk4).

CK_DBG_D1 clocks the trace components in the D1 power domain: System ROM table 2, CoreSight trace funnel, ETF, system CTI and TPIU. It is a gated version of the D1 domain system clock (rcc_hclk3).

TRACECLK is the trace port output clock. It is a gated version of the system clock (sys_ck), except when the PLL1 is the source for the system clock. In this case, TRACECLK is derived directly from the pll1_r_ck output. This is required in order to support the high data throughput on the trace port when the processor operates at its maximum frequency.

All the debug clocks (except DAPCLK) can be enabled and disabled by register bits in the DBGMCU. The DAPCLK domain is enabled by the debugger using the CDBGPWRUPREQ bit in the debug port CTRL/STAT register. The clock must be enabled before the debugger

can access any of the debug features on the device. It should be disabled at power up and when the debugger is disconnected, to avoid wasting energy.

The debug and trace components included in the processor (ETM ITM, DWG, FPB and so on) are clocked with the corresponding core clock (rcc_c_ck).

Debug with low-power modes

The device includes power-saving features allowing individual power domains to be switched off or stopped when not required. If a power domain is switched off or not clocked, all debug components in that domain are inaccessible to the debugger. To avoid this, power saving mode emulation is implemented. If the emulation is enabled for a domain, the domain still enters power saving mode, but its clock and power are maintained. In other words, the domain behaves as if it is in power saving mode, while the debugger does not lose the connection.

The emulation mode is programmed in the MCU Debug (DBGMCU) unit. For more information, refer to *Section 65.5.7*

Reset of debug infrastructure

The debug components, except for the debug port and access ports, are reset by their respective power domain resets. The debug port (SWJ-DP) is reset by a power-on reset of the D3 domain only.

65.4 Debug access port functional description

The debug access port (DAP) is a debug subsystem comprising serial-wire and JTAG debug port (SWJ-DP) and three access ports.

65.4.1 Serial-wire and JTAG debug port (SWJ-DP)

The SWJ-DP is a CoreSight component that implements an external access port for connecting debugging equipment.

The port can be configured as:

- a 5-pin standard JTAG debug port (JTAG-DP)
- a 2-pin (clock + data) “serial-wire” debug port (SW-DP)

The two modes are mutually exclusive, since they share the same IO pins.

By default, the JTAG-DP is selected on system or power-on reset. The five IOs are configured by hardware in debug alternative function mode. The SWJ-DP incorporates pull-up resistors on the JTDI, JTMS/SWDIO, and nJTRST lines, as well as a pull-down resistor on the JTCK/SWCLK line.

A debugger can select the SW-DP by transmitting the following serial data sequence on JTMS/SWDIO:

...,(50 or more ones),...,0,1,1,1,1,1,0,0,1,1,1,1,1,0,0,1,1,1,...,(50 or more ones),...

JTCK/SWCLK must be cycled for each data bit.

In SW-DP mode, the unused JTAG lines JTDI, JTDO and nJTRST can be used for other functions.

All SWJ port IOs can be reconfigured to other functions by software, in which case debugging is no longer possible.

Serial wire debug port

The serial wire debug protocol uses two pins:

- SWCLK: clock from host to target
- SWDIO: bi-directional serial data

Serial data is transferred LSB first, synchronously with the clock. A transfer comprises three phases:

1. packet request (8 bits) transmitted by the host
2. acknowledge response (3 bits) transmitted by the target
3. data transfer (33 bits) transmitted by the host (in the case of a write) or target (in the case of a read)

The data transfer only occurs if the acknowledge response is OK.

If the direction of the data is reversed between each phase, a single clock cycle turn-around time is inserted.

Table 614. Packet request

Field bits	Name	Description
0	Start	Must be “1”
1	APnDP	0: DP register access - see *Table 618* for a list of DP registers 1: AP register access - see *Section 65.4.2*
2	RnW	0: Write request 1: Read request
4:3	A(3:2)	Address field of the DP or AP register (refer to *Table 618* and *Table 619*)
5	Parity	Single bit parity of preceding bits
6	Stop	0
7	Park	Not driven by host. Must be read as “1” by target.

Table 615. ACK response

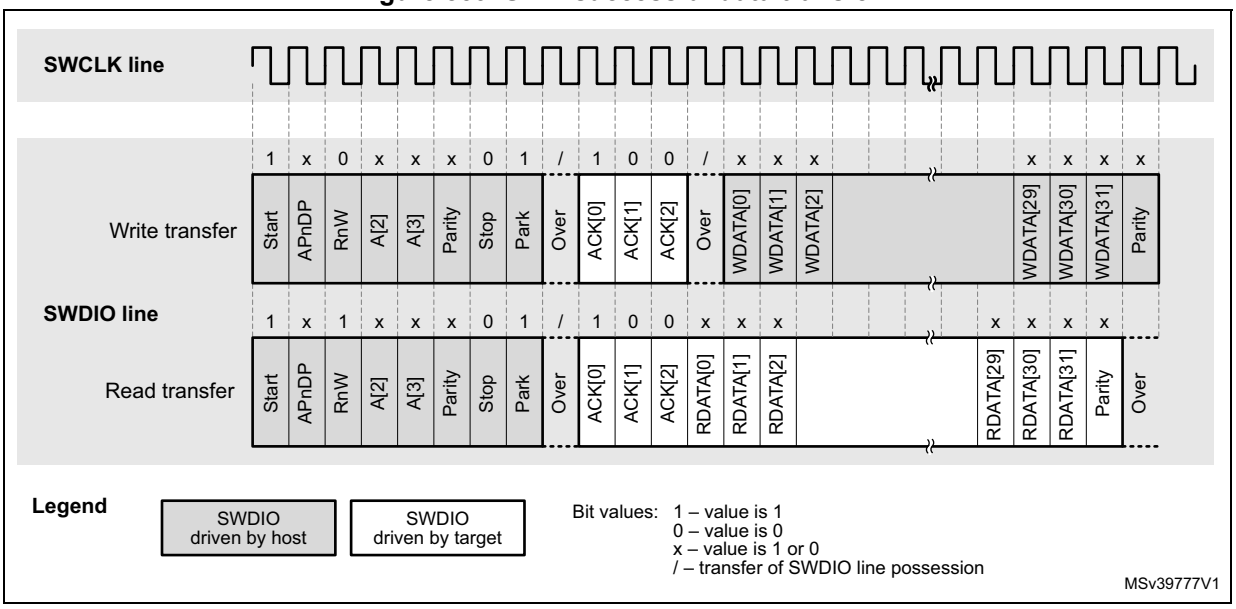
Field bits	Name	Description
2:0	ACK	000b: Fault 010b: Wait 100b: OK

Table 616. Data transfer

Bit field	Name	Description
31:0	WDATA or RDATA	Write or Read data
32	Parity	Single bit parity of 32 data bits

Figure 859 shows successful write and read transfers.

Figure 859. SWD successful data transfer



For any FAULT or WAIT ACK response from the target, the data transfer phase is canceled, unless overrun detection is enabled, in which case the data is be ignored by the target (in the case of a write), or not driven (in the case of a read).

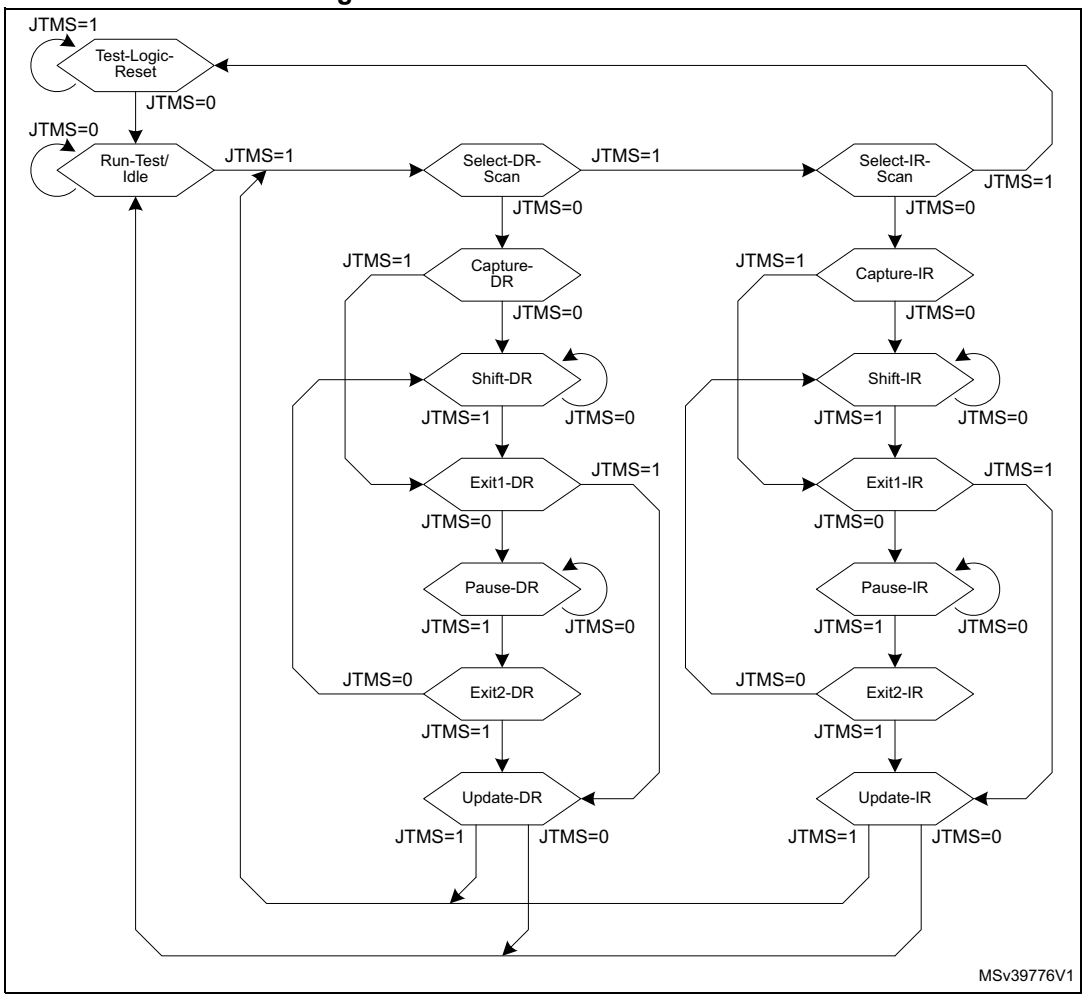
A line reset must be generated by the host when it is first connected, or following a protocol error. The line reset consists of 50 or more SWCLK cycles with SWDIO high, followed by two SWCLK cycles with SWDIO low.

For more details on the Serial Wire debug protocol, refer to the Arm® Debug Interface Architecture Specification *[1]*.

Note: The SWJ-DP implements SWD protocol version 2.

JTAG debug port

Figure 860. JTAG TAP state machine



The JTAG-DP implements a TAP state machine (TAPSM) based on IEEE 1149.1-1990. The state machine is shown in *Figure 860*. It controls two scan chains, one associated with an instruction register (IR) and one with a number of data registers (DR).

When the TAPSM goes through the Capture-IR state, 0b0001 is transferred into the instruction register (IR) scan chain. The IR scan chain is connected between JTDI and JTDO.

While the TAPSM is in the Shift-IR state, the IR scan chain shifts one bit for each rising edge of JTCK. This means that on the first tick:

- The LSB of the IR scan chain is output on JTDO
- Bit [n] of the IR scan chain is transferred to bit [n-1]
- The value on JTDI is transferred to the MSB of the IR scan chain.

When the TAPSM goes through the Update-IR state, the value scanned in the IR scan chain is transferred to the instruction register.

When the TAPSM goes through the Capture-DR state, a value is transferred from one of the data registers onto one of the DR scan chains, connected between JTDI and JTDO.

The value held in the instruction register determines which data register, and associated DR scan chain, is selected.

This data is then shifted while the TAPSM is in the Shift-DR state, in the same way as the IR shift in the Shift-IR state.

When the TAPSM goes through the Update-DR state, the value scanned in the DR scan chain is transferred to the selected data register.

When the TAPSM is in the Run-Test/Idle state, no special actions occur. The IDCODE instruction is loaded in IR.

When active, the nJTRST signal resets the state machine asynchronously to the Test-Logic-Reset state.

The data registers corresponding to the 4-bit IR instructions are listed in *Table 617*.

Table 617. JTAG-DP data registers

Instruction register	Data register	Scan chain length	Description
0000 to 0111	(BYPASS)	1	Not implemented: BYPASS selected
1000	ABORT	35	**Abort register** – Bits 31:1 = reserved – Bit 0 = APABORT: write 1 to generate an AP abort
1001	(BYPASS)	1	Reserved: BYPASS selected
1010	DPACC	35	**Debug port access register** Initiates the debug port and allows access to a debug port register. – When transferring data IN: Bits 34:3 = DATA[31:0] = 32-bit data to transfer for a write request Bits 2:1 = A[3:2] = 2-bit address of a debug port register. Bit 0 = RnW = Read request (1) or write request (0). – When transferring data OUT: Bits 34:3 = DATA[31:0] = 32-bit data which is read following a read request Bits 2:0 = ACK[2:0] = 3-bit Acknowledge: 010b = OK/fault 001b = Wait Other = reserved

Table 617. JTAG-DP data registers (continued)

Instruction register	Data register	Scan chain length	Description
1011	APACC	35	**Access port access register** Initiates an access port and allows access to an access port register. – When transferring data IN: Bits 34:3 = DATA[31:0] = 32-bit data to shift in for a write request Bits 2:1 = A[3:2] = 2-bit sub-address of an access port register. Bit 0 = RnW= Read request (1) or write request (0). – When transferring data OUT: Bits 34:3 = DATA[31:0] = 32-bit data which is read following a read request Bits 2:0 = ACK[2:0] = 3-bit Acknowledge: 010b = OK/Fault 001b = Wait Other = reserved
1100	(BYPASS)	1	Reserved: BYPASS selected
1101	(BYPASS)	1	Reserved: BYPASS selected
1110	IDCODE	32	**ID Code** 0x6BA00477: Arm® JTAG debug port ID code
1111	BYPASS	1	**Bypass** A single JTCK cycle delay is inserted between JTDI and JTDO

The DR registers are described in more detail in the Arm® Debug Interface Architecture Specification *[1]*.

Debug port registers

The SW-DP and JTAG-DP both access the debug port (DP) registers. These are listed in *Table 618*.

The debugger can access the DP registers as follows:

1. Program the SELECT register DPBANKSEL field in the DP to select the register bank to be accessed (see *Table 618*)
2. Program the A(3:2) field in the DPACC register, if using JTAG, with the register address within the bank. Program the R/W bit to select a read or a write. In the case of a write, program the DATA field with the write data. If using SWD, the A(3:2) and R/W fields are part of the Packet Request word sent to the SW-DP with the APnDP bit reset (see *Table 614*). The write data is sent in the data phase.

Table 618. Debug port registers

Address	A(3:2) field value	R/W	Description
0x0	00	R	DP_DPIDR register(2). Contains the IDCODE for the debug port.
		W	DP_ABORT register(1). Aborts the current AP transaction. This register is also used to clear the error flags in the DP_CTRL/STAT register.
0x4	01	R/W	If DPBANKSEL[3:0] = 0x0 (DP_SELECT register): CTRL/STAT register. Controls the DP and provides status information.
			If DPBANKSEL[3:0] = 0x1 (DP_SELECT register): DP_DLCR register(2). Controls the operating mode of the SWD Data Link.
			If DPBANKSEL[3:0] = 0x2 (DP_SELECT register): DP_TARGETID register. Provides target identification information.
			If DPBANKSEL[3:0] = 0x3 (DP_SELECT register): DLPIDR register(2). Provides the SWD protocol version.
0x8	10	R	RESEND register(2). Returns the value that was returned by the last AP read or DP_RDBUFF read, used in the event of a corrupted read transfer.
		W	DP_SELECT register. Selects the access port, access port register bank, and DP register at address 0x4.
0xC	11	R	DP_RDBUFF register Via JTAG-DP, enables the debugger to get the final result after a sequence of operations (without requesting new JTAG-DP operation). Via SW-DP, contains the result of the preceding AP read access, allowing a new AP access to be avoided.
		W	DP_TARGETSEL register(2). On a write to DP_TARGETSEL immediately following a line reset sequence, the target is selected if the following conditions are both met: – Bits [31:28] match bits [31:28] in the DP_DLPIDR register. – Bits [27:0] match bits [27:0] in the DP_TARGETID register. Writing any other value deselects the target. Debug tools must write 0xFFFFFFFF to deselect all targets. This is an invalid DP_TARGETID value. All other invalid DP_TARGETID values are reserved.

1. Access to the AP ABORT register from the JTAG-DP is done using the ABORT instruction.
2. Only accessible via SW-DP. Register is “reserved” via JTAG-DP.

Debug port identification register (DP_DPIDR)

Address offset: 0x00

Reset value: 0x6BA0 2477

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REVISION[3:0]				PARTNO[7:0]								Res.	Res.	Res.	MIN
r	r	r	r	r	r	r	r	r	r	r	r				r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VERSION[3:0]				DESIGNER[10:0]											Res.
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	

Bits 31:28 **REVISION[3:0]**: Revision code
0x6

Bits 27:20 **PARTNO[7:0]**: Debug port part number
0xBA

Bits 19:17 Reserved, must be kept at reset value.

Bit 16 **MIN**: Minimal debug port (MINDP) implementation
0: MINDP not implemented (transaction counter and pushed operations are supported)

Bits 15:12 **VERSION[3:0]**: DP architecture version
0x2: DPv2

Bits 11:1 **DESIGNER[10:0]**: JEDEC designer identity code
0x23B: Arm®

Bit 0 Reserved, must be kept at reset value.

Debug port abort register (DP_ABORT)

Address offset: 0x0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	ORUNERRCLR	WDERRCLR	STKERRCLR	STKCMPCLR	DAPABORT
											w	w	w	w	w

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **ORUNERRCLR**: Overrun error clear bit
0: No effect
1: Clear CTRL/STAT register's STICKYORUN bit

Bit 3 **WDERRCLR**: Write data error clear bit
0: No effect
1: Clear CTRL/STAT register's WDATAERR bit

Bit 2 **STKERRCLR**: Sticky error clear bit
0: No effect
1: Clear CTRL/STAT register's STICKYERR bit

Bit 1 **STKCMPCLR**: Sticky compare clear bit
0: No effect
1: Clear CTRL/STAT register's STICKYCMP bit

Bit 0 **DAPABORT**: Abort current AP transaction
The transaction is aborted if an excessive number of WAIT responses are returned, indicating that the transaction has stalled.
0: No effect
1: Abort transaction

Debug port control/status register (DP_CTRL/STAT)

Address offset: 0x4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CSYSPWRUPACK	CSYSPWRUPREQ	CDBGPWRUPACK	CDBGPWRUPREQ	CDBGRSTACK	CDBGRSTREQ	Res.	Res.	TRNCNT[11:4]							
r	rw	r	rw	r	rw			rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRNCNT[3:0]				MASKLANE[3:0]				WDATAERR	READOK	STICKYERR	STICKYCMP	TRNMODE[1:0]		STICKYORUN	ORUNDETECT
rw	rw	rw	rw	rw	rw	rw	rw	r	r	rw	w	w	w	w	w

Bit 31 **CSYSPWRUPACK**: System domain power-up status bit - not used in this device

Bit 30 **CSYSPWRUPREQ**: System domain power-up control bit - not used in this device

Bit 29 **CDBGPWRUPACK**: Debug domain power-up status bit
This bit is read-only. It returns the status of the debug domain power-up acknowledge signal from the power controller.

0: domain powered down
1: domain powered up

Bit 28 **CDBGPWRUPREQ:** Debug domain power-up/down control bit
This bit controls the debug domain power-up/down request signal to the power controller.

0: power-down requested
1: power-up requested

Bit 27 **CDBGRSTACK**: Debug domain reset status bit - not used in this device

Bit 26 **CDBGRSTREQ**: Debug domain reset control bit - not used in this device

Bits 25:24 Reserved, must be kept at reset value.

Bits 23:12 **TRNCNT[11:0]**: Transaction counter

To program a sequence of transactions to incremental addresses via an AP, TRNCNT bits are loaded with the number of transactions to perform. It is decremented on successful completion of each transaction.

Bits 11:8 **MASKLANE[3:0]**: Pushed-compare and pushed-verify masking bits

The field indicates the bytes to be masked in pushed-compare and pushed-verify operations (DP_CTRL/STAT register's field TRNMODE = 1 or 2). In the pushed operations, the word supplied in an AP write transaction is compared with the current value at the target AP address.

0b1XXX: include byte lane 3 in comparisons
0bX1XX: include byte lane 2 in comparisons
0bXX1X: include byte lane 1 in comparisons
0bXXX1: include byte lane 0 in comparisons

Bit 7 **WDATAERR**: Write data error in SW-DP

The bit indicates;

- a parity or a framing error on the data phase of a write operation, or
- a write operation that had been accepted by the DP has then been discarded without being submitted to the AP

This bit is read-only. It is reset by writing 1 to the WDERRCLR bit of the DP_ABORT register.

0: No error
1: Error has occurred

This bit is reserved in JTAG-DP.

Bit 6 **READOK**: AP read response in SW-DP

This bit indicates the response to the last AP read access. It is read-only.

0: Read not OK
1: Read OK

This bit is Reserved in JTAG-DP.

Bit 5 **STICKYERR**: Transaction error (read-only in SW-DP, R/W in JTAG-DP)

This bit indicates that an error occurred during an AP transaction.

0: No error
1: Error has occurred

In the SW-DP, this bit is reset by writing 1 to the STKERRCLR bit of the DP_ABORT register.
In the JTAG-DP, this bit is reset by programming it to 1.

Bit 4 **STICKYCMP**: Compare match (read-only in SW-DP, R/W in JTAG-DP)

This bit indicates that a match occurred in a pushed operation.

0: Match if TRNMODE = 0x1; no match if TRNMODE = 0x2
1: No match if TRNMODE = 0x1; match if TRNMODE = 0x2

In the SW-DP, this bit is reset by writing 1 to the STKCMPCLR bit in the DP_ABORT register.
In the JTAG-DP, this bit is reset by programming it to 1.

Bits 3:2 **TRNMODE[1:0]**: Transfer mode for AP write operations
For read operations, this field must be set to 0x0.

0x0: Normal operation - AP transactions are passed directly to the AP.
0x1: Pushed-verify operation. The DP stores the write data and performs a read transaction at the target AP address. The result of the read operation is compared with the stored data. If they do not match, the STICKYCMP bit is set.
0x2: Pushed-compare operation. The DP stores the write data and performs a read transaction at the target AP address. The result of the read is compared with the stored data. If they match, the STICKYCMP bit is set.
0x3: Reserved

In pushed operations, only the data bytes indicated by the MASKLANE field are included in the comparison.

Bit 1 **STICKYORUN:** Overrun (read-only in SW-DP, R/W in JTAG-DP)
This bit indicates that an overrun occurred (a new transaction received before previous transaction completed). This bit is only set if the ORUNDETECT bit is set.

0: No overrun
1: Overrun occurred

In the SW-DP, this bit is reset by writing 1 to the ABORT register's ORUNERRCLR bit. In the JTAG-DP, this bit is reset by writing a 1 to it.

Bit 0 **ORUNDETECT:** Overrun detection mode enable
0: Overrun detection disabled
1: Overrun detection enabled. In the event of an overrun, the STICKYORUN bit is set and subsequent transactions are blocked until the STICKYORUN bit is cleared.

Debug port data link control register (DP_DLCR)

Address offset: 0x4

Reset value: 0x0000 0040

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	TURNROUND[1:0]		Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
						rw	rw								

Bits 31:10 Reserved, must be kept at reset value.

Bits 9:8 **TURNROUND[1:0]**: Tristate period for SWDIO
0x0: 1 data bit period
0x1: 2 data bit periods
0x2: 3 data bit periods
0x3: 4 data bit periods

Bits 7:0 Reserved, must be kept at reset value.

Debug port target identification register (DP_TARGETID)

Address offset: 0x4

Reset value: 0x0483 0041

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TREVISION[3:0]				TPARTNO[15:4]											
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TPARTNO[3:0]				TDESIGNER[10:0]											Res.
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	

Bits 31:28 **TREVISION[3:0]**: Device revision number
0x0: revision 1

Bits 27:12 **TPARTNO[15:0]**: Target part number
0x4830: STM32H72x/3x

Bits 11:1 **TDESIGNER[10:0]**: Target designer JEDEC code
0x020: STMicroelectronics

Bit 0 Reserved, must be kept at reset value.

Debug port data link protocol identification register (DP_DLPIDR)

Address offset: 0x4

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TINSTANCE[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r												
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PROTSVN[3:0]			
												r	r	r	r

Bits 31:28 **TINSTANCE[3:0]**: Target instance number
These bits define the instance number for this device in a multi-drop system.
0x0

Bits 27:4 Reserved, must be kept at reset value.

Bits 3:0 **PROTSVN[3:0]**: Serial Wire Debug protocol version
0x1: Version 2

Debug port resend register (DP_RESEND)

Address offset: 0x8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RESEND[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESEND[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RESEND[31:0]**: Last AP read or DP RDBUFF read value

These bits contain the value that was returned by the last AP read or DP RDBUFF read. Used in the event of a corrupted read transfer.

Debug port access port select register (DP_SELECT)

Address offset: 0x8

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
APSEL[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
w	w	w	w												
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APBANKSEL[3:0]				DPBANKSEL[3:0]			
								w	w	w	w	w	w	w	w

Bits 31:28 **APSEL[3:0]**: Access port select bits

These bits select the access port for the next transaction.

0x0: AP0 - Cortex-M7 debug access port (AHB-AP)
0x1: AP1 - D3 access port (AHB-AP)
0x2: AP2 - System debug access port (APB-AP)
0x3 to 0xF: Reserved

Bits 27:8 Reserved, must be kept at reset value.

Bits 7:4 **APBANKSEL[3:0]**: AP register bank select bits

These bits select the 4-word register bank on the active AP for the next transaction.

Bits 3:0 **DPBANKSEL[3:0]**: DP register bank select bits

These bits select the register at address 0x4 of the debug port.

0x0: CTRL/STAT register
0x1: DLCR register
0x2: TARGETID register
0x3: DLPIDR register
0x4 to 0xF: Reserved

Debug port read buffer register (DP_RDBUFF)

Address offset: 0xC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RDBUFF[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RDBUFF[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RDBUFF[31:0]**: Last AP read value

The field contains the value returned by the last AP read access. There are two ways to retrieve the value returned by an AP read access:

- perform a second read access to the same address, which initiates a new transaction on the corresponding bus, or
- read the value returned by the last AP read access from the DP_RDBUFF register, in which case no new AP transaction occurs

Debug port target identification register (DP_TARGETSEL)

Address offset: 0xC

Reset value: 0x0000 XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TINSTANCE[3:0]				TPARTNO[15:4]											
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TPARTNO[3:0]				TDESIGNER[10:0]											Res.
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	

Bits 31:28 **TINSTANCE[3:0]**: Target instance number

The field defines the instance number for the target device in a multi-drop system. It must be programmed with the same value as TINSTANCE field of DP_DLPIDR register, in order to select this device.

Bits 27:12 **TPARTNO[15:0]**: Target part number

The field defines the part number for the target device. It must be programmed with the same value as TPARTNO field of DP_TARGETID register, in order to select this device.

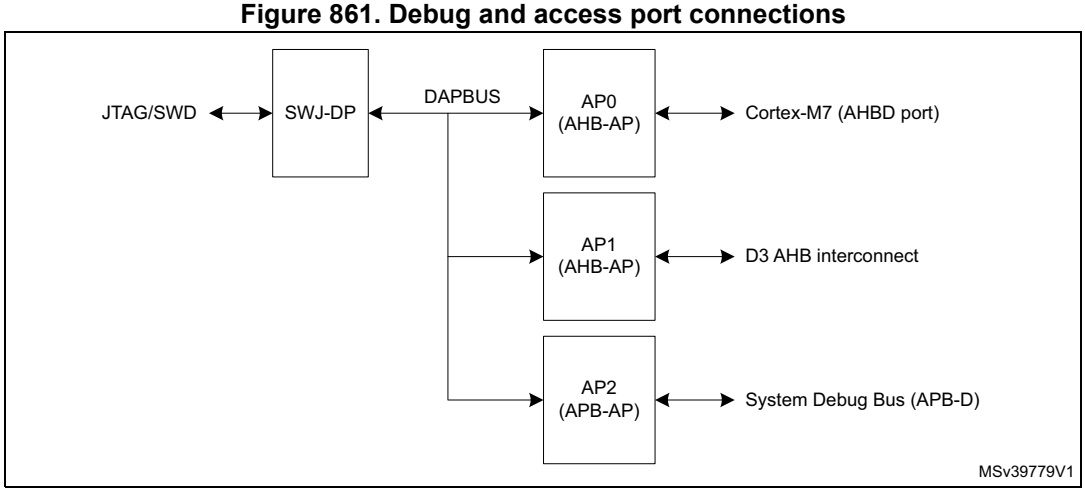
Bits 11:1 **TDESIGNER[10:0]**: Target designer JEDEC code

The field defines the JEDEC code for the target device. It must be programmed with the same value as TDESIGNER field of DP_TARGETID register, in order to select this device.

Bit 0 Reserved, must be kept at reset value.

65.4.2 Access ports

Figure 861. Debug and access port connections



Access ports (AP) attached to the DP:

1. AP0: Cortex-M7 access port (AHB-AP). Allows access to the debug and trace features integrated in the Cortex-M7 processor core via an AHB-Lite bus connected to the AHBD port of the processor.
2. AP1: D3 access port (AHB-AP). Allows access to the bus matrix in the D3 domain. This gives visibility of the D3 domain memory and peripherals when the D1 and D2 domains are switched off. No CoreSight components are accessible via this port.
3. AP2: System access port (APB-AP). Allows access to the debug and trace features on the system APB debug bus, that is, all components not included in the processor core.

All access ports are of MEM-AP type, that is, the debug and trace component registers are mapped in the address space of the associated debug bus. The AP is seen by the debugger as a set of 32-bit registers organized in banks of four registers each. Some of these registers are used to configure or monitor the AP itself, while others are used to perform a transfer on the bus. The AP registers are listed in *Table 619*.

The address of the AP registers is composed of:

- bits [7:4]: content of the DP_SELECT register's APBANKSEL field
- bits [3:2]: content of the A(3:2) field of the APACC data register in the JTAG-DP (see *Table 617*) or of the SW-DP Packet Request (see *Table 614*), depending on the debug interface used
- bits [1:0]: Always set to 0

The content of the SELECT register APSEL field in the DP defines which MEM-AP is being accessed.

The debugger can access the AP registers as follows:

1. Program the DP_SELECT register's APSEL field to choose one of the APs, and the APBANKSEL field to select the register bank to be accessed.
2. Program the A(3:2) field in the APACC register, if using JTAG, with the register address within the bank. Program the RnW bit to select a read or a write. In the case of a write, program the DATA field with the write data. If using SWD, the A(3:2) and RnW fields are part of the Packet Request word sent to the SW-DP with the APnDP bit set (see *Table 614*). The write data is sent in the data phase.

The debugger can access the memory mapped debug component registers through the MEM-AP registers (using the AP register access procedure described above) as follows:

1. Program the transaction target address in the TAR register.
2. Program the CSW register, if necessary, with the transfer parameters (AddrInc for example).
3. Write to or read from the DRW register to initiate a bus transaction at the address held in the TAR register. Alternatively, a read or write to banked data register BDn triggers an access to address TAR[31:4] + n (this allows an access to the next four consecutive addresses without changing the address in the TAR register).

For more detailed information on the MEM-AP, refer to the Arm® Debug Interface Architecture Specification *[1]*. To use the MEM-AP to connect the debug port to the debug components (in the example, a processor, an ETM and a ROM table), go to *Section 65.4.2: Access ports*.

MEM-AP registers

Table 619. MEM-AP registers

Address	APBANKSEL	A(3:2)	Name	Description
0x00	0x0	0	AP_CSW	Control/status word register
0x04	0x0	1	AP_TAR	Transfer address register Target address for the bus transaction.
0x08	-	-	-	Reserved
0x0C	0x0	3	AP_DRW	Data read/write register Access to this register triggers a corresponding transaction on the debug bus to the address in TAR[31:0]
0x10	0x1	0	AP_BD0	Banked data 0 register Access to this register triggers a corresponding transaction on the debug bus to the address in TAR[31:4] << 4 + 0x0
0x14	0x1	1	AP_BD1	Banked Data 1 register Access to this register triggers a corresponding transaction on the debug bus to the address in TAR[31:4] << 4 + 0x4
0x18	0x1	2	AP_BD2	Banked data 2 register Access to this register triggers a corresponding transaction on the debug bus to the address in TAR[31:4] << 4 + 0x8
0x1C	0x1	3	AP_BD3	Banked data 3 register Access to this register triggers a corresponding transaction on the debug bus to the address in TAR[31:4] << 4 + 0xC
0x20-0xEC	-	-	-	Reserved
0xF0	-	-	-	Reserved
0xF4	-	-	-	Reserved
0xF8	0xF	2	AP_BASE	Debug base address register (RO) Base address of the ROM table
0xFC	0xF	3	AP_IDR	Identification register (RO)

Access port control/status word register (AP_CSW)

Address offset: 0x0

Reset value: 0x0000 0002 (APB-AP), 0x4000 0002 (AHB-AP)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	SPROT	Res.	PROT[4:0]					SPISTATUS	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	rw		rw	rw	rw	rw	rw	r							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	MODE[3:0]				TRINPROG	DEVICEEN	ADDRINC[1:0]		Res.	SIZE[2:0]		
				rw	rw	rw	rw	r	r	rw	rw		rw	rw	rw

Bit 31 Reserved, must be kept at reset value.

Bit 30 **SPROT**: Secure transfer request bit

In the APB-AP, this field is reserved. In the AHB-APs, this field sets the protection attribute HPROT[6] of the bus transfer.

0: If SPIDEN is high, secure transfer. If SPIDEN is low, non-secure transfer.

1: Non-secure transfer.

Bit 29 Reserved, must be kept at reset value.

Bits 28:24 **PROT[4:0]** Bus transfer protection bits

In the APB-AP, this field is reserved. In the AHB-APs, this field sets the protection attributes HPROT[4:0] of the bus transfer.

0bXXXX0: Instruction fetch

0bXXXX1: Data access

0bXXX0X: User mode

0bXXX1X: Privileged mode

0bXX0XX: Non-bufferable

0bXX1XX: Bufferable

0bX0XXX: Non-cacheable

0bX1XXX: Cacheable

0b0XXXX: Non-exclusive

0b1XXXX: Exclusive

Bit 23 **SPISTATUS**: Status of SPIDEN option bit

This bit determines whether the debugger can access secure memory. This field is reserved in the APB-AP.

0: Secure AHB transfers are blocked

1: Secure AHB transfers are allowed

Bits 22:12 Reserved, must be kept at reset value.

Bits 11:8 **MODE[3:0]**: Barrier support enabled bit

These bits define if the memory barrier operation is supported.

0x0: Not supported

Bit 7 **TRINPROG**: Transfer in progress

This bit indicates that an AP bus transfer is in progress.

0: No transfer in progress.

1: Bus transfer in progress.

Bit 6 **DEVICEEN**: Device Enable bit
This bit defines whether the AP can be accessed or not.

1: AP access enabled.

Bits 5:4 **ADDRINC[1:0]**: Auto-increment mode bits
These bits define whether the TAR address is automatically incremented after a transaction.

0x0: no auto-increment
0x1: Address is incremented by the size in bytes of the transaction (SIZE field).
0x2: Packed transfers enabled (Only in AHB-APs - reserved in APB-AP). A 32-bit AP access generates a 1 x 32-bit, 2 x 16-bit or 4 x 8-bit bus transaction corresponding to the programmed transaction size. The data is packed or unpacked accordingly.
0x3: Reserved

Bit 3 Reserved, must be kept at reset value.

Bits 2:0 **SIZE[2:0]**: Size of next memory access transaction (only for AHB-APs)
0x0: Byte (8-bit)
0x1: Half-word (16-bit)
0x2: Word (32-bit)
0x3-0x7: Reserved

For APB-AP, this field is read-only and fixed at 0x2 (32-bit).

Access port base address register (AP_BASE)

Address offset: 0xF8

Reset value: 0xE00F E003 (AP0), 0x0000 0002 (AP1), 0xE00E 0003 (AP2)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
BASEADDR[19:4]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BASEADDR[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FORMAT	ENTRYPRESENT
r	r	r	r											r	r

Bits 31:12 **BASEADDR[19:0]**: Base address (bits 31 to 12) of the AP ROM table
The 12 LSBs are zero since the ROM table must be aligned on a 4 Kbyte boundary.
AP0 (Cortex-M7 AHB-AP): 0xE00FE
AP1 (D3 AHB-AP): 0x00000 (No ROM table present)
AP2 (System APB-AP): 0xE00E0

Bits 11:2 Reserved, must be kept at reset value.

Bit 1 **FORMAT**: Base address register format
1: Arm® debug interface v5.

Bit 0 **ENTRYPRESENT**: Debug component present status bit
This bit indicates that debug components are present on the access port bus.

0: Debug components are not present (AP1)
1: Debug components are present (AP0, AP2)

Access port identification register (AP_IDR)

Address offset: 0xFC

Reset value: 0x8477 0001 (AP0 and AP1), 0x5477 0002 (AP2)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REVISION[3:0]				JEDECBANK[3:0]				JEDECCODE[6:0]							MEMAP
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IDENTITY[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:28 **REVISION[3:0]**: Arm core revision
0x5: r1p0 (AP2)
0x8: r0p9 (AP0 and AP1)

Bits 27:24 **JEDECBANK[3:0]**: JEDEC bank
0x4: Arm®

Bits 23:17 **JEDECCODE[6:0]**: JEDEC code
0x3B: Arm®

Bit 16 **MEMAP**: Memory access port
1: Standard register map

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **IDENTITY[7:0]**: AP type identification
0x01: AHB-AP (AP0 and AP1)
0x02: APB-AP (AP2)
0x11: Reserved

65.5 Trace and debug subsystem functional description

The trace and debug subsystem features the following CoreSight components:

- System ROM tables
- System cross-trigger interface (CTI)
- Cross-trigger matrix (CTM)
- Trace port interface unit (TPIU)
- Trace bus funnel (CSTF)
- Embedded trace FIFO (ETF)
- Serial wire output (SWO)

These components are accessible by the debugger via the system APB-AP and its associated APB-D debug bus. They are also accessible by the Cortex-M7 processor.

The MCU debug unit (DBGMCU) is also accessed via the APB-D. This non-CoreSight component contains registers for configuring the device behavior in Debug mode.

Trace bus replicator branches the trace bus from the CPU's ITM CoreSight component to ETF and SWO, through trace bus funnels.

65.5.1 System ROM tables

There are two ROM tables on the APB-D bus. The ROM table is a CoreSight component that contains the base addresses of all the CoreSight components on the APB-D bus. These tables allow a debugger to discover the topology of the CoreSight components automatically.

The first table points to the second table, and to the CoreSight components located in D3 power domain: SWO. The table occupies a 4-Kbyte, 32-bit wide chunk of the APB-D address space, from 0xE00E0000 to 0xE00E0FFC when accessed by the debugger, and from 0x5C000000 to 0x5C000FFC when accessed from the system bus.

Table 620. System ROM table 1

Address offset in ROM table	Component name	Component base address (debugger)	Component base address (system bus)	Component address offset	Size	Entry
0x000	DBGMCU	0xE00E1000	0x5C001000	0x01000	4 Kbyte	0x00001003
0x004	-	-	-	-	4 Kbyte	0x00002002
0x008	SWO	0xE00E3000	0x5C003000	0x03000	4 Kbyte	0x00003003
0x00C	-	-	-	-	4 Kbyte	0x00004002
0x010	-	-	-	-	4 Kbyte	0x00005002
0x014	System ROM table 2	0xE00F0000	0x5C010000	0x10000	4 Kbyte	0x00010003
0x018	Top of table	-	-	-	-	0x00000000
0x01C to 0xFC8	Reserved	-	-	-	-	0x00000000
0xFCC to 0xFFC	ROM table registers	-	-	-	-	See *System ROM registers*

The second table occupies a 4-Kbyte, 32-bit wide chunk of APB-D address space, from 0xE00F0000 to 0xE00F0FFC when accessed by the debugger, and from 0x5C010000 to 0x5C010FFC when accessed from the system bus.

Table 621. System ROM table 2

Address offset in ROM table	Component name	Component base address (debugger)	Component base address (system bus)	Component address offset	Size	Entry
0x000	System CTI	0xE00F1000	0x5C011000	0x1000	4 Kbyte	0x00001003
0x004	-	-	-	-	4 Kbyte	0x00002002
0x008	Trace funnel	0xE00F3000	0x5C013000	0x3000	4 Kbyte	0x00003003
0x00C	ETF	0xE00F4000	0x5C014000	0x4000	4 Kbyte	0x00004003
0x010	TPIU	0xE00F5000	0x5C015000	0x5000	4 Kbyte	0x00005003
0x014	Top of table	-	-	-	-	0x00000000
0x018 to 0xFC8	Reserved	-	-	-	-	0x00000000
0xFCC to 0xFFC	ROM table registers	-	-	-	-	See *System ROM registers*

The top of each ROM table contains a number of read-only registers, including the standard CoreSight component and peripheral identity registers, see section *System ROM registers*.

Each debug component occupies one or more 4 Kbyte blocks of address space. This block of address space is referred to as the debug register file for the component.

The component address offset field of a ROM Table entry points to the start of the last 4 Kbyte block of the address space of the component. This block always contains the component and peripheral ID registers for the component, starting at offset 0xFD0 from the start of the block. The 4 Kbyte count field PIDR4 [7:4], specifies the number of 4 Kbyte

blocks for the component. Therefore, the process for finding the start of the address space for a component is:

1. Read the ROM-table entry for the component and extract its Address_Offset [18:0] from bits [31:12] of the ROM-table entry.
2. Use the address offset, together with the base address of the ROM table, ROM_Base_Address, to calculate the base address of the component:

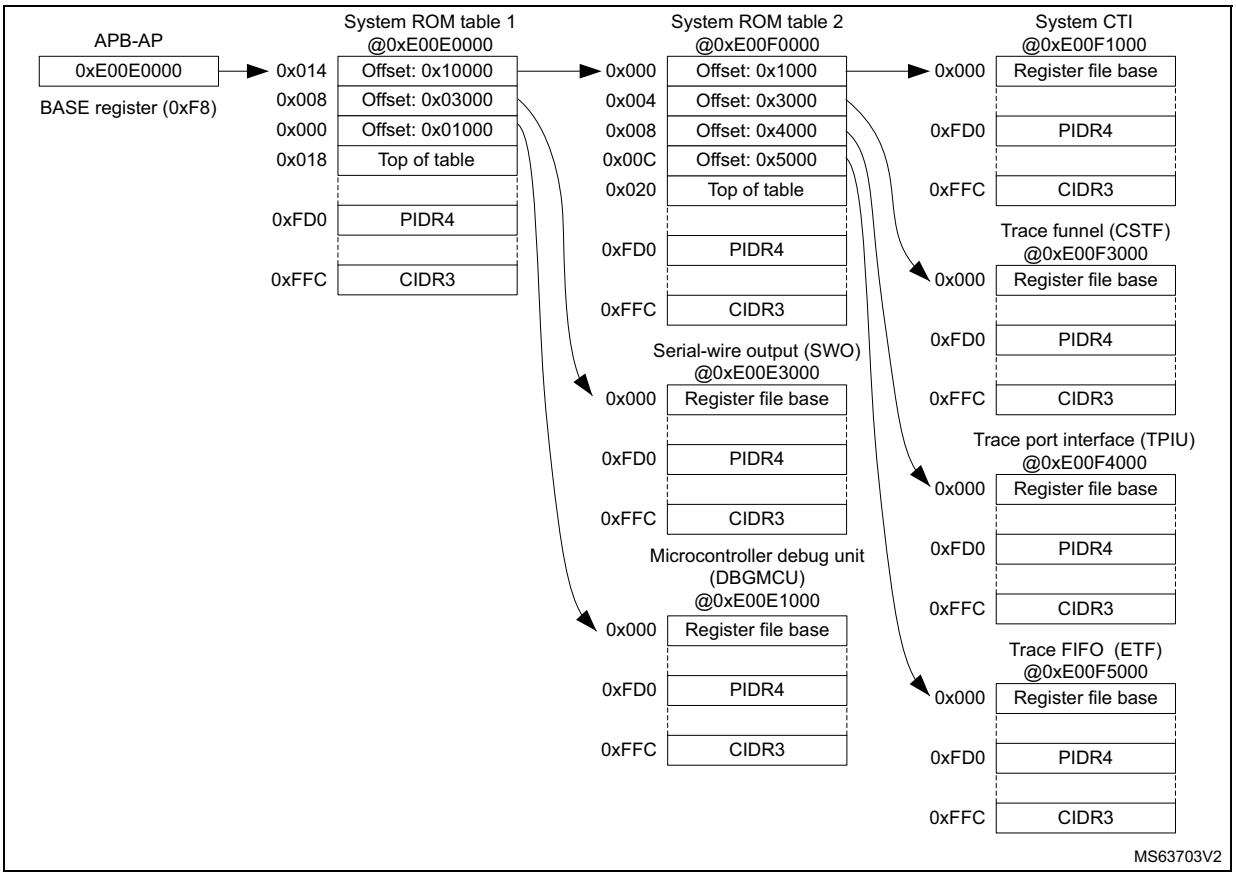
   Component_Base_Address = ROM_Base_Address + Address_Offset

   The Component_Base_Address is the start address of the 4 Kbyte block of the address space for the component.
3. Read the peripheral ID4 register for the component. The address of this register is:

   Peripheral_ID4_address = Component_Base_Address + 0xFD0
4. Extract the 4 Kbyte count field [7:4] from the value of the Peripheral ID4 Register.
5. Use the 4 Kbyte count field value to calculate the start address of the address space for the component. If the field value is 0b0000, which corresponds to a count value of 1, the address space for the component starts at Component_Base_Address obtained at stage 2.

The topology for the CoreSight components on the APB-D is shown in *Figure 862*.

Figure 862. APB-D CoreSight component topology



For more information on the use of the ROM table, refer to the Arm® Debug Interface Architecture Specification *[1]*.

System ROM registers

SYSROM memory type register (SYSROM_MEMTYPE)

Address offset: 0xFCC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSMEM
															r

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **SYSMEM**: System memory

0: No system memory is present on this bus

SYSROM CoreSight peripheral identity register 4 (SYSROM_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size

0x0: Register file occupies a single 4 Kbyte region

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code

0x0: STMicroelectronics JEDEC continuation code

SYSROM CoreSight peripheral identity register 0 (SYSROM_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0083 (System ROM table 1), 0x0000 0001 (System ROM table 2)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Device part number field, bits [7:0]
0x83: STM32H7 device (System ROM table 1)
0x01: STM32H7 device (System ROM table 2)

SYSROM CoreSight peripheral identity register 1 (SYSROM_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 0004 (System ROM table 1), 0x0000 00000 (System ROM table 2)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code field, bits [3:0]
0x0: STMicroelectronics JEDEC code

Bits 3:0 **PARTNUM[11:8]**: Device part number field, bits [11:8]
0x4: STM32H7 device System ROM table 1
0x0: STM32H7 device System ROM table 2

SYSROM CoreSight peripheral identity register 2 (SYSROM_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000A

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: Device revision number
0x1: Rev 1

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code field, bits [6:4]
0x2: STMicroelectronics JEDEC code

SYSROM CoreSight peripheral identity register 3 (SYSROM_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: Metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: Customer modified
0x0: No customer modifications

SYSROM CoreSight component identity register 0 (SYSROM_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component ID field, bits [7:0]
0x0D: Common ID value

SYSROM CoreSight component identity register 1 (SYSROM_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0010

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component ID field, bits [15:12] - component class
0x1: ROM table component

Bits 3:0 **PREAMBLE[11:8]**: Component ID field, bits [11:8]
0x0: Common ID value

SYSROM CoreSight component identity register 2 (SYSROM_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component ID field, bits [23:16]
0x05: Common ID value

SYSROM CoreSight component identity register 3 (SYSROM_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component ID field, bits [31:24]
0xB1: Common ID value

System ROM register map and reset values

Table 622. System ROM table 1 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFCC	SYSROM_ MEMTYPE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSMEM
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
0xFD0	SYSROM_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	SYSROM_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	0	0	0	1	1
0xFE4	SYSROM_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	0
0xFE8	SYSROM_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	1	0
0xFEC	SYSROM_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFF0	SYSROM_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	0	1
0xFF4	SYSROM_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1	0	0	0	0
0xFF8	SYSROM_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	1
0xFFC	SYSROM_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	1

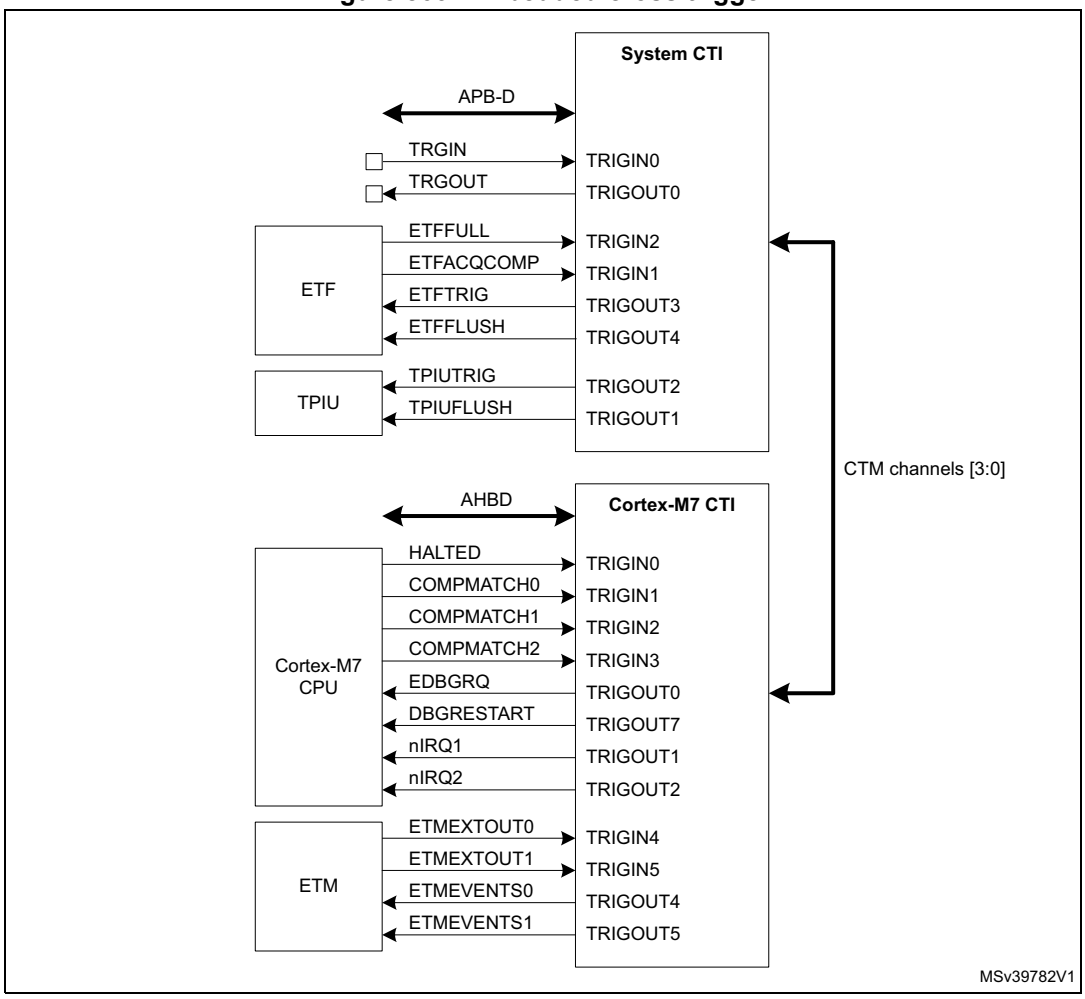
Table 623. System ROM table 2 register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFCC	SYSROM_ MEMTYPE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSMEM
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
0xFD0	SYSROM_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	SYSROM_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	1
0xFE4	SYSROM_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFE8	SYSROM_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	1	0
0xFEC	SYSROM_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFF0	SYSROM_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	0	1
0xFF4	SYSROM_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1	0	0	0	0
0xFF8	SYSROM_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	1
0xFFC	SYSROM_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	1

65.5.2 Cross trigger interfaces (CTI) and matrix (CTM)

The cross trigger interfaces (CTI) and cross trigger matrix (CTM) together form the CoreSight embedded cross trigger feature. There are two CTI components, one at system level and one dedicated to the Cortex-M7. The two CTIs are connected to each other via the CTM. The system-level CTI is accessible to the debugger via the system access port and associated APB-D. The Cortex-M7 CTI is physically integrated in the Cortex-M7 core, and is accessible via the Cortex-M7 access port and associated AHBD.

Figure 863. Embedded cross trigger



The CTIs allow events from various sources to trigger debug and/or trace activity. For example, a transition detected on an external trigger input can start code trace.

Each CTI has up to 8 trigger inputs and 8 trigger outputs. Any input can be connected to any output, on the same CTI, or on another CTI via the CTM.

The trigger input and output signals for each CTI are listed in *Table 624* to *Table 627*.

Table 624. System CTI inputs

#	Source signal	Source component	Comments
0	DBTRIGI	GPIO	External trigger input - allows an external signal to generate a debug event
1	ETFACQCOMP	ETF	ETF capture finished - allows a debug event to be generated when the trace FIFO is empty
2	ETFFULL	ETF	ETF full flag - allows a debug event to be generated when the trace FIFO is full
3	-	-	Not used
4	-	-	Not used
5	-	-	Not used
6	-	-	Not used
7	-	-	Not used

Table 625. System CTI outputs

#	Output signal	Destination component	Comments
0	DBTRIGO	GPIO	External IO trigger output - allows monitoring of events on the external DBTRIGO pin
1	TPIUFLUSH	TPIU	Trace port flush trigger - causes the TPIU FIFO to be flushed
2	TPIUTRIG	TPIU	Trace Port enable trigger - starts trace output on the external trace port
3	ETFTRIG	ETF	ETF enable trigger - starts filling the Trace FIFO
4	ETFFLUSH	ETF	ETF flush trigger - causes the Trace FIFO to be flushed
5	-	-	Not used
6	-	-	Not used
7	-	-	Not used

Table 626. Cortex-M7 CTI inputs

#	Source signal	Source component	Comments
0	HALTED	Cortex-M7 CPU	CPU halted - indicates CPU is in Debug mode
1	COMPMATCH0	Cortex-M7 DWT	DWT comparator 0 match
2	COMPMATCH1	Cortex-M7 DWT	DWT comparator 1 match
3	COMPMATCH2	Cortex-M7 DWT	DWT comparator 2 match
4	ETMEXTOUT0	Cortex-M7 ETM	ETM external trigger out
5	ETMEXTOUT1	Cortex-M7 ETM	ETM external trigger out

Table 626. Cortex-M7 CTI inputs (continued)

#	Source signal	Source component	Comments
6	-	-	Not used
7	-	-	Not used

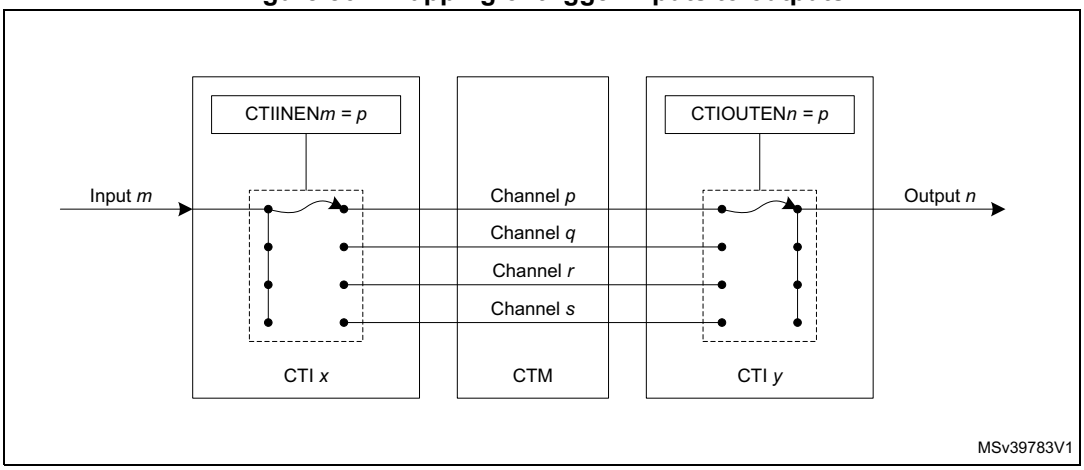
Table 627. Cortex-M7 CTI outputs

#	Output signal	Destination component	Comments
0	EDBGRQ	Cortex-M7 CPU	CPU halt request - puts CPU in Debug mode
1	nIRQ1	Cortex-M7 NVIC	Interrupt request
2	nIRQ2	Cortex-M7 NVIC	Interrupt request
3	-	-	Not used
4	ETMEVENTS0	Cortex-M7 ETM	ETM trig request - enables CPU execution trace
5	ETMEVENTS1	Cortex-M7 ETM	ETM trig request - enables CPU execution trace
6	-	-	Not used
7	DBGRESTART	Cortex-M7 CPU	CPU restart request - CPU exits Debug mode

There are four event channels in the cross trigger matrix, which allows up to four parallel bidirectional connections between trigger inputs and outputs on different CTIs. To connect input number *m* on CTI *x* to output number *n* on CTI *y*, the input must be connected to an event channel *p* using the CTIINEN*m* register of CTI *x*. The same channel *p* must be connected to the output using the CTIOUTEN*n* register of CTI *y*. Note: this applies even if the input and output belong to the same CTI.

An input can be connected to more than one channel (up to four), so an input can be routed to several outputs. Similarly, an output can be connected to several inputs. It is also possible to connect several inputs/outputs to the same channel.

Figure 864. Mapping of trigger inputs to outputs



For more information on the cross-trigger interface CoreSight component, refer to the Arm® CoreSight™ SoC-400 Technical Reference Manual *[2]*.

CTI registers

The register file base address for each CTI is defined by the ROM table for the bus to which it is connected. The registers are the same for each CTI.

CTI control register (CTI_CONTROL)

Address offset: 0x000

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GLBEN
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **GLBEN**: Global enable.

0: Cross-triggering disabled

1: Cross-triggering enabled

CTI trigger acknowledge register (CTI_INTACK)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INTACK[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **INTACK[7:0]**: Trigger acknowledge

There is one bit of the register for each CTITRIGOUT output. When a 1 is written to a bit in this register, the corresponding CTITRIGOUT output is acknowledged, causing it to be cleared.

CTI application trigger set register (CTI_APPSET)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APPSET[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **APPSET[3:0]**: Set channel event

Read:
0bXXX0: Channel 0 event inactive
0bXXX1: Channel 0 event active
0bXX0X: Channel 1 event inactive
0bXX1X: Channel 1 event active
0bX0XX: Channel 2 event inactive
0bX1XX: Channel 2 event active
0b0XXX: Channel 3 event inactive
0b1XXX: Channel 3 event active

Write:
0bXXX0: No effect
0bXXX1: Set event on Channel 0
0bXX0X: No effect
0bXX1X: Set event on Channel 1
0bX0XX: No effect
0bX1XX: Set event on Channel 2
0b0XXX: No effect
0b1XXX: Set event on Channel 3

CTI application trigger clear register (CTI_APPCLEAR)

Address offset: 0x018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APPCLEAR[3:0]			
												w	w	w	w

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **APPCLEAR[3:0]**: Clear channel event
0bXXX0: No effect
0bXXX1: Clear event on Channel 0
0bXX0X: No effect
0bXX1X: Clear event on Channel 1
0bX0XX: No effect
0bX1XX: Clear event on Channel 2
0b0XXX: No effect
0b1XXX: Clear event on Channel 3

CTI application pulse register (CTI_APPPULSE)

Address offset: 0x01C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APPPULSE[3:0]			
												w	w	w	w

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **APPPULSE[3:0]**: Pulse channel event
This register clears itself immediately.

0bXXX0: No effect
0bXXX1: Generate pulse on Channel 0
0bXX0X: No effect
0bXX1X: Generate pulse on Channel 1
0bX0XX: No effect
0bX1XX: Generate pulse on Channel 2
0b0XXX: No effect
0b1XXX: Generate pulse on Channel 3

CTI trigger IN x enable register (CTI_INENx)

Address offset: 0x020 + 4 * x, where x = 0 to 7

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGINEN[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **TRIGINEN[3:0]**: Cross-trigger event enable

Enables or disables a cross-trigger event on each of the four channels when CTITRIGINx is activated (x = 0 to 7).

0bXXX0: Trigger n does not generate events on Channel 0
0bXXX1: Trigger n generates events on Channel 0
0bXX0X: Trigger n does not generate events on Channel 1
0bXX1X: Trigger n generates events on Channel 1
0bX0XX: Trigger n does not generate events on Channel 2
0bX1XX: Trigger n generates events on Channel 2
0b0XXX: Trigger n does not generate events on Channel 3
0b1XXX: Trigger n generates events on Channel 3

CTI trigger OUT x enable register (CTI_OUTENx)

Address offset: 0x0A0 + 4 * x, where x = 0 to 7

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGOUTEN[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **TRIGOUTEN[3:0]**: Enable trigger upon event

For each channel, the field defines whether an event on that channel generates a trigger on CTITRIGOUTx (x = 0 to 7).

0bXXX0: Channel 0 events do not generate triggers on Trigger output n
0bXXX1: Channel 0 events generate triggers on Trigger output n
0bXX0X: Channel 1 events do not generate triggers on Trigger output n
0bXX1X: Channel 1 events generate triggers on Trigger output n
0bX0XX: Channel 2 events do not generate triggers on Trigger output n
0bX1XX: Channel 2 events generate triggers on Trigger output n
0b0XXX: Channel 3 events do not generate triggers on Trigger output n
0b1XXX: Channel 3 events generate triggers on Trigger output n

CTI trigger IN status register (CTI_TRGISTS)

Address offset: 0x130

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGINSTATUS[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **TRIGINSTATUS[7:0]**: Trigger input status

There is one bit of the register for each CTITRIGIN input. When a bit is set to 1 it indicates that the corresponding trigger input is active. When it is set to 0, the corresponding trigger input is inactive.

CTI trigger OUT status register (CTI_TRGOSTS)

Address offset: 0x134

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGOUTSTATUS[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **TRIGOUTSTATUS[7:0]**: Trigger output status

There is one bit of the register for each CTITRIGOUT output. When a bit is set to 1 it indicates that the corresponding trigger output is active. When it is set to 0, the corresponding trigger output is inactive.

CTI channel IN status register (CTI_CHINSTS)

Address offset: 0x138

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CHINSTATUS[3:0]			
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CHINSTATUS[3:0]**: Channel input status

There is one bit of the register for each channel input. When a bit is set to 1 it indicates that the corresponding channel input is active. When it is set to 0, the corresponding channel input is inactive.

CTI channel OUT status register (CTI_CHOUTSTS)

Address offset: 0x13C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CHOUTSTATUS[3:0]			
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CHOUTSTATUS[3:0]**: Channel output status

There is one bit of the register for each channel output. When a bit is set to 1 it indicates that the corresponding channel output is active. When it is set to 0, the corresponding channel output is inactive.

CTI channel gate register (CTI_GATE)

Address offset: 0x140

Reset value: 0x0000 000F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GATEEN[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **GATEEN[3:0]**: Channel output enable

For each channel, defines whether an event on that channel can propagate over the CTM to other CTIs.
0bXXX0: Channel 0 events do not propagate
0bXXX0: Channel 0 events propagate
0bXX0X: Channel 1 events do not propagate
0bXX1X: Channel 1 events propagate
0bX0XX: Channel 2 events do not propagate
0bX1XX: Channel 2 events propagate
0b0XXX: Channel 3 events do not propagate
0b1XXX: Channel 3 events propagate

CTI claim tag set register (CTI_CLAIMSET)

Address offset: 0xFA0

Reset value: 0x0000 000F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMSET[3:0]**: Set claim tag bits

Write:
0000: No effect
xxx1: Set bit 0
xx1x: Set bit 1
x1xx: Set bit 2
1xxx: Set bit 3

Read:
0xF: Indicates there are four bits in claim tag

CTI claim tag clear register (CTI_CLAIMCLR)

Address offset: 0xFA4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMCLR[3:0]**: Reset claim tag bits

Write:
0000: No effect
xxx1: Clear bit 0
xx1x: Clear bit 1
x1xx: Clear bit 2
1xxx: Clear bit 3

Read: Returns current value of claim tag

CTI lock access register (CTI_LAR)

Address offset: 0xFB0

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ACCESS_W[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACCESS_W[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **ACCESS_W[31:0]**: CTI register write access enable

Enables write access to some CTI registers by processor core (debuggers do not need to unlock the component)

0xC5ACCE55: Enable write access
Other values: Disable write access

CTI lock status register (CTI_LSR)

Address offset: 0xFB4

Reset value: 0x0000 0003

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKTYPE	LOCKGRANT	LOCKEXIST
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **LOCKTYPE**: Size of the CTI_LAR register

0: 32-bit

Bit 1 **LOCKGRANT**: Current status of lock

This bit always returns zero when read by an external debugger.

0: Write access is permitted
1: Write access is blocked. Only read access is permitted.

Bit 0 **LOCKEXIST**: Existence of lock control mechanism

The bit indicates whether a lock control mechanism exists. It always returns zero when read by an external debugger.

0: No lock control mechanism exists
1: Lock control mechanism is implemented

CTI authentication status register (CTI_AUTHSTAT)

Address offset: 0xFB8

Reset value: 0x0000 000A

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SNID[1:0]		SID[1:0]		NSNID[1:0]		NSID[1:0]	
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:6 **SNID[1:0]**: Security level for secure non-invasive debug
0x0: Not implemented

Bits 5:4 **SID[1:0]**: Security level for secure invasive debug
0x0: Not implemented

Bits 3:2 **NSNID[1:0]**: Security level for non-secure non-invasive debug
0x2: Disabled
0x3: Enabled

Bits 1:0 **NSID[1:0]**: Security level for non-secure invasive debug
0x2: Disabled
0x3: Enabled

CTI device configuration register (CTI_DEVID)

Address offset: 0xFC8

Reset value: 0x0004 0800

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NUMCH[3:0]			
												r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMTRIG[7:0]								Res.	Res.	Res.	EXTMUXNUM[4:0]				
r	r	r	r	r	r	r	r				r	r	r	r	r

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:16 **NUMCH[3:0]**: Number of ECT channels available
0x4: 4 channels

Bits 15:8 **NUMTRIG[7:0]**: Number of ECT triggers available
0x8: 8 trigger inputs and 8 trigger outputs

Bits 7:5 Reserved, must be kept at reset value.

Bits 4:0 **EXTMUXNUM[4:0]**: Number of trigger input/output multiplexers
0x0: None

CTI device type identifier register (CTI_DEVTYPE)

Address offset: 0xFCC

Reset value: 0x0000 0014

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE[3:0]				MAJORTYPE[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SUBTYPE[3:0]**: Sub-classification

0x1: Indicates that this component is a cross-triggering component.

Bits 3:0 **MAJORTYPE[3:0]**: Major classification

0x4: Indicates that this component allows a debugger to control other components in a CoreSight SoC-400 system.

CTI CoreSight peripheral identity register 4 (CTI_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size

0x0: Register file occupies a single 4 Kbyte region

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code

0x4: Arm® JEDEC code

CTI CoreSight peripheral identity register 0 (CTI_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0006

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Part number field, bits [7:0]
0x06: CTI part number

CTI CoreSight peripheral identity register 1 (CTI_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00B9

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code field, bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: Part number field, bits [11:8]
0x9: CTI part number

CTI CoreSight peripheral identity register 2 (CTI_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 005B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: Component revision number
0x5: r1p0

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code field, bits [6:4]
0x3: Arm® JEDEC code

CTI CoreSight peripheral identity register 3 (CTI_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: Metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: Customer modified
0x0: No customer modifications

CTI CoreSight component identity register 0 (CTI_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component ID field, bits [7:0]
0x0D: Common ID value

CTI CoreSight component identity register 1 (CTI_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0090

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component ID field, bits [15:12] - component class
0x9: CoreSight component

Bits 3:0 **PREAMBLE[11:8]**: Component ID field, bits [11:8]
0x0: Common ID value

CTI CoreSight component identity register 2 (CTI_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component ID field, bits [23:16]
0x05: Common ID value

CTI CoreSight component identity register 3 (CTI_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component ID field, bits [31:24]
0xB1: Common ID value

CTI register map and reset values

Table 628. CTI register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	CTI_CONTROL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GLBEN
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
0x010	CTI_INTACK	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INTACK[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x014	CTI_APPSET	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APPSET[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0x018	CTI_APPCLEAR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APPCLEAR[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0x01C	CTI_APPPULSE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	APPPULSE[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0x020 to 0x03C	CTI_INEN0 to CTI_INEN7	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGINEN[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0x040 to 0x09C	Reserved	Reserved																															
0x0A0 to 0x0BC	CTI_OUTEN0 to CTI_OUTEN7	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGOUTEN[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0x0C0 to 0x12C	Reserved	Reserved																															
0x130	CTI_TRIGISTS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGINSTATUS[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x134	CTI_TRIGOSTS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGOUTSTATUS[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x138	CTI_CHINSTS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CHISTATUS[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0x13C	CTI_CHOUTSTS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CHOSTATUS[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0x140	CTI_GATE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	GATEEN[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1
0x144 to 0xF9C	Reserved	Reserved																															

Table 628. CTI register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFA0	CTI_CLAIMSET	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1
0xFA4	CTI_CLAIMCLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0xFA8 to 0xFAC	Reserved	Reserved																															
0xFB0	CTI_LAR	ACCESS_W[31:0]																															
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0xFB4	CTI_LSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKTYPE	LOCKGRANT	LOCKEXIST
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	1
0xFB8	CTI_AUTHSTAT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SNID[1:0]		SID[1:0]		NSNID[1:0]		NSID[1:0]	
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	1	0
0xFC8	CTI_DEVID	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NUMCH[3:0]				NUMTRIG[7:0]								Res.	Res.	Res.	EXMUXNUM[4:0]				
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	0	1	0	0	0	0	0	0	1	0	0	0	-	-	-	0	0	0	0	0
0xFCC	CTI_DEVTYPE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE[3:0]				MAJORTYPE[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1	0	1	0	0
0xFD0	CTI_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	CTI_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	1	0
0xFE4	CTI_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	1	0	0	1
0xFE8	CTI_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	0	1	1	0	1	1
0xFEC	CTI_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFF0	CTI_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	0	1
0xFF4	CTI_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	1	0	0	0	0

Table 628. CTI register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFF8	CTI_CIDR2	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	PREAMBLE[19:12]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	1
0xFFC	CTI_CIDR3	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	res	PREAMBLE[27:20]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	1

65.5.3 Trace funnel (CSTF)

The trace funnel is a CoreSight component that combines the ATB buses from two trace sources into one single ATB. The CSTF has two ATB slave ports, and one ATB master port. An arbiter selects the slave ports according to a programmable priority.

The slave ports are connected as follows:

- S0: Cortex-M7 ETM
- S1: Cortex-M7 ITM

The CSTF registers allow the slave ports to be individually enabled, and their priority settings to be configured. The priorities can be modified only when the trace is disabled. The arbitration works as follows:

- The arbiter selects the slave port with the highest assigned priority that has data valid
- Transfers are passed from the selected slave to the master port until *min_hold_time is reached*, where *min_hold_time* is programmable in the CONTROL register.
- A new arbitration is then performed

High priority should be assigned to slave ports connected to sources with a small amount of buffering, or where data loss can not be tolerated. Low priority should be assigned to less critical sources or those with large buffers.

For more information on the ATB Funnel CoreSight component, refer to the Arm® CoreSight™ SoC-400 Technical Reference Manual *[2]*.

Trace funnel registers

CSTF control register (CSTF_CTRL)

Address offset: 0x000

Reset value: 0x0000 0300

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	MIN_HOLD_TIME[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	ENS1	ENS0
				rw	rw	rw	rw							rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:8 **MIN_HOLD_TIME[3:0]**: Number of transactions between arbitrations.
0x0: 1 transaction
:
0xE: 15 transactions
0xF: Reserved

Bits 7:2 Reserved, must be kept at reset value.

Bit 1 **ENS1**: S1 slave port enable
0: Disable port
1: Enable port

Bit 0 **ENS0**: S0 slave port enable
0: Disable port
1: Enable port

CSTF priority register (CSTF_PRIORITY)

Address offset: 0x004

Reset value: 0x0000 0688

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIPORT1[2:0]			PRIPORT0[2:0]		
										rw	rw	rw	rw	rw	rw

Bits 31:6 Reserved, must be kept at reset value.

Bits 5:3 **PRIPORT1[2:0]**: S1 slave port priority
0: Highest priority
:
7: Lowest priority

Bits 2:0 **PRIPORT0[2:0]**: S0 slave port priority
0: Highest priority
:
7: Lowest priority

CSTF claim tag set register (CSTF_CLAIMSET)

Address offset: 0xFA0

Reset value: 0x0000 000F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMSET[3:0]**: Set claim tag bits

Write:
0000: No effect
xxx1: Set bit 0
xx1x: Set bit 1
x1xx: Set bit 2
1xxx: Set bit 3

Read:
0xF: Indicates there are four bits in claim tag

CSTF claim tag clear register (CSTF_CLAIMCLR)

Address offset: 0xFA4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMCLR[3:0]**: Reset claim tag bits

Write:
0000: No effect
xxx1: Clear bit 0
xx1x: Clear bit 1
x1xx: Clear bit 2
1xxx: Clear bit 3

Read: Returns current value of claim tag

CSTF lock access register (CSTF_LAR)

Address offset: 0xFB0

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ACCESS_W[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACCESS_W[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **ACCESS_W[31:0]**: CSTF register write access enable
The field enables write access to some CSTF registers by the processor cores (debuggers do not need to unlock the component).

0xC5ACCE55: Enable write access
Other values: Disable write access

CSTF lock status register (CSTF_LSR)

Address offset: 0xFB4

Reset value: 0x0000 0003

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKTYPE	LOCKGRANT	LOCKEXIST
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **LOCKTYPE**: Size of the CSTF_LAR register
0: 32-bit

Bit 1 **LOCKGRANT**: Current status of lock
This bit always returns zero when read by an external debugger.

0: Write access is permitted
1: Write access is blocked. Only read access is permitted.

Bit 0 **LOCKEXIST**: Existence of lock control mechanism
The bit indicates whether a lock control mechanism exists. It always returns zero when read by an external debugger.

0: No lock control mechanism exists
1: Lock control mechanism is implemented

CSTF authentication status register (CSTF_AUTHSTAT)

Address offset: 0xFB8

Reset value: 0x0000 000A

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SNID[1:0]		SID[1:0]		NSNID[1:0]		NSID[1:0]	
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:6 **SNID[1:0]**: Security level for secure non-invasive debug
0x0: Not implemented

Bits 5:4 **SID[1:0]**: Security level for secure invasive debug
0x0: Not implemented

Bits 3:2 **NSNID[1:0]**: Security level for non-secure non-invasive debug
0x2: Disabled
0x3: Enabled

Bits 1:0 **NSID[1:0]**: Security level for non-secure invasive debug
0x2: Disabled
0x3: Enabled

CSTF CoreSight device identity register (CSTF_DEVID)

Address offset: 0xFC8

Reset value: 0x0000 0024

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SCHEME[3:0]				PORTCNT[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SCHEME[3:0]**: Priority scheme
0x2: Static priority

Bits 3:0 **PORTCNT[3:0]**: Number of input ports connected
0x4: Four input ports

CSTF CoreSight device type identity register (CSTF_DEVTYPE)

Address offset: 0xFCC

Reset value: 0x0000 0012

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEVTYPEID[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **DEVTYPEID[7:0]**: Device type identifier
0x12: Trace funnel

CSTF CoreSight peripheral identity register 4 (CSTF_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size
0x0: Register file occupies a single 4 Kbyte region

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC code

CSTF CoreSight peripheral identity register 0 (CSTF_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0008

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Part number field, bits [7:0]
0x08: CSTF part number

CSTF CoreSight peripheral identity register 1 (CSTF_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00B9

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code field, bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: Part number field, bits [11:8]
0x9: CSTF part number

CSTF CoreSight peripheral identity register 2 (CSTF_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 003B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: Component revision number
0x3: r1p1

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code field, bits [6:4]
0x3: Arm® JEDEC code

CSTF CoreSight peripheral identity register 3 (CSTF_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: Metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: Customer modified
0x0: No customer modifications

CSTF CoreSight component identity register 0 (CSTF_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component ID field, bits [7:0]
0x0D: Common ID value

CSTF CoreSight component identity register 1 (CSTF_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0090

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component ID field, bits [15:12] - component class
0x9: CoreSight component

Bits 3:0 **PREAMBLE[11:8]**: Component ID field, bits [11:8]
0x0: Common ID value

CSTF CoreSight component identity register 2 (CSTF_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component ID field, bits [23:16]
0x05: Common ID value

CSTF CoreSight component identity register 3 (CSTF_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component ID field, bits [31:24]
0xB1: Common ID value

Trace funnel register map and reset values

Table 629. CSTF register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	CSTF_CTRL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MIN_HOLD_TIME[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	ENS1	ENS0
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1	1	-	-	-	-	-	-	0	0
0x004	CSTF_PRIORITY	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIPORT1[2:0]			PRIPORT0[2:0]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1	0	0	0
0x008 to 0xF9C	Reserved	Reserved																															
0xFA0	CSTF_CLAIMSET	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	Res	CLAIMSET[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1

Table 629. CSTF register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFA4	CSTF_CLAIMCLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0xFA8to 0xFAC	Reserved	Reserved																															
0xFB0	CSTF_LAR	ACCESS_W[31:0]																															
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0xFB4	CSTF_LSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCTYPE	LOCKGRANT	LOCKEXIST
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	1
0xFB8	CSTF_AUTHSTAT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SNID[1:0]		SID[1:0]		NSNID[1:0]		NSID[1:0]	
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	1	0
0xFC8	CSTF_DEVID	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SCHEME[3:0]				PORTCNT[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1	0	0	1	0	0
0xFCC	CSTF_DEVTYPE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DEVTYPEID[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1	0	0	1	0
0xFD0	CSTF_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	CSTF_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	0	0
0xFE4	CSTF_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	1	0	0	1
0xFE8	CSTF_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1	1	1	0	1	1
0xFEC	CSTF_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0

Table 629. CSTF register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFF0	CSTF_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	0	1
0xFF4	CSTF_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	1	0	0	0	0
0xFF8	CSTF_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	1
0xFFC	CSTF_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	1

65.5.4 Embedded trace FIFO (ETF)

The ETF is a 2 Kbyte memory that captures trace data from two trace sources, namely the ETM and ITM of the CPU core. The ETF is a design configuration of the CoreSight™ trace memory controller component.

The ETF can be used in three modes (selected in the mode register):

1. Hardware FIFO mode

   The trace memory is used as a FIFO that is drained through the ATB master interface. Trace data is captured by the trace RAM and when full, the incoming trace stream is stalled. When the Trace buffer is not empty, trace data is drained out through the ATB master interface to the TPIU.

   In this mode, the role of the FIFO is to smooth the flow of trace information arriving at the trace port. Since the trace data can be very bursty by nature, the peak data rate can easily exceed the port capability, resulting in an overflow. The ETF allows a steady data rate at the trace port, which can then be sized according to the average rate rather than the peak. The trace is stored off-chip in real time by the trace port analyzer tool, and so the trace log can be very big.

2. Software FIFO mode

   The trace memory is used as a FIFO that can be read through the RRD Register while the trace is being captured. Trace data is captured by the trace RAM and when full, the incoming trace stream is stalled.

   This mode allows the trace to be transferred by DMA into the system memory, or to a high speed interface (SPI, USB and so on), or even monitored by software. Note that unlike the hardware FIFO mode, this mode is invasive, since it uses system resources which are shared by the processor.

3. Circular buffer mode

   The trace memory is used as a circular buffer. Trace data is captured in the trace memory starting from the location pointed to by the write pointer register. When the trace memory is full, incoming trace data continues to be overwritten in the trace memory until a stop condition occurs.

   In this mode, the ETF stores the trace data on-chip, so the trace log size is limited to that of the ETF SRAM, 2 Kbytes in this case. Being a circular buffer, when the FIFO is full, incoming trace data overwrites the oldest stored data and the oldest stored data is

lost. Therefore the content of the trace buffer represents the most recent activity of the processor, up to the point when the buffer was stopped, rather than all the activity since the trace was started.

There are three possible methods to read the buffer contents once the trace stops:

– via the Trace port - with the TPIU enabled, the contents of the buffer are output over the Trace port. This can be done by setting the DRAINBUF bit in the ETF_FFCR register.
– via the Debug port - the debugger can read the buffer via the RRD register that is accessible over the system APB-D.
– by software - the processor can read the buffer via the RRD register, since the APB-D is accessible from the system bus.

The ETF can be moved to any one of these states:

- **Disabled**

  This state is entered after a reset, or when trace capture is disabled. The ETF must only be programmed in this state.
- **Running**

  Trace capture is performed in this state. It is entered by enabling trace capture while in Disabled state.
- **Stopped**

  Trace capture is stopped in this state, but the contents of the buffer can be read out or drained. This state is entered after a stop event (trigger or flush).
- **Disabling**

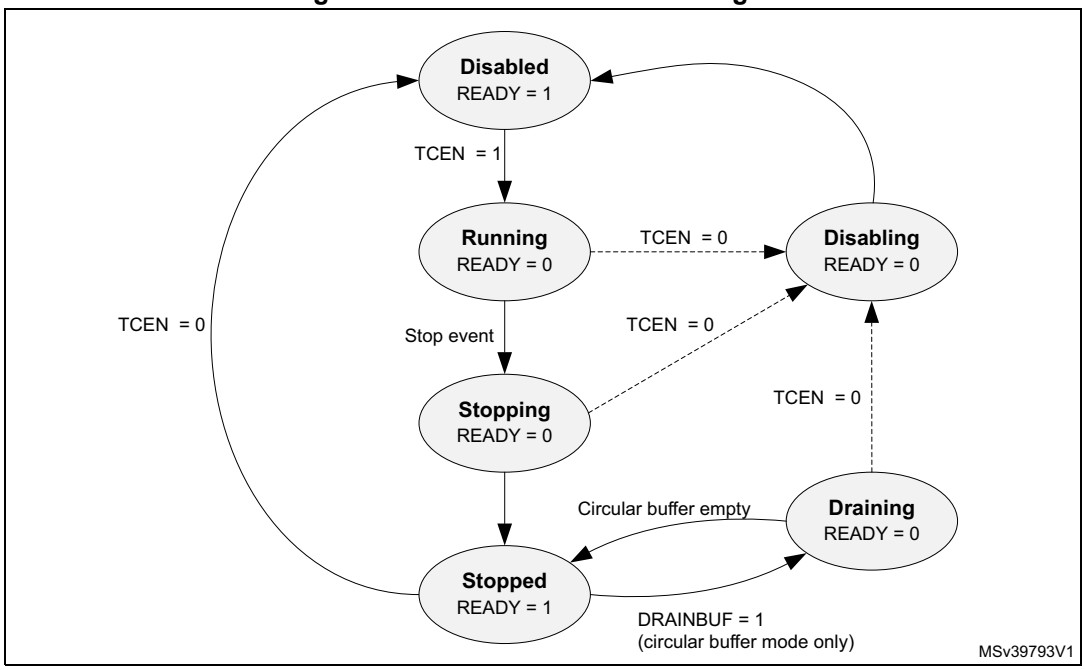
  This is a transition state while disabling trace capture.
- **Stopping**

  This is a transition state while stopping trace capture.
- **Draining**

  This state is entered while draining the buffer in Stopped state.

The state transition diagram is shown in *Figure 865*.

Figure 865. ETF state transition diagram



For more information on the CoreSight™ trace memory controller component, refer to the Arm® CoreSight™ trace memory controller technical reference manual *[3]*.

ETF registers

ETF RAM size register (ETF_RSZ)

Address offset: 0x004

Reset value: 0x0000 0200

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	RSZ[30:16]														
	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RSZ[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 Reserved, must be kept at reset value.

Bits 30:0 **RSZ[30:0]**: RAM size

The value of the field indicates the number of 32-bit words

0x200: 512 words = 2 Kbytes

ETF status register (ETF_STS)

Address offset: 0x00C

Reset value: 0x0000 001C

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EMPTY	FTEMPTY	READY	TRIGD	FULL
											r	r	r	r	r

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **EMPTY**: Trace FIFO empty

This bit is valid only when the TCEN bit of the ETF_CTL register is high. This bit reads as zero when TCEN is low.

0: Trace FIFO contains data

1: Trace FIFO is empty.

Note: Empty trace FIFO does not mean that the ETF pipeline is empty. The latter is indicated by the FTEMPTY bit.

Bit 3 **FTEMPTY**: Formatter empty

This bit is set when a trace capture has stopped, and all internal pipelines and buffers have been drained. Unlike READY, it is not affected by buffer drains. The ACQCOMP output reflects the value of this bit.

Bit 2 **READY**: ETF ready

This bit is set when a trace capture has stopped and all internal pipelines and buffers have been drained (Stopped or Disabled state)

Bit 1 **TRIGD**: Triggered

The Triggered bit is set when a trace capture is in progress and the TMC has detected a Trigger Event. This bit is cleared when leaving Disabled state.

This bit is operational only in the Circular buffer mode. In all other modes, this bit is always low.

This bit does not indicate that a trigger has been embedded in the formatted output trace data from the TMC. Trigger indication on the output trace stream is determined by the programming of the Formatter and Flush Control Register, ETF_FFCR.

Bit 0 **FULL**: Trace buffer full

In circular buffer mode, this flag is set when the RAM write pointer wraps around the top of the buffer, and remains set until the TCEN bit of the ETF_CTL register is cleared and set.

In software and hardware FIFO modes, this flag indicates that the current space in the trace memory is less than or equal to the value programmed in the ETF_BUFWM Register, that is, Fill level >= MEM_SIZE - BUFWM.

This bit is cleared when leaving Disabled state. The FULL output reflects the value of this register bit.

ETF RAM read data register (ETF_RRD)

Address offset: 0x010

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RRD[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RRD[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **RRD[31:0]**: RAM Read Data.

Circular buffer mode:

When in Stopped state and the buffer is not empty, reading this register returns the next word of data from the trace buffer. When the whole trace buffer has been read, the Empty bit in the ETF_STS Register is set, and subsequent reads return 0xFFFFFFF. Reading this register when not in Stopped state returns 0xFFFFFFFF.

Software FIFO mode:

Reading this register returns data from the FIFO. If this register is read when the FIFO is empty, the data returned is 0xFFFFFFFF.

Hardware FIFO mode:

Reading this register returns 0xFFFFFFFF.

ETF RAM read pointer register (ETF_RRP)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	RRP[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:0 **RRP[12:0]**: RAM Read Pointer

The RAM Read Pointer Register contains the value of the read pointer that is used to read entries from the trace memory over the APB interface via the ETF_RRD register. The pointer can be programmed with a byte address, 64-bit aligned (that is, bits 0 to 3 should be zero). The pointer is incremented by 8 each time a full 64-bit FIFO entry has been written. When the pointer reaches its maximum value, it wraps around.

This register can only be written to while in Disabled state. It can be read in Disabled state, in Stopped state in Circular buffer mode and SW FIFO mode, and also in Running and Stopping states in SW FIFO mode.

ETF RAM write pointer register (ETF_RWP)

Address offset: 0x018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	RWP[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:0 **RWP[12:0]**: RAM write pointer

The RAM write pointer register contains the value of the write pointer that is used to write entries into the trace memory over the APB interface via the ETF_RWD register. The pointer can be programmed with a byte address, 64-bit aligned (that is, bits 0 to 3 should be zero). The pointer is incremented by 8 each time a full 64-bit FIFO entry has been read. When the pointer reaches its maximum value, it wraps around.

This register can only be written to while in Disabled state. It can be read in Disabled state, in Stopped state in Circular buffer mode and SW FIFO mode, and also in Running and Stopping states in SW FIFO mode.

ETF trigger counter register (ETF_TRG)

Address offset: 0x01C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	TRG[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:0 **TRG[10:0]**: Trigger counter

In Circular buffer mode, specifies the number of 32-bit words to capture in the trace RAM following the detection of either a rising edge on the TRIGIN input or a trigger packet in the incoming trace stream, ATID = 7'h7D. On capturing the specified number of data words, a trigger event occurs. The effect of a trigger event on the ETF behavior is controlled by the FFCR Register.

The number of 32-bit words written into the trace RAM following the trigger is the value stored in this register, plus one. This register is ignored when the ETF is in Software FIFO mode or Hardware FIFO mode. When the trigger counter starts counting, any additional triggers, either on TRIGIN or in the incoming trace stream, are ignored until the counter reaches zero. When the trigger counter has reached zero, it remains at zero until it is re-programmed with a write to this register.

This register is cleared when READY goes high, so that the state of the counter when trace capture has stopped does not affect a subsequent trace capture session. Writing to this register when not in Disabled state results in unpredictable behavior.

A read access to this register is permitted at any time when in Disabled state, or in Circular buffer mode. A read access returns the current value of the trigger counter.

ETF control register (ETF_CTL)

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCEN
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **TCEN**: Trace capture enable

When writing:

0: Disable trace capture (moves from Running, Stopping or Stopped state into Disabling or Disabled state)

1: Enable trace capture (moves from Disabled state to Running state)

When reading, this bit is low when in Disabling or Disabled states, and high otherwise.

ETF RAM write data register (ETF_RWD)

Address offset: 0x024

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
RWD[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RWD[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **RWD[31:0]**: RAM write data

When in Disabled state, a write to this register stores data at the location pointed to by the RWP. Writes to this register when not in Disabled state are ignored. When a full memory width (64-bit) of data has been written, the data is written to memory and the RAM Write Pointer is incremented to the next memory word.

This register is used for test purposes.

ETF mode register (ETF_MODE)

Address offset: 0x028

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE[1:0]	
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bits 1:0 **MODE[1:0]**: Operation mode

00b: Circular buffer mode

In this mode, the trace memory is used as a circular buffer. Trace data is captured in the trace memory starting from the location pointed to by the write pointer register. Even when the trace memory is full, incoming trace data continues to be overwritten into the trace memory until a stop condition has occurred.

01b: Software FIFO mode

In this mode, the trace memory is used as a FIFO that can be read through the RRD Register while a trace is being captured. Trace data is captured in the trace RAM and when full, the incoming trace stream is stalled.

10b: Hardware FIFO mode

In this mode, the trace memory is used as a FIFO that is drained through the ATB master interface. Trace data is captured in the trace RAM and when full, the incoming trace stream is stalled. When the trace buffer is non-empty, trace data is drained out through the ATB master interface to the TPIU.

11b: Reserved

ETF latched buffer fill level register (ETF_LBUFLVL)

Address offset: 0x02C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	LBUFLEVEL[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **LBUFLEVEL[11:0]**: Latched buffer fill level

Reading this register returns the maximum fill level of the trace memory in 32-bit words since this register was last read. Reading this register also results in its contents being updated to the current fill level.

When entering Disabled state, this register retains its last value. While in Disabled state, reads from this register do not affect its value. When exiting Disabled state, the LBUFLEVEL register is cleared.

This register is used for performance analysis of the trace system.

ETF current buffer fill level register (ETF_CBUFLVL)

Address offset: 0x030

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	CBUFLEVEL[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **CBUFLEVEL[11:0]**: Current buffer fill level

Reading this register returns the current fill level of the trace memory in 32-bit words.

This register is cleared when TCEN is low.

ETF buffer level watermark register (ETF_BUFWM)

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	BUFWM[10:0]										
					rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:0 **BUFWM[10:0]**: Buffer level watermark

The value programmed into this register indicates the required threshold vacancy level of the trace memory in 32-bit words . When the space in the FIFO is less than or equal to this value, that is, fill level >= MEM_SIZE - BUFWM, the FULL output is pulled high and the FULL bit in the STS Register is set.

This register is used only in Software FIFO and Hardware FIFO modes. In Circular buffer mode, this functionality can be obtained by programming the RWP to the required vacancy trigger level, so that when the pointer wraps around, the FULL bit is set indicating that the vacancy level has fallen below the required level.

The maximum value that can be written into this register is MEM_SIZE - 1. In this case, the FULL bit output is asserted after the first 32-bit word is written to trace memory.

Writing to this register other than when in disabled state results in unpredictable behavior.

ETF formatter and flush status register (ETF_FFSR)

Address offset: 0x300

Reset value: 0x0000 0002

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FTSTOPPED	FLINPROG
														r	r

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **FTSTOPPED**: Formatter stopped

This bit behaves in the same way as the FTEMPTY bit in the ETF_STS register.

Bit 0 **FLINPROG**: Flush in progress

Indicates whether a flush on the ATB slave port is in progress. This bit reflects the status of the AFVALIDS output. A flush can be initiated by the flush control bits in the ETF_FFCR register, or requested by the ATB master port.

0: No flush in progress

1: Flush in progress

ETF formatter and flush control register (ETF_FFCR)

Address offset: 0x304

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	DRAINBUF	STPONTRGEV	STOPONFL	Res.	TRIGONFL	TRGONTRGEV	TRGONTRGIN	Res.	FLUSHMAN	FONTRGEV	FONFLIN	Res.	Res.	ENTI	ENFT
	rw	rw	rw		rw	rw	rw		rw	rw	rw			rw	rw

Bits 31:15 Reserved, must be kept at reset value.

Bit 14 **DRAINBUF**: Drain buffer

This bit is used to enable draining of the trace data through the ATB master interface after the formatter has stopped. This is useful in circular buffer mode to capture trace data into trace memory and then to drain the captured trace through the ATB master interface.

Writing a 1 to this bit when in Stopped state starts the drain of the trace buffer contents through the ATB Master interface. This bit always reads as zero. The READY bit in the ETF_STS register goes low while the drain is in progress.

This bit is only functional when the ETF is in Circular buffer mode and formatting is enabled, that is, the ENFT bit in the ETF_FFCR register is set. Setting this bit when the ETF is in any other mode, or when not in Stopped state, results in Unpredictable behavior.

When trace capture is complete in Circular buffer mode, all of the captured trace must be retrieved from the trace memory through the same mechanism, either read all trace data out through RRD reads, or drain all trace data by setting the DRAINBUF bit. Setting the DRAINBUF bit after some of the captured trace has been read out through RRD results in unpredictable behavior.

Bit 13 **STPONTRGEV**: Stop on trigger event

0: No effect

1: Stop trace capture when a trigger event occurs

Enabling the ETF in Software FIFO mode or Hardware FIFO mode with this bit set results in unpredictable behavior.

Bit 12 **STOPONFL**: Stop on flush

0: No effect

1: Stop trace capture when flush is completed

If a flush is initiated by the ATB master interface, its completion does not lead to a formatter stop regardless of the value programmed in this bit.

Bit 11 Reserved, must be kept at reset value.

Bit 10 **TRIGONFL**: Trigger on flush

0: No effect

1: Indicates a trigger in the trace stream when flush is completed

If ENFT and ENTI are both clear, this bit is ignored and no trigger is inserted into the trace stream.

If a flush is initiated by the ATB master interface, its completion does not lead to a trigger indication regardless of the value programmed in this bit.

Bit 9 **TRGONTRGEV**: Trigger on trigger event

0: No effect

1: Indicates a trigger in the trace stream when a trigger event occurs

If ENFT and ENTI are both clear, this bit is ignored and no trigger is inserted into the trace stream.

This bit is not supported in Software FIFO mode nor Hardware FIFO mode.

Bit 8 **TRGONTRGIN**: Trigger on trigger in

0: No effect

1: Indicate a trigger in the trace stream when a rising edge is detected on the TRIGIN input.

If ENFT and ENTI are both clear, this bit is ignored and no trigger is inserted into the trace stream.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **FLUSHMAN**: Manual flush

0: No effect

1: Flush the trace FIFO and pipeline

This bit is cleared automatically when the flush is complete. If the TCEN bit in the ETF_CTL register is 0, writes to this bit are ignored.

Bit 5 **FONTRGEV**: Flush on trigger event

0: No effect

1: Flush the trace FIFO and pipeline if a trigger event occurs

This bit is not supported in Software FIFO mode or Hardware FIFO mode. If STPONTRGEV is set, this bit is ignored.

Bit 4 **FONFLIN**: Flush on flush in

0: No effect

1: Flush the trace FIFO and pipeline if when a rising edge is detected on the FLUSHIN input

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **ENTI**: Enable trigger insertion

Setting this bit enables the insertion of triggers in the formatted trace stream. A trigger is indicated by inserting one byte of data 8'h00 with ATID 7'h7D in the trace stream. Trigger indication on the trace stream is further controlled by the register bits TRIGONFL, TRGONTRGEV, and TRGONTRGIN in the FFCR Register. This bit can only be changed when READY is high, and TCEN is low. This bit takes effect only when the ENFT register bit in this register is set. If ENTI bit is set to high when ENFT is low, it results in formatting being enabled.

Bit 0 **ENFT**: Enable formatting.

0: Formatting is disabled. Incoming trace data is assumed to be from a single trace source.
1: Formatting is enabled.

If multiple ATIDs are received by the ETF when trace capture is enabled and the formatter is disabled, an interleaving of trace data occurs. Disabling of formatting is supported only in Circular buffer mode. If the ETF is enabled in a mode other than Circular buffer mode with ENFT low, then formatting is enabled. If ENTI bit is set to high when ENFT is low, formatting is enabled.
This bit is ignored when in Disabled state.

ETF periodic synchronization counter register (ETF_PSCR)

Address offset: 0x308

Reset value: 0x0000 000A

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSCOUNT[4:0]				
											rw	rw	rw	rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bits 4:0 **PSCOUNT[4:0]**: Synchronization counter reload value

Determines the reload value of the Synchronization Counter. The reload value takes effect the next time the counter reaches zero. Reads from this register return the reload value programmed into this register. This register is set to 0xA on reset, corresponding to a synchronization period of 1024 bytes.

0x0: Synchronization disabled
0x1-0x6: Reserved
0x7-0x1B: Synchronization period is $2^{PSCOUNT}$ bytes
0x1C-0x1F: Reserved

ETF claim tag set register (ETF_CLAIMSET)

Address offset: 0xFA0

Reset value: 0x0000 000F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMSET[3:0]**: Set claim tag bits

Write:
0000: No effect
xxx1: Set bit 0
xx1x: Set bit 1
x1xx: Set bit 2
1xxx: Set bit 3

Read:
0xF: Indicates there are four bits in claim tag

ETF claim tag clear register (ETF_CLAIMCLR)

Address offset: 0xFA4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMCLR[3:0]**: Reset claim tag bits

Write:
0000: No effect
xxx1: Clear bit 0
xx1x: Clear bit 1
x1xx: Clear bit 2
1xxx: Clear bit 3

Read: Returns current value of claim tag

ETF lock access register (ETF_LAR)

Address offset: 0xFB0

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ACCESS_W[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACCESS_W[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **ACCESS_W[31:0]**: ETF register access enable

Enables write access to some ETF registers by the processor cores (debuggers do not need to unlock the component)

0xC5ACCE55: Enable write access
Other values: Disable write access

ETF lock status register (ETF_LSR)

Address offset: 0xFB4

Reset value: 0x0000 0003

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCK TYPE	LOCK GRANT	LOCK EXIST
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **LOCKTYPE**: Size of the ETF_LAR register

0: 32-bit

Bit 1 **LOCKGRANT**: Current status of lock

This bit always returns zero when read by an external debugger.

0: Write access is permitted
1: Write access is blocked. Only read access is permitted.

Bit 0 **LOCKEXIST**: Existence of lock control mechanism

The bit indicates whether a lock control mechanism exists. It always returns zero when read by an external debugger.

0: No lock control mechanism exists
1: Lock control mechanism is implemented

ETF authentication status register (ETF_AUTHSTAT)

Address offset: 0xFB8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SNID[1:0]		SID[1:0]		NSNID[1:0]		NSID[1:0]	
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:6 **SNID[1:0]**: Security level for secure non-invasive debug
0x0: Not implemented

Bits 5:4 **SID[1:0]**: Security level for secure invasive debug
0x0: Not implemented

Bits 3:2 **NSNID[1:0]**: Security level for non-secure non-invasive debug
0x0: Not implemented

Bits 1:0 **NSID[1:0]**: Security level for non-secure invasive debug
0x0: Not implemented

ETF device configuration register (ETF_DEVID)

Address offset: 0xFC8

Reset value: 0x0000 01C0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	MEMWIDTH[2:0]			CONFIGTYP[1:0]		CLK SCHEM	ATBINPORTCNT[4:0]				
					r	r	r	r	r	r	r	r	r	r	r

Bits 31:11 Reserved, must be kept at reset value.

Bits 10:8 **MEMWIDTH[2:0]**: Memory interface data bus width
0x3: 64 bits (corresponds to 32-bit ATB data)

Bits 7:6 **CONFIGTYP[1:0]**: Configuration type of component (ETB, ETR or ETF)
0x2: ETF

Bit 5 **CLKSCHEM**: RAM clocking scheme (synchronous or asynchronous)
0: Synchronous

Bits 4:0 **ATBINPORTCNT**[4:0]: Number/type of ATB input port multiplexing
0x0: None

ETF device type identifier register (ETF_DEVTYPE)

Address offset: 0xFCC

Reset value: 0x0000 0032

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE[3:0]				MAJORTYPE[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SUBTYPE[3:0]**: Sub-classification

0x3: Captures the ATB slave interface trace data in RAM which can then be drained through the ATB master interface

Bits 3:0 **MAJORTYPE[3:0]**: Major classification

0x2: The component is a trace link because it has an ATB master interface through which trace data can be drained out in Hardware FIFO mode.

ETF CoreSight peripheral identity register 4 (ETF_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size

0x0: Register file occupies a single 4 Kbyte region

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code

0x4: Arm® JEDEC code

ETF CoreSight peripheral identity register 0 (ETF_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0061

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Part number field, bits [7:0]
0x61: ETF part number

ETF CoreSight peripheral identity register 1 (ETF_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00B9

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code field, bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: Part number field, bits [11:8]
0x9: ETF part number

ETF CoreSight peripheral identity register 2 (ETF_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 001B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: Component revision number
0x1: r0p1

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code field, bits [6:4]
0x3: Arm® JEDEC code

ETF CoreSight peripheral identity register 3 (ETF_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: Metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: Customer modified
0x0: No customer modifications

ETF CoreSight component identity register 0 (ETF_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component ID field, bits [7:0]
0x0D: Common ID value

ETF CoreSight component identity register 1 (ETF_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0090

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component ID field, bits [15:12] - component class
0x9: CoreSight component

Bits 3:0 **PREAMBLE[11:8]**: Component ID field, bits [11:8]
0x0: Common ID value

ETF CoreSight component identity register 2 (ETF_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component ID field, bits [23:16]
0x05: Common ID value

ETF CoreSight component identity register 3 (ETF_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component ID field, bits [31:24]
0xB1: Common ID value

ETF register map and reset values

Table 630. ETF register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x004	ETF_RSZ	Res.	RSZ[30:0]																														
	Reset value	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0x008	Reserved	Reserved																															
0x00C	ETF_STS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EMPTY	FTEMPTY	READY	TRIGD	FULL
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	0	0
0x010	ETF_RRD	RRD[31:0]																															
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0x014	ETF_RRP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RRP[12:0]												
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0
0x018	ETF_RWP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RWP[12:0]												
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0
0x01C	ETF_TRG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRG[10:0]										
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0
0x020	ETF_CTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCEN
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
0x024	ETF_RWD	RWD[31:0]																															
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0x028	ETF_MODE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MODE[1:0]	
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0
0x02C	ETF_LBUFLVL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LBUFLEVEL[11:0]											
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
0x030	ETF_CBUFLVL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CBUFLEVEL[11:0]											
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
0x034	ETF_BUFWM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUFWM[10:0]										
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0
0x038 to 0x2FC	Reserved	Reserved																															

Table 630. ETF register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x300	ETF_FFSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FTSTOPPED	FLINPROG
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0
0x304	ETF_FFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DRAINBUF	STPONTRGEV	STOPONFL	Res.	TRGONFL	TRGONTRGEV	TRGONTRGIN	Res.	FLUSHMAN	FONTRGEV	FONFLIN	Res.	Res.	ENTI	ENFT
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	-	0	0	0	-	0	0	0	-	-	0	0
0x308	ETF_PSCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PSCOUNT[4:0]				
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	0	1	0
0x30C to 0xF9C	Reserved	Reserved																															
0xFA0	ETF_CLAIMSET	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1
0xFA4	ETF_CLAIMCLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0xFA8 to 0xFAC	Reserved	Reserved																															
0xFB0	ETF_LAR	ACCESS_W[31:0]																															
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0xFB4	ETF_LSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKTYPE	LOCKGRANT	LOCKEXIST
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	1
0xFB8	ETF_AUTHSTAT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SNID[1:0]		SID[1:0]		NSNID[1:0]		NSID[1:0]	
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFBC to 0xFC4	Reserved	Reserved																															
0xFC8	ETF_DEVID	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MEMWDTH[2:0]			CONFIGTYP[1:0]		CLKSCHEM	ATBINPORTCNT[4:0]				
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1	1	1	0	0	0	0	0	0

Table 630. ETF register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFCC	ETF_DEVTYPE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE[3:0]				MAJORTYPE[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1	1	0	0	1	0
0xFD0	ETF_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	ETF_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	1	0	0	0	0	1
0xFE4	ETF_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	1	0	0	1
0xFE8	ETF_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1	1	0	1	1
0xFEC	ETF_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFF0	ETF_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	0	1
0xFF4	ETF_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	1	0	0	0	0
0xFF8	ETF_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	1
0xFFC	ETF_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	1

65.5.5 Trace port interface unit (TPIU)

The TPIU is a CoreSight™ component that formats the trace stream and outputs it on the external trace port signals. The TPIU has a single ATB slave port for incoming trace data. The trace port is a synchronous parallel port, comprising a clock output, TRACECK, and four data outputs, TRACED(3:0). The trace port width is programmable in the range 1 to 4. Using a smaller port width reduces the number of test points/connector pins needed, and frees up IOs for other purposes. However it restricts the bandwidth of the trace port and hence the quantity of trace information that can be output in real time. The TRACECK output must be enabled by setting the TRACECLKEN bit in the DBGMCU_CR register

before a trace is sent to the TPIU. Furthermore, the TRACECK frequency can be programmed in the RCC.

For more information on the Trace port interface CoreSight™ component, refer to the Arm® CoreSight™ SoC-400 technical reference manual *[2]*.

TPIU registers

TPIU supported port size register (TPIU_SUPPSIZE)

Address offset: 0x000

Reset value: 0x0000 000F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PORTSIZE[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PORTSIZE[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **PORTSIZE[31:0]**: Indicates supported trace port sizes, from 1 to 32 pins. Bit n-1 when set indicates that port size n is supported.

0x0000 000F: Port sizes 1 to 4 supported

TPIU current port size register (TPIU_CURPSIZE)

Address offset: 0x004

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PORTSIZE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PORTSIZE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **PORTSIZE[31:0]**: Current trace port size

Setting bit n-1 indicates that the current port size is n-pin wide. The value of n must be within the range of supported port sizes (1-4). Only one bit can be set, or unpredictable behavior may result. This register should only be modified when the formatter is stopped.

TPIU supported trigger modes register (TPIU_SUPTRGM)

Address offset: 0x100

Reset value: 0x0000 011F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRGRUN	TRIGD
														r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCOUNT8	Res.	Res.	Res.	MULT64K	MULT256	MULT16	MULT4	MULT2
							r				r	r	r	r	r

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **TRGRUN**: Trigger running
- 0: Trigger has not occurred or counter is at 0
- 1: Trigger has occurred and counter is not at 0

Bit 16 **TRIGD**: Triggered
- 0: Trigger has not occurred
- 1: Trigger has occurred and counter has reached 0

Bits 15:9 Reserved, must be kept at reset value.

Bit 8 **TCOUNT8**: 8-bit counter register
- 1: Implemented

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **MULT64K**: Multiplying the trigger counter by 65536 support
- 1: Supported

Bit 3 **MULT256**: Multiplying the trigger counter by 256 support
- 1: Supported

Bit 2 **MULT16**: Multiplying the trigger counter by 16 support
- 1: Supported

Bit 1 **MULT4**: Multiplying the trigger counter by 4 support
- 1: Supported

Bit 0 **MULT2**: Multiplying the trigger counter by 2 support
- 1: Supported

TPIU trigger counter value register (TPIU_TRGCNT)

Address offset: 0x104

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGCOUNT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **TRIGCOUNT[7:0]**: Enable trigger delay indication

Enables delaying the indication of triggers to any externally connected trace capture or storage devices. This counter is only eight bits wide and is intended to be used only with the counter multipliers in the Trigger multiplier register, 0x108. When a trigger is started, this value, in conjunction with the multiplier, specifies the number of words before the trigger is indicated. When the trigger counter reaches 0, the value written here is reloaded. Writing to this register causes the trigger counter value to reset but does not reset any value on the multiplier. Reading this register returns the preset value, not the current count.

TPIU trigger multiplier register (TPIU_TRGMULT)

Address offset: 0x108

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MULT64K	MULT256	MULT16	MULT4	MULT2
											rw	rw	rw	rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bit 4 **MULT64K**: Multiply the trigger counter by 65536
0: Disabled
1: Enabled

Bit 3 **MULT256**: Multiply the trigger counter by 256
0: Disabled
1: Enabled

Bit 2 **MULT16**: Multiply the trigger counter by 16
0: Disabled
1: Enabled

Bit 1 **MULT4**: Multiply the trigger counter by 4
0: Disabled
1: Enabled

Bit 0 **MULT2**: Multiply the trigger counter by 2
0: Disabled
1: Enabled

TPIU supported test patterns/modes register (TPIU_SUPTPM)

Address offset: 0x200

Reset value: 0x0003 000F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCONTEN	PTIMEEN
														r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PATF0	PATA5	PATW0	PATW1
												r	r	r	r

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **PCONTEN**: Continuous mode support
1: Supported

Bit 16 **PTIMEEN**: Timed mode support
1: Supported

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **PATF0**: Support of FF/00 pattern
Indicates whether the FF/00 pattern is supported as output over the trace port.
1: Supported

Bit 2 **PATA5**: Support of AA/55 pattern
Indicates whether the AA/55 pattern is supported as output over the trace port.
1: Supported

Bit 1 **PATW0**: Support of walking 0’s pattern
Indicates whether the walking 0’s pattern is supported as output over the trace port.
1: Supported

Bit 0 **PATW1**: Support of walking 1’s pattern
Indicates whether the walking 1’s pattern is supported as output over the trace port.
1: Supported

TPIU current test pattern/mode register (TPIU_CURTPM)

Address offset: 0x204

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCONTEN	PTIMEEN
														rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PATF0	PATA5	PATW0	PATW1
												rw	rw	rw	rw

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **PCONTEN**: Continuous mode enable
0: Disabled
1: Enabled

Bit 16 **PTIMEEN**: Timed mode enable
0: Disabled
1: Enabled

Bits 15:4 Reserved, must be kept at reset value.

Bit 3 **PATF0**: FF/00 pattern enable
Indicates whether the FF/00 pattern is enabled as output over the trace port
0: Disabled
1: Enabled

Bit 2 **PATA5**: AA/55 pattern is enable
Indicates whether the AA/55 pattern is enabled as output over the trace port
0: Disabled
1: Enabled

Bit 1 **PATW0**: Walking 0's pattern enable
Indicates whether the walking 0's pattern is enabled as output over the trace port
0: Disabled
1: Enabled

Bit 0 **PATW1**: Walking 1's pattern enable
Indicates whether the walking 1's pattern is enabled as output over the trace port
0: Disabled
1: Enabled

TPIU test pattern repeat counter register (TPIU_TPRCR)

Address offset: 0x208

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PATTCOUNT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PATTCOUNT[7:0]**: Number of TRACECLKIN cycles

The field provides a 8-bit counter value to indicate the number of TRACECLKIN cycles for which a pattern runs before it switches to the next pattern.

TPIU formatter and flush status register (TPIU_FFSR)

Address offset: 0x300

Reset value: 0x0000 0002

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCPRESENT	FTSTOPPED	FLINPROG
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **TCPRESENT**: TRACECTL output pin availability

Indicates whether the optional TRACECTL output pin is available for use.

0: TRACECTL pin is not present in this device.

Bit 1 **FTSTOPPED**: Formatter stopped

The formatter has received a stop request signal and all trace data and post-amble is sent. Any additional trace data on the ATB interface is ignored.

0: Formatter has not stopped
1: Formatter has stopped

Bit 0 **FLINPROG**: Flush in progress

Indicates whether a flush on the ATB slave port is in progress. This bit reflects the status of the AFVALIDS output. A flush can be initiated by the flush control bits in the TPIU_FFCR register.

0: No flush in progress
1: Flush in progress

TPIU formatter and flush control register (TPIU_FFCR)

Address offset: 0x304

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	STOPTRIG	STOPFL	Res.	TRIGFL	TRIGEVT	TRIGIN	Res.	FONMAN	FONTRIG	FONFLIN	Res.	Res.	ENFCONT	ENFTC
		rw	rw		rw	rw	rw		rw	rw	rw			rw	rw

Bits 31:14 Reserved, must be kept at reset value.

Bit 13 **STOPTRIG**: Stop on trigger event
0: No effect
1: Stop formatter when a trigger event occurs

Bit 12 **STOPFL**: Stop on flush
0: No effect
1: Stop formatter when flush is completed

Bit 11 Reserved, must be kept at reset value.

Bit 10 **TRIGFL**: Trigger on flush
0: No effect
1: Indicate a trigger in the trace stream when flush is completed

Bit 9 **TRIGEVT**: Trigger on trigger event
0: No effect
1: Indicate a trigger in the trace stream when trigger event occurs

Bit 8 **TRIGIN**: Trigger on trigger in
0: No effect
1: Indicate a trigger in the trace stream when the TRIGIN input from the system CTI is asserted.

Bit 7 Reserved, must be kept at reset value.

Bit 6 **FONMAN**: Generate a manual flush
0: No effect
1: Flush the trace

This bit is cleared automatically when the flush completes.

Bit 5 **FONTRIG**: Flush on trigger event
A trigger event occurs when the trigger counter reaches 0, or, if the trigger counter is 0, when the TRIGIN input from the system CTI is high.

0: No effect
1: Flush the trace if a trigger event occurs

Bit 4 **FONFLIN**: Flush on flush in
0: No effect
1: Flush the trace if the FLUSHIN input from the system CTI is asserted

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **ENFCONT:** Enable continuous formatting
0: Continuous formatting is disabled
1: Continuous formatting is enabled

Bit 0 **ENFTC**: Enable the embedding of triggers in formatted trace
0: Formatting is disabled
1: Formatting is enabled

TPIU formatter synchronization counter register (TPIU_FSCR)

Address offset: 0x400

Reset value: 0x0000 0040

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	CYCCOUNT[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **CYCCOUNT[11:0]**: Enables effective use of TPAs

Enables effective use of different-sized TPAs without wasting large amounts of storage capacity of the capture device. This counter contains the number of formatter frames since the last synchronization packet of 128 bits. It is a 12-bit counter with a maximum count value of 4096. This equates to a synchronization every 65536 bytes, that is, 4096 packets x 16 bytes per packet. The default is set up for a synchronization packet every 1024 bytes, that is, every 64 formatter frames. If the formatter is configured for continuous mode, full and half-word sync frames are inserted during normal operation. Under these circumstances, the count value is the maximum number of complete frames between full synchronization packets.

TPIU claim tag set register (TPIU_CLAIMSET)

Address offset: 0xFA0

Reset value: 0x0000 000F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMSET[3:0]**: Set claim tag bits

Write:
0000: No effect
xxx1: Set bit 0
xx1x: Set bit 1
x1xx: Set bit 2
1xxx: Set bit 3

Read:
0xF: Indicates there are four bits in claim tag

TPIU claim tag clear register (TPIU_CLAIMCLR)

Address offset: 0xFA4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMCLR[3:0]**: Reset claim tag bits

Write:
0000: No effect
xxx1: Clear bit 0
xx1x: Clear bit 1
x1xx: Clear bit 2
1xxx: Clear bit 3

Read: Returns current value of claim tag

TPIU lock access register (TPIU_LAR)

Address offset: 0xFB0

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ACCESS_W[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACCESS_W[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **ACCESS_W[31:0]**: TPIU register access enable
Enables write access to some TPIU registers by the processor cores (debuggers do not need to unlock the component)

0xC5ACCE55: Enable write access
Other values: Disable write access

TPIU lock status register (TPIU_LSR)

Address offset: 0xFB4

Reset value: 0x0000 0003

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKTYPE	LOCKGRANT	LOCKEXIST
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **LOCKTYPE**: Size of the TPIU_LAR register
0: 32-bit

Bit 1 **LOCKGRANT**: Current status of lock
This bit always returns zero when read by an external debugger.

0: Write access is permitted
1: Write access is blocked. Only read access is permitted.

Bit 0 **LOCKEXIST**: Implementation of a lock control mechanism
The bit indicates whether a lock control mechanism is implemented. It always returns zero when read by an external debugger.

0: No lock control mechanism is available
1: Lock control mechanism is implemented

TPIU authentication status register (TPIU_AUTHSTAT)

Address offset: 0xFB8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SNID[1:0]		SID[1:0]		NSNID[1:0]		NSID[1:0]	
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:6 **SNID[1:0]**: Security level for secure non-invasive debug
0x0: Not implemented

Bits 5:4 **SID[1:0]**: Security level for secure invasive debug
0x0: Not implemented

Bits 3:2 **NSNID[1:0]**: Security level for non-secure non-invasive debug
0x0: Not implemented

Bits 1:0 **NSID[1:0]**: Security level for non-secure invasive debug
0x0: Not implemented

TPIU device configuration register (TPIU_DEVID)

Address offset: 0xFC8

Reset value: 0x0000 00A0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	SWOUARTNRZ	SWOMAN	TCLKDATA	FIFOSIZE[2:0]			CLKRELAT	MAXNUM[4:0]				
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:12 Reserved, must be kept at reset value.

Bit 11 **SWOUARTNRZ**: Support of SWO UART or NRZ
Indicates whether serial wire output, UART or NRZ, is supported.

0: Not supported

Bit 10 **SWOMAN**: Support of SWO Manchester format
Indicates whether serial wire output, Manchester encoded format, is supported.

0: Not supported

Bit 9 **TCLKDATA**: Support of trace clock plus data
0: Not supported

Bits 8:6 **FIFOSIZE[2:0]**: FIFO size in powers of 2
0x2: FIFO size = 4 (16 bytes)

Bit 5 **CLKRELAT**: ATB clock and TRACECLKIN relation
Indicates the relationship between the ATB clock and TRACECLKIN (synchronous or asynchronous)

1: Asynchronous

Bits 4:0 **MAXNUM[4:0]**: Number/type of ATB input port multiplexing
0x0: None

TPIU device type identifier register (TPIU_DEVTYPE)

Address offset: 0xFCC

Reset value: 0x0000 0011

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE[3:0]				MAJORTYPE[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SUBTYPE[3:0]**: Sub-classification
0x1: Trace port component

Bits 3:0 **MAJORTYPE[3:0]**: Major classification
0x1: Trace sink component

TPIU CoreSight peripheral identity register 4 (TPIU_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size
0x0: Register file occupies a single 4 Kbyte region

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC code

TPIU CoreSight peripheral identity register 0 (TPIU_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0012

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Part number field, bits [7:0]
0x12: TPIU part number

TPIU CoreSight peripheral identity register 1 (TPIU_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00B9

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code field, bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: Part number field, bits [11:8]
0x9: TPIU part number

TPIU CoreSight peripheral identity register 2 (TPIU_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 005B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: Component revision number
0x5: r1p0

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code field, bits [6:4]
0x3: Arm® JEDEC code

TPIU CoreSight peripheral identity register 3 (TPIU_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: Metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: Customer modified
0x0: No customer modifications

TPIU CoreSight component identity register 0 (TPIU_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component ID field, bits [7:0]
0x0D: Common ID value

TPIU CoreSight component identity register 1 (TPIU_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0090

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component ID field, bits [15:12] - component class
0x9: CoreSight component

Bits 3:0 **PREAMBLE[11:8]**: Component ID field, bits [11:8]
0x0: Common ID value

TPIU CoreSight component identity register 2 (TPIU_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component ID field, bits [23:16]
0x05: Common ID value

TPIU CoreSight component identity register 3 (TPIU_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component ID field, bits [31:24]
0xB1: Common ID value

TPIU register map and reset values

Table 631. TPIU register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	TPIU_SUPPSIZE	PORTSIZE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1

Table 631. TPIU register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x004	TPIU_CURPSIZE	PORTSIZE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x008 to 0x0FC	Reserved	Reserved																															
0x100	TPIU_SUPTRGM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRGRUN	TRIGD	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCOUNT8	Res.	Res.	Res.	MULT64K	MULT256	MULT16	MULT4	MULT2
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	-	-	-	-	-	-	1	-	-	-	1	1	1	1	1
0x104	TPIU_TRGCNT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRIGCOUNT[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x108	TPIU_TRGMULT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MULT64K	MULT256	MULT16	MULT4	MULT2
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0
0x10C to 0x1FC	Reserved	Reserved																															
0x200	TPIU_SUPTPM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCONTEN	PTIMEEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PATF0	PATA5	PATW0	PATW1
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1
0x204	TPIU_CURTPM	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PCONTEN	PTIMEEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PATF0	PATA5	PATW0	PATW1
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0x208	TPIU_TPRCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PATTCOUNT[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x20C to 0x2FC	Reserved	Reserved																															
0x300	TPIU_FFSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TCPRESENT	FTSTOPPED	FLINPROG
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	0
0x304	TPIU_FFCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STOPTRIG	STOPFL	Res.	TRiGFL	TRiGEVt	TRIGIN	Res.	FONMAN	FONTRIG	FONFLIN	Res.	Res.	ENFCONT	ENFTC
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	0	0	0	-	0	0	0	-	-	0	0
0x308	TPIU_FSCR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CYCCOUNT[11:0]											
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	0	0	0	0	0
0x30C to 0xF9C	Reserved	Reserved																															

Table 631. TPIU register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFA0	TPIU_CLAIMSET	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1
0xFA4	TPIU_CLAIMCLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0xFB0	TPIU_LAR	ACCESS_W[31:0]																															
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0xFB4	TPIU_LSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKTYPE	LOCKGRANT	LOCKEXIST
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	1
0xFB8	TPIU_AUTHSTAT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SNID[1:0]		SID[1:0]		NSNID[1:0]		NSID[1:0]	
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFBC to 0xFC4	Reserved	Reserved																															
0xFC8	TPIU_DEVID	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWOUARTNRZ	SWOMAN	TCLKDATA	FIFOSIZE[2:0]			CLKRELAT	MUXNUM[4:0]				
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	1	0	0	0	0	0
0xFCC	TPIU_DEVTYPE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE[3:0]				MAJORTYP[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1	0	0	0	1
0xFD0	TPIU_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	TPIU_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1	0	0	1	0
0xFE4	TPIU_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	1	0	0	1
0xFE8	TPIU_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	0	1	1	0	1	1

Table 631. TPIU register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFEC	TPIU_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFF0	TPIU_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	0	1
0xFF4	TPIU_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	1	0	0	0	0
0xFF8	TPIU_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	1
0xFFC	TPIU_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	1

65.5.6 Serial wire output (SWO)

The SWO is a CoreSight component that formats the trace stream from the processor ITM and outputs it on the single wire TRACESWO.

Compared to the TPIU, the SWO contains:

- no formatter
- no pattern generator
- an 8-bit ATB input
- no synchronous trace output, that is, no TRACEDATA or TRACECLK pins
- no support for flush, because this is not required
- no support for triggering

The SWO output supports Manchester encoded and UART NRZ formats.

For more information about the serial wire output CoreSight™ component, refer to the Arm® CoreSight™ Components Technical Reference Manual *[4]*.

SWO registers

SWO current output divisor register (SWO_CODR)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	PRESCALER[12:0]												
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bits 12:0 **PRESCALER[12:0]**: SWO baud rate scaling

The baud rate is the trace clock frequency divided by (PRESCALER + 1). The baud rate changes instantly, so it is recommended to stop the trace source and wait until the port is idle before writing to this register.

SWO selected pin protocol register (SWO_SPPR)

Address offset: 0x0F0

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PPROT[1:0]	
														rw	rw

Bits 31:2 Reserved, must be kept at reset value.

Bits 1:0 **PPROT[1:0]**: Pin protocol

0x0: Reserved
0x1: Manchester
0x2: NRZ
0x3: Reserved

SWO formatter and flush status register (SWO_FFSR)

Address offset: 0x300

Reset value: 0x0000 0008

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FTNONSTOP	TCPRESENT	FTSTOPPED	FLINPROG
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **FTNONSTOP**: Change of settings without stopping formatter

1: Change of settings is allowed with formatter running

Bit 2 **TCPRESENT**: TRACECTL pin present on SWO
0: TRACECTL pin not present

Bit 1 **FTSTOPPED**: Formatter stopped
0: Formatter running
The bit always returns 0 as the SWO formatter cannot be stopped in this device.

Bit 0 **FLINPROG**: Flush in progress
0: Flush is not in progress
The bit always returns 0 as SWO flushing is not supported in this device.

SWO claim tag set register (SWO_CLAIMSET)

Address offset: 0xFA0

Reset value: 0x0000 000F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMSET[3:0]**: Set claim tag bits
Write:
0000: No effect
xxx1: Set bit 0
xx1x: Set bit 1
x1xx: Set bit 2
1xxx: Set bit 3

Read:
0xF: Indicates there are four bits in claim tag

SWO claim tag clear register (SWO_CLAIMCLR)

Address offset: 0xFA4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMCLR[3:0]**: Reset claim tag bits

Write:
0000: No effect
xxx1: Clear bit 0
xx1x: Clear bit 1
x1xx: Clear bit 2
1xxx: Clear bit 3

Read: Returns current value of claim tag

SWO lock access register (SWO_LAR)

Address offset: 0xFB0

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ACCESS_W[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACCESS_W[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **ACCESS_W[31:0]**: SWO register write access enable

Enables write access to some SWO registers by the processor cores (debuggers do not need to unlock the component)

0xC5ACCE55: Enable write access
Other values: Disable write access

SWO lock status register (SWO_LSR)

Address offset: 0xFB4

Reset value: 0x0000 0003

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKTYPE	LOCKGRANT	LOCKEXIST
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **LOCKTYPE**: Size of the SWO_LAR register
0: 32-bit

Bit 1 **LOCKGRANT**: Current status of lock
This bit always returns zero when read by an external debugger.

0: Write access is permitted
1: Write access is blocked - only read access is permitted

Bit 0 **LOCKEXIST**: Implementation of a lock control mechanism
The bit indicates whether a lock control mechanism is implemented. It always returns zero when read by an external debugger.

0: No lock control mechanism available
1: Lock control mechanism is implemented

SWO authentication status register (SWO_AUTHSTAT)

Address offset: 0xFB8

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SNID[1:0]		SID[1:0]		NSNID[1:0]		NSID[1:0]	
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:6 **SNID[1:0]**: Security level for secure non-invasive debug
0x0: Not implemented

Bits 5:4 **SID[1:0]**: Security level for secure invasive debug
0x0: Not implemented

Bits 3:2 **NSNID[1:0]**: Security level for non-secure non-invasive debug
0x0: Not implemented

Bits 1:0 **NSID[1:0]**: Security level for non-secure invasive debug
0x0: Not implemented

SWO device configuration register (SWO_DEVID)

Address offset: 0xFC8

Reset value: 0x0000 0EA0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	SWO UARTNRZ	SWO MAN	TCLK DATA	FIFOSIZE[2:0]			CLK RELAT	MUXNUM[4:0]				
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:11 Reserved, must be kept at reset value.

Bit 11 **SWOUARTNRZ**: SWO UART or NRZ support
Indicates whether serial wire output, UART or NRZ, is supported.

1: Supported

Bit 10 **SWOMAN**: SWO Manchester format support
Indicates whether serial wire output, Manchester encoded format, is supported.
1: Supported

Bit 9 **TCLKDATA**: Trace clock plus data support
Indicates whether trace clock plus data is supported

1: Supported

Bits 8:6 **FIFOSIZE[2:0]**: FIFO size in powers of 2
0x2: FIFO size = 4 (16 bytes)

Bit 5 **CLKRELAT**: ATB clock to TRACECLKIN relation
Indicates the relationship between the ATB clock and TRACECLKIN (synchronous or asynchronous)

1: Asynchronous

Bits 4:0 **MUXNUM[4:0]**: Number/type of ATB input port multiplexing
0x0: None

SWO device type identifier register (SWO_DEVTYPE)

Address offset: 0xFCC

Reset value: 0x0000 0011

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE[3:0]				MAJORTYPE[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SUBTYPE[3:0]**: Sub-classification
0x1: Trace port component

Bits 3:0 **MAJORTYPE[3:0]**: Major classification
0x1: Trace sink component

SWO CoreSight peripheral identity register 4 (SWO_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size
0x0: Register file occupies a single 4 Kbyte region

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC code

SWO CoreSight peripheral identity register 0 (SWO_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0014

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Part number field, bits [7:0]
0x14: SWO part number

SWO CoreSight peripheral identity register 1 (SWO_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00B9

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code field, bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: Part number field, bits [11:8]
0x9: SWO part number

SWO CoreSight peripheral identity register 2 (SWO_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 002B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: Component revision number
0x2: r0p2

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code field, bits [6:4]
0x3: Arm® JEDEC code

SWO CoreSight peripheral identity register 3 (SWO_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: Metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: Customer modified
0x0: No customer modifications

SWO CoreSight component identity register 0 (SWO_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component ID field, bits [7:0]
0x0D: Common ID value

SWO CoreSight component identity register 1 (SWO_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0090

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component ID field, bits [15:12] - component class
0x9: CoreSight component

Bits 3:0 **PREAMBLE[11:8]**: Component ID field, bits [11:8]
0x0: Common ID value

SWO CoreSight component identity register 2 (SWO_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component ID field, bits [23:16]
0x05: Common ID value

SWO CoreSight component identity register 3 (SWO_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component ID field, bits [31:24]
0xB1: Common ID value

SWO register map and reset values

Table 632. SWO register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x010	SWO_CODR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRESCALER[12:0]												
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 632. SWO register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x014 to 0x0EC	Reserved	Reserved																															
0x0F0	SWO_SPPR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PPROT[1:0]	
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1
0x0F4 to 0x2FC	Reserved	Reserved																															
0x300	SWO_FFSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FTNONSTOP	TCPRESENT	FTSTOPPED	FLINPROG
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	0
0x304 to 0xF9C	Reserved	Reserved																															
0xFA0	SWO_CLAIMSET	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1
0xFA4	SWO_CLAIMCLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0xFA8 to 0xFAC	Reserved	Reserved																															
0xFB0	SWO_LAR	ACCESS_W[31;0]																															
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0xFB4	SWO_LSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKTYPE	LOCKGRANT	LOCKEXIST
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	1
0xFB8	SWO_AUTHSTAT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SNID[1:0]		SID[1:0]		NSNID[1:0]		NSID[1:0]	
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFBC to 0xFC4	Reserved	Reserved																															
0xFC8	SWO_DEVID	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SWOUARTNRZ	SWOMAN	TCLKDATA	FIFOSIZE[2:0]			CLKRELAT	MUXNUM[4:0]				
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	1	0	0	0	0	0

Table 632. SWO register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFCC	SWO_DEVTYPE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE[3:0]				MAJORTYPE[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
0xFD0	SWO_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	SWO_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1	0	1	0	0
0xFE4	SWO_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	1	0	0	1
0xFE8	SWO_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1	0	1	0	1	1
0xFEC	SWO_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFF0	SWO_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	0	1
0xFF4	SWO_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	1	0	0	0	0
0xFF8	SWO_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	1
0xFFC	SWO_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	1

65.5.7 Microcontroller debug unit (DBGMCU)

The DBGMCU component contains a number of registers that control the power and clock behavior in Debug mode. Specifically it allows the debugger, or debug software, to:

- maintain the clock and power to the processor cores when in low-power modes (sleep, stop or standby)
- maintain the clock and power to the system debug and trace components when in low power modes
- stop the clock to certain peripherals (CAN, SMBUS timeout, Watchdogs, Timers, RTC) when the processor core is stopped in Debug mode. For timers having complementary outputs, these outputs are disabled (as if the MOE bit was reset) for safety purposes when the counter is stopped (TIM1/8/15/16/17 = 1 in DBGMCU_APB2FZ1).

The DBGMCU registers are not reset by a system reset, only by a power on reset. They are accessible to the debugger via the APB-D bus at base address 0xE00E1000. They are also accessible by the processor core at base address 0x5C001000.

DBGMCU registers

DBGMCU identity code register (DBGMCU_IDC)

Address offset: 0x000

Reset value: 0x1000 0483

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REV_ID[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	DEV_ID[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:16 **REV_ID[15:0]**: Revision
0x1000 = Revision A
0x1001 = Revision Z

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **DEV_ID[11:0]**: Device ID
0x483: STM32H72x, STM32H73x

DBGMCU configuration register (DBGMCU_CR)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	TRGOEN	Res.	Res.	Res.	Res.	Res.	D3DBGCKEN	D1DBGCKEN	TRACECLKEN	Res.	Res.	Res.	Res.
			rw						rw	rw	rw				
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBGSTBY_D1	DBGSTOP_D1	DBGSLEEP_D1
													rw	rw	rw

Bits 31:29 Reserved, must be kept at reset value.

Bit 28 **TRGOEN**: External trigger output enable
This bit controls the direction of the bi-directional trigger pin, TRGIO.

0: Input - TRGIO is connected to TRGIN
1: Output - TRGIO is connected to TRGOUT

Bits 27:23 Reserved, must be kept at reset value.

Bit 22 **D3DBGCKEN**: D3 debug clock enable

This bit allows the debug components in the D3 domain (excluding the DAPCLK domain) to be switched off if they are not needed.

0: Disabled - D3 domain debug components are disabled and their clocks gated
1: Enabled - D3 domain debug components are clocked whenever the corresponding domain clock (CK_HCLK_D3) is active

Bit 21 **D1DBGCKEN**: D1 debug clock enable

This bit allows the debug components in the D1 domain (excluding those in the processor core) to be switched off if they are not needed.

0: Disabled - D1 domain debug components are disabled and their clocks gated
1: Enabled - D1 domain debug components are clocked whenever the corresponding domain clock (CK_HCLK_D1) is active

Bit 20 **TRACECLKEN**: Trace port clock enable

This bit enables the trace port clock, TRACECLK.

0: Disabled - TRACECLK is disabled
1: Enabled - TRACECLK is active

Bits 19:3 Reserved, must be kept at reset value.

Bit 2 **DBGSTBY_D1**: D1 domain debug in Standby mode enable

0: Normal operation - all clocks is disabled and the domain powered down automatically in Standby mode.
1: Automatic clock stop/power-down disabled - all active clocks and oscillators continue to run during Standby mode, and the domain supply is maintained, allowing full debug capability. On exit from Standby mode, a domain reset is performed.

Bit 1 **DBGSTOP_D1**: D1 domain debug in Stop mode enable

0: Normal operation - all clocks are disabled automatically in Stop mode
1: Automatic clock stop disabled - all active clocks and oscillators continue to run during Stop mode, allowing full debug capability. On exit from Stop mode, the clock settings are set to the Stop mode exit state.

Bit 0 **DBGSLEEP_D1**: D1 domain debug in Sleep mode enable

0: Normal operation - the processor clock is stopped automatically in Sleep mode
1: Automatic clock stop disabled - processor clock continues to run, allowing full debug capability

DBGMCU APB3 peripheral freeze register (DBGMCU_APB3FZ1)

Address offset: 0x034

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WWDG1	Res.	Res.	Res.	Res.	Res.	Res.
									rw						

Bits 31:7 Reserved, must be kept at reset value.

Bit 6 **WWDG1**: WWDG1 stop in debug

0: Normal operation - WWDG1 continues to operate while the core is in Debug mode

1: Stop in debug - WWDG1 is frozen while the core is in Debug mode

Bits 5:0 Reserved, must be kept at reset value.

DBGMCU APB1L peripheral freeze register (DBGMCU_APB1LFZ1)

Address offset: 0x03C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	I2C5	Res.	I2C3	I2C2	I2C1	Res.	Res.	Res.	Res.	Res.
						rw		rw	rw	rw					
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	LPTIM1	TIM14	TIM13	TIM12	TIM7	TIM6	TIM5	TIM4	TIM3	TIM2
						rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **I2C5:** I2C5 SMBUS timeout stop in debug

0: Normal operation - I2C5 SMBUS timeout continues to operate while the core is in Debug mode

1: Stop in debug - I2C5 SMBUS timeout is frozen while the Cortex-M7 is in Debug mode

Bit 24 Reserved, must be kept at reset value.

Bit 23 **I2C3**: I2C3 SMBUS timeout stop in debug

0: Normal operation - I2C3 SMBUS timeout continues operating while the core is in Debug mode

1: Stop in debug - I2C3 SMBUS timeout is frozen while Cortex-M7 is in Debug mode

Bit 22 **I2C2**: I2C2 SMBUS timeout stop in debug

0: Normal operation - I2C2 SMBUS timeout continues operating while the core is in Debug mode

1: Stop in debug - I2C2 SMBUS timeout is frozen while Cortex-M7 is in Debug mode

Bit 21 **I2C1**: I2C1 SMBUS timeout stop in debug

0: Normal operation - I2C1 SMBUS timeout continues operating while the core is in Debug mode

1: Stop in debug - I2C1 SMBUS timeout is frozen while the core is in Debug mode

Bits 20:11 Reserved, must be kept at reset value.

Bit 10 Reserved, must be kept at reset value.

Bit 9 **LPTIM1**: LPTIM1 stop in debug

0: Normal operation - LPTIM1 continues operating while the core is in Debug mode

1: Stop in debug - LPTIM1 is frozen while Cortex-M7 is in Debug mode

Bit 8 **TIM14**: TIM14 stop in debug

0: Normal operation - TIM14 continues operating while the core is in Debug mode

1: Stop in debug - TIM14 is frozen while Cortex-M7 is in Debug mode

Bit 7 **TIM13**: TIM13 stop in debug

0: Normal operation - TIM13 continues operating while the core is in Debug mode

1: Stop in debug - TIM13 is frozen while Cortex-M7 is in Debug mode

Bit 6 **TIM12**: TIM12 stop in debug
0: Normal operation - TIM12 continues operatinge while the core is in Debug mode
1: Stop in debug - TIM12 is frozen while Cortex-M7 is in Debug mode

Bit 5 **TIM7**: TIM7 stop in debug
0: Normal operation - TIM7 continues operatinge while the core is in Debug mode
1: Stop in debug - TIM7 is frozen while Cortex-M7 is in Debug mode

Bit 4 **TIM6**: TIM6 stop in debug
0: Normal operation - TIM6 continues operating while the core is in Debug mode
1: Stop in debug - TIM6 is frozen while Cortex-M7 is in Debug mode

Bit 3 **TIM5**: TIM5 stop in debug
0: Normal operation - TIM5 continues operating while the core is in Debug mode
1: Stop in debug - TIM5 is frozen while Cortex-M7 is in Debug mode

Bit 2 **TIM4**: TIM4 stop in debug
0: Normal operation - TIM4 continues operating while the core is in Debug mode
1: Stop in debug - TIM4 is frozen while Cortex-M7 is in Debug mode

Bit 1 **TIM3**: TIM3 stop in debug
0: Normal operation - TIM3 continues operating while the core is in Debug mode
1: Stop in debug - TIM3 is frozen while Cortex-M7 is in Debug mode

Bit 0 **TIM2**: TIM2 stop in debug
0: Normal operation - TIM2 continues operating while the core is in Debug mode
1: Stop in debug - TIM2 is frozen while Cortex-M7 is in Debug mode

DBGMCU APB1H peripheral freeze register (DBGMCU_APB1HFZ1)

Address offset: 0x044

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	TIM24	TIM23	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
						rw	rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:26 Reserved, must be kept at reset value.

Bit 25 **TIM24**: TIM24 stop in debug
0: Normal operation - TIM24 continues to operate while the core is in debug mode
1: Stop in debug - TIM24 is frozen while Cortex-M7 is in debug mode

Bit 24 **TIM23**: TIM23 stop in debug
0: Normal operation - TIM23 continues to operate while the core is in debug mode
1: Stop in debug - TIM23 is frozen while Cortex-M7 is in debug mode

Bits 23:0 Reserved, must be kept at reset value.

DBGMCU APB2 peripheral freeze register (DBGMCU_APB2FZ1)

Address offset: 0x04C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TIM17	TIM16	TIM15
													rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TIM8	TIM1
														rw	rw

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **TIM17**: TIM17 stop in debug

0: Normal operation - TIM17 continues operating while the core is in Debug mode

1: Stop in debug - TIM17 is frozen and TIM17 outputs are disabled while Cortex-M7 is in Debug mode

Bit 17 **TIM16**: TIM16 stop in debug

0: Normal operation - TIM16 continues operating while the core is in Debug mode

1: Stop in debug - TIM16 is frozen and TIM16 outputs are disabled while Cortex-M7 is in Debug mode

Bit 16 **TIM15**: TIM15 stop in debug

0: Normal operation - TIM15 continues operating while the core is in Debug mode

1: Stop in debug - TIM15 is frozen and TIM15 outputs are disabled while Cortex-M7 is in Debug mode

Bits 15:2 Reserved, must be kept at reset value.

Bit 1 **TIM8**: TIM8 stop in debug

0: Normal operation - TIM8 continues operating while the core is in Debug mode

1: Stop in debug - TIM8 is frozen and TIM8 outputs are disabled while Cortex-M7 is in Debug mode

Bit 0 **TIM1**: TIM1 stop in debug

0: Normal operation - TIM1 continues operating while the core is in Debug mode

1: Stop in debug - TIM1 is frozen and TIM1 outputs are disabled while Cortex-M7 is in Debug mode.

DBGMCU APB4 peripheral freeze register (DBGMCU_APB4FZ1)

Address offset: 0x054

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	IWDG1	Res.	RTC
													rw		rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	LPTIM5	LPTIM4	LPTIM3	LPTIM2	Res.	I2C4	Res.	Res.	Res.	Res.	Res.	Res.	Res.
			rw	rw	rw	rw		rw							

Bits 31:19 Reserved, must be kept at reset value.

Bit 18 **IWDG1**: Independent watchdog for D1 stop in debug
0: Normal operation - watchdog continues counting while the core is in Debug mode
1: Stop in debug - watchdog is frozen while Cortex-M7 is in Debug mode

Bit 17 Reserved, must be kept at reset value.

Bit 16 **RTC**: RTC stop in debug
0: Normal operation - RTC continues operating while the core is in Debug mode
1: Stop in debug - RTC is frozen while Cortex-M7 is in Debug mode

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **LPTIM5**: LPTIM5 stop in debug
0: Normal operation - LPTIM5 continues operating while the core is in Debug mode
1: Stop in debug - LPTIM5 is frozen while Cortex-M7 is in Debug mode

Bit 11 **LPTIM4**: LPTIM4 stop in debug
0: Normal operation - LPTIM4 continues operating while the core is in Debug mode
1: Stop in debug - LPTIM4 is frozen while Cortex-M7 is in Debug mode

Bit 10 **LPTIM3**: LPTIM2 stop in debug
0: Normal operation - LPTIM2 continues operating while the core is in Debug mode
1: Stop in debug - LPTIM2 is frozen while Cortex-M7 is in Debug mode

Bit 9 **LPTIM2**: LPTIM2 stop in debug
0: Normal operation - LPTIM2 continues operating while the core is in Debug mode
1: Stop in debug - LPTIM2 is frozen while Cortex-M7 is in Debug mode

Bit 8 Reserved, must be kept at reset value.

Bit 7 **I2C4**: I2C4 SMBUS timeout stop in debug
0: Normal operation - I2C4 SMBUS timeout continues operating while the core is in Debug mode
1: Stop in debug - I2C4 SMBUS timeout is frozen while the core is in Debug mode

Bits 6:0 Reserved, must be kept at reset value.

DBGMCU peripheral identity register 4 (DBGMCU_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size
0x0: Register file occupies a single 4 Kbyte region

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x0: STMicroelectronics JEDEC code

DBGMCU peripheral identity register 0 (DBGMCU_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Part number field, bits [7:0]
0x0: DBGMCU

DBGMCU peripheral identity register 1 (DBGMCU_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code field, bits [3:0]
0x0: STMicroelectronics JEDEC code

Bits 3:0 **PARTNUM[11:8]**: Part number field, bits [11:8]
0x0: DBGMCU

DBGMCU peripheral identity register 2 (DBGMCU_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000A

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: Component revision number
0x0: rev 0

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code field, bits [6:4]
0x2: STMicroelectronics JEDEC code

DBGMCU peripheral identity register 3 (DBGMCU_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: Metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: Customer modified
0x0: No customer modifications

DBGMCU component identity register (DBGMCU_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component ID field, bits [7:0]
0x0D: Common ID value

DBGMCU component identity register (DBGMCU_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 00F0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component ID field, bits [15:12] - component class
0xF: System component with non-standard register layout

Bits 3:0 **PREAMBLE[11:8]**: Component ID field, bits [11:8]
0x0: Common ID value

DBGMCU component identity register (DBGMCU_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component ID field, bits [23:16]
0x05: Common ID value

DBGMCU component identity register (DBGMCU_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]:** Component ID field, bits [31:24]
0xB1: Common ID value

DBGMCU register map and reset values

Table 633. DBGMCU register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	DBGMCU_IDC	REV_ID[15:0]																Res.	Res.	Res.	Res.	DEV_ID[11:0]											
	Reset value	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-	0	1	0	0	1	0	0	0	0	0	1	1
0x004	DBGMCU_CR	Res.	Res.	Res.	TRGOEN	Res.	Res.	Res.	Res.	Res.	D3DBGCKEN	D1DBGCKEN	TRACECLKEN	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DBGSTBD3	DBGSTPD3	Res.	DBGSTBD2	DBGSTPD2	DBGSLPD2	DBGSTBD1	DBGSTPD1	DBGSLPD1
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x008 to 0x030	Reserved	Reserved																															
0x034	DBGMCU_APB3FZ1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WWDG1	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-
0x038	Reserved	Reserved																															
0x03C	DBGMCU_APB1LFZ1	Res.	Res.	Res.	Res.	Res.	Res.	I2C5	Res.	I2C3	I2C2	I2C1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LPTIM1	TIM14	TIM13	TIM12	TIM7	TIM6	TIM5	TIM4	TIM3	TIM2
	Reset value	-	-	-	-	-	-	-	-	0	0	0	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0
0x040 to 0x43	Reserved	Reserved																															
0x044	DBGMCU_APB1HFZ1	Res.	Res.	Res.	Res.	Res.	Res.	TIM24	TIM23	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x045 to 0x48	Reserved	Reserved																															
0x04C	DBGMCU_APB2FZ1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TIM17	TIM16	TIM15	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TIM8	TIM1
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0
0x050	Reserved	Reserved																															
0x054	DBGMCU_APB4FZ1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	WDGLSD1	Res.	RTC	Res.	Res.	Res.	LPTIM5	LPTIM4	LPTIM3	LPTIM2	Res.	I2C4	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	0	-	-	-	0	0	0	0	-	0	-	-	-	-	-	-	-
0xFD0	DBGMCU_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xFE0	DBGMCU_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 633. DBGMCU register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFE4	DBGMCU_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xFE8	DBGMCU_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
0xFEC	DBGMCU_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0xFF0	DBGMCU_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1
0xFF4	DBGMCU_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
0xFF8	DBGMCU_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
0xFFC	DBGMCU_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1

65.6 Cortex-M7 debug functional description

The Cortex-M7 subsystem features the following CoreSight™ components:

- ROM tables
- System control space (SCS)
- Breakpoint unit (FPB)
- Data watchpoint and trace unit (DWT)
- Instrumentation trace macrocell (ITM)
- Embedded trace macrocell (ETM)
- Cross trigger interface (CTI)

These components are accessible by the debugger via the Cortex-M7 AHB-AP and its associated AHBD bus.

65.6.1 Cortex-M7 ROM tables

The ROM table is a CoreSight™ component that contains the base addresses of all the CoreSight debug components accessible via the AHBD. These tables allow a debugger to discover the topology of the CoreSight system automatically.

There are two ROM tables in the Cortex-M7 sub-system:

- Cortex-M7 CPU ROM table

  This table is pointed to by the BASE register in the Cortex-M7 AHB-AP. It contains the base address pointers for the ETM and CTI, as well as for the Cortex-M7 PPB ROM table.
- Cortex-M7 PPB (private peripheral bus) ROM table

  This table contains pointers to the Cortex-M7 System Control Space registers allowing the debugger to identify the CPU core, as well as to the remaining CoreSight components in the Cortex-M7 subsystem: FPB, DWT and ITM.

The CPU ROM table occupies a 4-Kbyte, 32-bit wide chunk of AHBD address space, from 0xE00FE000 to 0xE00FEFFC.

Table 634. Cortex-M7 CPU ROM table

Address in ROM table	Component name	Component base address	Component address offset	Size	Entry
0xE00FE000	Cortex-M7 PPB ROM table	0xE00FF000	0x00001000	4 Kbyte	0x00001003
0xE00FE004	Cortex-M7 ETM	0xE0041000	0xFFF43000	4 Kbyte	0xFFF43003
0xE00FE008	Cortex-M7 CTI	0xE0043000	0xFFF45000	4 Kbyte	0xFFF45003
0xE00FE00C	Reserved	-	-	-	0x1FF02002
0xE00FE010	Top of table	-	-	-	0x00000000
0xE00FE010 to 0xE00FEFC8	Reserved	-	-	-	0x00000000
0xE00FEFCC to 0xE00FEFFC	ROM table registers	-	-	-	See *Table 636*

The Cortex-M7 PPB ROM table occupies a 4-Kbyte, 32-bit wide chunk of APB-D address space, from 0xE00FF000 to 0xE00FFFFC.

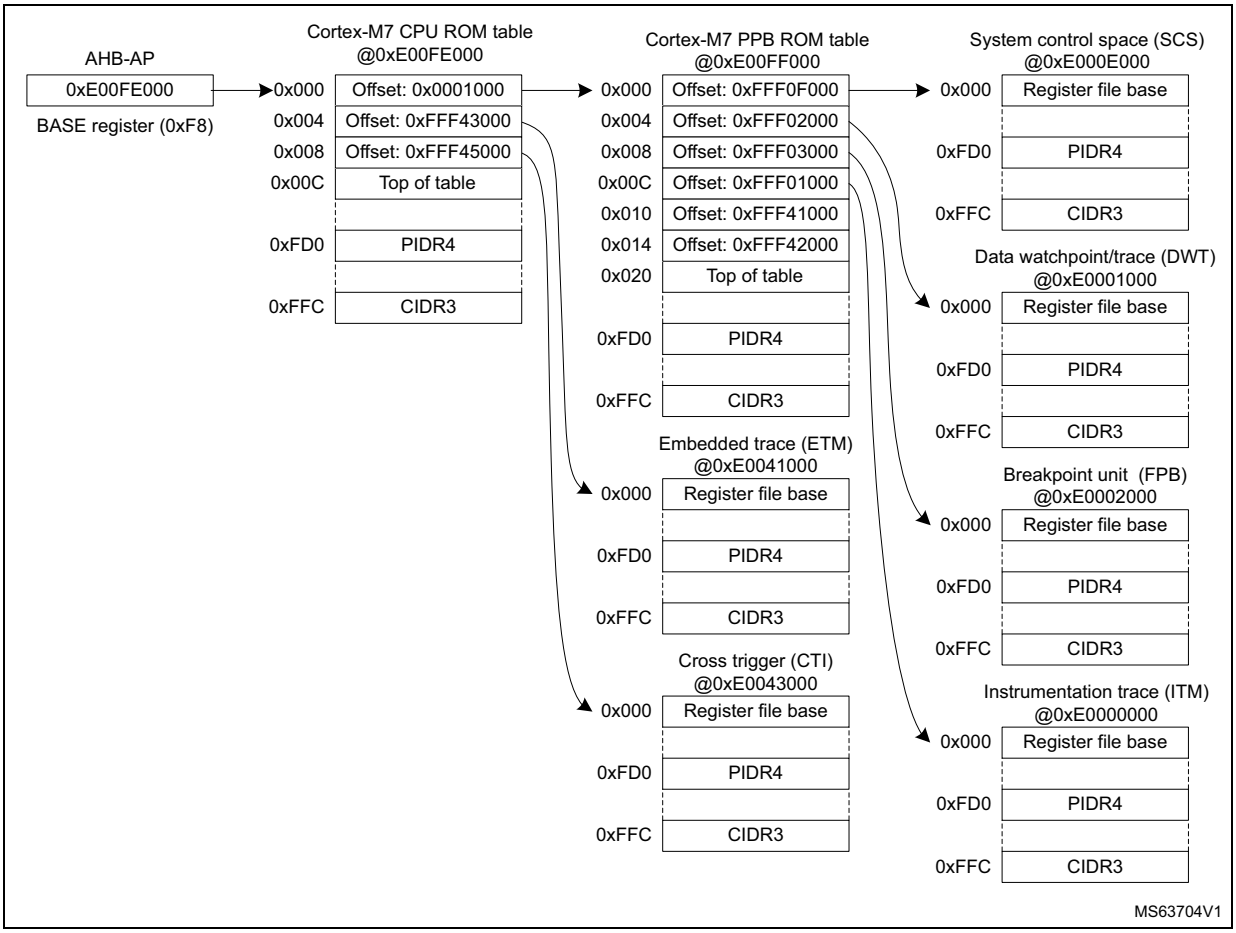
Table 635. Cortex-M7 PPB ROM table

Address in ROM table	Component name	Component base address	Component address offset	Size	Entry
0xE00FF000	SCS	0xE000E000	0xFFF0F000	4 Kbyte	0xFFF0F003
0xE00FF004	DWT	0xE0001000	0xFFF02000	4 Kbyte	0xFFF02003
0xE00FF008	FPB	0xE0002000	0xFFF03000	4 Kbyte	0xFFF03003
0xE00FF00C	ITM	0xE0000000	0xFFF01000	4 Kbyte	0xFFF01003
0xE00FF010	TPIU(1)	0xE0040000	0xFFF41000	4 Kbyte	0xFFF41002
0xE00FF014	ETM(1)	0xE0041000	0xFFF42000	4 Kbyte	0xFFF42002
0xE00FF018	Top of table	-	-	-	0x00000000
0xE00FF01C to 0xE00FFFC8	Reserved	-	-	-	0x00000000
0xE00FFFCC to 0xE00FFFFC	ROM table registers	-	-	-	See *Table 637*

1. The TPIU and ETM are included in this table by default, but bit 0 is reset to indicate that they are not present.

The Topology for the CoreSight™ components in the Cortex-M7 subsystem is shown in *Figure 866*.

Figure 866. Cortex-M7 CoreSight Topology



Cortex-M7 CPU ROM registers

CPU ROM memory type register (M7_CPUROM_MEMTYPE)

Address offset: 0xFCC

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSMEM
															r

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **SYSMEM**: System memory presence

1: System memory is present on this bus

CPU ROM CoreSight peripheral identity register 4 (M7_CPUROM_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size
0x0: Register file occupies a single 4 Kbyte region

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x0: STMicroelectronics JEDEC continuation code

CPU ROM CoreSight peripheral identity register 0 (M7_CPUROM_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0083

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Part number field, bits [7:0]
0x83: STM32H72/73

CPU ROM CoreSight peripheral identity register 1 (M7_CPUROM_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code field, bits [3:0]
0x0: STMicroelectronics

Bits 3:0 **PARTNUM[11:8]**: Part number field, bits [11:8]
0x4: STM32H72/73

CPU ROM CoreSight peripheral identity register 2 (M7_CPUROM_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000A

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: Component revision number
0x0: rev r0p0

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code field, bits [6:4]
0x2: STMicroelectronics

CPU ROM CoreSight peripheral identity register 3 (M7_CPUROM_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: Metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: Customer modified
0x0: No customer modifications

CPU ROM CoreSight component identity register 0 (M7_CPUROM_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component ID field, bits [7:0]
0x0D: Common ID value

CPU ROM CoreSight component identity register 1 (M7_CPUROM_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0010

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component ID field, bits [15:12] - component class
0x1: ROM table component

Bits 3:0 **PREAMBLE[11:8]**: Component ID field, bits [11:8]
0x0: Common ID value

CPU ROM CoreSight component identity register 2 (M7_CPUROM_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component ID field, bits [23:16]
0x05: Common ID value

CPU ROM CoreSight component identity register 3 (M7_CPUROM_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component ID field, bits [31:24]
0xB1: Common ID value

Cortex-M7 CPU ROM table register map and reset values

Table 636. Cortex-M7 CPU ROM table register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFCC	M7_CPUROM_MEMTYPE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSMEM
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
0xFD0	M7_CPUROM_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	M7_CPUROM_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	0	0	0	1	1
0xFE4	M7_CPUROM_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	0
0xFE8	M7_CPUROM_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	1	0
0xFEC	M7_CPUROM_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0

Table 636. Cortex-M7 CPU ROM table register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFF0	M7_CPUROM_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	0	1
0xFF4	M7_CPUROM_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1	0	0	0	0
0xFF8	M7_CPUROM_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	1
0xFFC	M7_CPUROM_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	1

Cortex-M7 PPB ROM registers

PPB ROM memory type register (M7_PPBROM_MEMTYPE)

Address offset: 0xFCC

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSMEM
															r

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **SYSMEM**: System memory presence

1: System memory is present on this bus

PPB ROM CoreSight peripheral identity register 4 (M7_PPBROM_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size
0x0: Register file occupies a single 4 Kbyte region

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC continuation code

PPB ROM CoreSight peripheral identity register 0 (M7_PPBROM_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 00C7

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Part number field, bits [7:0]
0xC7: Cortex-M7 PPB ROM table

PPB ROM CoreSight peripheral identity register 1 (M7_PPBROM_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00B4

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code field, bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: Part number field, bits [11:8]
0x4: Cortex-M7 PPB ROM table

PPB ROM CoreSight peripheral identity register 2 (M7_PPBROM_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: Component revision number
0x0: rev r0p0

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code field, bits [6:4]
0x3: Arm® JEDEC code

PPB ROM CoreSight peripheral identity register 3 (M7_PPBROM_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: Metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: Customer modified
0x0: No customer modifications

PPB ROM CoreSight component identity register 0 (M7_PPBROM_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component ID field, bits [7:0]
0x0D: Common ID value

PPB ROM CoreSight component identity register 1 (M7_PPBROM_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0010

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component ID field, bits [15:12] - component class
0x1: ROM table component

Bits 3:0 **PREAMBLE[11:8]**: Component ID field, bits [11:8]
0x0: Common ID value

PPB ROM CoreSight component identity register 2 (M7_PPBROM_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component ID field, bits [23:16]
0x05: Common ID value

PPB ROM CoreSight component identity register 3 (M7_PPBROM_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component ID field, bits [31:24]
0xB1: Common ID value

Cortex-M7 PPB ROM table register map and reset values

Table 637. Cortex-M7 PPB ROM table register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFCC	M7_PPBROM_MEMTYPE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSMEM
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
0xFD0	M7_PPBROM_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	M7_PPBROM_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	0	0	0	1	1	1
0xFE4	M7_PPBROM_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	1	0	0
0xFE8	M7_PPBROM_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	1	1
0xFEC	M7_PPBROM_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0

Table 637. Cortex-M7 PPB ROM table register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFF0	M7_PPBROM_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	0	1
0xFF4	M7_PPBROM_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1	0	0	0	0
0xFF8	M7_PPBROM_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	1
0xFFC	M7_PPBROM_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	1

65.6.2 Cortex-M7 data watchpoint and trace unit (DWT)

The DWT provides four comparators that can be used as:

- watchpoint
- ETM trigger
- PC sampling trigger
- data address sampling trigger
- data comparator (comparator 1 only)
- clock cycle counter comparator (comparator 0 only)

It also contains counters for:

- clock cycles
- folded instructions
- load store unit (LSU) operations
- sleep cycles
- number of cycles per instruction
- interrupt overhead

A DWT comparator compares one of the following with the value held in its DWT_COMP register:

- a data address
- an instruction address
- a data value
- the cycle count value, for comparator 0 only.

For address matching, the comparator can use a mask, so it matches a range of addresses.

On a successful match, the comparator generates one of the following:

- one or more DWT data trace packets, containing one or more of:
  - the address of the instruction that caused a data access
  - an address offset, bits[15:0] of the data access address
  - the matched data value
- a watchpoint debug event, on either the PC value or the accessed data address
- a CMPMATCH[N] event that signals the match outside the DWT unit

A watchpoint debug event either generates a DebugMonitor exception, or causes the processor to halt execution and enter Debug state.

For more details on how to use the DWT, refer to the Arm®v7-M Architecture Reference Manual *[5]*.

Cortex-M7 DWT registers

DWT control register (M7_DWT_CTRL)

Address offset: 0x000

Reset value: 0x4000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMCOMP[3:0].				NOTRCPKT	NOEXTTRIG	NOCYCCNT	NOPRFCNT	Res.	CYCEVTENA	FOLDEVTENA	LSUEVTENA	SLEEPEVTENA	EXCEVTENA	CPIEVTENA	EXCTRCENA
r	r	r	r	r	r	r	r		rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	PCSAMPLENA	SYNCTAP[1:0]		CYCTAP	POSTINIT[3:0]				POSTRESET[3:0]				CYCCNTENA
			rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:28 **NUMCOMP[3:0]**: Number of implemented comparators (read-only)
0x4: Four comparators

Bit 27 **NOTRCPKT**: Trace sampling and exception tracing support (read-only)
0: Supported

Bit 26 **NOEXTTRIG**: External match signal, CMPMATCH support (read-only)
0: Supported

Bit 25 **NOCYCCNT**: Cycle counter support (read-only)
0: Supported

Bit 24 **NOPRFCNT**: Profiling counter support (read-only)
0: Supported

Bit 23 Reserved, must be kept at reset value.

Bit 22 **CYCEVTENA**: Enable POSTCNT underflow event counter packet generation
0: Disabled
1: Enabled

Bit 21 **FOLDEVTENA**: Enable folded instruction counter overflow event generation
0: Disabled
1: Enabled

Bit 20 **LSUEVTENA**: Enable LSU counter overflow event generation
0: Disabled
1: Enabled

Bit 19 **SLEEPEVTENA**: Enable sleep counter overflow event generation
0: Disabled
1: Enabled

Bit 18 **EXCEVTENA**: Enable exception overhead counter overflow event generation
0: Disabled
1: Enabled

Bit 17 **CPIEVTENA**: Enable CPI counter overflow event generation
0: Disabled
1: Enabled

Bit 16 **EXCTRCENA**: Enable exception trace generation
0: Disabled
1: Enabled

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **PCSAMPLENA**: POSTCNT counter use enable
Enables the use of POSTCNT counter as a timer for Periodic PC sample packet generation.

0: Disabled
1: Enabled

Bits 11:10 **SYNCTAP[1:0]**: Position of synchronization packet counter tap on CYCCNT counter
This selection determines the synchronization packet rate.

0x0: Disabled - no synchronization packets
0x1: Tap at CYCCNT[24]
0x2: Tap at CYCCNT[26]
0x3: Tap at CYCCNT[28]

Bit 9 **CYCTAP**: Position of the POSTCNT tap on the CYCCNT counter
0: Tap at CYCCNT[6]
1: Tap at CYCCNT[10]

Bits 8:5 **POSTINIT[3:0]**: Initial value of the POSTCNT counter
Writes to this field are ignored if POSTCNT counter is enabled (that is, CYCEVTENA or PCSAMPLENA must be reset prior to writing POSTINIT).

Bits 4:1 **POSTRESET[3:0]**: Reload value of the POSTCNT counter.

Bit 0 **CYCCNTENA**: CYCCNT counter enable
0: Disabled
1: Enabled

DWT cycle count register (M7_DWT_CYCCNT)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CYCCNT[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CYCCNT[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **CYCCNT[31:0]**: Processor clock cycle counter

DWT CPI count register (M7_DWT_CPICNT)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CPICNT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **CPICNT[7:0]**: CPI counter

Counts additional cycles required to execute multi-cycle instructions, except those recorded by DWT_LSUCNT, and counts any instruction fetch stalls.

DWT exception count register (M7_DWT_EXCCNT)

Address offset: 0x00C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EXCCNT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **EXCCNT[7:0]**: Exception overhead cycle counter

Counts the number of cycles spent in exception processing.

DWT sleep count register (M7_DWT_SLPCNT)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SLEEPCNT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **SLEEPCNT[7:0]**: Sleep cycle counter
Counts the number of cycles spent in sleep mode (WFI, WFE, sleep-on-exit).

DWT LSU count register (M7_DWT_LSUCNT)

Address offset: 0x014

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LSUCNT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **LSUCNT[7:0]**: Load store counter
Counts additional cycles required to execute load and store instructions.

DWT fold count register (M7_DWT_FOLDCNT)

Address offset: 0x018

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FOLDCNT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **FOLDCNT[7:0]**: Folded instruction counter
Increments on each instruction that takes 0 cycles.

DWT program counter sample register (M7_DWT_PCSR)

Address offset: 0x01C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
EIASAMPLE[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EIASAMPLE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **EIASAMPLE[31:0]**: Executed instruction address sample value
Samples the current value of the program counter.

DWT comparator register x (M7_DWT_COMPx)

Address offset: 0x020 + x * 0x10 (for x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
COMP[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
COMP[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **COMP[31:0]**: Reference value for comparison.

DWT mask register x (M7_DWT_MASKx)

Address offset: 0x024 + x * 0x10 (for x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MASK[4:0]				
											rw	rw	rw	rw	rw

Bits 31:5 Reserved, must be kept at reset value.

Bits 4:0 **MASK[4:0]**: Comparator mask size
Provides the size of the ignore mask applied to the access address for address range matching by comparator n. A debugger can write 0b11111 to this field and then read the register back to determine the maximum mask size supported.

DWT function register x (M7_DWT_FUNCTx)

Address offset: 0x028 + x * 0x10 (for x = 0 to 3)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	MATCHED	Res.	Res.	Res.	Res.	DATAVADDR1[3:0]			
							r					rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DATAVADDR0[3:0]				DATAVSIZE[1:0]		LINK1ENA	DATAVMATCH	CYCMATCH	Res.	EMITRANGE	Res.	FUNCTION[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw		rw		rw	rw	rw	rw

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **MATCHED**: Comparator match (read-only)
Indicates if a comparator match has occurred since the register was last read.

0: No match
1: Match occurred

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **DATAVADDR1[3:0]**: Comparator number of a second comparator
When the DATAVMATCH and LNK1ENA bits are both 1, this field can hold the comparator number of a second comparator to use for linked address comparison.

Bits 15:12 **DATAVADDR0[3:0]**: Comparator number of a comparator
When the DATAVMATCH and LNK1ENA bits are both 1, this field can hold the comparator number of a comparator to use for linked address comparison.

Bits 11:10 **DATAVSIZE[1:0]**: Size of required data comparison
For data value matching, specifies the size of the required data comparison.

0x0: Byte
0x1: Half word
0x2: Word
0x3: Reserved

Bit 9 **LINK1ENA**: Support of a second linked comparator (read-only)
Indicates whether the use of a second linked comparator is supported (read-only).

1: Supported

Bit 8 **DATAVMATCH**: Cycle comparison enable
0: Perform address comparison
1: Perform data value comparison

Bit 7 **CYCMATCH**: Cycle count comparison enable on comparator 0
This field is reserved for other comparators.

0: No cycle count comparison
1: Compare DWT_COMP0 with the cycle counter, DWT_CYCCNT

Bit 6 Reserved, must be kept at reset value.

Bit 5 **EMITRANGE**: Data trace address offset packet enable
Enables the generation of data trace address offset packets (containing data address bits 0 to 15)
0: Disabled
1: Enabled

Bit 4 Reserved, must be kept at reset value.

Bits 3:0 **FUNCTION[3:0]**: Action on comparator match
The meaning of this bit field depends on the setting of the DATAVMATCH and CYCMATCH fields. See *[5]*.

DWT CoreSight peripheral identity register 4 (M7_DWT_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size
0x0: Register file occupies a single 4 Kbyte region

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC code

DWT CoreSight peripheral identity register 0 (M7_DWT_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0002

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Part number field, bits [7:0]
0x02: DWT part number

DWT CoreSight peripheral identity register 1 (M7_DWT_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00B0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code field, bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: Part number field, bits [11:8]
0x0: DWT part number

DWT CoreSight peripheral identity register 2 (M7_DWT_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: Component revision number
0x0: r0p0

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code field, bits [6:4]
0x3: Arm® JEDEC code

DWT CoreSight peripheral identity register 3 (M7_DWT_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: Metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: Customer modified
0x0: No customer modifications

DWT CoreSight component identity register 0 (M7_DWT_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component ID field, bits [7:0]
0x0D: Common ID value

DWT CoreSight component identity register 1 (M7_DWT_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 00E0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component ID field, bits [15:12] - component class
0xE: Trace generator component

Bits 3:0 **PREAMBLE[11:8]**: Component ID field, bits [11:8]
0x0: Common ID value

DWT CoreSight component identity register 2 (M7_DWT_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component ID field, bits [23:16]
0x05: Common ID value

DWT CoreSight component identity register 3 (M7_DWT_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component ID field, bits [31:24]
0xB1: Common ID value

Cortex-M7 DWT register map and reset values

The Cortex-M7 DWT registers are located at address range 0xE0001000 to 0xE0001FFC, on the AHBD.

Table 638. Cortex-M7 DWT register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	M7_DWT_CTRL	NUMCOMP[3:0]				NOTRCPKT	NOEXTTRIG	NOCYCCNT	NOPRFCNT	Res.	CYCEVTENA	FOLDEVTENA	LSUEVTENA	SLEEPEVTENA	EXCEVTENA	CPIEVTENA	EXCTRCENA	Res.	Res.	Res.	PCSAMPLENA	SYNCTAP[1:0]		CYCTAP	POSINIT[3:0]				POSTPRESET[3:0]				CYCCNTENA
	Reset value	0	1	0	0	0	0	0	0	-	0	0	0	0	0	0	0	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0
0x004	M7_DWT_CYCCNT	CYCCNT[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x008	M7_DWT_CPICNT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CPICNT[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x00C	M7_DWT_EXCCNT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EXCCNT[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x010	M7_DWT_SLPCNT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SLEEPCNT[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x014	M7_DWT_LSUCNT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LSUCNT[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x018	M7_DWT_FOLDCNT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	FOLDCNT[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x01C	M7_DWT_PCSR	EIASAMPLE[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x020	M7_DWT_COMP0	COMP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024	M7_DWT_MASK0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MASK[4:0]				
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0
0x028	M7_DWT_FUNCT0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MATCHED	Res.	Res.	Res.	Res.	DATAVADDR1[3:0]				DATAVADDR0[3:0]				DATAVSIZE[1:0]		LNK1ENA	DATAVMATCH	CYCMATCH	Res.	EMITRANGE	Res.	FUNCTION[3:0]			
	Reset value	-	-	-	-	-	-	-	0	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	-	0	0	0	0
0x02C	Reserved	Reserved																															
0x030	M7_DWT_COMP1	COMP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x034	M7_DWT_MASK1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MASK[4:0]				
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0
0x038	M7_DWT_FUNCT1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MATCHED	Res.	Res.	Res.	Res.	DATAVADDR1[3:0]				DATAVADDR0[3:0]				DATAVSIZE[1:0]		LNK1ENA	DATAVMATCH	CYCMATCH	Res.	EMITRANGE	Res.	FUNCTION[3:0]			
	Reset value	-	-	-	-	-	-	-	0	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	-	0	0	0	0

Table 638. Cortex-M7 DWT register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x03C	Reserved	Reserved																															
0x040	M7_DWT_COMP2	COMP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x044	M7_DWT_MASK2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MASK[4:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0
0x048	M7_DWT_FUNCT2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MATCHED	Res.	Res.	Res.	Res.	DATAVADDR1[3:0]				DATAVADDR0[3:0]				DATAVSIZE[1:0]		LNK1ENA	DATAVMATCH	CYCMATCH	Res.	EMITRANGE	Res.	FUNCTION[3:0]			
	Reset value	-	-	-	-	-	-	-	0	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	-	0	0	0	0
0x04C	Reserved	Reserved																															
0x050	M7_DWT_COMP3	COMP[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x054	M7_DWT_MASK3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MASK[4:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0
0x058	M7_DWT_FUNCT3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	MATCHED	Res.	Res.	Res.	Res.	DATAVADDR1[3:0]				DATAVADDR0[3:0]				DATAVSIZE[1:0]		LNK1ENA	DATAVMATCH	CYCMATCH	Res.	EMITRANGE	Res.	FUNCTION[3:0]			
	Reset value	-	-	-	-	-	-	-	0	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	-	0	0	0	0
0x05C to 0xFCC	Reserved	Reserved																															
0xFD0	M7_DWT_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	0
0xFD4 to 0xFCC	Reserved	Reserved																															
0xFE0	M7_DWT_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	1	0
0xFE4	M7_DWT_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	1	0	0	1
0xFE8	M7_DWT_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	1	1
0xFEC	M7_DWT_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFF0	M7_DWT_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	0	1

Table 638. Cortex-M7 DWT register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFF4	M7_DWT_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	1	1	0	0	0	0
0xFF8	M7_DWT_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	1
0xFFC	M7_DWT_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	1

65.6.3 Cortex-M7 instrumentation trace macrocell (ITM)

The ITM generates trace information as packets. There are four sources that can generate packets. If multiple sources generate packets at the same time, the ITM arbitrates the order in which packets are output. The four sources in decreasing order of priority are:

1. Software trace

   Software can write directly to any of 32 x 32-bit ITM stimulus registers to generate packets. The permission level for each port can be programmed. When software writes to an enabled stimulus port, the ITM combines the identity of the port, the size of the write access, and the data written, into a packet that it writes to a FIFO. The ITM outputs packets from the FIFO onto the trace bus. Reading a stimulus port register returns the status of the stimulus register (empty or pending) in bit 0.

2. Hardware trace

   The DWT generates trace packets in response to a data trace event, a PC sample or a performance profiling counter wraparound. The ITM outputs these packets on the trace bus.

3. Local timestamping

   The ITM contains a 21-bit counter clocked by the (pre-divided) processor clock. The counter value is output in a timestamp packet on the trace bus. The counter is reset to zero every time a timestamp packet is generated. The timestamps thus indicate the time elapsed since the previous timestamp packet.

4. Global system timestamping

   Timestamps can also be generated using the system-wide 64-bit count value coming from the Timestamp Generator component.

Cortex-M7 ITM registers

ITM stimulus register x (M7_ITM_STIMx)

Address offset: 0x000 + x * 0x4 (x = 0 to 31)

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
STIMULUS[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STIMULUS[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **STIMULUS[31:0]**: Software event packet / FIFOREADY

Write data is output on the trace bus as a software event packet. When reading, bit 0 is a FIFOREADY indicator:

0: Stimulus port buffer is full (or port is disabled)
1: Stimulus port can accept new write data

ITM trace enable register (M7_ITM_TER)

Address offset: 0xE00

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
STIMENA[31:16]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
STIMENA[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:0 **STIMENA[31:0]**: Stimulus port enable

Each bit n (31:0) enables the stimulus port associated with the M7_ITM_STIMn register.

0: Port disabled
1: Port enabled

ITM trace privilege registers (M7_ITM_TPR)

Address offset: 0xE40

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIVMASK[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **PRIVMASK[3:0]**: Enable unprivileged access to ITM stimulus ports
Each bit controls eight stimulus ports:

0bXXX0: Unprivileged access permitted on ports 0 to 7
0bXXX1: Only privileged access permitted on ports 0 to 7
0bXX0X: Unprivileged access permitted on ports 8 to 15
0bXX1X: Only privileged access permitted on ports 8 to 15
0bX0XX: Unprivileged access permitted on ports 16 to 23
0bX1XX: Only privileged access permitted on ports 16 to 23
0b0XXX: Unprivileged access permitted on ports 24 to 31
0b1XXX: Only privileged access permitted on ports 24 to 31

ITM trace control register (M7_ITM_TCR)

Address offset: 0xE80

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	BUSY	TRACEBUSID[6:0]						
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	GTSFREQ[1:0]		TSPRESCALE [1:0]		Res.	Res.	Res.	SWOE NA	TXENA	SYNC ENA	TSENA	ITM ENA
				rw	rw	rw	rw				r	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bit 23 **BUSY**: ITM busy
Indicates whether the ITM is currently processing events (read-only):

0: Not busy
1: Busy

Bits 22:16 **TRACEBUSID[6:0]**: Identifier for multi-source trace stream formatting
If multi-source trace is in use, the debugger must write a non-zero value to this field. Note: different IDs must be used for each trace source in the system.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:10 **GTSFREQ[1:0]**: Global timestamp frequency
Defines how often the ITM generates a global timestamp, based on the global timestamp clock frequency, or disables generation of global timestamps. The possible values are:

0x0: Disable generation of global timestamps
0x1: Generate timestamp request whenever the ITM detects a change in global timestamp counter bits [63:7]; this is approximately every 128 cycles
0x2: Generate timestamp request whenever the ITM detects a change in global timestamp counter bits [63:13]; this is approximately every 8192 cycles
0x3: Generate a timestamp after every packet, if the output FIFO is empty

Bits 9:8 TSPRESCALE[1:0]: Local timestamp prescale
Prescaler used with the trace packet reference clock The possible values are:

0x0: No prescaling
0x1: Divide by 4
0x2: Divide by 16
0x3: Divide by 64

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **SWOENA**: Asynchronous clocking enable for the timestamp counter (read-only)
0: Timestamp counter uses processor clock

Bit 3 **TXENA**: Hardware event packet forwarding enable
Enables forwarding of hardware event packets from the DWT unit to the trace port.

0: Disabled
1: Enabled

Bit 2 **SYNCENA**: Synchronization packet transmission enable
If a debugger sets this bit it must also configure the DWT_CTRL register SYNCTAP field in the DWT for the correct synchronization speed.

0: Disabled
1: Enabled

Bit 1 **TSENA**: Local timestamp generation enable
0: Disabled
1: Enabled

Bit 0 **ITMENA**: ITM enable
0: Disabled
1: Enabled

ITM CoreSight peripheral identity register 4 (M7_ITM_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size
0x0: Register file occupies a single 4 Kbyte region

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC code

ITM CoreSight peripheral identity register 0 (M7_ITM_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Part number field, bits [7:0]
0x01: ITM part number

ITM CoreSight peripheral identity register 1 (M7_ITM_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00B0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code field, bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: Part number field, bits [11:8]
0x1: ITM part number

ITM CoreSight peripheral identity register 2 (M7_ITM_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: Component revision number
0x0: r0p0

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code field, bits [6:4]
0x3: Arm® JEDEC code

ITM CoreSight peripheral identity register 3 (M7_ITM_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: Metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: Customer modified
0x0: No customer modifications

ITM CoreSight component identity register 0 (M7_ITM_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component ID field, bits [7:0]
0x0D: Common ID value

ITM CoreSight component identity register 1 (M7_ITM_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 00E0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component ID field, bits [15:12] - component class
0xE: Trace generator component

Bits 3:0 **PREAMBLE[11:8]**: Component ID field, bits [11:8]
0x0: Common ID value

ITM CoreSight component identity register 2 (M7_ITM_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component ID field, bits [23:16]
0x05: Common ID value

ITM CoreSight component identity register 3 (M7_ITM_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component ID field, bits [31:24]
0xB1: Common ID value

Cortex-M7 ITM register map and reset values

The ITM registers are located at address range 0xE0000000 to 0xE0000FFC, on the AHBD.

Table 639. Cortex-M7 ITM register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000 to 0x07C	M7_ITM_STIM0-31	STIMULUS[31:0]																															
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0x080 to 0xDFC	Reserved	Reserved																															
0xE00	M7_ITM_TER	STIMENA[31:0]																															
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0xE04 to 0xE3C	Reserved	Reserved																															
0x0E40	M7_ITM_TPR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PRIVMASK[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0xE44 to 0xE7C	Reserved	Reserved																															
0xE80	M7_ITM_TCR	Res	Res.	Res.	Res.	Res.	Res	Res.	Res.	BUSY	TRACEBUSID[6:0]							Res.	Res	Res.	Res.	GTSFREQ[1:0]		TSPRESCALE[1:0]		Res.	Res.	Res.	SWOENA	TXENA	SYNCENA	TSENA	ITMENA
	Reset value	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	-	-	-	-	0	0	0	0	-	-	-	0	0	0	0	0

Table 639. Cortex-M7 ITM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xE84 to 0xFCC	Reserved	Reserved																															
0xFD0	M7_ITM_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	M7_ITM_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	1
0xFE4	M7_ITM_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	0
0xFE8	M7_ITM_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	1	1
0xFEC	M7_ITM_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFF0	M7_ITM_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	0	1
0xFF4	M7_ITM_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	0	0	0	0	0
0xFF8	M7_ITM_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	1
0xFFC	M7_ITM_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	1

65.6.4 Cortex-M7 breakpoint unit (FPB)

The FPB allows hardware breakpoints to be set. It contains eight comparators which monitor the instruction fetch address and return a breakpoint instruction when a match is detected.The Cortex-M7 FPB does not support flash patch functionality.

Cortex-M7 FPB registers

FPB control register (M7_FPB_CTRL)

Address offset: 0x000

Reset value: 0x0000 0080

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	NUM_CODE[6:4]			NUM_LIT[3:0]				NUM_CODE[3:0]				Res.	Res.	KEY	ENABLE
	r	r	r	r	r	r	r	r	r	r	r			rw	rw

Bits 31:15 Reserved, must be kept at reset value.

Bits 14:12 **NUM_CODE[6:4]**: Instruction address comparator number field, three MSBs
This read-only field holds the three MSBs of the number of instruction address comparators supported.

0x0: the MSBs of the number are all 0

Bits 11:8 **NUM_LIT[3:0]**: Number of literal address comparators supported (read-only).
0x0: No literal comparators supported.

Bits 7:4 **NUM_CODE[3:0]**: Instruction address comparator number field, four LSBs
This read-only field holds the four LSBs of the number of instruction address comparators supported.

0x8: 8 instruction comparators supported

Bits 3:2 Reserved, must be kept at reset value.

Bit 1 **KEY**: Write protect key
A write to M7_FPB_CTRL register is ignored if this bit is not set to 1.

Bit 0 **ENABLE**: FPB enable
0: Disable
1: Enable

FPB remap register (M7_FPB_REMAP)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	RMPSPT	REMAP[23:11]												
		r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
REMAP[10:0]											Res.	Res.	Res.	Res.	Res.
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw					

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **RMPSPT**: Flash patch remap support (read-only)
0: Remapping not supported

Bits 28:5 **REMAP[23:0]**: Reserved - not supported

Bits 4:0 Reserved, must be kept at reset value.

FPB comparator registers (M7_FPB_COMPx)

Address offset: 0x008 + x * 0x4 (for x = 0 to 7)

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REPLACE[1:0]		Res.	COMP[26:14]												
rw	rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
COMP[13:0]														Res.	ENABLE
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw		rw

Bits 31:30 **REPLACE[1:0]**: Behavior upon COMP versus instruction fetch address match
Defines the behavior when a match occurs between the COMP field and the instruction fetch address:

0x0: Reserved
0x1: Breakpoint on lower half-word, upper half-word is unaffected.
0x2: Breakpoint on upper half-word, lower half-word is unaffected.
0x3: Breakpoint on both upper and lower half-words.

Bit 29 Reserved, must be kept at reset value.

Bits 28:2 **COMP[26:0]**: Value to compare with code memory access address
Value to compare with address bits 28:2 of accesses to instruction code memory (0x00000000 to 0x1FFFFFFF). If a match occurs, the action to take is defined by the REPLACE field.

Bit 1 Reserved, must be kept at reset value.

Bit 0 **ENABLE**: Comparator enable
The comparator is only enabled if both this bit and the FPB ENABLE bit in the M7_FPB_CTRL register are set.

0: Disabled
1: Enabled

FPB CoreSight peripheral identity register 4 (M7_FPB_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size
0x0: Register file occupies a single 4 Kbyte region

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC code

FPB CoreSight peripheral identity register 0 (M7_FPB_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 000E

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Part number field, bits [7:0]
0x0E: FPB part number

FPB CoreSight peripheral identity register 1 (M7_FPB_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00B0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code field, bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: Part number field, bits [11:8]
0x0: FPB part number

FPB CoreSight peripheral identity register 2 (M7_FPB_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 000B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: Component revision number
0x0: r0p0

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code field, bits [6:4]
0x3: Arm® JEDEC code

FPB CoreSight peripheral identity register 3 (M7_FPB_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: Metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: Customer modified
0x0: No customer modifications

FPB CoreSight component identity register 0 (M7_FPB_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component ID field, bits [7:0]
0x0D: Common ID value

FPB CoreSight component identity register 1 (M7_FPB_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 00E0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component ID field, bits [15:12] - component class
0xE: Trace generator component

Bits 3:0 **PREAMBLE[11:8]**: Component ID field, bits [11:8]
0x0: Common ID value

FPB CoreSight component identity register 2 (M7_FPB_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component ID field, bits [23:16]
0x05: Common ID value

FPB CoreSight component identity register 3 (M7_FPB_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component ID field, bits [31:24]
0xB1: Common ID value

Cortex-M7 FPB register map and reset values

The Cortex-M7 FPB registers are located at address range 0xE0002000 to 0xE0002FFC.

Table 640. Cortex-M7 FPB register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x000	M7_FPB_CTRL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	NUM_CODE[6:4]			NUM_LIT[3:0]				NUM_CODE[3:0]				Res.	Res.	KEY	ENABLE
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	1	0	0	0	-	-	0	0
0x004	M7_FPB_REMAP	Res.	Res.	RMPSP	REMAP[23:0]																								Res.	Res.	Res.	Res.	Res.
	Reset value	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-
0x008 to 0x020	M7_FPB_COMP0 to M7_FPB_COMP7	REPLACE[1:0]		Res.	COMP[26:0]																											Res.	ENABLE
	Reset value	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x024 to 0xFCC	Reserved	Reserved																															
0xFD0	M7_FPB_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	M7_FPB_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	1	0
0xFE4	M7_FPB_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	0
0xFE8	M7_FPB_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	1	1
0xFEC	M7_FPB_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFF0	M7_FPB_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	0	1
0xFF4	M7_FPB_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	0	0	0	0	0
0xFF8	M7_FPB_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	1
0xFFC	M7_FPB_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	1

65.6.5 Cortex-M7 embedded trace macrocell (ETM)

The Cortex-M7 ETM is a CoreSight™ component closely coupled to the CPU. The ETM generates trace packets that allow the execution of the Cortex-M7 core to be traced. In the STM32H7, the ETM is configured for instruction trace only, so data accesses are not included in the trace information.

The ETM receives information from the CPU over the processor trace interface, including:

- The number of instructions executed in the same cycle
- Changes in program flow
- The current processor instruction state
- The memory address locations accessed by load and store instructions
- The type, direction and size of a transfer
- Condition code information
- Exception information
- Wait for interrupt state information

For more information, refer to the Arm® CoreSight™ ETM™-M7 technical reference manual *[6]*.

Cortex-M7 ETM registers

ETM programming control register (M7_ETM_PRGCTL)

Address offset: 0x004

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EN
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **EN**: Trace program enable
0: Trace unit is disabled
1: Trace unit is enabled

ETM processor select control register (M7_ETM_PROCSEL)

Address offset: 0x008

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PROCSEL
															rw

Bits 31:1 Reserved, must be kept at reset value.

Bit 0 **PROCSEL**: Processor select

This field has no effect since only the Cortex-M7 uses this ETM.

ETM status register (M7_ETM_STAT)

Address offset: 0x00C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PMSTABLE	IDLE
														r	r

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **PMSTABLE**: Programmers model stable

Indicates whether the ETM registers are stable and can be read.

0: Registers are not stable

1: Registers are stable

Bit 0 **IDLE**: Trace unit inactive

0: ETM is not idle

1: ETM is idle

ETM trace configuration register (M7_ETM_CONFIG)

Address offset: 0x010

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DV	DA
														rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	RS	TS	COND[2:0]			Res.	Res.	Res.	CCI	BB	INSTP0[1:0]		Res.
			rw	rw	rw	rw	rw				rw	rw	r	r	

Bits 31:18 Reserved, must be kept at reset value.

Bit 17 **DV**: Data value tracing (read-only)
0: Disabled

Bit 16 **DA**: Data address tracing (read-only)
0: Disabled

Bits 15:13 Reserved, must be kept at reset value.

Bit 12 **RS**: Return stack enable
0: Disabled
1: Enabled

Bit 11 **TS**: Global timestamp tracing
0: Disabled
1: Enabled

Bits 10:8 **COND[2:0]**: Conditional instruction tracing
0x0: Conditional instruction tracing disabled
0x1: Conditional load instructions are traced
0x2: Conditional store instructions are traced
0x3: Conditional load and store instructions are traced
0x7: All conditional instructions are traced
Other: Reserved

Bits 7:5 Reserved, must be kept at reset value.

Bit 4 **CCI**: Cycle counting in instruction trace
0: Disabled
1: Enabled

Bit 3 **BB**: Branch broadcast mode
0: Disabled
1: Enabled

Bits 2:1 **INSTP0[1:0]**: Determines which instructions are P0 instructions (read-only)
0x0: Only branches are P0 instructions

Bit 0 Reserved, must be kept at reset value.

ETM event control 0 register (M7_ETM_EVENTCTL0)

Only accepts writes when trace unit is disabled

Address offset: 0x020

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TYPE1	Res.	Res.	Res.	SEL1[3:0]				TYPE0	Res.	Res.	Res.	SEL0[3:0]			
rw				rw	rw	rw	rw	rw				rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bit 15 **TYPE1**: Resource type for event 1
0: Single selected resource
1: Boolean combined resource pair

Bits 14:12 Reserved, must be kept at reset value.

Bits 11:8 **SEL1[3:0]**: Resource / Boolean combined resource pair, for event 1
When TYPE1 is 0, selects a single selected resource from 0-15 defined by bits[3:0]
When TYPE1 is 1, selects a Boolean combined resource pair from 0-7 defined by bits[2:0]

Bit 7 **TYPE0**: Resource type for event 0
0: Single selected resource
1: Boolean combined resource pair

Bits 6:4 Reserved, must be kept at reset value.

Bits 3:0 **SEL0[3:0]**: Resource / Boolean combined resource pair for event 0
When TYPE0 is 0, selects a single selected resource from 0-15 defined by bits[3:0]
When TYPE0 is 1, selects a Boolean combined resource pair from 0-7 defined by bits[2:0]

ETM event control 1 register (M7_ETM_EVENTCTL1)

Only accepts writes when trace unit is disabled

Address offset: 0x024

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	LPOVERRIDE	ATB	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INSTEN[3:0]			
			rw	rw								rw	rw	rw	rw

Bits 31:13 Reserved, must be kept at reset value.

Bit 12 **LPOVERRIDE**: Low power state behavior override
0: Low power state normal behavior
1: Entry to low power state does not affect resources and event trace generation

Bit 11 **ATB**: ATB trigger enable
0: Disabled
1: Enabled

Bits 10:4 Reserved, must be kept at reset value.

Bits 3:0 **INSTEN[3:0]**: Instruction trace event element enable
Each bit corresponds to an event:

0bXXX0: Event 0 does not cause an event element
0bXXX1: Event 0 causes an event element
0bXX0X: Event 1 does not cause an event element
0bXX1X: Event 1 causes an event element
0bX0XX: Event 2 does not cause an event element
0bX1XX: Event 2 causes an event element
0b0XXX: Event 3 does not cause an event element
0b1XXX: Event 3 causes an event element

ETM stall control register (M7_ETM_STALLCTL)

Only accepts writes when trace unit is disabled

Address offset: 0x02C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	DSTALL	ISTALL	Res.	Res.	Res.	Res.	LEVEL[1:0]		Res.	Res.
						rw	rw					rw	rw		

Bits 31:10 Reserved, must be kept at reset value.

Bit 9 **DSTALL**: Stall processor based on data trace buffer space
0: Do not stall processor
1: Stall processor

Bit 8 **ISTALL**: Stall processor based on instruction trace buffer space
0: Do not stall processor
1: Stall processor

Bits 7:4 Reserved, must be kept at reset value.

Bits 3:2 **LEVEL[1:0]**: Stalling threshold level
A low level minimizes the amount of processor stalling, with a higher risk of FIFO overflow. A high level minimizes the risk of FIFO overflow but increases the amount of processor stalling.

Bits 1:0 Reserved, must be kept at reset value.

ETM global timestamp control register (M7_ETM_TSCTL)

Only accepts writes when trace unit is disabled

Address offset: 0x030

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TYPE	Res.	Res.	Res.	SEL[3:0]			
								rw				rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bit 7 **TYPE**: Resource type for time stamp insertion
0: Single selected resource
1: Boolean combined resource pair

Bits 6:4 Reserved, must be kept at reset value.

Bits 3:0 **SEL[3:0]**: Resource / Boolean combined resource pair
When TYPE is 0, selects a single selected resource from 0-15 defined by bits[3:0]
When TYPE is 1, selects a Boolean combined resource pair from 0-7 defined by bits[2:0]

ETM synchronization period register (M7_ETM_SYNCP)

Address offset: 0x034

Reset value: 0x0000 000A

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PERIOD[4:0]				
											r	r	r	r	r

Bits 31:5 Reserved, must be kept at reset value.

Bits 4:0 **PERIOD[4:0]**: Trace bytes between synchronization requests
Defines the number of bytes of trace information between trace synchronization requests.
0xA: 1024 bytes

ETM cycle count control register (M7_ETM_CCCTL)

Address offset: 0x038

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	THRESHOLD[11:0]											
				rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:12 Reserved, must be kept at reset value.

Bits 11:0 **THRESHOLD[11:0]**: Threshold value for instruction trace cycle counting
The threshold represents the minimum interval between cycle count trace packets.
0x0: Reserved
Other: Threshold

ETM trace ID register (M7_ETM_TRACEID)

Address offset: 0x040

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRACEID[6:0]						
									rw	rw	rw	rw	rw	rw	rw

Bits 31:7 Reserved, must be kept at reset value.

Bits 6:0 **TRACEID[6:0]**: Trace ID
0x00: Reserved
0x01 to 0x6F: Valid ID
0x70 to 0x7F: Reserved

ETM ViewInst main control register (M7_ETM_VICTL)

Address offset: 0x080

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EXLEVEL_S3	Res.	Res.	EXLEVEL_S0
												rw			rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TRCERR	TRCRESET	SSSTATUS	Res.	TYPE	Res.	Res.	Res.	SEL[3:0]			
				rw	rw	rw		rw				rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bit 19 **EXLEVEL_S3**: Trace disable, exception level 3
Disables tracing in the specified exception level in Secure state for exception level 3.
0: Enable ViewInst in this exception level
1: Disable ViewInst in this exception level

Bits 18:17 Reserved, must be kept at reset value.

Bit 16 **EXLEVEL_S0**: Trace disable, exception level 0
Disables tracing in the specified exception level in Secure state for exception level 0.
0: Enable ViewInst in this exception level
1: Disable ViewInst in this exception level

Bits 15:12 Reserved, must be kept at reset value.

Bit 11 **TRCERR**: Tracing of system error exception
Selects whether a system error exception must always be traced.

0: System error exception is traced only if the instruction or exception immediately before the system error exception is traced
1: System error exception is always traced regardless of the value of ViewInst

Bit 10 **TRCRESET**: Tracing of reset exception
Selects whether a reset exception must always be traced.

0: Reset exception is traced only if the instruction or exception immediatelybefore the reset exception is traced
1: Reset exception is always traced regardless of the value of ViewInst

Bit 9 **SSSTATUS**: Current status of the start/stop logic
0: Stop state
1: Started state

Bit 8 Reserved, must be kept at reset value.

Bit 7 **TYPE**: Resource type
0: Single selected resource
1: Boolean combined resource pair

Bits 6:4 Reserved, must be kept at reset value.

Bits 3:0 **SEL[3:0]**: Resource / Boolean combined resource pair
When TYPE is 0, selects a single selected resource from 0-15 defined by bits[3:0]
When TYPE is 1, selects a Boolean combined resource pair from 0-7 defined by bits[2:0]

ETM ViewInst start/stop control register (M7_ETM_VISSCTL)

Address offset: 0x088

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STOP[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	START[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:24 Reserved, must be kept at reset value.

Bits 23:16 **STOP[7:0]**: Single address comparator selector to stop trace

Defines the single address comparators to stop trace with the ViewInst Start/Stop control. One bit is provided for each implemented single address comparator.

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **START[7:0]**: Single address comparator selector to start trace

Defines the single address comparators to start trace with the ViewInst Start/Stop control. One bit is provided for each implemented single address comparator.

ETM ViewInst start/stop processor comparator control register (M7_ETM_VIPCSSCTL)

Address offset: 0x08C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STOP[3:0]			
												rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	START[3:0]			
												rw	rw	rw	rw

Bits 31:20 Reserved, must be kept at reset value.

Bits 19:16 **STOP[3:0]**: Processor comparator input selector to stop trace

Selects which processor comparator inputs are in use with ViewInst start-stop control, for the purpose of stopping trace. One bit is provided for each processor comparator input.

Bits 15:4 Reserved, must be kept at reset value.

Bits 3:0 **START[3:0]**: Processor comparator input selector to start trace

Selects which processor comparator inputs are in use with ViewInst start-stop control, for the purpose of starting trace. One bit is provided for each processor comparator input.

ETM counter reload value register (M7_ETM_CNTRLDV)

Address offset: 0x140

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VALUE[15:0]															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **VALUE[15:0]**: Counter reload value

This value is loaded into the counter each time the reload event occurs.

ETM ID register 8 (M7_ETM_IDR8)

Address offset: 0x180

Reset value: 0x0000 0002

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MAXSPEC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MAXSPEC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **MAXSPEC[31:0]**: Maximum speculation depth

Indicates the maximum speculation depth of the instruction trace stream. This is the maximum number of P0 elements that have not been committed in the trace stream at any one time.

0x2: Maximum trace speculation depth is 2

ETM ID register 9 (M7_ETM_IDR9)

Address offset: 0x184

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMP0KEY[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMP0KEY[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **NUMP0KEY[31:0]**: Number of P0 right-hand keys used

0x0: No P0 keys used in instruction trace only configuration

ETM ID register 10 (M7_ETM_IDR10)

Address offset: 0x188

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMP1KEY[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMP1KEY[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **NUMP1KEY[31:0]**: Total number of P1 right-hand keys

Indicates the total number of P1 right-hand keys, including normal and special keys.

0x0: No P1 keys used in instruction trace only configuration

ETM ID register 11 (M7_ETM_IDR11)

Address offset: 0x18C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMP1SPC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMP1SPC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **NUMP1SPC[31:0]**: Total number of special P1 right-hand keys used

0x0: No special P1 keys used

ETM ID register 12 (M7_ETM_IDR12)

Address offset: 0x190

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMCONDKEY[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMCONDKEY[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **NUMCONDKEY[31:0]**:

Indicates the total number of conditional instruction right-hand keys, including normal and special keys.

0x1: One conditional instruction right hand-key implemented

ETM ID register 13 (M7_ETM_IDR13)

Address offset: 0x194

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMCONDSPC[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMCONDSPC[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **NUMCONDSPC[31:0]**: Number of special conditional instruction right-hand keys

0x0: No special conditional instruction right hand-keys implemented

ETM implementation specific register 0 (M7_ETM_IMSPEC0)

Address offset: 0x1C0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUPPORT[3:0]			
												r	r	r	r

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **SUPPORT[3:0]**: Support for implementation specific extensions
0x0: No implementation specific extensions are supported

ETM ID register 0 (M7_ETM_IDR0)

Address offset: 0x1E0

Reset value: 0x0C00 1EE1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	COMMOPT	TSSIZE[4:0]					Res.	Res.	Res.	Res.	Res.	Res.	Res.	QSUPP[1]
		r	r	r	r	r	r								r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
QSUPP[0]	Res.	CONDTYPE[1:0]		NUMEVENT[1:0]		RETSTACK	Res.	TRCCCI	TRCCOND	TRCBB	Res.	Res.	Res.	Res.	Res.
r		r	r	r	r	r		r	r	r					

Bits 31:30 Reserved, must be kept at reset value.

Bit 29 **COMMOPT**: Meaning of the commit field in some packets
0: Commit mode 0

Bits 28:24 **TSSIZE[4:0]**: Global timestamp size
0x08: Maximum of 64-bit global timestamp implemented

Bits 23:17 Reserved, must be kept at reset value.

Bits 16:15 **QSUPP[1:0]**: Q element support
0x0: Q elements not supported

Bit 14 Reserved, must be kept at reset value.

Bits 13:12 **CONDTYPE[1:0]**: Conditional result tracing type
0x1: APSR condition flag values traced

Bits 11:10 **NUMEVENT[1:0]**: Number of events supported in the trace
0x1: Two events supported for instruction only configuration

Bit 9 **RETSTACK**: Return stack support
1: Two entry return stack supported

Bit 8 Reserved, must be kept at reset value.

Bit 7 **TRCCCI**: Support for cycle counting in the instruction trace
1: Cycle counting in the instruction trace is implemented

Bit 6 **TRCCOND**: Support for conditional instruction tracing
1: Conditional instruction trace is implemented

Bit 5 **TRCBB**: Support for branch broadcast tracing
1: Branch broadcast trace is implemented

Bits 4:0 Reserved, must be kept at reset value.

ETM ID register 1 (M7_ETM_IDR1)

Address offset: 0x1E4

Reset value: 0x4100 F401

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DESIGNER[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
r	r	r	r	r	r	r	r								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	TRCARCHMAJ[3:0]				TRCARCHMIN[3:0]				REVISION[3:0]			
				r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 **DESIGNER[7:0]**: Trace unit designer entity
0x41: Arm®

Bits 23:12 Reserved, must be kept at reset value.

Bits 11:8 **TRCARCHMAJ[3:0]**: Major trace unit architecture version number
0x4: ETM v4

Bits 7:4 **TRCARCHMIN[3:0]**: Minor trace unit architecture version number
0x0: Minor version 0

Bits 3:0 **REVISION[3:0]**: Implementation revision number
0x1: Rev 1

ETM ID register 2 (M7_ETM_IDR2)

Address offset: 0x1E8

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	CCSIZE[3:0]				DVSIZE[4:0]					DASIZE[4:1]			
			r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DASIZE[0]	VMIDSIZE[4:0]					CIDSIZE[4:0]					IASIZE[4:0]				
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:29 Reserved, must be kept at reset value.

Bits 28:25 **CCSIZE[3:0]**: Cycle counter size
Indicates the size of the cycle counter in bits minus 12.
0x0: Cycle counter is 12 bits

Bits 24:20 **DVSIZE[4:0]**: Data value size in bytes
0x0: Data value size is not supported in instruction only configuration

Bits 19:15 **DASIZE[4:0]**: Data address size in bytes
0x0: Data address size is not supported in instruction only configuration

Bits 14:10 **VMIDSIZE[4:0]**: Virtual machine ID size
0x0: Virtual machine ID tracing not implemented

Bits 9:5 **CIDSIZE[4:0]**: Context ID size
0x0: Context ID tracing not implemented

Bits 4:0 **IASIZE[4:0]**: Instruction address size
0x4: 32-bit maximum address size

ETM ID register 3 (M7_ETM_IDR3)

Address offset: 0x1EC

Reset value: 0x0509 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NOOVERFLOW	NUMPROC[2:0]			SYSSTALL	STALLCTL	SYNCPR	TRCERR	Res.	Res.	Res.	Res.	EXLEVEL_S[3:0]			
r	r	r	r	r	r	r	r					r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	CCITMIN[11:0]											
				r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 **NOOVERFLOW**: Support of NOOVERFLOW
Indicates whether the NOOVERFLOW of trace stall control is implemented.
0: Not implemented

Bits 30:28 **NUMPROC[2:0]**: Number of processors available for tracing
0x0: Only one processor can be traced

Bit 27 **SYSSTALL**: System support for stall control of the processor
0: Not supported

Bit 26 **STALLCTL**: Stall control support
1: Trace stall control (TRCSTALLCTLR) is implemented

Bit 25 **SYNCPR**: Trace synchronization period support
0: TRCSYNCPR is read-only for instruction trace only configuration; the trace synchronization period is fixed

Bit 24 **TRCERR**: Support of TRCVICTLR.TRCERR
Indicates whether TRCVICTLR.TRCERR is implemented.
0x4: 32-bit maximum address size

Bits 23:20 Reserved, must be kept at reset value.

Bits 19:16 **EXLEVEL_S[3:0]**: Support of privilege levels
Privilege levels are implemented; one bit for each level.
0x9: Privilege levels Thread and Handler are implemented

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:0 **CCITMIN[11:0]**: Instruction trace cycle counting minimum threshold
0x4: Minimum threshold is 4 instruction trace cycle

ETM ID register 4 (M7_ETM_IDR4)

Address offset: 0x1F0

Reset value: 0x0001 4000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NUMVMIDC[3:0]				NUMCIDC[3:0]				NUMSSCC[3:0]				NUMRSPAIR[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NUMPC[3:0]				Res.	Res.	Res.	SUPPADC	NUMDVC[3:0]				NUMACPAIRS[3:0]			
r	r	r	r				r	r	r	r	r	r	r	r	r

Bits 31:28 **NUMVMIDC[3:0]**: Number of Virtual Machine ID comparators implemented
0x0: None

Bits 27:24 **NUMCIDC[3:0]**: Number of Context ID comparators implemented
0x0: None

Bits 23:20 **NUMSSCC[3:0]**: Number of single-shot comparator controls implemented
0x0: None

Bits 19:16 **NUMRSPAIR[3:0]**: Number of resource selection pairs implemented
0x1: None

Bits 15:12 **NUMPC[3:0]**: Number of processor comparator inputs implemented
0x4: Four

Bits 11:9 Reserved, must be kept at reset value.

Bit 8 **SUPPADC**: Support of data address comparisons
0: Not implemented

Bits 7:4 **NUMDVC[3:0]**: Number of data value comparators implemented
0x0: None

Bits 3:0 **NUMACPAIRS[3:0]**: Number of address comparator pairs implemented.
0x0: None

ETM ID register 5 (M7_ETM_IDR5)

Address offset: 0x1F4

Reset value: 0x90C7 0402

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
REDFUNCNTR	NUMCNTR[2:0]			NUMSEQSTATE[2:0]			Res.	LPOVERRIDE	ATBTRIG	TRACEIDSIZE[5:0]					
r	r	r	r	r	r	r		r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	NUMEXTINSEL[2:0]			NUMEXTIN[8:0]								
				r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 **REDFUNCNTR**: Support of reduced function counter
1: Implemented

Bits 30:28 **NUMCNTR[2:0]**: Number of counters implemented
0x1: One counter implemented

Bits 27:25 **NUMSEQSTATE[2:0]**: Number of sequencer states implemented
0x0: None

Bit 24 Reserved, must be kept at reset value.

Bit 23 **LPOVERRIDE**: Support of low-power state override
1: Implemented

Bit 22 **ATBTRIG**: Support of ATB trigger
1: Implemented

Bits 21:16 **TRACEIDSIZE[5:0]**: Number of trace ID bits
0x07: Seven-bit trace ID implemented.

Bits 15:12 Reserved, must be kept at reset value.

Bits 11:9 **NUMEXTINSEL[2:0]**: Number of implemented external input selectors
0x2: Two external input selectors implemented

Bits 8:0 **NUMEXTIN[8:0]**: Number of implemented external inputs
0x2: Two external inputs implemented

ETM resource selection register 2 (M7_ETM_RSCTL2)

Address offset: 0x208

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PAIRINV	INV	Res.	GROUP[2:0]		
										rw	rw		rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SELECT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:22 Reserved, must be kept at reset value.

Bit 21 **PAIRINV**: Inversion of result of a combined pair of resources
0: Not inverted
1: Inverted

Bit 20 **INV**: Inversion of the selected resources
0: Not inverted
1: Inverted

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **GROUP[2:0]**: Selects a group of resources

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **SELECT[7:0]**: Resource selector from desired group
Selects one or more resources from the desired group. One bit is provided per resource from the group.

ETM resource selection register 3 (M7_ETM_RSCTL3)

Address offset: 0x20C

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INV	Res.	GROUP[2:0]		
											rw		rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SELECT[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:21 Reserved, must be kept at reset value.

Bit 20 **INV**: Inversion of the selected resources
0: Not inverted
1: Inverted

Bit 19 Reserved, must be kept at reset value.

Bits 18:16 **GROUP[2:0]**: Selects a group of resources

Bits 15:8 Reserved, must be kept at reset value.

Bits 7:0 **SELECT[7:0]**: Resource selector from desired group
Selects one or more resources from the desired group. One bit is provided per resource from the group.

ETM single-shot comparator control register 0 (M7_ETM_SSCC0)

Address offset: 0x280

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
							rw								
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

Bits 31:25 Reserved, must be kept at reset value.

Bit 24 **RST**: Single-shot comparator resource reset enable

Enables the single-shot comparator resource to be reset when it occurs, which enables another comparator match to be detected.

0: Disabled

1: Reset enabled; multiple matches can occur

Bits 23:0 Reserved, must be kept at reset value.

ETM single-shot comparator status register 0 (M7_ETM_SSCS0)

Address offset: 0x2A0

Reset value: 0x0000 0001

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
STATUS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
rw															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DV	DA	INST
													r	r	r

Bit 31 **STATUS**: Single-shot status

This indicates whether any of the selected comparators have matched. If SSCC0.RST is set to 0, the STATUS bit must be written with 0 in order to enable single-shot comparator control.

0: No match occurred

1: Match has occurred at least once.

Bits 30:3 Reserved, must be kept at reset value.

Bit 2 **DV**: Data value comparator support

0: Single-shot data value comparisons not supported

Bit 1 **DA**: Data address comparator support

0: Single-shot data address comparisons not supported

Bit 0 **INST**: Instruction address comparator support

1: Single-shot instruction address comparisons supported

ETM single-shot processor comparator input control register (M7_ETM_SSPCIC0)

Address offset: 0x2C0

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PC[7:0]							
								rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PC[7:0]**: Comparator input selector for single-shot control

Selects one or more processor comparator inputs for single-shot control. One bit is provided for each processor comparator input.

ETM power-down control register (M7_ETM_PDC)

Address offset: 0x310

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PU	Res.	Res.	Res.
												r			

Bits 31:4 Reserved, must be kept at reset value.

Bit 3 **PU**: Power up request

Request to maintain power to the ETM and access to the trace registers.

0: Power not requested
1: Power requested

Bits 2:0 Reserved, must be kept at reset value.

ETM power-down status register (M7_ETM_PDS)

Address offset: 0x314

Reset value: 0x0000 0003

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STICKYPD	POWER
														r	r

Bits 31:2 Reserved, must be kept at reset value.

Bit 1 **STICKYPD**: Sticky power-down state

This bit is set to 1 when power to the ETM registers is removed, to indicate that programming state has been lost. It is cleared after a read of the TRCPDSR.

0: Trace register power uninterrupted since the last read of PDS register
1: Trace register power interrupted since the last read of PDS register

Bit 0 **POWER**: ETM powered up

1: ETM is powered up; all registers are accessible

ETM claim tag set register (M7_ETM_CLAIMSET)

Address offset: 0xFA0

Reset value: 0x0000 000F

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMSET[3:0]**: Set claim tag bits

Write:
0000: No effect
xxx1: Set bit 0
xx1x: Set bit 1
x1xx: Set bit 2
1xxx: Set bit 3

Read:
0xF: Indicates there are four bits in claim tag

ETM claim tag clear register (M7_ETM_CLAIMCLR)

Address offset: 0xFA4

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
												rw	rw	rw	rw

Bits 31:4 Reserved, must be kept at reset value.

Bits 3:0 **CLAIMCLR[3:0]**: Reset claim tag bits

Write:
0000: No effect
xxx1: Clear bit 0
xx1x: Clear bit 1
x1xx: Clear bit 2
1xxx: Clear bit 3

Read: Returns current value of claim tag

ETM lock access register (M7_ETM_LAR)

Address offset: 0xFB0

Reset value: 0xXXXX XXXX

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ACCESS_W[31:16]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ACCESS_W[15:0]															
w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w

Bits 31:0 **ACCESS_W[31:0]**: ETM register write access

Enables write access to some ETM registers by the processor (debuggers do not need to unlock the component)

0xC5ACCE55: Enable write access
Other values: Disable write access

ETM lock status register (M7_ETM_LSR)

Address offset: 0xFB4

Reset value: 0x0000 0003

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKTYPE	LOCKGRANT	LOCKEXIST
													r	r	r

Bits 31:3 Reserved, must be kept at reset value.

Bit 2 **LOCKTYPE**: Size of the M7_ETM_LAR register
0: 32-bit

Bit 1 **LOCKGRANT**: Current status of lock
This bit always returns zero when read by an external debugger.

0: Write access is permitted
1: Write access is blocked. Only read access is permitted.

Bit 0 **LOCKEXIST**: Existence of lock control mechanism
The bit indicates whether a lock control mechanism exists. It always returns zero when read by an external debugger.

0: No lock control mechanism exists
1: Lock control mechanism is implemented

ETM authentication status register (M7_ETM_AUTHSTAT)

Address offset: 0xFB8

Reset value: 0x0000 000A

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SNID[1:0]		SID[1:0]		NSNID[1:0]		NSID[1:0]	
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:6 **SNID[1:0]**: Security level for secure non-invasive debug
0x0: Not implemented

Bits 5:4 **SID[1:0]**: Security level for secure invasive debug
0x0: Not implemented

Bits 3:2 **NSNID[1:0]**: Security level for non-secure non-invasive debug
0x2: Disabled
0x3: Enabled

Bits 1:0 **NSID[1:0]**: Security level for non-secure invasive debug
0x2: Disabled
0x3: Enabled

ETM CoreSight device architecture register (M7_ETM_DEVARCH)

Address offset: 0xFBC

Reset value: 0x4770 4A13

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ARCHITECT[10:0]											PRESENT	REVISION[3:0]			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ARCHID[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:21 **ARCHITECT[10:0]**: Component architect
0x23B: Arm®

Bit 20 **PRESENT**: Indicates the presence of this register
1: Present

Bits 19:16 **REVISION[3:0]**: Architecture revision
0x0: Rev 0

Bits 15:0 **ARCHID[15:0]**: Architecture ID
0x4A13: ETMv4 component

ETM CoreSight device type identity register (M7_ETM_DEVTYPE)

Address offset: 0xFCC

Reset value: 0x0000 0013

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE[3:0]				MAJORTYPE[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **SUBTYPE[3:0]**: Device sub-type identifier
0x1: Processor trace

Bits 3:0 **MAJORTYPE[3:0]**: Device main type identifier
0x3: Trace source

ETM CoreSight peripheral identity register 4 (M7_ETM_PIDR4)

Address offset: 0xFD0

Reset value: 0x0000 0004

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **4KCOUNT[3:0]**: Register file size
0x0: Register file occupies a single 4 Kbyte region

Bits 3:0 **JEP106CON[3:0]**: JEP106 continuation code
0x4: Arm® JEDEC code

ETM CoreSight peripheral identity register 0 (M7_ETM_PIDR0)

Address offset: 0xFE0

Reset value: 0x0000 0075

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PARTNUM[7:0]**: Part number field, field, bits [7:0]
0x75: ETM part number

ETM CoreSight peripheral identity register 1 (M7_ETM_PIDR1)

Address offset: 0xFE4

Reset value: 0x0000 00B9

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **JEP106ID[3:0]**: JEP106 identity code field, bits [3:0]
0xB: Arm® JEDEC code

Bits 3:0 **PARTNUM[11:8]**: Part number field, bits [11:8]
0x9: ETM part number

ETM CoreSight peripheral identity register 2 (M7_ETM_PIDR2)

Address offset: 0xFE8

Reset value: 0x0000 001B

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVISION[3:0]**: Component revision number
0x1: rev 1

Bit 3 **JEDEC**: JEDEC assigned value
1: Designer ID specified by JEDEC

Bits 2:0 **JEP106ID[6:4]**: JEP106 identity code field, bits [6:4]
0x3: Arm® JEDEC code

ETM CoreSight peripheral identity register 3 (M7_ETM_PIDR3)

Address offset: 0xFEC

Reset value: 0x0000 0000

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **REVAND[3:0]**: Metal fix version
0x0: No metal fix

Bits 3:0 **CMOD[3:0]**: Customer modified
0x0: No customer modifications

ETM CoreSight component identity register 0 (M7_ETM_CIDR0)

Address offset: 0xFF0

Reset value: 0x0000 000D

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[7:0]**: Component ID field, bits [7:0]
0x0D: Common ID value

ETM CoreSight component identity register 1 (M7_ETM_CIDR1)

Address offset: 0xFF4

Reset value: 0x0000 0090

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:4 **CLASS[3:0]**: Component ID field, bits [15:12] - component class
0x9: Debug component with CoreSight-compatible registers

Bits 3:0 **PREAMBLE[11:8]**: Component ID field, bits [11:8]
0x0: Common ID value

ETM CoreSight component identity register 2 (M7_ETM_CIDR2)

Address offset: 0xFF8

Reset value: 0x0000 0005

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[19:12]**: Component ID field, bits [23:16]
0x05: Common ID value

ETM CoreSight component identity register 3 (M7_ETM_CIDR3)

Address offset: 0xFFC

Reset value: 0x0000 00B1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
								r	r	r	r	r	r	r	r

Bits 31:8 Reserved, must be kept at reset value.

Bits 7:0 **PREAMBLE[27:20]**: Component ID field, bits [31:24]
0xB1: Common ID value

Cortex-M7 ETM register map and reset values

The ETM registers are accessed by the debugger via the Cortex-M7 PPB, at address range 0xE0041000 to 0xE0041FFC.

Table 641. Cortex-M7 ETM register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x004	M7_ETM_PRGCTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EN
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
0x008	M7_ETM _PROCSEL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PROCSEL[2:0]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
0x00C	M7_ETM_STAT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PMSTABLE	IDLE
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0
0x010	M7_ETM_CONFIG	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DV	DA	Res.	Res.	Res.	RS	TS	COND[2:0]			VMID	CID	Res.	CCI	BB	INSTP0[1:0]		Res.
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	-	-	0	0	0	0	0	0	0	-	0	0	0	0	1
0x014 to 0x01C	Reserved	Reserved																															
0x020	M7_ETM _EVENTCTL0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TYPE1	Res.	Res.	Res.	SEL1[3:0]				TYPE0	Res.	Res.	Res.	SEL0[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	0	0	0	0	0	-	-	-	0	0	0	0
0x024	M7_ETM _EVENTCTL1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LPOVERRIDE	ATB	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INSTEN[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	-	-	-	-	-	-	0	0	0	0
0x02C	M7_ETM _STALLCTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DSTALL	ISATLL	Res.	Res.	Res.	Res.	LEVEL[1:0]		Res.	Res.
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	-	-	-	0	0	-	-
0x030	M7_ETM_TSCTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TYPE	Res.	Res.	Res.	SEL[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	0	0	0	0
0x034	M7_ETM_SYNCP	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PERIOD[4:0]				
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	0	1	0
0x038	M7_ETM_CCCTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	THRESHOLD[11:0]											
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
0x03C	Reserved	Reserved																															

Table 641. Cortex-M7 ETM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x040	M7_ETM_TRACEID	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRACEID[6:0]						
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0
0x044 to 0x07C	Reserved	Reserved																															
0x080	M7_ETM_VICTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	EXLEVEL_S3	Res.	Res.	EXLEVEL_S0	Res.	Res.	Res.	Res.	TRCERR	TRCRESET	SSSTATUS	Res.	TYPE	Res.	Res.	Res.	SEL[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	0	-	-	-	-	0	0	0	-	0	-	-	-	0	0	0	0
0x084	Reserved	Reserved																															
0x088	M7_ETM_VISSCTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STOP[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	START[7:0]							
	Reset value	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x08C	M7_ETM _VIPCSSCTL	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STOP[3:0]				Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	START[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0x090 to 0x13C	Reserved	Reserved																															
0x140	M7_ETM _CNTRLDV	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	VALUE[15:0]															
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x144 to 0x17C	Reserved	Reserved																															
0x180	M7_ETM_IDR8	MAXSPEC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0x184	M7_ETM_IDR9	NUMP0KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x188	M7_ETM_IDR10	NUMP1KEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x18C	M7_ETM_IDR11	NUMP1SPC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x190	M7_ETM_IDR12	NUMCONDKEY[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0x194	M7_ETM_IDR13	NUMCONDSPC[31:0]																															
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x198 to 0x1BC	Reserved	Reserved																															
0x1C0	M7_ETM_IMSPEC0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUPPORT[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0x1E0	M7_ETM_IDR0	Res.	Res.	COMMOPT	TSSIZE[4:0]					Res.	Res.	Res.	Res.	Res.	Res.	Res.	QSUPP[1:0]		CONDTYPE[1:0]		NUMEVENT[1:0]		RETSTACK	Res.	TRCCCI	TRCCOND	TRCBB	Res.	Res.	Res.	Res.	Res.		
	Reset value	-	-	0	0	1	1	0	0	-	-	-	-	-	-	-	0	0	-	0	1	1	1	1	-	1	1	1	-	-	-	-	1

Table 641. Cortex-M7 ETM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x1E4	M7_ETM_IDR1	DESIGNER[7:0]								Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TRCARCHMAJ[3:0]				TRCARCHMIN[3:0]				REVISION[3:0]			
	Reset value	0	1	0	0	0	0	0	1	-	-	-	-	-	-	-	-	-	-	-	-	0	1	0	0	0	0	0	0	0	0	0	1
0x1E8	M7_ETM_IDR2	Res.	Res.	Res.	CCSIZE[3:0]				DVSIZE[4:0]					DASIZE[4:0]					VMIDSIZE[4:0]			CIDSIZE[4:0]				IASIZE[4:0]							
	Reset value	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
0x1EC	M7_ETM_IDR3	NOOVERFLOW	NUMPROC[2:0]		SYSSTALL	STALLCTL	SYNCPR	TRCERR		Res.	Res.	Res.	Res.	EXLEVEL_S[3:0]				Res.	Res.	Res.	Res.	CCITMIN[11:0]											
	Reset value	0	0	0	0	0	1	0	1	-	-	-	-	1	0	0	1	-	-	-	-	0	0	0	0	0	0	0	0	0	1	0	0
0x1F0	M7_ETM_IDR4	NUMVMIDC[3:0]				NUMCIDC[3:0]				NUMSSCC[3:0]				NUMRSPAIR[3:0]				NUMPC[3:0]				Res.	Res.	Res.	SUPPDAC	NUMDVC[3:0]				NUMACPAIRS[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	-	-	-	0	0	0	0	0	0	0	0	0
0x1F4	M7_ETM_IDR5	REDFUNCNTR	NUMCNTR[2:0]			NUMSEQSTATE[2:0]			Res.	LPOVERRIDE	ATBTRIG	TRACEIDSIZE[5:0]						Res.	Res.	Res.	Res.	NUMEXTINSEL[2:0]		NUMEXTIN[8:0]									
	Reset value	1	0	0	1	0	0	0	-	1	1	0	0	0	1	1	1	-	-	-	-	0	1	0	0	0	0	0	0	0	1	0	
0x1F8 to 0x204	Reserved	Reserved																															
0x208	M7_ETM_RSCTL2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PAIRINV	INV	Res.	GROUP[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SELECT[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	0	0	-	0	0	0	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x20C	M7_ETM_RSCTL3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	INV	Res.	GROUP[2:0]			Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SELECT[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	0	-	0	0	0	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x210 to 0x27C	Reserved	Reserved																															
0x280	M7_ETM_SSCC0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.
	Reset value	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0x284 to 0x29C	Reserved	Reserved																															

Table 641. Cortex-M7 ETM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x2A0	M7_ETM_SSCS0	STATUS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DV	DA	INST
	Reset value	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1
0x2A4 to 0x2BC	Reserved	Reserved																															
0x2C0	M7_ETM_SSPCIC0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PC[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0x2C4 to 0x30C	Reserved	Reserved																															
0x310	M7_ETM_PDC	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PU	Res.	Res.	Res.
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-
0x314	M7_ETM_PDS	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	STICKYPD	POWER
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
0x318 to 0xF9C	Reserved	Reserved																															
0xFA0	M7_ETM _CLAIMSET	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMSET[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1
0xFA4	M7_ETM _CLAIMCLR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLAIMCLR[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
0xFA8to 0xFAC	Reserved	Reserved																															
0xFB0	M7_ETM_LAR	ACCESS_W[31:0]																															
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0xFB4	M7_ETM_LSR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	LOCKTYPE	LOCKGRANT	LOCKEXIST
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	1
0xFB8	M7_ETM _AUTHSTAT	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SNID[1:0]		SID[1:0]		NSNID[1:0]		NSID[1:0]	
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	0	1	0
0xFBC	M7_ETM _DEVARCH	ARCHITECT[10:0]											PRESENT	REVISION[3:0]				ARCHID[15:0]															
	Reset value	0	1	0	0	0	1	1	1	0	1	1	1	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	0	0	1	1
0xFC0to 0xFC8	Reserved	Reserved																															

Table 641. Cortex-M7 ETM register map and reset values (continued)

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0xFCC	M7_ETM _DEVTYPE	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SUBTYPE[3:0]				MAJORTYPE[3:0]			
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1
0xFD0	M7_ETM_PIDR4	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	4KCOUNT[3:0]				JEP106CON[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	0
0xFD4 to 0xFDC	Reserved	Reserved																															
0xFE0	M7_ETM_PIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PARTNUM[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	1	1	0	1	0	1
0xFE4	M7_ETM_PIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	JEP106ID[3:0]				PARTNUM[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	1	0	0	1
0xFE8	M7_ETM_PIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVISION[3:0]				JEDEC	JEP106ID[6:4]		
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1	1	0	1	1
0xFEC	M7_ETM_PIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	REVAND[3:0]				CMOD[3:0]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
0xFF0	M7_ETM_CIDR0	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[7:0]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	1	1	0	1
0xFF4	M7_ETM_CIDR1	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	CLASS[3:0]				PREAMBLE[11:8]			
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0	1	0	0	0	0
0xFF8	M7_ETM_CIDR2	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[19:12]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	1	0	1
0xFFC	M7_ETM_CIDR3	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	PREAMBLE[27:20]							
	Reset value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1	1	0	0	0	1

65.6.6 Cortex-M7 cross trigger interface (CTI)

See *Section 65.5.2*.

65.7 References for debug infrastructure

1. IHI 0031C (ID080813) - Arm® Debug Interface Architecture Specification ADIv5.0 to ADIv5.2, Issue C
2. DDI 0480F (ID100313) - Arm® CoreSight™ SoC-400 r3p2 Technical Reference Manual, Issue G
3. DDI 0461B (ID010111) - Arm® CoreSight™ Trace Memory Controller r0p1 Technical Reference Manual, Issue B
4. DDI 0314H - Arm® CoreSight™ Components Technical Reference Manual, Issue H
5. DDI 0403D (ID100710) - Arm®v7-M Architecture Reference Manual, Issue E.b
6. DDI 0494-2a (ID062813) - Arm® CoreSight™ ETM™-M7 r0p1 Technical Reference Manual, Issue D

66 Device electronic signature

The electronic signature is stored in the Flash memory area. It can be read using the JTAG/SWD or the CPU. It contains factory-programmed identification data that allow the user firmware or other external devices to automatically match its interface to the characteristics of the STM32H72x and STM32H73x microcontrollers.

66.1 Unique device ID register (96 bits)

The unique device identifier is ideally suited:

- for use as serial numbers (for example USB string serial numbers or other end applications)
- for use as security keys in order to increase the security of code in Flash memory while using and combining this unique ID with software cryptographic primitives and protocols before programming the internal Flash memory
- to activate secure boot processes, etc.

The 96-bit unique device identifier provides a reference number which is unique for any device and in any context. These bits can never be altered by the user.

The 96-bit unique device identifier can also be read in single bytes/half-words/words in different ways and then be concatenated using a custom algorithm.

Base address: 0x1FF1 E800

Address offset: 0x00

Read only = 0xXXXX XXXX where X is factory-programmed

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
U_ID(31:0)																															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **U_ID(31:0):** 31:0 unique ID bits

Address offset: 0x04

Read only = 0xXXXX XXXX where X is factory-programmed

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
U_ID(63:48)															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
U_ID(47:32)															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **U_ID(63:32):** 63:32 unique ID bits

Address offset: 0x08

Read only = 0xXXXX XXXX where X is factory-programmed

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
U_ID(95:80)															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
U_ID(79:64)															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **U_ID(95:64):** 95:64 Unique ID bits.

66.2 Flash size

Base address: 0x1FF1 E880

Address offset: 0x00

Read only = 0xXXXX where X is factory-programmed

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
F_SIZE[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 15:0 **F_ID[15:0]**: Flash memory size

This bitfield indicates the size of the device Flash memory expressed in Kbytes.
As an example, 0x0400 corresponds to 1024 Kbytes.

66.3 Line identifier

Base address: 0x1FF1 E8C0

Address offset: 0x00

Read only = 0xXXXX where X is factory-programmed

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
L_ID[31:16]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
L_ID[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:0 **L_ID[31:0]**: Line identifier

Ths bitfield indicates the device line expressed in ASCII. As an example, STM32H725 corresponds to 0x4837 3235:
0x48 = ‘H’
0x37 = ‘7’
0x32 = ‘2’
0x35 = ‘5’

66.4 Package data register

Bits 15:0 F_ID(15:0): Flash memory size

This bitfield indicates the size of the device Flash memory expressed in Kbytes.
As an example, 0x0400 corresponds to 1024 Kbytes.

Refer to SYSCFG package register (SYSCFG_PKGR) for package identification. The SYSCFG clock should be enabled first in the RCC_APB4ENR register.

67 Revision history

Table 642. Document revision history

Date	Revision	Changes
30-Oct-2019	1	Initial release.
24-Jun-2020	2	Added STM43H730xB microcontrollers. Added *Section 1.5: Availability of security features*. ***Section 4: Embedded Flash memory (FLASH)*** Added STM32H730xB devices and changed user Flash memory density to “up to 1 Mbyte” to take into account 128 Kbyte and 512 Kbyte devices. Updated *Table 16: FLASH recommended number of wait states and programming delay*. ***Section 5: Secure memory management (SMM)*** Changed part numbers on which the Secure memory management is available to STM32H73x. ***Section 6: Power control (PWR)*** Replace voltage regulator by LDO voltage regulator in the whole chapter. Replaced Run mode by Run and Autonomous modes in *Section : LDO voltage regulator*, *Section 6.4.3: PWR external supply* and *Section 6.6.3: Power control modes*. In *Section 6.4.4: Backup domain*, updated list of GPIOS whose use is restricted when V_{DD} is higher than the PDR threshold. Updated *Section 6.6.3: Power control modes*. Updated *Section 6.7.8: Stop mode*. Added note to DBP bit in *PWR control register 1 (PWR_CR1)*. ***Section 8: Reset and clock control (RCC)*** Updated max HSE frequency in *Section 8.1: RCC main features*. Updated *Section : External crystal/ceramic resonator*. Updated *Table 56: Kernel clock distribution overview*. Changed 500 MHz and 250 MHz to 550 MHz and 275 MHz in *Figure 49: Core and bus clock generation*. Updated internal signal names in *Figure 50: Kernel clock distribution for SAIs and SPDIFRX*. Changed SPDIFSEL into SPDIFRXSEL and IS2123SEL into SPI123SEL in *Figure 52: Kernel clock distribution for SPIs and SPI/I2S*. Changed OSPISEL into OCTOSPISEL, OSPI[2:1]EN/OSPI[2:1]LEN into OCTOSPI[2:1]EN/OCTOSPI[2:1]LPEN, and updated internal signal names in *Figure 56: Kernel clock distribution for SDMMC, OCTOSPI and FMC*. Updated *Figure 57: Kernel clock distribution for USB* (2). Renamed SWPMI-related bits in *Figure 59: Kernel clock distribution for ADCs, SWPMI, RNG and FDCAN* (2). Renamed LPTIM internal signals in *Figure 60: Kernel clock distribution for LPTIMs and HDMI-CEC* (2). Updated HSECSSON bit description in *RCC source control register (RCC_CR)*.

Table 642. Document revision history (continued)

Date	Revision	Changes
24-Jun-2020	2 (continued)	***Section 8: Reset and clock control (RCC)*** **(continued)** Replaced TMPSENS by DTS in RCC_APB4RSTR/ENR/LPENR and RCC_D3AMR and in RCC_C1_APB4ENR/LPENR. Renamed SPDIFSEL into SPDIFRXSEL and SWPSEL into SWPMISEL in *RCC domain 2 kernel clock configuration register (RCC_D2CCIP1R)*. Renamed OSPISEL into OCTOSPISEL in *RCC domain 1 kernel clock configuration register (RCC_D1CCIPR)*. renamed OCTO[2:1]RST into OCTOSPI[2:1]RST in *RCC AHB3 reset register (RCC_AHB3RSTR)*, OSPI[2:1]EN into OCTOSPI[2:1]EN in *RCC AHB3 clock register (RCC_AHB3ENR)*, and OSPI[2:1]LEN into OCTOSPI[2:1]LPEN in *RCC AHB3 Sleep clock register (RCC_AHB3LPENR)*. Renamed SWPRST into SWPMIRST in *RCC APB1 peripheral reset register (RCC_APB1HRSTR)*, SWPEN into SWPMIEN in WPMIRST in *RCC APB1 clock register (RCC_APB1HENR)*, and SWPLPEN into SWPMILPEN in *RCC APB1 clock register (RCC_APB1LENR)*. Updated DIVR2EN, DIVQ2EN, DIVP2EN, DIVR1EN of *RCC PLLs Configuration Register (RCC_PLLCFGR)*. ***Section 13: Block interconnect***. In *Table 94: Peripherals interconnect matrix details*, change PTPx and PPS into eth_ptp_trgx and eth_ptp_pps_out, respectively. ***Section 12: System configuration controller (SYSCFG)*** Added note related to PC3SO, PC2SO, PA1SO and PA0SO reset value and updated BOOSTVDDSEL bit description n *Section 12.4.1: SYSCFG peripheral mode configuration register (SYSCFG_PMCR)*. ***Section 15: Direct memory access controller (DMA)*** Bit 20 of *DMA stream x configuration register (DMA_SxCR)* changed from reserved to TRBUFF for the products listed. ***Section 17: DMA request multiplexer (DMAMUX)*** *Updated Section 17.4.4: DMAMUX request line multiplexer.* ***Section 24: Flexible memory controller (FMC)*** Updated *Section : General transaction rules* to clarify the behavior of the FMC when the AXI transaction data size is different from the device data width and add the case of unaligned addresses. Replaced FMC_CLK by fmc_ker_ck in the formulas of *Section : WAIT management in asynchronous accesses*. ***Section 25: Octo-SPI interface (OCTOSPI)*** Updated *Section 25.2: OCTOSPI main features and Section 25.3: OCTOSPI implementation*. *Updated* WRAP support part in *Section 25.4.6: Specific features.* *Updated Section 25.4.10: OCTOSPI Memory-mapped mode.* *Updated Section : Sending the instruction only once (SIOO).* Modified ABORT and EN bit description in *Section 25.7.1: OCTOSPI control register (OCTOSPI_CR),* FLEVEL bit description in *Section 25.7.6: OCTOSPI status register (OCTOSPI_SR) and* DLYBYP bit in *Section 25.7.2: OCTOSPI device configuration register 1 (OCTOSPI_DCR1).*

Table 642. Document revision history (continued)

Date	Revision	Changes
24-Jun-2020	2 (continued)	***Section 26: OCTOSPI I/O manager (OCTOSPIM)*** Updated ports for pin assignment from 3 to 2. ***Section 28: Analog-to-digital converters (ADC1/ADC2)*** Added adc_sclk in *Figure 160: ADC block diagram* and *Table 221: ADC input/output pins* and removed V_{REF+} and V_{REF-} ranges from this table. Updated *Section 28.4.3: ADC clocks*. Updated *Section : ADC overrun (OVR, OVRMOD)*. Added case of FIFO overflow in *Section : Managing a sequence of conversion without using the DMA*. Updated *Section : Single ADC operating modes support when oversampling* to remove the mention that the offset correction is not supported in oversampling mode. Updated RES[2:0] bitfield definition in *Section 28.6.4: ADC configuration register (ADC_CFGR)*. Replaced adc_hclk by adc_hclk in CKMODE[1:0] bitfield definition of *Section 28.7.2: ADC common control register (ADCx_CCR) (x=1/2)*. ***Section 29: Analog-to-digital converters (ADC3)*** Added description of output data and formula to compute the converted value in *Section 29.4.7: Single-ended and differential input channels*. Updated *Section : ADC overrun (OVR, OVRMOD)* and Added case of FIFO overflow in *Section : Managing a sequence of conversions without using the DMA*. Added SMP19[2:0] in *Section 29.6.7: ADC sample time register 2 (ADC_SMPR2)*. Added note to OFFSETy_CH[4:0] in *Section 29.6.17: ADC offset y register (ADC_OFRy)*. ***Section 30: Digital temperature sensor (DTS)*** Removed EN pin from *Figure 284: Temperature sensor functional block diagram*. Updated formula to calculate the temperature when PCLK is used in *Section 30.3.7: Temperature measurement principles*. Removed startup time value from *Section 30.3.11: On-off control and ready flag*. Removed TS1_EN of *Temperature sensor configuration register 1 (DTS_CFGR1)* and replaced list of triggers in TS1_INTRIG_SEL[3:0] by a reference to Table *Trigger configuration* in DTS_CFGR1. ***Section 31: Digital-to-analog converter (DAC)*** Removed DAC acronym in *Section 31.4.9: Noise generation* and *Section 31.4.10: Triangle-wave generation*. Updated the way to stop LSI clock in *Section 31.4.11: DAC channel modes*/*Section : Sample and hold mode*. In TSEL1/2 of *Section 31.7.1: DAC control register (DAC_CR)*, changed internal trigger signal names from dac_ch1_trigx/dac_ch2_trigx to dac_ch1_trgx/dac_ch2_trgx.

Table 642. Document revision history (continued)

Date	Revision	Changes
24-Jun-2020	2 (continued)	***Section 32: Voltage reference buffer (VREFBUF)*** Updated VRS in *Section 32.3.1: VREFBUF control and status register (VREFBUF_CSR)*. Updated TRIM in *Section 32.3.2: VREFBUF calibration control register (VREFBUF_CCR)*. ***Section 37: Parallel synchronous slave interface (PSSI)*** Updated *Figure 326: PSSI block diagram* and *Figure 327: Top-level block diagram*. ***Section 38: LCD-TFT display controller (LTDC)*** Updated *Figure 333: LTDC block diagram* and *Figure : Example of synchronous timings configuration*. ***Section 39: True random number generator (RNG)*** Updated *Section 39.1: Introduction*. Updated *Section 39.3.3: Random number generation*. Updated *Figure 339: NIST SP800-90B entropy source model* and *Figure 340: RNG initialization overview*. Updated *Section 39.6: RNG entropy source validation* and *Section 39.6.3: Data collection*. ***Section 43: Advanced-control timers (TIM1/TIM8)*** Updated *Figure 400: Control circuit in external clock mode 2*. Updated *Section 43.4.20: TIMx break and dead-time register (TIMx_BDTR)(x = 1, 8)*. Updated BKINP, BKCMP1P and BKCMP2P bit descriptions in TIMx_AF1 registers, and BK2INP in TIMx_AF2. ***Section 44: General-purpose timers (TIM2/TIM3/TIM4/TIM5/TIM23/TIM24)*** Updated *Figure 433: General-purpose timer block diagram*. Updated *Figure 457: Control circuit in external clock mode 2*. Updated *Figure 459: Capture/Compare channel 1 main circuit*. Updated *Figure 460: Output stage of Capture/Compare channel (channel 1)*. Updated *Section 44.4.2: TIMx control register 2 (TIMx_CR2)(x = 2 to 5, 23, 24)* and *Section 44.4.7: TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 2 to 5, 23, 24)*. Updated *Table 356: Output control bit for standard OCx channels*.

Table 642. Document revision history (continued)

Date	Revision	Changes
24-Jun-2020	2 (continued)	***Section 45: General-purpose timers (TIM12/TIM13/TIM14)*** Updated *Figure 484: General-purpose timer block diagram (TIM13/TIM14)*. Updated *Figure 497: Capture/compare channel 1 main circuit* and *Figure 498: Output stage of capture/compare channel (channel 1)*. Updated *Section 45.3.6: PWM input mode (only for TIM12)*. Added *Section 45.3.18: Using timer output as trigger for other timers (TIM13/TIM14)*. Updated *Section 45.4.2: TIM12 control register 2 (TIM12_CR2)* and *Section 45.4.7: TIM12 capture/compare mode register 1 [alternate] (TIM12_CCMR1)*. Updated *Section 45.5.5: TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 13 to 14)* and *Table 361: Output control bit for standard OCx channels*. ***Section 46: General-purpose timers (TIM15/TIM16/TIM17)*** Updated note below *Figure 509: TIM15 block diagram* and modified *Figure 510: TIM16/TIM17 block diagram*. Updated *Figure 524: Capture/compare channel 1 main circuit*, *Figure 525: Output stage of capture/compare channel (channel 1)* and *Figure 526: Output stage of capture/compare channel (channel 2 for TIM15)*. Updated *Section 46.4.7: PWM input mode (only for TIM15)*. Updated *Section 46.4.13: Using the break function* and *Figure 534: Break circuitry overview*. Added *Section 46.4.24: Using timer output as trigger for other timers (TIM16/TIM17)*. Updated *Section 46.4.13: Using the break function* and *Figure 534: Break circuitry overview*. Updated *Section 46.5.2: TIM15 control register 2 (TIM15_CR2)*, *Section 46.5.7: TIM15 capture/compare mode register 1 [alternate] (TIM15_CCMR1)* and *Table 365: Output control bits for complementary OCx and OCxN channels with break feature (TIM15)* Updated *Table 368: TIM16/TIM17 register map and reset values*. ***Section 48: Low-power timer (LPTIM)*** Updated *Section 48.2: LPTIM main features* and *Section 48.4.4: LPTIM reset and clocks*. Updated *Section 48.4.5: Glitch filter*. Updated *Section 48.7.4: LPTIM configuration register (LPTIM_CFGR)*. ***Section 49: System window watchdog (WWDG)*** Updated *Section 49.4.3: Enabling the watchdog*. ***Section 53: Universal synchronous/asynchronous receiver transmitter (USART/UART)*** Updated decimal and hexadecimal notation for values in *Section : How to derive USARTDIV from USART_BRR register values*. Updated SBKF bit description in *Section 53.8.10: USART interrupt and status register [alternate] (USART_ISR)*. Updated PSC[7:0] bitfield description in *Section 53.8.6: USART guard time and prescaler register (USART_GTPR)*.

Table 642. Document revision history (continued)

Date	Revision	Changes
24-Jun-2020	2 (continued)	***Section 54: Low-power universal asynchronous receiver transmitter (LPUART)*** Added *Section 54.3: LPUART implementation*. Updated SBKF bit description in *Section 54.7.7: LPUART interrupt and status register [alternate] (LPUART_ISR)*. ***Section 55: Serial peripheral interface (SPI)*** Updated *Section 55.2: SPI main features*, *Section 55.3: SPI implementation* and *Section 55.4.2: SPI signals* Updated *Section 55.4.5: Standard multi-slave communication*, *Section 55.4.7: Slave select (SS) pin management*, *Section 55.4.8: Communication formats*, *Section 55.4.9: Configuration of SPI*, *Section 55.4.10: Procedure for enabling SPI* and *Section 55.4.11: SPI data transmission and reception procedures*. Updated *Figure 653: Packing data in FIFO for transmission and reception*. Updated *Section 55.5.1: TI mode*, *Section 55.5.2: SPI error flags* and *Section 55.5.3: CRC computation*. Updated *Section 55.7: SPI wakeup and interrupts*. Updated *Section 55.11.6: SPI/I2S status register (SPI_SR)*, *Section 55.11.3: SPI configuration register 1 (SPI_CFG1)*, *Section 55.11.4: SPI configuration register 2 (SPI_CFG2)*, *Section 55.11.6: SPI/I2S status register (SPI_SR)*, *Section 55.11.8: SPI/I2S transmit data register (SPI_TXDR)*, *Section 55.11.9: SPI/I2S receive data register (SPI_RXDR)*, *Section 55.11.10: SPI polynomial register (SPI_CRCPOLY)*, *Section 55.11.11: SPI transmitter CRC register (SPI_TXCRC)*, *Section 55.11.12: SPI receiver CRC register (SPI_RXCRC)* and *Section 55.11.13: SPI underrun data register (SPI_UDRDR)*. Updated *Table 441: SPI register map and reset values*. ***Section 58: Single wire protocol master interface (SWPMI)*** Modified name of bit and register to select SWPMI in *Section Figure 716.: SWPMI block diagram*. Replaced SWPSCR of RCC_D2CCIP1R by SWPSEL of RCC_CDCCIP1R in *Figure 716: SWPMI block diagram*. ***Section 63: Ethernet (ETH): media access control (MAC) with DMA controller*** Replaced ptp_pps_o internal signal by eth_ptp_pps_out, ptp_aux_ts_trig_i by eth_ptp_trgx (where x = 0 to 3) and ptp_aux_trig_i[x] by eth_ptp_trgx in *IEEE 1588 auxiliary snapshots*. Updated ARPEN bit description in *Operating mode configuration register (ETH_MACCR)*. Removed sentence “This register is present only when the IEEE 1588 Timestamp feature is selected without external timestamp input” from *System time nanoseconds register (ETH_MACSTNR)*, *System time seconds update register (ETH_MACSTSUR)* and *System time nanoseconds update register (ETH_MACSTNUR)* register descriptions. ***Section 66: Device electronic signature*** Added *Section 66.3: Line identifier*.

Table 642. Document revision history (continued)

Date	Revision	Changes
13-Dec-2021	3	Added errata sheet in the list of reference documents as well as mention that patents apply to the microcontrollers on document cover page. ***Section 2: Memory and bus architecture*** Updated *Section : Embedded bootloader*. Updated DFSDM1 base address in *Table 7: Register boundary addresses*. ***Section 4: Embedded Flash memory (FLASH)*** Added note indicating the only sections 0 to 3 are available on 512 Kbyte devices in *Table 15: Flash memory organization (STM32H723/733 and STM32H725/735 devices)*. Better specified the registers reset by System reset in *Section 8.4.2: System reset*. *Section 4.4.7: Description of boot address option bytes*. Updated FAIL_ECC_ADDR[14:0] description in *FLASH ECC fail address (FLASH_ECC_FAR)*. ***Section 6: Power control (PWR)*** Updated *Figure 18: Power supply overview*. Added note on VDDLDO in *Table 28: PWR input/output signals connected to package pins or balls*. Updated *Section : VCORE supplied in Bypass mode (LDO and SMPS OFF)*. Added *Section : How to exit from Run* mode*. ***Section 8: Reset and clock control (RCC)*** Updated VREFRST bit description In *RCC APB4 peripheral reset register (RCC_APB4RSTR)* and VREFEN bit description in *RCC APB4 clock register (RCC_APB4ENR)* to mention VREFBUF. Updated *RCC reset status register (RCC_RSR)*, *RCC APB1 Low Sleep clock register (RCC_APB1LLPENR)* and *RCC APB2 Sleep clock register (RCC_APB2LPENR)* reset values. ***Section 9: Clock recovery system (CRS)*** Added note relative to the trimming step size in *Section : FELIM value*. Modified *CRS control register (CRS_CR)* reset value. ***Section 10: Hardware semaphore (HSEM)*** Updated *Section 10.3.2: HSEM internal signals*, *Section 10.3.3: HSEM lock procedures*, *Section 10.3.5: HSEM unlock procedures*, *Section 10.3.6: HSEM MASTERID semaphore clear*, *Section 10.3.7: HSEM interrupts* and *Section 10.3.8: AHB bus master ID verification*. Updated *HSEM register semaphore x (HSEM_Rx)*, *HSEM read lock register semaphore x (HSEM_RLRx)* and *HSEM interrupt status register (HSEM_MISR)*.

Table 642. Document revision history (continued)

Date	Revision	Changes
13-Dec-2021	3 (continued)	***Section 12: System configuration controller (SYSCFG)*** Updated BOOSTVDDSEL description and added note related to PC3SO, PC2SO, PA1SO and PA0SO reset value in *SYSCFG peripheral mode configuration register (SYSCFG_PMCR)*. ***Section 13: Block interconnect*** Updated TIM23/TIM24 in *Table 92: Peripherals interconnect matrix (D2 domain)*. ***Section 19: Nested vectored interrupt controller (NVIC)*** Replaced UART9_IT_OR_UART9_WKUP by UART9 in *Table 140: NVIC*. ***Section 20: Extended interrupt and event controller (EXTI)*** Remove note 4 related to WKUP sources in *Table 143: EXTI Event input mapping*. ***Section 14: MDMA controller (MDMA)*** Removed SM bit in *MDMA channel x control register (MDMA_CxCR)*. ***Section 17: DMA request multiplexer (DMAMUX)*** Updated *Section 17.4.4: DMAMUX request line multiplexer*. ***Section 18: Chrom-Art Accelerator controller (DMA2D)*** Updated *Section 18.3.2: DMA2D internal signals*. ***Section 21: Cyclic redundancy check calculation unit (CRC)*** Added note in *Section : Polynomial programmability* to clarify what are even and odd polynomials. Added CRC register access granularity in *Section 21.2: CRC main features* and *Section 21.4: CRC registers*. Updated *Figure 97: CRC calculation unit block diagram*. ***Section 25: Octo-SPI interface (OCTOSPI)*** Renamed DDR mode into DTR, Status-polling into Automatic status-polling, nCS and CS pins into NCS, and nCLK into NCLK. Updated *Section 25.2: OCTOSPI main features*, all block diagram and extended CSHT in *Table 209: OCTOSPI implementation* Updated *Section : Dual-quad configuration*. Added new note after *Figure 146*, *Figure 147*, and *Figure 148*. Updated *Section 25.4.8: OCTOSPI Indirect mode*. Updated note at the beginning of *Section 25.4.10: OCTOSPI Memory-mapped mode*. Updated *Section 25.4.14: OCTOSPI Regular-command mode configuration*. Added *Section 25.5: Address alignment and data number* Renamed DQM bit into DMM and updated FSEL bit in *OCTOSPI control register (OCTOSPI_CR)*. Updated DEVSIZE description in *OCTOSPI device configuration register 1 (OCTOSPI_DCR1)*. Updated REFRESH description in *OCTOSPI device configuration register 4 (OCTOSPI_DCR4)*.

Table 642. Document revision history (continued)

Date	Revision	Changes
13-Dec-2021	3 (continued)	***Section 26: OCTOSPI I/O manager (OCTOSPIM)*** Added *Table 214: OCTOSPIM implementation*. Updated *Section 26.4.3: OCTOSPIM multiplexed mode*. Changed nCS into NCS in *Section : Pin mapping in Multiplexed mode*, and in *Section 26.5.2: OCTOSPIM Port n configuration register (OCTOSPIM_PnCR)*. Changed CLKn into NCLK in *Section 26.5.2: OCTOSPIM Port n configuration register (OCTOSPIM_PnCR)*. Updated *Section 26.4.3: OCTOSPIM multiplexed mode* and *OCTOSPIM control register (OCTOSPIM_CR)*. ***Section 27: Delay block (DLYB)*** Updated *Section 27.3.3: General description*. Updated *Section 27.3.4: Delay line length configuration procedure*. Updated *Section 27.3.5: Output clock phase configuration procedure*. ***Section 28: Analog-to-digital converters (ADC1/ADC2)*** Remove ADC supply requirements from *Table 221: ADC input/output pins* Added *Section : Constraints between ADC clocks*. Updated *Figure 193: Example of overrun (OVRMOD = 0)*, *Figure 199: AUTDLY=1 in auto- injected mode (JAUTO=1)*, *Figure 208: Regular and injected oversampling modes used simultaneously*, and *Figure 209: Triggered regular oversampling with injection*. Replaced ADCx_CCR by ADCx_CDR in *Section : Regular simultaneous mode with independent injected*. ***Section 29: Analog-to-digital converters (ADC3)*** Remove ADC supply requirements from *Table 240: ADC input/output pins*. Added data register FIFO depth in *Table 239: ADC features*. Added *Section : Constraints between ADC clocks*. Reworded *Section : Offset compensation*. Updated *Figure 262: Example of overrun (OVRMOD = 0)*, *Figure 268: AUTODLY = 1 in auto- injected mode (JAUTO = 1)*, *Figure 278: Regular and injected oversampling modes used simultaneously*, and *Figure 279: Triggered regular oversampling with injection*. Updated *Section : Calculating the actual V_{REF+} voltage using the internal reference voltage* and *Section : Converting a supply-relative ADC measurement to an absolute voltage value*. Updated *Figure 276: Triggered regular oversampling mode (TROVS bit = 1)*. Suppressed *ADC common status register (ADC_CSR)*. Updated and *ADC common control register (ADC_CCR)* address offset. Updated master ADC in *Table 252: ADC global register map*. ***Section 32: Voltage reference buffer (VREFBUF)*** Updated *Section 32.2: VREFBUF functional description*.

Table 642. Document revision history (continued)

Date	Revision	Changes
13-Dec-2021	3 (continued)	***Section 30: Digital temperature sensor (DTS)*** Updated *Figure 284: Temperature sensor functional block diagram*. Updated signals to which ts1_trg0 to 3 are connected in *Table 257: Trigger configuration*. Changed TS1_T0[1:0] = 01 definition to 130 °C in *Temperature sensor T0 value register 1 (DTS_T0VALR1)*. Updated TS1_LITTHD bitfield description in *Temperature sensor interrupt threshold register 1 (DTS_ITR1)*. ***Section 39: True random number generator (RNG)*** Updated *Section 39.5: RNG processing time*. Updated CLKDIV[3:0] description in *RNG control register (RNG_CR)*. ***Section 40: Cryptographic processor (CRYP)*** Updated *Figure 342: AES-ECB mode overview*, *Figure 343: AES-CBC mode overview*, *Figure 344: AES-CTR mode overview*, *Figure 345: AES-GCM mode overview*, *Figure 346: AES-GMAC mode overview*, *Figure 347: AES-CCM mode overview*, *Figure 357: Message construction for the Counter mode*, *Figure 361: Message construction for the Galois Message Authentication Code mode*, *Figure 362: Message construction for the Counter with CBC-MAC mode*. Updated *Table 323: Counter mode initialization vector*,*Table 325: GCM mode IV registers initialization*, *Table 326: CCM mode IV registers initialization*. Updated introduction of *Section 40.4.16: CRYP data registers and data swapping*, *Section 40.4.17: CRYP key registers* and *Section 40.4.18: CRYP initialization vector registers*. Updated all CRYP_KxLR/RR and CRYP_IVxLR/RR register descriptions. ***Section 43: Advanced-control timers (TIM1/TIM8)*** Updated *Figure 396: Control circuit in normal mode, internal clock divided by 1*. Added note in *Section 43.3.16: Using the break function*. Updated OC1PE bit in *TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 1, 8)*. ***Section 45: General-purpose timers (TIM12/TIM13/TIM14)*** Updated *Figure 495: Control circuit in external clock mode 1*. Updated OC1PE bit in *TIM12 capture/compare mode register 1 [alternate] (TIM12_CCMR1)* and *TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1)(x = 13 to 14)*. ***Section 46: General-purpose timers (TIM15/TIM16/TIM17)*** Updated *Figure 520: Control circuit in normal mode, internal clock divided by 1*. Added *Section 46.4.15: 6-step PWM generation*. Added note in *Section 46.4.13: Using the break function*. Suppressed CC2DE bit in *TIM15 DMA/interrupt enable register (TIM15_DIER)*. Updated *TIM15 capture/compare mode register 1 [alternate] (TIM15_CCMR1)* and *TIMx capture/compare mode register 1 [alternate] (TIMx_CCMR1) (x = 16 to 17)*.

Table 642. Document revision history (continued)

Date	Revision	Changes
13-Dec-2021	3 (continued)	***Section 48: Low-power timer (LPTIM)*** Updated *Section 48.2: LPTIM main features* and *Section 48.4.4: LPTIM reset and clocks*. Added note to *Section 48.4.7: Trigger multiplexer*. Updated *Section 48.4.15: Encoder mode*. Updated *LPTIM interrupt and status register (LPTIM_ISR)*, *LPTIM interrupt clear register (LPTIM_ICR)* and *LPTIM configuration register (LPTIM_CFGR)*. ***Section 53: Universal synchronous/asynchronous receiver transmitter (USART/UART)*** Renamed SCLK pin into CK in the whole section. Added wakeup from Stop in *Section 53.2: USART main features*. Updated *Figure 623: RS232 RTS flow control* and *Figure 624: RS232 CTS flow control* to replace nRTS and nCTS by RTS and CTS, respectively. Updated *Table 427: Error calculation for programmed baud rates at lpuart_ker_ck_pres = 32.768 kHz*. Removed mention that usart_wkup interrupt is not mandatory when wakeup event is detected from *Section 53.5.21: USART low-power management*. Added *Section 53.6: USART in low-power modes*. Updated *Section 53.7: USART interrupts*. Updated ADD[7:0] bitfield descriptions in *USART control register 2 (USART_CR2)*. Updated EOBF and ABRE bit descriptions in *USART interrupt and status register [alternate] (USART_ISR)*. Updated ABRRQ bit description in *USART request register (USART_RQR)*. ***Section 54: Low-power universal asynchronous receiver transmitter (LPUART)*** Renamed SCLK pin to CK in the whole section. Removed mention that lpuart_wkup interrupt is not mandatory when wakeup event is detected in *Section 54.4.14: LPUART low-power management*. Added *Section 54.5: LPUART in low-power modes*. Updated *Section 54.6: LPUART interrupts*. Updated ABRE bit and ADD[7:0] bitfield description in *LPUART control register 2 (LPUART_CR2)*. ***Section 55: Serial peripheral interface (SPI)*** Updated *Section : Data handling via RxFIFO and TxFIFO* and *Section 55.5.3: CRC computation*. ***Section 56: Serial audio interface (SAI)*** Added *Table 449: TDM frame configuration examples*. In *Section 56.4.12: SPDIF output*, replaced $F_{SAI\_CK\_x}$ by $F_{sai\_x\_ker\_ck}$ in the formula enabling to compute the bit rate. Added note related to bitfield usage depending on Dx line availability in *SAI PDM delay register (SAI_PDMDLY)*.

Table 642. Document revision history (continued)

Date	Revision	Changes
13-Dec-2021	3 (continued)	***Section 57: SPDIF receiver interface (SPDIFRX)*** Added note in about RCC capabilities in *Section 57.2: SPDIFRX main features*, *Table 458: Minimum spdifrx_ker_ck frequency versus audio sampling rate*. Updated *Figure 698: SPDIFRX block diagram*, *Figure 703: SPDIFRX decoder* and *Figure 704: Noise filtering and edge detection*. ***Section 60: Secure digital input/output MultiMediaCard interface (SDMMC)*** Updated transmit FIFO and receive FIFO descriptions in *Section : Data FIFO*. Updated *SDMMC clock control register (SDMMC_CLKCR)*. updated DBLOCKSIZE[3:0] in *SDMMC data control register (SDMMC_DCTRL)*. Updated *Table 498: SDMMC register map*. ***Section 61: Controller area network with flexible data rate (FDCAN)*** Replaced host by user throughout the section. Updated *Software calibration* and *Clock calibration active*. ***Section 62: USB on-the-go high-speed (OTG_HS)*** Updated access types for: – Added ODDFRM bit in *OTG host channel x characteristics register (OTG_HCCHARx)* – REMWAKE + BESL[3:0 in *OTG core LPM configuration register (OTG_GLPMCFG)*, – STALL in *OTG device OUT endpoint x control register (OTG_DOEPCTLx)* and RXDPID(r) / TUPCNT[1:0] in *OTG device OUT endpoint x transfer size register (OTG_DOEPTSIZx)*. ***Section 63: Ethernet (ETH): media access control (MAC) with DMA controller*** *Table 543: Ethernet peripheral pins*: – Renamed ETH_RDX and ETH_TX port names into ETH_RXD and ETH_TXD, respectively. – Added CRS_DV input. Updated *Section 63.5.3: Packet filtering*. Reworked *Section 63.5.4: IEEE 1588 timestamp support*. Updated *Section 63.5.5: Checksum offload engine*. *Section 63.5.6: TCP segmentation offload*: – Added *Section : DMA operation with TSO feature* – Renamed section Enabling the TSO feature into *Section : Building the Descriptor and the packet for the TSO feature* and section updated. Updated *Section 63.5.7: IPv4 ARP offload*, *Section 63.5.8: Loopback*, *Section 63.5.9: Flow control* and *Section 63.5.10: MAC management counters*. Added MDIO Clause 45 in *Section : SMA functional overview*. Updated *Section : MII management write operations*. Added in *Section : Preamble suppression*, *Section : Trailing clocks and back-to-back transactions* and *Section : Interrupt for MDIO transaction completion*. Updated *Section 63.6.2: Media independent interface (MII)* and *Section 63.6.3: Reduced media independent interface (RMII)*. *Section 63.7: Ethernet low-power modes* deeply reworked.

Table 642. Document revision history (continued)

Date	Revision	Changes
13-Dec-2021	3 (continued)	***Section 63: Ethernet (ETH): media access control (MAC) with DMA controller*** (continued) Updated DMA initialization sequence in *Section 63.9.1: DMA initialization*. Updated *Section 63.9.3: MAC initialization* and *Section 63.9.5: Stopping and starting transmission*. Added *Section 63.9.6: Programming guidelines for switching to new descriptor list in RxDMA*, *Section 63.9.7: Programming guidelines for switching the AHB clock frequency* and *Section 63.9.10: Programming guidelines for PTP offload feature*. Updated *Section 63.9.11: Programming guidelines for Energy Efficient Ethernet (EEE)* and *Section 63.9.13: Programming guidelines for TSO*. Updated *Table 580: TDES2 normal descriptor (read format)*, *Table 581: TDES3 normal descriptor (read format)*, *Table 585: TDES3 normal descriptor (write-back format)* and *Table 589: TDES3 context descriptor*. Updated *Figure 842: Receive normal descriptor (read format)* as well as *Table 590: RDES0 normal descriptor (read format)* and *Table 593: RDES3 normal descriptor (read format)*. Updated *Figure 843: Receive normal descriptor (write-back format)* as well as *Table 597: RDES3 normal descriptor (write-back format)*. Updated *Table 601: RDES3 context descriptor*. *Section 63.11.2: Ethernet DMA registers*: – Several registers updated (register reset value changed, bitfields added or description updated, bit access modified). – Removed MMCIE/MMCRSIPIS and GPIIS/GPIIE from *Figure 845: Generation of ETH_DMAISR flags*. *Section 63.11.3: Ethernet MTL registers*: – several registers updated (bitfield description updated or bit access modified). *Section 63.11.4: Ethernet MAC and MMC registers*: – Several registers updated (register reset value changed, bitfields added or description updated, bit access modified). – Added *VLAN inclusion register (ETH_MACVIR)*. – Moved Table Timestamp snapshot dependency on register bits from *Timestamp control Register (ETH_MACTSCR)* to *Section : Clock types*. – Updated *System time seconds update register (ETH_MACSTSUR)* and *System time nanoseconds update register (ETH_MACSTNUR)*. ***Section 65: Debug infrastructure*** Removed 100 kΩ pull-up requirement in *Section : Serial wire debug port*. Updated PRESCALER[12:0] bitfield description in *SWO current output divisor register (SWO_CODR)*.

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