TRAINING MANUAL

EMBEDDED SYSTEMS DESIGN AND IOT APPLICATIONS

USING CLOUD COMPUTING

Unit 10.1

Embedded System Programming

Time allocation: Week 10

Objectives

The aim of this module is to get immersed into embedded programming on a real hardware. To complete the basic workflow, simple applications are developed, implemented, and demonstrated in an Embedded System work environment. Experiment(s) in this module are conducted using Real-Time OS (RTOS) to demonstrate some of the most common practical applications.

Resources

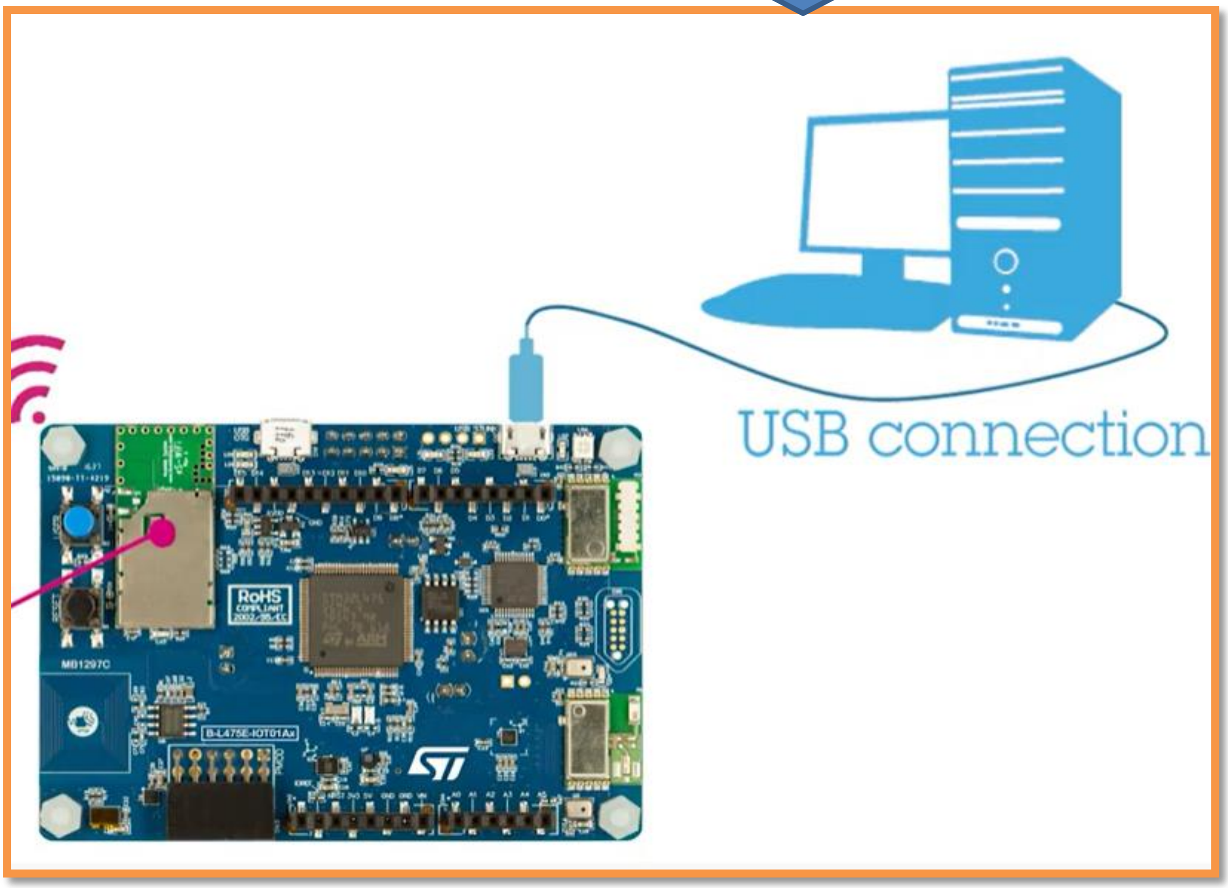
- Desktop PC / Laptop
- Software development Tools
- Embedded Kit (ARM Cortex Series)
- Jumper Wires / Breadboard / LEDs, Switches

Topics to be covered:

1. Getting Started a Tutorial Project
2. ARM Cortex M4 I/O Programming
3. GPIO (General Purpose I/O) Programming and Interfacing
4. Reading Switches and Displaying the same on LEDs
5. Standard Application(s) Interfacing and Programming
6. Internet-of-Things (IOT) Application(s) Interfacing and Programming

Embedded System Setup

STM32 (ARM Cortex M4) Starter Kit - Development and Education Board



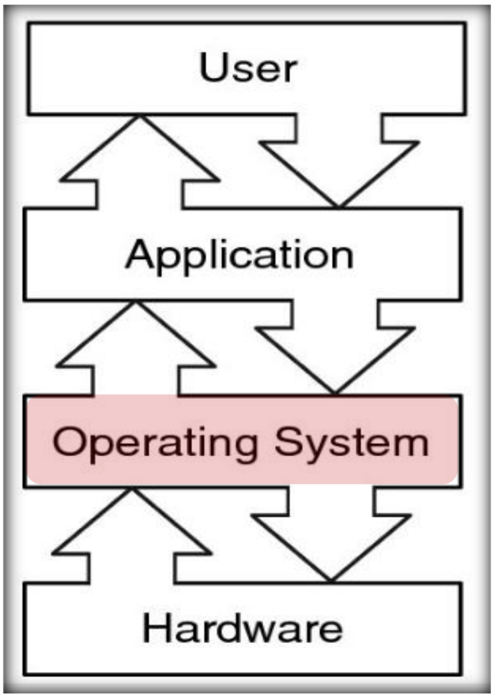
(STM32 µController)

Document: Datasheet (stm32l4s5) and Reference manual (stm32l4s5)

Getting started with embedded RTOS (freeRTOS)

What is an RTOS and Multitasking?

A RTOS is a real-time operating system which manages **software and hardware resources** on a computing system and provides services to application software which are **not** possible with bare metal.



RTOS Architecture

Examples:

- freetRTOS
- Keil RTX
- µC/OS

A RTOS is basically a software component that rapidly switches between tasks, giving the impression that multiple programs are being executed at the same time on a single processing core.

In actual fact the processing core can only execute one program at any one time, and what the RTOS is actually doing is rapidly switching between individual programming threads (or Tasks) to give the impression that multiple programs are executing simultaneously.

When switching between **Tasks** the RTOS has to choose the most appropriate task to load next. There are several scheduling algorithms available. However, to provide a responsive system most RTOS use a pre-emptive scheduling algorithm.

In a pre-emptive system each Task is given an individual priority value. The faster the required response, the higher the priority level assigned. When working in pre-emptive mode, the task chosen to execute is the highest priority task that is able to execute. This results in a highly responsive system.

While selecting a RTOS, one of the most important considerations is what type of response is desired – Is a hard real time response required? This means that there are precisely defined deadlines that, if not met, will cause the system to fail. Alternatively, would a non-deterministic, soft real time response be appropriate? In which case there are no guarantees as to when each task will complete.

The choice of RTOS can greatly affect the development of the design.

By selecting an appropriate RTOS the developer gains:

- A Task based design that enhances modularity, simplifies testing and encourages code reuse;
- An environment that makes it easier for engineering teams to develop together;
- Abstraction of timing behaviour from functional behaviour, which should result in smaller code size and more efficient use of available resources.

Peripheral support, memory usage and real-time capability are key features that govern the suitability of the RTOS. Using the wrong RTOS, particularly one that does not provide sufficient real time capability, will severely compromise the design and viability of the final product.

The RTOS needs to be of high quality and easy to use. Developing embedded projects is difficult and time consuming – the developer does not want to be struggling with RTOS related problems as well. The RTOS must be a trusted component that the developer can rely on, supported by in-depth training and good, responsive support.

What is FreeRTOS?

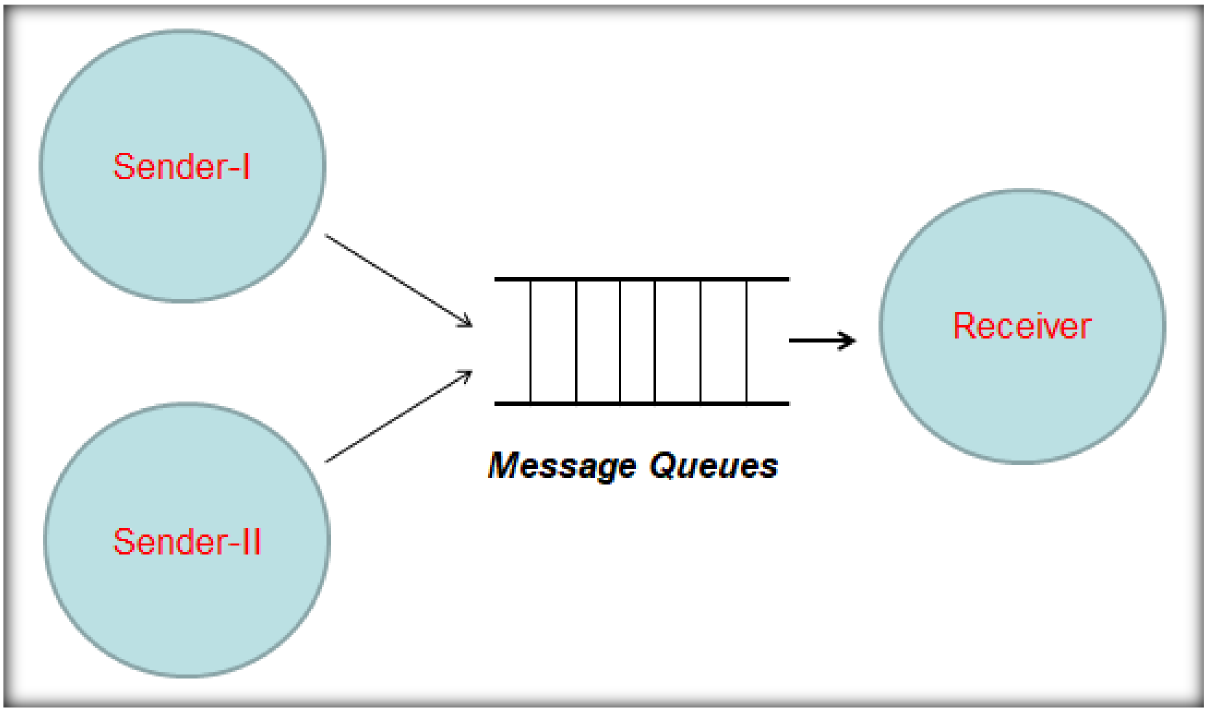
FreeRTOS is a class of RTOS that is designed to be small enough to run on a microcontroller (µC). A microcontroller is a small and resource constrained processor that incorporates, on a single chip, the processor itself, read only memory (ROM / Flash) to hold the program to be executed, and the random access memory (RAM) needed by the programs it executes. Typically the program is executed from the read only memory. One of the main attractions in freeRTOS is its free of cost licensing model.

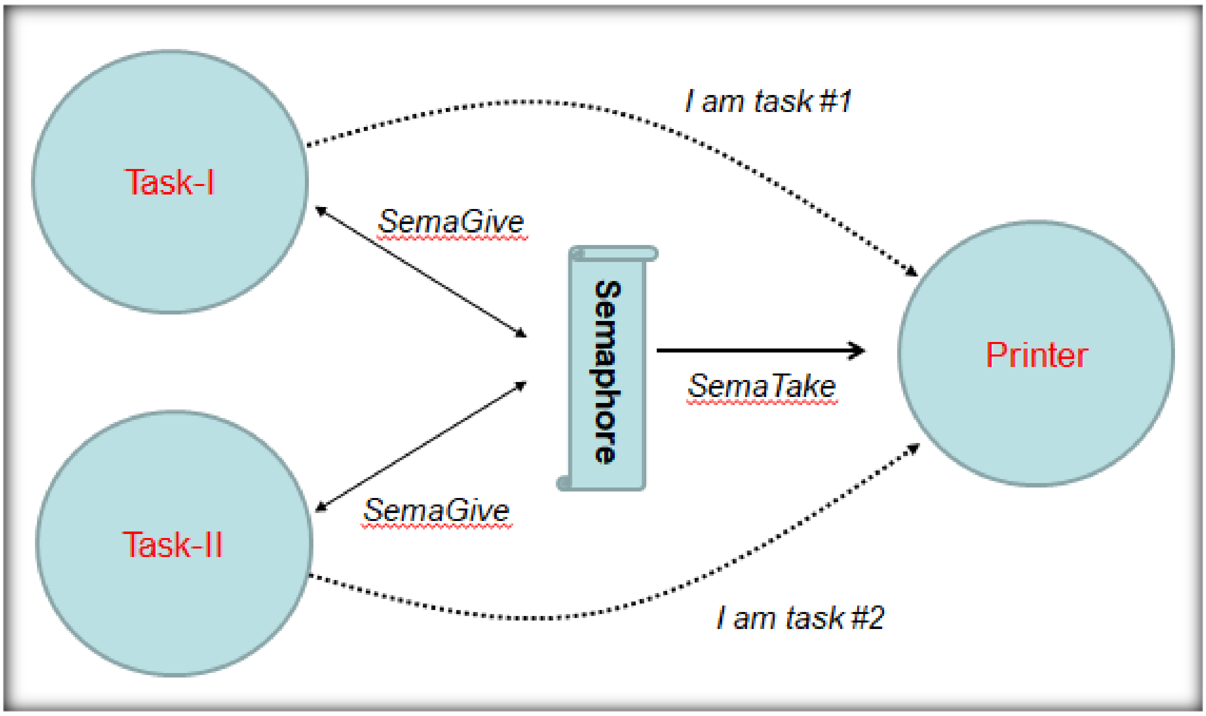
Microcontrollers are a central piece of the embedded systems that normally have a very specific job to do. The size constraints, and dedicated end application nature, rarely warrant the use of a full package implementation.

Applications - few to mention:

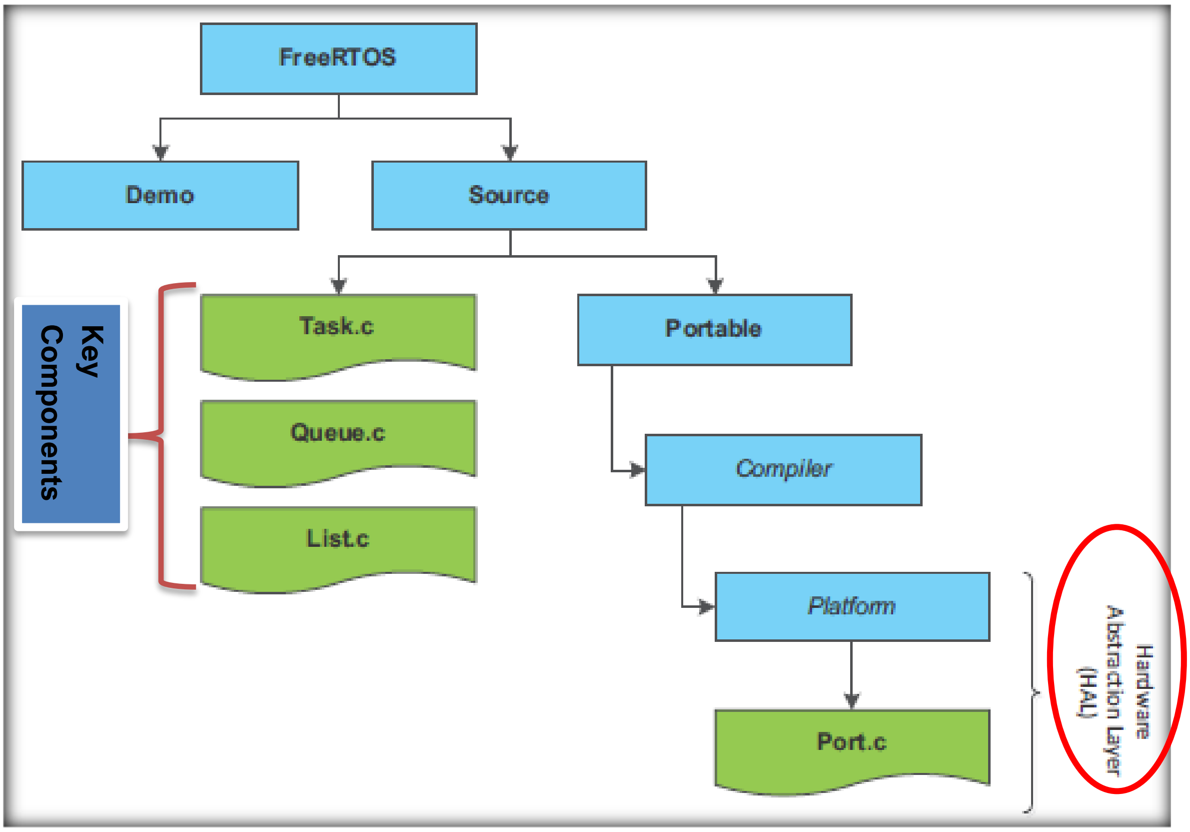
Command and control systems, heart pacemaker, industrial automation, and modern robotics systems

Key Features - Tasks Synchronization through Semaphores / Queues

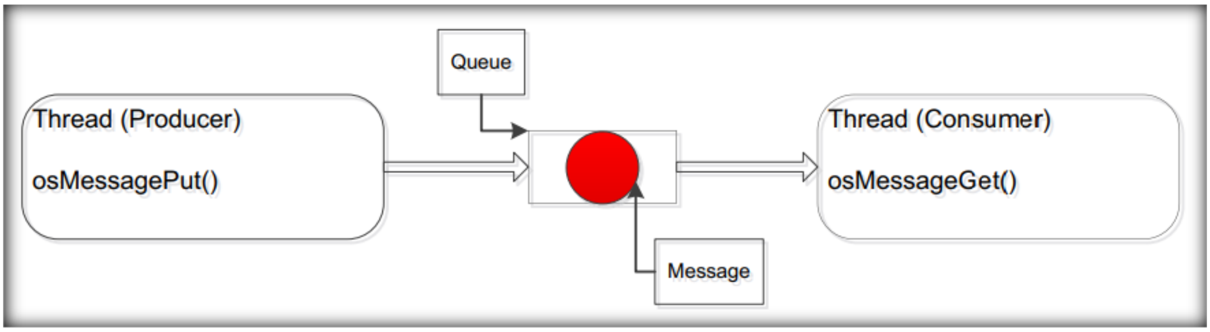




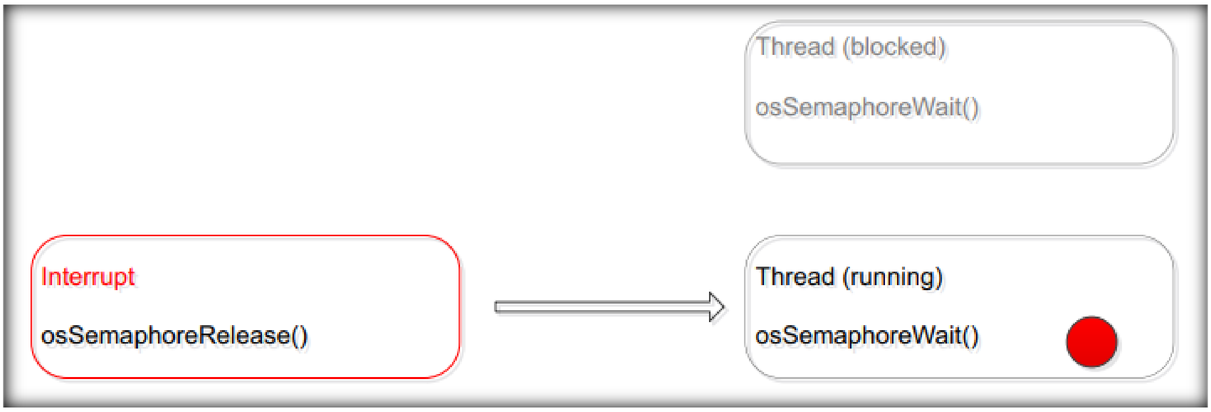
FreeRTOS architecture



Queue process



Semaphore from ISR



FreeRTOS configuration

FreeRTOSConfig.h

```
#ifdef __NVIC_PRIO_BITS
       /* __BVIC_PRIO_BITS will be specified when CMSIS is being used. */
       #define configPRIO_BITS                         __NVIC_PRIO_BITS
#else
       #define configPRIO_BITS                    4           /* 15 priority levels */
#endif

/* The lowest interrupt priority that can be used in a call to a "set priority"
function. */
#define configLIBRARY_LOWEST_INTERRUPT_PRIORITY        0xf
```

Reference:

https://www.st.com/resource/en/user_manual/dm00105262-developing-applications-on-stm32cube-with-rtos-stmicroelectronics.pdf

Free RTOS APIs

APIs Categories	API
Task Creation	– xTaskCreate – vTaskDelete
Task Control	– vTaskDelay – vTaskDelayUntil – uxTaskPriorityGet – vTaskPrioritySet – vTaskSuspend – vTaskResume – xTaskResumeFromISR – vTaskSetApplicationTag – xTaskCallApplicationTaskHook
Task Utilities	– xTaskGetCurrentTaskHandle – xTaskGetSchedulerState – uxTaskGetNumberOfTasks – vTaskList – vTaskStartTrace – ulTaskEndTrace – vTaskGetRunTimeStats
Kernel Control	– vTaskStartScheduler – vTaskEndScheduler – vTaskSuspendAll – xTaskResumeAll
Queue Management	– xQueueCreate – xQueueSend – xQueueReceive – xQueuePeek – xQueueSendFromISR – xQueueSendToBackFromISR – xQueueSendToFrontFromISR – xQueueReceiveFromISR – vQueueAddToRegistry – vQueueUnregisterQueue
Semaphores	– vSemaphoreCreateBinary – vSemaphoreCreateCounting – xSemaphoreCreateMutex – xSemaphoreTake – xSemaphoreGive – xSemaphoreGiveFromISR

Task-0

This task demonstrates:

- Simple working of a **freeRTOS** on **STM32L4S5** device

Objective

- Learn bare metal set up dealing with the hardware
- ~~Learn how to set up the **RTOS** with DMA and Interrupt in STM32CubeMX.~~
- Generate code in STM32CubeMX and using HAL functions.
- Create applications to start the **freeRTOS** and learn how to set **freeRTOS** in different modes.

On the target board,

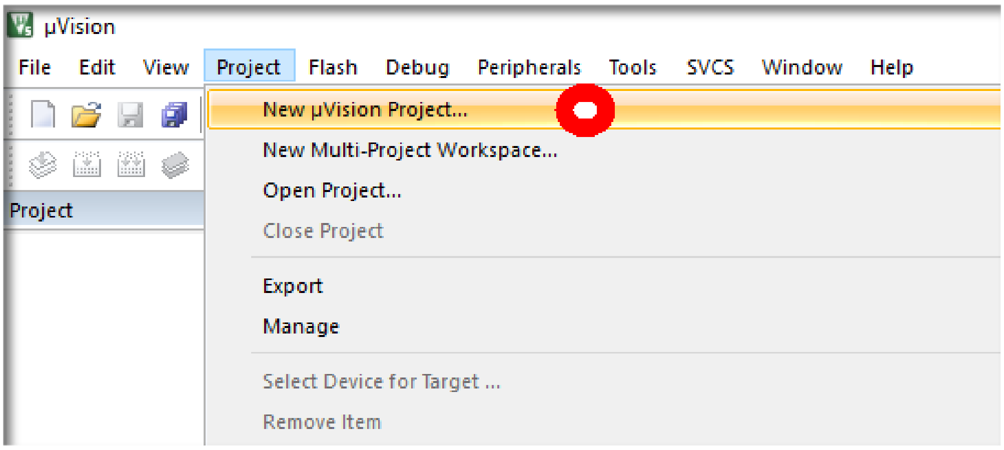
You will use GPIOs (**LEDs**) and/or USART (**Tera-Term**) to demonstrate the working of RTOS;

- Using the IOT board, based on **STM32L4S5** µController from ST-Microelectronics Ltd.

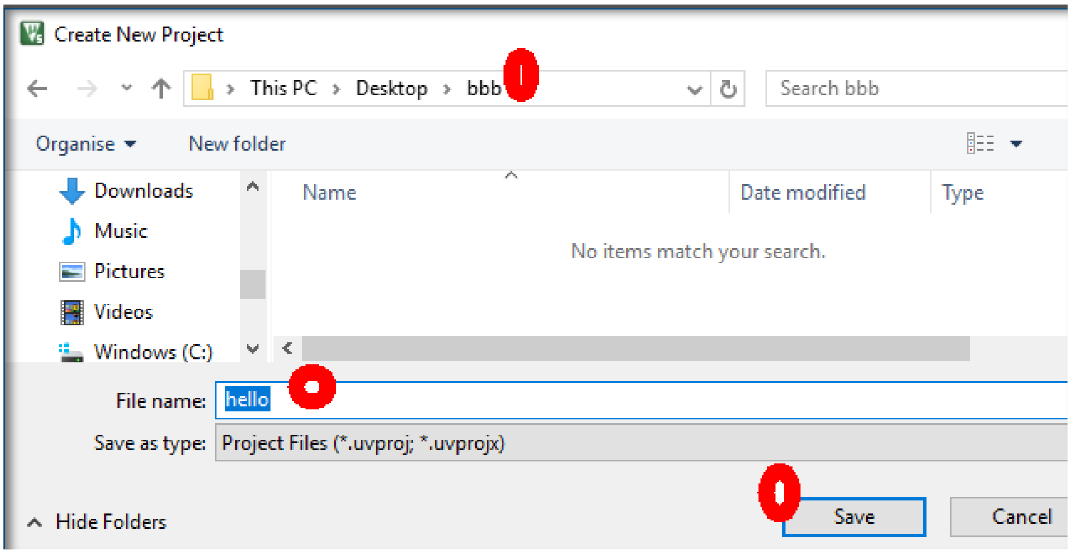
Procedure

Launch Keil µVision Development Tools

Double Click the Icon

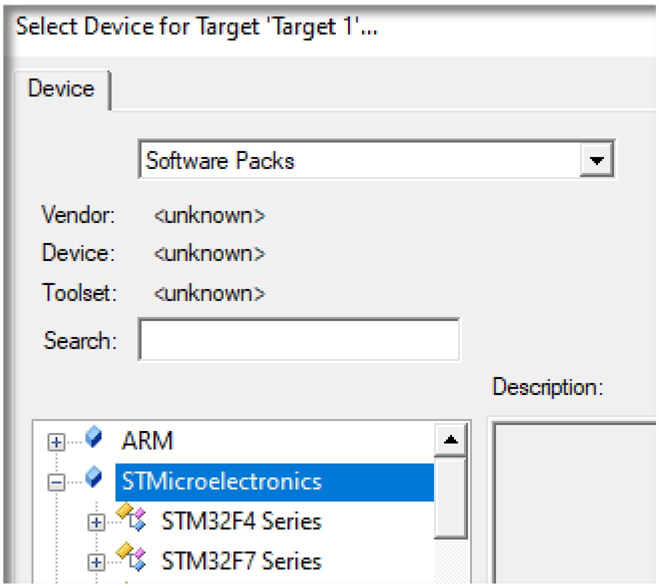


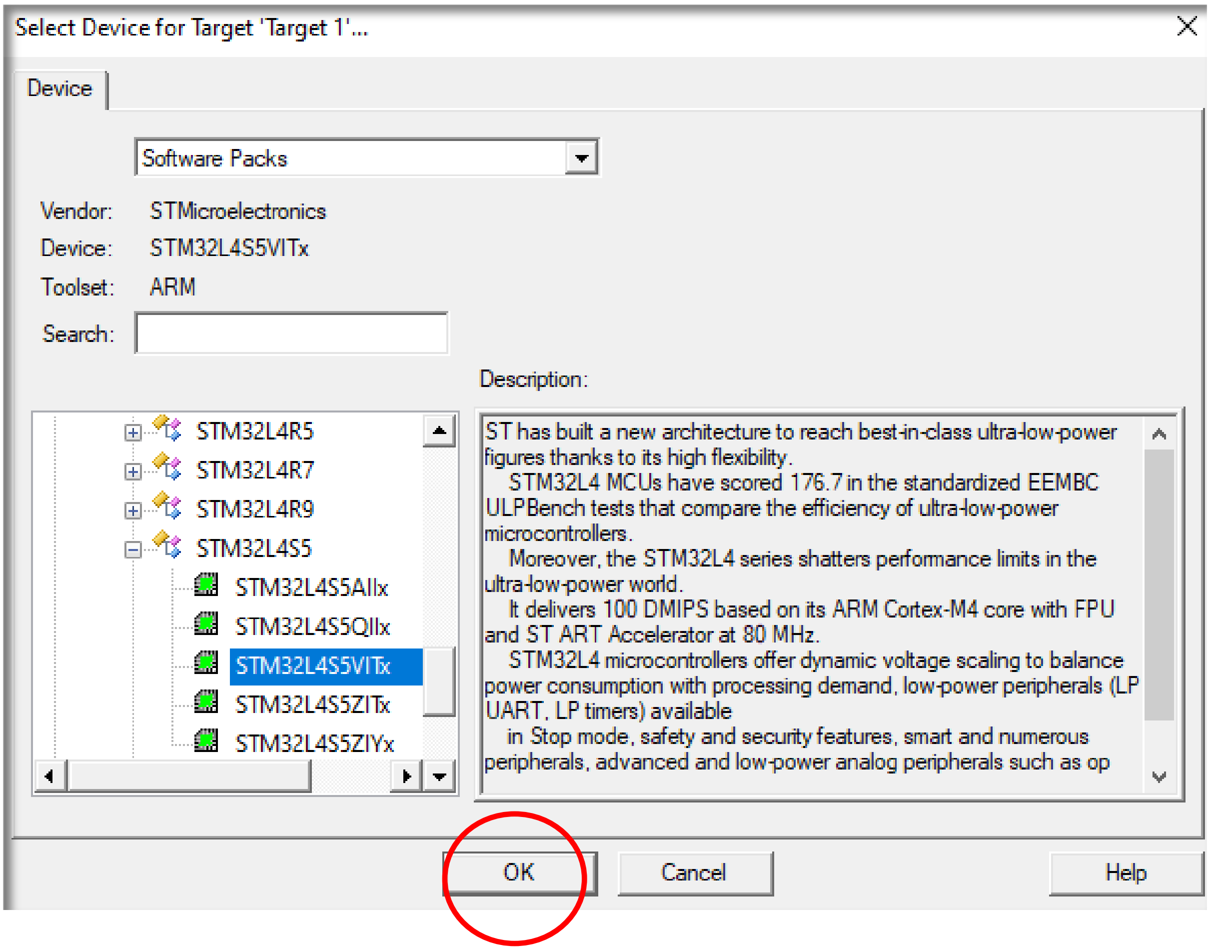
- ✓ In the New µVision Project window, browse to the folder "**bbb**" you just created
- ✓ Enter a name for the project file. We will call it "**hello**" and click **Save**



Select Device for Target

✓ STMicroelectronics STM32L4S5VITx



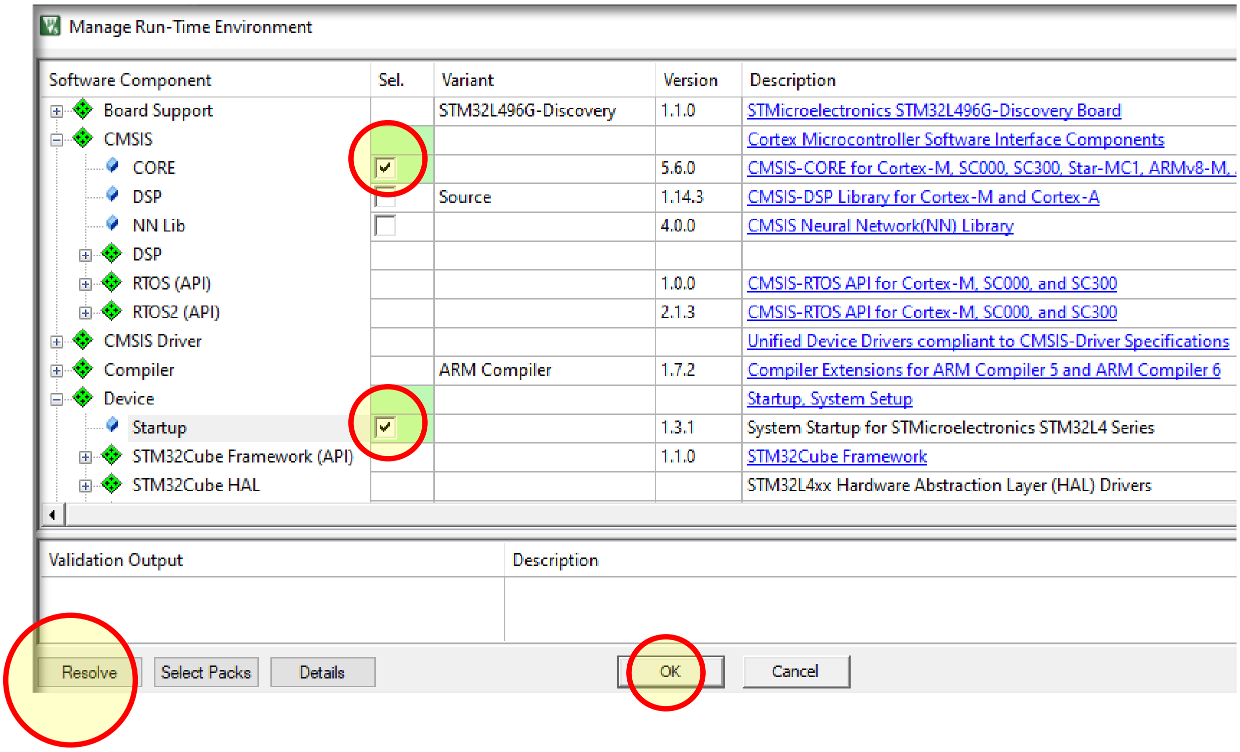


Alternatively: Try,

Project -> Options for Target 'Target 1'-> Device,

Scroll down, and select "STM32L4S5VITx"

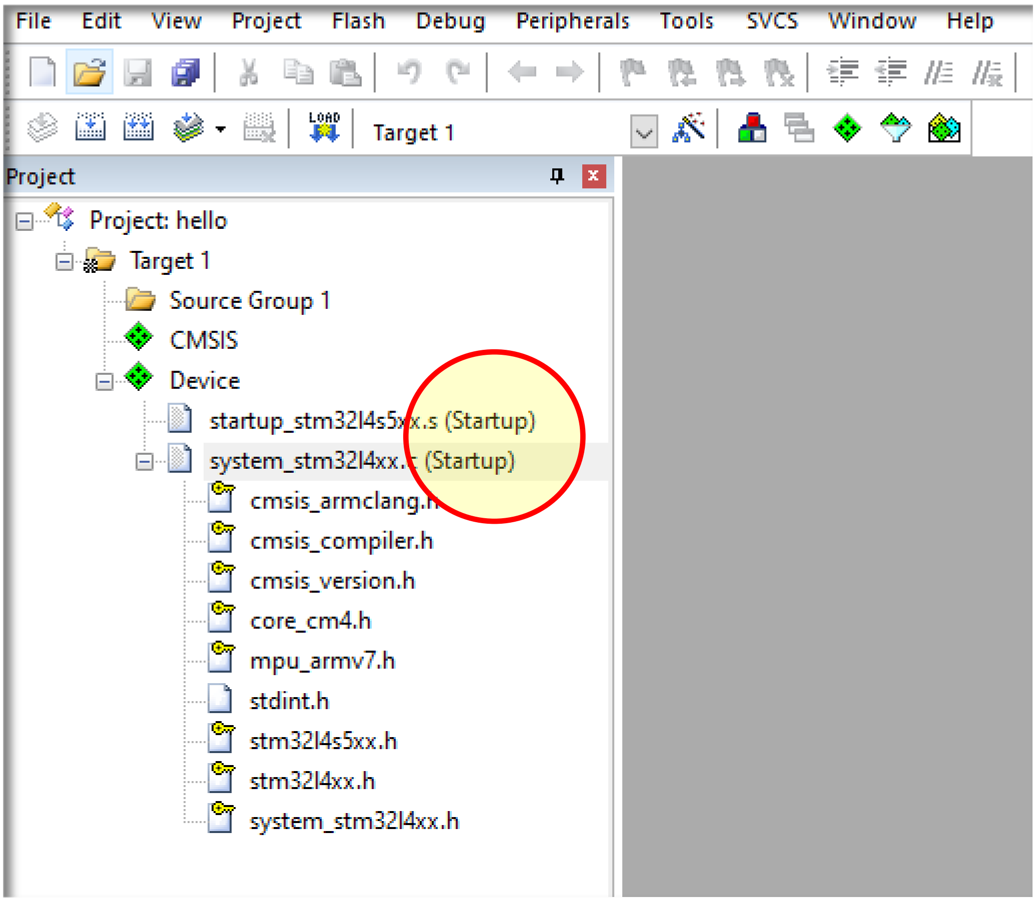
Configure default Initialization files



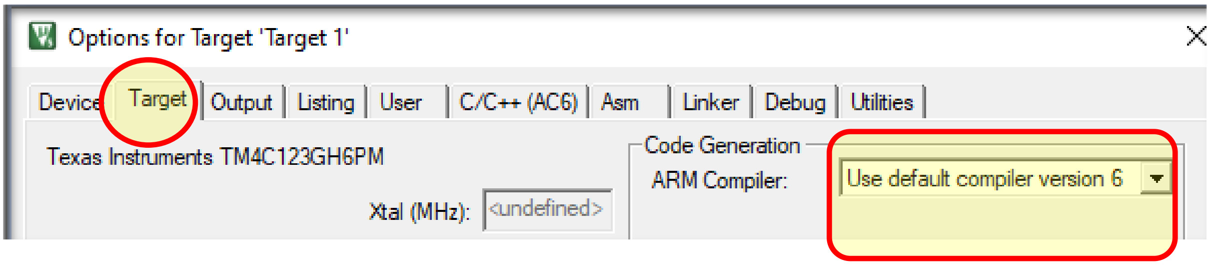
Alternatively: Try,

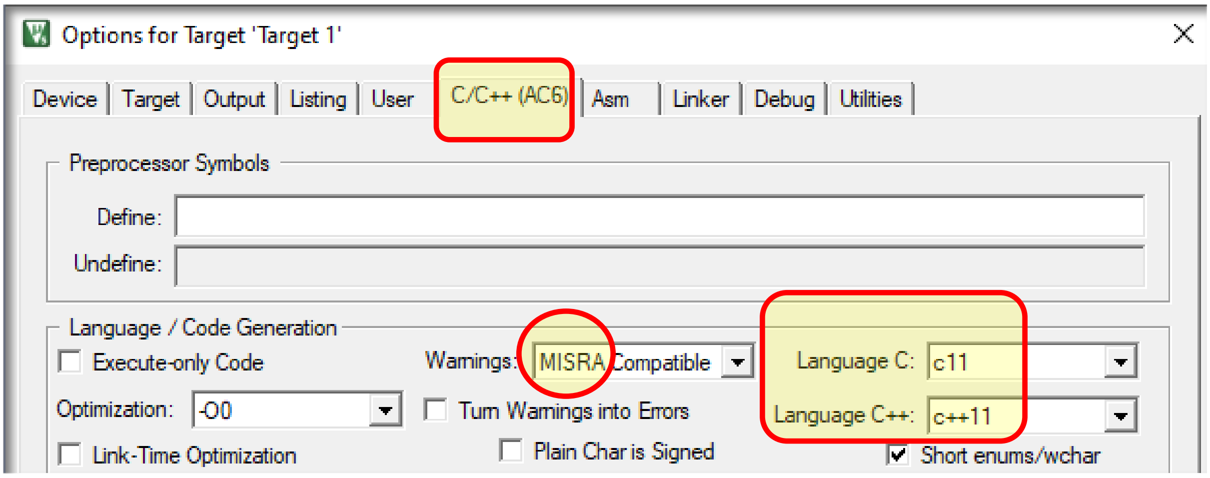
Project -> Manage -> Manage Run-Time Environment,

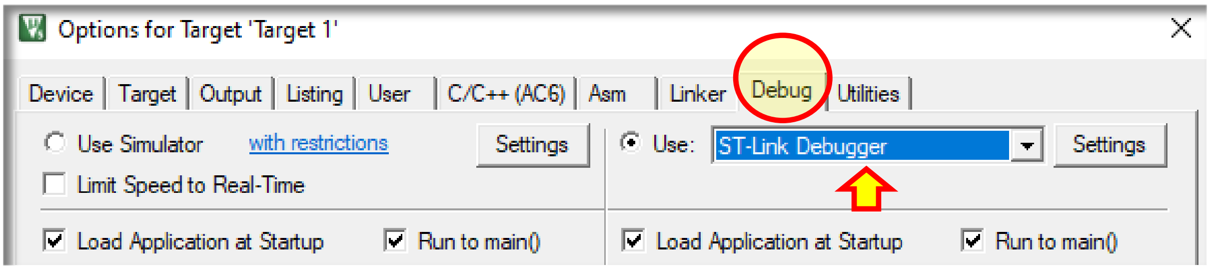
Project Outlook

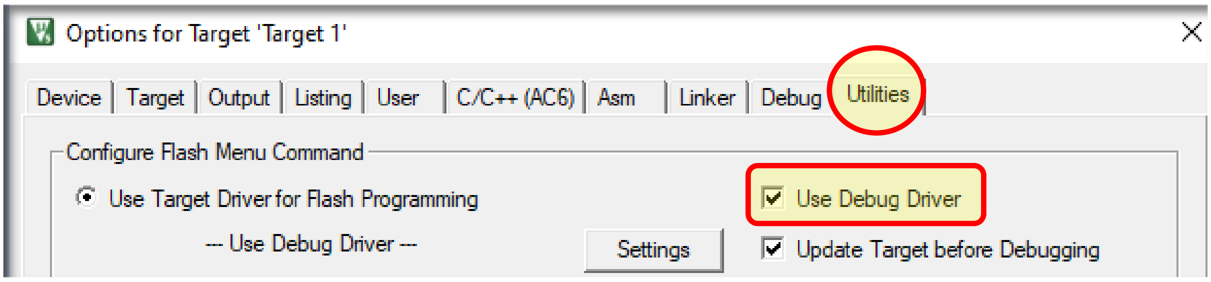


Compiler & Debugger Setting (Project → Options for Target)





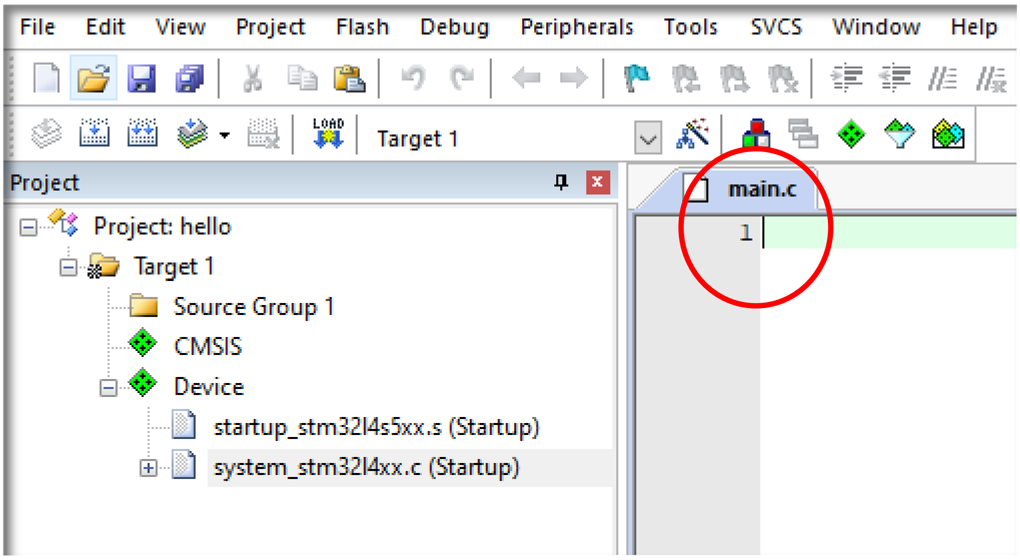




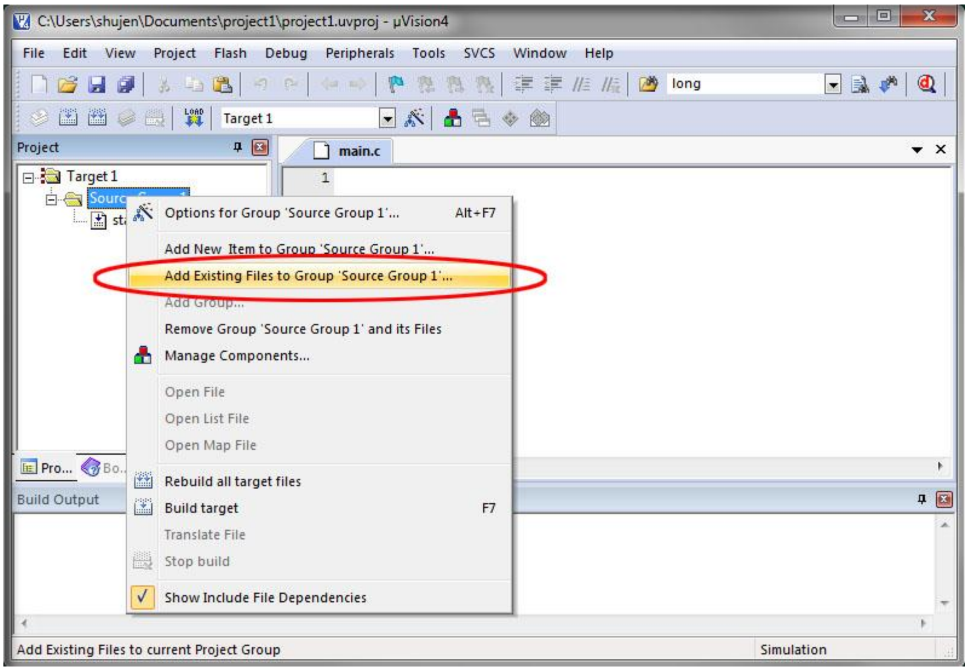
<OK>

Add a Source File to the Project

- ✓ Click the **File->New** button to add a new text file to the display with the default name **Text1**.
- ✓ From the menu, select **File > Save As…** to open the Save As dialog box. Browse to the project folder if it is not already there. Type in the file name "**main.c**" and click **Save**.

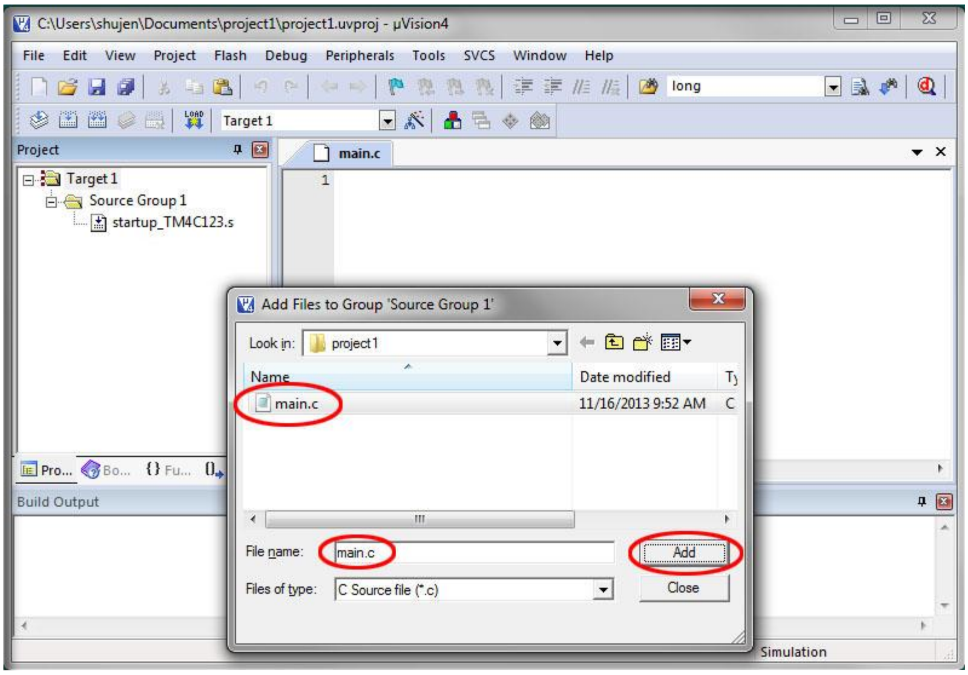


- ✓ The new file needs be added to the project. **Right click** on the folder **Source Group 1** in the Project window and select **Add Existing Files to Group 'Source Group 1'…**

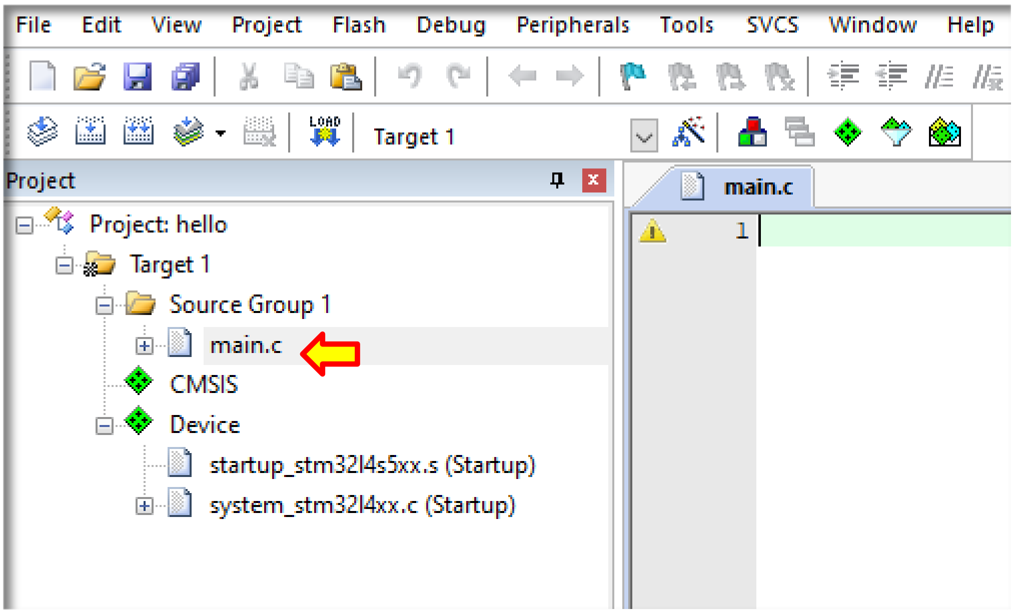


- ✓ In the dialog box, browse to the project folder if it is not already there.

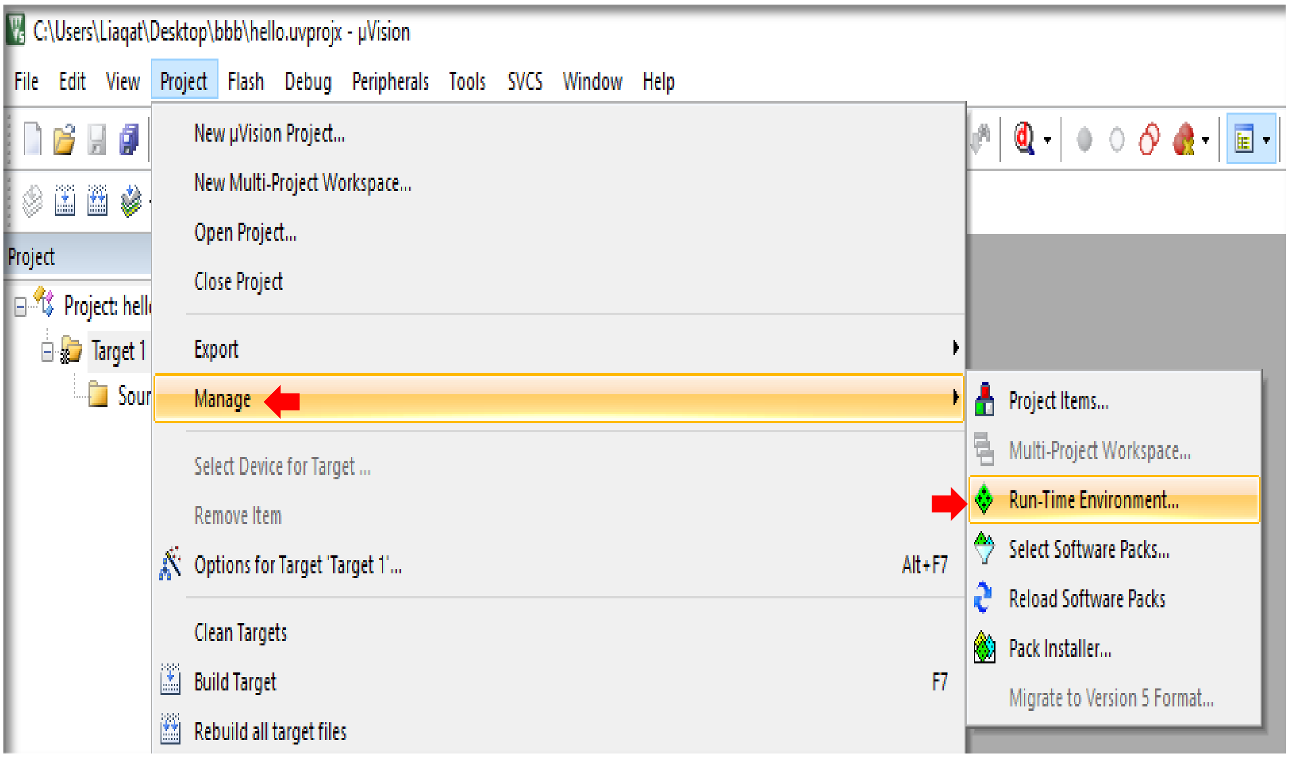
Click select **main.c** then click **Add**.



✓ The file should appear in the project window under Source Group 1 folder. Click **Close** to close the dialog box.



Create RTOS based Project Configuration



There are two (2) versions of **freeRTOS** implementation.

- **Standard** (Traditional – original implementation)
- **CMSIS-RTOS2** (An ARM version which is platform independent)

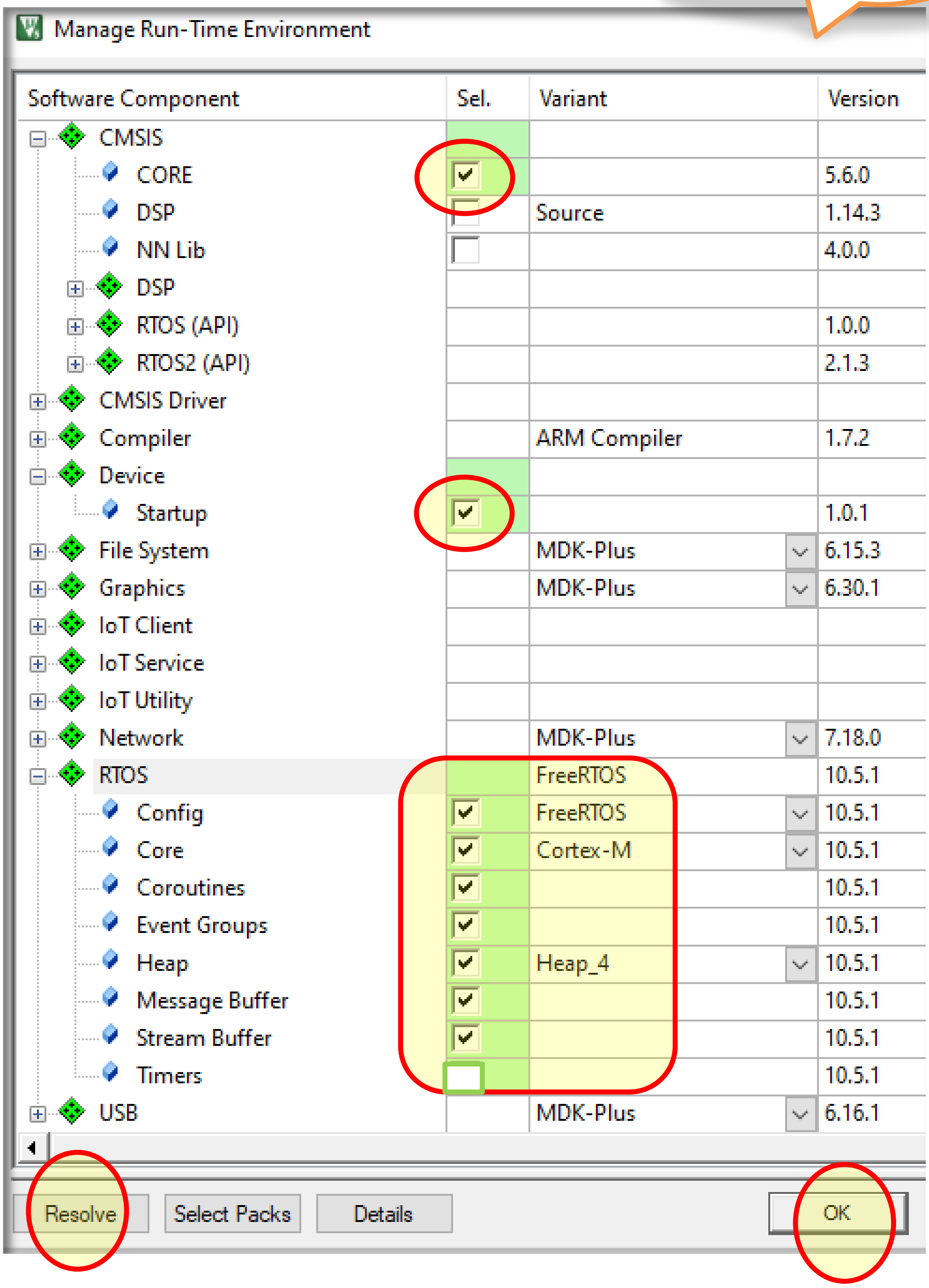
NOTE:

Make sure there is **one and only one** configuration produced in any working folder.

If necessary, make the working folder an empty folder by deleting everything from there.

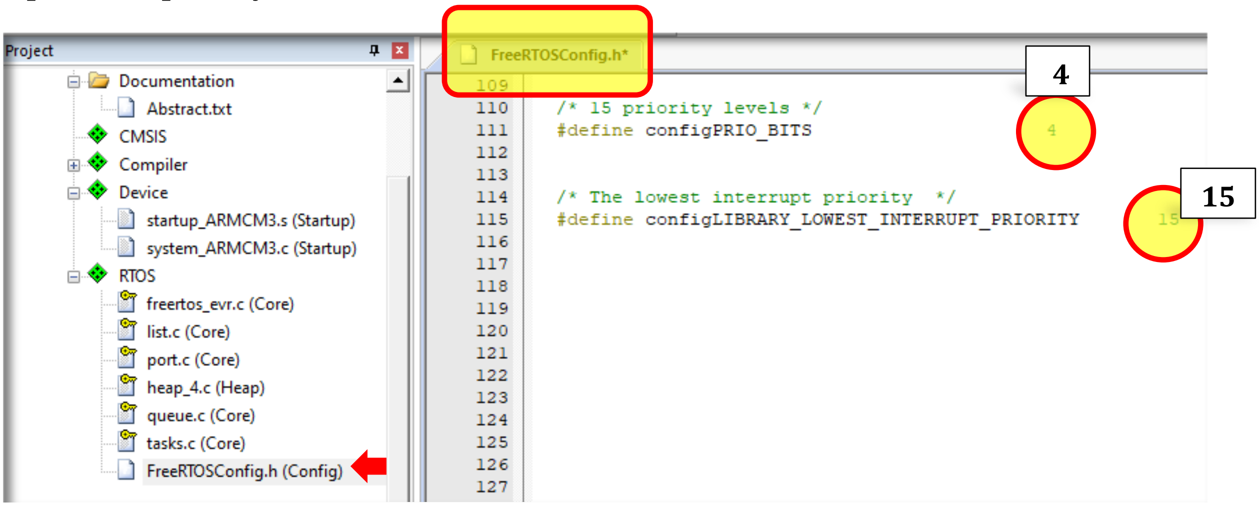
Standard freeRTOS Configuration

1 of 2 options



Correction!!

Update the priority levels



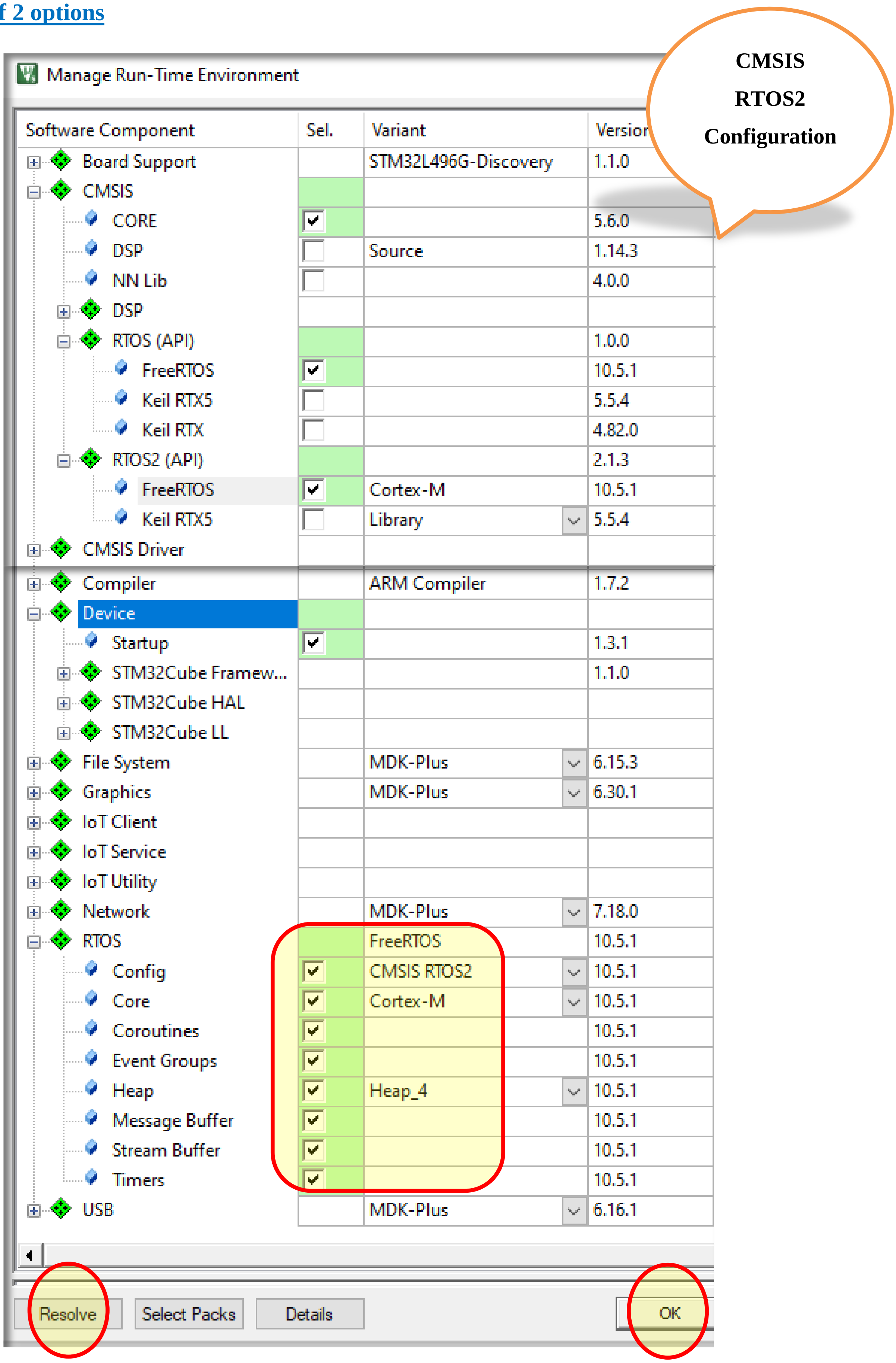
Cross checked (Reference Manual - STM32L4S5)

15 Nested vectored interrupt controller (NVIC)

15.1 NVIC main features

- 95 maskable interrupt channels (not including the sixteen Cortex®-M4 with FPU interrupt lines)
- 16 programmable priority levels (4 bits of interrupt priority are used)

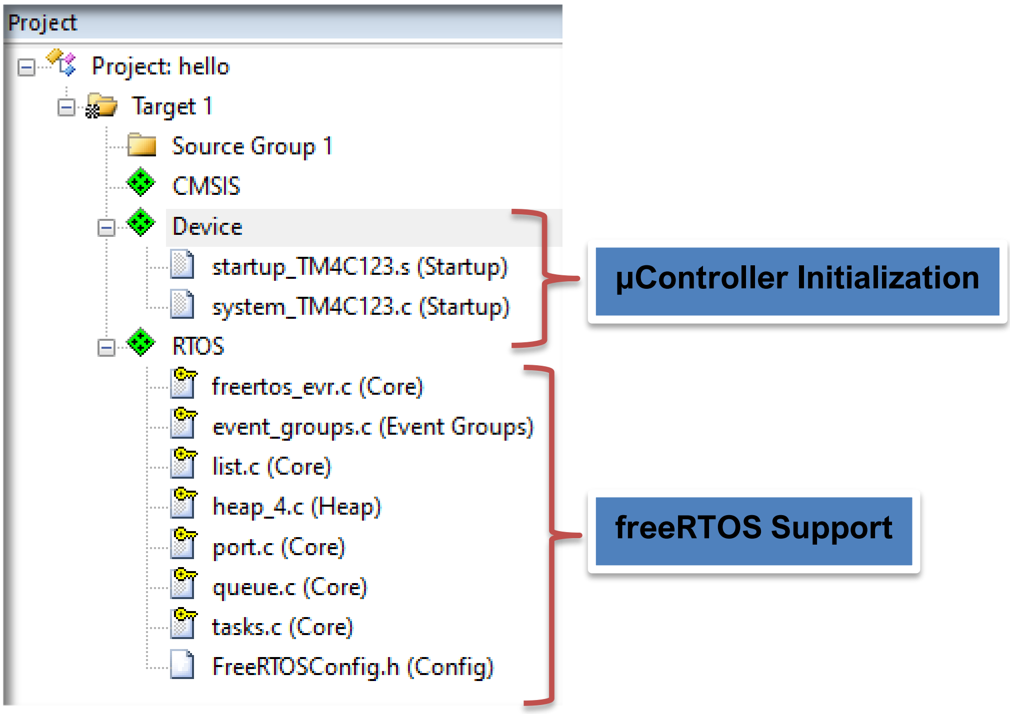
2 of 2 options



a)

b)

c)



d)

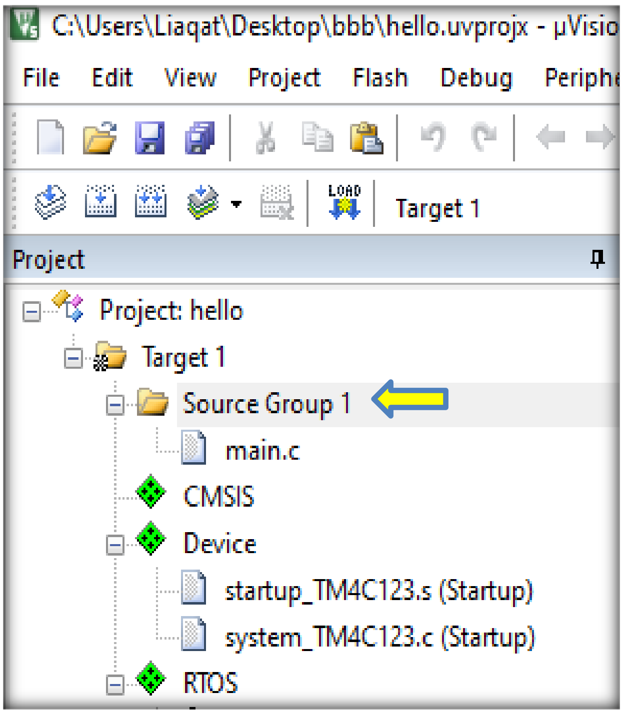
Ignore this step, if "***main.c***" file is already in the project otherwise complete the below listed steps.

- ✓ **Open a new blank file**
  File → New

  File → Save As:

  "*main.c*"

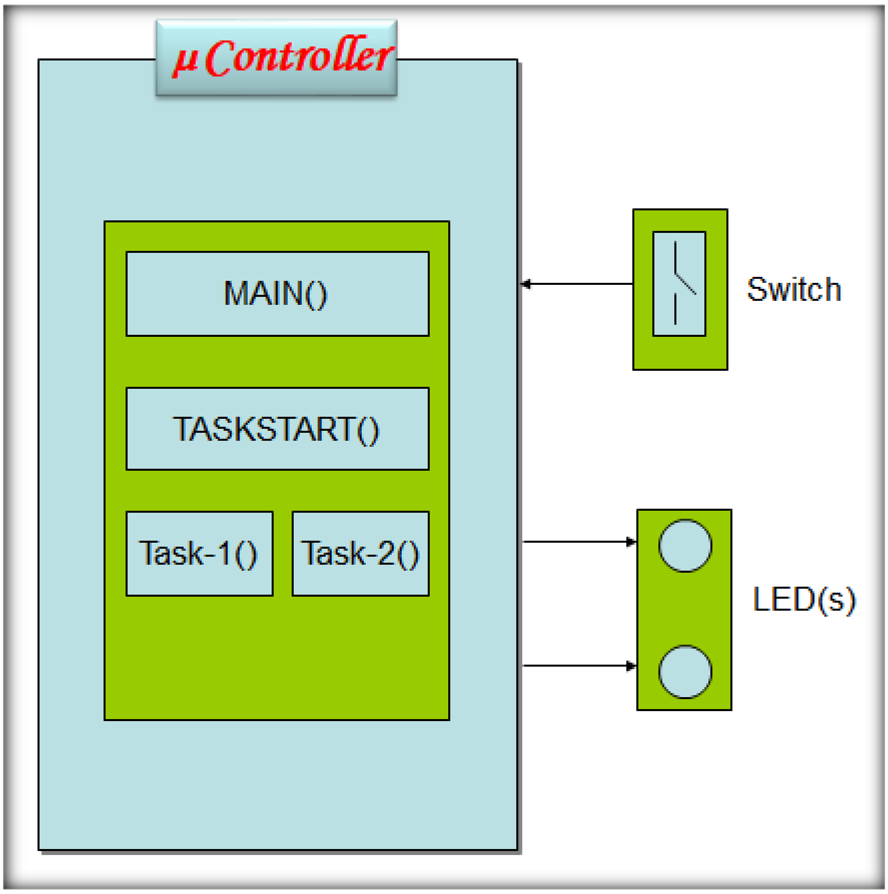
- ✓ **Add this file into the project**



Task-1

This task demonstrates how to:

- Configure **GPIO** ports
- Create multiple Tasks in RTOS (**FreeRTOS**)
- Toggles a set of LEDs (**PA5 & PB14**) of PORTA & PORTB through **Tasks- 1 & 2**



- **C** Programming Code for this task is given next
- Copy & Paste the same in "**main.c**" file
- Build, Download, and Run on the Embedded Kit / Board
- Monitor the LEDs toggling patterns (sequences)

Copy and paste the sample code into the "**main.c**" editor window.

```
// Example-1: RTOS based multitasking
//


#include <stdio.h>

#include "RTE_Components.h"          // Component selection
#include CMSIS_device_header

#include "FreeRTOS.h"              // Keil::RTOS:FreeRTOS:Core
#include "task.h"                  // Keil::RTOS:FreeRTOS:Core

#include "stm32l4s5xx.h"



/*-----------------------------------------------------------*/
void vTask1( void *pvParameters )  {
        /* As per most tasks, this task is implemented in an infinite loop. */
        for( ;; )   {
                        GPIOA->ODR ^= (0x1 << 5); //PA5 ON
                        vTaskDelay(100); // freeRTOS function
        }
}

/*-----------------------------------------------------------*/
void vTask2( void *pvParameters )  {
        /* As per most tasks, this task is implemented in an infinite loop. */
        for( ;; )   {
                        GPIOB->ODR ^= (0x1 << 14); //PB14 ON
                        vTaskDelay(500); // freeRTOS function
        }
}


// ***********************************************************************
// Initialize FreeRTOS and start the initial set of tasks.
// ***********************************************************************

int main(void){

/* Create required number of task(s) */

        xTaskCreate( vTask1,        /* Pointer to the function that implements the task. */
                                "Task 1", /* Text name for the task.  */
                                200,            /* Stack depth in words. */
                                NULL,           /* We are not using the task parameter. */
                                1,              /* This task will run at priority 1. */
                                NULL );         /* We are not using the task handle. */

        xTaskCreate( vTask2, "Task 1", 200, NULL, 1, NULL );
```

```
/* GPIO Port configuration */

 // Enable the clock to GPIO Port B
 RCC->AHB2ENR |= 0x2; //RCC_AHB2ENR_GPIOB_EN;

        // MODE: 00: Input mode, 01: General purpose output mode
 //      10: Alternate function mode, 11: Analog mode (reset state)
 GPIOB->MODER &= (unsigned int)~(0x3 << 14*2); // Clear bit PB14
 GPIOB->MODER |=  (0x1 << 14*2); // Set bit PB14 Output


 // Enable the clock to GPIO Port A
 RCC->AHB2ENR |= 0x1; //RCC_AHB2ENR_GPIOA_EN;

        // MODE: 00: Input mode, 01: General purpose output mode
 //      10: Alternate function mode, 11: Analog mode (reset state)
 GPIOA->MODER &= (unsigned int)~(0x3 << 5*2); // Clear bit PA5
 GPIOA->MODER |=  (0x1 << 5*2); // Set bit PA5 Output


/* Start the scheduler so our tasks start executing. */

        vTaskStartScheduler();


/* If all is well we will never reach here as the scheduler will now be
        running.  If we do reach here then it is likely that there was insufficient
        heap available for the idle task to be created. */

        while(1) {

        }

} // Program ends here
```

Exercise:

- ✓ *Change priorities of;*
    - *task1 to **1**,*
    - *task2 to **2***
    - *What is the impact and difference?*
- ✓ *Change priorities of;*
    - *task1 to 2,*
    - *task2 to **1***
    - *What is the impact and difference?*

Task-2

This task is similar to Task-1. It uses xTaskDelayUntil( ) function.

The given activities are synchronized through “**Semaphore**” functions.

```
// Example-1: RTOS based multitasking
// This task uses "Semaphore" function

#include <stdio.h>

#include "RTE_Components.h"          // Component selection
#include CMSIS_device_header

#include "FreeRTOS.h"               // Keil::RTOS:FreeRTOS:Core
#include "task.h"                   // Keil::RTOS:FreeRTOS:Core
#include <semphr.h> // Keil::RTOS:FreeRTOS:Core

#include "stm32l4s5xx.h"


// declare semaphore
SemaphoreHandle_t xSemaphore;

/*---------------------------------------------------------*/
// This thread generates semaphore
void vTask1( void *pvParameters ) {

        portTickType xLastWakeTime;

 xLastWakeTime = xTaskGetTickCount(); // Initialized with the current tick

        // Infinite loop.
        for( ;; )   {
                xSemaphoreGive( xSemaphore );  // Post Sema

                GPIOA->ODR ^= (0x1 << 5); //PA5 ON

                vTaskDelayUntil( &xLastWakeTime, ( 500 ) ); // Absolute delay of 500 ticks
        }
}
```

```
/*----------------------------------------------------------*/
// This thread picks up semaphore
void vTask2( void *pvParameters ) {


	// Infinite loop.
	for( ;; )   {
		xSemaphoreTake( xSemaphore, portMAX_DELAY  ); // Pend Sema (0xffff, max. ticks)

		GPIOB->ODR ^= (0x1 << 14); //PB14 ON
	}
}



// ***********************************************************************
// Initialize FreeRTOS and start the initial set of tasks.
// ***********************************************************************

int main(void){

/* Create required number of task(s) */

	xTaskCreate( vTask1,		/* Pointer to the function that implements the task. */
				"Task 1", /* Text name for the task.  */
				200,		/* Stack depth in words. */
				NULL,		/* We are not using the task parameter. */
				1,		/* This task will run at priority 1. */
				NULL );		/* We are not using the task handle. */

	xTaskCreate( vTask2, "Task 2", 200, NULL, 2, NULL );


/* GPIO Port configuration */

 // Enable the clock to GPIO Port B
 RCC->AHB2ENR |= 0x2; //RCC_AHB2ENR_GPIOB_EN;

// MODE: 00: Input mode, 01: General purpose output mode
 //       10: Alternate function mode, 11: Analog mode (reset state)
 GPIOB->MODER &= (unsigned int)~(0x3 << 14*2); // Clear bit PB14
 GPIOB->MODER |=  (0x1 << 14*2); // Set bit PB14 Output
```

```
 // Enable the clock to GPIO Port A
 RCC->AHB2ENR |= 0x1; //RCC_AHB2ENR_GPIOA_EN;

// MODE: 00: Input mode, 01: General purpose output mode
 //      10: Alternate function mode, 11: Analog mode (reset state)
 GPIOA->MODER &= (unsigned int)~(0x3 << 5*2); // Clear bit PA5
 GPIOA->MODER |=  (0x1 << 5*2); // Set bit PA5 Output


/* Attempt to create a semaphore. */
	xSemaphore = xSemaphoreCreateBinary();

	if( xSemaphore != NULL )  {
		/* The semaphore was created successfully. */
		/* Start the scheduler so our tasks start executing. */

		vTaskStartScheduler();
	}
	else {
		// Sema creation failed, do something else
	}


/* If all is well we will never reach here as the scheduler will now be
	running.  If we do reach here then it is likely that there was insufficient
	heap available for the idle task to be created. */

	while(1) {

	}


} // Program ends here
```

Task-3

This task is similar to Task-1.

The given activities are synchronized through "**Queue**" functions.

Monitor Tera-Term Window to see the messages movement from sender to receiver blocks.

```
// Example-1: RTOS based multitasking
// This lab uses "QUEUE" to synchronize the tasks.
// Monitor Tera-Term Window for the data movement
//
// Task 1 (PRODUCER) - Generates messages
// Task 2 (CONSUMER) - Displays data on "Tera-Term" window
//

#include <stdio.h>

#include "RTE_Components.h"          // Component selection
#include CMSIS_device_header

#include "FreeRTOS.h"               // Keil::RTOS:FreeRTOS:Core
#include "task.h"                   // Keil::RTOS:FreeRTOS:Core
#include <queue.h>


#include "stm32l4s5xx.h"

// Define the data type that will be queued
typedef struct {      // object data type
  uint8_t msgID;
  uint8_t msgData[5];
} MSGQUEUE_OBJ_t;

// Define the queue parameters
#define QUEUE_LENGTH 16
#define QUEUE_ITEM_SIZE sizeof( MSGQUEUE_OBJ_t )

static void vSenderTask( void *pvParameters ) ;
static void vReceiverTask( void *pvParameters );

// ********************************************************************
// Initialize FreeRTOS and start the initial set of tasks.
// ********************************************************************
int main(void) {
        // Enable the clock to GPIO Port A
        RCC->AHB2ENR |=  1;                /* enable GPIOA clock */

        // MODE: 00: Input mode, 01: General purpose output mode
        //      10: Alternate function mode, 11: Analog mode (reset state)
        GPIOA->MODER &= (unsigned int)~(0x3 << 5*2); // Clear bit PA5
        GPIOA->MODER |=  (0x1 << 5*2); // Set bit PA5 Output
```

```
        // Enable the clock to GPIO Port B
        RCC->AHB2ENR |= 0x2; //RCC_AHB2ENR_GPIOB_EN;

        // MODE: 00: Input mode, 01: General purpose output mode
        //       10: Alternate function mode, 11: Analog mode (reset state)
        GPIOB->MODER &= (unsigned int)~(0x3 << 14*2); // Clear bit PB14
        GPIOB->MODER |=  (0x1 << 14*2); // Set bit PB14 Output

// ------------------------------------------------------------------
// Configure USART1

                // Enable the clock to GPIO Port B
                RCC->AHB2ENR |= 0x2; //RCC_AHB2ENR_GPIOB_EN;

                GPIOB->AFR[0] &= ~0x0F000000;
                GPIOB->AFR[0] |=  0x07000000;   /* PB6 for USART1 TX */

                GPIOB->AFR[0] &= ~0xF0000000;
                GPIOB->AFR[0] |=  0x70000000;   /* PB7 for USART1 RX */

                // MODE: 00: Input mode, 01: General purpose output mode
                //       10: Alternate function mode, 11: Analog mode (reset state)
                GPIOB->MODER &= (unsigned int)~(0x3 << 6*2); // Clear bit PB6
                GPIOB->MODER |=  (0x2 << 6*2); // Set bit PB6 Alternate

                GPIOB->MODER &= (unsigned int)~(0x3 << 7*2); // Clear bit PB7
                GPIOB->MODER |=  (0x2 << 7*2); // Set bit PB7 Alternate


  RCC->APB2ENR |= 0x4000;           /* enable USART1 clock */

  USART1->CR1 = 0x000C;      /* enable Tx, Rx, 8-bit data */
  USART1->CR2 = 0x0000;      /* 1 stop bit */
  USART1->CR3 = 0x0000;      /* no flow control */
  USART1->BRR = 0x0023;                /* 115200 baud @ 16 MHz */
  USART1->CR1 |= 0x0001;     /* enable USART1 */

// ------------------------------------------------------------------
// Create the queue, storing the returned handle in the xQueue variable.

        QueueHandle_t xQueue;
        xQueue = xQueueCreate( QUEUE_LENGTH, QUEUE_ITEM_SIZE );

        if( xQueue != NULL ) {
                // Create two instances of the PRODUCER task
                // Tasks pass on the queue handle as the task parameter
                // Both instances of tasks are created at priority 1

                xTaskCreate( vSenderTask,
                                "Sender1",
                                100,
                                ( void * ) xQueue, // The queue handle is used as the task parameter.
                                1,
                                NULL
                        );
```

```
                xTaskCreate( vSenderTask, "Sender2", 100, ( void * ) xQueue, 1, NULL );

                // Create a CONSUMER task at priority 2
                xTaskCreate( vReceiverTask, "Receiver", 100, ( void * ) xQueue, 2, NULL );

                // Start the task executing
                vTaskStartScheduler();
        }

// Execution will only reach here if there was not enough FreeRTOS heap memory
// remaining for the idle task to be created

        while(1) {
        }

} // main() ends here


/*-----------------------------------------------------------*/
// Generate data stream
static void vSenderTask( void *pvParameters ) {

        portBASE_TYPE xStatus;
        MSGQUEUE_OBJ_t xMessage [2] = {
                        {'A', 11,2,3,4,5},
                        {'B', 16,7,8,9,0xa}
                };

        int i=0;

        // The queue handle is passed into this task as the task parameter.
        // Cast the parameter back to a queue handle.
        QueueHandle_t xQueue;
        xQueue = ( QueueHandle_t ) pvParameters;

        for( ;; ) {
                GPIOA->ODR ^= (0x1 << 5); //PA5 ON
                vTaskDelay( 100);


        // Send the message to the queue, waiting for 10 ticks for space to become
                // available if the queue is already full.

                i ^= 0x1; // update #msg index

                do {
                        xStatus = xQueueSendToBack( xQueue, &xMessage[ i ], 10 );
                } while ( xStatus != pdPASS );

// Allow the other sender task to execute.
                taskYIELD();
        }


} // Thread ends here
```

```
/*----------------------------------------------------------*/
// Pick up received messages
static void vReceiverTask( void *pvParameters ) {

		portBASE_TYPE xStatus;
		MSGQUEUE_OBJ_t xMessage;

		int i, mm;
		uint8_t data;

// The queue handle is passed into this task as the task parameter
		QueueHandle_t xQueue;
		xQueue = ( QueueHandle_t ) pvParameters;

		for( ;; ) {
				GPIOB->ODR ^= (0x1 << 14); //PB14 ON
				vTaskDelay( 100);

				// Wait for the maximum period for data to become available on the queue.
				xStatus = xQueueReceive( xQueue, &xMessage, 1000 ); // xTicksToWait = 1000

				if( xStatus == pdPASS ) {
						// xMessage now contains the received data.

						mm = sizeof(xMessage.msgData) /  sizeof(uint8_t);

						for (i=0; i< mm; i++) {
								data = xMessage.msgData[i];
								printf("%d ", data & 0xff); // // write to monitor
						}
				}

		}

} // Thread ends here


// ------------------------------------------------------------------
// The code below is the interface to the C standard I/O library.
// All the I/O are directed to the console, which is UART1.

FILE __stdout = {1};

/* Called by C library console/file output */
				int fputc(int ch, FILE *f) {

				while (!(USART1->ISR & 0x0080)) {}   // Wait until Tx buffer empty
				USART1->TDR = ch;

				return ch;
}
```

Task-3/b

This task is similar to Task-1.

This task uses “**freeRTOS_V2**” variant

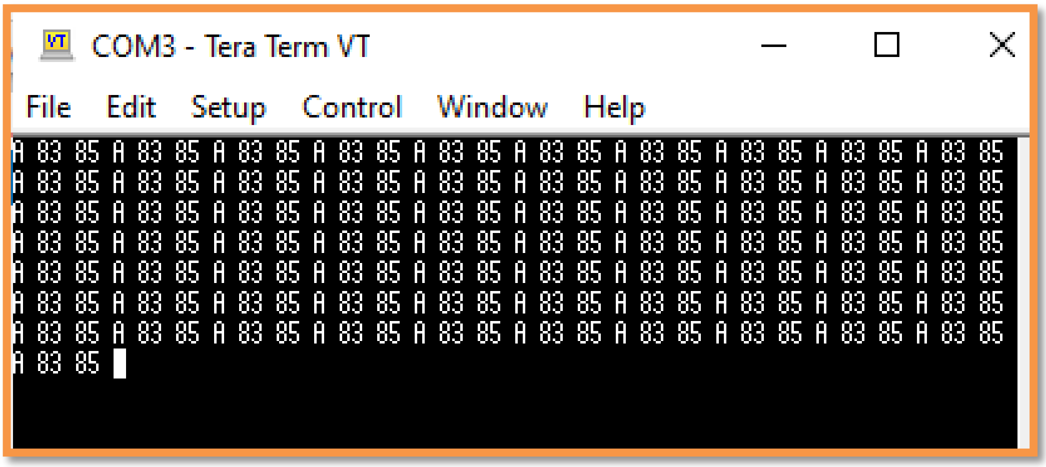
The given activities are synchronized through “**Queue**” functions.

Monitor Tera-Term Window to see the messages movement from sender to receiver blocks.

Procedure

- Create an empty folder
- Open a New Project
- Walk-through the necessary steps
- Create “**CMSIS freeRTOS-V2**” based Project Configuration

- Edit “main.c”
- Insert the sample code (listed below)
- Build / Flash download code / Run, and Monitor LEDs on the h/w board
- Monitor “Tera-Term” Window, the below shown messages should be there




```
// Example-1: RTOS based multitasking
// This lab uses "QUEUE" to synchronize the tasks.
// Monitor Tera-Term Window for the data movement
//
// Task 1 (PRODUCER) - Generates messages
// Task 2 (CONSUMER) - Displays data on “Tera-Term” window
//

#include "RTE_Components.h"          // Component selection
#include CMSIS_device_header
```

```
#include "FreeRTOS.h"              // Keil::RTOS:FreeRTOS:Core
#include "task.h"                  // Keil::RTOS:FreeRTOS:Core
#include <queue.h>

#include "stm32l4s5xx.h"

#include "cmsis_os2.h"                     // CMSIS RTOS header file

#include <stdio.h>

typedef struct {        // object data type
                        uint8_t Idx;
                        char Buf[5];
} MSGQUEUE_OBJ_t;


/*----------------------------------------------------------------------------
 *      Message Queue creation & usage
 *---------------------------------------------------------------------------*/

#define MSGQUEUE_OBJECTS 16                  // number of Message Queue Objects


osMessageQueueId_t mid_MsgQueue;             // message queue id

osThreadId_t tid_Thread_MsgQueue1;           // thread id 1
osThreadId_t tid_Thread_MsgQueue2;           // thread id 2

void Thread_MsgQueue1 (void *argument);       // thread function 1
void Thread_MsgQueue2 (void *argument);       // thread function 2

int Init_MsgQueue (void) {

  mid_MsgQueue = osMessageQueueNew(MSGQUEUE_OBJECTS, sizeof(MSGQUEUE_OBJ_t), NULL);
  if (mid_MsgQueue == NULL) {
    ; // Message Queue object not created, handle failure
  }

  tid_Thread_MsgQueue1 = osThreadNew(Thread_MsgQueue1, NULL, NULL);
  if (tid_Thread_MsgQueue1 == NULL) {
    return(-1);
  }

  tid_Thread_MsgQueue2 = osThreadNew(Thread_MsgQueue2, NULL, NULL);
  if (tid_Thread_MsgQueue2 == NULL) {
    return(-1);
  }

  return(0);
}

void Thread_MsgQueue1 (void *argument) {

          MSGQUEUE_OBJ_t msg = {0};

          msg.Idx = 'A';
          msg.Buf[0] = 83;
          msg.Buf[1] = 85;

  while (1) {
                        GPIOA->ODR ^= (0x1 << 5); //PA5 ON
                        vTaskDelay( 100);
```

```
                    osMessageQueuePut(mid_MsgQueue, &msg, 0U, 0U);

                    osThreadYield();       // Suspend thread for a system tick
 }

}

void Thread_MsgQueue2 (void *argument) {

          MSGQUEUE_OBJ_t msg = {0};

          osStatus_t status;

          char str_tmp[100] = {0};

 while (1) {
                    GPIOB->ODR ^= (0x1 << 14); //PB14 ON
                    vTaskDelay( 100);

  status = osMessageQueueGet(mid_MsgQueue, &msg, NULL, 0U);   // wait for message

  if (status == osOK) {
                              snprintf(str_tmp, sizeof(str_tmp), "%c %d %d \n", msg.Idx, msg.Buf[0], msg.Buf[1]);

                              int i=0;
                              while (str_tmp[i] != '\n') {

                                        while (!(USART1->ISR & 0x0080)) {}   // Wait until Tx buffer empty
                                                  USART1->TDR = str_tmp[i];

                                        i++; if (i > sizeof(str_tmp)) {i=0; break;}
                              }

  }

 }

}


// ******************************************************************
// Initialize FreeRTOS and start the initial set of tasks.
// ******************************************************************
int main(void) {

          // Enable the clock to GPIO Port A
          RCC->AHB2ENR |=  1;                  /* enable GPIOA clock */

          // MODE: 00: Input mode, 01: General purpose output mode
          //       10: Alternate function mode, 11: Analog mode (reset state)
          GPIOA->MODER &= (unsigned int)~(0x3 << 5*2); // Clear bit PA5
          GPIOA->MODER |=  (0x1 << 5*2); // Set bit PA5 Output


          // Enable the clock to GPIO Port B
          RCC->AHB2ENR |= 0x2; //RCC_AHB2ENR_GPIOB_EN;

          // MODE: 00: Input mode, 01: General purpose output mode
          //       10: Alternate function mode, 11: Analog mode (reset state)
          GPIOB->MODER &= (unsigned int)~(0x3 << 14*2); // Clear bit PB14
          GPIOB->MODER |=  (0x1 << 14*2); // Set bit PB14 Output
```

```
// ---------------------------------------------------------------------
// Configure USART1

                        // Enable the clock to GPIO Port B
                        RCC->AHB2ENR |= 0x2; //RCC_AHB2ENR_GPIOB_EN;

                        GPIOB->AFR[0] &= ~0x0F000000;
                        GPIOB->AFR[0] |=  0x07000000;   /* PB6 for USART1 TX */

                        GPIOB->AFR[0] &= ~0xF0000000;
                        GPIOB->AFR[0] |=  0x70000000;   /* PB7 for USART1 RX */

                        // MODE: 00: Input mode, 01: General purpose output mode
                        //       10: Alternate function mode, 11: Analog mode (reset state)
                        GPIOB->MODER &= (unsigned int)~(0x3 << 6*2); // Clear bit PB6
                        GPIOB->MODER |=  (0x2 << 6*2); // Set bit PB6 Alternate

                        GPIOB->MODER &= (unsigned int)~(0x3 << 7*2); // Clear bit PB7
                        GPIOB->MODER |=  (0x2 << 7*2); // Set bit PB7 Alternate


  RCC->APB2ENR |= 0x4000;          /* enable USART1 clock */

  USART1->CR1 = 0x000C;      /* enable Tx, Rx, 8-bit data */
  USART1->CR2 = 0x0000;      /* 1 stop bit */
  USART1->CR3 = 0x0000;      /* no flow control */
  USART1->BRR = 0x0023;                  /* 115200 baud @ 16 MHz */
  USART1->CR1 |= 0x0001;     /* enable USART1 */



                        // Start the task executing


                        Init_MsgQueue();


                        vTaskStartScheduler();


// Execution will only reach here if there was not enough FreeRTOS heap memory
// remaining for the idle task to be created

            while(1) {
            }



} // main() ends here
```

Task-4

Launch STM32CubeMX Development Tools

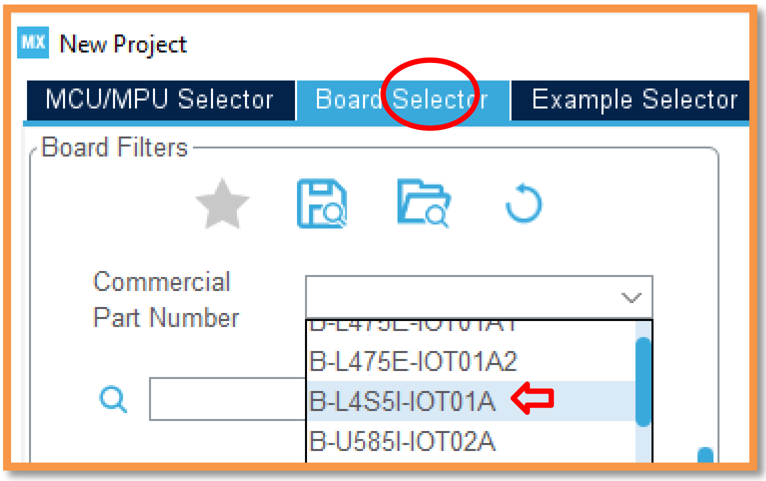
Double Click the Icon

THIS GRAPHICAL TOOL IS TO ASSIST THE EMBEDDED SYSTEM HARDWARE INITIALIZATION AND SETTING OF THE RELEVANT PARAMETERS WITHOUT A DIRECT ENGAGEMENT AT THE REGISTERS LEVEL. BASICALLY, THE LOW-LEVEL INITIALIZATION REMAINS HIDDEN FOR A SIMPLE, CLEAN, AND HASSLE FREE TASK IMPLEMENTATIONS (I.E., APPLICATION SPECIFIC CONFIGURATIONS).

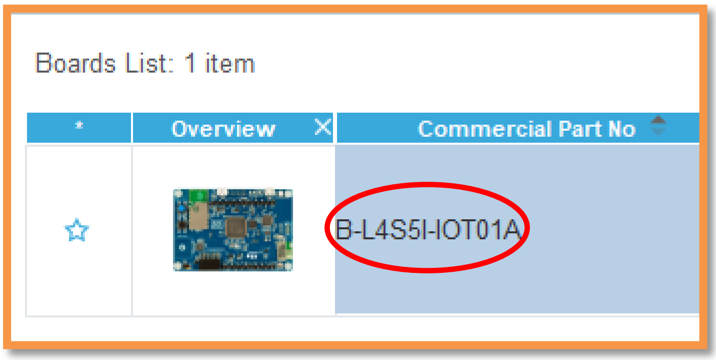
File → New Project

Select "**Hardware Platform**"

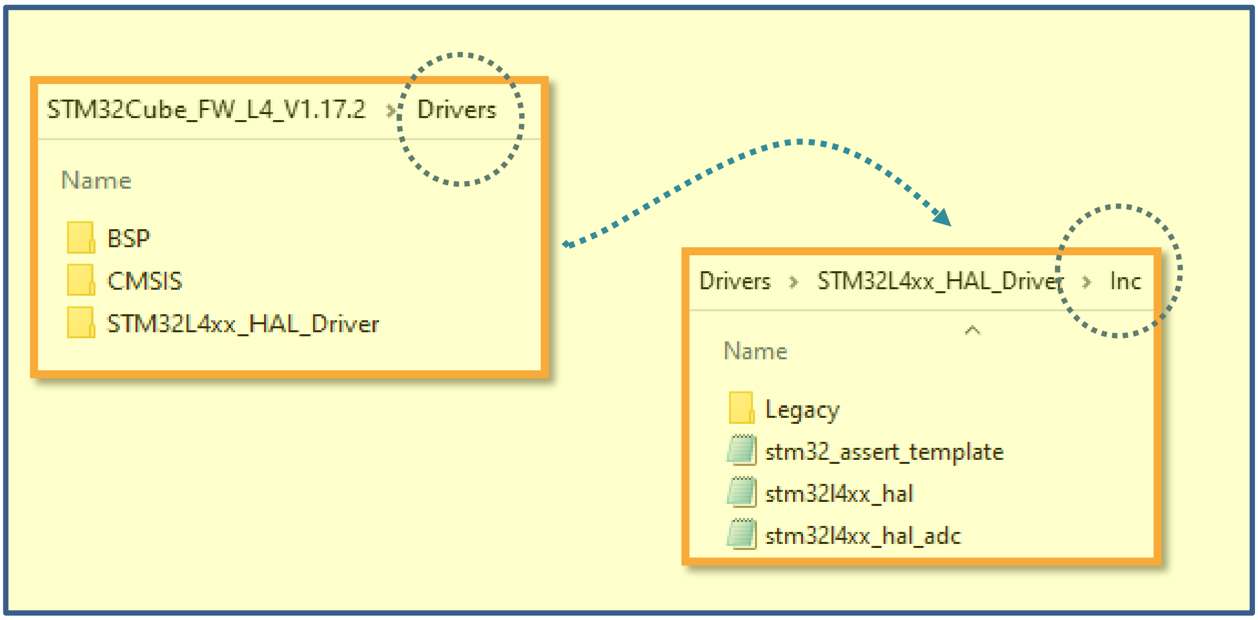
Board Selector



Select the "h/w board",

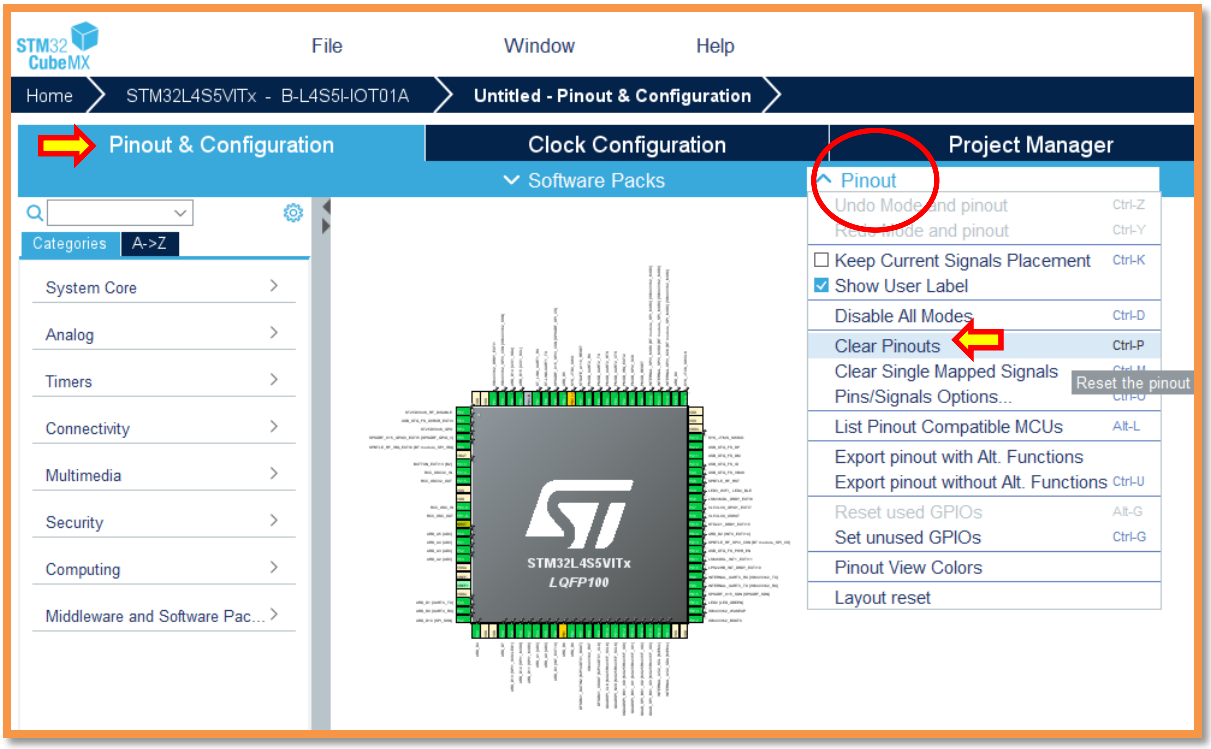


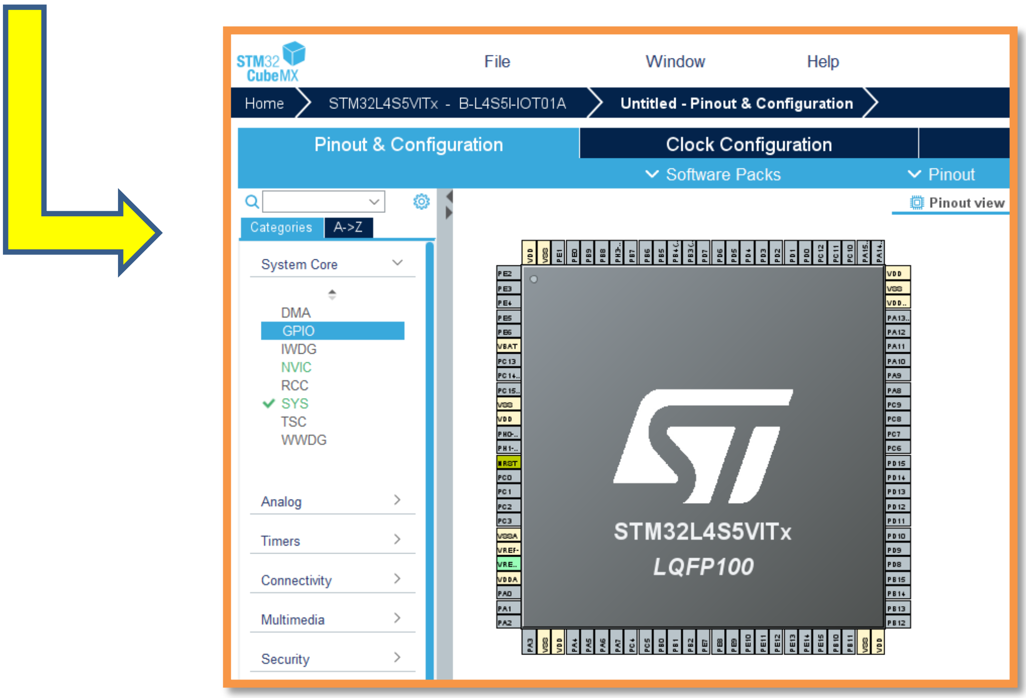
Click "Start Project"



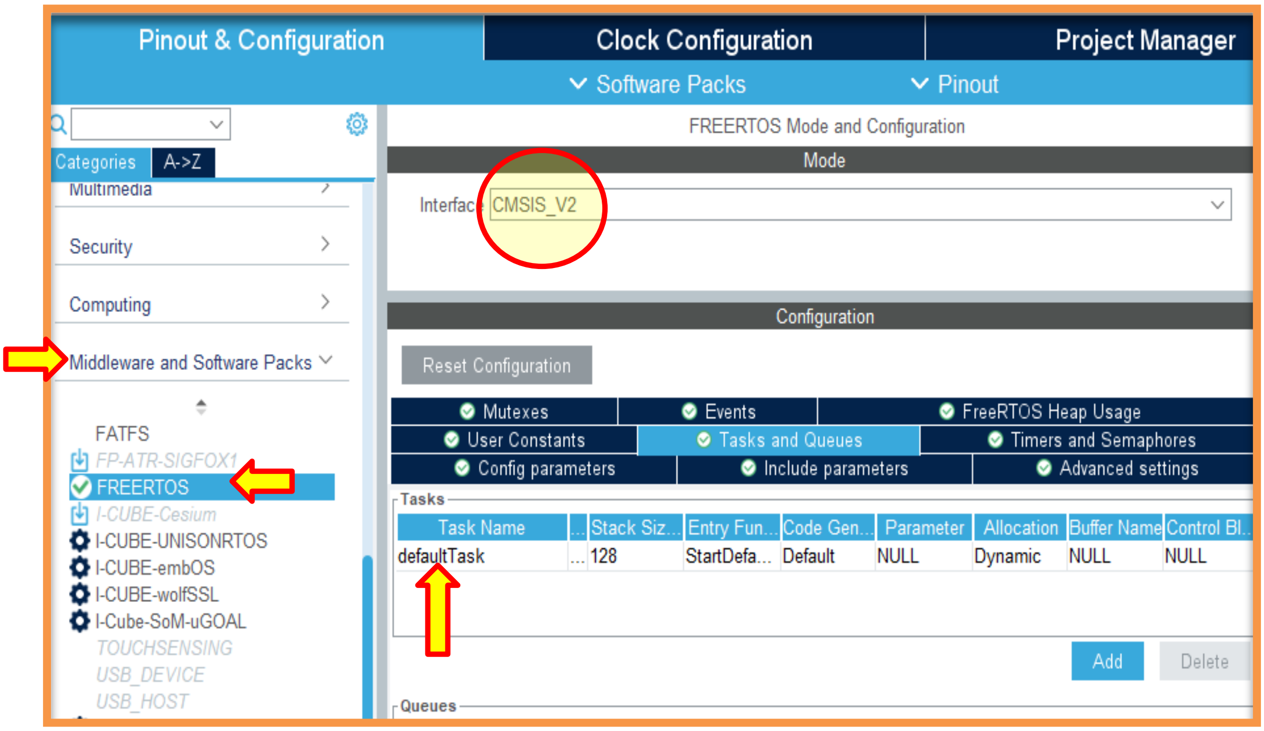
Reset “Preconfigured Pinout”

- **Select** “Pinout & Configuration”,
- **Click** “Pinout”
- **Right Click**, “Clear Pinouts”

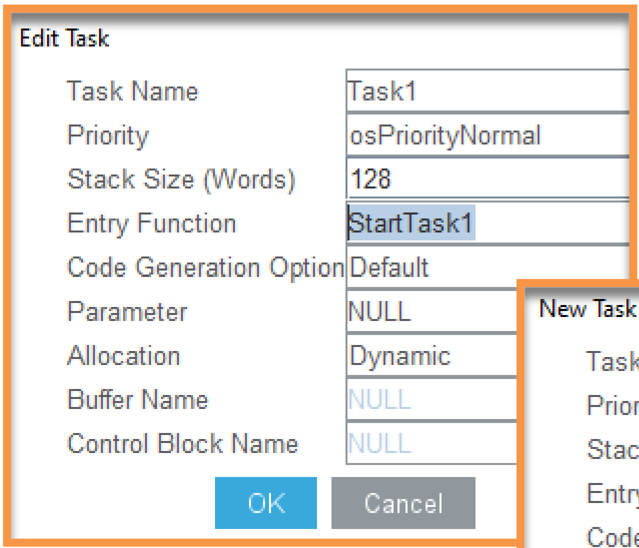


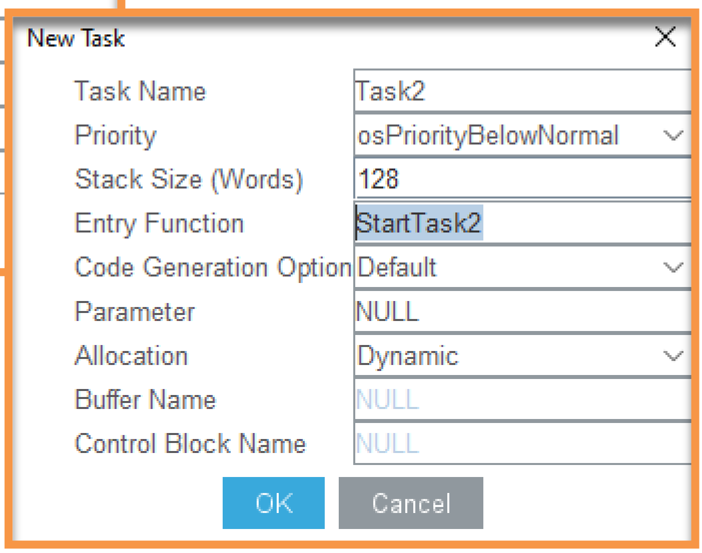


Configure FreeRTOS



Configure / Edit default Tasks

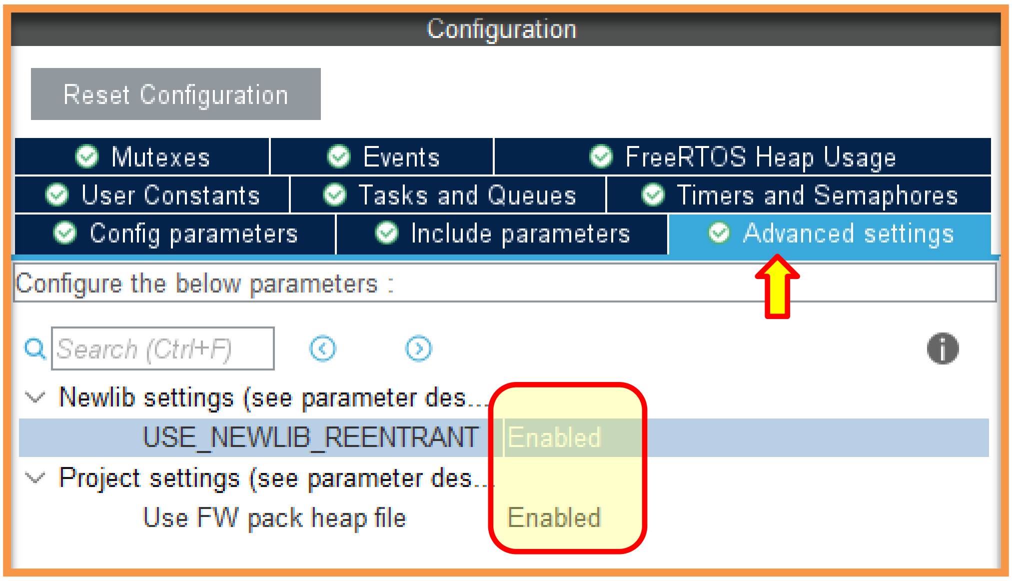




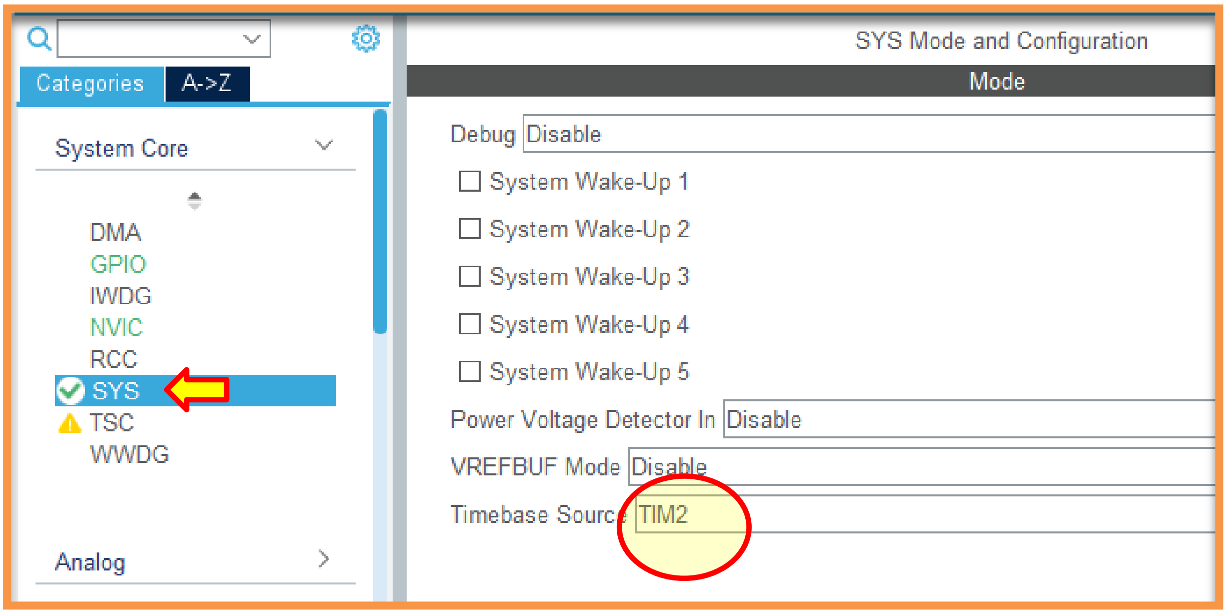
Add a **2nd** Task

- **Click** "Add"

Optional – Enable library (new version)



Choose Timer as the HAL Timebase Source (Instead of Systick)



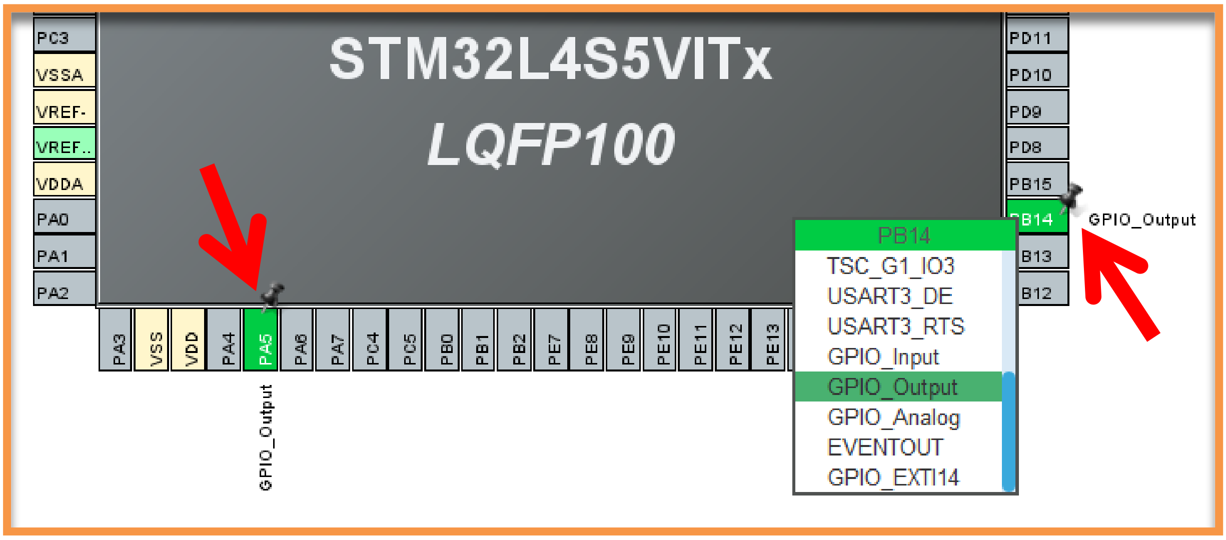
NOTE:

The **SysTick** is a special timer in most ARM processors that's generally reserved for operating system purposes. By default, SysTick will be used for things like HAL_Delay() and HAL_GetTick(). As a result, the STM32 HAL framework gives SysTick a very high priority. However, **FreeRTOS** needs SysTick for its scheduler, and it requires SysTick to be a much lower priority. **Therefore**, a quick work around is to use a **Timer** as a Time-base source in the cases of freeRTOS.

Click "Pinout and Configuration"

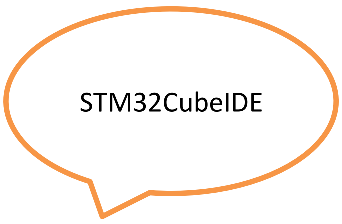
Right Click on "**PA5**", and declare it as a "**GPIO Output**" signal

Right Click on "**PB14**", and declare it as a "**GPIO Output**" signal



Click "Project Manager"

Click "Project"



Write "Project Name"

Select "Toolchain / IDE)

Click "Generate Code"

Open "Project" in "STM32CubeIDE"

Update "main.c"

```
void StartTask1(void *argument)
{
 /* USER CODE BEGIN 5 */
 /* Infinite loop */
 for(;;)
 {
        GPIOB->ODR ^= (0x1 << 14); //PB14 ON
        osDelay(100);
 }
 /* USER CODE END 5 */
}
```

```
void StartTask2(void *argument)
{
 /* USER CODE BEGIN StartTask2 */
 /* Infinite loop */
 for(;;)
 {
         GPIOA->ODR ^= (0x1 << 5); //PA5 ON
         osDelay(50);
 }
 /* USER CODE END StartTask2 */
}
```

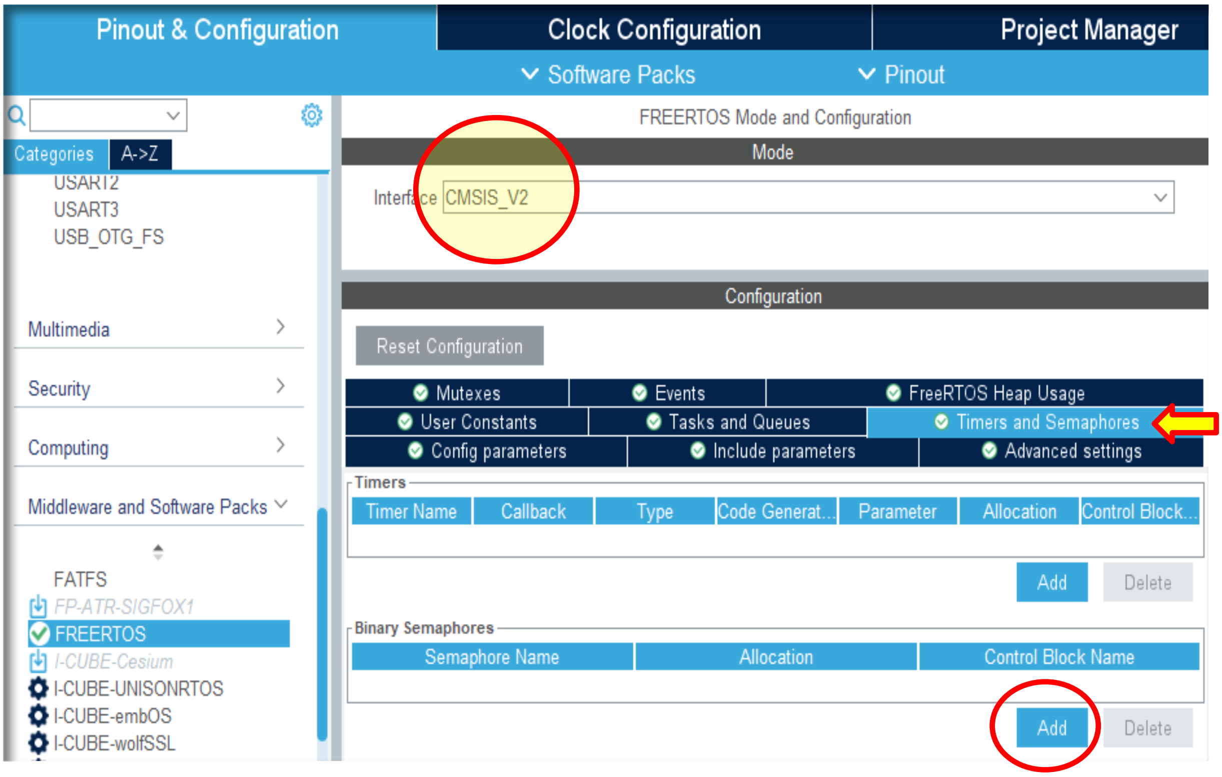
- **Build** "Project" (In STM32CubeIDE)
- **Flash** "binary code" on the h/w board (In STM32CubeProgrammer)
- **Reset h/w board (**By pressing switch/button on the board**)**
- **Monitor** "LEDS" toggling on the h/w board

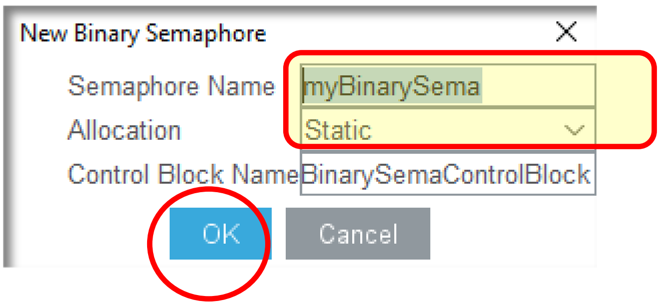
Reference

https://www.keil.com/pack/doc/CMSIS/RTOS2/html/group__CMSIS__RTOS__SemaphoreMgmt.html

Task-4/b

Add "Semaphore" feature (Continuation to previous task)





STM32CubeIDE

Click "Generate Code"

Open “Project” in “STM32CubeIDE”

Update “main.c”

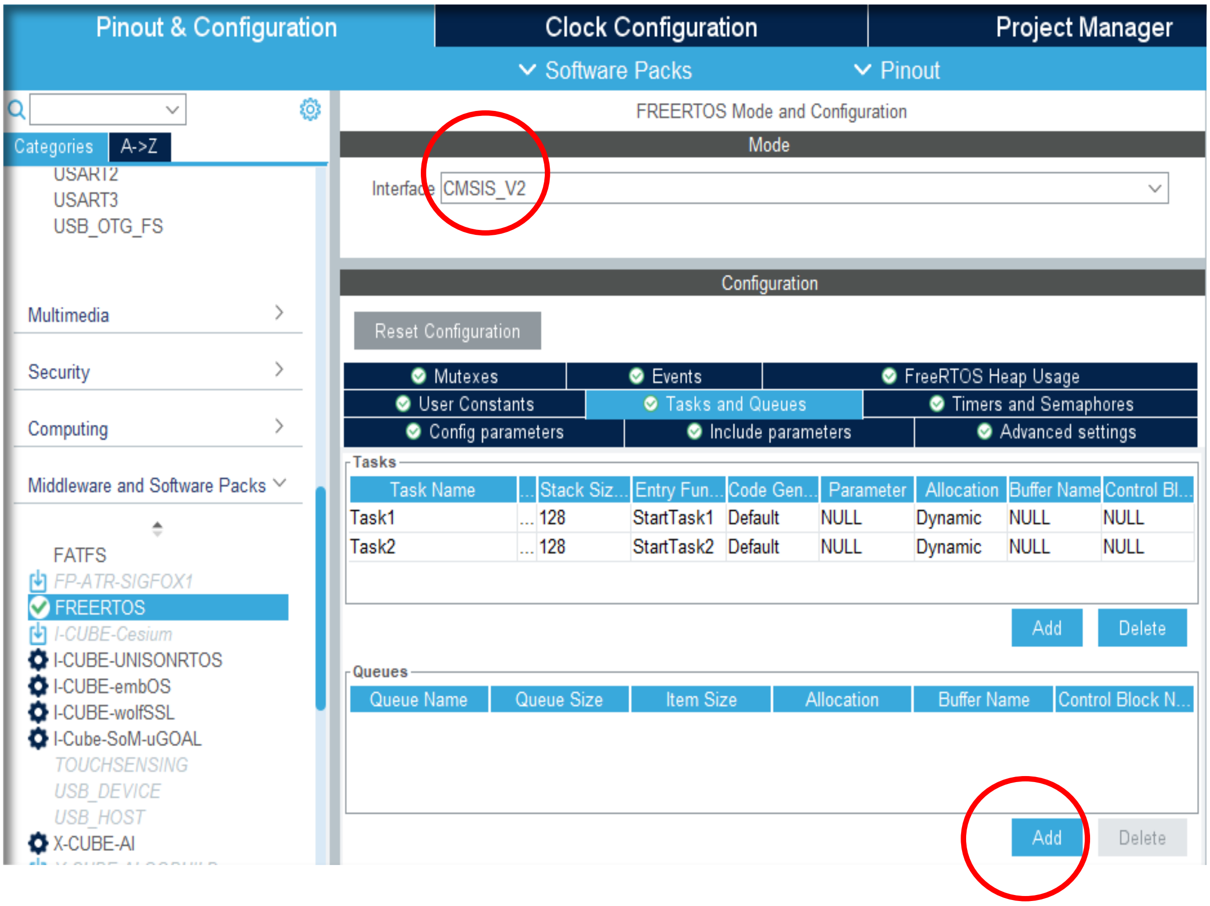
```
void StartTask1(void *argument)
{
  /* USER CODE BEGIN 5 */
  /* Infinite loop */
  for(;;)
  {
	osSemaphoreRelease(myBinarySemaHandle);

	GPIOB->ODR ^= (0x1 << 14); //PB14 ON
	osDelay(100);

  }
  /* USER CODE END 5 */
}
```

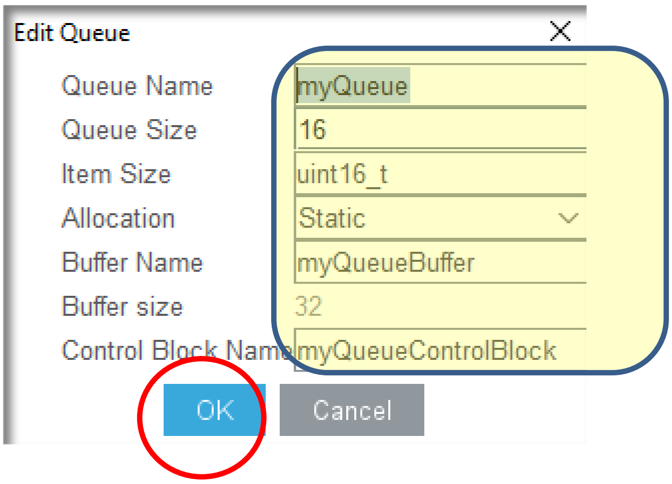
```
void StartTask2(void *argument)
{
  /* USER CODE BEGIN StartTask2 */
  /* Infinite loop */
  for(;;)
  {
	osSemaphoreAcquire(myBinarySemaHandle, osWaitForever);

	GPIOA->ODR ^= (0x1 << 5); //PA5 ON

  }
  /* USER CODE END StartTask2 */
}
```

- **Build** “Project” (In STM32CubeIDE)
- **Flash** “binary code” on the h/w board (In STM32CubeProgrammer)
- **Reset h/w board (**By pressing switch/button on the board**)**
- **Monitor** “LEDS” toggling on the h/w board

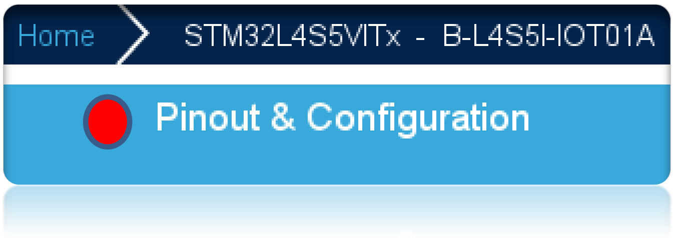
Task-4/c

Add "Queue" feature (Continuation to previous task)

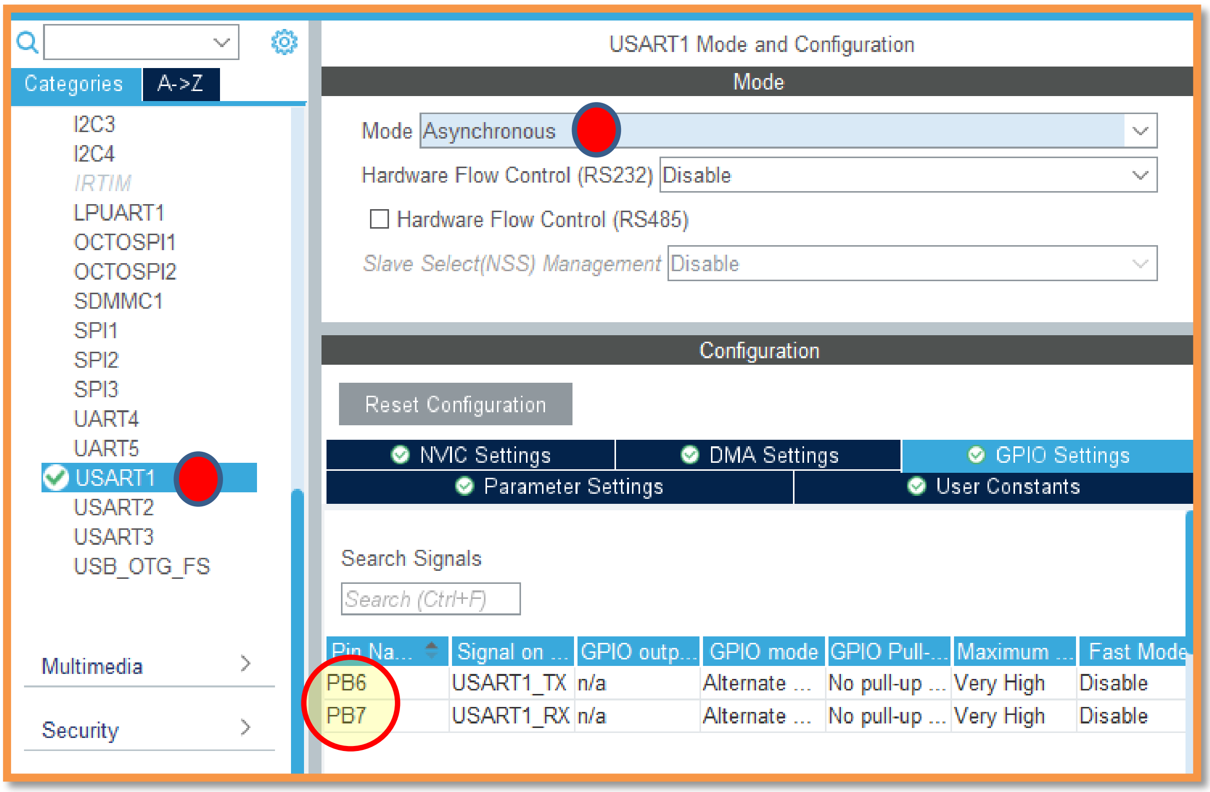


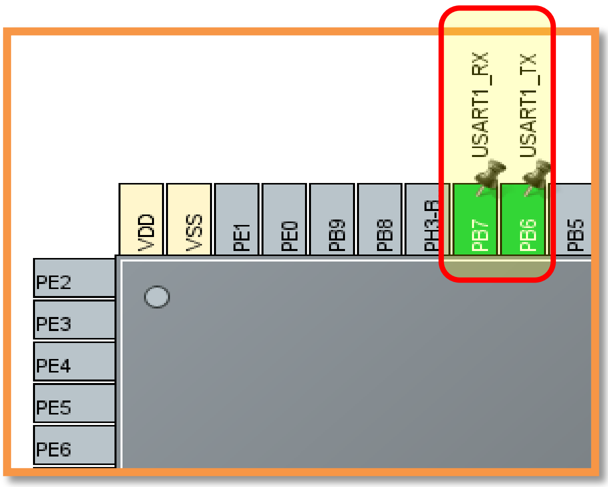


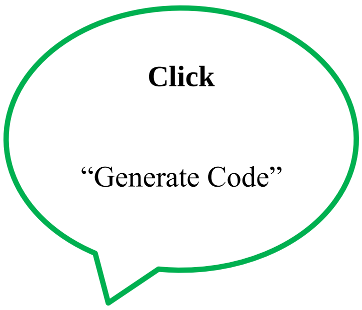
Add "UART1" feature



Configure USART Pins







Open “Project” in “STM32CubeIDE”

Update “main.c”

```
#include <stdio.h>

typedef struct {   // object data type
  uint8_t Buf[32];
  uint8_t Idx;
} MSGQUEUE_OBJ_t;
```

```
void StartTask1(void *argument)
{
        MSGQUEUE_OBJ_t msg;

        while (1) {
                GPIOB->ODR ^= (0x1 << 14); //PB14 ON
                osDelay(100);

                msg.Buf[0] = 0x55U;           // do some work...
                msg.Idx    = 0U;
                osMessageQueuePut(myQueueHandle, &msg, 0U, 0U);
                osThreadYield();   // suspend thread
        }

}
```

```
void StartTask2(void *argument)
{
        char str_tmp[100] = "";       // To display formatted messages

        MSGQUEUE_OBJ_t msg;
        osStatus_t status;

        while (1) {
        status = osMessageQueueGet(myQueueHandle, &msg, NULL, 0U);   // wait for message

                if (status == osOK) {
                        GPIOA->ODR ^= (0x1 << 5); //PA5 ON
                        osDelay(50);

                        snprintf(str_tmp,100," %d \n\r", msg.Buf[0]);
                        HAL_UART_Transmit(&huart1,( uint8_t * )str_tmp,sizeof(str_tmp),1000);
                }

        }
}
```

- **Build** “Project” (In STM32CubeIDE)

- **Flash** “binary code” on the h/w board (In STM32CubeProgrammer)

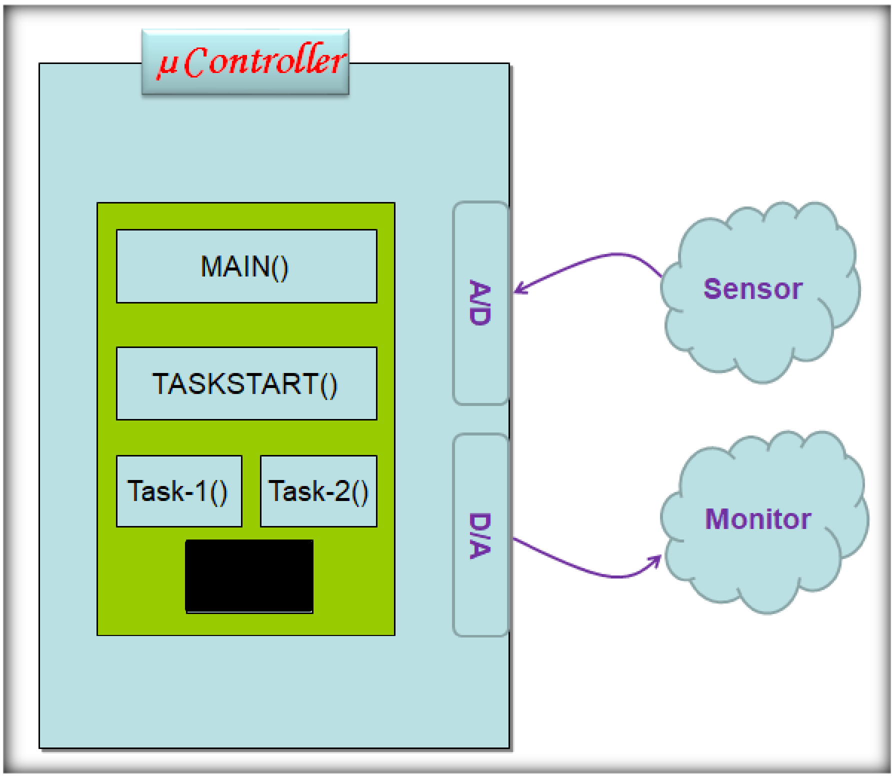
- **Reset h/w board (**By pressing switch/button on the board**)**

- **Monitor** “LEDS” toggling on the h/w board and “Tera-Term” Console window for the messages

Exercise

This task demonstrates how to:

- Configure GPIO ports
- Create multiple Tasks in RTOS (Free RTOS)
- Generate A/D data (Task 1)
- Generate D/A data (Task 2)



Construct a C program to demonstrate and verify the design behaviour.

Review Questions

Q1.

Q2

Q3