Experiment 1

Laboratory Hardware and Tools

Each day, our lives become more dependent on ‘embedded systems’, digital information technology that is embedded in our environment. Try making a list and counting how many devices with embedded systems you use in a typical day. Here are some examples: if your clock radio goes off, and you hit the snooze button a few times in the morning, the first thing you do in your day is interact with an embedded system. Heating up some food in the microwave oven and making a call on a cell phone also involve embedded systems. That is just the beginning. Here are a few more examples: turning on the television with a hand held remote, playing a hand held game, using a calculator, and checking your digital wristwatch. All those are embedded systems devices that you interact with.

Exponentially increasing computing power, ubiquitous connectivity and the convergence of technology have resulted in hardware/software systems being embedded within everyday products and places. The last few years has seen a renaissance of hobbyists and inventors building custom electronic devices. These systems utilize off-the-shelf components and modules whose development has been fueled by a technological explosion of integrated sensors and actuators that incorporate much of the analog electronics which previously presented a barrier to system development by non-engineers. Microcontrollers with custom firmware provide the glue to bind sophisticated off-the-shelf modules into complex custom systems.

What are Embedded Systems?

Embedded systems are combination of hardware and software combined together to perform a dedicated task. Usually, they are used to control a device, a process or a larger system. Some examples of embedded systems include those controlling the structural units of a car, the automatic pilot and avionics of aircraft, telematic systems for traffic control, the chipset and software within a set-top box for digital TV, a pacemaker, chips within telecommunication switching equipment, ambient devices, and control systems embedded in nuclear reactors. The block diagram of embedded system is shown in Figure 1.1

Lab Objective

Development of an embedded system requires that combination of both hardware and software components should perform their assigned tasks under the predefined circumstances. This lab provides a series of experiments aimed at teaching hardware interfacing and embedded

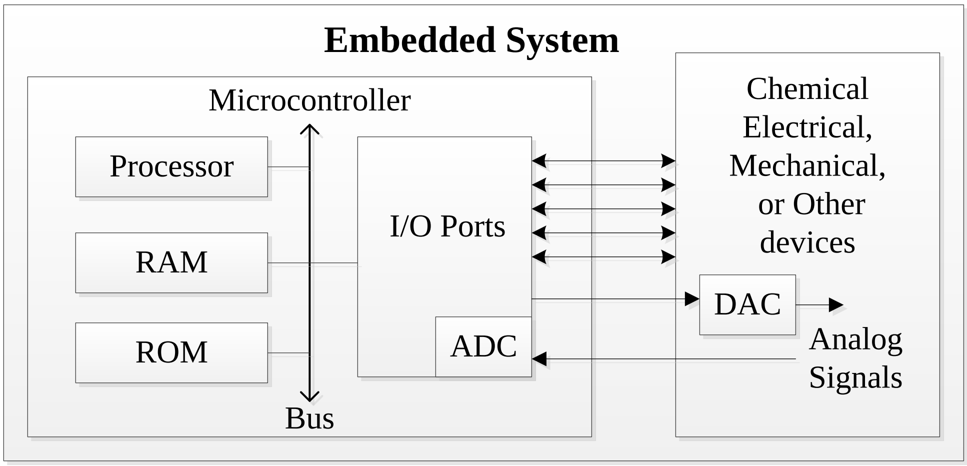


Figure 1.1: Block diagram of an embedded system

programming skills. We follow the bottom up approach by starting with simpler tasks and gradually building on that to develop a complete embedded system.

Prerequisites for Lab

This lab is designed for the students having some experience in 'C' programming, but no prior experience with embedded systems. In this lab, we assume that you have basic understanding of digital logic design and analog electronics.

Hardware Required

Hardware required for the experiments in this lab is listed below:

1. Stellaris Launchpad Board based on LM4F120H5QR microcontroller
2. Expansion Board based on different electronic components required to perform lab assignments.

Stellaris Launchpad Board

The key component used in the tutorials is the Stellaris Launchpad board produced by Texas Instruments (TI). The board, illustrated in Figure 1.2, includes a user configurable LM4F120H5QR micro-controller with 256 KB flash and 32 KB RAM as well as integrated circuit debug interface (ICDI). With appropriate software running on the host it is possible to connect to the LM4F120 processor to download, execute and debug user code.

In Figure 1.2, there is a horizontal white line slightly above the the midpoint. Below the line are the LM4120H5QR, crystal oscillators, user accessible RGB LED, user accessible push-buttons and a reset push button. Above the line is the hardware debugger interface including a 3.3V

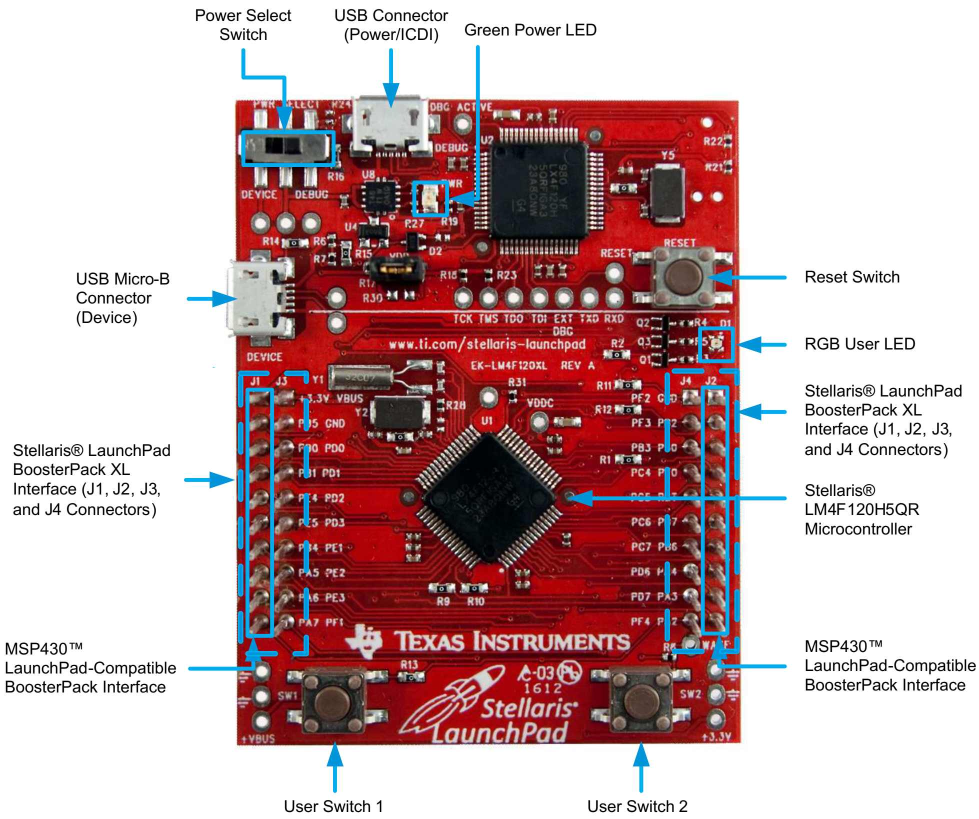


Figure 1.2: Launchpad Board

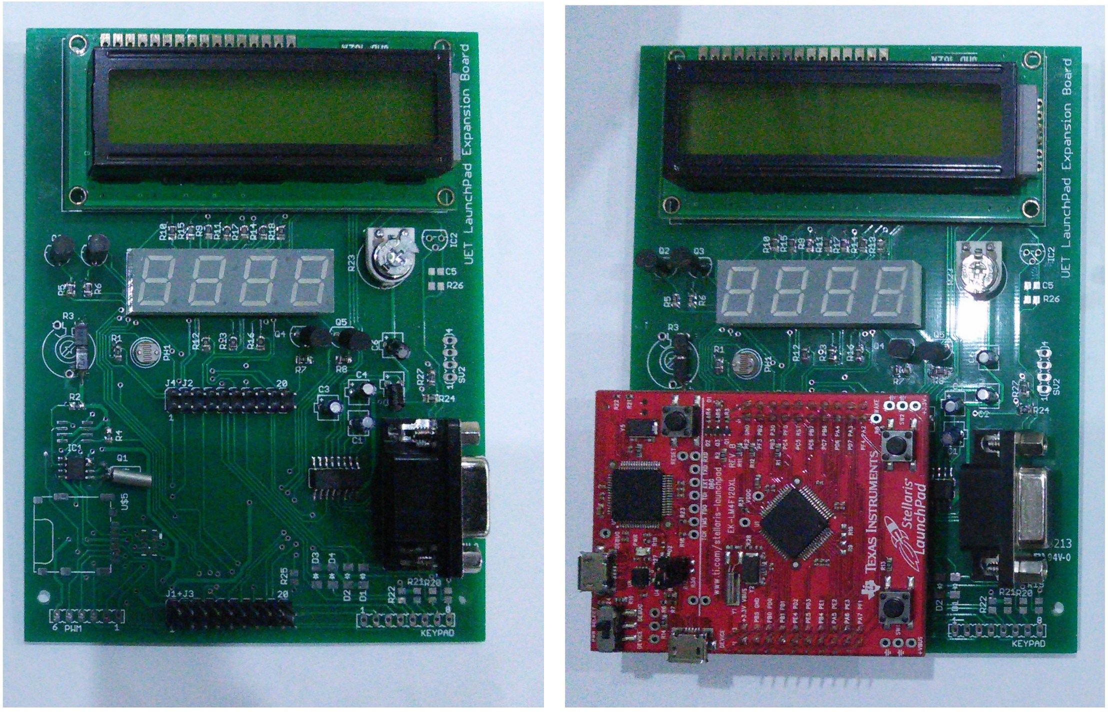
voltage regulator and other components. The regulator converts the 5V supplied by the USB connection to 3.3V for the processors and also available at the board edge connectors.

All the pins of Stellaris Launchpad are brought out to well labeled headers as we shall see the pin labels directly correspond to the logical names used throughout the documentation rather than the physical pins associated with the particular part/package used. This use of logical names is consistent across the family and greatly simplifies the task of designing portable software.

The LM4F120H5QR is a member of the Stellaris processors and offers 80 MHz Cortex-M4 processor with FPU, a variety of integrated memories and multiple programmable GPIO. This board provides far more computation and I/O horsepower than is required for the tasks performed in the lab. Furthermore, the LM4F120H5QR microcontroller is code-compatible to all members of the extensive Stellaris family, providing flexibility to fit precise needs.

Expansion Board

The headers on the Launchpad can be used to connect the external peripherals and electronic devices to develop a custom application. Like other expansion boards, we designed our own expansion board for Stellaris Launchpad to explore different applications that our MCU can support. This board helps students get familiar with different peripherals of MCU by interacting with simple electronic components like seven segment display, 16x2 character LCD, temperature sensor (LM35), analog potentiometer, MAX232 and DB9 connector for interfacing UART using



(a) UET Launchpad expansion board (b) Launchpad mounted on expansion board

Figure 1.3: UET Launchpad Expansion board

level shifter, real time clock (DS1307) for I2C interfacing. Figure 1.3 shows the expansion board with and without launchpad mounted on it

Stellaris LM4F Series Overview

The LM4F120 microcontrollers are based on the ARM Cortex-M4 core. The Cortex-M4 differs from previous generations of ARM processors by defining a number of key peripherals as part of the core architecture including interrupt controller, system timer and, debug and trace hardware (including external interfaces). This additional level of integration means that system software such as real-time operating systems and hardware development tools such as debugger interfaces can be common across the family of processors.

The LM4F microcontroller provides a wide range of connectivity features such as CAN, USB Device, SPI/SSI, I2C, UARTs. It supports high performance analog integration by providing two 1MSPS 12-bit ADCs and analog and digital comparators. It has best-in-class power consumption with currents as low as 370μA/MHz, 500μs wakeup from low-power modes and RTC currents as low as 1.7μA. This Stellaris series offers a solid road map with higher speeds, larger memory and ultra low currents.

Feature	Description
Core	ARM Cortex-M4F processor core
Performance	80-MHz operation; 100 DMIPS performance
Flash	256 KB single-cycle Flash memory
System SRAM	32 KB single-cycle SRAM
EEPROM	2KB of EEPROM
Internal ROM	Internal ROM loaded with StellarisWare® software
Communication Interfaces	
Universal Asynchronous Receivers/Transmitter (UART)	Eight UARTs
Synchronous Serial Interface (SSI)	Four SSI modules
Inter-Integrated Circuit (I^2C)	Four I^2C modules with four transmission speeds including high-speed mode
Controller Area Network (CAN)	CAN 2.0 A/B controllers
Universal Serial Bus (USB)	USB 2.0 Device
System Integration	
Micro Direct Memory Access (μDMA)	ARM® PrimeCell® 32-channel configurable μDMA controller
General-Purpose Timer (GPTM)	Six 16/32-bit GPTM blocks and six 32/64-bit Wide GPTM blocks
Watchdog Timer (WDT)	Two watchdog timers
Hibernation Module (HIB)	Low-power battery-backed Hibernation module
General-Purpose Input/Output (GPIO)	Six physical GPIO blocks
Analog Support	
Analog-to-Digital Converter (ADC)	Two 12-bit ADC modules with a maximum sample rate of one million samples/second
Analog Comparator Controller	Two independent integrated analog comparators
Digital Comparator	16 digital comparators
JTAG and Serial Wire Debug (SWD)	One JTAG module with integrated ARM SWD
Package	64-pin LQFP
Operating Range	Industrial (-40°C to 85°C) temperature range

Figure 1.4: Stellaris LM4F120H5QR Microcontroller Features

LM4F120H5QR Microcontroller Overview

The Stellaris LM4F120H5QR microcontroller combines complex integration and high performance with the features shown in Figure 1.4.

The Cortex-M4 core architecture consists of a 32-bit processor with a small set of key peripherals. The Cortex-M4 core has a Harvard architecture meaning that it uses separate interfaces to fetch instructions and data. This helps ensure the processor is not memory starved as it permits accessing data and instruction memories simultaneously. From the perspective of the CM4, everything looks like memory it only differentiates between instruction fetches and data accesses. The interface between the Cortex-M4 and manufacturer specific hardware is through three memory buses ICode, DCode, and System which are defined to access different regions of memory.

The block diagram of Stellaris Launchpad evaluation board in Figure 1.5 gives an overview of how the Stellaris ICDI and other peripherals are interfaced with microcontroller.

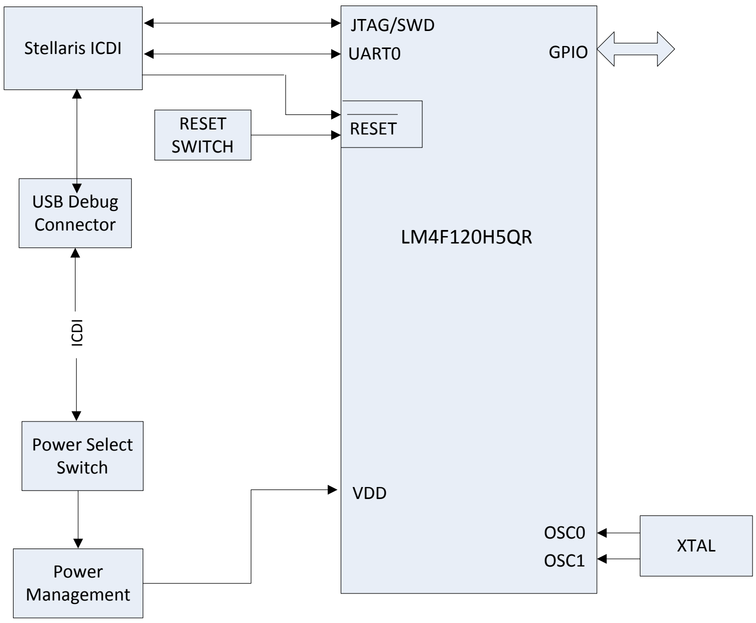


Figure 1.5: Block Diagram of Stellaris Launchpad Board

	mentor embedded	IAR SYSTEMS	ARM KEIL	Code Composer Studio
Eval Kit License	**30-day full function. Upgradeable**	**32KB code size limited. Upgradeable**	**32KB code size limited. Upgradeable**	**Full function. Onboard emulation limited**
Compiler	**GNU C/C++**	**IAR C/C++**	**RealView C/C++**	**TI C/C++**
Debugger / IDE	**gdb / Eclipse**	**C-SPY / Embedded Workbench**	**µVision**	**CCS/Eclipse-based suite**

Figure 1.6: Stellaris Development Tools

Stellaris Development Tools

To develop an application and run it on Stellaris Launchpad, a software is required to write our code, debug it and download it to the device. Fortunately, many IDEs are available for the application development of Stellaris Launchpad. Figure 1.6 shows different IDEs available for Stellaris development. In this lab, we will use Sourcery Codebench as our development tool.

Setup Keil μVision to Write Code

1. Run the software by clicking the icon on desktop, if available, or by clicking on **Start** $\rightarrow$ **All Programs** $\rightarrow$**Keil** μ**Vision**. An interface similar to one shown in Figure 1.7 will open.

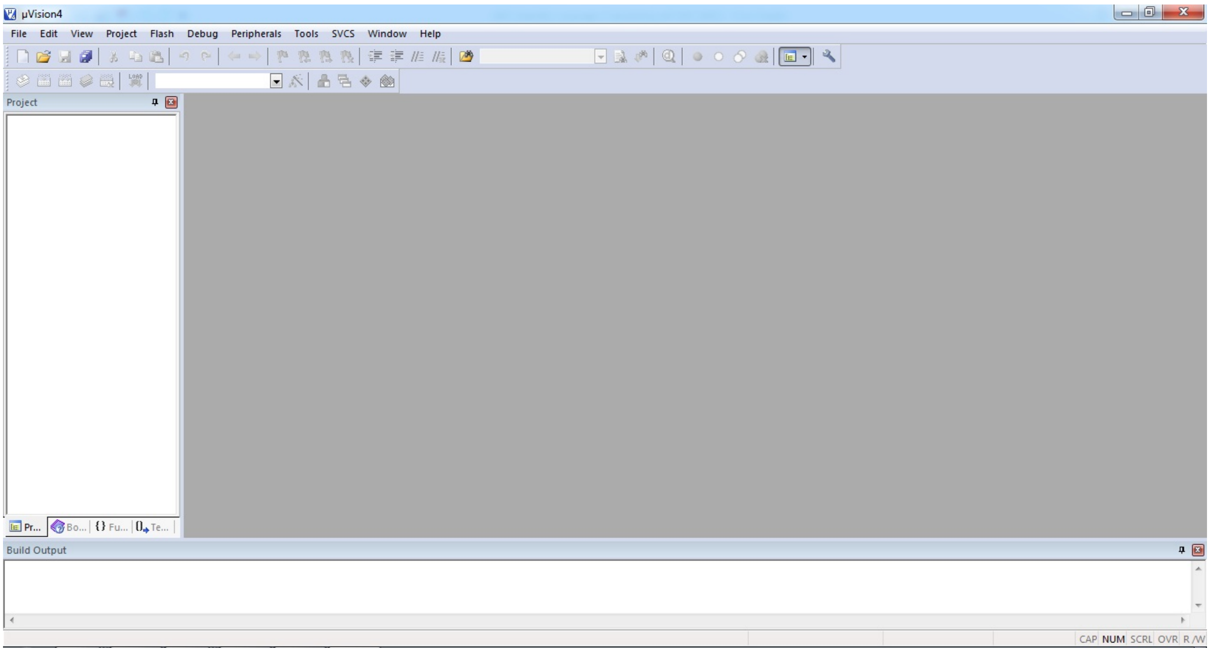


Figure 1.7: Keil interface on start

2. Click on *Project* tab and choose **New** μ**Vision Project** from the drop-down list as shown in Figure 1.8

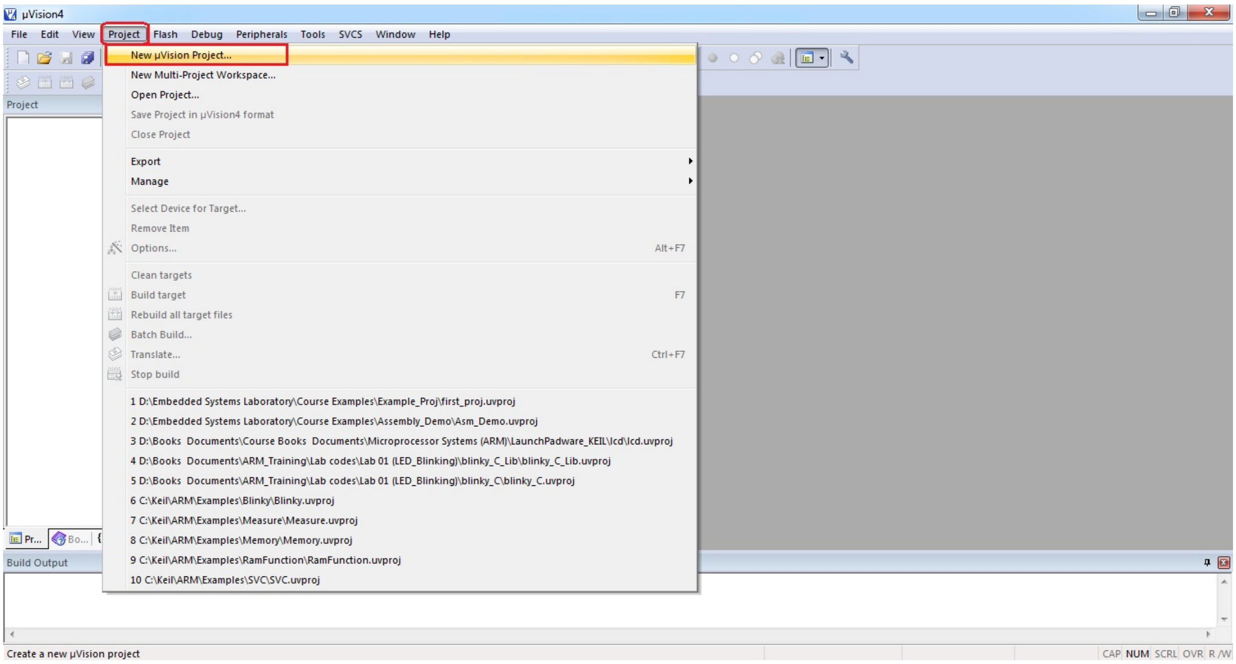


Figure 1.8: Create new μVision project

3. Select and create a directory, then assign a name to your project (project name can be different from folder name) then click on **Save**. **Do not make a directory, file or project name with a space in it**. A space will prevent simulation from working properly.

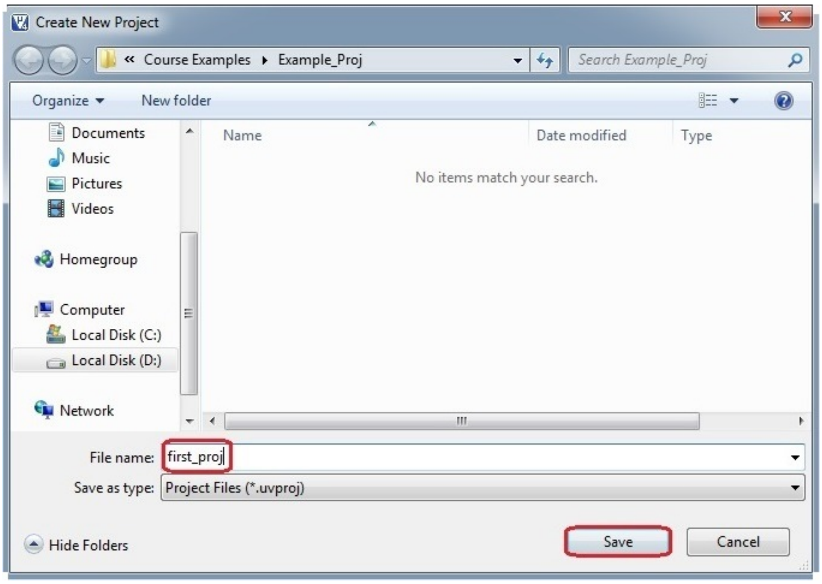


Figure 1.9: Type the name of the project in Keil and save it

4. To select a microcontroller double click on *Texas Instruments* and select **TM4C1233H6PM**. Click *OK*.(See Figure 1.10 and 1.11)

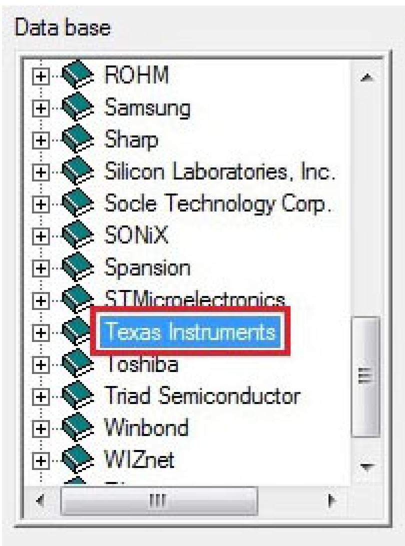


Figure 1.10: Select the manufacturer of your microcontroller

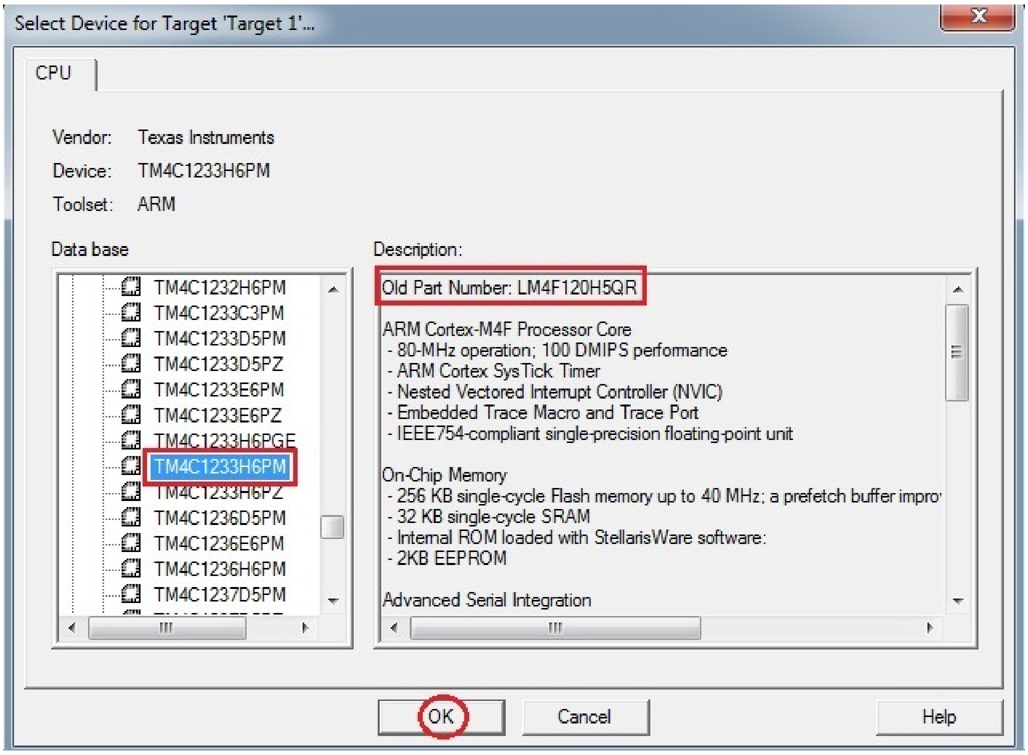


Figure 1.11: Select the part number for your microcontroller

5. When prompted to copy **'Startup_TM4C123.s to project folder'** click on *Yes* or *No* according to the requirement of your project.

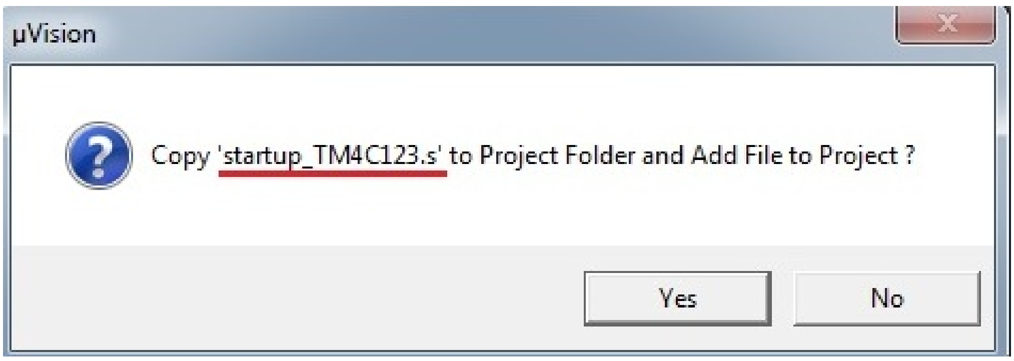


Figure 1.12: Add or discard the startup file to the project

6. Right click on *Source Group 1* under *Target 1*, click on **Add New Item to Group 'Source Group 1'...** and elect the type of file you want to add (**.s** for assembly and **.c** for C file), write its name in given space and click *OK*. (See Figure 1.13 and 1.14)

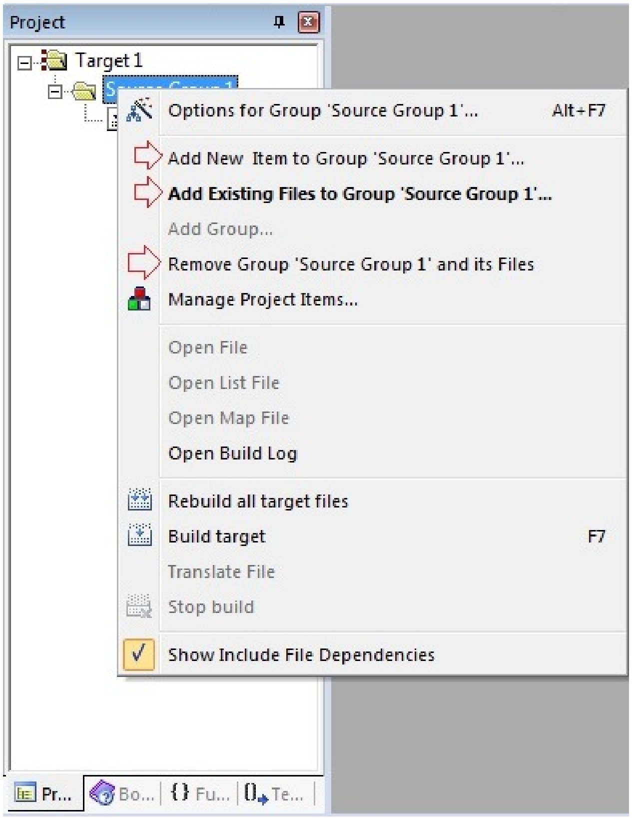


Figure 1.13: Add new file to the project

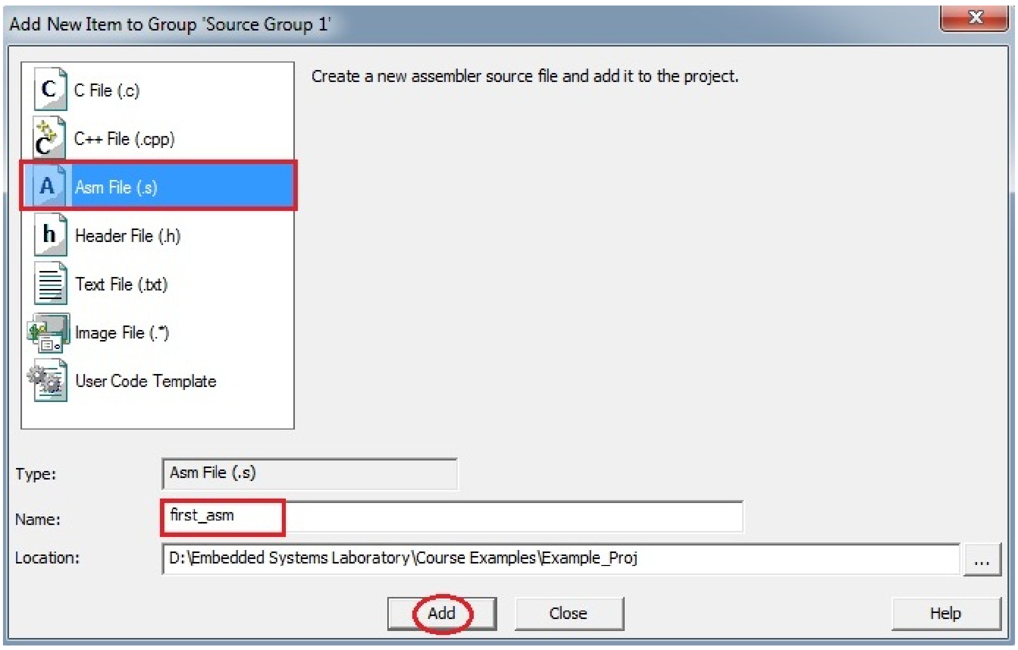


Figure 1.14: Select file type and save the new file

7. Double click on the file name under *Source Group 1* in *Project* window to open it in the editor pane. Here, you can write and edit the code.

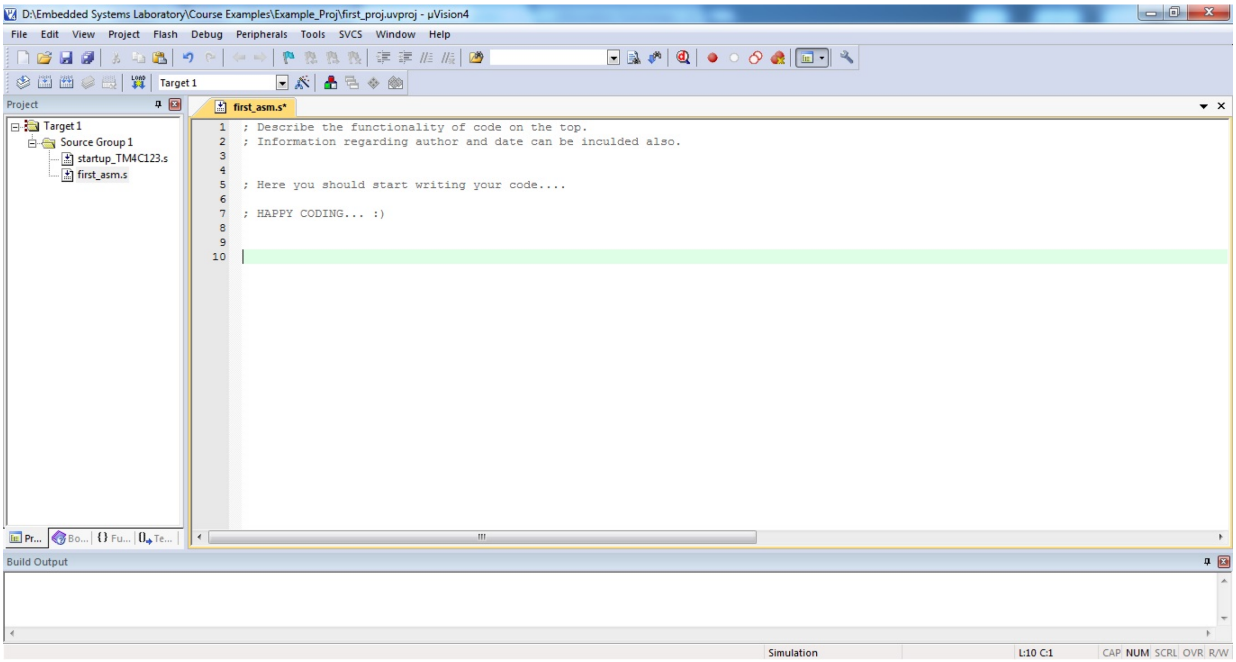


Figure 1.15: Edit the file in the text editor window

8. Next step after writing the code is to build your code. As shown in Figure 1.16 click on *Project* menu and select *Build Target* from the drop down list. You can also build your project by clicking *Build* button in *Build bar*. *Build Output* window at displays the errors, warning and build messages during build process. Double-click a message to open the corresponding source file. *Build* button translates modified or new source files and generates the executable file. The *Rebuild* command translates all source files regardless of modifications. *Simulation* highlighted at the bottom signifies that we are not downloading our code on hardware.

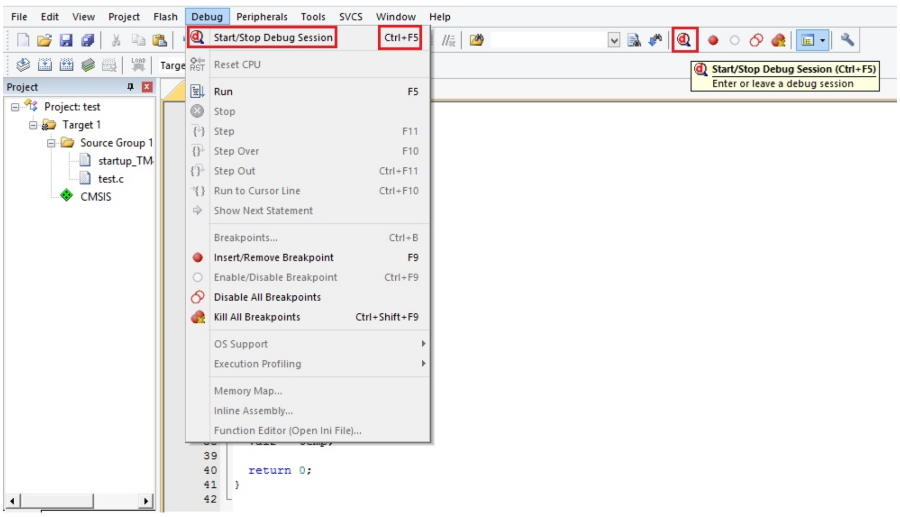


Figure 1.16: Build the project

9. After successsfully building the code, you can run the program through the *Debug* menu. As shown in Figure 1.17 select the *Start/Stop Debug Session* option from the debug menu

or press the debug button. Click on "OK" for the pop up window showing "EVALUATION MODE, Running with Code Size Limit: 32K".

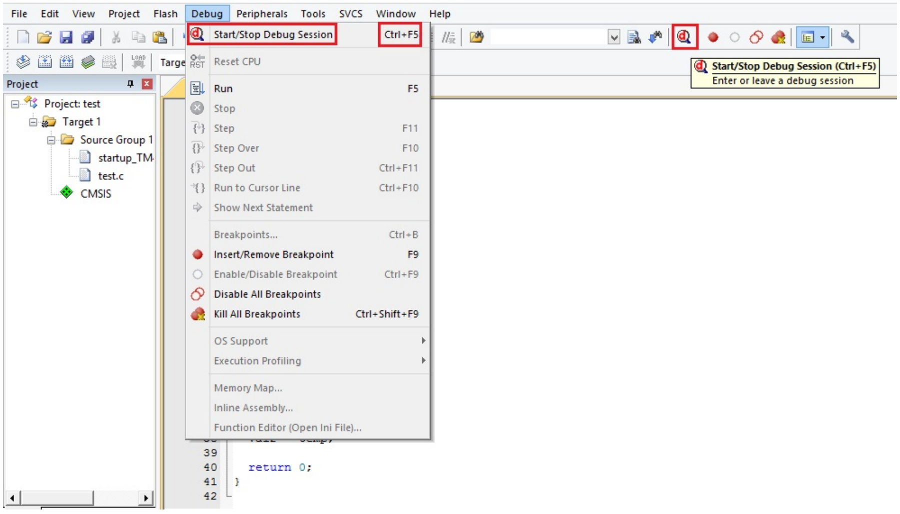


Figure 1.17: Build the project

10. Open your uVision to full screen to have a better and complete view. In Figure 1.18 the left hand side window shows you the registers and the right side window shows the program code. There are some other windows open. You may adjust the size of them to see better. Run the program step by step as shown in, you can observe the change of the values in the registers. Click on the *Start/Stop Debug Session* again to stop executing the program.

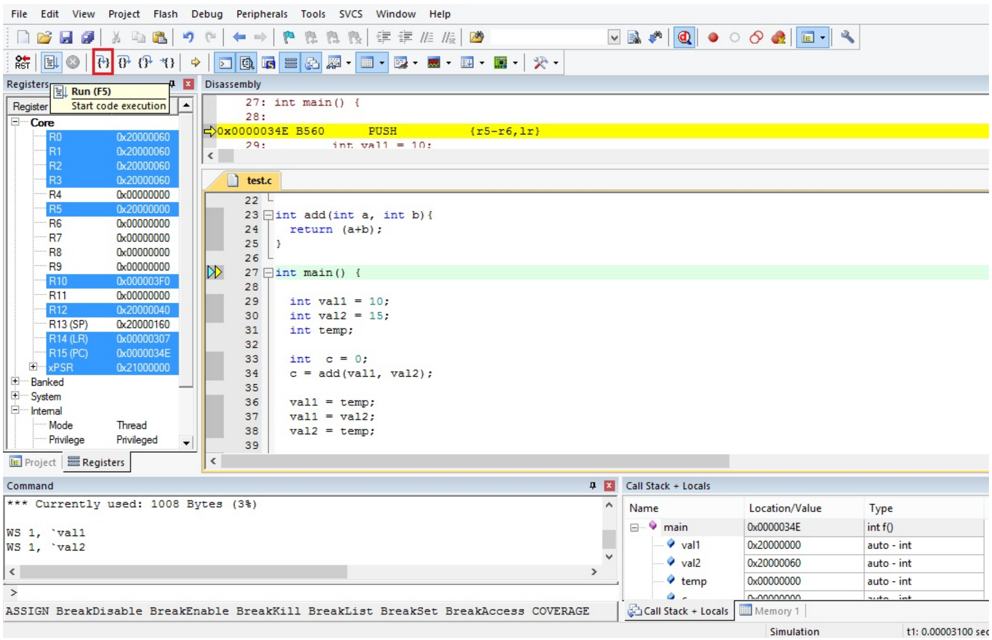


Figure 1.18: Debug window in Keil