This laboratory assignment accompanies the book, This laboratory assignment accompanies the book, [*Embedded Systems: Real-Time Interfacing to ARM Cortex M Microcontrollers, ISBN-13: 978-1463590154*](https://www.amazon.com/Embedded-Systems-Real-Time-Interfacing-Microcontrollers/dp/1463590156), by Jonathan W. Valvano, copyright © 2021.

**Goals** • Build and test an embedded system.

**Review**  • none

**Starter files** • none

**Team size: 4**

## Background

You will complete the embedded system you began in Lab 7. This lab includes hardware construction, software debugging and system evaluation. There will be a “Science Fair”-like public demonstration for Lab 11. I will present special awards to the team of four with the best design. The preliminary round will be judged by your TA during your lab session, and the final round will be judged by other students and observers.

## Preparation (do this before your lab period)

1. Write the main high-level application that implements the final objective of the embedded system. If you want change what your system does, please get approval from your TA.
2. Add more detail to the **requirements document** you began in Lab 7. In particular, give more detail about how the system will be evaluated. Increase the length from one page to two pages.
3. Gather all the parts needed to build the system. Update your bill of materials (BOM)
4. Solder all parts needed to download code to the board. This procedure is described below as steps 1–3. *You should build the board in this order (steps 1-3 are prep, remaining steps are procedure).* You should be ready to begin step 4 at the start of your first lab period. We recommend you demonstrate to the TA you can power the PCB and program the LaunchPad before you soldering other components to the board. I.e., demonstrate steps 1-3 to the TA before moving on to step 4.

*One of the hardest problems to debug is a short from power to ground. Notice these directions require you to check for shorts after each step. This way if a short were to develop you will have a good idea where to look for it.*

## Procedure for bring up a TM4C123 LaunchPad system

1. Before you start, verify there are no shorts between +3.3V power, ground, battery input, or 5V power line. Clean the pads with isopropyl alcohol. Solder the +3.3V, +5V, battery, and ground test points first.
2. Verify there are no shorts between +3.3V power, ground, battery input, or 5V power line. Solder the power input connectors, on-off switch, regulator(s), and regulator capacitors. With a current meter across the input power, test the regulator to see that all supply voltages are correct. Without any load, the current should be very small.
3. Verify there are no shorts between +3.3V power, ground, battery input, or 5V power line. Solder LaunchPad headers connectors and any other parts absolutely necessary to program the TM4C123 LaunchPad. Normally we expect you will need to remove the 2-pin jumper on the LaunchPad. With a current meter across the input power, test the regulator/LaunchPad to see that all supply voltages are correct. With the LaunchPad, the current should 20 to 40mA.
4. Verify there are no shorts between +3.3V power, ground, battery input, or 5V power line. Solder all test-points and logic analyzer headers. Solder any other debugging components like power supply LEDs and heartbeats. Run TM4C code to test these debugging components.
5. Verify there are no shorts between +3.3V power, ground, battery input, or 5V power line. Solder components in the order of height. The lowest ones come first. Check for shorts from power to ground before applying power again. The basic idea is to solder a functionally complete submodule and then test it. Record the current required to run the entire PCB each time you test it. We will expect 3 or 4 current measurements for this part in your lab report because we expect your system has three or four functional submodules.
6. Debug your embedded system application. Use appropriate hardware/software debugging skills as appropriate.
7. Record a 2-3-minute video of your system and post it on YouTube. Please mention your names at the start and the end of the video. Submit the video link on Canvas. Due Thursday 11pm 5/5
8. If your project satisfies the requirements for the “best design” competition listed in Lab 7, you will be invited to the science-fair demonstrations on the last class day in EER 0 floor lobby

## Procedure for bring up a stand-alone TM4C123 (no LaunchPad), including JTAG Connection

1. Before you start, verify there are no shorts between +3.3V power, ground, battery input, or 5V power line. Solder the TM4C123 first. Clean the TM4C123 pads with isopropyl alcohol. Align the TM4C123 on the board. Apply solder flux to the pin. Align the TM4C123 on the board again. Gently touch the solder iron then the solder to the pin. You use VERY little solder. Solder one pin and show it to a TA/professor or Mark Innmon. Align the TM4C123 on the board. This is critical. Solder a second pin and again have someone check it. Then solder the rest of the 48 pins. Clean solder-bridges with solder-removal braid.
2. Verify there are no shorts between +3.3V power, ground, battery input, or 5V power line. Check for shorts between adjacent pins on the processor. Use thin wire (28 or 30 gauge) to touch the ohmmeter probes to processor pins. If you can see excessive solder between pins, remove it with solder wick. If adjacent pins are connected but you see no excessive solder, very gently cut between processor pins with a sharp knife.
3. Solder crystal and all caps around the processor. Make sure crystal caps are 10 pF ceramic C0G. Place tantalums in polarized direction, and double check all values. For example, ceramic 104 means 10\*104pF= 0.1uF. Verify there are no shorts between +3.3V power, ground, battery input, or 5V power line.
4. Carefully mark on your board where JTAG pin 1 is. Solder the reset button, pull up, and JTAG connector. Verify there are no shorts between +3.3V power, ground, battery input, or 5V power line.
5. Solder the 1 MΩ resistor attached to Wake, also solder your 3.3V and ground test points. Verify there are no shorts between +3.3V power, ground, battery input, or 5V power line. Before proceeding to the next step, please attach the bench power supply to the 3.3V power rails by connecting to the 3.3V and ground test points you should have. Please set the bench supply current limit to 100mA to ensure safe operation and prevent damage. Make sure to test with a multi-meter to get the polarity right as to not damage the processor. You should be able to observe the 16 MHz periodic wave on both crystal pins.
6. Before soldering the 3.3V regulator, please put together and test your regulator circuit(s) to verify you have connected up the power rails correctly. Now proceed to soldering the regulator by attaching the caps regulator to the PCB from your breadboard (everything you need to create 3.3V power). Include 3.3V and ground testpoints. Essentially, in steps 3–6, you will need to solder all the parts included in the Lab 6 starter SCH except the LCD. As part of the procedure, you will solder the rest. Verify there are no shorts between +3.3V power, ground, battery input, or 5V power line.
7. Test the power and crystal. Connect voltmeter(s) to the regulated power line(s) 3.3V and 5V if present. Use a bench supply and limit the input current to 50 mA. Apply power your TM4C123 board (remove power immediately if not 3.3V). Record the current required to run just the processor. When powered, you should be able to see 16 MHz oscillations on both sides of the crystal.
8. Test it with the Flash programmer
   1. <http://users.ece.utexas.edu/~valvano/EE345L/Labs/Fall2011/Ifyoumessuptheboard.pdf>
   2. Download, install, but do not run the Flash programmer yet.
   3. Connect the 5-pin JTAG cable from LaunchPad to your TM4C123 board (see “How to program the board”)
   4. Attach a voltmeter to 3.3V pin on your board
   5. Both the LaunchPad and your board must be independently and separately powered. Apply power your LaunchPad board and apply power to your TM4C123 board (remove power immediately if not 3.3V)
   6. Run the Flash programmer as instructed in the pdf. If this flash procedure finishes without error, then means the TM4C123 is operational. If the flash procedure fails then there is a mistake in power, reset, crystal, or JTAG. The two most common reasons to fail are 1) the TM4C123 has no 3.3 power; and 2) the JTAG cable is backwards.
9. Download a very simple TM4C123 program that has no I/O
   1. <http://users.ece.utexas.edu/%7Evalvano/arm/SimpleProject_4C123asm.zip>
   2. Connect the 5-pin JTAG cable from LaunchPad to your TM4C123 board (see “How to program the board”)
   3. Attach a voltmeter to 3.3V pin on your board
   4. Power LaunchPad board, apply power to your board (remove power immediately if not 3.3V)
   5. Download the **SimpleProject\_4C123asm** project to your TM4C123
   6. Run debugger
10. Solder components in the order of height. The lowest ones come first. Check for shorts from power to ground before applying power again. If your system has both 3.3V and 5V power, please place a voltmeter on the 5V output and measure the current while testing it for the first time. Record the current required to run the entire PCB.

## How to program the board

With power removed

1) Remove the 2-pin jumper from a LaunchPad (this will disconnect power from the target TM4C123 leaving just the debugger on the LaunchPad) it is the only jumper on the LaunchPad; make sure no two regulator outputs are connected together (even if only one is powered)

2) Solder/connect 5 wires between your target to your LaunchPad

ground to ground

TCLK to SCLK

TMS to TMS

TDO to TDO

TDI to TDI

*Search "female female jumper wires" on Amazon, female jumper wires could be used if male headers are soldered onto your LaunchPad and your target PCB*

3) Apply power to both your LaunchPad and to your target PCB

4) Use the Keil debugger in usual way

5) Cut/disconnect the 5 wires when done

## Deliverables (exact components of the lab report)

1. Objectives
   1. 2-page requirements document
2. Hardware Design
   1. Detailed circuit diagram of the system (from Lab 7)
3. Software Design (no software printout in the report)
   1. Briefly explain how your software works (1/2 page maximum)
4. Measurement Data
   1. Include data as appropriate for your system. Explain how the data was collected.
5. Analysis and Discussion (none).

## Checkout (show this to the TA)

You should demonstrate the operation of the embedded system. Be prepared to discuss any difficulties or challenges you had in implementing the embedded system. You will also need to describe your testing procedure.

**A software and report files must be uploaded as instructed by your TA.**

## Lab 11 grading (different from labintro.pdf)

Lab 11 is the third of three parts to your own project. The grading rubric for this lab will be different from the one mentioned in the labintro.pdf document.

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**Preparation (20)** shown to TA before lab starts

High level application for the system, graded on completeness rather than style (10)

Complete BOM and having all parts (5)

2-page requirements document (5)

**Checkout (30)**

Project demonstration, quality of design (25)

Description of how the system was tested (5)

**Software Quality (30)**

Modularity and organization (10)

Readability (10)

Functionality (10)

**Report (20)**

Testing procedure and testing data (20)

Hints**:**

1. When pick up your PCB boards, make sure you get your board
2. You should have collected all parts as part of Lab 7, including nuts/bolts/screws. Think about your system mechanically. Will it all fit together? Put it together before soldering. This will help to determine the proper order of construction.
3. Take the system with you on job interviews.