Contents

What's the minimum I need to do for this assignment?

There are many worthless pieces of information in this document that your professor does not want you to know. Never read datasheets. Always ask someone else for an opinion. Use assumptions. Any internet article is true. IR emitters and detectors work like flashlights. Sparkfun is the ultimate engineering authority. You have always known more than anyone else. Experience is for wimps.

All conductors are the same. They only carry voltages, never current. Complex impedances and frequency-dependence are concepts invented to lower the grades of students that professors don't like. Good software can always fix bad hardware.

CPE students don't need to know circuits. EE students don't need to know how to program.

Scholar has a magic way of hiding resources from students.

Now that you have all the secrets, just go ask Bob what is the minimum you need to do for this assignment. Then you can skip the rest of this document.

"*It is helpful to understand the design choices that were made (and explained in the write-up) as these choices are very similar to the choices that your group will have to make in the design of your project board. Understanding the technical details behind these choices is always the difference between a successful and an unsuccessful project."* Dr. Paul Plassmann

CEL I2C Bus

The I2C bus (also called train bus) was conceived to solve a problem. We needed an affordable, extensible serial bus that supplied power to remote devices, and the bus transactions needed to be easy to comprehend, measure, and write code.

Common ribbon cable and connectors are inexpensive, flexible, and robust. They have been used in computer systems for decades. Common ribbon cables have a 0.050 inch pitch, meaning the parallel insulated conductors are spaced 0.050 inch apart. Common connectors support two rows of 0.025 inch square pins and sockets on 0.10 inch centers.

The sockets are normally connected to the ribbon cable using insulation-displacement. The connector has sharp blades, which pierce each conductor's insulation during assembly, making a gas-tight connection. If a gas cannot contaminate the connection, neither can liquids or dirt.

The sockets are only designed for 0.025 inch square pins. Breadboard wire (22 AWG copper) does not make a good electrical or mechanical connection.

The ribbon cable we use (3M 3365) employs 28 AWG stranded copper wire. This size wire is too fragile to solder.

The capacitance of 3M 3365 cable is 14.47 pF per foot. For more information, download the datasheet.

The maximum capacitive load on the PIC18F45J10 SCL and SDA lines is 400 pF. [I found this spec in the DC characteristics section of the datasheet. But this is an AC property! The datasheet writer must have graduated from VT.]

So theoretically, we can attach a 27 foot ribbon cable directly to the PIC processor, right? We tried using a 3 foot cable and the I2C bus was not happy! That's why we use I2C active terminators [buffers for novices] between most all devices and the I2C ribbon cable bus. We have successfully implemented 30 foot I2C busses using active terminators.

I2C Bus Power

The CEL I2C bus is normally powered by a 5 volt wall-wart (120 VAC to 5 VDC converter). If we load the bus with a device, some of the voltage will disappear as conductor heat. Our experience shows we can use 3.3 volt devices on our I2C bus, using low dropout (LDO) voltage regulators on each device.

Each device draws two kinds of current: steady-state and rapidly-fluctuating.

Examples of steady-state currents are: basic device current, LED current, resistor current, and bus conductor resistance current. Steady-state currents are commonly found in datasheets.

Examples of rapidly-fluctuating currents are: transistor switching currents, capacitor charging or discharging currents, and bus reflection currents.

Recall from basic circuit theory the experiment of charging a capacitor through a resistor. If you skipped this exercise, search google images for “capacitor charging”. Note that the voltage across a charging or discharging capacitor is not constant. Could this reset the processor? Yes.

Every time a digital device changes state, a large amount of rapidly-fluctuating current is required. Bypass capacitors, connected directly adjacent to a device, can mitigate the effect of some of this voltage fluctuation if and only if the capacitor value is appropriate and the return current impedance approaches zero for all frequencies. We want to employ a contiguous ground plane to minimize the impedance on our printed circuit board (PCB).

I2C Bus Signals

Using snap judgment and decades of experience, we decided to use 14 conductor ribbon cable, with 7 active pins.

VSS	SCL	VDD	VDD	VDD	SDA	VSS

This arrangement allows several layers of redundancy and safety.

VDD (+) has 3 conductors; VSS (-) has 2. VSS was chosen for the outside signals so the solder connection to the ground plane gives the connector more mechanical strength. The best mechanical strength is obtained through mechanical fasteners, not solder.

The cable has two independent 7-conductor busses. If one set of conductors fails, use the other. Clever designers could employ two independent busses on the same cable segment.

Cables can be connected in almost any orientation without shorting VDD (+) to VSS (-).

If the remote device has no power, try using the other set of 7 wires.

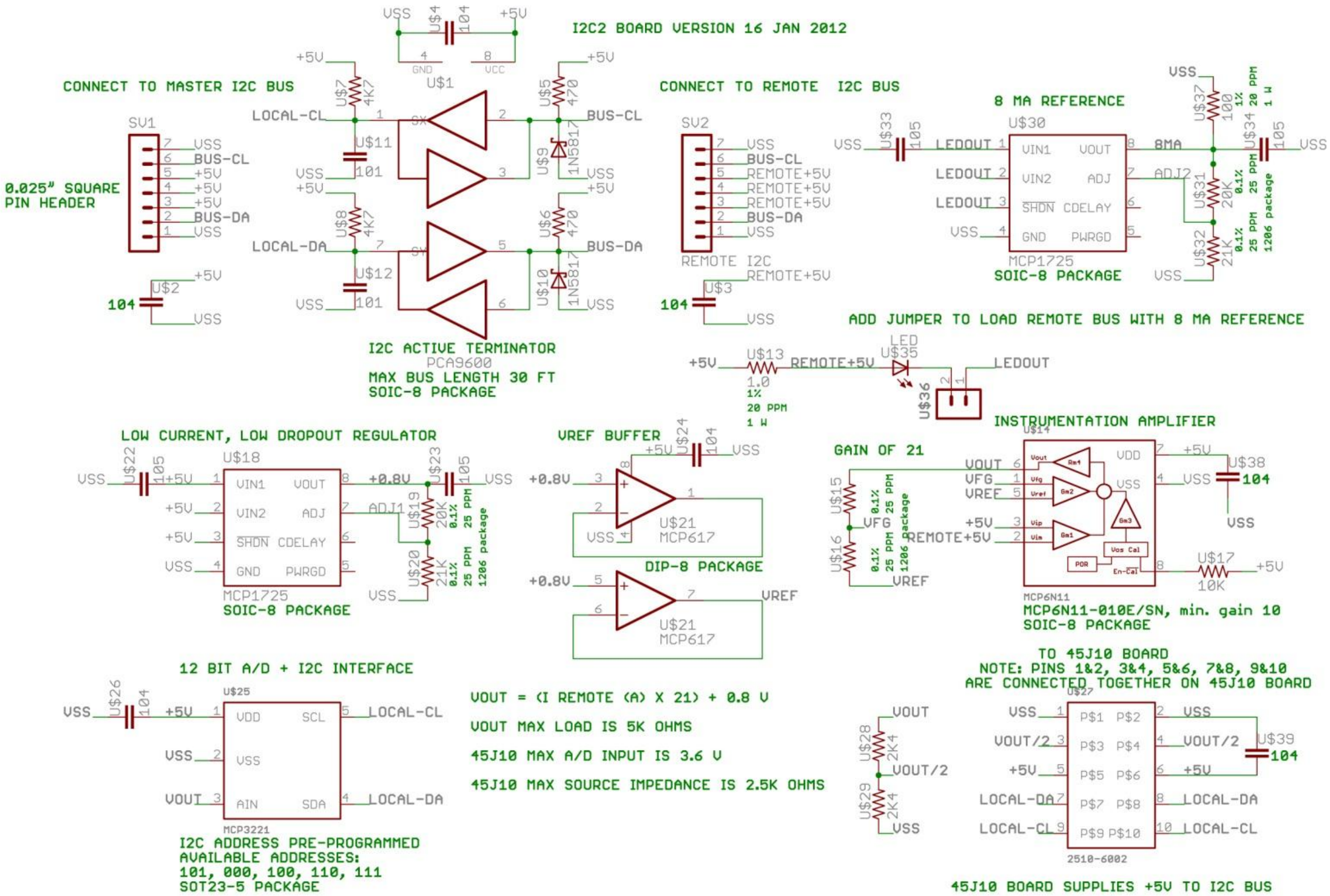
If the I2C bus is hung, try flipping the connector over.

I2C Current on a Remote Bus Segment

We could employ a current measurement technique on each I2C device. The I2C2 design measures the current on an I2C bus segment. As you study the schematic and accompanying explanations, the concept of segment should become clearer.

Why I2C2? Inter-Integrated Circuit (ugly) was shortened to I^2C (marginally better). This project measures IIC Current or IICC or I2C2. The name sounded funny like R2-D2 in Star Wars. Those of us who have no life find humor in the strangest of places.

I2C2 Schematic



1/26/2012 5:16:17 PM f=1.20 C:\Eagle\projects\I2C2\I2C2.sch (Sheet: 1/1)

Don't worry; a larger version of the schematic is available in Scholar -- Resources.

Circuit Description

It helps to study the schematic while you are reading its description. For this document, the Master I2C bus segment will be connected to the Keil MCB1760 system.

During locker checkout, each team received a powered [MSSP Mark 2] 45J10 board. [The 45J10 has 2 MSSP modules. Dr. Mark Jones initiated this particular tool board idea. A name like Mark II was used in the "old days" to designate a design revision. Now you know.]

The I2C2 design will employ our standard 10-pin shrouded [3M N2510-6002-RB] connector. A 10 pin ribbon cable connects the I2C2 board to the 45J10 board. While the pin-out of the 2510-6002 on the I2C2 side should be as shown in the schematic for reducing noise on the [Vout/2] signal, the non-dedicated connector pin-out on the 45J10 board allows signal routing freedom.

The remote I2C segment will not be connected until the I2C2 board is calibrated. More on the 8 mA reference later.

Note the signals that are common on both the Master and Remote I2C interfaces:

VSS	BUS-CL				BUS-DA	VSS

The 5 volt power signal is interrupted by a precision 1.00 ohm resistor. This makes the math easier. If the remote device draws 1 amp of current, how much voltage drop will occur across the resistor?

The current measuring resistor is 1.00 ohms. The stated precision is +/- 1%. The temperature coefficient is +/-20 ppm/C° [this means that over a significant temperature variation, the value of the resistor will not change more than +/- 1%]. The Ohmite WNM resistors are manufactured using the Aryton Perry winding such that the resistor's inductance is less than 1 nH at 1MHZ. The resistor will probably never need to dissipate power close to its 1 watt rating. This keeps the resistor cool and reduces resistance change with temperature even more. The resistor was available in a through-hole package. If the designer does not think about such specification details, the stated resistance value becomes arbitrary.

Each end of the current measuring resistor is connected to a MCP6N11 instrumentation amplifier (INAMP). This INAMP has rail-to-rail inputs, allowing the inputs (VIP and VIM) to operate normally down to [VSS – 0.2 V] and up to [VDD + 0.15 V] at room temperature. Since both inputs will be very close to VDD, this characteristic is desirable.

The gain of the INAMP is set to 21 so the student can refer to the datasheet example, "High Side Current Detector". The resistors in the appropriate value and accuracy range are not available in a through-hole package. Large surface mount packages (1206) were chosen to make first-time soldering easier. To obtain close to +/- 1% temperature coefficient, +/- 25 ppm/C° components were chosen. The standard room temperature resistance variation was specified at +/- 0.1%, which is overkill for this application.

A voltage reference (Vref) is required to operate the INAMP from a single supply (+5 V and ground). This reference should be a voltage source, able to sink or source current. To maintain accuracy, the voltage should not vary with temperature.

Temperature-compensated low-voltage references have always been expensive. Here, we try a new approach. The MCP1725 is low in cost and requires a minimum of external components. The I2C2 design utilized a precision resistor divider to set the voltage, although a fixed voltage part is available.

The output of the MCP1725 voltage regulator [reference] is buffered through a unity gain MCP617 op-amp to provide a more appropriate Vref for the MCP6N11 INAMP. Other designers might cut corners here to reduce parts count. The design principle is stability under all normal operating conditions [including student abuse].

Vout, from the INAMP, is a voltage directly proportional to the current through the current measuring resistor. Because the INAMP gain is set to 21 and the Vref supplies a 0.8 V offset,

Vout = [(Remote current in amps) X 21] + 0.8 V

For 1 mA remote current, Vout = 0.821 V

For 200 mA remote current, Vout = 5.0 V

The practical range of current measurement is about 1 to 200 mA. One of the optional exercises will be to determine how low a current value is achievable with accuracy and repeatability. In other words, how many of the lesser significant bits of an A-to-D converter are in random states due to noise.

The 8 mA reference uses a MCP1725 voltage regulator, set to an output of 0.8 V, with a precision load of 100 ohms (Ohmite WNM resistor). This design yields almost exactly 8 mA across temperature. The LED draws current in series with this circuit to indicate that the reference is loading the remote I2C bus. The LED also acts as a power indicator for trivial conditions.

The MCP3221 converts Vout to I2C messages. Fixed I2C addresses are hard-coded into these chips. The chip number displays this address. Available addresses are: MCP3221A5, A0, A4, A6, and A7. If your group needs multiple I2C addresses to measure current on multiple remote segments, be sure to specify which MCP3221 addresses you need.

It is recommended that designers choose MCP3221 addresses wisely before soldering. De-soldering surface mount chips can ruin a board.

The MCP6N11 INAMP, like many op-amps, does not like to drive low impedances. The minimum resistive load that does not degrade performance is about 5 K ohms.

The PIC18F45J10 supply voltage is 3.3 V. Its absolute maximum A-to-D input voltage is 3.6 V. If the MCP6N11 INAMP Vout maximum is 5.0 V, a voltage divider is needed.

The PIC18F45J10 A-to-D input source impedance must be less than 2.5 K ohms.

For once in your career, a simple voltage divider of two 2.4 K ohm resistors satisfies all criteria. The INAMP is loaded with 4.8 K ohms, the A-to-D input sees 2.4 K ohms, and the maximum Vout/2 is 2.5 V.

Modes of Operation

- ARM Master <-> I2C2 slave [self-test mode]
- ARM Master <-> I2C2 slave <-> remote I2C board [measure I2C current on remote I2C segment]
- 45J10 Board Master <-> I2C2 slave [self-test mode]
- 45J10 Board Master <-> I2C2 slave <-> remote I2C board [measure I2C current on remote I2C segment]
- 45J10 Board <-> I2C2 A/D <-> remote I2C board [measure I2C current on remote I2C segment]
- ARM Master <-> 45J10 Board slave [metadata] <-> I2C2 slave <-> remote I2C board [measure I2C current on remote I2C segment]
- ARM Master <-> 45J10 Board slave [metadata] <-> I2C2 A/D <-> remote I2C board [measure I2C current on remote I2C segment]
- ARM Master <-> 45J10 Board slave [remap I2C2 slave address] <-> I2C2 slave <-> remote I2C board

Eagle Software

Google cadsoft usa. Download your preferred version of Eagle freeware.

Install the Eagle freeware version to C:\Eagle. Since this is a unix port, windows file structure is not always friendly. Bob places all his projects in “C:\Eagle\projects\”.

Open the Eagle Control Panel, navigate to Projects, hover over ~\Projects, right-click, New Project. This will create the folder and “eagle.epf” (the project file).

In the Eagle Control Panel window, right-click the new project folder and New – Schematic. From the Schematic window, File – SaveAs “I2C2.sch” (in the new project folder).

From the Control Panel, File – Close Project.

Copy “I2C2.sch” from Scholar – Resources into ~\Projects\$newprojectname\

From Eagle Control Panel, File -- Open recent projects – ~\$newprojectname. The previously blank schematic window will now have lots of stuff on the page.

All components are in one library, “4534_I2C2.lbr”, which can be copied from Scholar – Resources into the students “$EAGLEDIR\lbr”. It is not clear if one can create a working board layout without this library, since the schematic is based on it.

Refer to the Eagle tutorials in Scholar – Resources.

Bob created a board design that will be used during soldering certification. The design turned out to be 2.50 x 2.50 inches, which makes rotating the board in the Panavise easier during soldering. Bob gave up trying to eliminate the last via, which will be filled by a wire and soldered on both sides. Don’t shrink the board outline until the placement, routing, and silkscreen decisions have been made.

PCB Layout Criteria

Plusses:

- Neatness
- Correct use of ground plane
- Intelligent silkscreen labeling
- Intelligent placement of connectors
- Ample space between components

Minuses:

- ERC or DRC errors without intelligent “approval” [Eagle terminology]
- Useful silkscreen legend hidden by component on top
- Crowded components
- Large expanses of unused board
- Vias
- Bypass capacitors that are not directly adjacent to their respective chips
- Ground plane not connected to ground

Fatal errors:

- Board and schematic are not consistent

Files to Submit as a zip file

- I2C2_group#_version#.sch (Eagle schematic file)
- I2C2_group#_version#.brd (Eagle board file)
- I2C2_group#_version#.cam (Eagle cam processor file)
- I2C2_group#_version#.bor (Gerber border file)
- I2C2_group#_version#.drd (Gerber drill file)
- I2C2_group#_version#.sol (Gerber solder side file)
- I2C2_group#_version#.cmp (Gerber component side file)
- I2C2_group#_version#.plc (Gerber component silkscreen file)
- I2C2_group#_version#.gwk (GC-Prevue file)

Where to Post your zip file

Since Scholar and email have variable performance records, the board designer should post to Scholar – Resources – Groups: Spring 2012 – Group # -- Milestone1B folder – I2C2_group#_version#.zip

The board designer should also email Bob2012L@vt.edu with the zip file attached.

Feedback to Expect

Bob will review the gwk file and print to pdf. Bob will markup the pdf with comments, both good and bad.

Bob will post to Scholar and email the author, as suggested above.

Revisions

Bob will accept revisions until Professors Jones and Plassmann say stop. The current schedule indicates that the last revision is due Feb 28, 2012 8:00 am.

Grading

If Professors Jones and Plassmann want grades for this assignment, Bob will provide them.