

**ECE471: Embedded Systems – Homework 7**  
SPI, A/D and Temperature Probe

**Due: Friday, 1 November 2019, 1:00pm**

1. Use your Raspberry Pi for this homework.

You will need an MCP3008 SPI A/D converter as well as a TMP36 temperature sensor (looks like a transistor) that I handed out in class. If you missed class, you can stop by my office to pick these up.

You can view the datasheet for the MCP3008:

[http://web.eece.maine.edu/~vweaver/classes/ece471\\_2014f/datasheets/MCP3008.pdf](http://web.eece.maine.edu/~vweaver/classes/ece471_2014f/datasheets/MCP3008.pdf)

You can view the datasheet for the TMP36:

[http://web.eece.maine.edu/~vweaver/classes/ece471\\_2014f/datasheets/TMP35\\_36\\_37.pdf](http://web.eece.maine.edu/~vweaver/classes/ece471_2014f/datasheets/TMP35_36_37.pdf)

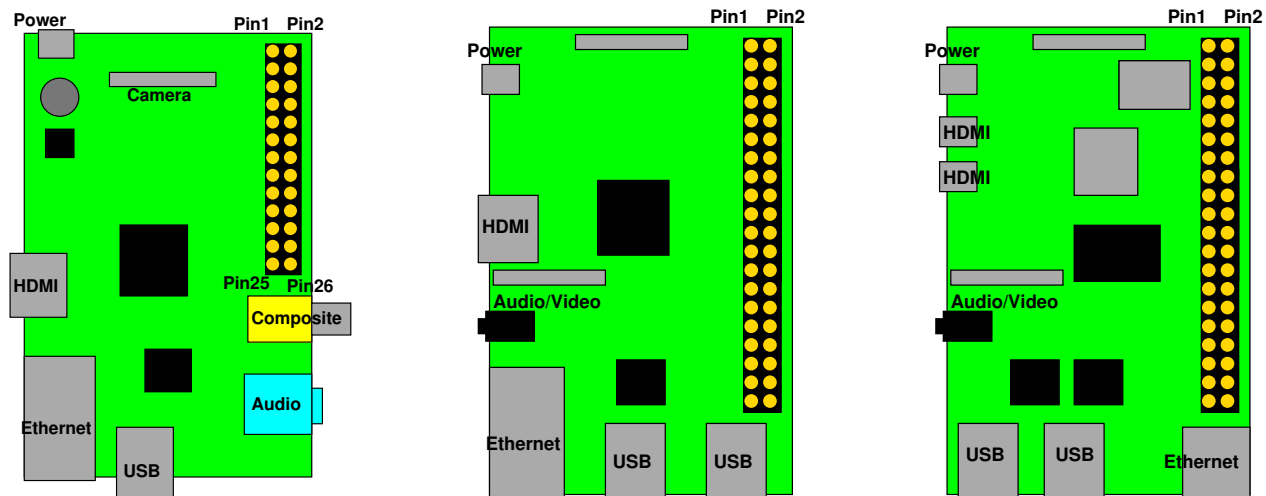


Figure 1: Location of header on Raspberry Pi Model B and B+/2/3, 4B

2. **Get the MCP3008 providing values over SPI** (3 points)

First wire up the SPI device to the Raspberry Pi. You can use Figure 1, Figure 2 and Table 1 for guidance.

(a) Put the MCP3008 on a breadboard and connect to your Pi:

- i. Connect 3.3V on the Pi to  $V_{DD}$  (pin16) on the MCP3008. Also connect 3.3V to  $V_{REF}$  (pin15) on the MCP3008.
- ii. Connect GND on the Pi to AGND (pin14) on the MCP3008. Also connect GND to DGND (pin9) on the MCP3008.
- iii. Connect SCLK on the Pi to CLK (pin13) on the MCP3008.
- iv. Connect MOSI on the Pi to  $D_{IN}$  (pin11) on the MCP3008.
- v. Connect MISO on the Pi to  $D_{OUT}$  (pin12) on the MCP3008.
- vi. Connect CE0 on the Pi to  $\overline{CS}$  (pin10) on the MCP3008.

Table 1: Raspberry Pi Header Pinout

3.3V	1	2	5V
GPIO2 (SDA)	3	4	5V
GPIO3 (SCL)	5	6	GND
GPIO4 (1-wire)	7	8	GPIO14 (UART_TXD)
GND	9	10	GPIO15 (UART_RXD)
GPIO17	11	12	GPIO18 (PCM_CLK)
GPIO27	13	14	GND
GPIO22	15	16	GPIO23
3.3V	17	18	GPIO24
GPIO10 (MOSI)	19	20	GND
GPIO9 (MISO)	21	22	GPIO25
GPIO11 (SCLK)	23	24	GPIO8 (CE0)
GND	25	26	GPIO7 (CE1)
ID_SD (EEPROM)	27	28	ID_SC (EEPROM)
GPIO5	29	30	GND
GPIO6	31	32	GPIO12
GPIO13	33	34	GND
GPIO19	35	36	GPIO16
GPIO26	37	38	GPIO20
GND	39	40	GPIO21

- (b) For this first part, we will measure 0V on CH0 (pin1) and 3.3V on input CH1 (pin2). Hook up power and ground to those pins on the MCP3008.
- (c) Enable SPI support in Linux running on your Pi. This is a bit confusing as they have changed the directions for this at least three times over the years.
- The current way to do this is to run the `sudo raspi-config` command, select “advanced options”, select “spi” and then say “yes” that you want this enabled and “yes” you want to load the module.
  - This should load the `spi-bcm2835` kernel module, as well as the `spidev` modules which Linux will use to talk to the SPI device.
  - You can look at `dmesg | grep spi` after reboot to see if SPI support was found and enabled.
- (d) Modify the `test_spi.c` file to read values from the MCP3008 and print them to the screen. See the classnotes for more details.
- Open the `/dev/spidev0.0` file for read/write access.
  - Use `ioctl` to set the mode to `SPI_MODE_0`
  - In an infinite loop, read the value of CH0 and CH1 once a second and print the voltages to the screen.
    - As described in class use `ioctl` to transmit 3 bytes:
      - \* Be sure to clear out your transmit buffer with zeroes first (using `memset` or similar) or you may get errors!
      - \* Transmit three bytes:

- i. the first byte contains just the start bit,
  - ii. the second byte has the single-ended mode bit, followed by 3 bits indicating the channel to read, followed by zeros
  - iii. the third byte should be all zeros.
- \* Receive 3 bytes. The first byte can be ignored, the bottom 2 bits of the second byte are bits 9 and 8, and the third byte is the bottom 8 bits of the result.
- Put the 10 bits you receive into an integer, then use  $V_{IN} = \frac{value \times V_{REF}}{1024}$  to convert to a floating-point voltage.
  - CH0 should be roughly 0V and CH1 should be 3.3V.

(e) Be sure to comment your code and check for errors!



Figure 2: TMP36 and MCP3008 Pinouts

### 3. Hook up the TMP36 to the SPI device (3 points)

- (a) Copy your test\_spi.c file to display\_temp.c
- (b) Connect the TMP36 temperature probe to CH2.  
Connect pin1 (3.3V) of the TMP36 to 3.3V  
Connect pin2 (Vout) of the TMP36 to CH2 on the MCP3008  
Connect pin3 (GND) of the TMP36 to ground  
**WARNING!** the datasheet shows the pins from the *bottom* not the top. If you reverse the power/ground settings on the chip it will quickly heat up to 100+ degrees and will possibly be ruined! Follow the diagram in Figure 2 and you will be OK.
- (c) Modify the code to print the current temperature as read by the probe, once a second. You can print degrees C or F as per your preference, but make sure the units are displayed.
- (d) The temperature can be determined with the following equation:  
 $deg\_C = (100 \times voltage) - 50$
- (e) Also the following might be useful:  
 $deg\_F = (deg\_C \times \frac{9}{5}) + 32$   
Beware of C floating point/integer conversion rules!
- (f) Be sure to comment your code!

#### 4. **Something Cool** (1 point)

Copy your code to `temp_cool.c` and modify it to do something cool. Describe what you did in the README file.

- Monitor the temperature, and after a while print the high/low temperatures recorded.
- Monitor the temperature and print a message if a temp is exceeded (for example, print a message if someone touches the probe long enough to raise the temperature).
- Hook up the analog discovery board and plot one SPI transaction on the MOSI/MISO/CS0/CLK lines. Send the plot in with your assignment.
- Note: Homework 9 involves displaying the temperature on the LED display so while it would be cool to do that, you might as well wait a few weeks.

#### 5. **Questions** (2 points)

Answer the following in the README file:

- (a) You are designing an embedded system for a car that controls the anti-lock brakes. The specification says that to work properly the brakes needed to start pulsing within 10ms. Would this be a hard, firm, or soft real-time task? Why?
- (b) You are designing another part of the car. The specification says that if you push the “tune” button on the stereo that it should switch stations within 1s. Would this be a hard, firm, or soft real-time task? Why?
- (c) You are working on the “info-tainment” system for the car, and it has a movie player for the backseat. The specification calls for the video decoder to be able to maintain a framerate of 60Hz. Is this a hard, firm, or soft real-time task? Why?
- (d) What is one disadvantage of SPI compared to i2c?
- (e) What is one advantage SPI has over i2c?
- (f) You want to connect a second temperature probe to the MCP3008 from this homework, but with the TMP36 at the end of a 150-foot cable. Would this work? Why or why not?
- (g) The MCP3008 datasheet says:  
“... the time between the end of the sample period and the time that all 10 data bits have been clocked out must not exceed 1.2 ms (effective clock frequency of 10 kHz). Failure to meet this criterion may introduce linearity errors into the conversion outside the rated specifications.”  
Your boss asks you to talk an MCP3008 by bitbanging SPI via GPIO from regular Linux. How might this be a problem?

## 6. Linux Fun (1 point)

Linux shells have what's known as job control. This isn't a question, but you can try it out and see how it works. To suspend something, press Control-Z. So if you are editing code in nano, try pressing Control-Z. It should bring you back to the prompt. To get back to nano again type `fg`. You can use this to run `make` while editing and going back without losing your place. You can also use `bg` to put programs running in the background, but be careful (you don't want that to happen to nano for example).

Linux has very useful devices under `/dev` besides the `i2c` and `spi` nodes.

- (a) The first is `/dev/null`. What happens if you pipe a command to it?  
For example `ls > /dev/null`?
- (b) The next is `/dev/full`. What happens if you pipe a command to it?  
For example `ls > /dev/full`?
- (c) `/dev/zero` contains nothing but zeros. Why might that be useful?
- (d) What do you think `/dev/random` contains?

## 7. Submitting your work

- Run `make submit` which will create a `hw7_submit.tar.gz` file containing `Makefile`, `README`, `test_temp.c`, `temp_cool.c` and `display_temp.c`.  
You can verify the contents with `tar -tzvf hw7_submit.tar.gz`
- e-mail the `hw7_submit.tar.gz` file to me by the homework deadline. Be sure to send the proper file!