<p style="text-align:center">**MECH 421 – Mechatronic Systems Instrumentation**
Lab 4: Op Amp Circuits for Noisy Environments</p>

Introduction and Outline

This lab teaches the design and construction of op amp circuits to create a non-contact optical distance sensor. There are 7 exercises in this lab:

1. Optical transmitter
2. Photodiode amplifier
3. High-pass filter and AC amplifier
4. Rectifier and low-pass filter
5. Assemble complete circuit
6. Build firmware and C# program to transmit and acquire data from the distance sensor
7. Calibrate distance sensor, measure resolution

Demonstration of Phase 3 indicates full functionality required by this lab, and will receive a full demonstration mark. Check-off for Phase 1 and Phase 2 is optional and only for partial marks, in case you could not complete Phase 3.

The lab report should still answer **all** questions in this lab manual.
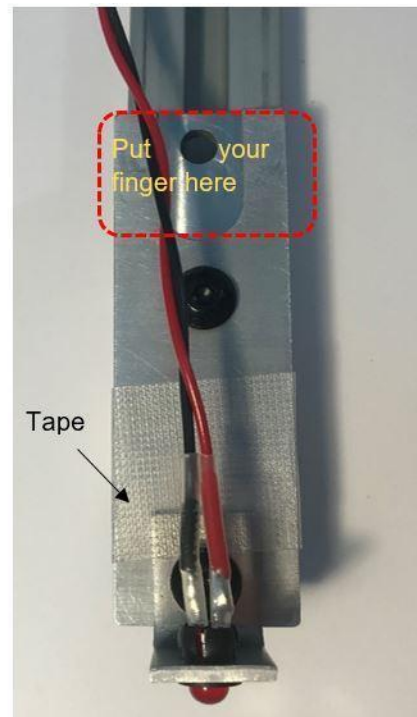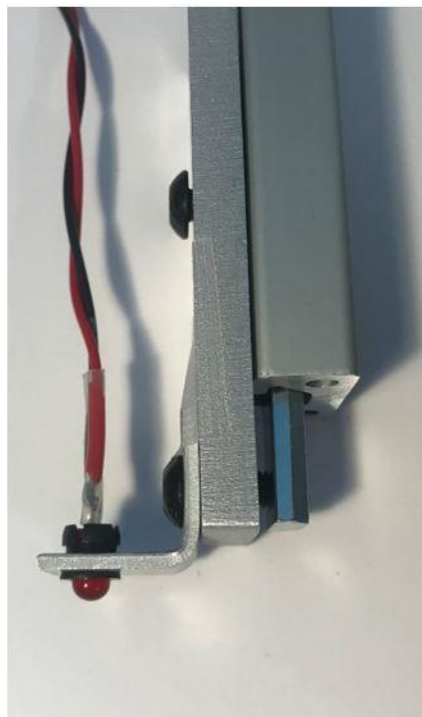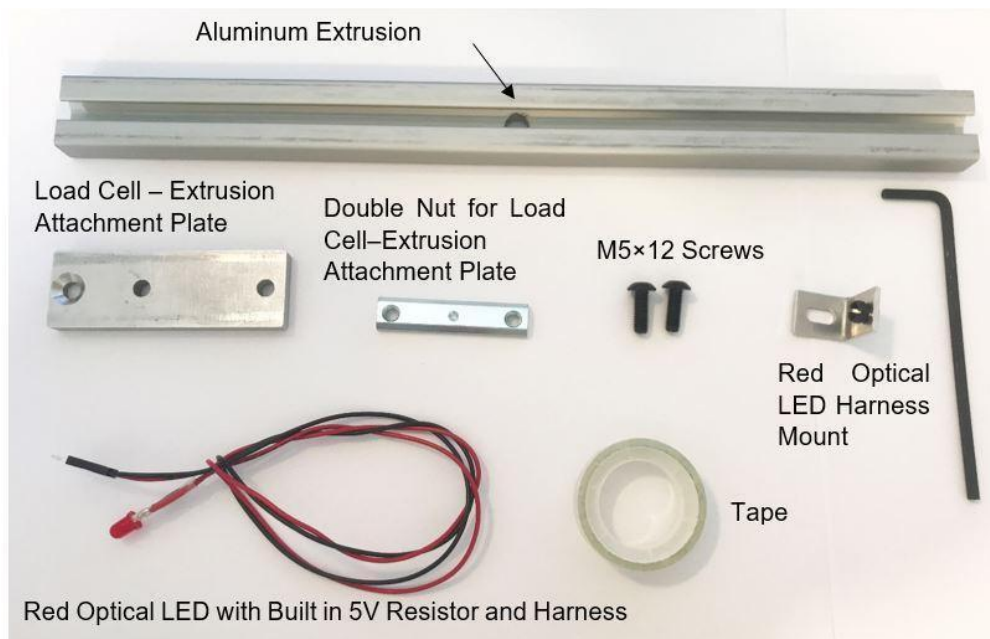
Phase 1

Exercise 1: Optical transmitter

1. The optical distance sensor will use a red LED as a transmitter. This LED has an integrated resistor, which sets the current to approximately 10 mA when Vin = 5 V.
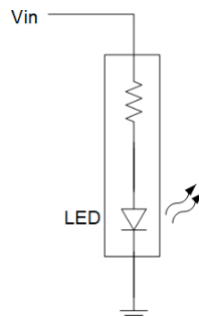
2. Set up the AD2 waveform generator. Hook up Vin and Gnd on the LED. Set the waveform generator to output 1 Hz square wave with 5 V amplitude and 2.5V DC offset. See the LED produce a flashing signal.
3. Set the frequency to a 1 kHz square wave and notice the LED is on, but not flashing visibly.

You will need to assemble the LED mount for the remaining exercises. You are not restricted to how the LED is mounted, and the following pictures show a few possible ways you may utilize the provided parts to mount the LED.

Aluminum Extrusion

Load Cell – Extrusion Attachment Plate

Double Nut for Load Cell–Extrusion Attachment Plate

M5×12 Screws

Red Optical LED Harness Mount

Tape

Red Optical LED with Built in 5V Resistor and Harness

Put your finger here

Tape

- Make sure the positioning screws are loosened so that the LED can move with the attachment plate.
- Use the tape to make sure that the LED Harness Mount doesn't rotate.
- While moving the LED away from the photodiode, do not touch anywhere close to the LED Harness Mount.
- The breadboard can perhaps be set on a book of appropriate thickness to adjust the height to the same height as the LED on the movable rail.

Exercise 2: Photodiode amplifier and high-pass filter

1. Design and build the photodiode amplifier circuit shown below, suppose that the photodiode has an output current of 1 μA, select the value of R2 to give an output of 100 mV deviation from V1.
2. Select the value of R3 and R4 to make V1 = 0.5 V.
3. Select the value of C1 and R5 to give a cut-off frequency of ~100 Hz (i.e. $\omega_c = 500\ rad/s$).
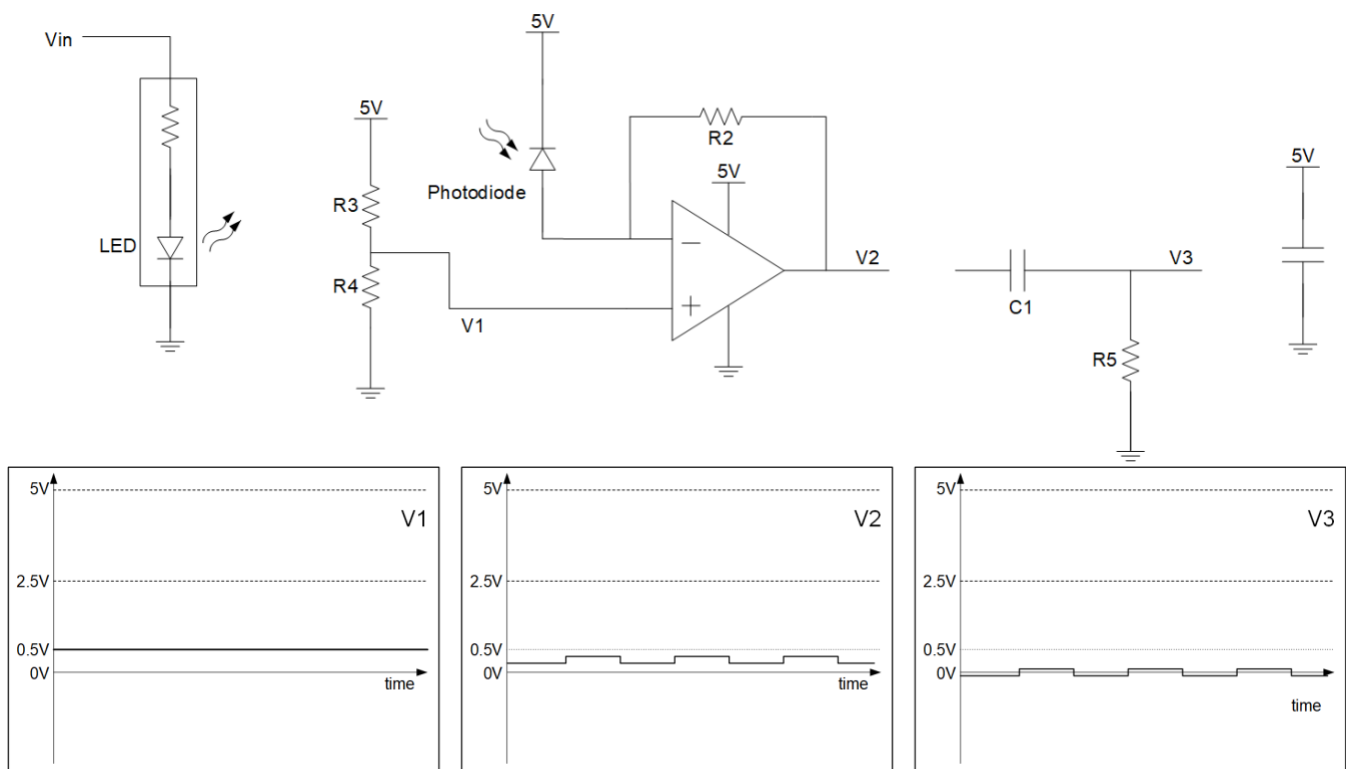
4. Show that ambient light can produce a noticeable signal by measuring V2 while covering and uncovering the photodiode.
5. Move the LED close to the photodiode. Look for a small 1 kHz square wave on top of the ambient light signal.
6. Connect the input of the high-pass filter to V2. Probe V3 using the AD2 oscilloscope. Magnify the voltage signal and look for the 1 kHz square wave signal. Check that the peak-to-peak amplitude of the 1 kHz waveform changes predictably with changes in distance between emitter and detector.
7. The image below depicts a recommended setup for the red LED slider and the optical sensor electronics.
   a. Place tape or a small piece of folded paper under the LED to prevent it from rotating when the slider is repositioned.
   b. The photodiode is bent to be directly in-line with the sliding LED.
   c. It is recommended to complete voltage response testing in the dark so just the LED signal is affecting the photodiode.
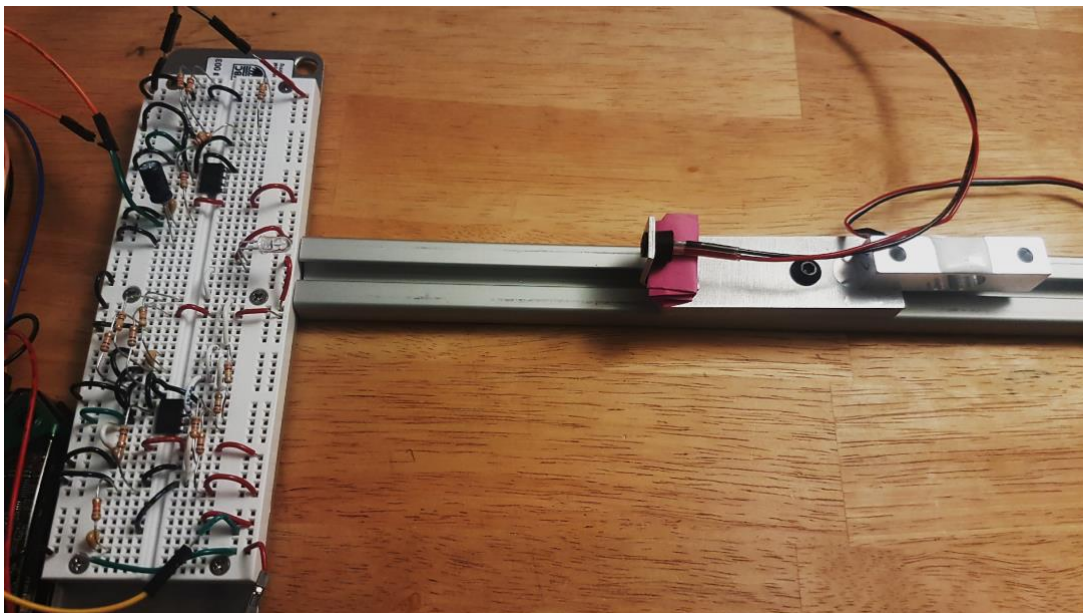
Exercise 3: High-pass filter and AC amplifier

1. Design and build a high-pass filter with gain as shown below. Select R7 and R8 to make V4 = 2.5V. Use C1 and R5 from the previous exercises. Select the value of R6 to give a gain of -10.
2. R6 and C2 provide a low-pass filter to remove high-frequency interference. Select the value of C2 to give a low-pass cut-off frequency of ≥16 kHz (i.e. $\omega_c \geq 10^5 \ rad/s$).
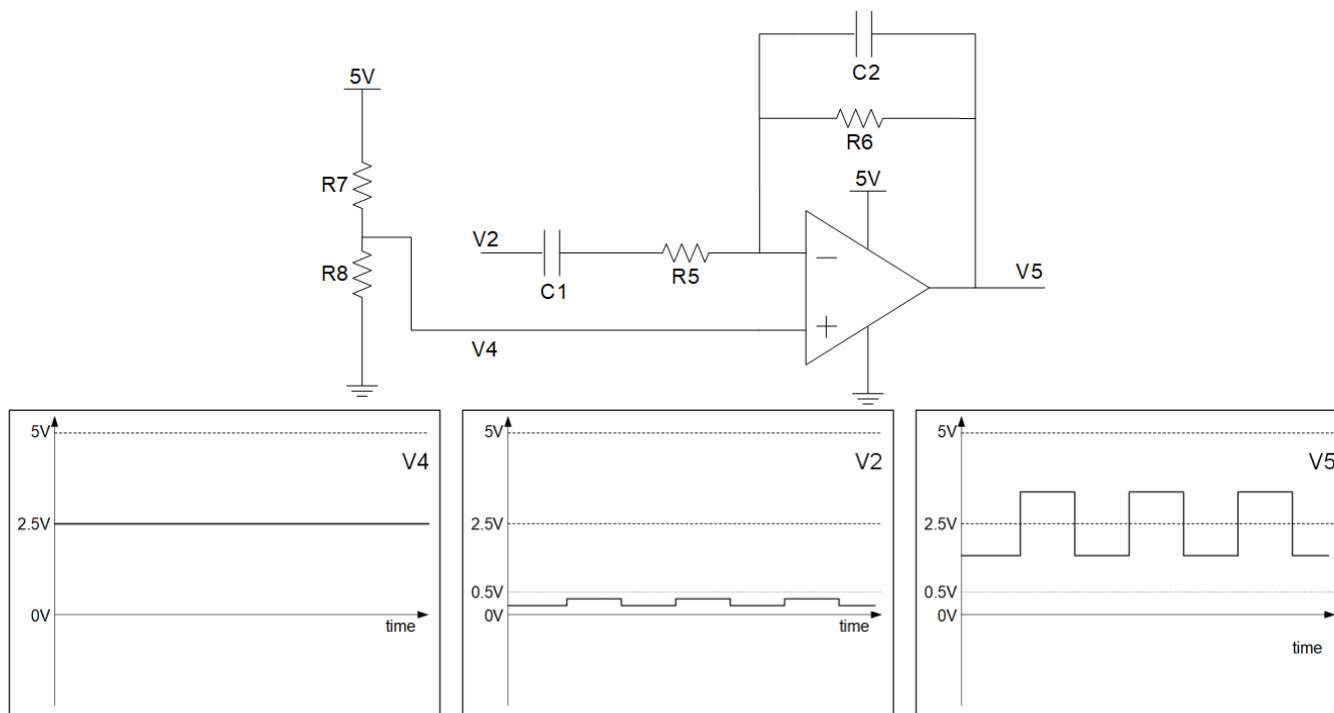
3. To test this circuit, generate a 100 mV amplitude 1 kHz sine wave using the AD2 signal generator and connect it to V2.
4. Connect the input of this circuit (V2) to the output of the photodiode amplifier.
5. Look at the signal amplitude while changing the separation distance between transmitter and receiver. The circuit should produce a detectable 1 kHz square wave signal over the range of the separation distance (25 cm) and should not be saturated (<5 V) when the separation is too close (i.e. >3 cm). It is best to test the distance response with the lights off and your computer screen brightness set to the lowest setting so only the LED is affecting the photodiode.
6. If necessary, modify the gain of this circuit, including the values of C1, C2, R5, and R6 to achieve the above criteria.

Final values of circuit components:

C1 = _____; C2 = _____; R5 = _____; R6 = _____;

Phase 1 check-off

1. Demonstrate completion of your Exercises 3 to your TA. Show V5 waveform from 3cm to 25cm separation.

Phase 2

Exercise 4: High-pass filter, Rectifier, and low-pass filter

1. Design and build another RC high-pass filter below using C3 and R9. Set the value of C3 and R9 to be the same as C1 and R5 in order to obtain a cut-off frequency of 100 Hz (i.e. $\omega_c = 500\ rad/s$).
2. Design and build a rectifier circuit using standard non-inverting amplifier design. Select the value of R10 and R11 to give a gain of 11.
3. Design and build an RC low-pass filter using C4 and R12. Select the value of C4 and R12 to obtain a cut-off frequency of 1.6 Hz (i.e. $\omega_c = 10\ rad/s$).
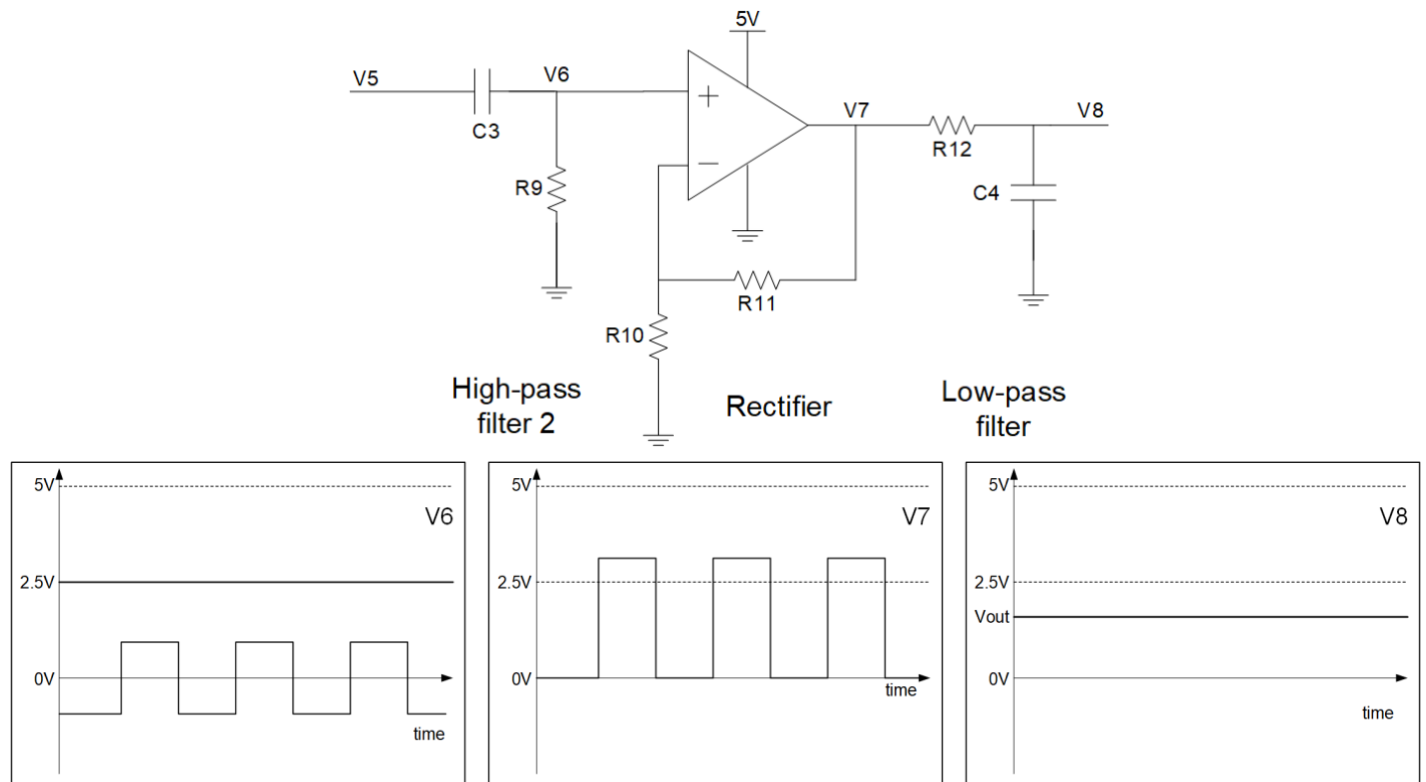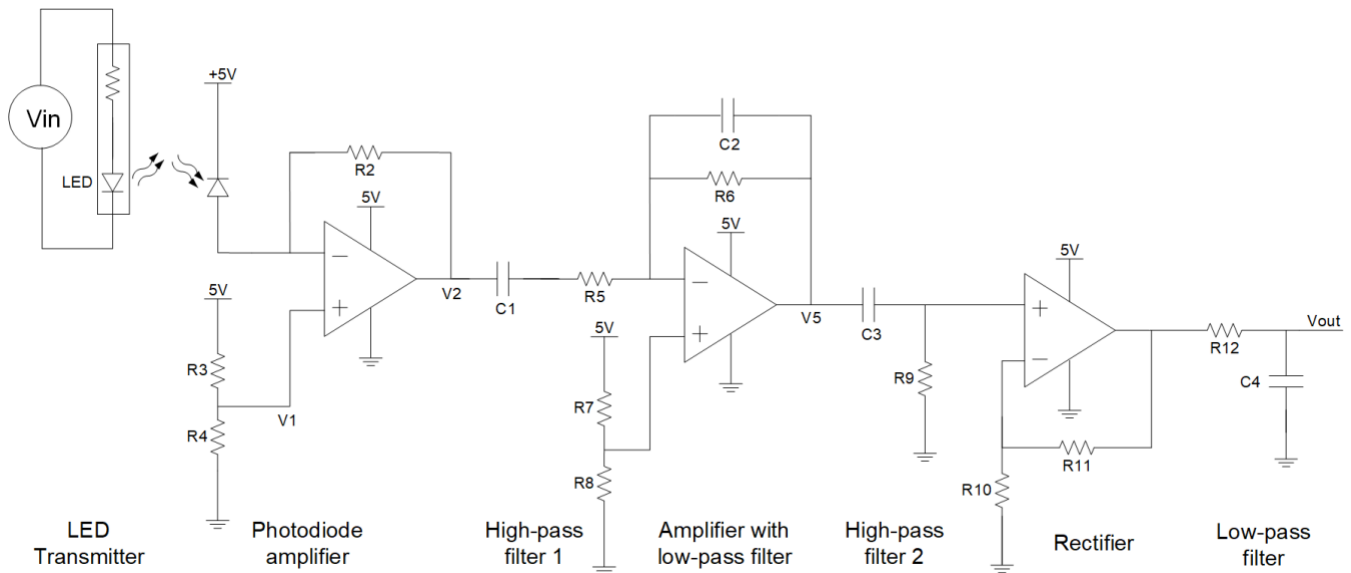

4. Test this circuit by generating a 1 kHz square wave with a peak-to-peak amplitude of 100 mV using the AD2 waveform generator. Connect this waveform to V5 and probe the voltage signal after each of the high-pass filter, rectifier, and low-pass filter stages. Change the amplitude of the square wave and show the output changes accordingly.

Final values of circuit components:

C3 = _____; R9 = _____; R10 = _____; R11 = _____;

R12 = _____; C4 = _____;

Exercise 5: Assemble complete circuit

1. Connect together the circuits from exercise 2-4 as shown below.
2. Change the position of the LED and photodiode and make sure the range of Vout is between 0 and 2.5V. If necessary, adjust the rectifier gain by changing the value of R10 and R11 to get Vout in this range.

| LED Transmitter | Photodiode amplifier | High-pass filter 1 | Amplifier with low-pass filter | High-pass filter 2 | Rectifier | Low-pass filter |

Final values of circuit components:

R10 = _____; R11 = _____;

Phase 2 check-off

2. Demonstrate completion of your Exercises 4-5 to your TA.

Phase 3

Exercise 6: Build a C# based program to acquire data from the distance sensor

1. Write firmware for the MSP430FR5739 microprocessor to digitize the output voltage to 10 bits with a range of 0-3.3V. Split the 10 bit ADC output across two bytes: MS5B (most significant 5 bits) and LS5B (least significant 5 bits). The output data stream should be formatted as follows:

Out byte 1	Out byte 2	Out byte 3
255	MS5B	LS5B

2. As before, write a C# program to acquire data from the distance sensor
    a. Connect the serialport
    b. Write code to re-assemble the MS5B and LS5B into a 10 bit number.
    c. Write code to display, graph, and store the ADC data stream.
    d. Make an interesting and useful user interface for measuring distance.

Exercise 7: Calibrate distance sensor, measure resolution

1. Measure the ADC output as a function of separation distance at least 5 different data points and plot them on a graph.
2. Fit a function to this graph using Excel, C#, MATLAB, Python, etc. Visualize raw data and the fitted function in your report. Comment on fitting quality.
3. Convert ADC output to position. Hint: use the fitted function.
4. Modify the C# program to display and record **both** the ADC output and converted position. Let the user know when the distance sensor is out of range. Reported values **and** graphs are required.
5. Set the distance sensor in the middle of its range. Record the converted position for ~10 s. Measure the standard deviation of the converted position. This value is your RMS noise level. Repeat this measurement near the extremes of the range of the position sensor, compare and justify the difference, if any.

Phase 3 demonstration and lab report

1. Demonstrate completion of your Exercises 6-7 to your TA. Bring a ruler or draw ticks on the extrusion. Report your distance sensor's working range. Show measurement on 3 random distances within this range, and show the out-of-range indicator when too close or too far.
2. Write a lab report describing exercises 1-7 in the standard format. Where appropriate, include diagrams of circuits, list component values, waveforms acquired in the lab, and screenshots of the software user interface design.