MECH 421 – Mechatronic Systems Instrumentation
Lab 3: Op Amp Circuits for DC Signal Processing

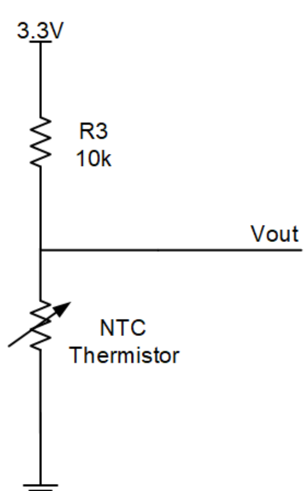
Introduction and Outline
This lab teaches the design and construction of op amp circuits for DC signal processing to measure temperature and weight.

Part 1: Temperature Sensing
1. Measure temperature using a thermistor
2. Develop firmware and C# program to transmit and acquire data from the thermistor
3. Lab report

Part 2: Weight Scale
1. Assemble load cell and weight scale set up
2. Design and build a 2.5 V reference
3. Build a mock strain gage
4. Design and build an instrumentation amplifier
5. Design and build an output stage to remove offset and amplify signal
6. Build firmware and C# based program to transmit and acquire data from the strain gage
7. Calibrate the strain gage
8. Build a C# based UI for measuring weight
9. Lab report

Part 1: Temperature Sensing

Exercise 1: Measure temperature using a thermistor
1. Hook up the thermistor in a circuit shown below. The thermistor datasheet can be found [here](). This thermistor is specified with $B_{25/85}$=3435K with an operating range from -40℃ to 105℃.



2. Use the AD2 oscilloscope to measure the voltage across the thermistor in ice water, as well as in water baths warmed to 40°C and 60°C. Simultaneously measure the water bath temperatures using a provided thermometer. Calculate the thermistor resistance and the equivalent temperature. Show your calculations in your report. What is the error in the measured temperature?
3. In your report, present an error compensation scheme to minimize the error over the range of 0 to 60°C.

Exercise 2: Build data acquisition program for the thermistor

1. Connect the output of the thermistor to an analog input port on the MSP430FR5739
    a. Write firmware for the MSP430FR5739 microprocessor to digitize the output voltage to 10 bits based on 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

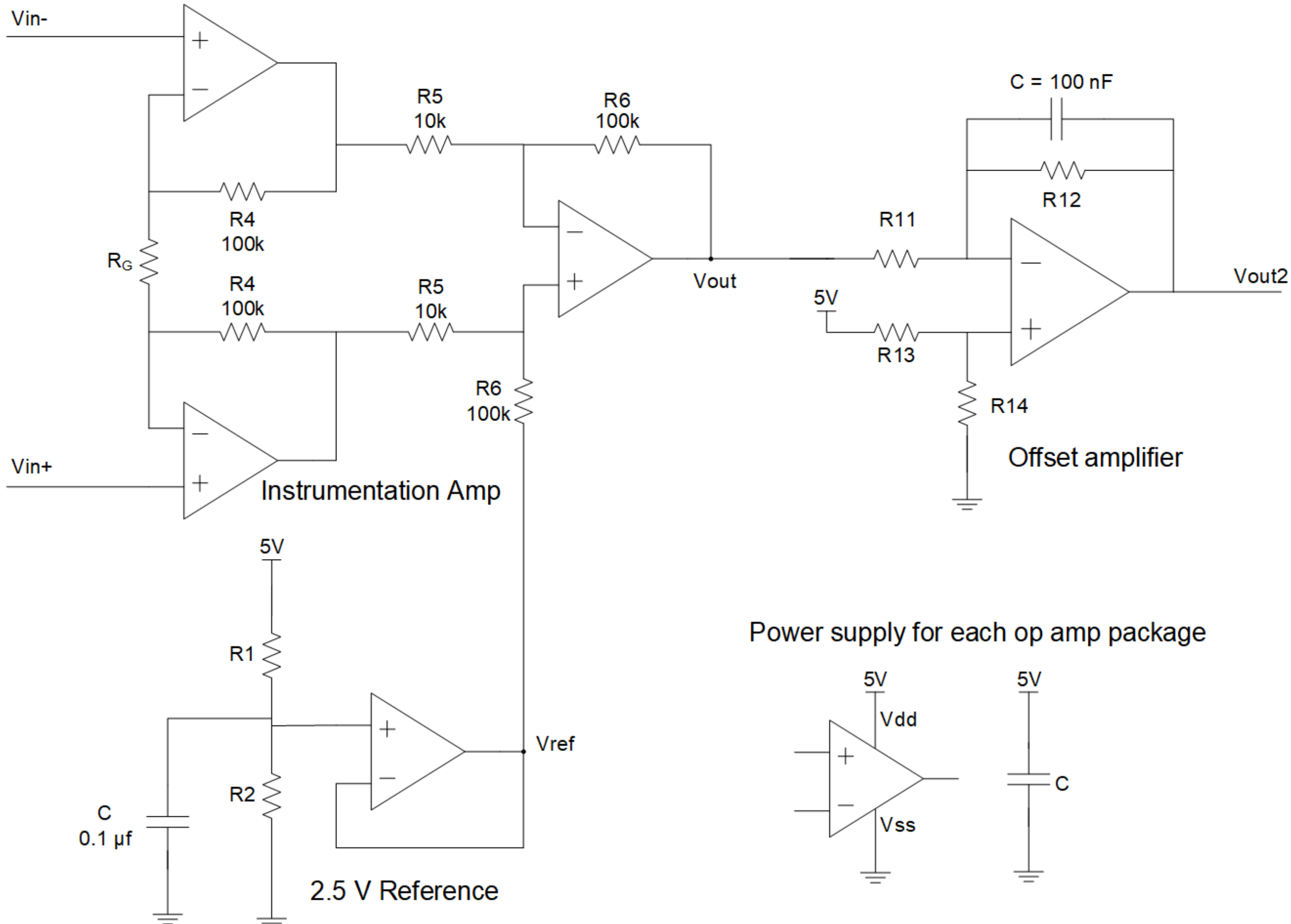
2. Write a C# program to acquire data from the microprocessor
    a. Connect the serialport
    b. Write code to re-assemble the MS5B and LS5B into a 10 bit number.
    c. Write code to convert the ADC readings to temperature in Celsius degrees.
    d. Implement the error compensation scheme devised in Exercise 1. One textbox for error output and one textbox for adjusted temperature in Celsius degrees.
    e. Write code to graph the temperature data stream and record to a file
    f. Design a user interface to display and graph the data. Use your creativity and artistic sense to improve the overall look and feel.
3. Capture temperature waveform when the thermistor transitions from 0°C to 40°C and 0°C to 60°C, as well as back again in each case (i.e. four waveforms in total).
4. Graph this waveform. Estimate the thermal time constant as a first order exponential. Show the estimation process and discuss the quality of the results in your report.

Part 1 check-off and lab report

1. Demonstrate Exercise 2 to your TA during the lab session. Show live measurements of the three temperatures in Exercise 2.
2. Write a lab report describing exercises 1-2. Where appropriate, include diagrams of circuits, calculations to obtain desired quantities, lists of components and values, acquired waveforms, and screenshots of the software user interface design.

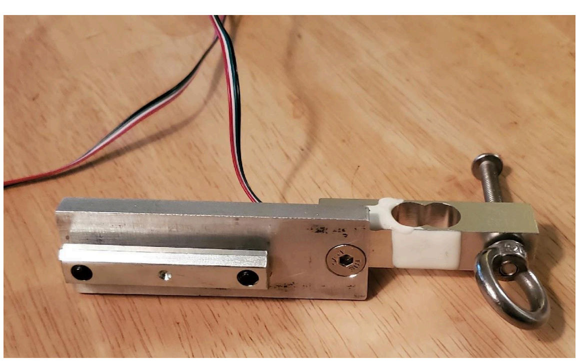
Part 2: Weight Scale

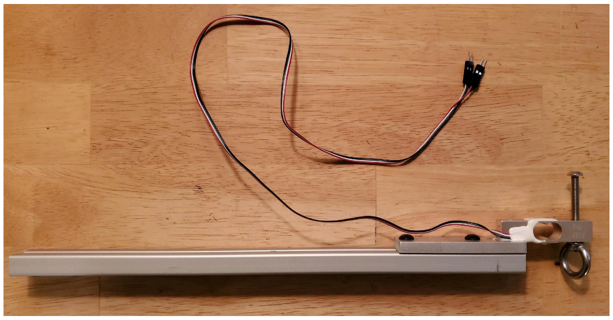
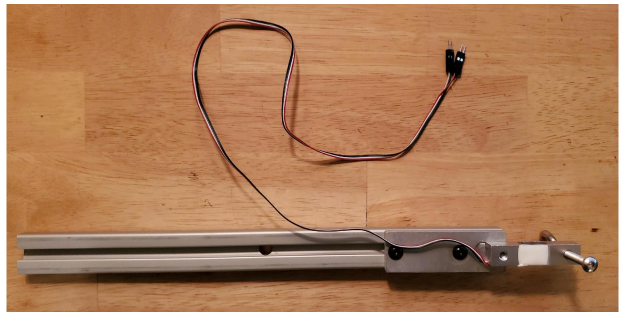
Overall schematic



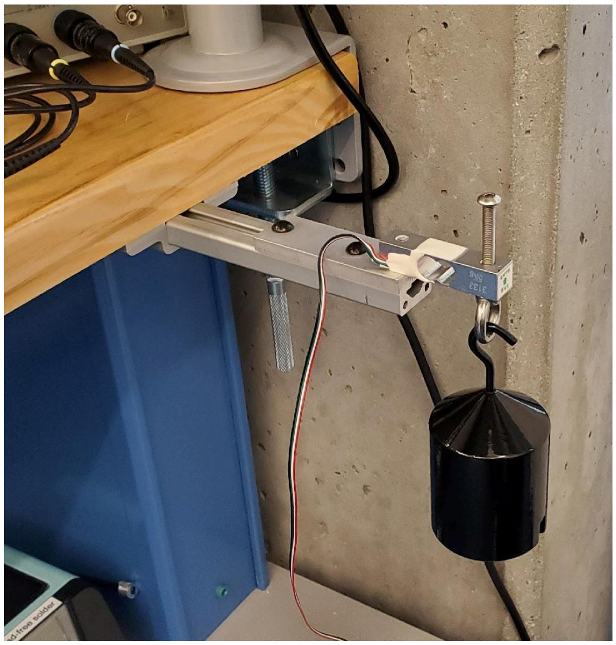
Exercise 1: Assemble load cell and weight scale set up

1. Assemble the load cell and aluminum strut from your lab kit.



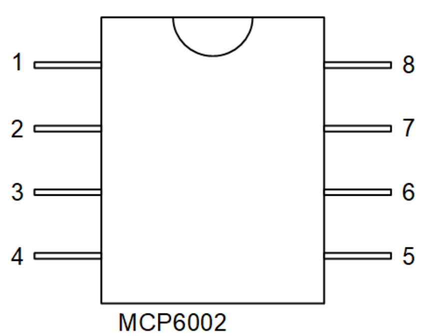
 

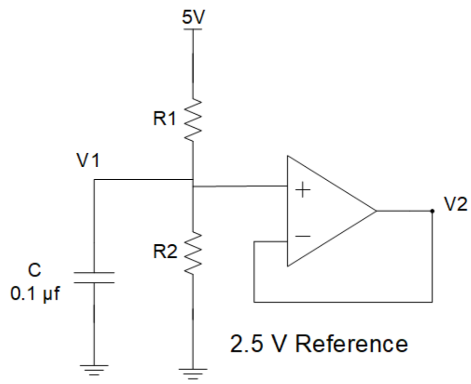
2. Mount the aluminum strut on the benchtop fixture for weight mounting.

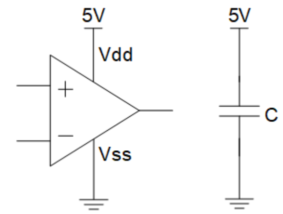


Exercise 2: 2.5 V reference circuit

1. Download the datasheet for the MCP6002 op amp and draw the pin out in the space below. Identify pins for V+, V-, Vout, Vdd (power supply), Vss (ground).
2. Using the 2.5 V reference circuit below, select values for R1 and R2 to provide an output of 2.5 V.
3. Build this circuit. Be sure to include a 0.1 µf capacitor between power supply and ground near the power pins of the op amp. Measure the value of V1 and V2 using the AD2 oscilloscope.



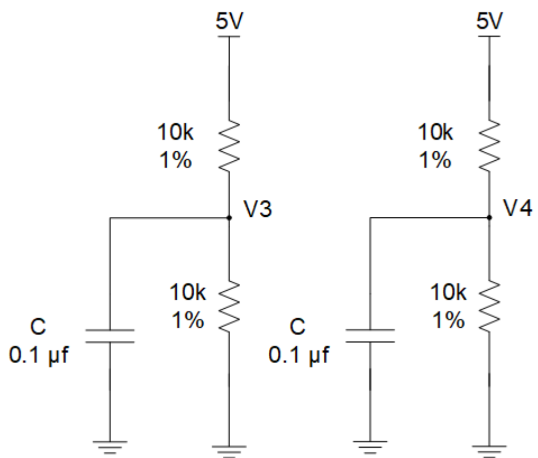




Check point: V2 should provide a steady output near 2.5V (within 50 mV)

Exercise 3: Mock strain gauge

1. Make a mock strain gauge using 4 precision 1% 10 k resistors and two capacitors as shown.
2. Use the AD2 to measure the voltage at V3 and V4.
3. Our goal is to make V3 and V4 ~2.5 V and make 1 mV < |V3 - V4| < 10 mV. If |V3 - V4| is outside of this range, then try switching resistors until |V3 - V4| is in range. Additionally, add small resistors (e.g. 100 ohm) in series or large resistors (e.g. 1 M) in parallel until |V3 - V4| is within this range.



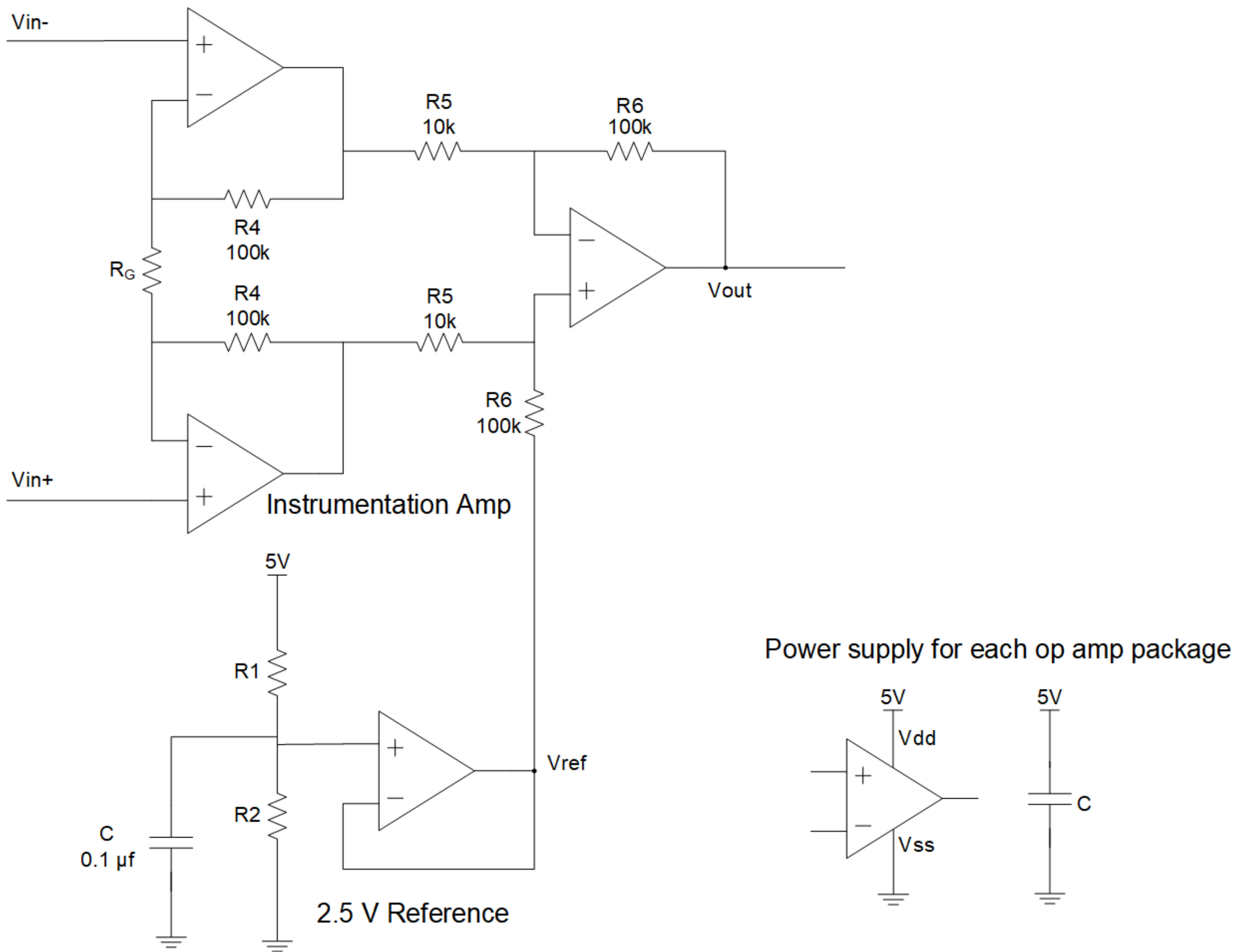
Check point: |V3 - V4| should be between 1 mV and 10 mV

Alternatively, without building a mock strain gauge, use the two outlets of a power supply (with voltage divider, if the power supply cannot output <10mV) as Vin- and Vin+ in the instrumentation amplifier. **Note** that this power supply should **NOT** connect to op-amp Vdd or Vss. For example, op-amp 5V from benchtop power supply, AD2 V+/V- as Vin+/Vin-. Do not share AD2 ground and benchtop power supply ground.

Exercise 4: Instrumentation amplifier

1. The following instrumentation amplifier is used to amplify signals from a Wheatstone bridge (see circuit on next page). Derive Vout/Vin as a function of Vin+, Vin-, Vref, R4, R5, R6, and R_G.

Expression for Vout = ____



2. Select a value of R_G to achieve a theoretical gain of 210.

R_G = ____

3. Build this circuit on a breadboard with the 2.5 V reference circuit from Exercise 2. Be sure to power each op amp package and include a 0.1 µf capacitor between power supply and ground near the power pins.
4. Connect the mock strain gage to the input of the instrumentation amplifier at Vin+ and Vin-. Measure the voltage at Vout when the differential input signal is 0 mV and 10 mV. Estimate the total input offset of the instrumentation amplifier. Calculate the overall differential gain.

Vout(Vin = 0 mV) = ____

Vout(Vin = 10 mV) = ____

Total input offset = ____

Differential gain = ____

5. Connect the actual load cell to the instrumentation amplifier. Measure the voltages at Vin+, Vin-, and Vout with no load. Add a 2 kg load to the load cell. Again, measure Vin+, Vin-, and Vout.

No-load output = ____

Maximum-load output = ____

6. If either the no-load or maximum-load output is saturated (e.g. near 0V or 5V), then the 2.5 V reference needs to be adjusted. Adjust Vref (via changing R1 and R2) to ensure both the no-load output and maximum-load output are between 0.5 V and 4.5 V. Ideally close to 2.5 V.

Check point: From no-load to maximum-load, |Vin+ - Vin-| should change by ~2 mV, while Vout should change by ~400 mV. The value of Vout should be between 0.5 V and 4.5 V, ideally close to 2.5 V.

Exercise 5: Output amplifier

1. Based on the no-load and maximum-load output, design an op amp circuit to offset and amplify the signal from the instrumentation amplifier so that the no-load and maximum-load output signal ranges between 0.5 V to 2.5 V. Select values for the following resistors.

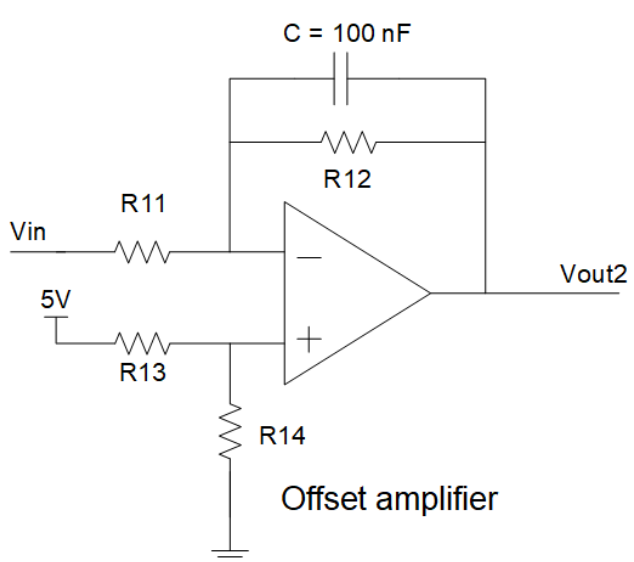
Desired differential gain = _______________________________

R11 = ____

R12 = ____

R13 = ____

R14 = ____



Check point: No-load output should be ~2.5V, maximum-load output should be ~0.5V

Exercise 6: Acquire data from load cell using C#

1. Ensure the no-load output and maximum-load output are both <2.5V
2. Similar to before, connect the output of the thermistor to an analog input port on the MSP430FR5739
    a. Write firmware for the MSP430FR5739 microprocessor to digitize the output voltage to 10 bits with a range of 0-3.6 V. 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

3. Write a C# program to re-assemble the MS5B and LS5B into a 10-bit number.
4. Write code to display the latest data point in textboxes and display the data stream using the graphing objects.

Exercise 7: Calibrate load cell

1. Use your load cell to measure objects that are <2 kg and have reasonably accurately known masses. Weight sets are available in the lab.
2. Take several measurements for each object. Graph and fit a function to this data.
3. Use the equation of fit function to determine a relationship between measured output and masses between 0 and 2 kg.

Exercise 8: Build a C# based UI for your weight scale

1. Modify your C# program from Exercise 6 to display weight instead of ADC values. Using the relationship developed in Exercise 7 to convert ADC values to weight.
    a. Note: The LS5B values may be noisy compared to the MS5B values and this may cause the combined 10-bit number to vary. By taking a rolling average of the past couple hundred combined bytes a more stable result can be obtained.
2. Add a tare function to zero your measurement baseline. For example, with no weights, hit tare to make the output zero. Next, add 500 g mass, and the output should report 0.5 kg.
3. Weight scales typically assess whether measurements are stable before reporting the result as valid. Add a signal processing function to continuously measure data variability over the past 500 ms. Indicate to the user when the measurement is stable.
4. Design a user interface to display and graph the data. Use your creativity and artistic sense to improve the overall look and feel.

Part 2 check-off and lab report

1. Demonstrate your Exercises 6-8 to the TA. Show 10-bit ADC data, reported weight value, tare functionality and stable indicator in your C# program. And demonstrate measurements of 3 known weights, randomly selected from 0-2kg.
2. Write a lab report describing the lab exercises 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.