

Chapter 5

Final Project

5.1 Section Overview

The final project is to monitor an environment for a period of time, and then analyze the data collected. It is entirely self-designed, but should be related to your major. An operational amplifier must be used to expand the output range of the sensor circuit, increasing the clarity of the results.

5.2 Procedure

In this section, the following items will be covered.

1. Amplifying the output of a sensor
2. Final project

5.2.1 Amplifying the Sensor Output

This section is designed to help build basic understanding of operational amplifiers, such as what is shown in Figure 5.1. Operational amplifiers (op-amps) are differential amplifiers, meaning that the output is the difference between the inputs. A basic operational amplifier enables mathematical difference operation and can be modified to perform addition, integration and differentiation. It is designated as 'operational' because it can be used as a building block to perform several mathematical operations.

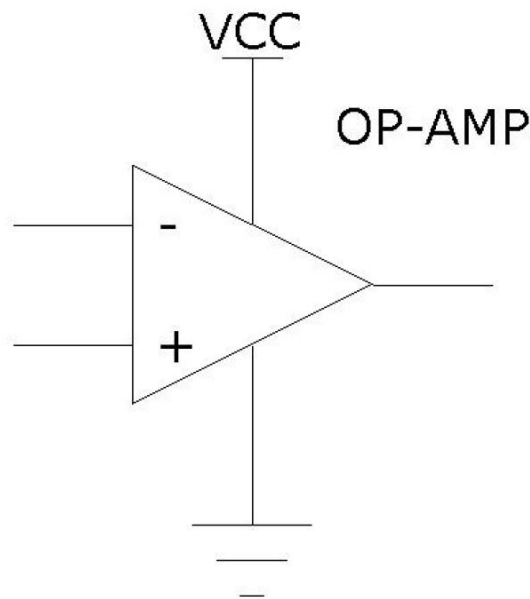


Figure 5.1: This is the symbol for an operational amplifier

In this lab the op-amp will be an inverting amplifier that converts a narrow set of input voltages into a larger range of output voltages, allowing for precise measurements from the data logger. This section walks through setting up the TS912 op-amp for a sensor circuit. Apply this knowledge to the values and ranges specific to the final project. The final schematic for this lab will look like the one in Figure 5.2.

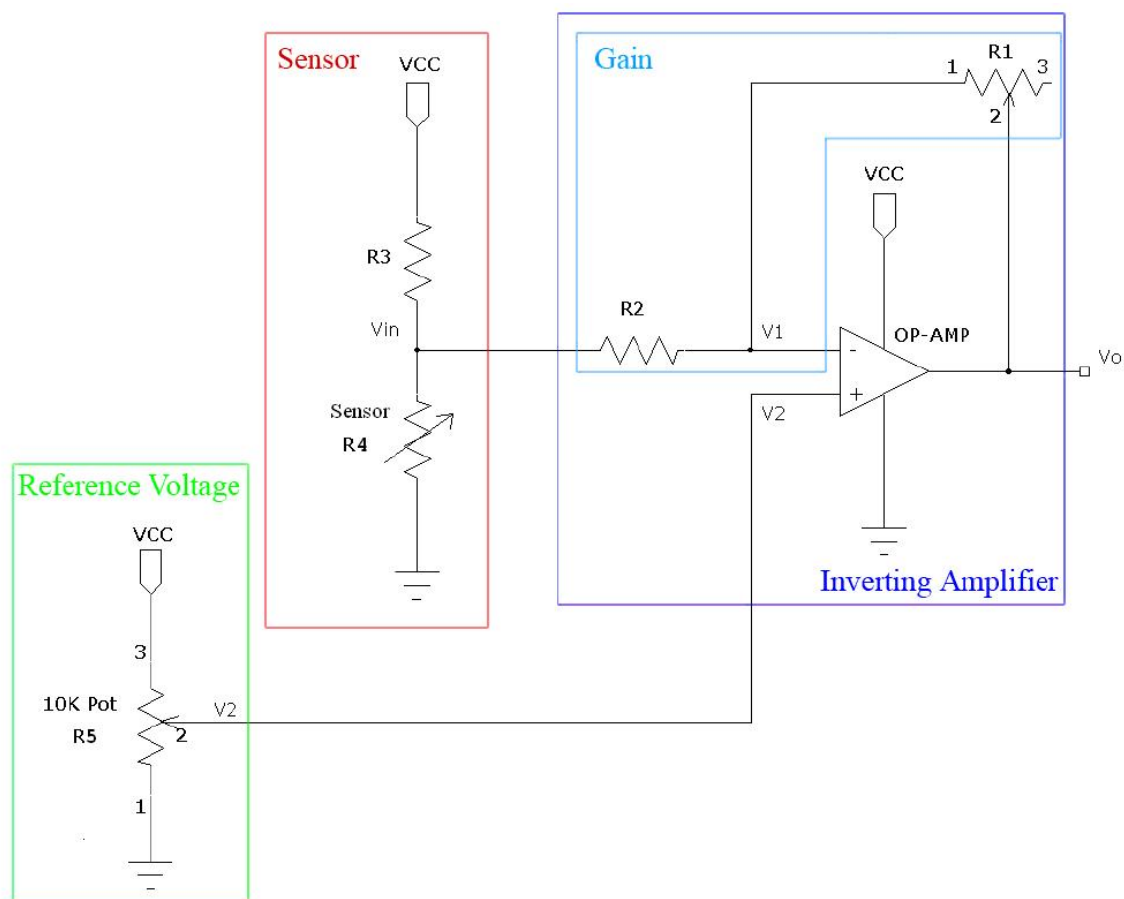


Figure 5.2: This is the schematic for the operational amplifier in ENGR 201

Notice these features of Figure 5.2:

1. The sensor circuit (the red block) is a voltage divider that provides the input voltage into the inverting amplifier.
2. The gain (A) is defined by $\frac{R1}{R2}$.
3. The difference between the reference voltage at V_2 and the voltage at V_1 is multiplied by the gain to give the proper output voltage (V_o).

5.2.2 Calculate the reference voltage and gain

Find the reference voltage and gain needed to produce the correct output. Start by finding a general equation for V_o . Figure 5.3 shows the schematic for the inverting amplifier connected to the sensor. The solution is shown below; be sure to understand it and substitute the particular sensor endpoints in order to calculate an appropriate V_2 and gain.

Use this process to find V_o :

1. Write the node voltage equation for V_1 , refer to Figure 5.3.

$$I_{in} = I_{out} \quad (5.1)$$

$$\frac{V_{in} - V_1}{R_2} = \frac{V_1 - V_o}{R_1} \quad (5.2)$$

2. Solve the node voltage equation for V_o . Use the following equations to further simplify the result:

$$A_V = \frac{R_1}{R_2} = Gain \quad V_1 = V_2 \quad (5.3)$$

Solution:

$$\frac{R_1}{R_2}(V_{in} - V_1) = V_1 - V_o \quad (5.4)$$

$$V_o = V_1 - \frac{R_1}{R_2}(V_{in} - V_1) \quad (5.5)$$

$$V_o = \left(1 + \frac{R_1}{R_2}\right)V_1 - \frac{R_1}{R_2} * V_{in} \quad (5.6)$$

$$V_o = (1 + A_V)V_1 - A_V * V_{in} \quad (5.7)$$

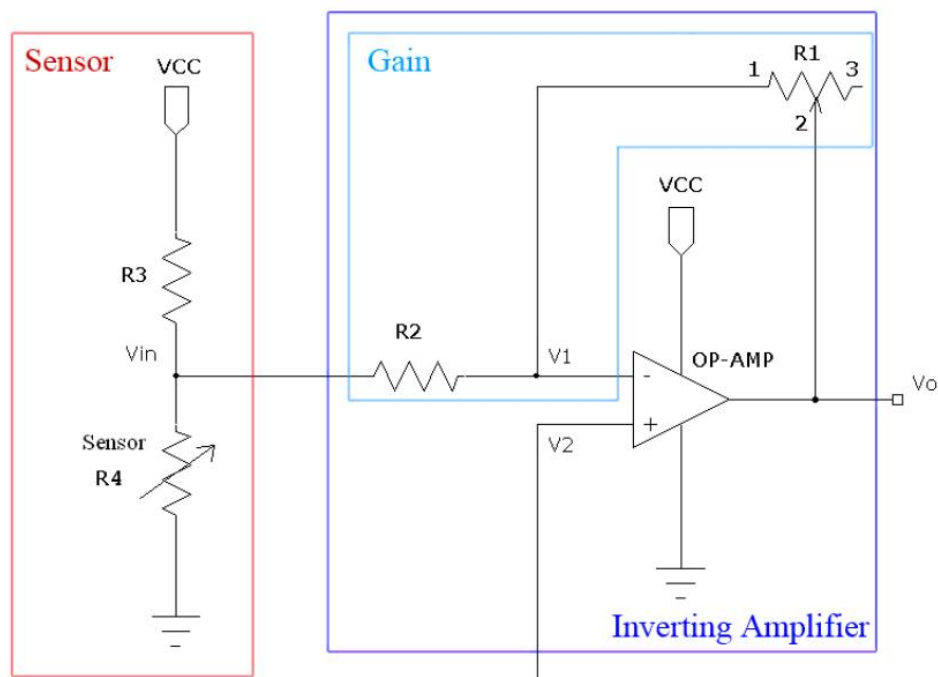


Figure 5.3: This highlights the two adjustable sections, reference voltage and gain, of the operational amplifier circuit

3. Decide on a range for the output voltage. Although an ideal op-amp can output voltage as high as Vcc and as low as ground, real world op-amps cannot. Choose a range near Vcc and ground. For example, Vcc is 5V, which it is not, and ground is at 0V, then an appropriate range might be 0.1V to 4.9V (DONT USE THIS RANGE- it is an example).

$V_{out-low}$ -----

$V_{out-high}$ -----

4. Set up a resistive sensor for this project, add a sensor and a fixed resistor in series. Determine the exact range of V_{in} , using the range of temperature, light, or strain that is specific to the project (similar to lab 4).

$$V_{in-low} \text{ -----} \qquad V_{in-high} \text{ -----}$$

5. Substitute the extreme values of V_o and V_{in} , and subtract the two equations. Solve for the gain.



Remember that this is an inverting amplifier: when V_{in} is low, V_o is high.

Solution:

$$V_{0-high} = (1 + A_V)V_1 - A_V * V_{in-low} \quad (5.8)$$

$$V_{0-low} = (1 + A_V)V_1 - A_V * V_{in-high} \quad (5.9)$$

Difference:

$$V_{0-high} - V_{0-low} = -A_V * (V_{in-low} - V_{in-high}) \quad (5.10)$$

$$(V_{0-high} - V_{0-low}) = (V_{in-high} - V_{in-low}) * A_V \quad (5.11)$$

$$A_V = \frac{V_{0-high} - V_{0-low}}{V_{in-high} - V_{in-low}} \quad (5.12)$$

A_V (gain) = -----

6. Using gain, solve for V_2 (hint: V_1 and V_2 are equal).

$$V_{0-high} = (1 + A_V)V_1 - A_V * V_{in-low} \quad (5.13)$$

$$V_{0-high} + A_V V_{in-low} = (1 + A_V)V_2 \quad (5.14)$$

$$V_2 = \frac{V_{0-high} + A_V V_{in-low}}{1 + A_V} \quad (5.15)$$

V_2 (reference voltage) = -----

5.2.3 Building the ENGR201.0 board

The ENGR201.0 op-amp board is designed specifically for this project. Many students will find it necessary to collect data outside of the lab, but do not have their own protoboard. The op-amp board contains everything necessary for the project in place of a protoboard. Use the time provided in the lab to solder the board together and calibrate it before collecting data outside of lab.

Examine the ENGR201.0 board, shown in Figure 5.4.

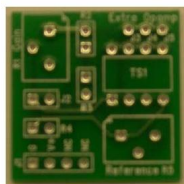


Figure 5.4: This is the PCB for operational amplifier circuit

The board lays out the same schematic from Figure 5.2. The 'Op-amp board guide' on the webpage diagrams each section and will aid in understanding the board. Begin by soldering the components from the sensor kit to the board, as follows:

1. Locate the op-amp chip, the TS912. It is a black integrated circuit with 8 pins. Notice that on the top surface (the side with the writing on it), there is a small, circular indentation above a corner pin. Place the chip into TS1 such that the circular indentation lines up with the square pinhole on the board. The chip will be on the same side of the board as the outlines and labels. Solder each of the pins securely to the board.



To double check that the chip is orientated correctly, take a look at the 'TS912 OP-Amp Datasheet' located on the lab website.

2. Place the two potentiometers (see Figure 5.5) in positions R1 and R. Solder all three pins on each potentiometer.



If using the strain gauge in the experiment, the required gain is larger than can be achieved using the lab kit potentiometers. A fixed resistor must be used instead.



A potentiometer is another type of variable resistor. Unlike the thermistors and photocell, the potentiometer does not change resistance based on its environment. Instead, the small white knob on the front of the potentiometer may be rotated to increase or decrease the observed resistance. On these particular potentiometers, the resistance between the two outer pins is constant at 10 k Ω . The middle pin is adjusted such that the resistance between it and either outer pin is between 0 and 10 k Ω . Hence, using all three pins it behaves like a voltage divider, with the output at the middle pin.

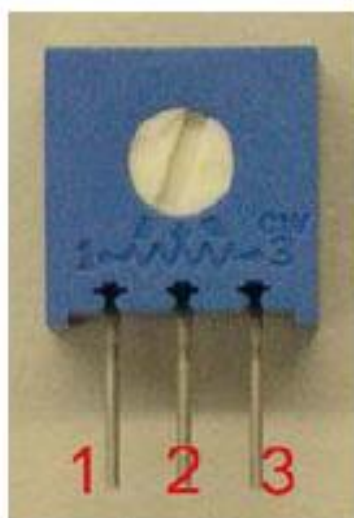


Figure 5.5: This is a potentiometer, a variable resistor

3. As explained in the ‘Op-amp board guide,’ the resistor R_2 is fixed and helps to control the gain of the op-amp. Make R_2 a $1\text{ k}\Omega$ resistor, and then apply the equation for the gain to determine what resistance R_1 should be in the circuit (recall that the gain was calculated earlier). Record the values below:

R_1 ----- R_2 -----

4. Solder a $1\text{ k}\Omega$ resistor into R_2 . Keep it as close to the board as possible, and clip the excess wire afterwards.
5. Given the calculated value of R_1 , set the potentiometer appropriately. Figure 5.5 shows a potentiometer (pot), with the pin-outs labeled. Connect a multimeter to the two leftmost pins of the pot and rotate the dial using a screwdriver or fingernail until it outputs the calculated resistance. R_1 is the resistance between these two pins; the third pin does not connect to anything.



As mentioned previously, if using the strain gauge R_1 should be a fixed resistor instead of a pot to achieve a gain of approximately 1000.



It is not important to try and match the resistor values perfectly to the calculated gain, since there is too much error in other areas of the circuit. (For example, the resistors in this kit can be 5% of the stated value).

6. The reference voltage, V_2 , is also set by a potentiometer. The center pin of R_5 should output the desired voltage when connected to a 3.3 volt source. Use the power supply to provide this V_{cc} to the board (connect the probes to the pins labeled V_+ and G), and probe the center pin using a voltmeter. Turn the center dial on the potentiometer until the value of volts that was calculated earlier is reached.
7. For the remaining resistors, R_3 and R_4 , use the resistive sensor that is specific to the project. These must be the two components used in step 4 of the ‘Calculate the reference voltage and gain’ section above, and they must be oriented as they were when the range for the input voltages to the op-amp was calculated.
8. To be able to reuse the ENGR201.0 board for other projects outside of this lab, with different resistive sensors, it is best to solder female headers into R_3 and R_4 such that the voltage divider may be easily removed and replaced without soldering. These may be purchased from the IEEE store for less than a dollar, but are not

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necessary for the project. If not using headers, solder the two resistors directly onto the board being careful to keep them close to the surface.

9. In order to connect the ENGR201.0 board to the DataLogger to record samples, solder three pieces of wire onto the board in the following locations:

‘G’ on the op-amp board goes to ‘GND’ on the DataLogger.

‘V+’ on the board goes to ‘V+’ on the DataLogger.

The positive terminal at J2 (i.e. the square pin from J2) on the board goes to IN1 on the DataLogger. This is the output of the op-amp, which is being sampled.

Testing with the oscilloscope:

1. To ensure that the op-amp is properly configured, use two oscilloscope cables to measure V_{in} and V_{out} simultaneously with reference to ground.
2. Power the circuit by setting the power supply to 3.3V and connecting the micro-grabbers to ‘V+’ and ‘G’ on the op-amp board.
3. Turn on the oscilloscope and observe the waveform behavior.
4. At initial test conditions the input and output voltages should be less than 3.3V and greater than 0V.
5. If the output voltage is 0V or 3.3V increase or decrease V_2 respectively by adjusting R4 until the signal is approximately 1.65V at initial conditions.
6. Introduce the sensor to the minimum and maximum conditions that may be experienced during testing.
7. If the output voltage does not vary to the desired maximum and minimum voltage range, increase the gain. If the output voltage becomes fixed at 3.3V or 0V, decrease the gain.

5.3 Implement the Final Project

Now that the circuit is calibrated for testing, implement a final project by designing a sensor circuit using the theoretical concepts learned this term and the DataLogger. Show a personally-designed circuit to the TA before collecting data.

The objectives for the final project are:

1. Use an operational amplifier to calibrate and optimize the output of the resistive sensor. In the report, the calculations for reference voltage and gain must be included. Review ‘Amplifying the Sensor Output’ to assist with this.
2. Go ‘into the field’ for a period of time (about an hour if during lab, or up to several days depending on the project), and collect data using this new circuit.
3. Collect data on anything that relates to your field. Strain gauges are also available in addition to the thermistors and photocells.
4. When done collecting data, go back to the lab and import the data into the computer.
5. Graph the changes that occurred during the collection time.
6. If a unique experiment cannot be devised, possible projects are listed at the end of the section.

5.4 Lab Report

Write a clear and concise report. Turn in the typed report following the second week of this lab. The report should include the following:

1. The type of data collected, where it was collected, and any conclusions that can be drawn from the data.
2. Any graphs that might help to display changes in the measurements. Check that the graphs are properly labeled with titles, correct axes and correct scale.
3. A schematic drawing of the sensor circuit used (using LTSpice or a similar program).
4. The OpenChoice waveform that shows the circuit was properly calibrated and the inverting nature of the op-amp.
5. A simulation showing the output and input voltages produced by sweeping a variable resistance to simulate the experiment.
6. A written explanation of the graphs and the data received (along with equations that were used to calculate the final and intermediate values). Be aware that there is some error in DataLogger measurements.
7. Explain how the lab relates to your discipline and where you might be able to use some of the information learned in lab. (Be as specific as possible, citing real-life examples)

Current guidelines and an example lab report are available on the lab website.

5.5 Challenge

Challenges can be completed for extra credit. This credit can be used to replace missing lab points, or to improve overall class grade.

3 points - For this project, a significant effort to bring innovation to a project will be awarded with extra points from the TA.