ELECTRICAL ENGINEERING DEPARTMENT / CAL POLY STATE UNIVERSITY

EE143 Lab #7a

Building and Testing a Practical Current Source to Use with a Sensor

PRELAB:

Consider the Op Amp circuit shown in Figure 1. Assume the Op Amp output is not saturated. Note the node voltage labelled V1 in the schematic.

1) What is the voltage at the noninverting input of the Op Amp, in terms of (or given) V1?
2) What is the load current, in terms of V1?
3) What is the sensor voltage Vs, in terms of V1?
4) In terms of V1 and A0, what is the resistance of R_SENSOR in Ohms?

PURPOSE:

- To verify Op Amp operation as predicted by theory
- To learn about practical limitations of an Op Amp
- To gain further practice bread boarding circuits, this time involving an Op Amp
- To develop proper laboratory procedures relative to collecting, recording, and analyzing data.

This experiment relates to the following course learning objectives:

1. Acquire practice in recording data and results.
2. Ability to relate practical laboratory results with lecture theory.
3. Ability to analyze and evaluate data.

STUDENT PROVIDED EQUIPMENT:

1 Arduino
1 LM358 Op Amp
1 Breadboard
1 10kΩ potentiometer
1 20kΩ 1⁄4 Watt Resistor   1 820Ω 1⁄4 Watt Resistor
Miscellaneous Resistors between 100-5kΩ

BACKGROUND:

Current sources are useful in a variety of applications including LED lighting and battery chargers. They are also helpful when interfacing to resistive sensors (such as a thermistor). When used to supply current through a resistive sensor the voltage across the sensor is directly proportional to resistance. This is not the case when using a constant voltage source with a voltage divider circuit (as was done in Experiment #3 with a thermistor). See Figures 1 and 2. Having a voltage that is directly proportional permits the sensitivity of the measurement to remain constant over a wide range of resistance values for the sensor. This is not the case for the voltage divider circuit, as we discuss further, in Table 1.

Recall that the Arduino's A/D provides an integer 10-bit value. Since the A/D value is an integer we have no knowledge of true (analog) signal values that are in the range of +/- 0.5 counts. Hence, we may be curious about the "sensitivity" of a given circuit. In other words, how much the count changes relative to the change in resistance of the sensor. This sensitivity differs for the approach using a current source versus using a voltage divider circuit. The "Delta Count / Delta Ohm" columns of Table 1 describe the sensitivity for the two approaches.

As seen in Table 1, the "A/D Count via I Source" shows values for the count in a low, middle and high range. Given this count and using the current source approach, the R_SENSOR value may be computed, as shown in the second column. Given that R_SENSOR value, the corresponding A/D count using a voltage divider circuit is shown next. (The counts vary because the circuits are different). These three columns allow us to compare changes in counts versus changes in sensor values (in Ohms), for the two approaches.

Table 1. Sensitivity of Measurement Circuits to Changes in Sensor Resistance

A/D Count Via I Source	R_SENSOR Via I Source	A/D Count Via V Source	Sensitivity Delta Count / Delta Ohm Via I Source	Sensitivity Delta Count / Delta Ohm Via V Source
100	15.8	164.8	1.02	8.69
101	16.7	173.3	1.02	8.52
102	17.7	181.7	1.02	8.36
103	18.7	189.8	1.02	8.20
104	19.7	197.9		
500	406.8	851.4	1.02	0.35
501	407.7	851.7	1.02	0.35
502	408.7	852.1	1.02	0.35
503	409.7	852.4	1.02	0.35
504	410.7	852.7		
1019	914.1	938.8	1.02	0.08
1020	915.1	938.9	1.02	0.08
1021	916.0	938.9	1.02	0.08
1022	917.0	939.0	1.02	0.08
1023	918.0	939.1		

Note the sensitivity for the current source is constant across all ranges of the measurement. Compare this to the voltage divider approach. In the lower range of measurements, the sensitivity is eight times higher than the current source. This is great! A change in resistance of 1 Ohm would cause a change of 8 counts. However, at the middle and high ranges of the measurement, the change in count less than 1, for a change in resistance of 1 Ohm. Thus, the sensitivity varies considerably for the voltage divider approach.

Note, for Table 1 and referring to Figure 1, Rs = 82 Ohms and the current source is set to 5 mA. The voltage divider was assumed to have a 5 V source and a resistor, Rs, in series with the sensor (Figure 2).

The current source built in this lab is a simple one, involving just an Op Amp. Other common designs use an Op Amp (to monitor and adjust the amount of current) and a power transistor (to regulate the current flow). In our design the Op Amp both monitors the amount of current and supplies the current to the load. Our design is simpler than other approaches but is also more limited in the range of currents it can supply, due to Op Amp limitations. The LM358 has a maximum current output of 40 mA. Also note that its maximum output voltage is approximately 1.4 V below Vcc – this limits the maximum voltage that the current source can generate.

This current source is able to maintain a constant current thanks to the virtual short that results from the feedback connection. The voltage at the non-inverting input, Vp, is fixed by the potentiometer. With a virtual short, the voltage V1 is held at a value equal to Vp. The load current is thus V1/820.

PROCEDURE and ANALYSIS:

1. Build the circuit shown in Figure 1. Use one of the Op Amps in the LM358. Only two connections are needed for the potentiometer, the middle wiper and one end. Leave the third connection open.
2. Select a resistor to use for the "sensor" and install it in your circuit. You may use your thermistor, or any other resistor in the range of 100 <= R <= 5000 Ohms.
3. Power up the Arduino and connect 5V and GND to the breadboard.
4. Measure the current through the R_SENSOR and adjust the potentiometer to obtain a value for the current of 0.5 mA. Complete the entries in Table 2.

Table 2. Nominal Conditions of Current Source

R_SENSOR (Ohms)	
Measured value of 820 Ohm resistor (Ohms)	
Voltage V1 (Volts), with the load current adjusted to 0.5 mA	
Voltage at the non-inverting input of the Op Amp (Volts), with the load current adjusted to 0.5 mA	

5. Change the resistor used for R_SENSOR and measure the current through it. Select resistor values in the range of 100 <= R <= 5000 Ohms. Your selection may vary depending on resistors available in your parts kit. You can combine resistors in series to create additional cases. Record data in Table 3.
6. For Case 6 in Table 3, replace R_SENSE with a wire and measure the load current
7. For Case 7, experiment with larger resistor values and find one that results in the current source failing to maintain the desired 0.5 mA.

Table 3. Consistency and limitations of Constant Current Source

Case	R_SENSOR (Ohms)	Load current (mA)	% Error in load current
1			
2			
3			
4			
5			
6	Zero Ohms		
7			

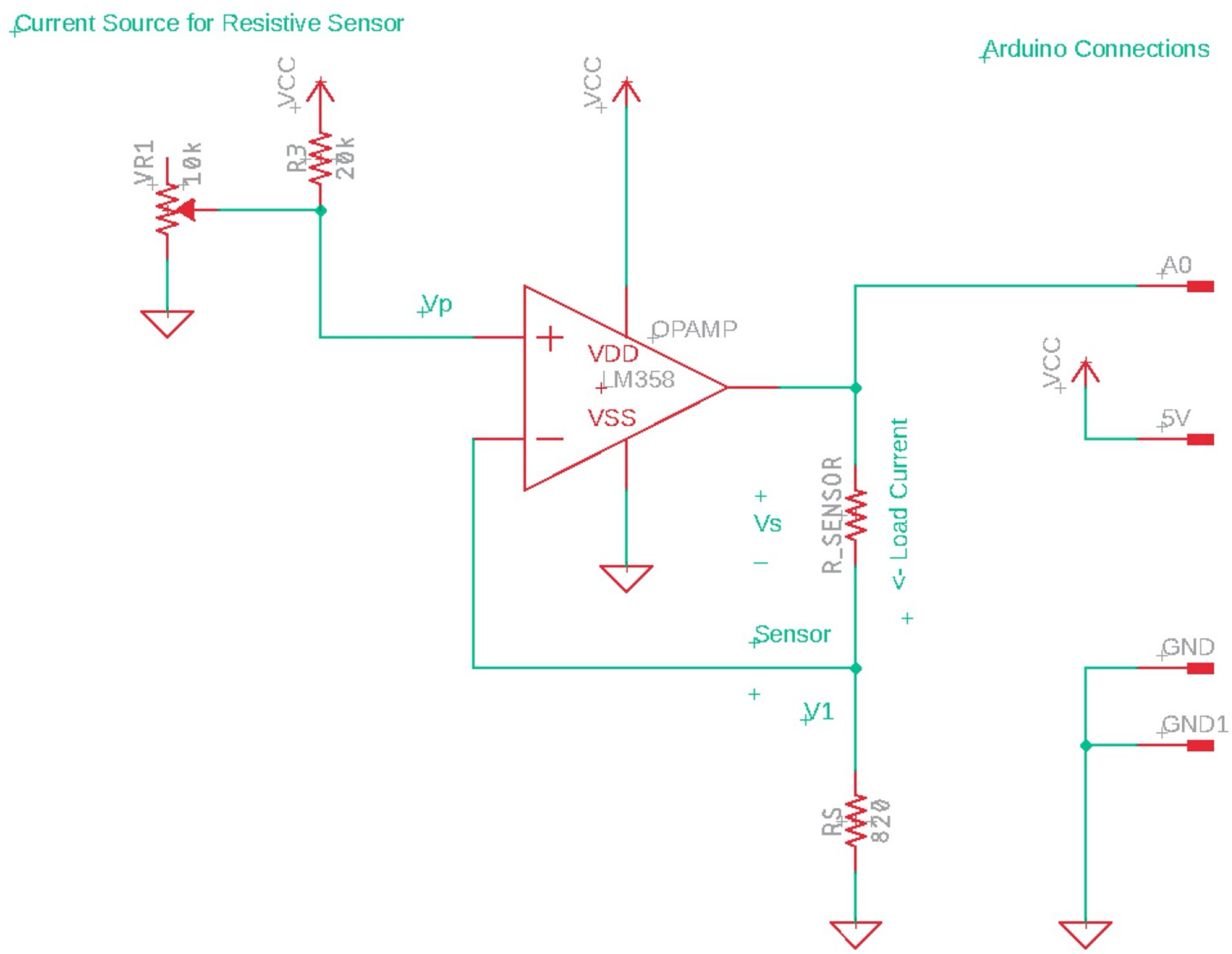

Figure 1. Current Source for Sensor Measurement

DISCUSSION:

Consider the change in A/D count for the case of your circuit with the current source set at 0.5mA, versus using the voltage divider of Figure 2. Use Rs = 820 Ohms. Find the A/D count for the two cases below. Would the given change in resistance result in a change in count of approximately one for the approach with the current source? Would it result in a change in count of approximately one for the voltage source?

A/D Count	**R_SENSOR**	**A/D Count**
via I Source		**via V Divider**
	4060 Ohms	
	4070 Ohms	

Hint for the current source: The analog voltage read by the A/D is determined by both the 820 Ohm resistor and R_SENSOR. When the A0 voltage is zero the A/D reads a count of 0, and when A0 = 5V the A/D reads 1023.

Hint for the voltage divider: A0 = (5) (R_SENSOR) / (R_SENSOR + 820)

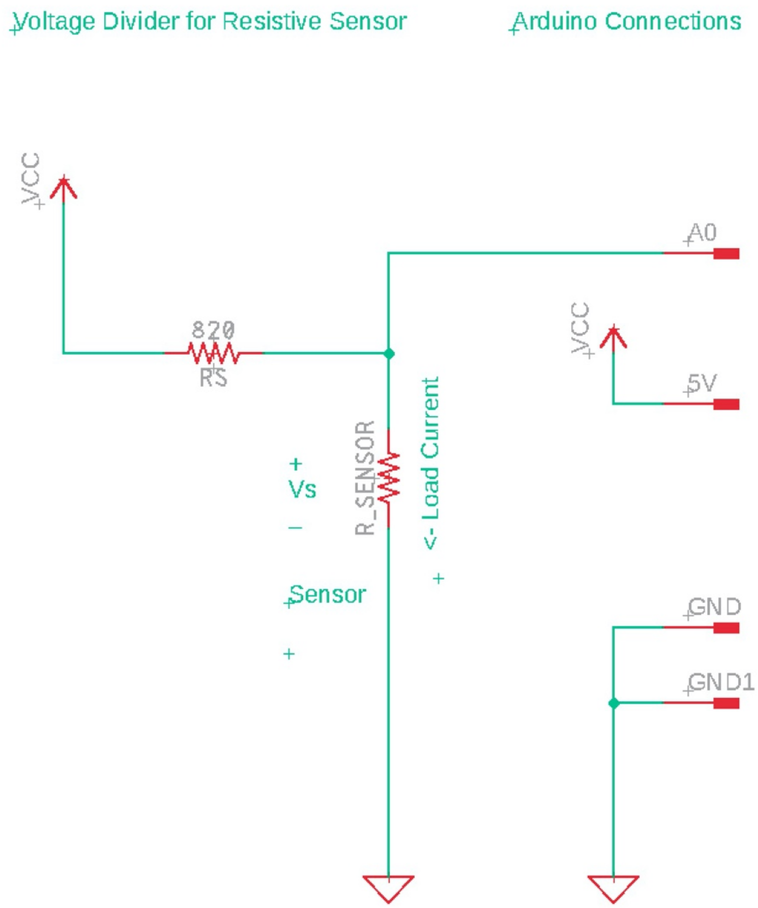

Figure 2. Voltage Divider for Sensor Measurement