ME4405 - Fundamentals of Mechatronics (Fall 2019)

Lab Assignment One

Sensors and Signal Conditioning

Due Thursday, September 5th, 2019

Objective: The main objective of this lab is to acquire experience in circuit prototyping and soldering, and to improve your understanding of signal conditioning circuits. The lab also covers use of lab equipment such as power supplies, digital multimeters, and oscilloscopes.

Deliverables and Grading:

To get credit for this lab assignment you must:

1) Demonstrate operation of your circuit to Dr. Hammond during office hours or to the lab TA during the TA office hours (located at the Mechatronics lab). You must demonstrate your circuit **prior to** the due date to receive credit. **(30 points)**

2) Turn in a typed report answering the questions at the end of the lab (four pages max, can be shorter). This is due by 5pm on the above due date. **(30 points)**

Required Hardware:

- LM34 Fahrenheit temperature sensor
- LM741 Operational Amplifier
- Resistors (0.9kΩ, 1kΩ, and 2kΩ), 10kΩ potentiometers (2), power supply

The circuit used in this Lab is illustrated in Figure 1.

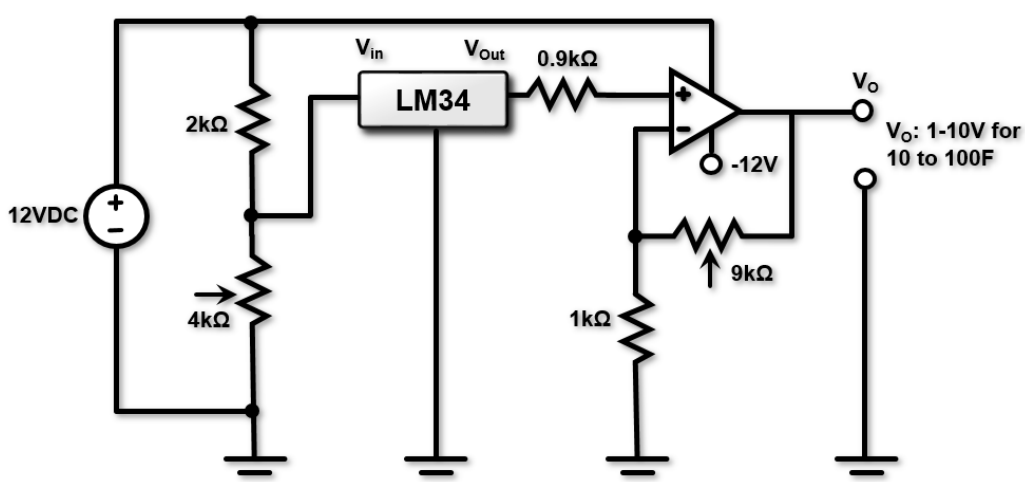

Fig 1: Circuit for LM34 signal conditioning

The circuit shows a voltage divider used to generate a suitable input voltage for the LM34 temperature sensor. The output of the sensor is subjected to amplification using a non-inverting amplifier consisting of an op-amp. The entire circuit is driven from a 12V DC source and the output is scaled to 1 to 10 V corresponding to 10°F to 100°F.

The input to the LM34 IC should be 8V DC. To obtain 8V DC from 12V DC, a voltage divider may be used. The voltage divider in this circuit consists of a resistor and a potentiometer. The output of the voltage divider can be adjusted to 8V DC using the potentiometer. The calculations involving the voltage divider are shown below.

Voltage divider calculations:

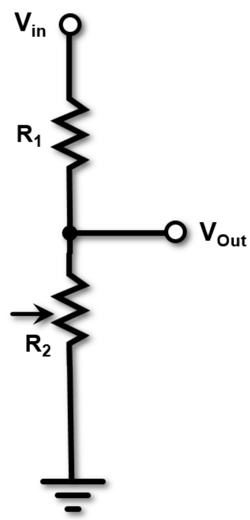

Fig 2: Voltage divider circuit

The output of the voltage divider, shown in figure 2, is the voltage across R_2. To design a voltage divider is to determine the resistor values to create an appropriate drop across R_1 and maintain the output point (point between R_1 and R_2) at the desired potential. The equation describing the input-output relationship between input and output voltages is given by the following equation:

$$V_{out} = \left(\frac{R_2}{R_1 + R_2}\right) V_{in}$$

Here, we have one equation and two unknowns. One typically chooses the value of R_1 and computes the value of R_2. Let the value of R_1 be 2kΩ. Usually the value of R_1 is chosen as a standard resistor value and a potentiometer is used for $R_{2,}$ adjusted to obtain the desired output.

$$(R_1 + R_2)V_{out} = R_2 V_{in}$$

$$R_1 V_{out} = R_2 (V_{in} - V_{out})$$

$$R_2 = \frac{R_1 V_{out}}{(V_{in} - V_{out})}$$

Substituting V_{in}=12V, V_{out}= 8V, R_1= 2kΩ in the above equation for R_2,

$$R_2 = \frac{2k * 8}{(12 - 8)}$$

The value of R_2 is thus 4kΩ. A potentiometer is used for R_2 to achieve this value. Note that use of a potentiometer also allows this value to be adjusted to account for tolerance in R_1.

Signal Conditioning Circuit calculations:

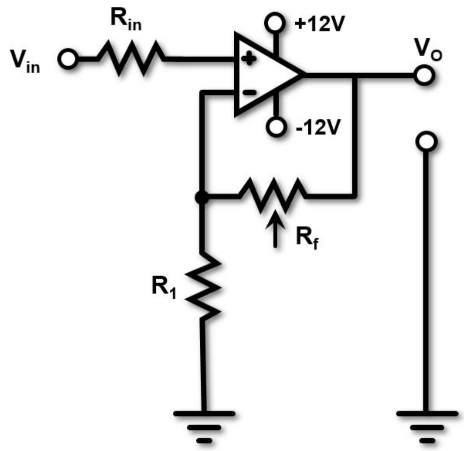

Fig 3: Non-inverting amplifier

Oftentimes, the voltage output of sensors is quite small in amplitude and must be amplified before being read by a microcontroller or data acquisition system. To make sensors compatible with other devices, signal conditioning methods are employed. Signal conditioning may encompass amplification, filtering, or both. Typical signal conditioning circuits consists of op-amp circuits that can be used to amplify signals over a large range of gains, also providing reduced output impedance.

A number of different types of amplifiers can be made using operational amplifiers. The one used here is a non-inverting amplifier as shown in Figure 3. The gain of this amplifier is dependent on the resistor pair in the feedback loop. Let these resistors be R_f and R_1. The gain, G, is given by the following equation:

$$G = \left(1 + \frac{R_f}{R_1}\right)$$

The voltage can thus be calculated as:

$$V_o = G * V_{in}$$

The output of the sensor is linearly proportional to the temperature in Fahrenheit. The temperature sensor LM34 output voltage is 10mV/°F. So, a range of 10°F to 100°F provides an output voltage range of 100mV to 1000mV. In this lab, the amplifier gain is set to 10 so as to give a corresponding output range as 1V to 10V. Similar to the voltage divider, setting the gain is achieved by calculating the values of the resistors in the circuit. Again, we have one equation and two unknowns. Let us choose R_1 to be 1kΩ.

$$G = \left(1 + \frac{R_f}{1k}\right)$$

$$R_f = (10 - 1)1k$$

Thus, we get the value of R_f to be 9kΩ.

A resistor, R_{in}, of value 0.9kΩ is added to the inverting terminal of the op-amp to improve the input impedance of the amplifier. This value is generally computed as the equivalent resistance of the parallel combination of resistors involved in feedback path (R_f and R_1).

Now that all the calculations are completed, the circuit can be soldered and tested. Solder the circuit as shown in Figure 1 and demonstrate its working to the TA or Dr. Hammond. Specifically, you will need to verify that the sensor is powered by the appropriate voltage and that the sensor output voltage is in the appropriate range.

Procedure:

The TA will demonstrate the procedure to solder components to the general purpose PCB. Students should create their circuit and adjust potentiometers to get exactly 8V at the output of the voltage divider circuit. The second potentiometer should be adjusted at 9kΩ. The resulting voltage from the signal conditioning circuit should reflect the ambient temperature in the room.

****** Be careful to ensure that you have identified the correct pins of the LM34 temperature sensor from the data sheet. The data sheet shows the temperature sensor FROM THE BOTTOM in an upright orientation. This is a common mistake - double check your orientation to make sure. ******

Questions:

For the below questions, show all your calculations (**6 points each**):

1. Using the rule above, show that the resistor R_{in} should be selected as 900Ω given the selected values for R_f and R_1.
2. What resistor values should be used for the voltage divider to get 6.67V provided to the sensor if a 10V supply is used?
3. Find a voltage regulator through Digikey, or another electronics supplier, which can take an input of 12VDC and supply the required 8VDC output. Provide the part name and manufacturer of the regulator. What is the maximum current output of the regulator?
4. Calculate the resistor values to set the gain of the non-inverting amplifier at 8 for the same range of temperatures.
5. What gain should you use if you want the output of the amplifier to be 0.4V when measuring a temperature of 10°F? When using this gain, what range of temperatures can be measured if your microcontroller can only read voltages between 500mV and 4.5V?