

# Introduction to Mechatronics (ME/AE 6705)

## Lab Assignment 1

### Sensors and Signal Conditioning

#### 1.1 Objective

The main objective of this lab is to acquire experience in implementing circuits on breadboards and to improve your understanding of signal conditioning circuits. The lab also covers use of lab equipment such as power supplies and digital multimeters.

#### 1.2 Deliverables and Grading

To get credit for this lab assignment you must:

1. Demonstrate proper operation of your circuit to TAs or instructor during office or demo hours. You must demonstrate your circuit prior to the due date specified on Canvas to receive credit. (30 points)
2. Submit a typed report as a PDF file to Canvas, answering the questions at the end of the lab assignment (4 pages max, can be shorter). This is due at the beginning of class on the due date specified on Canvas. (30 points)

#### 1.3 Setup

This lab requires a *breadboard*, a *LM34* analog temperature sensor, an *OPA340* Op-Amp, two  $10k\Omega$  *potentiometers*, two  $1k\Omega$  *resistors*, and a  $820\Omega$  *resistor*.

You will need a power supply to power your circuit. DC power supplies are available in the Mechatronics lab for you to use.

#### 1.4 Problem Statement

Build a signal conditioning circuit to measure the environment temperature using an analog temperature sensor. The sensor is powered on with a 5v supply generated by a voltage divider circuit connected to a power supply. The power supply should be set to operate at 6 VDC. The temperature sensor provides an output voltage of  $10mV$  per  $^{\circ}F$ , which is

amplified using an Op-Amp circuit with a gain of 5 in order to have an output of 0.5V to 5 V corresponding to  $10^{\circ}F$  to  $100^{\circ}F$ . The output of the circuit can be measured using a voltmeter.

More details about the hardware requirements will be discussed in the next sections.

## 1.5 Hardware

### 1.5.1 LM34 Temperature Sensor

The LM34 series devices are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Fahrenheit temperature. It provides an accuracy of  $1.0^{\circ}F$  and a linear  $+10.0mV/^{\circ}F$  scale factor.

The pinout of the sensor in 3-pin TO92 package is shown in Figure 1. Note that Figure 1 shows the pinout in “**Bottom View**”.

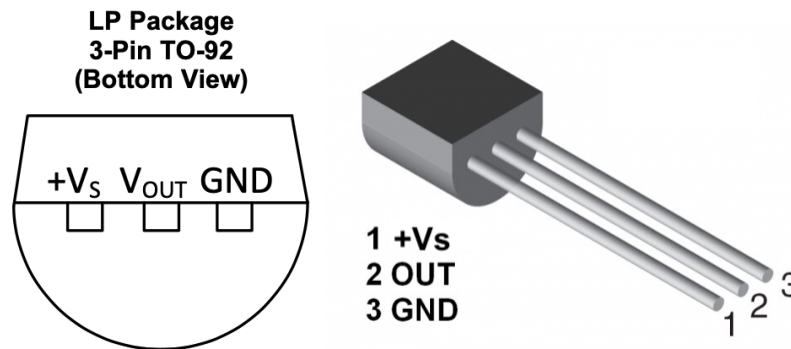


Figure 1: LM34 Pinout.

More details about the LM34 sensor can be found in its datasheet, available at <https://www.ti.com/lit/ds/symlink/lm34.pdf>.

**Warning:** Pay extra attention to the pinout of the LM34 sensor before using it in a circuit. Attaching wrong signals to the sensor pins may damage the sensor. Note that Figure 1 shows the pinout in “**Bottom View**”.

### 1.5.2 OPA340 Op-Amp

The OPA340 series rail-to-rail CMOS operational amplifiers are optimized for low-voltage, single-supply operation.

The pinout of the OPA340 IC in PDIP package is shown in Figure 2.

More details about the OPA340 Op-Amp can be found in its datasheet, available at <https://www.ti.com/lit/ds/symlink/opa340.pdf>.

**OPA340: P and D Packages  
8-Pin PDIP and SOIC  
Top View**

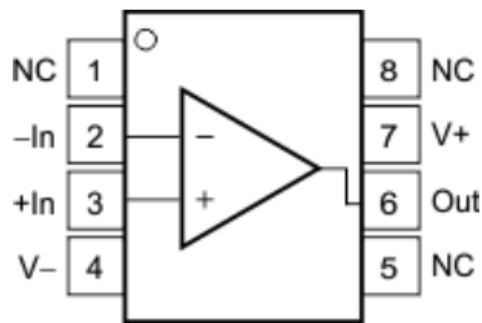


Figure 2: OPA340 Pinout.

### 1.5.3 Potentiometer

Potentiometers are three-terminal mechanically operated rotary analog devices which can be found and used in a large variety of electrical and electronic circuits. They are passive devices, meaning they do not require a power supply or additional circuitry in order to perform their basic linear or rotary position function.

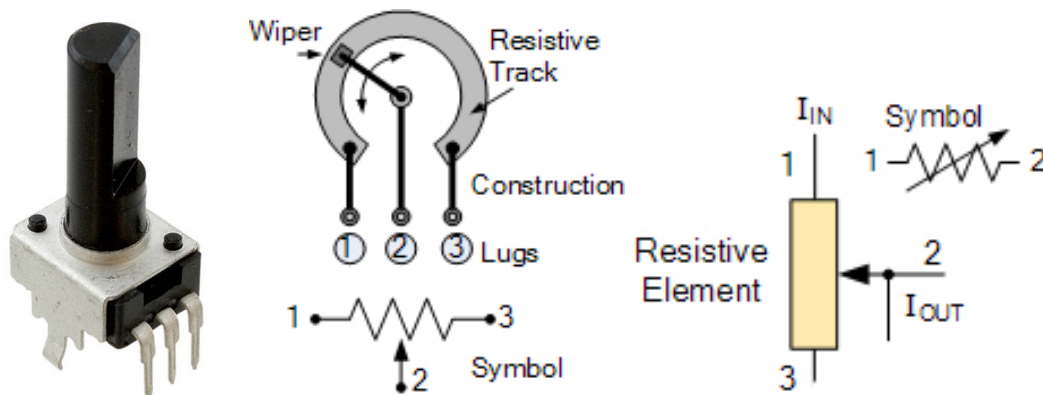


Figure 3: Potentiometer as a variable resistor.

In this lab, we will use potentiometers as “variable resistors”. A variable resistor is a two-wire resistive device that provides an infinite number of resistance values controlling the current offered to the connected circuit in proportion to the physical position of the wiper along the track.

When used as a variable resistor, connections are made to only one end of the resistive track (either pin 1 or pin 3) and the wiper (pin 2) as shown in Figure 3 on the right. The position of the wiper is used to vary or change the amount of effective resistance connected between itself, the movable contact, and the stationary fixed end.

### 1.5.4 Circuit Schematic

The circuit used in this Lab is illustrated in Figure 4.

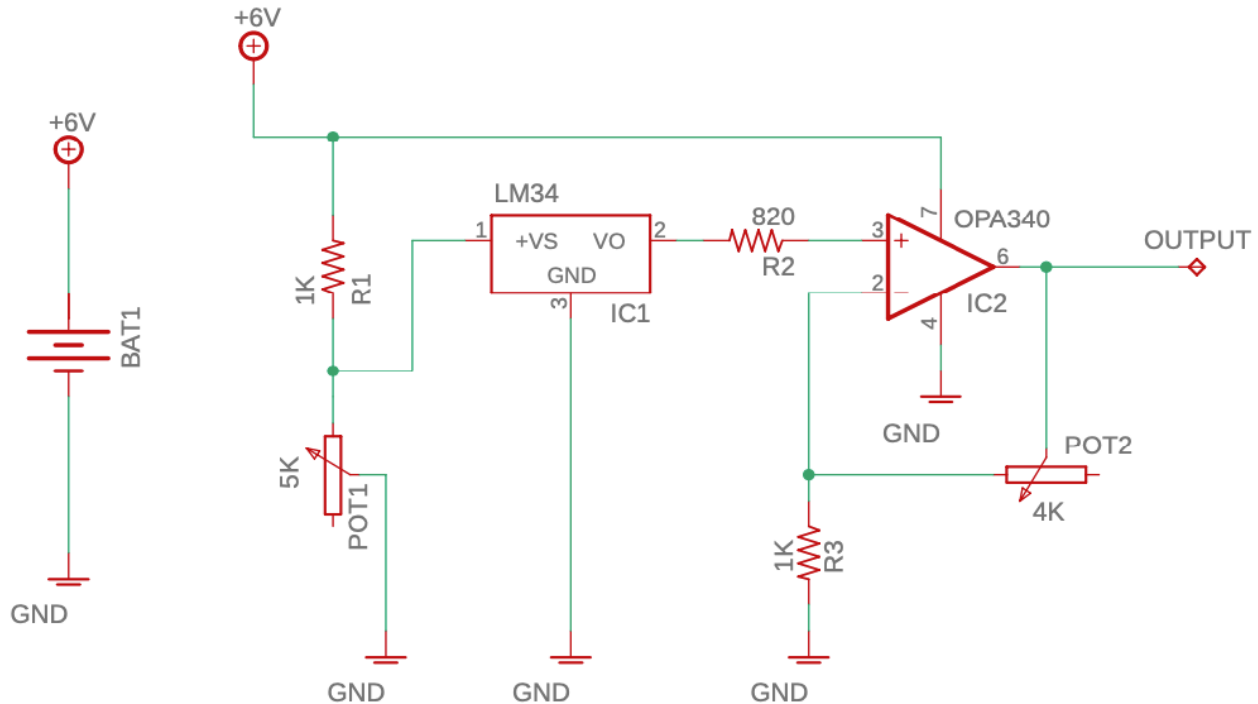


Figure 4: Circuit diagram for LM34 signal conditioning.

The circuit shows a voltage divider used to generate a suitable input voltage (5V) 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 6V DC source (generated from a DC power supply) and the output is scaled to 0.5 to 5 V corresponding to  $10^{\circ}F$  to  $100^{\circ}F$ .

The input to the LM34 IC should be 5V DC. To obtain 5V DC from 6V 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 5V DC using the potentiometer. The calculations involving the voltage divider are shown below.

### 1.5.5 Voltage Divider Calculations

The output of the voltage divider, shown in Figure 5, is the voltage across  $R_2$ . To design a voltage divider is to determine the values of the resistor 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:

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

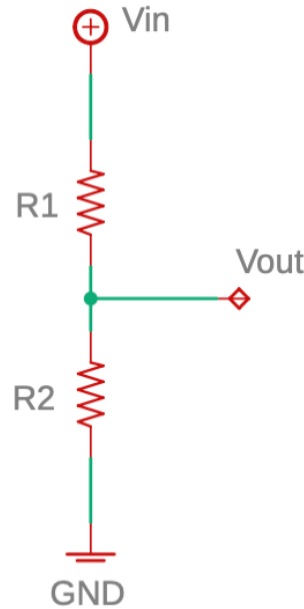


Figure 5: Voltage divider circuit

Here, we have one equation and two unknowns. So, one typically chooses the value of  $R_1$  and computes the value of  $R_2$  from the equation. Let the value of  $R_1$  be  $1k\Omega$ . 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.

$$(R_1 + R_2)V_{out} = R_2V_{in}$$

$$R_1V_{out} = R_2(V_{in} - V_{out})$$

$$R_2 = \frac{R_1V_{out}}{V_{in} - V_{out}}$$

Substituting  $V_{in} = 6V$ ,  $V_{out} = 5V$ ,  $R_1 = 1k\Omega$  in the above equation for  $R_2$ ,

$$R_2 = \frac{1k \times 5}{6 - 5}$$

The value of  $R_2$  is thus  $5k\Omega$ . 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  $R_1$ .

### 1.5.6 Signal Conditioning Circuit Calculations

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 consist of op-amp circuits that can be used to amplify signals over a large range of gains, also providing reduced output impedance.

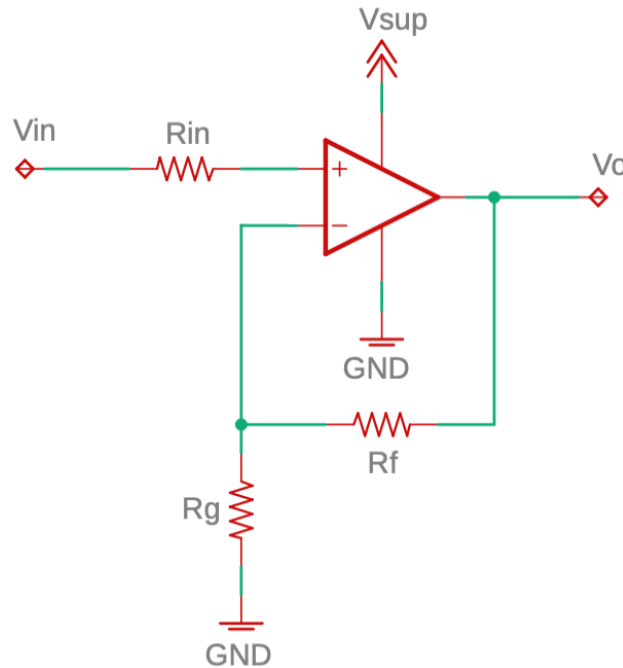


Figure 6: Non-inverting amplifier using a single-supply Op-Amp.

A number of different types of amplifiers can be made using operational amplifiers. The one used here is a non-inverting amplifier using a single supply Op-Amp, as shown in Figure 6. The gain of this amplifier is dependent on the resistor pair in the feedback loop. Let these resistors be  $R_f$  and  $R_g$ . The gain,  $G$ , is given by the following equation:

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

The voltage can thus be calculated as:

$$V_{out} = G \times V_{in}$$

The output of the sensor is linearly proportional to the temperature in Fahrenheit. The temperature sensor LM34 output voltage is  $10\text{mV}/^\circ\text{F}$ . So, a range of  $10^\circ\text{F}$  to  $100^\circ\text{F}$  provides an output voltage range of  $100\text{mV}$  to  $1000\text{mV}$ . In this lab, the amplifier gain is set to 5 so as to give a corresponding output range as  $0.5\text{V}$  to  $5\text{V}$ . 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  $R_g$  to be  $1k\Omega$ .

$$G = (1 + \frac{R_f}{1k})$$
$$R_f = (5 - 1) \times 1k$$

Thus, we get the value of  $R_f$  to be  $4k\Omega$ .

A resistor,  $R_{in}$ , of value  $800\Omega$  is added to the non-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  $R_g$ ).

Now that all the calculations are completed, the circuit can be fully implemented on the breadboard and tested. Implement the circuit as shown in Figure 4 and demonstrate its working to the TA or the instructor. 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.

**Note:** Remember to adjust the resistance of the potentiometers to appropriate values using a multimeter before using them in the circuit. Measuring the resistance of a resistor while it is used in a circuit often result in faulty readings.

### 1.5.7 Breadboard

A solderless breadboard is provided for this course. Solderless breadboards are commonly used for prototyping because they allow you to quickly build temporary circuits without soldering.

The breadboard makes it easy to connect the electronic components of a project by inserting component leads and jumper cables into pins on the breadboard. When you are done or want to change your circuit, it is easy to take your circuit apart.

The pins are arranged in groups of 5. The 5 pins in each group are electrically connected to each other at the back of the board. You connect leads and cables together by inserting them into pins within the same group.

Power rails at the top and bottom are marked with red (+) and blue (−) stripes. The groups in each rail are electrically connected along the entire length of the stripe. The remaining 5-pin groups on the board are labeled with numbers and letters. Each group is electrically isolated from the others.

The gap at the center of the breadboard allows easy connection of electronic components provided as dual-inline packages, such as the OPA340 IC.

For best results, use solid wires when breadboarding; you will find pre-cut jumper wires available in the Mechatronics lab.

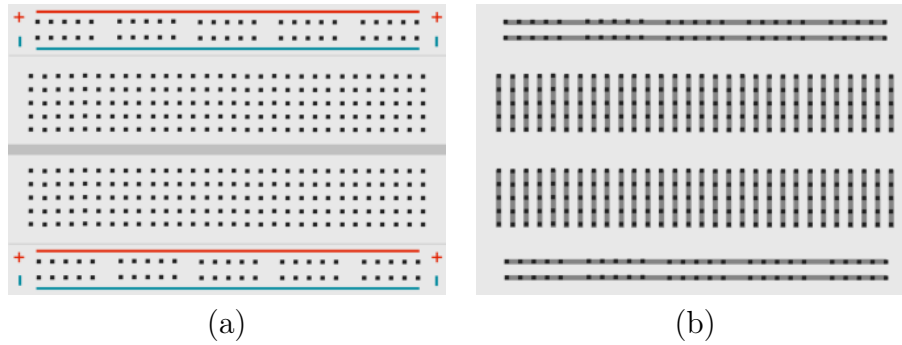


Figure 7: (a) Front of solderless breadboard showing power rails and connection pins. (b) Interconnections at back of board (normally hidden). The 5-pin groups in each power rail are interconnected. All other 5-pin groups are isolated (Image courtesy of Texas Instruments).

**Note:** To make the 3 pins of the potentiometers (shown in Figure 3) fit into the breadboard, you can remove the metal clips on the sides of the component, or just simply fold them up.

## 1.6 Expected Performance

Attach the positive and negative leads from the power supply to the 6V and GND power lines of the circuit, respectively. While measuring the output voltage of the voltage divider on the breadboard, turn the knob of the potentiometer to set the voltage divider output to 5V.

Measure the output of the LM34 temperature sensor directly on the circuit using the voltmeter and verify that the output corresponds the correct room temperature. Note that the sensor output is  $10mV$  per  $^{\circ}F$ .

Then measure the output of the Op-Amp and verify that the output voltage is amplified by a gain of 5. You can adjust the Op-Amp gain by adjusting the potentiometer connected to the output.

## 1.7 Questions

For the below questions, show all your calculations:

1. Using the rule above, show that the resistor  $R_{in}$  should be selected as  $800\Omega$  given the selected values for  $R_f$  and  $R_g$ .
2. What resistor values should be used for the voltage divider to get 5V provided to the sensor if a 12V supply is used?
3. Calculate the resistor values to set the gain of the amplifier at 10 for the same range of temperatures.



4. What gain should you use if you want the output of the amplifier to be  $0.4V$  when measuring a temperature of  $10^{\circ}F$ ? When using this gain, what range of temperatures can be measured if your microcontroller can only read voltages between  $400mV$  and  $5V$ ?

## 1.8 Requirements

1. Successfully demonstrate the performance of your circuit and all the required functionalities to TAs or instructor. When demonstrating the circuit, make sure to have a voltmeter available to measure the outputs of the sensor and the Op-Amp.
2. Submit the report to Canvas.