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 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. (40 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. (40 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 820Ω *resistor*.

All components needed for this lab are included in the Mechatronics kit designed for the course. Four AA batteries (not included in the kit) will be needed to power your circuit. You can use disposable alkaline or rechargeable NiMH 1.5V batteries.

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 four AA batteries. 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**".

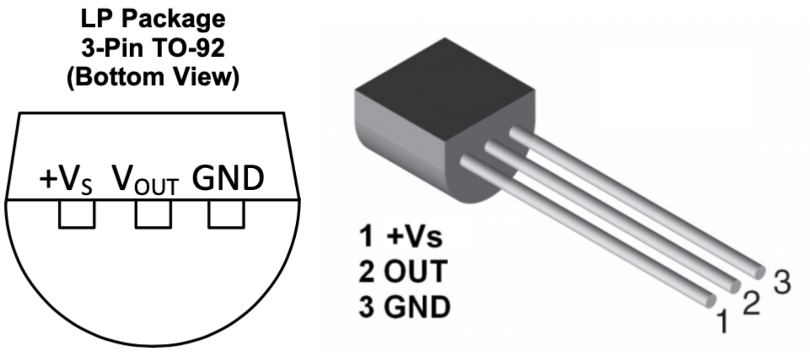


Figure 1: LM34 Pinout.

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 signlas 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.

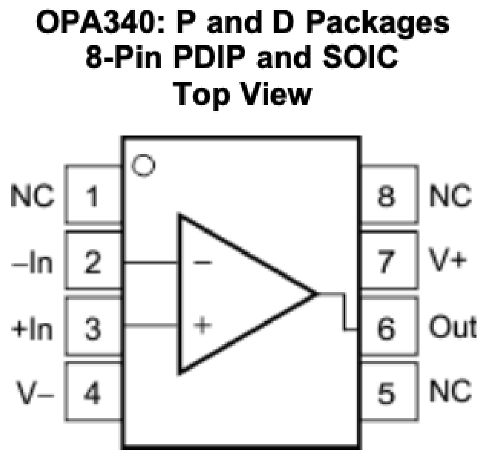


Figure 2: OPA340 Pinout.

1.5.3 Circuit Schematic

The circuit used in this Lab is illustrated in Figure 3.

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 by four AA batteries in series, installed in a battery holder) and the output is scaled to 0.5 to 5 V corresponding to $10°F$ to $100°F$.

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.

1.5.4 Voltage Divider Calculations

The output of the voltage divider, shown in Figure 4, 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:

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

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.

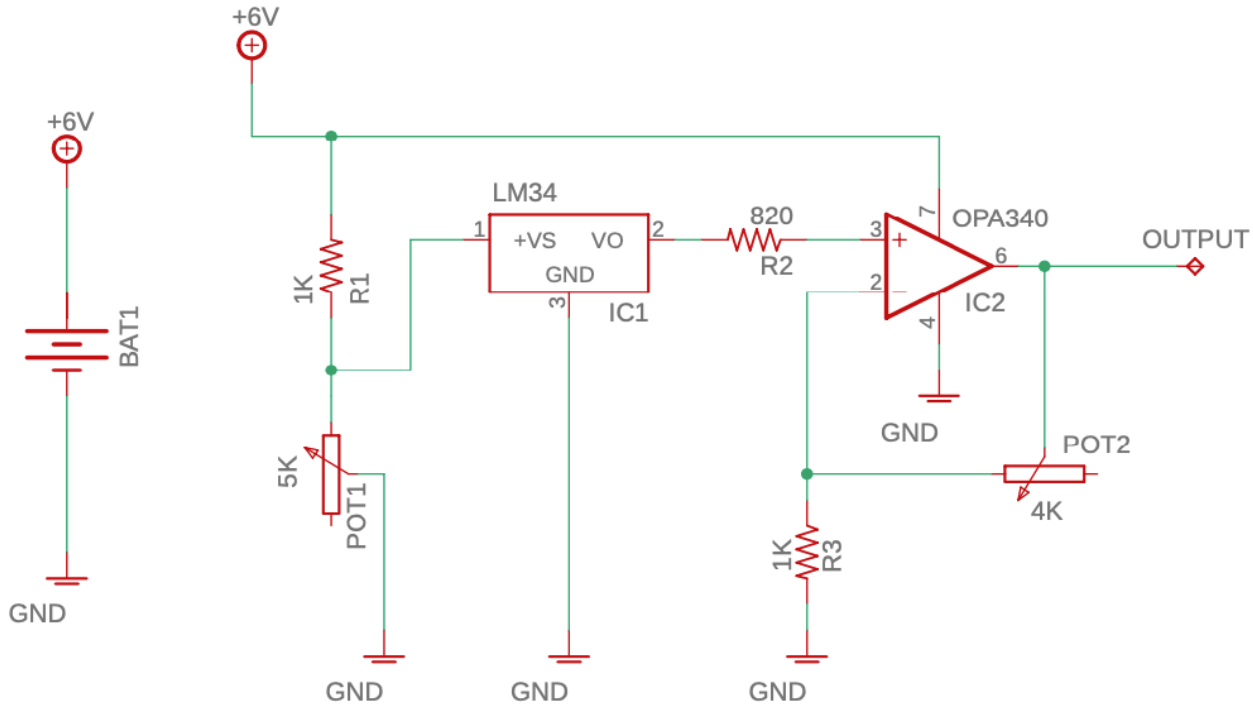


Figure 3: Circuit diagram for LM34 signal conditioning.

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

Substituting $V_{in} = 6V$, $V_{out} = 5V$, $R_1 = 1k\Omega$ 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.

1.5.5 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.

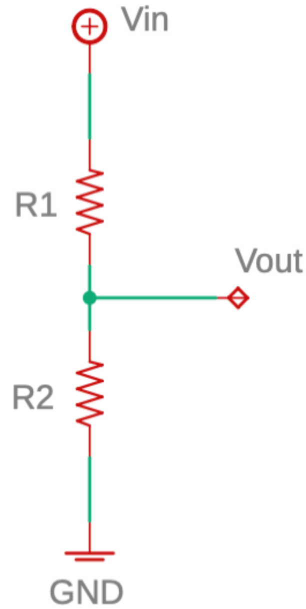


Figure 4: Voltage divider circuit

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 5. 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:

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

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 $10mV/°F$. 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 5 so as to give a corresponding output range as $0.5V$ to $5V$. 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 800Ω 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).

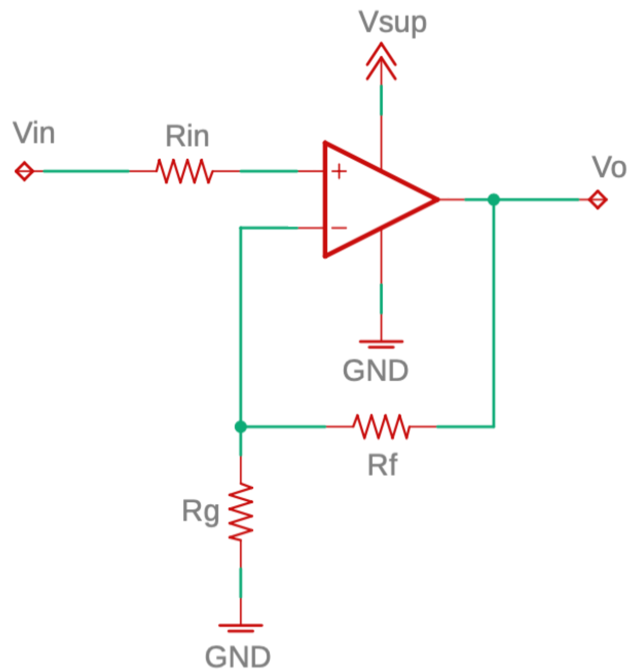


Figure 5: Non-inverting amplifier using a single-supply Op-Amp.

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 3 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.

1.5.6 400-Point Breadboard

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

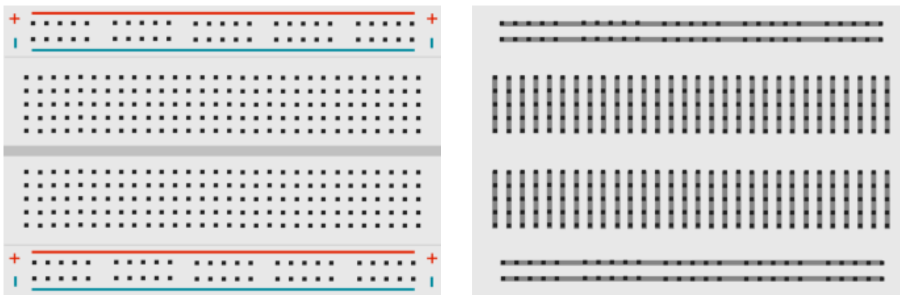
The breadboard makes it easy to connect the electronic components of a project by inserting component leads and jumper cables into pins on the breadboard. When you are done or want to change your circuit, it is easy to take your circuit apart.

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 a pre-cut jumper wire kit in the Mechatronics kit.



(a) (b)

Figure 6: (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).

1.6 Expected Performance

Attach the positive and negative terminals of the battery holder to the 6V and GND power lines of the circuit, respectively. While measuring the output voltage of the voltage divider on the breadbord, 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 800Ω 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 $10°F$? 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.
2. Submit the report to Canvas.