EK307 Lab: Introduction to Operational Amplifiers

Laboratory Goal: Use operational amplifiers to build voltage amplifiers and condition sensor signals. Introduce the potentiometer. Circuit measurements with the oscilloscope.

For level 2, complete level 1 and one of the two choices for level 2.

Introduction: OP AMPS were invented to simplify signal processing in electronics. They can be used to multiply, sum, invert, subtract, divide, log, threshold, and generate waveforms, and many more. The most common use is as a voltage amplifier. Today you will build an amplifier that amplifies (or multiplies) an input voltage by a positive constant and the result appears on the output of the amplifier as a voltage. A common example of this can be found in an electric guitar amplifier. The amplifier increases the intensity of the signal generated in the pickup to be large enough to power a loudspeaker.

A potentiometer is a resistor that has a moveable tap or connection along its length. The tap functions to divide the resistor in two. The resistance of the two parts varies inversely as the knob is turned. A potentiometer is a quick way to make an adjustable voltage source. You connect the potentiometer ‘ends’ across your power supply. The voltage that appears on the tap depends on the position of the knob. The range of voltage appearing at the tap is the same as the voltage across the resistor. For example, if I connect the potentiometer resistor across the +15 and -15 volt power supplies of my bench supply, the voltage at the tap can be adjusted with the knob to be anywhere within +-15 volts. You will use the potentiometer as the input to your amplifier. This voltage will be amplified by a positive gain and the product will appear at the output terminal. See the appendix for more information on the potentiometer.

PRELAB: due at the beginning of your lab session

Design a non-inverting amplifier using an OP AMP. It should have a gain of approximately 3. Draw the schematic in your notebook. **When choosing resistance values for the gain setting resistors keep them in the range of 2k Ohm to 470k Ohms.** The reason for this constraint is that ideal OP AMPS don’t exist in nature. Using values outside of this range exposes the non-ideal behavior of the TL081 OP AMP integrated circuit. The non-ideal behavior is something you will learn about in later classes.

LEVEL 1: Introduction to the OP AMP non inverting amplifier

a) Use the Internet to find the datasheet for the TL081 OP AMP (they are a very popular component that has been around since the days when dot matrix printers ruled. We chose the TL081 because it is rugged, well behaved, and low cost.). Keep the datasheet open on your computer desktop. The datasheet will be useful to help you connect to the proper pins.

b) Draw a complete schematic of what you are going to build. Figures 1 and 2 show you the power supply and potentiometer schematic and layout. Your task is to add the gain setting resistors (that you designed in the prelab) to the OP AMP on the schematic (Figure 1) and breadboard (Figure 2) in this document. You are in essence combining the prelab schematic and the figure 1 schematic. Before starting to build the circuit make sure you have a complete schematic in your notebook. It will help you make and troubleshoot your circuit.

c) The potentiometer voltage divider shown in figures 1 and 2 is used as the input for your non-inverting amplifier. It is the grey box in figure two. The potentiometer divides the +15 and -15 volt supplies in a way where the voltage on the tap pin (the arrow) can be adjusted to be any voltage within this range by turning the knob. The potentiometer is available from the parts counter. It is a small blue box with a knob on the top and three wire legs on the bottom. Note; potentiometers are available in different colors, with a knob or a screw. The one in figure 2 is grey with a screw, the ones at the part desk are blue with a knob. The potentiometer tap pin at node A on the schematic is the input to your amplifier. Be sure to make the connection on the schematic.

d) Construct your circuit on a breadboard. The circuit is powered with +-15 Volts from the bench power supply. Use decoupling capacitors as shown in the schematic across both positive and negative voltage supplies. What is a decoupling capacitor? It is typically a 0.1 micro Farad (100 nano Farad) capacitor that is placed across each voltage supply in close proximity to the OP AMP. They help stabilize the voltage supplies. You don’t need to know the intricate details of why just yet. Take our word that it is standard industry practice to ‘decouple your supplies’.

e) Double check your wiring to make sure nothing is wired reverse polarity. OP AMPS are fragile. They will not withstand much electrical abuse. Power up the breadboard. Immediately after switching the power on check the +15V and -15V current meters on the bench supply. The breadboard should be drawing less than +-20 mA. If it is drawing more immediately turn off the supply and check your wiring. If things go up in smoke, laugh it off, regroup, find your wiring or voltage mistake, and try again. The voltmeter is a great tool to help you debug problems.

f) Once your circuit powers up properly it is time to make measurements. Connect Channel A of the oscilloscope to the input of the amplifier which is also the output of your potentiometer (node A in figure 1). Turn the knob on the potentiometer to get a reading of approximately zero volts on the ‘scope A trace. Connect Channel B of the oscilloscope to the output pin of your amplifier. If your node A is approximately zero the output of your opamp should also be approximately zero. Why? Because zero multiplied by any constant gain results in zero out.

g) Using a spreadsheet record the measured voltage at the output of the amplifier (scope channel B) when the voltage on the input of the amplifier is varied by turning the potentiometer knob. Make approximately 20 measurements for inputs ranging from -10 to 10 volts.

h) Using a spreadsheet program plot the Voltage on Channel A along the abscissa vs. Channel B along the ordinate. This plot is called a transfer function. You will see it often in engineering. It shows the relationship of the output to the input of a system. In this case it is showing the DC transfer function. Calculate the slope near the origin. What is it? Why does the slope change as you approach the Voltage supply values?

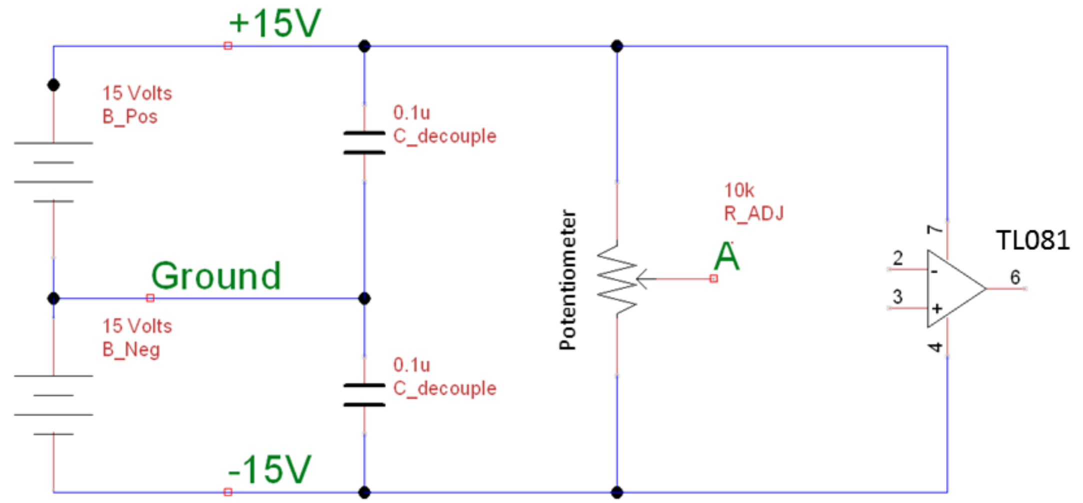

Figure 1: OP AMP power supply and potentiometer schematic. The two 15 Volt batteries represent your bench top power supply. The ground node is the same as ‘com’ on the HP supplies. The 0.1 uF capacitors are necessary for proper OP AMP operation. The resistor with the arrow is a potentiometer or adjustable resistor. Turning the screw adjusts the position of the arrow or tap along the resistance. It forms an adjustable Voltage divider. The TL081 has its power pins connected but no input or output circuitry. That is up to you to design.

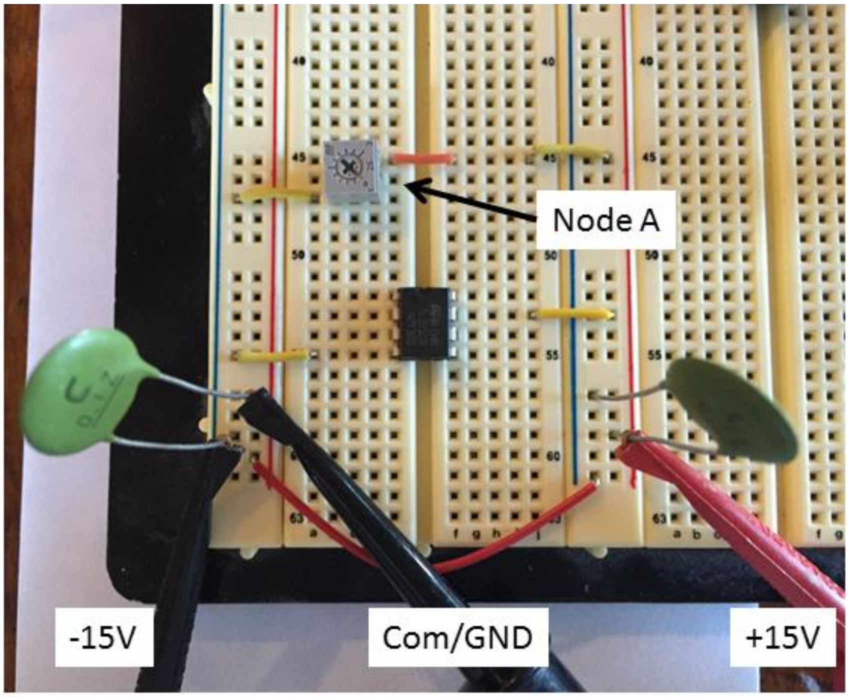

Figure 2: An example layout of the figure 1 schematic. An OP AMP with its power supply and a voltage divider potentiometer ‘pot’ circuit. Note the use of the green decoupling capacitors’ leads as points to attach the power supply leads. The capacitor leads are left long to show the connection. Ideally you would want to cut them shorter. Neatness of your layout will help you navigate the circuit and make the correct connections.

For level 2, complete level 1 and one of the two choices for level 2.

LEVEL 2, choice A: Current Montior

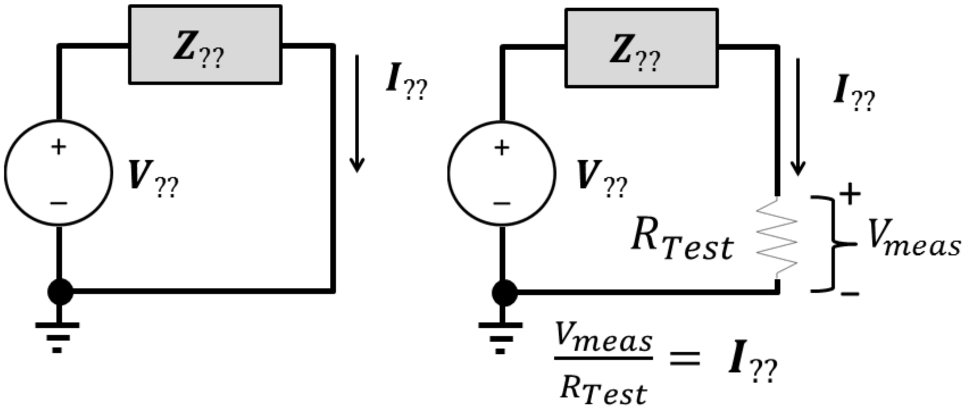

Figure 3: Method of using a test resistor to measure the current in an unknown circuit. We want to measure the current in the circuit on the left. As shown in the right circuit, insert R_{Test} into the loop and measure the voltage across its terminals. Calculate current by dividing the measured voltage by the resistance value of R_{Test}. Note that R_{Test} will increase the resistance in the loop thus will introduce error.

A common method of measuring current is to measure the voltage across a resistor of known resistance and then calculate the current. Usually the resistor is inserted into the circuit during measurement and is part of the ammeter (Figure 3). Ideally the resistor value is very small to prevent its presence from affecting the circuit's operating characteristics. The smaller the resistor the smaller the measured voltage will be. This is problematic because it is difficult to accurately measure small voltages. Fortunately it is possible to use an amplifier to increase the magnitude of the small voltage that will be across the resistor.

a) Your challenge is to build an ammeter to measure the current in the circuit in figure 4. This task will be easier if one of the leads from the current sense resistor is connected to ground as shown in figure 3. You can use your level one circuit as an amplifier to amplify the voltage across the test resistor. It might be necessary to change the gain.

b) What affect will inserting a current sense resistor into the circuit have on the current of the original circuit? Should it be a large or small value relative to the 6.8k resistor in figure 4?

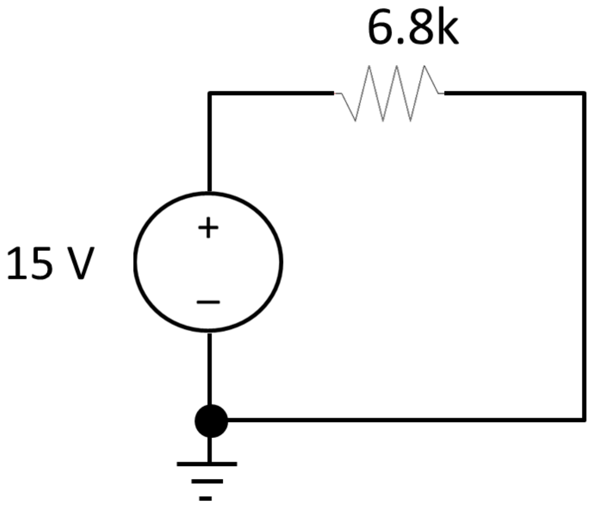

Figure 4: Test circuit for current monitor

c) Draw a complete schematic in your lab notebook, be able to answer the question in b, and demonstrate your working circuit to receive credit for level 2.

LEVEL 2, choice B: Sensor Scaling

a) Connect the loudspeaker from your parts kit to the input of a Picoscope, and measure the nominal zero-to-peak voltage produced by the microphone when you speak into it with a normal speaking voice. The speaker should be about six inches from your lips. To get a reliable electrical connection to the speaker you may want to solder wires to its two terminals. We can show you how.

Note: Your lips should not touch the speaker cone. One of the common mistakes made by many stage singers is to make direct lip contact with the microphone. At this close proximity, the microphone’s diaphragm may vibrate so strongly that it hits its mechanical limits and distorts the sound. This effect is probably OK for some rock music which is generally unintelligible anyway. Although it may be perfectly acceptable for electronic music.

Tip: Using a shielded coaxial cable will reduce the magnitude of 60-Hz line noise from the building’s wiring system that is picked up by the oscilloscope.

USE: 

b) An important characteristic to consider when working with sensors is dynamic range. In the current era of digital systems, sensor signals such as those coming from microphone are frequently observed by an analog-to-digital converters (ADC). The latter process the sensor signal so that it can be digitized by a microcontroller or computer. ADCs are usually designed to read voltages over a range of zero to 5 V or zero to 3 V.

In order for an ADC to make the most accurate measurement of a sensor over its entire dynamic range, an interface circuit is often needed to convert its signal into one that fills the range the ADC is able to measure.

Design and build an op-amp circuit that shifts and scales the output of your microphone so that it fills the ADC measurement range of a 0 to 5 V. The signal should be centered around 2.5 V, have a minimum of about 0 V, and a peak value of about 5 V. In any case, the output of your circuit should never go negative and never exceed 5 V. Power your op-amps from ±10-V to ±12 V voltage sources.

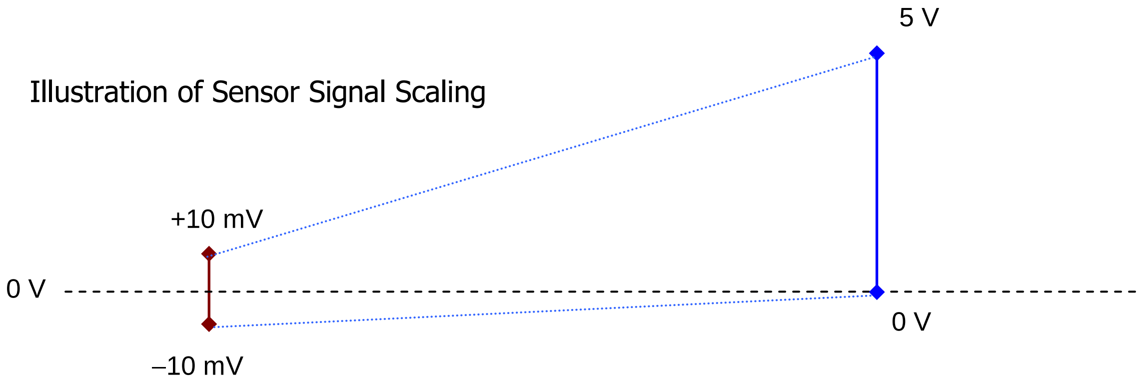

Illustration of Sensor Signal Scaling

Appendix

Potentiometer:

The physical potentiometer device can be seen in the left pane of figure 1A. It is a plastic box with a knob and three terminals. The three terminals are connected to a tapped resistor as seen in the center panel of figure 1A. Pins 1 and 3 are the ends of the resistor and pin 2 is called the tap. The resistance measured between pins 1 and 3 is specified as the resistance of the potentiometer. The tap physically touches the resistor material and literally taps the resistor at that point. You can think of it as tapping off current or voltage depending on what other circuit elements are connected to the tap. One can think of the tap as dividing the resistor into two segments where the sum of the resistance of the two segments equals the part value. The right pane in figure 1A illustrates a two resistor equivalent circuit of the potentiometer. The knob can be used to adjust the position of the tap.

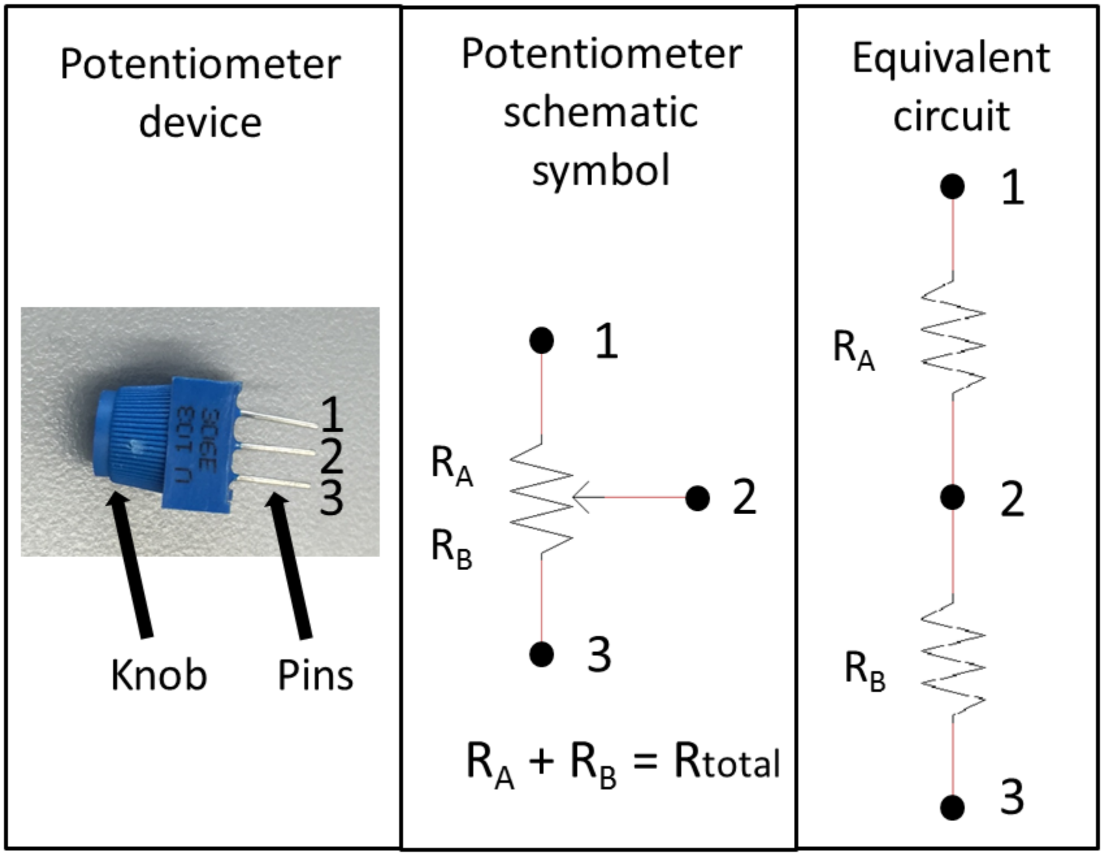

Figure 1A: The potentiometer and its schematic symbol. The left panel shows the actual device with its three pins. The center panel is the schematic symbol and resistance equation. The right panel is the equivalent of a potentiometer constructed with two resistors.

Figure 2A illustrates how the resistance changes as the knob is turned. If you rotate it in one direction the tap moves up the resistor and RA is reduced and RB is increased. The change in resistance is proportional because the sum of RA and RB always will equal the total resistance. Rotating the knob in the opposite direction results in RA increasing and RB being reduced.

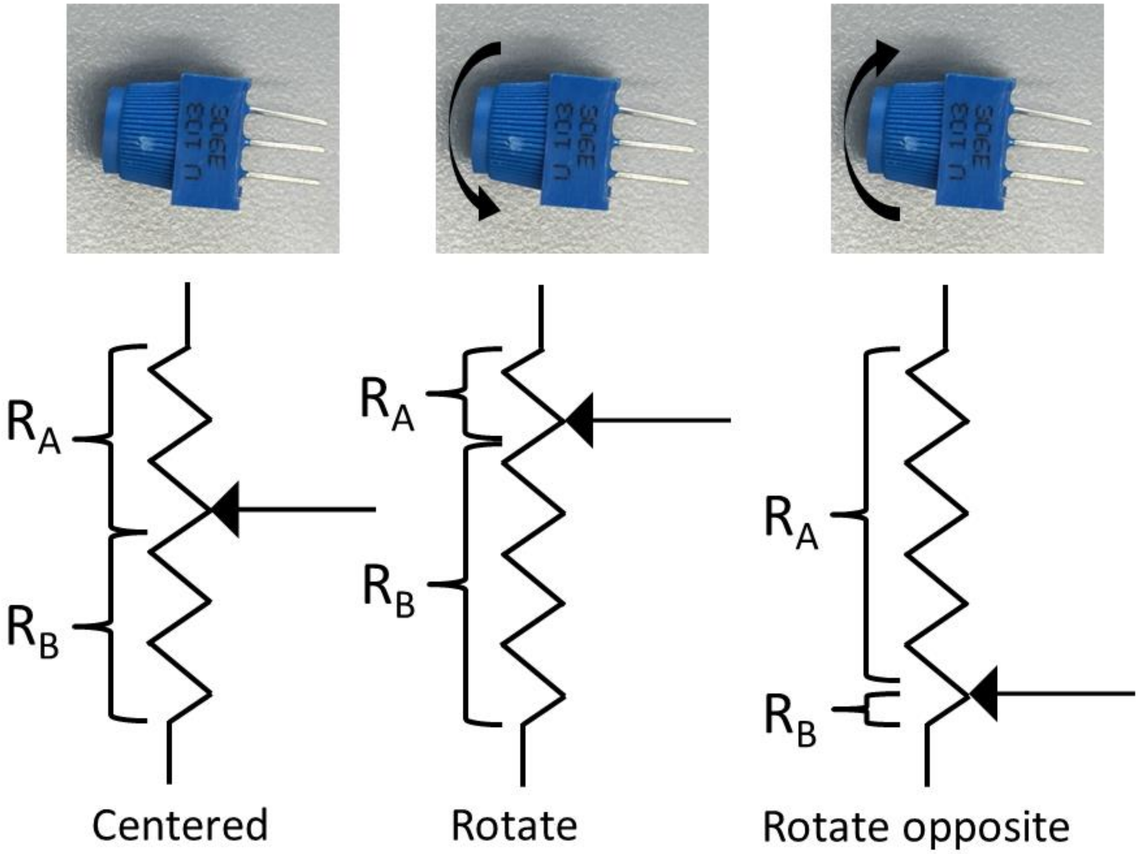

Figure 2A: The effect of turning the knob on the potentiometer. As the knob is rotated the tap (arrow) moves along the body of the resistor. Note, not all potentiometers are blue and have a knob. Some may have a screw instead of a knob.