

# ENGR 210 Lab 7

## Introduction to the Operational Amplifier

**Purpose:** To become familiar with some applications of the operational amplifier (OP AMP), and to gain experience using this device in electronic circuits.

### Equipment Required:

- Keithley Model 2000 Digital Multimeter
- 2 - 8.2k ohm Resistors
- 1 - 36k ohm Resistor
- 1 - 10k ohm Potentiometer<sup>1</sup>
- 1 - 741 OP AMP
- Tool Kit (red tool boxes from the instrument room)

### Background:

Review the following general handling precautions for semiconductor devices and use these precautions when handling Operational Amplifiers.

#### Caution

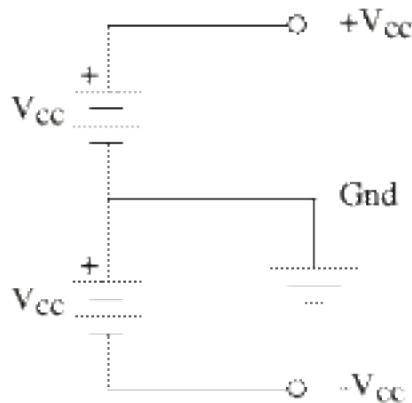
An OP AMP, as well as any other semiconductor device, can be destroyed by over-current, over-voltage or static discharge. Over-current conditions are usually due to a wiring error. Over-voltage occurs when the power supply voltage exceeds the voltage rating for the device. Static discharge can occur when semiconductor devices are handled during placement into the circuit board. These conditions can be avoided by ensuring you are using the proper device, and double-checking the circuit layout to catch — and correct — wiring errors. In the laboratory, damage from static discharge is often controlled by the use of grounded anti-static mats on the floor and the work surface. Manufacturers of static-sensitive devices recommend the use of a grounded wrist strap when working on sensitive electronics. You can help avoid damage from static discharge by touching an earth ground before picking up a semiconductor device. Earth grounds are available throughout a modern circuits lab, in the form of any metal case on a grounded instrument. Some power supplies provide a ground jack (green) separate from the negative side of the supply. The ground lug provides a good quality connection to earth ground through the third wire (round pin) on the AC power cord. Touching the metal portion of this ground lug will discharge any static electricity you have accumulated, and significantly reduce the likelihood of damaging static-sensitive components.

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<sup>1</sup> Actual value is not critical. Basically anything over 1k should be usable.

## Procedure:

1. Prepare the HP 3631A power supply and potentiometer as follows
  - a. Configure the  $\pm V_{CC}$  outputs of the HP power supply.
    1. The schematic below (Figure 1) shows a standard  $\pm V_{CC}$  configuration for an OP AMP bipolar power supply. The schematic symbols for batteries are used in Figure 1 to indicate that the power supplies need to be a constant DC voltage.  **$+V_{CC}$  and  $-V_{CC}$  are POWER SUPPLY CONNECTIONS for both the OpAmp and for the potentiometer.**

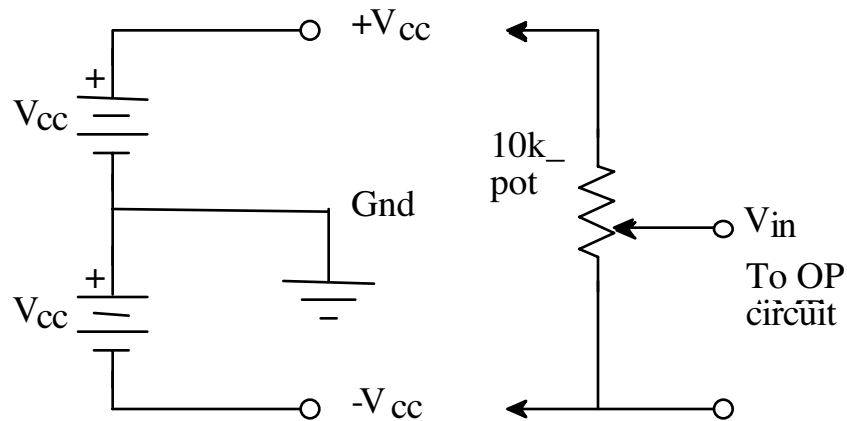


**Figure 1: OpAmp and Potentiometer Power Supply Configuration**

Your HP power supply has three variable outputs, a single output supply on the left, and a dual output bipolar power supply (+25V and -25V outputs) on the right (which you will use for this lab).

Note that the common output of this power supply is generally not internally connected to the ground (green output terminal). It is often necessary to connect the “common” output to the ground of the power supply with banana plug leads. This connection prevents power supply voltages from “floating” and causing inaccurate measurements. As shown in Figure 1, the connection labeled "Gnd" between the  $V_{CC}$  supplies is used as the circuit ground. This corresponds to the common (COM) binding post that you will also connect to the green grounding binding post on your power supply.

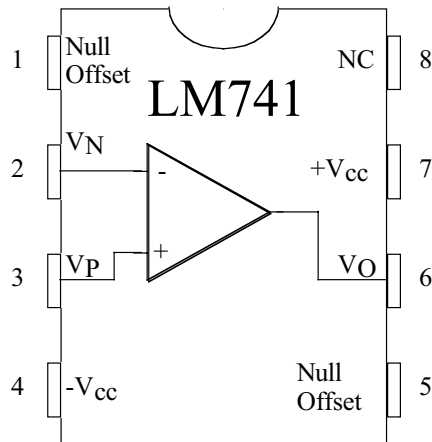
2. Adjust the bipolar power supply output so the  $+V_{CC}$  and  $-V_{CC}$  are equal to +15V and -15V respectively.
- b. Configure the signal source using the potentiometer as a voltage divider as shown in Figure 2 below. Note that  $V_{in}$  is the input voltage to the OP-AMP circuit, but is an output of the power supply-resistor circuit.



**Figure 2: DC Source Signal Connections to Input of the Op Amp**

1. Connect both  $+V_{cc}$  and  $-V_{cc}$  to the potentiometer as shown in Figure 2. This circuit configuration will provide a variable DC voltage source with a range from approximately  $+V_{cc}$  to  $-V_{cc}$  for input to the OP AMP circuit. The potentiometers that are available in the lab should fit directly into the protoboard. Be very careful NOT to short out the potentiometer when positioning it on the protoboard.
  2. The way in which the power supplies are connected to each other, and to the potentiometer, produces four nodes,  $+V_{cc}$ ,  $-V_{cc}$ ,  $V_{in}$  and ground (GND) as a reference. The DMM should be configured to measure voltage and it should also be connected across the center terminal of the potentiometer and the common ground of the power supply. Check the signal source circuit (Figure 2) to ensure that it provides the range of voltages desired by adjusting the variable resistance using the rotating wheel or knob on the potentiometer and record your  $V_{in}$  maximum,  $V_{in}$  minimum,  $+V_{cc}$ , and  $-V_{cc}$  measured voltages in Data Table 1.
- c. To reduce the risk of connecting the wrong voltage level to your OP AMP, you may want to label each point on the protoboard with its appropriate voltage:  $V_{in}$ ,  $+V_{cc}$ ,  $-V_{cc}$ , GND. You can do this by putting a sheet of paper under the protoboard and labeling the connections on the paper. Turn the power supply on and verify that the voltage at each of these points matches your labels.
  - d. Use the Output On/Off button to turn the power supply output off.

## 2. Connections to the inverting OP AMP configuration



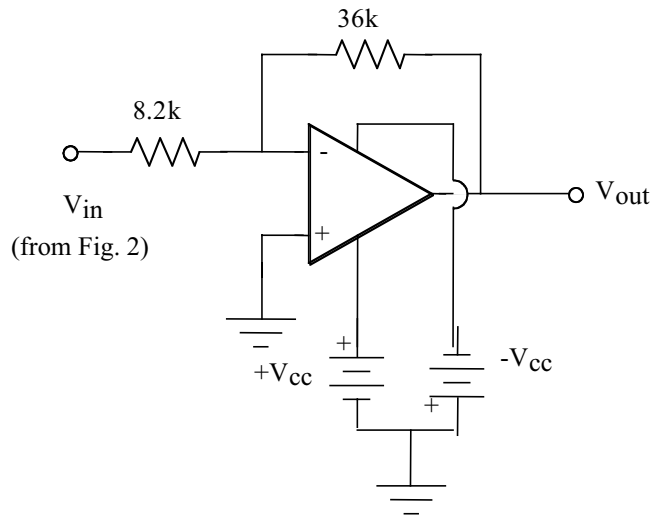
**Figure 3: 741 Chip Layout Pin Connections**

- a. Examine the chip layout of Figure 3. The standard procedure on DIP (dual in-line package) "chips" is to identify pin 1. Pin 1 is usually identified with a dot or it is positioned to the left of a notch at one end of the chip package. Generally, the notch separates pin 1 from the last pin on the chip. In the case of the 741, the notch is positioned between pins 1 and 8.

Pin 2 is the inverting input,  $V_N$ . Pin 3 is the non-inverting input,  $V_P$ , and the amplifier output,  $V_O$ , is at pin 6. These three pins are the three terminals that normally appear in an OP AMP circuit schematic diagram. Even though the  $\pm V_{CC}$  connections, Pin 4 and Pin 7, must be completed for the OP AMP to work, they usually are omitted from the circuit schematic to improve clarity.

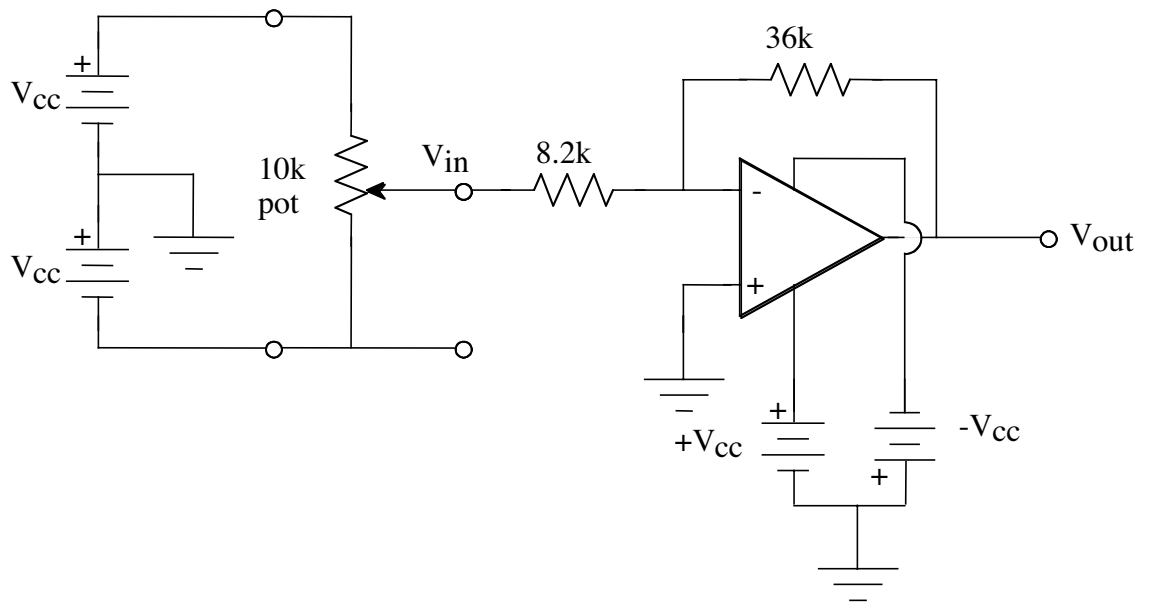
The null offset pins (1 and 5) provide a way to eliminate any "offset voltage" in the output voltage of the amplifier. The offset voltage (usually denoted by  $V_{os}$ ) is an artifact of the integrated circuit. When present, the offset voltage is added to the output  $V_O$  (pin 6 in this case), it can be either positive or negative and is normally less than 10 mV. Because the offset voltage is so small, in most cases we can ignore the contribution that  $V_{os}$  makes to  $V_O$  and we leave the null offset pins open. Pin 8, labeled "NC", has no connection to the internal circuitry of the 741 OpAmp, and is therefore not used.

- b. Examine the circuit shown in Figure 4. **Note: +Vcc and -Vcc are obtained from the HP power supply.** The schematic symbols for batteries are used to indicate a constant DC power supply voltage. **Batteries are not required in this Lab!**



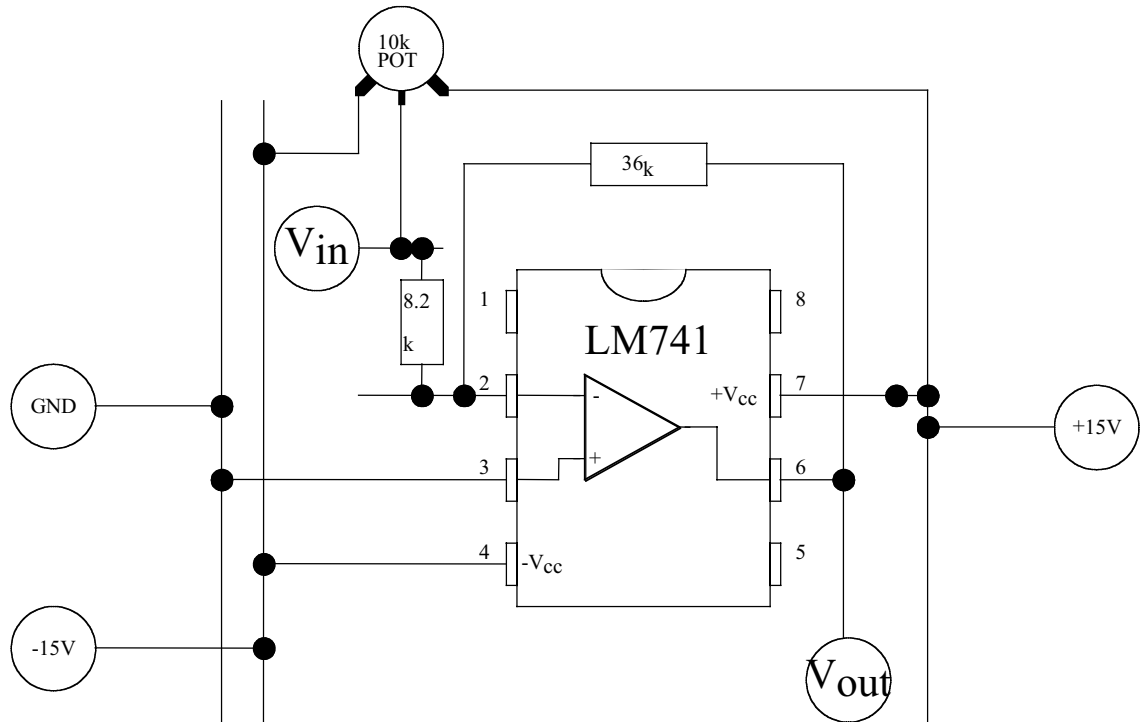
**Figure 4: INVERTING 741 OP-AMP Circuit**

- c. Figure 5 represents a first step in transferring our circuit schematic of Figure 4 into the circuit that you will build in the lab. This figure shows all the elements that we will use to implement the inverting amplifier circuit in Figure 4.



**Figure 5: Inverting OP-AMP DC Amplifier with Variable DC Input**

- d. Figure 6 translates the schematic of Figure 5 into a wiring “layout” diagram (or pseudo-schematic) showing the physical lay out of the circuit and the required connections on the protoboard.



**Figure 6: Pseudo-schematic of Figure 5**

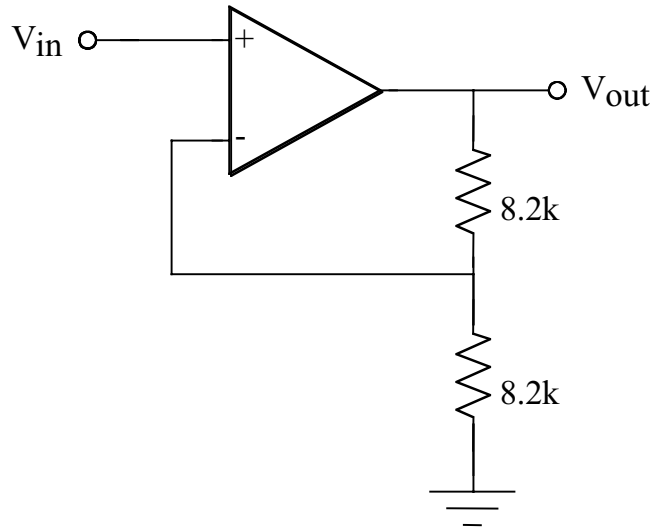
- e. Although we won't go through this level of detail in future lab write-ups, it may be useful to draw a pseudo-schematic in future labs before actually trying to wire your circuit.

### 3. Hook up of the inverting amplifier

Carefully measure the values of the resistors that will be used in the circuit of Figure 4. Record these values in Data Table 2. Use these measured values to compute the calculated circuit gain,  $K$  and record this value in Data Table 2. With the power supply output turned off, construct the inverting OP AMP circuit using Figure 6 as a guide. **Ask a TA to check the circuit carefully before turning on the power supply.** Adjust the  $10k\Omega$  ohm potentiometer to achieve a  $V_{in}$  of approximately 1 V. Measure  $V_{in}$  and  $V_{out}$  and verify that the actual  $V_{out} = KV_{in}$ . If  $V_{out}$  is close to your calculated value, your amplifier circuit is probably working correctly, and you may proceed. If the measured  $V_{out}$  is different than  $KV_{in}$  by more than 10%, you probably have an error in the circuit. Troubleshoot the circuit until it is operating properly.

- a. Use the potentiometer to obtain a  $V_{in}$  of about -10 V, carefully measure  $V_{in}$  and  $V_{out}$  using the DMM. Record  $V_{in}$  and  $V_{out}$  in Data Table 3. Increment  $V_{in}$  by 1 volt, and repeat the  $V_{in}$  and  $V_{out}$  measurements and record your results in Data Table 3. Collect data in this manner 19 more times, incrementing  $V_{in}$  by 1 V after each measurement until  $V_{in} = +10$  V. Continue to record your values for  $V_{in}$  and  $V_{out}$  in

- Data Table 3. For each line of data in Data Table 3, compute and record  $KV_{in}$  and the error between  $KV_{in}$  and  $V_{out}$ . (NB: Table 3 has more lines than you'll need.)
- At  $V_{in} = 2$  volts, accurately measure and record  $V_{in}$ ,  $+V_{CC}$ ,  $-V_{CC}$ ,  $V_P$  and  $V_N$  in Data Table 4. Measure and record the voltage difference  $V_{P-N}$ .
  - Turn off the power supply output. Without removing the OP AMP, disassemble the resistors in the circuit shown in Figure 6.



**Figure 7: Non-Inverting DC OP-AMP Amplifier**

- The non-inverting amplifier
  - Calculate and record the expected gain for the circuit of Figure 7 in Data Table 5.
  - You will use the source circuit as shown in Figure 2 to provide  $V_{in}$  for the non-inverting amplifier of Figure 7. Draw a circuit diagram (similar to Figure 5) for the non-inverting Op Amp in Figure 7 and include this diagram in Drawing 1 section of the write-up. Also draw a pseudo-schematic (similar to Fig. 6) for the non-inverting Op Amp and include this in the Drawing 1 section of the write-up.
  - Connect the circuit of Figure 7, using your pseudo-schematic as a guide. **Ask a TA to check the circuit before testing it and verifying that  $V_{out}$  is equal to  $KV_{in}$ .** If  $V_{out}$  is not close to your calculated value, troubleshoot the circuit until it is operating properly.
  - Starting at a  $V_{in}$  of  $-10$  V, make 21 measurements of  $V_{in}$  and  $V_{out}$ , incrementing  $V_{in}$  by 1 V after each measurement. Record  $V_{in}$  and  $V_{out}$  in Data Table 6. Fill in the remaining two columns of the table with the required calculated values.

# DATA AND REPORT SHEET FOR LAB 7

Student Name (Print): \_\_\_\_\_ Student ID: \_\_\_\_\_

Student Signature: \_\_\_\_\_ Date: \_\_\_\_\_

Student Name (Print): \_\_\_\_\_ Student ID: \_\_\_\_\_

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Student Signature: \_\_\_\_\_ Date: \_\_\_\_\_

Laboratory Day and Time: \_\_\_\_\_

Measurement	Measured Value (V)
+Vcc	
-Vcc	
V <sub>in</sub> (maximum positive)	
V <sub>in</sub> (maximum negative)	

**Data Table 1: DC Voltage Source Measurements**

Parameter	Calculated (Theoretical) Value	Measured Resistance Value	% Difference
8.2 kΩ resistor	8.2 kΩ resistor	kΩ	
36 kΩ resistor	36 kΩ resistor	kΩ	
K (voltage gain of amplifier)			

**Data Table 2: Resistor Values**







**Drawing 1: Schematic and Pseudo-schematic for Non-Inverting Amplifier**