



## Introduction to the Operational Amplifier

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### Purpose:

Become familiar with the operational amplifier (OP AMP), and gain experience using this device in electric circuits.

### Equipment Required:

- 1 - Agilent 34401A Digital Multimeter
- 1 - Agilent E3631A Power Supply
- 1 - Protoboard
- 2 - 10-k $\Omega$  Resistors
- 1 - 33-k $\Omega$  Resistor
- 1 - 10-k $\Omega$  Potentiometer
- 1 - 741 OP AMP

### Prelab:

Read Sections 4-4 and 4-5 on OP AMPs in the textbook. Review Procedure 1 in the lab exercise "Introduction to the Transistor" which describes handling precautions for semiconductor devices. Use these precautions when handling OP AMPs.

### Procedure:

1. Prepare the power supplies

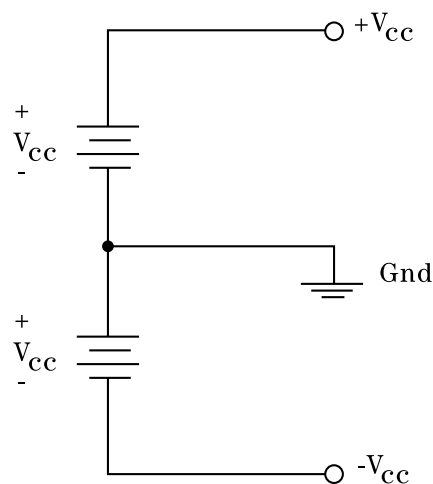


Figure 1

- a. Configure the  $\pm V_{cc}$  supplies.

1. The schematic of Fig. 1 shows a standard  $\pm V_{cc}$  configuration for OP AMPs. The schematic symbols for a battery are used in this schematic to remind us that these supplies need to be a constant DC voltage. They are not signal sources.



The Agilent E3631A power supply provides two variable supplies with a common ground and a variable low voltage supply.

As shown in Fig. 1, the jack labeled “COM” between the  $V_{CC}$  supplies is connected to circuit ground.

2. Adjust the output so the  $+V_{CC}$  and  $-V_{CC}$  are equal — but opposite in sign — at 15 V.

b. Configure the signal source.

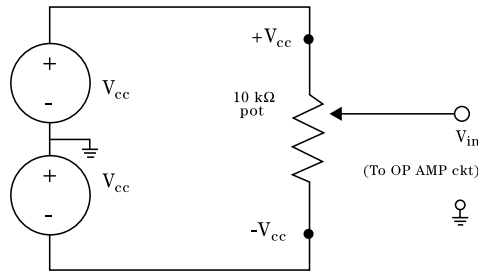


Figure 2

1. Connect the  $\pm V_{CC}$  to the potentiometer as shown in Fig. 2. This will provide a variable-output DC signal source from  $-V_{CC}$  to  $+V_{CC}$ , for input to the OP AMP circuit.

2. Check the signal source circuit to ensure that it provides the range of voltages desired. The voltmeter should be connected to the center terminal of the potentiometer and the common ground between  $\pm V_{CC}$ .

c. 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) or reference. 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. Turn the power supply on and verify that the voltage at each of these points matches your labels. Record actual values for  $+V_{CC}$  and  $-V_{CC}$ , and the range of voltages produced by the signal source circuit, at the node labeled  $V_{in}$  in Fig. 2.

d. Turn the output of the power supply off. —

2. Connect the OP AMP

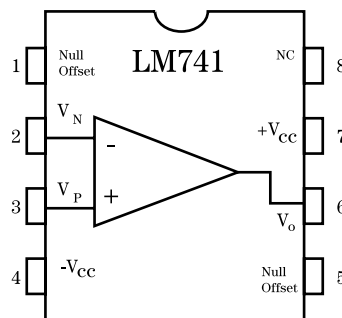


Figure 3

a. Study the chip layout of Fig. 3. The standard procedure on DIP (dual in-line package) “chips” is to identify pin 1 with a notch in the end of the chip package. The notch always separates pin 1 from the last pin on the chip. In the case of the 741, the notch is 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 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” in the output voltage of the amplifier. The offset voltage (usually denoted by  $V_{os}$ ) is an artifact of the integrated circuit. The offset voltage is additive with  $v_O$  (pin 6 in this case), can be either positive or negative and is normally less than 10 mV. Because the off-set voltage is so small, in most cases we can ignore the contribution  $V_{os}$  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, and is not used.

- b. The goal here is to connect the circuit shown in Fig. 4. This is an easy task . . . if you’ve done this before! For this lab we’ll walk through how we will actually wire up an OP AMP.

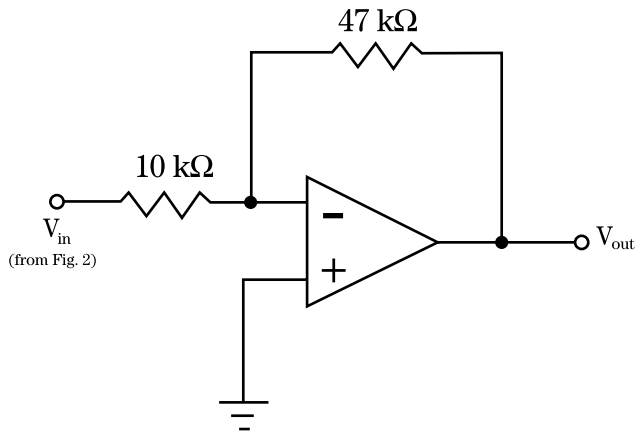


Figure 4

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

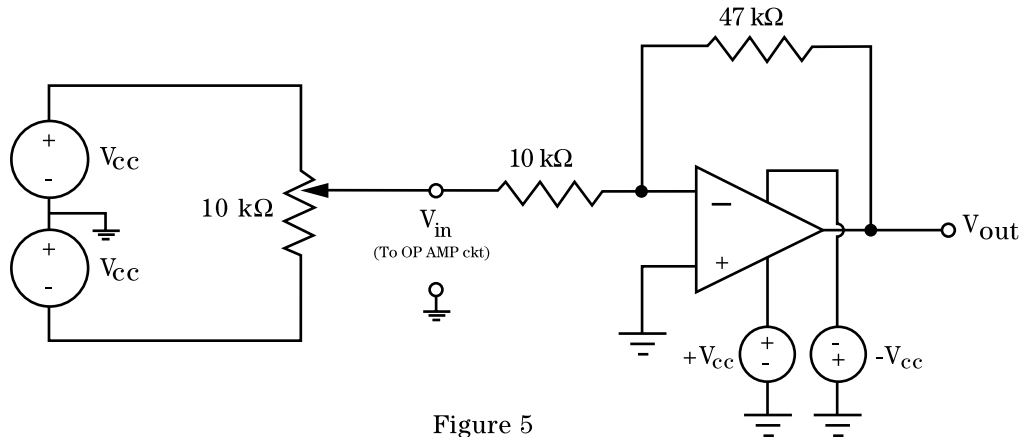


Figure 5



- d. Figure 6 translates the schematic of Figure 5 into a mechanical representation (or pseudo-schematic) showing the physical lay out of the circuit and the connections on the protoboard.

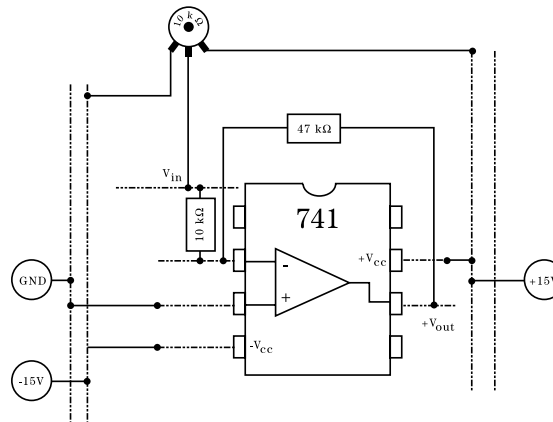


Figure 6

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

### 3. The inverting amplifier

Carefully measure the values of the resistors that will be used in the circuit of Fig. 4. Use these measured values to compute the circuit gain,  $K$ . *With the power supply output off*, construct the inverting OP AMP circuit using Fig. 6 as a guide. Check the circuit carefully. Turn on the power supply. Adjust the 10 kΩ potentiometer to achieve a  $V_{in}$  of 1 V. Measure  $V_{in}$  and  $V_{out}$  and verify that the actual  $V_{out} = KV_{in}$ . If  $V_{out}$  is correct, 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. Create a table in your lab journal with four columns labeled  $V_{in}$ ,  $KV_{in}$  (the theoretical output voltage),  $V_{out}$  (the actual output), and percent error. Leave enough room to record 21 rows of data. Turn on the power supply output and for a  $V_{in}$  of about -10 V, carefully measure  $V_{in}$  and  $V_{out}$ . Increment  $V_{in}$  by 1 volt, and repeat the measurements. Collect data in this manner 19 more times, incrementing  $V_{in}$  by 1 V after each measurement until  $V_{in} = +10$  V. For each line of data, compute and record  $KV_{in}$  and the error between  $KV_{in}$  and  $V_{out}$ .
- b. At  $V_{in} = 2$  volts, accurately measure and record  $V_{in}$ ,  $+V_{CC}$ ,  $-V_{CC}$ ,  $v_P$  and  $v_N$ . If measured using a sensitive voltage scale, a *very small* difference in  $v_P$  and  $v_N$  can be measured. Measure and record the voltage difference  $\Delta v_{P-N}$ .
- c. Turn off the power supply output. Without removing the OP-AMP, disassemble the circuit of Fig. 6.

### 4. The non-inverting amplifier

- a. Calculate and record the expected gain for the circuit of Fig. 7.
- b. You will use the source circuit of Fig. 2 to provide  $V_{in}$  for the non-inverting amplifier of Fig. 7. Draw a circuit diagram similar to Fig. 5 for the schematic of Fig. 7. You may want to draw a pseudo-schematic similar to Fig. 6 for this circuit.
- c. Connect the circuit of Fig. 7, using your pseudo-schematic as a guide. Test the circuit by verifying that  $V_{out}$  is equal to  $KV_{in}$ . If not, troubleshoot the circuit until it is operating properly.

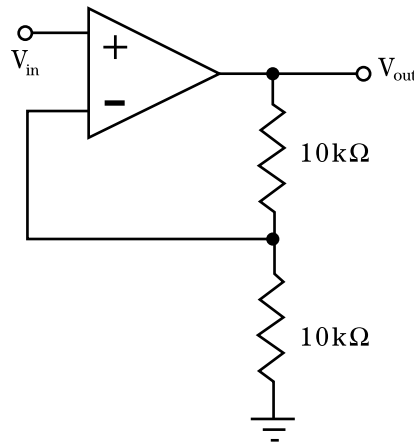


Figure 7

- d. Create a table for recording the  $V_{in}$ ,  $KV_{in}$ ,  $V_{out}$  and % error. Starting at a  $V_{in}$  of  $-10\text{ V}$ , make 21 measurements of  $V_{in}$  and  $V_{out}$ , incrementing  $V_{in}$  by  $1\text{ V}$  after each measurement. Fill in the remaining two columns of the table with the needed calculated values.

### Conclusion

For the inverting amplifier circuit, plot  $V_{out}$ ,  $KV_{in}$ , and error vs.  $V_{in}$  in your journal (three plots superimposed onto the same graph). Repeat for the non-inverting amplifier circuit. On each graph, draw a vertical line at the transition between the saturated and active regions of operation for these amplifier circuits. Label the mode of operation for each of these regions. Measure the slope of the curve in the active region. How well does the slope agree with the theoretical gain computed from the measured values of the circuit elements?

For the active regions for both circuits, discuss the possible sources of any error between  $V_{out}$  and  $KV_{in}$ .

\* Roland E. Thomas and Albert J. Rosa, The Analysis and Design of Linear Circuits, Prentice Hall, (New Jersey, 1994)