

Introduction to the Operational Amplifier

Purpose: Become familiar with the operational amplifier (op amp), and gain experience using this device in electric circuits.

Equipment Required

- 1 - Digital Multimeter
- 1 - Triple Power Supply
- 1 - Protoboard
- 2 - 10k Ω Resistors
- 1 - 33k Ω Resistor
- 1 - 10k Ω Potentiometer
- 1 - 741 op amp

Prelab

Read Section 4-5 on op amps in the textbook. Review the procedure in Lab 6 describing handling precautions for semiconductor devices. Use these precautions when handling op amps.

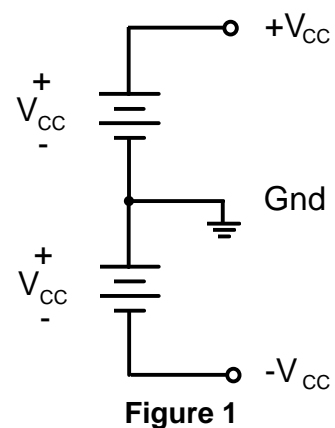
Procedure

1. Prepare the power supplies

- 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 dynamic signal sources.

A triple power supply provides two identical — usually variable — independent supplies, and a fixed 5V supply. Connecting the negative terminal of one supply to the positive terminal of the other forms the $\pm V_{cc}$ supplies. As shown in Fig. 1, this common point between the $\pm V_{cc}$ supplies is connected to circuit ground. We call the supplies



"independent" when a configuration like this does not short out the "negative" supply. Shorting will occur if the minus terminals of the supplies are internally tied to ground or "earth" through the 120VAC power line. Most good laboratory supplies are independent.

2. If your power supplies are variable, adjust the output so the $+V_{cc}$ and $-V_{cc}$ are equal — but opposite in sign — and about 15V.

b. Configure the signal source.

1. Connect the potentiometer to the $\pm V_{cc}$ supplies as shown in Fig. 2. This will provide a variable DC signal source from $-V_{cc}$ to $+V_{cc}$, which will be used for the 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 $\pm V_{cc}$.

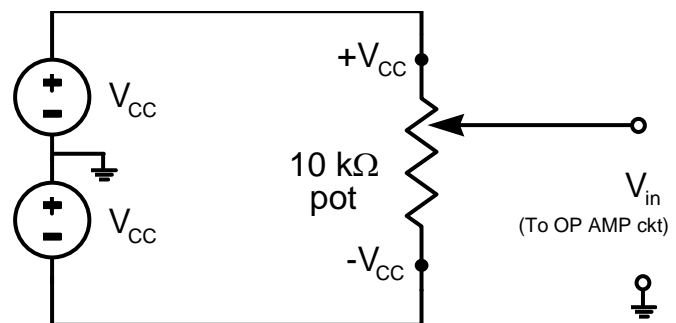


Figure 2

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 power supply off — wait for the power supply voltage to drop to zero before proceeding.

2. Connect the op amp

- 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.

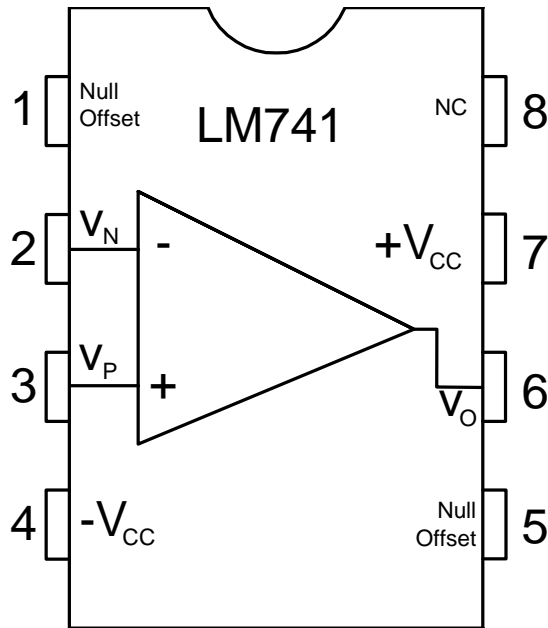


Figure 3

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 often 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 offset voltage is so small, in many cases we can ignore the contribution V_{os} makes to v_o and we leave the null offset pins open.

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

Pin 8, labeled "NC", has no connection to the internal circuitry of the 741 and is not used.

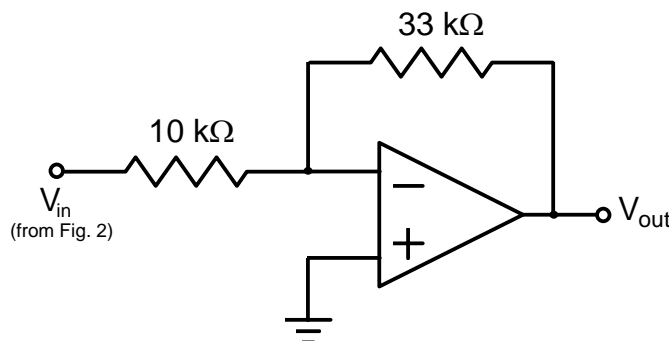


Figure 4

- 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.

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

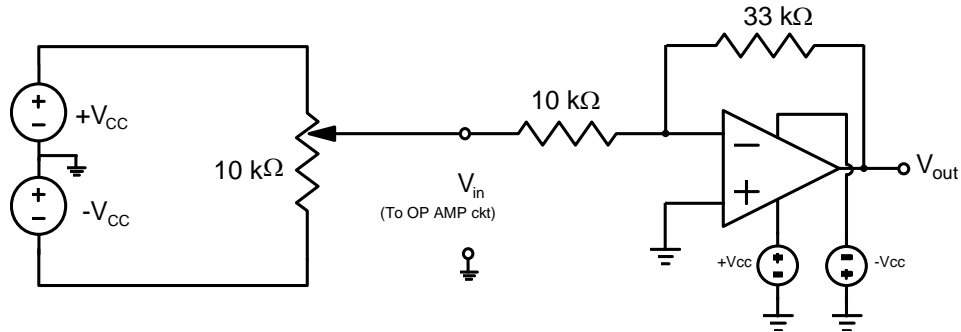


Figure 5

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

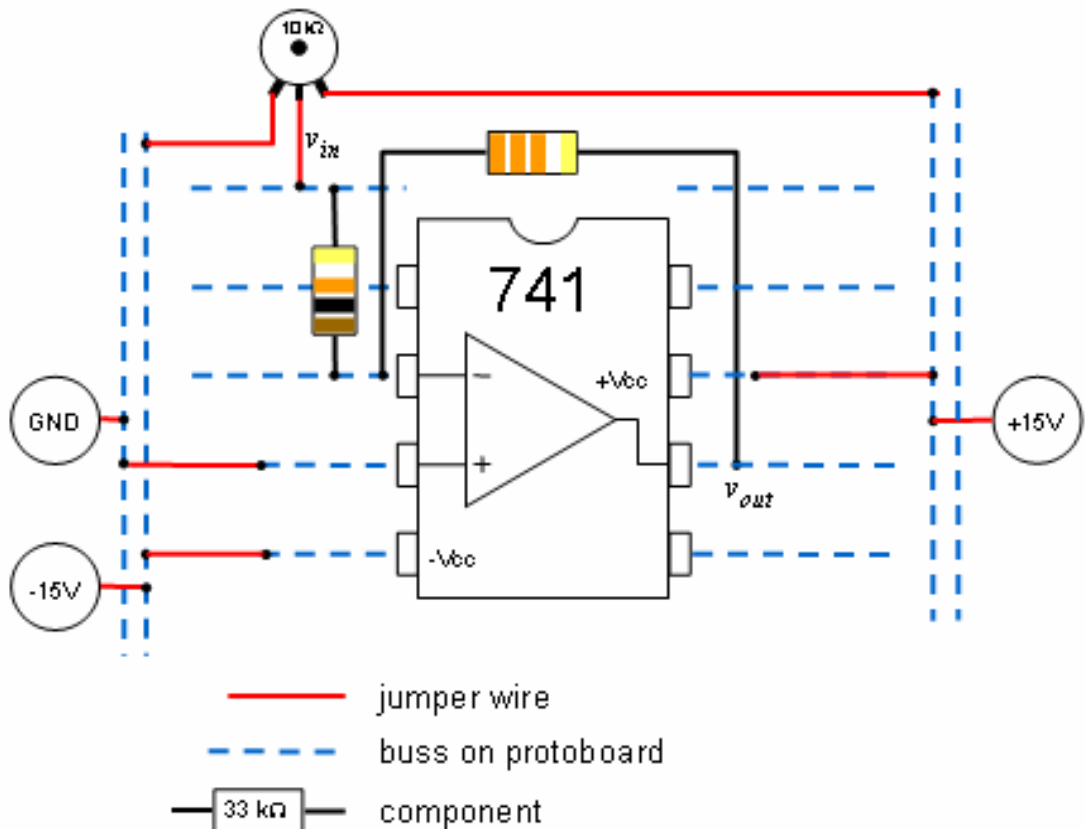


Figure 6

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 off*, construct the inverting op amp circuit using Fig. 6 as a guide. Check the circuit carefully. Turn on the power supply. Adjust the $10\text{k}\Omega$ potentiometer to achieve a v_{in} of almost 1V . 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.

- 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 and for a v_{in} of about -10V , carefully measure v_{in} and v_{out} . Increment v_{in} by 1 volt, and repeat the measurements. Collect data in this manner until $v_{in} = +10\text{V}$. For each line of data, compute and record Kv_{in} and the error between Kv_{in} and v_{out} .
- At $v_{in} = 0\text{V}$ disconnect the wiper of the pot from your circuit and short the input of your amp to ground, ensuring that v_{in} is *precisely* equal to 0V . Carefully measure and record v_{in} , $+V_{CC}$, $-V_{CC}$, v_p and v_n . You will probably discover a *very small* difference in v_p and v_n and even with the input shorted the output is not precisely zero as the theory would predict. Measure and record the voltage difference Δv_{p-n} .
- Turn off the power. Without removing the Op amp, disassemble the circuit of Fig. 6.

4. The non-inverting amplifier

- Calculate and record the expected gain for the circuit of Fig. 7.
- 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.
- 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.

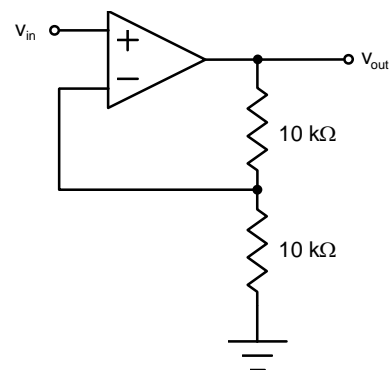


Figure 7

d. Create a table for recording the v_{in} , Kv_{in} , v_{out} and % error. Starting at a v_{in} of $-10V$, make 21 measurements of v_{in} and v_{out} , incrementing v_{in} by $1V$ 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. You are encouraged to create these plots using a computer.

On each graph draw a vertical line at the transition between the saturated and active operation for these amplifier circuits and label the mode of operation in each of these regions.

In the active regions fit straight lines ($y=mx+b$) to your data. Theory says that the slope of these lines should be the gain of the amp and the y-intercept should be precisely zero. Comment on your actual results. For the active regions for both circuits, discuss the possible sources of any error between v_{out} and Kv_{in} .