Lab 5: Operation Amplifiers

OBJECTIVES
- To reinforce the concepts behind operational amplifier analysis.
- Verification of operational amplifier theory and analysis.
- To successfully interpret and implement a chip pin-out diagram.
- To reinforce and verify typical operational amplifier circuit configurations.

MATERIALS
- The lab assignment (this document)
- Your lab parts.
- LM741 datasheet (on our website)
- Pre-lab questions including Multisim.
- Printouts (required) of the below documents:
  - Pre-lab analyses
  - Multisim screenshots e-mailed to course e-mail
- Graph paper.

INTRODUCTION

Op Amp Brief Description
Operational amplifiers (op amps) are important components of many electronic circuits. Although internally an op amp is an extremely sophisticated electronic circuit, the external operation can be understood without reference to the internal components. In other words, an op amp can usually be considered to be a “black box” component.

The simplified op amp circuit diagram symbol is shown in Fig. 1. The negative-designated terminal is called the inverting input terminal, the positive-designated terminal is called the noninverting input terminal, and terminal on the right is the output terminal. Inputs of positive and negative DC supply voltages are required, but they are often not shown on the circuit diagram.

Fig. 5.2 shows a uA741 Operational Amplifier circuit diagram and includes both the power supply pins (labeled V+ and V-). The two offset null voltage inputs (labeled OS1 and OS2) are rarely used and we will not discuss them.

Ideal Op Amp Model
The input terminals usually terminate on an insulating material. Consequently, the input currents are so small that they can usually be neglected and can be considered to be zero. It is important to remember this important approximation of zero input currents. Do not think that because the input currents can be considered to be zero that the current in the output line is zero. The output current is seldom zero. Thus, KCL does not apply to a closed surface around the op amp symbol of Fig. 5.1.
Lab 5: Operation Amplifiers

There is also an important approximation for the voltage across the input terminals. If the output voltage is less in magnitude than the supply voltages, which it is for normal (nonsaturated) operation, the voltage across the input terminals is so small that it can be considered to be zero. This approximation of zero volts across the input terminals is extremely important to remember in the determination of op amp circuit operation. Although there is approximately zero volts across the input terminals, it would be a serious error to assume that there is a short circuit across these terminals because actually there is approximately an open circuit across them. Thus, as seen from the input terminals of an op amp, the element acts as a “virtual” short circuit as well as a “virtual” open circuit. Remember that this is only an approximation.

For an illustration of the analysis of an op amp circuit, consider finding the output voltage $v_0$ and current $i_L$ in the load resistor $R_L$ in terms of the input voltage $v_i$ in the circuit shown in Fig. 2. Because of the 0 V drop across the op amp input terminals, the voltage across the 1 k$\Omega$ resistor is also $v_i$ as shown. Because of the zero current flow into the inverting input terminal, the 1 k$\Omega$ and 2 k$\Omega$ resistors are in series. Thus, by voltage division,

$$v_i = \left[ \frac{1}{1 + 2} \right] * v_0 = \frac{v_0}{3} \ \ \text{or} \ \ v_0 = 3v_i$$

Consequently, the circuit of Fig. 3 is a voltage amplifier that has a gain of three. However, the peak output voltage cannot exceed the magnitude of the DC supply voltages; when this occurs, it is called clipping. The current through the load, $i_L$, can be found as follows

$$i_L = \frac{v_0}{9} = \frac{3v_i}{9} = \frac{v_i}{3} \text{ mA}$$

The particular op amp that will be used in the laboratory is the popular 741 (in particular, the LM741CN). It is an integrated circuit (IC) in DIP (dual in-line package) form. It has eight connecting pins with four to a side. A isometric top view (the side from which you can read the writing) of this IC is shown in Fig. 4 along with an the pinout description, again viewed from the top. [Note that Figure 5.1 in our Nilsson/Riedel 8th edition textbook considers the view in Fig. 4 the bottom view.]
Lab 5: Operation Amplifiers

This package has a designation at one end of the top side that is typically a half-moon or a dot. This designation is important for pin number determination. The pin numbers do not appear on the package, but must be determined from the location of the pins with respect to the designator. For this determination, the 741 package should be held with the designator upwards facing the person (as in the right diagram in Fig. 4, and with the pins extending underneath the package. Then the pin locations are as follows, in agreement with the pin numbering shown in Fig. 4:

- Pin 1 is to the left of the designator.
- Pin 2 is under pin 1.
- Pin 3 is under pin 2.
- Pin 4 is under pin 3.
- Pin 5 is directly across from pin 4.
- Pin 6 is above pin 5.
- Pin 7 is above pin 6.
- Pin 8 is above pin 7 and across from pin 1.

From Fig. 4, note that pin 2 is the inverting (-) input, pin 3 is the noninverting (+) input, and pin 6 is the output. Pin 8 is labeled NC, which stands for no connection.

The energization of this op amp IC requires two power supplies, one of +15 V and the other of -15 V, both with respect to ground. The connection of these power supplies in the proper manner is crucial because if they are connected incorrectly, the IC will probably be permanently damaged. As shown in Fig. 5, the negative supply must be connected to pin 4, and the positive supply to pin 7. Proper

Figure 4 – LM741 IC isometric top view (left) and top view pinout (right). Pin 1 on the left figure is the lowest pin in the figure. Notice the notch and dot indicating the location of pin 1.

Figure 5 – Power Supply Connections for the LM741 op amp.
Lab 5: Operation Amplifiers

connection of the power supplies is shown in Fig. 5. If you are not certain how to determine which pin is which, ask the lab TA before applying power to avoid destroying the op amp. Also, when power is first applied, it is a good idea to keep a finger on the op amp for 5 or 10 seconds to observe if the temperature is increasing rapidly. If it becomes noticeably hot in this time, turn off or remove the power to the circuit and re-check the connections.

In this laboratory, no connections will be made to the other pins (pins 1, 5, and 8). Pins 1 and 5 are special purpose pins for obtaining optimum performance, which are seldom necessary except for some very special circuits. Pin 8 serves only for structural support.

PRE-LAB AND QUESTIONS
1. Derive the gain, $V_{out}/V_1$, for the circuit of Fig. 6.
2. Derive $V_{out}$ in terms of $V_1$ and $V_2$ for the circuit of Fig. 7.
3. Derive the gain, $V_{out}/V_1$, for the circuit of Fig 8.
4. Use your derived expression from 1 to calculate the expected value of $V_{out}$ in the inverting configuration of Fig. 6, when $R_f = 3k\Omega$, $R_1 = 1k\Omega$, $V_1 = 2V$, and the power supplies are +/- 15V. Construct this circuit in Multisim (use the LM741CN by selecting the “place analog” button and typing “LM741CN” in the component box) and measure the value of $V_{out}$, as in Fig 9. Take a screenshot of this.
Lab 5: Operation Amplifiers

5. In this same circuit (Fig. 6 and Fig 9), change V1 to 8V. Take a screenshot of this and explain the result.

6. Using this same circuit, change V1 back to 2V. Add in V2 and R2, as in Fig. 7, using values of 1V and 1kΩ for V2 and R2, respectively.

7. Using your derived expression from 2, calculate the expected value of Vf. Measure this value in Multisim and take a screenshot.

8. Using your other derived expression from 3, calculate the expected value of V3 in problem 8, if Rf = 120kΩ and R1 = 33 kΩ. Build this circuit in Multisim, measure Vout, and take a screenshot.

**LAB PROCEDURE AND QUESTIONS**

**Voltage Divider**

1. Construct the voltage-divider circuit shown in Fig. 10.
2. Calculate $V_1$ and $V_2$. Then, turn on the power supply and measure $V_1$ and $V_2$. Compare the measured and calculated values. Then, turn off the power supply, but do not dismantle the circuit.

![Figure 10 – Voltage divider circuit used for input voltages.](image)

**Inverting Amplifier**

3. Construct the inverter in Fig. 6. Make sure the power is connected to the op amps, as shown in Fig. 5. (Note: there are two separate voltage supplies.) Use $R_1 = 33 \text{ kΩ}$, $R_f = 120 \text{ kΩ}$, and $R_L \rightarrow \infty$ (open circuit).
4. Connect the free end of $R_1$ to the $V_1$ node of the voltage divider (from Fig. 10).
5. From the prelab solution, what should be the output voltage $V_{out}$? Record the measured value. Compare it with the calculated value.
6. Shut off the power supply. From the prelab analysis, it should have been apparent that, for an ideal op amp, the voltage $V_{out}$ is determined entirely by $R_1$, $R_f$, and $V_1$. The resistor $R_L$ has no effect. In other words, the output voltage $V_{out}$ is independent of the load placed on the inverter with the exception of a short circuit (for an ideal op amp). To test this observation, connect a decade resistor box as the load $R_L$. Then, measure $V_{out}$ for loads of 3 kΩ, 500 Ω, 300 Ω, and 200 Ω.

**Do not decrease $R_L$ to less than 100 Ω or else the IC may be damaged.** Turn off the power supply and explain why $V_{out}$ is not quite independent of the resistance of $R_L$. 
Lab 5: Operation Amplifiers

Summing Amplifier
7. Now construct the circuit shown in Fig. 7. R_f remains the same as in the inverter experiment (120 kΩ). Use a 33 kΩ resistor for R_2 and connect the free end to V_2 of the voltage divider. Temporarily remove R_1 and V_1 from the circuit.
8. From the prelab solution, what should be the output voltage V_{out}? Power up the circuit and measure V_{out}. Compare it with the calculated value.
9. Shut off the power supply, and connect the free end of R_1 (again use a 33 kΩ resistor) to the V_1 node again, leaving R_2 connected as in Step 7. Repeat Step 8.
10. Measure and record the voltage between pins 2 and 3 of the op amp. Explain the reading.

Noninverting Amplifier
11. Construct the noninverting op amp circuit in Fig. 8 with R_f = 120 kΩ and R_1 = 33 kΩ. Connect the circuit input V_1 to the V_2 node of the voltage divider in Fig. 10.
12. Turn on the power supply, measure V_{out}, and compare the measured value with the one calculated in the prelab solution.
13. What should be the voltage across pins 2 and 3 of the op amp? Measure it. Shut off the power supply.

Voltage-Follower
14. Construct the voltage-divider circuit of Fig. 11.
15. Calculate V_1. Turn on the power supply and measure V_1 with a DMM and record the reading. Is it close to the calculated value? If not, explain.
16. Build the circuit in Fig. 12, which is called a voltage follower. Derive the voltage gain V_{out}/V_1.
17. Connect the V_1 terminal of the voltage divider of Fig. 11 to the input of the voltage follower. Then, turn on the power supply, and measure the output voltage V_{out} with a DMM and record this measurement. Compare with the value expected from calculations.