

UNIVERSITY OF NORTH CAROLINA AT CHARLOTTE
Department of Electrical and Computer Engineering

EXPERIMENT 3 – OPERATIONAL AMPLIFIERS

OBJECTIVES

In this laboratory the student will acquire an understanding of AC and DC amplification, input and output impedance, and some basic circuit analysis tools.

INTRODUCTION

Operational amplifiers are versatile and useful devices. For example, they can be configured to function as:

- Amplifiers
- Attenuators
- Summers
- Integrators
- Differentiators
- Filters
- Oscillators

An Operational Amplifier is a very high-gain, direct-coupled, differential amplifier that uses feedback for control of its response characteristic. (A direct-coupled amplifier is capable of amplifying DC as well as time varying signals). The standard symbol for an op-amp is shown in Figure 3-1. Voltages V_1 and V_2 are applied to the inverting and non-inverting input terminals, respectively. V_o appears at the output terminal.

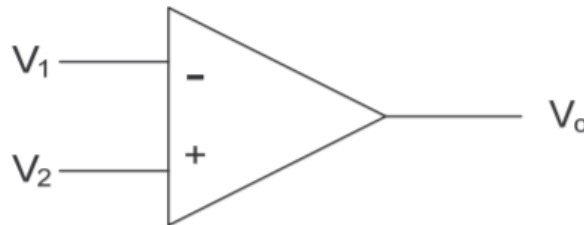


Figure 3-1 Operational Amplifier Symbol

A simple single stage amplifier can be built with one transistor. However, the gain of such an amplifier is often insufficient, and cascaded, or multistage, amplifiers are required. Multistage amplifiers are built on a single “chip”, using integrated circuit technology. In addition to the increased packaging density, integrated circuit amplifiers offer other advantages, including: a) improved noise immunity, b) superior frequency response, c) stability, d) low power consumption and e) low cost.

The output voltage of an op-amp is the difference between the voltages applied to its input terminals multiplied by its open loop gain, A . The output voltage is positive when the voltage applied to the positive (non-inverting) input exceeds that applied to the negative (inverting) input, and vice versa. An ideal op-amp has an infinite open-loop gain, requiring that the difference between V_1 and V_2 be infinitesimally small in order for the output voltage V_o to be finite. Thus, for circuit analysis purposes, this voltage difference is assumed to be zero.

Furthermore, the ideal op-amp has infinite input impedance and zero output impedance. These are, of course, the desired characteristics for a buffer amplifier used between a high impedance source and a low impedance load. For circuit analysis purposes, the current at the input terminals is assumed to be zero, while the output voltage when driving a load is assumed to be the same as the open circuit output voltage. The output voltage of an op-amp is given by

$$V_o = A (V_2 - V_1)$$

In this equation, observe that when A is infinite, the difference between V_2 and V_1 must be zero in order for V_o to be finite.

A 741 op-amp in a typical DIP (Dual In-line Package) is shown in Figure 3-2a. Notice the orientation dimple that indicates the location of pin 1. Figure 3-2b shows another 741 op- amp DIP package that uses a semicircular notch to identify the pin 1 end of the package.

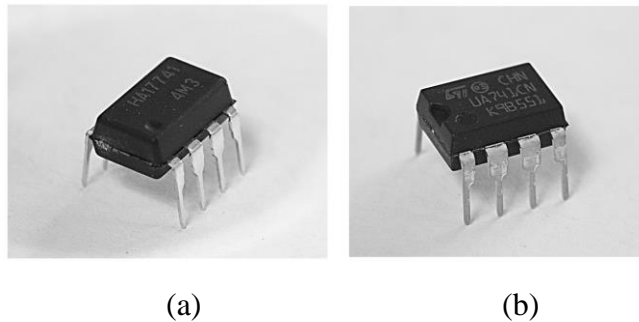


Figure 3-2 (a)DIP with Dimple (b)DIP with Notch

The pin-out diagram for the 741 op-amp appears in Fig. 3-3. Pins are numbered sequentially counter-clockwise around the DIP. Pin 1 and the last pin (pin 8, in this case) are opposite each other. This is typical of dual in-line packaging regardless of pin count.

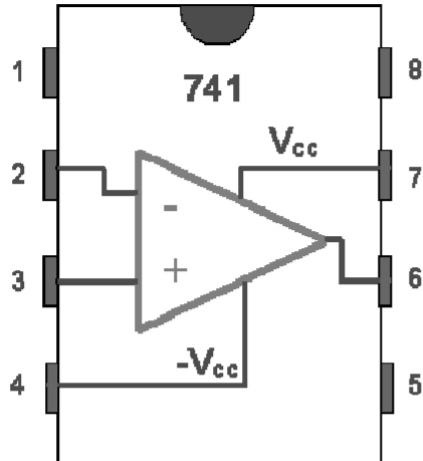


Figure 3-3 741 Op-Amp Pinout

Pin 2 is the inverting input, pin 3 is the non-inverting input, and the amplifier output is pin 6. These three pins are the terminals that normally appear on the op-amp symbol in a circuit diagram. Even though the $\pm V_{cc}$ connections must be made for the op-amp to work, they are often omitted from the circuit schematic for simplicity. The null-offset pins (1 and 5) provide a way to eliminate spurious offset voltage at the output. This offset voltage is normally less than 10 mV and is the output voltage that would be measured when both inputs are grounded. In many applications it is not important, and in these situations, the null-offset pins are not connected. Pin 8 has no connection to the internal circuitry of the 741, and is not used.

This laboratory experiment will investigate inverting and non-inverting amplifiers, along with the voltage follower -- which is generally used as a buffer or driver amplifier.

PRELAB

1. Referring to Figure 3-4, develop a formula that will give the voltage gain, V_o/V_i , in terms of R_1 and the feedback resistance, R_f . Assume the voltage difference between pins 2 and 3 to be zero, and that the current flowing into these pins is also zero.

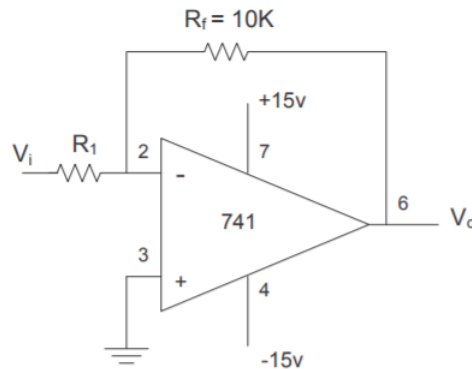


Figure 3-4 Inverting Amplifier

- Referring to Figure 3-5, develop a formula that will give the voltage gain, V_o/V_i in terms of R_1 and the feedback resistance, R_f . Assume the voltage difference between pins 2 and 3 to be zero, and the current flowing into these pins also to be zero.

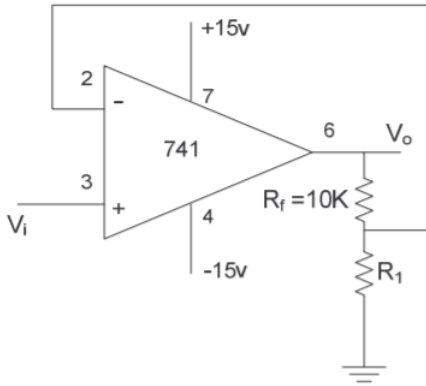


Figure 3-5 Non-Inverting Amplifier

- In the circuit of Figure 3-6, what is the relationship between V_o and V_i ?

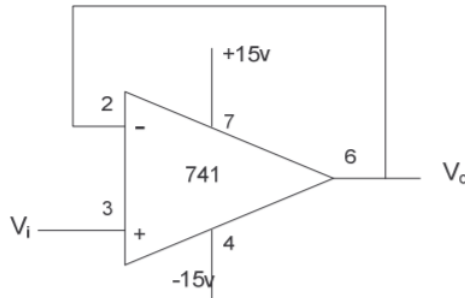


Figure 3-6 Voltage Follower

PROCEDURE

- Prepare the dc power supplies in the configuration of Figure 3-7. Adjust the power supplies so that $+V_{CC} = +15V_{dc}$ and $-V_{CC} = -15V_{dc}$.

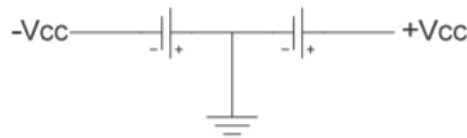


Figure 3-7 Power Supply Set-up

- Build the DC driver circuits as shown in Figure 3-8. The value of resistor R in the voltage divider is selected to provide a DC drive voltage adjustable approximately from -100 mV to $+100\text{ mV}$. For the DC driver, the AC voltage is adjusted for minimum amplitude while the DC offset is enabled and adjusted to give the desired DC input.

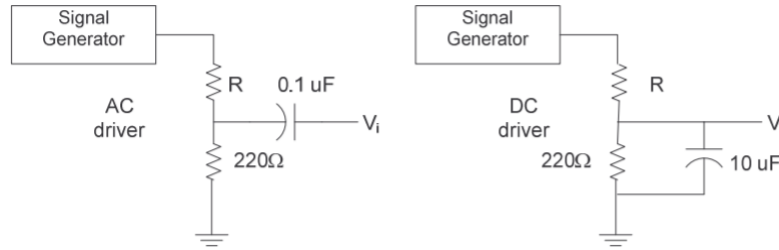


Figure 3-8 Amplifier Driver Circuit

3. Refer to the pin diagram of Figure 3-3 and construct the open loop amplifier of Figure 3-9.

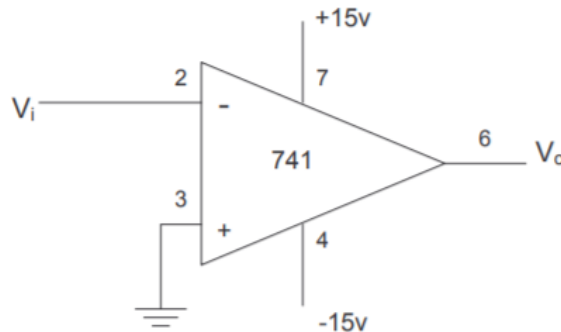


Figure 3-9 Open Loop Amplifier

- a) Connect the DC driver and apply a +2 mV input. Measure and record the output voltage. Repeat for an input voltage of -2 mV.
 - b) Now try to adjust the input to give an output voltage between -10V and +10V. Is this amplifier inverting or non-inverting?
 - c) Can you draw any conclusions concerning the gain and stability of an open loop amplifier?
 - d) Are the attainable output voltages close to the power supply voltages? Are they larger or smaller and how close are they?
4. Construct the amplifier of Figure 3-10.

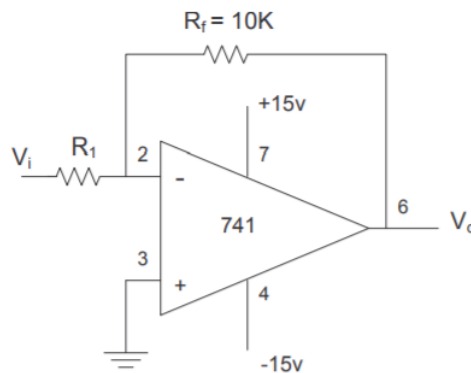


Figure 3-10 Inverting Amplifier

- a) Connect the DC driver and adjust to provide a DC input voltage of approximately 50 mV. Measure and record both input and output voltages for R1 values of 100Ω and 1000Ω. Use either the DMM or oscilloscope for these measurements.
 - b) Connect the AC driver and adjust the input voltage for approximately 100 mV p-p at 1 kHz. The DC offset should now be disabled. Use a dual trace oscilloscope to simultaneously display the input and output voltages for R1 values of 100Ω and 1000Ω. Measure the input and output voltage and the relative phase of the output voltage relative to the input voltage.
5. Construct the amplifier of Figure 3-11.

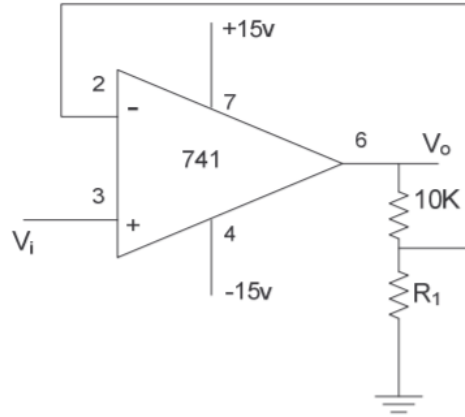


Figure 3-11 Non-Inverting Amplifier

- a) Connect the DC driver and adjust to provide a DC input voltage of approximately 50 mV. Measure and record both input and output voltages for R1 values of 100Ω and 1000Ω. Remember to adjust the AC output to its minimum. Use either the DMM or oscilloscope to measure the input and output voltage.
 - b) Connect the AC driver and adjust the input voltage for approximately 100 mV p-p at 1 kHz. The DC offset should now be disabled. Used a dual trace oscilloscope to simultaneously display the input and output voltages for R1 values of 100Ω and 1000Ω. Measure the input and output voltage and the relative phase of the output voltage relative to the input voltage.
6. Construct the amplifier of Figure 3-12.

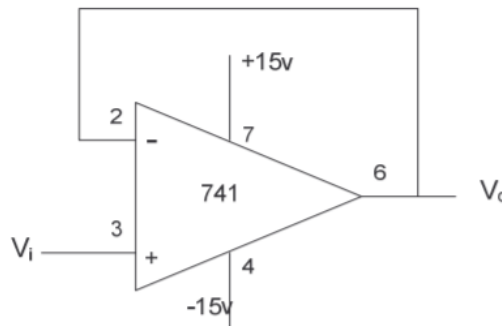


Figure 3-12 Voltage Follower

- a) Connect the DC driver and adjust to provide a DC input voltage of approximately 1 V. Measure and record both input and output voltages. Use either the DMM or oscilloscope for these measurements.
- b) Connect the AC driver and adjust the input voltage for approximately 1 V p-p at 1 kHz. The DC offset should be disabled. Used a dual trace oscilloscope to simultaneously display the input and output voltages. How do the input and output voltages compare in amplitude and phase?

POSTLAB

Post-Lab questions must be answered in each experiment's laboratory report.

1. Explain why a coupling capacitor is used in the AC driver and why a bypass capacitor is used in the DC driver.
2. Is it possible for the output voltage of an op-amp to be outside of the range defined by $\pm V_{cc}$? Assuming that $|V_{cc}| = 15$ V, approximately what are the most positive and most negative output voltages?
3. Assume that the open-loop gain of your op-amp is 10,000. How accurately would you need to adjust the input voltage to avoid railing the output in the open-loop circuit?
4. How well do your measured and calculate gains compare for the inverting amplifier? You have four gain values to compare (two DC and two AC). Attempt to explain any deviations greater than 10%.
5. How well do your measured and calculated gains compare for the non-inverting amplifier? Again, you have four gain values to compare (two DC and two AC). Attempt to explain any deviations greater than 10%.
6. For the voltage follower, gain is unity. Provide at least one application for such an amplifier.