ECE201 Laboratory – 2

Introduction To
Operational Amplifiers
(Created by Prof. Walter Green, Edited by Prof. M. J. Roberts)

Objectives

The objective of this laboratory is to gain analytical and practical experience with operational amplifiers (op amps). In this laboratory exercise you will:

- verify basic properties of the op amp in inverting and noninverting configurations,
- build a low-pass filter and obtain the frequency response of the filter.

Operational Amplifiers

An operational amplifier, more commonly referred to as an op amp, was first introduced as an electronic device constructed from vacuum tubes, resistors and capacitors. The vacuum tube op amps were rather expensive, costing in the range of $40 to $90 per unit. Today, operational amplifiers are built on a single chip (often, more than one op amp is placed on a chip) and fabricated as double-in-line (DIP) packages. An ordinary LM741 op amp costs less than $1.00.

From the early 1940s to the mid 1960s, operational amplifiers were the building blocks of analog computers. Analog computers were used to solve linear, nonlinear and time varying differential equations. Analog computers are rare now. Their functions have been taken over by digital computers. But op amps are still very widely used today. They are used extensively in instrumentation, control systems, signal processing and as a buffer between analog signals and digital computers.

Historically, operational amplifiers have been used to perform such diversified functions as addition, subtraction, multiplication, and integration of electrical signals. Hence, the name "operational" amplifier – emphasizing the many operations this device can perform.

The op amp that will be used for this laboratory exercise, the LM 741, has two signal inputs; an inverting input (pin 2) and a non-inverting input (pin 3) as shown in Figure 3.1. Pin 6 is the output pin.   Pin 7 is for V_{CC}(+) and pin 4 is for V_{EE}(-), which are supply voltages. Pins 1 and 5 are used to adjust for offsets of the op amp output voltage. We will not be using the offset null during this laboratory exercise.
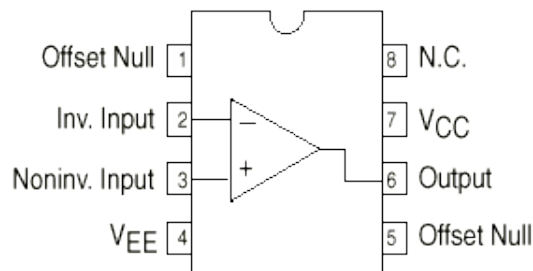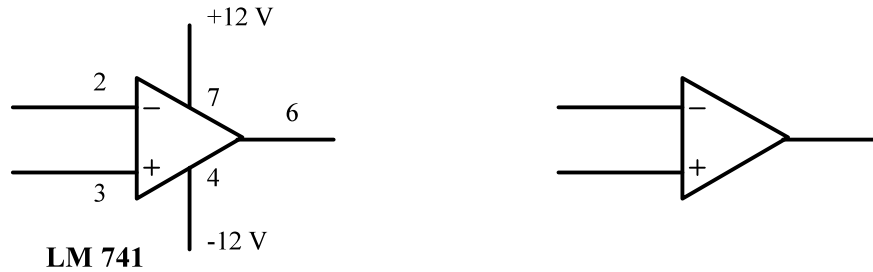

Figure 3.1 Pin diagram of an LM741 operational amplifier.

The customary way of showing the pin connections of the operational amplifier of Figure 3.1 is in Figure 3.2a. Often, the supply terminals and pin connection numbers are omitted and one will normally encounter the basic op amp schematic representation as shown in Figure 3.2b.

(a) op amp with pin identification   (b) customary op amp schematic

Figure 3.2 Basic representations of an operational amplifier.

An equivalent circuit model of an operational amplifier is shown in Figure 3.3 where the circuit is configured within the triangle shape of the op amp.
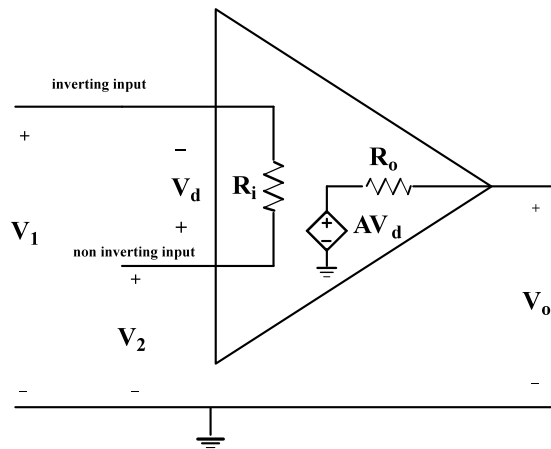

Figure 3.3 An equivalent circuit representation of an op amp.

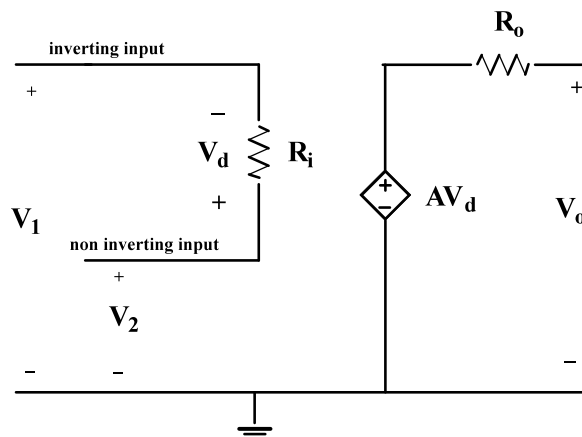The model of Figure 3.3 is often drawn in a circuit form similar to that of Figure 3.4.

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Figure 3.4 Basic op amp model, non ideal.

The above model produces very accurate results for calculating performance of the op amp. In this laboratory exercise we will use the ideal op amp model. For the ideal model, the assumptions are

- A (open loop gain of the op amp) is infinite
- R_i (input resistance of the op amp) is infinite
- R_o (output resistance of the op amp) is zero

Using the above assumptions allow us to say the following about the input voltages and currents (Figure 3.5).

- $i_1 = i_2 = 0$. Due to infinite input resistance.

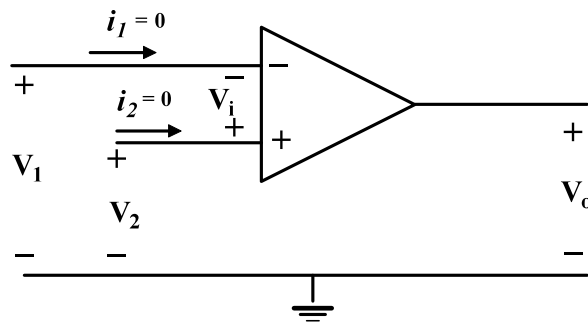- V_i is negligible and $V_1 = V_2$.

Figure 3.5 An ideal op amp.

Inverting Amplifier

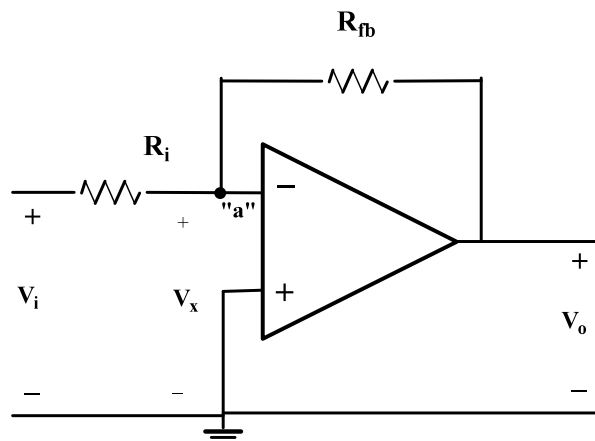A very common configuration of the op amp is shown in Figure 3.6.

Figure 3.6 Inverting amplifier op amp circuit.

Writing a nodal equation at point "a", $\dfrac{V_x - V_i}{R_i} + \dfrac{V_x - V_o}{R_{fb}} = 0$. With $V_x = 0$ (for the ideal op amp)

we can express the output voltage in terms of the input voltage as $V_o = -\dfrac{R_{fb}}{R_i} V_i$. The output is

equal to the input, *inverted*, times a gain of R_{fb} / R_i. The gain magnitude can be greater than or less than one.

Noninverting Amplifier

In the circuit diagram of Figure 3.7 the input signal is applied to the noninverting terminal of the op amp.
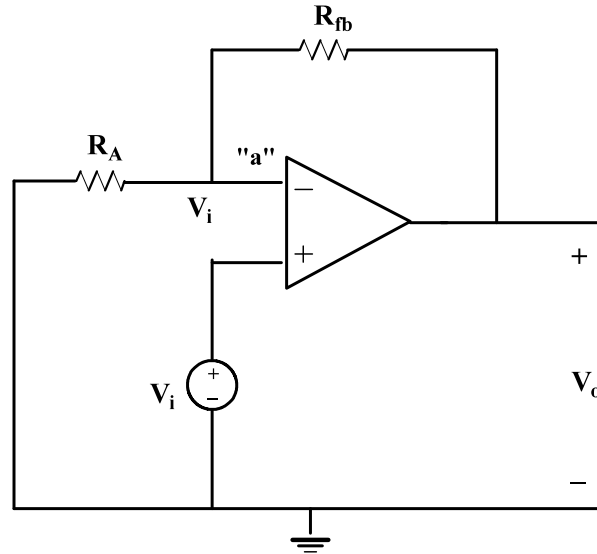

Figure 3.7 Noninverting amplifier op amp circuit.

The equation relating the output and input is found to be

$$V_o = V_i \left[1 + R_{fb} / R_A \right]$$

We note that the output voltage is a gain factor of $\left[1 + R_{fb} / R_A \right]$ times the input voltage, *not inverted*. Thus, the noninverting amplifier op amp circuit provides a positive voltage gain.

Prelab Exercises

Complete the following exercises prior to coming to the lab. As usual, turn-in your prelab work to the lab instructor before starting the Laboratory Exercises.

Part 1PE: Inverting Amplifier.

Figure 3.8 is a circuit illustrating that an operational amplifier can be used for adding signals. You will be building this same circuit in the lab to determine V_o.
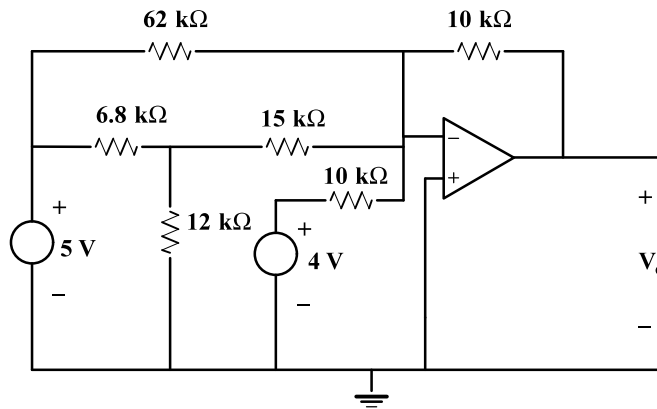
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Figure 3.8 Op Amp Circuit used for adding two signals.

*For the prelab part you are to analytically **determine Vo using circuit theory** as applied to this op amp configuration.* This analytical value will be compared to the measured value you obtain in the lab.

Part 2PE: Noninverting Amplifier. Refer to the circuit in Figure 3.7.

(a) **Derive** the Equation 3.6 for the noninverting amplifier.

(b) If $R_{fb} = 0$, (and all other circuit values remain the same) what is the value of V_o in terms of V_i?

(c) If $R_i = \infty$, (and all other circuit values remain the same) what is the value of V_o in terms of V_i?

Laboratory Exercises

Part 1LE: Inverting Operational Amplifier Circuit

(a) Construct the circuit shown in Figure 3.9. You may use either ¼ watt or ½ watt resistors.
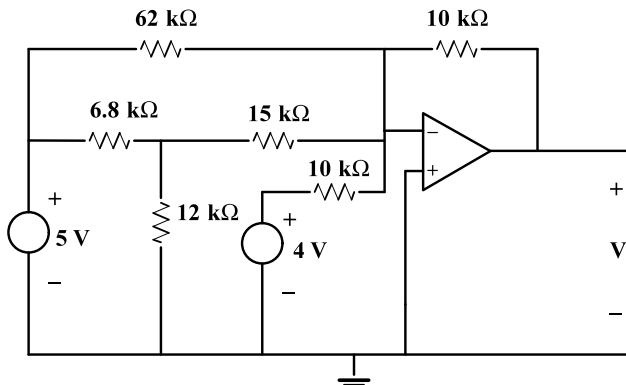(b) Measure and record the output voltage V_o.

Figure 3.9 Laboratory circuit for an inverting operational amplifier.

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Part 2LE: Noninverting Operational Amplifier Circuit.

(a) Construct the circuit shown in Figure 3.10.

(b) Measure and record the voltage V_o.

(c) Change R_{fb} to zero. Keep all other circuit values as in Fig. 3.10. Measure and record V_o.

(d) Change R_A to infinity. Keep all other circuit values as in Fig 3.10. Measure and record V_o.
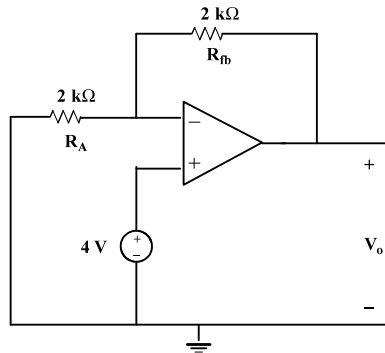

Figure 3.10 Laboratory circuit for noninverting operational amplifier, Part 2LE.

Before Leaving The Laboratory

Be sure the following is complete before leaving the laboratory.

(a) Make sure you have all the necessary readings and printouts.

(b) Have your readings checked off by the TA.

(c) Restore your lab station (equipment and chairs) to the condition they were in when
     you arrived and remove any debris from the work area and floor.

   Thank you for your cooperation.

Questions, Comparisons and Discussions

Compare your prelab voltage values with the output voltages obtained in the lab for the inverting
amplifier and noninverting amplifier circuits.   Make comments that you think are appropriate.

Laboratory Report

The following should be included in your laboratory report. If you have any questions be
sure to contact the lab instructor.

(a) Give a short summary (50 to 100 words) of what is to be accomplished in the laboratory.

(b) Write the procedure followed for each part of the work.

(c) Tabulate all your readings. Be sure to give table numbers, figure numbers and captions, as appropriate.

(d) Answer the questions and present the necessary diagrams (plots) along with Figure numbers and captions.

(e) Write a brief conclusion (approximately 200 words).

(f) Attach the graded prelab at the end of your report.