ELG3336: Experiment 1
Inverting Operational Amplifier
(Duration: 90 minutes)

Objectives
- To understand the main characteristics of operational amplifier circuits.
- To analyze and implement the inverting operational amplifier circuit.
- To illustrate the power supply regulation properties of operational amplifiers.

Introduction
Figure 1 shows the circuit diagram and symbols for the operational amplifier (op-amp). Refer to Chapter 8 of the textbook for further information. Refer to "FOCUS ON METHODOLOGY" pp. 410-412 for op-amp data sheet.

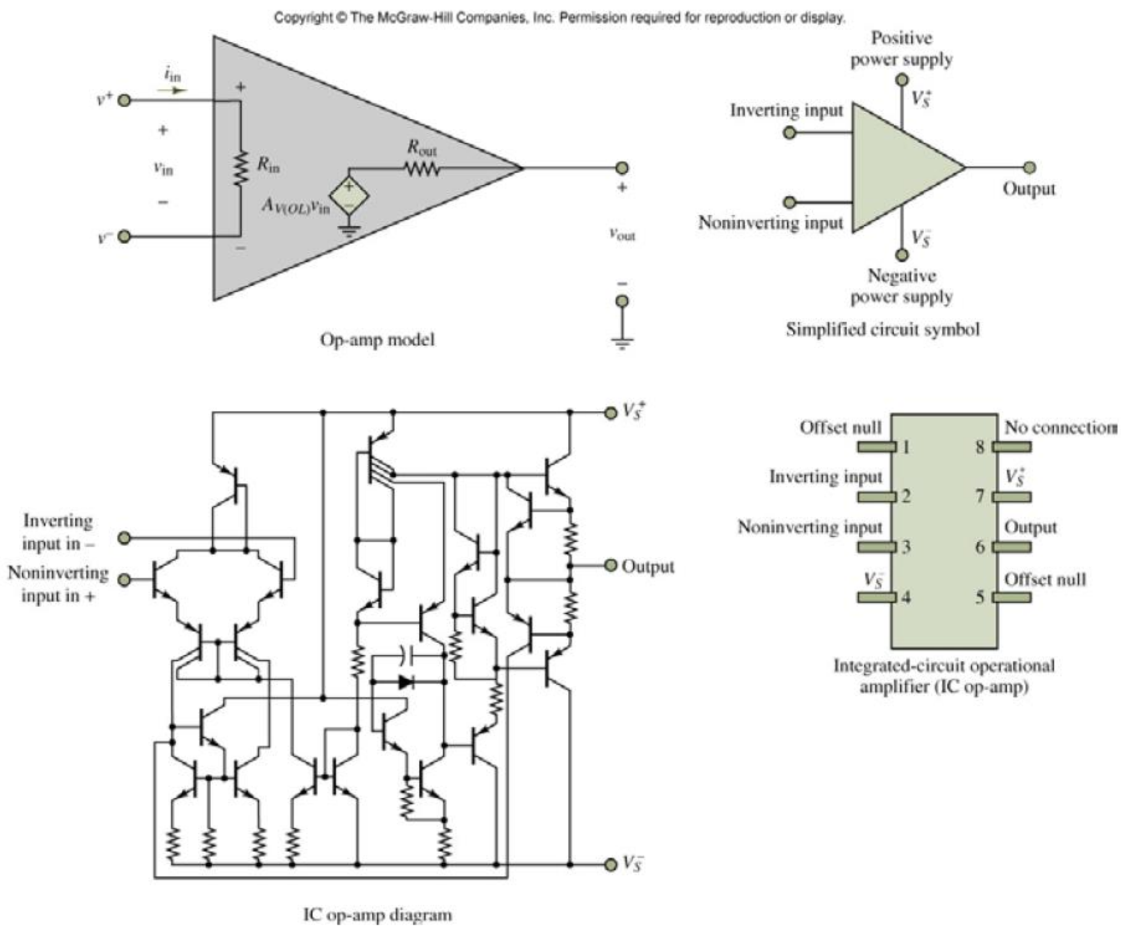

Figure 1 Operational Amplifier model, symbols, and circuit diagram.

Theory

An amplifier has an input port and an output ports. In a linear amplifier, the output signal = A × input signal, where A is the amplification factor or gain. Depending on the nature of the input and output signals, we may have four types of amplifier gain: voltage gain (voltage out / voltage in), current gain (current out / current in), transresistance (voltage out / current in) and transconductance (current out / voltage in). Since most op-amps are used as voltage-to-voltage amplifiers, we will limit the discussion here to this type of amplifier.

The circuit model of an amplifier is shown in Figure 2 (center dashed box, with an input port and an output port). The input port plays a passive role, producing no voltage of its own, and is modeled by a resistive element R_i called the input resistance. The output port is modeled by a dependent voltage source AV_i in series with the output resistance R_o, where V_i is the potential difference between the input port terminals.

Figure 2 shows a complete amplifier circuit, which consists of an input voltage source V_s in series with the source resistance R_s, and an output "load" resistance R_L. From this figure, it can be seen that we have voltage-divider circuits at both the input port and the output port of the amplifier. This requires us to re-calculate V_i and V_o whenever a different source and/or load is used:

$$V_i = \left(\frac{R_i}{R_s + R_i}\right)V_s \tag{1}$$

$$V_o = \left(\frac{R_L}{R_o + R_L}\right)AV_i \tag{2}$$

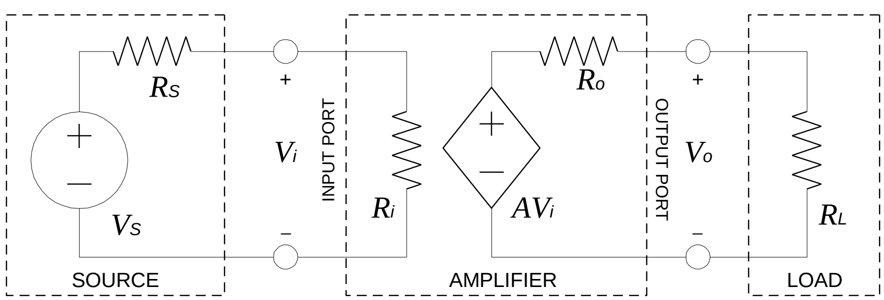

Figure 2 Circuit model of an amplifier circuit.

The amplifier model shown in Figure 2 is redrawn in Figure 3 showing the standard op-amp notation. An op-amp is a "differential-to-single-ended" amplifier, for example, it amplifies the voltage difference $V_p – V_n = V_i$ at the input port and produces a voltage V_o at the output port that is referenced to the ground node of the circuit in which the op-amp is used. Applying these assumptions to the standard op-amp model results in the ideal model shown in Figure 4.

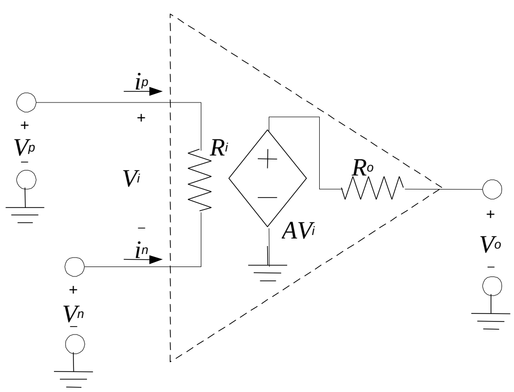

Figure 3 Standard op-amp.

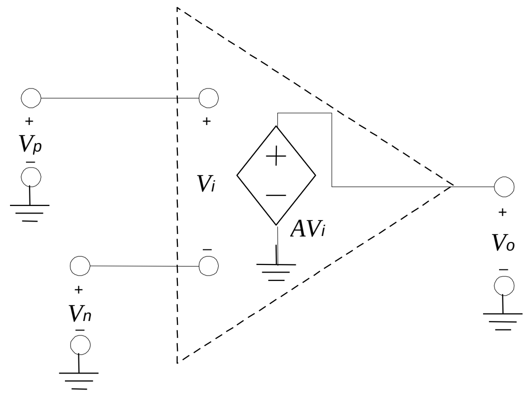

Figure 4 Ideal op-amp.

The ideal op-amp model is derived to simplify circuit analysis and it is commonly used by engineers for first-order approximate calculations. The ideal model makes the following simplifying assumptions:

Gain is infinite: $A = \infty$ (3)

Input resistance is infinite: $R_i = \infty$ (4)

Output resistance is zero: $R_o = 0$ (5)

Figure 5 shows another useful basic op-amp circuit, the inverting amplifier. It is similar to the non-inverting circuit studies in the class except that the input signal is applied to the inverting terminal via R_1 and the non-inverting terminal is grounded. Let us derive a relationship between the input voltage V_{in} and the output voltage V_{out}. First, since $V_n = V_p$ and V_p is grounded, $V_n = 0$. Since the current flowing into the inverting input of an ideal op-amp is zero, the current flowing through R_1 must be equal in magnitude and opposite in direction to the current flowing through R_2 (by Kirchhoff's Current Law).

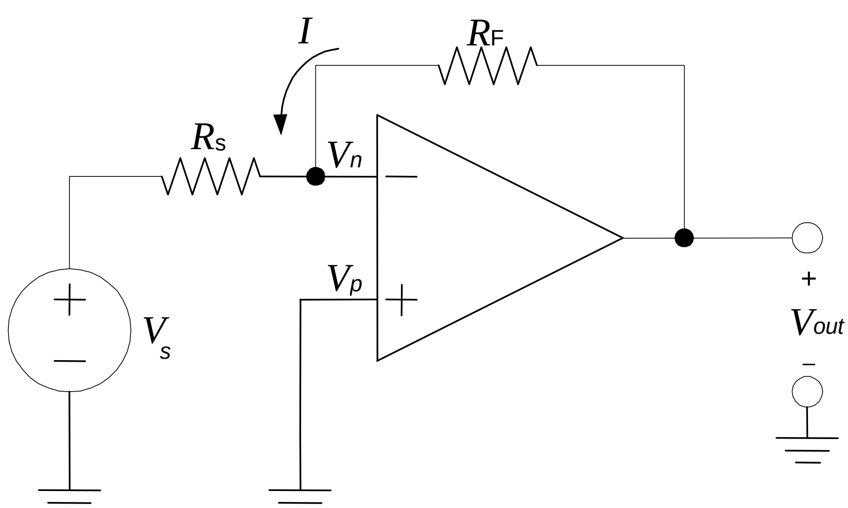

Figure 5 Inverting operational amplifier circuit.

$$\frac{V_{in} - V_n}{R_1} = \frac{V_{out} - V_n}{R_2} \tag{6}$$

Since $V_n = 0$, we have:

$$V_{out} = \left(-\frac{R_2}{R_1}\right)V_{in} \tag{7}$$

The gain of inverting amplifier is always negative.

Pre-Lab Preparation

The lab preparation using MULTISIM simulation tool must be completed before coming to the lab. Show it to your TA for checking and grading at the beginning of the lab and get his/her signature. A tutorial on MULTISIM is available at the course Webpage:

Equipment and Components

- 741 op-amp
- DC power supply
- Oscilloscope
- Functional generator
- Digital multimeter
- Resistors

Experimental Procedure

1. Assemble the circuit shown in Figure 5 with $R_F = 20\ R_s$. The power supply should be ±15 V.
2. Measure and plot its output voltage against its input voltage using an oscilloscope. Set the input *vs* to a sine wave with frequency 100 Hz and peak-to-peak amplitude 2 V.
3. Reduce the power supply to ±10 V and see what will happen.
4. Return to ±15 V and change the frequency to 100 kHz and see what will happen.

Lab Report

1. Comment on how circuit behavior changes when the power supply changes.
2. Comment on how circuit behavior changes when the frequency changes.
3. Attach the results of the simulation to your lab report.