Lab Exercise # 9

Operational Amplifier Circuits

Objectives:

1. To understand how to use multiple power supplies in a circuit.
2. To understand the distinction between "signals" and "power".
3. To understand the principle of feedback.
4. To explore some of the many ways in which operational amps (op-amps) may be used in electronic instrumentation and measurement.

THEORY

Figure 9. 1 shows the configuration of an op-amp and its simplified equivalent circuit.

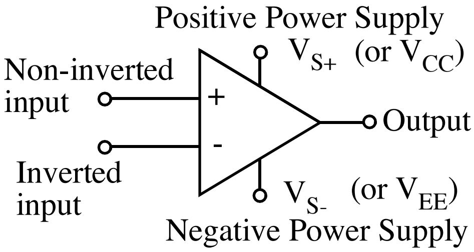

Figure 9.1 (a) Op-amp configuration

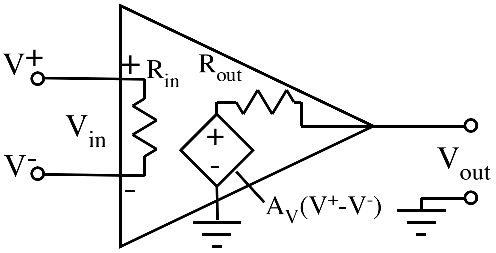

Figure 9.1(b) Simplified equivalent circuit

For an ideal op-amp, the open loop gain $A_{V(OL)}$ and the input resistance R_{in} are very large, and the output resistance R_{out} is very small. Typical values of A, R_{in} and R_{out} are 10^5, 2 MΩ and 75 Ω respectively. Analysis of an op-amp circuit can be made simple by assuming that

(1) The voltages at the inverting input and at the non-inverting input are equal and

(2) The currents entering these terminals are negligible.

(3) Almost all op-amp circuits use feedback. The principle is that the output Voltage is whatever it needs to be to make the input Voltages balance. If the op-amp circuit is operating properly, V_{out} is NOT close to either supply Voltage, and $V^- = V^+$.

Pin Configuration:

The pin configuration for the general-purpose Op-amp LM741 is as in Figure 9.2. A dot or a circular/semicircular cut on the top surface of the device will identify pin 1. (If you are given a different op-amp to work with, you should refer the data book provided by the manufacturer for the pin configuration and the specifications regarding the supply voltage and other important parameters.) We won't use the "offset null" pins.

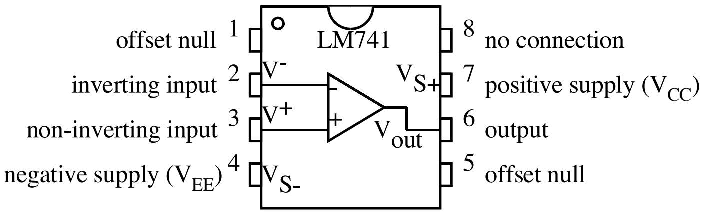

Figure 9.2 Pin Configuration (top view) of the LM741 Op-amp, Top View

Power Supply to an Op-amp:

The LM741 will be supplied with +15 Volts for V_S^+ (V_{CC}) and -15 Volts for V_S^- (V_{EE}). Adjust the right variable unit of the power supply unit to provide +15 Volts (using the DMM to measure the voltage) and the left unit to provide -15 volts. The "Common" terminal (positive end of left supply, negative end of right supply) may be connected to the (protective) "Ground" terminal of the power supply unit as well as the 'Ground' connection for the circuits. The positive terminal (right unit) provides V_S^+ (V_{CC}) and the Negative terminal of the left unit provides V_S^- (V_{EE}) for the op-amp. This is shown in Figure 9.3.

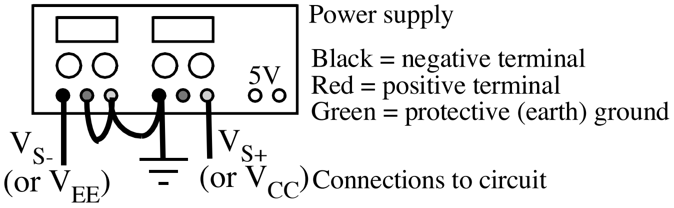

Figure 9.3. Power Supply Connections to an Op-amp

Basic Steps for Op-amp Connections:

a. Insert the op-amp so that it straddles the breadboard "trench." HANDLE WITH CARE AND DO NOT FORCE THE INSERTION. You may break one of the legs.

b. Be careful to keep the wiring neat and compact. This will minimize the chance of unwanted instability and oscillation in these high-gain circuits.

c. Use one of the long rows along the edges of the breadboard for the "Ground" connection.

d. Use color-coded wiring. Use Red (or Yellow) for the positive supply, White (Black for banana leads since there's no White) for the negative supply, Black for ground.

Procedure:

9.1 Voltage amplifier

It is often desirable to boost the sensitivity of a voltmeter, and also reduce its loading effect on the measurement. Both are achieved by the circuit in Figure 9.4. The resistor potentiometer circuit is used to supply a DC Voltage. The signal generator is substituted for this to supply an AC input signal.

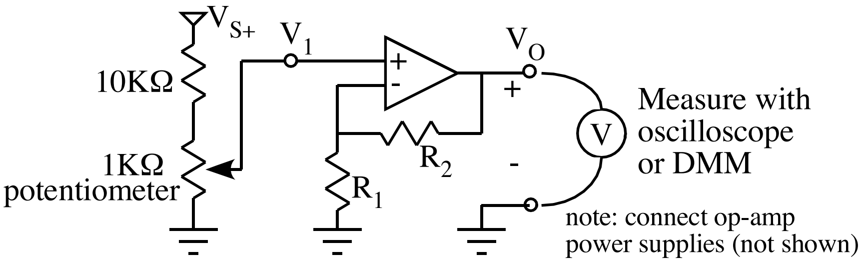

Figure 9.4. Voltage Amplifier

Assuming the op-amp to be ideal, and remembering that due to feedback $V^+ = V^-$, show that

$$\text{voltage gain } A = \frac{V_0}{V_1} = \frac{R_1 + R_2}{R_1} \qquad (9.1)$$

1. Assume that the voltage V_1 to be measured is of the order 0.8 volt (DC). Since the op-amp will saturate at about 15 volts, choose R_2 and R_1 for a gain of, say, 11 (As the lab instructor directs). Measure the resistor values using a DMM. (Suggested values are 10 kΩ and 1 kΩ for a factor of 11 difference.)
2. Supply the unknown Voltage, and measure the output Voltage. (Use the DMM or the oscilloscope).
3. Calculate the gain of the amplifier, $A = \frac{V_0}{V_1}$
4. Compare it with calculated gain as given by equation (9.1)
5. Repeat this measurement for an AC sinusoidal voltage (the frequency may be 1 kHz and the input voltage about 1V peak-peak).
6. Repeat Step # 5 for an input voltage of 4 V (p-p). What do you observe?

9.2 Electronic Integrator

Figure 9.5 shows an integrating circuit. It is called a "negative" integrator since the signal goes to the negative terminal of the op-amp.

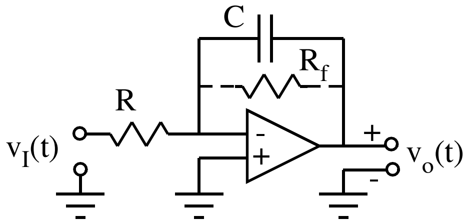

Figure 9.5 Negative Integrating circuit

Assuming an ideal op-amp, and also that the value of R_f is very large compared to the capacitive reactance, derive the relation below. Recall that feedback means that $V^+ = V^-$.

$$v_0(t) = -\frac{1}{RC}\int v_1(t)dt \qquad (9.2)$$

1. Connect the circuit shown in Figure 9.5. Choose the values of R and C as 1000 Ω and 0.05 μF respectively (or as directed). To get a better stable pattern, you can connect a resistor R_f of value between 100 kΩ and 1 MΩ across the capacitor. Connect the input to channel 1 and the output to channel 2 of the oscilloscope.
2. Supply a square wave Voltage at about 2 kHz and about 6 V peak-to-peak (or as appropriate). Verify the waveform is symmetrical about the time-axis, or equivalently, it has a positive and negative maximum of 3V and –3V. Draw neatly the input and output waveforms, one below the other for easy comparison, and record important characteristics.

   Repeat this for a sine waveform and a triangular waveform. Choose appropriate peak values and frequencies like the square waveform. Record the input and output waveforms.

9.3 Voltage Follower

1. Use two 1.0 MΩ resistors to construct a Voltage divider between +15 V and ground. Measure and record the Voltage drop between the two resistors and ground using (a) analog Voltmeter, (b) two digital multimeters (the one in the lab kit and the lab DMM), and (c) oscilloscope. Does the Voltage range selected on the measuring instrument affect the Voltage values observed?
2. Construct the Voltage follower circuit shown in Figure 9.6. Now, feed the Voltage from the Voltage divider to the Voltage follower input and measure the Voltage follower output. Compare this measurement to those without the Voltage follower, in terms of accuracy, and explain your results.

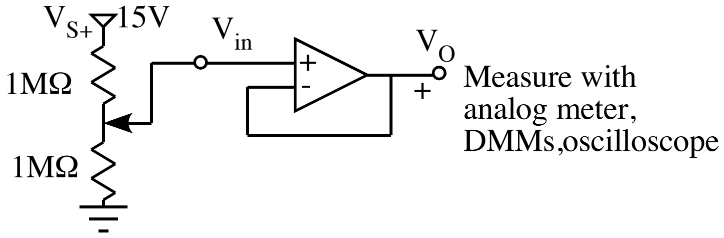

Figure 9.6 Voltage Follower

9.4 **Report:** Fill out the form report and hand it in at the end of the lab period

Lab Exercise # 9 **Date:________**

Operational Amplifier Circuits

Students:____Section:_____Station:______

9.1 Voltage Amplifier

Circuit: R1=_______(nominal)________(measured) R2=_____(nominal)________(measured)

For DC: Vin:___________Vout:___________Measured Gain:_________Calculated gain:________

For AC:

Sketch Input and output waveforms (properly annotated graphs) Sketch circuit

Frequency =_______________Input Voltage = ___________( )

9.2 Negative Integrator

Circuit: R1=_______(nominal)________(measured) C=______(nominal) R_f=______(nominal)

Sketch Input and output waveforms (properly annotated graphs) for sinusoid

Frequency =_______________Input Voltage = ___________( )

9.2 Negative Integrator

Sketch Input and output waveforms (properly annotated graphs) for square wave

Frequency =______________Input Voltage = ___________(   )

Sketch Input and output waveforms (properly annotated graphs) for triangle wave

Frequency =______________Input Voltage = ___________(   )

9.3 Voltage Follower:

Direct measurement: Analog:_______DMM(lab)_________DMM(kit)_________scope:_______

Voltage follower: Analog:_______DMM(lab)_________DMM(kit)_________scope:_______

Explanation: