

Lab 6

Operational Amplifier Characteristics

Purpose

The purpose of this lab is to study the characteristics of the operational amplifier. Some of the characteristics that will be investigated include offset voltage, gain-BW product, and open-loop gain.

Material and Equipment

NI ELVIS

741 Op Amp, 5k pot, Assorted Resistors (10k, 100k, 220k (2), 100 (2), 560)

Background

An operational amplifier (or op-amp) is a high gain amplifier which is usually powered using equal but opposite polarity voltage sources. The symbol and the circuit model can be seen in Figure 6-1.

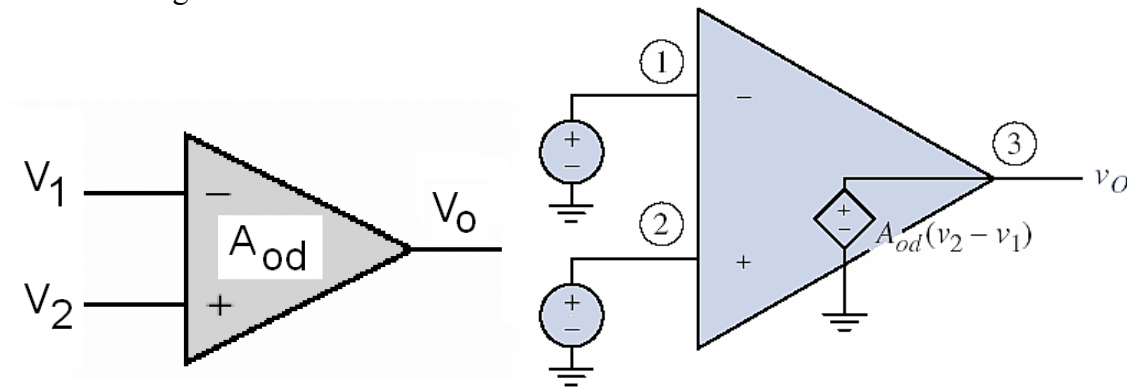


Figure 6-1: Symbol and circuit model for an op-amp

As it can be seen, the amplifier takes the difference between the two input signals and amplifies it by a factor of A_{od} .

$$v_o = A_{od} (v_2 - v_1) = A_{od} v_d$$

R_{in} represents the input impedance and R_{out} represents the output impedance of the amplifier. An ideal op-amp amplifier has the following ideal characteristics:

- Input Resistance is infinite
- Output resistance is zero
- Open-loop voltage gain, A_{od} , is infinite
- Bandwidth is infinite
- $v_o=0$ when $V_2 = V_1$

Because of these parameters, the op-amp is designed to be used in a feedback loop rather than as a stand alone (open-loop) device. This means that in a practical op-amp circuit, there is usually an external path which feeds some of the output of the op-amp back into its input. This will be investigated further in the next lab. The parameters of an actual op-amp such as the 741 differs from the ideal op-amp. Table 6-1 shows these differences.

Parameter	Ideal	General Purpose 741 Op-Amp
Voltage Gain, G	∞	1×10^5
Output Impedance, R_o	0	75Ω
Input Resistance, R_{in}	∞	$2 \text{ M}\Omega$
Offset Current, I_{io}	0	20 nA
Offset Voltage, V_{io}	0	2 mV
Bandwidth, BW	∞	1 MHz
Slew Rate, SR	∞	.7 V/uS

Table 6-1: Comparison of the parameters of an ideal op amp to a real op-amp(741).

The parameters which characterize the op-amp can be described in the following manner.

Input and Output Resistances, R_{in} and R_o

The input resistance looking into the two input terminals of the op-amp is ideally infinite. This means that the device draws no current. For a real 741 op-amp, the input resistance is about $2\text{M}\Omega$. For FET op-amps, this resistance can be much higher (10^{12} ohms). The output resistance on the other hand is ideally zero. For the 741, it is about 75 ohms. This makes the op-amp ideal for driving low resistance loads.

Open Loop Gain, G

This is the gain of the op-amp if a signal is fed differentially into the input of the amp and no feedback loop is present. This gain is ideally infinite, but in a real op-amp the maximum gain is finite (about 10^5). The gain also depends strongly on frequency. For low frequency inputs it takes on its maximum value, but the gain decreases rapidly as the input frequency goes up. For a 741, the gain decreases until it is only 1 at 1MHz.

Input Offset Voltage, V_{io}

When the difference between the two input signals is zero, ideally the output is zero also. However, in a real op-amp, because of manufacturing methods, this is not the case. For a 741, the output voltage when $v_d = 0$ is about 2mV. This can be measured by tying both inputs of the amplifier to ground and measuring the output voltage. This is the output offset voltage. This voltage is then divided by the open-loop gain of the device to get the input offset voltage.

Input Offset Current, I_{ion}

Because the ideal op amp has an infinite input resistance, it draws no current (it looks like an open circuit). Each input draws a small amount of current. The difference between the amount of current drawn into the positive and negative input terminals is called the input offset current ($I_{io} = I_{B+} - I_{B-}$). This can cause errors in the output voltage.

Gain - Bandwidth Product

As mentioned before, the gain of the op-amp is frequency dependent. The frequency response of the open loop gain is such that the frequency decreases with gain. By looking at the graph in Figure 6-2, it can be seen that the op-amp displays the property that the open-loop gain times the frequency is a constant. This constant is defined as the gain-bandwidth product and it is 1×10^6 for the 741 amplifier.

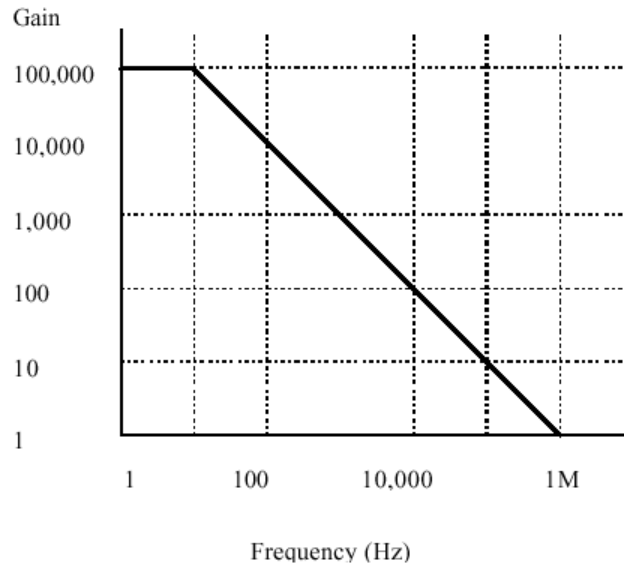


Figure 6-2: Frequency versus Open Loop Gain for a 741 Op-amp

Slew Rate

An ideal op-amp has an infinite frequency response. This means that no matter how fast the input changes, the output will be able to keep up. In a real op-amp, this is not the case. If the input signal changes too fast then the output will not be able to keep up. This is defined as slewing and it results in distortion of the output waveform. Stated more formally,

$$\text{Slew Rate} = \text{SR} = \text{maximum } dv_o/dt$$

or the maximum rate at which the output can change without distorting. This can be measured by applying a high frequency square wave signal. The frequency of the waveform should be increased until the waveform becomes a triangular wave. The slope of the triangular waveform is the slew rate. ($\text{SR} = \Delta V/\Delta T$)

Procedure

The 741 op-amp is an 8 pin dual inline package chip. The pin-out for this chip can be seen in Figure 6-3. This chip is typically powered using $\pm 15\text{V}$ supplies on pins 7 and 4; however, it is possible to power the amp using a single supply. This will be covered in a later lab.

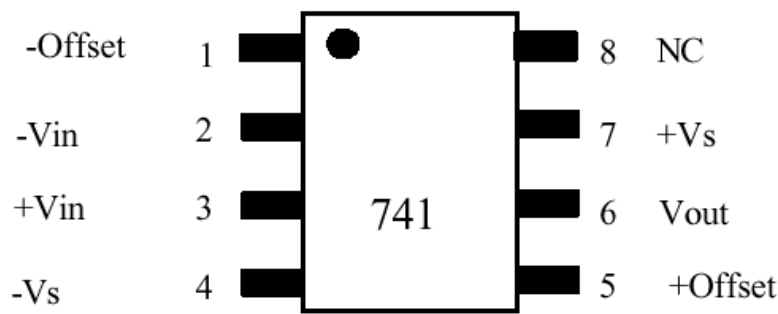


Figure 6-3: The pin out for the 741 op-amp

1) Open-Loop Gain

- Place the chip on the proto board and use the dual power supply to apply $\pm 15V$ to the power pins. Using the signal generator attempt to apply a very small 100Hz sinusoidal signal to the non-inverting input and measure the output amplitude. The magnitude of the needed input is very small and can be calculated. You may need to feed the chip through a voltage divider in order to get a small enough input signal. Connect signal generator to a series circuit consisting of 10k resistor and 560 ohm, and use the voltage on 560 ohms to drive the op-amp. (Hint: Signal generator output is usually around 120 mV, and the voltage to the opamp around 6mV.)
- Measure the amplitude of the input and output waveforms. Calculate the gain if possible.
- Repeat the experiment for the inverting input.

2) Input Offset Current

- Connect the circuit in Figure 6-4. And apply the $\pm 15V$ power. Then, measure the voltages across the two 220k resistors.
- Use ohms law to calculate the respective currents. Label these currents I_{B+} for the resistor connected to the non-inverting input, and I_{B-} for the resistor connected to the inverting input.

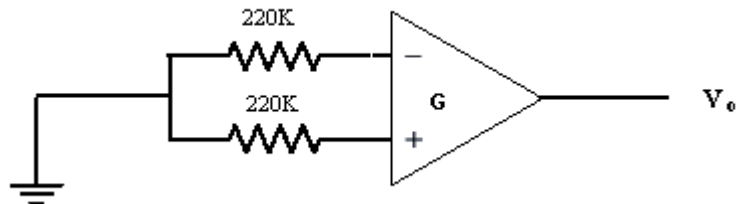


Figure 6-4: Circuit for measuring offset current.

- Find the input offset current from the previous data.
- Repeat steps a, b, c with 100k resistors and then with 100 Ohms resistors.
- Report your results.

3) Input and Output Offset Voltage

- a) Connect the circuit in Figure 6-5. Again make sure that you have powered the chip with the dual power supply ($\pm 15\text{V}$). This is called an inverting amplifier circuit. It will be analyzed in more detail in the next lab. For this test, the input to the amp is grounded. Measure the output voltage. This is the output offset voltage.

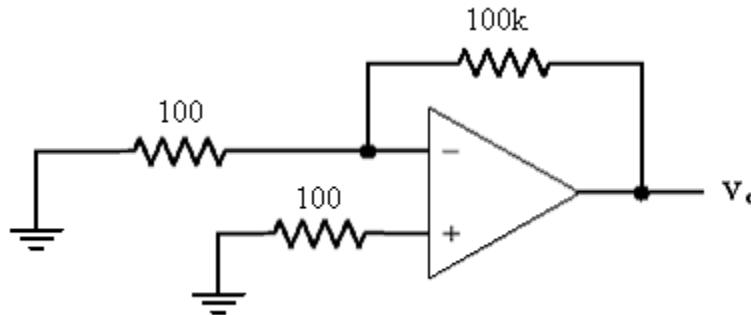


Figure 6-5: Offset Voltage Measurement Circuit

- b) The input offset voltage of the amplifier can be calculated by dividing the output offset voltage by the gain (1000).
c) Replace the 100k resistor with a 220k resistor and repeat steps a) and b). Note that the gain this time is 2200.
d) Repeat steps a) and b) with a 1k resistor.
e) Report your results.
f) To eliminate this offset voltage, connect the stationary ends of a 5k pot to pins 1 and 5. Now connect the wiper of the pot to the -15V supply. Use the pot to zero the output of the amp. This is how offset voltage is eliminated. (See Figure 6-6)

In your experiment due to the pot sensitivity, you may not get a full zero on the output. A 10 mV voltage at the output will be sufficient.

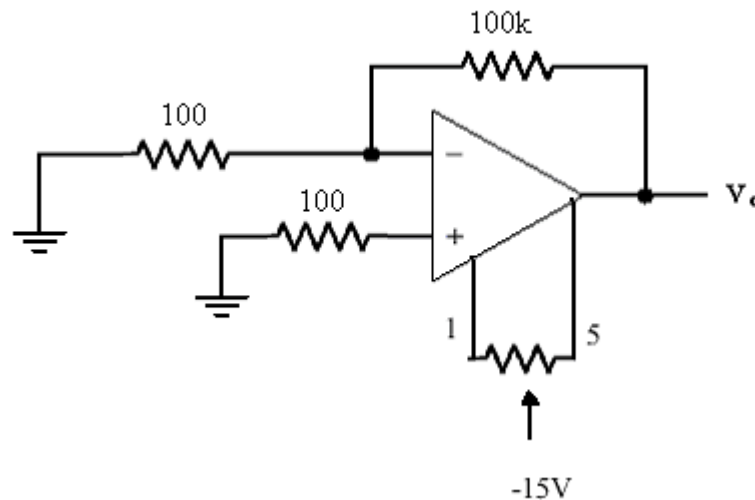


Figure 6-6: Elimination of offset voltage

Questions and Requirements for the Lab Report

- 1) Tabulate all of the parameters measured in lab. Look up the same parameters on a data sheet for the 741 op-amp. Calculate the percent differences between your measurements and the specified values.
- 2) Why is it so difficult to measure the open loop gain of an op amp? Explain in your own words.
- 3) Explain how using the potentiometer helped to null the offset voltage.
- 4) While measuring the offset current, you used resistors of 100, 100k and 220k. In which cases were the measurements most accurate? Explain why this is so.
- 5) While measuring the offset voltage, we used gains of 1000, 2200 and 10. Does measurement accuracy improve with increasing gain? Why or why not? Is gain the only criterion or are absolute values of the individual resistors also a criterion for increased accuracy? Explain your answer.