Operational Amplifiers

1. Introduction

The student will be introduced to the application and analysis of operational amplifiers in this laboratory experiment. The student will apply circuit analysis techniques to study circuits containing operational amplifiers.

2. Background

Operational Amplifiers, or Op Amps, are undoubtedly the most versatile analog device in common use. In addition, circuit analysis of Op Amp circuits is a straightforward endeavor. It has become common practice therefore to introduce Op Amp circuits to beginning engineering students as a means to reinforce their newly acquired analysis skills. Without getting into the details of design and construction, an Op Amp can be modeled as shown in Figure 1.

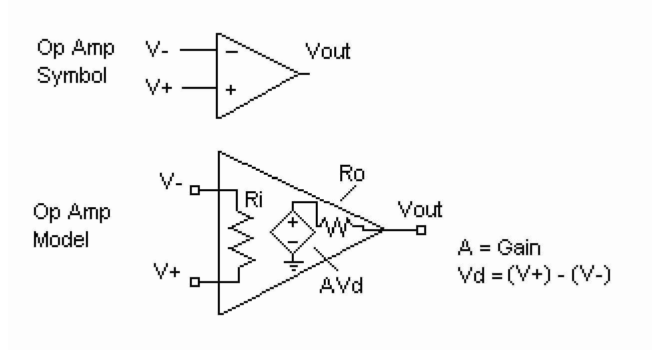

Figure 1: Operational Amplifier Diagram

It can be seen in Figure 1 that the difference in voltage across the input terminals, $v_+(t)$ and $v_-(t)$, is multiplied by the gain, A, and is available at the output terminal as $v_{out}(t)$ (with respect to ground).

The ideal Op Amp is characterized by the following parameters:

- R_i (the input impedance) is infinite.
- R_o (the output impedance) is zero.
- A (the open loop gain) is Infinite.

From this idealization, it is possible to make the following assumptions:

- $i_{in}(t)$ (the input current to the Op Amp) is zero.
- $v_d(t) = v_+(t) – v_-(t) = 0$
- Thus, $v_+(t) = v_-(t)$

These conditions make Nodal Analysis of an ideal Op Amp circuit very simple.

3. Procedure

3.1. Equipment

- PSpice® on Personal Computer
- Agilent E3631A DC Power Supply
- Fluke 8050A Digital MultiMeter (DMM)
- (1) 100 kΩ, (1) 390 kΩ, (1) 10 kΩ, and (2) 1 kΩ Resistors
- (1) LM 741 Op-Amp
- (1) Light Emitting Diode (LED)

3.2. PRELAB – Theoretical Procedure and Datasheet

Using circuit analysis techniques, analyze the circuit in Figure 3 to solve for V_o. Assume that the effective resistance of the Light Emitting Diode (LED) is 50 kΩ. **Record your result in Table 2**.

Open the datasheet for the LM741 (found under the reference material on the ECE 2006 web page). In addition to noting the pinout diagram, find the following and **record your answers in Table 3**:

- The maximum (in magnitude) supply voltages
- The maximum (in magnitude) input voltage
- Slew Rate (the maximum rate of change in the output voltage)
- List all the types of elements present in the schematic diagram (actual circuit)

Obtain your instructor's signature for completing the prelab.

3.3. Experimental Procedure

Connect the DC circuit shown in Figure 2. Power up the adjustable DC power supply and set it for an output voltage of 6.00 Volts. Turn ON the <u>output</u> of the power supply. Measure V_o, the voltage drop across the 390 kΩ resistor, using the DMM. **Record this result in Table 1**.

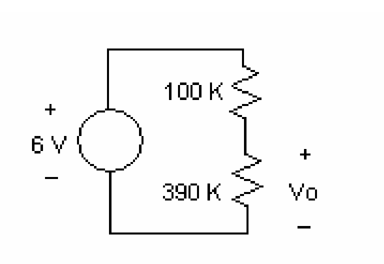

Figure 2: DC Voltage Divider

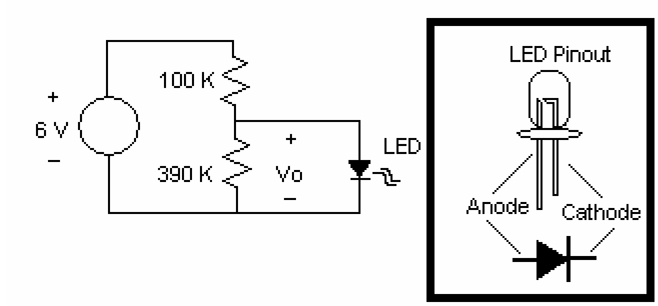

Figure 3: LED Circuit

Turn OFF the <u>output</u> of the power supply. Now connect a Light Emitting Diode (LED) across V_o as shown in Figure 3.

Turn ON the output of the power supply. Measure again the output voltage, V_o, using the DMM. **Record this result in Table 2.**

Why is the value of V_o different? Answer this question in your lab report.

Turn OFF the output of the power supply.

Calculate the "effective resistance" of the LED by performing nodal analysis at the output node (between the 100 & 390 kΩ resistors) and **record your result in Table 2**.

A V_o of approximately 2.0 Volts or above is sufficient to make the LED glow, provided that it receives enough current.

Does the LED turn on (light up) in this circuit? Answer this question in your lab report.

Insert an Op Amp into the previous network in order to produce the circuit shown in Figure 4 (note that a minus-six volt source is needed to prevent saturation).

> The Op Amp circuit in Figure 4 is called a "Voltage Follower" circuit (also "buffer" or "unity gain" circuit), denoted by the unity feedback loop to the inverting input (i.e. v_{Out} is short-circuited to v_-). Similarly to the lab with the transistor, a voltage follower is useful when the same voltage is needed with a greater amount of current (and therefore power, too). As stated in the background, the theoretical difference between v_- and v_+ is zero. Thus, since there is a direct connection between v_- and v_{Out}, the positive input voltage would also be equal to v_{Out}. Lastly, since the positive input voltage is directly connected above the 390 kΩ resistor, this produces $v_o \approx v_{Out}$.

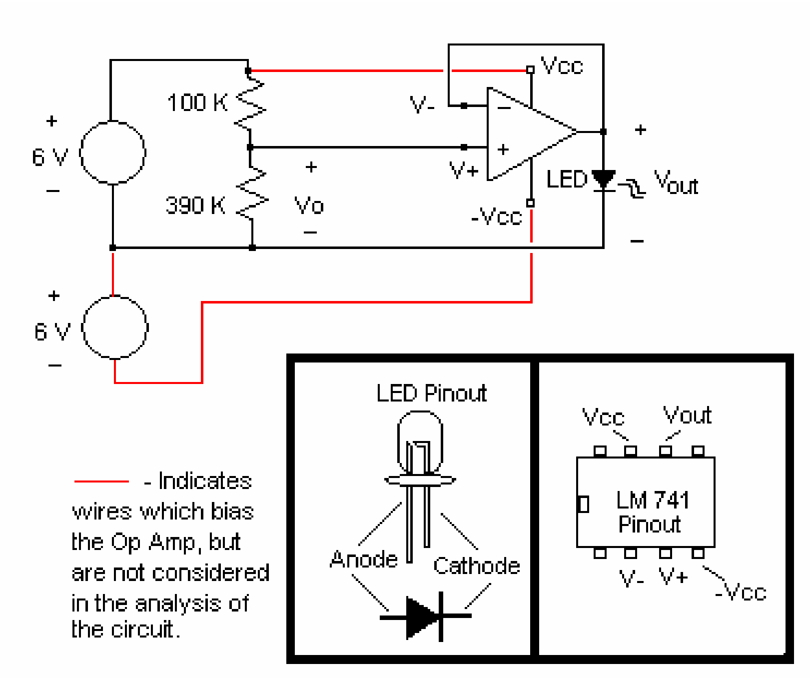

Figure 4: Voltage Follower

Turn ON the output of the power supply. Measure V_o and V_{Out} with the DMM. **Record these results in Table 4**.

Turn OFF the output of the power supply. Remove the LED. Turn ON the power supply and measure V_{Out} now that the load (LED) has been removed. **Record this measurement in Table 4**.

Turn OFF the output of the power supply.

Compare V_o for Figure 4 with Vo for Figures 2 and 3.

> Which is it closer to? Does the LED turn on (light up) in this circuit? Answer these questions in your lab report.

Describe the impact of putting the Op Amp Voltage Follower between the output voltage, V_o, and the load (the LED). Include this discussion in your lab report.

> The Op Amp is probably the most versatile analog chip available. It has a host of applications in a broad range of circuits. The key to making Op Amps do different things is to understand the impact of feedback on Op Amp performance. The first step to such understanding is to analyze the Inverting Amplifier circuit.

Connect the Op Amp circuit shown in Figure 5.

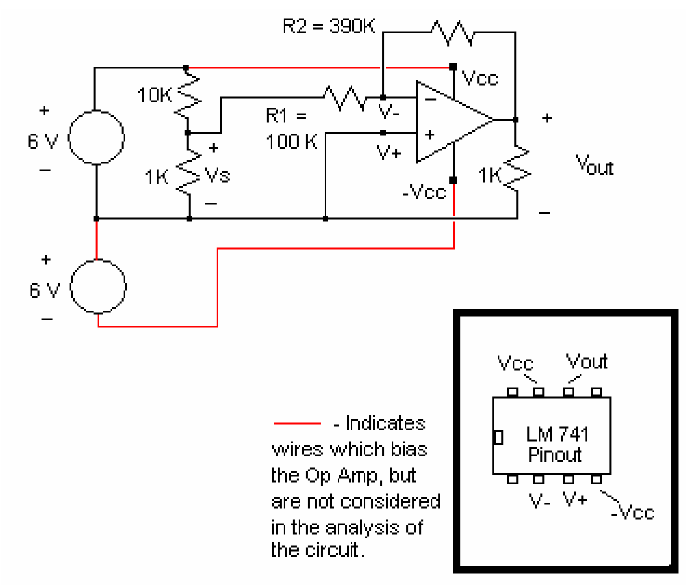

Figure 5: Inverting Amplifier

Turn ON the output of the power supply and verify V_s and V_{Out} with the DMM. **Record these results in Table 5**.

Turn OFF the power supply output. Now exchange R_1 and R_2 resistors, such that the circuit is the same, but R_1 = 390 kΩ and R_2 = 100 kΩ.

Turn ON the output of the power supply and measure V_s and V_{Out} with the DMM. **Record these results in Table 5**. *Obtain your instructor's signature for all measurements*.

3.4. Simulated Procedure

Model the Inverting Amplifier of Figure 5 in PSpice® for both the original diagram and for the diagram with R_1 and R_2 swapped. Use the "OPAMP" model from the parts list to represent the LM741. This model does not have external connections for V+ and V-, so there is no need to model two voltage sources. Use a single 6 Volt source and make sure to set the attributes for VPOS and VNEG to +6V and -6V respectively in the OPAMP model. Include the two schematics (one for each combination of resistor values with the V_s and V_{Out} voltages displayed as an appendix to your report and compare their results to the experimental values.

4. Conclusions and Questions

In addition to the questions posed in the procedure, please answer the following questions in your lab report:

1. Calculate the theoretical value of V_{Out} in Figure 5 for both the original diagram and the diagram with R_1 and R_2 swapped and record your values in Table 6. Compare your experimental results for V_{Out} (Table 5) with the theoretical values you just calculated and the results of your PSpice® simulation. Explain any differences. Incorporating what was learned about the accuracy of resistors in Lab 1 may be helpful.

2. What is the maximum output voltage of the Op-Amp? Given this value and the calculated resistance of the LED, what is the maximum output current of the Op-Amp for Figure 4?

3. How does the percentage difference in the voltage of the Op-Amp compare to the voltage follower from Lab 3 with the transistor?

Data Entry and Lab Instructor Signature Page

Attach this page to your report.

Table 1: Measurement for Figure 2

V_o (Volts)

Table 2: Measurements for Figure 3

Measurement	V_o (Volts)	R_{LED}
Theoretical		**N/A**
Experimental		**N/A**
Calculated	**N/A**	

Table 3: Datasheet Specifications

Maximum Supply Voltage	
Maximum Input Voltage	
Slew Rate	
Types of Elements in Schematic Diagram	

Signature for 3.2. – Prelab ______________________

Table 4: Measurements for Figure 4

Measurement	V_o (Volts)	V_{Out} (Volts)
With LED Load		
Without LED Load	**N/A**	

Table 5: Measurements for Figure 5

Measurement	V_S (Volts)	V_{Out} (Volts)
Original Circuit		
With Swapped Resistors		

Table 6: Theoretical Values for Figure 5

Theoretical Value	V_S (Volts)	V_{Out} (Volts)
Original Circuit		
With Swapped Resistors		

Signature for Measurements and Values ______________________