OPERATIONAL AMPLIFIERS

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.

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.

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

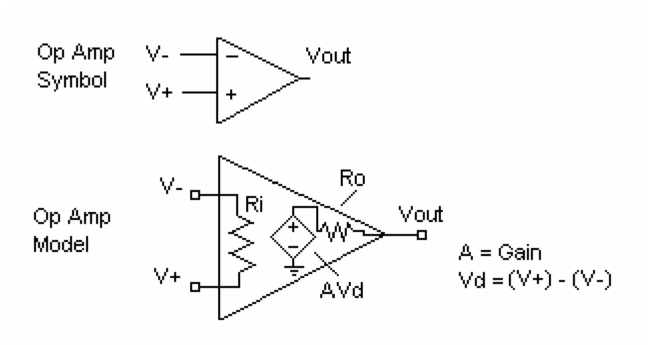

Figure 1: Operational Amplifier Diagram

The ideal Op Amp is characterized by the following parameters:

Ri (the input impedance) is Infinite.
Ro (the output impedance) is Zero.
A (the gain) is Infinite.

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

Ii (the input current to the Op Amp) is Zero.
Vd = (V+) – (V-) = Zero
Thus, V+ = V-

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

THEORETICAL PROCEDURE

Using circuit analysis techniques, analyze the circuit in Figure 3 to solve for Vo. Assume that the effective resistance of the LED is 50 KΩ.

Vo = ____________________ Volts

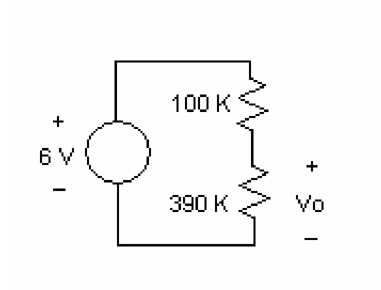

Figure 2: DC Voltage Divider

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 output of the power supply.

Measure Vo, the voltage drop across the 390 K-Ohm resistor, using the DMM.

Vo = ____________________ Volts

Turn OFF the output of the power supply.

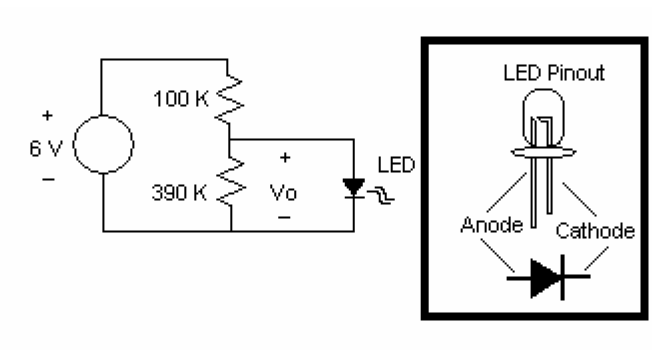

Figure 3: LED Circuit

Now connect a Light Emitting Diode (LED) across Vo as shown in Figure 3.

Turn ON the output of the power supply.

Measure again the output voltage, Vo, using the DMM.

Vo = ____________________ Volts

Obtain your Instructor's Signature: ____________________________

Turn OFF the output of the power supply.

Why is the value of Vo different? Answer question in lab report.

Calculate the "effective resistance" of the LED, by performing nodal analysis at the output node (between the 100 and 390 K-Ohm resistors). Since Vo is known, solve for R_{LED}.

At the Node: $\dfrac{Vo - Vs}{100\text{ K}} + \dfrac{Vo - 0}{390\text{K} \mathbin{//} R_{LED}} = 0$

R_{LED} = _______________ Ohms

A Vo 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? ___________

It may be useful to consider the 6-Volt source and the 100 k-Ohm resistor as a Thevenin Pair (i.e. Vth and Rth). If the resistance of the LED were very, very small, say zero ohms, the current delivered by the 6-Volt source would be 60 μ-A. (100 K-Ohm * 60 μ-A = 6 Volts). This is not enough current to make the LED glow. Also, if R_{LED} were extremely small, Vo would be almost zero.

Thus the *Load Impedance*, R_{LED}, is too small for the resistor bridge and collapses the output voltage, Vo. Or, in other words, the *Output Impedance* of the source, (Rth), is too high to provide the current necessary to make the LED glow. A practical way to "lower" the output impedance of this bridge circuit is to use an Operational Amplifier (Op Amp).

Op Amps have very high input impedance, meaning they don't draw much current from a source in order to work properly. In addition, they have reasonably low output impedance, and can supply a fair amount of current to a load.

Insert an Op Amp into the previous network in order to produce the circuit shown in Figure 4 below: (Note that a minus-six volt source is needed to properly bias the op amp)

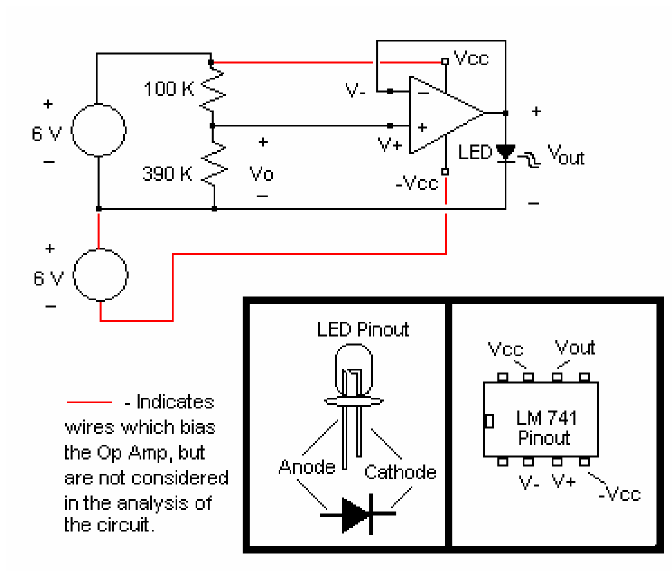

Figure 4: Voltage Follower

The Op Amp circuit above is called a “Voltage Follower” circuit, denoted by the unity feedback loop to the inverting input (i.e. Vout is short-circuited to V-). A voltage follower performs as denoted. Its output follows the input. An ideal voltage follower has an input of Vo volts and an output of Vo volts. One might argue that a piece of wire also acts as a voltage follower and is much cheaper and easier to use than an Op Amp. The beauty of the Op Amp voltage follower is the gain of the circuit. The circuit above has an input current of much less than the 60 µ-A available, but the output current of the Op Amp can be much higher. A wire cannot duplicate that. The Op Amp looks like a high impedance load to the resistor bridge source, and also looks like a low impedance source to the LED load.

Turn ON the output of the power supply.

Measure Vo and Vout with the DMM.

Vo = _______________ Volts Vout = ____________________ Volts

Turn OFF the output of the power supply. Remove the LED.

Turn ON the power supply and measure Vout now that the load (LED) has been removed.

Vout (no load) = ____________________ Volts

Turn OFF the output of the power supply.

Compare Vo 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? ___________

Describe the impact of putting the Op Amp Voltage Follower between the output voltage, Vo, and the load (the LED). Note the effect on Vo and on source and load impedances. Include Discussion in 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.

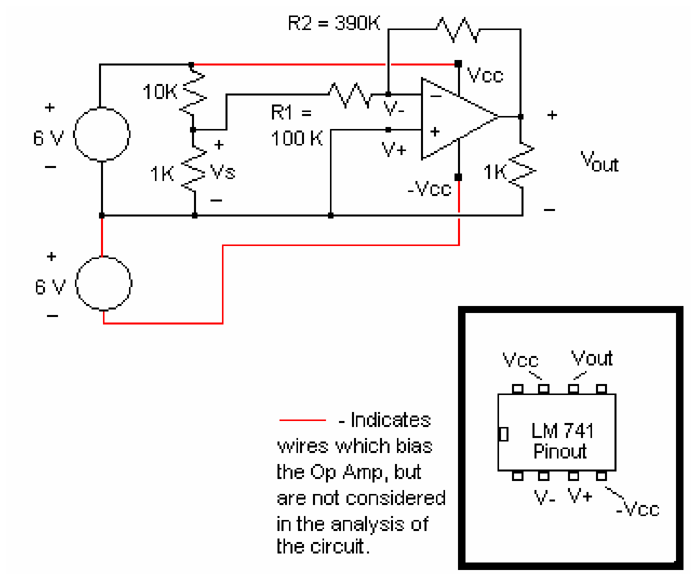

Figure 5: Inverting Amplifier

Connect the Op Amp circuit shown in Figure 5.

Nodal analysis at the node labeled V- (between resistors R1 and R2) produces the following results:

$\frac{(V-) - Vs}{100\ K} + \frac{(V-) - (Vout)}{390\ K} = 0$; and $(V-) \approx (V+) = 0$
$Vout = -\frac{390\ K}{100\ K} * Vs = -3.9\ Vs$; $Vs = \frac{1\ K}{(1 + 10)\ K} * 6\ Volts = 0.55\ Volts$
$Vout = -\ 2.15\ Volts$

Turn ON the output of the power supply and verify Vs and Vout with the DMM.

Vs = ___________Volts Vout = ___________Volts

Turn OFF the power supply output.

Now exchange R1 and R2 resistors, such that the circuit is the same, but R1 = 390 K and R2 = 100K.

Turn ON the output of the power supply and measure Vs and Vout with the DMM.

Vs = ____________ Volts Vout = ____________ Volts

Calculate Vout for R1 = 390 K and R2 = 100K in this circuit using Nodal Analysis. Include calculation in lab report.

SIMULATED PROCEDURE

Model the Inverting Amplifier of Figure 5 in PSPICE, Schematics. 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 output file as an appendix to the report and compare its results to experimental values.

CONCLUSION

Summarize what has been learned about the input and output impedance of a circuit and the value of an Op Amp for changing them.

Compare your experimental results for Vout versus calculated values from Step 29 above for the Inverting Amplifier. Explain any differences. Incorporating what was learned about the accuracy of resistors in Lab 1 may be helpful.