Electronics and Instrumentation

Name _______________ ENGR-4220 Spring 1999 Section ____________

Experiment 4
Introduction to Operational Amplifiers

Purpose: Become sufficiently familiar with the operational amplifier (op-amp) to be able to use it with a bridge circuit output. We will need this capability in our first project.

Equipment Required:

- HP 34401A Digital Multimeter
- HP 33120A 15 MHz Function / Arbitrary Waveform Generator
- HP E3631A Power Supply
- Protoboard
- Some Resistors
- 741 op-amp or 1458 dual op-amp

Background

Some of the following material was taken from Introduction to the OP Amp, by John Getty of the University of Denver at http://www.tmo.hp.com/tmo/iia/edcorner/English/Exp26.html The interested reader is also encouraged to look over the op-amp links on the course webpage.

The schematic of Fig. 1 shows a standard ± V_{CC} configuration for op-amps. The schematic symbols for a battery are used in this schematic to remind us that these supplies need to be a constant DC voltage. They are not signal sources.

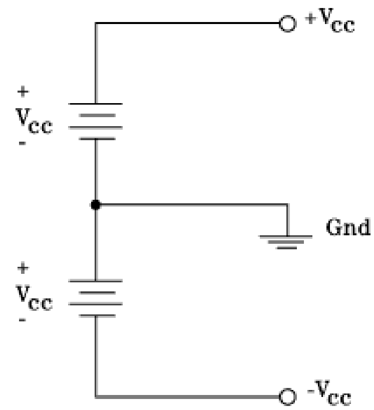


Figure 1

The HP E3631A power supply provides two variable supplies with a common ground and a variable low voltage supply. As shown in Fig. 1, the jack labeled "COM" between the V_{CC} supplies is connected to circuit ground. Adjust the output so the +V_{CC} and **-** V_{CC} are equal, but opposite in sign, at 15 V. It is possible to turn the output voltages off without turning off the power supply by pushing the OUTPUT ON/OFF button. Pushing the button again returns the supply to its previous settings. This is the approach to use when testing circuits. However, at this point, we will turn the power supply off. You will have to set it up again later when you connect it to your op-amp circuit.

Study the chip layout of the 741 op-amp in Fig. 3. (You may be using the 1458 dual op-amp chip instead of the 741. In that case, the chip layout will be somewhat different. The layouts and other specs for these two chips can be found on the course website and on pages 8 and 9 of the *Radio Shack Mini-Notebook on Op Amp IC Circuits*.) The standard procedure on DIP (dual in-line package) "chips" is to identify pin 1 with a notch in the end of the chip package. The notch always separates pin 1 from the last pin on the chip. In the case of the 741, the notch is between pins 1 and 8. Pin 2 is the inverting input, V_N. Pin 3 is the non-inverting input, V_P and the amplifier output, V_O is at pin 6. These three pins are the three terminals that normally appear in an op-amp circuit schematic diagram. Even though the $\pm V_{CC}$ connections (7 and 4) must be completed for the op-amp to work, they usually are omitted from simple circuit schematics to improve clarity.

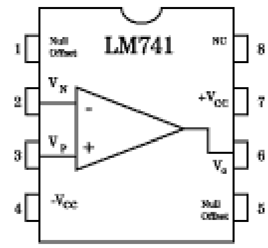


Figure 3

The null offset pins (1 and 5) provide a way to eliminate any "offset" in the output voltage of the amplifier. The offset voltage (usually denoted by Vos) is an artifact of the integrated circuit. The offset voltage is additive with V_O (pin 6 in this case), can be either positive or negative and is normally less than 10 mV. Because the off-set voltage is so small, in most cases we can ignore the contribution V_{OS} makes to V_O and we leave the null offset pins open. Pin 8, labeled "NC", has no connection to the internal circuitry of the 741, and is not used.

Fig. 4 shows a standard op-amp configuration known as an inverting amplifier. For this case, we have V_{out} = -4.7 V_{in}. That is, the output voltage is equal to minus the input voltage times the ratio of the feedback resistor to the input resistor. Feedback resistors feedback the output voltage to the inverting input. Essentially anything that connects the output terminal of the op-amp to the inverting input terminal will provide feedback.

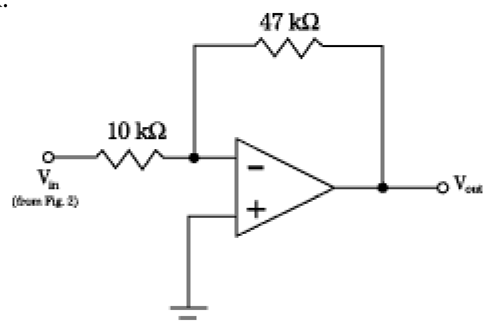


Figure 4

In Fig. 7 (you may have noticed that we skipped some figures here) we have another op-amp configuration known as a non-inverting amplifier. Here we have V_{out} = 2 V_{in}. That is, the output voltage is equal to the input voltage times one plus the ratio of the feedback resistor to the resistor connecting the inverting input to ground.

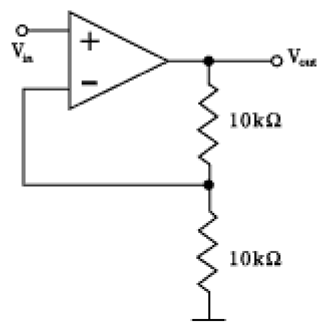


Figure 7

The more commonly used configuration is the inverting op-amp, which means that, much of the time, the output will be negative if the input is positive.

The mysterious properties of the op-amp are actually quite easy to understand. When connected correctly, an op-amp is a circuit with a very, very large voltage gain, where voltage gain is defined as the ratio of the output voltage to the input voltage of the op-amp itself. The input voltage is the difference between the voltage connected to the plus terminal and the voltage connected to the minus terminal. If we call these V_+ and V_-, the gain is defined as

$$A = V_{out}/(V_+ - V_-) \rightarrow \infty$$

Typical values for this gain can be 100,000, so it is indeed a very large number. If the voltage at the output terminal is the order of a volt or so, then the difference between V_+ and V_- must be very, very small. It is important to realize that there are two kinds of gains we will be using. There is the gain just mentioned that characterizes the op-amp device itself. Usually, we will not be too interested in this gain, since we will just assume that it is so big that we can assume it is infinite. The other more useful gain is the amplification of the circuit configuration (i.e. inverting or non-inverting op-amp) in which the op-amp is used.

If we connect an op-amp into either of these or other standard configurations, it will do a very good job of following what are known as the *golden rules for op-amps.* There are two such rules:

First, since the voltage gain of the op-amp itself is so high, a fraction of a millivolt between the input terminals will swing the output voltage over its entire range, so we ignore that small voltage and state that

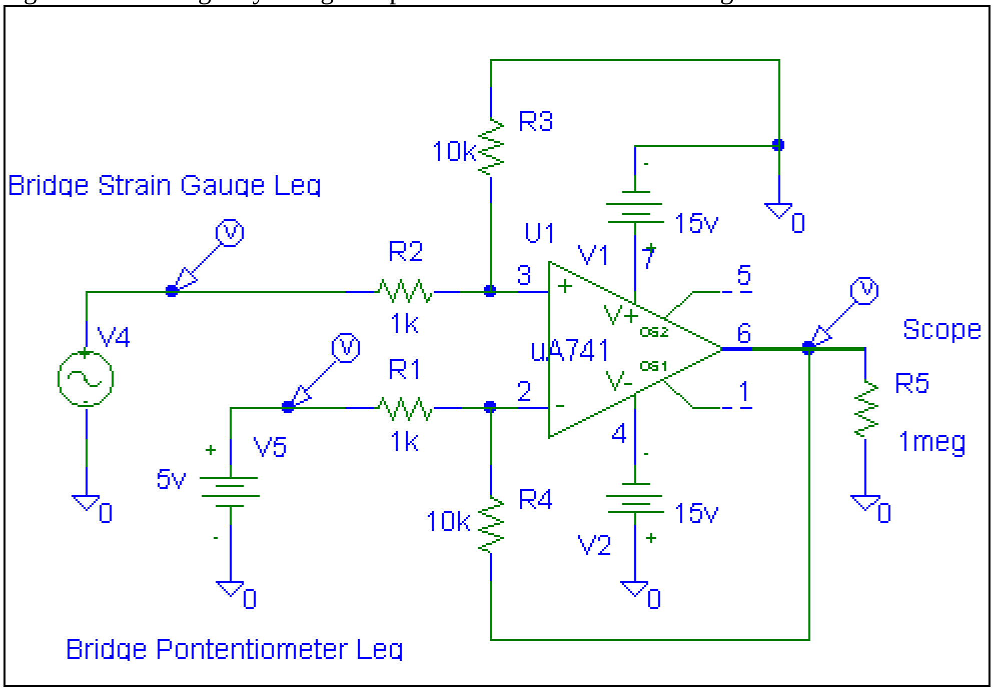
I. The output attempts to do whatever is necessary to make the voltage difference between the two inputs zero.

Second, op-amps draw very little input current (0.08µA for the 741; picoamps for FET-input types); we round this off, stating that

II. The inputs draw no current

Apply these two rules to both circuits and produce a simplified circuit with no op-amp in it. Then analyze the circuit to show that the gains given above are correct. Instead of using actual numbers for the resistors, label them R_1 and R_2 for the resistor connected to the minus input and the feedback resistor, respectively.

We can combine these two amplifiers, in a sense, and obtain a device that amplifies the difference between two voltages. We will begin by doing a PSpice simulation of such a configuration.



The properties of all components in this circuit are obvious except for the sinusoidal source. The two sources V4 and V5 represent the output points of the bridge circuit we build when we use the cantilever beam strain gauge. V5 is a constant value of 5 volts while V4 has a DC OFFSET of 5 volts and a small sinusoidal amplitude of 100 mV at 20 Hertz These values are chosen somewhat arbitrarily, but are typical. You will have to change these numbers when you consider the actual output of your bridge. This schematic is set up to obtain a particularly simple gain. Do the transient simulation, displaying about 4 cycles of the output and determine what this gain is. Print out one probe plot per group and discuss why you think the output is correct.

Change the values of the resistors R2 to 1.5 k and R1 to 1.25 k. Do not print out this plot, but describe what happened to the output voltage. That is, how did this voltage change and why?

Please note that our primary purpose here is to learn a little about an op-amp configuration that we can use with our cantilever beam bridge circuit output. We will return to op-amps to look at the simpler inverting and non-inverting amplifiers more thoroughly. However, you might want to play around a little with your PSpice simulation at this point and configure both of these circuits. If you do, you will have to be sure that your test input voltages are not too large. The output of an op-amp cannot exceed $\pm V_{CC}$. Thus, if you have an overall gain of 100, the largest input must be somewhat less than $\pm V_{CC}/100$. This is one of the other properties of op-amps we must take into account when we use them. There are several others which we will introduce when necessary.

You will notice that the voltage sources we have used do not show an internal resistance. When you apply this kind of analysis to your bridge circuit, you will have to incorporate these resistances. (That is why we did the exercise of changing the input resistors.) In your project report, you will have to discuss how these resistances will affect the performance of your circuit. Thus, it might be a good idea to think about this now and try out any ideas you might have with your partners and a TA or instructor.

Build the circuit as shown on your protoboard. Use the function generator for V4 and one of the DC supplies for V5. The function generator limits the offset voltage, so you will not be able to use the 5V value of your PSpice simulation. Rather, use the largest possible offset for the 100mV sinusoidal signal amplitude. Set the DC supply to the same value as the offset voltage so that the two sources are balanced when the sinusoidal signal is passing through zero. Up to this point we have assumed that the circuit will be made with a 741 op-amp, because there is no PSpice model for the 1458 dual op-amp. However, if your parts kit contains 1458 op-amps rather than 741 op-amps, you will have to build with what you have. Be sure that you have your circuit checked over before you do your experimental test. Observe the function generator output and the output of the amplifier on the scope. Use the HP Benchlink software to print out a copy of the scope traces, but only after you show the scope traces to a TA or instructor. They can also show you how to use this very simple software, if you have not already done so.

Report and Conclusions

- What overall gain did you find for the basic differential amplifier?
- Describe any problems you encountered in building the amplifier circuit and what you did to solve them..

Questions

- Aside from the number of op-amps in the package, find one significant difference in the specifications of these devices. Indicate where you found this information.
- Give an example of a system with negative feedback
- Give an example of a system with positive feedback

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Experiment 4

Student #1 ____________________ TA ____________________ Date _________

Student #2 ____________________ TA ____________________ Date _________

Please answer any questions asked above under ***Report and Conclusions****. Also, attach any plots requested. On each plot, describe what is being displayed and why the results make sense. Include a hand-drawn circuit diagram for any PSpice output or plots of measurements indicating where and how the measurements were made. Summarize the key points of this experiment. Discuss any problems you encountered or mistakes you made and how you addressed them. Use additional pages if necessary*