

**EE 230**  
**Experiment 6**  
**Fall 2006**

**Measurement and Management of Operational Amplifier Parameters**

**Objectives:** The primary objective of this experiment is to investigate some of the performance parameters that are commonly used to characterize the performance of an operational amplifier and to develop a strategy for measuring some of these parameters. A second objective is to develop an appreciation for how these parameters affect the performance of practical circuits using the operational amplifier. A third objective will be to investigate methods for overcoming the limitations introduced by some of the parameters of the operational amplifier. Finally, you will be asked to design some circuits in which the non-ideal characteristics of the operational amplifier must be considered as part of the design process.

**Equipment:**

Computer with SPICE, Signal Express, GP-IB capability, and appropriate IVI drivers  
HP E3631A or equivalent power supply (GP-IB Capable)  
HP 33120A or equivalent signal generator (GP-IB Capable)  
HP 34401A or equivalent multimeter (GP-IB Capable)  
HP 54602B or equivalent oscilloscope

**Parts:**

Assortment of Resistors and Capacitors  
Potentiometer  
2 741 op amps  
660 op amp  
E Thermocouple wire  
Heat source  
Thermometer

**Practical Details:** In the last experiment you looked at several different practical applications of an operational amplifier and hopefully you observed that these circuits worked very much as expected if one assumed that the operational amplifiers were ideal. You were then asked to make some changes in your circuit that caused some undesired behavior. Although the purpose of the undesired behavior was not discussed in the previous experiment, you were asked to make a list of the situations that resulted in the undesired behavior. In this experiment you will be asked to identify the cause of the undesired behavior.

To be sure that you identify all sources of undesired behavior, make a list of the non-ideal behavior along with the symptoms you observed. The undesired behavior should have been due to one of the following: Finite GB of the op amp, input offset voltage, output voltage saturation, output current saturation, slew rate limits.

We will return to this list later but you should let your list guide you in investigating the different parts of this experiment.

You will be asked to measure several different parameters of the operational amplifier in this experiment. The direct measurement of operational amplifier parameters is often quite difficult. A much more common approach is to identify a basic application where the parameter of interest adversely affects the performance of the circuit and to determine what that parameter is by knowing how the non-ideal performance of this circuit relates to that of the parameter of interest. For example, it has been observed that the 3dB bandwidth of the basic non inverting amplifier of Fig. 1

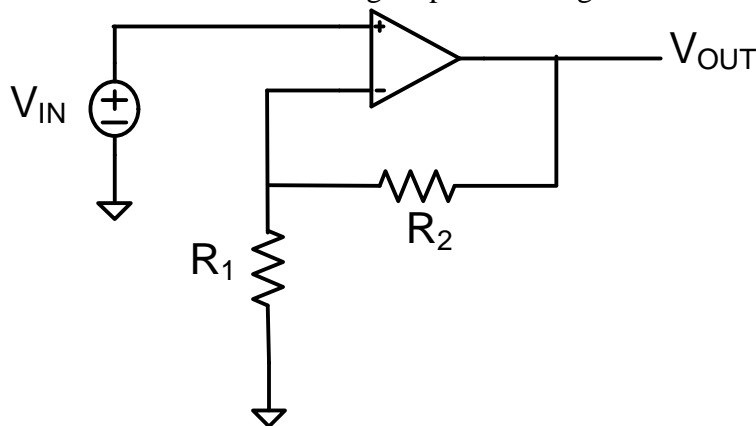


Fig. 1 Basic Non-inverting Amplifier

satisfies the relationship

$$K_0 \cdot BW = GB \quad (1)$$

where  $K_0 = 1 + \frac{R_2}{R_1}$  and GB is the gain-bandwidth product of the Op Amp. Thus this

circuit can be used to determine the GB of the Op Amp by selecting some practical value for the gain (maybe  $K_0=100$ ), measuring the BW, and then determining GB from (1). Following this approach, it is important that you do not have other parameters that cause the relationship in (1) to be altered. That is, you do not want to be experiencing voltage or current saturation, offset voltage, or slew rate limitations. Selecting a rather large value for the dc gain helps drive the BW to a lower frequency making this measurement easier to make. Using an ac source rather than a dc source helps eliminate potential effects of a dc offset voltage. Keeping the frequency and magnitude relatively small helps eliminate a potential slew rate problem. Keeping the voltage amplitude and current levels reasonably small helps eliminate potential voltage or current saturation problems.

The gain-bandwidth product (GB) of an operational amplifier characterizes the frequency response of the op amp. It is the key parameter that determines how high in frequency you can operate a circuit using an operational amplifier. Although it is defined as the product of the dc gain ( $A_0$ ) and the 3dB bandwidth ( $\omega_{3dB}$ ), both the dc gain and the 3dB bandwidth are difficult to measure but the GB itself can be readily measured.

The finite GB of the operational amplifier places a fundamental limit on the bandwidth achievable with the basic inverting and non-inverting amplifiers. In many cases this bandwidth limit is unacceptably low. Two methods of partially overcoming the bandwidth limitations will be considered in this laboratory. One method is to use an op amp with a larger GB. A second method is to use different amplifier architectures that may have a different bandwidth limit.

### Part 1 Gain Bandwidth Product

Measure the GB of the 741 operational amplifier and compare your measurements with those given in the datasheet.

### Part 2 Bandwidth Enhancement

- How does the GB of the 660 op amp compare to that of the 741? What closed-loop bandwidth improvements are expected when building a basic noninverting amplifier with a dc gain of +10 if the 741 op amp is replaced with the 660 op amp? How does the prediction agree with measurements?
- Calculate the 3dB bandwidth of the following circuit and compare both theoretically and experimentally with that of the basic noninverting amplifier that has the same dc gain.

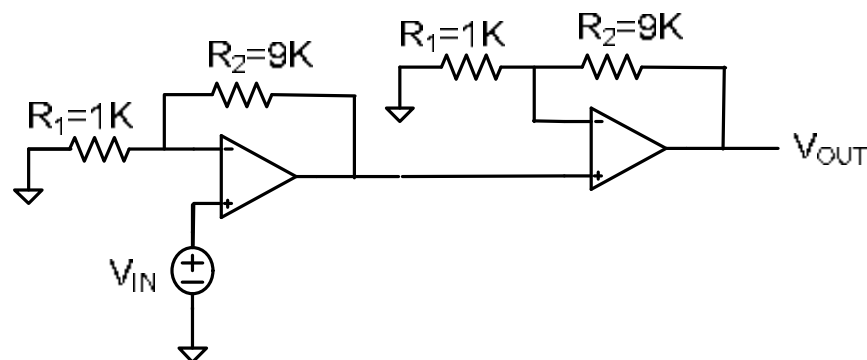


Fig. 2 Cascaded Amplifier Structure

### Part 3 Slew Rate

Devise a circuit for measuring the slew rate of an operational amplifier and use this to measure the slew rate of the 741. Compare the measured slew rate with that specified in the datasheet.

### Part 4 Output Voltage Saturation

Devise a circuit for measuring the output voltage saturation of an operational amplifier and use this to measure the output voltage saturation of the 741. In this measurement, bias your op amp with  $\pm 15V$  supplies. Compare the measured output voltage saturation with that specified in the datasheet.

### Part 5 Output Current Saturation

Devise a circuit for measuring the output current saturation of an operational amplifier and use this to measure the output current saturation of the 741. In this measurement, bias your op amp with  $\pm 15\text{V}$  supplies. Compare the measured output current saturation with that specified in the datasheet.

### Part 6 Offset Voltage

Devise a circuit for measuring the input offset voltage of an operational amplifier and use this to measure the input offset voltage of the 741. In this measurement, bias your op amp with  $\pm 15\text{V}$  supplies. Compare the measured offset voltage with that specified in the datasheet.

### Part 7 Reconciliation of the non-ideal performance observed in Previous Laboratory Experiment

Return now to the list of non-ideal performance you made last week. Identify the source of the non-ideality in each case and provide a convincing argument that you have identified the correct source of non-ideality.

### Part 8 Measurement of dc gain of the Op Amp

Attempt to measure the dc gain of the op amp. This is a difficult measurement to make. Spend no more than 15 minutes on this part of the experiment. If you are successful at making the measurement in the 15 minutes, give your results and compare with those in the datasheet. If you are not successful at the end of 15 minutes, identify what challenges make this measurement difficult. Please note that although this measurement is difficult, it is something that we could do in this laboratory. It may take the better part of the entire laboratory period to make this measurement and that is the reason we have limited the time you spend on this part to 15 minutes.

### Part 9 Further Exploration

a) Consider the circuit shown in Fig. 3.

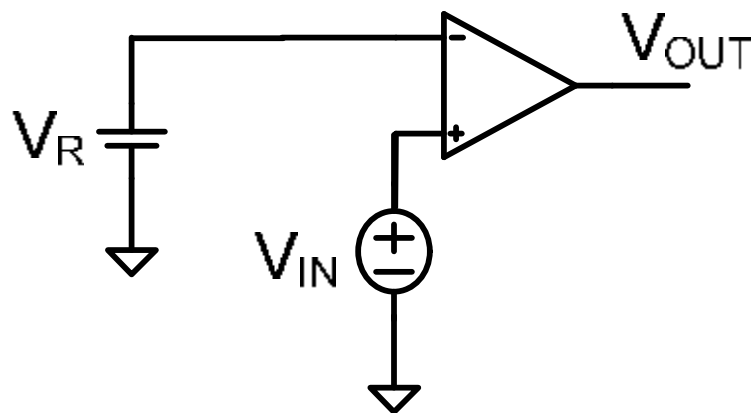


Fig. 3 Open-Loop Amplifier

Construct this circuit and observe the output if a 5V p-p sinusoid at 500Hz is applied to the input. Change the value of  $V_R$  to -1V and observe how the output

changes. Change the value of  $V_R$  to +1V and observe how the output changes. This is a very useful circuit. Can you identify what function this circuit is performing? Can you explain the observed operation of this circuit? Plot the transfer characteristics of this circuit for the three different values of  $V_R$  considered above.

- b) The following two circuits have the same behavior if the op amp is ideal but the circuit on the right has a pole in the RHP when a practical model for the op amp is included.

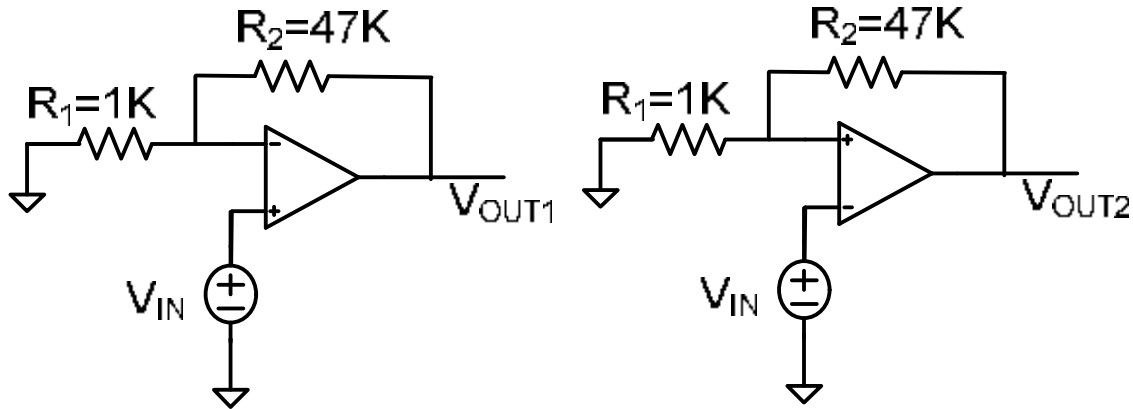


Fig. 4 Basic noninverting amplifier with alternative feedback approaches

Measure the dc transfer characteristics for these circuits by slowly increasing  $V_{IN}$  from -2V to +2V. Repeat by slowly decreasing  $V_{IN}$  from +2V to -2V. You can vary this several ways but be sure that however you make these variations you do not include any discontinuities in the input waveform. One way to make these variations is by using a potentiometer connected between +2V and -2V and using the wiper voltage as the output. Another is to use a very low frequency triangle waveform. This circuit exhibits some behavior that is different than what we have observed previously. Can you explain how this circuit operates?

- c) The circuit shown in Fig. 5 is a slight variant of the circuit on the right of Fig. 4. Assume the op amp is biased with  $\pm 15V$  supplies. Although the capacitor  $C$  is likely not needed, please include it to reduce the chances of an occasional surprise in the performance of this circuit.

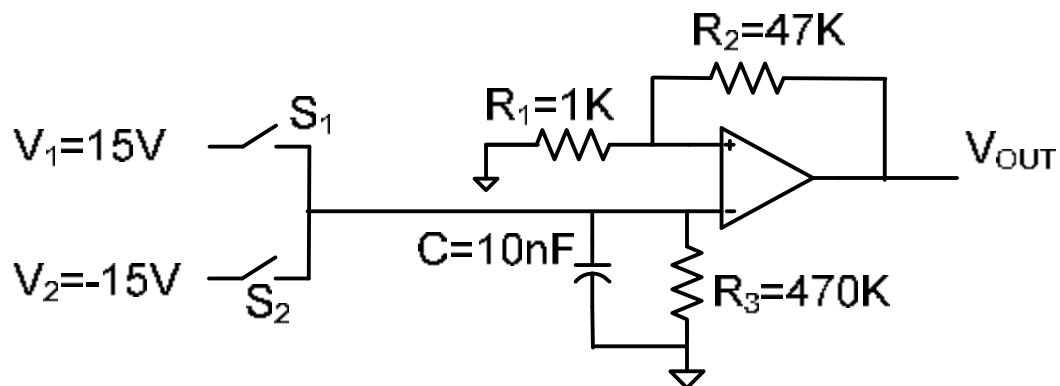


Fig. 5 Positive Feedback Circuit

The switches  $S_1$  and  $S_2$  are to be momentary switches that are normally open. A single piece of wire will work fine for these switches. When  $S_1$  is to be closed, momentarily touch the wire from the  $-$  terminal of the op amp to  $+15V$ . When  $S_2$  is to be closed, momentarily touch the wire to the  $-15V$  supply. Describe what happens to the output when these momentary switches are operated. Can you explain what is happening with this circuit? Can you identify potentially useful applications for this circuit?

(The values of  $V_1$  and  $V_2$ ,  $C$  and  $R_3$  are non-critical and play a minor role on the performance of this circuit.).

## Part 10 High-Gain Amplifier

Design and demonstrate a circuit that will provide a dc output voltage of  $+5V$  when the hot end of a thermocouple is at  $100^\circ C$  and the cool end is at room temperature and that will provide a dc output voltage of  $0V$  when both ends are at room temperature. Identify what nonideal characteristics of the operational amplifier will affect your design and describe what you will do to mitigate these effects.

You can get a strip of thermocouple wire from your TA. The thermocouple is constructed by twisting the bare ends of two wires of different compositions together to form an electrical contact. The twisted bare ends are then used as the temperature sensing point. The output voltage of the thermocouple is measured on the other two ends. A thermocouple is depicted in Fig. 6.

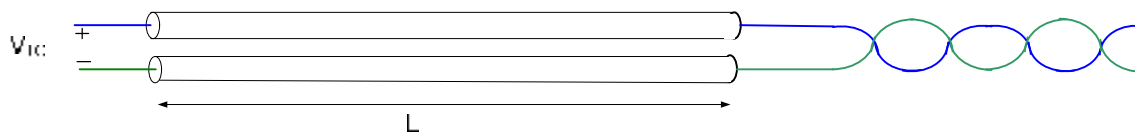


Fig. 6 Thermocouple

The thermocouple has an output voltage given by the expression

$$V_{TC} = K_{TC}(T_2 - T_1) \quad (2)$$

where  $K_{TC}$  is a constant dependent upon the characteristics of the two metals used to form the thermocouple and  $T_1$  and  $T_2$  are the temperatures at the two ends of the thermocouple. The thermocouple wire used for this experiment is GG-E-24-50, Glass Insulated, 24 AWG, Type E available from Omega. Characteristics of this thermocouple can be found at <http://www.omega.com/temperature/Z/pdf/z206.pdf> A tutorial on thermocouples also appears on the Omega web site at <http://www.omega.com/thermocouples.html>

For our experiment we will assume that  $T_1$  is at room temperature. Unfortunately room temperature varies a little bit so you may see some minor variations in  $T_1$  throughout your design and measurement but these changes should not cause a major problem in meeting the design requirements.

The length  $L$  can be quite large. We will work with a length  $L$  of somewhere around 2 feet.