Mechatronics I Laboratory Exercise 5
Operational Amplifiers

Operational amplifier (op-amps) is one of the most useful integrated circuits available. The schematic of an op-amp consists of three connections (see Figure 1): the inverting input (-), the non-inverting input (+), and the output.

There are two main assumptions: the internal-gain of the amplifier and its input impedance is high that you can consider it to be infinite. These two assumptions allows the following simple design rules, which are approximations that suffice for our purposes:

1. The voltage at the inverting input point , "-", is the same as the voltage at the non-inverting input point "+". For example, if the point "+" is connected to ground (as shown in Figure 1) then this potential can be considered as zero. Then this statement says that the potential at point "-" is also zero;
2. The current flow between - and + is zero. Hence Kirchoff's current law states that the sum of the currents entering node 1 (see Figure 1) is zero.

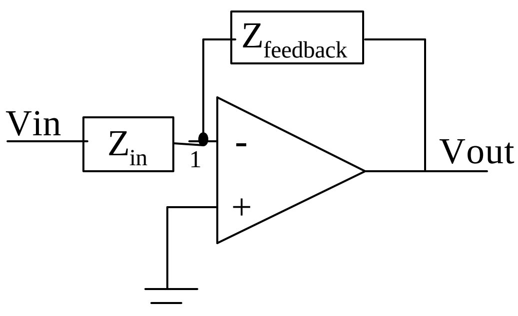

Figure 1. Schematic of a typical op-amp circuit.

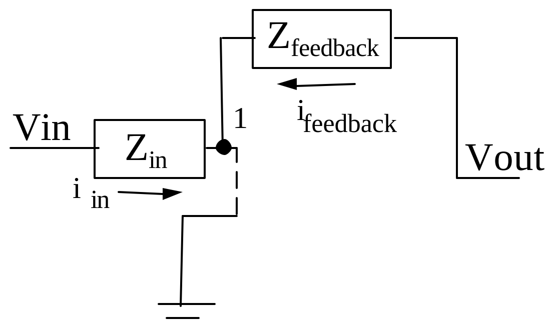

Figure 2. Simplified circuit.

Using the two simplifying assumptions, the circuit can be simplified to the circuit shown in Figure 2. The dashed line indicates a virtual ground at the inverting input since the first design rule says that the voltages are equal at the two input points. Summing currents at node 1, results in Equation 1.

$$i_{IN} = -i_{FEEDBACK} \tag{1}$$

Putting in the relationships for the currents results in equation 2.

$$\frac{V_{IN}}{Z_{IN}} = -\frac{V_{OUT}}{Z_{FEEDBACK}} \tag{2}$$

In the case of an inverting amplifier, as shown in Figure 3,

$$V_{OUT} = -\frac{R_{feedback}}{R_{in}} V_{IN} \tag{3}$$

A differentiator can be formed by replacing R_{in} with a capacitor, as shown in Figure 4. The input-output relationship of the differentiator is,

$$V_{OUT} = -RC\frac{dV_{IN}}{dt} \tag{4}$$

Likewise, a voltage follower (which avoids prevents loads from being applied directly to the voltage source, V_{in}) is shown in Figure 5. The input-output relationship of the voltage follower is described by,

$$V_{OUT} = V_{IN} \tag{5}$$

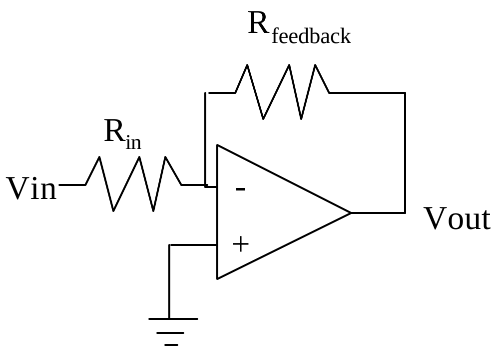

Figure 3. Inverting Amplifier Circuit

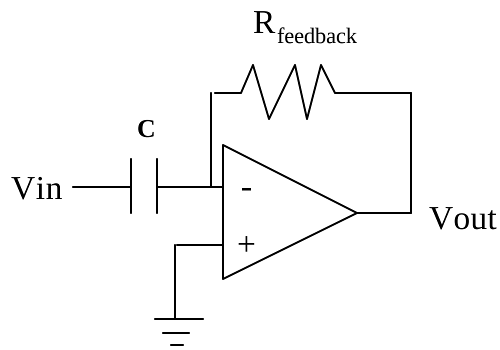

Figure 4. Differentiator Circuit

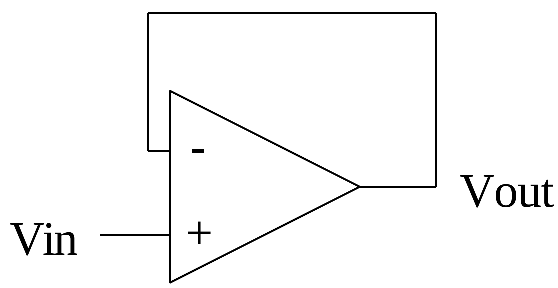

Figure 5. Voltage Follower Circuit.

Pre-lab Assignment

Consider a sinusoidal input signal with frequency 5Hz and amplitude 2 Volts.

The objective is to differentiate a signal and to record it using computer data acquisition system. Keep in mind that the A/D system saturates at ±5 volts and that the output of the op-amps saturate at ±12volts (the op-amp supply voltage). Be sure to consider saturation in your design.

For your Pre-lab, design a circuit to differentiate your signal. Use variables whenever possible so you can consider different signals. Your design must:

1. First buffer the signal using a voltage follower,
2. Differentiate the signal from the voltage follower, and
3. Amplify the differentiated signal (to maximize resolution) before passing it into the A/D.

Design and analyze the circuit using the resistor and capacitor values listed below. Resistors may be chosen from: 1K, 2.0K, 3.3K, 10K, 33K, 68K, 100K, 200K, 330K, and 1M (ohms), or combinations thereof. Capacitors can only be: 0.1µF, .01µF, .001µF, and 1nF. Remember saturation!

Now, consider an input sinusoid with a frequency 500 Hz and amplitude of 2 Volts. Select another set of resistor and capacitors to avoid saturation.

Laboratory Exercise

Equipment Needed: Breadboard, function generator, and oscilloscope.

1. Build the circuit you designed in the pre-lab. To verify the input and output relationship for your circuit, start LabWindows CVI and load the project "OP_AMP.PRJ" from "C:\CVI\PROGRAMS\LABS\OP_AMP" folder. Take the output from your circuit (op-amp signal) and connect it to **AI_CHO** on the A/D board. Connect the output from the function generator to **AI_CH1** (input signal).
2. Using a function generator, apply a sinusoidal signal with an amplitude of 2 Volts (4V peak-to-peak) and a frequency of 5 Hz to your circuit. Verify the sine wave using the oscilloscope. Set the appropriate sampling rate and number of samples and start the program. There should be two waveforms captured by CVI, one is the output from your circuit (op-amp signal) and the other is the input sine wave (input signal). Save the data to file and show the plot in your report. The data file contains three columns. The first column is time, the second column is output signal, and the third column is input signal. How does the output appear? Why?
3. Gradually increase the frequency of the sinusoid until saturation occurs. Again save this data to file and note the sinusoidal frequency. What is causing this saturation?
4. Apply a 2 Volt 500 Hz signal as the input to the circuit. Set the appropriate sampling rate and number of samples and start the program. Again note the output of the circuit and save the data to file. Is the saturation any different than the saturation noted in step 3 above?
5. Change the circuit elements to those determined in the pre-lab for the 2Volt 500 Hz signal. Save the data to file and note the change in signal appearance. If your calculations are correct, you should not have any saturation.
6. Apply a 2 Volt 5 Hz signal to the circuit and note the output. Save the data to file and comment on the quality of the differentiated signal.

Post-Lab Report

Analytically derive the symbolic equation relating V_{OUT} and V_{IN} for the circuit you designed in the pre-lab. Be sure to begin with the ideal op-amp assumptions and derive all op-amp circuit equations. Substitute the parameter values you determined for each input signal and compare the equations.

You have witnessed saturation multiple times in this lab. Do the following:

- Comment on all of the potential sources of saturation in your circuit,
- Recommend strategies for limiting these sources of saturation,
- Comment on the disadvantages of the strategies that you recommend for limiting saturation.

BE SURE TO ANSWER ALL QUESTIONS MENTIONED IN THE LABORATORY EXERCISES ABOVE. PRESENT AND DISCUSS PLOTS OF YOUR SAVED DATA.