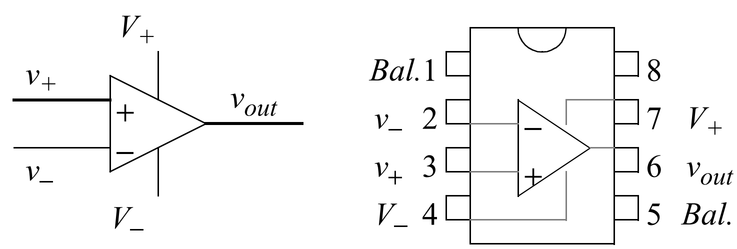
Physics 375, Laboratory 13
Analog Math

Overview

The purpose of these experiments is to use op-amps to perform mathematical operations on input voltages. Operations include sum, difference, logarithm, differential and integral.

Background

An operational amplifier (op-amp) is a differential amplifier with very high gain, very high input impdance, and very low output impedance. The 741 op-amp is an integrated circuit thaat comes in an 8-pin dual in-line package (DIP). The connections for the chip looking down with the notch facing up is:

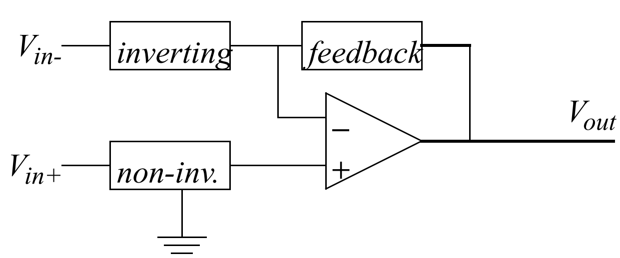


For large gain, low input current amplifiers used with feedback to the negative input there are two rules to follow:

1. $I_+ = I_- = 0$. *The input currents are 0.*

2. $v_+ - v_- = 0$. *The input voltage difference is 0.*

For feedback to the negative input, the general steps for analysis are to find the voltage at the non-inverting input and use rule two to assign that same voltage to the inverting input. The next step is to find the current flowing at the inverting input from any voltage source. Based on rule one all tis current is assumed to flow into the feedback network, and generate a voltage drop at the output voltage.



1. Summing Amplifier

Connect a 741 op-amp on the Powerace breadboard, and use the +15 V and -15 V supplies to power the chip. Use the variable supply to provide +1 V.

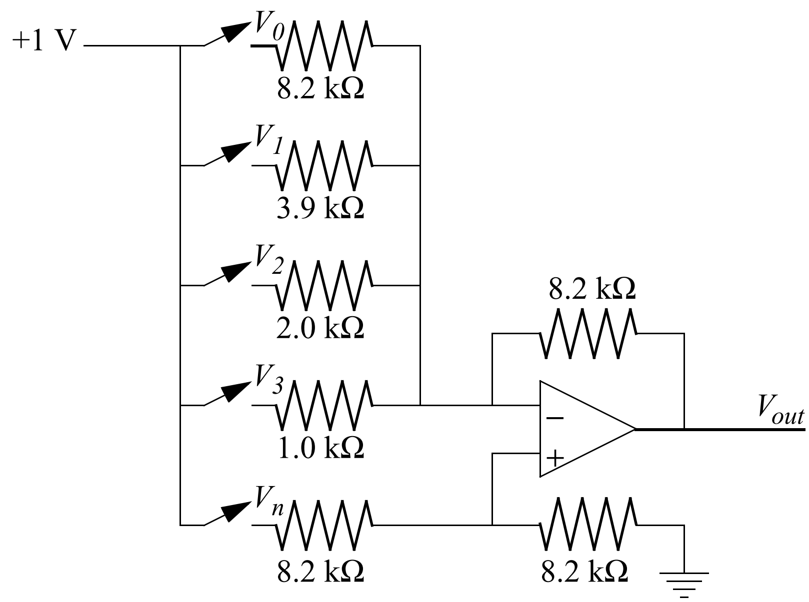


Figure 1: Summing Amplifier

Connect wires from the +1 V supply to each possible combination of resistors on the inverting input and measure V_{out} with the DMM. How close is the output voltage to the binary value of the input switches:

$$-V_{out} = V_0 2^0 + V_1 2^1 + V_2 2^2 + V_3 2^3$$

What is causing the lack of precision?

Use a wire to connect the +1 V to V_n on the non-inverting input for no inverting input voltage. What is V_{out}? Check a couple of inverting input settings to verify the following:

$$-2V_{out} = V_0 2^0 + V_1 2^1 + V_2 2^2 + V_3 2^3 - V_n 2^0$$

2. Differentiator

Build the circuit in figure 2 and use sine waves of 0.5 V amplitude for v_{in}.

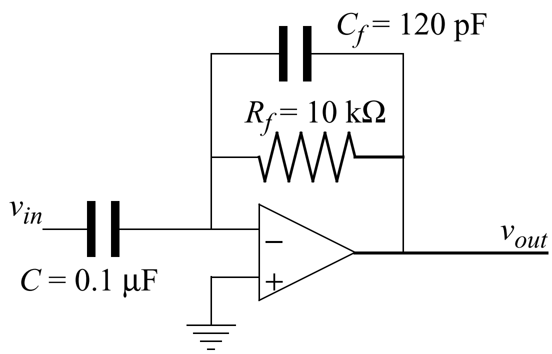


Figure 2: Differentiator

Measure v_{in} and v_{out} with oscilloscope and calculate the gain as a function of frequency, and graph the gain on a Bode plot (gain in dB vs log*f*). An ideal differentiator has the relationship:

$$v_{out} = -R_f C \frac{dv_{in}}{dt}$$

How well does this circuit agree with the ideal? The feedback capacitor should be neglible. Try a triangle wave, and a square wave input and observe the ouput waveforms. Is the slew rate of the op-amp a factor?

3. Integrator

Build the circuit in figure 3 and use sine waves of 0.5 V amplitude for v_{in}.

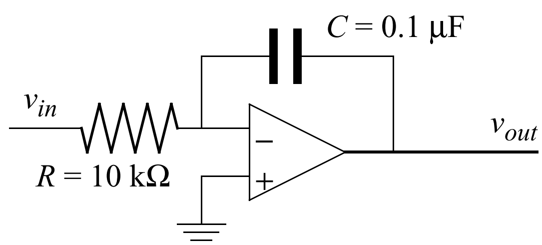


Figure 3: Integrator

Measure v_{in} and v_{out} with oscilloscope and calculate the gain as a function of frequency, and graph the gain on a Bode plot (gain in dB vs log *f*). An ideal integrator has the relationship:

$$v_{out} = -\frac{1}{RC}\int v_{in} dt$$

How well does this circuit agree with the ideal? Try a square wave input and observe the ouput waveforms. Is the slew rate of the op-amp a factor for the integrator?

4. Logarithmic Amplifier

Use a 2N2222 transistor and 1N914 diode in parallel in the feedback network of an inverting amplifier.

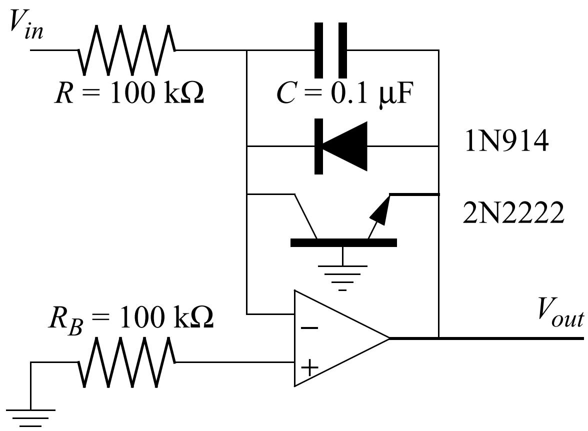


Figure 4: Logarithmic Amplifier

The diode and capacitor are present to protect the circuit, and R_B will conpensate for the bias current. Use the variable power supply to provide V_{in}. The current I_{in} is given by

$$I_{in} = \frac{V_{in}}{R}$$

This current must flow into the collector of the transistor which has the relationship

$$I_C = I_0 e^{V_{BE}/V_T}$$

The base-emitter voltage is equal to the negative of V_{out} and the collector current equals the input current so,

$$\frac{V_{in}}{R} = I_0 e^{-V_{out}/V_T}$$

$$V_{out} = -V_T \log \frac{V_{in}}{I_0 R}$$

Measure V_{out} for a number of values of V_{in} and compare to an ideal logarithmic amplifier. If V_T = 0.026 V, derive a value for I_0 from the data.