Lab 8: Operational Amplifiers

Goal

The goal is to construct few applications of operational amplifiers.

Objectives

1. Construct an inverting amplifier
2. Construct a comparator

Expectations

1. You are expected to take detailed notes during each step outlined in the procedure that can be used during the lab report write-up.
2. You are expected to provide a neat table of the data that you measured where you clearly label what each data set is and include units for all measured quantities.
3. You are expected to clearly record the measured values of any components that you use.
4. You are expected to clearly record the detail related to images captured by the oscilloscope.
5. You are expected to make your final plots in a program such as Excel. Make sure that your data points appear clearly on the plots, that all axes are clearly labeled and have units.
6. If it is possible to compare your measurements with an expectation or a prediction, you are expected to do so in your lab report
7. You are expected to answer the questions encountered in this manual as well as discuss exercises given during the lectures in your lab write up.

Introduction to Concepts

The op-amp model 741 will be used for all the op-amp circuits in this lab. The pin configuration of the 741 op-amp is shown in the Figure 1

Op-amp Inverting Amplifier

The feedback system provides much stability to the gain of the amplifier and Figure 2 shows an op-amp inverting amplifier using negative feedback. Using the simple op-amp rules, the gain of the inverting amplifier is given by,

$$G = -\frac{R_f}{R_{in}} \tag{1}$$

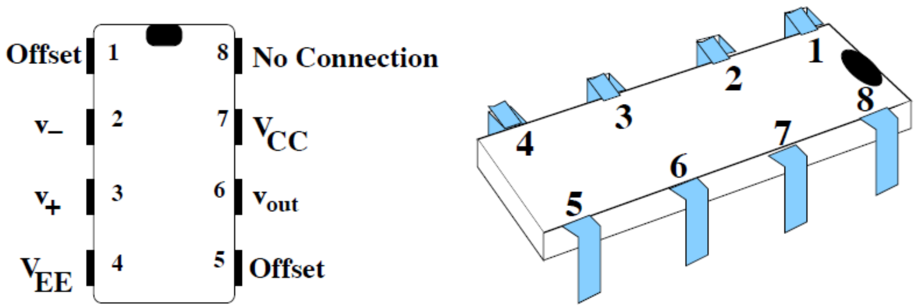

Figure 1: The pin connections for the 741 op-amp chip. The V_{CC} is connected to the positive power supply and V_{EE} is connected to the negative power supply. The pins V_- and V_+ are inverting and non-inverting inputs, respectively.

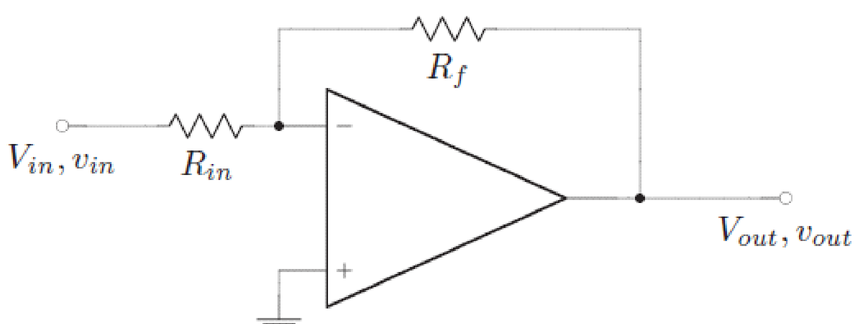

Figure 2: The op-amp inverting amplifier circuit.

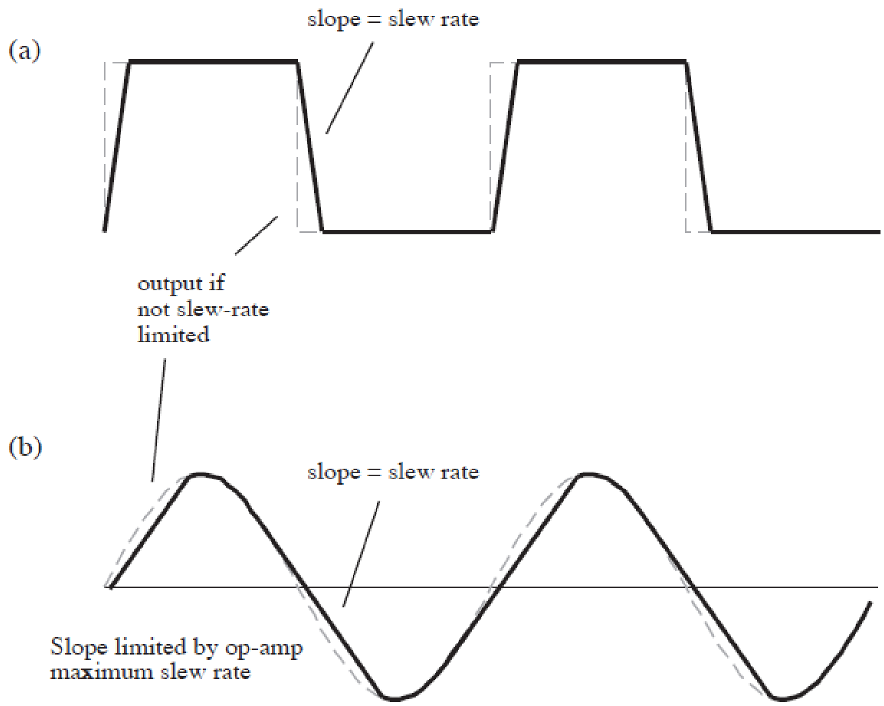

Figure 3: The limitations due to slew rate for a square-wave and sine-wave output of an op-amp.

Op-amp Slew Rate

The rate at which the output voltage of an op-amp can change is known as the slew rate which is measured in $V/\mu s$. If we have a square wave input to an op-amp circuit, then the output will be limited by the slew rate as shown in Figure 3(a). The same problem can apply to other types of signals. If an input voltage has time dependence of $sin(\omega t)$, and produces an output voltage of $V_{out} = V_o sin(\omega t)$, then the rate of change of this output voltage is

$$\frac{dV(t)}{dt} = \omega V_o cos(\omega t) \tag{2}$$

If the maximum rate of change is larger than the slew rate of the op-amp, then the output signal will be distorted as shown in Figure 3(b).

Op-amp Comparator

A comparator compares an input voltage to some reference voltage. The output has binary states where if the input is larger than the reference, output will be at one state and if the input is smaller than the reference, output will be at the other state. A simple comparator circuit is shown in the Figure 4. The potentiometer provides an adjustable reference voltage between 0 and V_{ref}.

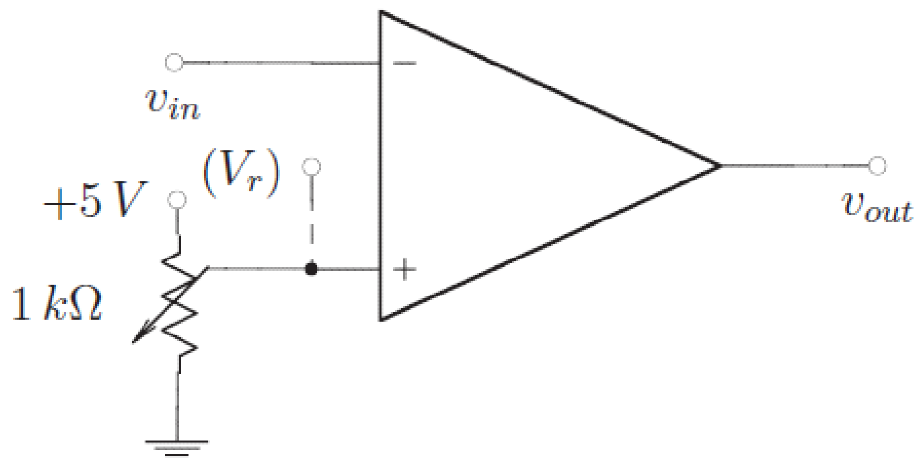

Figure 4: A comparator circuit where reference can be adjusted to be between V_{ref} and the ground using a potentiometer, R_{ref} .

Preliminary Lab Questions

You will find useful to complete the preliminary lab questions before starting the procedure.

1. Find the maximum rate of change for a sine-wave signal at $\omega = 2\pi f$ (exploit the equation 2)?

Equipment and Parts

1. Signal generator (Instek GFG-8216G)
2. Power supply (EXTEC 18 V DC power supply)
3. Oscilloscope (RIGOL DS11002E)
4. Two multimeters
5. proto-board with power supply (PB500)

You will also need the following components in order to carry out this lab.

1. 741 Op-Amp
2. 1 kΩ, 10.0 kΩ, and 100 kΩ resistors
3. 1 kΩ potentiometer
4. Four pairs of crocodile cables
5. Connecting wires (4 - 6)
6. Three BNC to crocodile cables

Procedure

Op-amp Inverting Amplifier

To measure the DC gain follow the steps below,

- Build the inverting amplifier shown in Figure 5
- Connect V_{CC} to $+12.0\ V$ and V_{EE} to $-12.0\ V$ (see Figure 1)
- Use the $\pm 12\ V$ power supply in the proto-board
- Connect the DC power supply into the V_{in} of the inverting amplifier
- Vary V_{in} from $-2.0\ V$ to $2.0\ V$ in steps of $0.5\ V$ and measure the V_{out}
- Use the multimeter to measure both V_{in} and V_{out}
- Make a plot of V_{out} vs. V_{in}
- Determine the DC gain of the amplifier

To measure frequency response follow the steps below,

- Start with the circuit shown in Figure 5 (built for the previous procedure)
- Set the signal generator to sine-wave and amplitude around 1 V
- Connect the signal generator into the V_{in} of the inverting amplifier
- Connect the channel 1 of the oscilloscope into the V_{in} and channel 2 into the V_{out} of the amplifier
- Vary the signal generator frequency from 50 Hz to 1000 Hz in steps of 200 Hz and measure the V_{in} and V_{out} amplitudes
- Capture oscilloscope image of V_{in} and V_{out} amplitudes only at 50 Hz and 1000 Hz
- Vary the signal generator frequency from 1000 Hz to 15000 Hz in steps of 2000 Hz and measure the V_{in} and V_{out} amplitudes
- Capture oscilloscope image of V_{in} and V_{out} amplitudes only at 15000 Hz
- Vary the signal generator frequency from 16000 Hz to 20000 Hz in steps of 500 Hz and measure the V_{in} and V_{out} amplitudes
- Capture oscilloscope image of V_{in} and V_{out} amplitudes only at 20000 Hz
- Based on your observations find the frequency at which the gain falls to 0.707 of the maximum gain.
- Capture oscilloscope image of V_{in} and V_{out} amplitudes at a frequency where the gain is0.707 of the maximum gain?

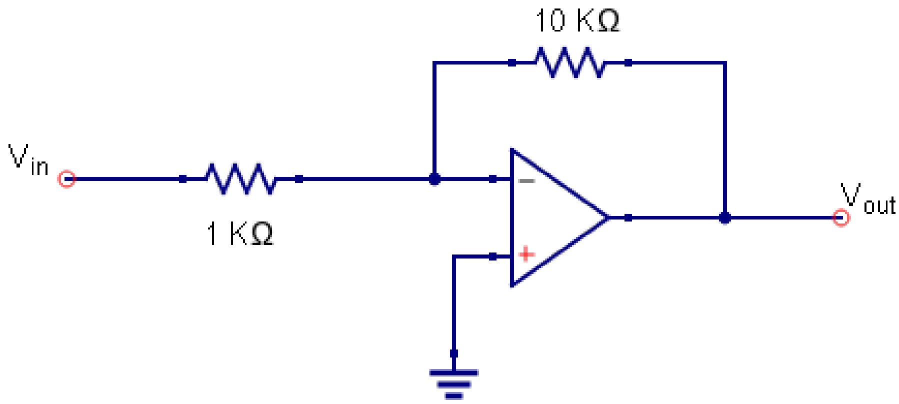

Figure 5: The op-amp inverting amplifier circuit.

- Plot V_{out}/V_{in} vs. frequency for the data you have taken
- Utilizing the specification sheet for the 741 op-amp compare bandwidth for the amplifier with your measurements.
- When the slope of the sine-wave signal goes beyond the slew rate of the amplifier, you will see distortion of the output signal. The output will resemble a triangular wave rather than sine-wave due to this effect.
- Increase the input frequency until the output will resemble a triangular wave rather than sine-wave due to this effect.
- Measure the slope of the output signal ($\Delta V/\Delta t$ during rising or failing slope of the wave) see Figure 3(b)
- Capture oscilloscope image of the V_{out} amplitude to show the observed distortions. Note down the frequency at which this was observed.
- Utilizing the specification sheet for the 741 op-amp compare maximum slew rate the op-amp can tolerate with your measurement.

Op-amp Comparator

- Build the op-amp comparator circuit shown in Figure 6
- Using the multimeter, set the $V_{ref} = 2.5\ V$ by adjusting the potentiometer
- Connect the DC power supply into the V_{in} of the inverting amplifier
- Vary V_{in} from 1.0 V to 3.0 V in steps of 0.5 V and measure the V_{out}
- What is the output V_{out} for $V_{in} < V_{ref}$ and $V_{in} > V_{ref}$?
- Remove the DC power supply from the V_{in}

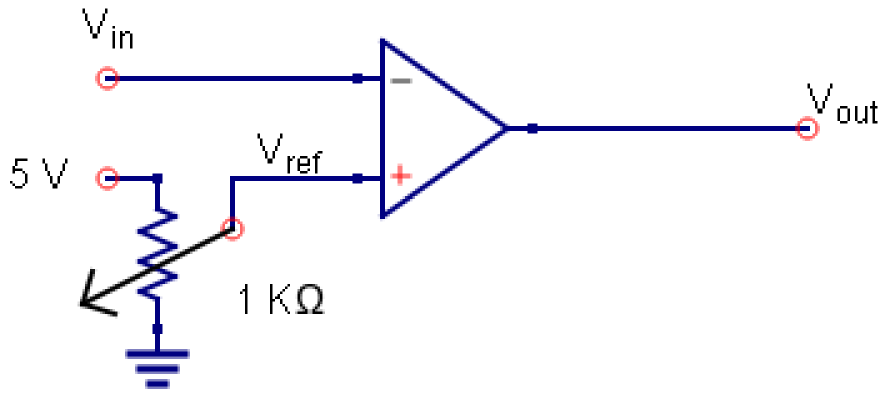

Figure 6: The simple op-amp comprator circuit. The reference voltage at the non-inverting input is controlled by a potentiometer

- Set the signal generator to triangle-wave at 50 Hz
- Set both channels of the oscilloscope to "DC" mode
- Connect the signal generator into the V_{in}
- Connect the channel 1 of the oscilloscope into the V_{in} and channel 2 into the V_{out} of the amplifier
- Set the input amplitude to 3.0 V using the oscilloscope
- What is the output V_{out} for $V_{in} < V_{ref}$ and $V_{in} > V_{ref}$? Measure using the oscilloscope
- Capture oscilloscope image showing the V_{out} and V_{in}
- Using the multimeter, set the $V_{ref} = 2.9\ V$ by adjusting the potentiometer
- Capture oscilloscope image showing the V_{out} and V_{in}
- Using the multimeter, set the $V_{ref} = 0.5\ V$ by adjusting the potentiometer
- Capture oscilloscope image showing the V_{out} and V_{in}
- Discuss how the duty-cycle of the V_{out} vary when V_{ref} is increased or decreased.
- **Note that A duty cycle is the percentage of the waveform that occurs above the $V_{out} > V_{ref}$.**
- Discuss practical applications for an op-amp comparator

References