Lab 8
Op Amps Revisited

OBJECTIVES
1. Practice using the oscilloscope to observe voltage waveforms using op amps.
2. Observe the limitations of real op amps: slew rate and saturation voltage.
3. Observe an integrator and differentiator op amp circuit.

EQUIPMENT
Lab Kit, power supply, oscilloscope, and Function Generator

THEORY
Real Op Amps
Op amps are not perfect; there are many things that cause them to behave in a nonideal fashion, that is, not operate linearly. There are a number of factors that must be considered in real-world op amp use such as slew rate, fall-off frequency and the saturation voltage. The goal of this week’s lab is for you to experience and to understand some of the real-world limitations of op-amps.

Integrator and Differentiator Circuits
When a combination of resistors and capacitors are connected to an op amp, the input/output voltage relationship is given by

\[ v_{\text{out}} = -\left( v_{\text{out}}(0) + \frac{1}{RC} \int_0^t v_{\text{input}} \, dt \right) \]

\[ v_{\text{out}} = -RC \frac{dv_{\text{input}}}{dt} \]

That is, the input signal is either integrator or differentiator.

Warnings
- Make sure that the ground of the oscilloscope and power supply are the same.
- After completing each circuit, turn off the power to allow the op amp to completely discharge. Use the oscilloscope to observe the voltage waveform as it goes to zero (in 5 – 10 seconds).

Part 1: Measuring the Slewing Rate
Op-amps cannot make instantaneous changes in their output voltage. The maximum rate at which an op-amp can change its output voltage is called the slew rate SR \( \equiv \Delta v / \Delta t \). It can be determined by examining the slope of the op-amp output at instantaneous (step) input voltage changes.

a. Before constructing the voltage follower circuit, use the oscilloscope to set the voltage of the Function Generator (FG), then construct the voltage follower circuit

![Voltage Follower Circuit Diagram]

b. If the input voltage \( v_{\text{in}} \) is a square voltage waveform, what should the op amp output voltage \( v_{\text{out}} \) look like? Explain your reasoning.

c. Energize the circuit, display \( v_{\text{in}} \) (square waveform plus 1kΩ resistor) on Channel 1 (CH1) and \( v_{\text{out}} \) on CH2. Adjust the scale of the plot so that you can observe the rise and fall of the square waveform clearly. Using the dual trace feature, is the output following the input voltage?
d. Starting from 2kHz, increase the frequency of the FG slowly to about 100kHz. As the frequency increases, does the voltage follower gets worse and worse at doing its job or is the ability to follow the voltage about the same; that is, does \( v_{\text{out}} \) stops following \( v_{\text{in}} \). Why does this happen?

e. Measure/estimate the slew rate for both the rising and falling edges by observing the slopes of the output transitions for 2kHz, 10kHz, and 100kHz. Remember to constantly adjust the time/div knob to get a good measurement of the slope change. Express the slew rate in volts/\( \mu \)s. Draw a sketch of this on paper.

f. Compare your measured value of the slew rate with the manufacturer’s claimed value of 0.5 V/\( \mu \)s using a percent difference? How do they compare?

Part 2: Clipping

Op-amps cannot provide infinite output voltage and have saturation voltages of \( \pm 15V \). At the saturation voltages, the op-amp will begin “clipping”. In periodic waveforms, clipping appears as a “flattening out” of the output voltage at the peaks of input wave. Construct the inverting amplifier circuit. Make sure to set the frequency using the oscilloscope, not the FG.

\[ \text{inverting amplifier circuit diagram} \]

a. Calculate the output voltage \( v_{\text{out}} \) of the inverting amplifier. At what input voltage would you expect to start seeing clipping of the output voltage? Explain your reasoning.

b. Energize the circuit, display \( v_{\text{in}} \) on CH1 and \( v_{\text{out}} \) on CH2. Starting with a 2V peak-to-peak sine voltage waveform, gradually increase the amplitude of the input signal and (i) measure the input amplitude when the output starts clipping. Is this what you expected? (ii) Sketch the input and output signals, and note the voltages at which the output begins to exhibit clipping. Don’t forget about the phase of the voltage waveform.

c. With the input set at the amplitude that is producing clipping, slowly lower the supply voltage of the op-amp from its initial value of \( \pm 15V \). What happens to the output’s clipping? Can you explain this?

d. Set your input amplitude back to 1V. Repeat the same process for a triangle wave input.
Part 3A: The Integrator
In addition to the sine wave and the square wave, there are two other common signals in
electronic instruments, the triangle and sawtooth voltage waveforms. Both waveforms
consist of voltages that change in time.
Construct the integrator circuit and drive the circuit with a 1kHz square voltage waveform
as the input.

One easy way to generate a triangle wave is by “integrating” a square wave.

a. PSpice the integrator circuit (only for the square wave) first before trying to make any
measurements. Make sure to define the $v_{in}$ and $v_{out}$ nodes in PSpice.
b. Energize the circuit, display $v_{in}$ on CH1 and $v_{out}$ on CH2. Change the scale of CH2
such that the $v_{out}$ amplitude is close to the $v_{in}$ amplitude. Is the integrator signal (i.e.
the output signal) a triangle wave?
  - Is the integrator signal (i.e. the output signal) a “triangle” waveform? Explain why
the output signal is a "triangle" wave?
  - Sketch the input and output signals. Don’t forget about the phase of the voltage
waveform.
  - Is the sign of the slope of the input the same as the sign of the slope of the output
voltage? In other words, are the voltage waveforms in-phase or out-of-phase?
c. The integrator circuit is very sensitive to any asymmetry in the square wave input. To
see this, adjust the offset of your square wave signal using the offset adjust control
on your function generator. What happens?
d. Repeat this with a sine wave input but only observe it.

Part 3B: Differentiator
One easy way to generate a sawtooth wave is by “differentiating” a triangle wave.

a. Construct the differentiator circuit by switching the 0.1µF capacitor in-between the
1kΩ resistor and the Op Amp. However, now drive the circuit with a 1kHz triangle
voltage waveform as the input.
b. Answer the following questions:
  - Is the differentiator signal a sawtooth wave? Explain why the output signal is a "
sawtooth " wave?
  - Sketch the input and output signals. Don’t forget about the phase of the voltage
waveform.
  - Is the sign of the slope of the input the same as the sign of the slope of the output
voltage? In other words, are the voltage waveforms in-phase or out-of-phase?
c. Does this circuit reverse the process that was performed by the integrator to the
square wave input? Also try a sine wave input signal. Is the derivative of a sine wave
another sinusoidal waveform? Explain your reasoning.