Lab 5 - Operational Amplifiers I

Objectives

In this lab you will build a number of simple circuits containing operational amplifiers (op-amps) and characterize their performance as a function of frequency and input pulse shape.

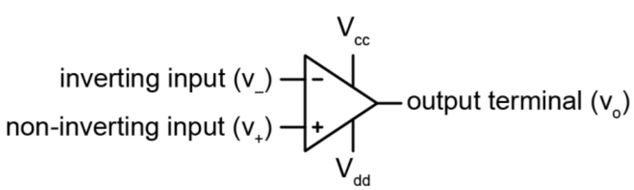
Laboratory Equipment

In this lab, you will use the following instruments:

- Operational amplifier (integrated circuit)
- Function/waveform generator
- Digital oscilloscope

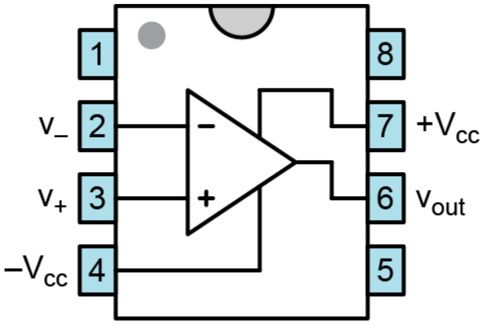
Background

The following figure shows the electrical schematic symbol used to represent an operational amplifier (op-amp):



An op-amp has two input voltages, which are typically denoted by v+ and v–. The ± label does not necessarily indicate the polarity or sign of the applied input voltage, but taken together they define the differential input voltage input ($v_+ - v_-$) that gets amplified by the device. Op-amps have two DC supply voltages, which are often labeled V_{cc} and V_{dd}. For this lab, we will use V_{cc} = +5 V and V_{dd} = –5 V. The op-amp device produces an output voltage, denoted v_o, that is an amplified version of the differential input voltage. The full-scale range of output voltage is limited by the power supply voltages (also called the "rails"), and hence for the experiments considered here the output voltage will always be less than 5 V.

A general-purpose (and inexpensive) op-amp is the TLV271. It comes in a number of packages, including the 8-pin DIP package, whose pin connections are shown below For us, $Vdd = -Vcc$:



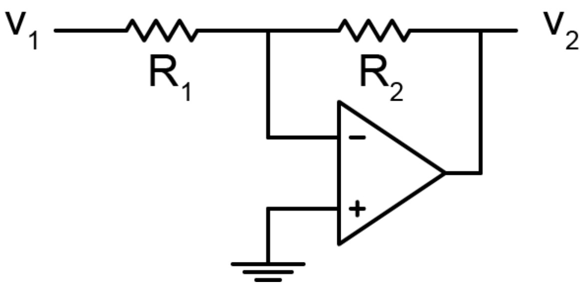
There are thousands of different types of op-amps, but the majority of the differences in op-amp performance characteristics are beyond the scope of this course. A partial list of operational differences include: the number of op-amps in each integrated circuit, the family of transistors used to construct the op-amp (CMOS, JFET, bipolar) the number of power supplies needed (1 or 2), the range of acceptable power supply voltages, the range of possible output voltages, and the deviation of the op-amp characteristics from the ideal values.

In this lab, you will design, build, and measure four basic op-amp circuits:

- Inverting amplifier
- Non-inverting amplifier
- Differentiating circuit
- Integrating circuit

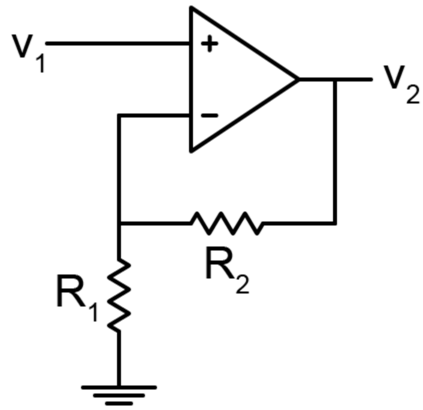
These circuits are fundamental building blocks that are very widely used in practical circuits. The principle of operation and analysis of these circuits will be covered in the lectures, but the basic design equations for these circuits is summarized below:

Inverting amplifier:



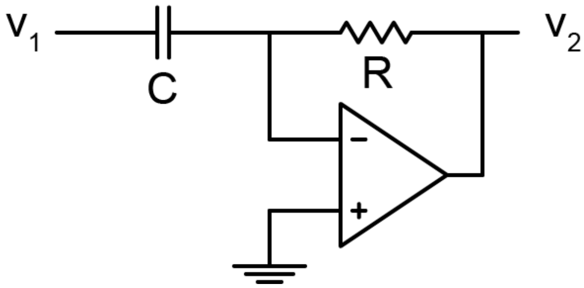
$$v_2 = -\frac{R_2}{R_1} v_1$$

Non-inverting amplifier:



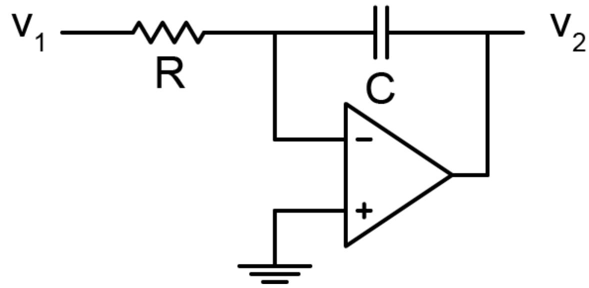
$$v_2 = \frac{R_1 + R_2}{R_1} v_1$$

Differentiating Amplifier:



$v_2 = -RC\frac{d}{dt}v_1 \hat{V}_2 = -j\omega RC\hat{V}_1$

Integrating Amplifier:



$v_2 = -\frac{1}{RC}\int \quad v_1(t)dt \qquad \hat{V}_2 = -\frac{1}{j\omega RC}\hat{V}_1$

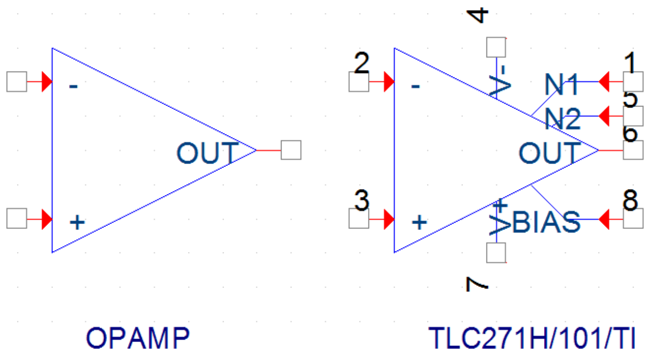
Pre-lab Preparation

1. **Design** each of the following op-amp circuits.
    a. An inverting amplifier op-amp circuit, with a gain of -5
    b. A non-inverting amplifier circuit with a gain of +6
    c. A differentiator circuit with a specified AC "gain" of 2 when the input frequency is $\omega/2\pi$ = 3.2 kHz. (Here we mean that the output voltage amplitude is 2x larger than input amplitude when the input is a 3.2 kHz sinusoid.)
    d. An integrator circuit with a specified AC "gain" of 5 at 3.2 kHz.

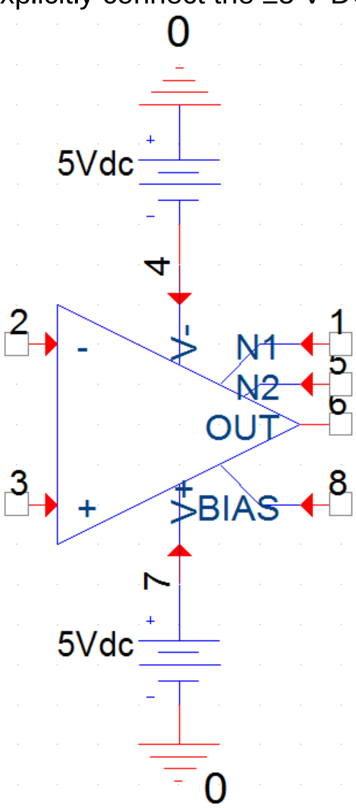
Your design should use only the components available to you in the standard set distributed to all students. For your pre-lab design, please submit a large, clearly labeled circuit schematic that shows the power supplies in addition to the inputs and outputs. Label each of the terminals of the op-amp with the pin number from the corresponding DIP package.

2. **Build** the inverting amplifier circuit that you designed in 1a above. Use your solderless breadboard and one of the TLV271 op-amp chips provided. Take a photograph of your assembled circuit on the breadboard. You do not need to connect the input or power supplies.
3. Use PSpice to **simulate** the inverting amplifier circuit that you designed and built.
    a. To begin, you can use the generic PSpice part called "OPAMP", which models an ideal op-amp and can be found in:
    Place►PSpice Component...►Discrete►OpAmp
    For the ideal op-amp, you do not need to connect the power supplies.
    b. Connect the input to a sinusoidal AC source:
    Place►PSpice Component...►Source►Voltage Sources►Sine
    c. Set the frequency to be 5 kHz, and the AC amplitude to be 0.1 V
    d. Perform a time-domain (transient) solution and show that the circuit exhibits the expected gain.
4. Real op-amps chips can exhibit a variety of non-deal behaviors, including an output voltage that is limited by the DC power supplies. Change your PSpice model to include a more realistic op-amp model.

a. The TLC271 is a general-purpose CMOS op-amp that has characteristics similar to the TLV271 contained in your kit. You can access this part in PSpice by: Place►PSpice Component...►Search
And then typing "TLC271" into the search box that appears. Here is a comparison between the generic ideal op-amp and the more realistic TLC271:



b. In addition to the feedback resistors needed for your inverting amplifier, you must explicitly connect the ±5 V DC power supplies to the op-amp, like this:



c. Increase the AC voltage amplitude to +1V, and use PSpice to simulate the output voltage for this case. Submit a time-domain trace showing the output time-domain waveform.

5. A realistic op-amp circuit also has a limited bandwidth, meaning that the gain will diminish at sufficiently high frequencies. Change your PSpice simulation profile to "AC Sweep" mode, and simulate the output voltage amplitude vs. frequency

a. Replace the input source to an AC voltage source with an amplitude of 0.1 V:
   Place▶PSpice Component...▶Source▶Voltage Sources▶AC
   Note that the AC source leaves the frequency unspecified, because in this case the frequency will be adjusted by the simulation.
b. Create a new simulation profile for AC Sweep, with a logarithmic frequency range from 100 Hz to 1 MHz.
c. Plot the AC output amplitude vs. frequency

Instructions

Inverting Amplifier

1. Connect and measure the inverting amplifier circuit that you built for your pre-lab. Be careful to properly connect the ±5 V power supplies.
2. Use the waveform generator to produce a 5 kHz sinusoidal input voltage with an amplitude of 0.1 Vpp. Use the oscilloscope channels to measure both the input and output voltages. Save both a screenshot and the trace data.
3. Increase the input amplitude to 2 Vpp and measure the (saturated) output voltage.
4. Reset the input amplitude to 1 Vpp, and sweep the frequency from 100 Hz to 500 kHz. Take at least 3 points per decade (for example, in a 1,2,4 sequence.) At each frequency, measure the amplitude of the output voltage.

Non-inverting Amplifier

5. Construct the non-inverting amplifier op-amp circuit that you designed for the pre-lab. Use a triangular input signal with a 2 Vpp amplitude and plot and record the output and input time dependence for a 3.2 kHz signal.

Differentiator Circuit

6. Construct the differentiator circuit that you designed for the pre-lab. Measure the output and input signals when the input signal is 2 Vpp and the frequency is 3.2 kHz and the shape is (a) a sine wave and (b) a square wave.
7. With a sine wave, sweep the frequency from 100 Hz to 500 kHz. Take at least 3 points per decade (for example, in a 1,2,4 sequence.) At each frequency, measure the amplitude of the output voltage.

Integrator Circuit

8. Construct the integrator circuit. Use a square wave input signal with a peak-peak voltage of 1 Vpp and a frequency of 3.2 kHz. Plot the output and input signals.
9. Sweep the frequency from 100 Hz to 500 kHz. Take at least 3 points per decade (for example, in a 1,2,4 sequence.) At each frequency, measure the amplitude of the output voltage.

Post-lab Analysis

Generate a lab report following the sample reports. Mention any difficulties encountered during the lab. Describe any results that were unexpected and try to account for the origin of these results (i.e. explain what happened). In ADDITION, answer the following questions:

1. Was there any degradation in the output pulse shape for any of the op-amp circuits in any frequency range or voltage range? If so, when and why?
2. How did the experimental results compare with the computer simulations for the inverting amplifier circuit?
3. Was the output from the differentiator as expected for both input sources? Explain.
4. Was the output from the integrator as expected? Explain.
5. Which op-amp circuit performed most like the ideal op-amp model predicted?
6. Which op-amp circuit performed least like the ideal op-amp model predicted?