**Lab 5: Op Amps**

Objectives:

- become familiar with the properties of op amps (with and without negative feedback)
- use the Golden Rules to understand the behavior of op amps in circuits
- observe and analyze several different types of op-amp circuits

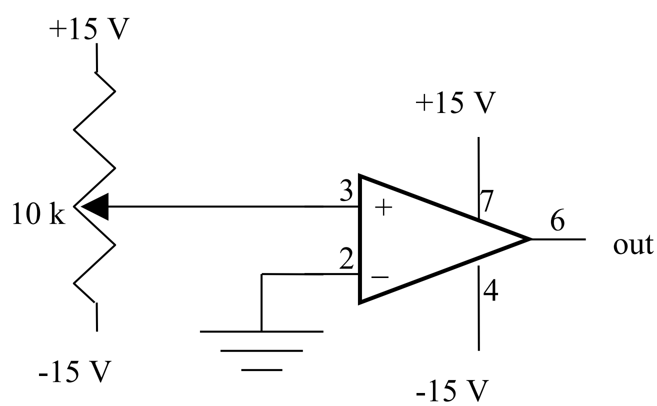
**General notes:**

- The DIP (dual in-line package) chip should straddle the trench in the breadboard (that's what the trench is there for!)
- We don't always show power to the chip on the circuit diagram, but it <u>always</u> needs to be there (usually ±15 V). Check your breadboard supplies and adjust them to be fairly close to ±15V.
- If you see "fuzz" on your output voltages, try putting a small capacitor (few tenths of a μF) between each of the power supplies and ground (to act as a short for very high frequencies; this will tend to eliminate the oscillations that cause the "fuzz").

**5-1 Open-loop gain**

Set up an LF411 in the circuit shown below. The funny looking resistor at left is a variable resistor or potentiometer. Note that there is no feedback. Do the Golden Rules apply here? Why or why not?

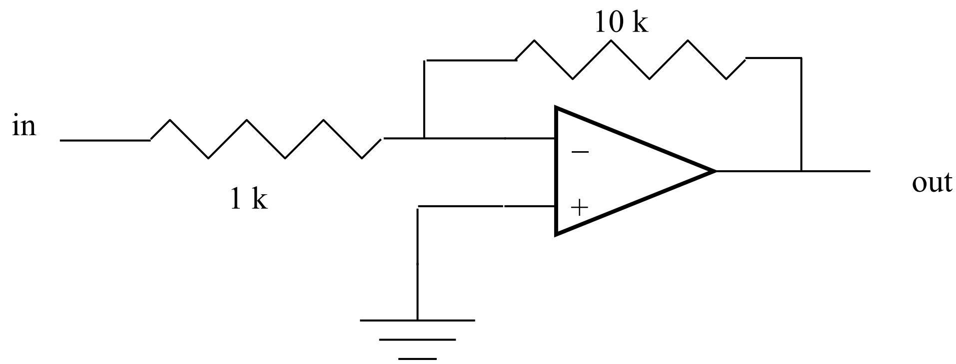
Watch the input and the output voltage as you slowly twiddle the potentiometer to change the input voltage. What does the output voltage do? Why? Hint: the LF411 open-loop gain specification is 200 V/mV. To get 15 V or less out, what would the difference in voltage between the two inputs have to be? (And what are the chances you can adjust the pot this precisely?)




**5-2 Inverting amplifier**

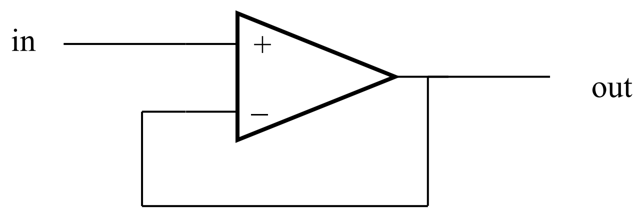
Build the circuit below. Look at the voltage at the inverting input; what is it? Is it what you expect, and why? Predict the voltage gain using the Golden Rules. (Should it be the same as for the previous amplifier?) Now measure the voltage gain at 1 kHz. Is there agreement? Sketch or describe $V_{in}$ and $V_{out}$ at 1 kHz.

Predict $R_{in}$, then measure $R_{in}$ by putting an appropriate resistor in series with the input. Does the result agree with what you expect?




**5-3 Op-amp follower**

Build the follower below. Put in a signal from the function generator. Look at $V_{in}$ and $V_{out}$ on the scope, and sketch or describe them. Change the frequency and amplitude of $V_{in}$ ; what happens to $V_{out}$? (Do you see why this circuit is called a "follower"? How is it similar to the transistor emitter follower circuit you built earlier?)




Try to measure the input resistance ($R_{in}$, which should be very large) at 1 kHz by using a 10 M resistor in series with the input. If you get an answer of 10 M, stop and think about what else is in the circuit that has an impedance of 10M! What does this result imply about $R_{in}$ of the follower?

The <u>slew rate</u> of the op amp is the maximum rate at which it can change the output voltage. Put the circuit back in the original follower configuration. Switch the input to square waves and set f=10 kHz. Adjust the amplitude of the function generator so that $V_{out}$ is as large as possible. Measure the slew rate by measuring $dV_{out}/dt$ (use a straight section of the voltage rise; you'll have to play with the scope controls to make the interesting part of the signal easily visible). Compare the slew rate on the rise to the slew rate on the fall—do the rates differ? Compare your measured slew rates to the values listed in the LF411 data sheet. (optional: Repeat for the LM741 (which has the same pinout as the 411).)

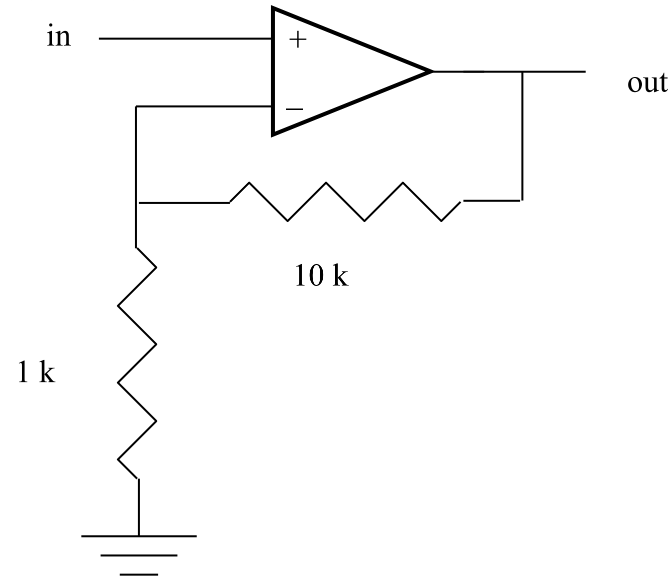
Suppose you want to use the follower on an input signal consisting of a sine wave of 10 V peak-to-peak. What is the maximum frequency you can use before the output signal begins to be distorted by the finite slew rate of the amplifier? Make a prediction for the maximum frequency, then set up the situation and describe or sketch what happens when you exceed that frequency.

**5-4 Non-inverting amplifier**

Build the circuit below. Note that we use a voltage divider to make the op amp output voltage larger than the input voltage. Look at the voltage at the inverting input; what is it? Is it what you expect, and why?

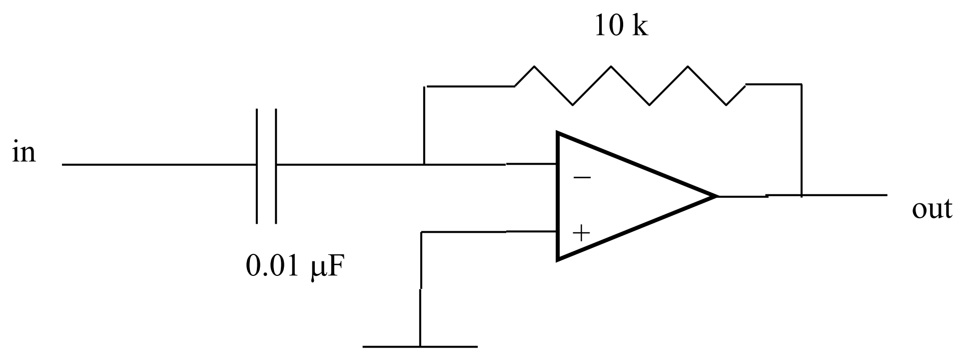
Predict the voltage gain using the Golden Rules. Now measure the voltage gain for a 1 kHz sine wave. Is there agreement? Sketch or describe (frequency, amplitude, phase) $V_{in}$ and $V_{out}$ at 1 kHz.

Increase $V_{in}$ till it produces clipping of the output; at what voltages (+ and -) is the output clipped? Sketch $V_{in}$ and $V_{out}$ for a slightly larger voltage than produces clipping.




**5-5 Differentiator**

Set up the circuit below. Try it with square waves at around 1 kHz. If the input and output don't look like you expect, read the *note* below. Sketch input and output. Also try it with triangles and sines. In what way(s) is this circuit an improvement over the passive RC-filter-based integrator you built earlier in the semester?




*Note*: at high frequencies the phase introduced by the differentiator adds to the phase produced in the op amp and the negative feedback becomes positive, causing instabilities. To get around this problem, you can try adding a small capacitor (say, 560 pF) in parallel with the feedback resistor. This capacitor will have little effect at low frequencies (because it has a large impedance at low frequencies), but will serve as a short for higher frequencies.

For a triangle wave input with peak $V=V_{in}$, use the Golden Rules to derive an expression for the peak $V_{out}$ in terms of R,C, the frequency, and $V_{in}$. Use this to calculate $V_{out}$ for a input triangle wave of frequency 1 kHz and amplitude 0.5 V, then measure for your circuit and compare calculated to measured.

**5-6 Current-to-voltage converter (optional)**

In many cases, we want to take a small current and convert it to a voltage. For example, a photodiode or phototransistor produces a current proportional to the light intensity falling on it, but a voltage proportional to that current is easier to work with. A large resistor will produce a reasonably-sized voltage from a small current, but a large resistor has impedance properties that are often not useful in a circuit. A better solution is an op-amp based current-to-voltage converter, shown below.

Use the I-to-V converter to look at the current from a PN168 phototransistor, hooked up as shown below (the longer leg is the emitter). Carefully sketch the output signal (be sure to show where ground is). What is the average voltage output? What average current from the phototransistor does this correspond to?

What is the frequency of the output signal? Why does it have that frequency?

Cover the photodiode with your hand and describe what happens to the output. Try shining a flashlight on the phototransistor. Explain what happens and why.

What could you do to prevent the output from saturating if you wanted to measure the intensity of the brighter light from the flashlight?