Lab 9: Op-amp I: Negative Feedback

Before You Begin:

(a) Most of the time we will use $\pm 15\,\mathrm{V}$ as the supply voltages (you can and should check whether this is safe by referring to the Absolute Maximum Ratings). Often, the power supply connections will not be explicitly shown on diagrams. Don't forget them — we can't get gain for free!

(b) In addition, you should always place *bypass capacitors* between the supply lines and ground, close to the power supply pins. The datasheet recommends $0.1\,\mu\mathrm{F}$, but the precise value isn't critical. These capacitors help ensure that the voltage supplied to the op-amp remains constant; it also prevents oscillation. If you don't bypass (and sometimes even if you do), you may find that the scope traces appear fuzzy, as in Figure 1-left. What's that fuzzy stuff on the bottom of the otherwise nice sine wave? We expanded the horizontal trace and got the detail seen in Figure 1-right — aha, an oscillation at 120 MHz! Active circuits that have amplification can do this, because if some of the output gets back into the input, it can produce a self-sustaining oscillation. We'll talk about this more in later labs. For now, just remember to bypass, bypass, bypass!

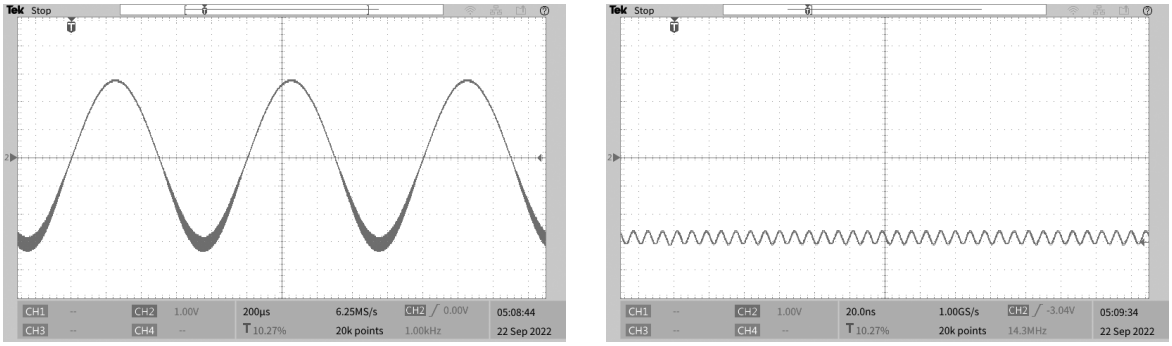


Figure 1: A *parasitic oscillation* often appears as "fuzz" on a scope trace, as here (we encouraged it by removing bypass capacitors). The right figure is an expanded version of the left figure at 20 ns/div, showing the 120 MHz oscillation.

1 Exploring the enormous open-loop gain of an op-amp

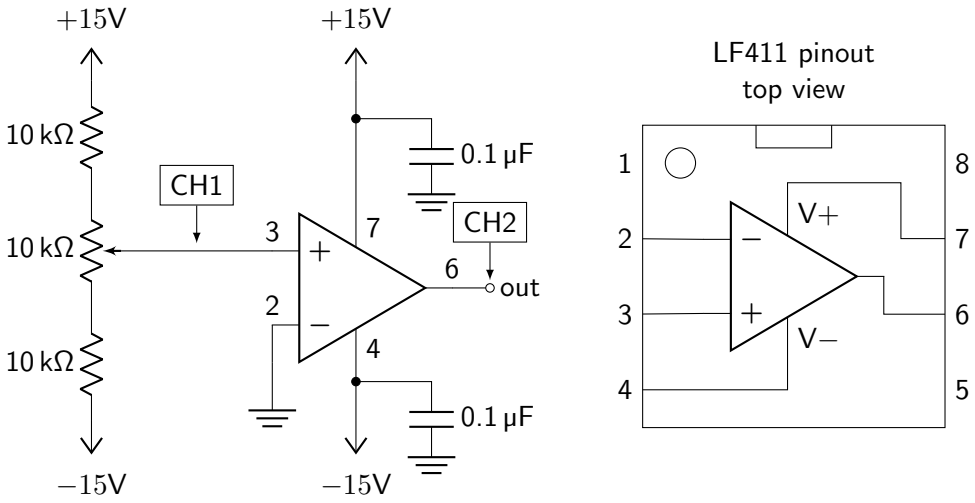
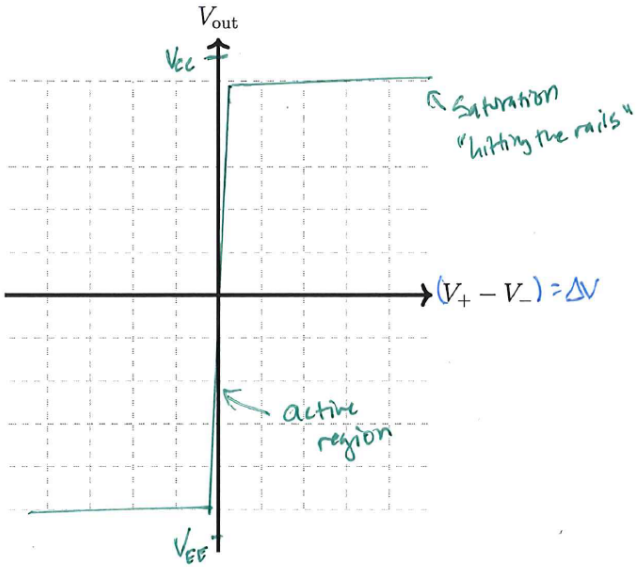


Figure 2: Circuit to explore an op-amp's open-loop response to an input dc voltage near zero.

Pull up the datasheet for the LF411 general-purpose op-amp. Place the chip across the center of the breadboard, so that each pin attaches to its own column, noting the location of the notch (or dot) shown in Figure 2. Then wire up the circuit in the figure, which lets you smoothly vary the DC input voltage to the non-inverting input of the (open-loop) op-amp. Watch the input and output on the scope and see if you can balance it on a knife edge (but don't try too hard; you almost certainly can't!).

(a) Sketch a qualitative plot below of V_{out} vs V_{in}, where V_{in} is the voltage at the non-inverting input. Use this plot to rationalize the statement: "if the output of the op-amp is somewhere between its extremes, then the voltage difference between the inverting and non-inverting inputs is practically zero."



The active region is so narrow, that the difference must be basically zero if the output is within the active region.

The lesson: don't try to use op-amps without negative feedback; they've got way too much gain.

2 Inverting and non-inverting amplifiers

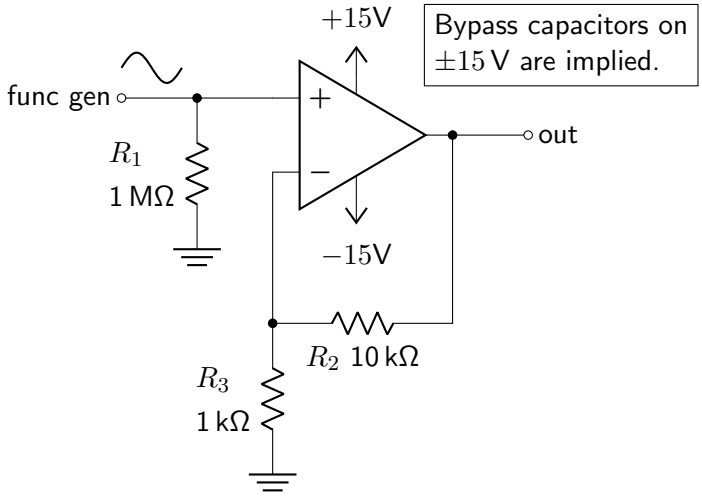


Figure 3: Classic op-amp voltage-amplifier.

(a) Wire up the circuit of Figure 3. What kind of amplifier is it? What is the expected (closed-loop) gain?

This is a non-inverting amplifier, which takes its input at the non-inverting terminal of the op amp. Therefore, the gain is $G = 1 + \frac{R_2}{R_1}$. We have to be careful about the resistor numbering, since the diagram numbers the resistors differently from our normal topology. The gain should be: $G = 1 + \frac{10\,\text{k}\Omega}{1\,\text{k}\Omega} = 11$.

(b) Drive the circuit with a 100 mVpp sinewave at 1 kHz. Does it behave as expected?

Hopefully!

(c) Now increase the amplitude of the input sinewave in 100 mV steps, going all the way up to 4 Vpp. Explain what is happening at the higher amplitudes.

Once the output peaks approach the rails (± 15 V), you start to see them flatten out or "clip." This is because the output voltage of the op amp cannot exceed the power supply, and for most op amps is limited to being within one or two volts of the power supply. Special op amps that advertise "rail-to-rail" capability can output voltages closer to the rails.

(d) What is the input impedance of this amplifier? (You know the value of the external resistor R_1, but what about the op-amp's input resistance, which is in parallel? See if you can estimate it from looking at the datasheet.)

The datasheet specifies $R_{in} = 10^{12}\ \Omega$! This is in parallel with the 1 Meg (i.e $10^6\ \Omega$) resistor that we added (which prevents the input from floating when the function generator is disconnected). So the total input impedance of this circuit is dominated by the 1M resistor and is about 1 Megaohm.

(e) Now wire up the circuit of Figure 4.[1]

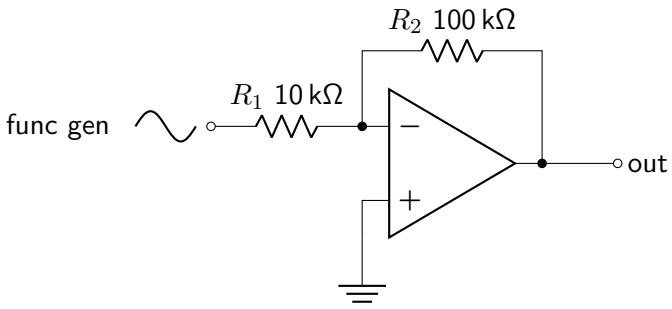


Figure 4: Another kind of voltage amplifier.

What kind of amplifier is it? What is the expected (closed-loop) gain, and what is the input impedance?

This is now an inverting amplifier, which takes its input at the inverting terminal of the op amp. The gain is $G = -\dfrac{R_2}{R_1} = -\dfrac{100\,\text{k}\Omega}{10\,\text{k}\Omega} = -10$.
The input impedance is $R_1 = 10\,\text{k}\Omega$, which is the impedance from the input to the virtual ground at the inverting terminal of the op amp (the point that is held at ground by the feedback of the op amp). Note that this is only the input impedance when the op amp is operating in the active region; if the output saturates, the inverting terminal is no longer held at ground, and the input impedance is no longer just R_1.

(f) Drive the circuit with a 100 mVpp sinewave at 1 kHz. Does it behave as expected?

Hopefully!

(g) Now increase the amplitude in 100 mV steps, as with the previous amplifier. Explain again what is happening at the higher amplitudes.

As before, when the output approaches ± 15 V, it can no longer go any higher/lower, and the waveform clips.

[1] Note: We are now entirely omitting the op-amp's power supply pins in the diagram, but they are still necessary. Don't forget to connect them to ± 15 V and bypass them.