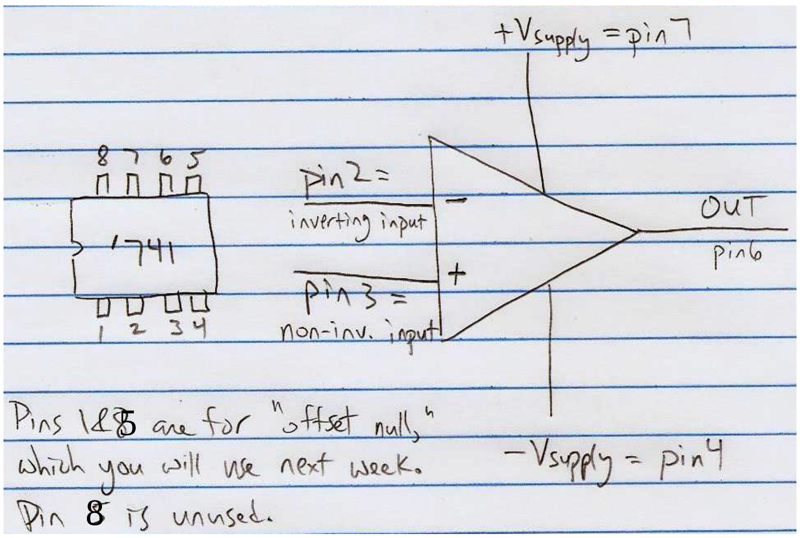
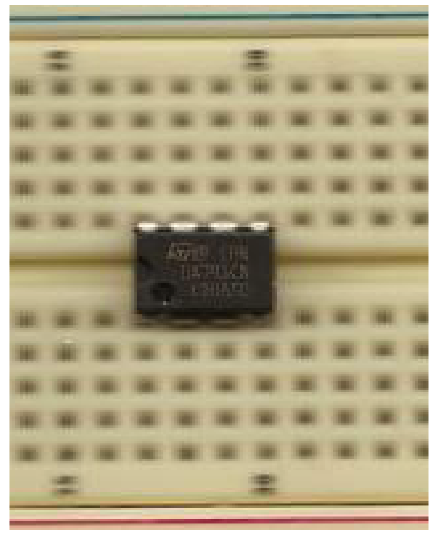
**Physics 364 – fall 2010 – lab #3 – due by lecture, Monday 2010-10-04**

We will spend this week and next on opamps. Lab #3 will focus on straightforward use of the Golden Rules, while Lab #4 will look a bit at opamps' real-world limitations.

**<u>Part 1.</u>** We'll start by building an opamp follower and illustrating how a follower (a.k.a. "buffer amplifier") can be useful as a kind of go-between for sources and loads that don't obey the Zout(A) << Zin(B) rule of thumb.

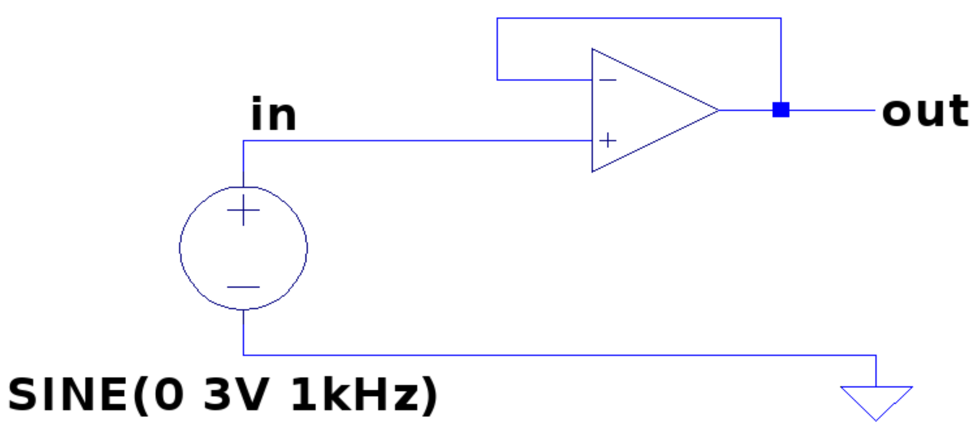


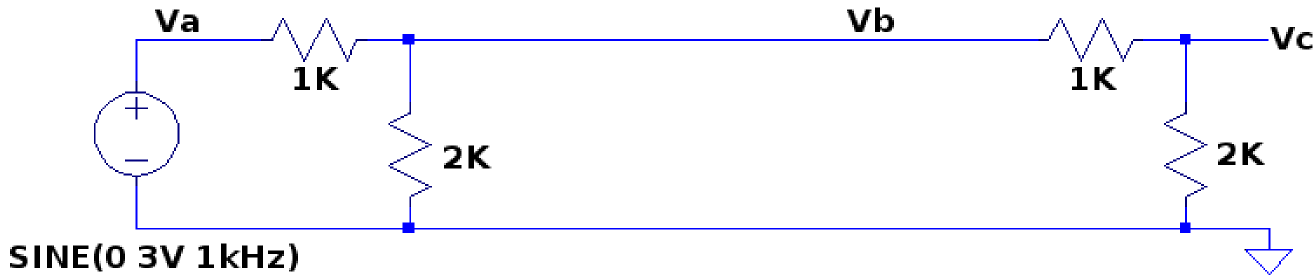
First get to know the conventional 8-pin opamp DIP pinout, illustrated above. Connect a '741 on your breadboard as shown, so that the breadboard does not short any of the opamp's pins together.

Now connect +15V to pin7 and -15V to pin4, to power the opamp. We'll omit this part of the instructions from now on.

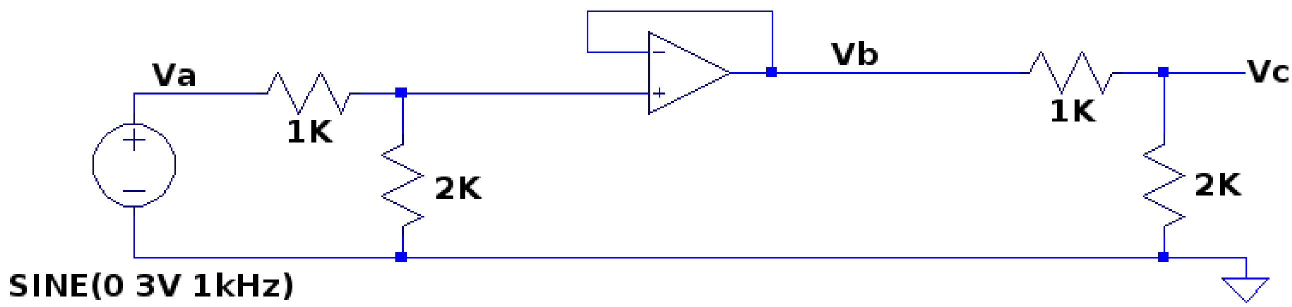
Now wire up the follower, as shown in the LTspice drawing below. Try driving Vin with a 6Vpp, 1kHz sine wave, and verify that Vout is a copy of (it "follows") Vin. Try other waveforms if you like.



Now rebuild (or at least imagine that you have rebuilt) the divider-loads-divider combination from Lab 1, part 3, with 1K:2K for each divider. (Note that we used DC signals in Lab 1, and AC signals below. You can try them both if you like.)

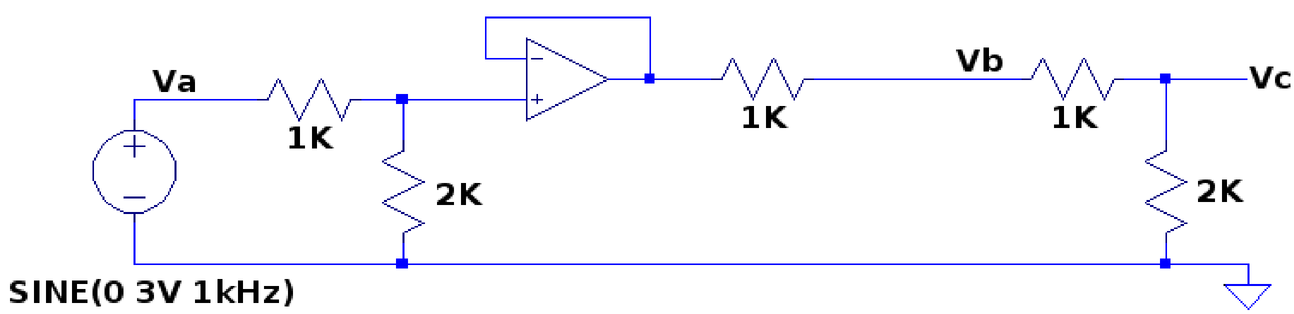



Recall that the second divider loads the first divider, reducing Vb from 2V to about 1.64V in amplitude. Now insert the follower between the first divider and the second:



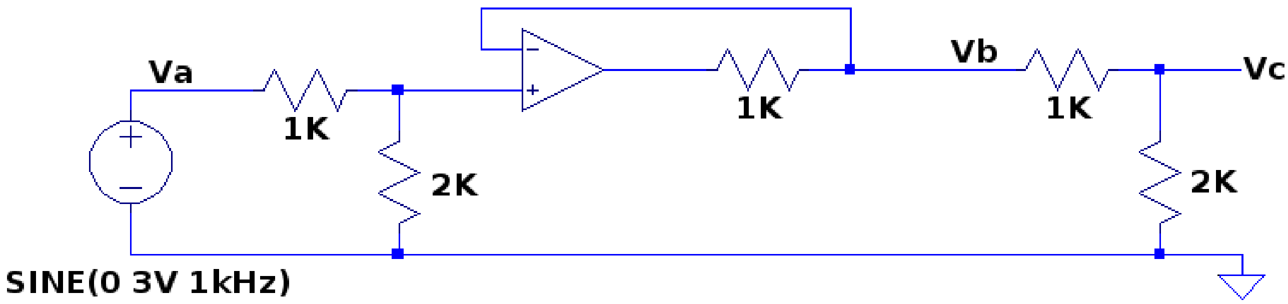

Voilà! No more loading. You should see 2V amplitude at Vb now, which is what you saw in Lab 1 when the second divider's resistors were chosen to be large enough (100K:200K) to produce negligible loading.

Now let's explore the very low output impedance of the follower. The opamp itself has a low output impedance, but negative feedback makes the follower's output impedance even smaller than that of the opamp itself. Insert a 1K resistor between the follower's output and the second divder's input, as shown below:




How does 1K compare with the input impedance of the second divider? How large is Vb now? (You should calculate in your head the answer you expect before you measure it!) Clearly a 1K output impedance makes it difficult to drive the 3K input impedance of the second divider without sagging.

Now move the feedback to the other side of the new 1K resistor:

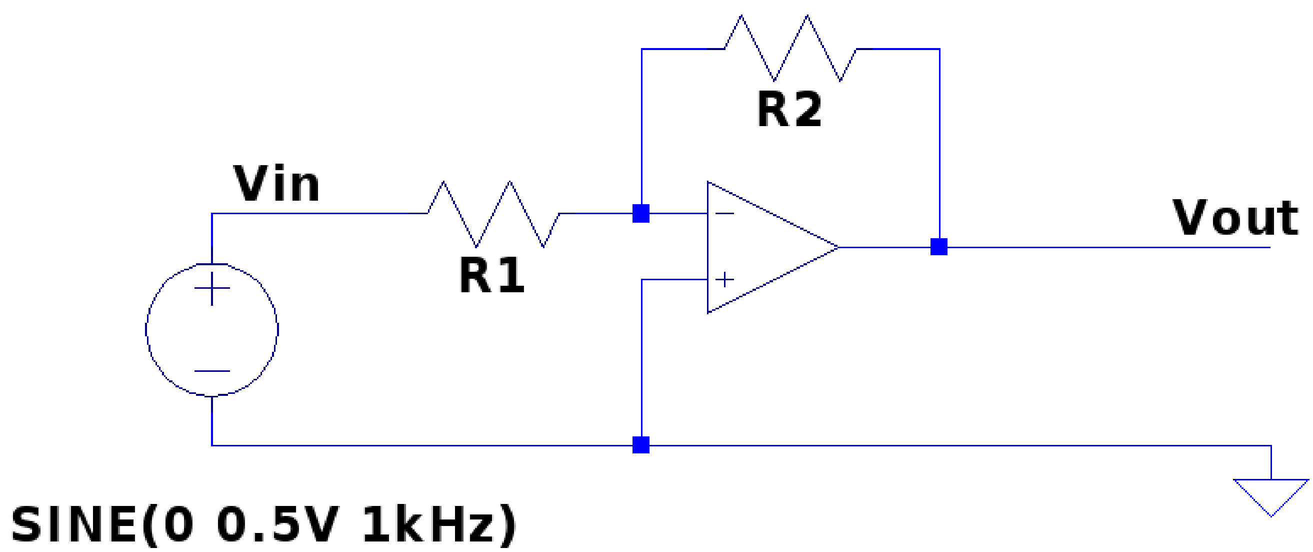



Now how large is Vb? What do you infer about the follwer's output impedance now? In effect, you have shown that even if you changed the output impedance of the opamp itself to 1K, the feedback would cause the output impedance of the follower as a whole to be far less than 1K. The power of feedback! Are you impressed?

**Part 2.** Next, we'll make a basic inverting amplifier. This is the circuit (though with different components) that I used to boost the signal from my wimpy AM radio antenna in Lab 2.

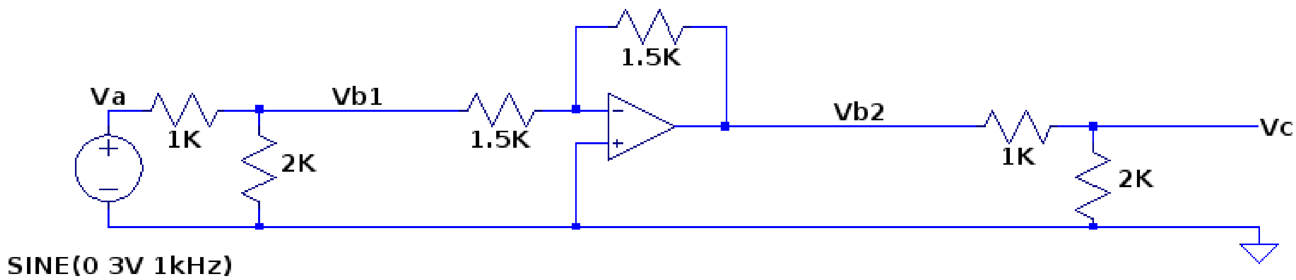
Don't take apart your voltage dividers yet.

Build the inverting amplifier drawn below. Choose resistors for a gain of -2. Drive Vin with a 1Vpp sine wave and look at Vout. Try triangle waves and square waves, too.



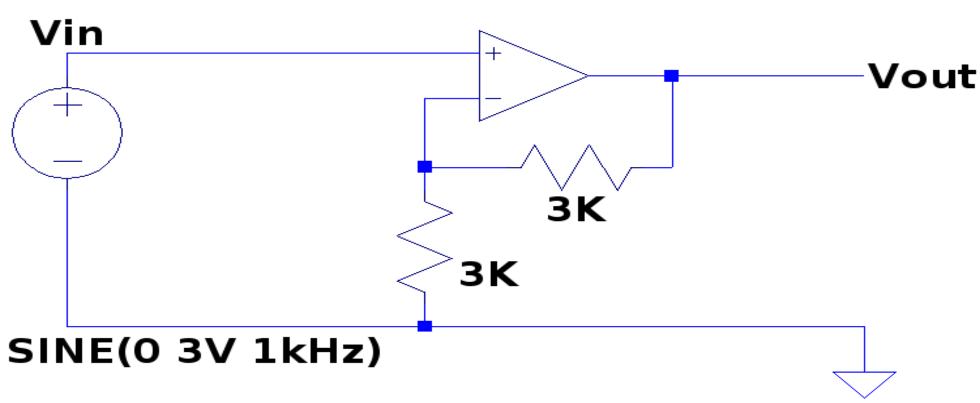

Now choose resistors for a gain of -10. Try 1Vpp inputs; look at Vout. Now try 5Vpp inputs. What happens? Now go back to 1Vpp sine waves and try increasing the frequency. Notice that the ideal behavior breaks down once you get up beyond a few hundred kHz – see data sheet if you're curious. (We'll discuss opamp real life next week.)

Now change both resistors to 1.5K to make a gain of -1. Try it out with a 1kHz sine wave. What happens when you plug your gain -1 amplifier between the two voltage dividers from above, where the follower used to be? (I draw the configuration below, to be clear.) How is the gain -1 amplifier different from the follower (in addition to the sign change)? How big was Vb1 with the follower? How big is it with this amplifier? Is the amplifier doing its job? (Compare Vb1 and Vb2.) What is the input impedance of your inverting amplifier circuit? (In other words, what impedance does the output of the first divider see when looking from Vb1 into the 1.5K resistor?)

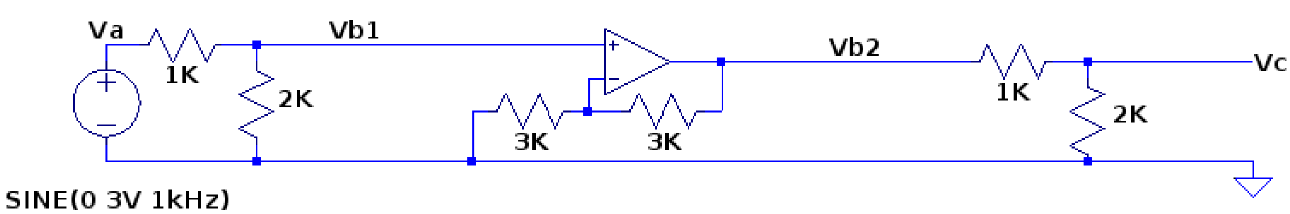



Now replace the two 1.5K resistors with 33K resistors. What happens to Vb1 and Vb2? Do you see how the input impedance of the inverting configuration depends on the resistor choices?

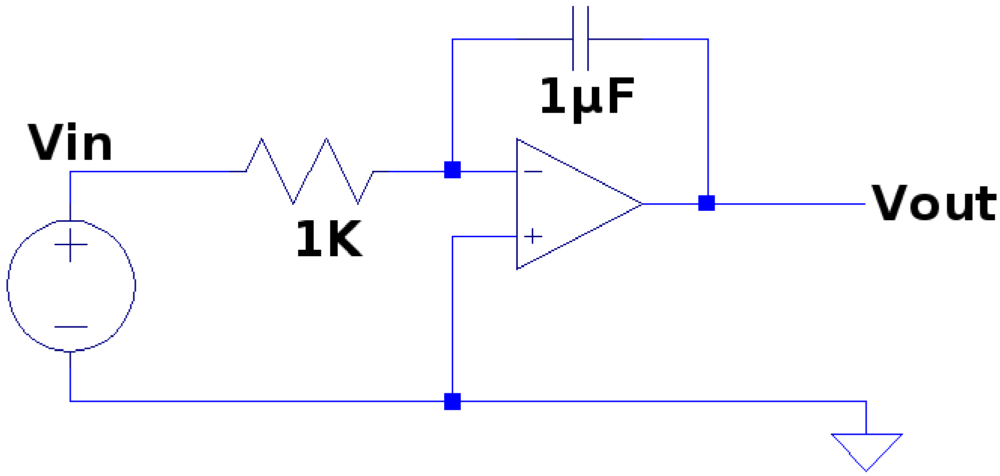
**<u>Part 3.</u>** Let's try the non-inverting amplifier configuration next. *Keep your voltage dividers handy!* Build the non-inverting amplifier drawn below. What is its gain? (Try to work out what it should be before you measure it.)



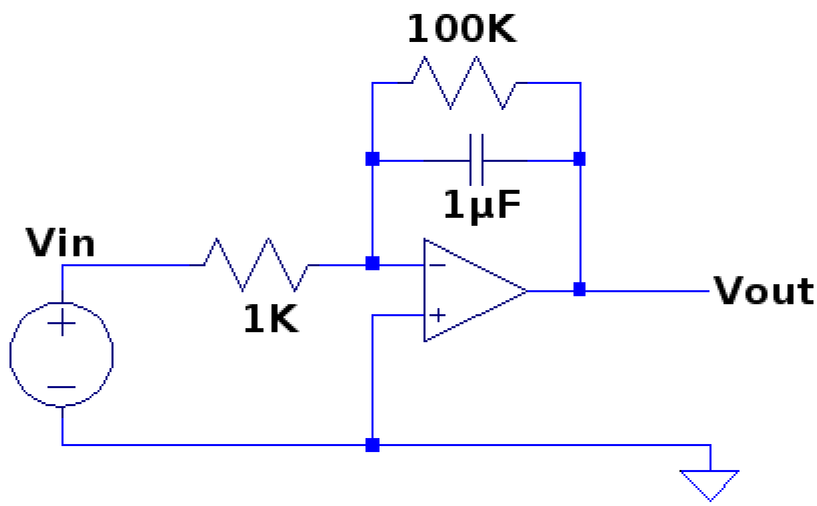

Now insert your non-inverting amplifier where the inverting amp was before (and where the follower was before that). What are Vb1 and Vb2 in this configuration? What do you infer about the input impedance of the non-inverting amplifier circuit?



**Part 4.** Next, we'll make an opamp *integrator*. Ideally, the integrator looks like the circuit drawn below, and $V_{\mathrm{out}} = (\text{-}1/RC) \int V_{\mathrm{in}}(t)\,\mathrm{d}t$. (Do you see why this circuit integrates Vin?)



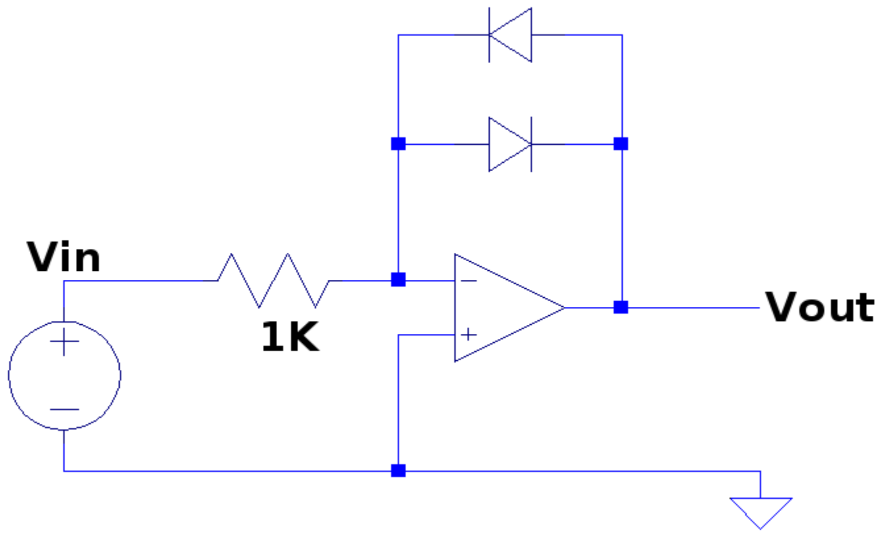

In real life, the lack of a DC feedback path will cause the above circuit to drift fairly quickly into saturation near one rail or the other. One needs either to zero the charge on the capacitor with a switch to start each new integration or to drain the capacitor continuously through a large feedback resistor. Let's do the latter. Build this integrator, with a 100K bleeder resistor. (What is the time constant for draining the capacitor?) Try it out with a number of different input waveforms. Does it integrate?




Question (nothing to build here): If you wanted to make a differentiator instead of an integrator, how would you change this circuit?

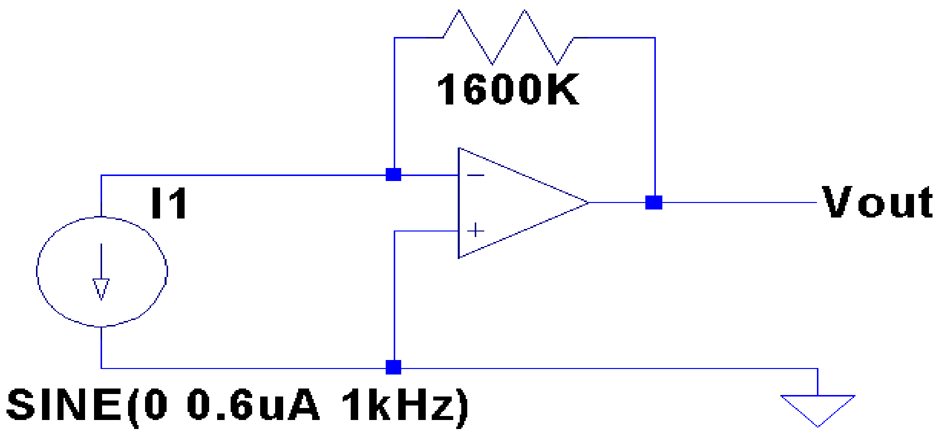
Another question (nothing to build here): Can you look at the integrator circuit (you can omit the bleeder resistor to simplify the math) as a special case of the inverting amplifier, with impedances replacing the resistors in the gain expression? If you do so, what is Vout/Vin for a sine wave? Is this expression equivalent to integrating the sine wave?

**Part 5.** Logarithmic amplifier. (*Check in with Bill or Jose before starting this part, in case any component changes are needed.)* The idea here is to put something unusual (and nonlinear!) into the feedback loop, to illustrate the generality of feedback. Try this circuit with an input waveform that is DC biased, so that it is always positive (or always negative) – for example, a 2Vpp sine wave with a 1V DC offset. See if Vout appears to respond logarithmically. Now try it without the DC offset. Can you make sense of the behavior, from the opamp golden rules and the Shockley diode equation? (Don't work too hard. Just work out roughly what is going on.)



**<u>Part 5.</u>** Current-to-voltage amplifier. *(Check in with Bill or Jose before starting this part, as it requires parts (photodiodes) that we ordered last week, due in this Wednesday.)* When struck by incoming light, a photodiode should look like a very weak current source, emitting current in proportion to detected light. The amplifier drawn below is basically the inverting configuration with R1=0Ω. The current source looks right into a virtual ground, with ~ zero input impedance. Remember that the output of a weak voltage source is preserved by a load having a very large input impedance; conversely, the output of a weak current source is preserved by a load having a very small input impedance. A voltage source prefers to drive an open circuit, while a current source prefers to drive a short circuit.

Using the enormous 1.6M resistor shown below, what is the output of this amplifier for an input current of 0.6 microamps? (Optimal component values will be figured out once the photodiodes arrive.)




The idea, if all goes well, is for you to drive an LED (protected by a resistor) with the function generator, and then to detect that light with the photodiode, whose signal you will amplify and display on the scope. A rough illustration is shown below – though the details remain to be worked out.