Circuits Week 7: Op-Amps

<u>Reading</u>:

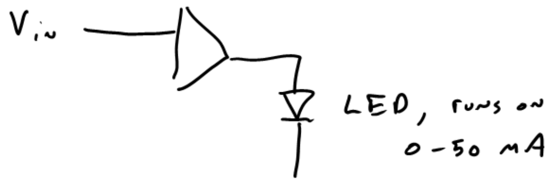
- Read the lab manual first!
  - Horowitz and Hayes, Lab Manual, pp.171, 175-176 (worked examples).
- Solutions to last week's problems (they are a good study guide.)
- Horowitz and Hill, Art of Electronics, 2^{nd} ed., Ch 4:
  - p180 (only – not 181; focus on figs 4.9 and 4.10. Stop <u>*before*</u> "Current sources for loads returned to ground".)
  - pp §4.08, 4.09, skipping , pp182-186 (stop <u>*before*</u> "power booster".)
  - pp 232-234, "Feedback with finite-gain amplifiers"; stop at "Input impedance.")
  - Optional/Advanced:
    - Read 188 – 195, 209-210 on op-amp limitations
  - We will do labs 8-7, 9-1, 9-2, plus possibly some additional material, this week

<u>Exercises</u>:

Due dates:
#1, #2 **Due <u>Thursday</u>** before class:
All the rest **Due Friday**, by 4:30 PM in the box outside my office (1010 Lab I); if you are going to the conference, then the due date is 10AM Monday in the box outside my office.

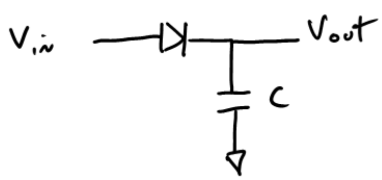
1. A limitation on op-amps is that they can only change output voltage (V_{out}) so fast. That's usually pretty fast, say about 100,000 V/s.
   a. How fast does a signal change? For a voltage $V = V_0 \sin(2\pi f t)$, where V_0 is a constant, what is the <u>*maximum*</u> rate of change of V, in volts/sec?
   b. At what point in the signal V (top? Middle? Bottom? Halfway up?) will the rate of change be largest?
   c. Say your op-amp has a maximum output rate of change of 100,000V/s (known as the "slew rate".)
      i. For a sine wave output with $1.0V_{pp}$ amplitude (pp = "peak to peak"), what is the highest frequency you could use before something bad would happen to the output signal?
      ii. What bad thing would happen, and where would it show up first in the signal?
      iii. For a sine wave output with $10.0V_{pp}$ amplitude, what is the highest frequency you could use before problems would arise?

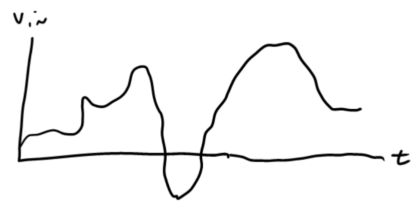
2. Design a circuit, starting with what you see here, that provides 0 – 50mA of current to control an LED. V_{in} = 0 to 5V, so ideally for V_{in} = 0V → 0mA and V_{in} = 5V → 50mA.



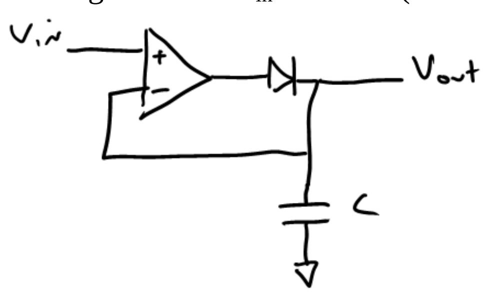
   a. Hints:
      i. How could you get feedback to use (to connect back to the op-amp inputs) that is proportional to the current going through the LED?
      ii. You can assume the op-amp runs from ± 12V supplies, which is plenty to power the LED.

3. What does the following circuit do, assuming V_{in} varies up and down as shown? Be precise – draw V_{out} and V_{in} on the same plot to show any differences.

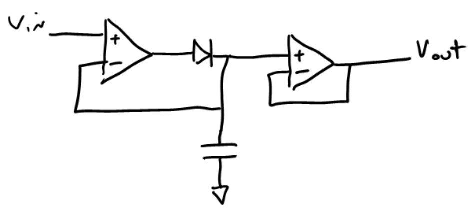




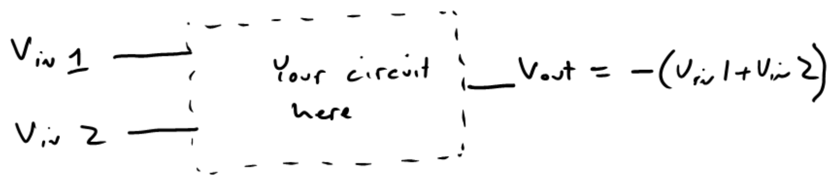
   a. What does this circuit do? On a second plot, draw the output of this circuit Draw the output from it, assuming the same V_{in} as above (draw both on the same plot.)



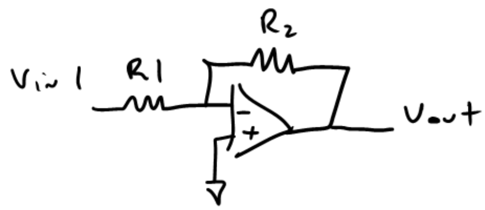
   b. Explain what advantages the following circuit has over the last one. Hint: what happens if you attach an oscilloscope (or other probe) with input impedance R? Be precise about what happens.



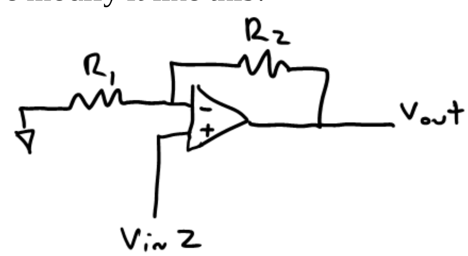
4. We want an "adder circuit", that adds two voltages. It's OK if they are inverted at the output; we can always fix that later. Design an op-amp circuit to do this:



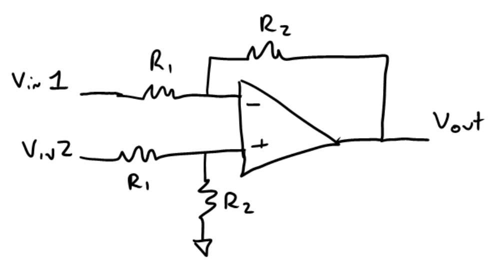
5. Differential amplifier:
   a. What is the output of the following circuit?



   b. What is the output if we modify it like this?



   c. So what is the output of this circuit?



   d. A good example of where you use a circuit like this is in pro audio, where you run both positive and negative versions of the signal from the stage to the mixing board using so-called "balanced" cables. Any interference shows up on BOTH the "+" and the "-" wires, so if you use a differential amplifier to receive the signal at the far end, you cancel all the interference and only get the clean audio signal (at twice the amplitude on either line.) Assuming the R2's are exactly the same, but the R1's are only within 0.01% tolerance (which is really good), what fraction of a "common mode" signal, say, 1V on <u>both</u> V_{in1} and V_{in2}, gets through? This is known as the "CMRR", or the "Common Mode Rejection Ratio", and is the fraction of the interference that will get through. CMRR is usually quoted in dB.