6.200 Circuits and Electronics

Week 6, Lecture A:
Operational Amplifiers

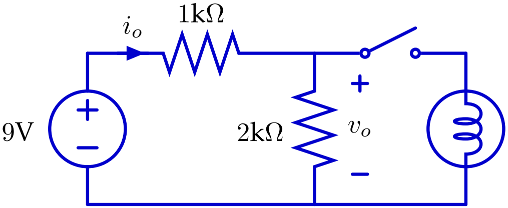
Grab participation sheet by the door.

Midterm: Tuesday after the break (info and review materials on web).

No p-set this week.

Loading

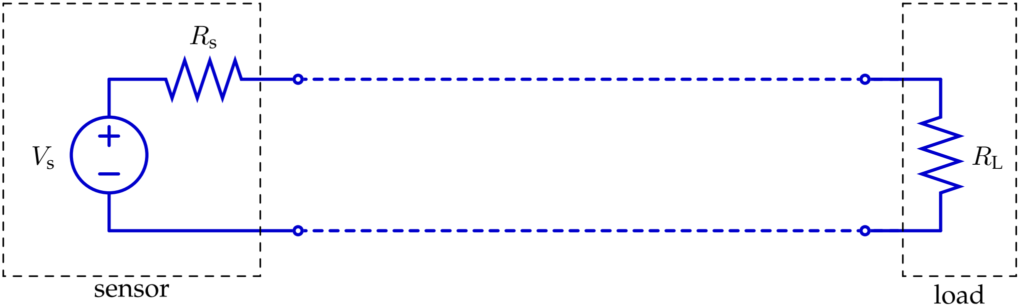
Circuit design is complicated by interactions among the elements. Adding an element changes voltages and current *throughout* the circuit. For example, what happens when the switch is closed in the following circuit (effectively adding the light bulb as a new component)?



0. v_o and i_o stay the same
1. v_o decreases, i_o decreases
2. v_o decreases, i_o increases
3. v_o increases, i_o decreases
4. v_o increases, i_o increases
5. depends on the bulb's resistance

Memories...

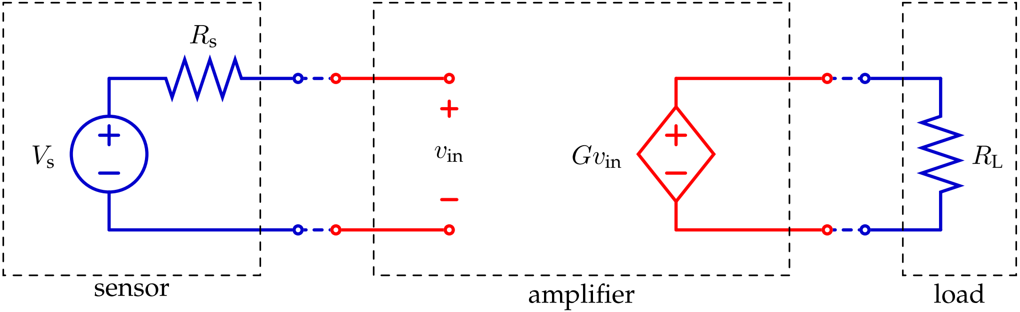
Consider an arbitrary sensor with a small output voltage, driving a load of some kind:



What is the problem here?

Amplifiers

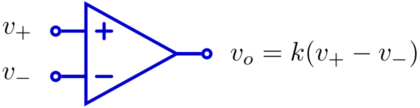
We could resolve this issue by building a circuit that behaves like the following, to isolate the sensor and the load (and also scale up the sensor's voltage):

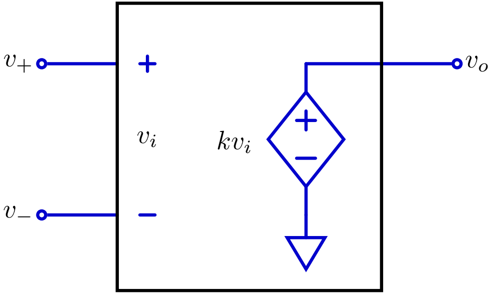


Goals: $v_{\text{load}} = G \times V_s$, where G is adjustable and reliable

Operational Amplifiers

An operational amplifier ("op-amp") can be modeled* as a voltage-controlled voltage source, where k is intentionally large (typically $\sim 10^5 - 10^7$):

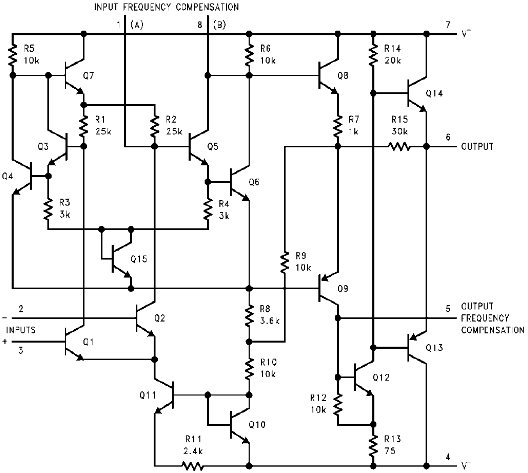




* sometimes

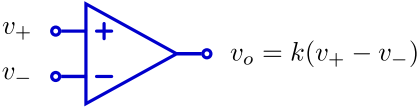
Operational Amplifiers

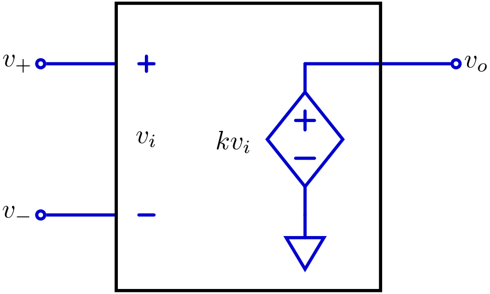
What's *actually* in an op-amp? Here is a more accurate circuit model of a μA709 op-amp:



But that's a pain...

Characterizing an Op-amp (VCVS Model)





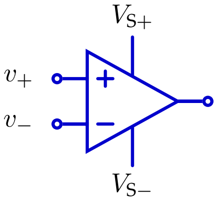
$$v_o = k(v_+ - v_-)$$
$$i_+ = i_- = 0$$

Sketch a graph of v_o versus $(v_+ - v_-)$

Supply Rails

Op-amps derive power from connections to a power supply, and the output voltage is typically constrained by that power supply:

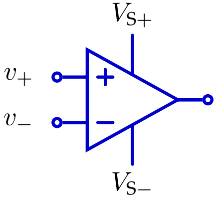
$$V_{\mathsf{S}-} < v_o < V_{\mathsf{S}+}$$



$$v_o = \begin{cases} V_{\mathsf{S}+} & \text{if } k(v_+ - v_-) > V_{\mathsf{S}+} \quad \text{(positive saturation region)} \\ V_{\mathsf{S}-} & \text{if } k(v_+ - v_-) < V_{\mathsf{S}-} \quad \text{(negative saturation region)} \\ k(v_+ - v_-) & \text{otherwise} \quad \text{(linear region)} \end{cases}$$

Op-Amps as Comparators

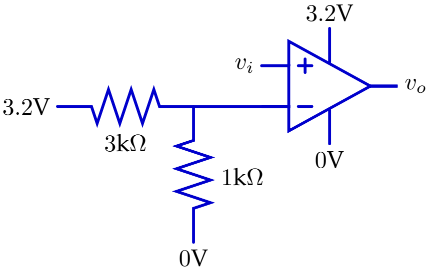
Other than the (tiny) range of $v_+ - v_-$ values where we're operating in the linear region, the op-amp's output voltage will be forced to one or the other of the supply rails, so the op-amp naturally behaves as a comparator:



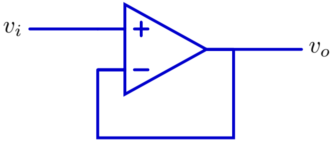
$$v_o = \begin{cases} V_{S+} & \text{if } k(v_+ - v_-) > V_{S+} \quad \text{(positive saturation region)} \\ V_{S-} & \text{if } k(v_+ - v_-) < V_{S-} \quad \text{(negative saturation region)} \\ k(v_+ - v_-) & \text{otherwise} \quad \text{(linear region)} \end{cases}$$

Under (approximately) what conditions is the output equal to V_{CC}?
Under (approximately) what conditions is the output equal to V_{EE}?

Check Yourself



Check Yourself



Check Yourself