ECE 207 - OP AMP CIRCUITS - INVESTIGATION 7
POSITIVE GAIN OP AMP CIRCUITS

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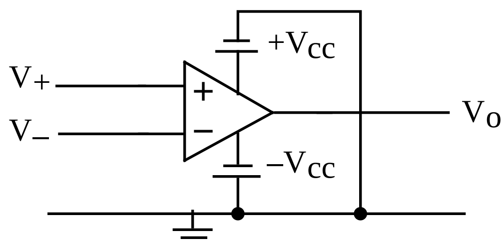
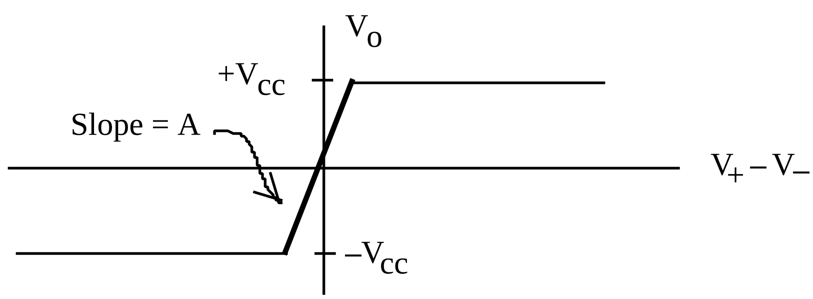
To do "well" on this investigation you must not only get the right answers but must also do neat, complete and concise writeups that make obvious what each problem is, how you're solving the problem and what your answer is. You also need to include drawings of all circuits as well as appropriate graphs and tables.

The objective of this and the next investigation is to apply our results on controlled sources to the analysis of operation amplifier circuits. **Operation amplifiers** (op amps) are extremely useful voltage amplifiers commonly available as integrated circuits with symbols as follows



Op amps (powered by DC supplies $+V_{CC}$ and $-V_{CC}$ that are typically on the order of 15 volts) are voltage amplifiers characterized by transfer characteristics as follows

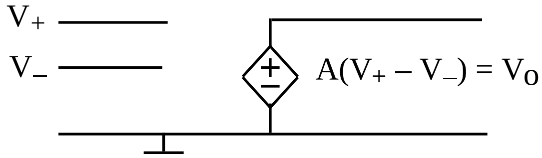


where the output voltage V_O is a function of the **difference** $(V_+ - V_-)$ between the two inputs V_+ and V_-. As a result of this we refer to op amps as **differential** voltage amplifiers.

The overall voltage transfer characteristics of op amps are clearly not linear but as we can see from the above curve, V_O and $(V_+ - V_-)$ are linearly related with

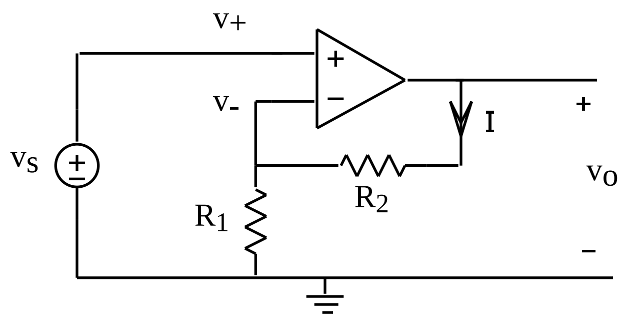
$$V_O = A\left(V_+ - V_-\right)$$

when $(V_+ - V_-)$ is sufficiently small - in which case the op amp can be modeled by an ideal voltage controlled voltage source as follows



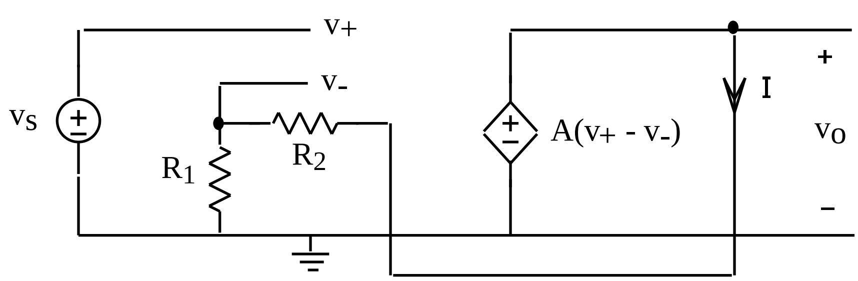
We then say our op amp is **operating** in its **linear region**. Note that no current can flow into the + or – terminals of our ideal op amp model. This is a reasonable approximation to real op amps because they typically have equivalent input resistances of at least 200M.

We look at op amps in some depth because they are very useful building blocks in many applications. The objective of this investigation is to learn about the basic positive gain op amp circuit as follows



We call this a positive gain amplifier because, as we will show, v_S is equal to a positive constant times v_S. Note that we usually don't draw in the power supplies when we draw op amp circuits.

1. The objective of this first problem is to calculate V_O in an example where the op amp is operating in its linear active region with $v_S = 2$ volts, $R_1 = 1K$, $R_2 = 2K$ and $A = 10^5$
   a. Draw the corresponding positive gain op amp circuit
   b. Redraw your circuit in part (a) with the op amp replaced by its linear equivalent circuit as follows



   c. From inspection of the equivalent circuit in part (b) we see that the value of v_- at the input to the op amp depends on v_O. And so we see that v_O "plays a role" in determining its own value. This is an example of what we refer to as **feedback**. We also see that the larger A, the larger v_O and so the larger v_-. And so the smaller the op amp input $(v_+ - v_-)$. Writing out the equations we have

$$V_o = A(V_+ - V_-) = A\left(V_s - \frac{R_1}{R_1 + R_2}V_o\right)$$

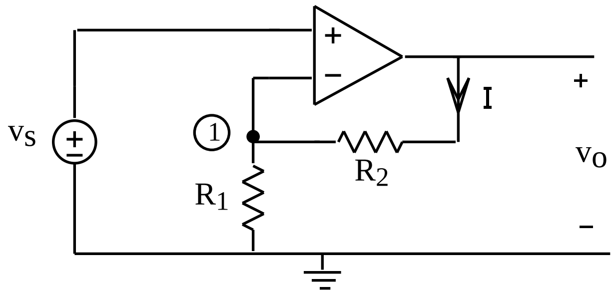
   Make use of this equation to find V_O.
   d. Make use of your result in part (c) to find the voltage gain $G = V_O/V_S$
   e. Make use of your result in part (c) to find the differential input $(V_+ - V_-)$

2. From Problem (1) we see that when a positive gain op amp circuit is operating in its linear

active region and the op amp itself has a large gain A as it does for real op amps with gains on the order of 10^5 then

$$V_+ - V_- \approx 0$$

and so for all practical purposes we can assume $V_+ = V_-$ when writing our circuit analysis equations. The objective of this problem is to make use of this result to show that voltages and currents like V_o and I in positive gain op amp circuits as follows

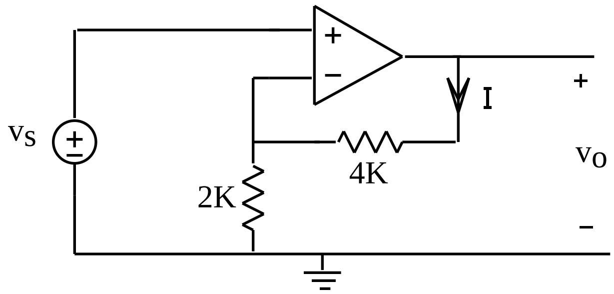


are independent of the op amp gain A when the op amp is operating in its linear active region. This is particularly nice because it means that A is not a critical parameter - all A has to do is be large. This is nice because it makes op amps easier and cheaper to build.

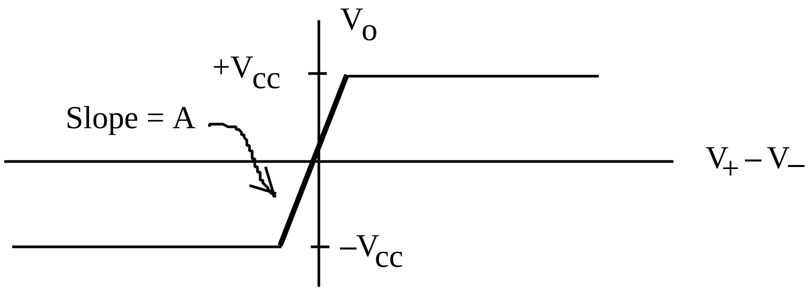
a. Find I as a function of V_s and the resistors assuming A is large
b. Find $G = V_o/V_s$ assuming A is large by simply writing the node equation at node 1

3. Given the positive gain op amp circuit of Problem (2)
   a. Sketch I as a function of R_1
   b. Sketch I as a function of R_2
   c. Sketch V_o as a function of R_1
   d. Sketch V_o as a function of R_2

4. Up to now we've been working with positive gain op amp circuits like the following



operating in their linear active regions. From the op amp transfer characteristic



we see that the op amp will go into **saturation** - will reach its maximum value - when V_O reaches the value of V_{CC}. The way to determine if an op amp is in saturation is to simply calculate its output voltage assuming the op amp is operating in its linear active region and see what you get. If the linear model predicts $V_O \geq V_{CC}$ then the op amp is in saturation with $V_O = V_{CC}$. Otherwise it's operating in its linear active region. Assuming $V_{CC} = 15$ volts

a. Find V_O when $V_S = 4$ volts. Is the op amp in saturation.
b. Find V_O when $V_S = 6$ volts. Is the op amp in saturation.
c. Sketch $v_O(t)$ when $v_S(t) = 4 \cos(2\pi\, 1000t)$
d. Sketch $v_O(t)$ when $v_S(t) = 6 \cos(2\pi\, 1000t)$

5. Math Review - sketch the following signal

$$v(t) = \begin{cases} 5 - 5e^{-1000t} & 0 \leq t \leq 3 \text{ msec} \\ 4.75e^{-1000(t-0.003)} & t \geq 3 \text{ msec} \end{cases}$$