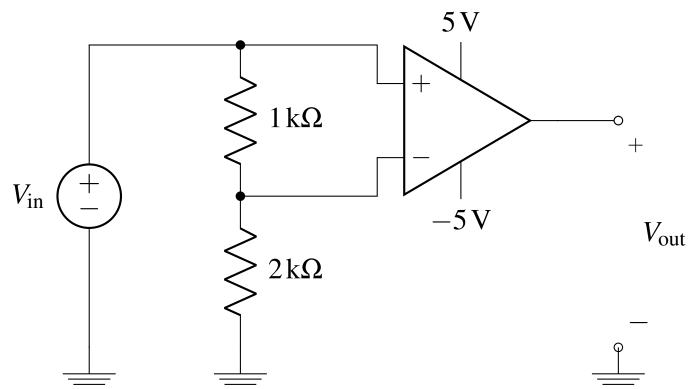
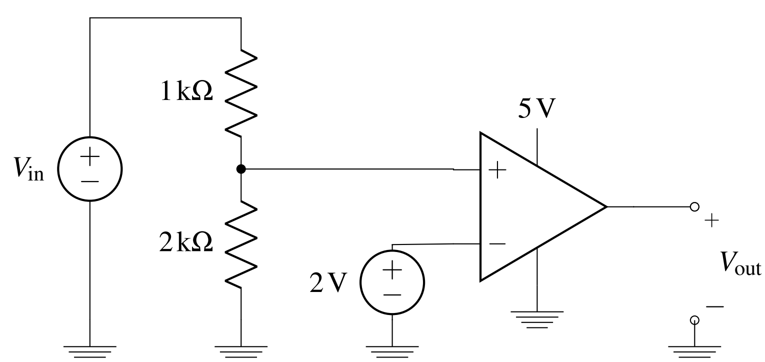
1. **Op-Amps As Comparators**

   For each of the circuits shown below, plot V_{out} for V_{in} ranging from -10 V to 10 V for part (a) and from 0 V to 10 V for part (b). Let $A = 100$ for your plots.

   (a)

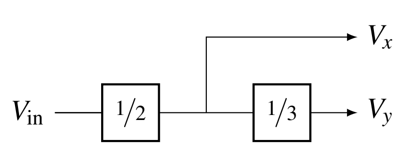


   (b)



2. **Modular Circuits**

   In this problem, we will explore the design of circuits that perform a set of (arbitrary) mathematical operations. (Note that the so-called analog signal processing – where these kinds of mathematical operations are performed on continuously-valued voltages by analog circuits – is extremely common in real-world applications; without this capability, essentially none of our radios or sensors would actually work.) Specifically, let's assume that we want to implement the block diagram shown below:



In other words, we want to implement a circuit with two outputs V_x and V_y, where $V_x = \frac{1}{2}V_{\text{in}}$ and $V_y = \frac{1}{3}V_x$.

(a) Design two voltage divider circuits that each independently would implement the two multiplications shown in the block diagram above (i.e., multiply by 1/2 and multiply by 1/3). Note that you do not need to include the input voltage sources in your design – you can simply define the input to each block as being at the appropriate potential (e.g., V_{in} or V_x).

(b) Assuming that V_{in} is created by an ideal voltage source, implement the original block diagram as a circuit by directly replacing each block with the designs you came up with in part (a).

(c) For the circuit from part (b), do you get the desired relationship between V_y and V_x? How about between V_x and V_{in}? Be sure to explain why or why not each block retains its desired functionality.

(d) Now let's assume that we have discovered compose-able circuits that implement mathematical operations. In particular, we have these blocks that implement:

i. $V_o = 5V_i$

ii. $V_o = -2V_i$

iii. $V_o = V_{i_1} + V_{i_2}$

Using just these blocks, draw the block diagram that implements:

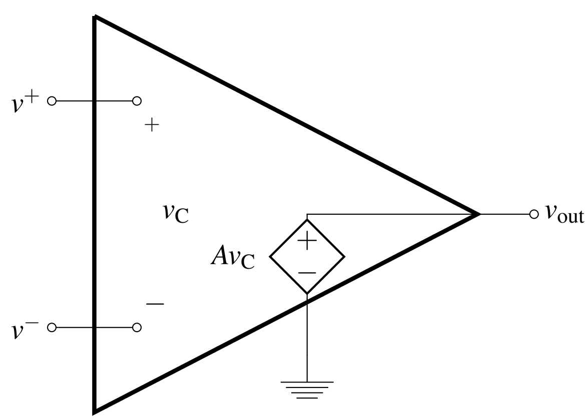
i. $V_o = -12V_{\text{in}_1}$

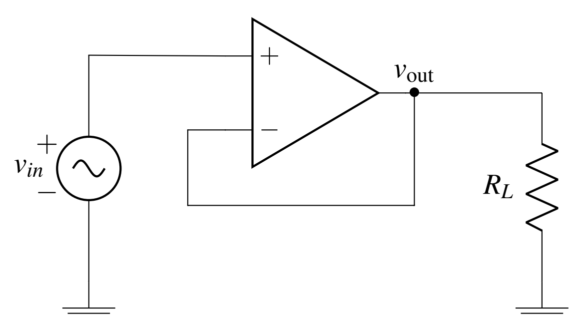
ii. $V_o = -10V_{\text{in}_1} - 2V_{\text{in}_2}$

iii. $V_o = -V_{\text{in}_1} + V_{\text{in}_2}$

3. Op-Amp Golden Rules

On the left is the equivalent circuit of an op-amp for reference.





(a) What are the currents flowing into the positive and negative terminals of the op-amp (i.e., what are I^+ and I^-)? What are some of the advantages of your answer with respect to using an op-amp in your circuit designs?

(b) Suppose we add a resistor of value R_L between v_{out} and ground. What is the value of v_{out}? Does your answer depend on R_L? In other words, how does R_L affect Av_C? What are the implications of this with respect to using op-amps in circuit design?

(c) Now consider the circuit on the right. Assuming that this is an ideal op-amp, what is v_{out}?

(d) Draw the equivalent circuit for this op-amp and calculate v_{out} in terms of A, v_{in}, and R_L. Does v_{out} depend on R_L? What is v_{out} in the limit as $A \to \infty$?