1. Op-Amps As Comparators

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

(a)

![Circuit Diagram for Part A](image)

(b)

![Circuit Diagram for Part B](image)

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:

![Block Diagram for Modular Circuits](image)
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 \( \frac{1}{2} \) and multiply by \( \frac{1}{3} \)). 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., \( V_{\text{in}} \) or \( V_x \)).

(b) Assuming that \( V_{\text{in}} \) 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 \( V_{\text{in}} \)? 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. \( V_o = 5 V_i \)

ii. \( V_o = -2 V_i \)

iii. \( V_o = V_{i_1} + V_{i_2} \)

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

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

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

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 \( v_{\text{out}} \) and ground. What is the value of \( v_{\text{out}} \)? Does your answer depend on \( R_L \)? In other words, how does \( R_L \) affect \( A_{\text{in}} \)? 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 \( v_{\text{out}} \)?

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