1. Op-Amp Rules

Here is an equivalent circuit of an op-amp (where we are assuming that $V_{SS} = -V_{DD}$) for reference:

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

(b) Suppose we add a resistor of value $R_L$ between $u_{out}$ 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?

For the rest of the problem, consider the following op-amp circuit in negative feedback:

(c) 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 $R_L$ for the circuit in negative feedback. Does $v_{out}$ depend on $R_L$? What is $v_{out}$ in the limit as $A \rightarrow \infty$?
2. Modular Circuit Buffer

Let’s try designing circuits that perform a set of mathematical operations using op-amps. While voltage dividers on their own cannot be combined without altering their behavior, op-amps can preserve their behavior when combined and thus are a perfect tool for modular circuit design. We would like to implement the block diagram shown below:

In other words, create a circuit with two outputs \( V_x \) and \( V_y \), where \( V_x = \frac{1}{2} V_{in} \) and \( V_y = \frac{1}{3} V_x = \frac{1}{6} V_{in} \).

(a) Draw two voltage dividers, one for each operation (the 1/2 and 1/3 scalings). What relationships hold for the resistor values for the 1/2 divider, and for the resistor values for the 1/3 divider?

(b) If you combine the voltage dividers, made in part (a), as shown by the block diagram (output of the 1/2 voltage divider becomes the source for the 1/3 voltage divider circuit), do they behave as we hope (meaning \( 6V_{in} = 3V_x = V_y \))?

HINT: The following circuit and formula may be handy:

\[
V_{out} = \left( \frac{1}{2 + \frac{R_x}{R_y}} \right) V_{in}
\]

(c) Perhaps we could use an op-amp (in negative-feedback) to achieve our desired behavior.

Modify the implementation you tried in part (b) using a negative feedback op-amp in order to achieve the desired \( V_x, V_y \) relations \( V_x = (1/2)V_{in} \) and \( V_y = (1/3)V_x = (1/6)V_{in} \).

HINT: Place the op-amp in between the dividers such that the \( V_x \) node is an input into the op-amp, while the source of the 2nd divider is the output of the op-amp!