Learning Objectives
1. Modular design and loading → Demo (if time)
2. Op amp design

Music
1. Prep - Who's got you singing again
2. Tyler - See you again
3. Sure Sure - Funky

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## Reference: Op-Amp Example Circuits

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<td>Unity Gain Buffer</td>
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1. 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 $V_x = \frac{1}{2} V_{\text{in}}$ and $V_y = \frac{1}{3} V_x = \frac{1}{6} V_{\text{in}}$.

(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?

\[ \frac{R_1}{R_1 + R_2} \cdot V_{\text{in}} = \frac{1}{2} V_{\text{in}} \]
\[ V_y = \frac{1}{6} V_x \]
\[ \frac{R_4}{R_3 + R_4} = \frac{1}{3} \]
\[ 3R_4 = R_3 + R_4 \]
\[ 2R_4 = R_3 \]
\[ R_4 = 2200 \Omega \]

\[ R_1 = \frac{R_2}{2} \]
\[ R_1 + R_2 = 2R_2 \]
\[ R_1 = 1 \Omega \]
\[ R_2 = 1 \Omega \]
(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:
(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!
2. Modular Op-Amp Circuits

Let’s expand our toolbox of op-amp circuits that perform mathematical operations by designing blocks that implement the following operations:

(a) Scale the input voltage so that: \( V_{\text{out}} = +5 \, V_{\text{in}} \)
(b) Scale and invert the input voltage so that: \( V_{\text{out}} = -2 \, V_{\text{in}} \)
(c) Sum two input voltages together so that: \( V_{\text{out}} = V_{\text{in}_1} + V_{\text{in}_2} \)

Use the reference above for help!
Would connecting any of these blocks together modify their intended functionality?