EECS16A DIS 11A

Learning Objectives

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

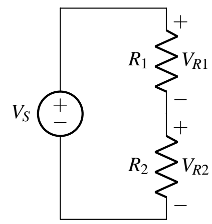
Music

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

EECS 16A Designing Information Devices and Systems I
Fall 2020 Discussion 11A

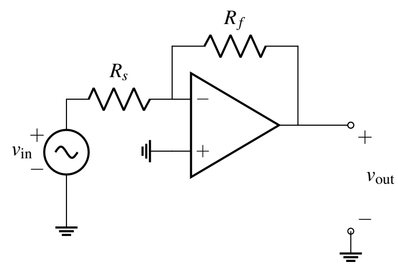
Reference: Op-Amp Example Circuits

Voltage Divider



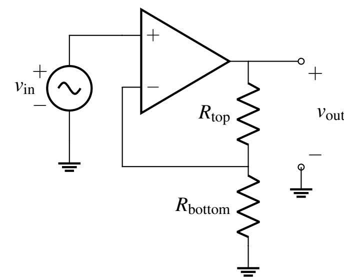
$$V_{R_2} = V_S\left(\frac{R_2}{R_1+R_2}\right)$$

Inverting Amplifier



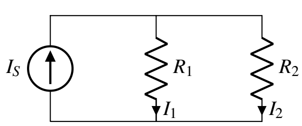
$$v_{out} = v_{in}\left(-\frac{R_f}{R_s}\right)$$

Noninverting Amplifier



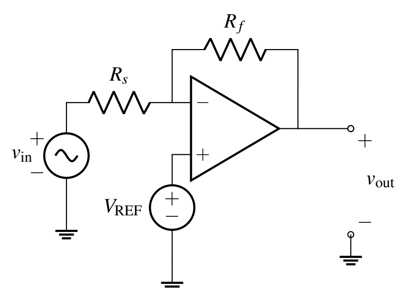
$$v_{out} = v_{in}\left(1+\frac{R_{top}}{R_{bottom}}\right)$$

Current Divider



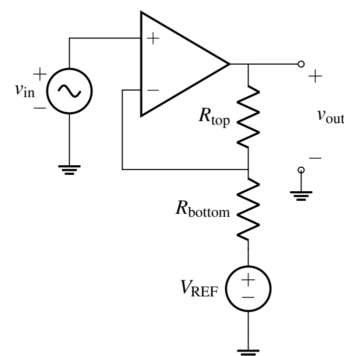
$$I_1 = I_S\left(\frac{R_2}{R_1+R_2}\right)$$

Inverting Amplifier with Reference



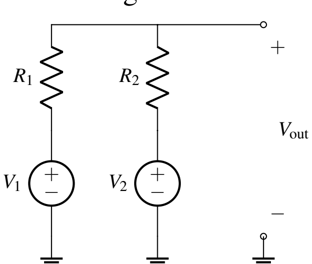
$$v_{out} = v_{in}\left(-\frac{R_f}{R_s}\right)+V_{REF}\left(\frac{R_f}{R_s}+1\right)$$

Noninverting Amplifier with Reference



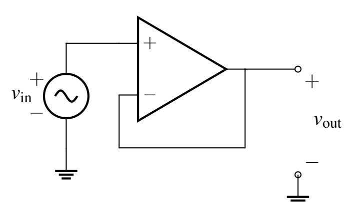
$$v_{out} = v_{in}\left(1+\frac{R_{top}}{R_{bottom}}\right)-V_{REF}\left(\frac{R_{top}}{R_{bottom}}\right)$$

Voltage Summer



$$V_{out} = V_1\left(\frac{R_2}{R_1+R_2}\right)+V_2\left(\frac{R_1}{R_1+R_2}\right)$$

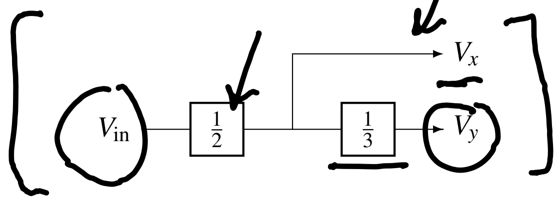
Unity Gain Buffer



$$v_{out} = v_{in}$$

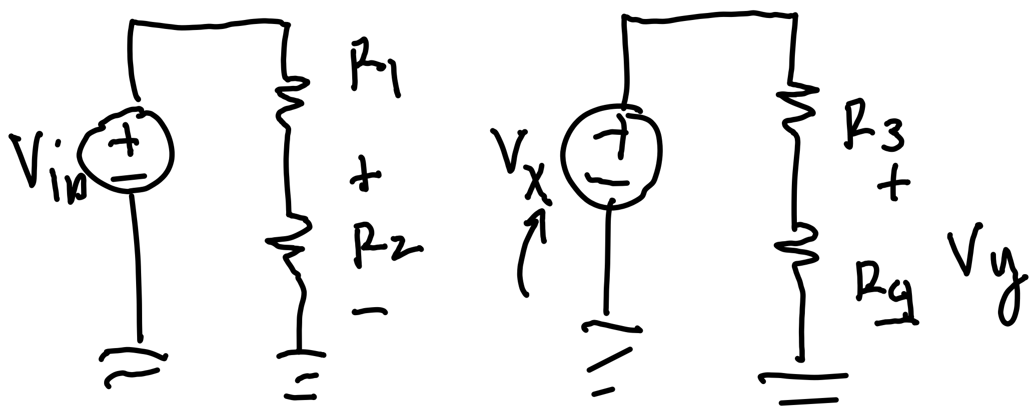
1. Modular Circuit Buffer

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 $V_x = \frac{1}{2}V_{in}$ 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?



Want ⇒ $\frac{1}{2} V_{in}$

$V_y = \frac{1}{3} V_x$

$\frac{R_2}{R_1+R_2} V_{in}$

$\frac{R_4}{R_3+R_4} = \frac{1}{3}$

$\frac{1}{2} = \frac{R_2}{R_1+R_2}$

$3R_4 = R_3 + R_4$

$R_1 + R_2 = 2R_2$

$2R_4 = R_3$

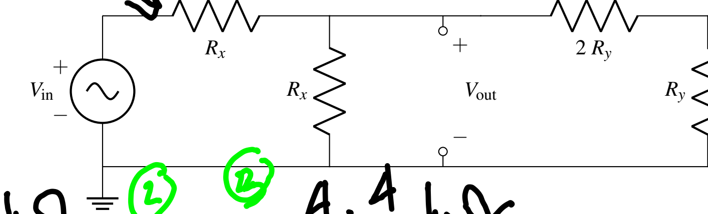
$R_1 = R_2$ $\quad R_1 = 1k\Omega$

$R_4 = 2200\Omega$

(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 $6V_{\text{in}} = 3V_x = V_y$)?

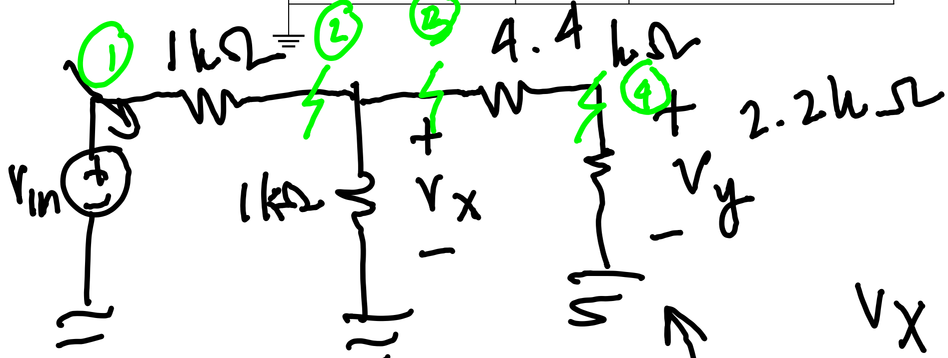
HINT: The following circuit and formula may be handy:

$$V_{\text{out}} = \left(\frac{1}{2 + \frac{R_x}{3R_y}}\right) V_{\text{in}}$$

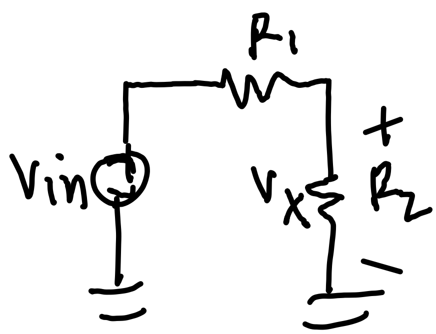


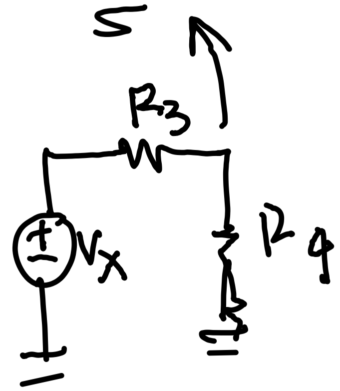
$R_x = 1\text{k}\Omega$

$R_y = 2.2\text{k}\Omega$



$V_x = \boxed{0.46} V_{in}$



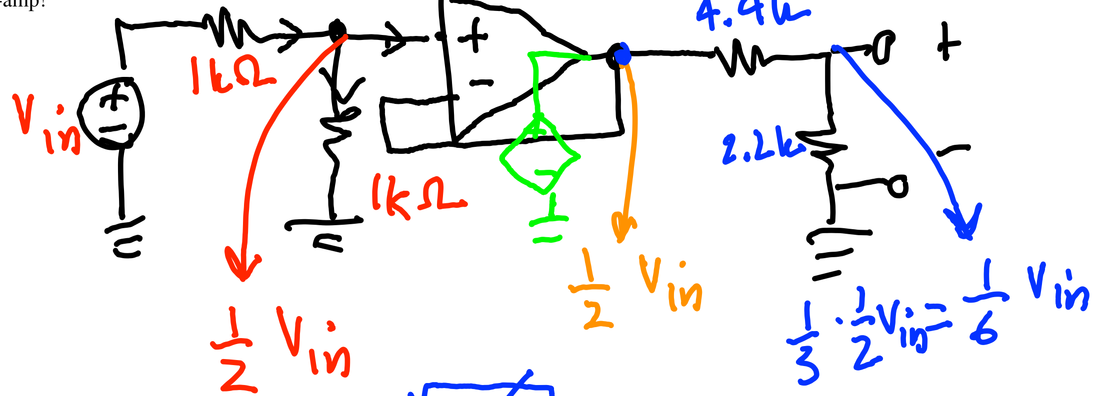


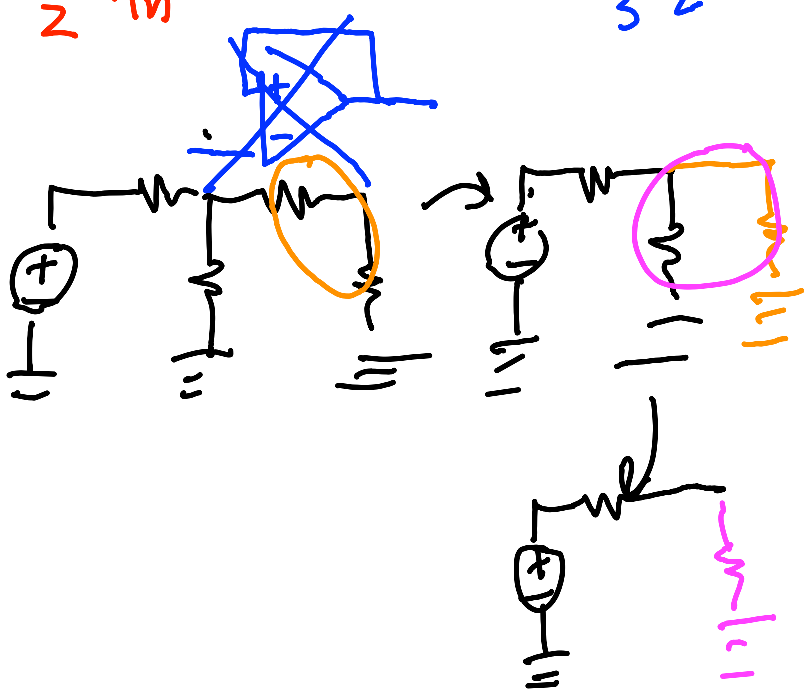
Want

$V_x = \frac{1}{2} V_{in}$

(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 $V_x = (1/2)V_{\text{in}}$ and $V_y = (1/3)V_x = (1/6)V_{\text{in}}$.

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

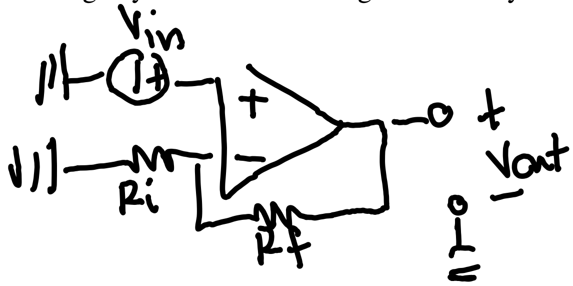
(a) Scale the input voltage so that: $V_{\text{out}} = +5\,V_{\text{in}}$

(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?

a

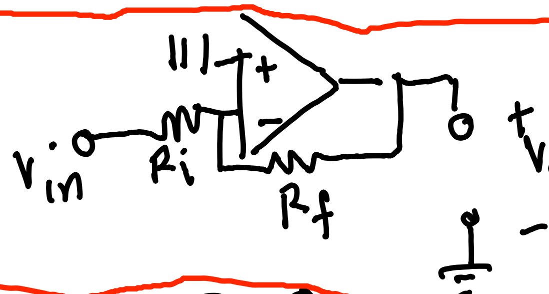


$\frac{R_f}{R_i} = 4$ $R_i = 1\,\Omega$

$V_{out} = \left(1 + \frac{R_f}{R_i}\right) V_{in}$

$R_f = 4 R_i \Leftarrow R_f = 4\,\Omega$

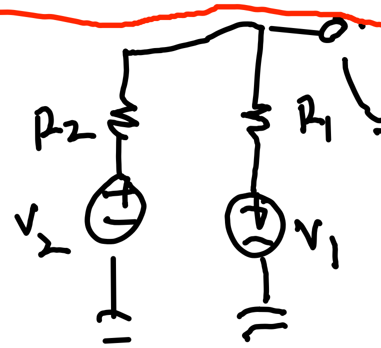
b



$V_{out} = -\frac{R_f}{R_i} V_{in}$

$R_f = 2 R_i$

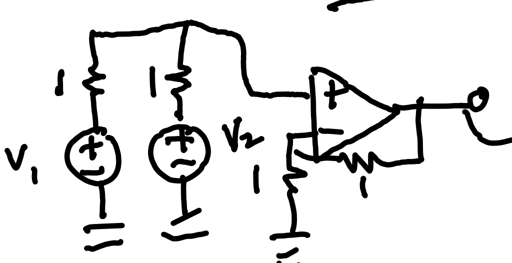
c



$V_{out} = \frac{R_2}{R_1 + R_2} V_1 + \frac{R_1}{R_2 + R_1} V_2$ → non inv. amp

$\frac{1}{2} V_1 + \frac{1}{2} V_2$

$\left(1 + \frac{R_f}{R_i}\right) = 2$



$V_{out} = V_1 + V_2$