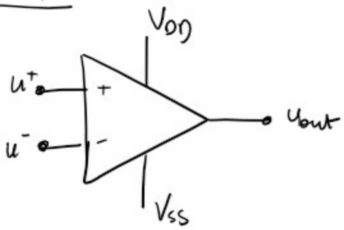
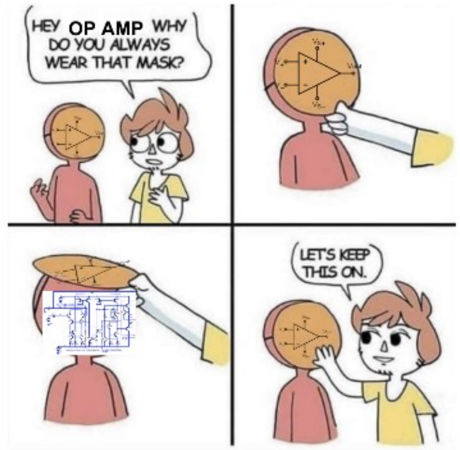
Dis 9B EECS16A

tinyurl.com/miyuki-feedback

Op Amps

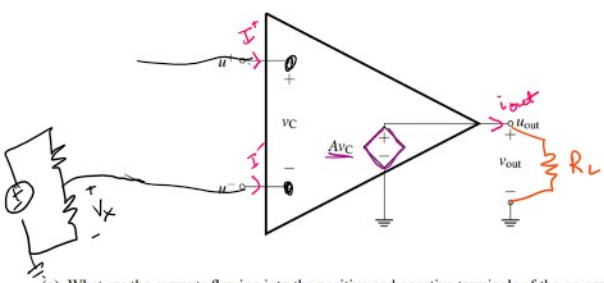


complex circuit that we analyze using an equivalent circuit



1. Op-Amp Rules and Negative Feedback Rules

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

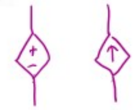


* dependent source

↓

depend on other voltages or currents in the circuit with a gain

↳ scalar multiplier



(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?

$I^+ = I^- = 0$ * because open circuits @ u^+, u^-

useful because it doesn't load a circuit connected to the nodes u^+, u^-

* won't change our circuit

(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 $A v_C$? What are the implications of this with respect to using op-amps in circuit design?

$V_{out} = A v_C$

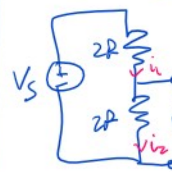
↑ doesn't depend on R_L

* i_{out} does depend on R_L

* useful because V_{out} won't change no matter what we load it with

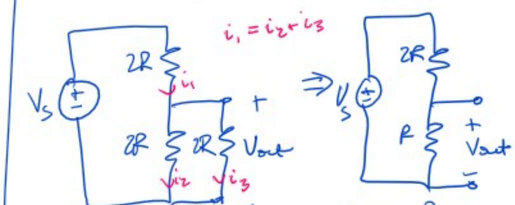
Loading a circuit

$i_1 = i_2$



$V_{out} = \frac{2R}{2R+2R} V_s = \frac{1}{2} V_s$

$i_1 = i_2 + i_3$



$V_{out} = \frac{R}{2R+R} V_s$
$= \frac{1}{3} V_s \neq \frac{1}{2} V_s$

* loading means connecting your circuit to another circuit that will draw a current and change the original circuit's behavior

Negative Feedback

feedback: output is fed back into the input
(V_{out}) (u^+, u^-)

negative feedback: feedback ↑ output ↓

* most op amp problems in this course are in neg feedback

* can typically assume it's in neg feedback when V_{out} is somehow connected to u^-

Ideal Op Amp in Neg Feedback

can use the golden rules

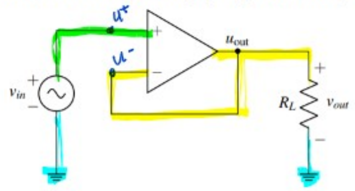
① $I^+ = I^- = 0$ * applies all the time

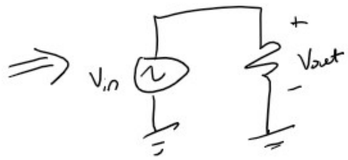
② $u^+ = u^-$

* ideal: $A \to \infty$

↳ don't use dependent source model

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}?

$u^- = u_{out} = V_{out}$

$u^+ = V_{in}$

* golden rule #2: $u^+ = u^-$

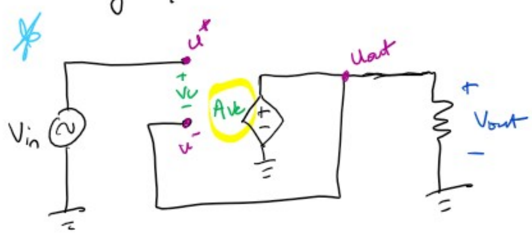
$u^+ = u^-$

$$\boxed{V_{out} = V_{in}}$$

* doesn't depend on R_L

(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 $A \to \infty$?

using equivalent circuit:



$V_{out} = u_{out} - 0$

$= Av_c$

$= A(v_{in} - V_{out})$

$v_c = u^+ - u^-$

$= V_{in} - u_{out}$

$= V_{in} - V_{out}$

$V_{out} + AV_{out} = AV_{in}$

$V_{out}(1 + A) = AV_{in}$

$$\boxed{V_{out} = \frac{A}{1+A} V_{in}}$$

← non ideal

ideal: $A \to \infty$

$$\lim_{A\to\infty} V_{out} = \lim_{A\to\infty}\left(\frac{A}{1+A}V_{in}\right) = \lim_{A\to\infty}\left(\frac{1}{\underbrace{\cancel{\tfrac{1}{A}}}_{0}+1}v_{in}\right)$$

$$\boxed{V_{out} = V_{in}}$$

← ideal! consistent w/ part c

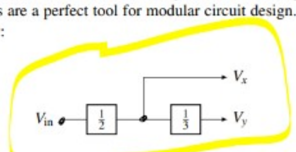
* if $u^+ = u^-$

$v_c = 0$

$V_{out} = Av_c = \infty \cdot 0$

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:

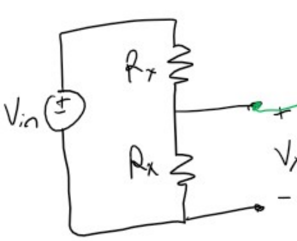


In other words, create a circuit with two outputs V_x and V_y, where $V_x = \frac{1}{2}V_{in}$ and $V_y = \frac{1}{3}V_x = \frac{1}{6}V_{in}$.

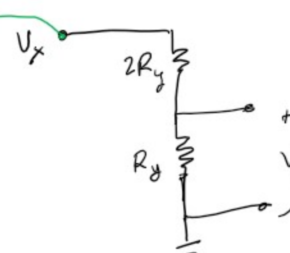
(a) Draw two voltage dividers, one for each operation (the 1/2 and 1/3 scalings). What relationships hold for the resistor values for the 1/2 divider, and for the resistor values for the 1/3 divider?

$V_{in} \longrightarrow \boxed{\tfrac{1}{2}} \longrightarrow V_x$

$V_x \longrightarrow \boxed{\tfrac{1}{3}} \longrightarrow V_y$



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

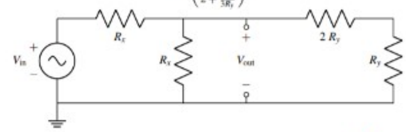


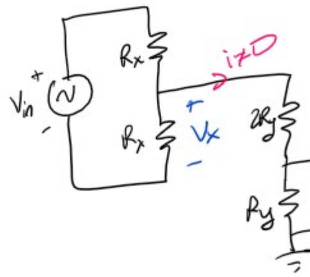
$V_y = \frac{R_y}{2R_y + R_y} V_x = \frac{1}{3} V_x$

(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 $V_y = \frac{1}{3}V_x = \frac{1}{6}V_{in}$)?

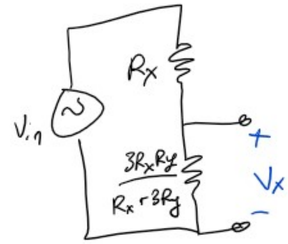
HINT: The following circuit and formula may be handy:

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





series parallel equivalence ⇒



$$V_x = \frac{\frac{3R_xR_y}{R_x+3R_y}}{R_x+\frac{3R_xR_y}{R_x+3R_y}}V_{in} = \left(\frac{1}{\frac{R_x}{3R_y}+2}\right)V_{in} \neq \frac{1}{2}V_{in}$$

$$V_y = \frac{R_y}{2R_y+R_y}V_x = \frac{1}{3}V_x = \frac{1}{3}\left(\frac{1}{\frac{R_x}{3R_y}+2}\right) \neq \frac{1}{6}V_{in}$$

* do not acheive desired effect because of loading

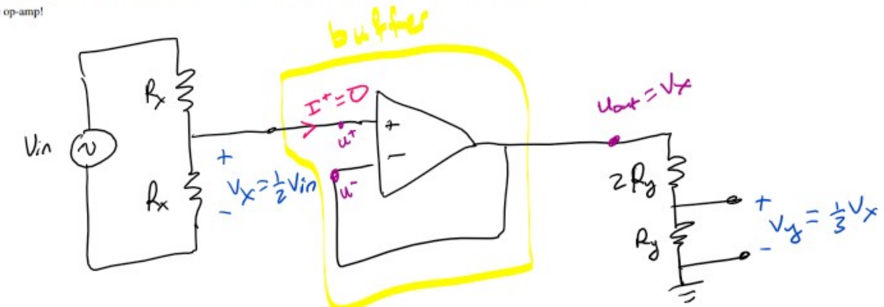
(c) Perhaps we could use an op-amp (in negative-feedback) to achieve our desired behavior. Modify the implementation you tried in part (b) using a negative feedback op-amp in order to achieve the desired V_x, V_y relations $V_x = (1/2)V_{in}$ and $V_y = (1/3)V_x = (1/6)V_{in}$.

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!

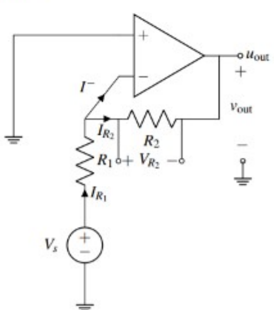
assume ideal neg feedback

→ $u^+ = u^-$

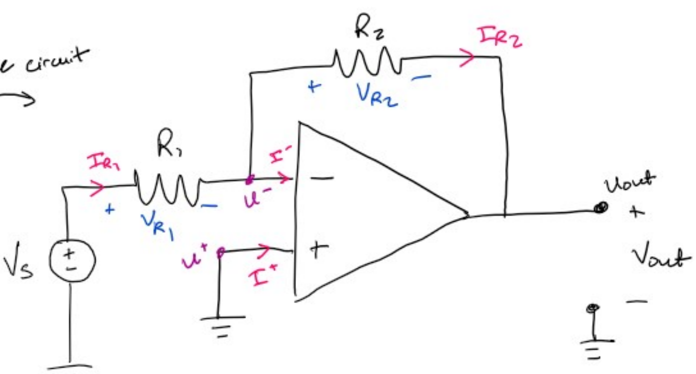
$V_x = u_{out}$



3. (Practice) An Inverting Amplifier



same circuit →



Calculate v_{out} as a function of V_s and R_1 and R_2.

* assume ideal negative feedback? yes!

→ can use golden rules

1. $u^+ = u^-$
2. $I^+ = I^- = 0$

$u^+ = 0 \rightarrow u^- = 0$

KCL @ u^-: $I_{R_1} = I_{R_2} + \cancel{I^-}^{0}$

Ohm's Law: $I_{R_1} = \frac{V_{R_1}}{R_1} = \frac{V_s - u^-}{R_1} = \frac{V_s}{R_1}$

$I_{R_2} = \frac{V_{R_2}}{R_2} = \frac{u^- - V_{out}}{R_2} = \frac{-V_{out}}{R_2}$

Solve: $I_{R_1} = I_{R_2}$

$\frac{V_s}{R_1} = \frac{-V_{out}}{R_2}$

$$\boxed{V_{out} = -\frac{R_2}{R_1}V_s}$$