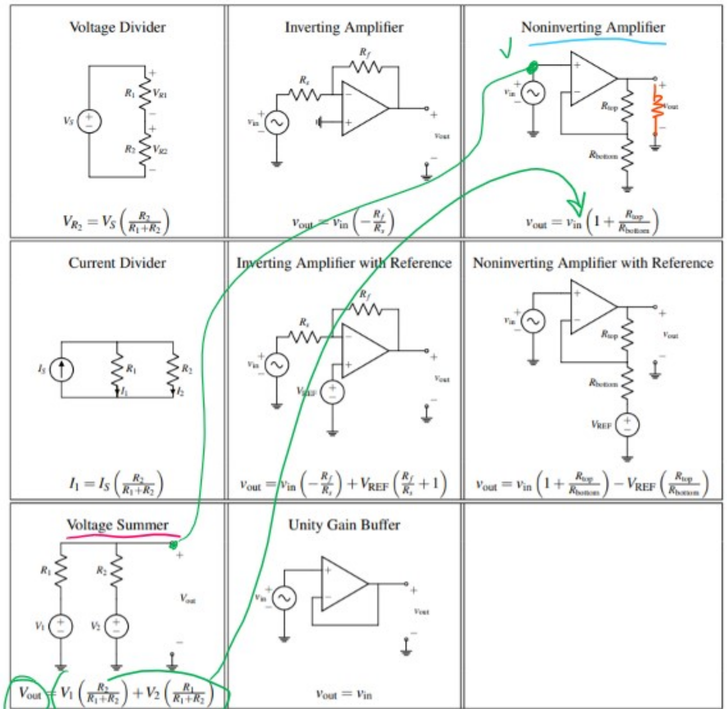
Dis 10A EECS16A

tinyurl.com/miyuki-feedback

Reference Circuits



$$V_o = \left(V_1\left(\frac{R_2}{R_1+R_2}\right) + V_2\left(\frac{R_1}{R_1+R_2}\right)\right)\left(1+\frac{R_t}{R_b}\right)$$

1. Testing for Negative Feedback

While it is tempting to say "if the feedback voltage is connected to the negative op-amp terminal, then we have negative feedback," this is not always true. Here is a two-step procedure for determining if a circuit is in negative feedback:

① • **Step 1: Zero out all** input **independent sources**, replacing voltage sources with wires and current sources with opens as we did in superposition. You do not need to zero out the voltage sources that serve as the power supplies to the op-amp, since they are not treated as signals and almost considered part of the op-amp.

turn off sources

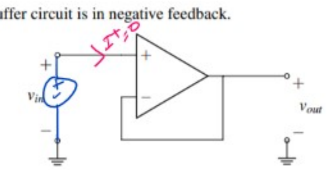
② • **Step 2: Wiggle the output and check the loop**. The goal is to see how the feedback loop responds to a change. Assume that the output increases slightly. Check the direction of change of the feedback signal and the error signal from the circuit. Any change in the error signal will cause a new change in the output. This change is the feedback loop's response to the initial change.

  – If the error signal decreases, then the output must also decrease. This is the *opposite direction* we initially assumed, i.e. the loop is trying to correct for the change. So the circuit is in negative feedback.

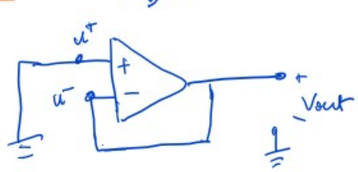
  – If the error signal instead increased, then the output would also increase. This is the *same direction* we initially assume, i.e. the initial increase lead to further increase. We call this positive feedback.

(a) Show that the voltage buffer circuit is in negative feedback.

unity gain buffer



$\Rightarrow$

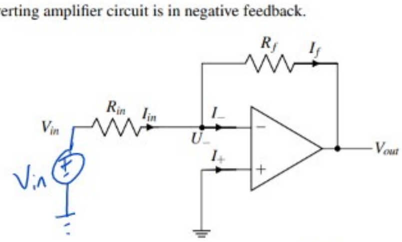


negative feedback ✓

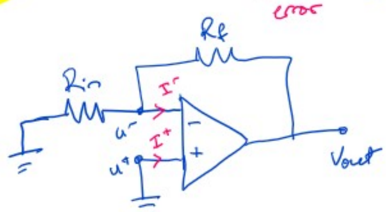
output V_{out} ↑ u^- ↑ $V_{out} = A(\underbrace{u^+ - u^-}_{error})$ ↓

(b) Show that the inverting amplifier circuit is in negative feedback.

inverting amplifier



$\Rightarrow$



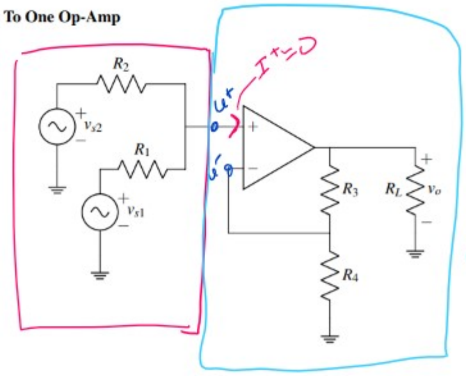
$$u^- = \frac{R_{in}}{R_f + R_{in}} V_{out}$$

output V_{out} ↑ u^- ↑ error ↓ output ↓

negative feedback ✓

2. Multiple Inputs To One Op-Amp

voltage summer



noninverting amplifier

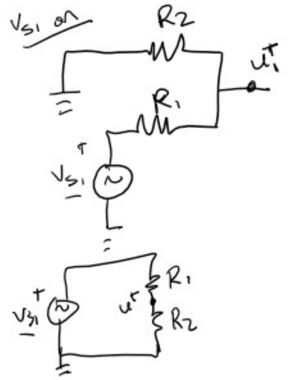
Negative feedback/ideal
golden rules
(1) $I^+ = I^- = 0$
(2) $u^+ = u^-$

* superposition 2 options
(1) use to find u^+
or
(2) use to find V_o

we are going to use this approach

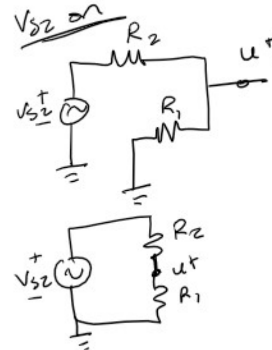
(a) For the circuit above, find an expression for v_o. *(Hint: Use superposition.)*

(1) V_{s1} on



$$u_1^+ = \frac{R_2}{R_1+R_2}V_{s1}$$

V_{s2} on

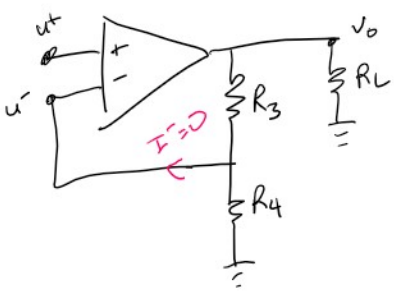


$$u_2^+ = \frac{R_1}{R_1+R_2}V_{s2}$$

$$u^+ = u_1^+ + u_2^+ = \frac{R_2}{R_1+R_2}V_{s1} + \frac{R_1}{R_1+R_2}V_{s2}$$

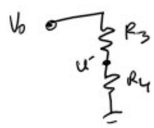
$$V_s = \frac{\cancel{R_3+R_4}}{\cancel{R_4}}\left(\frac{\cancel{R_4}}{\cancel{R_3+R_4}}V_o\right)$$

$$V_s = V_o$$



* $u^+ = u^-$

$$u^- = \frac{R_4}{R_3+R_4}V_o$$

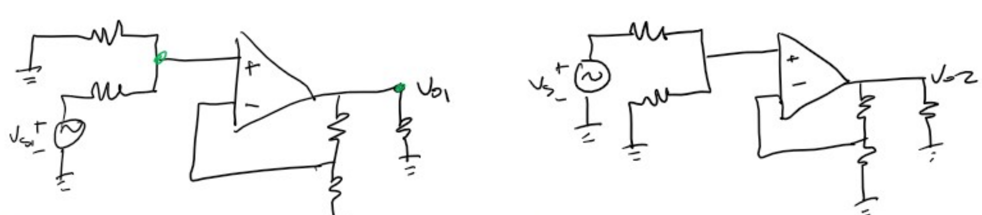


$$u^+ = \frac{R_4}{R_3+R_4}V_o$$

$$V_o = \frac{R_3+R_4}{R_4}u^+ = \left(1+\frac{R_3}{R_4}\right)u^+$$

$$\boxed{V_o = \left(1+\frac{R_3}{R_4}\right)\left(\frac{R_2}{R_1+R_2}V_{s1} + \frac{R_1}{R_1+R_2}V_{s2}\right)}$$

(2)



$$V_o = V_{o1} + V_{o2}$$

(b) How could you use this circuit to find the sum of different signals, i.e. $V_{s1}+V_{s2}$? What about taking the sum and adding multiplying by 2, i.e. $2(V_{s1}+V_{s2})$?

$V_o = V_{s1} + V_{s2}$ by choosing R_1, R_2, R_3, R_4

$R_1 = R_2$ $\quad$ $R_3 = R_4$

$$V_o = \underbrace{\left(1+\frac{R_3}{R_4}\right)}_{2}\left(\frac{1}{2}V_{s1} + \frac{1}{2}V_{s2}\right) = (1+1)\left(\frac{1}{2}V_{s1} + \frac{1}{2}V_{s2}\right) = V_{s1} + V_{s2}$$

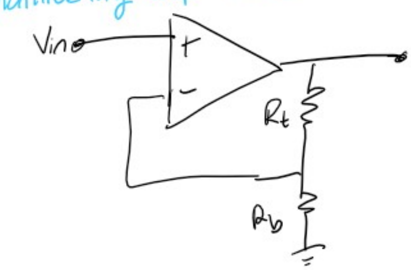
3. Modular Op-Amp Circuits

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

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

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

noninverting amp

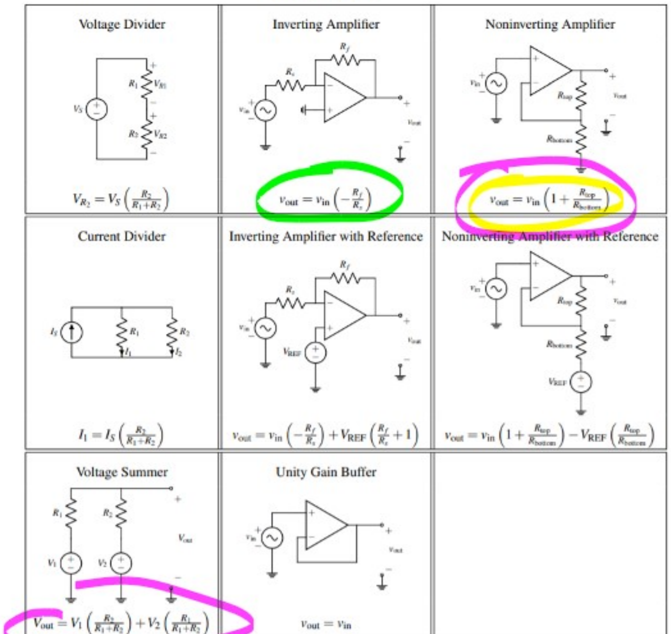


$$V_{out} = V_{in}\left(1 + \frac{R_t}{R_b}\right) = 5V_{in}$$

$$\frac{R_t}{R_b} + 1 = 5$$

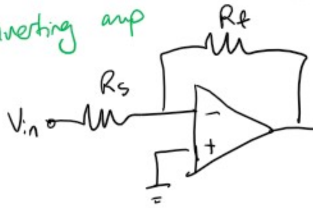
$$\frac{R_t}{R_b} = 4 \qquad \boxed{R_t = 4R_b}$$

Reference Circuits



(b) Scale and invert the input voltage so that: $V_{out} = -2\,V_{in}$

inverting amp



$$V_{out} = V_{in}\left(-\frac{R_f}{R_s}\right) = -2V_{in}$$

$$-\frac{R_f}{R_s} = -2 \qquad \boxed{R_f = 2R_s}$$

(c) Sum two input voltages together so that: $V_{out} = V_{in_1} + V_{in_2}$

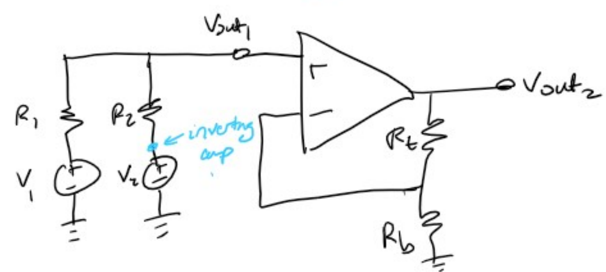
* same as 2b

$\boxed{R_1 = R_2}$

$$V_{out_1} = V_1\left(\frac{R_2}{R_1+R_2}\right) + V_2\left(\frac{R_1}{R_1+R_2}\right) = \frac{1}{2}V_1 + \frac{1}{2}V_2$$

* combine w/ noninverting amp w/ gain of 2

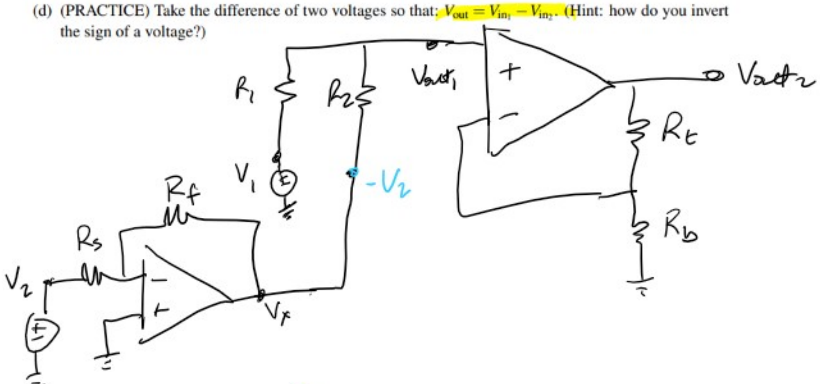
$$V_{out_2} = V_{out_1}\left(1 + \frac{R_t}{R_b}\right) = 2\,V_{out_1} \qquad \boxed{R_t = R_b}$$



$$V_{out_2} = \left(1 + \frac{R_t}{R_b}\right)\left(V_1\left(\frac{R_2}{R_1+R_2}\right) + V_2\left(\frac{R_1}{R_1+R_2}\right)\right)$$

$$= V_1 + V_2$$

(d) (PRACTICE) Take the difference of two voltages so that: $V_{out} = V_{in_1} - V_{in_2}$. (Hint: how do you invert the sign of a voltage?)



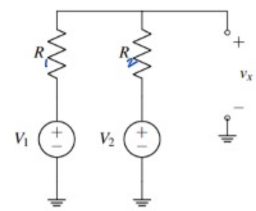
$$R_f = R_s$$

$$V_x = -\frac{R_f}{R_s}V_2 = -V_2$$

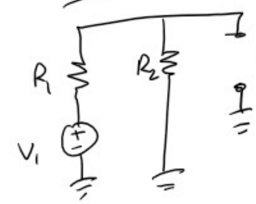
4. Practice: Dividers for Days

(a) Solve the following circuit for v_x.

* voltage summer

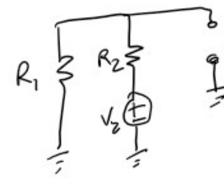


V_1 only



$$V_{x_1} = \frac{R_2}{R_1+R_2} V_1$$

V_2 only



$$V_{x_2} = \frac{R_1}{R_1+R_2} V_2$$

$$V_x = \frac{R_2}{R_1+R_2} V_1 + \frac{R_1}{R_1+R_2} V_2$$

if $R_1 = R_2 = R$

$$\boxed{V_x = \frac{1}{2} V_1 + \frac{1}{2} V_2}$$

(b) You have access to two voltage sources, V_1 and V_2. You can use two resistors (as long as $0 \le R < \infty$). How would you design a circuit that produces a voltage $v_x = \frac{1}{3}V_1 + \frac{2}{3}V_2$?

$$V_x = \frac{R_2}{R_1+R_2} V_1 + \frac{R_1}{R_1+R_2} V_2$$
$$= \frac{1}{3} V_1 + \frac{2}{3} V_2$$

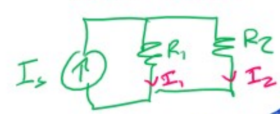
$$\boxed{R_1 = 2R_2}$$

using voltage summer circuit

(c) You have two current sources I_1 and I_2. You also have a load resistor $R_L = 6\,\text{k}\Omega$. Similar to the first part, you can use whatever resistors you want (as long as they are finite integer multiples of $1\,\text{k}\Omega$). How would you design a circuit such that the current running through R_L is $I_L = \frac{2}{5}(I_1 + I_2)$?

* similar to how a voltage summer is 2 voltage dividers when we use superposition, we can design a circuit that is 2 current dividers when we use superposition

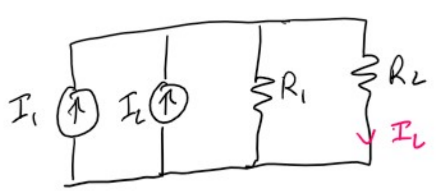
* reference circuit current divider



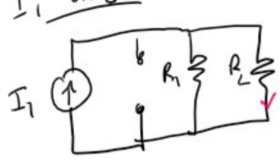
$$I_1 = \frac{R_2}{R_1+R_2} I_s$$

$$I_2 = \frac{R_1}{R_1+R_2} I_s$$

can derive using NVA



I_1 only



$$I_{L_1} = \frac{R_1}{R_1+R_L} I_1$$

I_2 only

$$I_{L_2} = \frac{R_1}{R_1+R_L} I_2$$

$$I_L = I_{L1} + I_{L2}$$
$$= \frac{R_1}{R_1+R_L} I_1 + \frac{R_1}{R_1+R_L} I_2$$
$$= \frac{R_1}{R_1+R_L}(I_1 + I_2)$$
$$= \frac{2}{5}(I_1 + I_2)$$

$$\frac{R_1}{R_1+R_L} = \frac{2}{5}$$

$$5R_1 = 2(R_1 + R_L)$$
$$3R_1 = 2R_L$$
$$R_1 = \frac{2}{3} R_L$$

* $R_L = 6\text{k}\Omega$

$R_1 = 4\text{k}\Omega$