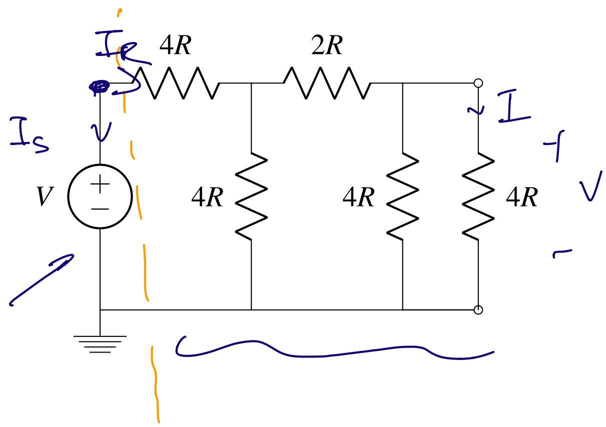
EECS 16A Designing Information Devices and Systems I
Spring 2021 Discussion 11A

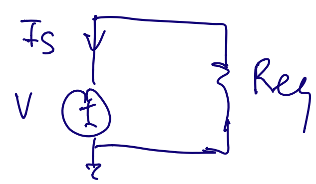
:: Pre-Midterm Discussion ::
Choose which of the following problems you would like to review.
GOOD LUCK!!

1. OPTIONAL: Power to Resist (from Spring 2018 midterm 2)

Find the power dissipated by the voltage source in the circuit below. Be sure to use passive sign convention.



$P = IV$ power dissipated in PSC



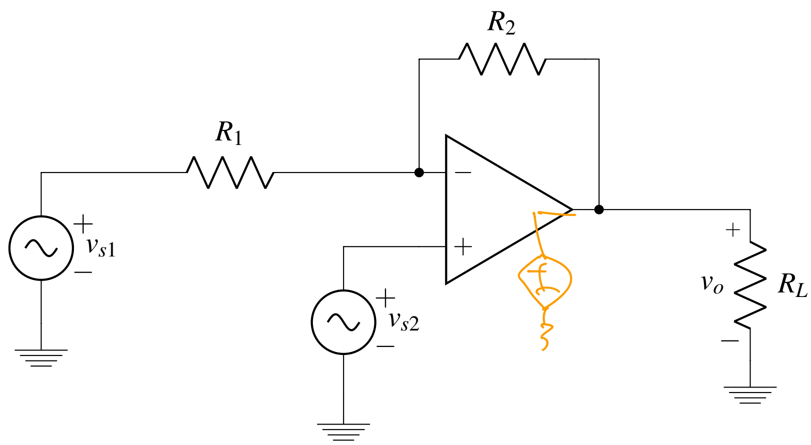
$P = \frac{V^2}{R}$

$P = V \cdot I_s$ I_s will be negative here

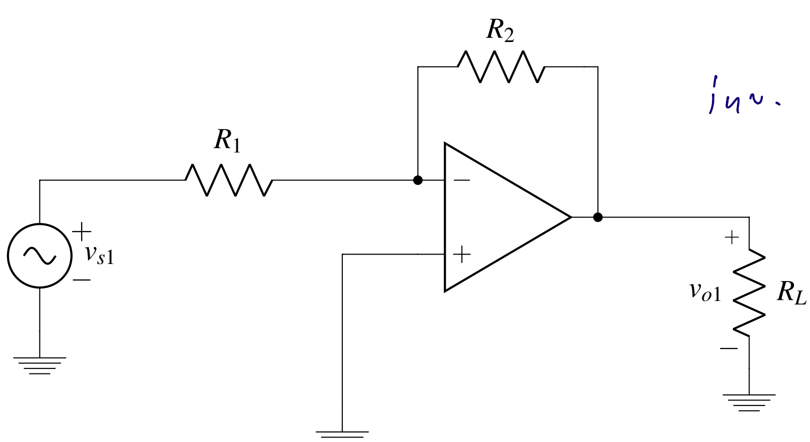
so P will be negative.

2. OPTIONAL: Amplifier with Multiple Inputs

In this problem we will use superposition and the Golden Rules to find the output of the following op amp circuit with multiple inputs:

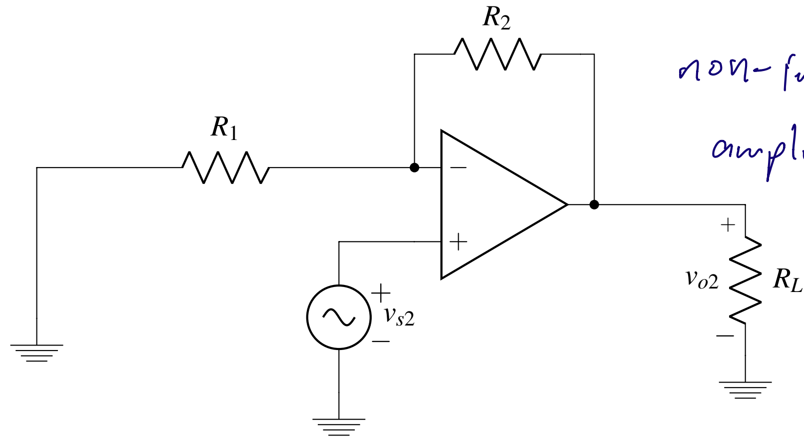


(a) First, let's turn off v_{s2}. Use the **Golden Rules** to find v_{o1} for the circuit below.



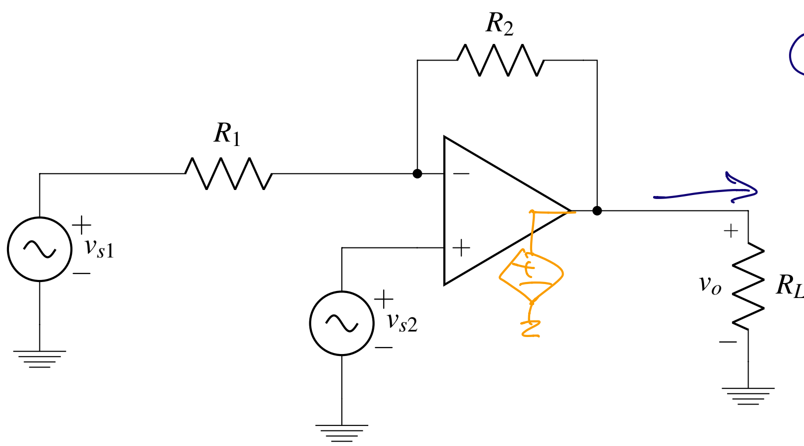
inv. amplifies

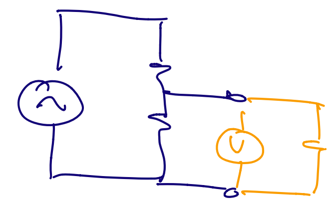
(b) Now let's turn off v_{o1}. Use the **Golden Rules** to find v_{o2} for the circuit below.



non-inverting amplifier

(c) Use **superposition** to find the output voltage v_o for the circuit shown below.



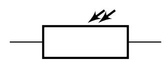


$$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{S_2} - \frac{R_2}{R_1} V_{S_1}$$

3. OPTIONAL: PetBot Design (from Fall 2016 Final exam)

In this problem you will design circuits to control PetBot, a simple robot designed to follow light. PetBot measures light using a photoresistor, which is a light-sensitive resistor. *As it is exposed to more light, its resistance decreases.* The diagram below shows the circuit symbol for a photoresistor.

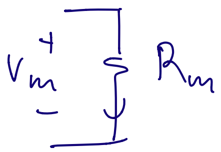
L ↑ R ↓

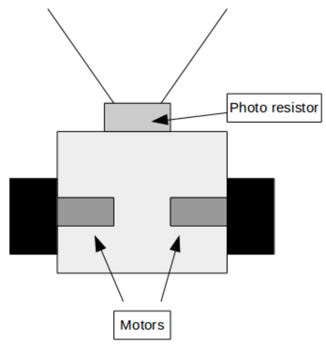


R_{ph}

The basic layout of PetBot can be seen below. It is driven by one motor that will be modeled as a resistor. PetBot drives forward (towards the said light source) when a positive voltage is applied across the motor, and conversely a negative applied voltage drives PetBot backward (away from the light source). In this system the light sensor is mounted to the front of the robot, and the speed of PetBot is proportional to the applied voltage to the motor.

motor





$V_m > 0 \Rightarrow$ forward

$V_m < 0 \rightarrow$ backward

$|V_m| \propto$ speed

(a) **Speed control**

In our first circuit design, we will begin by making PetBot decrease speed as it drives towards light. **Design a motor-driving circuit that outputs a decreasing positive motor voltage as PetBot drives toward the light source.** The motor voltage should be at least 5 V when far away from the light. At this far away from the light source, the photoresistor value will be 10 kΩ, and then drop towards 100 Ω as it approaches the light.

In your design, you may use any number of resistors and op-amps. You also have access to voltage sources of 10 V and −10 V. **Based on your circuit, derive an expression for the motor voltage as a function of the circuit components that you used.**

NOTE! Since the motor is a resistor, the circuit design MUST have a buffer so that the applied voltage to the motor does not depend on its resistance.

$\boxed{R \uparrow \rightarrow V \uparrow}$

if you can, develop this logic first

D ↑ S ↑

① Specs: (~~Distance ↓~~ , speed ↓
↳ "decreasing positive voltage")

→ $V_m \geq 5V$ when "far away" (D ↑↑)

"far away" $R_{ph} = 10K\Omega$

nearby $R_{ph} = 100\Omega$

Given op-amps, resistors, +10V, -10V

② strategy: - decreasing
- positive → don't need inverting.

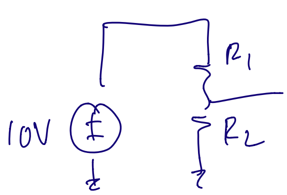
↳ decreasing as function of distance

"??" — voltage

D ↑ L ↓ R_{ph} ↑

$\boxed{\text{can I build something to measure resistance? ↳ output voltage}}$

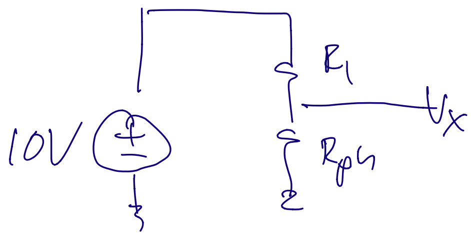
Try voltage divider.



$$V_x = \frac{R_2}{R_1 + R_2} 10V = \frac{1}{1 + \frac{R_1}{R_2}} 10V.$$

R_1 ↑ $\left(\frac{R_1}{R_2}\right)$ ↑ V_x ↓

R_2 ↑ $\left(\frac{R_1}{R_2}\right)$ ↓ V_x ↑ → make $R_2 = R_{ph}$



$$V_x = \frac{1}{1+\frac{R_1}{R_{ph}}} 10V$$

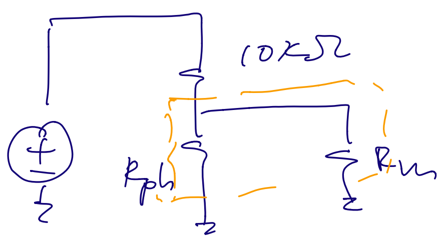
$$D\uparrow \quad L\downarrow \quad R_{ph}\uparrow \quad \left(\frac{R_1}{R_{ph}}\right)\downarrow \quad V_x\uparrow$$

from spec

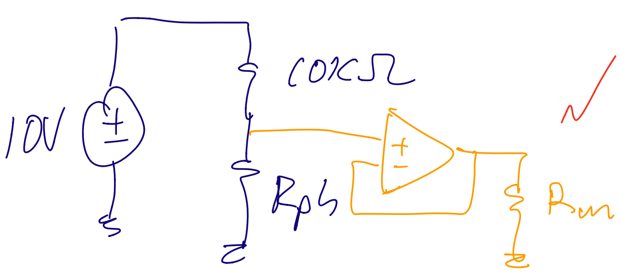
$V_x = 5V$ when $R_{ph} = 10k\Omega$

$$\boxed{R_1 = 10k\Omega}$$

plug values into V_x eqn. and solve for R_1



R_m adds loading



add a buffer

Not covered live

(b) **Distance control**

When the PetBot stops at a distance of 1 m away from the light, the photo-resistor has a value 1 kΩ. We would like to have the PetBot drive away when closer than 1m from the light (so for lower R_p), and drive towards the light when exceeding 1m (so for greater R_p).

Design a comparator circuit that outputs a positive motor voltage when the PetBot exceeds 1 m **in distance from the flashlight (making the PetBot move toward it), and a negative voltage when PetBot is within** 1 m **of flashlight (making the PetBot back away from the flashlight.**

In your design, you may use any number of resistors along with the comparator. You also have access to voltage sources of 10 V and −10 V.

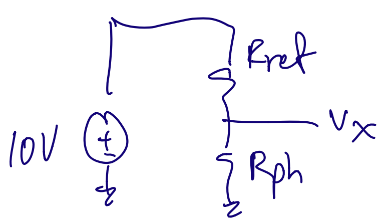
① "stop" at 1 m / 1kΩ

- output > 0 when > 1m ($D \uparrow$)
- output < 0 when < 1m ($D \downarrow$)

Recall $R_{ph} \uparrow$ when $D \uparrow$

$R_{ph} \downarrow$ when $D \downarrow$

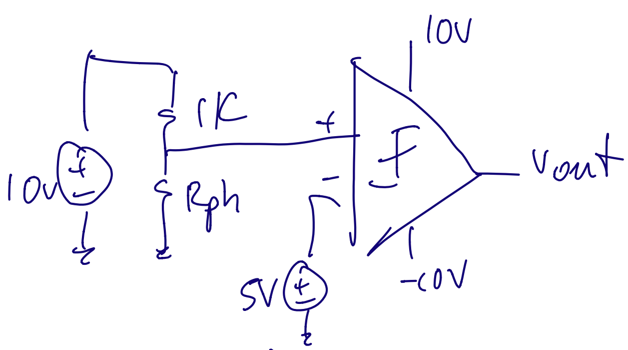
② $D \uparrow \rightarrow R_{ph} \uparrow \rightarrow$ voltage change $\rightarrow$ output $\uparrow$



$$V_x = \frac{R_{ph}}{R_{ref}+R_{ph}} V_{in}$$

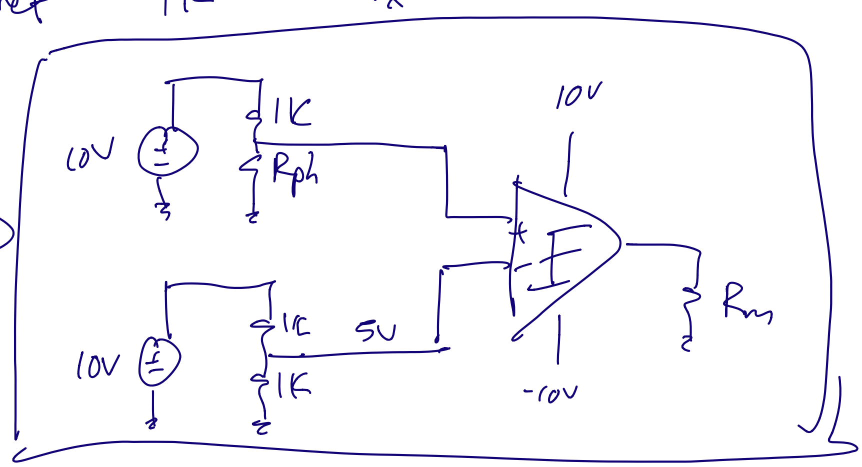
$D \uparrow$ $R_{ph} \uparrow$ $V_x \uparrow$

Pick $R_{ref} = 1K \Rightarrow V_x = 5V$ @ 1m



↳ make a 5V

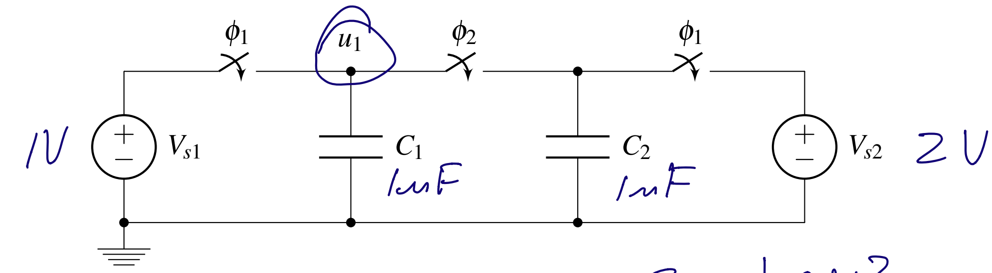
$\Rightarrow$



(one possible soln.)

4. OPTIONAL: Capacitive Charge Sharing (from Spring 2020 Midterm 2)

Consider the circuit below with $C_1 = C_2 = 1\,\mu\text{F}$ and two switches ϕ_1, ϕ_2. Suppose that initially the switch ϕ_1 is closed and ϕ_2 is open such that C_1 and C_2 are charged through the corresponding voltage sources $V_{s1} = 1\,\text{V}$ and $V_{s2} = 2\,\text{V}$.



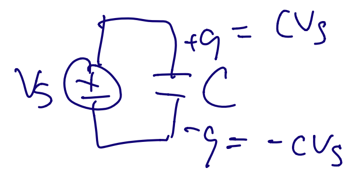
$E = \frac{1}{2}CV^2 = \frac{1}{2}QV$

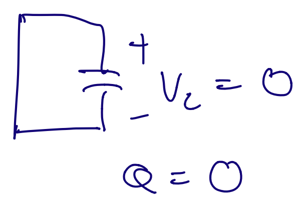
(a) How much charge is on C_1 and C_2? How much energy is stored in each of the capacitors? What is the total stored energy?

(b) Now suppose that some time later, switch ϕ_1 opens and switch ϕ_2 closes. What is the value of voltage u_1 at steady state?

Charge Sharing : - $Q = CV$

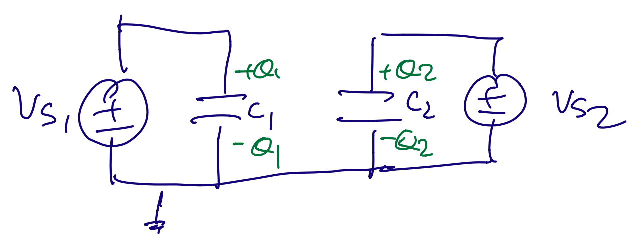
- solve circuit for each phase
- charge conserved





(a) C_1 : $Q_1 = C_1 V_{s1}$

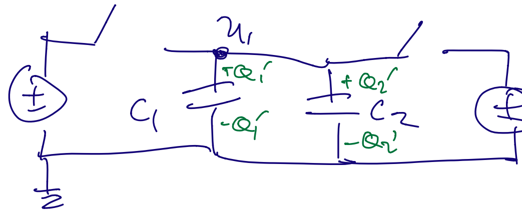
C_2 : $Q_2 = C_2 V_{s2}$



$E_1 = \frac{1}{2} C_1 V_{s1}^2$ $\quad E_2 = \frac{1}{2} C_2 V_{s2}^2$

$E_{tot} = E_1 + E_2$

(5)



ϕ_1 : $Q_1 = C_1 V_{s_1}$

$Q_2 = C_2 V_{s_2}$

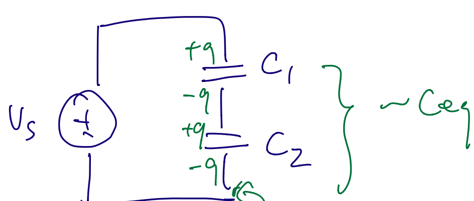
ϕ_2 : $Q_1' = C_1 V_{s_1}'$ $\qquad V_{s_1}' = V_{s_2}' = u_1$

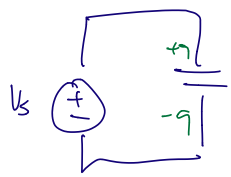
$Q_2' = C_1 V_{s_2}'$

$$Q_1 + Q_2 = Q_1' + Q_2'$$

$$C_1 V_{s_1} + C_2 V_{s_2} = C_1 u_1 + C_2 u_1$$

$$\boxed{u_1 = \frac{C_1 V_{s_1} + C_2 V_{s_2}}{C_1 + C_2}}$$



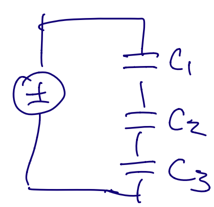


$C_{eq} = \dfrac{C_1 C_2}{C_1 + C_2}$

$$Q = C_{eq} V_s = \frac{C_1 C_2}{C_1 + C_2} V_s$$

$$V_1 = \frac{Q}{C_1} = \frac{C_2}{C_1 + C_2} V_s$$

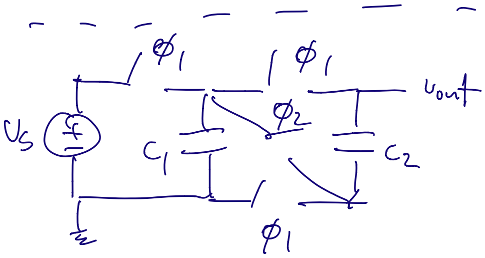
$$V_2 = \frac{C_1}{C_1 + C_2} V_s$$



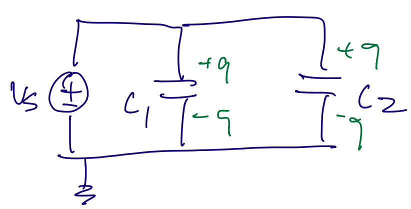
$$C_{eq} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)^{-1}$$

$$Q = C_{eq} V_s$$

$$V_1 = \frac{Q}{C_1} = \frac{C_{eq}}{C_1} V_s$$



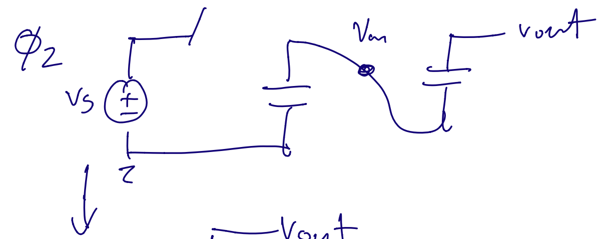
ϕ_1

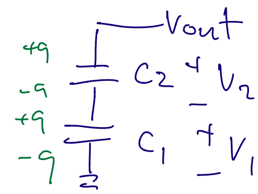


$Q_1 = C_1 V_s$

$Q_2 = C_2 V_s$

@ V_{in} : $+q \; -q$ is conserved
$\uparrow \quad \uparrow$
$C_1 \quad C_2$





@ Vout : floating node charge is conserved.

$$Q_{vout}^{\phi_2} = Q_{vout}^{\phi_1} = C_2 V_s$$

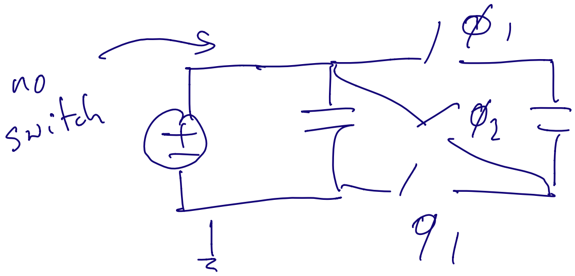
All the charges on the plates are the same as in ϕ_1.

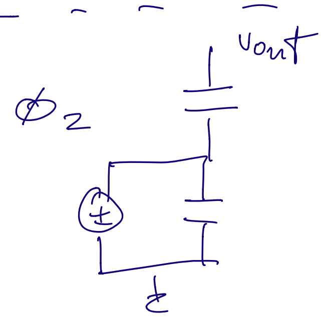
b/c $Q = CV$, all the voltages on the caps are the same as in ϕ_1.

$$V_{out} = V_2^{\phi_2} + V_1^{\phi_2} = V_2^{\phi_1} + V_1^{\phi_1}$$

$$= V_s + V_s$$

$$V_{out} = 2V_s.$$

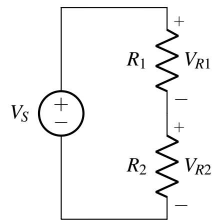




now we care about V_s in ϕ_2

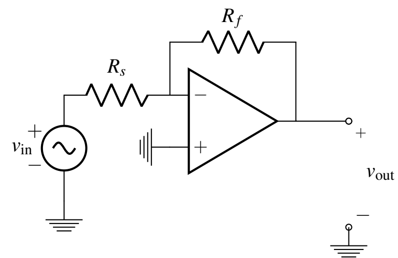
Reference Circuits

Voltage Divider



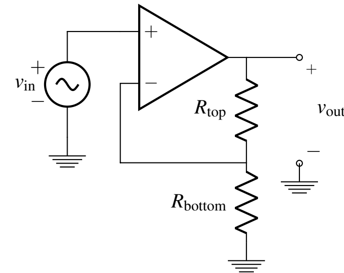
$$V_{R_2} = V_S\left(\frac{R_2}{R_1+R_2}\right)$$

Inverting Amplifier



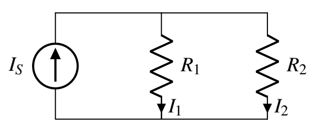
$$v_{out} = v_{in}\left(-\frac{R_f}{R_s}\right)$$

Noninverting Amplifier



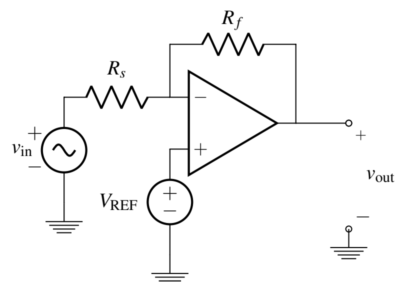
$$v_{out} = v_{in}\left(1+\frac{R_{top}}{R_{bottom}}\right)$$

Current Divider



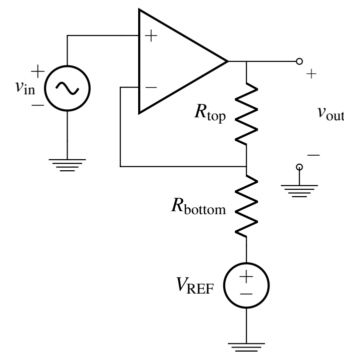
$$I_1 = I_S\left(\frac{R_2}{R_1+R_2}\right)$$

Inverting Amplifier with Reference



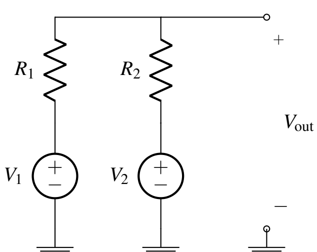
$$v_{out} = v_{in}\left(-\frac{R_f}{R_s}\right) + V_{REF}\left(\frac{R_f}{R_s}+1\right)$$

Noninverting Amplifier with Reference



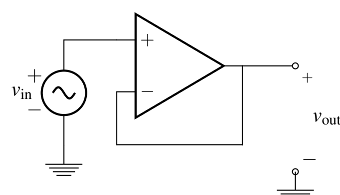
$$v_{out} = v_{in}\left(1+\frac{R_{top}}{R_{bottom}}\right) - V_{REF}\left(\frac{R_{top}}{R_{bottom}}\right)$$

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



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