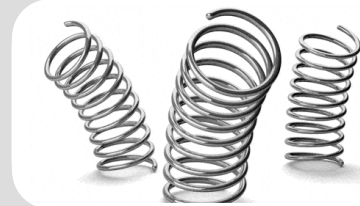


Welcome to EECS 16A!

Designing Information Devices and Systems I

Ana Arias and Miki Lustig



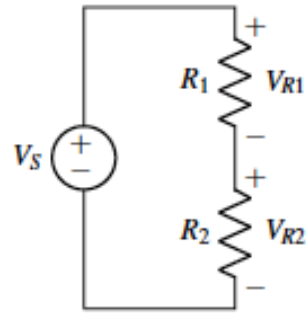
2022

Lecture 10A
Design Procedure and Examples



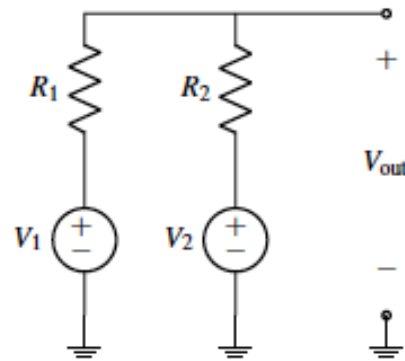
Today

Voltage Divider



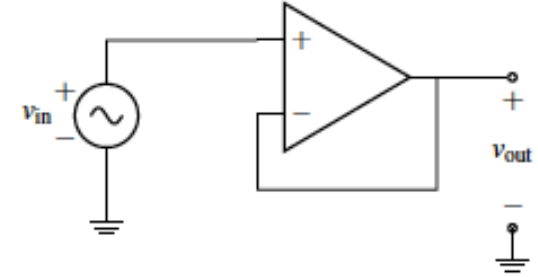
$$V_{R2} = V_S \left(\frac{R_2}{R_1 + R_2} \right)$$

Voltage Summer



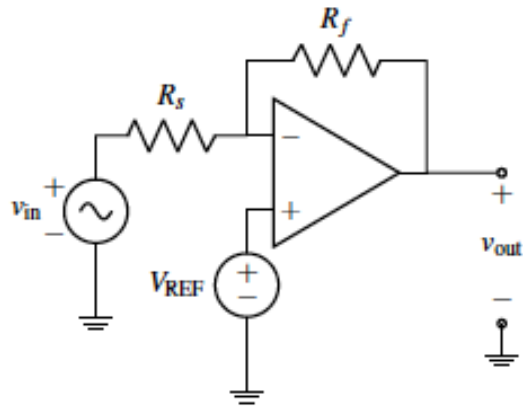
$$V_{out} = V_1 \left(\frac{R_2}{R_1 + R_2} \right) + V_2 \left(\frac{R_1}{R_1 + R_2} \right)$$

Unity Gain Buffer



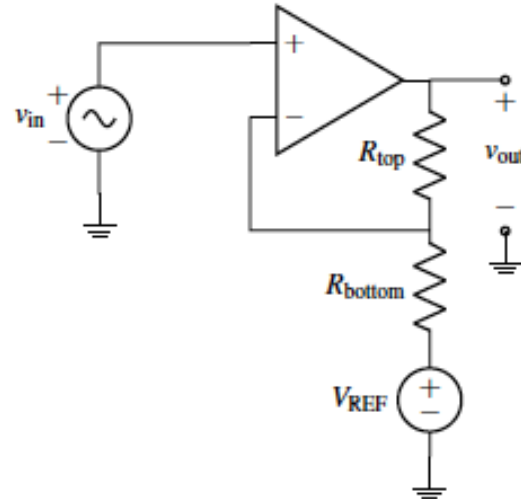
$$\frac{v_{out}}{v_{in}} = 1$$

Inverting Amplifier



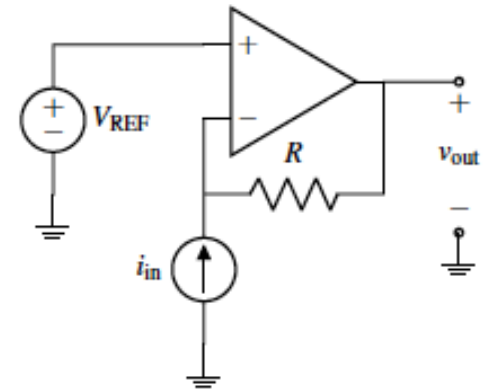
$$v_{out} = v_{in} \left(-\frac{R_f}{R_s} \right) + V_{REF} \left(\frac{R_f}{R_s} + 1 \right)$$

Non-inverting Amplifier



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

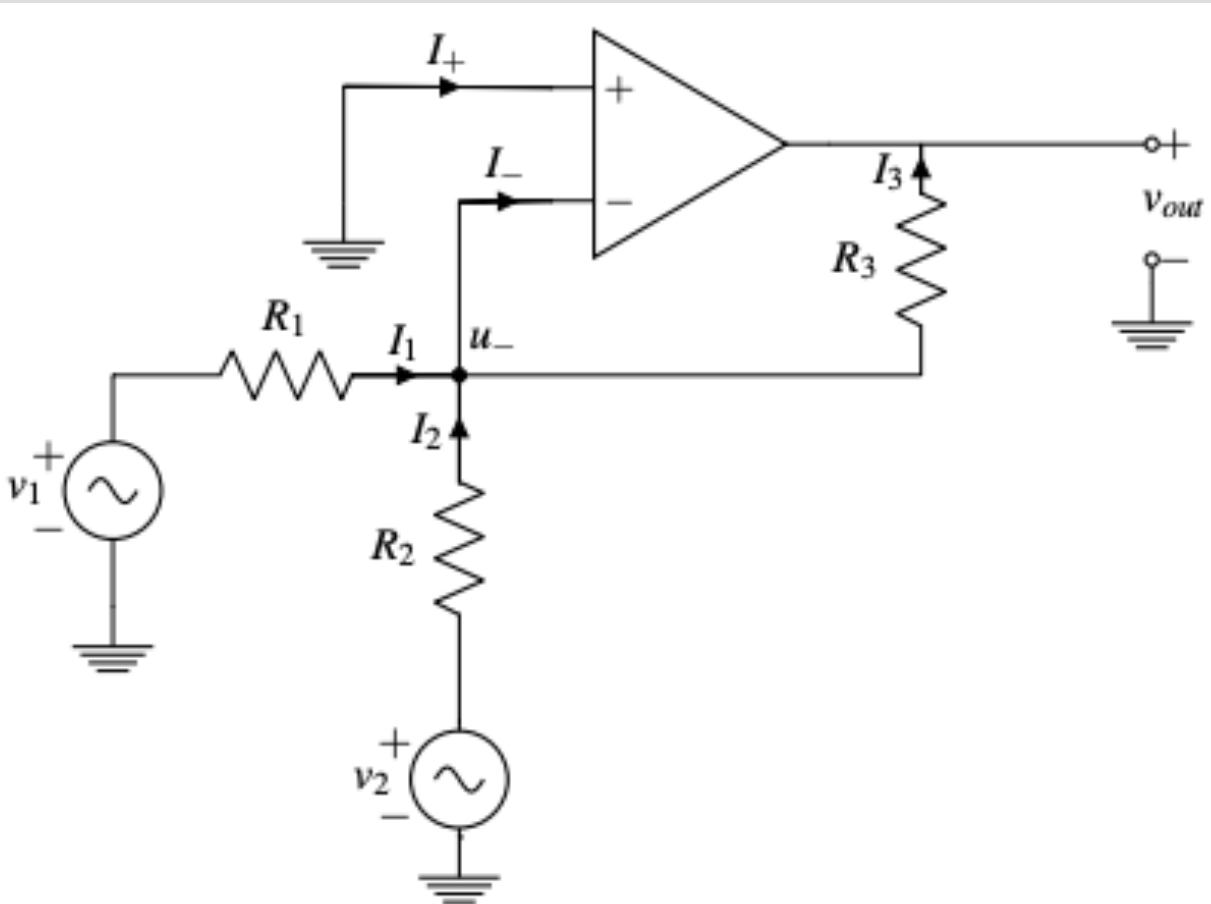
Transresistance Amplifier



$$v_{out} = i_{in} (-R) + V_{REF}$$

“Artificial Neuron “

- Neurons in our brain are interconnected.
- The output of a single-neuron is dependent on inputs from several other neurons.
- This idea is represented with vector-vector multiplication – the output is a linear combination of several inputs.
- An artificial neuron circuit must perform addition and multiplication.



NFB \Rightarrow Golden Rule #2 $\Rightarrow U^- = U^+$

$U^+ = 0 \Rightarrow U^- = 0$

KCL: $I_1 + I_2 = I_3 + I_-$

$$\frac{\cancel{U^-} - V_1}{R_1} + \frac{\cancel{U^-} - V_2}{R_2} = \frac{V_{out} - \cancel{U^-}}{R_3}$$

$$-\frac{V_1}{R_1} - \frac{V_2}{R_2} = \frac{V_{out}}{R_3}$$

$$V_{out} = -\frac{R_3}{R_1}V_1 - \frac{R_3}{R_2}V_2 \dots - \frac{R_3}{R_i}V_i \dots$$

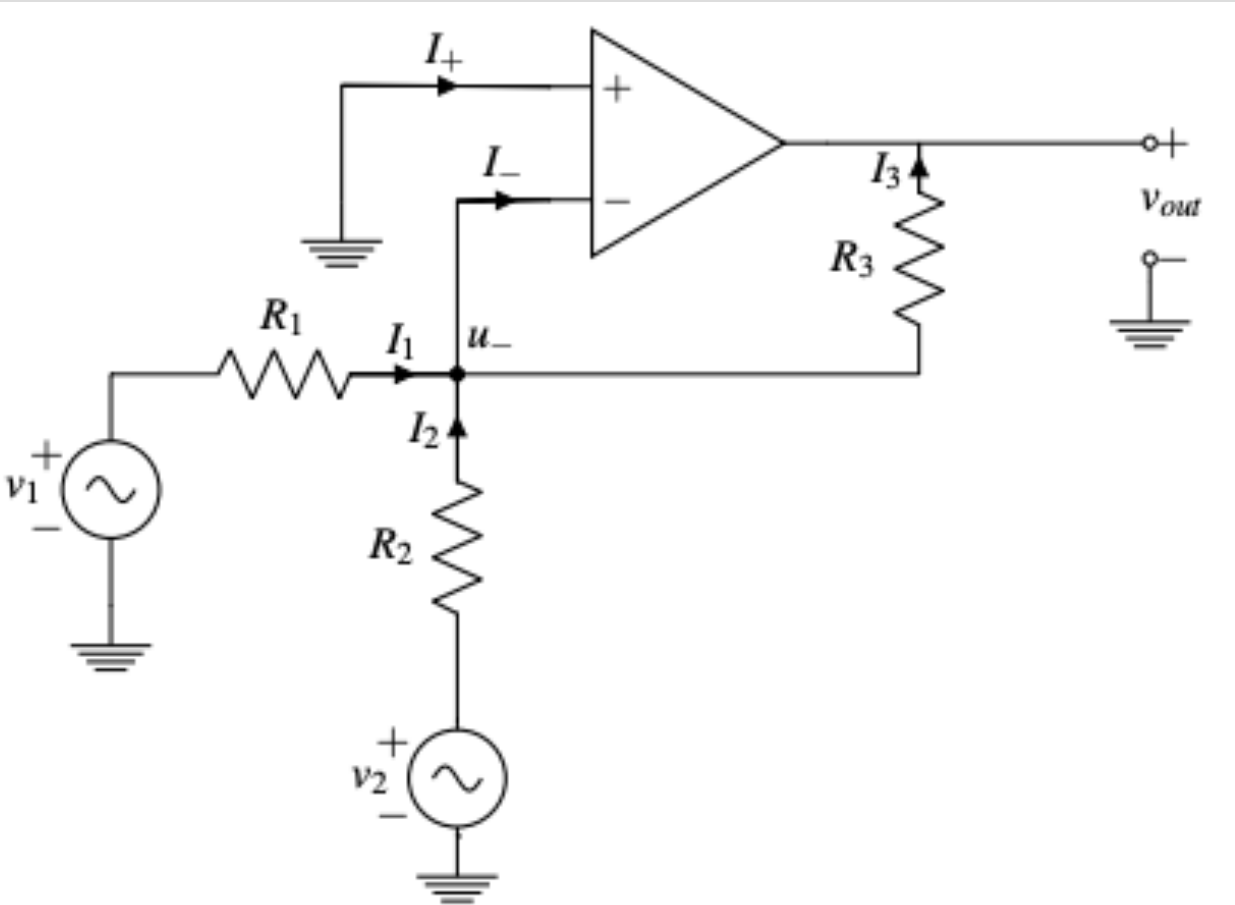
Artificial Neuron

$$V_{out} = -\frac{R_3}{R_1}V_1 - \frac{R_3}{R_2}V_2 \cdots - \frac{R_3}{R_i}V_i \cdots$$

ω_1 ω_2 ω_i

Q: All weights are negative. How can we change sign?

A: Add an inverting amp circuit?

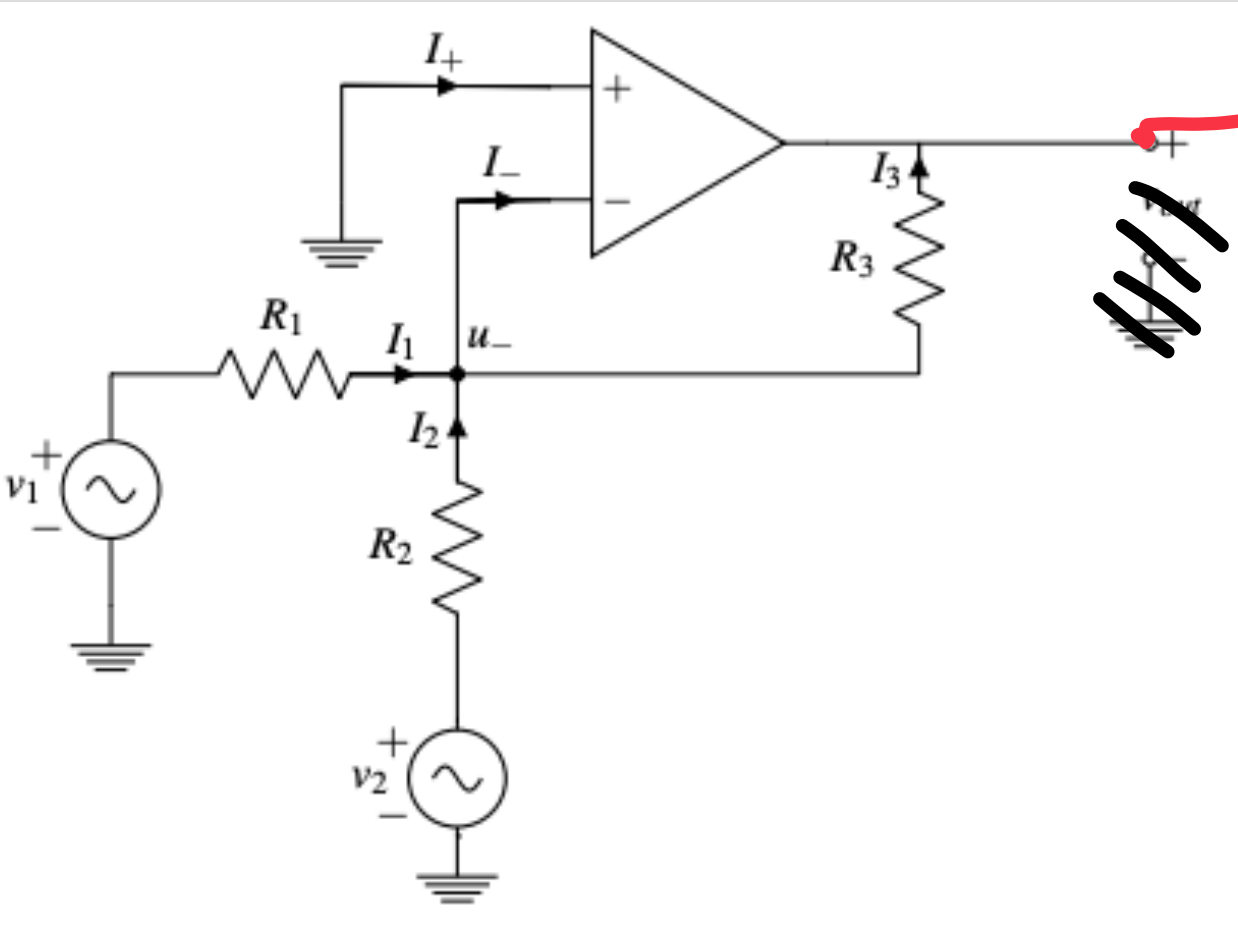


Artificial Neuron

$$V_{\text{out}} = - \underbrace{\frac{R_3}{R_1}}_{w_1} V_1 - \underbrace{\frac{R_3}{R_2}}_{w_2} V_2 \cdots - \underbrace{\frac{R_3}{R_i}}_{w_i} V_i \cdots$$

Q: All weights are negative. How can we change sign?

Q: Can we add an inverting amp circuit?

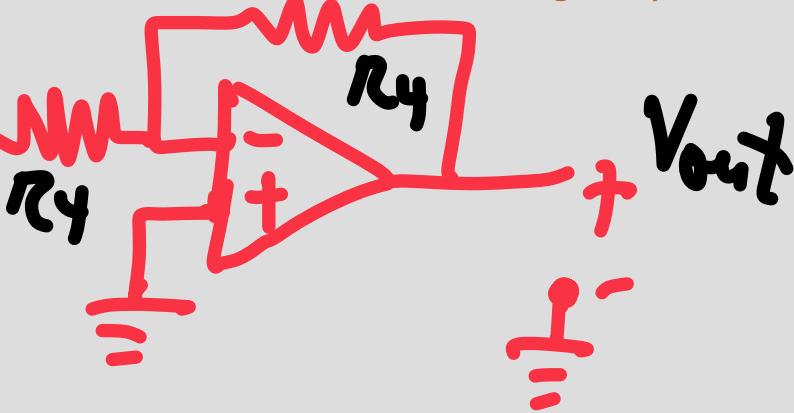
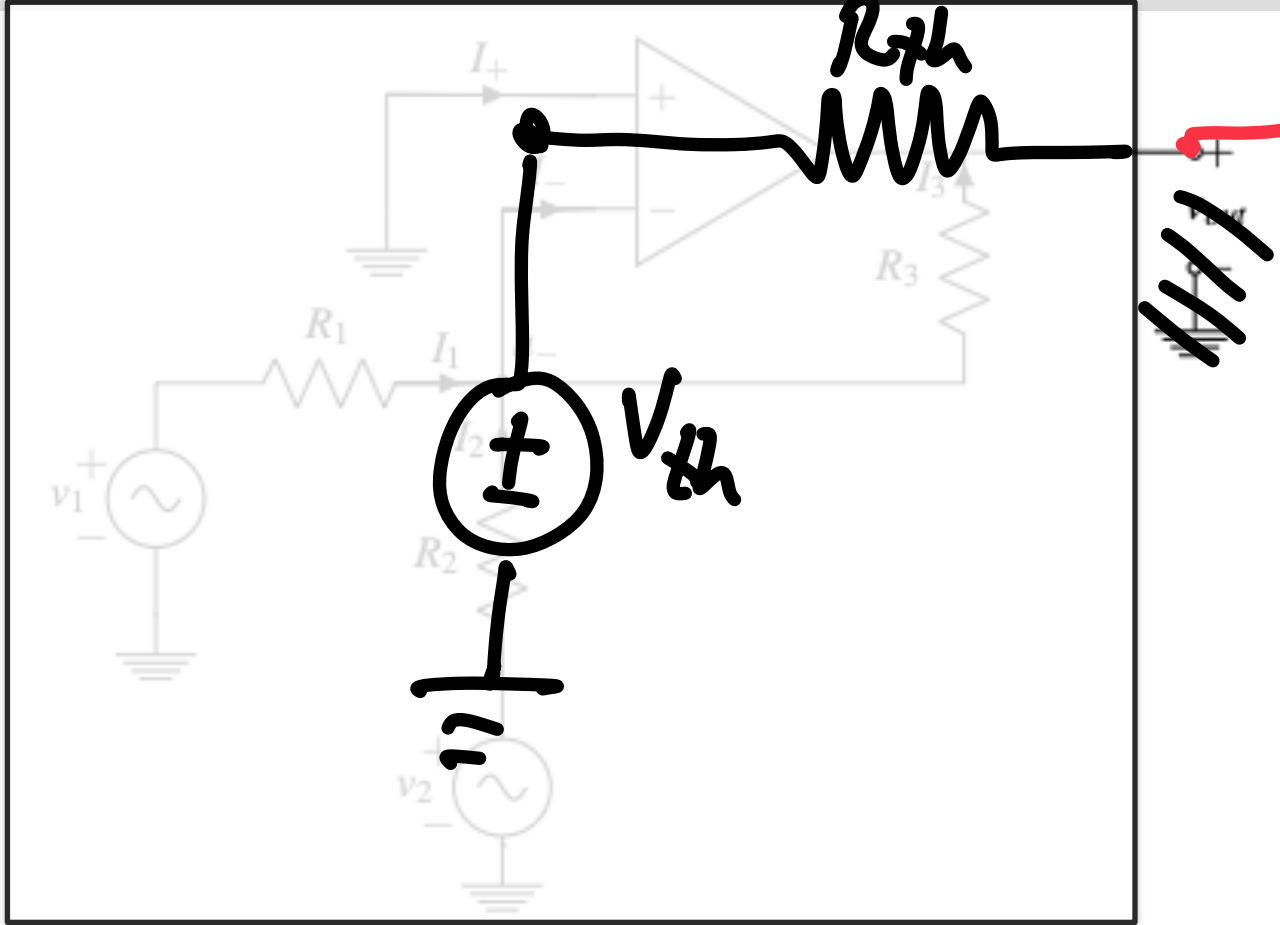


Artificial Neuron

$$V_{out} = - \underbrace{\frac{R_3}{R_1}}_{w_1} V_1 - \underbrace{\frac{R_3}{R_2}}_{w_2} V_2 \dots - \underbrace{\frac{R_3}{R_i}}_{w_i} V_i \dots$$

Q: All weights are negative. How can we change sign?

Q: Can we add an inverting amp circuit?



A: Not always.... But perhaps here is OK.

Q: What's the requirement on Rth?

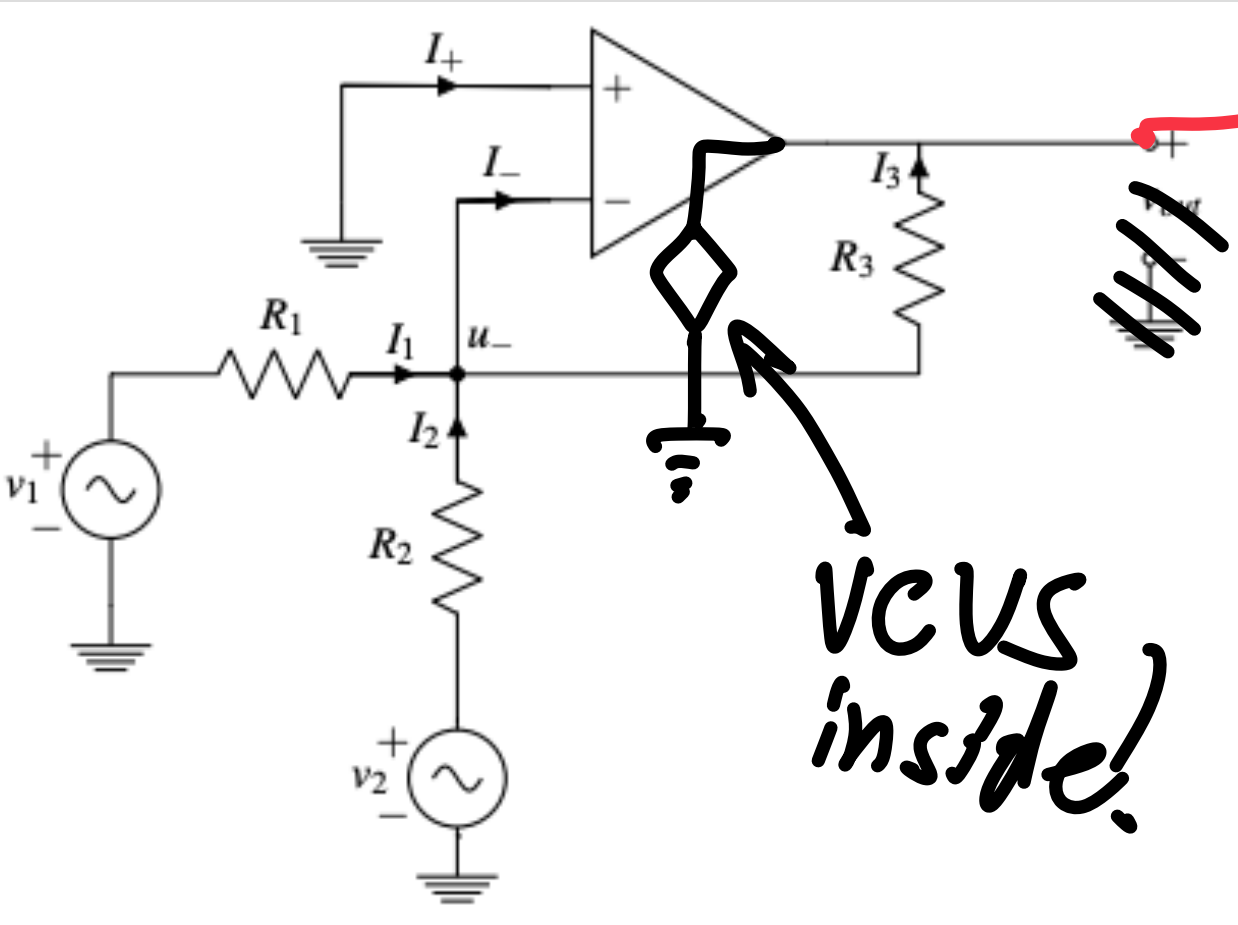
A: Rth = 0?

Artificial Neuron

$$V_{out} = - \underbrace{\frac{R_3}{R_1}}_{w_1} V_1 - \underbrace{\frac{R_3}{R_2}}_{w_2} V_2 \dots - \underbrace{\frac{R_3}{R_i}}_{w_i} V_i \dots$$

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Q: Can we add an inverting amp circuit?



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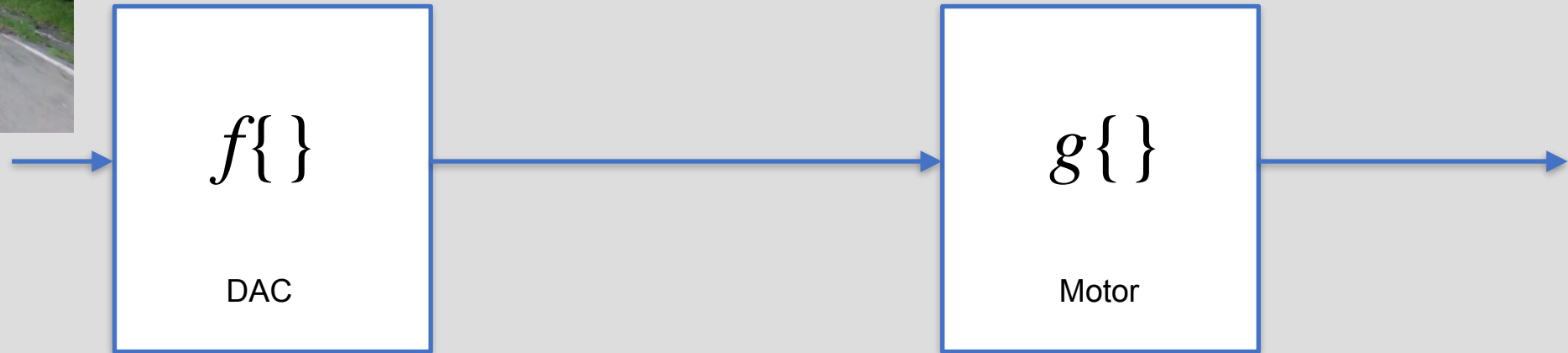
Q: What's the requirement on Rth?

A: Rth = 0?

Cascading blocks

- Safely cascading circuit modules

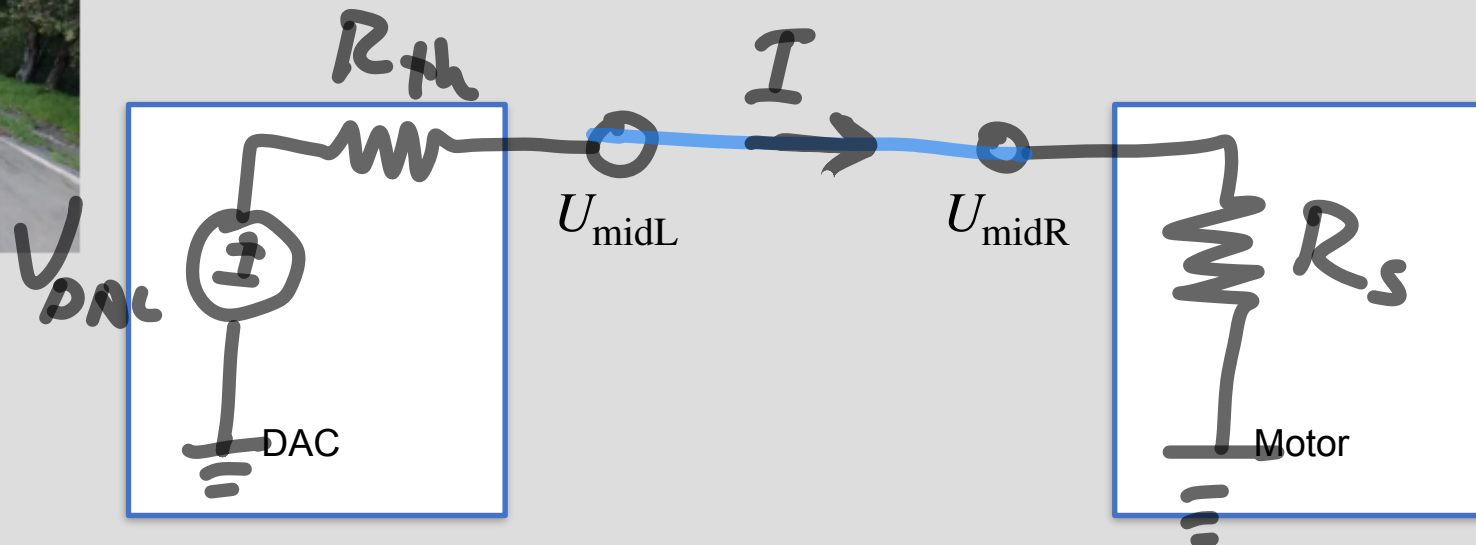
Want to blocks $f\{\}$, and $g\{\}$ to keep their functionality without $g\{\}$ affecting $f\{\}$ and vice versa.



Cascading blocks

- Safely cascading circuit modules

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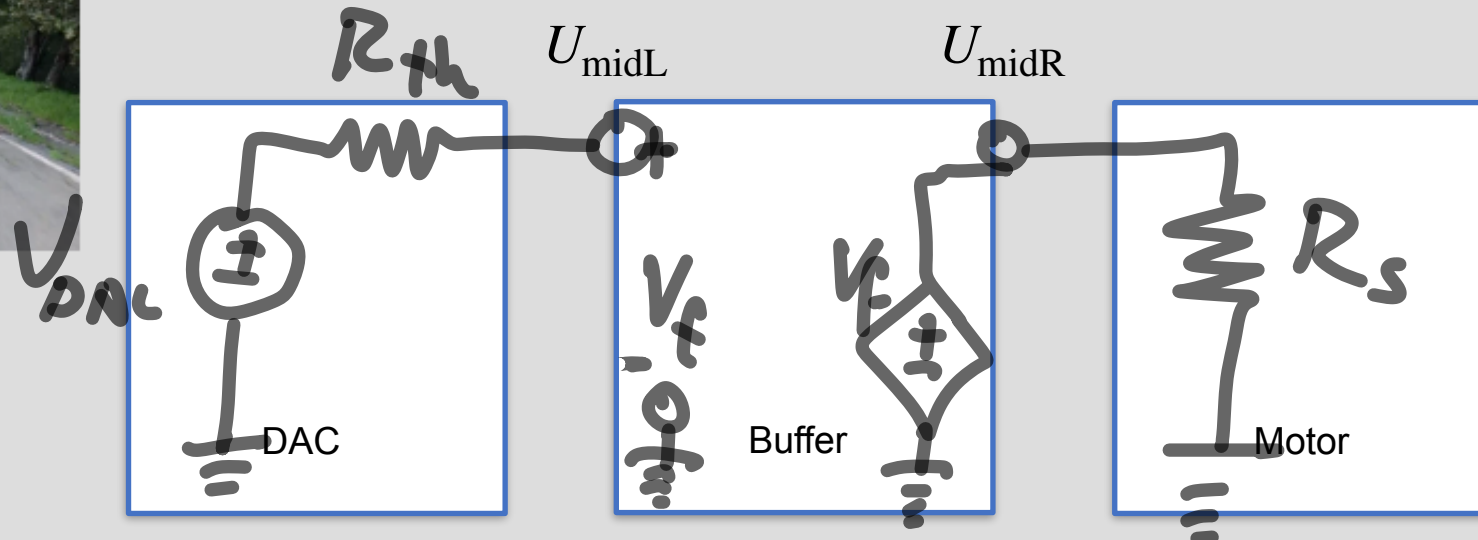


$$\text{After connection: } U_{midL} = U_{midR} = \frac{R_s}{R_{th} + R_s} V_{DAC}$$

Cascading blocks

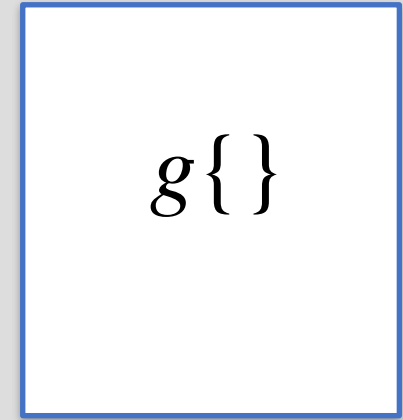
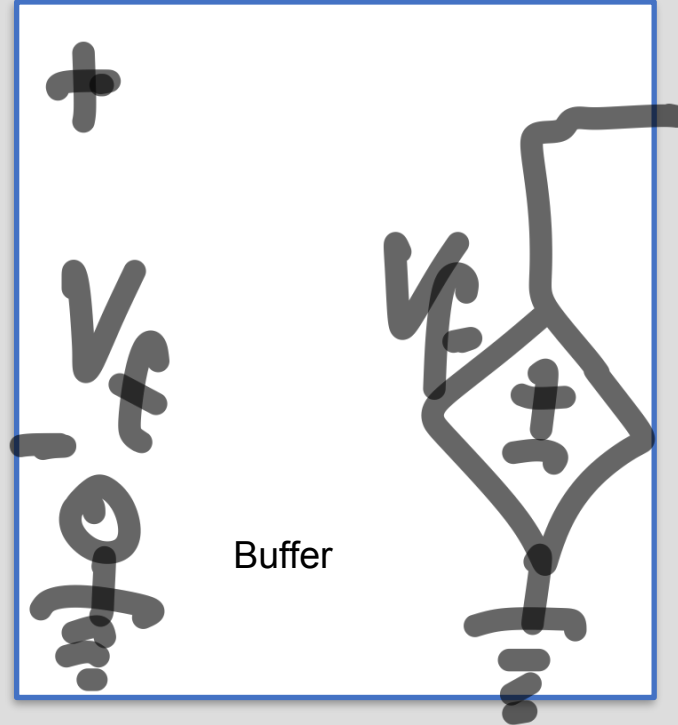
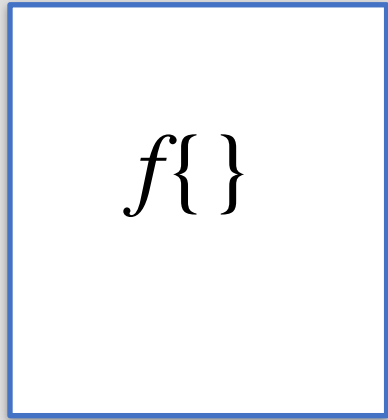
- Safely cascading circuit modules

Want to blocks $f\{\}$, and $g\{\}$ to keep their functionality without $g\{\}$ affecting $f\{\}$ and vice versa.



After connection: $U_{midL} = U_{midR} = V_{DAC}$

Buffer / Unity Gain Amplifier



From perspective of block $f\{\}$: See open circuit

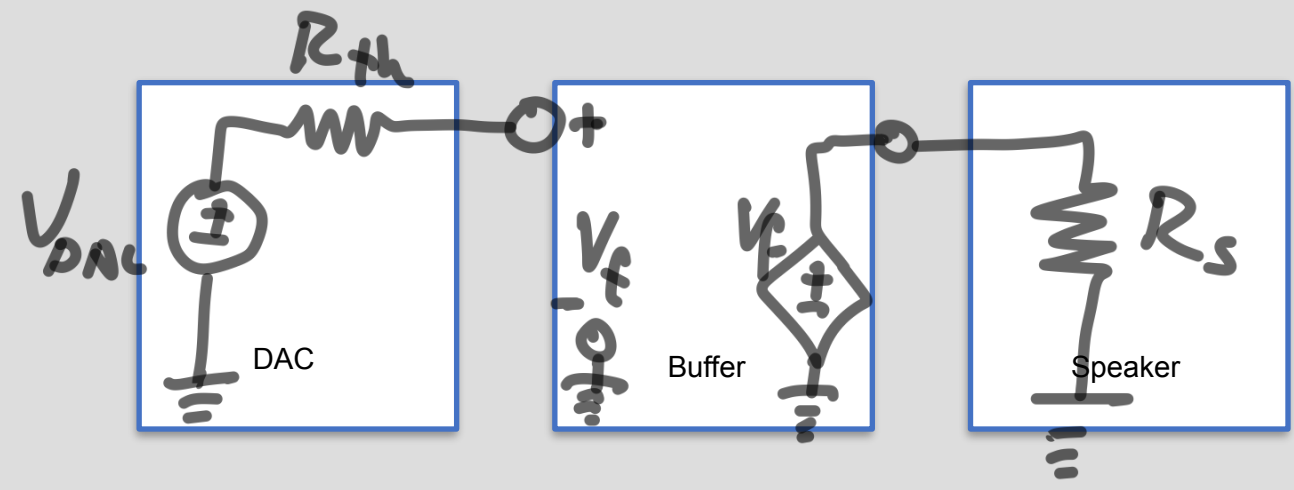
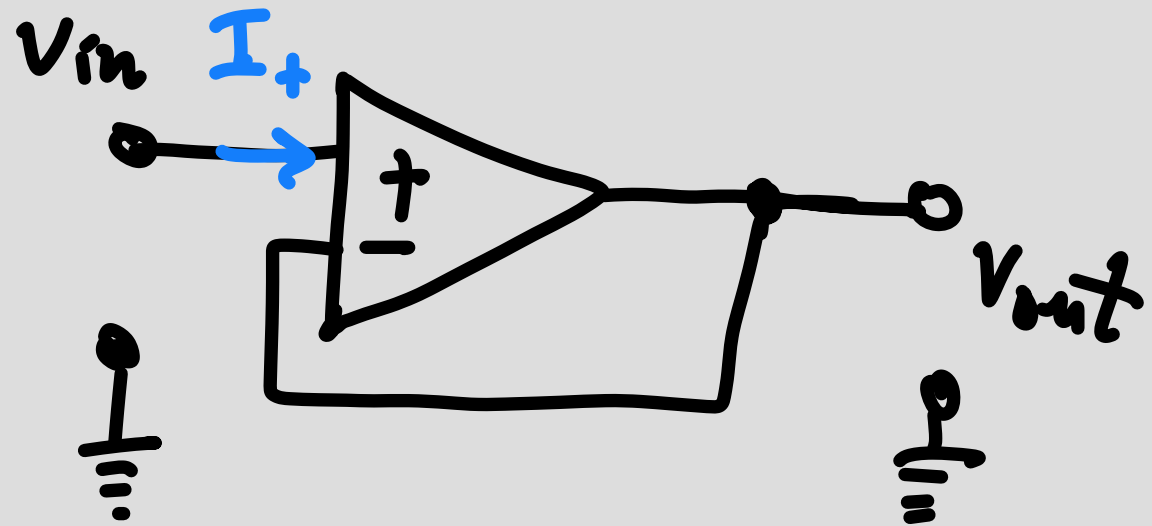
$$R_{th} =$$

From perspective of block $g\{\}$: See a voltage source

$$R_{th} =$$

Unity Gain Buffer

- Safely cascading circuit modules



$$U^+ = V_{in}$$

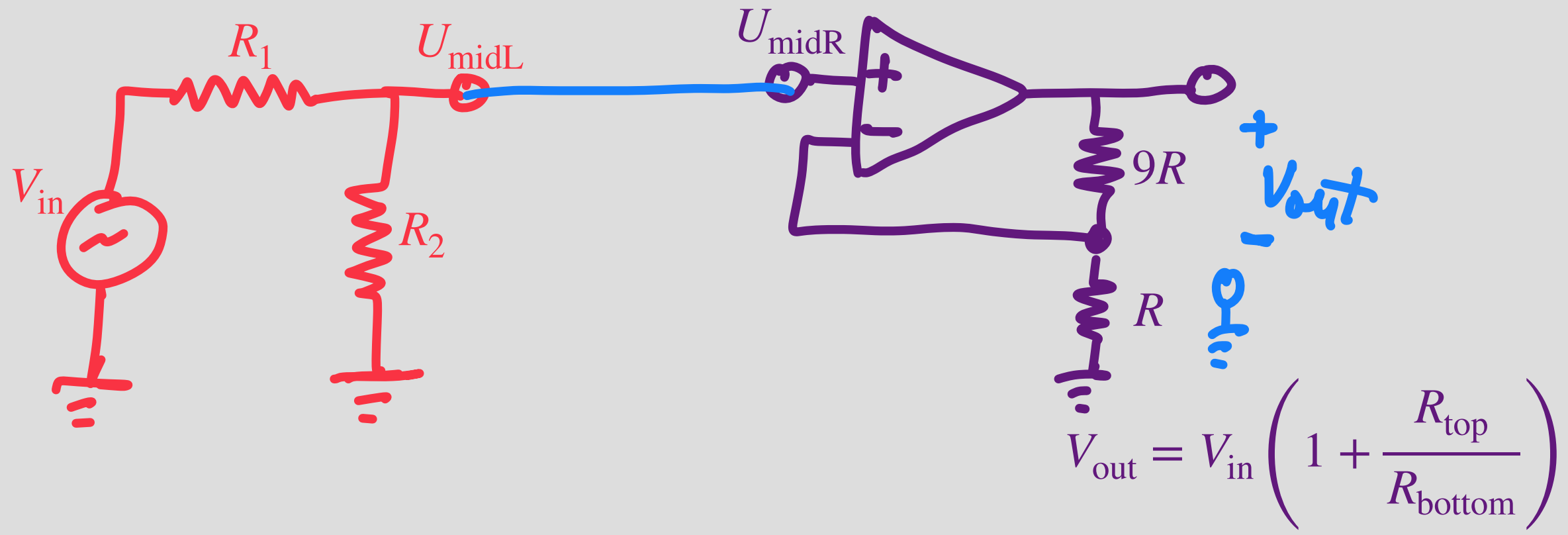
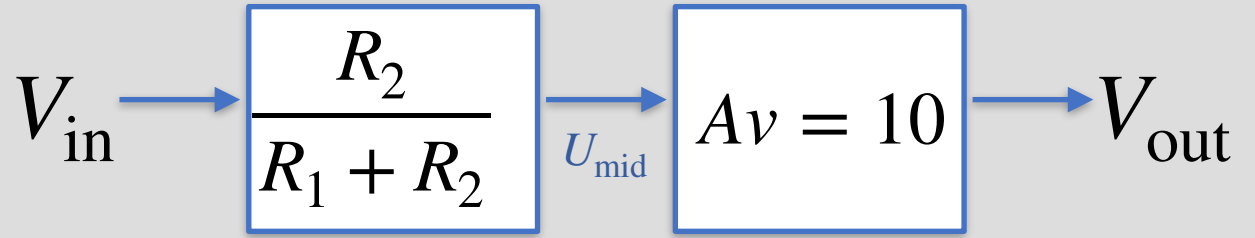
$$U^- = V_{out}$$

NFB \Rightarrow Golden Rule #2 $\Rightarrow U^- = U^+$

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

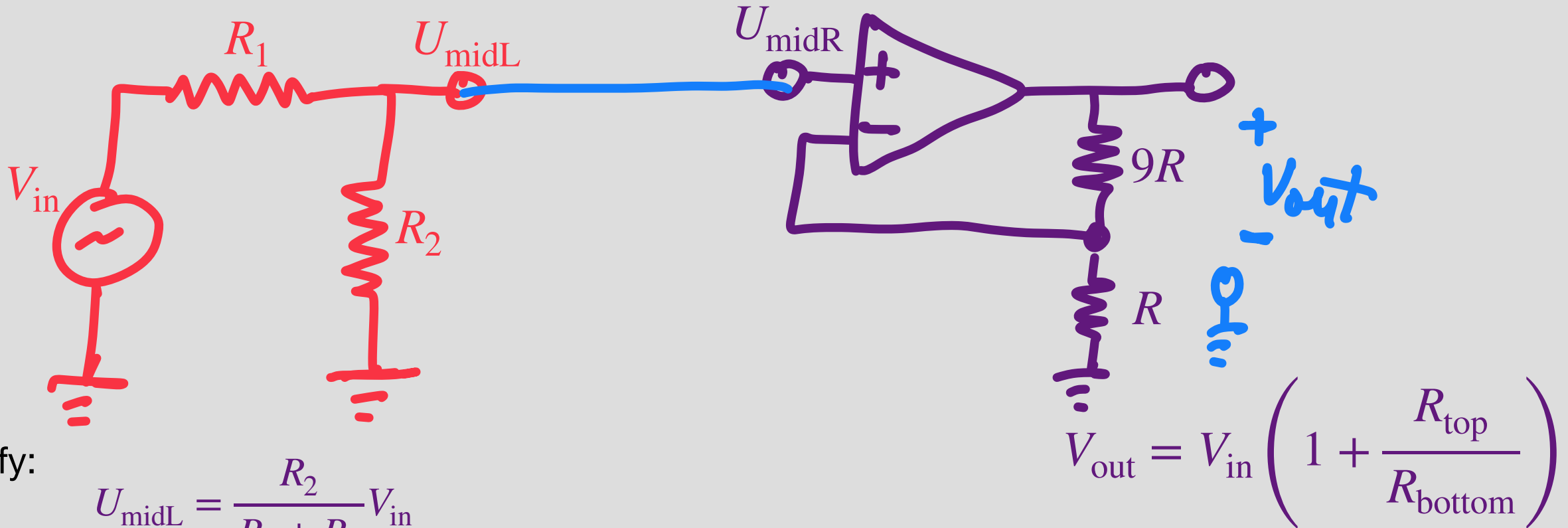
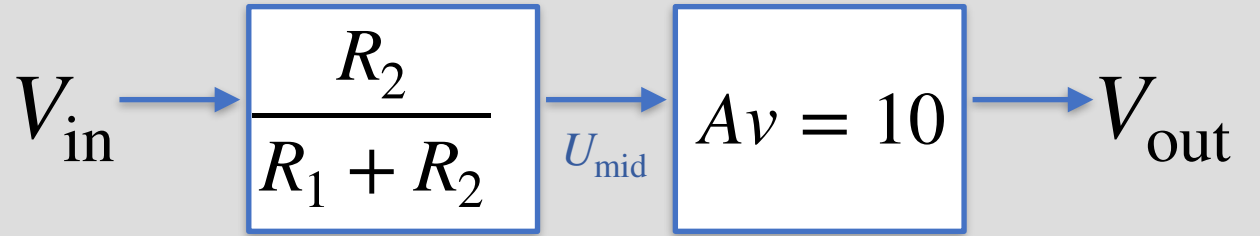
Example 1:

- Want to cascade two blocks:



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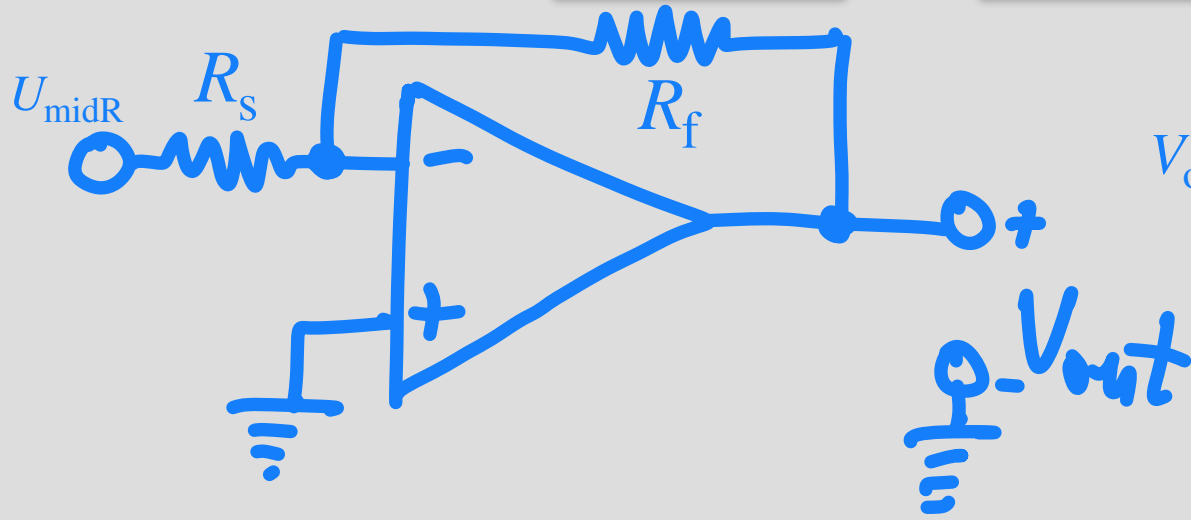
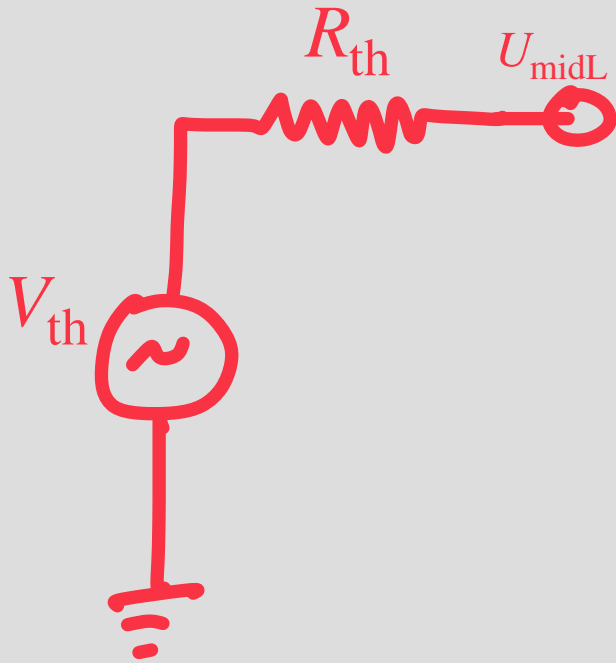
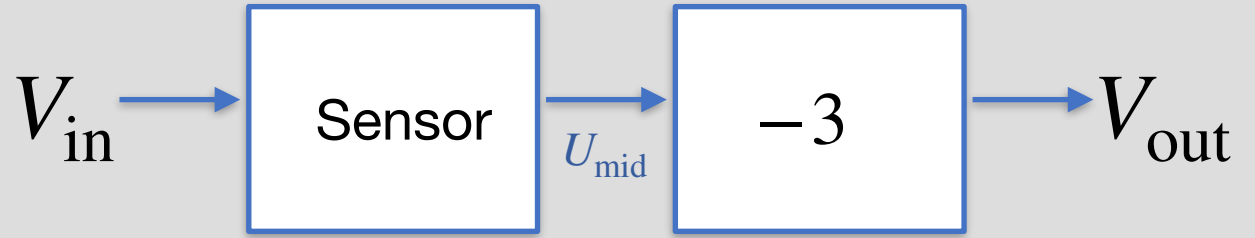
Verify:

$$U_{midL} = \frac{R_2}{R_1 + R_2} V_{in}$$

$$U_{midL} = U_{midR} \Rightarrow Av = \frac{V_{out}}{U_{midR}} = 10$$

Example 2:

- Want to cascade two blocks:



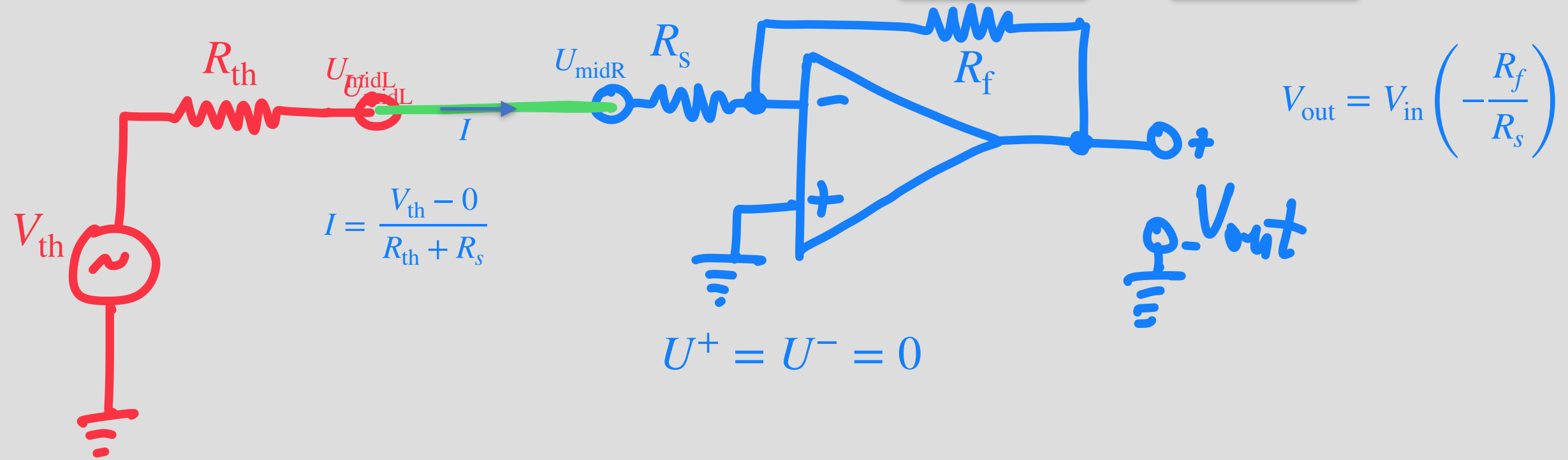
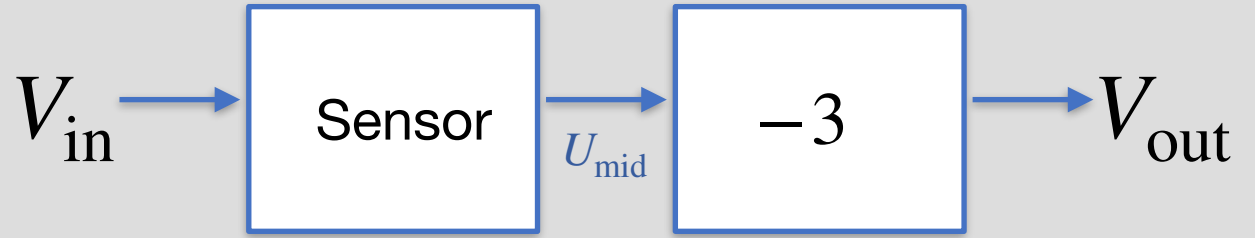
$$V_{out} = V_{in} \left(-\frac{R_f}{R_s} \right)$$

Before connection:

$$U_{midL} = V_{th}$$

Example 2:

- Want to cascade two blocks:



Before connection:

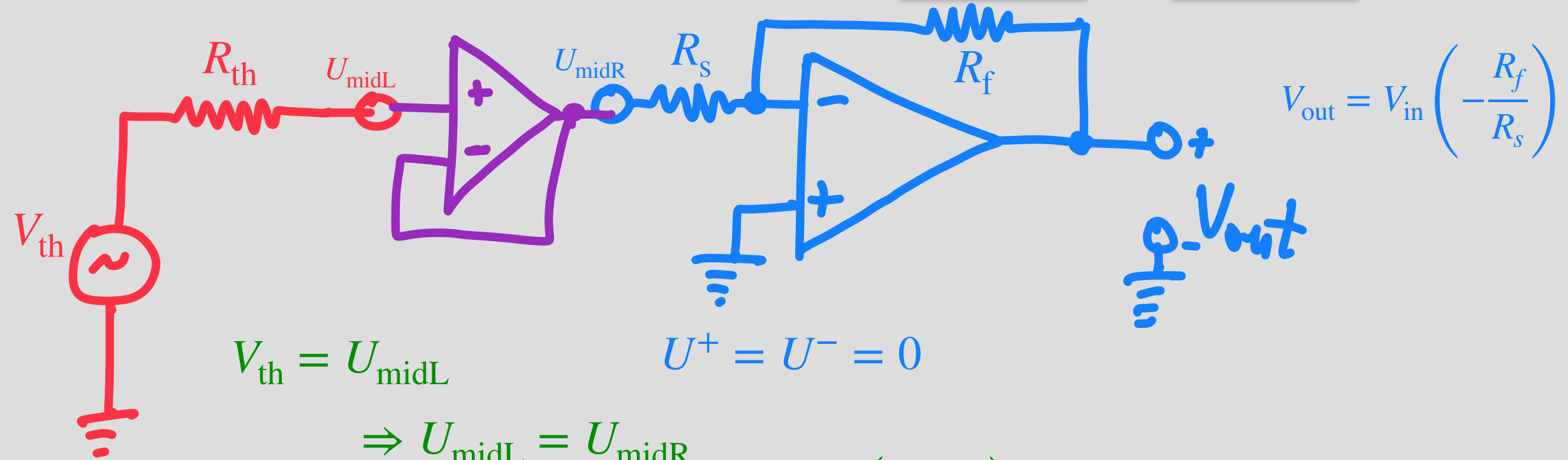
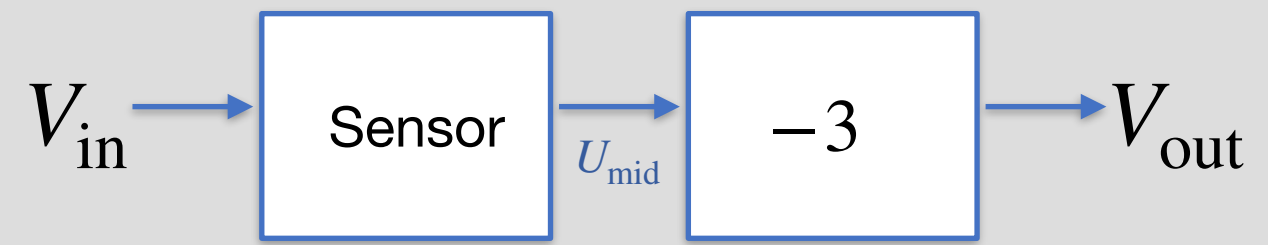
$$U_{midL} = V_{th}$$

When connected:

$$U_{midL} = \frac{R_s}{R_{th} + R_s} V_{th} \neq V_{th}$$

Example 2:

- Want to cascade two blocks:



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

$$V_{th} = U_{midL}$$

$$U^+ = U^- = 0$$

$$\Rightarrow U_{midL} = U_{midR}$$

$$\Rightarrow V_{out} = V_{in} \left(-\frac{3R}{R} \right)$$

Buffer:

Design Procedure

Step 1 (Specification): Concretely restate the goals for the design.

Frequently, a design prompt will include a lot of text, so we'd like to restate all of the most important features of our design. We'll refer to these specifications later to determine if our design is complete.

Step 2 (Strategy): Describe your strategy (often in the form of a block diagram) to achieve your goal. To do this, start by thinking about what you can measure vs. what you want to know.



Step 3 (Implementation): Implement the components described in your strategy. This is where pattern matching is useful: remind yourself of blocks you know, (ex. voltage divider, inverting amplifier) and check if any of these can be used to implement steps of your strategy.

Design Procedure

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Step 4 (Verification): Check that your design from Step 3 does what you specified in Step 1.

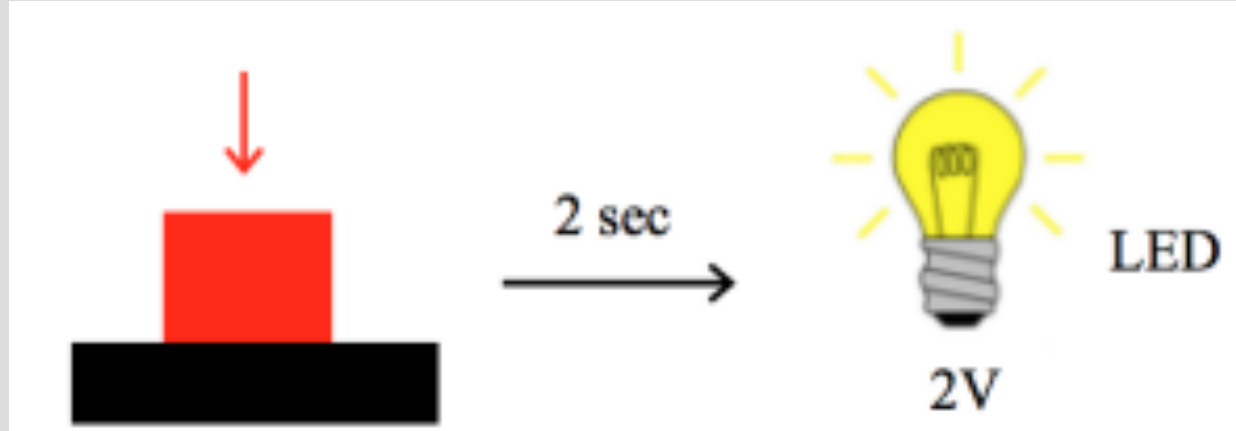
Check block-to-block connections, as these are the most common point for problems.

Does one block load another block causing it to behave differently than expected?

Are there any contradictions (ex. a voltage source with both ends connected by a wire, or a current source directed into an open circuit)?

Example 3

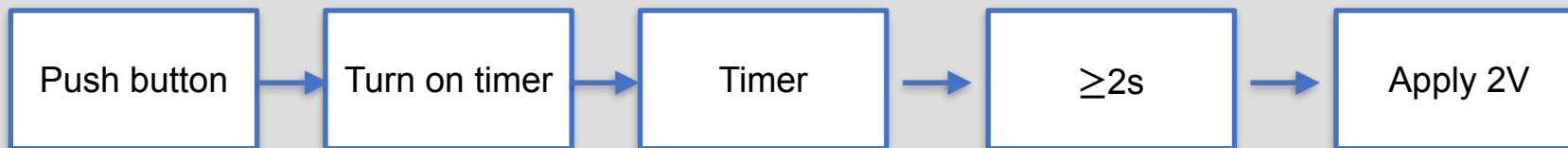
Your boss comes to you and asks you to build a countdown timer that will turn on a Light Emitting Diode (LED) two seconds after a button is pressed. She tells you that the LED will emit light when 2V is applied across it.



Step 1 (Specification):

Build a circuit that measures 2s after a button is pressed, then applies 2V across an LED. (Assume button is pressed only once.)

Step 2 (Strategy): Describe your strategy

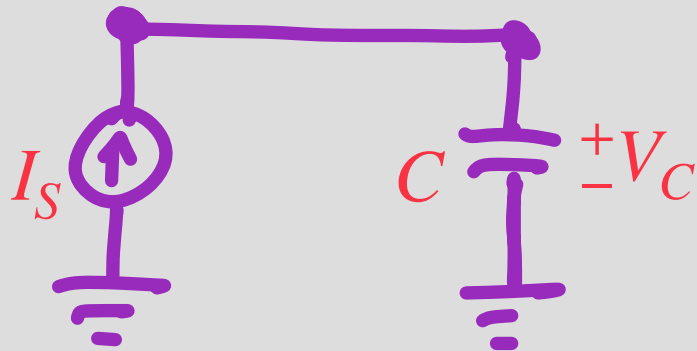


Step 3 (Implementation): Implement the components described in your strategy

Turn on circuit? :



Timer:

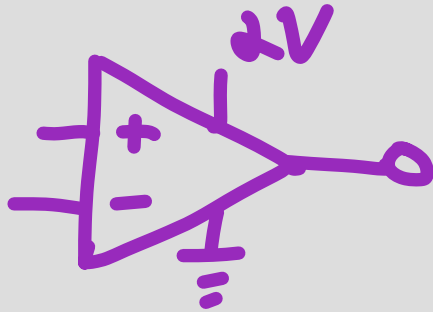


$$I_c = C \frac{dV_C}{dt}$$

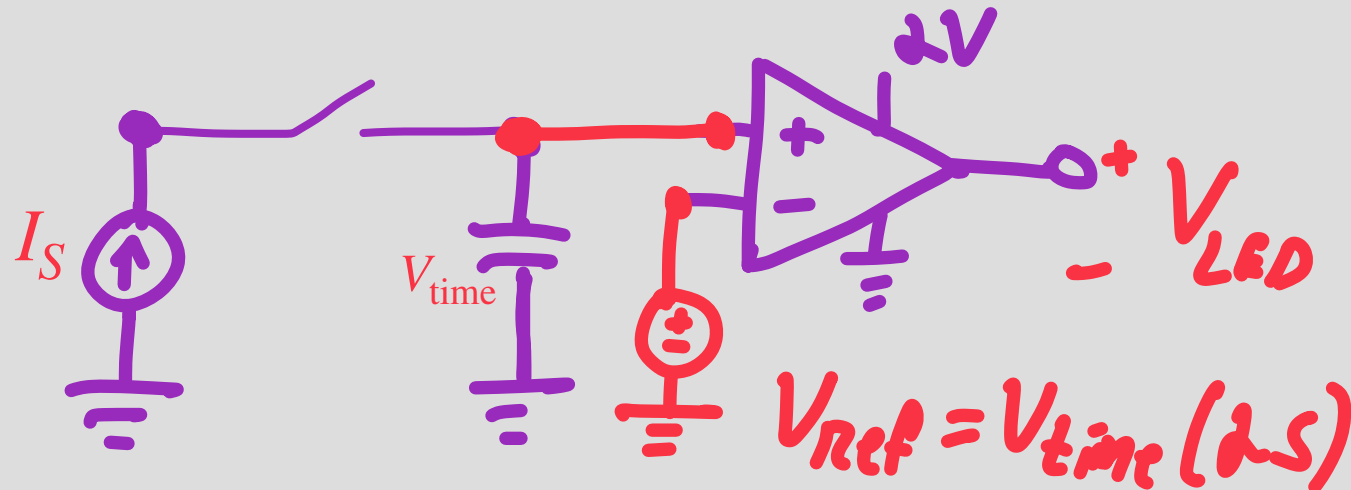
$$V_c(t) = \frac{I_s}{C}t + V_c(0)$$

V_{Time}

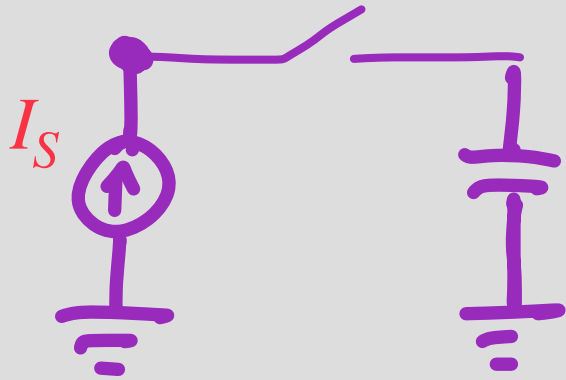
OpAmp:



Together:

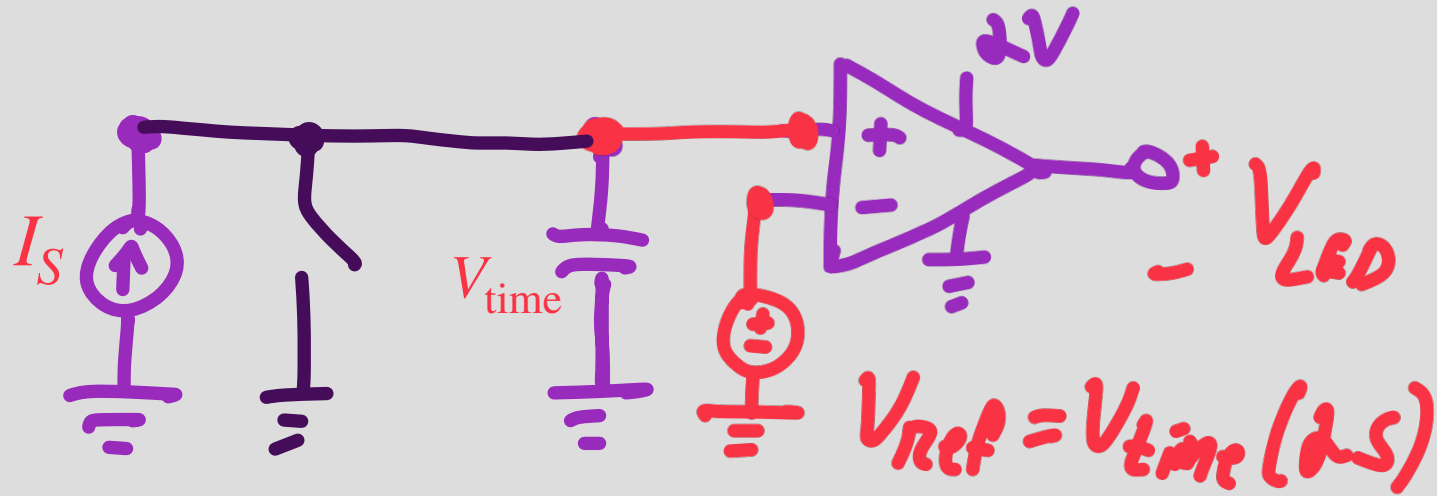


Step 4 Verify:

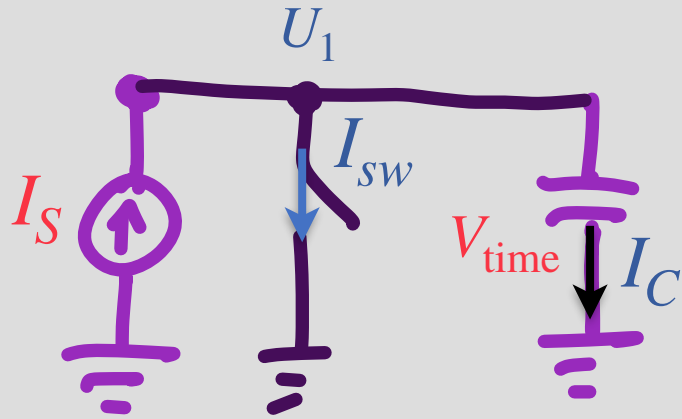


Q: Why is this a problem?

Revise:



Before button is pushed, the switch is on



$$V_{time} = ?$$

$$U_1 = 0$$

$$V_{time} = U_1 = 0$$

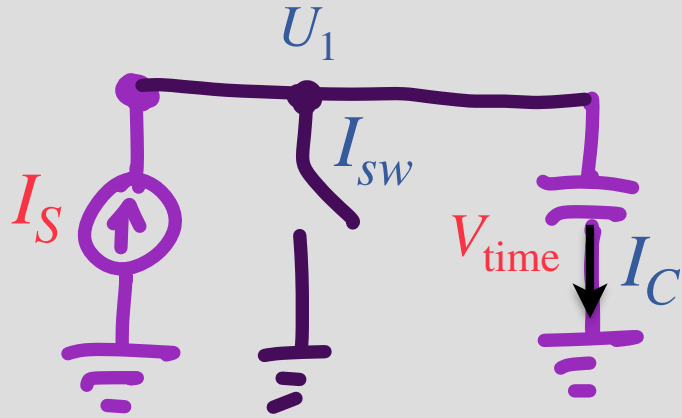
$$I_C = C \frac{dV_{time}}{dt} = 0$$

KCL:

$$I_S = I_{sw} + I_C$$

$$I_S = I_{sw}$$

After button is pushed, the switch is off



@ $t = t_0$

$$V_{\text{time}}(t_0) = 0$$

$$V_{\text{time}}(t) = \frac{I_S}{C}(t - t_0) + 0$$

$$V_{\text{time}}(t + 2) = V_{\text{ref}}$$

