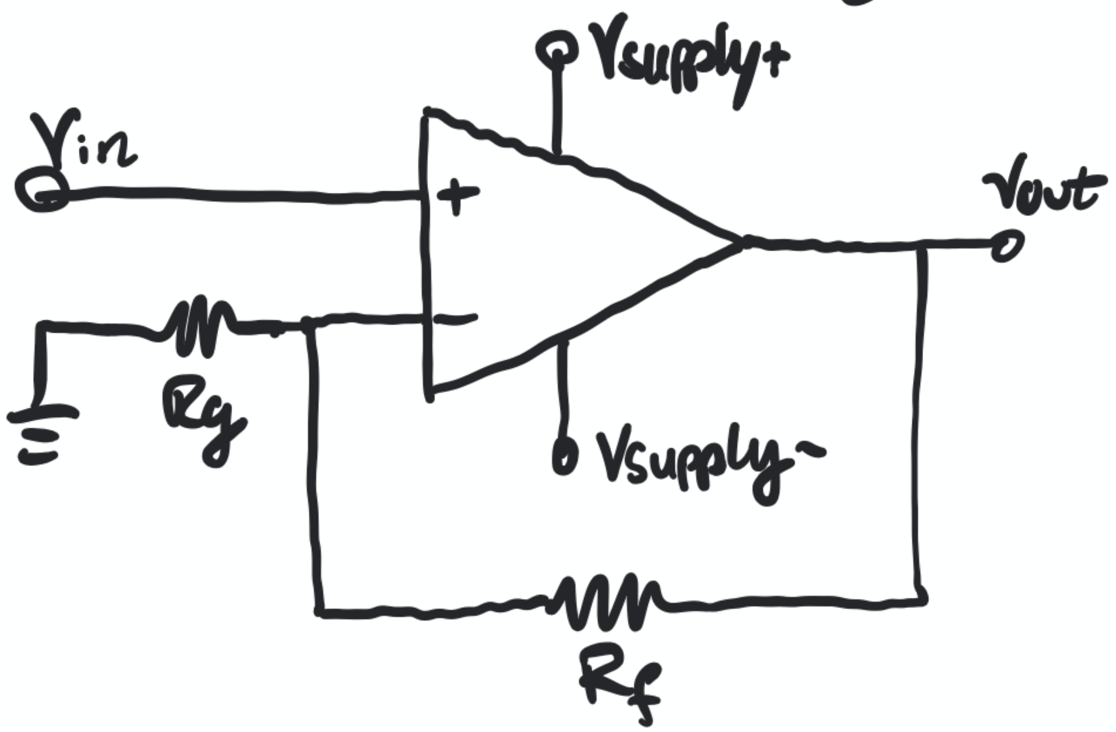
Intro to ECSE Lecture Notes 3/21/23

1) Cascading Op-Amps

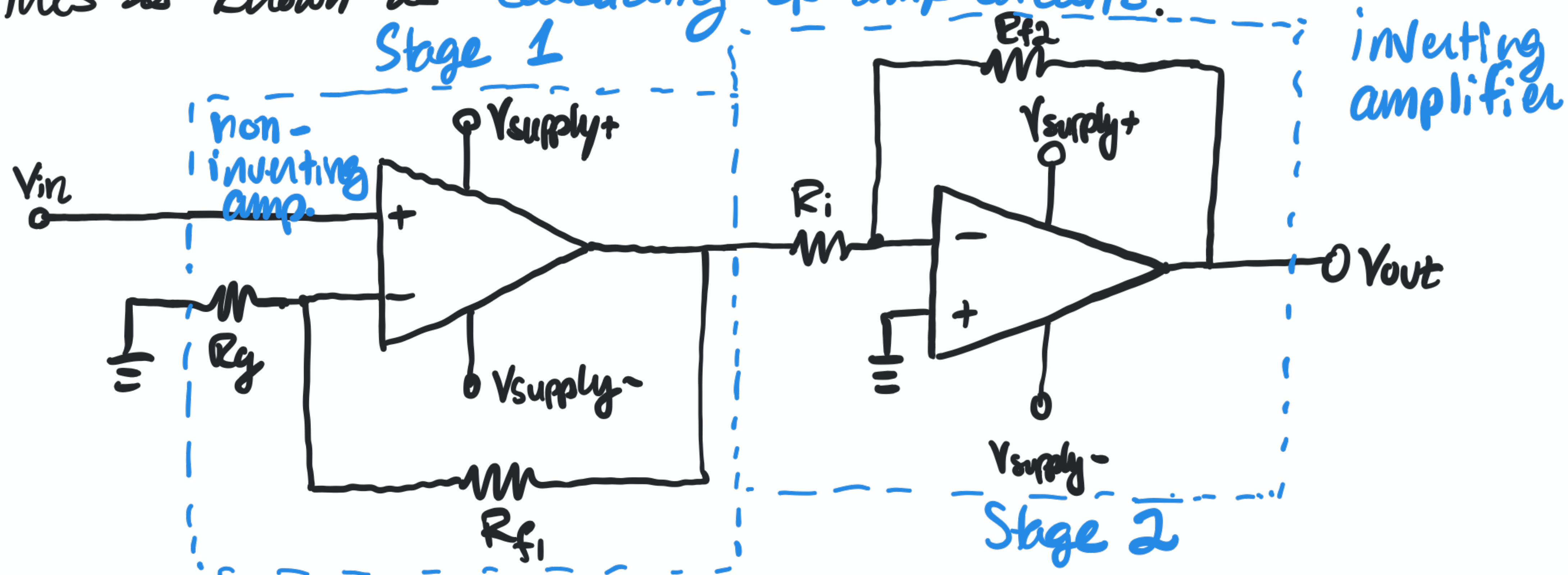
- We have seen that most op-amp circuits have a transfer function: $H = \frac{V_{out}}{V_{in}}$

Ex: For a non-inverting amplifier:



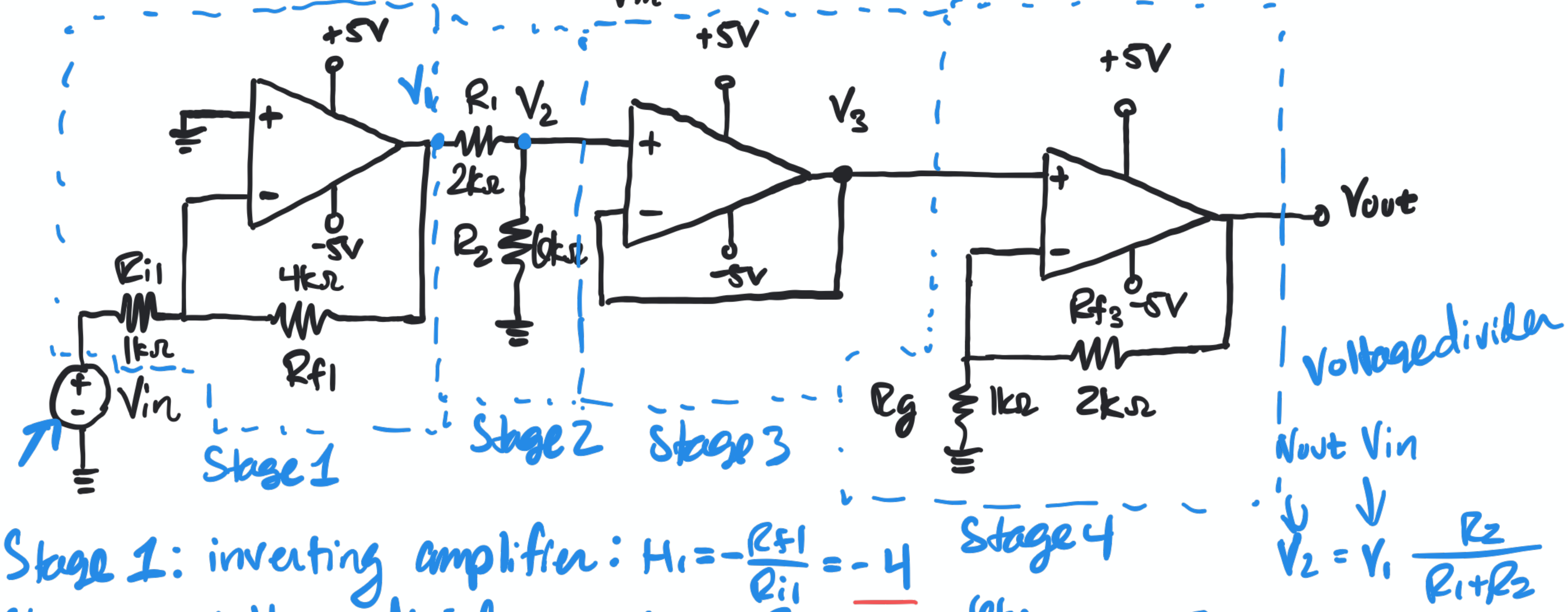
$$H = \frac{V_{out}}{V_{in}} = \left(1 + \frac{R_f}{R_g}\right) = \text{gain}$$

- But what if we have multiple op-amp circuits chained together? This is known as cascading op-amp circuits.



- How do we analyze this type of circuit?
  1) identify stages - draw boxes around / dividing lines between stages
  2) identify type of circuit - identify the function of each stage
  3) write H for each stage → $H_1 = \left(1+\frac{R_{f1}}{R_g}\right)$; $H_2 = -\frac{R_{f2}}{R_i}$
  4) Write total transfer function → $H_{total} = H_1 \times H_2$
     Product of the individual transfer functions
     $= \left(1+\frac{R_{f1}}{R_g}\right)\left(-\frac{R_{f2}}{R_i}\right)$

Example : What is $H_{total} = \frac{V_{out}}{V_{in}}$?



Stage 1: inverting amplifier: $H_1 = -\frac{R_{f1}}{R_{i1}} = -4$

Stage 2: Voltage divider : $H_2 = \frac{R_2}{R_1+R_2} = \frac{6k\Omega}{8k\Omega} = 0.75$

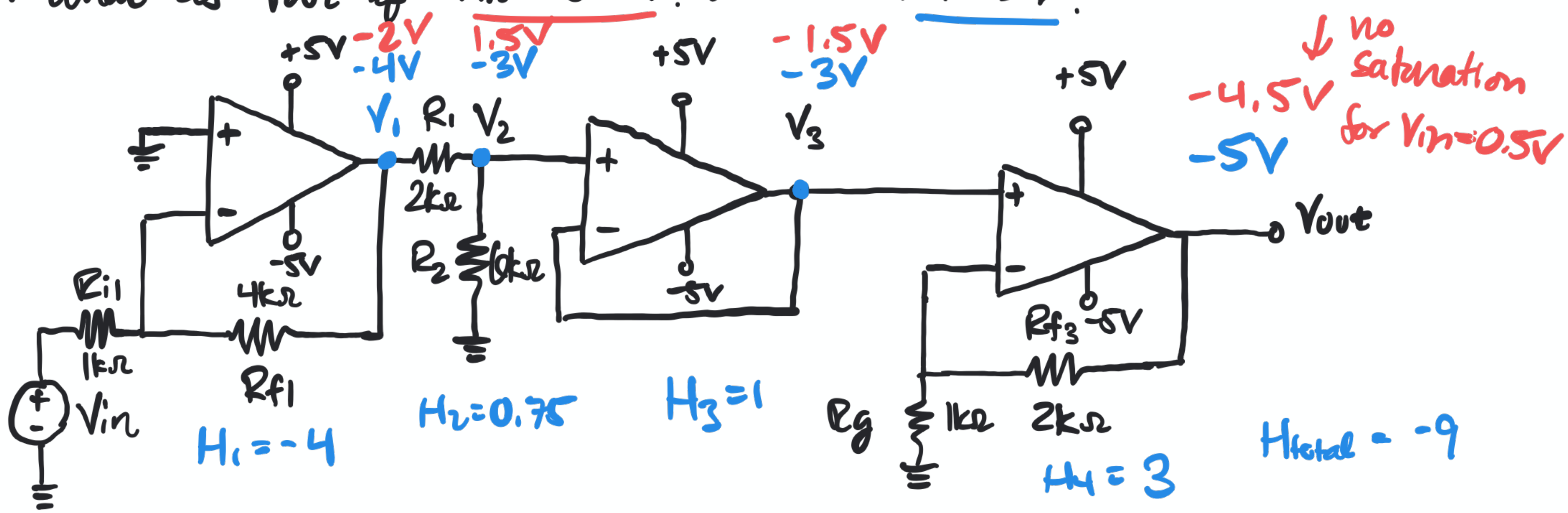
Stage 3: Voltage follower (buffer): $H_3 = 1$

Stage 4: non-inverting amplifier : $H_4 = \left(1 + \frac{R_{f3}}{R_g}\right) = \left(1 + \frac{2k\Omega}{1k\Omega}\right) = 3$

Total Transfer function $H_{Total} = H_1 \cdot H_2 \cdot H_3 \cdot H_4 = (-4)(.75)(1)(3)$

$= -9$ | $V_{out} = -9V_{in}$

Ex: What is Vout if Vin = 0.5V? What if Vin = 1V?



- For Vin = 1; $V_1 = H_1 \cdot V_{in} = -4V$ ✓,

$+5V = -4 \cdot V_{in,max} \rightarrow V_{in,max} = -\frac{5}{4}V$

$V_{out,max} = H_1 \cdot V_{in,max}$

$V_2 = H_2 \cdot V_1 = 0.75 \cdot (-4) = -3V$

$V_3 = H_3 \cdot V_2 = 1 \cdot (-3V) = -3V$ ✓

$V_4 = H_4 \cdot V_3 = 3 \cdot (-3V) = -9V$ ✗ → actually $-5V$ (Vsupply-)

signal will be distorted

$V_{out,max} = H_3 \cdot V_{in,max}$

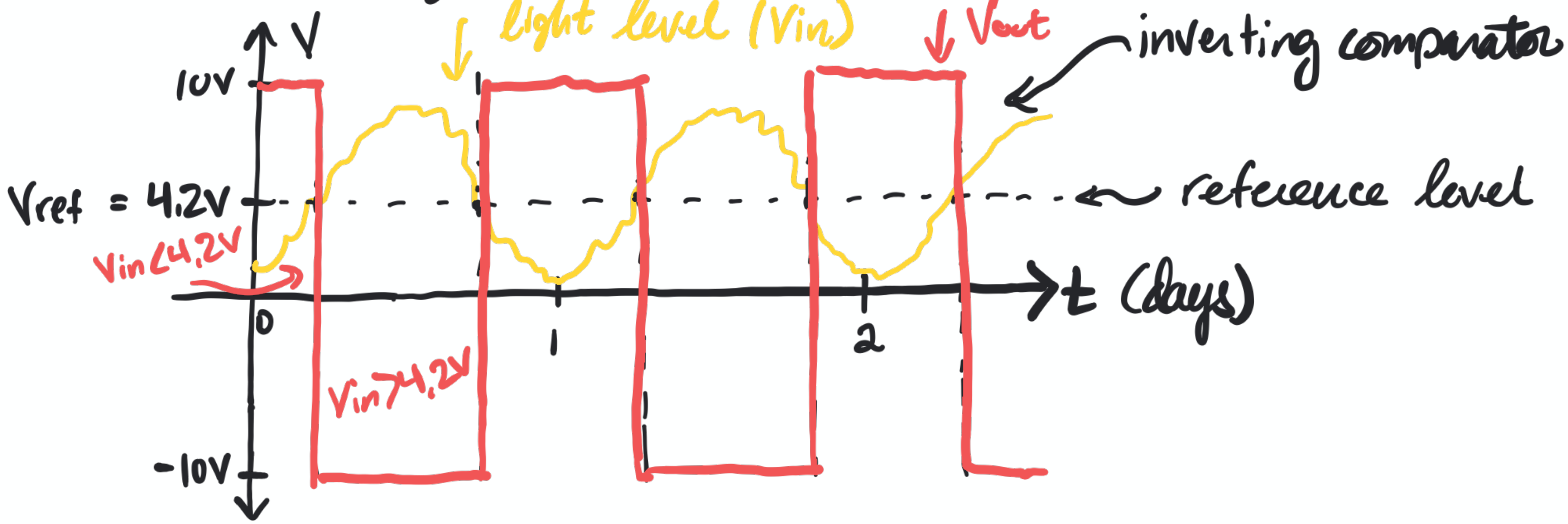
$-5V = 3 \cdot V_{in,min} \rightarrow V_{in,min} = -\frac{5}{3}V$

- For Vin = 0.5V

2) Setting Thresholds / Reference Levels for Sensors

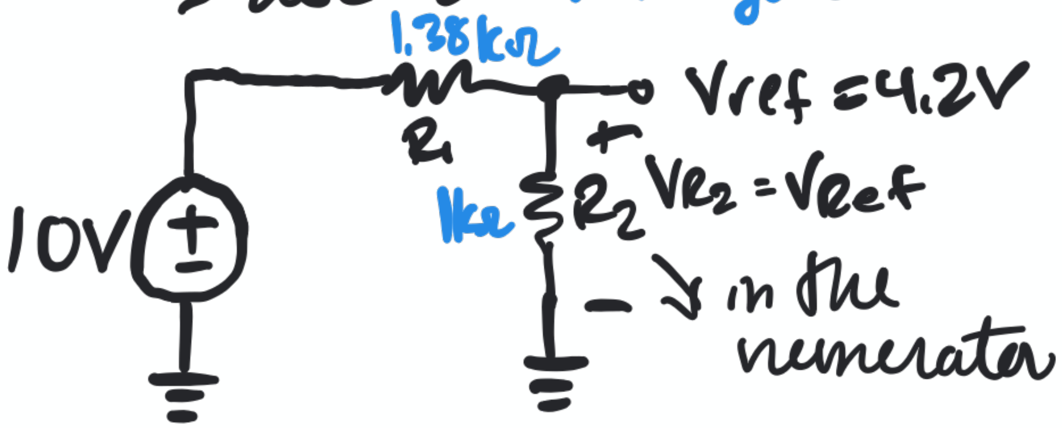
Task: you are given +10V and −10V voltage supplies. Design a circuit that switches the output to 10V when the input voltage is less than 4.2V and −10V when the input is greater than 4.2V.

· **Rationale**: Sensing. Suppose you have a sensor that changes the voltage it outputs depending on the level of light. You want to do something (say turn on a light) when the light level crosses a certain threshold.



1) Generate the reference voltage from the available supply

↳ use a voltage divider to convert 10V to 4.2V



$$V_{ref} = V_s \frac{R_2}{R_1 + R_2}$$

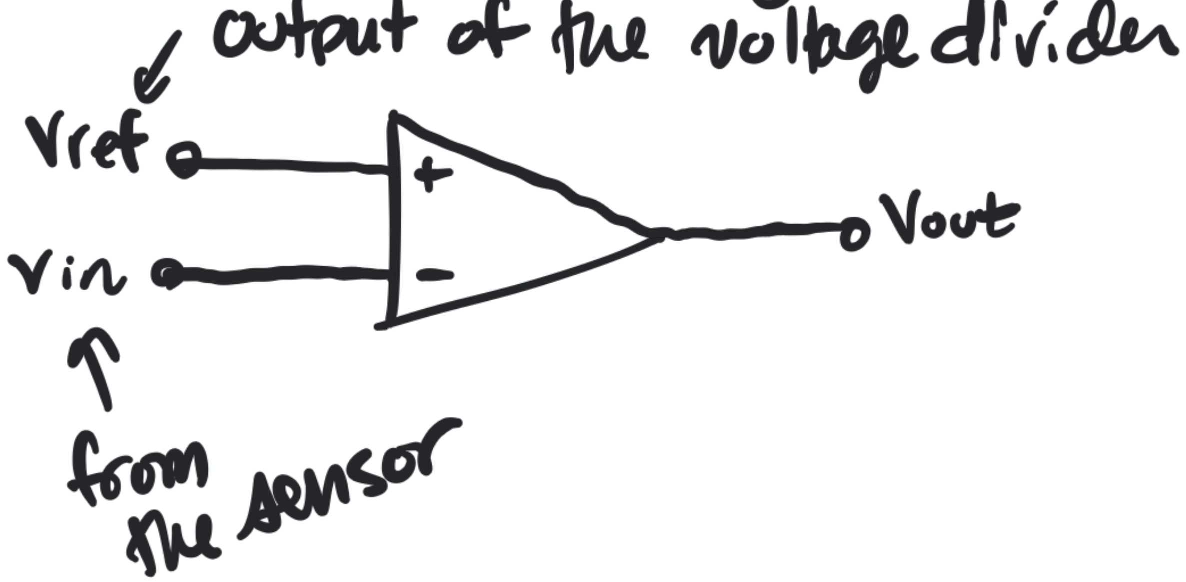
$$4.2V = 10V \frac{R_2}{R_1 + R_2}$$

Choose

$R_2 = 1k\Omega \rightarrow R_1 = 1.38k\Omega$

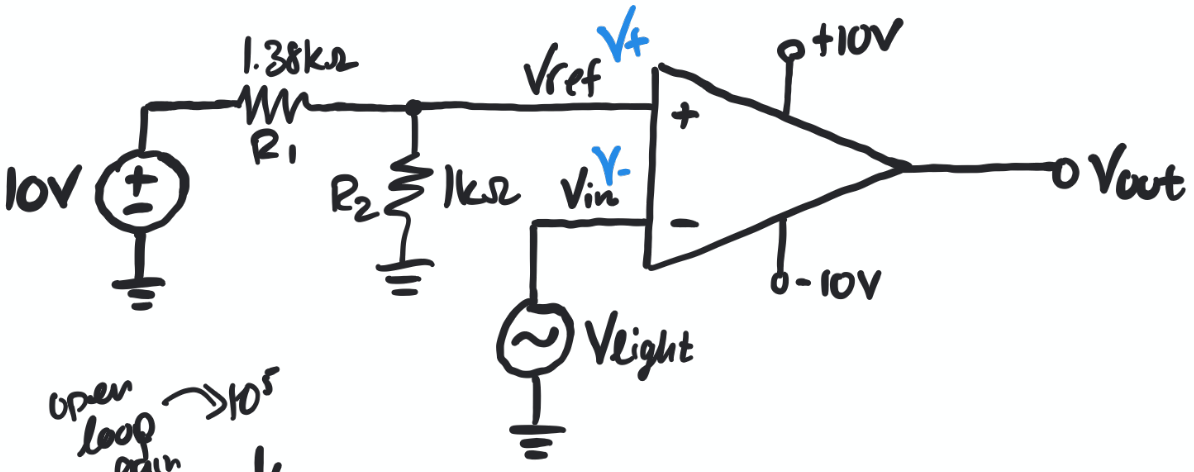
$$\frac{R_2}{R_1+R_2} \approx 0.42$$

2) Set up the circuit (inverting comparator)



2) Use the correct decision-making circuit (comparator)

↳ <u>Inverting Comparator</u>



open loop gain → 10^5

$V_{out} = A_0 (V_+ - V_-)$ → $V_{max,out} = +V_{supply}$, $V_{min,out} = -V_{supply}$ ⇒ $V_{out} = \begin{cases} +V_{supply} & \text{when } (V_+ - V_-) > 0 \\ -V_{supply} & \text{when } (V_+ - V_-) < 0 \end{cases}$

- How do we decide what type of comparator we have?

$V_{out} = \begin{cases} V_{out} = +V_{supply} & \text{when } (V_{in} - V_{ref}) > 0 \\ V_{out} = -V_{supply} & \text{when } (V_{in} - V_{ref}) < 0 \end{cases}$ } non-inverting comparator, $V_+ = V_{in}$, $V_- = V_{ref}$

$V_{out} = \begin{cases} V_{out} = -V_{supply} & \text{when } (V_{in} - V_{ref}) > 0 \\ V_{out} = +V_{supply} & \text{when } (V_{in} - V_{ref}) < 0 \end{cases}$ } inverting comparator, $V_+ = V_{ref}$, $V_- = V_{in}$ (circuit above)

- Which one to choose depends on the application

- How Could we use this circuit to make a decision?
  - ↳ Turn on an LED when $V_{light} < 4.2V$