Review Session: Op-Amps and Circuit Design

EECS 16A

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Reminders: a) Course evals by Sun (course-evaluations.berkeley.edu)

b) Last Prof. OH

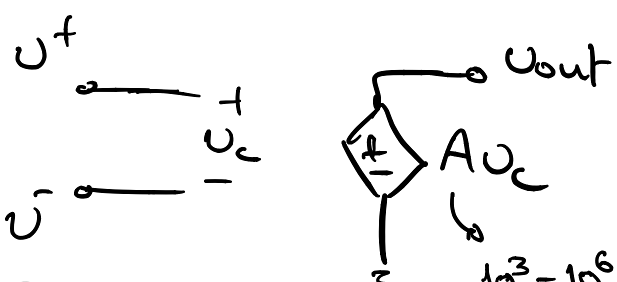
Prof. Zarkos : 8/13 – 10-11am , 8/14 – 10-11am

Prof Kuo : 8/13 – 2-3pm

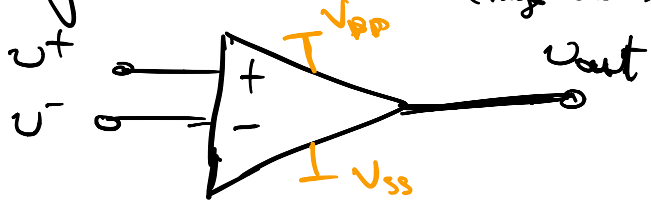
Prof Sikder: 8/14 – 1-2pm

1) Op-Amp Fundamentals

Model:

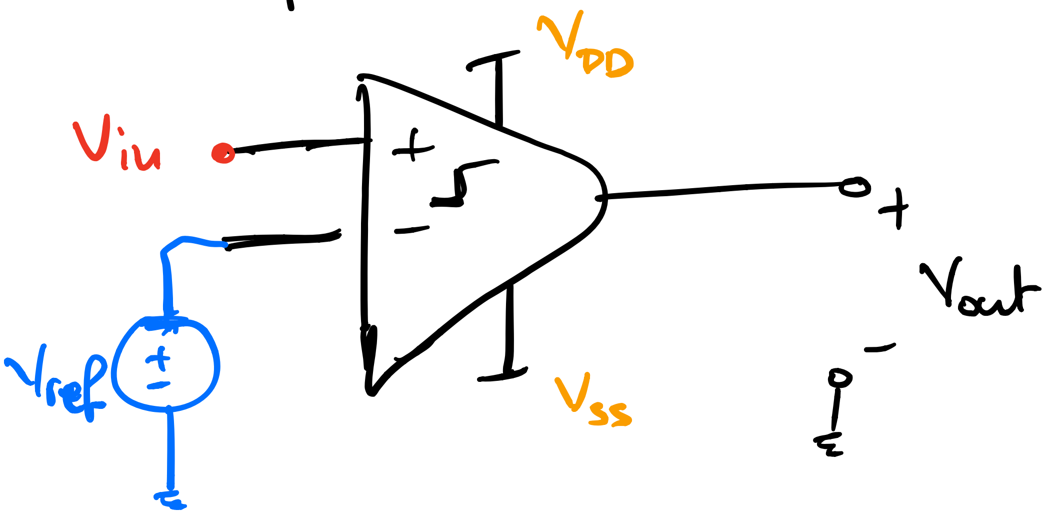


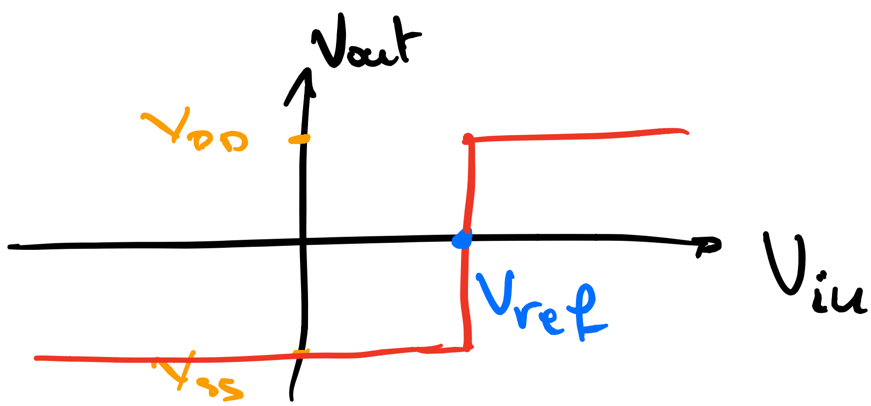
Symbol:



Caveat: V_{DD} and V_{SS} supply power to the op amp (often not drawn for convenience)

a) Comparators





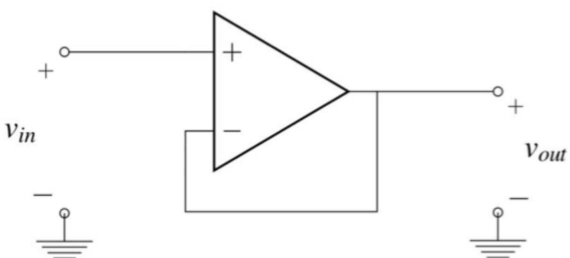
b) Amplifiers and Buffers

In NFB we have two...

GOLDEN RULES:

1) $i_+ = i_- = 0$

2) $v_+ = v_-$ (if $A \to \infty$)

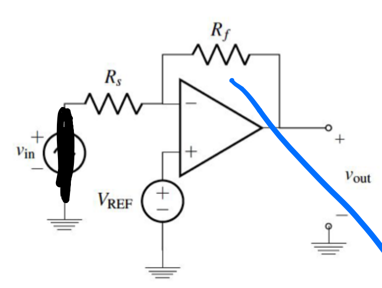


Unity gain buffer

$V_{out} = V_{in}$

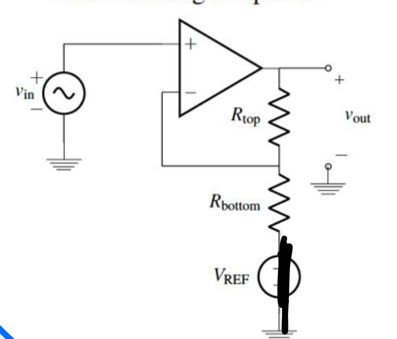
More Useful Op Amp Topologies

Inverting Amplifier



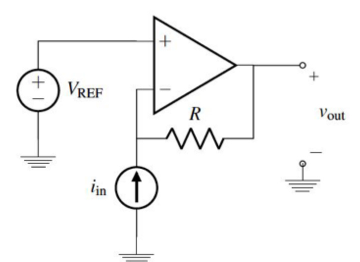
$v_{out} = v_{in}\left(-\frac{R_f}{R_s}\right) + V_{REF}\left(\frac{R_f}{R_s} + 1\right)$

Non-inverting Amplifier

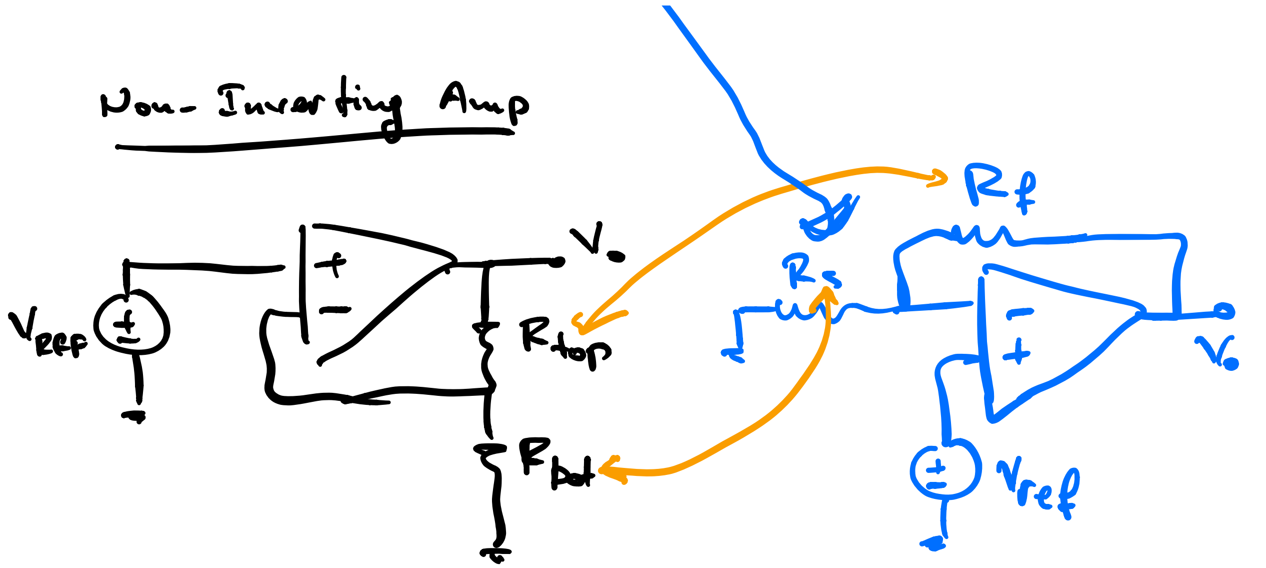


$v_{out} = v_{in}\left(1 + \frac{R_{top}}{R_{bottom}}\right) - V_{REF}\left(\frac{R_{top}}{R_{bottom}}\right)$

Transresistance Amplifier



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



Design Procedure

Patient
Don't get intimidated.

1) Specification → restate the goal (concisely and concretely)

↺ iteration

2) Strategy → Divide + Conquer!

Block Diagrams

→ what can I measure?
→ what do I need to know?

) Relationship

3) Implementation → ckts that I know
↪ extensions of these ckts

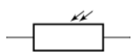
4) Verification → does step 3 do what was stated in step 1
↪ check block-to-block connections (loading)

2) Practice Time!

Design #1: Fa'16 Final / HW 5A

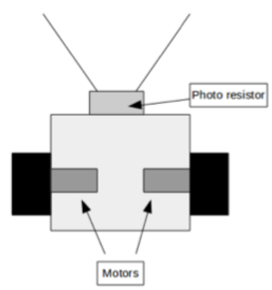
2. PetBot Design

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



$R_p \uparrow$ when light $\downarrow$, $R_p \downarrow$ when light $\uparrow$

Below is the basic layout of the PetBot. It has one motor on each wheel. We will model each motor as a $1\,\Omega$ resistor. When motors have positive voltage across them, they drive forward; when they have negative voltage across them, they drive backward. At zero voltage across the motors, the PetBot stops. The speed of the motor is directly proportional to the magnitude of the motor voltage. The light sensor is mounted to the front of the robot.



$R_{mot} = 1\,\Omega$

$V_{Rmot} = 0$: stop

$V_{Rmot} > 0$: move fwd

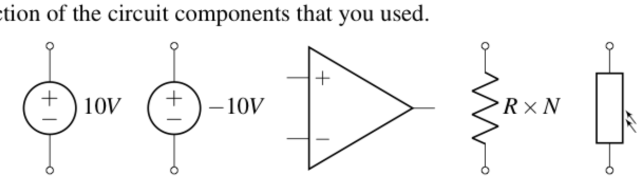
$V_{Rmot} < 0$: move back

when $R_p = 10k\Omega$ (far away) I want $V_{motor} = 5V$

Smaller R_p as I approach the light

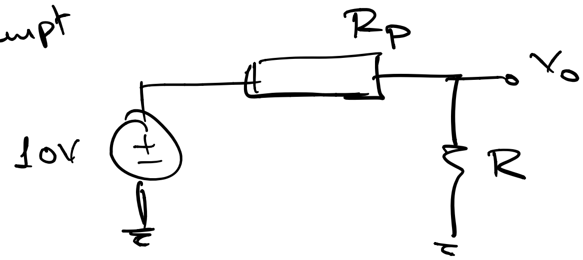
(a) **Speed control** – Let us begin by first having PetBot decrease its speed as it drives toward the flashlight. Design a motor driver circuit that outputs a decreasing positive motor voltage as the PetBot drives toward the flashlight. The motor voltage should be at least 5 V far away from the flashlight. When far away from the flashlight, the photoresistor value will be $10\,k\Omega$ and dropping toward $100\,\Omega$ as it gets closer to the flashlight.

In your design, you may use any number of resistors with any value and just 1 op-amp. 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.



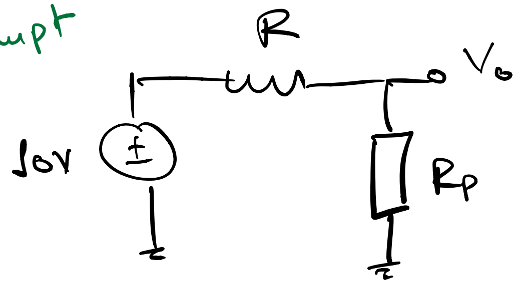
when I approach $R_p \downarrow$ ⇒ $V_o \downarrow$

Attempt #1



$$V_o = \frac{R}{R + R_p} \cdot 10V$$

Attempt #2



$$V_o = \frac{R_p}{R + R_p} 10V$$

$\nearrow \frac{1}{2}$

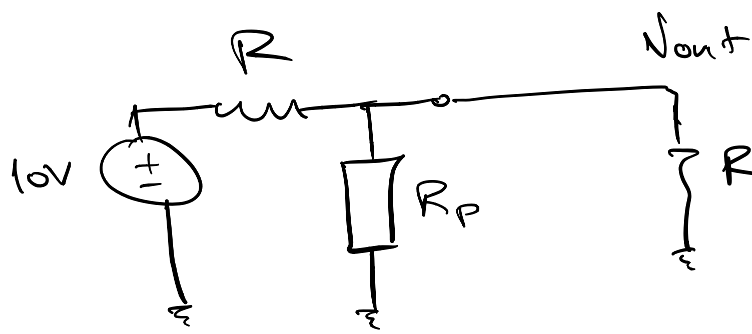
when I approach

$R_p \downarrow \Rightarrow V_o \downarrow$

Want $V_o = 5$

$\Rightarrow \frac{R_p}{R + R_p} = 1/2$ I know R_p far away is 10kΩ

$R = 10k$ or $R < 10k$ since $V_o \geq 5V$ is required

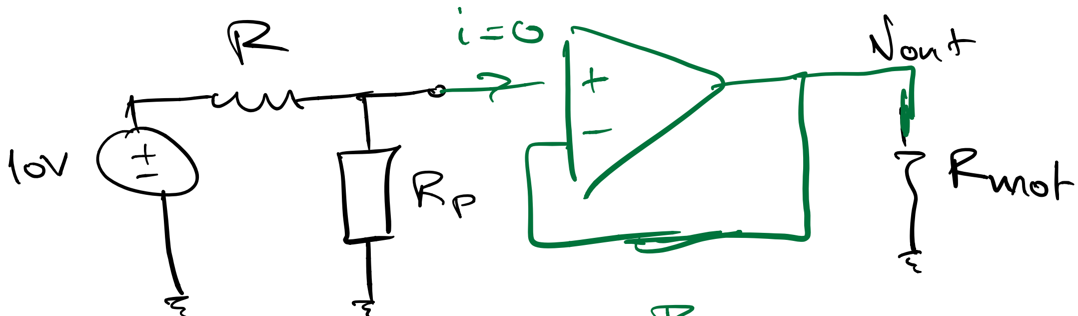


$$V_o = \frac{R_p}{R + R_p} \cdot 10V \quad \text{(desired)}$$

$$V_o = \frac{R_p // R_{mot}}{R_p // R_{mot} + R} \cdot 10V$$

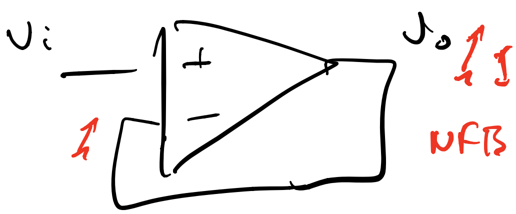
LOADING :(

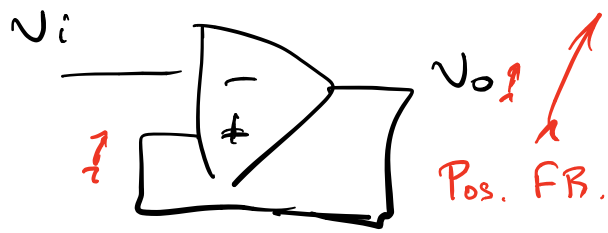
different than the desired V_o!



$$V_{out} = V_+ = \frac{R_p}{R + R_p} \cdot 10V$$

Desired :)



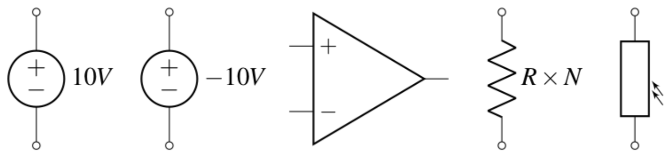


$$V_o = A(v^+ - v^-)$$

(b) **Distance control** – Let us now have PetBot drive up to a flashlight (or away from the flashlight) and stop at distance of 1 m away from the light. At the distance of 1 m from the flashlight, the photoresistor has a value 1 kΩ.

Design a circuit to output a motor voltage that is positive when the PetBot is at a distance greater than 1 m from the flashlight (making the PetBot move toward it), zero at 1 m from the flashlight (making the PetBot stop), and negative at a distance of less than 1 m from the flashlight (making the PetBot back away from the flashlight.)

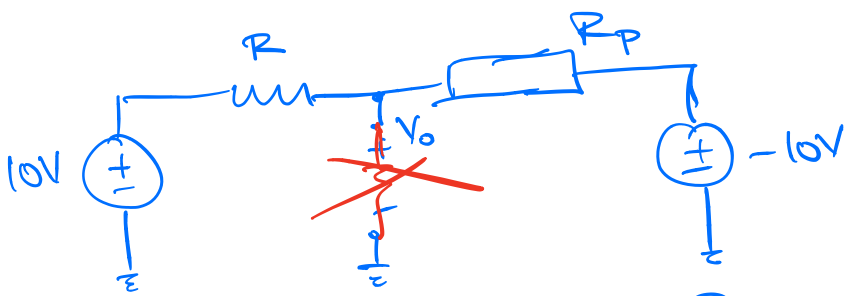
In your design, you may use any number of resistors of any value and just 1 op-amp. You also have access to voltage sources of 10 V and −10 V. Based on your circuit, derive an expression for the motor voltage as a function of the values of circuit components that you used.



Want $V_{mot} = 0$ when $d = 1m \to R_p = 1k\Omega$

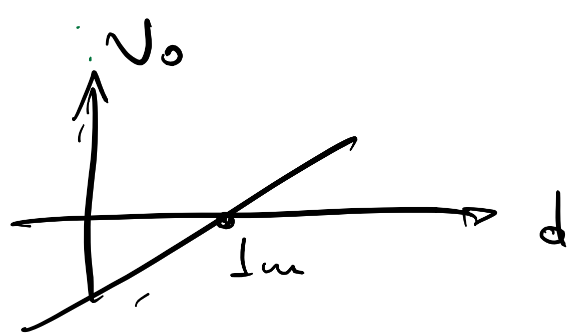
$V_{mot} > 0$ when $R_p > 1k$

$V_{mot} < 0$ when $R_p < 1k$



$$V_o = \frac{R_p}{R+R_p}\cdot 10V + \frac{R}{R+R_p}(-10V)$$

I want:



$$V_o = \frac{R_p - R}{R_p + R} 10V$$

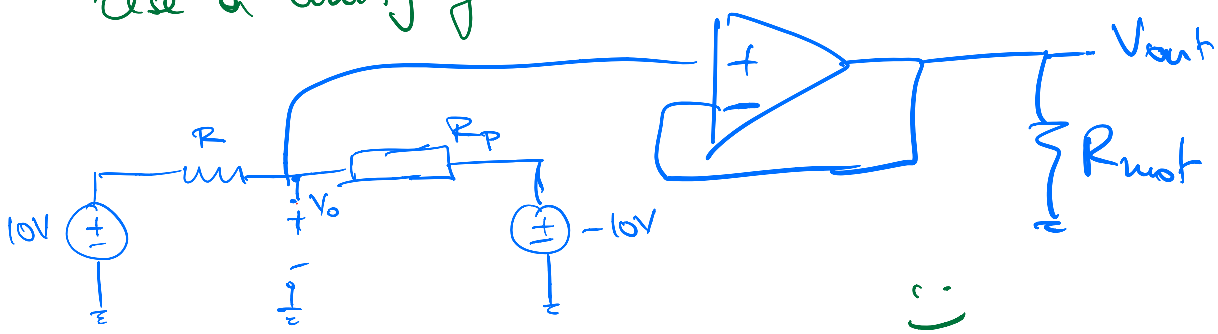
Want $V_o = 0V$ when $R_p = 1k\Omega$

$\Rightarrow R_p - R = 0$ when $R_p = 1k\Omega$

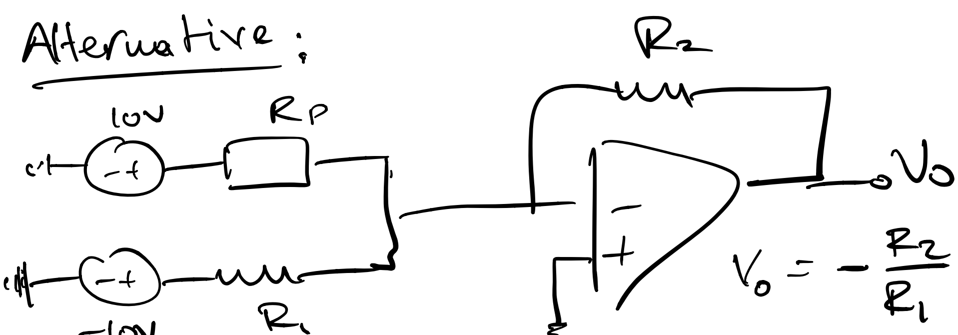
$\Rightarrow R = 1k\Omega$

If $d > 1m \Rightarrow R_p > 1k\Omega \Rightarrow V_o > 0$

Use a unity gain buffer to avoid loading!



Alternative:



$$V_o = -\frac{R_2}{R_1}(-10V) - \frac{R_2}{R_p}10V$$

$$= R_2 \cdot 10V \left(\frac{1}{R_1} - \frac{1}{R_p} \right)$$

Design #2: Fa' 19 Final

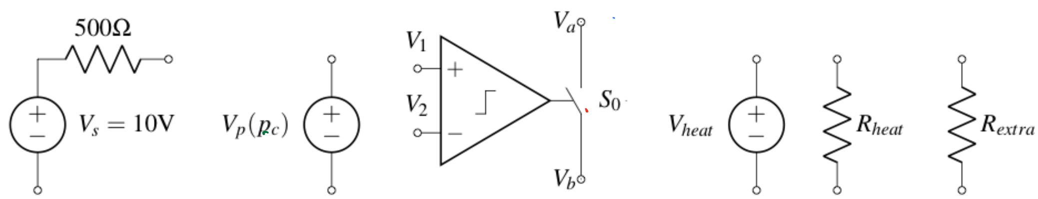
(e) **Pressure Regulation** (8 points)

You are finally ready to complete the design of your pressure cooker.

Using the circuit elements below, make a circuit that will turn the heater to on (i.e. current flowing through R_{heat}) when the pressure is less than 500 kPa, and off (i.e. no current flowing through R_{heat}) when the pressure is greater than 500 kPa.

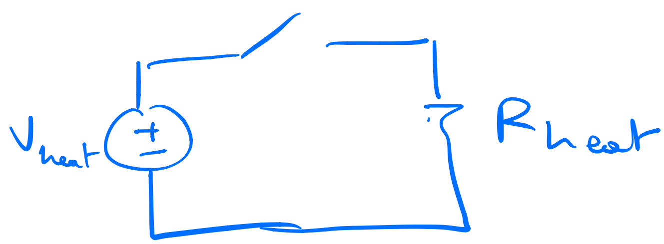
The elements are:

- A voltage source $V_s = 10\text{V}$ with a Thevenin resistance of 500Ω.
- A voltage source $V_p(p_c) = V_o \times \frac{p_c}{p_{ref}}$, with V_o = 1V and $p_{ref} = 100\text{kPa}$. (This is a voltage source whose voltage is a function of pressure p_c, unrelated to any previous parts of the question.)
- A comparator that controls switch S_0. The switch is normally opened (i.e. an open circuit between nodes V_a and V_b), and is closed only when $V_1 > V_2$ (i.e. a short circuit between nodes V_a and V_b).
- The heater supply ($V_{heat} = 100\text{V}$).
- The heater resistor R_{heat}.
- One additional resistor R_{extra}. If you use this resistor you must calculate and note its value on your circuit diagram.
- You may assume you have access to a ground node.



$I_{Heat} > 0$ when $P < 500\text{kPa}$

$I_{Heat} = 0$ when $P > 500\text{kPa}$

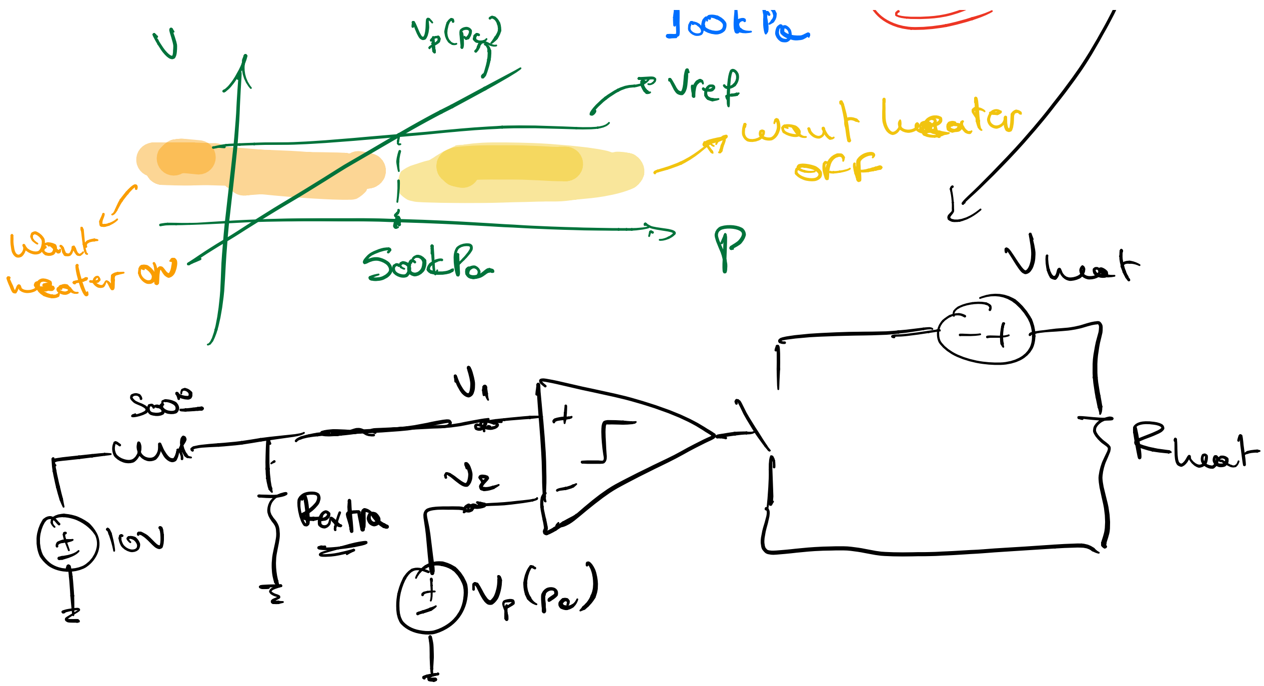


(hold on to this)

Look at the input:

$$V_p(p_c) = V_o \cdot \frac{p_c}{p_{ref}}$$

$$V_p(500\text{kPa}) = 1\text{V} \cdot \frac{500\text{kPa}}{\ } = 5\text{V}$$



$$10V \cdot \frac{R_{extra}}{R_{extra} + 500} = 5V \Rightarrow R_{extra} = 500\Omega$$