Op-amp Hysteresis Voltage Comparators

Comparators with positive feedback

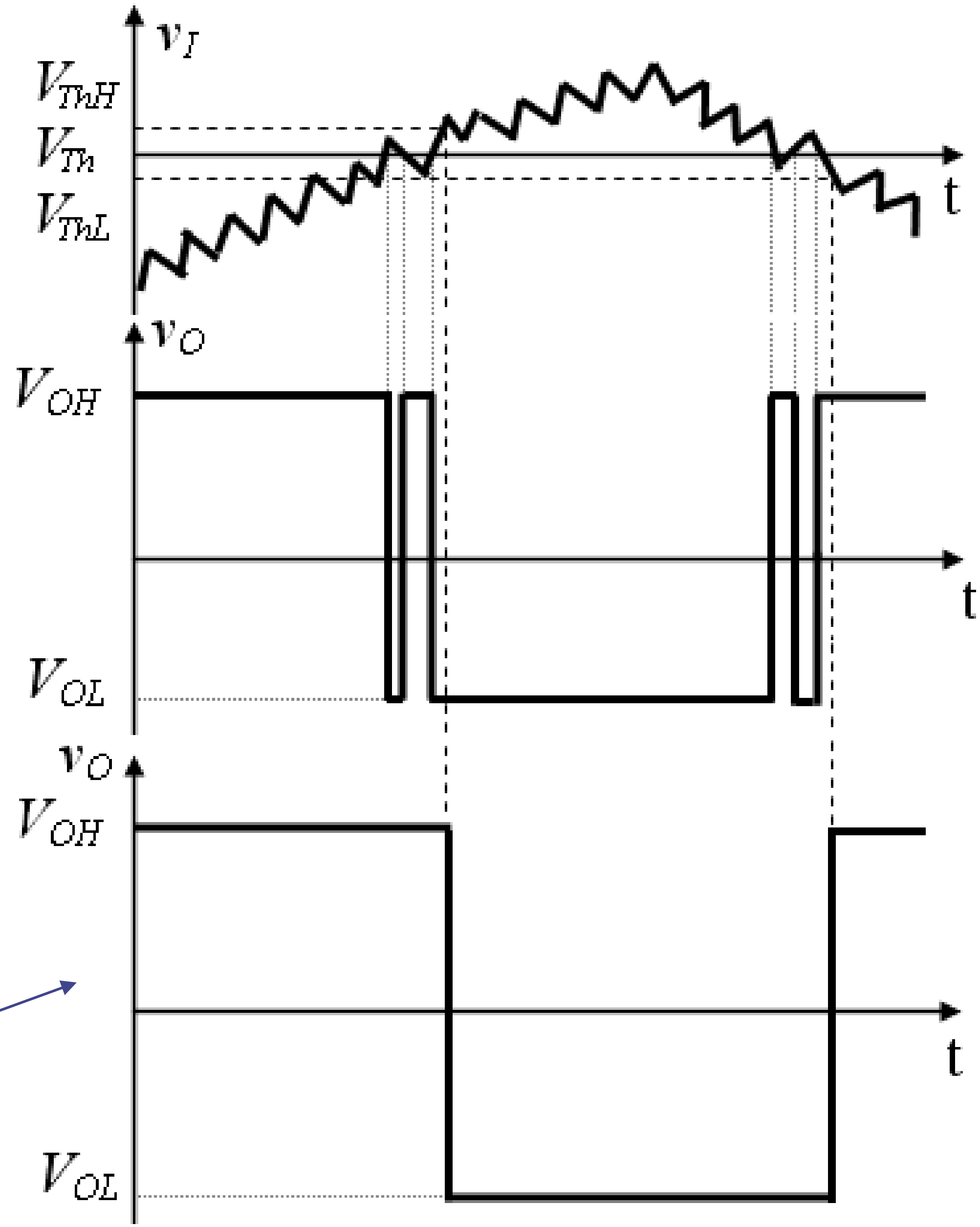
Hysteresis = phenomenon according to which the **actual value** of a quantity (material) also **depends on previous values** of quantities determining it.

= property of a system such that an output value is not a strict function of the corresponding input, but also incorporates some lag, delay, or **history** dependence

❖ **the response for a decrease in the input variable differs from the response for an increase in the input variable**.

Simple comparators have two drawbacks:

- For a very slowly varying input, output switching can be rather slow.
- For a noisy input signal, the output may present several unwanted (parasitic) transitions (commutations) as the input passes through the threshold voltage value (trigger point)



no more unwanted transition

How can one implement this time response ?

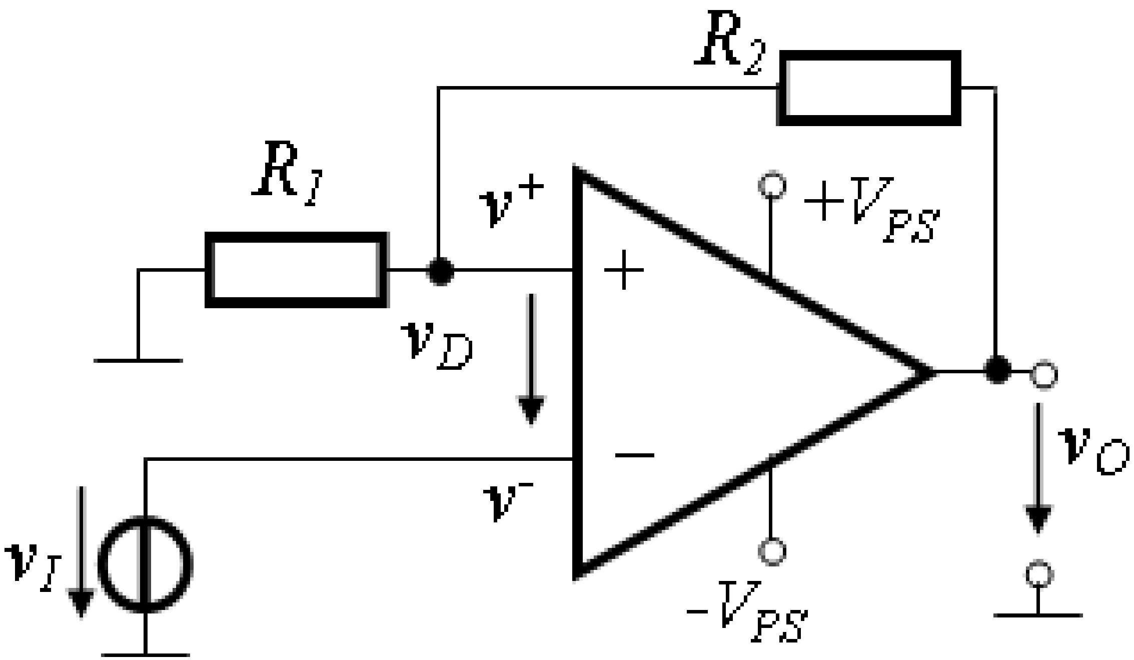
Solution

- Two different threshold values V_{ThH} and V_{ThL}
- Two distinct output values: V_{OH} and V_{OL}
- The commutation takes place at
  - V_{ThH} only if $v_O = V_{OH}$
  - V_{ThL} only if $v_O = V_{OL}$

$\Rightarrow$ The threshold values should depend on the output value $\rightarrow$ The output voltage should be brought back to the input to contribute to the threshold values: ***positive feedback*** (intensifies the effect)

- **Feeding back one fraction of the output voltage to the non-inverting input by means of a resistive divider**

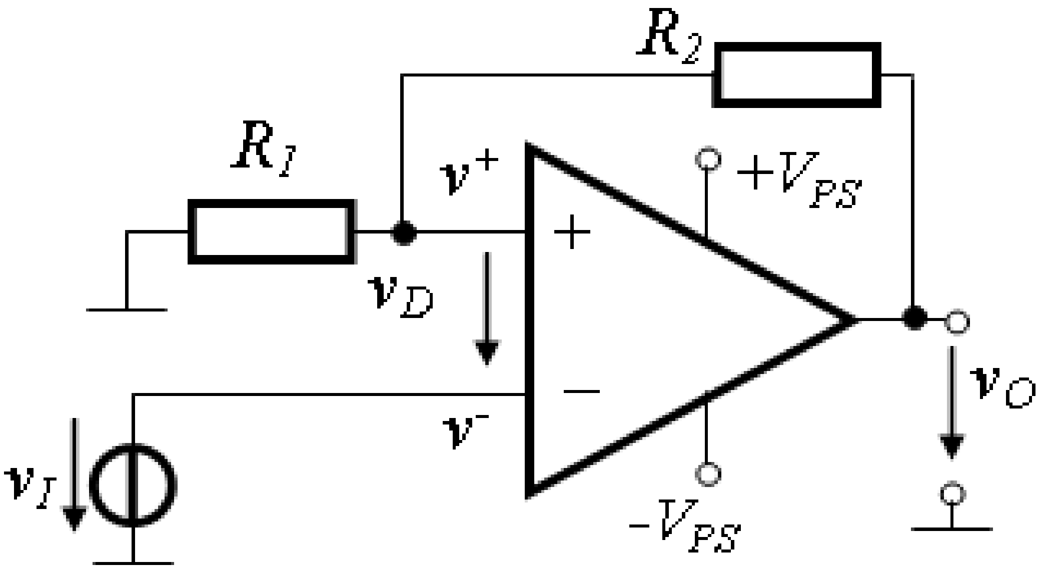
How does VTC look like?



R_1, R_2 – assure positive feedback (PF)

A fraction of the output voltage is **fed back to the noninverting input**

Inverting hysteresis comparator



$$v^+ = \frac{R_1}{R_1 + R_2} v_O$$

$$v^- = v_I$$

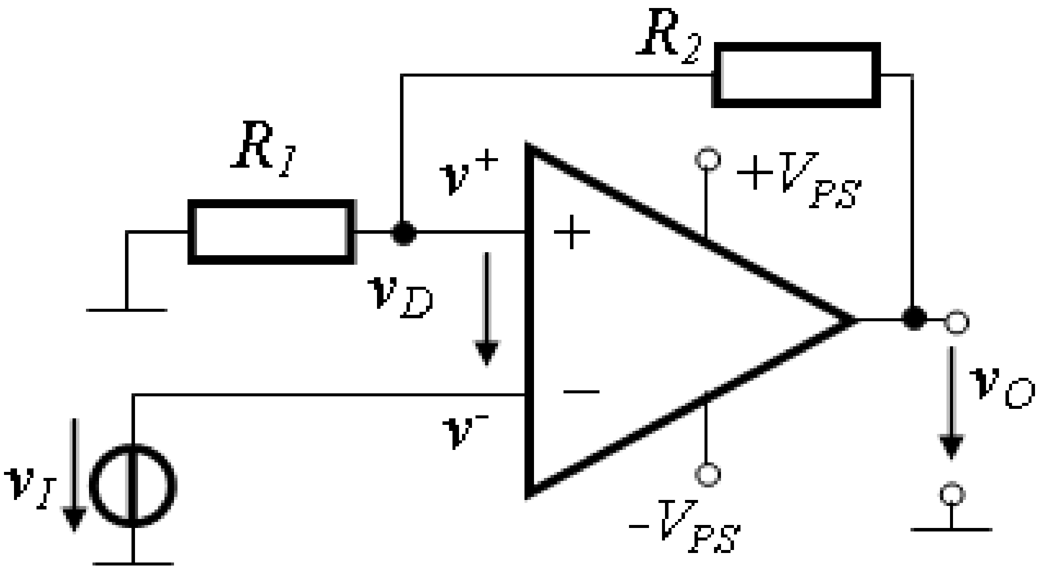
$$v_D = \frac{R_1}{R_1 + R_2} v_O - v_I$$

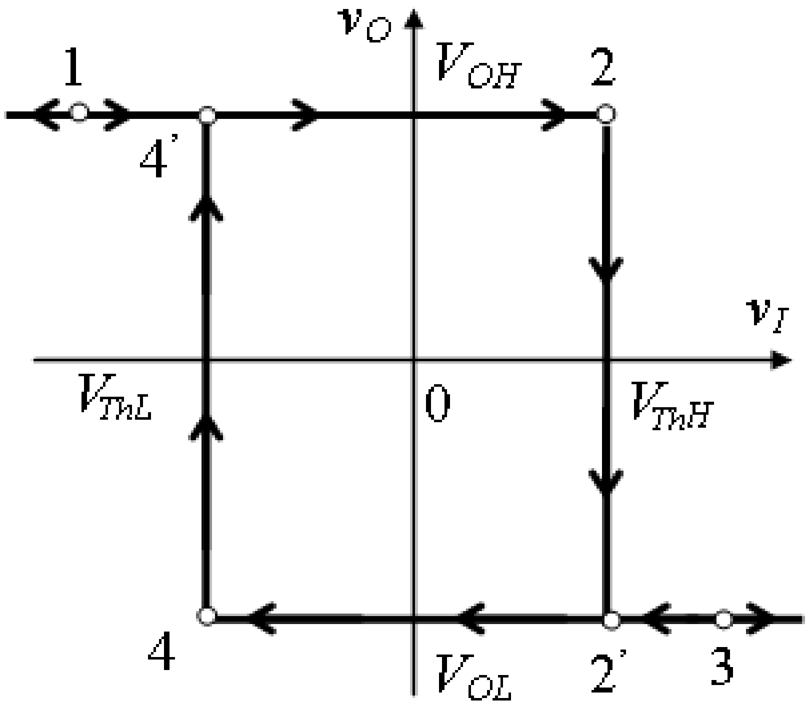
$$\text{For } v_D = 0,\ v_I \to V_{Th}$$

$$V_{ThH} = \frac{R_1}{R_1 + R_2} V_{OH}$$

$$V_{ThL} = \frac{R_1}{R_1 + R_2} V_{OL}$$

Inverting hysteresis comparator





$$v^{+} = \frac{R_1}{R_1 + R_2} v_O$$

$$v^{-} = v_I$$

$$v_D = \frac{R_1}{R_1 + R_2} v_O - v_I$$

$$\text{For } v_D = 0,\ v_I \rightarrow V_{Th}$$

$$V_{ThH} = \frac{R_1}{R_1 + R_2} V_{OH}$$

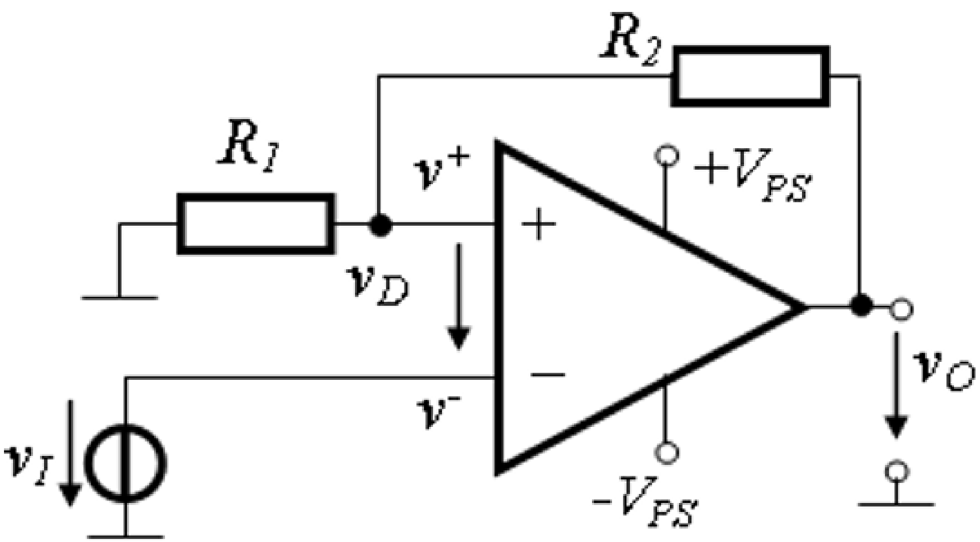
$$V_{ThL} = \frac{R_1}{R_1 + R_2} V_{OL}$$

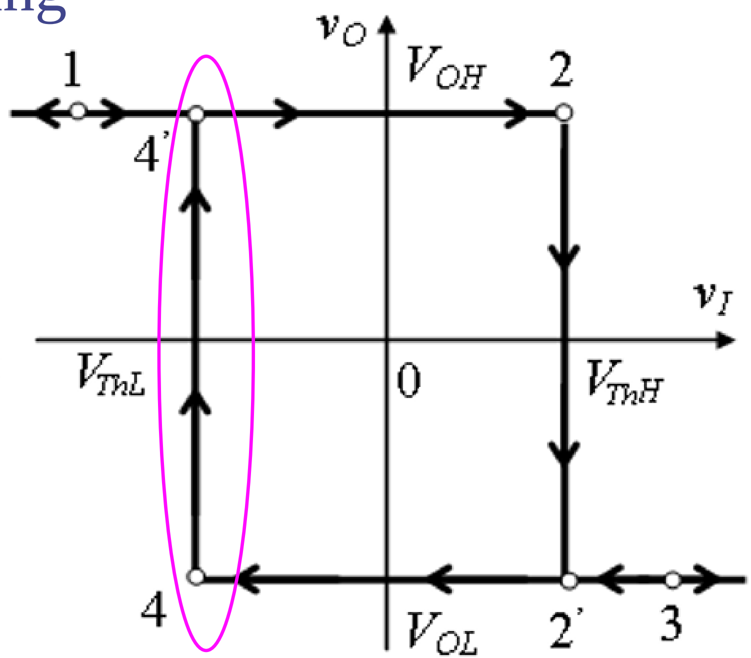
Features

- moving direction on the hysteresis
- **at a certain moment only one threshold is "active"**
- the input signal triggers the switching of the output, the switching process being then further sustained by the PF
- let's suppose $v_O = V_{OL}$, $v_I > V_{ThL}$,

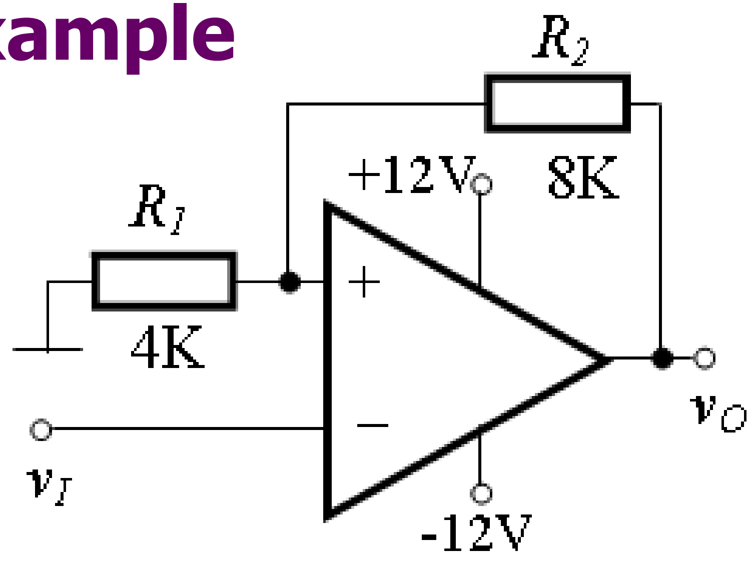
  $v_I \downarrow$, when v_I passes through V_{ThL} $v_D \uparrow$, $\mathbf{v_O \uparrow}$, $v^+ \uparrow$, $v_D \uparrow$, $\mathbf{v_O \uparrow}$
- once the v_O starts to change its value **the transition is sustained by the circuit itself due to its PF**

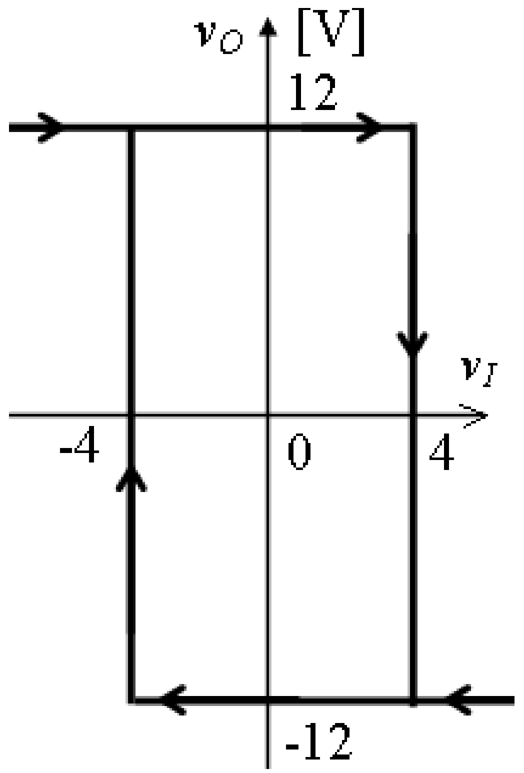
  $\Rightarrow$ fast (accelerated) switching
- Bistable circuit or Schmidt triggers

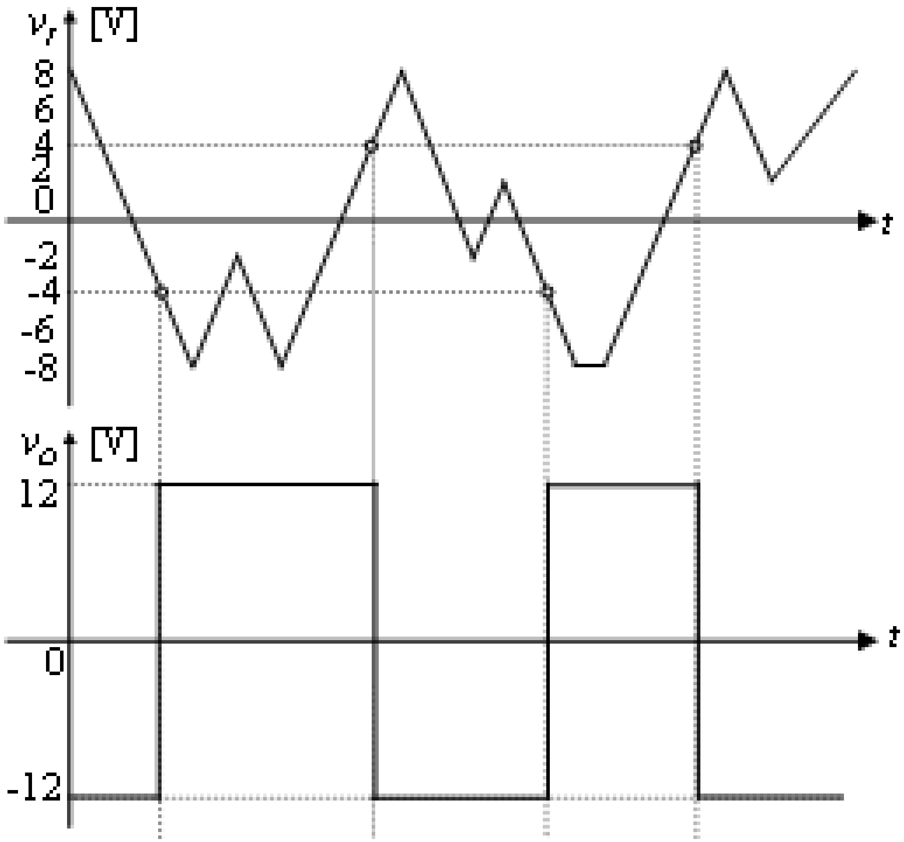




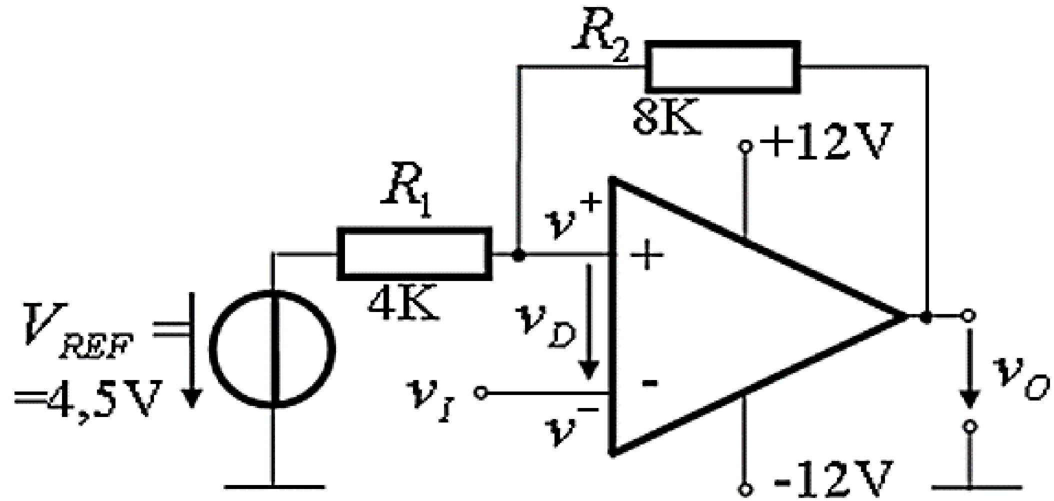
Example


R2
8K
+12V
R1
4K
+
−
vO
vI
-12V


vO
[V]
12
vI
-4
0
4
-12


vI
[V]
8
6
4
2
0
-2
-4
-6
-8
t
vO
[V]
12
0
-12
t

Inverting comparator with asymmetric thresholds



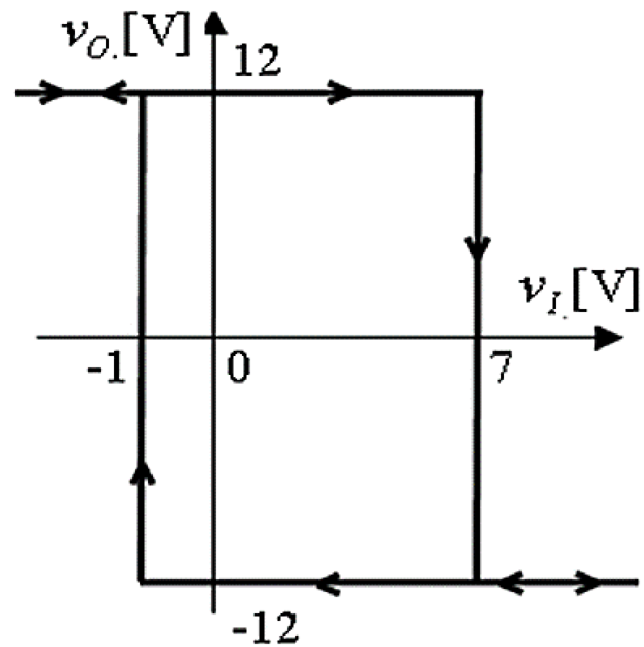
$$v^+ = \frac{R_1}{R_1 + R_2} v_O + \frac{R_2}{R_1 + R_2} V_{REF}$$

$$v_D = v^+ - v^- = \frac{R_1}{R_1 + R_2} v_O + \frac{R_2}{R_1 + R_2} V_{REF} - v_I$$

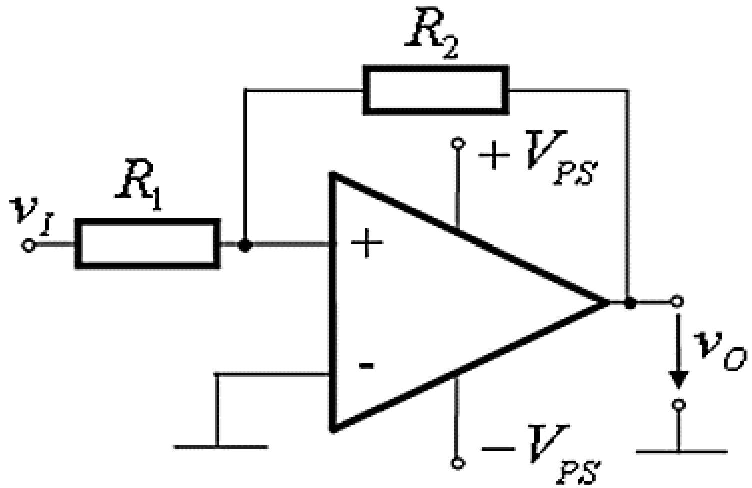
For $v_D = 0, \; v_I \rightarrow V_{Th}$

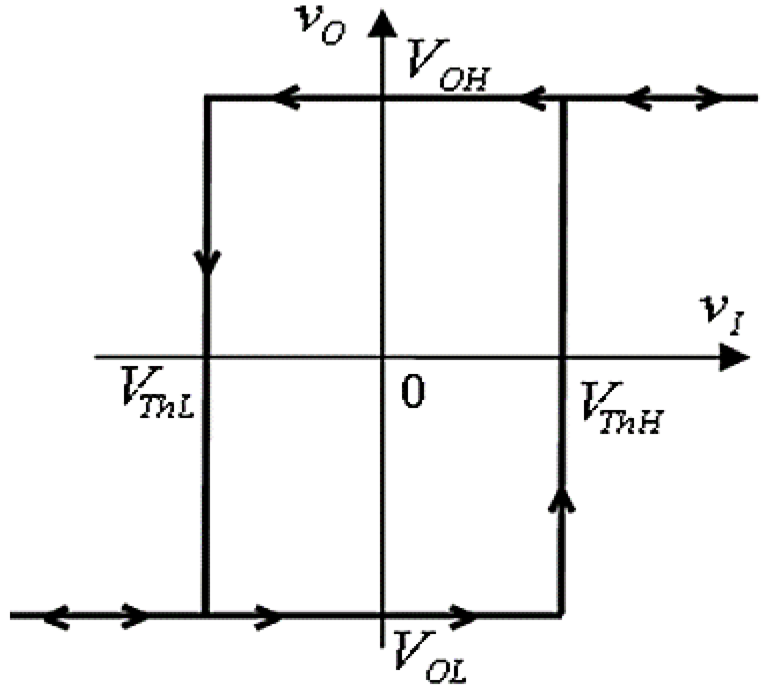
$$V_{ThL} = \frac{R_1}{R_1 + R_2} V_{OL} + \frac{R_2}{R_1 + R_2} V_{REF}$$

$$V_{ThH} = \frac{R_1}{R_1 + R_2} V_{OH} + \frac{R_2}{R_1 + R_2} V_{REF}$$



Non-inverting hysteresis comparators





$$v_D = v^+ - v^- = \frac{R_1}{R_1+R_2} v_O + \frac{R_2}{R_1+R_2} v_I - 0$$

For $v_D = 0,\ v_I \rightarrow V_{Th}$

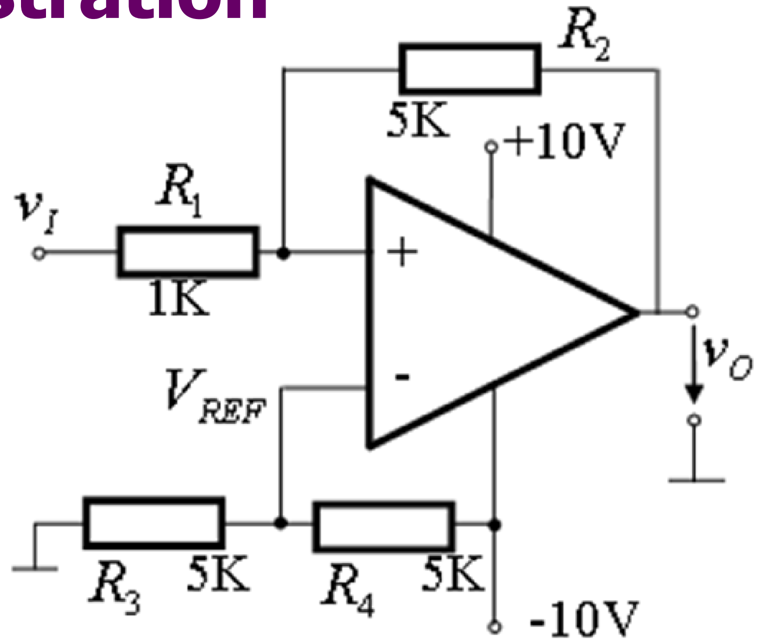
$$\frac{R_1}{R_1+R_2} v_O + \frac{R_2}{R_1+R_2} V_{Th} = 0$$

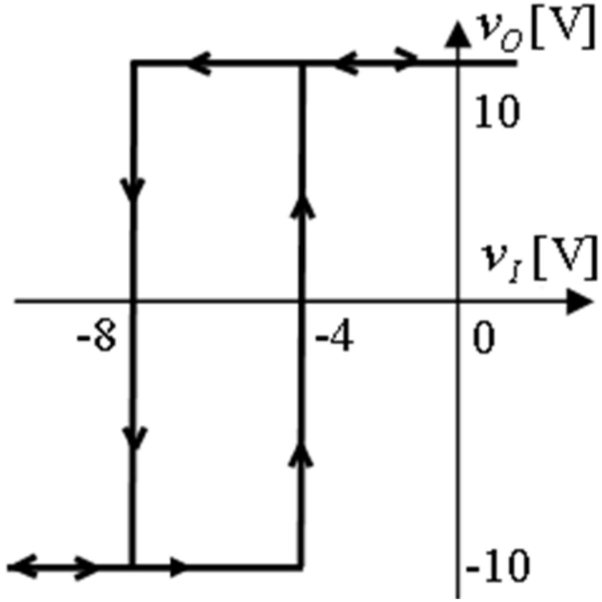
$$V_{Th} = -\frac{R_1}{R_2} v_O$$

$$V_{ThL} = -\frac{R_1}{R_2} V_{OH}$$

$$V_{ThH} = -\frac{R_1}{R_2} V_{OL}$$

Illustration





$$v_D = v^+ - v^- = \frac{R_1}{R_1 + R_2} v_O + \frac{R_2}{R_1 + R_2} v_I - V_{REF}$$

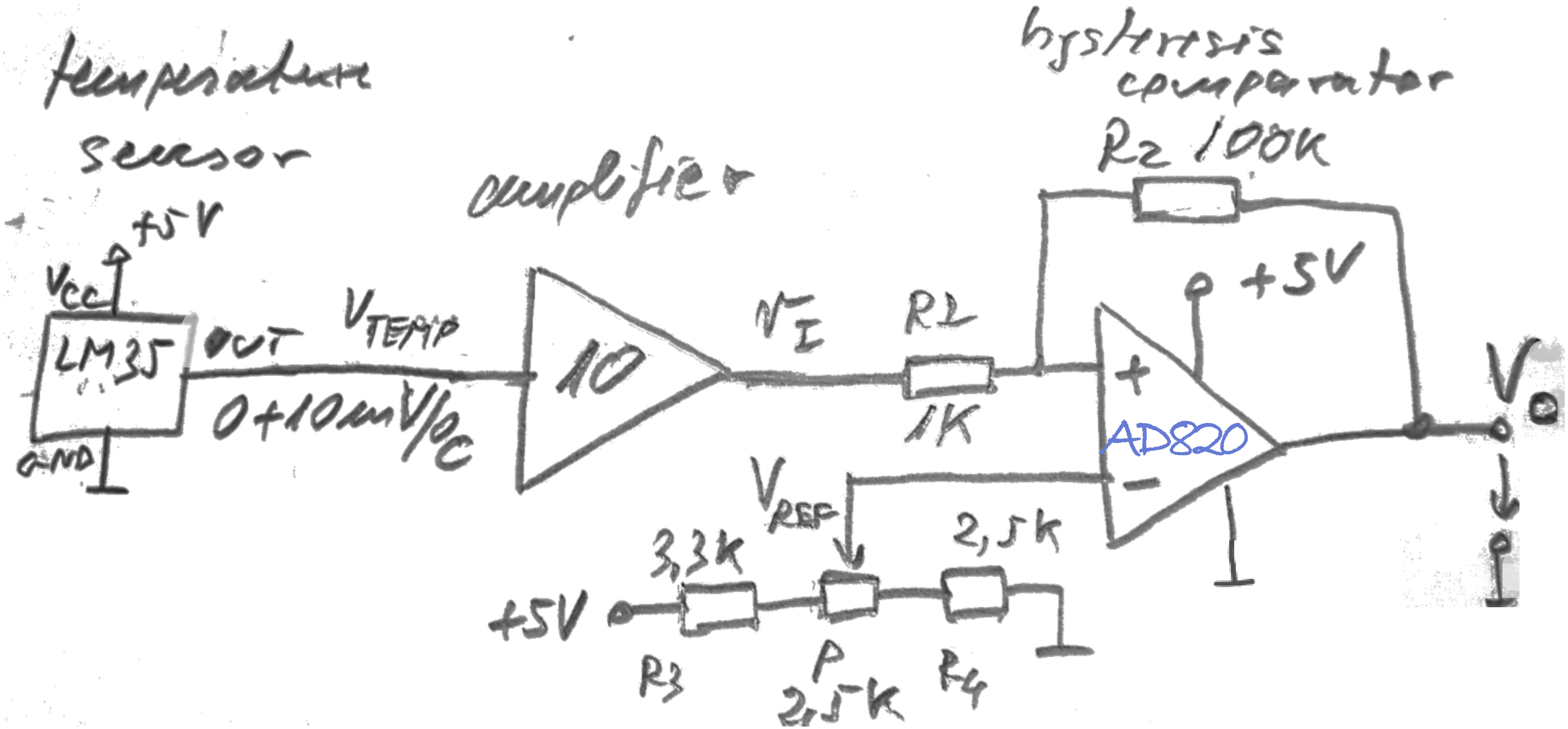
$$v_{ThH} = -\frac{R_1}{R_2} V_{OL} + \left(1 + \frac{R_1}{R_2}\right) V_{REF} = -\frac{1}{5}(-10) + \left(1 + \frac{1}{5}\right)(-5) = -4\text{V}$$

$$v_{ThL} = -\frac{R_1}{R_2} V_{OH} + \left(1 + \frac{R_1}{R_2}\right) V_{REF} = -\frac{1}{5}(10) + \left(1 + \frac{1}{5}\right)(-5) = -8\text{V}$$

Applications of hysteresis comparators

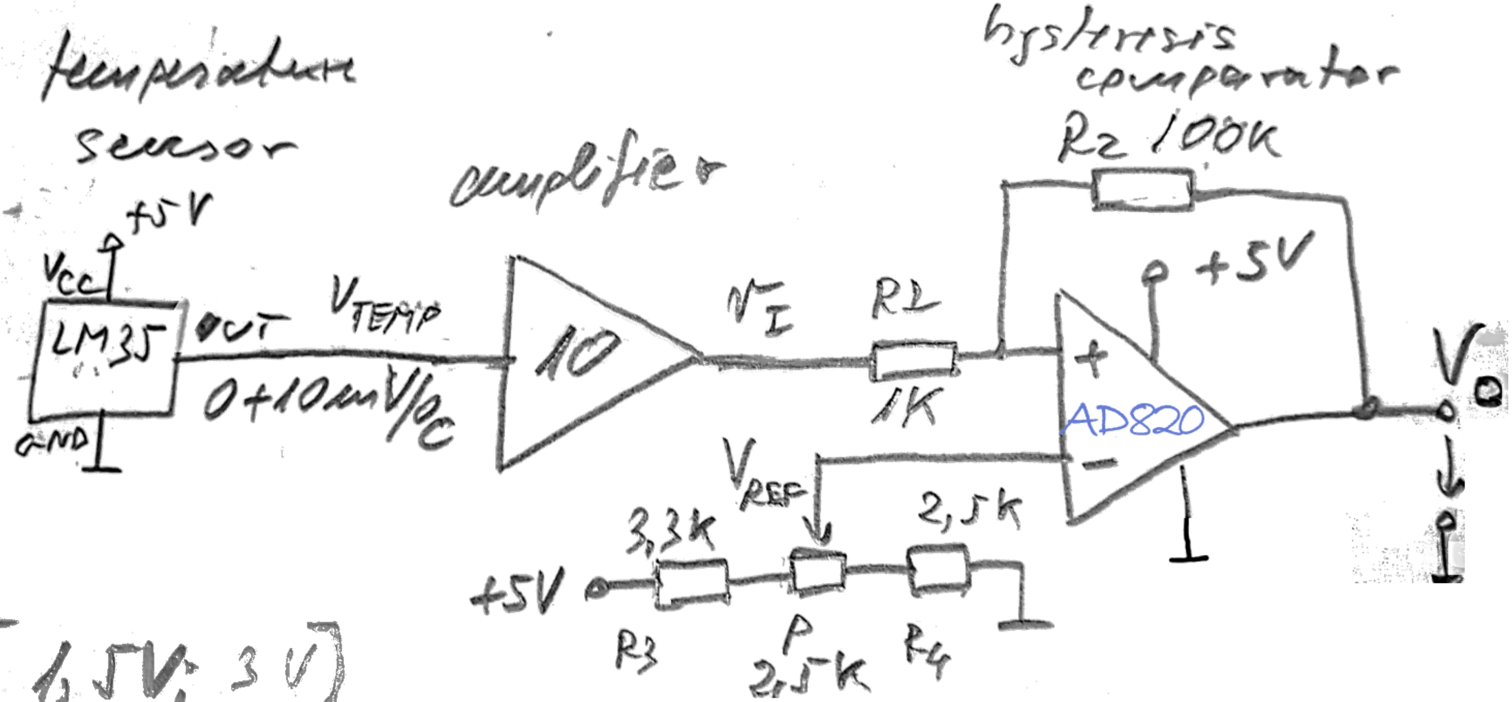
- Solution for one-threshold comparator in a noisy environment (the hysteresis width > noise magnitude (peak-to-peak))
- In control system for "on-off control"
- …..example

Thermostat



LM35 http://www.ti.com/product/LM35

AD 820 https://www.analog.com/media/en/technical-documentation/data-sheets/ad820.pdf



$$V_{REF} \in [1{,}5V; 3V]$$

$$V_{Th} = -\frac{R_1}{R_2} V_o + \left(1 + \frac{R_1}{R_2}\right) V_{REF}$$

$$V_{REF} = 1{,}98\,V \quad (\simeq 2V)$$

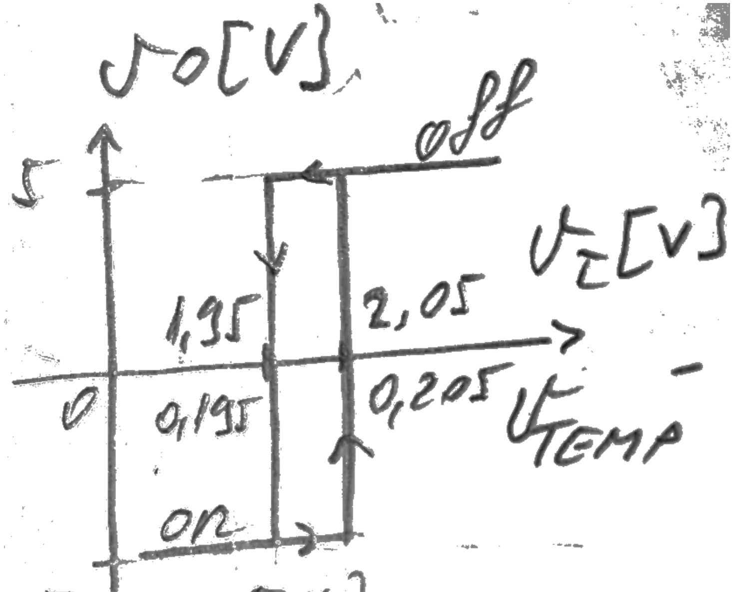
$V_{ThL} = 1{,}95V$; $V_{ThH} = 2{,}05V$

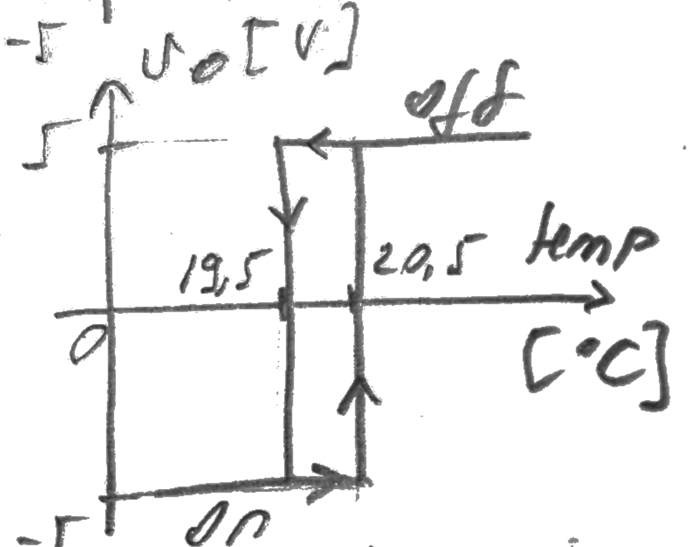
↓ ↓

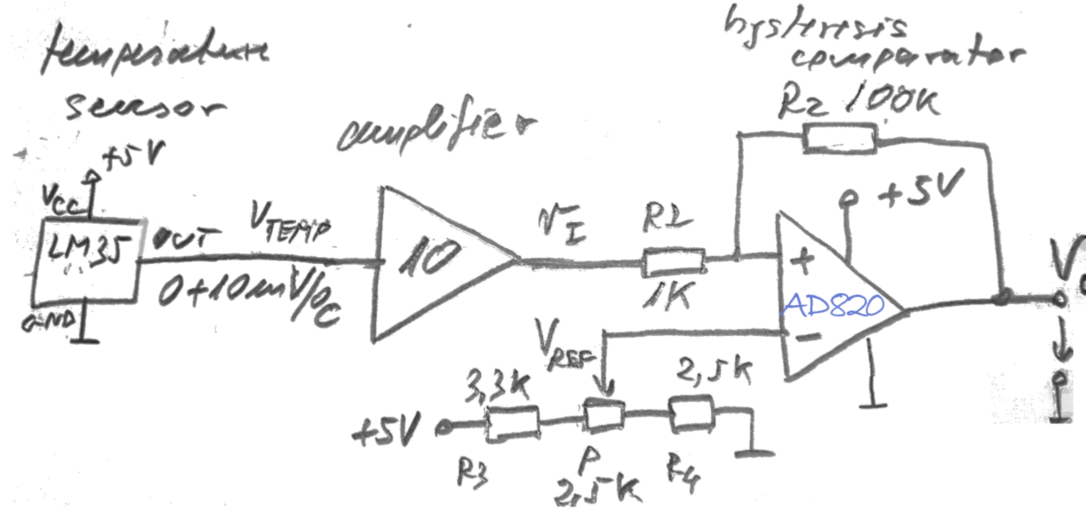
$V_{TEMP} = 195\,mV$ $V_{TEMP} = 205\,mV$

↓ ↓

$temp = 19{,}5\,°C$ $temp = 20{,}5\,°C$







set point temperature 20°C

$$V_{REF} \in [1{,}5V; 3V]$$

$$V_{Th} = -\frac{R_1}{R_2} V_o + \left(1 + \frac{R_1}{R_2}\right) V_{REF}$$

$$V_{REF} = 1{,}98\,V \quad (\approx 2V)$$

$V_{ThL} = 1{,}95V$; $V_{ThH} = 2{,}05V$

↓ ↓

$V_{TEMP} = 195\,mV$ $V_{TEMP} = 205\,mV$

↓ ↓

temp = 19,5 °C temp = 20,5 °C