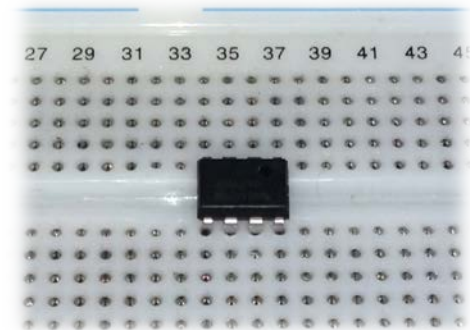




ELECTRONIC DEVICES

Assist. prof. Laura-Nicoleta IVANCIU, Ph.D.

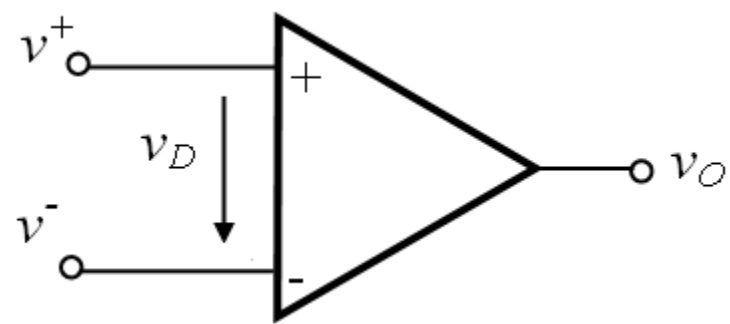
C7 – Hysteresis comparators with OpAmp.



Contents

- Hysteresis (PF) comparators with OpAmp
 - Motivation
 - Difference between simple and hysteresis comparators
 - Inverting hysteresis comparators
 - w/ symmetric threshold voltages
 - w/ asymmetric threshold voltages
 - Non-inverting hysteresis comparators
 - Applications

Previously on ED (C5):



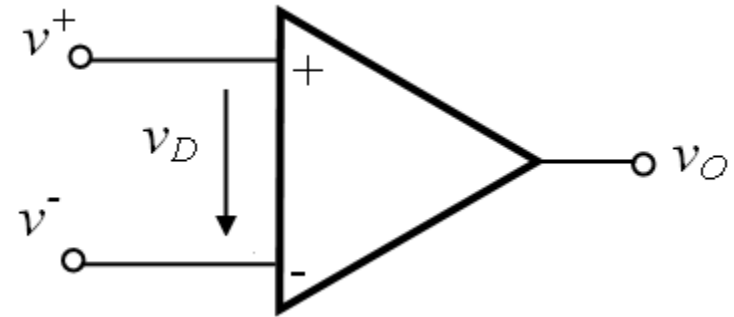
$$v_D = v^+ - v^-$$

$$v_O = av_D$$

$$\left\{ \begin{array}{l} v_{O\max} = +V_{PS} \\ v_{O\min} = -V_{PS} \end{array} \right.$$

Previously on ED (C5):

$$v_O = a v_D = \infty \cdot v_D$$



I. Utilization as **comparator**, in switching mode

$$v_O \in \{V_{OL} ; V_{OH}\}$$

$v_D > 0$, $v_O \rightarrow +\infty$, v_O limited by the positive supply $v_O = V_{OH} \approx +V_{PS}$

$v_D < 0$, $v_O \rightarrow -\infty$, v_O limited by the negative supply $v_O = V_{OL} \approx -V_{PS}$

II. Utilization as **amplifier**

$$v_O \in (V_{OL} ; V_{OH})$$

It is mandatory that $v_D = 0$, so then $v_O = a \cdot v_D = \infty \cdot 0$ - indetermination

v_D is kept at 0 by means of external components (R)

Previously on ED (C5):

Types of voltage comparators:

- Simple comparators – **without** feedback, **one** threshold voltage – **C6**
- Hysteresis comparators – **positive** feedback, **two** threshold voltages

Threshold voltage V_{Th} = particular value(s) of the input voltage, for which the output voltage switches (changes states) (hence $v_D = 0$)

$$V_{Th} = v_I |_{v_D=0}$$

Feedback = (backward) connection, between output and input

- positive feedback = output is connected to non-inverting input
- negative feedback = output is connected to inverting input

Hysteresis comparators

- aka PF (positive feedback) comparators

Positive feedback = (backward) connection, between output and non-inverting input

- some of the output voltage is **fed back** to the non-inverting input, by means of a resistive divider
- the output voltage **strengthens** the effect of the input voltage

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

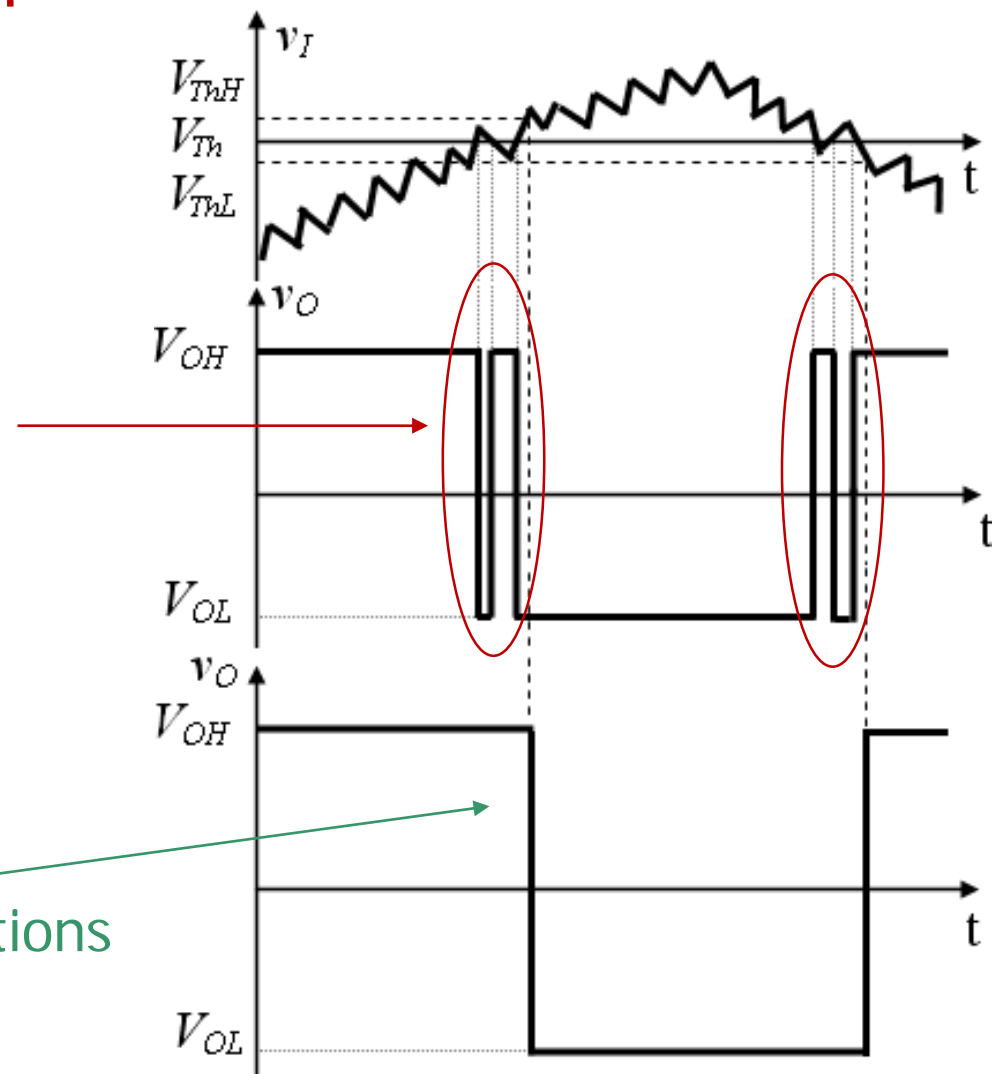
= property of a system such that an output value is not a strict function of the corresponding input, but also incorporates some **lag, delay, or history dependence**

Drawbacks of simple comparators

- For a slowly varying input, the output **switching** can be **slow**.
- For a **noisy** input signal, the output makes several **unwanted (parasitic) transitions** (commutations, switches).

For every intersection between input and threshold, a transition occurs.

Output w/out unwanted transitions



Drawbacks of simple comparators - solution

- ❑ Two 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, previously, $v_o = V_{OH}$
- ❑ the commutation takes place at V_{ThL} only if, previously, $v_o = V_{OL}$

The threshold values depend on the previous output values (lag/delay/history).

The output voltage should be fed back to the input, to contribute to the threshold values: **positive feedback (PF)**

Inverting hysteresis comparators

➤ w/ symmetric threshold voltages

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

$$v^- = v_I$$

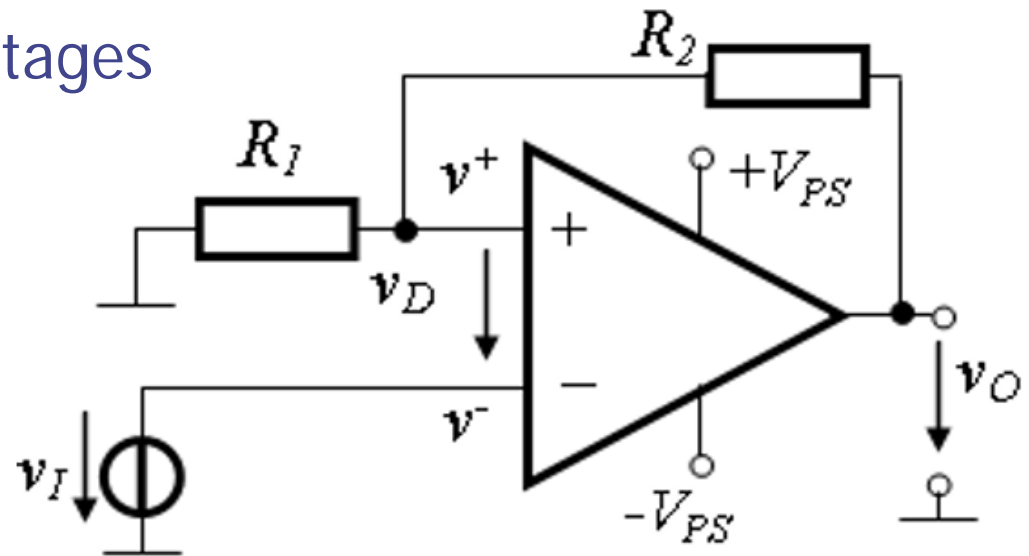
$$v_D = \frac{R_1}{R_1 + R_2} v_O - v_I$$

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

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

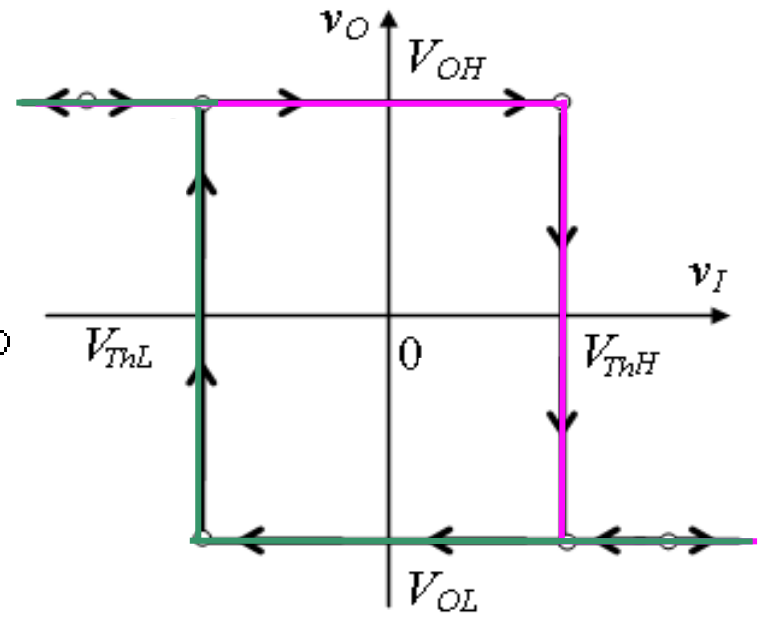
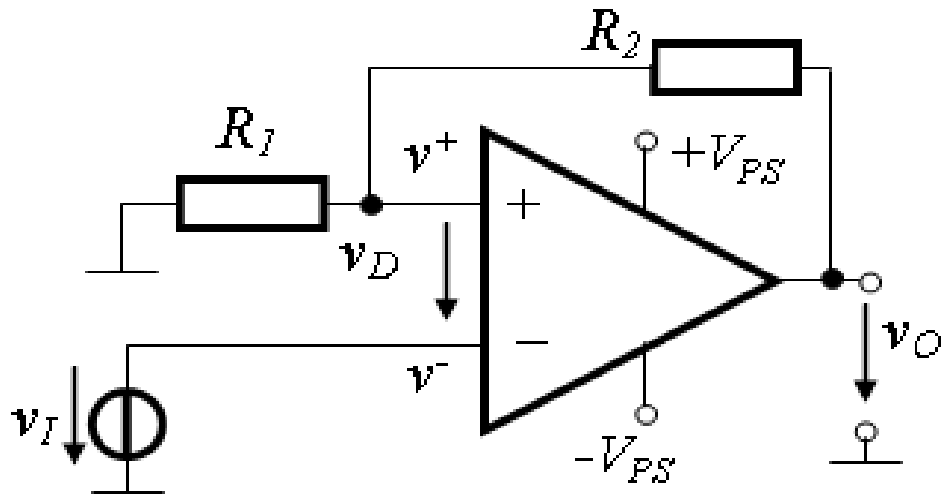
$$V_{ThL} = \frac{R_1}{R_1 + R_2} V_{OL}$$

VTC?



Inverting hysteresis comparators

➤ w/ symmetric threshold voltages



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

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

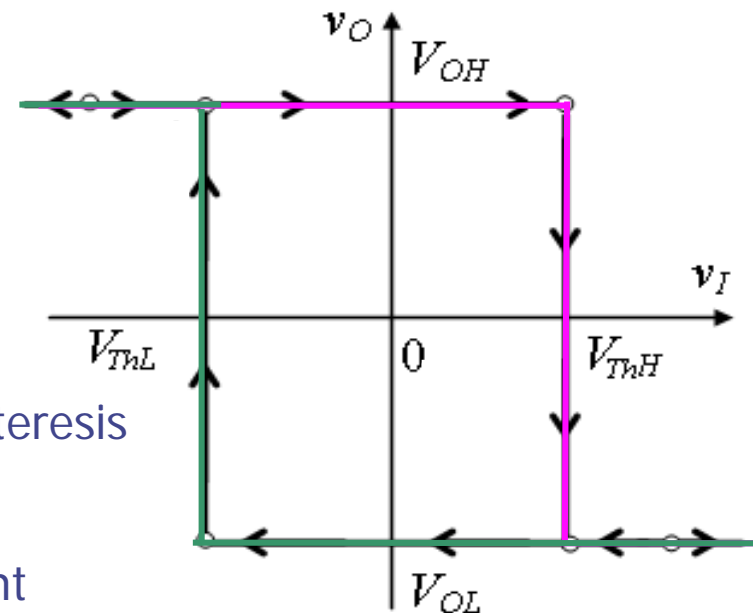
Hysteresis width

$$\Delta V_{Th} = V_{ThH} - V_{ThL} = \frac{R_1}{R_1 + R_2} (V_{OH} - V_{OL})$$

Inverting hysteresis comparators

➤ w/ symmetric threshold voltages

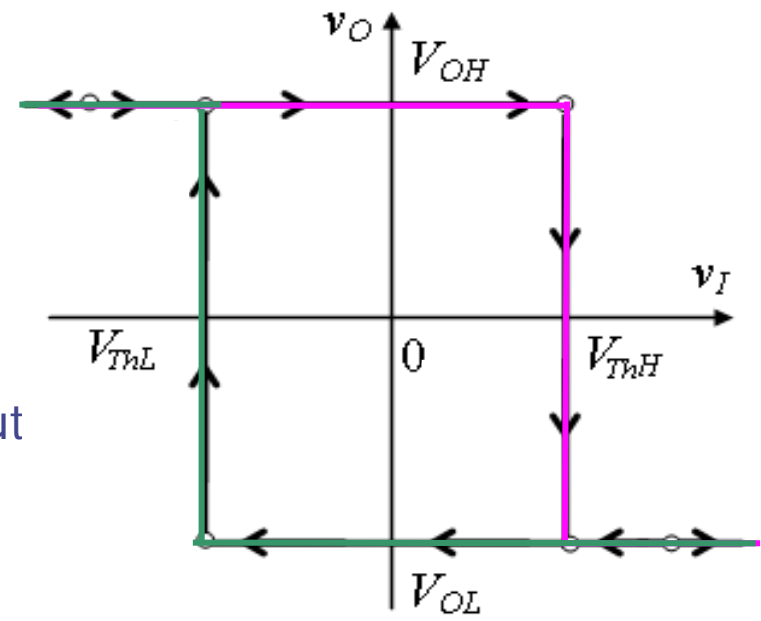
- arrows indicate the moving direction on the hysteresis
- only one threshold is **active** @ any given moment
- hysteresis comparators = **bistable** circuits
- bistable multivibrator circuit or Schmitt triggers (Otto H. Schmitt, American researcher, 1934 – as a student)



Inverting hysteresis comparators

➤ w/ symmetric threshold voltages

The input signal triggers the switching of the output
 The switching process is sustained by the **PF**.



Suppose $v_O = V_{OL}$:

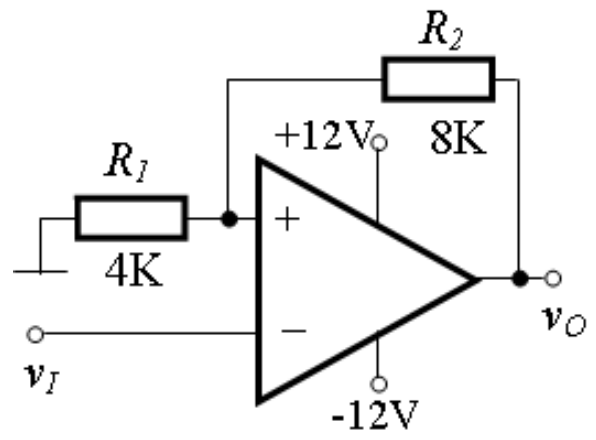
$v_I > V_{ThL}$, $v_I \downarrow$, when v_I passes through V_{ThL}

$v_I \downarrow$, $v_D \uparrow$, **$v_O \uparrow$** , $v^+ \uparrow$, $v_D \uparrow$, **$v_O \uparrow$** **PF**

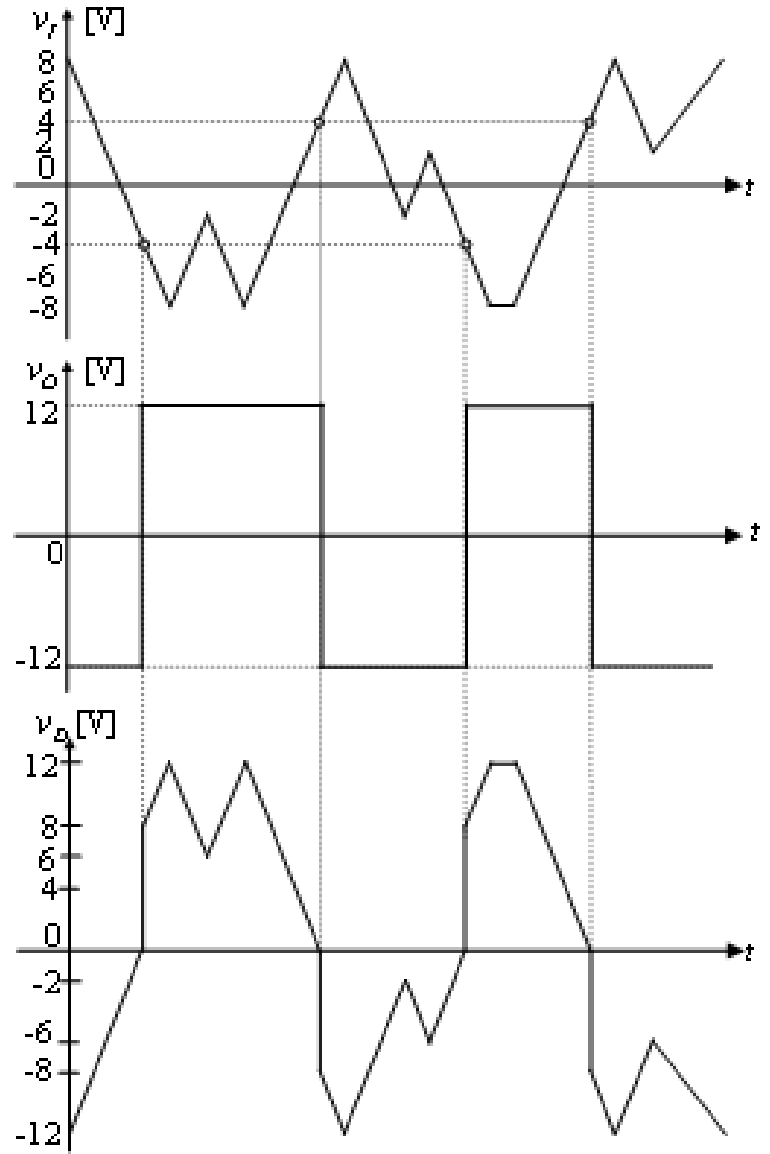
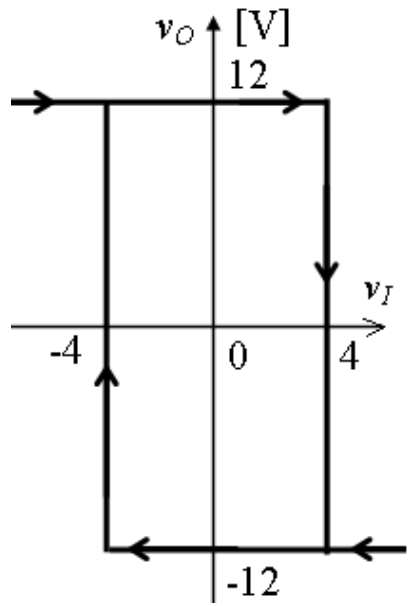
Once v_O starts to change its value, the transition is sustained by the circuit itself, due to its **PF** \Rightarrow fast (accelerated) switching.

Inverting hysteresis comparators

Illustration



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



Inverting hysteresis comparators

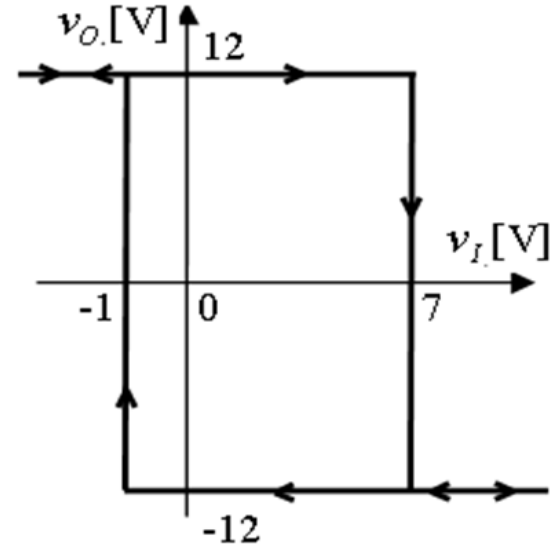
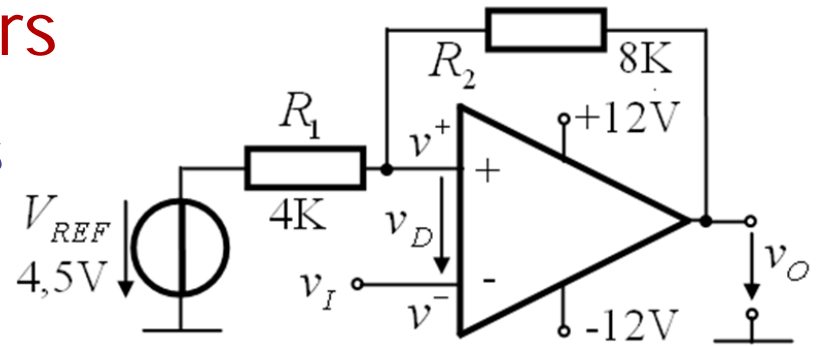
➤ w/ asymmetric threshold voltages

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

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

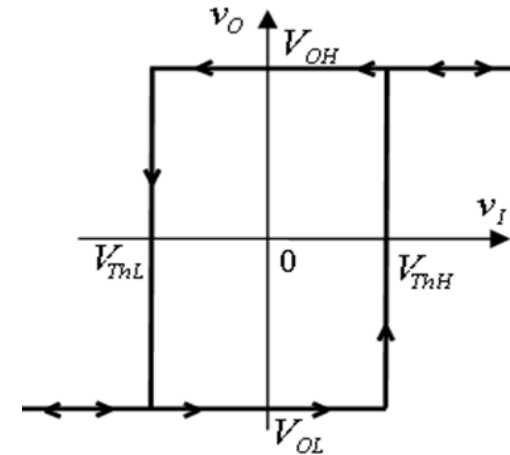
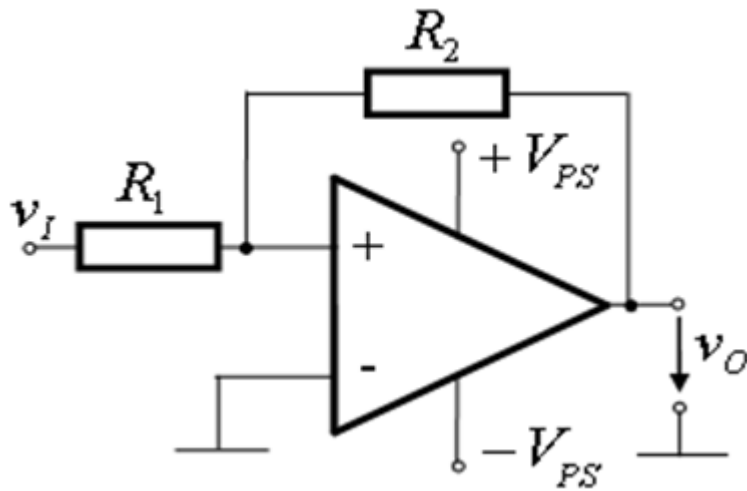
For $v_D = 0$, $v_I \rightarrow V_{Th}$

$$\begin{cases} V_{ThL} = \frac{R_1}{R_1 + R_2} V_{OL} + \frac{R_2}{R_1 + R_2} V_{REF} \\ V_{ThH} = \frac{R_1}{R_1 + R_2} V_{OH} + \frac{R_2}{R_1 + R_2} V_{REF} \end{cases}$$



- Output voltage for a triangular input voltage with 10V amplitude, and then for 5V amplitude.

Non-inverting hysteresis comparators

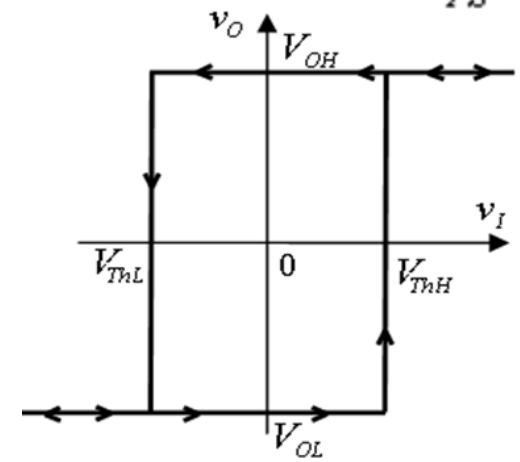
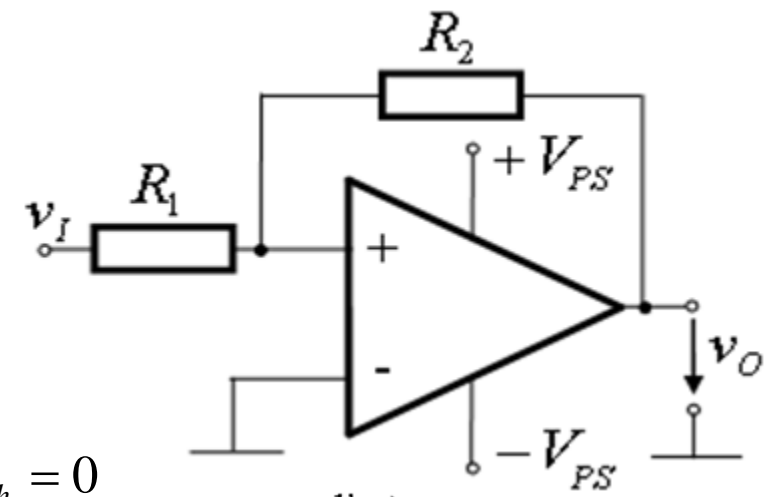


Non-inverting hysteresis comparators

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

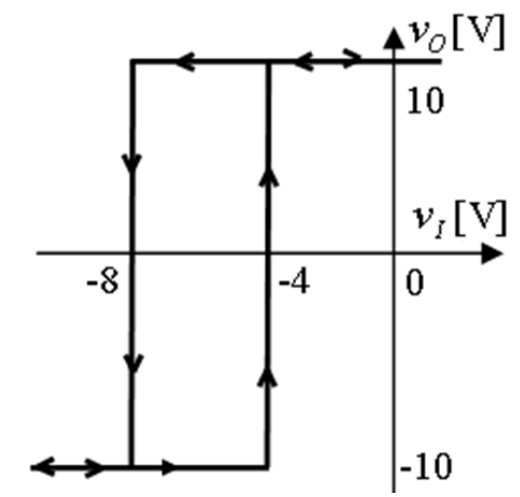
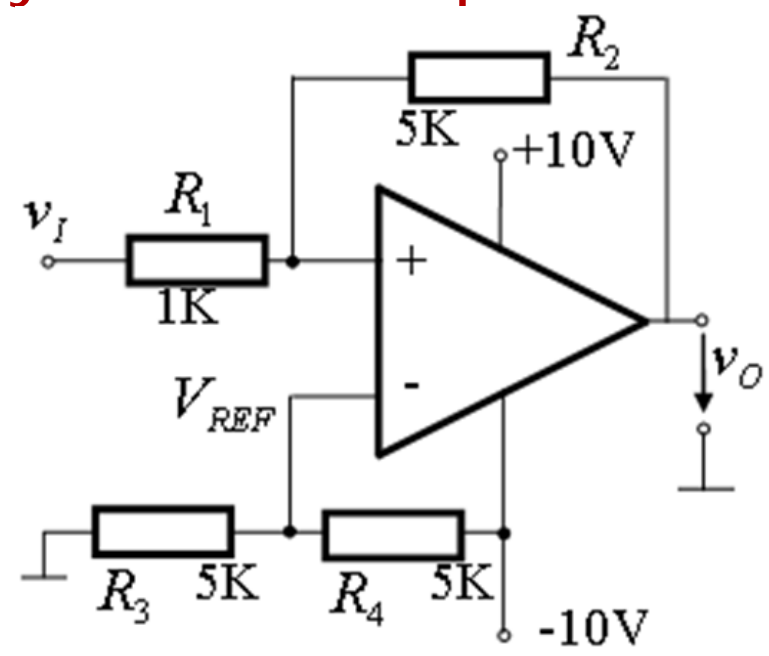
For $v_D = 0$, $v_I \rightarrow V_{Th}$ $\frac{R_1}{R_1 + R_2} v_O + \frac{R_2}{R_1 + R_2} V_{Th} = 0$

$$V_{Th} = -\frac{R_1}{R_2} v_O \quad \left\{ \begin{array}{l} V_{ThL} = -\frac{R_1}{R_2} V_{OH} \\ V_{ThH} = -\frac{R_1}{R_2} V_{OL} \end{array} \right.$$



Non-inverting hysteresis comparators

Illustration



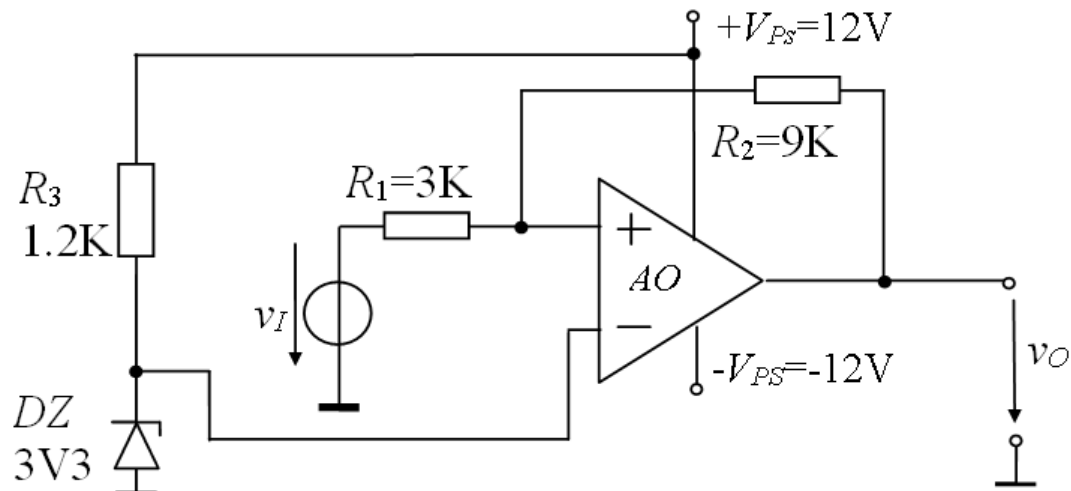
$$v_D = v^+ - v^- = \frac{R_1}{R_1 + R_2} v_O + \frac{R_2}{R_1 + R_2} v_I - V_{REF}$$

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

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

Non-inverting hysteresis comparators

Example



- Draw qualitatively the VTC $v_O(v_I)$. What is the application of the circuit?
- What are the expressions and values of: V_{OH} , V_{OL} , V_{ThH} , V_{ThL} ? Redraw the VTC in accordance with numerical values.
- $v_I(t)$ is a triangular wave with 11 V amplitude. Plot $v_I(t)$ and $v_O(t)$.
- Modify the circuit so that by keeping the same supply voltages, the thresholds became $V_{ThH} = 5$ V, $V_{ThL} = -5$ V.

Applications of hysteresis comparators

- ❑ Solution for one-threshold comparator in a noisy environment
the hysteresis width $>$ noise peak-to-peak value
- ❑ In control systems, for “on-off control”: thermostats, light switches
- ❑ Logic circuits

Summary

The *little black bug* (OpAmp) can also be used to build:

- Hysteresis (PF) comparators with OpAmp
 - Motivation
 - Difference between simple and hysteresis comparators
 - Inverting hysteresis comparators
 - w/ symmetric threshold voltages
 - w/ asymmetric threshold voltages
 - Non-inverting hysteresis comparators
 - Applications

Next week: Electronic amplifiers. Amplifiers with OpAmp.

To do: Homework 5