ELECTRONIC DEVICES

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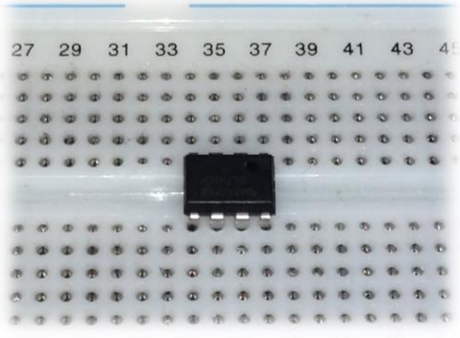
C7 – Hysteresis comparators with OpAmp.



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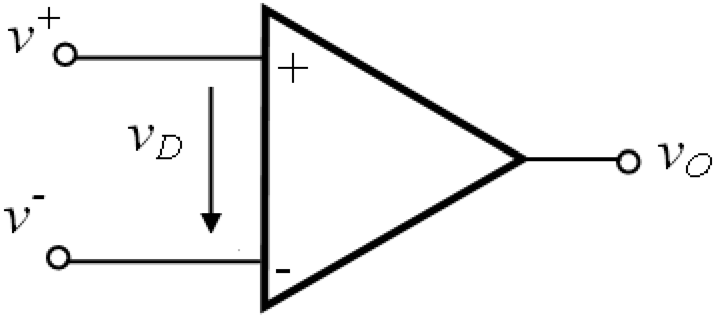
- Hysteresis (PF) comparators with OpAmp
  - Motivation
  - Inverting hysteresis comparators
    - w/ symmetric threshold voltages
    - w/ asymmetric threshold voltages
  - Non-inverting hysteresis comparators
  - Applications

Previously on ED (C5):

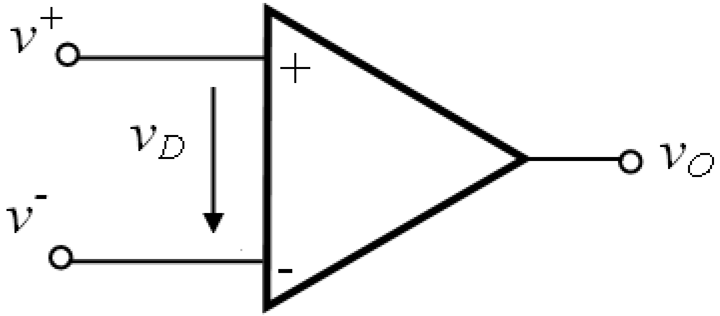


$$\boxed{v_O = a v_D}$$

$$\boxed{v_D = v^+ - v^-}$$

$$\begin{cases} v_{O\max} = +V_{PS} \\ v_{O\min} = -V_{PS} \end{cases}$$

Previously on ED (C6):



$$v_O = av_D = \infty \cdot v_D$$

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 $v_D = 0$)

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

Feedback = (backward) connection, between output and input

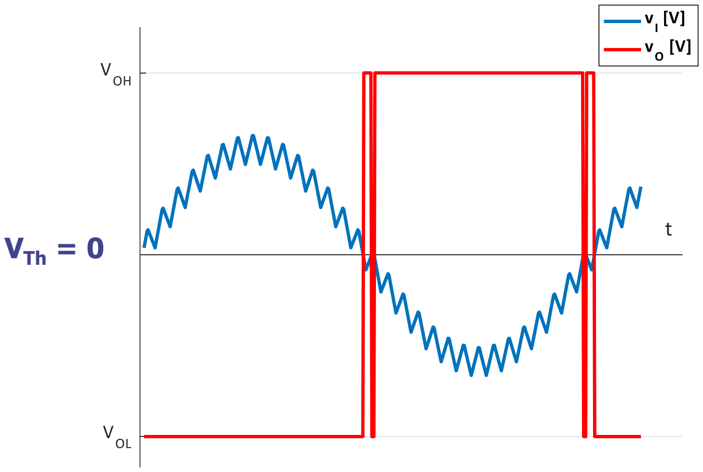
- positive feedback = output is connected to non-inverting input
- negative feedback = output is connected to inverting input

Drawbacks of simple comparators

- For a **noisy** input signal, the output makes several **unwanted (parasitic) transitions** (commutations, switches).

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

Solution?



Drawbacks of simple comparators - solution

- ☐ Two threshold values: $\mathbf{V_{ThH}}$ and $\mathbf{V_{ThL}}$
- ☐ Two distinct output values: $\mathbf{V_{OH}}$ and $\mathbf{V_{OL}}$
- ☐ the commutation takes place at $\mathbf{V_{ThH}}$ only if, previously, $\mathbf{v_O = V_{OH}}$
- ☐ the commutation takes place at $\mathbf{V_{ThL}}$ only if , previously, $\mathbf{v_O = V_{OL}}$

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

The output voltage is fed back into the non-inverting input, to contribute to the threshold values: **positive feedback (PF)**

Drawbacks of simple comparators - solution

- ☐ Two threshold values: $\mathbf{V_{ThH}}$ and $\mathbf{V_{ThL}}$
- ☐ Two distinct output values: $\mathbf{V_{OH}}$ and $\mathbf{V_{OL}}$
- ☐ the commutation takes place at $\mathbf{V_{ThH}}$ only if, previously, $\mathbf{v_O = V_{OH}}$
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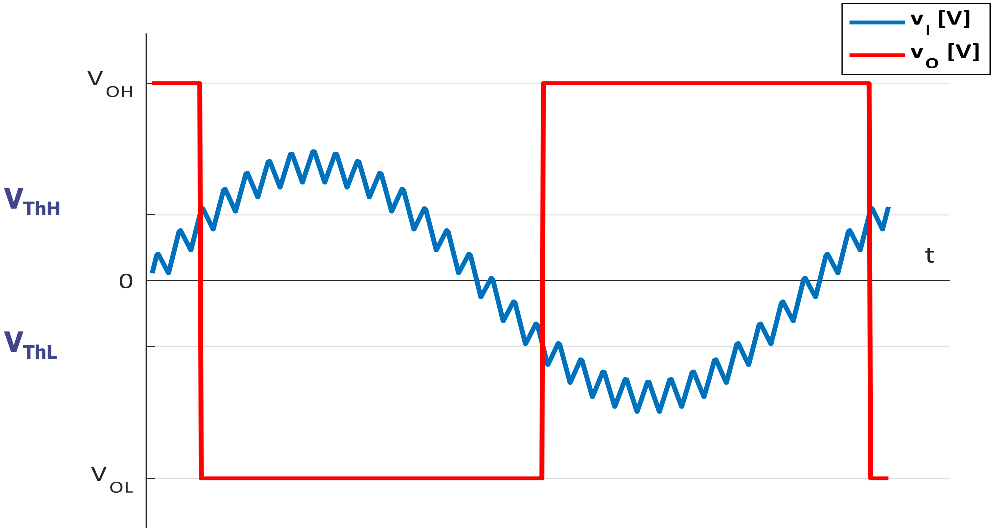


Motivation

Hysteresis comparators

- aka PF (positive feedback) comparators

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

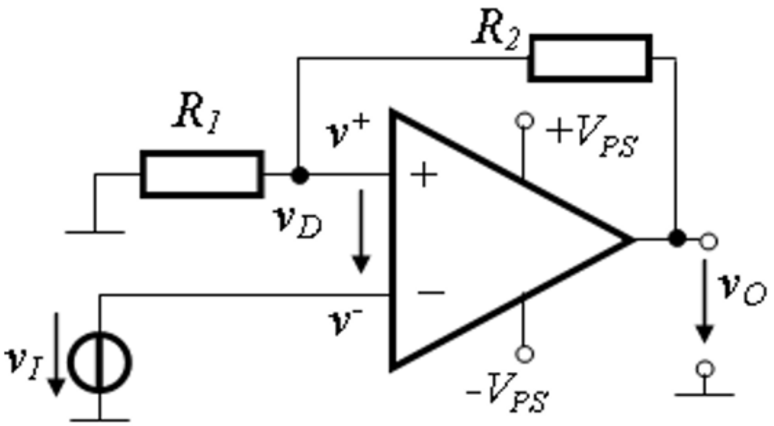
- some of the output voltage is fed back to the non-inverting input, by means of a resistive divider
- the output voltage strengthens the effect of the input voltage

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

Inverting hysteresis comparators

- w/ symmetric threshold voltages



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

$$v^- = v_I$$

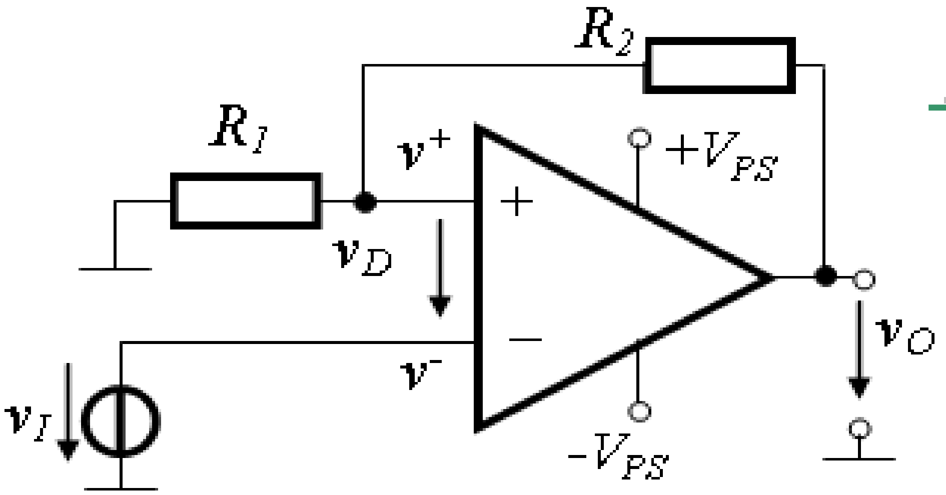
$$v_D = \frac{R_1}{R_1 + R_2} v_O - v_I$$

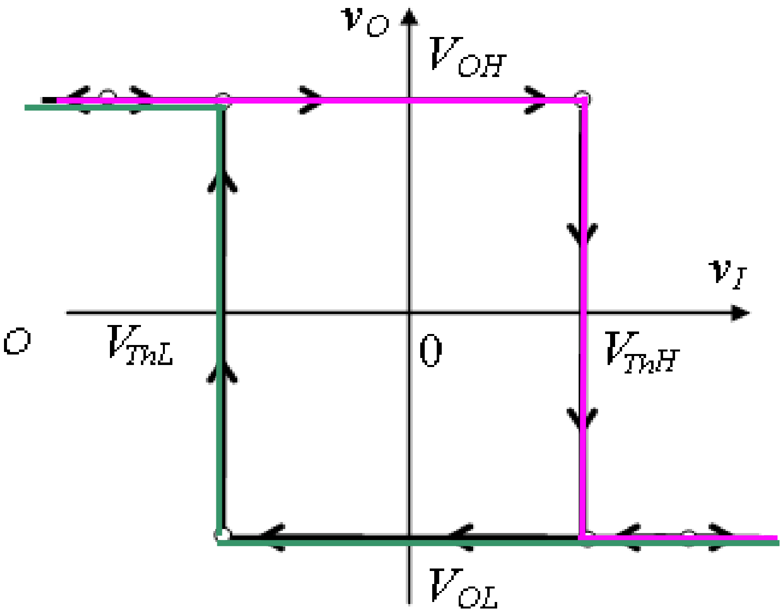
$$\text{For } v_D = 0,\ v_I = V_{Th} \quad \left\{ \begin{aligned} V_{ThH} &= \frac{R_1}{R_1 + R_2} V_{OH} \\ V_{ThL} &= \frac{R_1}{R_1 + R_2} V_{OL} \end{aligned} \right.$$

VTC?

Inverting hysteresis comparators

- w/ symmetric threshold voltages





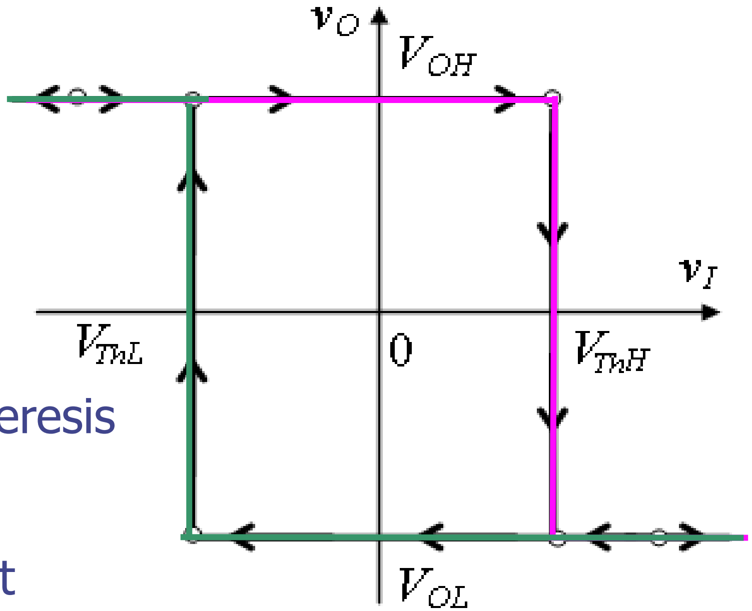
$$V_{ThH} = \frac{R_1}{R_1 + R_2} V_{OH}$$

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

Hysteresis width

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

Inverting hysteresis comparators

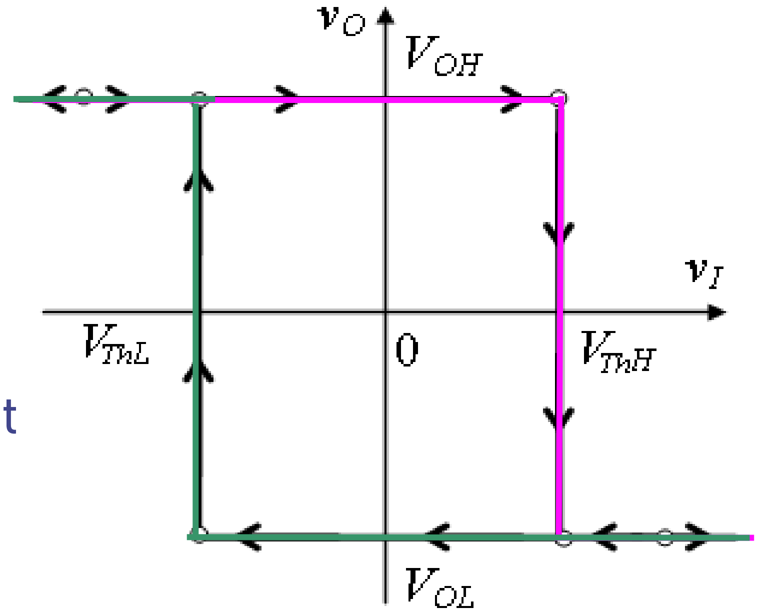


➢ w/ symmetric threshold voltages

- 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 $v_O = V_{OL}$:

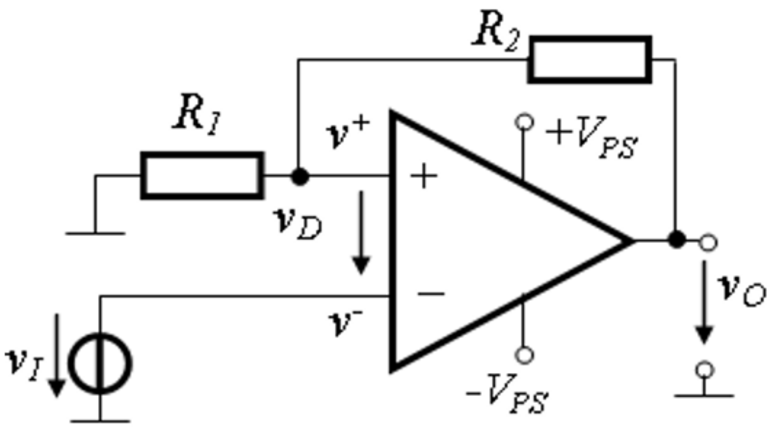
$v_I < V_{ThL}$, v_I ↓, when v_I passes through V_{ThL}

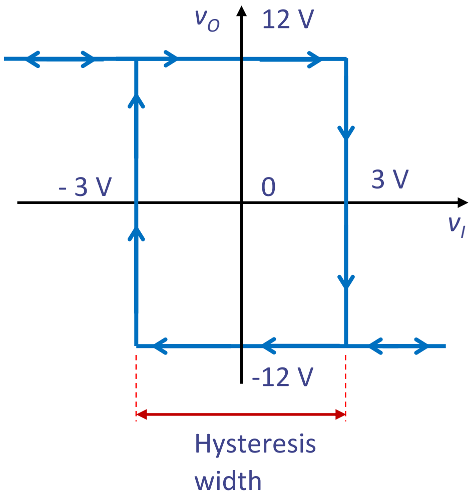
v_I ↓, v_D ↑, $\mathbf{v_O}$ **↑,** v^+↑, v_D↑, $\mathbf{v_O}$ ↑ **PF**

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

Inverting hysteresis comparators

Illustration

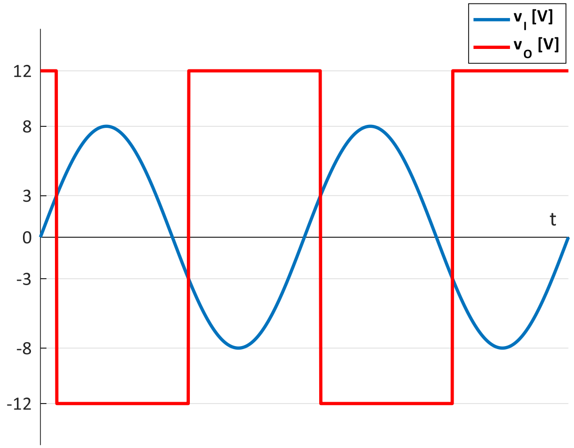




R_1 = 5 k, R_2 = 15 k, ± V_{PS} = ± 12V

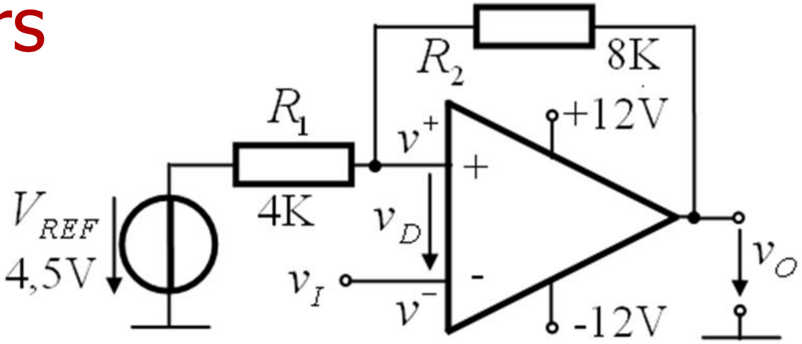
Input: 8 V sinewave

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



Inverting hysteresis comparators

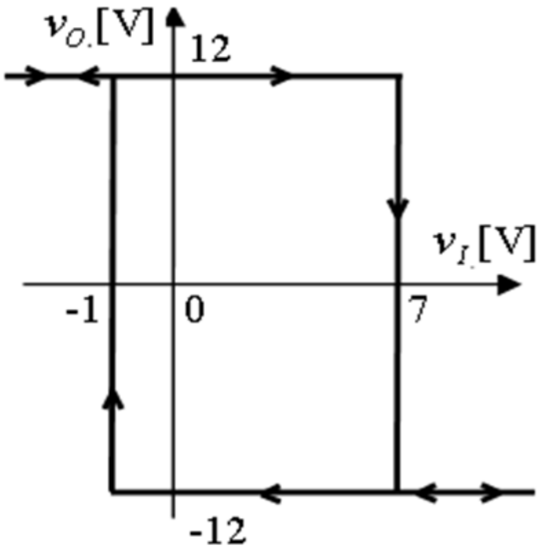
- w/ asymmetric threshold voltages



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

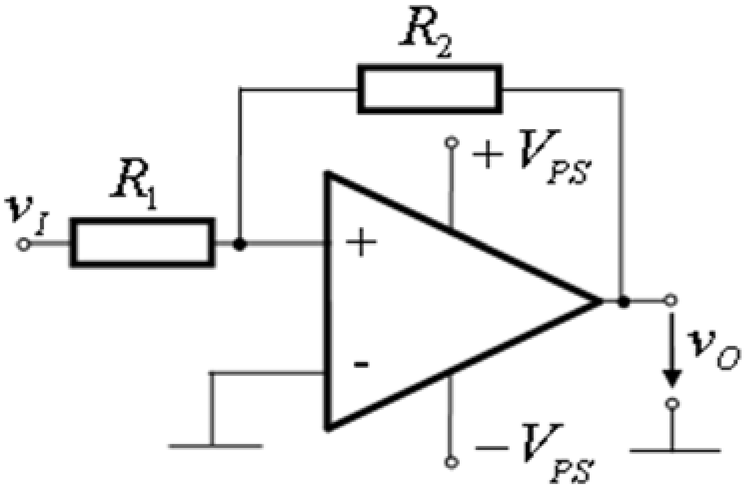
$$v_D = v^{+} - v^{-} = \frac{R_1}{R_1 + R_2} v_O + \frac{R_2}{R_1 + R_2} V_{REF} - v_I$$

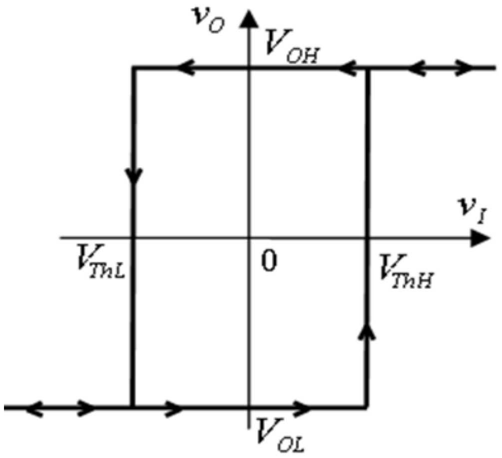
$$\text{For } v_D = 0,\; v_I \to V_{Th} \begin{cases} V_{ThL} = \dfrac{R_1}{R_1 + R_2} V_{OL} + \dfrac{R_2}{R_1 + R_2} V_{REF} \\ V_{ThH} = \dfrac{R_1}{R_1 + R_2} V_{OH} + \dfrac{R_2}{R_1 + R_2} V_{REF} \end{cases}$$



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

Non-inverting hysteresis comparators



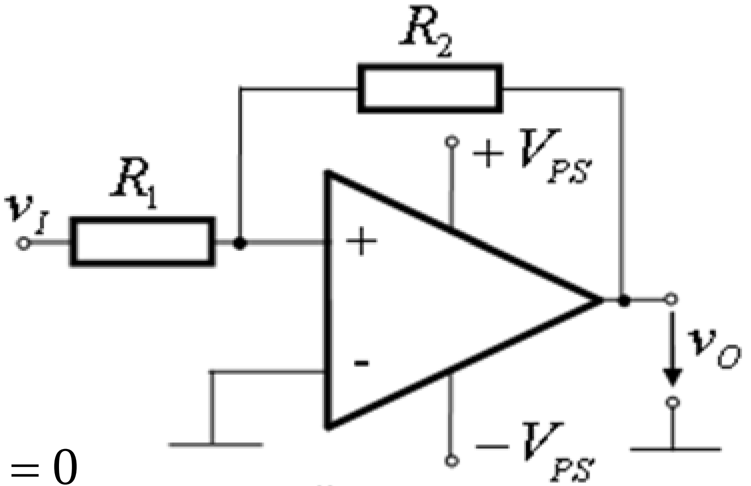


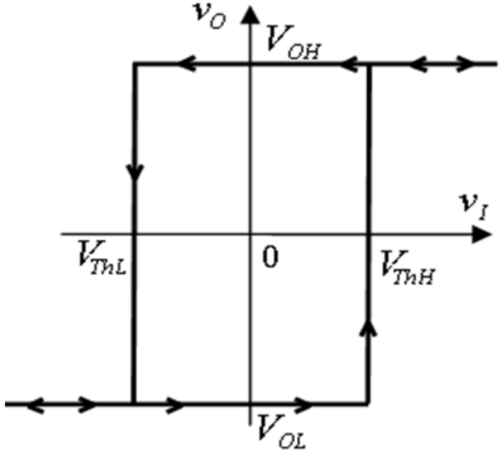
Non-inverting hysteresis comparators

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

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

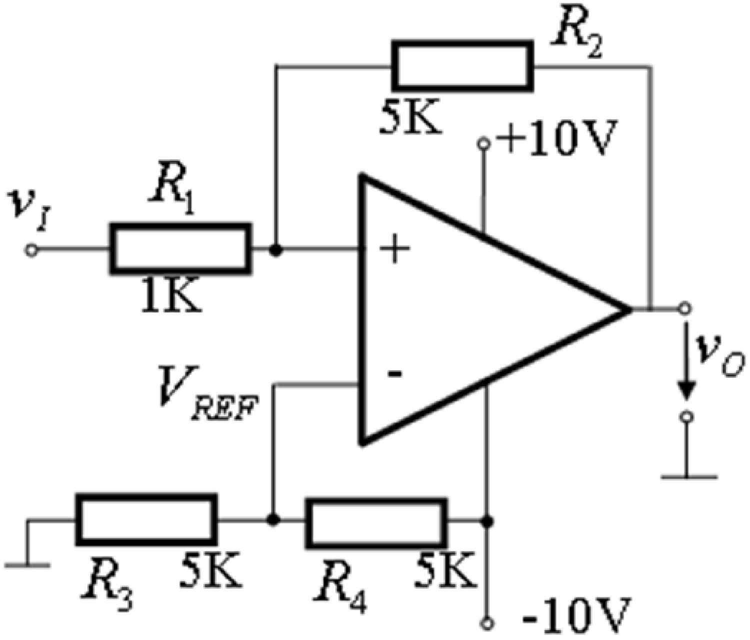
$$V_{Th} = -\frac{R_1}{R_2} v_O \quad \left\{ \begin{array}{l} V_{ThL} = -\frac{R_1}{R_2} V_{OH} \\ V_{ThH} = -\frac{R_1}{R_2} V_{OL} \end{array} \right.$$

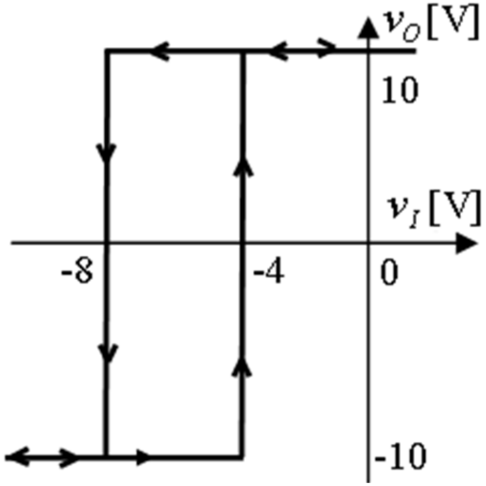




Non-inverting hysteresis comparators

Illustration





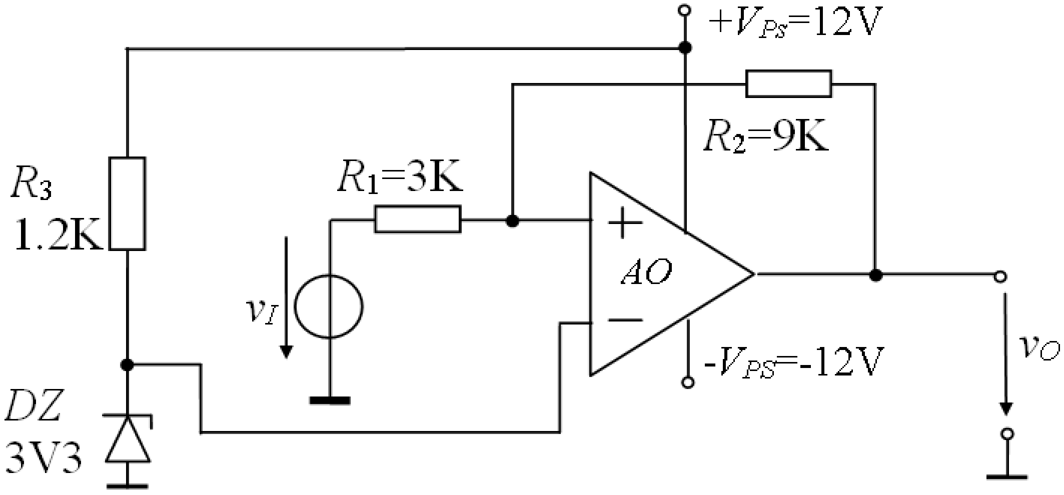
$$v_D = v^+ - v^- = \frac{R_1}{R_1 + R_2} v_O + \frac{R_2}{R_1 + R_2} v_I - V_{REF}$$

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

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

Non-inverting hysteresis comparators

Example



a) Draw the VTC $v_O(v_I)$ qualitatively (no numerical values). What is the application of the circuit?

b) What are the expressions and values of: V_{OH}, V_{OL}, V_{ThH}, V_{ThL}? Redraw the VTC in accordance with numerical values.

c) $v_I(t)$ is a triangular wave with 11 V amplitude. Plot $v_I(t)$ and $v_O(t)$.

d) Modify the circuit so that by keeping the same supply voltages, the thresholds become 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
    - Inverting hysteresis comparators
        - w/ symmetric threshold voltages
        - w/ asymmetric threshold voltages
    - Non-inverting hysteresis comparators
    - Applications

Next week: Electronic amplifiers. Amplifiers with OpAmp.