ELECTRONIC DEVICES

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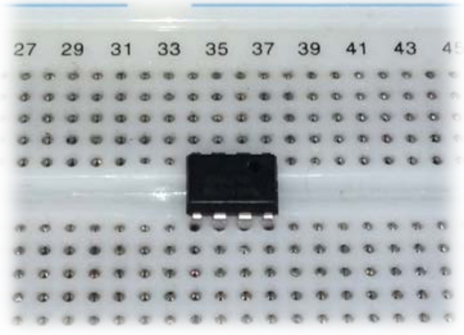
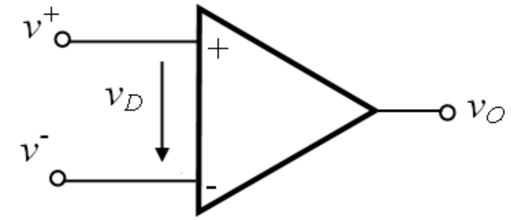
C6 – Simple comparators with OpAmp



Contents

Relation between output and input voltages

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



I. Utilization as comparator, in switching mode

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

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

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

II. Utilization as amplifier

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

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)

OpAmp comparators

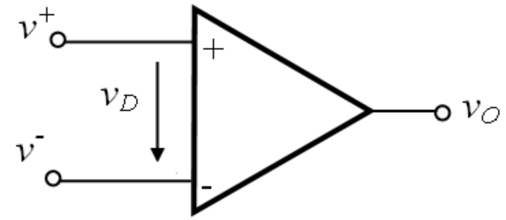
OpAmp in switching mode => OpAmp comparator

Voltage comparator = circuit that signalizes the relative state of two input voltages, through two different states of the output voltage

? relative state of two input voltages = ?

? two different states of the output voltage = ?

OpAmp comparators



Voltage comparator = circuit that signalizes the relative state of two input voltages, through two different states of the output voltage

relative state of two input voltages = one input voltage is bigger/smaller than the other

= their difference is positive/negative

For OpAmp comparators, a single input is considered, namely $v_D = v^+ - v^-$

two different states of the output voltage = low/high

$V_O \in \{V_{OL}, V_{OH}\}$

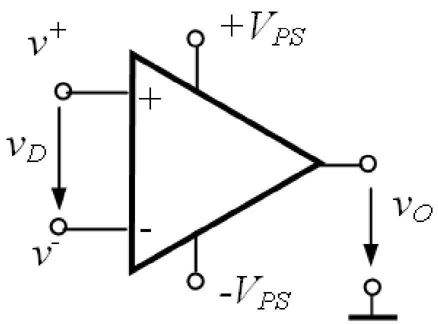
$\mathbf{v_D > 0}$, meaning $v^+ > v^-$, $\mathbf{v_O = V_{OH} \approx +V_{PS}}$

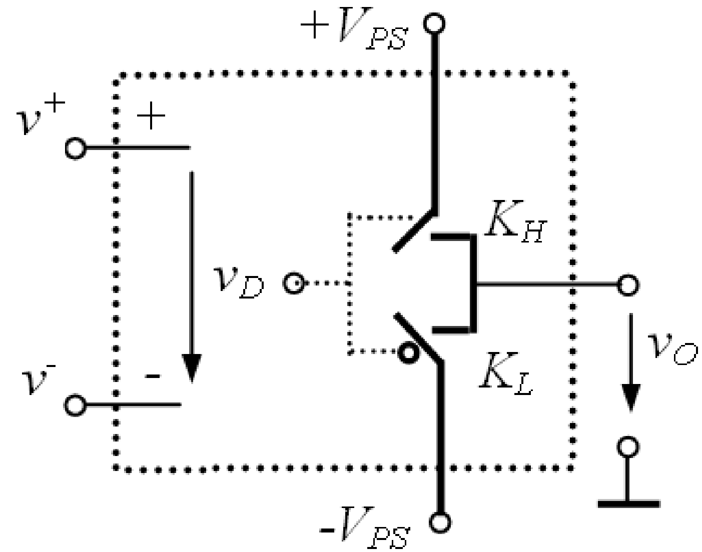
$\mathbf{v_D < 0}$, meaning $v^+ < v^-$, $\mathbf{v_O = V_{OL} \approx -V_{PS}}$

Simple comparators with OpAmp

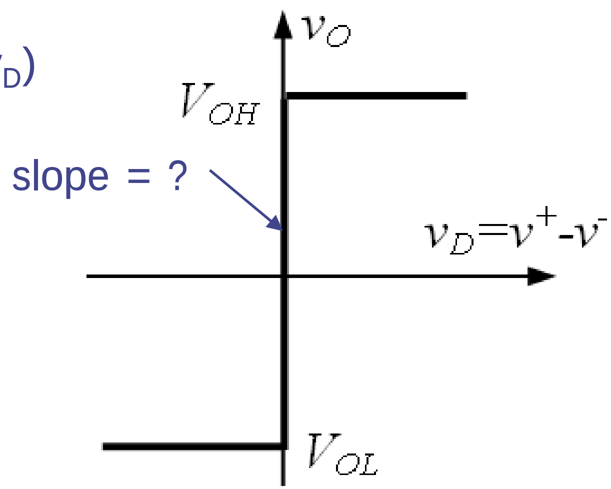
OpAmp comparators

OpAmp model in switching regime





VTC $v_O(v_D)$



v_D	K_H	K_L	v_O
>0	*on*	*off*	$V_{OH}=+V_{PS}$
<0	*off*	*on*	$V_{OL}=-V_{PS}$

Suitable for rail-to-rail op-amp

OpAmp comparators

Types of voltage comparators:

- Simple comparators – without feedback, one threshold voltage
- 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

Simple comparators

= comparators without feedback, one threshold voltage

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

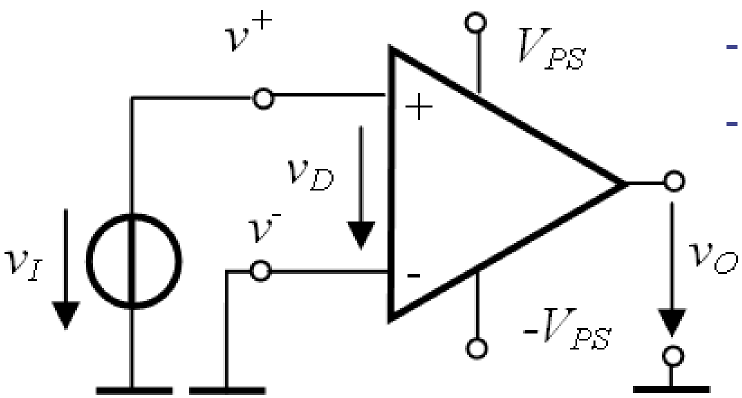
$$V_{Th} = v_I \,\big|_{v_D = 0}$$

Steps for finding V_{Th}:

- Step 1: write down the expressions for v^+ and v^- (Ohm's law, KVL, voltage divider, Millman)
- Step 2: write down $v_D = v^+ - v^-$
- Step 3: set v_D to 0 and replace v_I with V_{Th}
- Step 4: compute the numerical value of V_{Th}

➢ Simple comparators with V_{Th} = 0 V

▪ Non-inverting



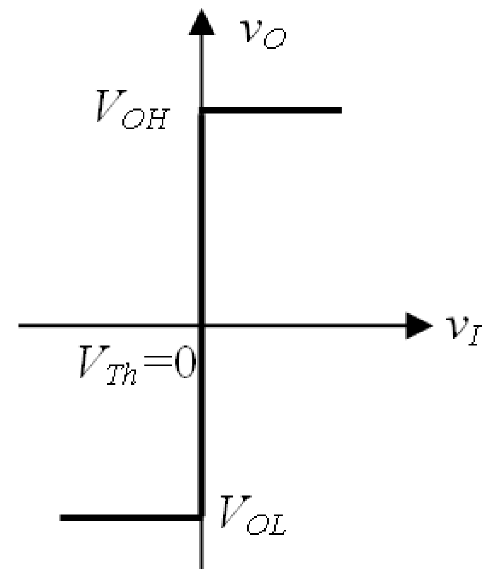
- v_I is applied at the non-inverting input (v^+)
- the inverting input (v^-) is connected to ground (0 V)

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

$$v^+ = v_I;\quad v^- = 0$$

$$v_D = v_I$$

$$v_D = 0;\quad V_{Th} = 0$$

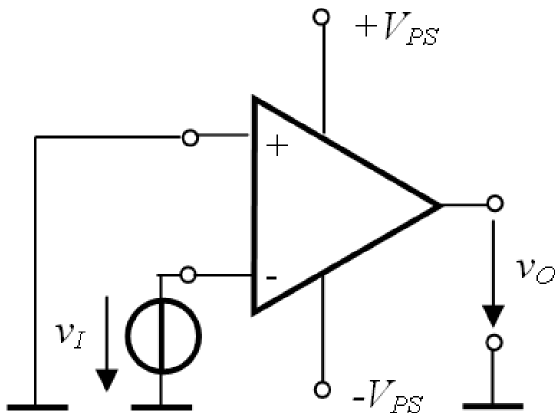


$$v_O = \begin{cases} V_{OH} & \text{if } v_D > 0, \text{ this is } v_I > 0 \\ V_{OL} & \text{if } v_D < 0, \text{ this is } v_I < 0 \end{cases}$$

Plot the input and output voltages, if the input voltage is a sine wave with 5 V amplitude and the supply is $\pm V_{PS} = \pm 15$ V.

➢ Simple comparators with V_{Th} = 0 V

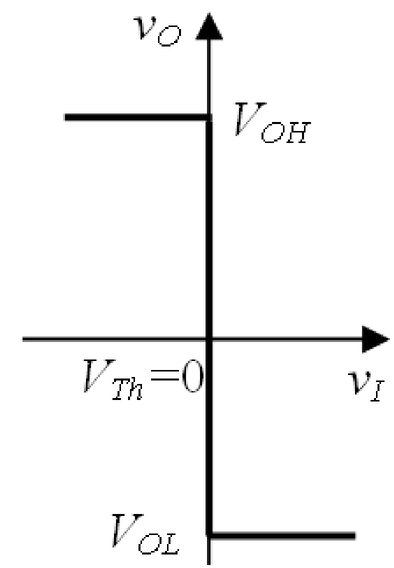
▪ Inverting



- v_I is applied at the inverting input (v^-)

- the non-inverting input (v^+) is connected to ground (0 V)

$$v_D = v^+ - v^-$$
$$v^+ = 0; \quad v^- = v_I$$
$$v_D = -v_I$$
$$v_D = 0; \quad V_{Th} = 0$$

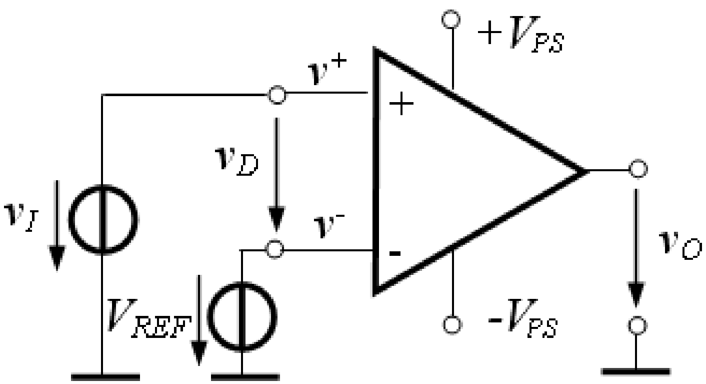


$$v_O = \begin{cases} V_{OH} & \text{if } v_D > 0, \text{ this is } v_I < 0 \\ V_{OL} & \text{if } v_D < 0, \text{ this is } v_I > 0 \end{cases}$$

Plot the input and output voltages, if the input voltage is a sine wave with 5 V amplitude and the supply is $\pm V_{PS} = \pm 15$ V.

Simple comparators with $V_{Th} \neq 0$ V

Non-inverting

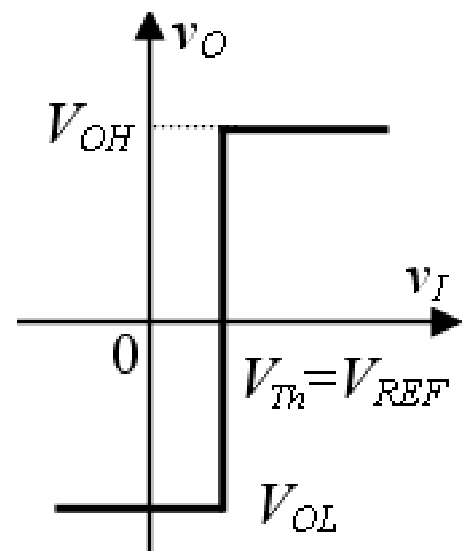


- v_I is applied at the non-inverting input (v^+)

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

$$v_D = v_I - V_{REF}$$

$$v_D = 0; \quad V_{Th} = V_{REF}$$

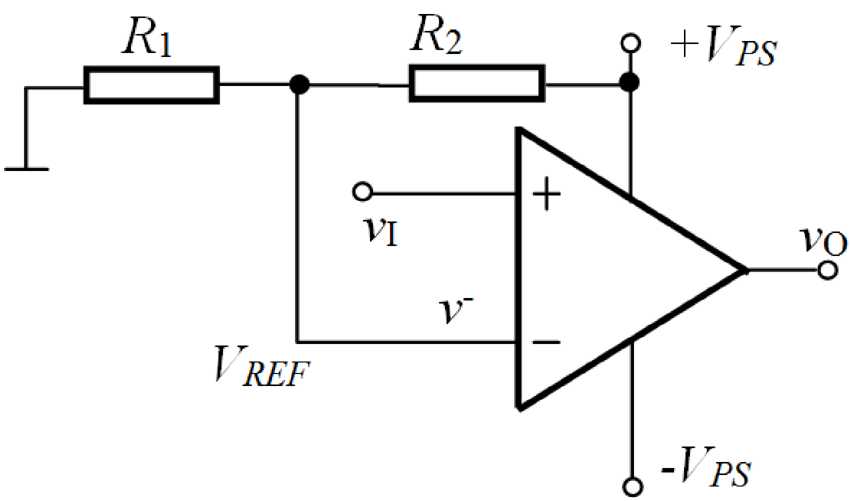


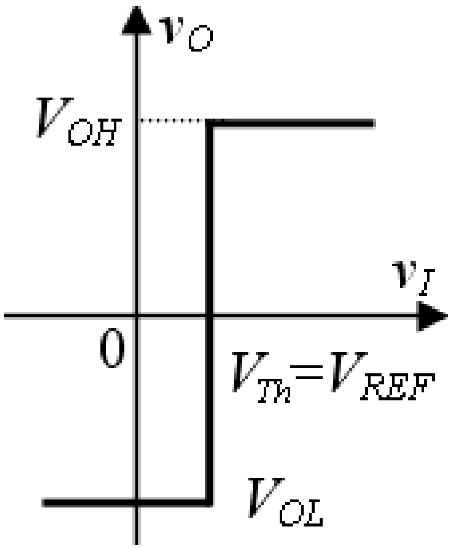
How can V_{REF} be obtained, using the already available dc supplies?

Simple comparators with OpAmp

➢ Simple comparators with $V_{Th} \neq 0$ V

- **Non-inverting**



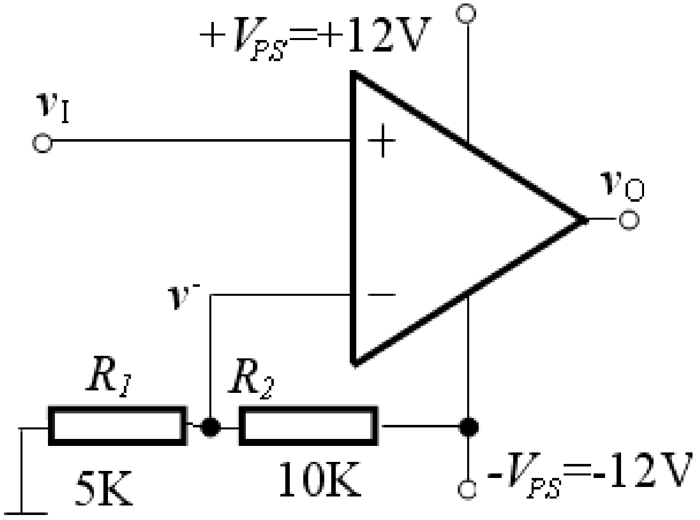


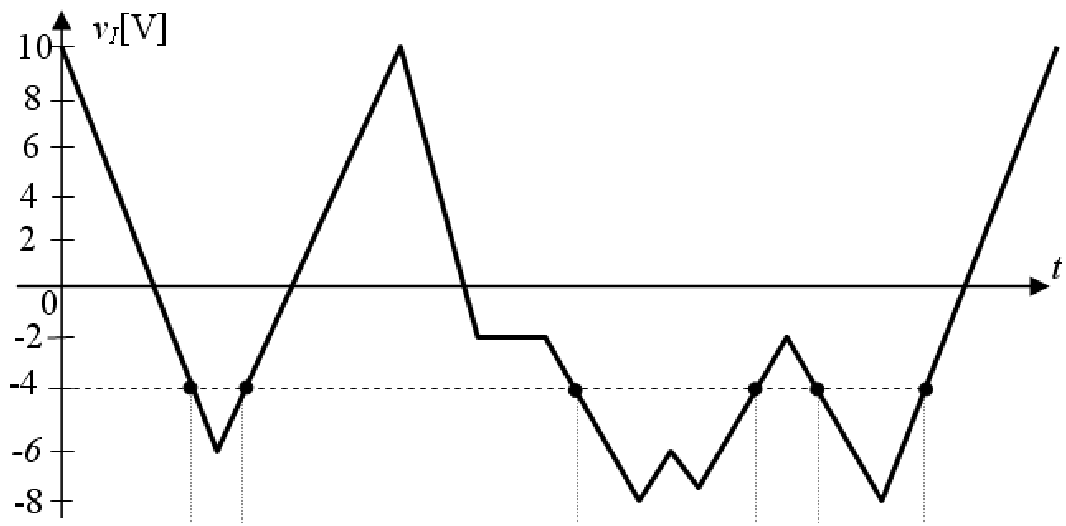
$$V_{REF} = \frac{R_1}{R_1 + R_2} V_{PS}$$

Negative V_{REF}?

Simple comparators with $V_{Th} \neq 0$ V

- **Example**



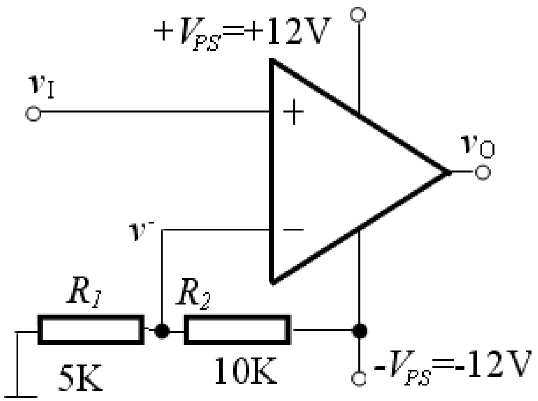


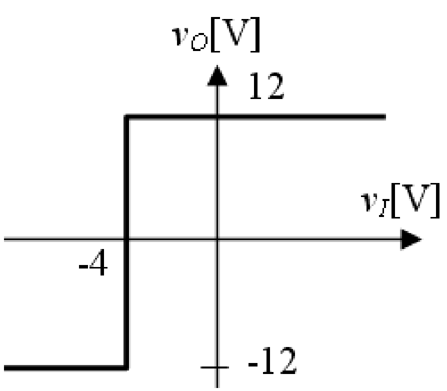
a) Deduce and plot VTC $v_O(v_I)$. What is the application of the circuit?
b) Plot $v_O(t)$ for the given $v_I(t)$.
c) Change the circuit, so that is becomes an inverting comparator, with V_{Th} = 6 V.

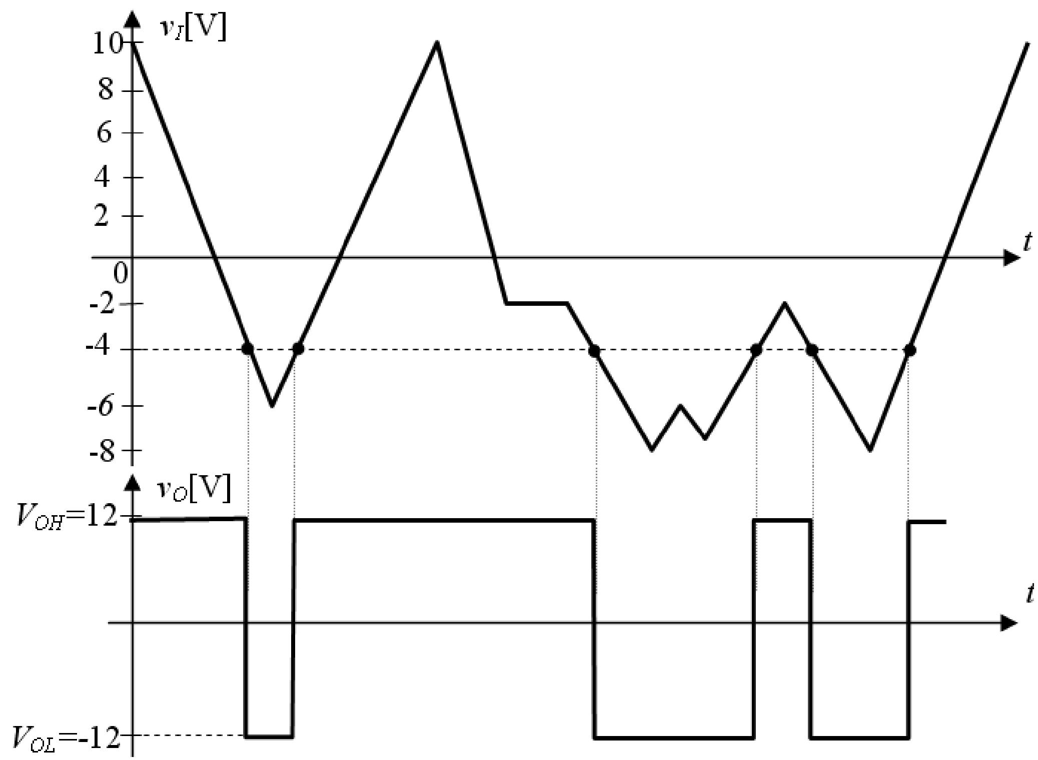
Simple comparators with OpAmp

➢ Simple comparators with $V_{Th} \neq 0$ V

- **Example**



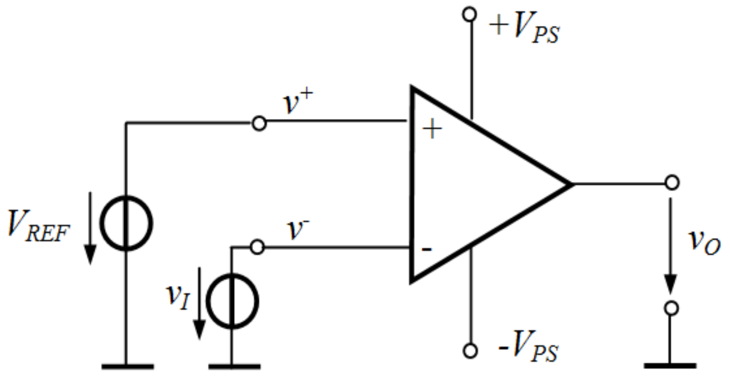




Simple comparators with OpAmp

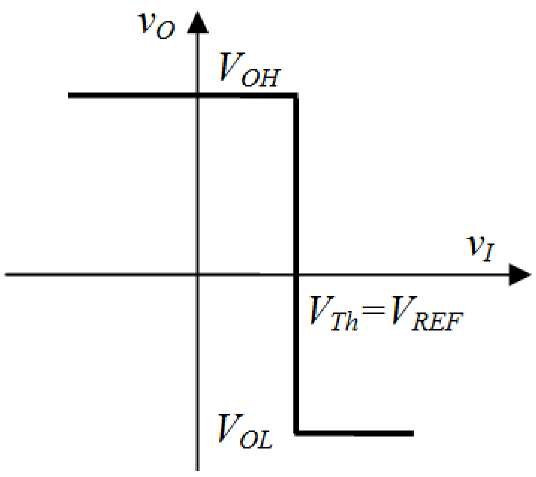
➢ Simple comparators with $V_{Th} \neq 0$ V

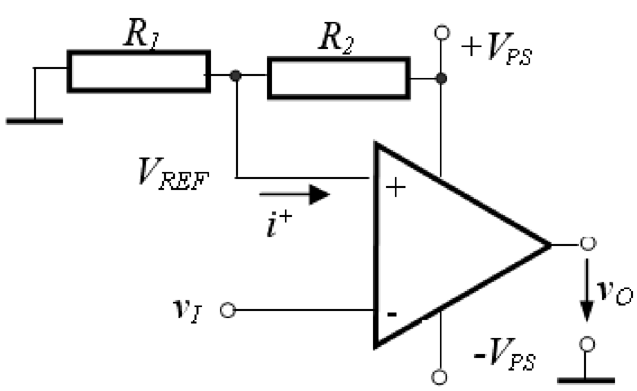
▪ Inverting



- v_I is applied at the inverting input (v^-)

$$v_D = v^+ - v^-$$
$$v_D = V_{REF} - v_I$$
$$v_D = 0; \quad V_{Th} = V_{REF}$$





$i^+ <<$ current through R_1, R_2 divider ($i^+ \cong 0$)

$$V_{REF} = \frac{R_1}{R_1 + R_2} V_{PS}$$

Applications

- general-purpose OpAmps are often used as comparators
- **special class** of ICs, intended for use as comparators:

  LM 306, LM 311 ,LM 399, LM 393, LM 339

  - high differential input voltage
  - high-speed response (high slew-rate)
  - open collector (open drain)
  - many comparators have a ground terminal that is not present in usual OpAmps

Simple comparators with OpAmp

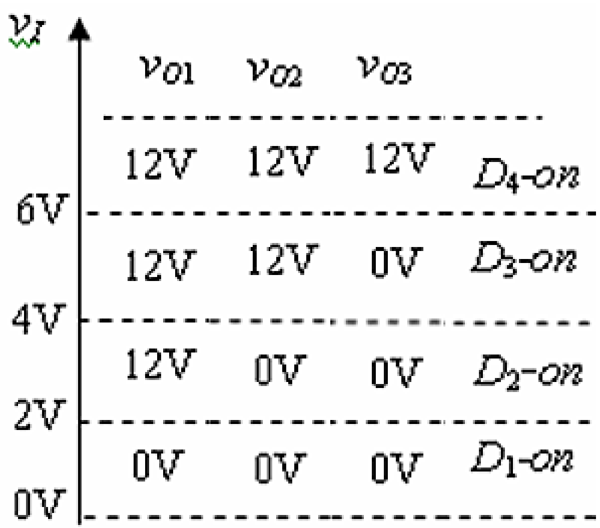
Applications

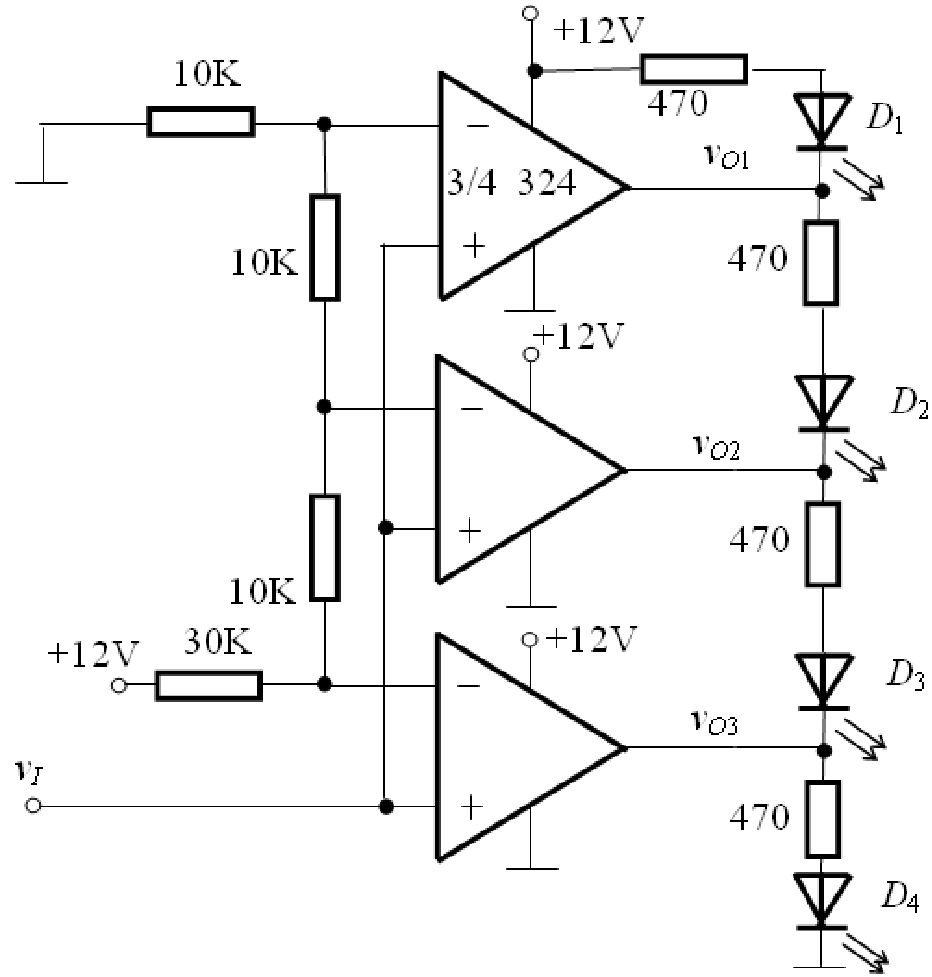
- Logic circuits
- Interface between analog and logic circuits
- Obtaining rectangular signal from sinusoidal (triangular) signal
- Optical indicator for voltage level (L10)
- Pulse width modulation
- Signalizing and control circuits
- Analog to digital converters, etc

Simple comparators with OpAmp

➢ Applications

- Optical indicator for voltage level

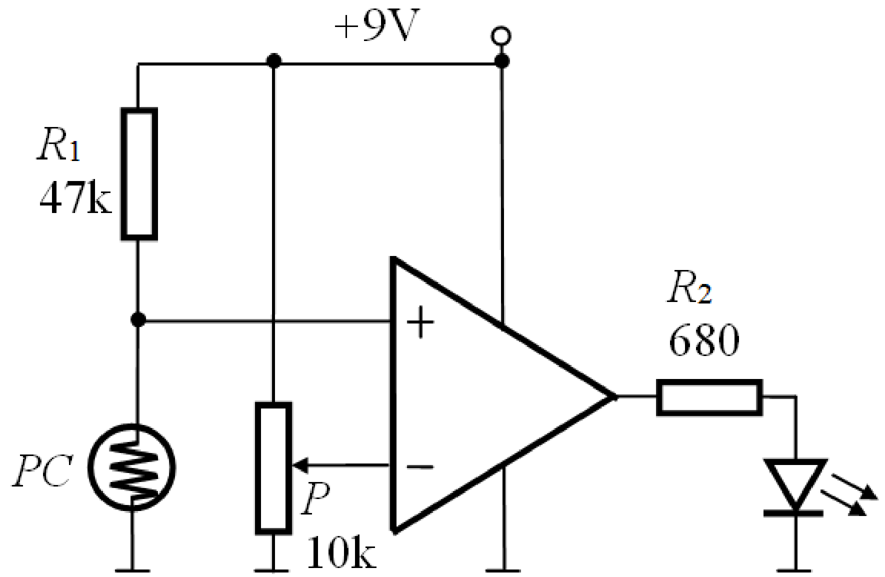




Simple comparators with OpAmp

➢ Applications

- Light sensor circuit



PC : CdS Photoconductive Photocells

PDV-P8001

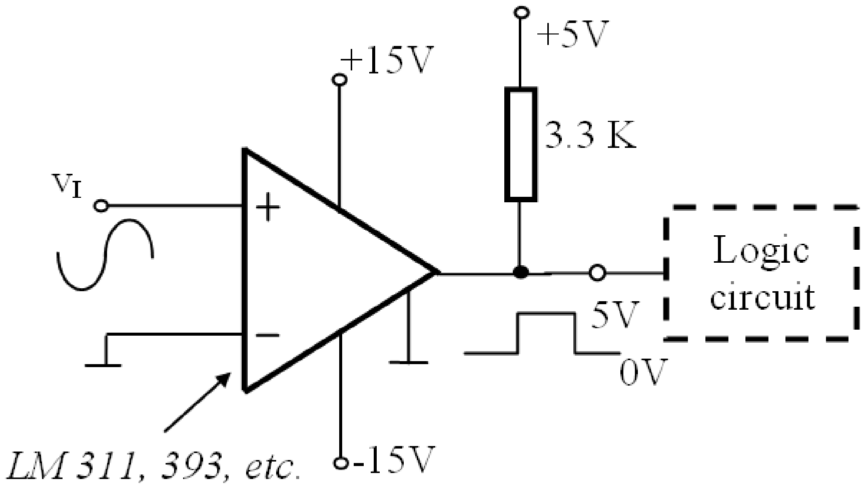
LDR - light dependent resistor

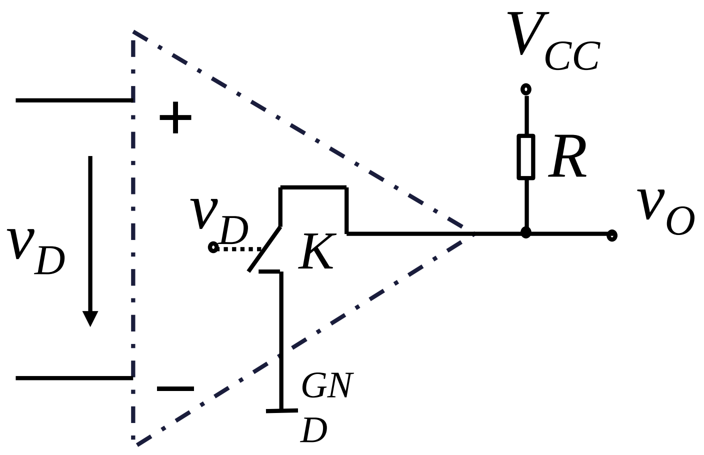
Dark resistance: R_D > 200 kΩ

Illuminated Resistance: $R_I \in (3; 11)$ kΩ

➢ Applications

- Analog to logic circuits interfacing





Comparator model

$v_D > 0$	K – (off)	$v_O = V_{CC}$
$v_D < 0$	K – (on)	$v_O = 0$

Summary

- Simple comparators with OpAmp
  - Simple comparators with $V_{Th} = 0$ V
  - Simple comparators with $V_{Th} \neq 0$ V
  - Applications

Next week: Hysteresis comparators with OpAmp.

To do: Homework 4