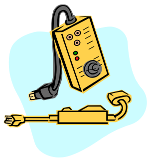
VOLTAGE COMPARATORS WITH OPERATIONAL AMPLIFIERS - SIMPLE COMPARATORS

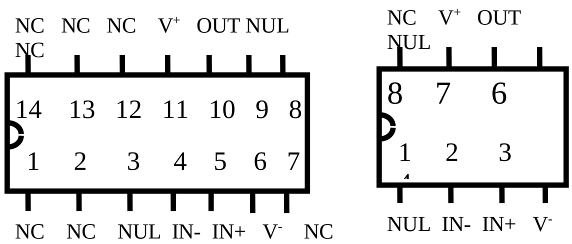
I. OBJECTIVES

a) Determining the voltage transfer characteristics (VTC) for simple voltage comparators (without feedback).
b) Determining the output voltage in accordance with the configuration of the circuits and the input voltage.
c) Determining the effects of modifying the supply and reference voltages on the VTC of comparators.



II. COMPONENTS AND INSTRUMENTATION

You will use the experimental board equipped with two 741 operational amplifiers (see Fig. 1), a 10KΩ potentiometer, resistors of different values and a 10nF capacitor. In order to supply the assembly you will use a dual dc regulated power supply, and as a sinusoidal signal source you will use a signal generator. In order to visualize the voltages you need a dual channel cathodic oscilloscope and for some dc voltages you need a dc voltmeter.



NC – not connected
NUL – offset compensator
IN^- - inverting input
IN^+ - non-inverting input
V^- - negative voltage supply
V^+ - positive voltage supply
OUT – output

Fig. 1. 741 OP-AMP. Connection diagrams

III. THEORETICAL ASPECTS

Op-Amp Comparators

The switching regime for an electronic device is an operating regime where the device switches from one extreme state to another extreme state. The op amps have very useful applications in this operating regime. In this case the two extreme states are the saturation regions of the op amp, when the output voltage can take only one of two limit values:

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

The circuits where op amps are used in *switching mode* are called *op-amp comparators*. A voltage comparator is a circuit that points out through two different states of the output voltage, the relative state of two input voltages.

The comparison of the voltages is done through the determination of their difference. The comparator response is one of the two possible output values, depending on the sign of that difference. For an op-amp comparator we can consider a single input namely the difference between v^+ and v^-, that is v_D.

When $v_D>0, \; v^+>v^-, \; v_O=V_{OH}$

$v_D<0, \; v^+<v^-, \; v_O=V_{OL}$

Simple Comparators

In many cases a reference source is applied at one of the op-amp inputs and the input voltage v_I is applied to the other input. We define as *threshold voltage* V_{Th} that particular value of the input voltage v_I for which the output switches from one state in the other state, or in other words for which v_D=0.

- **Comparators with V_{Th}=0V**

A simple voltage comparator with zero threshold voltage can be easily obtained, connecting one of the inputs to the ground and applying the voltage v_I to the other input. Fig. 2.a) presents a noninverting comparator that has a high (low) value of the output voltage when the input voltage is greater (less) than the threshold voltage.

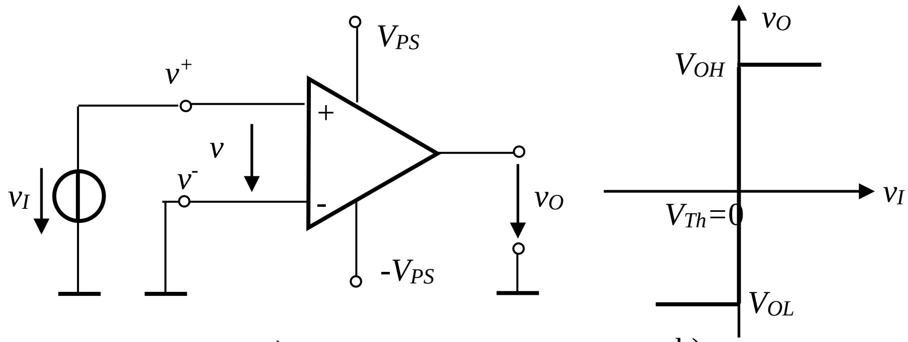
The analysis of the circuit and determination of its VTC relay on finding the v_D expression and comparing it to zero (see Fig. 2. b).

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

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

$$v_D= v_I$$

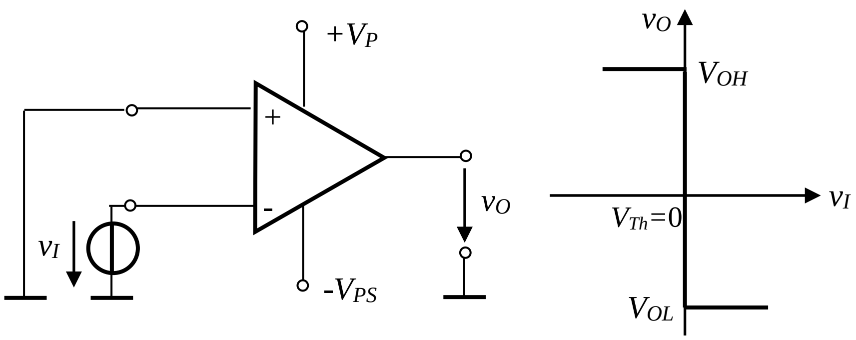
$$v_O=\begin{cases} V_{OH} & \text{if } v_D>0, \text{ this is } v_I>0 \\ V_{OL} & \text{if } v_D<0, \text{ this is } v_I<0 \end{cases}$$



a) b)

Fig. 2 Noninverting comparator with V_{Th}=0: a) circuit ; b) VTC.

The inverting voltage comparator is presented in Fig. 3.a). It responds with the low (high) value of the output voltage to an input voltage greater (lower) than the threshold voltage and the VTC presented in Fig. 3.b)

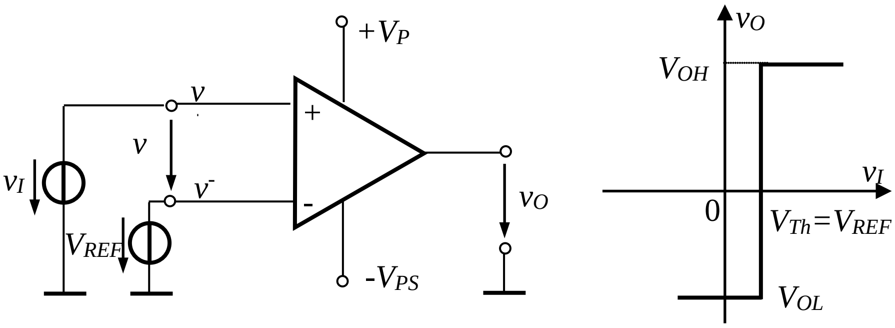


a) b)

Fig. 3 Inverting comparator with V_{Th}=0V: a) circuit; b) VTC

- **Comparators with $V_{Th} \neq 0$**

Many times, it is necessary to compare the input voltage with a reference value V_{REF} different from zero. This is simple to solve by applying v_I at one op-amp input and applying the reference voltage at the other input, as for example in Fig. 4, for a noninverting comparator.



a) b)

Fig. 4 Non-inverting comparator with $V_{Th} \neq 0$V: a) circuit; b)VTC.

To deduce the *VTC* :

$$v^+ = v_I \; ; \; v^- = V_{REF}$$

$$v_D = v^+ - v^- = v_I - V_{REF}$$

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

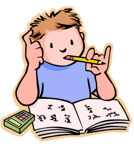
It is obvious that $V_{Th}=V_{REF}$ because the threshold voltage is that particular value of the input voltage for which the output switches (or v_D=0). Setting the condition v_D=0 and replacing v_I by V_{Th} one obtains:

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

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

$$V_{Th} = V_{REF}$$

The resulted VTC for the non-inverting comparator is plotted in Fig. 4.b).



IV. PREPARATION

1. P. INVERTING COMPARATOR

Use the circuit from Fig. 5 supplied with $+V_{PS}$=12V, $-V_{PS}$=-12V.

A. Waveforms

- What does v_O(t) look like, if v_I(t) is a sinusoidal voltage with 5V amplitude and 200Hz frequency, for V_{REF} =0V? But for V_{REF} =4V?
- Which is the value of the threshold voltage V_{Th} (the value of v_I for which the comparator switches)?

- What does $v_O(t)$ look like for a 1V amplitude of v_I?

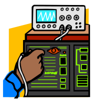
B. VTC
- What does VTC $v_O(v_I)$ look like for $V_{REF} = 0V$?
- What does VTC $v_O(v_I)$ look like for $V_{REF} = 4V$? But for $V_{REF} = -4V$?

C. The effects of modifying the supply voltage
What does the $v_O(t)$ look like for a sinusoidal v_I with a 8V amplitude and 200Hz frequency, V_{REF} =0V, if $+V_{PS}$=9V, $-V_{PS}$=-9V? What if $+V_{PS}$=15V, $-V_{PS}$=-9V?

2. P. NON- INVERTING COMPARATOR
- Draw the schematic of a non- inverting voltage comparator with the possibility of adjusting V_{Th} between $+V_{PS}$ and $-V_{PS}$.
- What does VTC for the non- inverting comparator look like, for V_{Th}=0V?

IV. EXPLORATIONS AND RESULTS

1. INVERTING COMPARATOR
Consider the experimental circuit of Fig. 5.



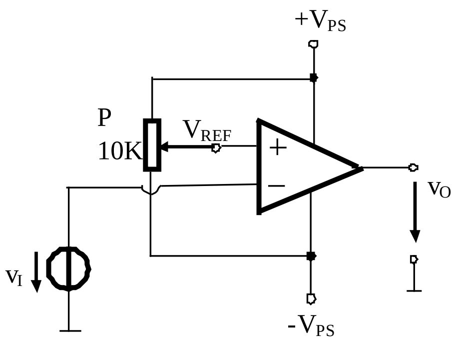
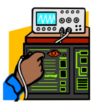


Fig. 5. Basic inverting comparator

Exploration

The assembly is supplied with a symmetrical differential voltage, $+V_{PS}$=12V, $-V_{PS}$=-12V from the dual dc regulated power supply.
- $v_I = 8sin2\pi \cdot 200t$[V][Hz] from the signal generator.
- Using P, adjust the value of V_{REF}; measure this value with a dc voltmeter.

A. Waveforms



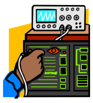
Exploration

- Using the calibrated oscilloscope you will visualize $v_I(t)$ and $v_O(t)$ for V_{REF}=0V and for V_{REF} = 4V.
- Modify the amplitude of v_I to 2V.
- You will visualize $v_O(t)$ and $v_I(t)$ for V_{REF} = - 4V.
- For a v_I amplitude of 8V and for V_{REF} = - 4V you will see $v_O(t)$ and $v_I(t)$ on the oscilloscope.

Results

- $v_I(t)$ and $v_O(t)$ for a v_I amplitude of 8V, for V_{REF} = 0V and for V_{REF} = 4V.
- What are the values of the threshold voltage V_{Th} of the comparator in the two situations above? To find V_{Th} from the waveforms of v_I and v_O, remember that V_{Th} is the instantaneous value of v_I, when the comparator switches.
- What is the relation between V_{Th} and V_{REF}?
- $v_O(t)$ for a v_I amplitude of 2V and V_{REF} = 4V.
- Why isn't $v_O(t)$ a rectangular voltage anymore ?
- V_{Th} =?

B. VTC



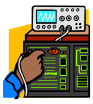
Exploration

- Adjust $v_I = 8\sin 2\pi \cdot 200t$ [V][Hz] and V_{REF} = 0V.
- Using the calibrated oscilloscope, Y-X mode, visualize VTC $v_O(v_I)$, applying to the two inputs X and Y of the oscilloscope the two voltages $v_I(t)$ and respectively $v_O(t)$.
- Visualize VTC for V_{REF} = 4V.
- Visualize VTC for V_{REF} = - 4V.

Results

- VTC for V_{REF}=0V, 4V, -4V.
- How does VTC change, on the coordinate system v_I-v_O, when modifying V_{REF}? Why?

C. The effects of modifying the supply voltage



Exploration

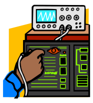
The assembly is supplied with a symmetrical differential voltage, $+V_{PS}$=9V, $-V_{PS}$=-9V from the dual dc regulated power supply.

- $v_I = 8\sin 2\pi \cdot 200t$[V][Hz] from the signal generator.
- V_{REF} = 0V by adjusting P.
- Using the oscilloscope, Y- t mode, visualize $v_I(t)$ and $v_O(t)$.
- Modify the supply voltages: $+V_{PS}$=15V, $-V_{PS}$=-9V.
- Visualize $v_I(t)$ and $v_O(t)$ on the oscilloscope.

Results

- $v_I(t)$ and $v_O(t)$ for $+V_{PS}$=9V, $-V_{PS}$=-9V and for $+V_{PS}$=15V, $-V_{PS}$=-9V.
- What is the effect of modifying the supply voltage on the V_{Th}?
- Which are the maximum and minimum values of the output voltage of the comparator, V_{OH} and V_{OL}, if the values of the supply voltage change? Compare the values of V_{OH} and V_{OL} with the ones you have obtained at sections **A** and **B**.

2. NON- INVERTING COMPARATOR



Exploration

Build the experimental circuit drawn at **2. P.**

- $v_I = 8sin2\pi \cdot 200t$[V][Hz] from the signal generator.
- Using P, adjust V_{REF}, which is measured with a dc voltmeter.
- Visualize $v_I(t)$ and $v_O(t)$ for V_{REF}=, 4V, -4V
- Visualize VTC $v_O(v_I)$ for V_{REF}=0V, 4V, -4V

Results

- $v_I(t)$ and $v_O(t)$ for V_{REF}=, 4V, -4V
- VTC for V_{REF}=, 4V, -4V
- What is the difference between the current VTC and the one obtained at **1.B**?

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