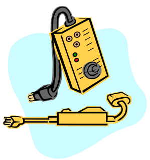
VOLTAGE COMPARATORS WITH OPERATIONAL AMPLIFIERS - HYSTERESIS COMPARATORS

I. OBJECTIVES

a) Determining the voltage transfer characteristics (VTC) for hysteresis comparators.
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 hysteresis comparators.
d) Deduction of the noise effect, overlapped on the input voltage on the comparator's switchings.



II. COMPONENTS AND INSTRUMENTATION

Use the experimental board equipped with two operational amplifiers 741, a 10KΩ potentiometer, resistances of different values and a 10nF capacitor. In order to supply the assembly, you will use a double dc regulated source, and as a sinusoidal signal source you will use a signal generator. In order to visualise the voltages, you need a dual channel oscilloscope and for some dc voltages you need a dc voltmeter.

III. THEORETICAL ASPECTS

<u>Comparators with Hysteresis</u>

Simple comparators, without feedback have two shortcomings:

- for input signal with slow variations, the output switching from one value to another can be slow as well;
- if the input signal has, as it usually does have, noise superimposed on it (with a frequency much higher than that of the signal), the signal might cross the threshold value a number of times around each threshold-crossing. At the output, there will be multiple unwanted switching, instead of only one at each signal threshold-crossing.

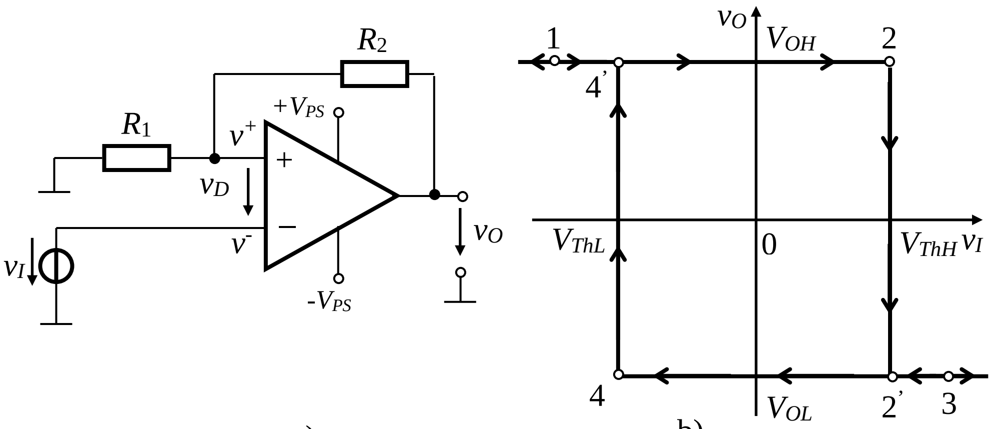
The unwanted switching can be avoided if two threshold values depending on the output voltage values are introduced. If the two threshold voltages are denoted by V_{ThH} (the high threshold) and V_{ThL} (the low threshold), the difference between these two threshold $\Delta V_{Th}=V_{ThH}-V_{ThL}$ must be greater than the peak-to-peak value of the noise. At a certain moment there is (active) only one threshold voltage, depending on the output voltage value. We name such a circuit a *comparator with hysteresis*.
Since every threshold value depends on one of the two possible values of the output voltage, we must find a way to feed back the output voltage to the input of the comparator. The used technique is called *positive feedback* and this means to bring a fraction of the output voltage back to the noninverting input of the op amp through a resistive divider.

1. Inverting Comparator with PF

The circuit of an inverting comparator with hysteresis looks like in Fig. 1.a) and the VTC looks like in Fig.1.b). The potentials at the op-amp inputs are (op-amp inputs do not draw any current):

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

$$v^- = v_I$$



a) b)

Fig.1. Inverting comparator with hysteresis: a) circuit; b) VTC.

Due to the positive feedback, through R_1 and R_2, a fraction $R_1/(R_1 + R_2)$ from the output voltage v_O is brought to the noninverting input of the op amp. To know the output state we must determine v_D:

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

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

Suppose that v_I has a negative value, low enough to have $v_D>0$. In this case $v_O=V_{OH}$, and we are in the point 1 on the VTC in Fig. 1.b) .

Therefore, we have:

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

Assume now that v_I increases, so v_D decreases getting close to zero. The moment when v_D crosses through zero towards negative values, the op-amp output switches. The value of v_I for which $v_D=0$ between the points 2 and 2' on the VTC, is the V_{ThH} threshold value:

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

If v_I continues to increase, $v_I > V_{ThH}$, $v_D<0$ and $v_O=V_{OL}$ (we are for example in point 3 on the characteristic). We consider now that v_I starts to decrease, which means an increase towards zero of v_D. The moment when v_D crosses through zero towards positive values, the output of the op amp switches over. The value of v_I for which $v_D=0$ (between the points 4 and 4' on the VTC) is the V_{ThL} threshold voltage:

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

If v_I continues to decrease, $v_D<0$ and $v_O=V_{OH}$ (we are for example in point 1 on the characteristic).

We proved that the op-amp circuit with positive feedback in Fig..1a) behaves as a comparator with hysteresis with the VTC presented in Fig. 1.b). The hysteresis is centered on zero, the width of the hysteresis being:

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

The direction of going over the hysteresis curve is clockwise. Note that at a certain moment only one threshold is "active". To center the hysteresis on a different from zero value, a reference voltage is applied to the noninverting input.

2. Noninverting Comparator with PF

The circuit of a noninverting comparator with hysteresis is depicted in Fig.2.a) and the VTC is depicted in Fig.2.a).

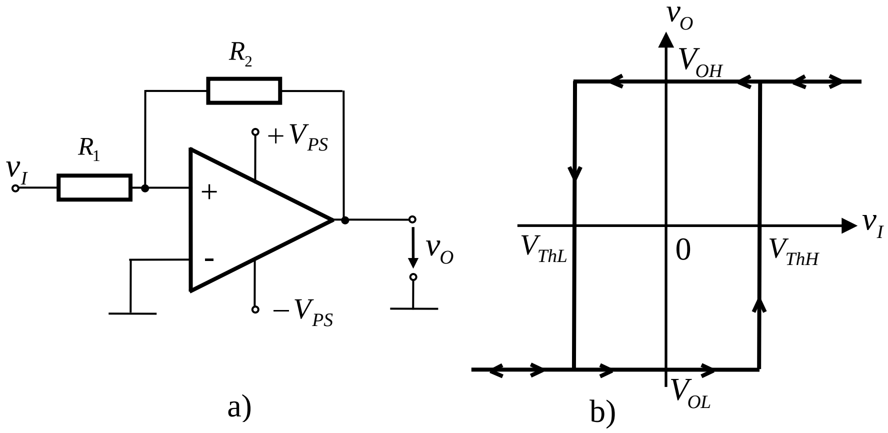


Fig.2. Noninverting comparator with hysteresis: a) circuit; b) VTC.

The threshold voltages are determined for $v_D = 0$V, when v_I becomes V_{ThL}, respectively V_{ThH}.

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

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

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

$$V_{ThL} = -\frac{R_1}{R_2} V_{OH} \; ; \qquad V_{ThH} = -\frac{R_1}{R_2} V_{OL}$$

Remark that for the noninverting comparator the low threshold value V_{ThL} is obtained for the high value of the output voltage V_{OH} and vice-versa, V_{ThH} is obtained for V_{OL}.

The hysteresis is centered on 0V having the width ΔV_{Th}:

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

To center the hysteresis on a different from zero value, a reference voltage is applied to the inverting input.

IV. PREPARATION

1.P. NONINVERTING COMPARATOR

For the schematic of Fig. 3 the following data is given: $+V_{PS}$=12V, $-V_{PS}$=-12V.

- Which is VTC for the non-inverting comparator with positive feedback?
- What does $v_O(t)$ look like for $v_I(t)$ sinusoidal voltage with 3V amplitude and 200Hz frequency ? What happens if the amplitude of v_I is 8V?

2.P. INVERTING COMPARATOR

Use the schematic of Fig. 4.

- Which are the expression of the threshold voltages $V_{Th,L}$ and $V_{Th,H}$?
- What are the values of $V_{Th,L}$ and $V_{Th,H}$ for V_{REF} = 0V, $+V_{PS}$=12V, $-V_{PS}$=-12V?
- Which is the VTC $v_O(v_I)$? What is the sense of movement on the hysteresis curve?
- What is the width of the hysteresys curve $\Delta V_{Th}=V_{Th,H}-V_{Th,L}$?
- What are the effects of modifying the supply voltage over VTC?
- What are the effects of modifying V_{REF} over VTC?
- What does $v_O(t)$ look like when $v_I = 8\sin 2\pi \cdot 200t$ [V][HZ], for the above data ? What happens if the amplitude of v_I is 1V?

3.P. INVERTING COMPARATOR FOR NOISY SIGNAL

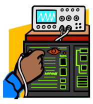
Use the schematic in Fig. 5. We want to study the effect of the noise overlapped on the input voltage, on the switches of the comparator without feedback. In Fig. 5 the input signal of the comparator (v_I) is obtained by summing the sinusoidal input voltage (v_s), with 10V amplitude and 200Hz frequency with a triangular signal v_n (considered to be the noise) with 2.2V amplitude and 2.7KHz frequency. The summing is made using the R_1 and R_2 resistors. The noise voltage is generated by a multivibrator circuit (framed by the marked area).

- What do $v_s(t)$, $v_n(t)$, $v_I(t)$ look like?
- What does $v_O(t)$ look like?

V. EXPLORATIONS AND RESULTS

1. NONINVERTING COMPARATOR

Use the circuit shown in Fig. 3.



Exploration

- Supply the assembly with $+V_{PS}$=12V, $-V_{PS}$=-12V.
- v_I is a sinusoidal voltage with 8V amplitude and 200Hz frequency from the signal generator.
- Using the calibrated oscilloscope, you will see $v_I(t)$, $v_O(t)$ and VTC $v_O(v_I)$.

Results

- $v_I(t)$, $v_O(t)$.
- VTC

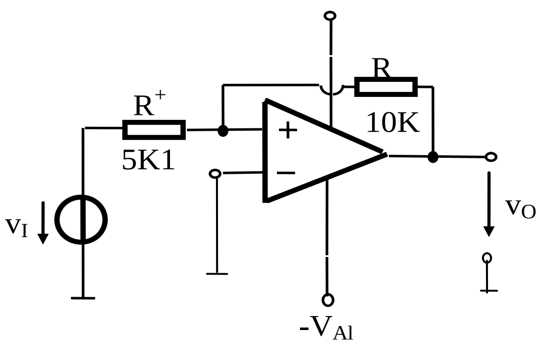


Fig. 3. Noninverting comparator with positive feedback

2. INVERTING COMPARATOR

Exploration

Use the experimental schematic from Fig. 4.

- $+V_{PS}$=12V, $-V_{PS}$=-12V from the dual dc regulated power supply.
- Adjust V_{REF} = 0V, using P.
- $v_I = 8\sin 2\pi \cdot 200t$[V][Hz] from the signal generator.
- Using the oscilloscope, Y-t mode, visualize $v_I(t)$ and $v_O(t)$.
- Using the oscilloscope, Y-X mode visualize VTC $v_O(v_I)$, applying the voltages v_I and v_O on the X and Y inputs of the oscilloscope .
- Modify the amplitude of v_I to 1V.
- Using the oscilloscope, Y-t mode, visualize $v_I(t)$ and $v_O(t)$.

Results

- $v_I(t)$ and $v_O(t)$ for a v_I amplitude of 8V and 1V.
- VTC $v_O(v_I)$ when the amplitude of v_I is 8V.
- What are the values of the threshold voltages $V_{Th,H}$ and $V_{Th,L}$, and of the output voltage V_{OH} and V_{OL}?

A. The effects of modifying the voltage supply

Exploration

- Modify the supply voltages to $+V_{PS}$=9V, $-V_{PS}$=-9V.
- Using the oscilloscope visualize $v_I(t)$, $v_O(t)$, then VTC $v_O(v_I)$ for V_{REF}= 0V and v_I amplitude of 8V.
- Modify the supply voltages to $+V_{PS}$=15V, $-V_{PS}$=-9V.
- Visualize $v_I(t)$, $v_O(t)$ and VTC.

Results

- $v_I(t)$, $v_O(t)$,$v_O(v_I)$ for $+V_{PS}$=9V, $-V_{PS}$=-9V., and for $+V_{PS}$=15V, $-V_{PS}$=-9V.

B. The effects of modifying V_{REF}

Exploration

- Supply the assembly with $+V_{PS}$=12V, $-V_{PS}$=-12V.
- Adjust P until V_{REF} =3V.
- Using the oscilloscope, visualize $v_I(t)$, $v_O(t)$ and $v_O(v_I)$.
- Set V_{REF} = -3V. Using the oscilloscope visualize $v_I(t)$, $v_O(t)$ and $v_O(v_I)$.

Results

- $v_I(t)$, $v_O(t)$, $v_O(v_I)$ for $V_{REF} = 3V$ and for $V_{REF} = -3V$

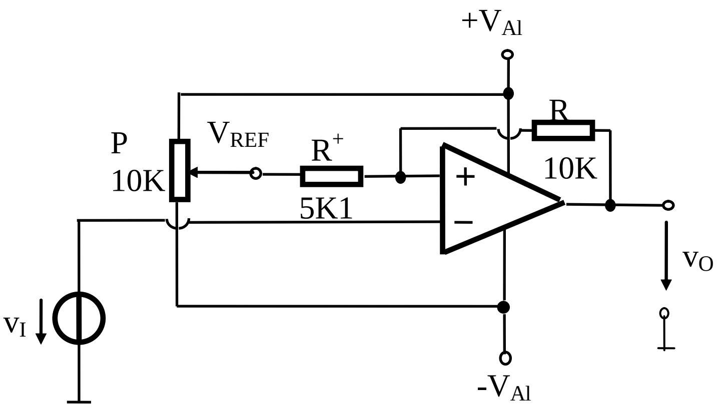


Fig. 4. Inverting comparator with positive feedback

3. INVERTING COMPARATOR FOR NOISY SIGNAL

Use the circuit shown in Fig. 5.

Exploration

- Supply the assembly with $+V_{PS}$=12V, $-V_{PS}$=-12V.
- Using the oscilloscope, visualize v_I and v_O at the same time.

Results

- $v_I(t)$,$v_O(t)$.

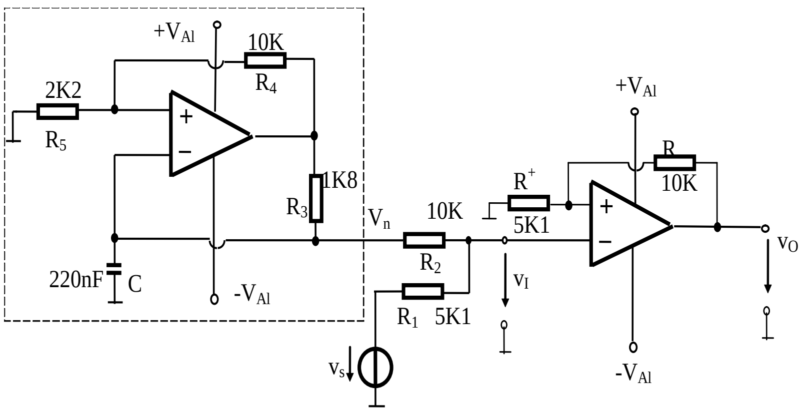


Fig. 5 Inverting comparator with positive feedback and noisy signal

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