EXPERIMENT NO. 4

DATE: : -- / -- /----

SCHMITT TRIGGER CIRCUITS USING OP–AMPS

AIM

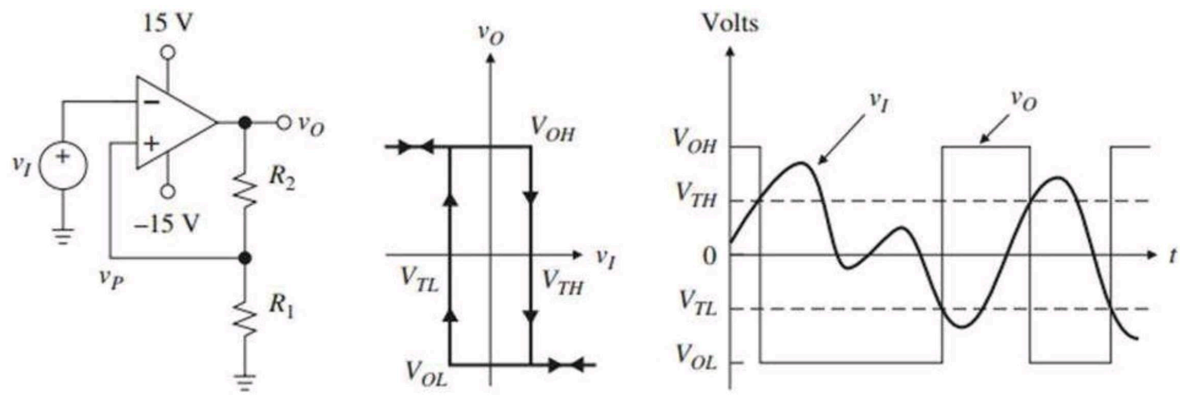
To design and setup,

1 Inverting Schmitt trigger circuits using op-amp IC 741
   a) For Symmetric Trigger Points, $v_{TH} = 6.5V$ and $v_{TL} = -6.5V$
   b) For Asymmetric Trigger Points, $v_{TH} = 8V$ and $v_{TL} = 3V$
2. A non-inverting Schmitt trigger circuit using op-amp IC 741
   a) For Symmetric Trigger Points, $v_{TH} = 6.5V$ and $v_{TL} = -6.5V$

THEORY

Schmitt triggers are special type of comparators with hysteresis, which can be implemented by providing operational amplifiers/comparators with positive feedback. Its output voltage has two stable states namely $v_O = V_{OH}$ and $v_O = V_{OL}$. For an op-amp $V_{OH} = +V_{sat}$ and $V_{OL} = -V_{sat}$ respectively

INVERTING SCHMITT TRIGGER



The inverting Schmitt trigger circuit can be viewed as an inverting-type threshold detector whose threshold is controlled by the output. Since the output has two stable states, this threshold has two possible values, namely $V_{TH} = \frac{R_1}{R_1+R_2}.V_{OH}$ & $V_{TL} = \frac{R_1}{R_1+R_2}.V_{OL}$

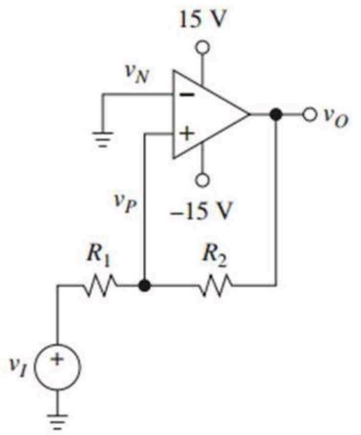
For $v_I \ll 0$, the amplifier saturates at V_{OH}, giving $v_O = V_{OH}$ and $v_P = V_{TH}$. Increasing v_I moves the operating point along the upper segment of the Voltage Transfer Curve(VTC) until v_I reaches V_{TH}. At this point, the regenerative action ofpositive feedback causes v_O to snap from V_{OH} to V_{OL}. This, in turn, causes v_P to snap from v_{TH} to V_{TL}. If we wish to change the output state again to V_{OH}, we must now lower v_I all the way down to $v_P = V_{TL}$

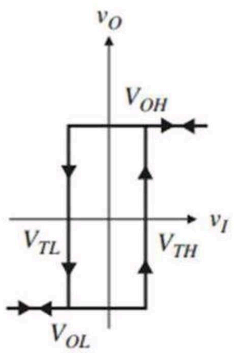
Thus, the Voltage Transfer Curve of an Inverting Schmitt trigger exhibits hysteresis (i.e., has two separate tripping points). When coming from the left, the threshold is V_{TH}, and when coming from the right, it is V_{TL}. The horizontal portions of the VTC can be traveled in either direction, but the vertical portions can be traveled only clockwise

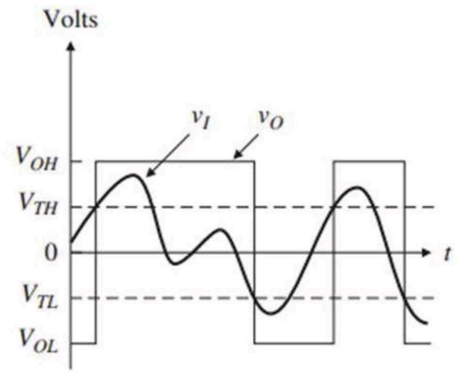
The hysteresis width, $\Delta V_T = V_{TH} - V_{TL} = \frac{R_1}{R_1+R_2}.(V_{OH} - V_{OL})$

ΔV_T can be varied by changing the ratio R_1/R_2. Decreasing R_1/R_2 will bring V_{TH} and V_{TL} closer together

NON-INVERTING SCHMITT TRIGGER







For $v_I \ll 0$, the op-amp saturates at V_{OL}. For v_O to switch state, v_I must be raised to a high enough value(called V_{TH}) to cause $v_P > v_N (= 0V)$

$$\Rightarrow \frac{V_{TH}-0}{R_1} = \frac{0-V_{OL}}{R_2} \qquad \Rightarrow V_{TH} = -\frac{R_1}{R_2}.V_{OL}$$

Once v_O has reached V_{OH}, in order to step it back to V_{OL}, v_I must be lowered below V_{TL}

$$\Rightarrow \frac{V_{OH}-0}{R_2} = \frac{0-V_{TL}}{R_1} \qquad \Rightarrow V_{TL} = -\frac{R_1}{R_2}.V_{OH}$$

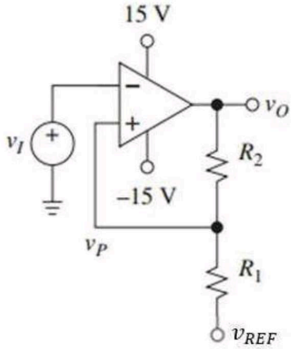
The hysteresis width is $\Delta V_T = \frac{R_1}{R_2}.(V_{OH} - V_{OL})$. It can be varied by changing the ratio $\frac{R_1}{R_2}$

Thus, the Voltage Transfer Curve of a Non-inverting Schmitt trigger exhibits hysteresis (i.e., has two separate tripping points). When coming from the left, the threshold is V_{TH}, and when coming from the right, it is V_{TL}. The horizontal portions of the VTC can be traveled in either direction, but the vertical portions can be traveled only counter-clockwise

SCHMITT TRIGGERS WITH ASYMMETRICAL TRIGGER POINTS

The hysteresis loop can be shifted to either side of zero point by connecting a reference voltage source as shown.

The following circuit shows an inverting Schmitt trigger with asymmetric trigger points.



For the above circuit,

$$v_P = \frac{R_1}{R_1 + R_2} . v_O + \frac{R_2}{R_1 + R_2} . v_{REF}$$

Hence, $V_{TH} = \frac{R_1}{R_1+R_2} . V_{OH} + \frac{R_2}{R_1+R_2} . v_{REF}$

And $V_{TL} = \frac{R_1}{R_1+R_2} . V_{OL} + \frac{R_2}{R_1+R_2} . v_{REF}$

$\Delta V_T = V_{TH} - V_{TL} = \frac{R_1}{R_1+R_2} . (V_{OH} - V_{OL})$ i.e., the hysteresis width remains the same

If v_{REF} is positive, the hysteresis loop is shifted to right side; if v_{REF} is negative, the loop is shifted to the left side.

DESIGN

INVERTING SCHMITT TRIGGER

$V_{TH} = \frac{R_1}{R_1+R_2} . V_{sat}$ & $V_{TL} = \frac{R_1}{R_1+R_2} . (-V_{sat})$

For $\pm 15V$ supply for uA741, $V_{sat} \cong +13V$ and $-V_{sat} \cong -13V$

Required $v_{TH} = 6.5V = \frac{R_1}{R_1+R_2} . (+13V) \Rightarrow \frac{R_1}{R_1+R_2} = \frac{1}{2}$

Choose $R_1 = 10k, R_2 = 10k$ so that, $V_{TH} = \frac{V_{sat}}{2} \cong 6.5V$ and $V_{TL} = \frac{-V_{sat}}{2} \cong -6.5V$

Hysteresis width = $\Delta V_T = V_{TH} - V_{TL} \cong 13V$

NON-INVERTING SCHMITT TRIGGER

$$V_{TH} = -\frac{R_1}{R_2} . V_{OL} = -\frac{R_1}{R_2} . (-V_{sat})$$

$$V_{TL} = -\frac{R_1}{R_2} . V_{OH} = -\frac{R_1}{R_2} . (V_{sat})$$

$$\Delta V_T = \frac{R_1}{R_2}.(V_{OH} - V_{OL}) = \frac{R_1}{R_2}(V_{sat} - (-V_{sat}))$$

For $\pm 15V$ supply for uA741, $V_{sat} \cong +13V$ and $-V_{sat} \cong -13V$

Required $v_{TH} = 6.5V = \frac{R_1}{R_2}.(13V) \Rightarrow \frac{R_1}{R_2} = \frac{1}{2}$

Take $R_1 = 10k$ and $R_2 = 20k$ (Use two $10k$ in series) so that $V_{TH} \cong 6.5V$ and $V_{TL} \cong -6.5V$

INVERTING SCHMITT TRIGGER WITH ASYMMETRICAL TRIGGER POINTS

Required value of $v_{TH} = 8V, v_{TL} = 3V$

Hence required $\Delta V_T = V_{TH} - V_{TL} = \frac{R_1}{R_1+R_2}.(V_{OH} - V_{OL}) = 8 - 3 = 5V$

For $\pm 15V$ supply for uA741, $V_{sat} \cong +13V$ and $-V_{sat} \cong -13V$

$$\Rightarrow 5V = \frac{R_1}{R_1 + R_2}\left(V_{sat} - (-V_{sat})\right) = \frac{R_1}{R_1 + R_2} \times 26V$$

$$\Rightarrow \frac{R_1}{R_1 + R_2} = \frac{5}{26}$$

Take $R_1 = 8.2k; \Rightarrow R_2 = 33k$ std.

Now $V_{TH} = \frac{R_1}{R_1+R_2}.V_{sat} + \frac{R_2}{R_1+R_2}.v_{REF}$

$\Rightarrow 8V = \frac{R_1}{R_1+R_2}.V_{sat} + \frac{R_2}{R_1+R_2}.v_{REF} = \frac{8.2k}{41.2k} \times 13 + \frac{33k}{41.2k} v_{REF}$

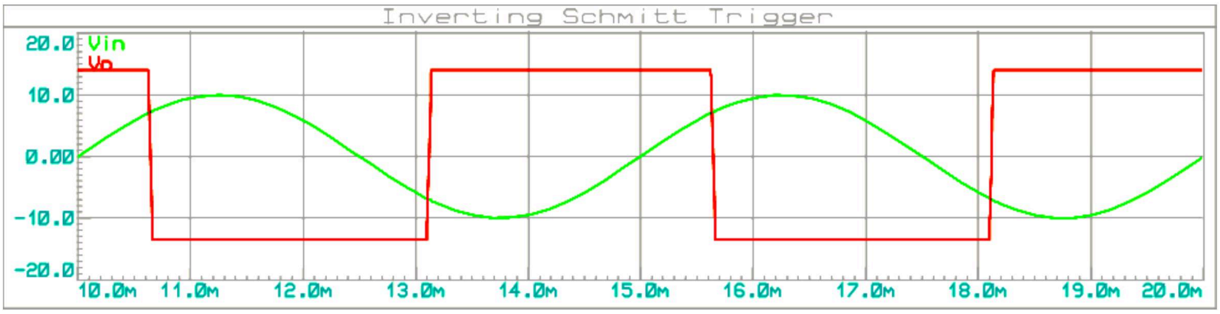
$\Rightarrow v_{REF} \cong 6.8V$

PROCEDURE (Common For all three circuits)

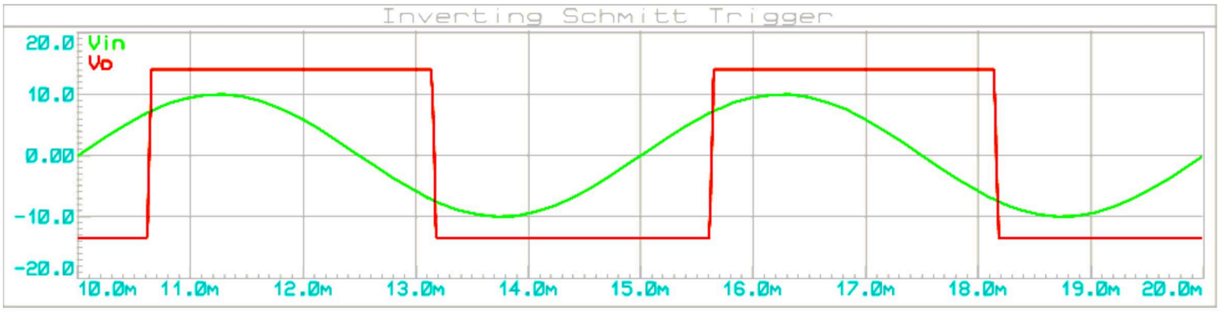
- Setup the circuit and apply supply voltages to the op-amp terminals
- Give a $20Vpp$ sinewave with a frequency of $200Hz$ as v_I

- Observe the input waveform v_I and the output waveform v_O simultaneously on the CRO
- Draw the observed waveforms and note down the upper and lower threshold voltages for the inputs
- Draw the transfer curve(v_O vs. v_I) from the above observations and compute the hysteresis width

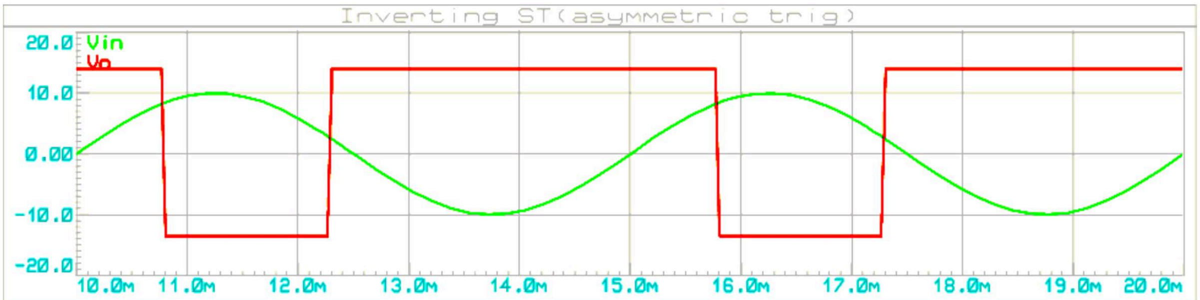
Expected Waveforms: Inverting Schmitt Trigger Circuit(Symmetric Trigger Points)



Expected Waveforms: Non-inverting Schmitt Trigger Circuit(Symmetric Trigger Points)



Expected Waveforms: Inverting Schmitt Trigger Circuit (Asymmetric Trigger Points)



OBSERVATIONS

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RESULTS

The following Schmitt trigger circuits were designed and setup using op-amp IC 741 The transfer characteristics were plotted.

1 An inverting Schmitt trigger with symmetric threshold points
   - Designed threshold voltages: V_{TH} = — and V_{TL} = —
   - Designed Hysteresis width: ΔV_T = __
   - Observed threshold voltages: V_{TH} = — and V_{TL} = —
   - Observed Hysteresis width: ΔV_T = __

2. A non-inverting Schmitt trigger with symmetric threshold points
   - Designed threshold voltages: V_{TH} = — and V_{TL} = —
   - Designed Hysteresis width: ΔV_T = __
   - Observed threshold voltages: V_{TH} = — and V_{TL} = —
   - Observed Hysteresis width: ΔV_T = __

3. An inverting Schmitt trigger with asymmetric threshold points
   - Designed threshold voltages: V_{TH} = — and V_{TL} = —
   - Designed Hysteresis width: ΔV_T = __
   - Observed threshold voltages: V_{TH} = — and V_{TL} = —
   - Observed Hysteresis width: ΔV_T = __