EE230: Experiment 3
Schmitt Trigger, Monostable, and Astable Circuits

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1 Overview of the experiment

1.1 Aim of the experiment

- Design the circuit of Schmitt Trigger and compare the threshold voltages V_{TH} and V_{TL} with the values you expect theoretically.
- Wire up the circuit of astable multivibrator and compare the minimum and maximum period of oscillation with your calculation.
- Wire up the circuit of monostable multivibrator and measure the duration of the output pulse. Compare it with your calculation.

1.2 Theory

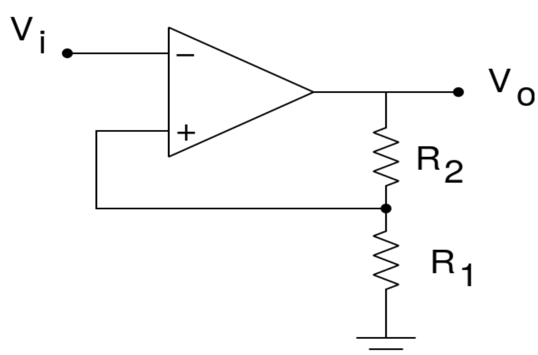

Figure 1: Schmitt trigger

When V_i is sufficiently large, the ouput voltage V_o of the circuit (known as the "Schmitt trigger") is V_{sat} as shown in Fig. 1. The voltage at the non-inverting input terminal of the op amp V_+ (with respect to ground) is then $V_+ \equiv V_{TL} = V_{sat} \times (\frac{R_1}{R_1+R_2})$. As V_i is reduced and becomes smaller than V_{TL}, the op amp output changes from $-V_{sat}$ to $+V_{sat}$ (since $V_- < V_+$). Now, V_+ is equal to $V_+ \equiv V_{TH} = +V_{sat} \times (\frac{R_1}{R_1+R_2})$. If V_i is reduced further, this state of affairs continues to hold. If V_i is increased, the output flips when V_i crosses V_{TH}.

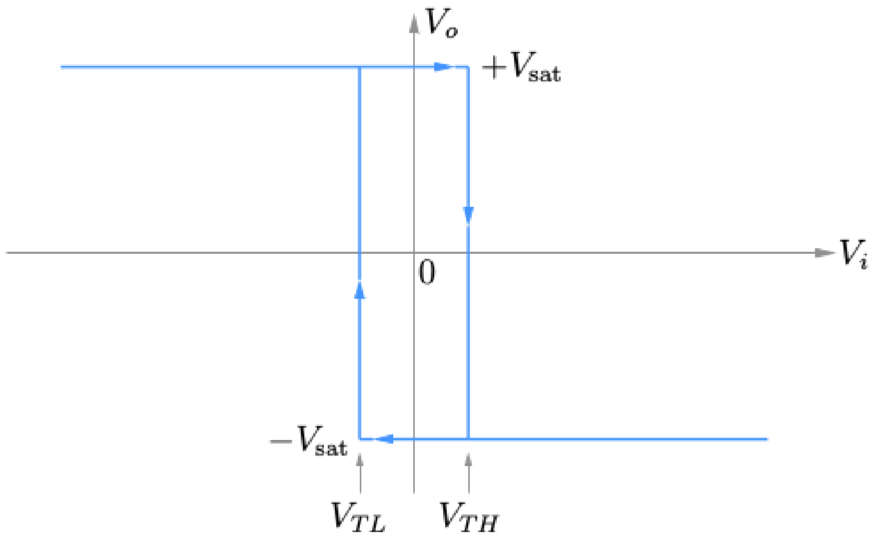

Figure 2: V_o versus V_i relationship for Schmitt trigger

The Schmitt trigger is a comparator with hysterisis (or "memory"). Since the input threshold voltage (V_{TH} or V_{TL}), at which the output flips, depends on the "state" of the circuit. Note that the high and low threshold voltages, V_{TH} and V_{TL}, respectively, are symmetric about 0 V for the Schmitt trigger circuit i.e., $V_{TH} = V_{TL}$. By connecting a DC voltage source V_a , we can make them asymmetric (see Fig. 3), as shown below.

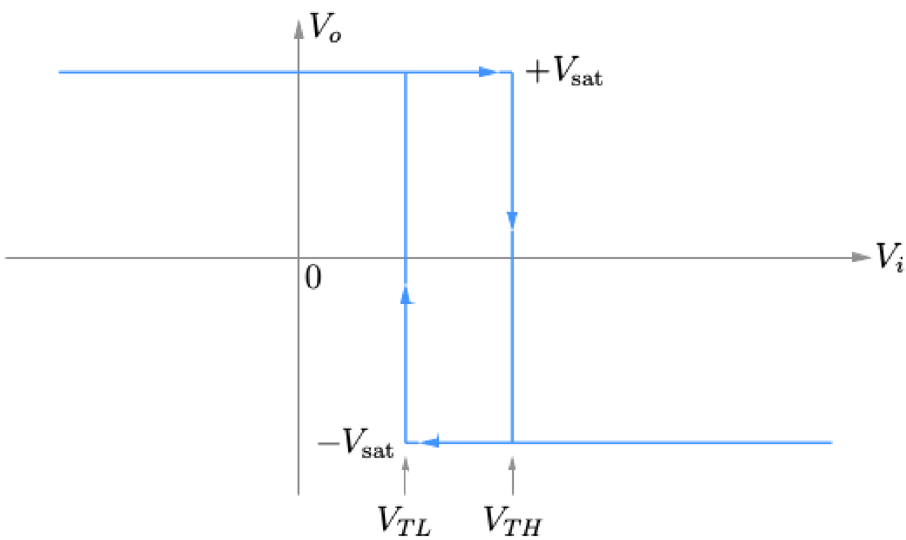

Figure 3: V_o versus V_i relationship for the asymmetric Schmitt trigger

When V_o is $+V_{sat}$, we have

$$V_+ = +V_{sat}\frac{R_1}{R_1 + R_2} + V_a\frac{R_2}{R_1 + R_2} \tag{1}$$

since the current entering the non-inverting input of the op amp can be neglected. Similarly, when V_o is V_{sat}, we have

$$V_+ = -V_{sat}\frac{R_1}{R_1+R_2} + V_a\frac{R_2}{R_1+R_2} \tag{2}$$

The output voltage of the Schmitt trigger can be limited by using a Zener pair as shown in Fig. 4. Let the breakdown voltage of the Zener diode be V_Z and the turn-on voltage be V_{on}. Consider the op amp output V_{o1} to be $+V_{sat}$. Because of the diode pair, the output voltage V_o gets limited to $V_{on}+V_Z$, with D_1 in forward conduction, and D_2 in reverse breakdown.

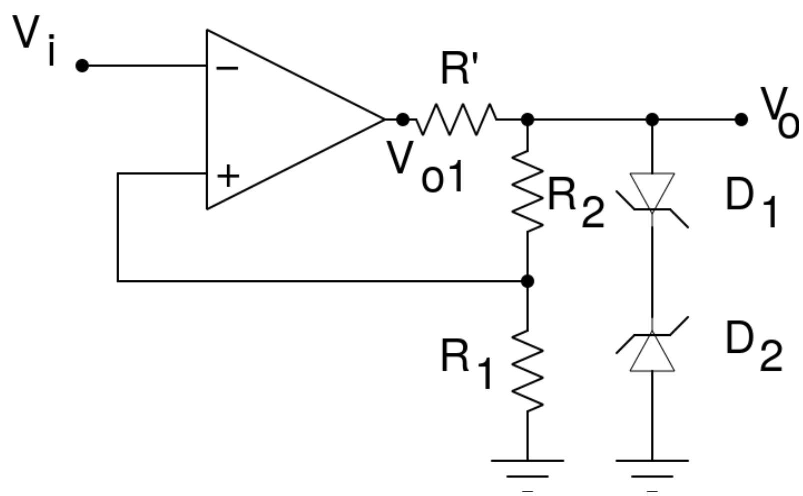

Figure 4: Schmitt trigger circuit with V_o limited to (V_Z+V_{on})

Note that the difference between V_{o1} and V_o appears across the resistor R which must be chosen to limit the op amp output current to a reasonable value (a few mAs). Connecting the diode pair directly to the op-amp output would lead to unhealthy events. In a similar manner, when V_{o1} is V_{sat}, the output voltage V_o gets limited to $(V_{on}+V_Z)$, with D_2 in forward conduction, and D_1 in reverse breakdown.

2 Experimental results

2.1 Schmitt trigger

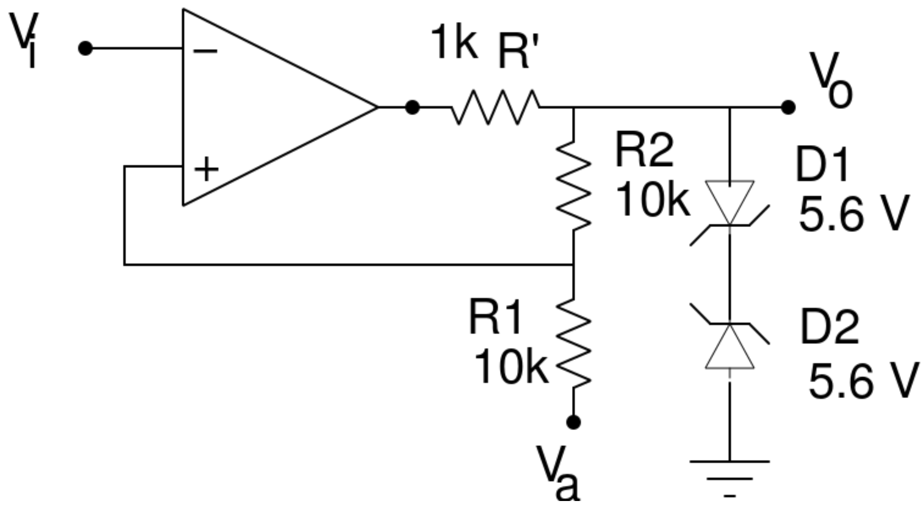

Figure 5: Schmitt trigger

(A) With $\mathbf{V_a = 0V}$:

$$V_{TL} = -V_{sat} \times (\frac{R_1}{R_1 + R_2}) \tag{3}$$

$$V_{TH} = +V_{sat} \times (\frac{R_1}{R_1 + R_2}) \tag{4}$$

The actual resistance of resistors shown in fig 5 are, $R_1 = 9.7k$, $R_2 = 9.82k$, $R' = 0.96k$
Drop across zener diodes is $V_Z + V_{ON} = 5.6V + 1.12V = 6.72V$

$$V_{TL} = -6.72 \times (\frac{9.7}{9.7 + 9.82}) \tag{5}$$

$$\boxed{V_{TL} = -3.34V} \tag{6}$$

Similarly,

$$\boxed{V_{TH} = +3.34V} \tag{7}$$

Hence, theoretical values of $\mathbf{V_{TH}}$ and $\mathbf{V_{TL}}$ are **+3.34V** and **-3.34V** respectively.

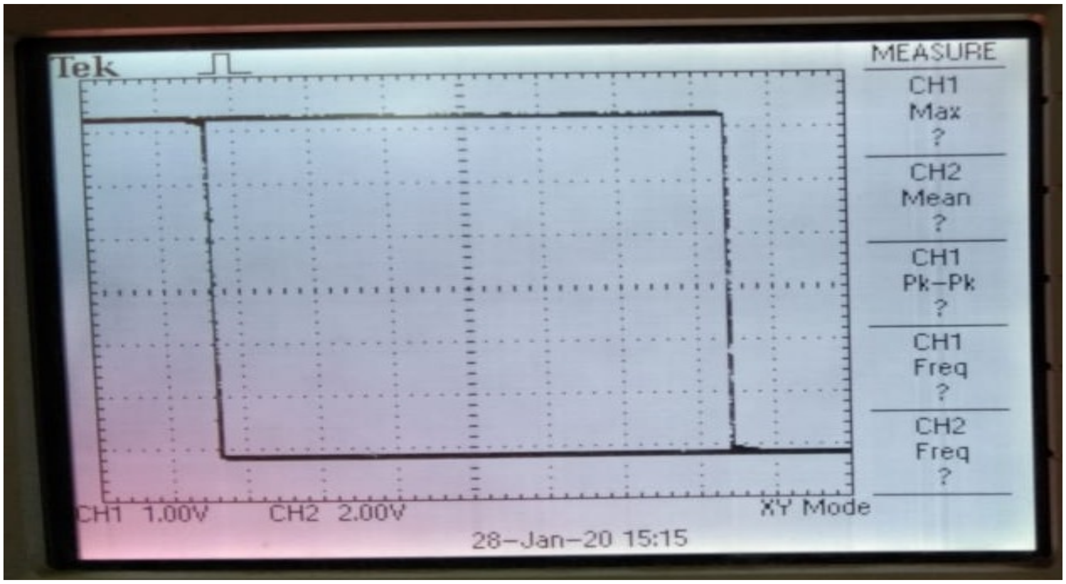

Figure 6: V_o versus V_i relationship for $V_a = 0V$

The observed value of $\mathbf{V_{TH} = +3.4V}$ and $\mathbf{V_{TL} = -3.4V}$

(B) With $\mathbf{V_a = 3V}$:

$$V_{TL} = -V_{sat} \times (\frac{R_1}{R_1 + R_2}) \tag{8}$$

$$V_{TH} = +V_{sat} \times (\frac{R_1}{R_1 + R_2}) \tag{9}$$

The actual resistance of resistors shown in fig 5 are, $R_1 = 9.7k$, $R_2 = 9.82k$, $R' = 0.96k$
Drop across zener diodes is $V_Z + V_{ON} = 5.6V + 1.12V = 6.72V$

$$V_{TL} = -6.72 \times (\frac{9.7}{9.7 + 9.82}) + 3 \times (\frac{9.82}{9.7 + 9.82}) \tag{10}$$

$$\boxed{V_{TL} = -1.83V} \tag{11}$$

Similarly,

$$V_{TH} = 6.72 \times (\frac{9.7}{9.7 + 9.82}) + 3 \times (\frac{9.82}{9.7 + 9.82}) \tag{12}$$

$$\boxed{V_{TH} = +4.85V} \tag{13}$$

Hence, theoretical values of $\mathbf{V_{TH}}$ and $\mathbf{V_{TL}}$ are **+4.85V** and **-1.83V** respectively.

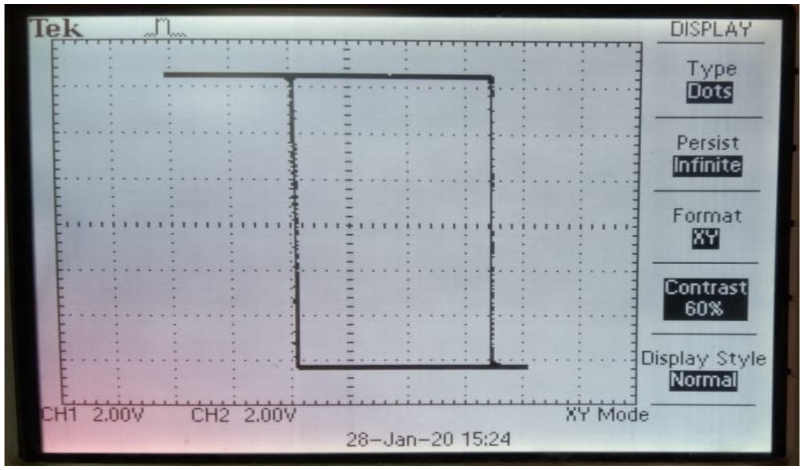

Figure 7: V_o versus V_i relationship for $V_a = 0V$

The observed value of $\mathbf{V_{TH} = +4.8V}$ and $\mathbf{V_{TL} = -1.8V}$

2.2 Astable multivibrator

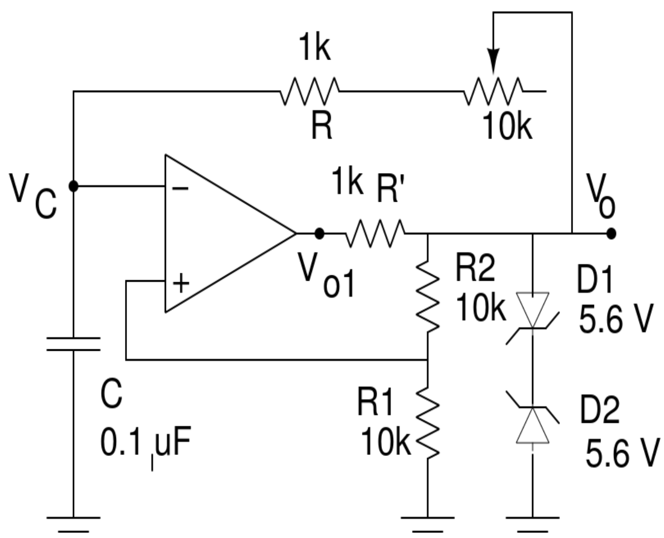

Figure 8: Astable multivibrator

The actual resistance of resistors shown in fig 8 are, $R_1 = 9.7k$, $R_2 = 9.82k$, $R' = 0.99k$, $R = 0.96k$

(A) For maximum time period :

The resistance between V_C and V_O comes out to be $\mathbf{10.73k\Omega}$
Since here $V_a = 0V$,

$$V_{TH} = -V_{TL} \equiv V_T \tag{14}$$

The period of oscillation is

$$T = 2\tau \log(\frac{V_m + V_T}{V_m - V_T}) \qquad where \quad \tau = RC \tag{15}$$

$$T = 2(10.73k)(0.1\mu)\log(\frac{6.72 + 3.4}{6.72 - 3.4}) \tag{16}$$

$$\boxed{T = 2.39ms} \tag{17}$$

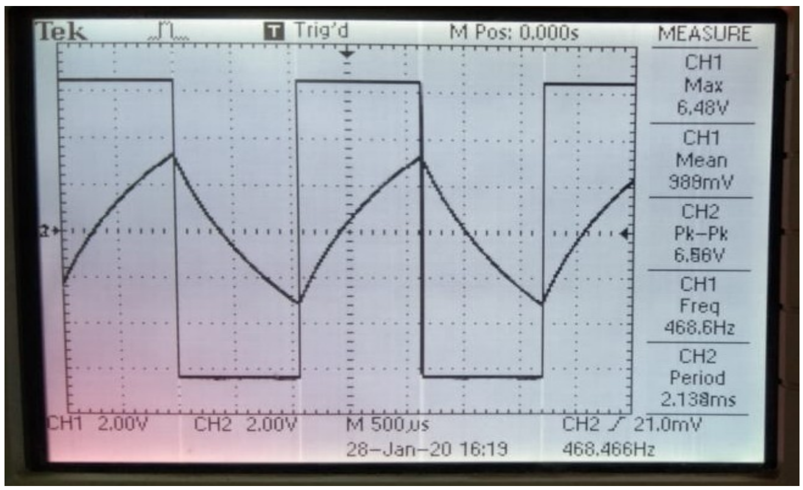

Figure 9: Output for maximum time period

The observed maximum time period is $\mathbf{T = 2.138ms}$

(B) For minimum time period :

The resistance between V_C and V_O comes out to be **0.96kΩ**
Again, the period of oscillation is given by

$$T = 2\tau \times \log(\frac{V_m + V_T}{V_m - V_T}) \qquad where \quad \tau = RC \tag{18}$$

$$T = 2 \times (0.96k) \times (0.1\mu) \times \log(\frac{6.72 + 3.4}{6.72 - 3.4}) \tag{19}$$

$$\boxed{T = 214\mu s} \tag{20}$$

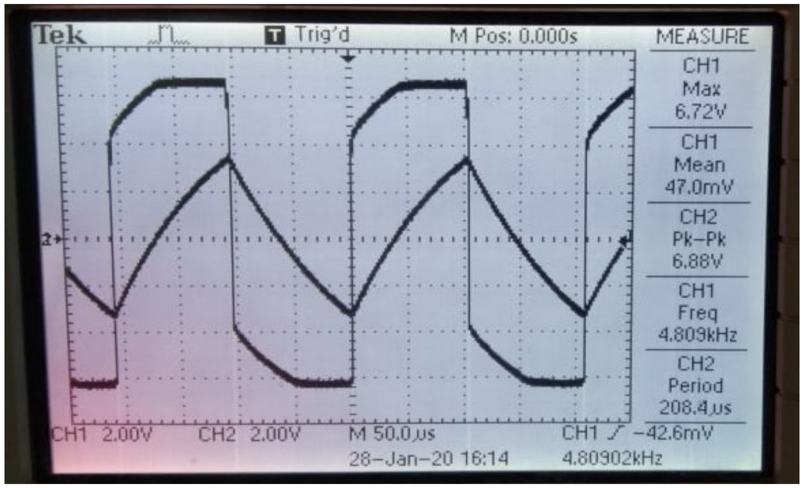

Figure 10: Output for minimum time period

The observed minimum time period is $\mathbf{T = 208.4\mu s}$

2.3 Monostable multivibrator

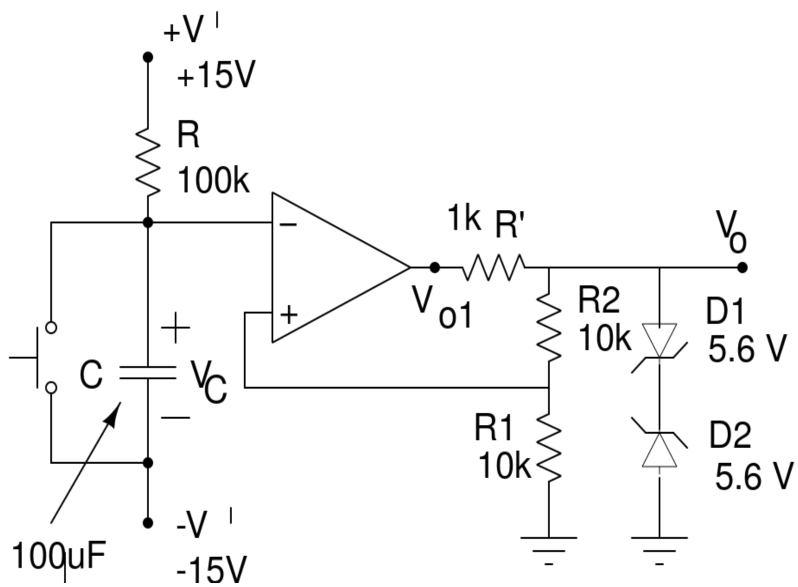

Figure 11: Monostable multivibrator

The actual resistance of resistors shown in fig 11 are, $R_1 = 9.7k$, $R_2 = 9.82k$, $R' = 0.99k$, $R = 100.5k$

The voltage to which the capacitor charges is $2V' = 10.6V$

The output pulse width, T is given by the expression

$$T = RC \times \log(\frac{V'}{V' - V_{TH}})$$
$$= (100.5k) \times (100\mu) \times \log(\frac{5.3}{5.3 - 3.4})$$
$$\boxed{T = 10.25s} \quad (21)$$

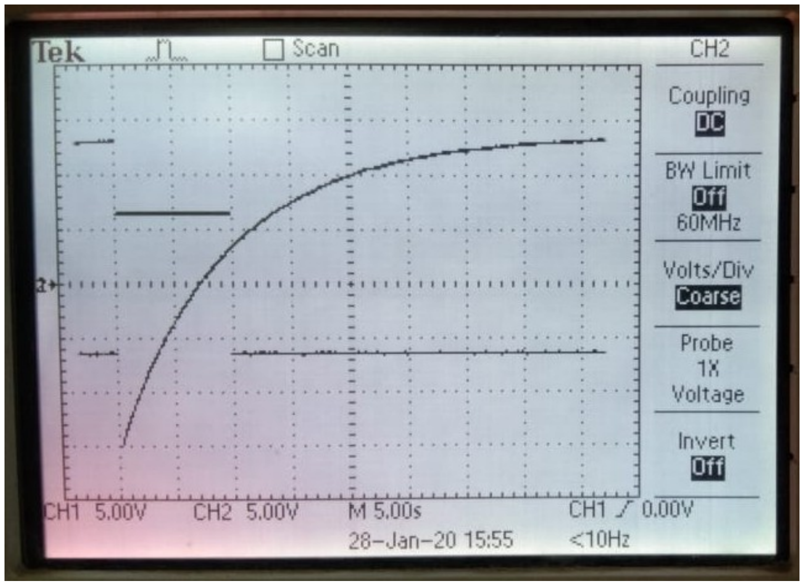

Figure 12: Waveforms of V_- and V_o

The observed pulse width comes out to be $\mathbf{T = 10.1s}$

References

[1] Scmitt supporting document
https://moodle.iitb.ac.in/pluginfile.php/302403/mod_resource/content/0/schmitt_astable_support.pdf