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Design and Implementation of Schmitt Trigger using Operational Amplifier

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ABSTRACT
A Schmitt trigger is an electronic circuit, a Comparator that is used to detect whether a voltage has crossed over a given reference level. It has two stable states and is very useful as signal conditioning device. When an input waveform in the form of sinusoidal waveform, triangular waveform, or any other periodic waveform is given, the Schmitt trigger will produce a Rectangular or square output waveform that has sharp leading and trailing edges. Such fast rise and fall times are desirable for all digital circuits. The state of the art presented in the paper is the design and implementation of Schmitt trigger using operational amplifier µA-741, generating a Rectangular waveform. Furthermore, the Schmitt trigger exhibiting hysteresis is also presented in the paper. Due to the phenomenon of hysteresis, the output transition from HIGH to LOW and LOW to HIGH will take place at various thresholds.
Keywords: Comparator, digital circuits, hysteresis, operational amplifier µA-741, rectangular waveform, Schmitt trigger,

I. INTRODUCTION

Noise is any type of unwanted signal or disturbance that is not derived from or harmonically related to the input signal. Electric motors, neon signs, power lines, car ignitions, lightning and so on, produce electromagnetic fields that can induce noise voltages into electronic circuits. Power supply ripple is also classified as noise since it is not related to the input signal. By the use of regulated power supplies and shielding, the ripple and induced noise can be minimized to an acceptable level. If the input to a comparator contains noise in large amounts, then obviously the output will be erratic when input voltage is near the trip point. One possible way to minimize the effect of noise is to use a comparator with positive feedback. Two separate trip points would be produced with positive feedback that helps to prevent a noisy input from producing false transitions. Thus the standard solution for a noisy input is to use a comparator with positive feedback which is usually called a Schmitt trigger [1], [2].

The Schmitt trigger is also called as a Squaring circuit, as it converts an irregular shaped input waveform to a square wave. The only condition is that the input signal should have large excursion to carry the input voltage beyond the limits of the hysteresis range. The output voltage changes its state every time when the input voltage crosses the threshold voltage. The input voltage at which the output switches from $+V_{SAT}$ to $-V_{SAT}$ is called the Upper triggering point or upper trip point (U.T.P). Likewise the input voltage at which the output switches from $-V_{SAT}$ to $+V_{SAT}$ is called the Lower triggering point or lower trip point (L.T.P) [3], [4].

The rest of the paper is organized into sections as follows: section II describes the Schmitt trigger overview. Section III focuses on the system design. Results and discussions are reported in section IV. Finally section V summarizes the paper and presents the concluding remark.

II. SCHMITT TRIGGER OVERVIEW

The Schmitt trigger circuit is a slight variation of the bistable multivibrator circuit. Fig. 1 shows the basic Schmitt trigger circuit.

When V_{in} is zero, transistor Q_1 is in cut-off. Coupling from Q_1- collector to Q_2- base drives transistor Q_2 to saturation resulting in LOW output voltage V_o. If the voltage $V_{CE2\ (SAT)}$ is assumed as zero, then the voltage across R_E is given by (1)

Voltage across $R_E = (V_{cc} \times R_E) / (R_E+R_{C2})$ (1)

Equation (1) is also the emitter voltage of transistor Q_1. To make the transistor Q_1 conduct, V_{in} must be at least equal to 0.7V more than the voltage across R_E. This is given by (2),

$V_{in} = [(V_{cc} \times R_E) / (R_E+R_{C2})] + 0.7$ (2)

When V_{in} exceeds this voltage, Q_1 starts conducting. Due to regenerative action Q_2 is driven to cut off. The output goes to the HIGH state. Voltage across R_E changes and its new value is given by (3)

Voltage across $R_E = (V_{cc} \times R_E) / (R_E+R_{C1})$ (3)

Q_1 will continue to conduct as long as V_{in} is equal to or greater than the value given by (4)

$V_{in} = [(V_{cc} \times R_E) / (R_E+R_{C1})] + 0.7$ (4)

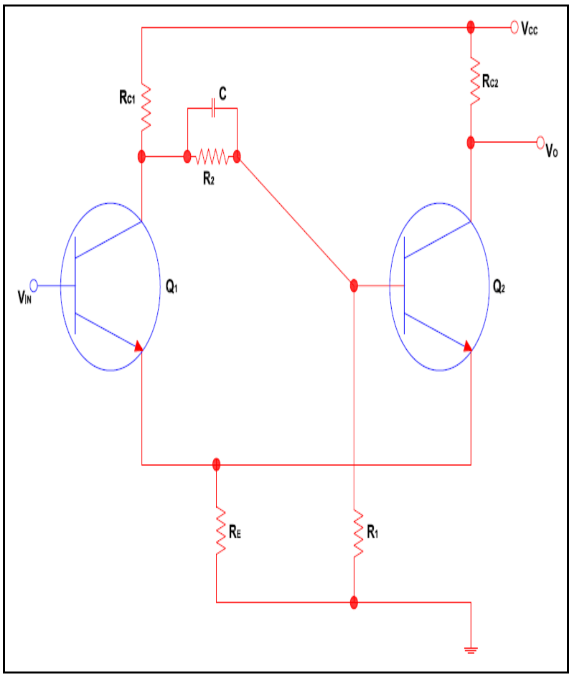

Fig. 1 Basic Schmitt trigger circuit.

When V_{in} falls below the value given in (4), Q_1 tends to come out of saturation and conducts to a smaller extent. The rest of the operation is carried out due to regenerative action culminating in Q_1 going to cut-off and Q_2 to saturation. Thus the output states (HIGH or LOW) depends on the input voltage level. The HIGH and LOW states of the output correspond to two distinct input levels given by equations (2) and (4) and hence they depend on the values of R_{C1}, R_{C2}, R_E and V_{cc}. The Schmitt trigger circuit of fig. 1 therefore exhibits hysteresis. [1], [4], [5], [9.] Fig. 2 shows the transfer characteristics of the Schmitt trigger circuit.

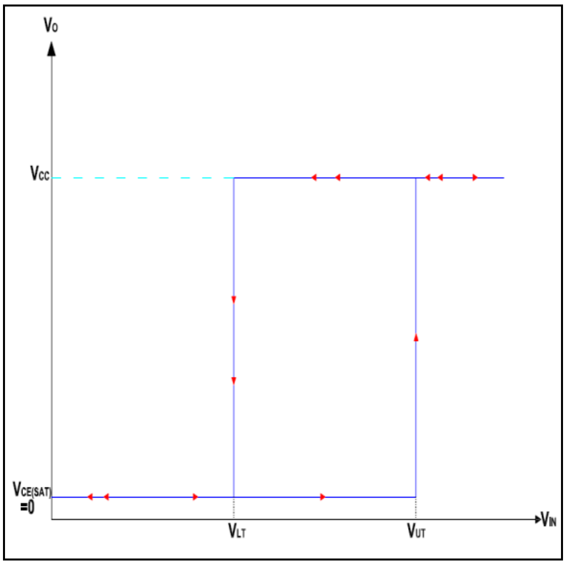

Fig. 2 Schmitt trigger transfer characteristics

The lower trip point V_{LT} and upper trip point V_{UT} of these characteristics are respectively given by (5) and (6).

$$V_{LT} = [(V_{cc} \times R_E) / (R_E+R_{C1})] + 0.7 \quad (5)$$

$$V_{UT} = [(V_{cc} \times R_E) / (R_E+R_{C2})] + 0.7 \quad (6)$$

III. SYSTEM DESIGN

3.1 Hardware design

From the theory of Schmitt trigger circuit using opamp, the trip points are given by (7) and (8) respectively

$$U.T.P = [(R_1 V_{REF})/ (R_1+R_2)] + [(R_2 V_{SAT})/ (R_1+R_2)] \quad (7)$$

Where V_{SAT} is the positive saturation of the opamp and is 90% of V_{CC}.

$$L.T.P = [(R_1 V_{REF})/ (R_1+R_2)] - [(R_2 V_{SAT})/ (R_1+R_2)] \quad (8)$$

Hence given the U.T.P and L.T.P values to find R_1, R_2 and V_{REF}, the following design is used,

$$U.T.P + L.T.P = [(2 R_1 V_{REF})/ (R_1+R_2)] \quad (9)$$

$$U.T.P - L.T.P = [(2 R_1 V_{SAT})/ (R_1+R_2)] \quad (10)$$

Let V_{SAT} = 10V, U.T.P = 4V and L.T.P = 2V, then equation 4 yields R_1= 9R_2.

Let R_2= 10 KΩ then R_1= 90KΩ. Using equation 4 and substituting the above design values we get V_{REF} = [(U.T.P + L.T.P) (R_1+R_2) / (2 R_1)] = 3.33 V. Choosing the resistor values as R_1= 10 KΩ and R_2= 220Ω the circuit schematic is designed for Schmitt trigger.

The fig. 3 illustrates the circuit schematic for the designed system.

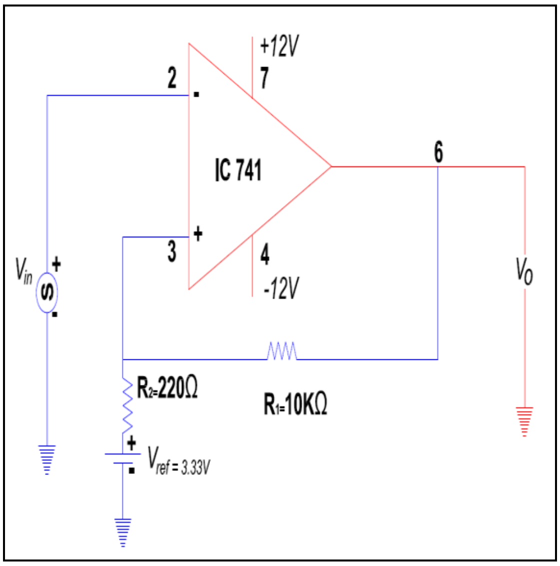

Fig.3 Circuit schematic

3.2 System specifications

The system specifications are illustrated in Table 1.

TABLE 1. System specifications

Sl. No	Specifications
1	Domain: Analog electronics, Electronic circuits.
2.	Digital IC trainer kit
3.	Power supply: DC regulated power supply (+12V, -12V)
4.	Opamp I.C: µA-741
5.	Resistors : 1 KΩ, 220Ω
6.	Bread board
7.	Multimeter
8.	Cathode ray oscilloscope (CRO)
9.	Connecting probes, patch cords, single stranded connecting wires, crocodile clips.
10.	Simulation software: Multisim 11
11.	Applications: Squaring circuit, digital circuitry, amplitude comparator.

3.3 Opamp IC µA-741 overview

The IC µA-741is a general purpose operational amplifier featuring offset voltage null capability. The device is short circuit protected and the internal frequency compensation ensures stability without external components. The µA-741 is specified for operation from ±5 V to ±15 V and is characterized for operation from 0° C to 70° C. Fig. 4 shows the pin diagram of opamp IC µA-741. It is an 8 pin IC and is packed in dual in line package. [10].

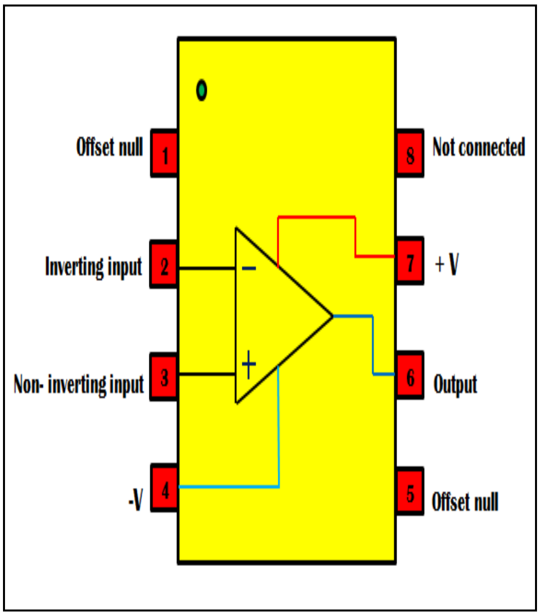

Fig. 4 pin diagram Opamp IC µA-741

Different pins of the IC are designated as Offset null (pin no.1), Inverting input (pin no.2), Non-inverting input (pin no.3), Negative supply –V (pin no.4), Offset null (pin no.5), Output (pin no.6), Positive supply (pin no.7) and No connection (pin no.8).

3.4 System set up

The experimental set up for the system was carried out in Analog and Digital electronics laboratory. Based on the system design, the required components were taken and the resistors were checked using a Multimeter. The system was rigged up as per the circuit diagram on the bread board and the supply voltage to the system was provided from the digital trainer kit. Power supply was switched ON to get required the output waveform. The figure 5 depicts the photographic view of the system.

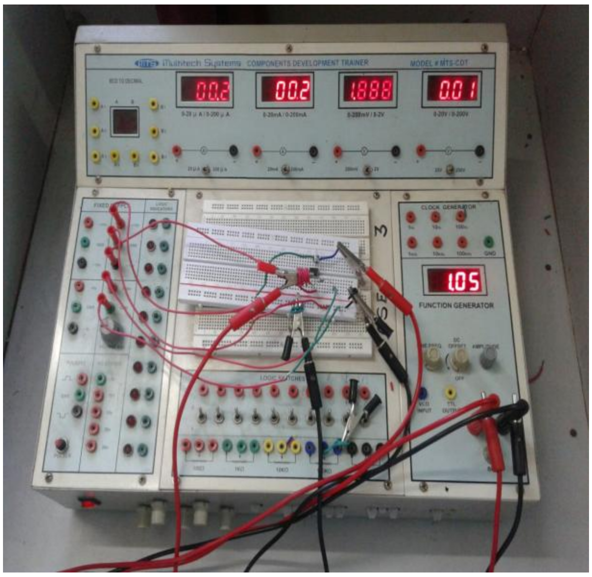

Fig. 5 Photographic view of the system set up

IV. EXPERIMENTAL RESULTS

4.1 Hardware Results

A Sinusoidal input waveform is applied to the circuit from the function generator which is inbuilt in the digital trainer kit. The amplitude of the input signal is 10 volts peak to peak and frequency is 1 KHz. A CRO has two channels namely channel 1 and channel 2. In the proposed system channel 1 is used as input channel and channel 2 is used as output channel. The positive probe from channel 1 is connected to pin number 2 of the opamp IC 741 and negative probe connected to the ground. The output waveform in the form of rectangular wave was observed on the CRO when the positive probe from channel 2 is connected to pin number 6 of the opamp IC 741 and negative probe connected to the ground. The CRO was kept in dual mode and in order to view the input and output waveforms together. The input and output waveforms are shown in fig. 6.

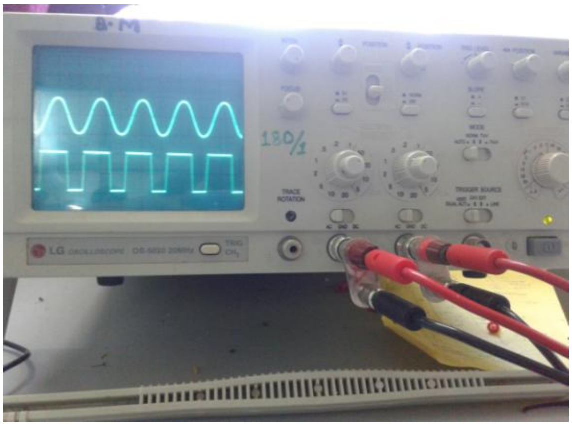

Fig.6 Photographic view of Input and Output waveforms

The amplitude of the output waveform is calculated as follows

Amplitude = [Number of divisions covered by the wave along y-axis (vertically) x Multiplying factor]

Amplitude = [2 x 5]
= 10 V

The sine wave and rectangular wave are overlapped. The point of intersection of the sine wave and rectangular wave in the positive half cycle gives the upper threshold point (U.T.P) and the point of intersection of the sine wave and rectangular wave in the negative half cycle gives the lower threshold point (L.T.P). the U.T.P and L.T.P are calculated as follows

U.T.P = [Divisions covered by the intersection of both the waves in positive cycle along y-axis (vertically) x Multiplying factor]

U.T.P = [0.8 x 5]
= 4 V.

L.T.P = [Divisions covered by the intersection of both the waves in negative cycle along y-axis (vertically) x Multiplying factor]
= [0.4 x 5]
= 2 V.

The overlapped sine and rectangular wave for U.T.P and L.T.P calculation is depicted in fig 7.

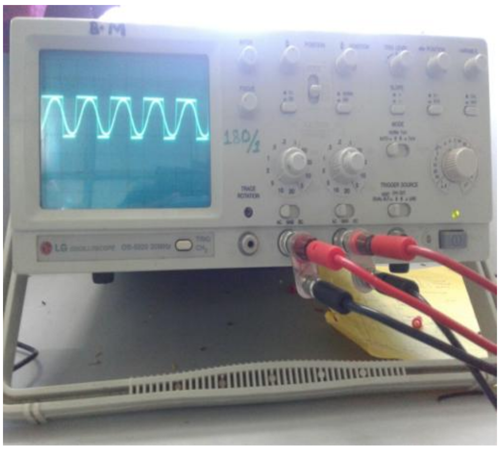

Fig. 7 Calculation of U.T.P and L.T.P values

The hysteresis curve is observed on the CRO when the time/ division dial is kept in X-Y mode. This is illustrated in fig. 8

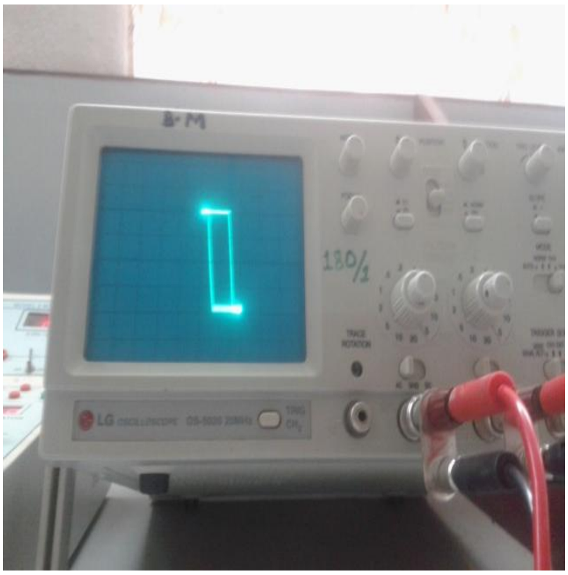

Fig. 8 Hysteresis curve

4.2 Simulation Results

The Schmitt trigger circuit using opamp was designed and implemented using Multisim simulation package. The simulation circuit is shown in fig. 9. The waveform for the simulation circuit schematic and the hysteresis curve are shown in fig.10 and 11 respectively

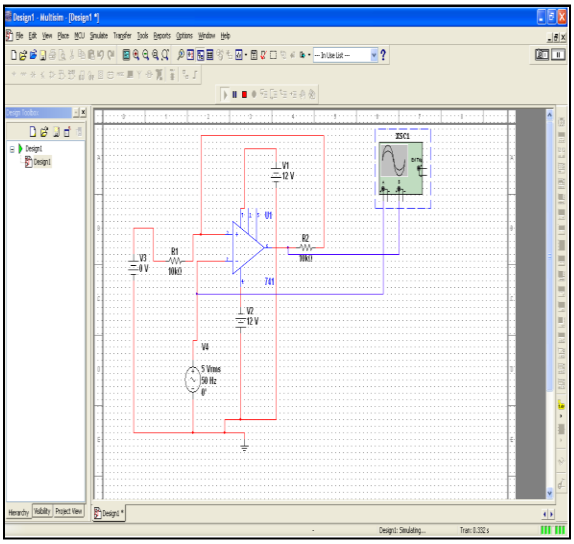

Fig.9 Simulation circuit schematic

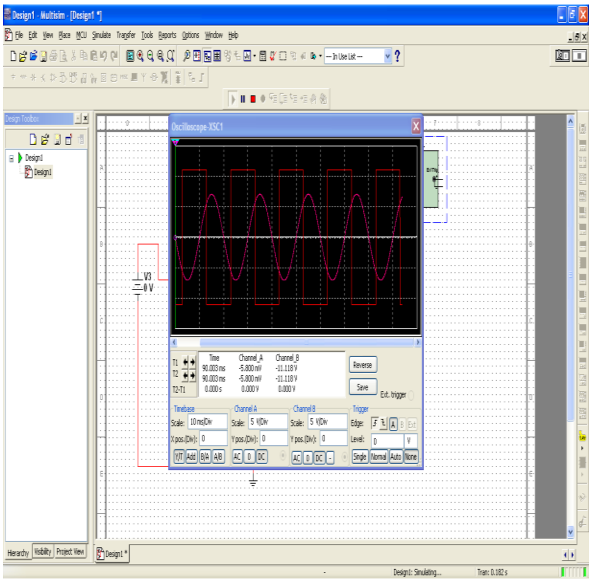

Fig.10 waveforms for the Simulation circuit

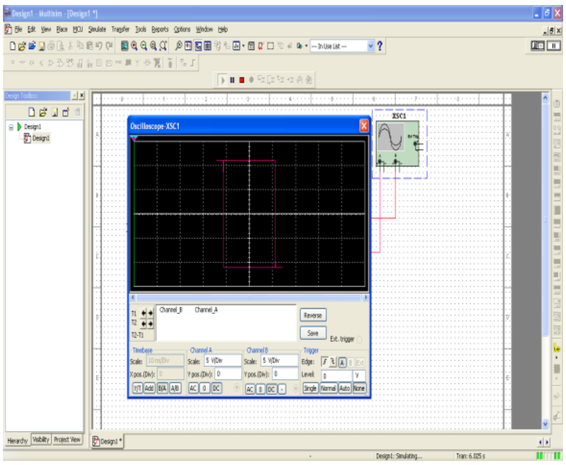

Fig.11 Hysteresis curve for simulation circuit.

V. CONCLUSION

Schmitt trigger circuit was designed and implemented using opamp IC µA-741. The designed system showed excellent characteristics and precise results were obtained. From the results, it can be concluded that a sinusoidal input signal is converted into a rectangular output signal. In other words an Analog signal is converted into a Digital signal. The amplitude of the Rectangular wave was calculated and it was independent of the peak to peak value of the input waveform. The time period and frequency of the rectangular waveform was also calculated. Schmitt trigger circuit is very simple and easy to design requiring very few components. Low power consumption is one of the salient features of the system as it uses opamp IC µA-741. Furthermore, the designed system is very stable, reliable, and easy to use and requires less cost. Due to these advantages it finds use in many applications in different domain of electronics such as Analog to Digital and Digital to Analog conversion, level detection and line reception etc.

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