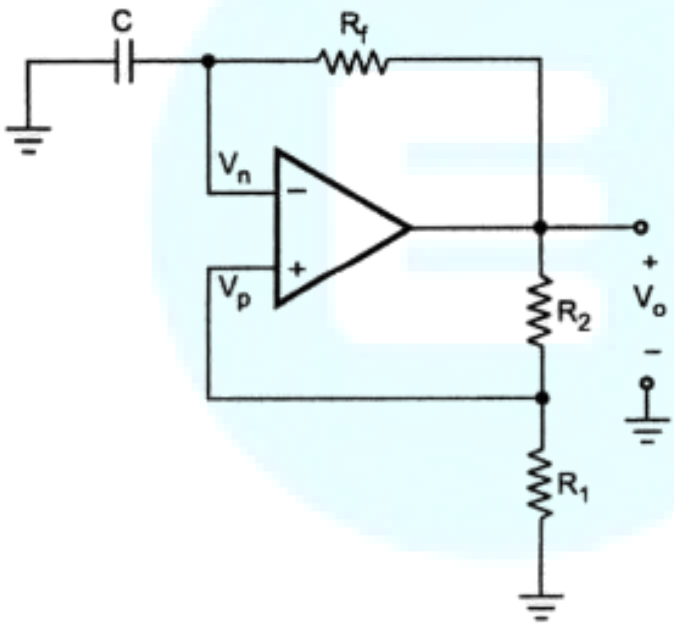
Electronics -Part 3

Op-Amp based multivibrators

The astable multivibrator

The Operational Amplifier or Op-amp for short, is a very versatile device that can be used in a variety of different electronic circuits and applications, from voltage amplifiers, to filters, to signal conditioners. But one very simple and extremely useful op-amp circuit based around any general-purpose operational amplifier is the Astable Op-amp Multivibrator.

The astable multivibrator is also called as a free-running multivibrator. It has two quasi-stable states i.e., no stable state such. No external signal is required to produce the changes in state. The component values used to decide the time for which circuit remains in each state. Usually, as the astable multivibrator oscillates between two states, is used to produce a square wave. The circuit diagram for a typical astable multivibrator is given below:



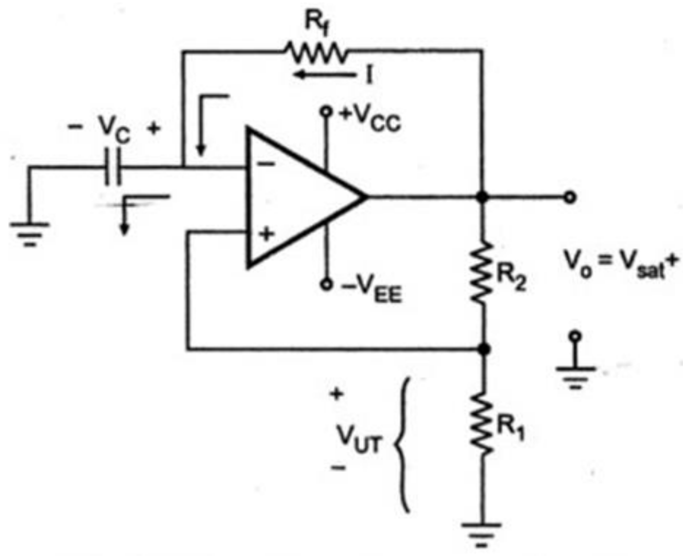
When Vo is at Vsat, the feedback voltage is called the upper threshold voltage V_{UT} and is given as

$$V_{\mathrm{UT}} = \left(R_1 \frac{V_{sat}}{R_1 + R_2} \right)$$

When Vo is at -Vsat, the feedback voltage is called the lower threshold voltage V_{LT} and is given as

$$V_{\mathrm{LT}} = - \left(\frac{R_1 V_{\mathrm{sat}}}{R_1 + R_2} \right)$$

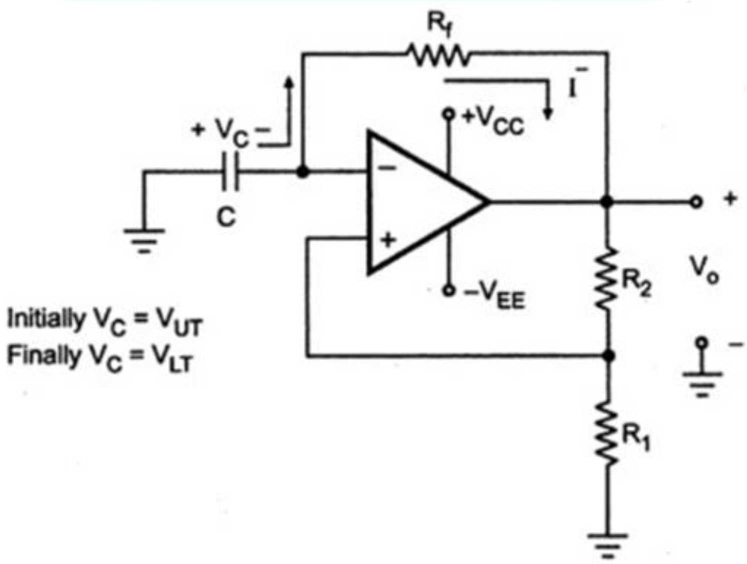
Circuit Operation



(a) When $V_o = +V_{sat}$, capacitor charges towards V_{UT}

(i) When power is turned ON, Vo automatically swings either Vsat or to -Vsat since these are the only stable states allowed by Schmitt trigger. Assume it swings to +Vsat.

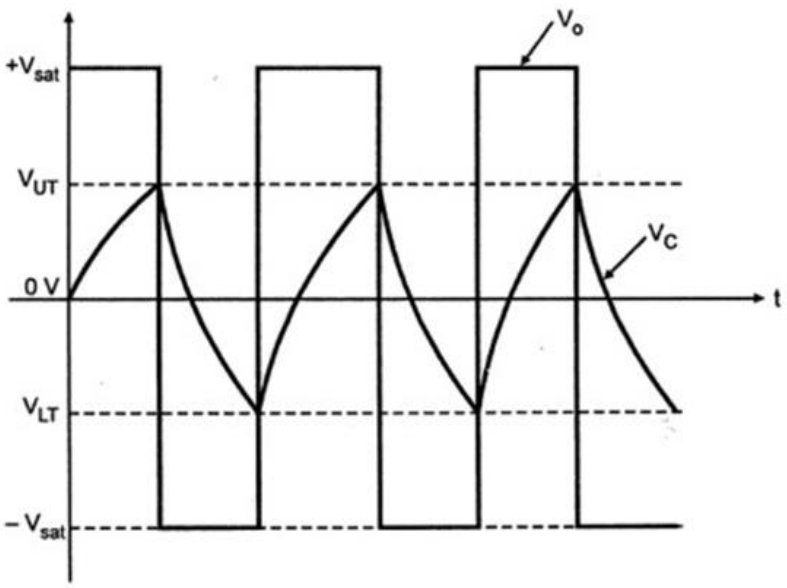
(ii) Now capacitor starts charging towards +Vsat through the feedback path provided by the resistor R_f to the inverting input. As long as the capacitor voltage Vc is less than V_{UT}, the output voltage remains at Vsat.



(b) When $V_o = -V_{sat}$, capacitor charges towards V_{LT}

(iii) As soon as Vc charges to a value slightly greater than V_{UT} , the input goes positive with respect to the input. This switches the output voltage from +Vsat to -Vsat.

(iv) As Vo switches to -Vsat , capacitor starts discharging via. The current I discharges capacitor to 0 V and recharges capacitor to V_{LT} When Vc becomes slightly more negative than the feedback voltage V_{LT} , output voltage switches back to +Vsat.



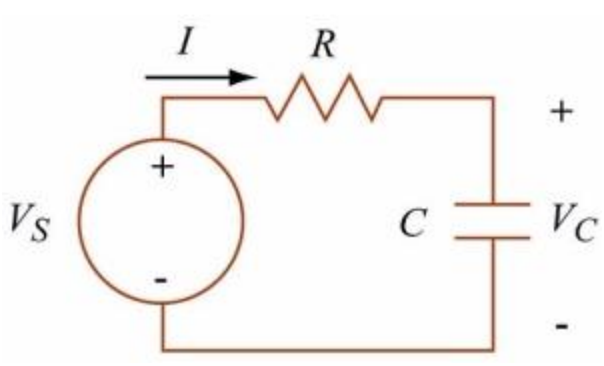
(c) Waveforms

Frequency of Oscillation

The frequency of oscillation is determined by the time it takes the capacitor to charge from V_{LT} to V_{UT} and vice versa.

Initial voltage (at t=0) across Capacitor

Vco = -βVsat



Here Role of supply Voltage will play, the output voltage

Vs=Vo= +Vsat

Voltage across Capacitor at time t is given by the

At t= Tc

Vo = -Vsat

Vc(Tc) = + βVsat

$+\beta Vsat = (-\beta Vsat + Vsat)e^{-(\frac{Tc}{RC})}$ + Vsat

Tc = RC In $\frac{1+\beta}{1-\beta}$

$\beta = \frac{R_2}{R_1 + R_2}$

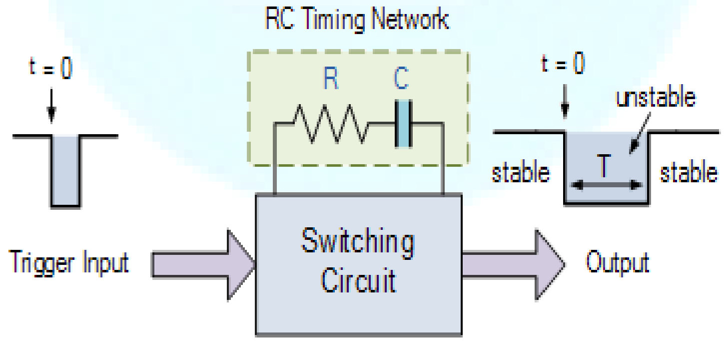
Tc = Td

T = Tc+ Td

T = 2RC In $\frac{1+\beta}{1-\beta}$

Op-amp Monostable Multivibrators

Op-amp Monostable Multivibrators are electronic circuits which produces a single timed rectangular output pulse when externally triggered.



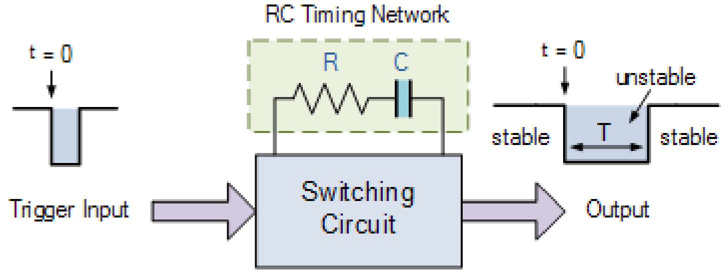
Monostable circuits can easily be made using discrete components or digital logic gates but monostable circuits can also be constructed using operational amplifiers.

Op-amp Monostable Multivibrator (one-shot multivibrator) circuits are positive-feedback (or regenerative) switching circuits that have only one stable state, producing an output pulse of a specified duration T.

An external trigger signal is applied for it to change state and after a set period of time, either in microseconds, milliseconds or seconds, a time period which is determined by

RC components, the monostable circuit then returns back to its original stable state where it remains until the next trigger input signal arrives.

The basic monostable multivibrator block diagram is given as:

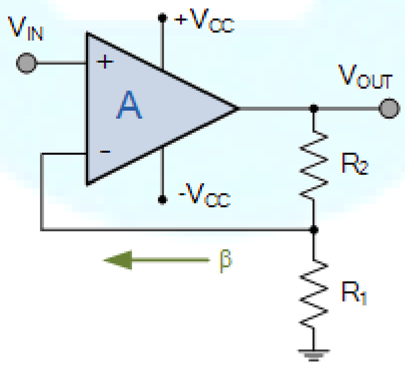


The above block diagram shows that a monostable multivibrator is constructed by adding an external resistor, (R) and capacitor, (C) across a switching circuit. The switching circuit can be made using transistors, digital logic gates or general-purpose operational amplifiers. The time constant, τ of the resistor-capacitor combination determines the length of the pulse, T.

In this tutorial we will construct a monostable multivibrator circuit using an operational amplifier comparator circuit with a positive feedback path. As the feedback is positive the circuit is regenerative, that is it adds to the differential input signal.

Op-amp Monostable Circuit

Firstly, let's consider the Inverting Amplifier circuit as shown.



In this inverting operational amplifier configuration, some of the output signal (called the feedback fraction) is fed back to the inverting input of the operational amplifier via the resistive network.

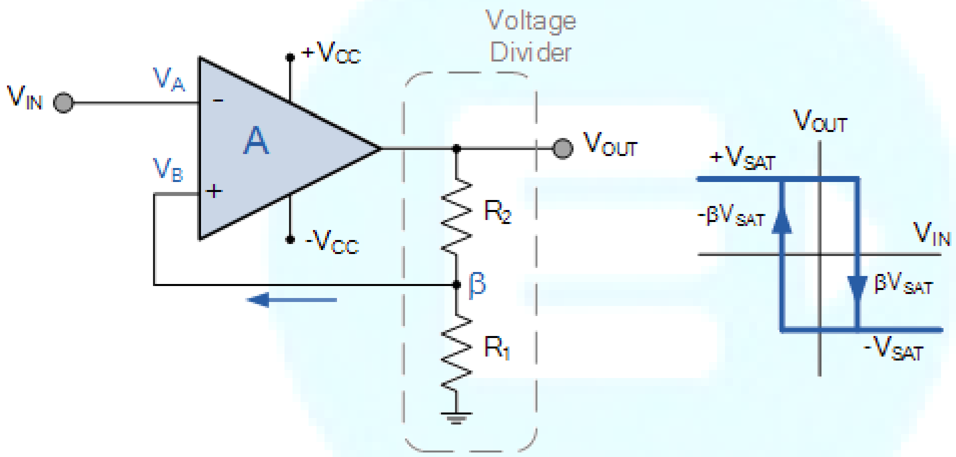
In this basic inverting configuration, the feedback fraction is therefore negative as it is fed back to the inverting input. This negative feedback configuration between the output and the inverting input terminal forces the differential input voltage towards zero.

The result of this negative feedback is that the op-amp produces an amplified output signal which is 180o out-of-phase with the input signal. So an increase in the inverting terminal voltage, -V fed back from the output causes a decrease in the output voltage, VO producing a balanced and stable amplifier operating within its linear region.

Consider now the same identical operational amplifier circuit in which the inverting and non-inverting inputs of the op-amp have been interchanged. That is the feedback signal is fed back to the non-inverting input and the feedback process is now positive producing a basic op-amp comparator circuit with built-in hysteresis.

The op-amp monostable multivibrator circuit is constructed around an operational amplifier configured as a closed-loop Schmitt Trigger circuit that uses positive feedback provided by resistors R1 and R2 to generate the required hysteresis. The use of positive feedback means that the feedback is regenerative and provides the required state dependence which in effect changes the op-amp into a bistable memory device.

Op-amp Schmitt Comparator



A resistive network is connected between the op-amps output and non-inverting (+) input. When Vout is saturated towards the positive supply rail, (+Vcc), a positive voltage, with respect to ground is applied to the op-amps non-inverting input. Likewise, when Vout is saturated towards the negative supply rail, (-Vcc), a negative voltage, with respect to ground is applied to the op-amps non-inverting input.

Since the two resistors are configured across the output in the form of a voltage divider network, the voltage V_B present at the non-inverting input will therefore be dependant on the fraction of the output voltage fed back by the ratio of the two resistors. This feedback fraction, β is given as:

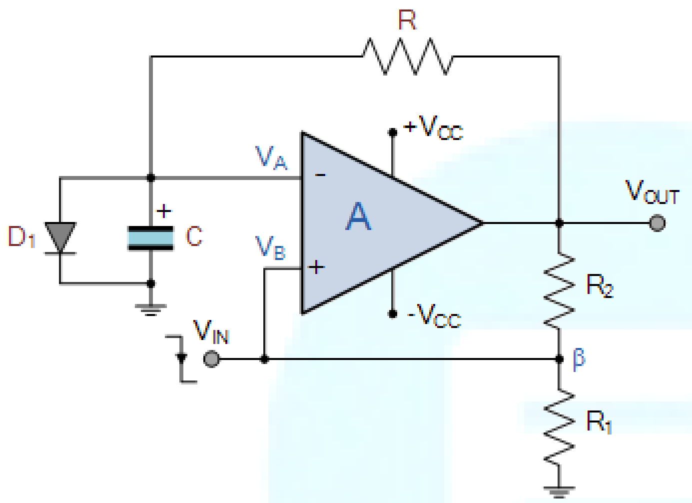
$$\beta = \frac{R1}{R1+R2}$$

we can make the value of β variable by replacing resistors R1 and R2 with a potentiometer in which the potentiometers wiper is connected directly to the op-amps non-inverting input thereby allowing us to vary the feedback fraction.

As the amount of hysteresis is directly related to the amount of feedback fraction, it is best to avoid constructing a Schmitt trigger op-amp (regenerative comparator) with very small amounts of hysteresis (small β) as this may result in the op-amp oscillating between the upper and lower points when switching.

If we now place a feedback network across the Schmitt trigger between the output and the inverting (-) input, we can control the amount of time that it takes for the Schmitt op-amp to change state. By doing this, the signal to the op-amps inverting input is now provided by the op-amp itself via the external RC feedback network as shown.

Basic Op-amp Monostable Circuit



At initial power on (that is t = 0), the output (V_{OUT}) will saturate towards either the positive rail (+Vcc), or to the negative rail (-Vcc), since these are the only two stable states allowed by the op-amp. Lets assume for now that the output has swung towards the positive supply rail, +Vcc. Then the voltage at the non-inverting input, V_B will be equal to +Vcc x β where β is the feedback fraction.

The inverting input is held at 0.7 volts, the forward volt drop of diode, D_1 and clamped to 0v (ground) by the diode, preventing it from going any more positive. Thus the potential at V_A is much less than that at V_B and the output remains stable at +Vcc. At the same time, the capacitor, (C) charges up to the same 0.7 volts potential and is held there by the forward-biased voltage drop of the diode.

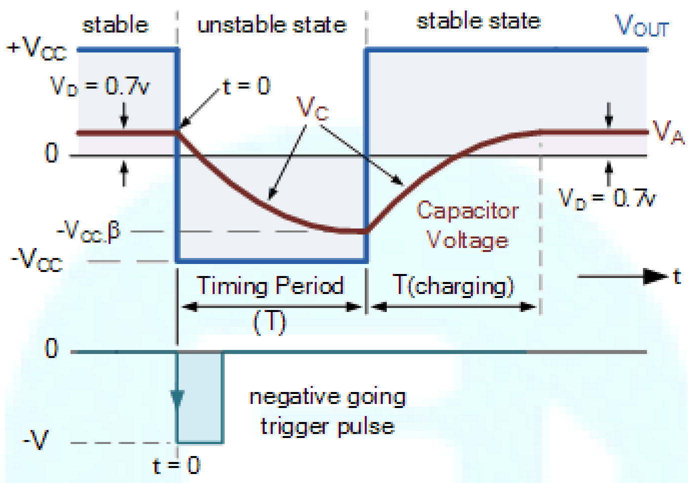
If we were to apply a negative pulse to the non-inverting input, the 0.7v voltage at V_A now becomes greater than the voltage at V_B since V_B is now negative. Thus the output of the Schmitt configured op-amp switches state and saturates towards the negative supply rail, -Vcc. The result is that the potential at V_B is now equal to -Vcc x β.

This temporary meta-stable state causes the capacitor to charge up exponentially in the opposite direction through the feedback resistor, R from +0.7 volts down to the saturated output which it has just switched too, -Vcc. Diode, D_1 becomes reverse-biased so has no effect. The capacitor, C will discharge at a time constant $\tau = RC$.

As soon as the capacitor voltage at V_A reaches the same potential as V_B, that is -Vcc*β, the op-amp switches back to its original permanent stable state with the output saturated once again at +Vcc.

Note that once the timing period is complete and the op-amps output changes back to its stable state and saturates towards the positive supply rail, the capacitor tries to charge up in reverse to +Vcc but can only charge to a maximum value of 0.7v given by the diodes forward voltage drop. We can show this effect graphically as:

Op-amp Monostable Waveforms



Then we can see that a negative-going trigger input, will switch the op-amp monostable circuit into its temporary unstable state. After a time delay, T while the capacitor, C charges up through the feedback resistor, R, the circuit switches back to its normal stable state once the capacitor voltage reaches the required potential.

This time delay period (T) of the rectangular pulse at the output, the unstable state time, is given as:

Op-amp Monostable Timing Period

$$T = RC \times \ln\left(1 + \frac{R_1}{R_2}\right)$$

If the two operational amplifiers feedback resistors are of the same value, that is: $R_1 = R_2$, then the above equation simplifies down too:

$$T = 0.693RC$$

Obviously, there is a a certain amount of time that the capacitor takes to charge again from -Vcc x β to V_D (0.7v) and therefore during this period a second negative pulse may not start a new timing period.

Then in order to ensure the correct operation of the op-amp monostable circuit upon the application of the next trigger pulse, the time period between trigger pulses, (T_{total})

must be greater than the timing period, T plus the time required for the capacitor to recharge, ($T_{charging}$).

The charging recovery time is given as:

$$T_{(charging)} = RC.\ln\left(\frac{V_{CC}+\beta(-V_{CC})}{V_{CC}-V_D}\right) = RC.\ln\left(\frac{1+\beta}{1-\frac{V_D}{V_{CC}}}\right)$$

Where: Vcc is the supply voltage, V_D is the diodes forward voltage drop, (usually about 0.6 to 0.7 volts) and β is the feedback fraction.

In order to ensure that the op-amp monostable circuit has a good negative trigger signal which starts the timing period on the leading edge of the negative going pulse, and also to stop any false triggering of the circuit when it is in its stable state, we can add a RC differentiating circuit to the input.

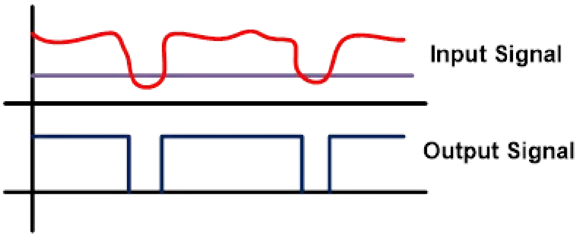
A differentiator circuit is useful in producing a negative output spike from a square or rectangular input waveform. The sharp and abrupt reduction of the comparator's threshold voltage below its feedback fraction, β value drives the op-amp monostable into its timing period.

Schmitt Trigger

A Schmitt Trigger is a comparator circuit with hysteresis implemented by applying positive feedback to the noninverting input of a comparator or differential amplifier. A Schmitt Trigger uses two input different threshold voltage level to avoid noise in the input signal. The action from this dual-threshold is known as hysteresis.

The Schmitt Trigger was invented by American scientist Otto H Schmitt in 1934.

The normal comparator contains only one threshold signal. And it compares the threshold signal with an input signal. But, if the input signal has noise, it may affect the output signal.



In the above figure, because of the noise at locations A and B, the input signal (V1) crosses the level of the reference signal (V2). During this period, the V1 is less than V2 and the output is low.

Hence, the output of the comparator is affected by the noise in the input signal. And the comparator is not protected from the noise.

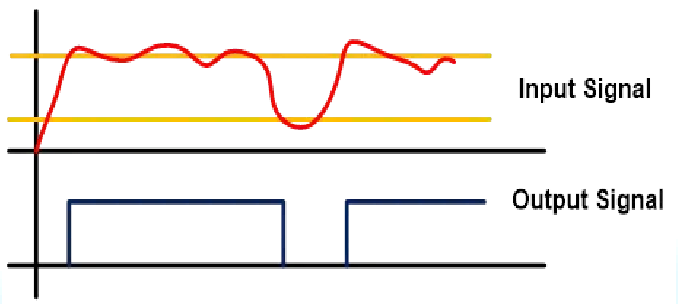
The “trigger” in the name “Schmitt Trigger” comes from the fact that the output retains its value until the input varies sufficiently to “trigger” a change.

Working

The Schmitt trigger gives proper results even if the input signal is noisy. It uses two threshold voltages; one is the upper threshold voltage (VUT) and the second is lower threshold voltage (VLT).

The output of the Schmitt trigger remains low until the input signal crosses VUT. Once the input signal crosses this limit VUT, the output signal of the Schmitt trigger remains high until the input signal is below the level of VLT.

Let’s understand the working of Schmitt trigger with an example. Here we assume that the initial input is zero.



Noise effect with Schmitt Trigger

Here, we have assumed that the initial input signal is zero and it increases gradually as shown in the above figure. The input signal is noisy. But the noise is not affected in the output signal.

Schmitt Trigger Circuit

The Schmitt trigger circuit uses positive feedback. Therefore, this circuit is also known as the regenerative comparator circuit. The Schmitt Trigger circuit can be designed with the help of Op-Amp and Transistor. And it classified as;

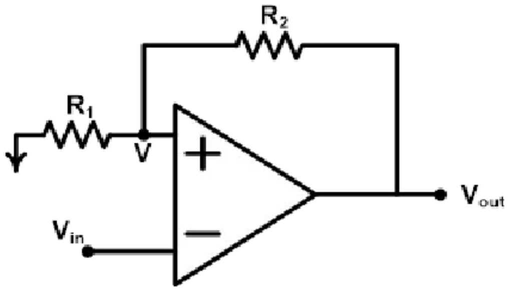
- Op-amp based Schmitt trigger
- Transistor based Schmitt trigger

Op-Amp based Schmitt Trigger

The Schmitt trigger circuit can be designed using Op-Amp in two ways. If the input signal is connected at the inverting point of Op-Amp, it is known as Inverting Schmitt Trigger. And if the input signal is connected at the non-inverting point of Op-Amp, it is known as Non-inverting Schmitt Trigger.

Inverting Schmitt Trigger

In this type of Schmitt trigger, the input is given at the inverting terminal of op-amp. And the positive feedback from output to input. The circuit diagram of the inverting Schmitt Trigger is as shown in the below figure.



If the applied voltage Vin is greater than V, the output of the circuit will be low. And if the applied voltage Vin is less than V, the output of the circuit will be high.

Vin > V , Vout = V_L

Vin < V , Vout = V_H

Now, calculate the equation of V.

Applying Kirchhoff's Current Law (KCL),

$$\frac{V-0}{R_1} + \frac{V-Vout}{R_2} = 0$$

$$\frac{v}{R_1} + \frac{V}{R_2} - \frac{Vout}{R_2} = 0$$

$$V\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{Vout}{R_2}$$

$$V\left(\frac{R_1+R_2}{R_1R_2}\right) = \frac{Vout}{R_2}$$

$$V = \frac{R_1}{R_1+R_2}Vout$$

Now, let's assume that the output of the Schmitt trigger is high. In this condition,

Vout= V_H and V= V1

From the above equation

$$V1 = \frac{R_1}{R_1+R_2}V_H$$

The output will remain low until the input signal is less than V. when the output of the Schmitt trigger is low, in this condition,

Vout = V_L and V= V2

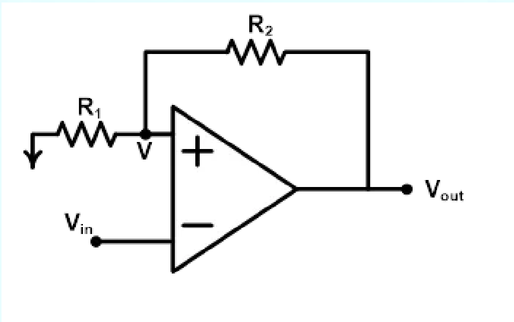
V2 = $\frac{R_1}{R_1+R_2} V_L$

Now, the output remains high until the input signal is less than V2. Hence, the V2 is known as a lower threshold voltage (VLT).

V_{LT} = $\frac{R_1}{R_1+R_2} V_L$

Non-Inverting Schmitt Trigger

In non-inverting Schmitt trigger, the input signal is applied at the non-inverting terminal of Op-Amp. And positive feedback is applied from output to input. The inverting terminal of Op-Amp is connected to the ground terminal. The circuit diagram of the non-inverting Schmitt trigger is as shown below figure.



In this circuit, the output of the Schmitt trigger will high when voltage V is greater than zero. And the output will low when voltage V is less than zero.

Vin > 0, Vout = V_H

Vin < 0 , Vout = V_L

Now, let's find the equation of voltage V. For that, we apply KCL at that node.

$$\frac{V - Vin}{R_1} + \frac{V - Vout}{R_2} = 0$$

$$\frac{v}{R_1} - \frac{Vin}{R_1} + \frac{V}{R_2} - \frac{Vout}{R_2} = 0$$

$$V\left(\frac{R_1+R_2}{R_1 R_2}\right) = \frac{Vin}{R_1} + \frac{Vout}{R_2}$$

$$V = \frac{R_2}{R_1{+}R_2}Vin + \frac{R_1}{R_1{+}R_2}Vout$$

Now, assume that the output of Op-Amp is low. Hence, the output voltage of the Schmitt trigger is V_L. And voltage V is equal to V1.

In this condition,

Vout = V_L and V=V1

From the above equation,

$$V = \frac{R_2}{R_1{+}R_2}Vin + \frac{R_1}{R_1{+}R_2}Vout$$

When the voltage V1 is greater than zero, the output will high. In this condition,

$$\frac{R_2}{R_1{+}R_2}Vin > \frac{R_1}{R_1{+}R_2}Vout$$

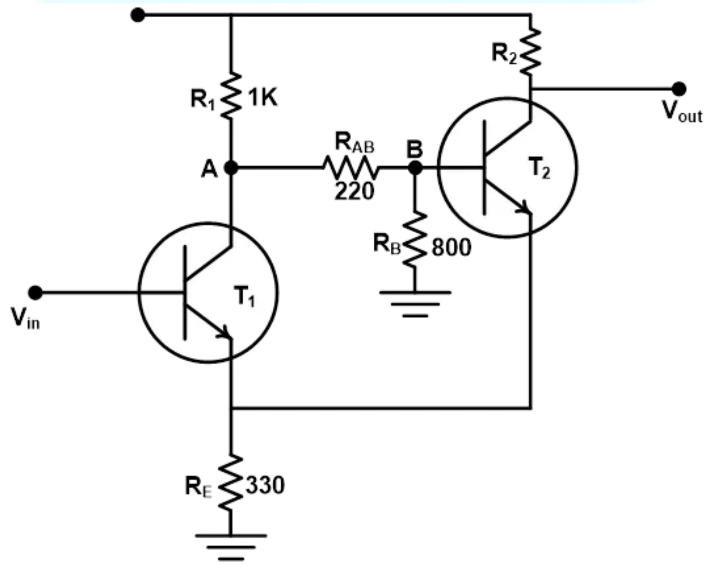
$$Vin > -\frac{R_1}{R_2}V_L$$

The above equation gives the value of the lower threshold voltage (V_{LT}).

$$V_{LT} = -\frac{R_1}{R_2}V_H$$

Transistor based Schmitt Trigger

The Schmitt trigger circuit can be designed with the help of two transistors. The circuit diagram of the transistor-based Schmitt trigger is given in the below circuit.



Vin = input voltage

Vref = Reference voltage = 5V

Let's assume that, at starting, an input voltage Vin is zero. The input voltage is given to the base of transistor T1. Hence, in this condition, the transistor T1 operates in the cut-off region and it remains non conducting.

Va and Vb are node voltage. The reference voltage is given 5V. So, we can calculate the value of Va and Vb by the voltage divider rule.

Voltage Vb is given to the base of transistor T2. And it is 1.98V. Therefore, the transistor T2 is conducting. And due to this, the output of the Schmitt trigger is low. The drop at an emitter is about 0.7V. So, the base of the transistor voltage is 1.28V.

The emitter of transistor T2 is connected with the emitter of transistor T1. Hence, both transistors operate at the same level at 1.28V.

It means that the transistor T1 will operate when the input voltage is 0.7V above 1.28V or more than 1.98V (1.28V + 0.7V).

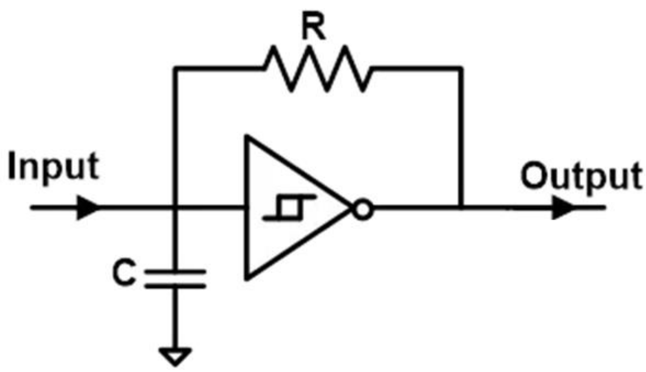
Now, we increase the input voltage more than 1.98V, and transistor T1 will start conducting. This causes the voltage drop of the base of transistor T2 and it will cut off the transistor T2. And due to this, the output of the Schmitt trigger is high.

The input voltage starts decreasing. The transistor T1 will cut off when the input voltage is 0.7V less than 1.98V and it is 1.28V. In this condition, the transistor T2 gets sufficient voltage from the reference voltage, and it will turn on. This makes the output of Schmitt trigger low.

Therefore, in this condition, we have two thresholds, a lower threshold at 1.28V and a higher threshold at 1.98V.

Schmitt Trigger Oscillator

The Schmitt Trigger can be used as an oscillator by connecting a single RC integrated circuit. The circuit diagram of the Schmitt trigger oscillator is as shown in the below figure.



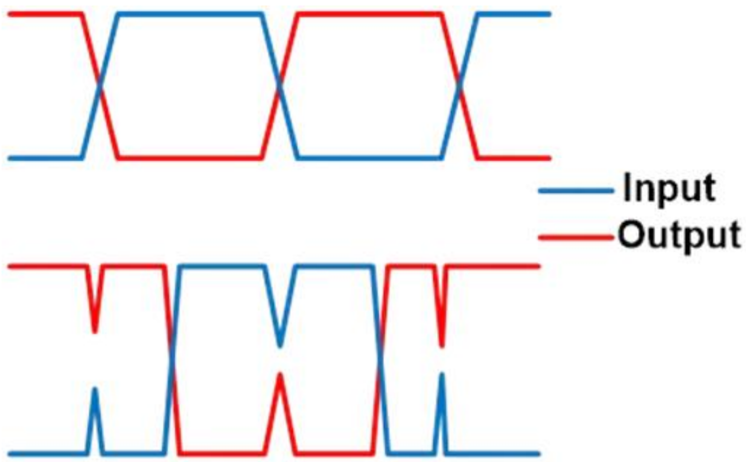
The output of the circuit is a continuous square wave. And the frequency of the waveform depends on the value of R, C, and threshold point of Schmitt Trigger.

$$f = \frac{k}{RC}$$

Where k is a constant and it ranges between 0.2 and 1.

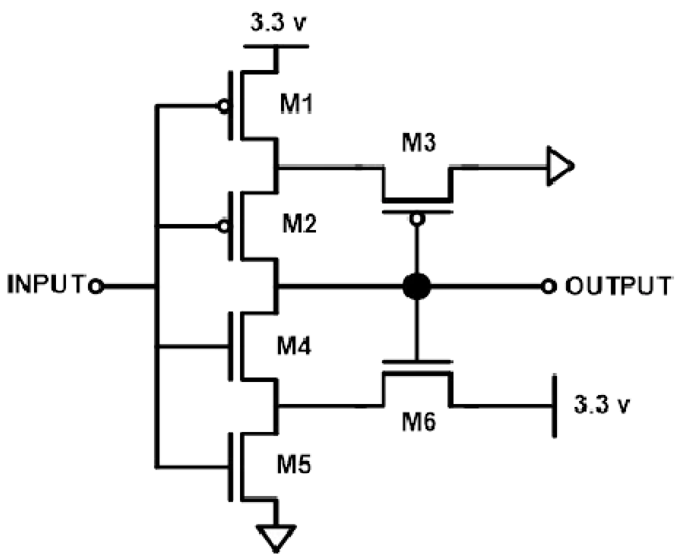
CMOS Schmitt Trigger

The simple signal inverter circuit gives the opposite output signal from the input signal. For example, if the input signal is high, the output signal is low for a simple inverter circuit. But if the input signal has spikes (noise), the output signal will react change on a spike. That we don't want. Therefore, the CMOS Schmitt trigger is used.



In the first waveform, the input signal has no noise. So, the output is perfect. But in the second figure, the input signal has some noise. The output is also reacting to this noise. To avoid, this condition, CMOS Schmitt trigger is used.

The below circuit diagram shows the construction of the CMOS Schmitt trigger. The CMOS Schmitt Trigger consists of 6 transistors including PMOS and NMOS transistors.



NMOS transistor conducts when V_G is greater than V_S or V_D. And PMOS transistor conducts when V_G is less than V_S or V_D. In CMOS Schmitt trigger, one PMOS and one NMOS transistors are added in a simple inverter circuit.

In the first case, the input voltage is high. In this condition, the PN transistor is ON and the NN transistor is OFF. And it creates a path to ground for node-A. Therefore, the output of the CMOS Schmitt trigger will be zero.

In the second case, the input voltage is high. In this condition, the NN transistor is ON and the PN transistor is OFF. It will create a path to voltage V_{DD} (High) for node-B. Therefore, the output of the CMOS Schmitt trigger will be high.

Applications

- Schmitt trigger is used to a sine wave and triangular wave into square waves.
- The most important use of the Schmitt triggers to remove noise in the digital circuit.
- It is also used as a function generator.
- It is utilized to implement an oscillator.
- Schmitt triggers with the RC circuit is used as switch debouncing.