CHAPTER SIX

WAVE SHAPING CIRCUITS

Topics to be covered

· RC & RL Integrator and Differentiator circuits

· Storage, Delay and Calculation of Transistor Switching Times

· Speed-up Capacitor

· Diode clippers

· Diode comparator

· Clampers

· Collector coupled and Emitter coupled Astable multivibrator

· Monostable multivibrator

· Bistable multivibrators

· Triggering methods for Bistable multivibrators

· Schmitt trigger circuit.

RC Integrator

· The RC integrator is a series connected Resistor-Capacitor network that produces an output signal which corresponds to the mathematical process of integration.

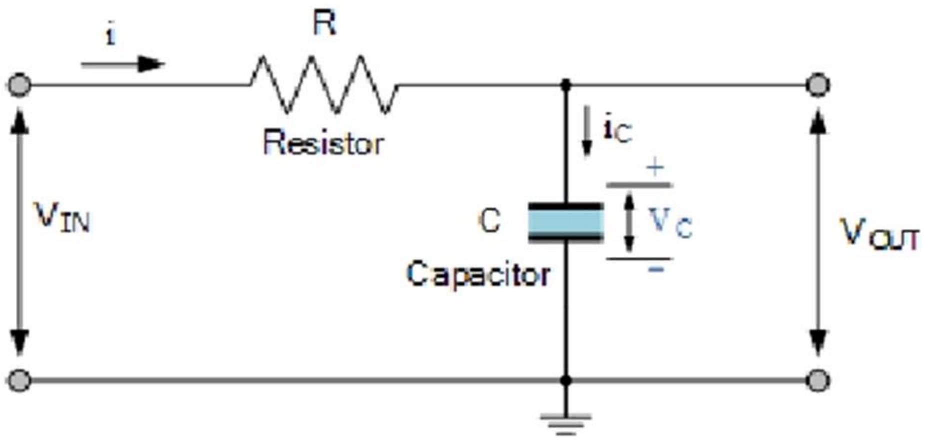
· For a passive RC integrator circuit, the input is connected to a resistance while the output voltage is taken from across a capacitor being the exact opposite to the RC Differentiator Circuit. The capacitor charges up when the input is high and discharges when the input is low.

· A passive RC network is nothing more than a resistor in series with a capacitor, that is a fixed resistance in series with a capacitor that has a frequency dependant reactance which decreases as the frequency across its plates increases.

· Thus at low frequencies the reactance, Xc of the capacitor is high while at high frequencies its reactance is low due to the standard capacitive reactance formula of $X_c = 1/(2\pi fC)$.

· Then if the input signal is a sine wave, an **rc integrator** will simply act as a simple low pass filter (LPF) with a cut-off or corner frequency that corresponds to the RC time constant (tau, τ) of the series network and whose output is reduced above this cut-off frequency point. Thus when fed with a pure sine wave an RC integrator acts as a passive low pass filter.

· Thus the rate of charging or discharging depends on the RC time constant, $\tau = RC$.



· For an RC integrator circuit, the input signal is applied to the resistance with the output taken across the capacitor, then V_{OUT} equals V_C.

· As the capacitor is a frequency dependant element, the amount of charge that is established across the plates is equal to the time domain integral of the current.

· That is it takes a certain amount of time for the capacitor to fully charge as the capacitor can not charge instantaneously only charge exponentially.

· herefore the capacitor current can be written as:

$$i_{C(t)} = C\frac{dV_{C(t)}}{dt}$$

· This basic equation above of $i_C = C(dV_c/dt)$ can also be expressed as the instantaneous rate of change of charge, Q with respect to time giving us the following standard equation of: $i_C = dQ/dt$ where the charge $Q = C \times V_c$, that is capacitance times voltage.

· The rate at which the capacitor charges (or discharges) is directly proportional to the amount of the resistance and capacitance giving the time constant of the circuit.

· Since capacitance is equal to Q/V_c where electrical charge, Q is the flow of a current (i) over time (t), that is the product of i x t in coulombs, and from Ohms law we know that voltage (V) is equal to i x R, substituting these into the equation for the RC time constant gives:

· **RC Time Constant**

$$RC = R\frac{Q}{V} = R\frac{i \times T}{i \times R} = \cancel{R}\frac{\cancel{i} \times T}{\cancel{i} \times \cancel{R}} = T$$

$$\therefore T = RC$$

· **Capacitor Voltage**

· The capacitors current can be expressed as the rate of change of charge, Q with respect to time.

· Therefore, from a basic rule of differential calculus, the derivative of Q with respect to time is dQ/dt and as i = dQ/dt we get the following relationship of:

· $Q = \int i dt$ (the charge Q on the capacitor at any instant in time)

· Since the input is connected to the resistor, the same current, i must pass through both the resistor and the capacitor ($i_R = i_C$) producing a V_R voltage drop across the resistor so the current, (i) flowing through this series RC network is given as:

$$i(t) = \frac{V_{IN}}{R} = \frac{V_R}{R} = C\frac{dV}{dt}$$

$$V_{OUT} = V_C = \frac{Q}{C} = \frac{\int i dt}{C} = \frac{1}{C}\int i(t) dt$$

As $i = V_{IN}/R$, substituting and rearranging to solve for V_{OUT} as a function of time gives:

$$V_{OUT} = \frac{1}{C}\int\left(\frac{V_{IN}}{R}\right)dt = \frac{1}{RC}\int V_{IN} dt$$

· Then assuming the initial charge on the capacitor is zero, that is $V_{OUT} = 0$, and the input voltage V_{IN} is constant, the output voltage, V_{OUT} is expressed in the time domain as:

$$V_{OUT} = \frac{1}{RC}\int_0^t V_{IN(t)} dt$$

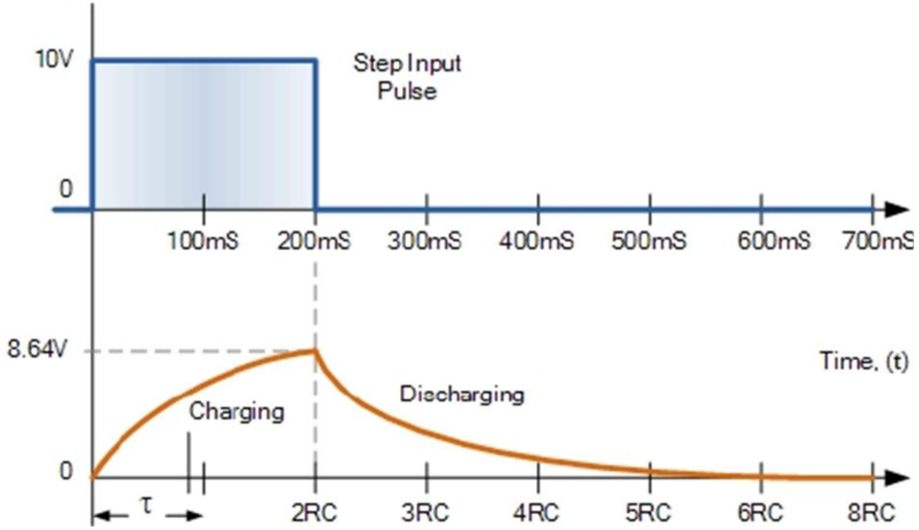
Capacitor Charging

$$V_{C(t)} = V\left(1 - e^{-\left(\frac{t}{RC}\right)}\right)$$

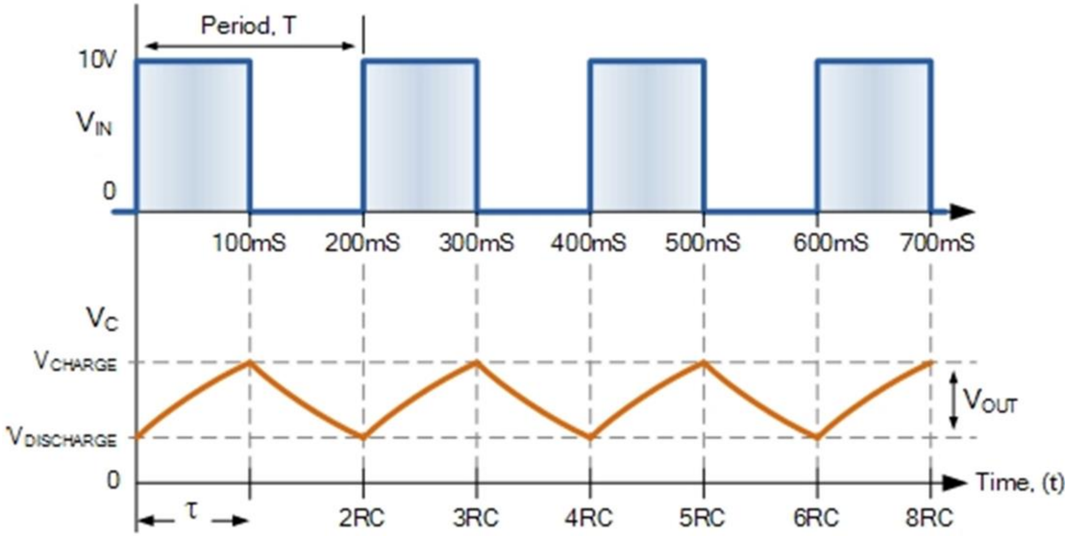
Capacitor Discharging

$$V_{C(t)} = V\left(e^{-\left(\frac{t}{RC}\right)}\right)$$

RC Integrator Charging/Discharging Curves

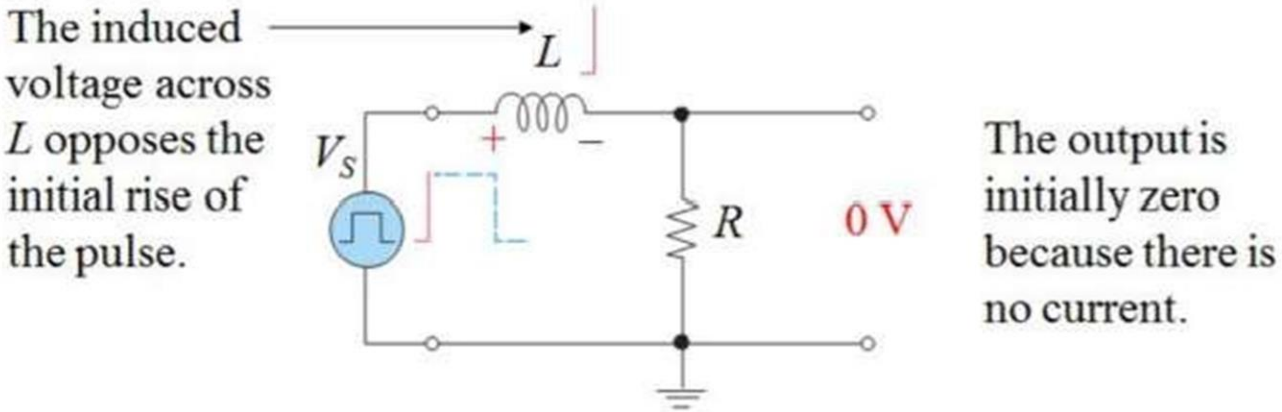


Fixed RC Integrator Time Constant



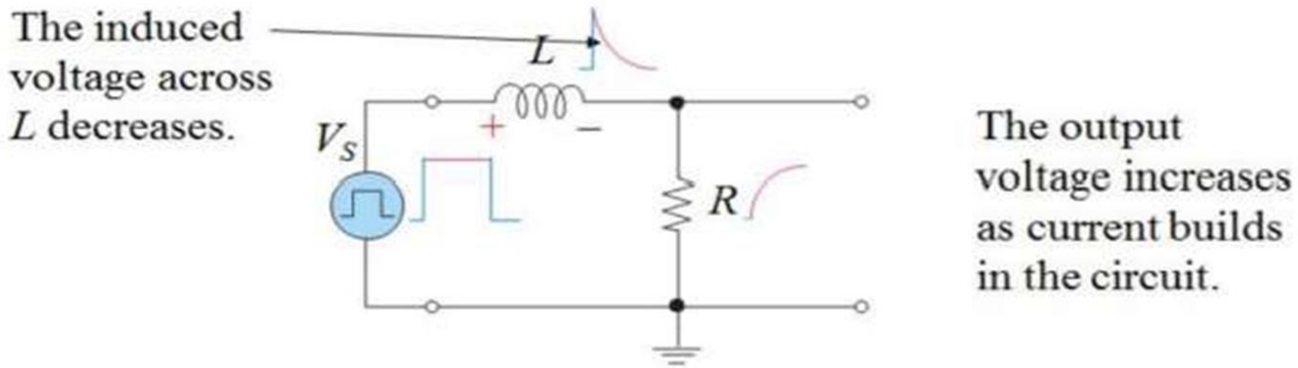
The RL Integrator

- Like the RC integrator, an RL integrator is a circuit that approximates the mathematical process of integration. Under equivalent conditions, the waveforms look like the RC integrator.
- For an RL circuit, t = L/R.
- A basic RL integrator circuit is a resistor in series with an inductor and the source. The output is taken across the resistor.
- When the pulse generator output goes high, a voltage immediately appears across the inductor in accordance with Lenz's law.
- The instantaneous current is zero, so the resistor voltage is initially zero.



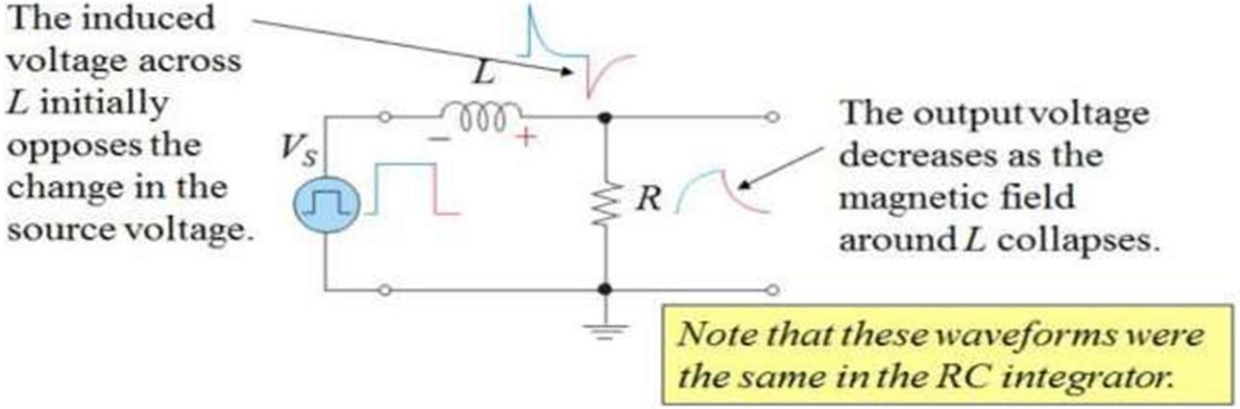
· At the top of the input pulse, the inductor voltage decreases exponentially and current increases.

· As a result, the voltage across the resistor increases exponentially. As in the case of the RC integrator, the output will be 63% of the final value in 1t.



· When the pulse goes low, a reverse voltage is induced across L opposing the change.

· The inductor voltage initially is a negative voltage that is equal and opposite to the generator; then it exponentially increases.



RC Differentiator

· The passive RC differentiator is a series connected Resistor-Capacitor network that produces an output signal which corresponds to the mathematical process of differentiation.

· For a passive RC differentiator circuit, the input is connected to a capacitor while the output voltage is taken from across a resistance being the exact opposite to the RC Integrator Circuit.

· A passive RC differentiator is nothing more than a capacitance in series with a resistance, that is a frequency dependent device which has reactance in series with a fixed resistance (the opposite to an integrator).

· Just like the integrator circuit, the output voltage depends on the circuits RC time constant and input frequency.

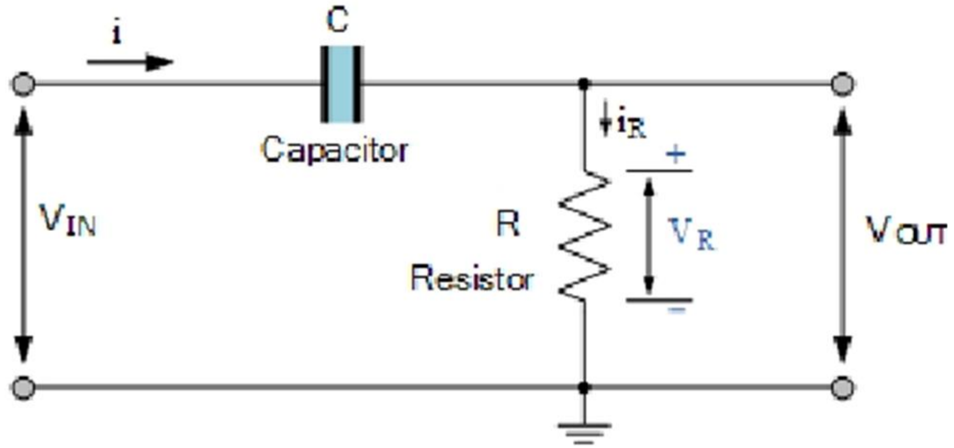
· Thus at low input frequencies the reactance, Xc of the capacitor is high blocking any d.c. voltage or slowly varying input signals.

· While at high input frequencies the capacitors reactance is low allowing rapidly varying pulses to pass directly from the input to the output.

· This is because the ratio of the capacitive reactance (Xc) to resistance (R) is different for different frequencies and the lower the frequency the less output.

· So for a given time constant, as the frequency of the input pulses increases, the output pulses more and more resemble the input pulses in shape.

· When fed with a pure sine wave an RC differentiator circuit acts as a simple passive high pass filter due to the standard capacitive reactance formula of $X_c = 1/(2\pi f C)$.



· For an RC differentiator circuit, the input signal is applied to one side of the capacitor with the output taken across the resistor, then V_{OUT} equals V_R

· **Capacitor Current**

$$i_{(t)} = \frac{dQ}{dt} = \frac{d(C \times dV_C)}{dt} = C\frac{dV_C}{dt} = C\frac{dV_{IN}}{dt}$$

Therefore the capacitor current can be written as:

$$i_{C(t)} = C\frac{dV_{IN(t)}}{dt}$$

As V_{OUT} equals V_R where V_R according to ohms law is equal too: i_R x R. The current that flows through the capacitor must also flow through the resistance as they are both connected together in series. Thus:

$$V_{OUT} = V_R = R \times i_R \qquad i_C = C\frac{dV_{IN}}{dt}$$

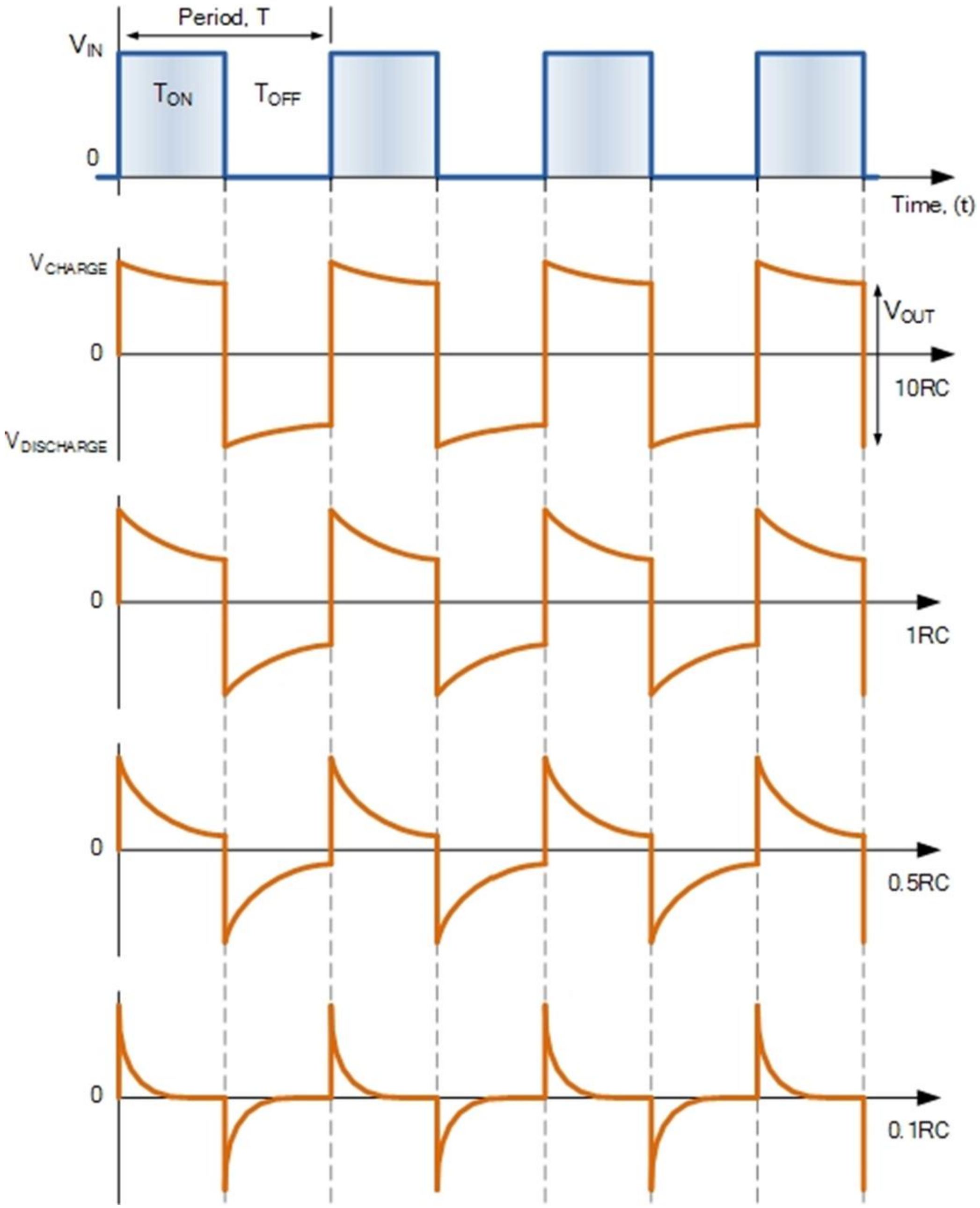
$$\text{As } i_R = i_C, \text{ therefore: } \quad V_{OUT} = RC\frac{dV_{IN}}{dt}$$

RC Differentiator Formula

$$V_{OUT} = RC\frac{dV_{IN}}{dt}$$

Then we can see that the output voltage, V_{OUT} is the derivative of the input voltage, V_{IN} which is weighted by the constant of RC. Where RC represents the time constant, τ of the series circuit.

RC Differentiator Output Waveforms



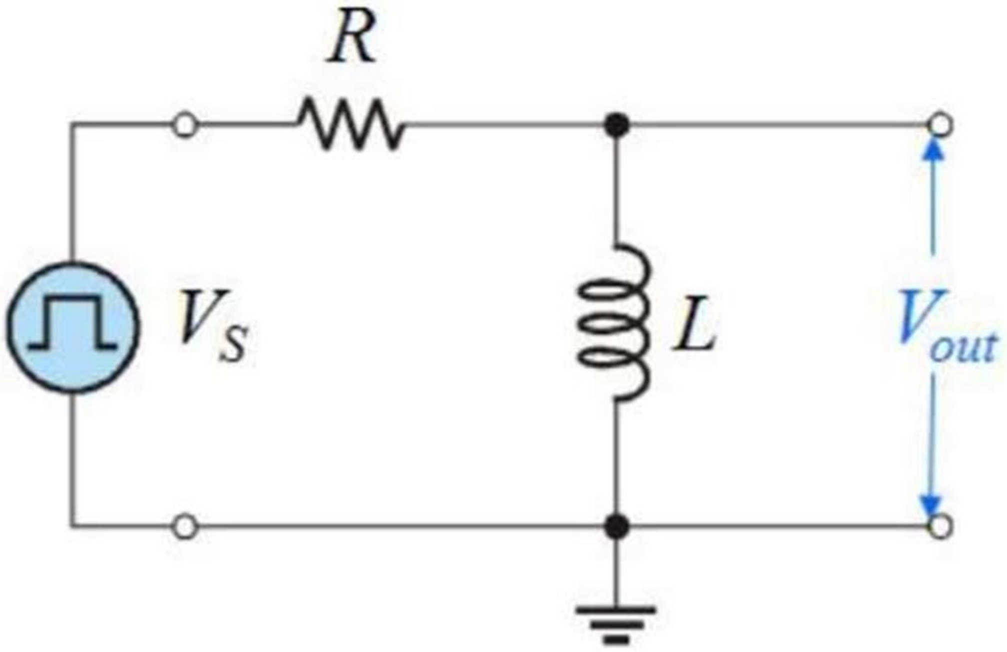
The RL Differentiator

· An RL differentiator is also a circuit that approximates the mathematical process of differentiation.

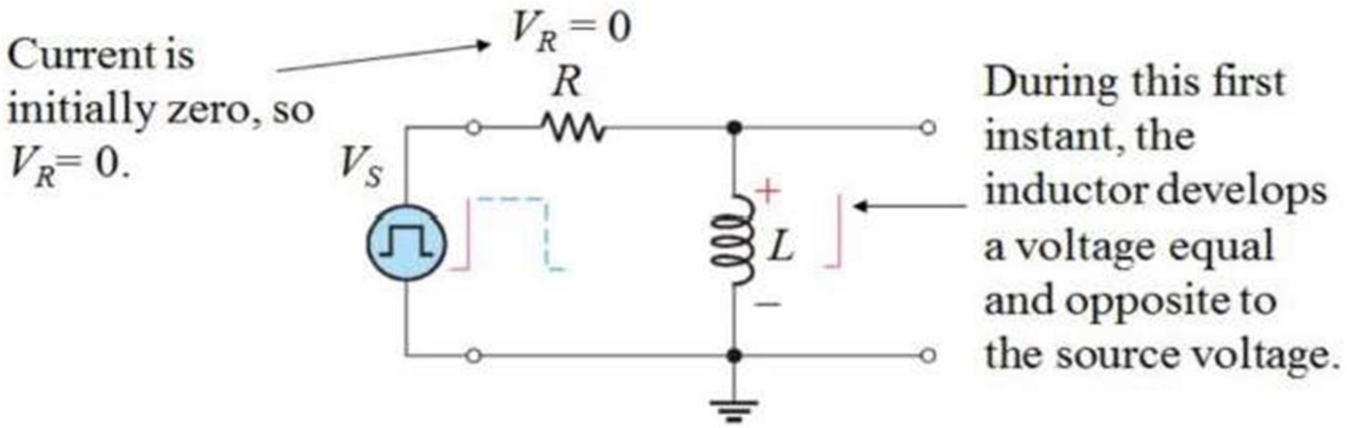
· It can produce an output that is the rate of change of the input under certain conditions.

· A basic RL differentiator circuit is an inductor in series with a resistor and the source.

· The output is taken across the inductor.

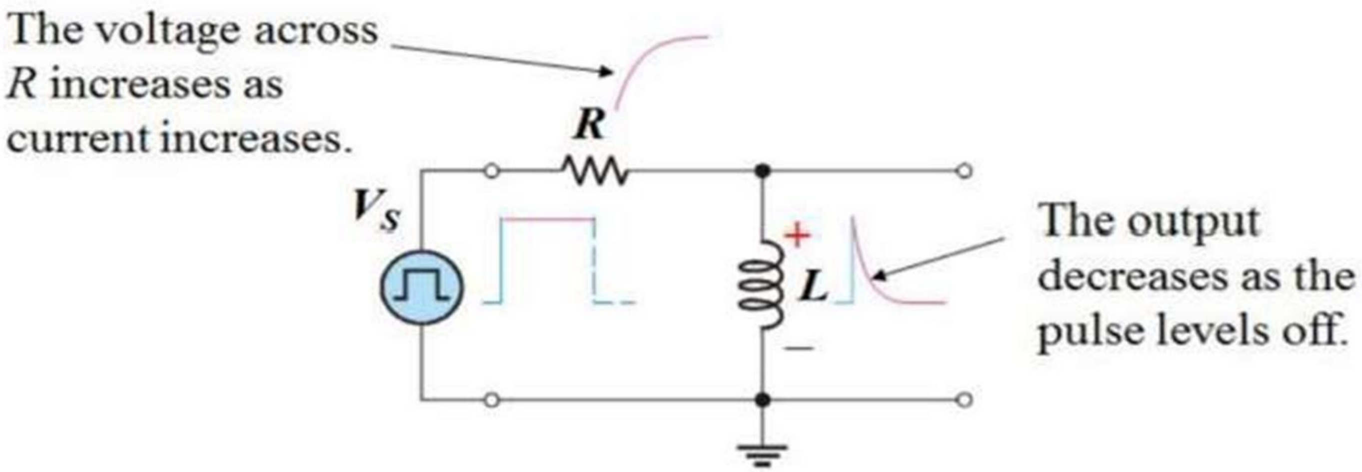


· When a pulse generator is connected to the input of an RL differentiator, the inductor has a voltage induced across it that opposes the source; initially, no current is in the circuit.



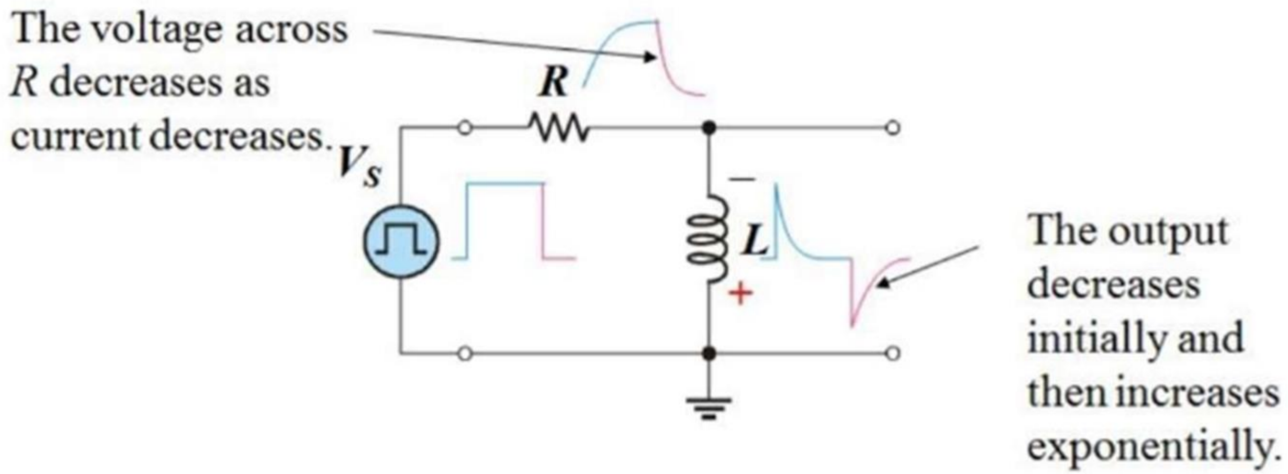
· After the initial edge has passed, current increases in the circuit.

· Eventually, the current reaches a steady state value given by Ohm's law.



· Next, the falling edge of the pulse causes a (negative) voltage to be induced across the inductor that opposes the change.

· The current decreases as the magnetic field collapses.



· An application of an integrator is to generate a time delay.

· The voltage at B rises as the capacitor charges until the threshold circuit detects that the capacitor has reached a predetermined level.

Diode clippers

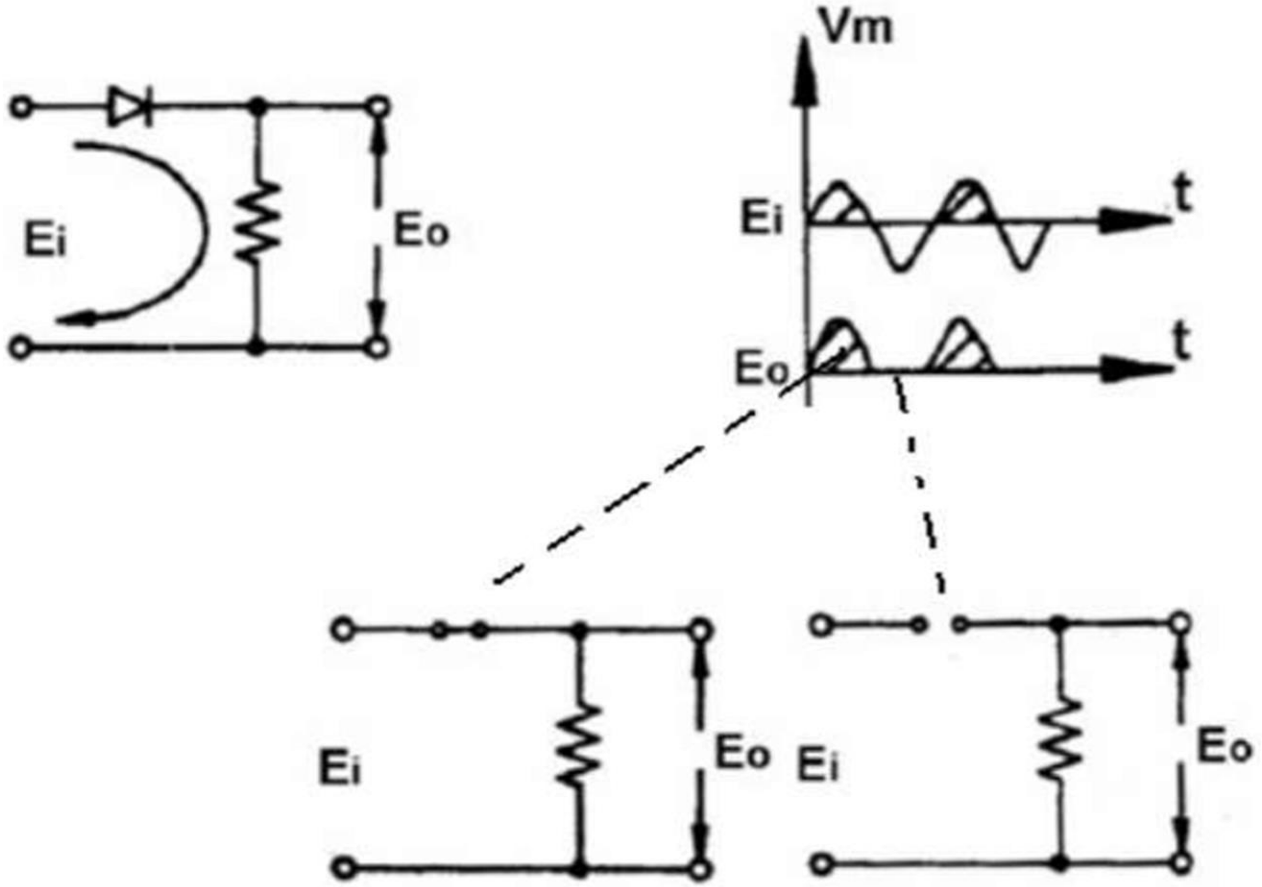
· The **Diode Clipper**, also known as a *Diode Limiter*, is a wave shaping circuit that takes an input waveform and clips or cuts off its top half, bottom half or both halves together.

· There are two types of clipper circuits, the series and parallel diode clipping circuits.

· Series Diode Clipping Circuit

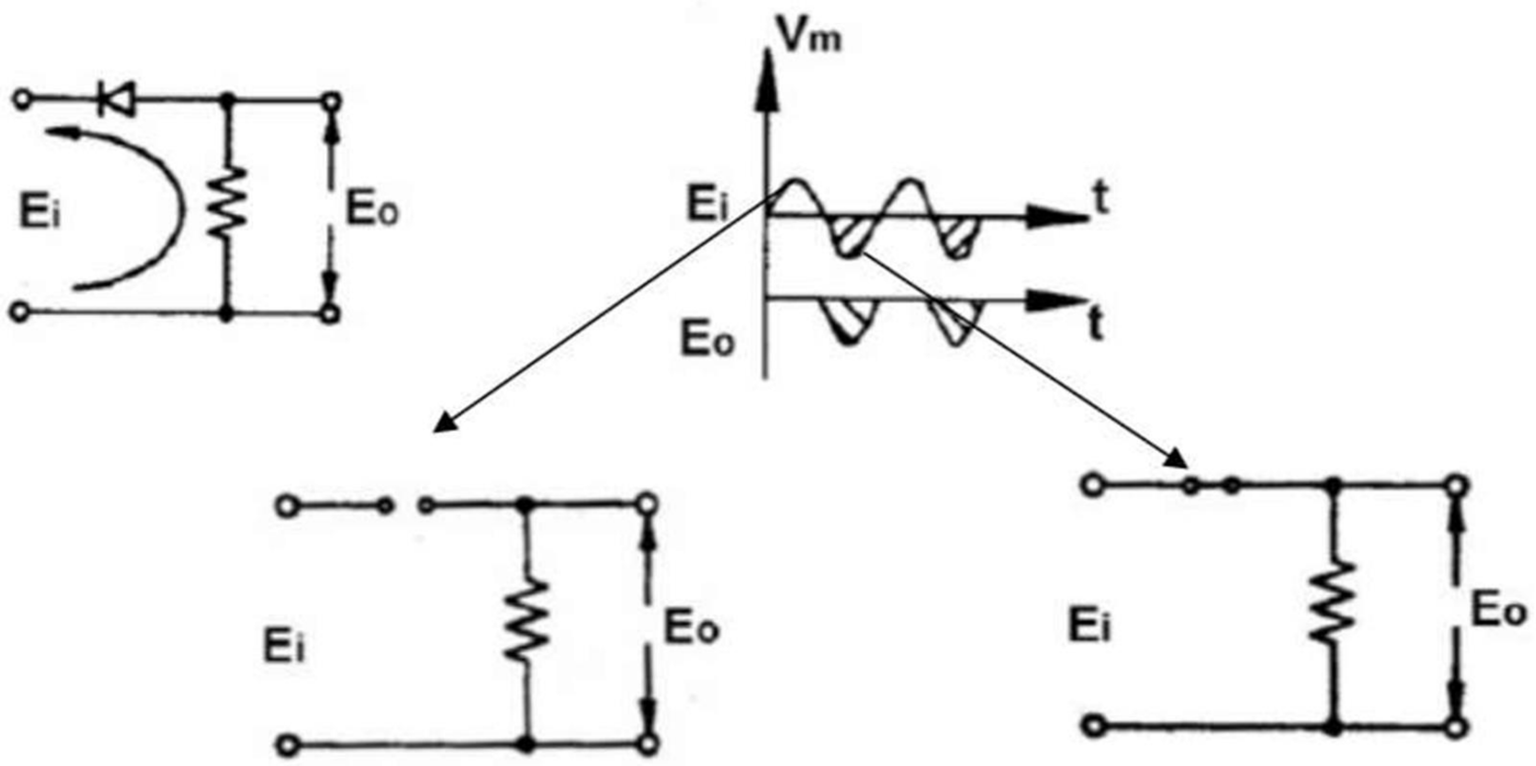
· In these type of circuits, the diode is connected between the input and output voltage terminals.

· As the following figure reveals, the negative cycle of the input voltage can be clipped of by this type of series clippers.



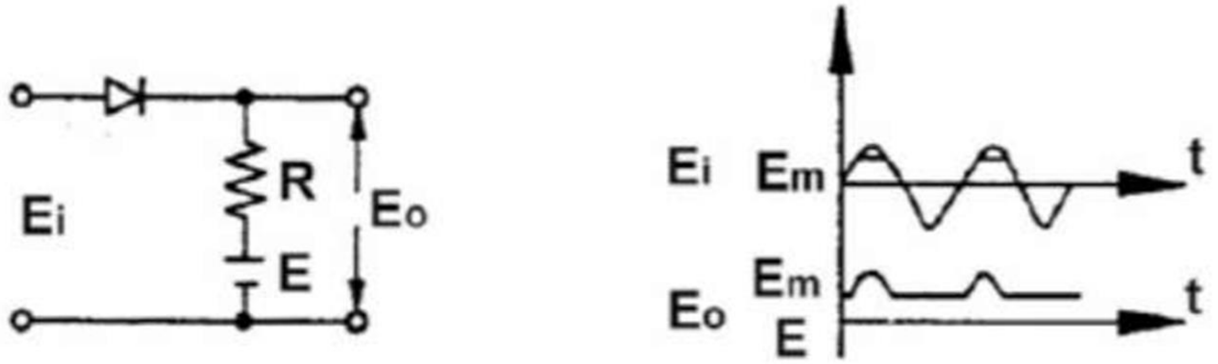
Vm
Ei
t
Eo
t
Ei
Eo
Ei
Eo
Ei
Eo

· Reverse of the diode pins yields to a positive cycle clipping circuit

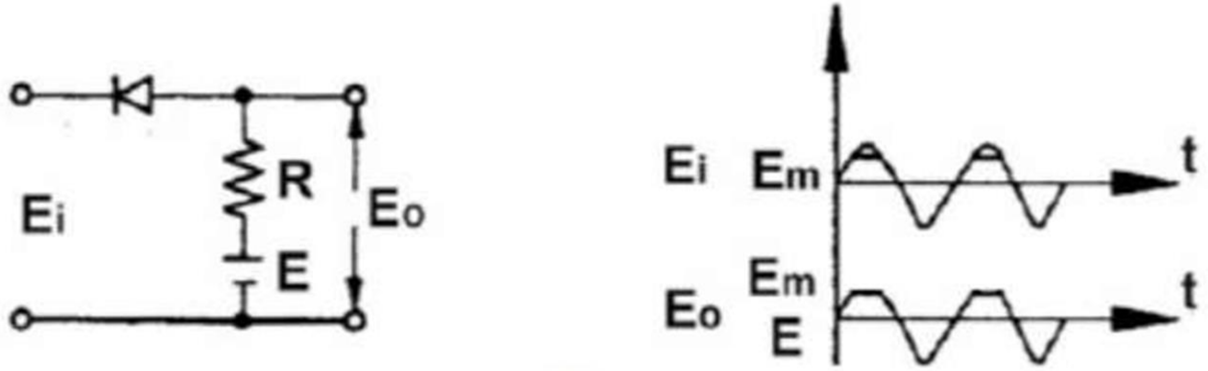


· Previous circuits clip the values larger or smaller than zero voltage. This voltage, technically called “threshold voltage” and can be changed to a desired value by inserting a D.C. voltage source. This is achieved in two different ways.

· In the first type, the voltage source of Em (positive or negative) is connected through output terminals



a



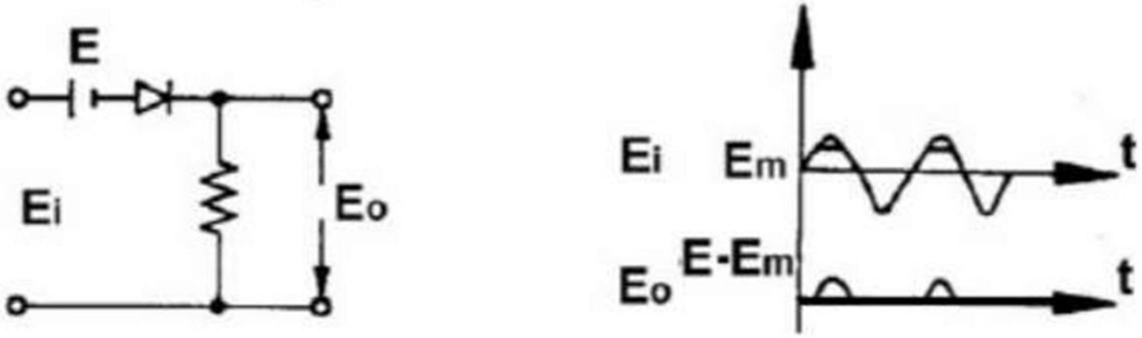
b

· Depending on the diode connection (normal or reverse), the values smaller (Fig a) or greater (Fig b) than Em is clipped and assigned as Em.

· Note that if Em is negative, (where the voltage source is reversely connected) again the values smaller or larger than this negative value is clipped, do not get confused.

· In the second type of thresholded series clipping, the voltage source is applied between the input and output terminals, series with the diode.

· This time, the clipped values are assigned to zero and the net output voltage equals to the difference between the input and threshold values.(If Em is negative, then E0 = E – Em = E + |Em|)



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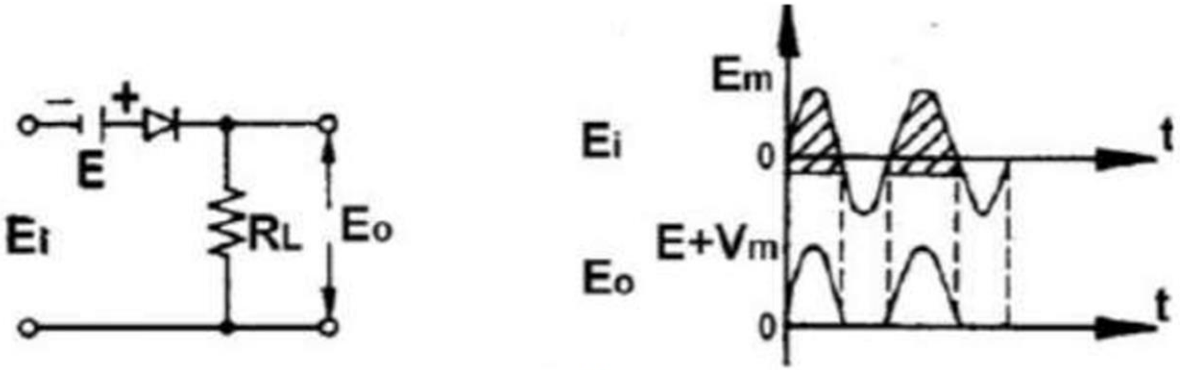


b

· **Parallel Diode Clipping Circuit**

· In this type of clippers, the diode is connected between output terminals. The on/off state of diode directly affects the output voltage.

· These type of clippers may also have a non-zero threshold voltage by addition of a voltage series with diode. Following figures illustrate the clipping process.

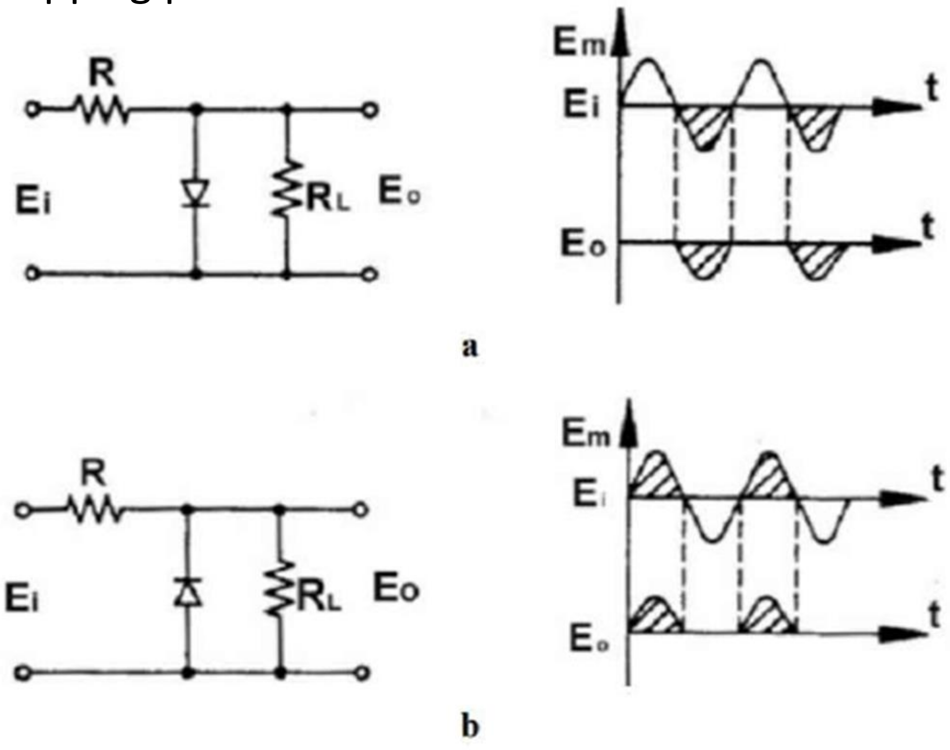
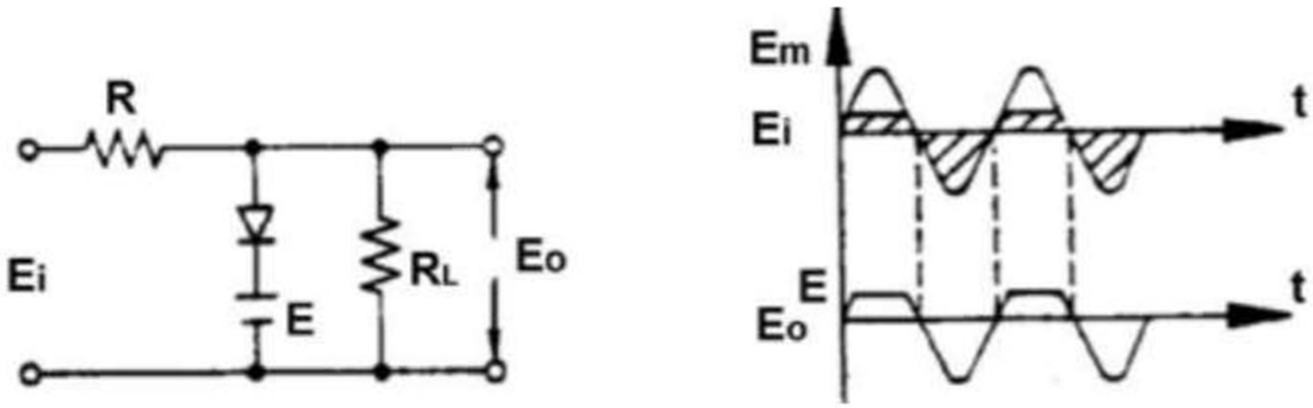
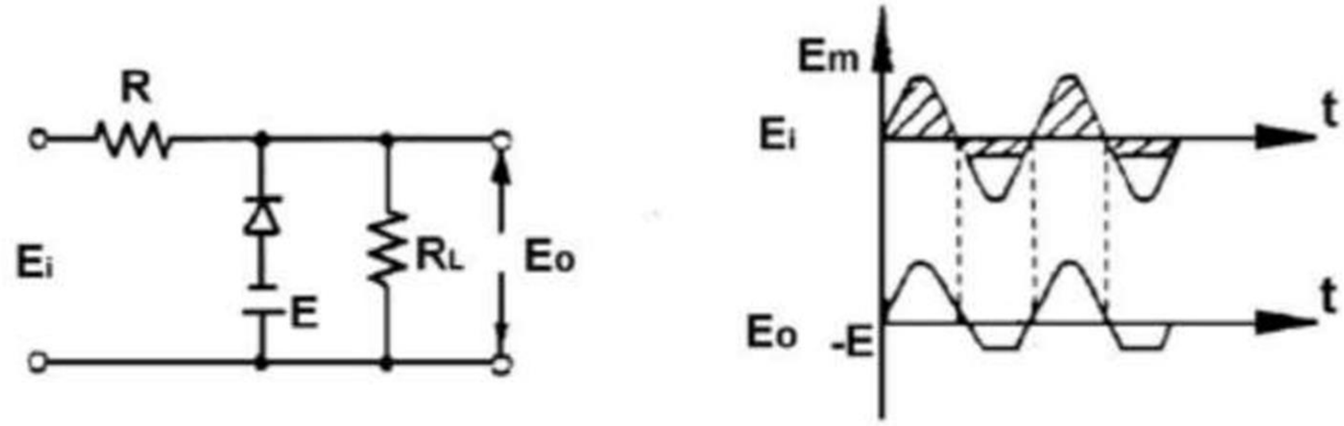


Fig. 2.6 – Zero Threshold Parallel Clippers



a

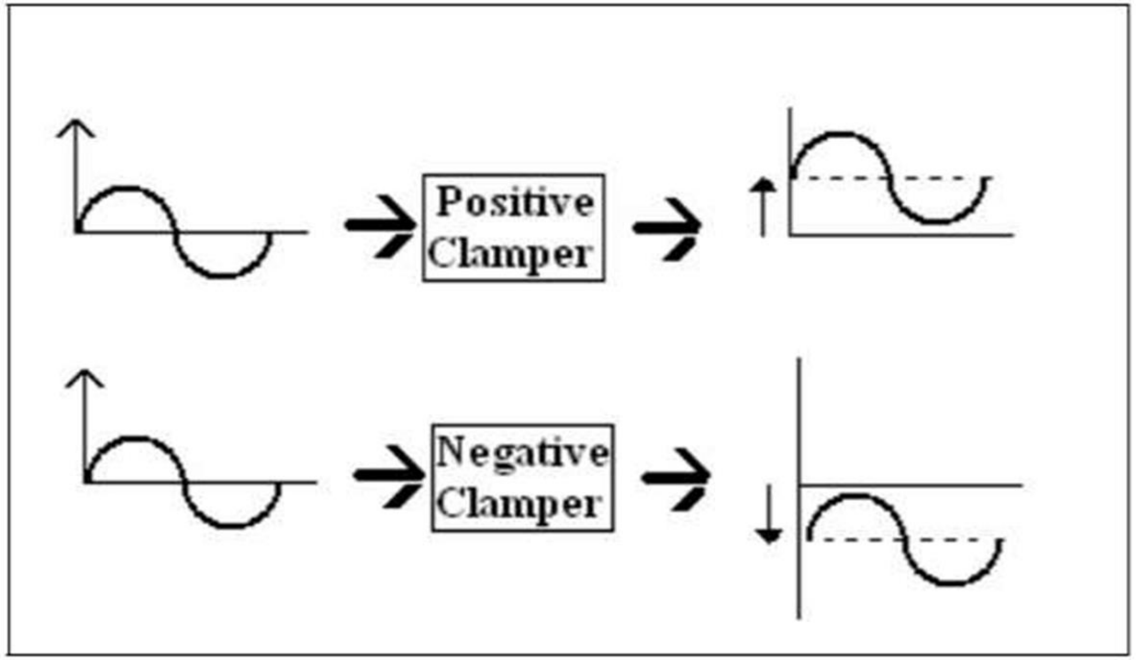


b

Fig. 2.7 – Thresholded Parallel Clippers

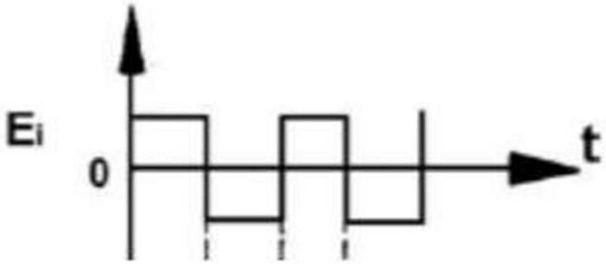
Clamper Circuits

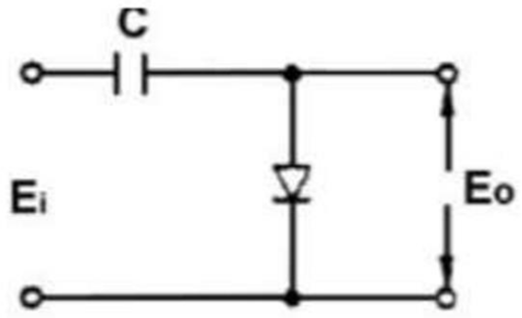
· Clamper Circuits, or briefly clampers are used to change the D.C. level of a signal to a desired value.



· Being different from clippers, clamping circuits uses a capacitor and a diode connection. When diode is in its on state, the output voltage equals to diode drop voltage (ideally zero) plus the voltage source, if any.

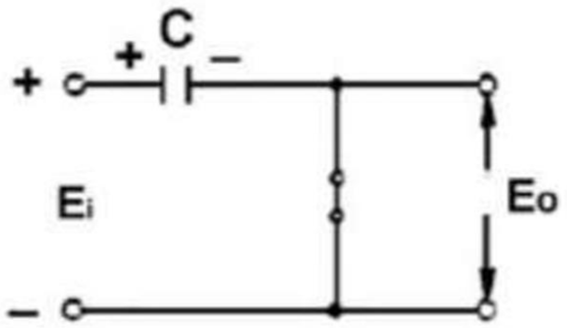
Typical Clamping Circuit





- As you know, this circuit, in fact, is a series R-C circuit.
- The resistance of diode (several ohms above its drop voltage) and the small capacitance yield to a small time-constant for this circuit.
- This means that the capacitor will rapidly be charged if any input voltage, that is enough to swtich on the diode, is applied.
- The diode will conduct during the positive cycle of the input signal and output voltage will be ideally zero (in practice this voltage equals ~0.6 V).

Diode conducts during positive cycle

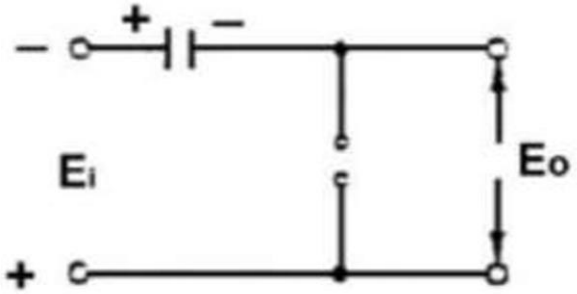


· Note that during positive cycle the capacitor is rapidly charged in inverse polarity with the input voltage. After transition to negative cycle, the diode becomes to its off state.

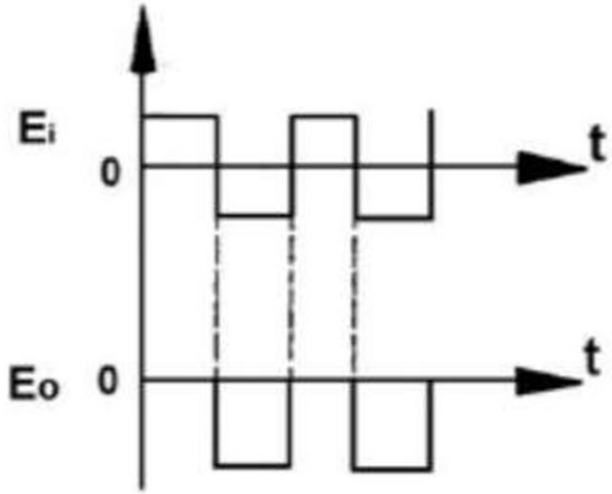
· In this case, the output voltage equals to the sum of the input voltage and the voltage across the terminals of the capacitor which have the same polarity with each other.

· **E0 = - (|Ei |+ |Ec |)**

Diode is switched off during negative cycle



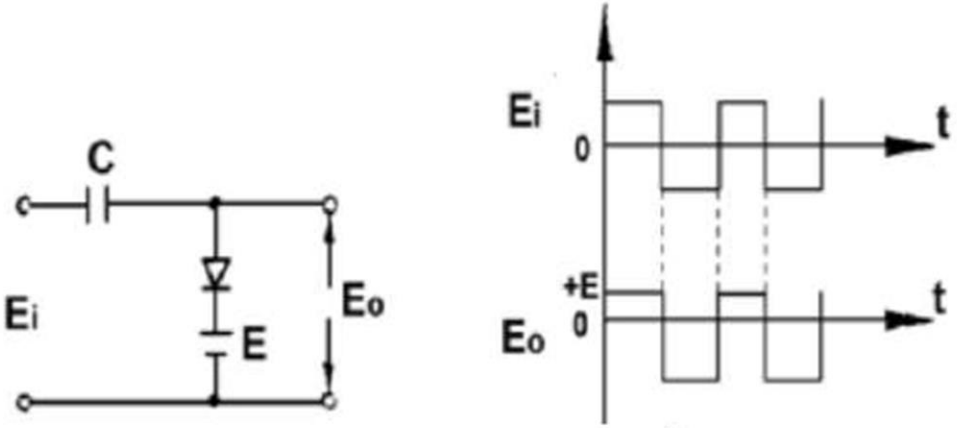
· The resulting signal after a complete cycle is shown below.

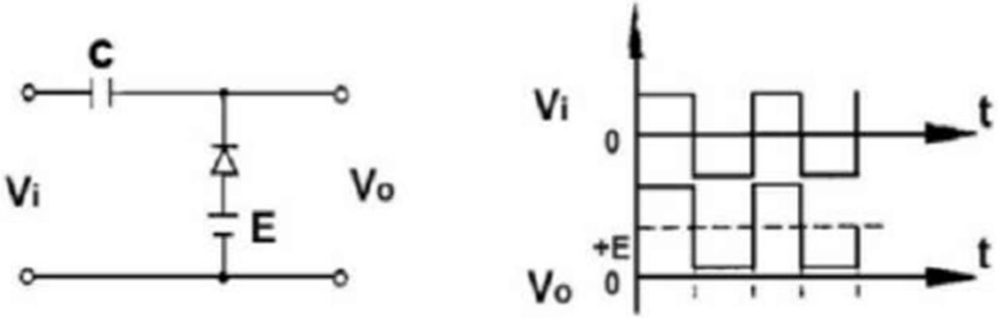


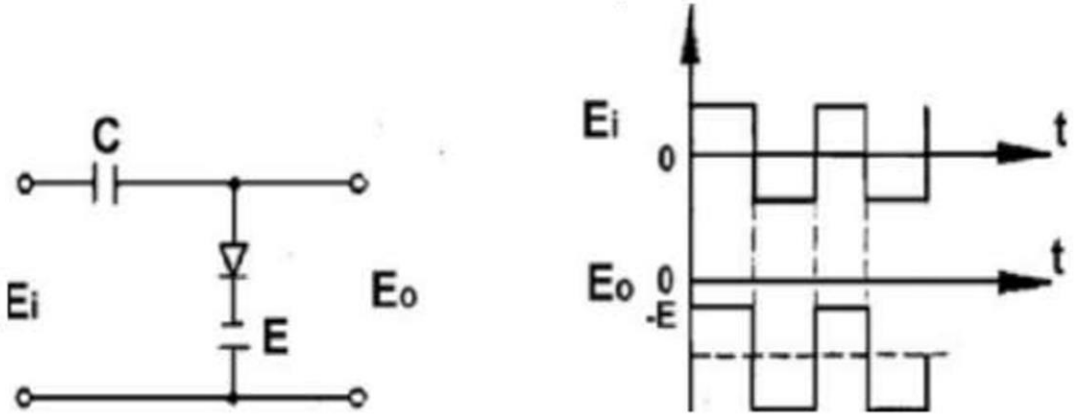
· By this process, the input signal is shifted to negative D.C. value (its maximum value is ideally zero) without any change in its amplitude ideally.

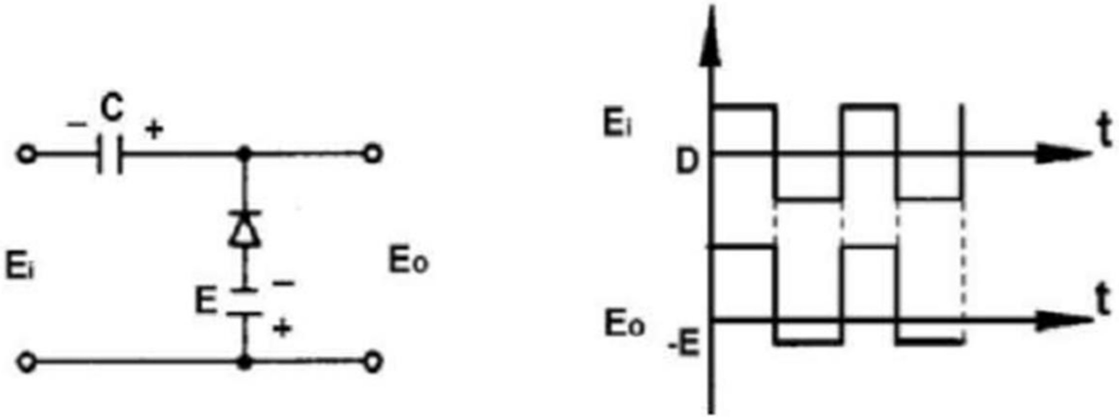
· There exist again modified versions of this circuit inwhich a threshold value is inserted for clamping.

Following figures illustrate these modifications and resulting outputs.









Comparators

· A comparator is a device which is used to sense when an arbitrary varying signal reaches some threshold or reference level.

· Comparators find application in many electronics systems: for example, they may be used to sense when a linear ramp reaches some defined voltage level, or to indicate whether or not a pulse has an amplitude greater than a particular value. Provided that suitable output limiting is provided, comparator outputs may be used to drive logic circuits.

· Diode Comparator

· The non-linear circuits to perform the operation of clipping may also be used to perform the operation of comparison.

· The basic difference between the two is that in comparator there is no interest in reproducing any part of the signal waveform.

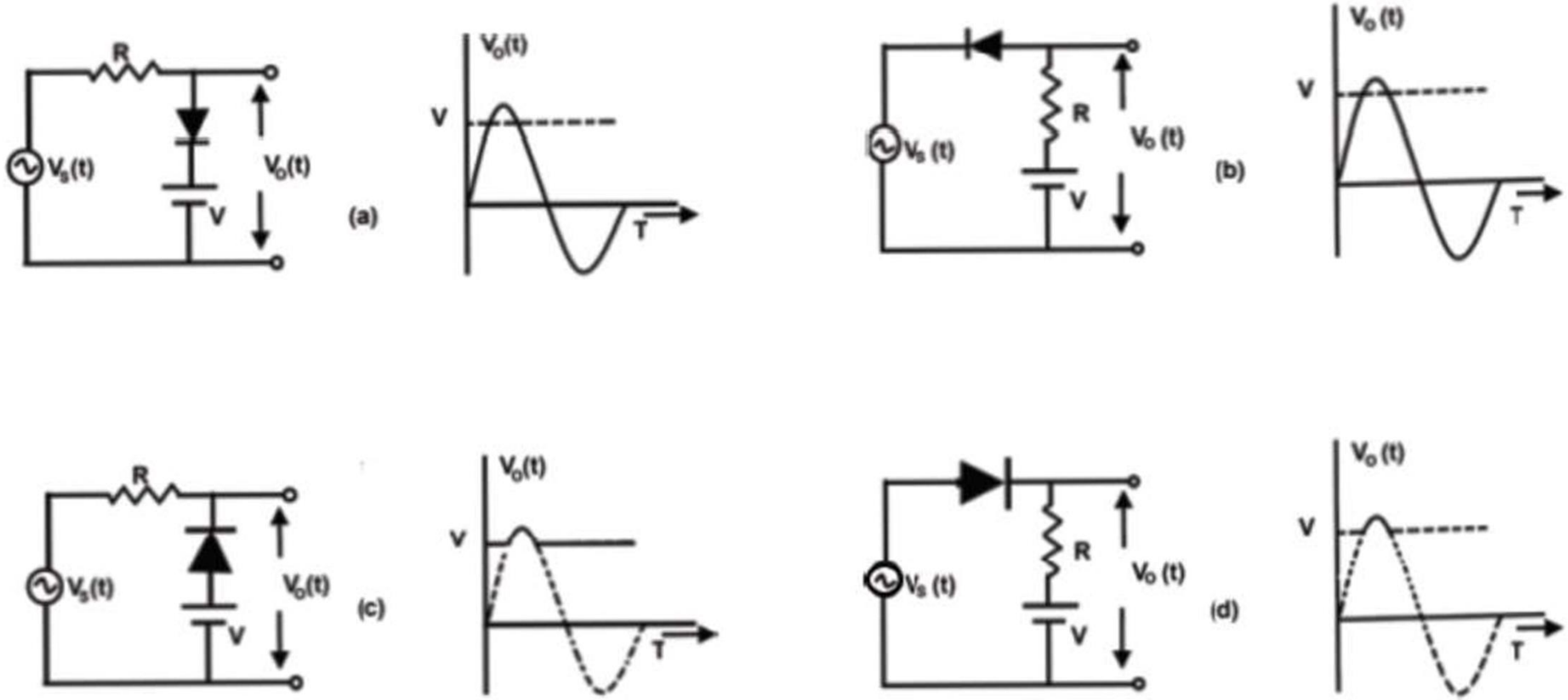
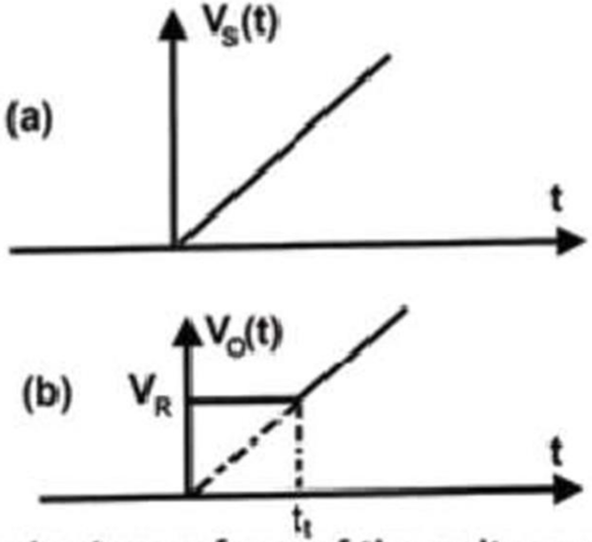
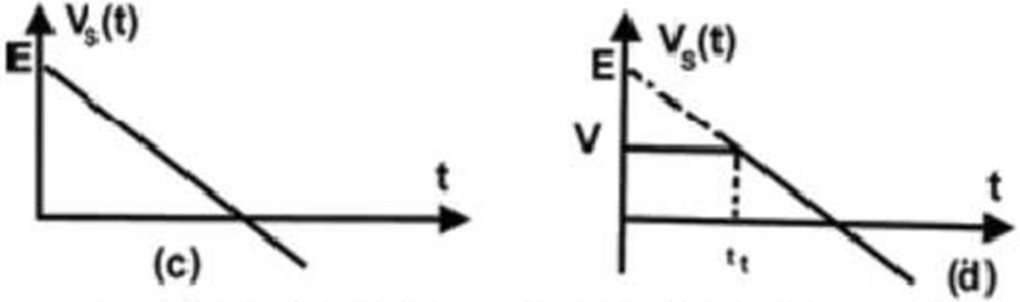


Figure 1: Comparators

- If we assume that ramp signal is applied to the input, as shown in Figure 1(a) the output Figure 1(b) is constant VR volts until the ramp signal reduces a value equal to VR volts until the ramp signal reduces a value equal to VR volts then the diode conducts and the input signal appears at the output.
- In a circuit a clipper was important that the portion of the wave form passed by the diode was not distorted.
- The exact time t1 at which the diode began conducting was of secondary importance.
- Now this circuit will be considered as a voltage comparator, (since it compares the varying signal voltage with the reference voltage and hence the name voltage comparator) and of primary concern is the time at which the input signal voltage reaches the reference level VR.
- The shape of the output waveform is of secondary importance. A diode used for this purpose called pick-off diode.
- Similarly with an increasing ramp at its input the circuit of Figure 1(c) will be continue to operate as a comparator. Its response will be same as shown in Figure 2(b).
- The diode of this circuit is then referred to as a breakaway diode.
- The other two circuits shown in Figure 1 (a) and (b) will act as comparators with a decreasing ramp. Their response is shown in Figure 2 (c) and (d).



The output waveform of the voltage comparator
shown in Figure 1 (c) and (d)



The output waveform of the voltage comparator
shown in Figure 1 (a) and (b)

Figure 2

MULTIVIBRATOR

· A MULTIVIBRATOR is an electronic circuit that switches rapidly by means of positive feedback between two or more states.

· Its basically a two amplifier circuit.

· A multivibrator generates square, pulse, triangular waveforms.

· Also called as nonlinear oscillators or function generators.

· **Classification:**

· Astable Multivibrator

· Monostable multivibrator

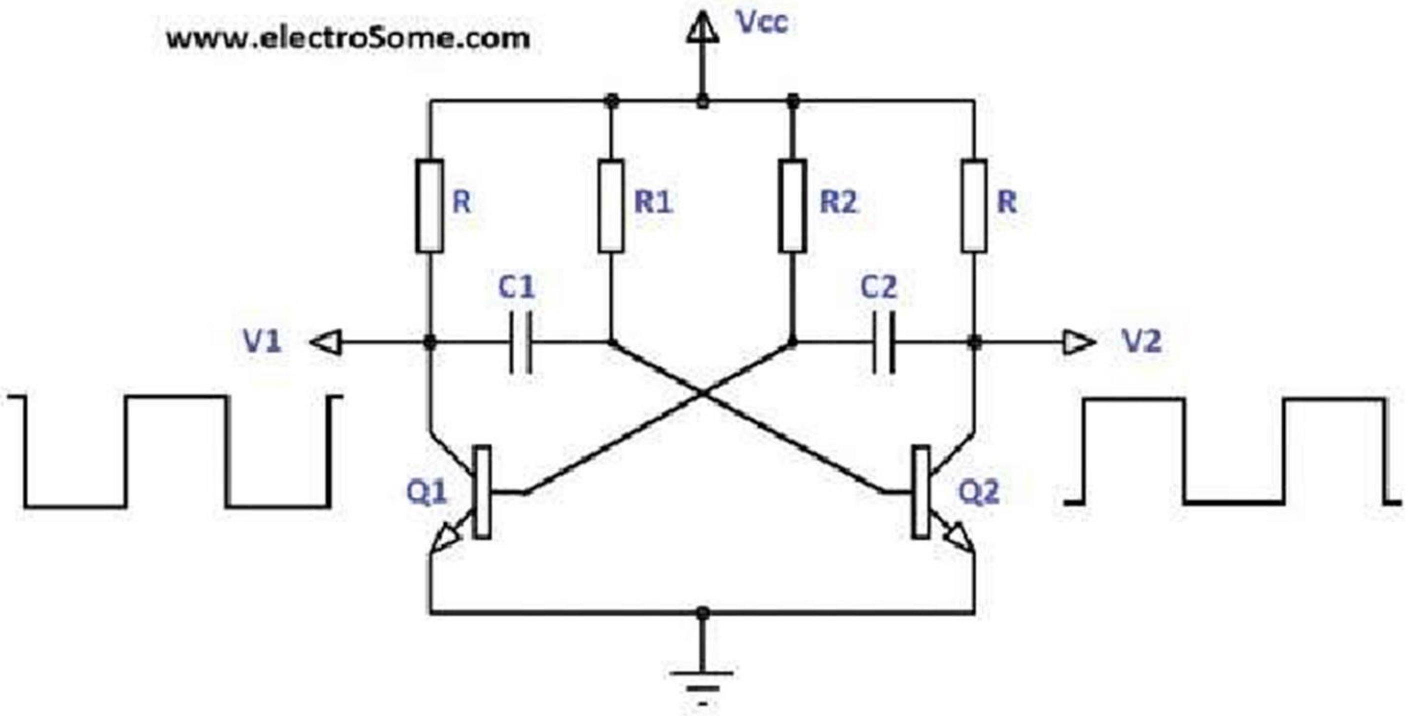
· Bistable multivibrators

Astable Multivibrator

· An Astable Multivibrator or a Free Running Multivibrator is the multivibrator which has no stable states.

· Its output oscillates continuously between its two unstable states without the aid of external triggering.

· The time period of each states are determined by Resistor Capacitor (RC) time constant.



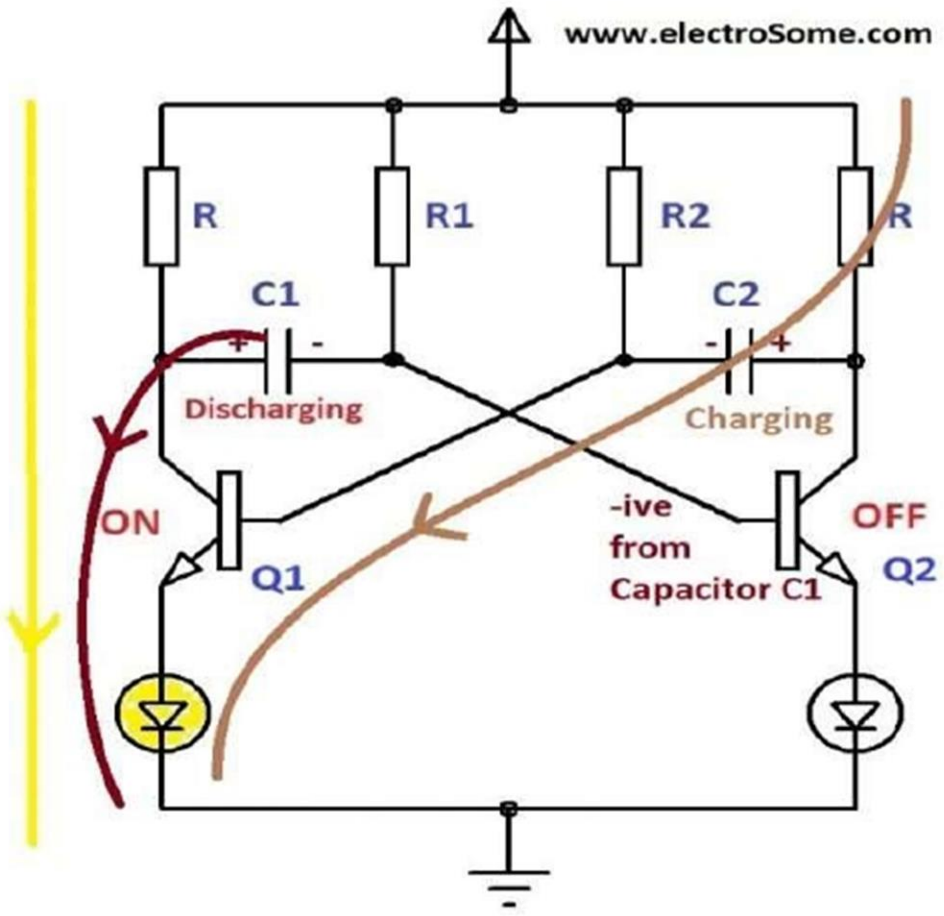
· In the above diagram we can find two transistors which is wired as a switch.

· **Working**

· When the circuit is switched on one transistor will driven to saturation (ON) and other will driven to cutoff (OFF). Consider Q1 is ON and Q2 is OFF.

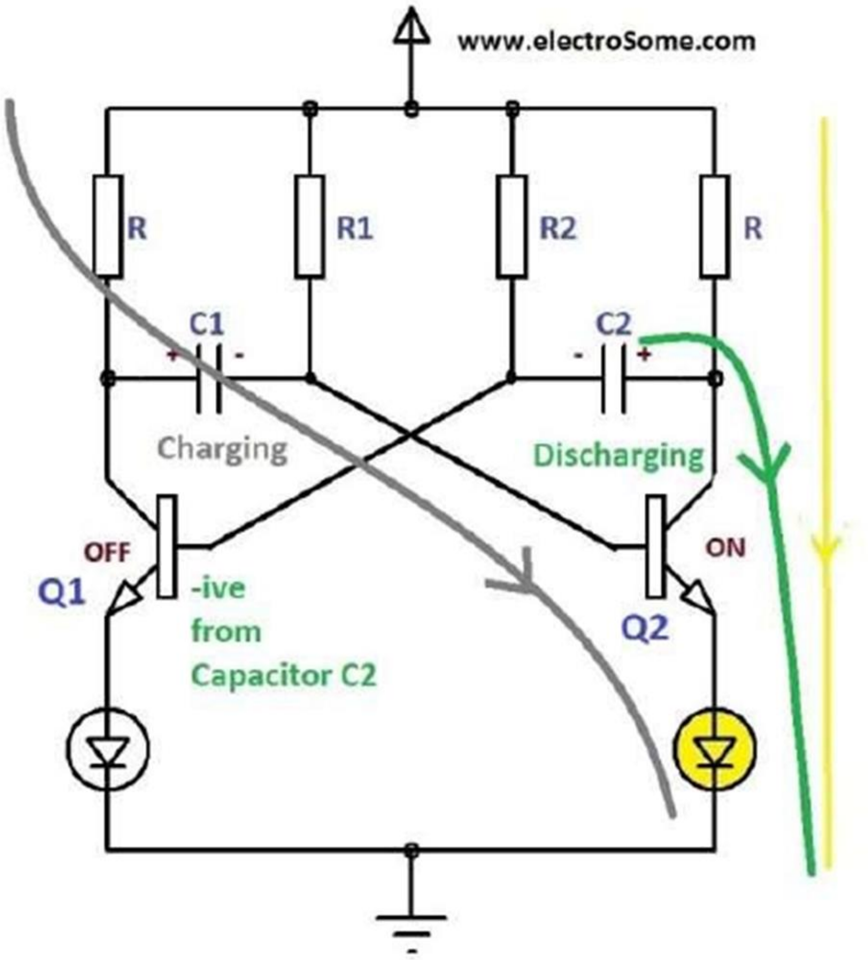
· During this time Capacitor C2 is charging to Vcc through resistor R.

· Q2 is OFF due to the -ive voltage from the discharging capacitor C1 which is charged during the previous cycle. So the OFF time of Q2 is determined by R1C1 time constant.



· After a time period determined by R1C1 time constant the capacitor C1 discharges completely and starts charging in reverse direction through R1.

· When the Capacitor C1 charges to a voltage sufficient provide base emitter voltage of 0.7V to the transistor Q2, it turns ON and capacitor C2 starts discharging.



· The negative voltage from the capacitor C2 turns off the transistor Q1 and the capacitor C1 starts charging from Vcc through resistor R and base emitter of transistor Q2. Thus the transistor Q2 remains in ON state.

· As in the previous state, when the capacitor C2 discharges completely it starts charging towards opposite direction through R2.

· When the voltage across the capacitor C2 is sufficient to turn ON transistor Q1, Q1 will turn ON and capacitor C1 starts discharging.

· This process continuous and produces rectangular waves at the collector of each transistors.

· Note : Charging time is very less compared to discharging time.

· Design

· R – Collector Resistor

· The resistance R should be designed to limit the collector current Ic with in a safe limit.

· **R = V/Ic** , where V is the voltage across the resistor R.

· In normal cases, **V = (Vcc – Vce) = (Vce – 0.3)** but when an emitter load like LED is connected,

· V = (Vcc – Vce – Vled) , where Vled is the voltage drop across LED.

· Usually the maximum collector current Ic will be much higher than than the current required for emitter load such as LED. In these cases Ic should be chosen in such a way that it should not exceed the max current limit of emitter load.

· So, **R = (Vcc – Vce – Vload) / Ic**

· **R1 & R2 – Base Resistors**

· R1 & R2 should be chosen such that it should give the required collector current during saturation state.

· Min. Base Current, Ib_{min} = Ic / β, where β is the hFE of the transistor

· Safe Base Current,Ib = 10x Ib_{min}= 3 x Ic / β

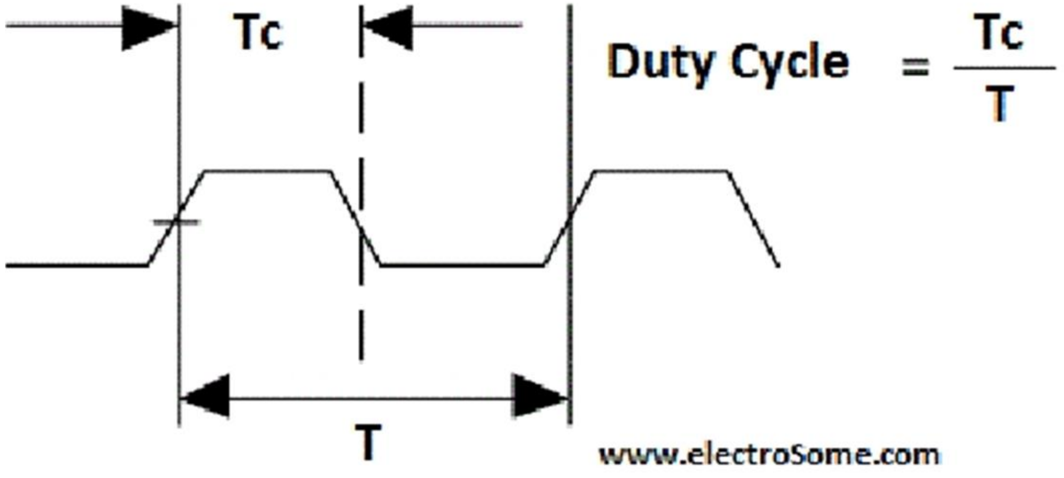
· **R1, R2 = (Vcc – Vbe) / Ib**

· T1 & T2 – Time Period

· T2 = OFF Period of transistor Q1 = ON Period of Transistor Q2 = **0.693R2C2**

· T1 = OFF Period of transistor Q2 = ON Period of Transistor Q1 = **0.693R1C1**

· From these equations we can find the value of C1 and C2.

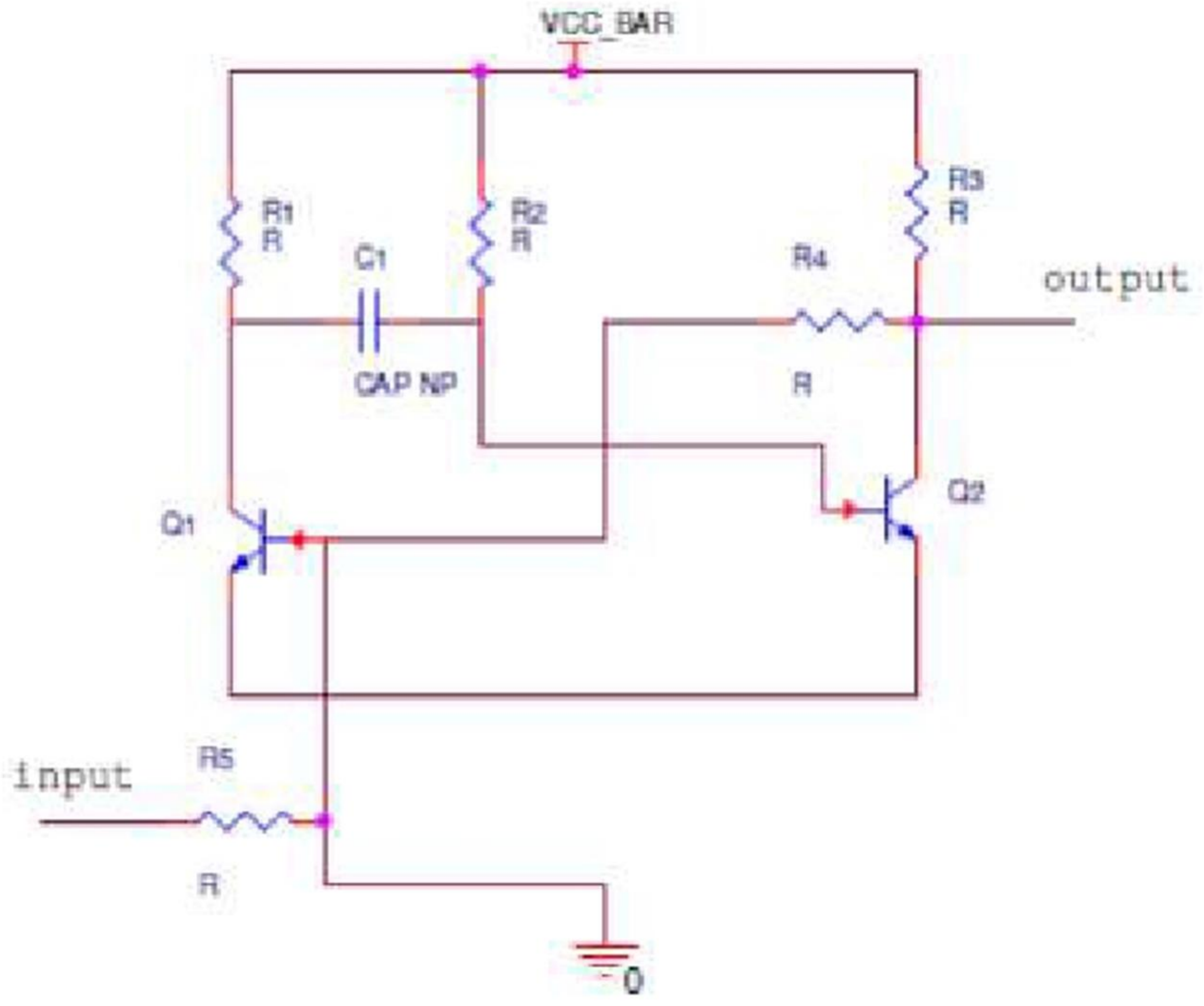


· It is the ratio of time Tc during which the output is high to total time period T of the cycle.

· Thus here, **Duty Cycle = Toff/(Toff + Ton)** when the output is taken from the collector of the transistor T.

Monostable Multivibrator

- Monostable is also called one shot multivibrator.
- Monostable multivibrator has one stable state and one quasi stable state (astable state).
- In the multivibrator the output of first stage is given to the second stage and the second stage output is again feed back to the first stage by this the cutoff state will become saturate and saturate state will become to cutoff.
- Because of the transition of states the multivibrator can be used as oscillators, timers and flip-flops.
- When an external trigger applied to the circuit, the multivibrator will jump to quasi stable state from stable state.
- After the period of time it will automatically set back to the stable state, for returning to the stable state multivibrator does not require any external trigger.
- The time period to returning to stable state circuit is always depends on the passive elements in the circuit (resistor and capacitor values)



Monostable Multivibrator Circuit Diagram

· **Circuit Operation:**

· When there is no external trigger to the circuit the one transistor will be in saturation state and other will be in cutoff state. Q1 is in cutoff mode and put at negative potential until the external trigger to operate, Q2 is in saturation mode.

· Once the external trigger is given to the input Q1 will get turn on and when the Q1 reaches the saturation the capacitor which is connected to the collector of Q1 and base of Q2 will make transistor Q2 to turn off. This is state of turn off Q2 transistor is called astable stable or quasi state.

· When capacitor charges to VCC the Q2 will turn on again and automatically Q1 is turn off. So the time period for charging of capacitor through the resistor is directly proportional to the quasi or astable state of multivibrator when a external trigger occurred (t=0.69RC).

· **Uses of Monostable Multivibrator:**

· The monostable multivibrators are used as timers, delay circuits, gated circuits etc.

Bistable Multivibrator

· The bistable multivibrator has two absolutely stable states. It will remain in whichever state it happens to be until a trigger pulse causes it to switch to the other state.

· For instance, suppose at any particular instant, transistor Q1 is conducting and transistor Q2 is at cut-off.

· If left to itself, the bistable multivibrator will stay in this position for ever.

· However, if an external pulse is applied to the circuit in such a way that Q1 is cut-off and Q2 is turned on, the circuit will stay in the new position. Another trigger pulse is then required to switch the circuit back to its original state.

· In other words a multivibrator which has both the state stable is called a bistable multivibrator. It is also called flip-flop, trigger circuit or binary.

· The output pulse is obtained when, and why a driving (triggering) pulse is applied to the input. A full cycle of output is produced for every two triggering pulses of correct polarity and amplitude.

· Here the output of a transistor Q2 is coupled put of a transistor Q1 through a resistor R2.

· Similarly, the output of a transistor Q1 is coupled to the base of transistor Q2 through a resistor R1.

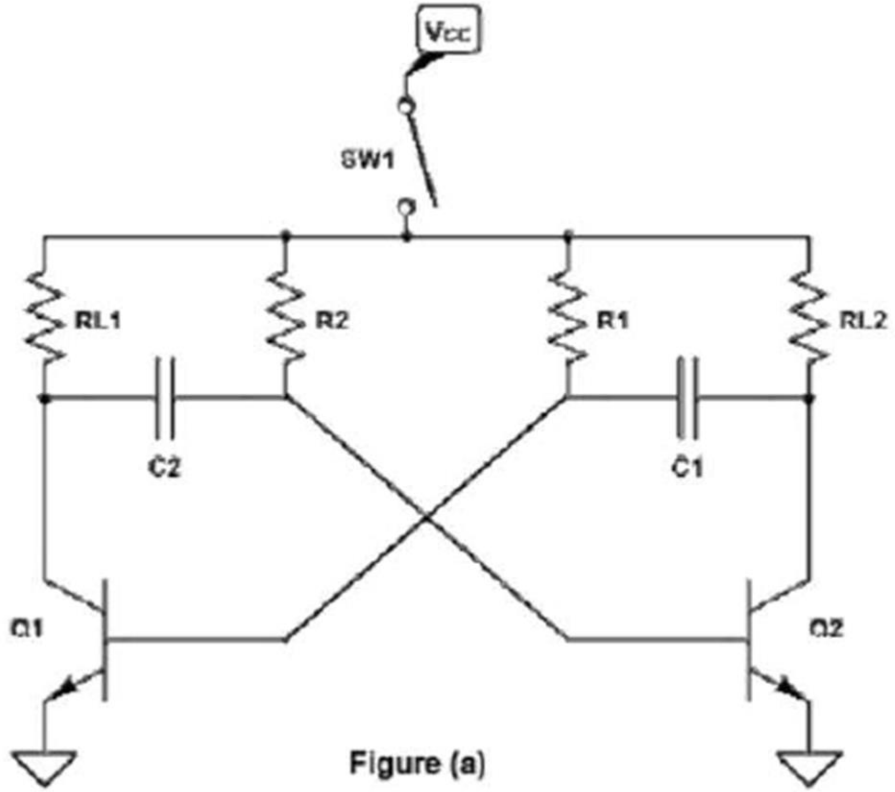


Figure (a)

Bistable Astable Multivibrator

· The capacitors C2 and C1 are known as speed up capacitors.

· Their function is to increase the speed of the circuit in making abrupt transition from one stable state to another stable state.

· The base resistors (R3 and R4) of both the transistors are connected to a common source (-VBB).

· The output of a bistable multivibrator is available at the collector terminal of the both the transistor Q1 and Q2.

· However, the two outputs are the complements of each other.

· Let us suppose, if Q1 is conducting, then the fact that point A is at nearly ON makes the base of Q2 negative (by the potential divider R2 - R4) and holds Q2 off.

· Similarly with Q 2 OFF, the potential divider from VCC to -VBB (RL2 , R 1 , R3) is designed to keep base of Q1 at about 0.7V ensuring that Q1 conducts. It is seen that Q1 holds Q2 OFF and Q 2 hold Q1 ON.

· Suppose, now a positive pulse is applied momentarily to R. It will cause Q2 to conduct. As collector of Q 2 falls to zero, it cuts Q1 OFF and consequently, the BMV switches over to its other state.

· Similarly, a positive trigger pulse applied to S will switch the BMV back to its original state.

· **Uses:**

· 1. In timing circuits as frequency divider

· 2. In counting circuits

· 3. In computer memory circuits

Bistable Multivibrator Triggering

· To change the stable state of the binary it is necessary to apply an appropriate pulse in the circuit, which will try to bring both the transistors to active region and the resulting regenerative feedback will result on the change of state.

· Triggering may be of two following types:

I. Asymmetrical triggering

II. Symmetrical triggering

(I) Asymmetrical triggering

· In asymmetrical triggering, there are two trigger inputs for the transistors Q1 and Q2.

· Each trigger input is derived from a separate triggering source.

· To induce transition among the stable states, let us say that initially the trigger is applied to the bistable.

· For the next transition, now the identical trigger must appear at the transistor Q2.

· Thus it can be said that the asymmetrical triggering the trigger pulses derived from two separate source and connected to the two transistors Q1 and Q2 individually, sequentially change the state of the bistable.

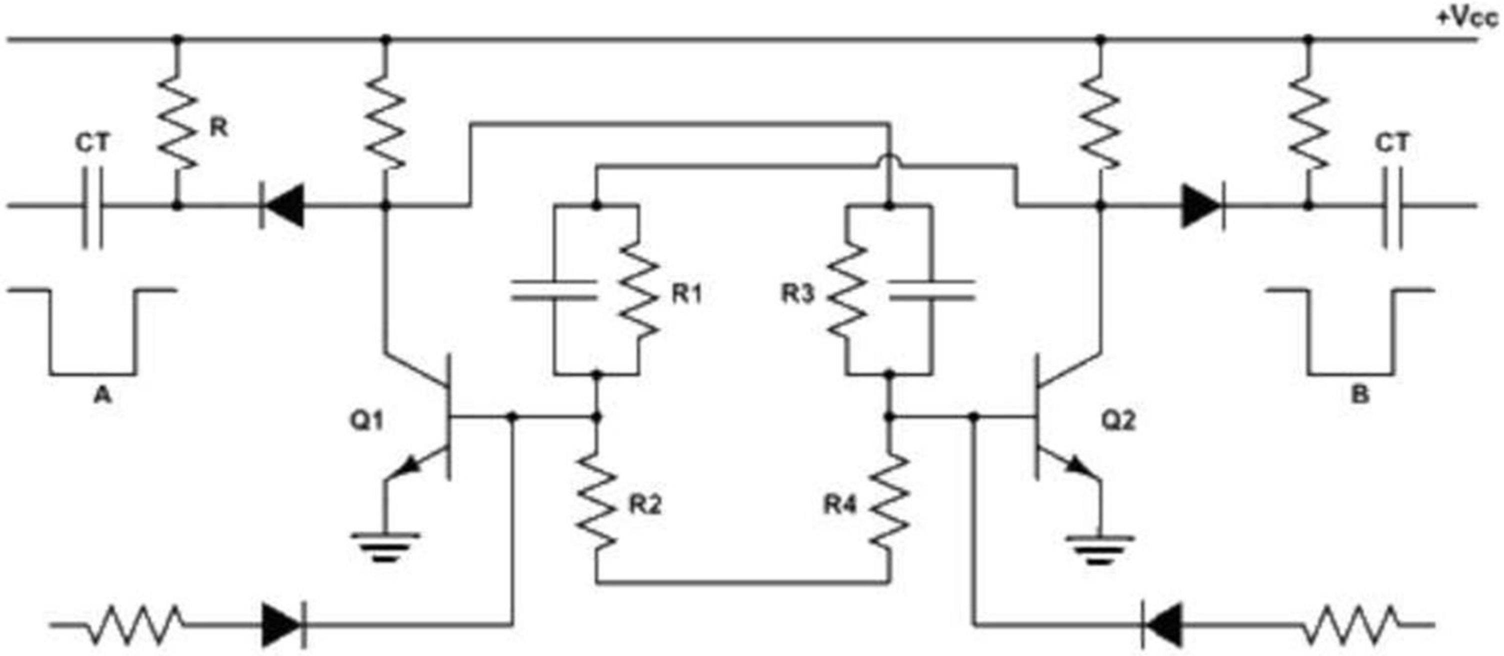


Figure: (b) Asymmetrical triggered bistable multivibrator

Bistable Astable Multivibrator

· Initially Q1 is OFF and transistor Q2 is ON.

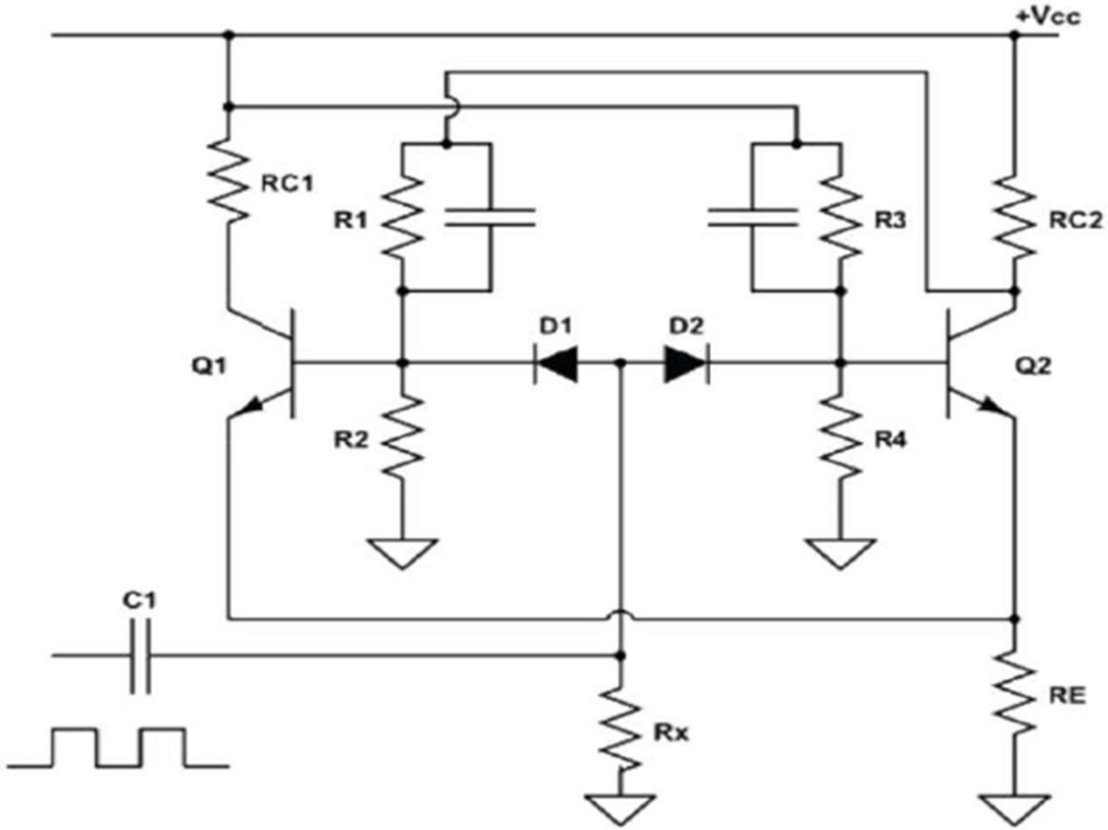
· The first pulse derived from the trigger source A, applied to the terminal turn it OFF by bringing it from saturation region to active transistor Q1 is ON and transistor Q2 is OFF.

· Any further pulse next time then the trigger pulse is applied at the terminal B, the change of stable state will result with transistor Q 2 On and transistor Q1 OFF.

(II) Symmetrical Triggering

· There are various symmetrical triggering methods called symmetrical collector triggering, symmetrical base triggering and symmetrical hybrid triggering.

· Here we would liked to explain only symmetrical base triggering (positive pulse) only as given under symmetrical Base Triggering



Bistable Astable Multivibrator

· Diodes D1 and D2 are steering diodes. Here the positive pulses, try to turn ON and OFF transistor.

· Thus when transistor Q1 is OFF and transistor Q2 is ON, the respective base voltages and V B1N, OFF and V B2N, ON. It will be seen that V B1N, OFF > V B1N, ON. Thus diode D 2 is more reverse-biased compared to diode D1.

· When the positive differentiated pulse of amplitude greater than (V B1N, OFF + Vɣ) appears, the diode D 1 gets forward biased, and transistor Q1 enters the active region and with subsequent regenerative feedback Q1 gets ON, and transistor Q2 becomes OFF.

· On the arrival of the next trigger pulse now the diode D2 will be forward biased and ultimately with regenerative feedback it will be in the ON state.

Schmitt trigger circuit.

· A Schmitt trigger is a comparator circuit with hysteresis, implemented by applying positive feedback to the noninverting input of a comparator or differential amplifier.

· It is an active circuit which converts an analog input signal to a digital output signal.

· The circuit is named a "trigger" because the output retains its value until the input changes sufficiently to trigger a change.

· Schmitt trigger devices are typically used in signal conditioning applications to remove noise from signals used in digital circuits, particularly mechanical switch bounce.

· They are also used in closed loop negative feedback configurations to implement relaxation oscillators, used in function generators and switching power supplies.

· **Classic emitter-coupled circuit**

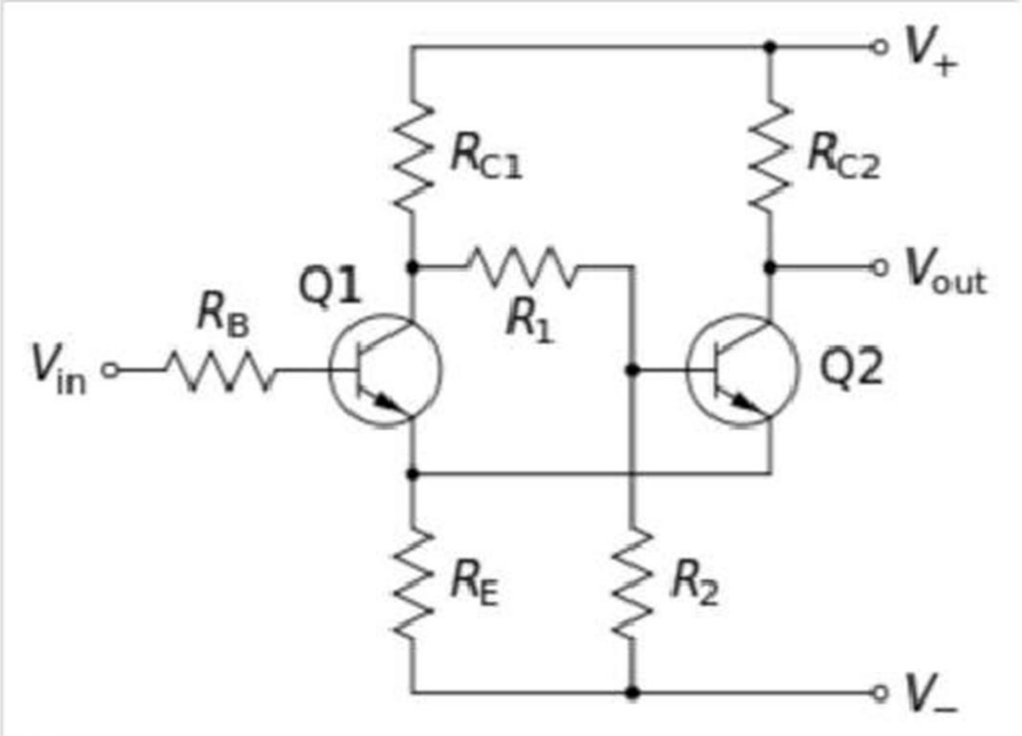
· The original Schmitt trigger is based on the dynamic threshold idea that is implemented by a voltage divider with a switchable upper leg (the collector resistors RC1 and RC2) and a steady lower leg (RE).

· Q1 acts as a comparator with a differential input (Q1 base-emitter junction) consisting of an inverting (Q1 base) and a non-inverting (Q1 emitter) inputs.

· The input voltage is applied to the inverting input; the output voltage of the voltage divider is applied to the non-inverting input thus determining its threshold.

· The comparator output drives the second common collector stage Q2 (an emitter follower) through the voltage follower R1-R2.

· The emitter-coupled transistors Q1 and Q2 actually compose an electronic double throw switch that switches over the upper legs of the voltage divider and changes the threshold in a different (to the input voltage) direction



Schmitt trigger implemented by two emitter-coupled transistor stages

· **Initial state.**

· For NPN transistors as shown, imagine the input voltage is below the shared emitter voltage (high threshold for concreteness) so that Q1 base-emitter junction is backward-biased and Q1 does not conduct.

· Q2 base voltage is determined by the mentioned divider so that Q2 is conducting and the trigger output is in the low state.

· The two resistors RC2 and RE form another voltage divider that determines the high threshold.

· Neglecting VBE, the high threshold value is approximately

$$V_{\mathrm{HT}} = \frac{R_{\mathrm{E}}}{R_{\mathrm{E}} + R_{\mathrm{C2}}} V_{+}.$$

· **Crossing up the high threshold:**

· When the input voltage (Q1 base voltage) rises slightly above the voltage across the emitter resistor RE (the high threshold), Q1 begins conducting.

· Its collector voltage goes down and Q2 begins going cut-off, because the voltage divider now provides lower Q2 base voltage

· The common emitter voltage follows this change and goes down thus making Q1 conduct more.

· The current begins steering from the right leg of the circuit to the left one. Although Q1 is more conducting, it passes less current through RE (since RC1 > RC2); the emitter voltage continues dropping and the effective Q1 base-emitter voltage continuously increases.

· This avalanche-like process continues until Q1 becomes completely turned on (saturated) and Q2 turned off.

· The trigger is transitioned to the high state and the output (Q2 collector) voltage is close to V+.

· Now, the two resistors RC1 and RE form a voltage divider that determines the low threshold. Its value is approximately

$$V_{\mathrm{LT}} = \frac{R_{\mathrm{E}}}{R_{\mathrm{E}} + R_{\mathrm{C1}}} V_{+}.$$

· **Crossing down the low threshold.**

· With the trigger now in the high state, if the input voltage lowers enough (below the low threshold), Q1 begins cutting-off.

· Its collector current reduces; as a result, the shared emitter voltage lowers slightly and Q1 collector voltage rises significantly. R1-R2 voltage divider conveys this change to Q2 base voltage and it begins conducting.

· The voltage across RE rises, further reducing the Q1 base-emitter potential in the same avalanche-like manner, and Q1 ceases to conduct. Q2 becomes completely turned-on (saturated) and the output voltage becomes low again.

· **Applications**

· Schmitt triggers are typically used in open loop configurations for noise immunity and closed loop configurations to implement function generators.

· **Noise immunity**

· One application of a Schmitt trigger is to increase the noise immunity in a circuit with only a single input threshold.

· With only one input threshold, a noisy input signal [nb 4] near that threshold could cause the output to switch rapidly back and forth from noise alone.

· A noisy Schmitt Trigger input signal near one threshold can cause only one switch in output value, after which it would have to move beyond the other threshold in order to cause another switch.

· **Use as an oscillator**

· A Schmitt trigger is a bistable multivibrator, and it can be used to implement another type of multivibrator, the relaxation oscillator.