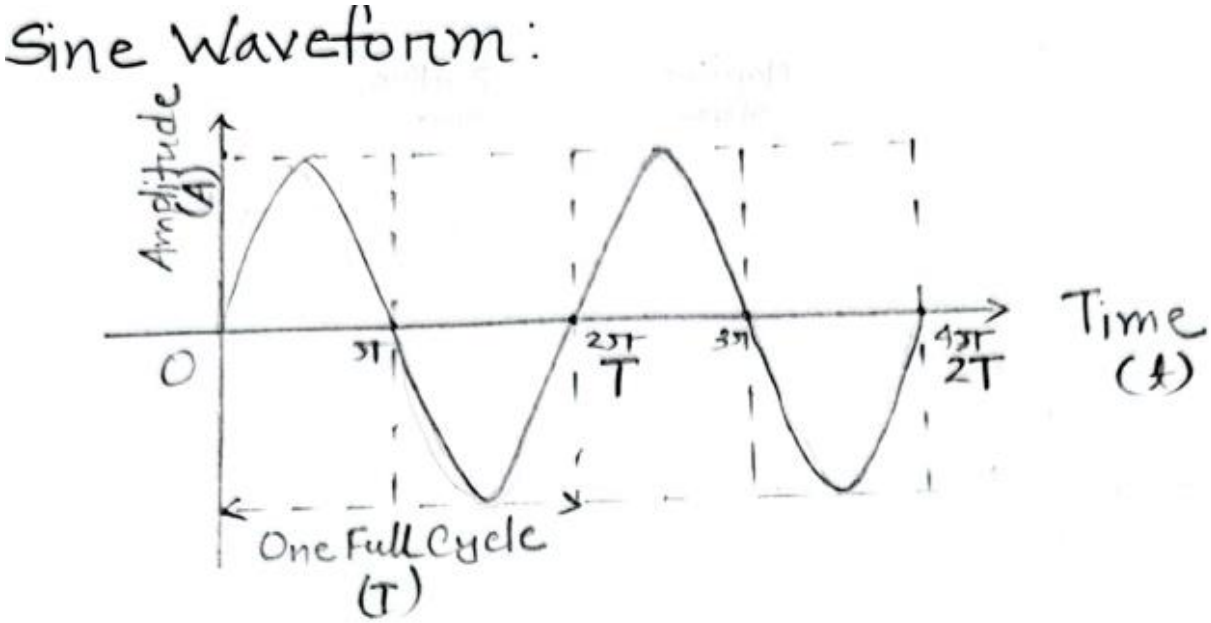
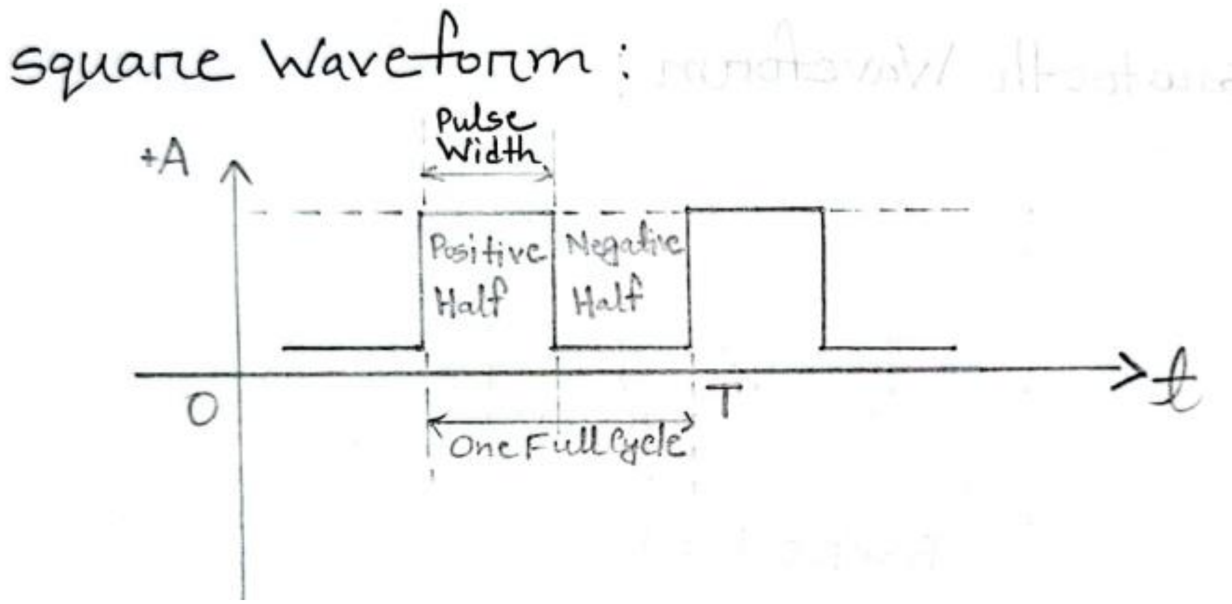
Different Types of waves:

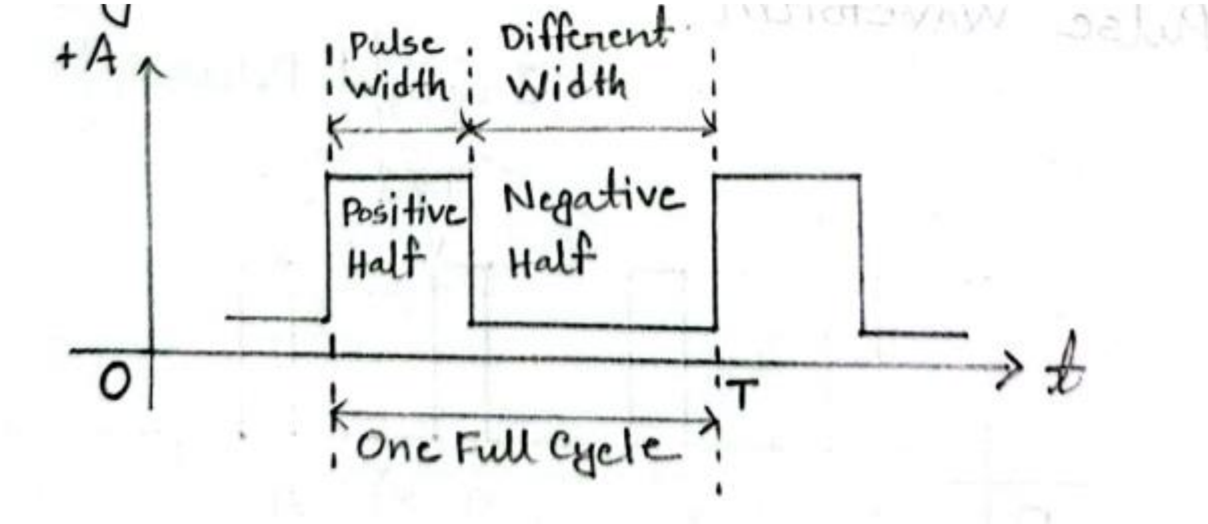
Sin waveform:



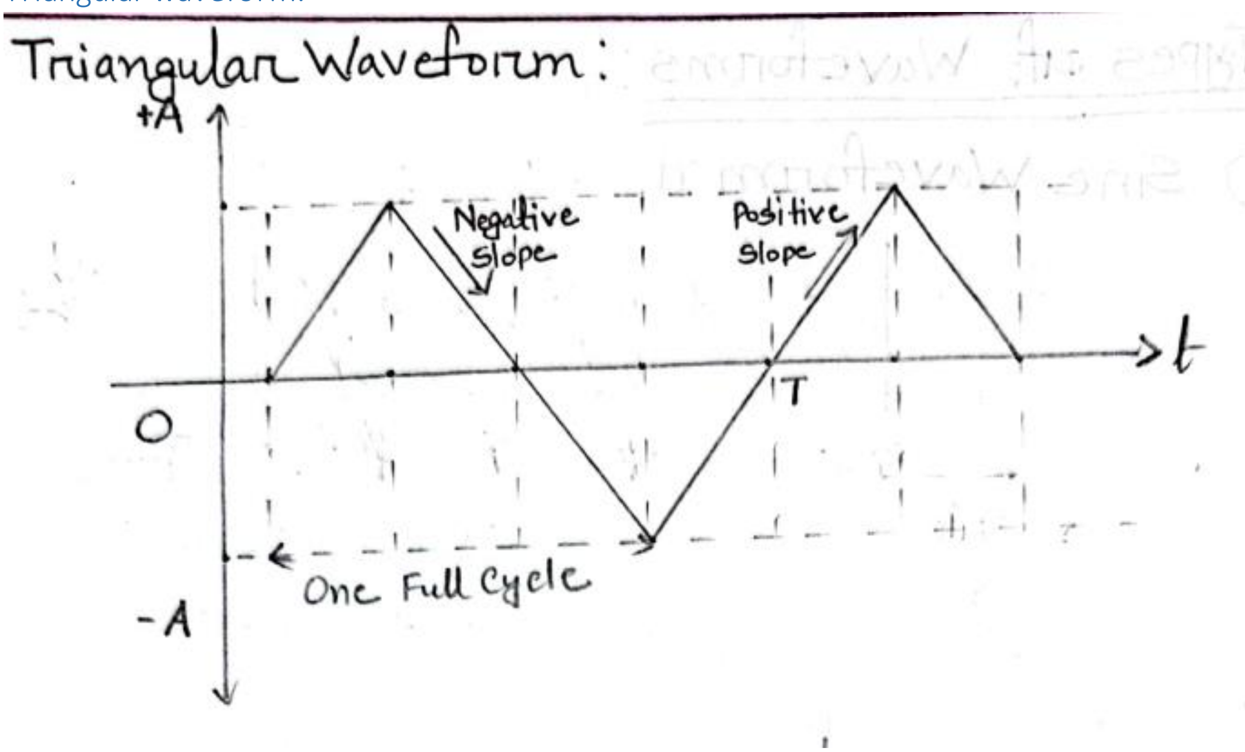
Square waveform:



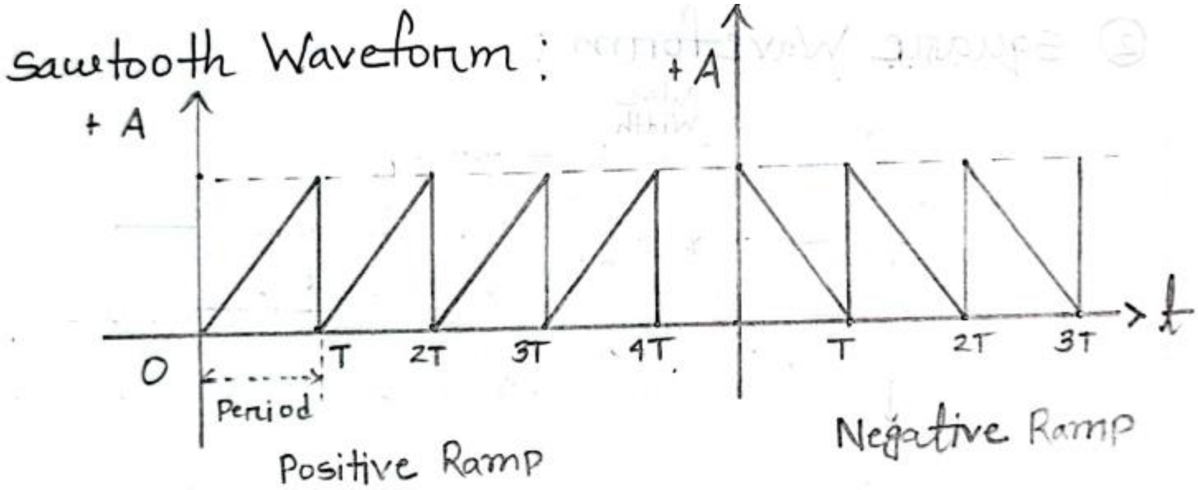
Rectangular waveform:



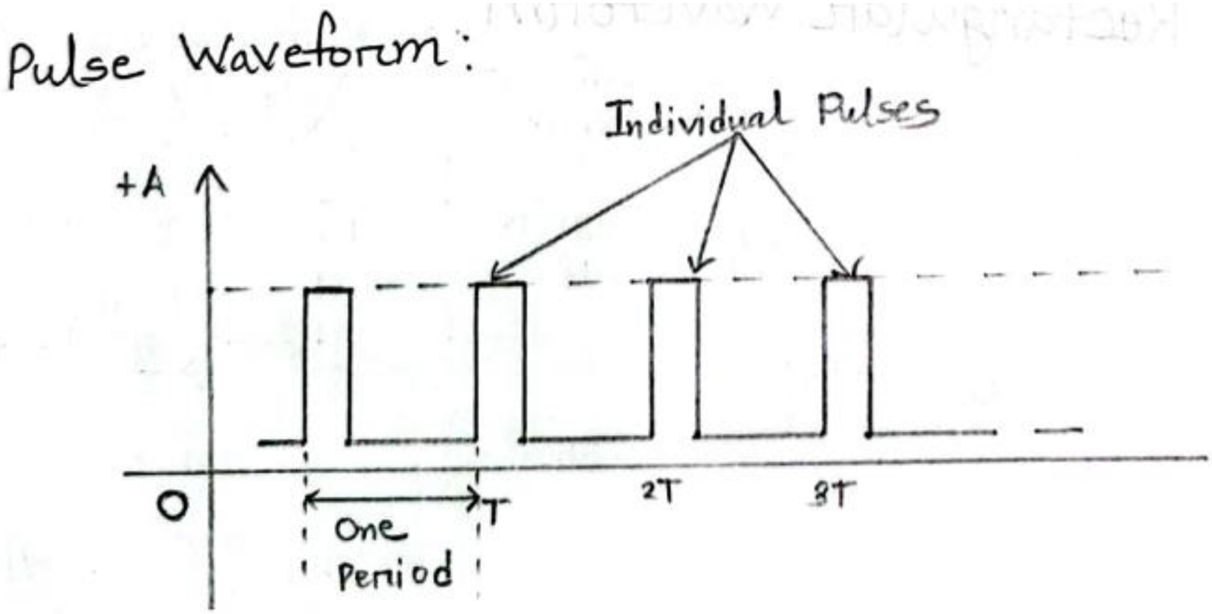
Triangular waveform:



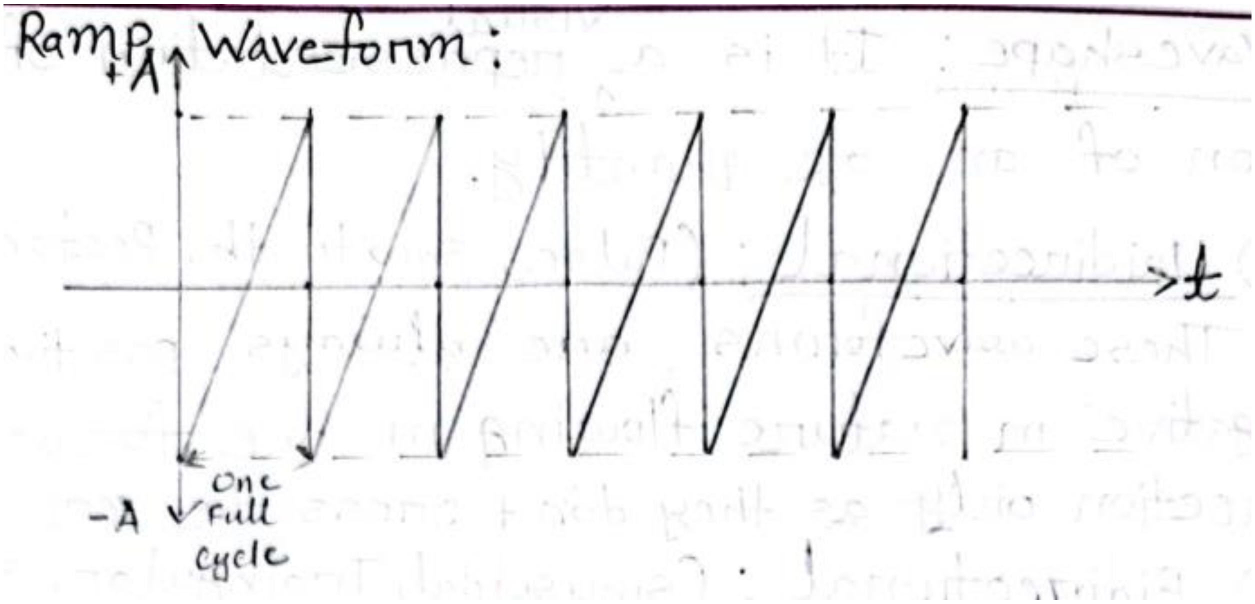
Sawtooth waveform:



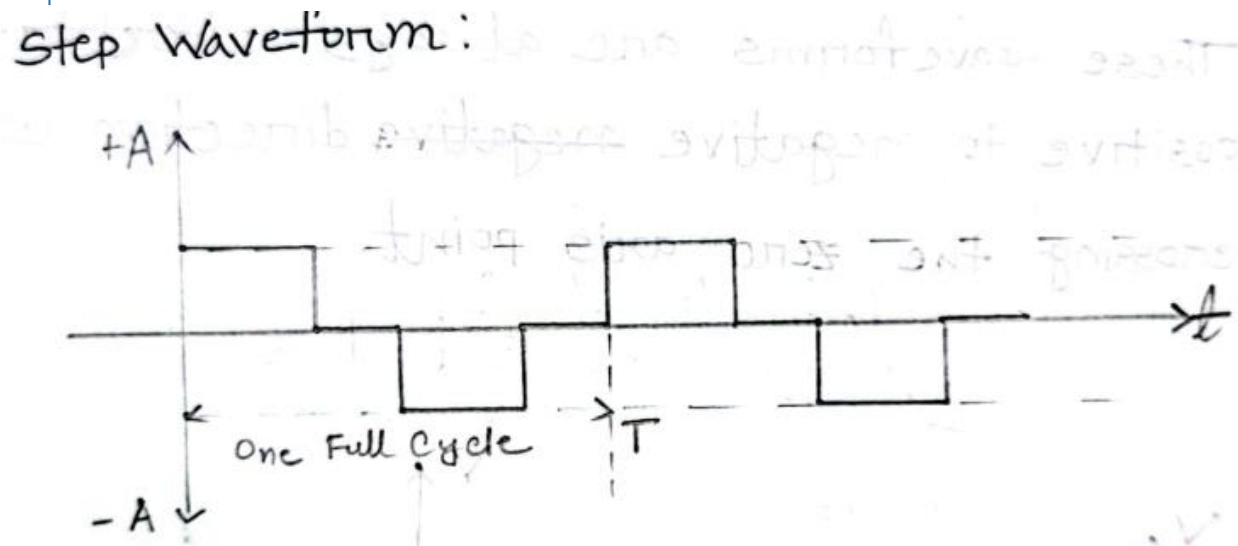
Pulse waveform:



Ramp Waveform:



Step waveform:



Waveshape:

Waveshape is the visual representation of variation of an AC quantity.

It's of two types:

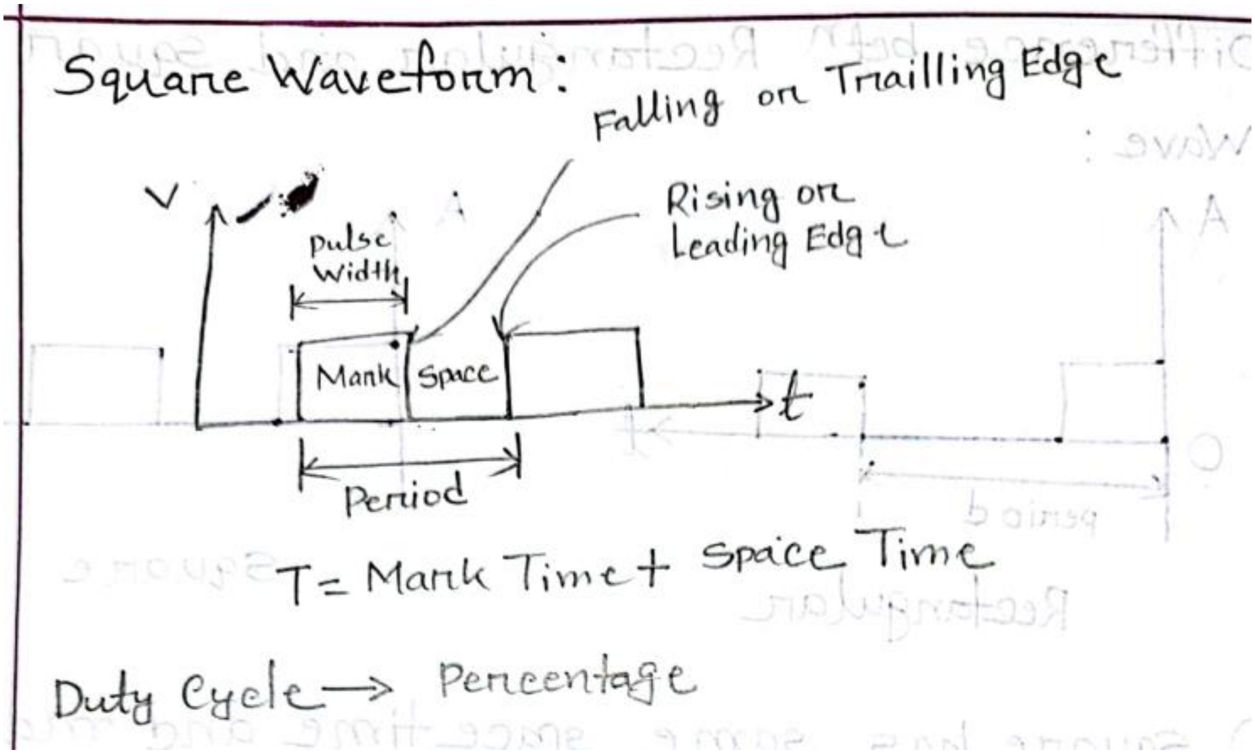
Unidirectional:

These waveforms are either always positive or always negative, and flows in one forward direction as they don't cross the zero axis point. E.g. **pulse, sawtooth, rectangular.**

Bidirectional:

Always alters between positive and negative as they always cross the zero axis point. E.g. **Sinusoidal, Triangular, Square.**

Parts of square waveforms:



Duty cycle:

In digital circuit, the percentage of the positive pulse or mark time is called the duty cycle.

Math:

In a waveshape, the pulse width (mark time) is 20ms and duty cycle is 33%. Calculate its frequency.

20ms is 33% or 1/3rd

Solution: positive $= x \rightarrow 20ms$

negative $= 2x \rightarrow 40ms$

$T = 20 + 40 = 60ms$

$f = \frac{1}{60 \times 10^{-3}}$ Hz (Ans)

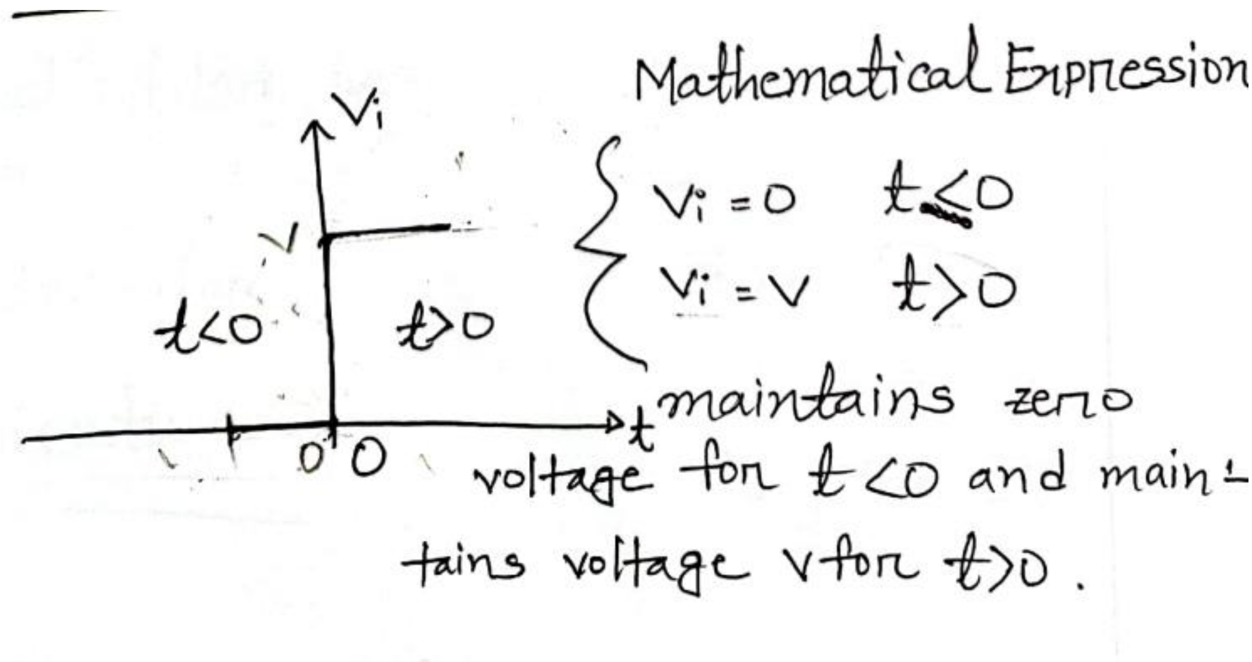
Difference between Rectangular and square waves:

- Square has same space and mark time, thus 50% duty cycle.
- Square is symmetrical.
- Square is used in electronics and micro electronic devices. Used to generate clock signals and timing circuits.

- Rectangular wave is used for varying any electrical quantity by varying the power supplied to a load.

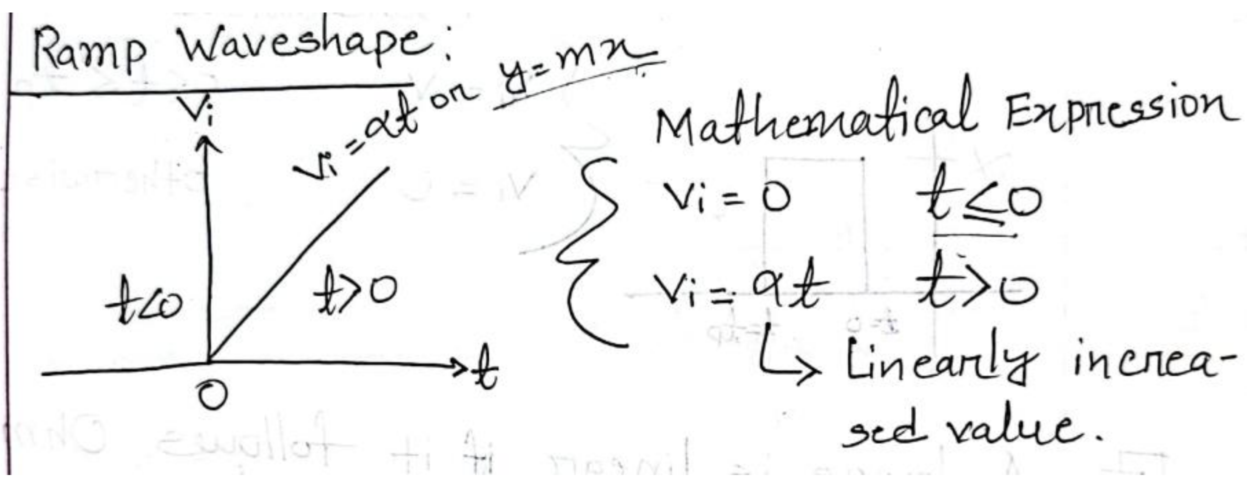
Step waveshape:

A step voltage is one which maintains voltage 0 when t<0 and voltage v when t>0.



Ramp waveshape:

A ramp voltage is one where voltage 0 is maintained when t<=0 and voltage linearly increased when t>0.

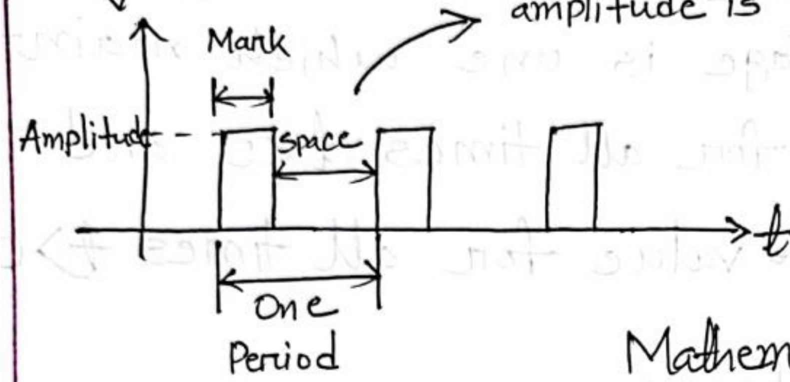


Pulse waveshape:

A pulse voltage is when voltage is maintained at v when 0<=t<=tp, otherwise maintained at v=0.

Here time duration is too small for mark, but amplitude is high.

Pulse:

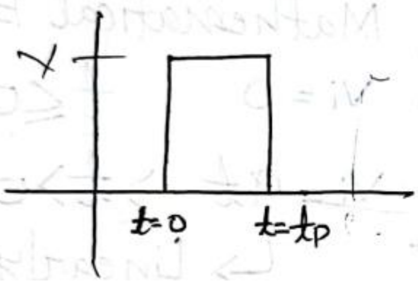


Time duration is too little but amplitude is high.

Differentiator provides these types of waveshapes

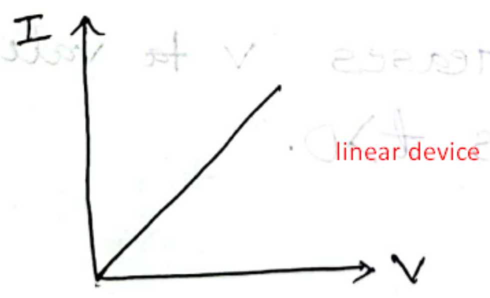
Mathematical Expression:

$$\begin{cases} V_i = V & 0 \leq t \leq t_p \\ V_i = 0 & \text{otherwise} \end{cases}$$



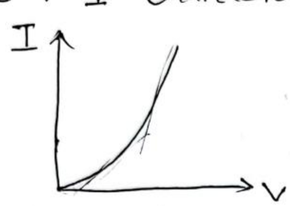
V-I characteristics:

A device is linear when it follows ohm's law i.e. R, L, C.



Diode and transistors are nonlinear devices:

Diode V-I Characteristic:



Linear waveshaping:

Linear elements such as resistors, capacitors and inductors are employed to shape a signal in this linear wave shaping.

Filtering:

Filtering is the process where unwanted portion of a signal is removed.

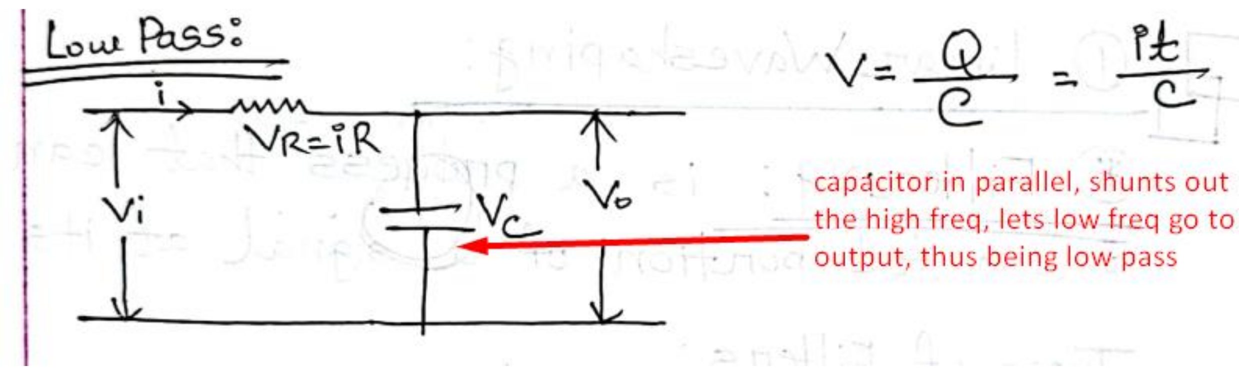
1. Low pass filter
2. High pass filter

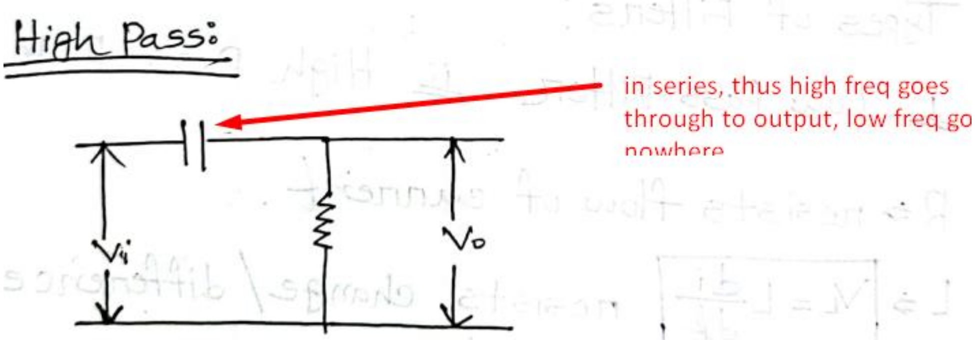
Capacitive reactance:

Capacitor blocks DC current. In DC, frequency is zero, thus reactance in infinite, thus blocking it. For AC, the higher the frequency or f, lower reactance, thus letting higher frequencies pass and blocking low frequencies.

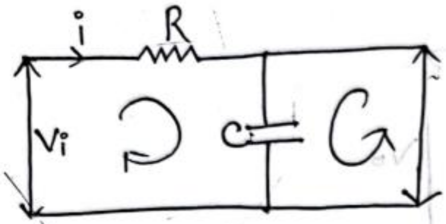
$$X_c = \frac{1}{2\pi f C}$$

Here:





Low pass filter as integrator:



$$V_i = iR + \frac{1}{C}\int i\,dt \quad \text{—— (1)}$$

$$V_o = \frac{1}{C}\int i\,dt \quad \text{—— (2)}$$

since, $\frac{1}{C}\int i\,dt \ll iR$

low pass, so DC is way higher
iR represents DC

from (1)

$$V_i = iR$$

$$\Rightarrow i = \frac{V_i}{R}$$

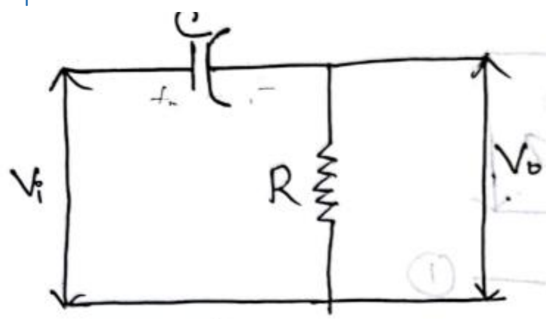
(2) $V_o = \frac{1}{C}\int i\,dt$

$$= \frac{1}{C}\int \frac{V_i}{R}\,dt$$

$$\therefore V_o = \frac{1}{RC}\int V_i\,dt$$

$\therefore V_o \propto \int V_i\,dt$ as $\frac{1}{RC}$ is constant.

High pass filter as differentiator:



$$V_i = \frac{1}{C}\int i\,dt + iR \quad \text{--- (1)}$$

$$V_o = iR \quad \text{--- (2)}$$

since, $iR \ll \frac{1}{C}\int i\,dt$

From (2) $\Rightarrow$ $i = \frac{V_o}{R}$

From (1) $\Rightarrow$

$$V_i = \frac{1}{C}\int i\,dt$$

$$= \frac{1}{C}\int \frac{V_o}{R}\,dt$$

$$V_i = \frac{1}{RC}\int V_o\,dt$$

differentiating both sides,

$$\frac{dV_i}{dt} = \frac{V_o}{RC}$$

or, $V_o = RC\frac{dV_i}{dt}$

$\therefore V_o \propto \frac{dV_i}{dt}$ as RC is constant.

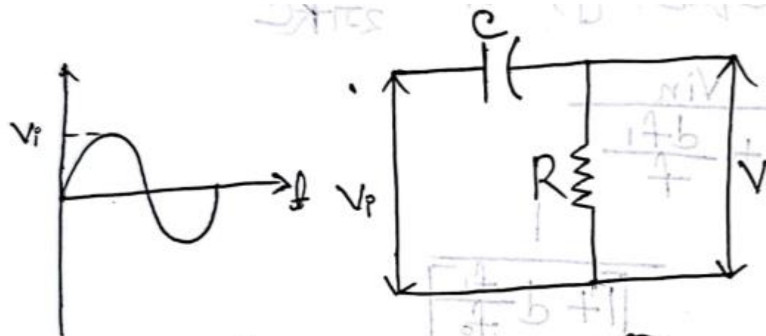
Sinusoidal input to a High pass filter:

Cut off frequency:

This "Cut-off", "Corner" or "Breakpoint" frequency is defined as being the frequency point where the capacitive reactance and resistance are equal. Capacitive resistance increases with frequency.

$$fc = \frac{1}{2\pi RC}$$

Calculation:



$$i = \frac{V}{Z} \rightarrow \text{impedance}$$

$$= \frac{V}{R + dX_c}$$

d = complex const i

$$\cancel{V_i = \frac{1}{C}\int i\,dt + iR} \text{ —— (1)} \qquad \text{where } X_c = \frac{1}{2\pi fC}$$

$$V_o = iR \text{ —— (1)}$$

$$\therefore i = \frac{V_{in}}{R + d.\frac{1}{2\pi fC}} = \frac{V_{in}}{R\left[1 + \frac{d}{2\pi fCR}\right]} \text{ —— (2)}$$

From ① $\Rightarrow$

$$V_o = \frac{V_{in}}{\cancel{R}\left[1+\frac{d}{2\pi fCR}\right]}\cancel{R}$$

or, $$V_o = \frac{V_{in}}{1+\frac{d}{2\pi fRC}}$$

$$X_C = \frac{1}{2\pi fC}$$

$$f = \frac{1}{2\pi X_C C}$$

Let;

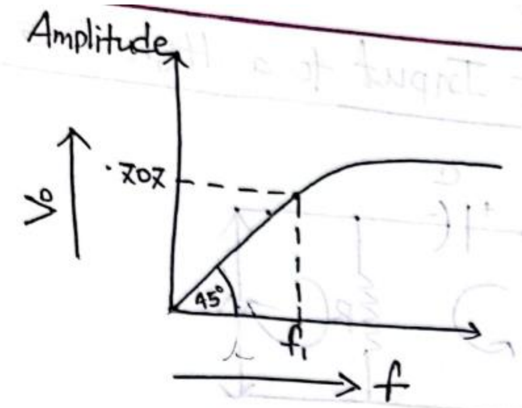
cut off frequency, $f_1 = \frac{1}{2\pi RC}$

or, $$V_o = \frac{V_{in}}{1+\frac{df_1}{f}}$$

$$A = \frac{V_o}{V_{in}} = \frac{1}{\left[1+d\frac{f_1}{f_0}\right]}$$

$$|A| = \frac{1}{\sqrt{1+\left(\frac{f_1}{f_0}\right)^2}}$$

$$\theta = \tan^{-1}\left(\frac{f_1}{f}\right)$$ it is being calculated in complex plane



~~some~~ we will find one such frequency point for which $f_1 = f$.

When $f_1 = f$,

$$\text{Amplitude} = \frac{1}{\sqrt{1+(1)^2}} = \frac{1}{\sqrt{2}} = 0.707$$

$$\theta = \tan^{-1}(1) = 45^\circ$$

The point where $f_1 = f$ is called 3dB point

Step input to a high pass filter:

Step input is when for t>0 Vin = v and t<0 Vin = 0.

The transition between two voltage occurs at $t=0$

$V_i = 0$ when $t = 0^-$

$V_i = V$ when $t = 0^+$

$$V_i = \frac{1}{C}\int i\,dt + iR \quad \text{——— (1)}$$

$$V_o = iR \;(2) \Rightarrow \; i = \frac{V_o}{R} \quad \text{——— (2)}$$

From ① $\Rightarrow$

$$V_i = \frac{1}{C}\int \frac{V_o}{R}\,dt + \frac{V_o}{R}\cdot R$$

$$= \frac{1}{RC}\int V_o\,dt + V_o$$

Differentiating both sides

$$\frac{dV_i}{dt} = \underbrace{\frac{1}{RC}\times V_o}_{\text{steady state response}} + \frac{dV_o}{dt} \quad \text{——— ③}$$

$\frac{1}{RC}\times V_o \rightarrow$ constant value

$\frac{dV_o}{dt} \rightarrow$ transient state

If $V_i = V$ [V is a constant]

$$\frac{dV_i}{dt} = \frac{dV}{dt} = 0 \quad \text{——— ④}$$

From ③ $\Rightarrow$

$$\frac{1}{RC}V_o + \frac{dV_o}{dt} = 0 \longrightarrow \text{Differential Eqn}$$

The general solution will be,

V_o = complementary function + particular integral ——— ⑤

Complementary Equation :

$$\frac{dV_i}{dt} = \frac{V_o}{RC} + \frac{d}{dt}V_o \quad \text{———} \quad (6)$$

Let us consider,

$$D = \frac{d}{dt}$$

Then (6) is,

$$DV_i = \frac{V_o}{RC} + DV_o$$

or, $DV_i = V_o\left(D + \frac{1}{RC}\right)$.

L.H.S. .. R.H.S.

To find complementary function,

$$V_o\left[D + \frac{1}{RC}\right] = 0$$

$$\Rightarrow D = -\frac{1}{RC}$$

$\therefore$ Complementary Function $= K\,e^{+Dt}$

$$= K.\,e^{(-)\frac{t}{RC}}$$

<u>Particular Integral:</u>

DV_i

$$\Rightarrow \frac{d}{dt}V = 0$$

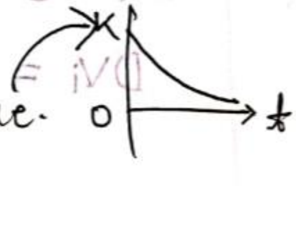
$\therefore$ Particular Integral $= 0$

From (5) $\Rightarrow$

$$\boxed{V_o = K e^{-\frac{t}{RC}} + 0}$$ (exponential curve)

$\rightarrow$ we don't know the value of "K" yet.

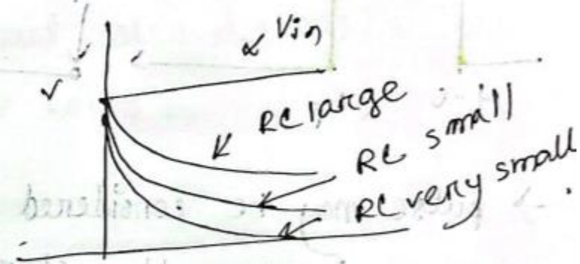
Curve will degrade from K value.



$$V_0 = V e^{-t/RC}$$

i) At, $t = RC$

$$V_0 = V e^{-RC/RC} = 0.3678\,V$$



ii) At, $t = 2RC$

$$V_0 = V e^{-2RC/RC} = 0.135\,V$$

iii) At, $t = 3RC$, $V_0 = V e^{-3RC/RC} = 0.049\,V$

iv) At, $t = 5RC$, $V_0 = V e^{-5RC/RC} = 0.007\,V$.

$\therefore$ The output voltage V_0 becomes practically zero after 5 time-constants.

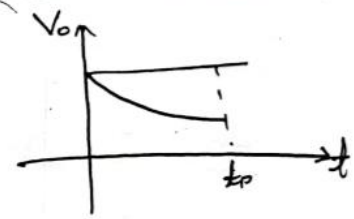
Pulse waveform as input to a HPF:

May be considered as the sum of two step wave, +v when t=0 and –v when t=tp.

There are three situations to this output:

For ① If the pulse is applied to the High Pass Filter, the response for time $t < t_p$ is same as step voltage input.

$$\boxed{V_p = V_o = V e^{-\frac{t_p}{RC}}}$$



where t < tp

② At the end of the pulse, the input falls quickly by the amount V.

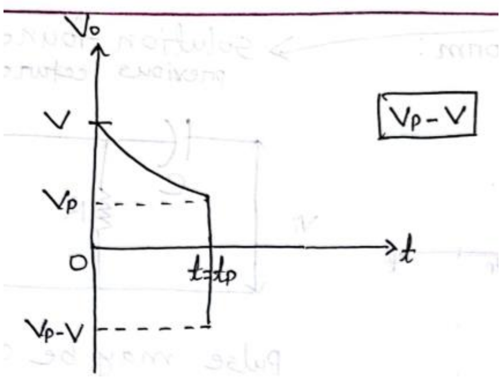
So, the output voltage also decreases by the same amount V.

At $t = t_p$, $\boxed{V_o = V_p - V}$

where t = tp

$$\text{or, } V_o = V e^{-t_p/RC} - V$$

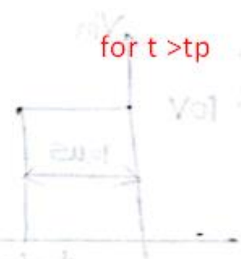
$$= V\left[e^{-t_p/RC} - 1\right]$$



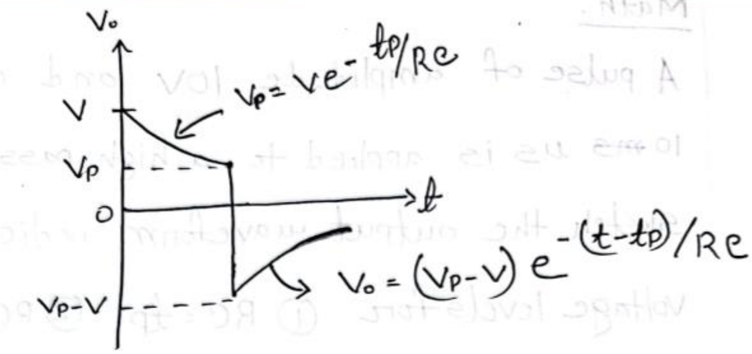
③ $t = t_p^+$ or $t > t_p$

$$V_o = (V_p - V)\, e^{-\frac{(t - t_p)}{RC}}$$

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



If we know t_p, V_p and $V_p - V$ then we can draw the curve

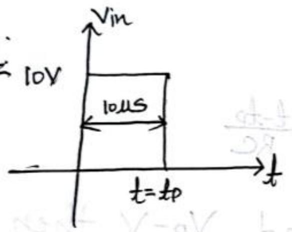


If we know tp, Vp, and Vp-V then we can draw the curve.

MATH:

A pulse of amplitude 10V and duration 10 ~~ms~~ us is applied to a high pass filter. Sketch the output waveform indicating the voltage levels for ① $RC = t_p$ ② $RC = 0.5t_p$ ③ $RC = 2t_p$

Soln.

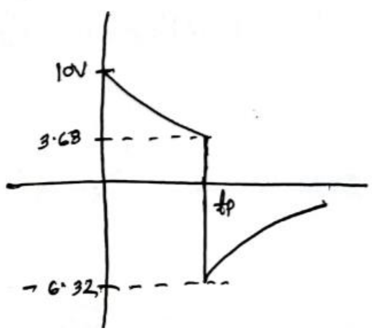


Input Waveshape

① When $RC = t_p = 10\mu s$

$$V_p = Ve^{-\frac{t_p}{RC}} = 10 \cdot e^{-1} = 3.68\text{ V}$$

$$V_p - V = 3.68 - 10 = -6.32$$

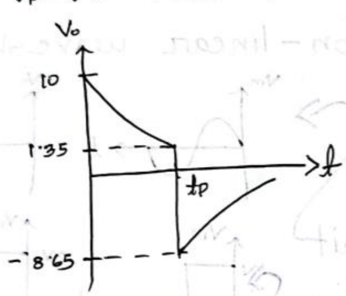


Output Waveshape

② When $RC = 0.5t_p$

$$V_p = Ve^{-\frac{t_p}{RC}} = 10 \cdot e^{-2} = 1.35$$

$$V_p - V = 1.35 - 10 = -8.65$$



Output Waveshape

Nonlinear waveshaping:

The circuits where the output waves are non-sinusoidal for sinusoidal input, are called non-linear waveshaping.

1. Clipper
2. Clamper

Application of clipper circuit:

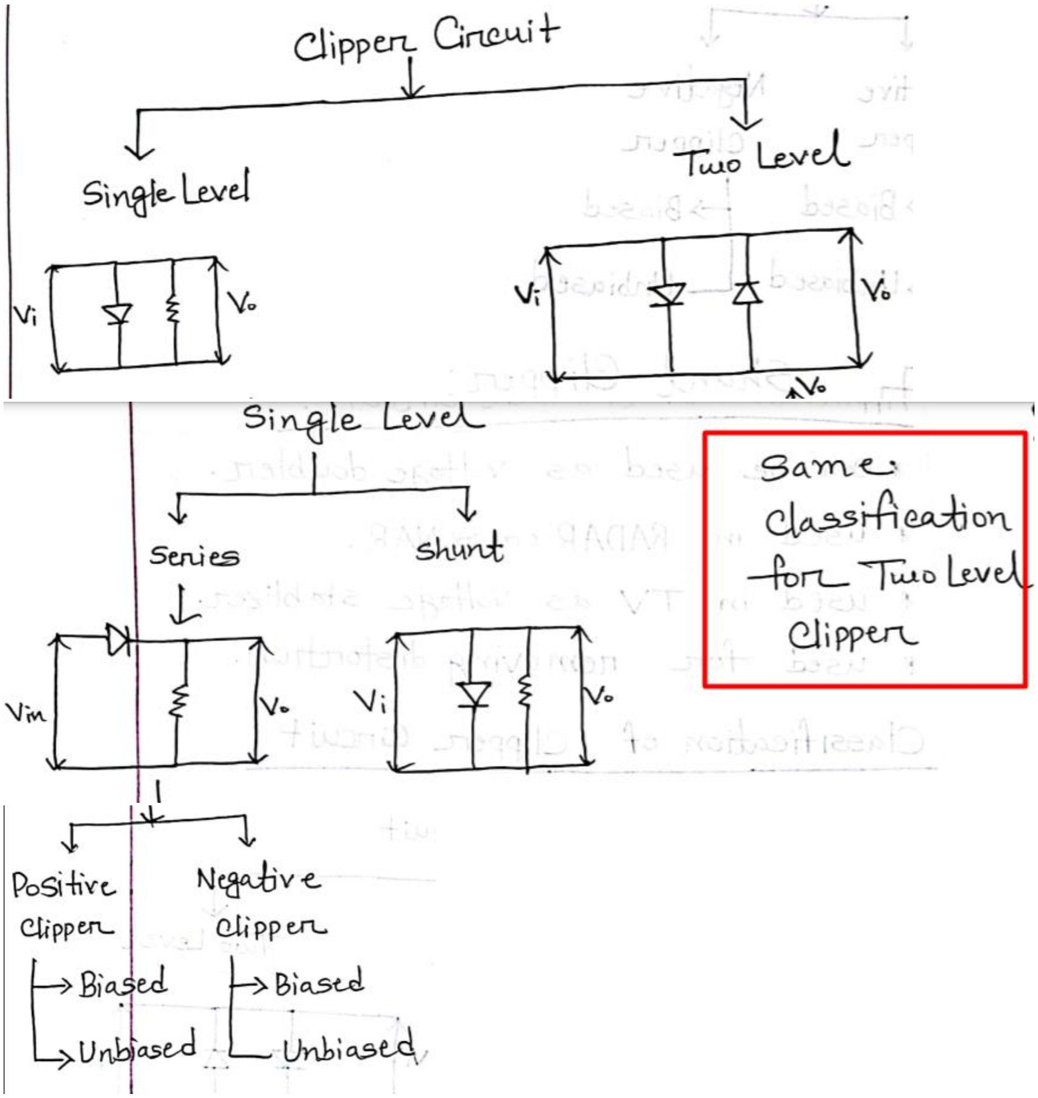
1. For shaping of the wave
2. For removing noise peak
3. For limiting the magnitude of voltage

Application of clamper:

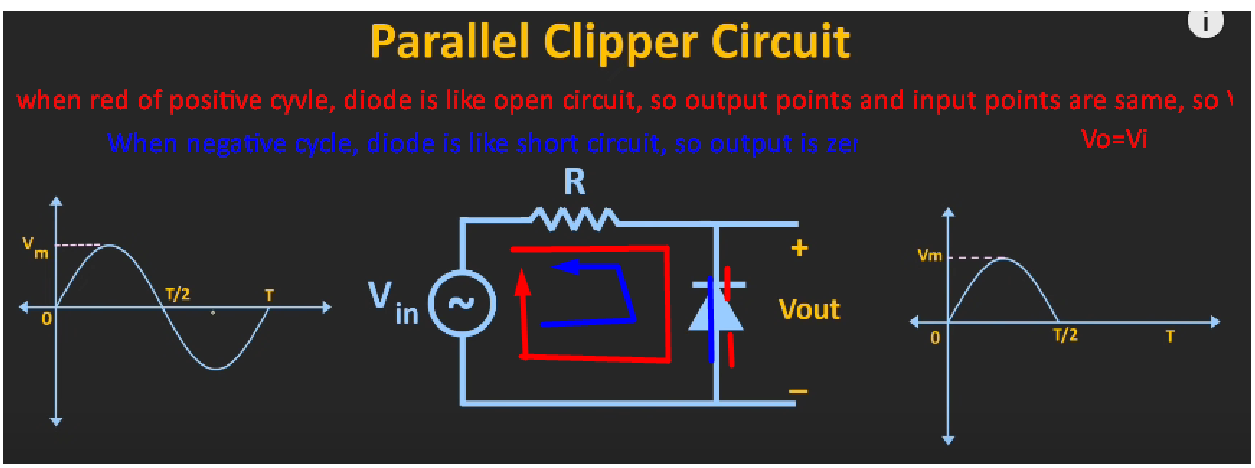
1. Can be used as voltage doubler
2. Used in SONAR and RADAR
3. Used in TV as voltage stabilizer
4. Used for removing distortion

Clipper:

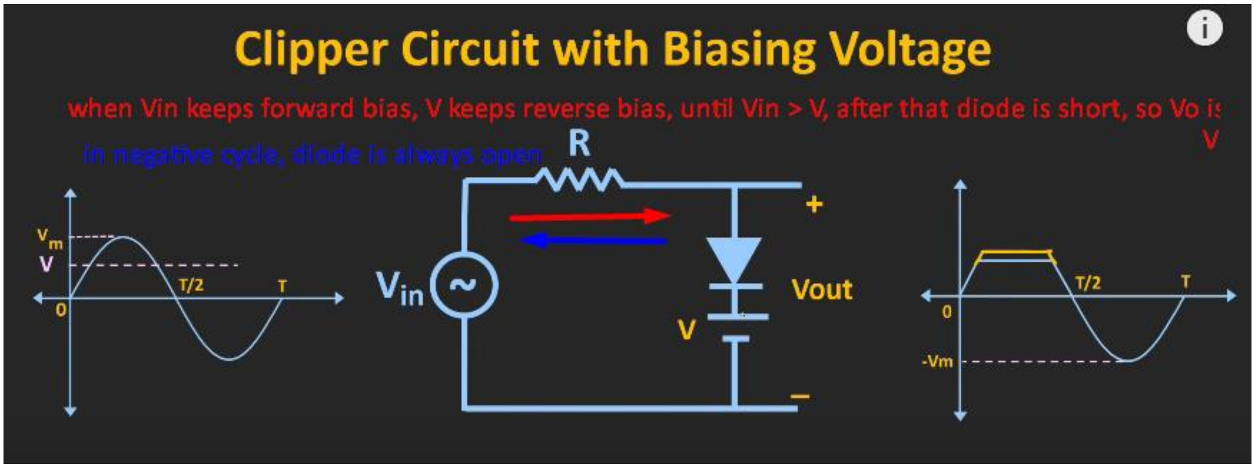
Classifications:



EXAMPLE:

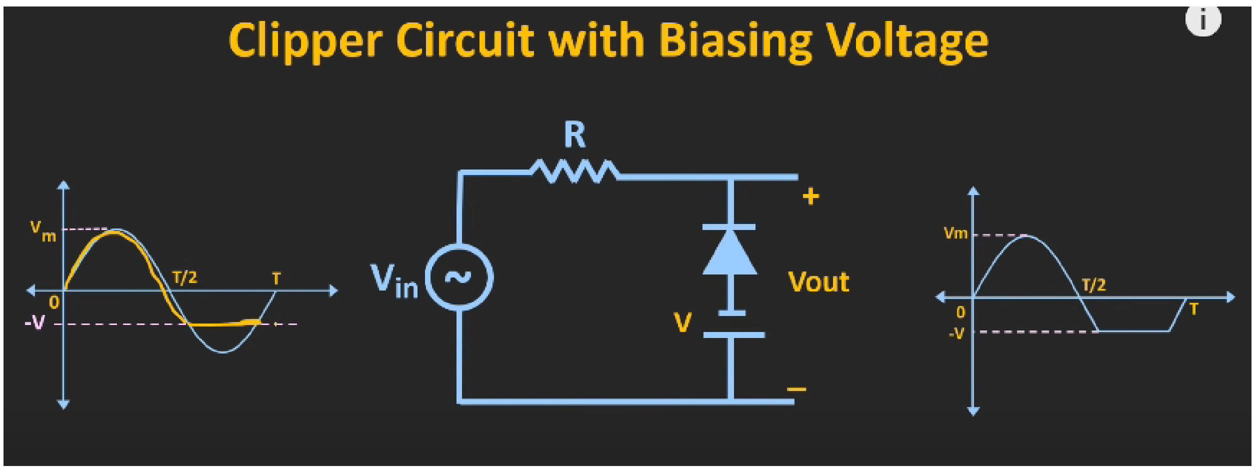


If diode voltage is given, when in forward bias, there will be a voltage drop, so output will not be exact zero, it will be -Vd.

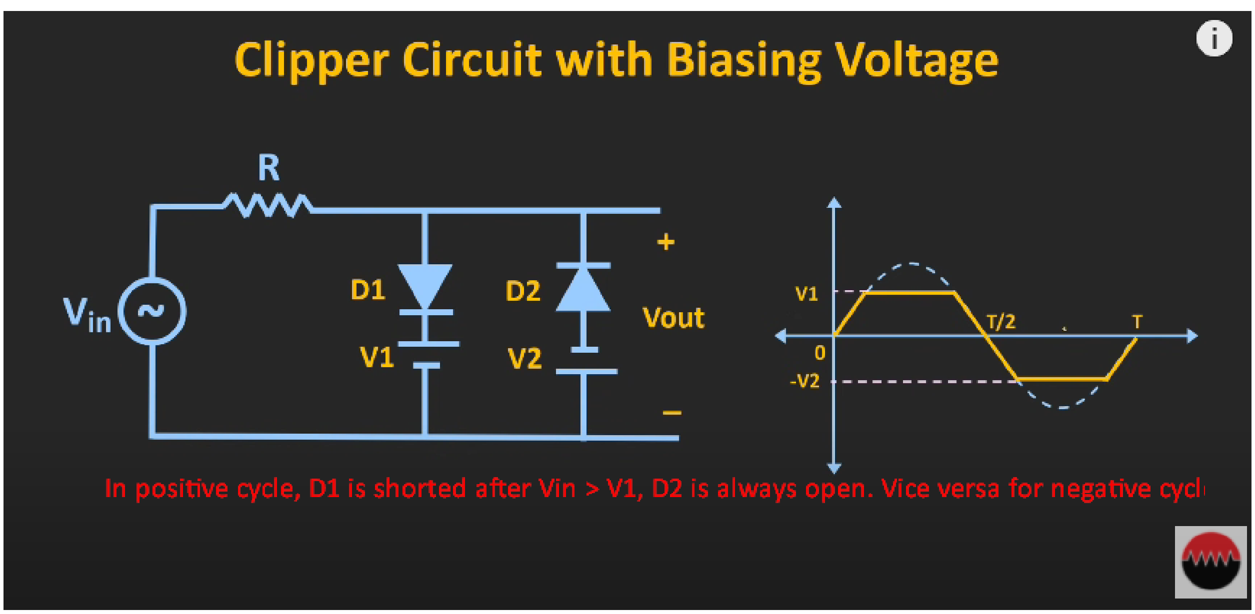


While biasing in clipper, the V is always makes the diode reverse biased if waveshape is on axis.

Here is **Negative biased clipper:**

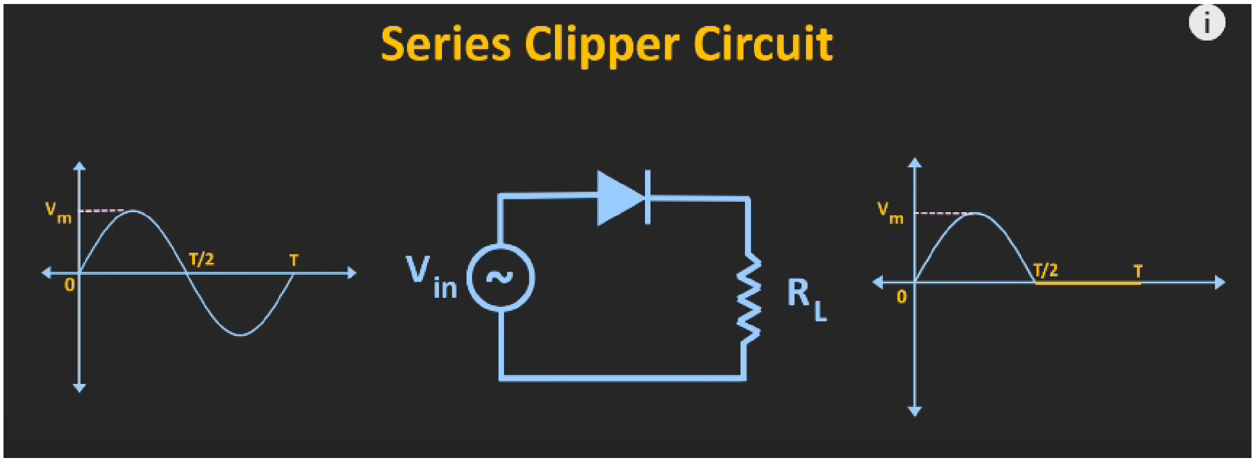


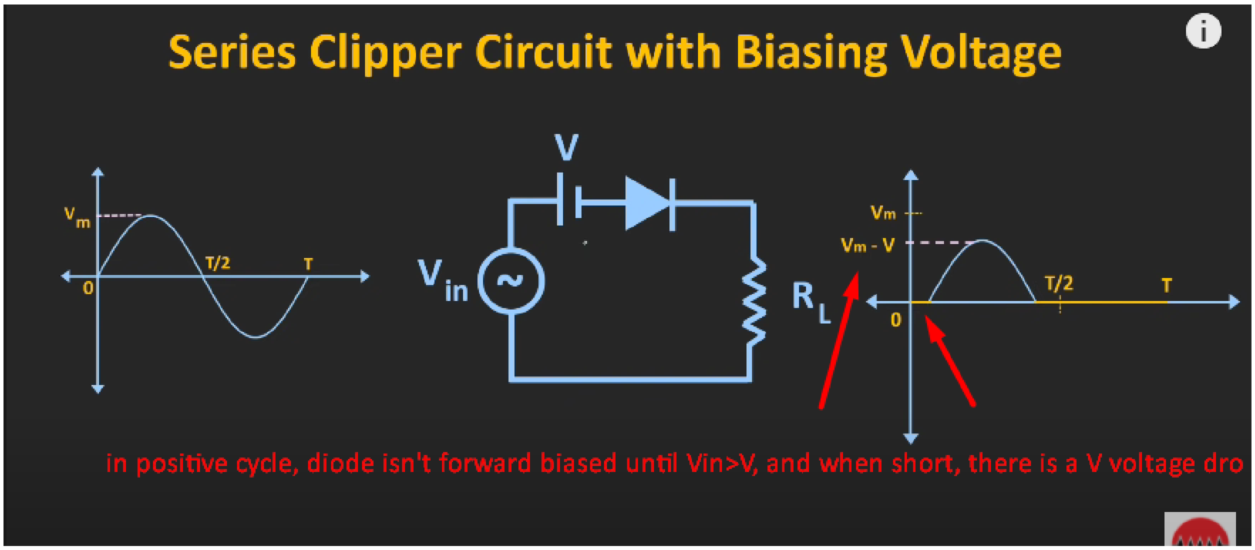
Two ways:

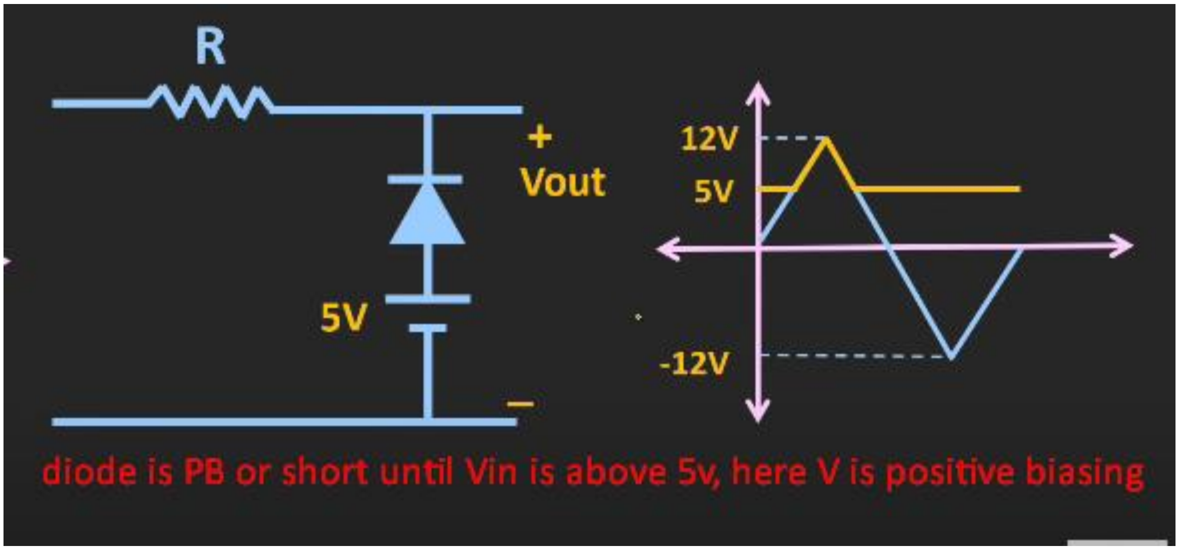


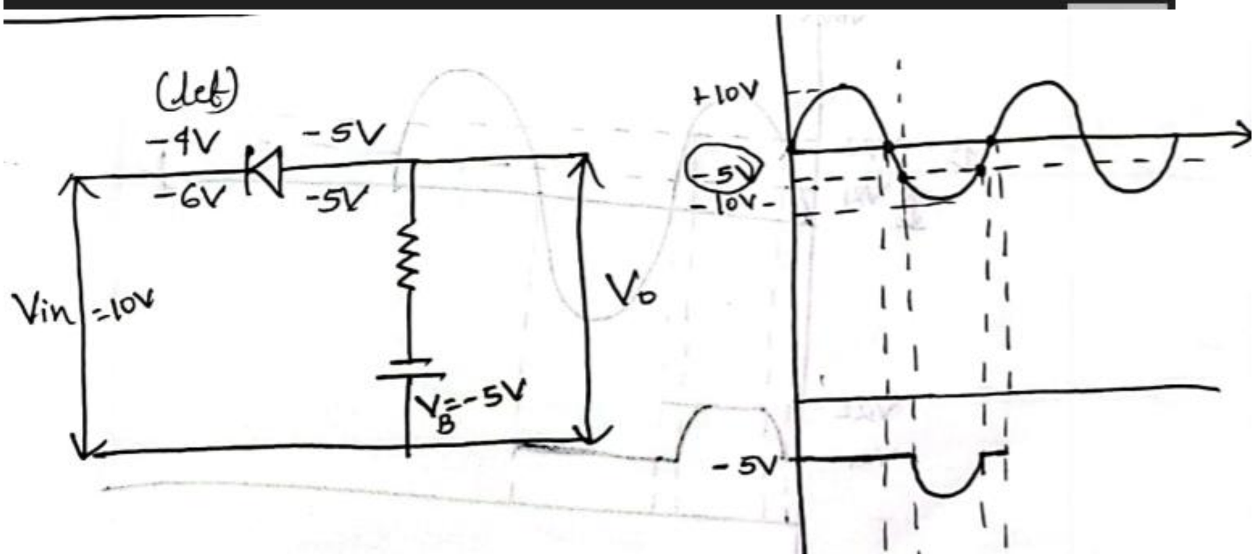
Series Clippers:

Are simple, one cycle goes other doesn't.


Series Clipper Circuit
Vm
T/2
T
0
Vin
RL
Vm
T/2
T
0


Series Clipper Circuit with Biasing Voltage
Vm
T/2
T
0
V
Vin
RL
Vm
Vm - V
T/2
T
0
in positive cycle, diode isn't forward biased until Vin>V, and when short, there is a V voltage dro



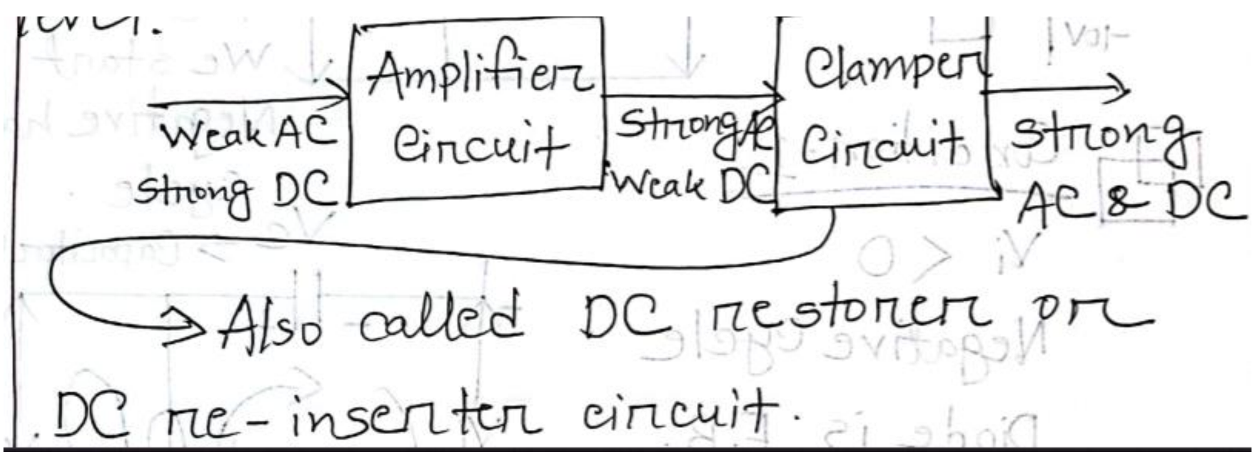


Here output is always -5v until there is a higher voltage source, meaning, when Vin<-5v

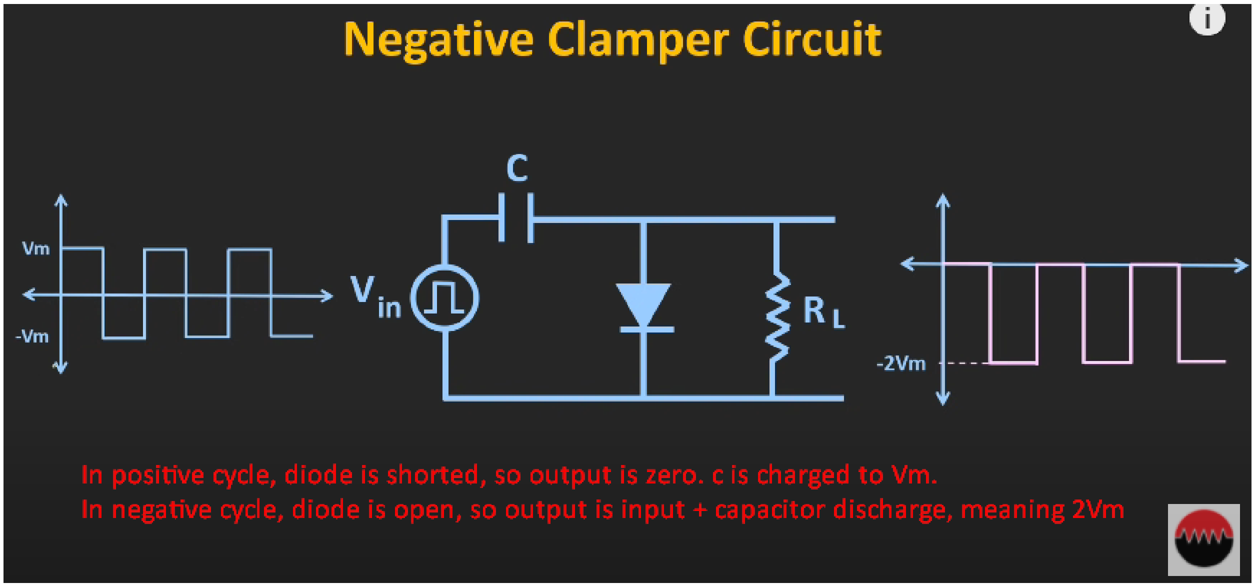
Clamper:

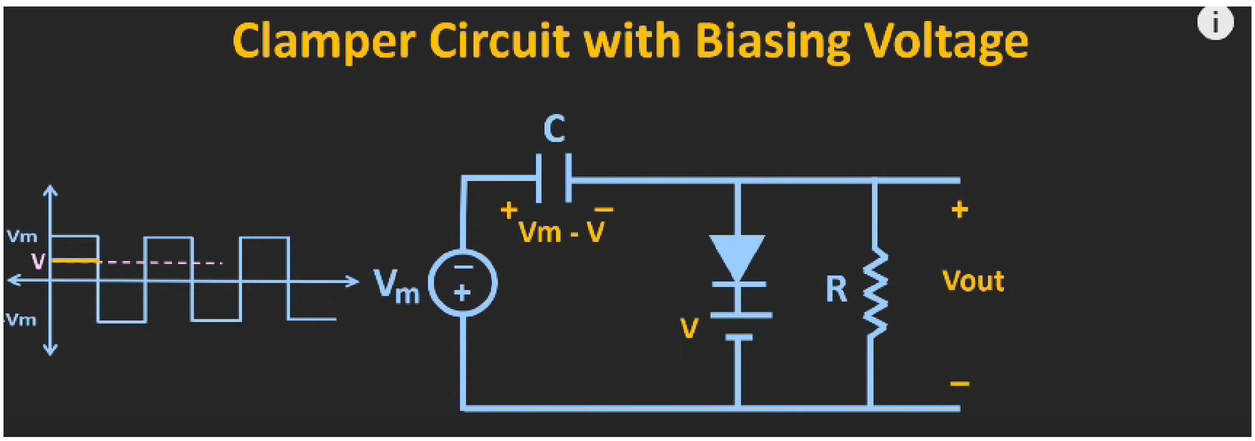
A clamping circuit is one which takes an input waveform and provides a faithful replica of its shape, but has one edge tightly clamped to zero voltage reference point.

Why use: Clamping is used to introduce a DC component to a signal after going through a capacitor coupling.



EXAMPLE:





Here, the capacitor is charged to Vm-V in positive half cycle, and diode is shorted, so output is V. In negative half, diode is open. So output is input + discharge. So -2Vm+V.

Calculation is given below.

Condition - 1 :

$V_i < 0$

Negative Cycle

Diode is F.B.

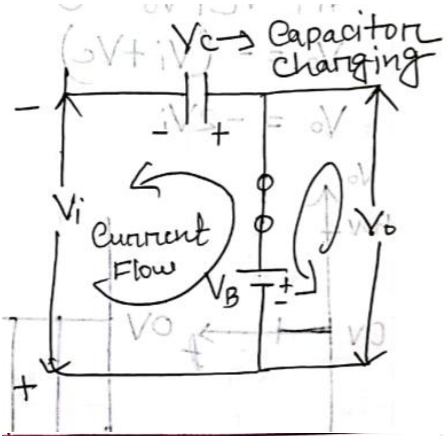
So, act as short circuit

$V_o = V_B$

Apply KVL,

$-V_i - V_B + V_c = 0$

$V_c = V_i + V_B$



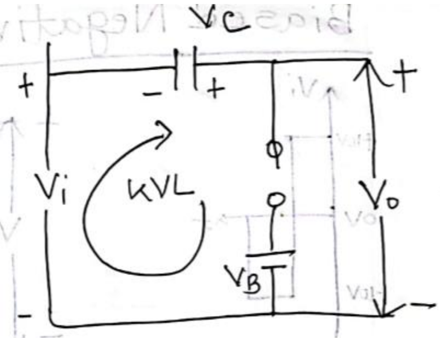
Condition - 2 :

$V_i > 0$

Positive Cycle

Diode is R.B.

So, act as open circuit

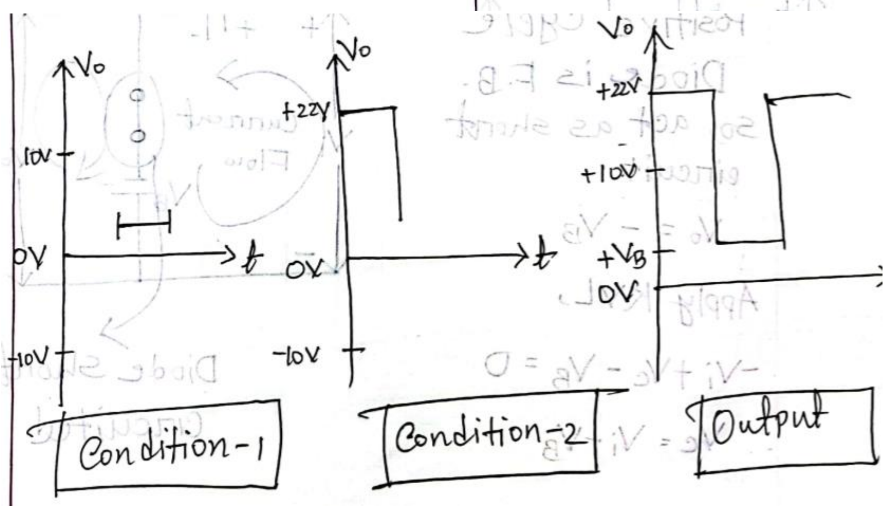


Apply KVL,

$-V_i - V_c + V_o = 0$

or, $V_o = V_i + V_c$

$\therefore V_o = 2V_i + V_B$



Switching circuit:

A circuit which can turn on or off in an electrical circuit is known as a switching circuit.

Has two parts:

1. A switch:
    a. Mechanical switch
    b. Electro-mechanical switch

c. Electronic switch
2. Associated circuitry

Characteristics of different switches:

Electro-mechanical switch:

A mechanical switch that is operated electrically.

Pros:

- Requires very small amount of current
- Can turn on or off from a distance
- No danger of sparking

Cons:

- Has moving parts, thus has friction
- Less than 5 operations per second at maximum.

Electrical switches:

Switches that can turn on or off electrically with help of diode, transistors etc.

Pros:

- Cheaper and smaller
- No noise and friction
- 10^9 operations per second
- Trouble free service because of solid state

Diode as switching device:

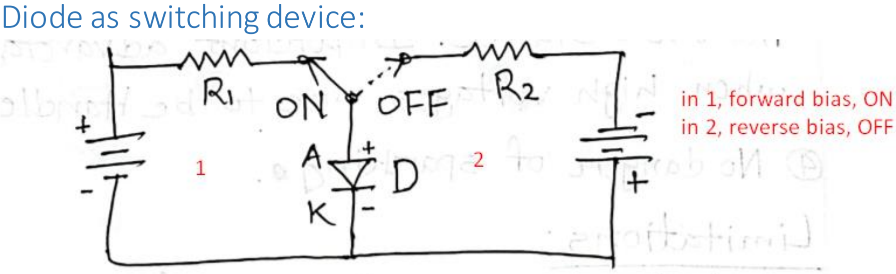
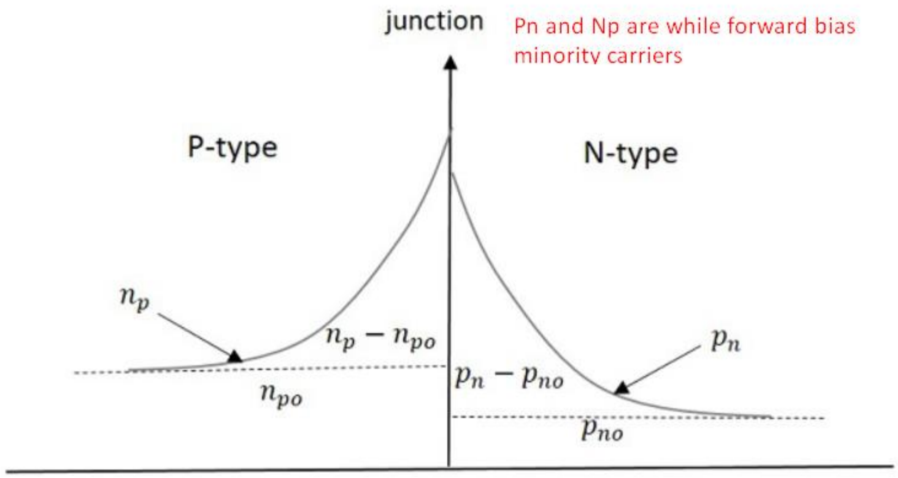


Fig: switching circuit using diode.

If,

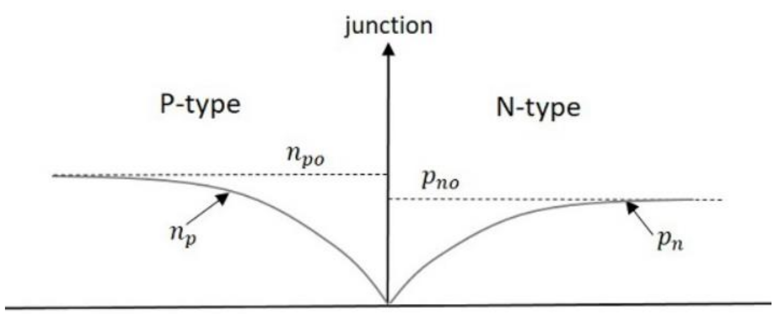
- The majority carriers in P-type holes = Ppo
- The majority carriers in N-type electrons = Nno
- The minority carriers in P-type electrons = Npo
- The majority carriers in N-type holes = Pno

During forward bias:

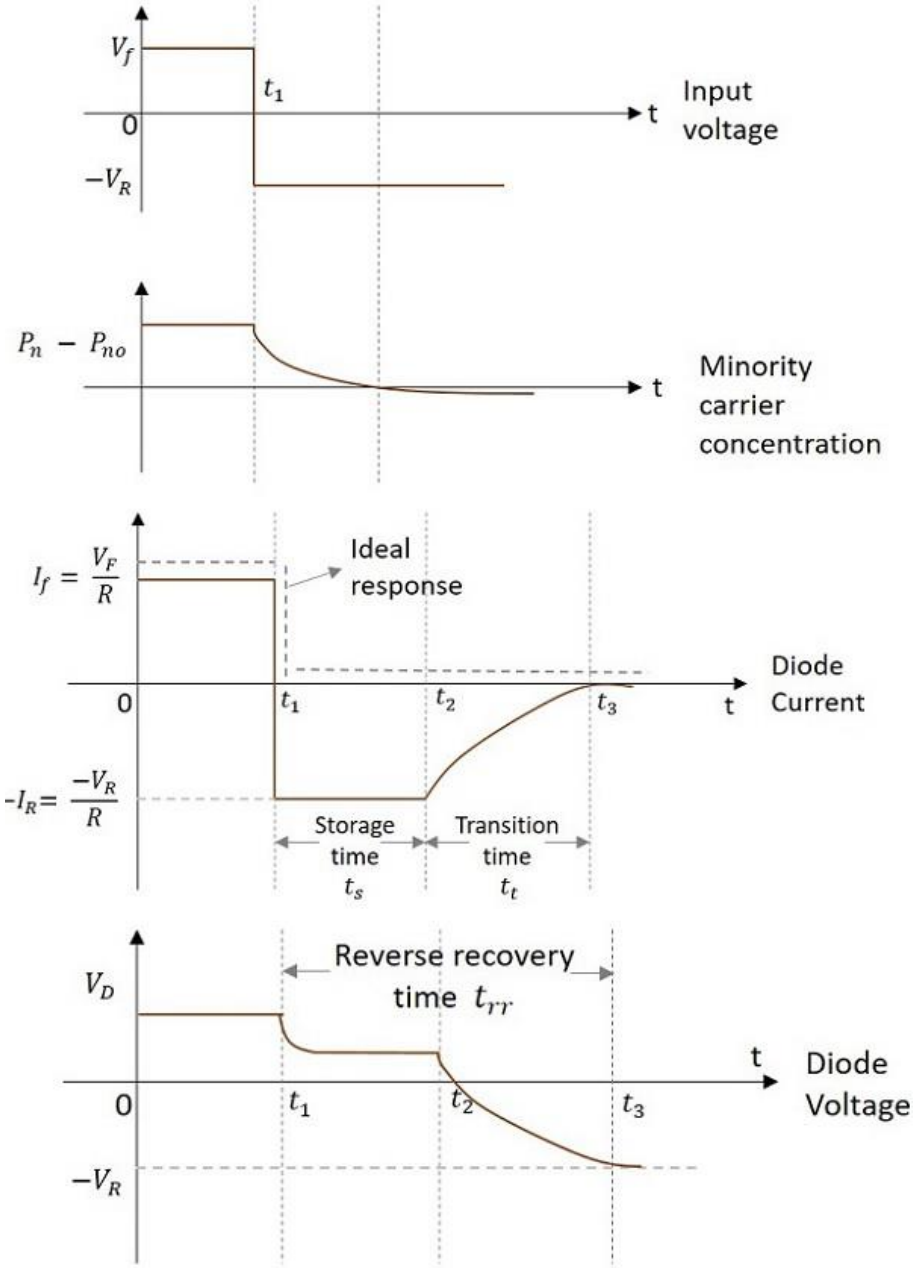


Number of minority carriers increase. So, Excess minority carrier charge in P-type = Pn−Pno with Pno steadystatevalue, Excess minority carrier charge in N-type = Np−Npo with Npo steadystatevalue

Then after giving **Reverse bias**, opposite happens:



As the current due to minority charge carriers is large enough to conduct, the circuit will be ON until this excess charge is removed.



In minority carrier concentration graph, because of the excess minority charge, diode doesn't immediately turn off.

So for diode current, ideal would be zero current immediately, but instead goes negative. For storage time.

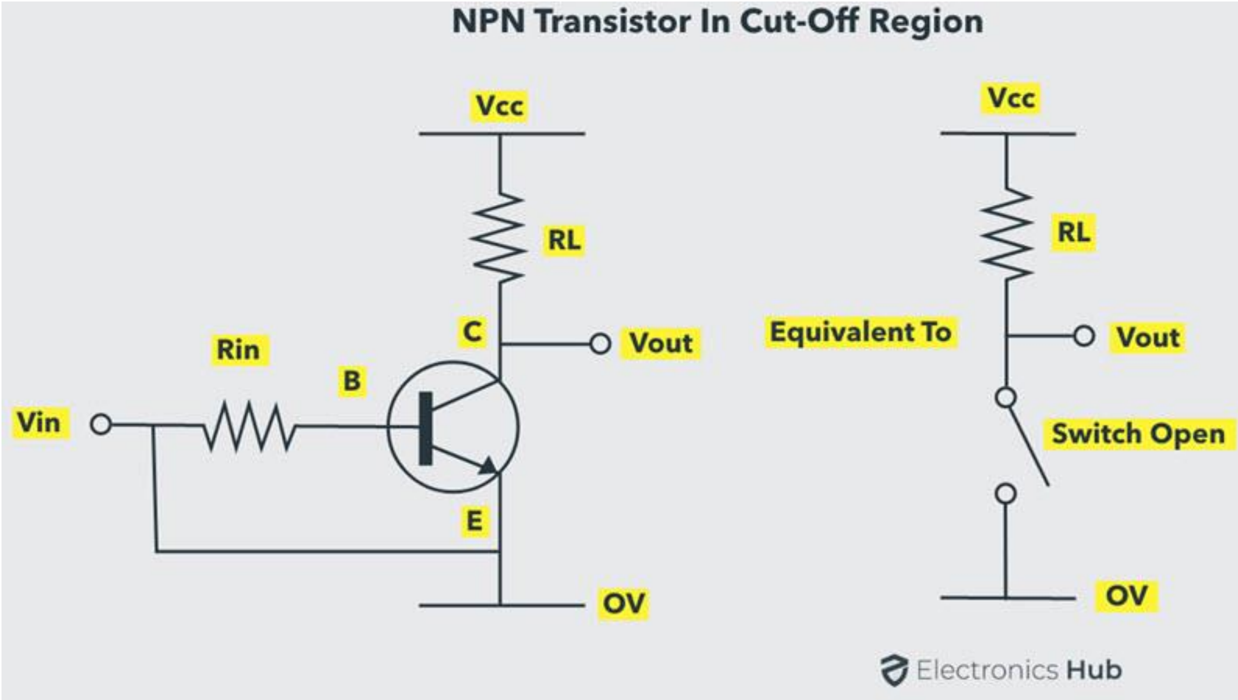
Diode voltage goes to negative infinity to become a open circuit, but needs Reverse recovery time which is storage time + transition time.

Storage time − The time period for which the diode remains in the conduction state even in the reverse biased state, is called as Storage time.

Transition time − The time elapsed in returning back to the state of non-conduction, i.e. steady state reverse bias, is called Transition time.

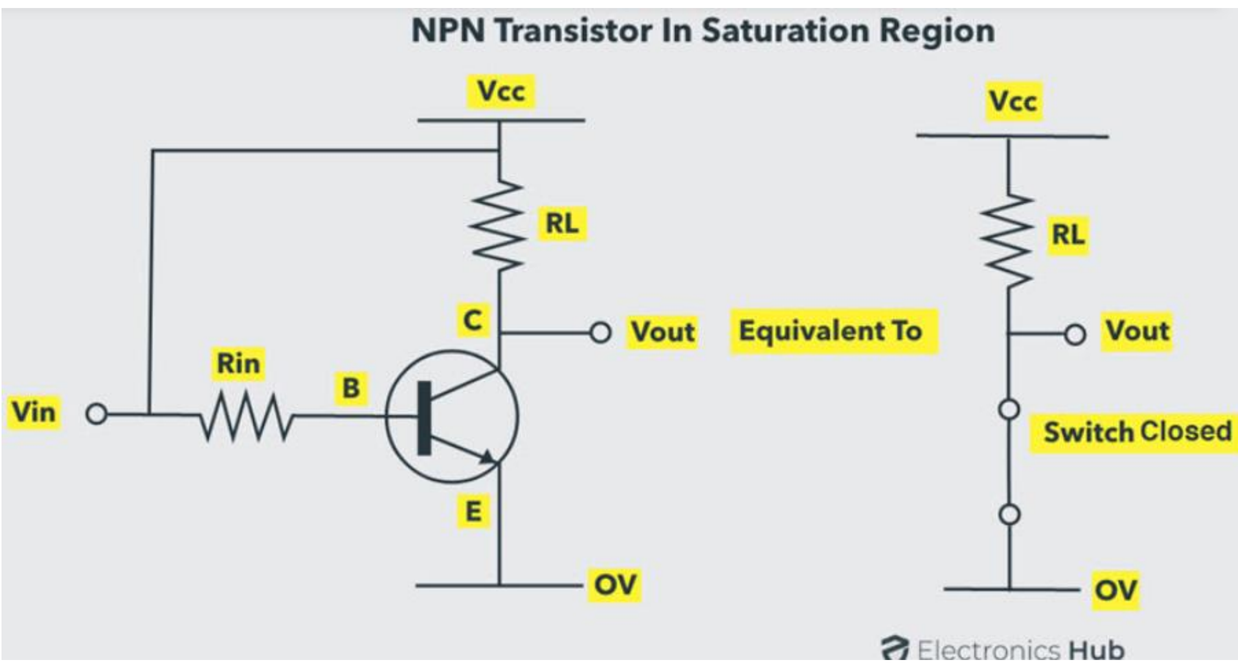
Reverse recovery time − The time required for the diode to change from forward bias to reverse bias is called as Reverse recovery time.

Transistor as switching device:



Here, Ic or collector current is zero. Vcc = Vce

Both P-N junctions are reverse biased.



Here, Ic = Vcc/Rc

Both P-N junctions are forward biased.

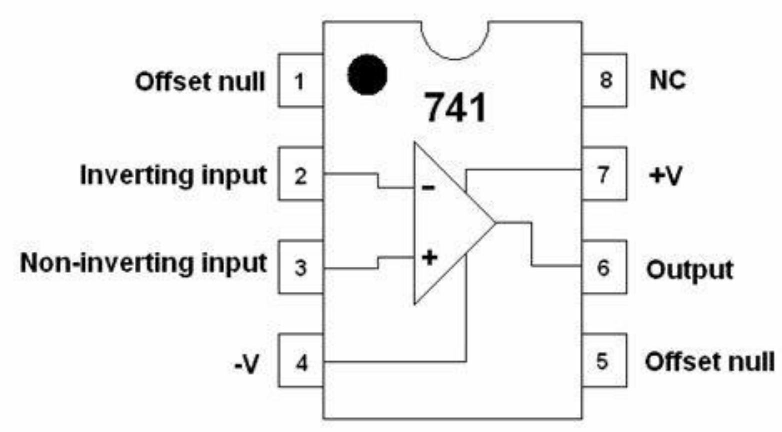
OP-AMP as comparator:

OP-AMP Usages:

1. Amplification
2. Math operation

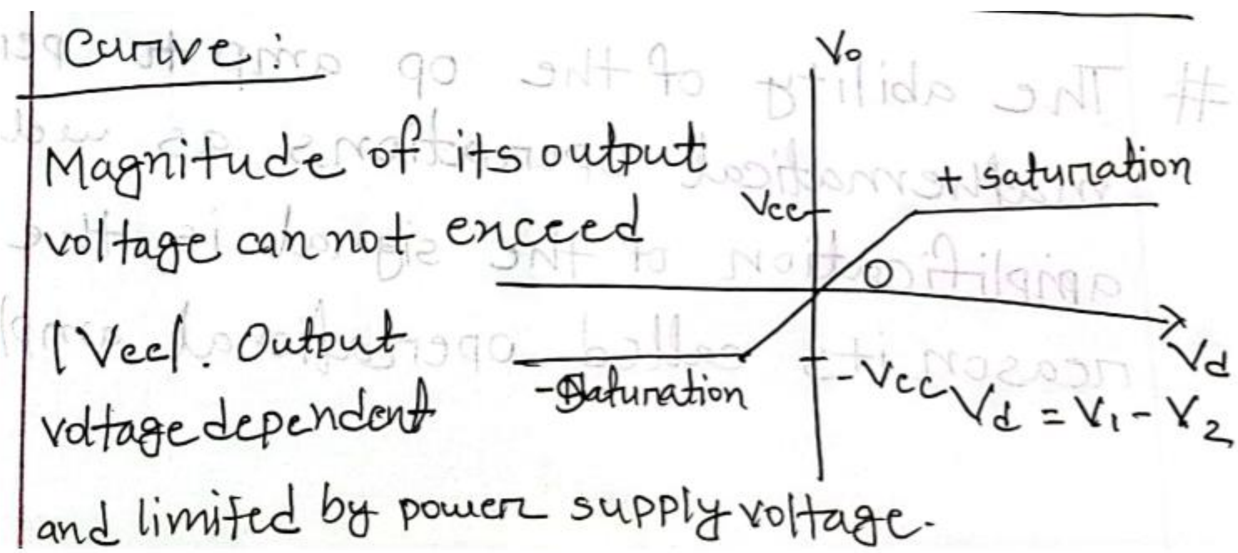
3. Signal shaping (Comparator)

Named OP-AMP from OP(mathematical operation) – AMP(amplification)



-V and +V are biasing voltage

Characteristic curve:



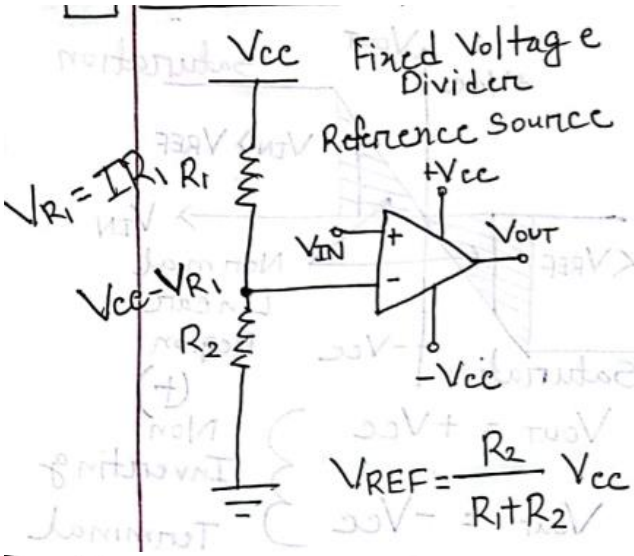
Comparator:

Basically, Output is High/Low if input is higher than a reference voltage, and Low/High if lower than reference voltage. (Non-inverting/ Inverting)

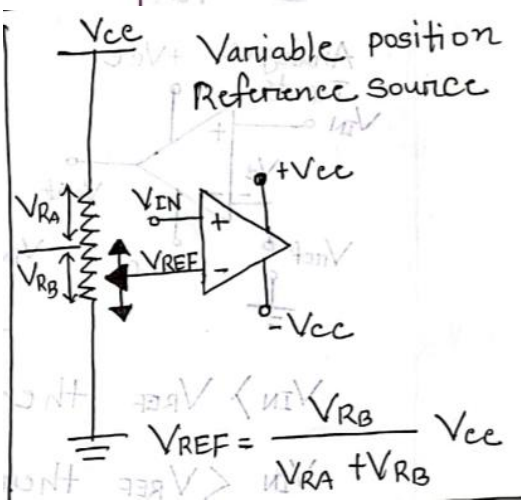
Comparator cause compares with reference voltage.

Comparator is used to generate square or pulse waves.

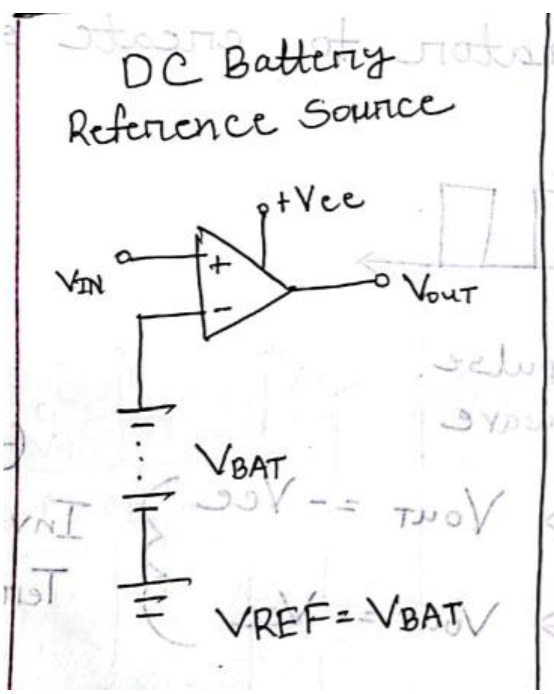
Comparator reference voltage methods:

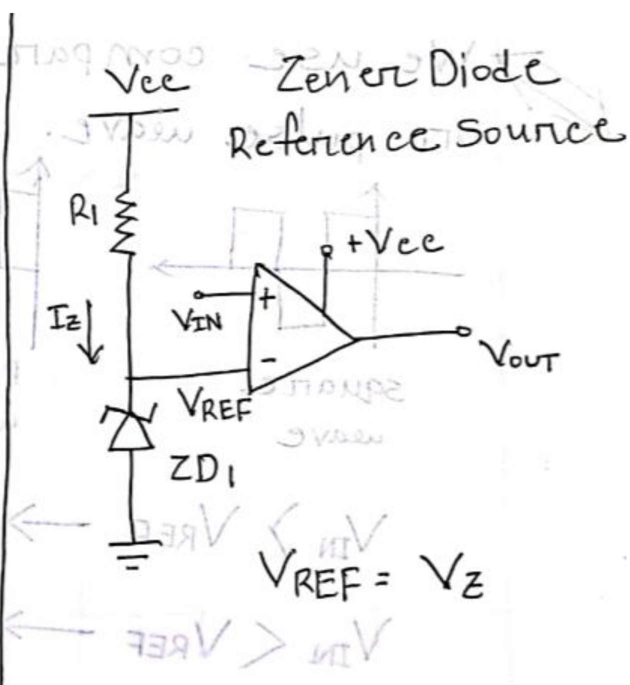


R1 and R2 are controlled to give proper reference voltage as input.

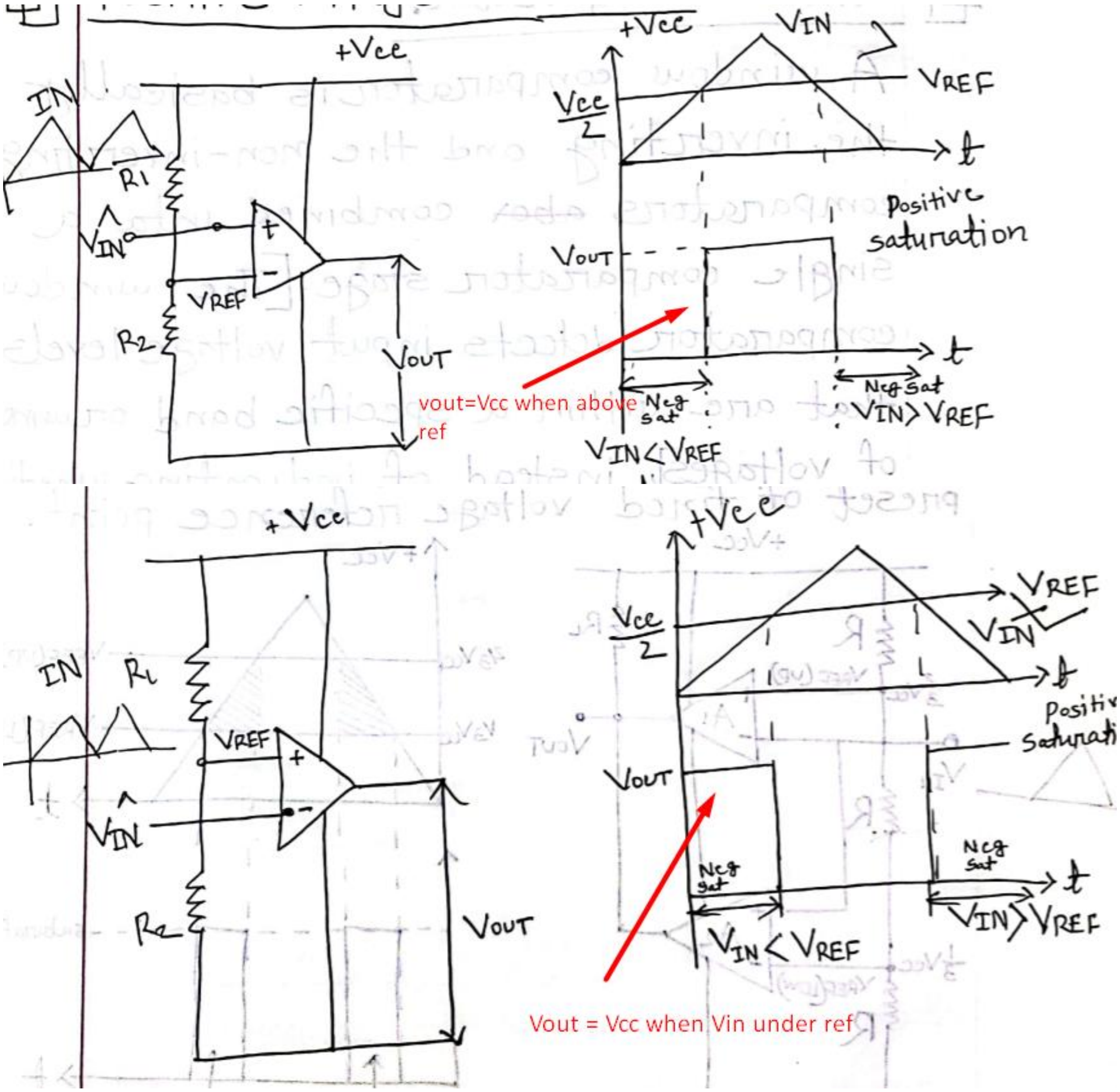


Variable resistor for proper reference voltage.



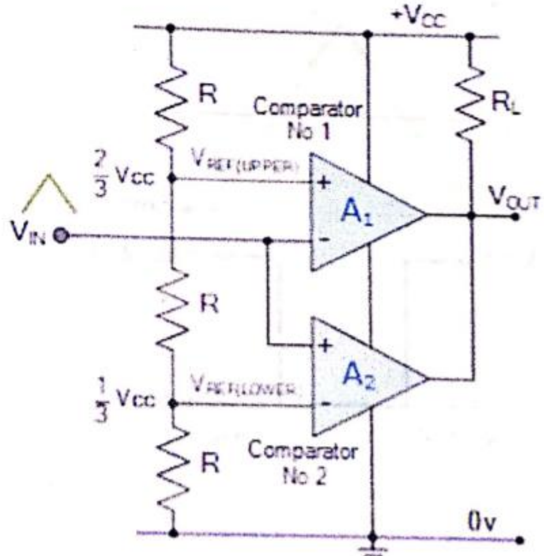


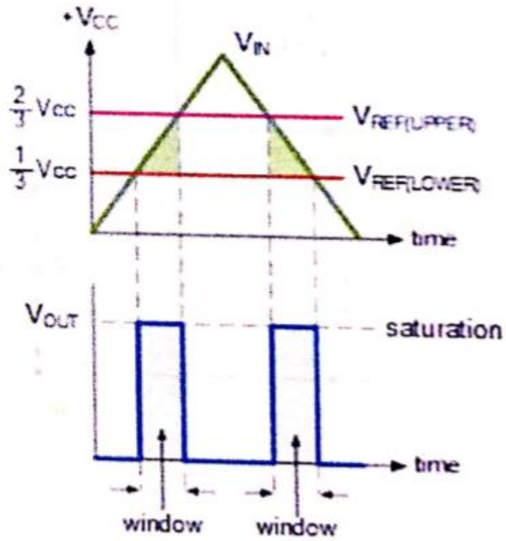
Positive and negative voltage comparator:



Window comparator:

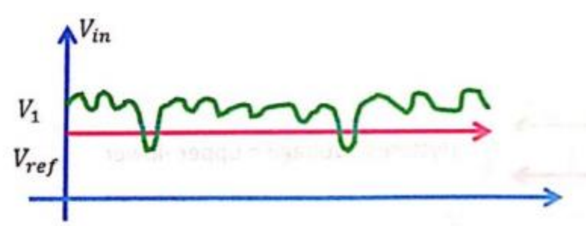
Window comparator is when two comparators, one negative and one positive comparator is used to detect voltage input within a window of voltages.



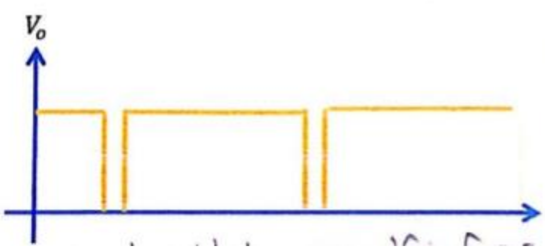


Negative Comparator (Comparator 1)	Positive Comparator (Comparator 2)
VIN < VREF ==== VOUT = Positive Saturation	VIN > VREF ==== VOUT = Positive Saturation
VIN > VREF ==== VOUT = Negative Saturation	VIN < VREF ==== VOUT = Negative Sturation

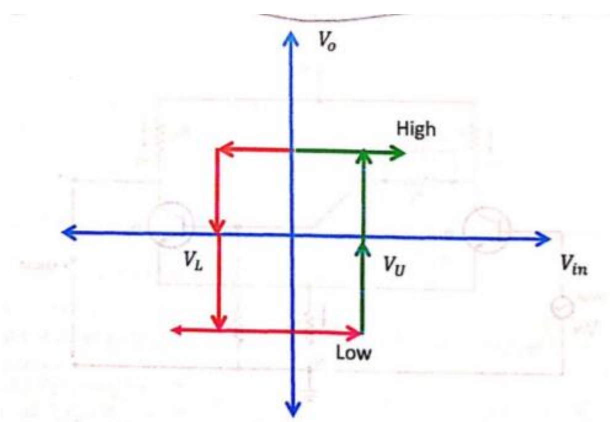
Problem with OP-AMP comparator:



Because of noise, OP-AMP can sometimes get false triggered, creating problems. To solve this, something with a threshold for noise should be used, like Schmitt trigger.

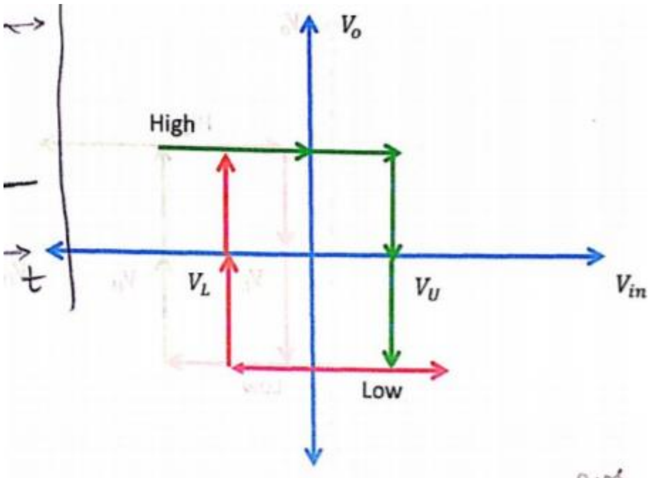


Transfer characteristics graph:



This is non-inverting Schmitt Trigger

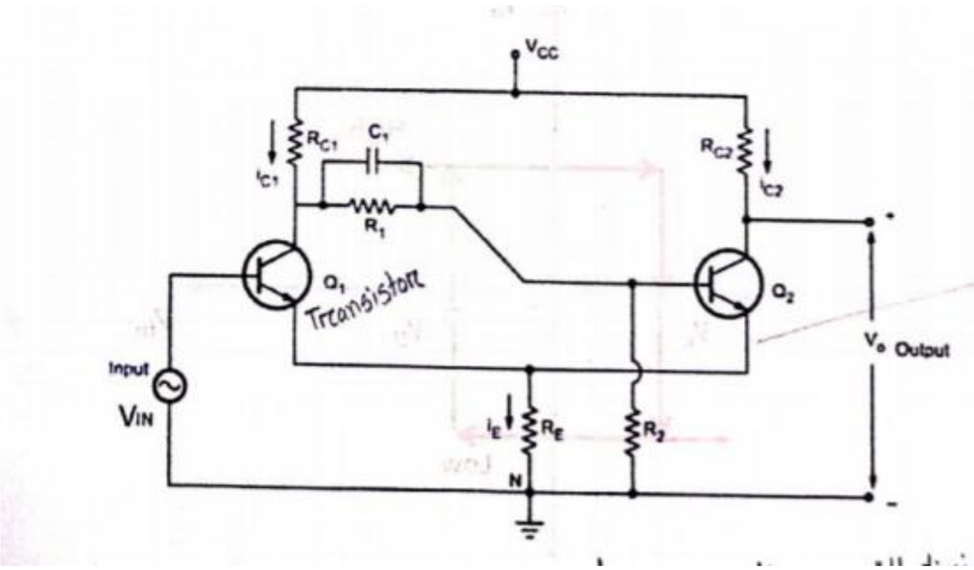
When Vin is lower than Vlow, Vo is low, then when Vin is higher than Vup, Vo is high. For inverting, its just reversed.



This is Inverting Schmitt Trigger

Schmitt trigger using transistors:

Schmitt triggers work like window comparator by providing upper and lower thresholds before counting input as a trigger.



- When Vin is zero, Vcc turns on Q2, so Q2 is saturated thus works as short circuit, thus Vo being low or zero.
- There is a voltage across Re through the Rc2->Re->ground path. It is denoted by,

$$V_{RE} = I \cdot R_E = \frac{V_{CC}}{(R_{C_2}+R_E)} \times R_E$$

nsistors

- Which is also the emitter voltage of Q1, so to turn on Q1, Vin should be Vre + 0.7
- When Vin turns on Q1, as long the voltage is higher, output is high. The Vre has a new value now,

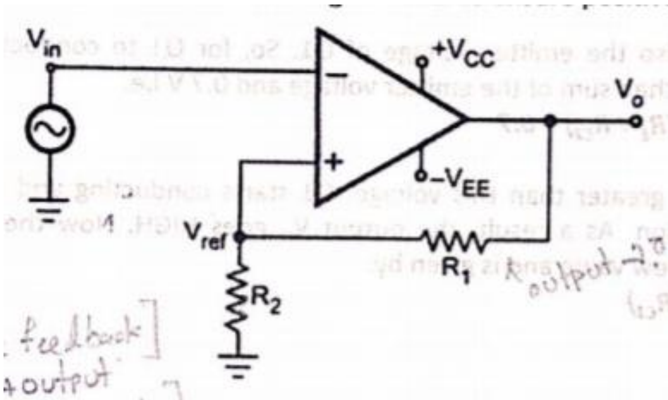
$$V_{IN} = (V_{CC} \times R_E) / (R_E + R_{C1}) + 0.7$$

This is how it works, the lower threshold and upper threshold is denoted by,

$$V_{LT} = (V_{CC} \times R_E) / (R_E + R_{C1}) + 0.7$$
$$V_{UT} = (V_{CC} \times R_E) / (R_E + R_{C2}) + 0.7$$

OP-AMP based Schmitt trigger:

Inverting Schmitt trigger circuit:



1. A threshold is introduced by using the Vo as a positive feedback.
2. Vo is either +Vcc or -Vcc. That is taken and then controlled using R1 and R2 to use as Vref.
3. When +Vcc is Vo, it is upper threshold and vice versa.

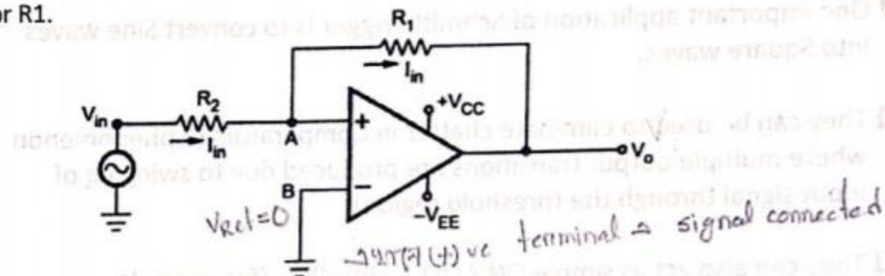
, $V_{REF} = (V_{SAT} \times R2) / (R1 + R2)$

e; $-V_{REF} = (-V_{SAT} \times R2) / (R1 + R2)$

Non inverting Schmitt trigger:

Non-Inverting Schmitt Trigger Circuit

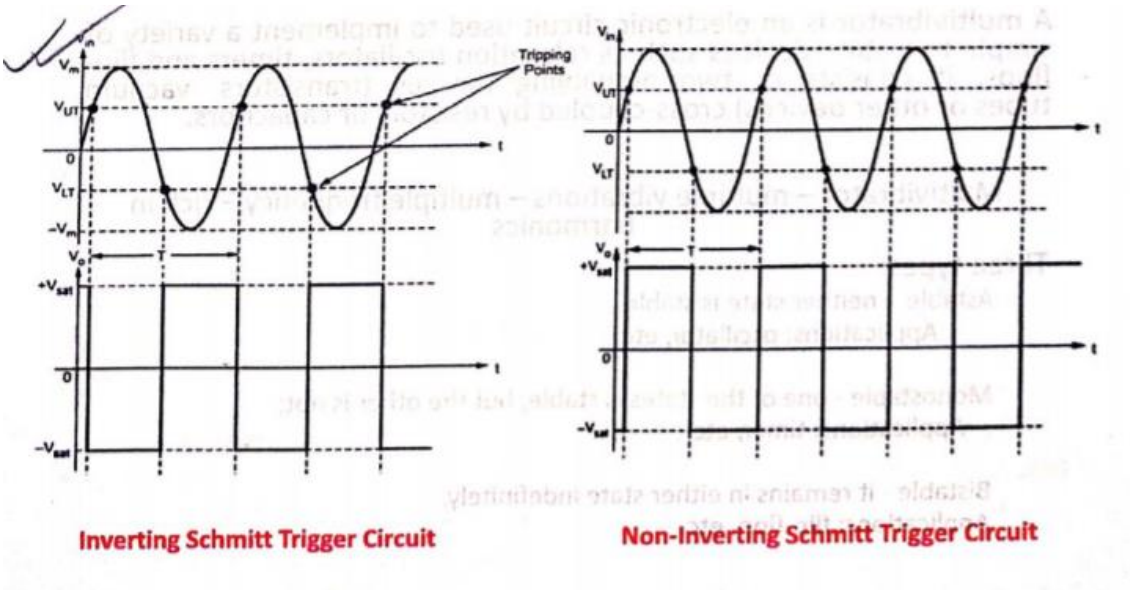
Coming to Non-Inverting Schmitt Trigger, the input in this case is applied to the non-inverting terminal of the Op-Amp. The output voltage is fed back to the non-inverting terminal through the resistor R1.



Let us assume that initially, the output voltage is at V_{SAT}. Until V_{IN} becomes less than V_{LT}, the output stays at this saturation level. Once the input voltage crosses the lower threshold voltage level, the output changes state to $-V_{SAT}$.

The output remains at this state until the input rises beyond the upper threshold voltage.

OUTPUT WAVES:



Inverting Schmitt Trigger Circuit

Non-Inverting Schmitt Trigger Circuit

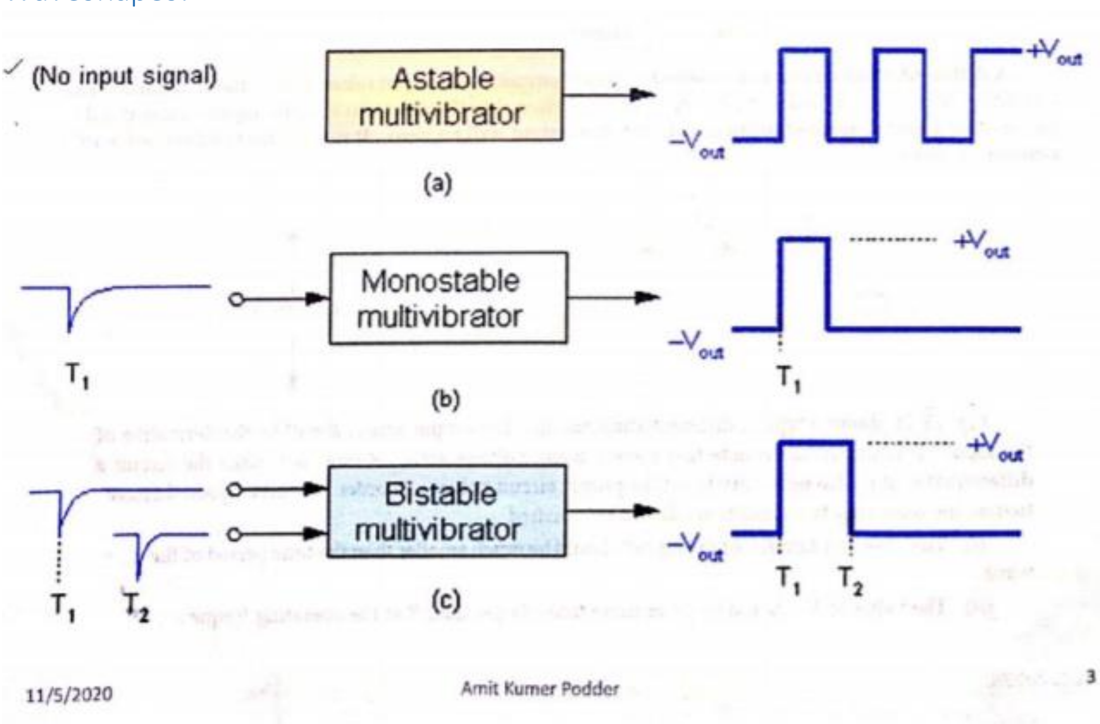
Multi-Vibrator:

A multivibrator is an IC that is used to create different two state devices. It consists two amplifying devices that are cross coupled.

Three types:

1. Astable – Oscillator
2. Monostable – Timer
3. Bistable – flipflop

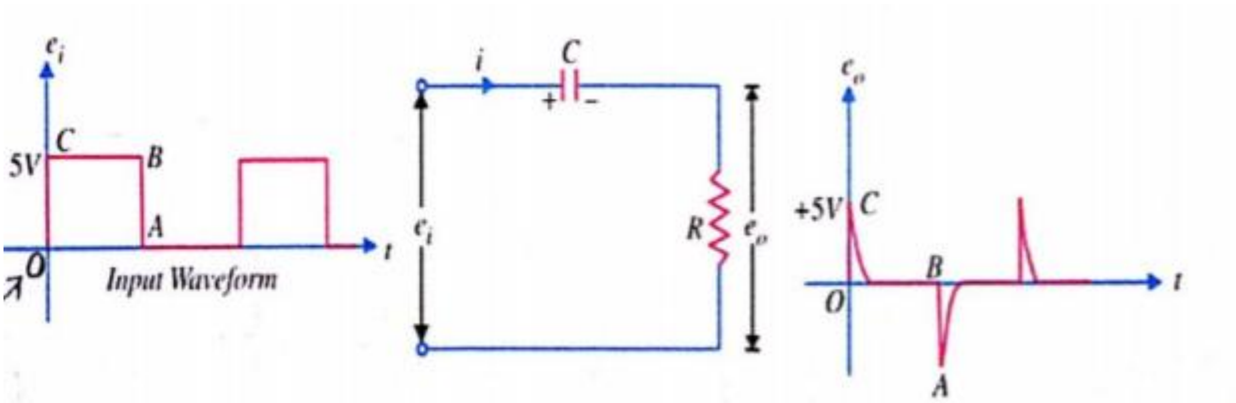
Waveshapes:



Trigger pulse generation:

A circuit where the output is derivative of the input

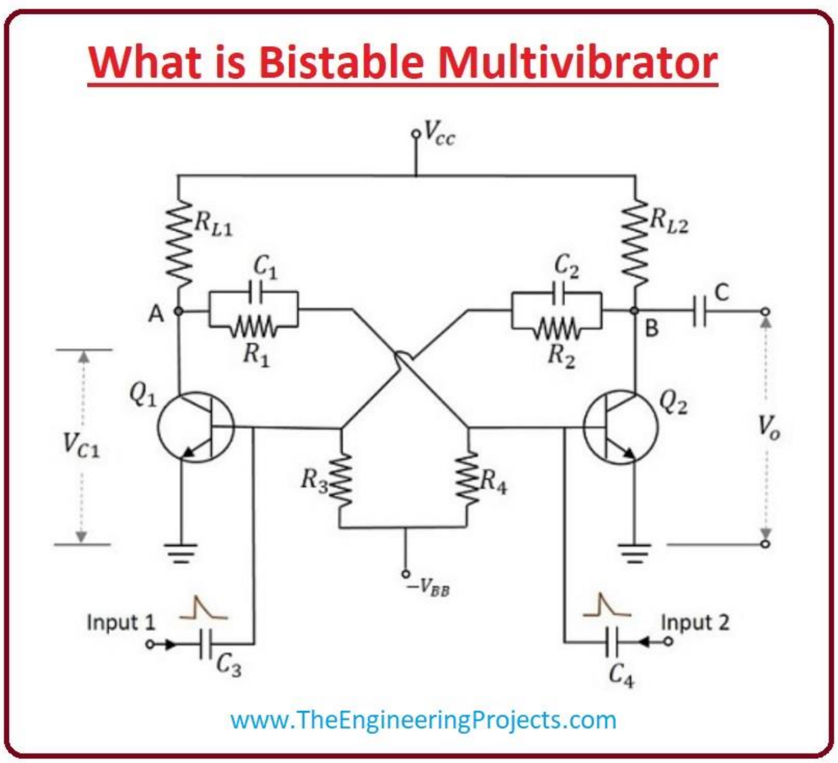
Vo = d/dt(Vin)



Requirements:

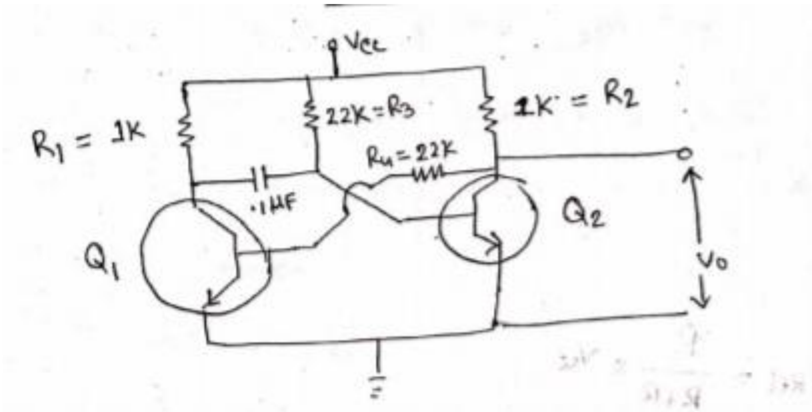
1. RC circuit time constant .69RC should be much smaller than input wave period.
2. Capacitive resistance should be 10 or more times higher than R.

Bistable:



1. When turned on, one of either of the transistors are on, lets say Q2.
2. When given trigger to Q1, collector current of Q1 is quickly increased, and collector voltage decreases.
3. Which is applied to the Q2 base, thus decreasing its collector current and increase base voltage, which is than applied to Q1 base, thus creating a loop. Eventually collector current of Q2 is zero and Q1 is on.

Monostable:



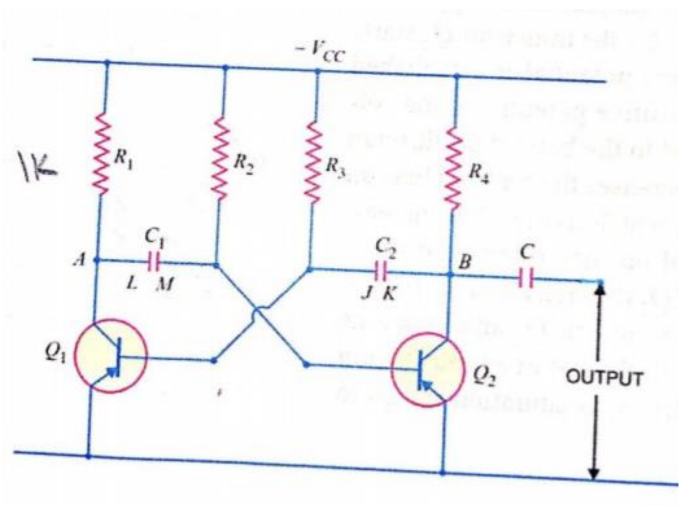
When applied initial Vcc, Q1 is off so goes R3>Q2 Base, which is the lowest resistance path.

Q2 is turned on, so Vcc now goes through R2 to ground. So Vo is low as short circuit. Capacitor is being charged.

When applied trigger, Q1 is turned on, so Vcc goes through R1 to ground. Q2 is off. Then after a time capacitor is discharged, turning on Q2, which in result turns off Q1. Q2 is stable state transistor.

Astable:

It is the non-stable part of Monostable x2. Doesn't need any trigger to switch state.



Vcc first turns on either, let say Q1.

C1 is being charged. After some time, C1 discharges, turning on Q2 and starting charging of C2.

The on off time is determined by RC constant.

ON or OFF time. The time for which either transistor remains ON or OFF is given by :

ON time for Q_1 (or OFF time for Q_2) is

$$T_1 = 0.694\, R_2 C_1$$

OFF time for Q_1 (or ON time for Q_2) is

$$T_2 = 0.694\, R_3 C_2$$

Total time period of the square wave is

$$T = T_1 + T_2 = 0.694\,(R_2 C_1 + R_3 C_2)$$

As $R_2 = R_3 = R$ and $C_1 = C_2 = C$,

$$\therefore \quad T = 0.694\,(RC + RC) \simeq 1.4\, RC \text{ seconds}$$

Frequency of the square wave is

$$f = \frac{1}{T} \simeq \frac{0.7}{RC} \text{ Hz}$$