

## Active filters and oscillators...

### Introduction :-

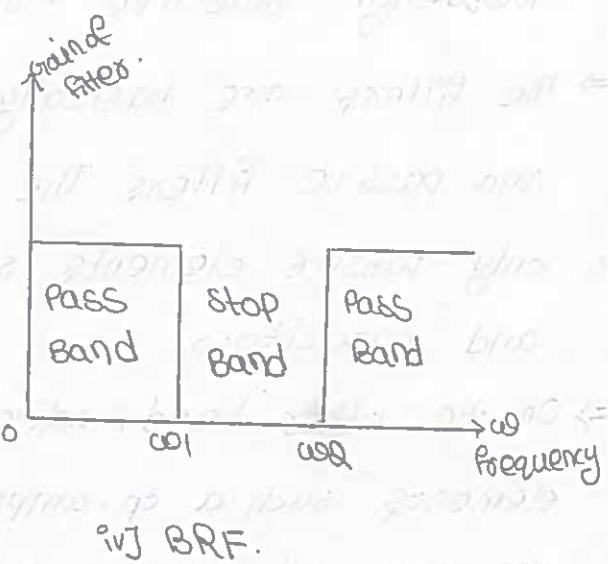
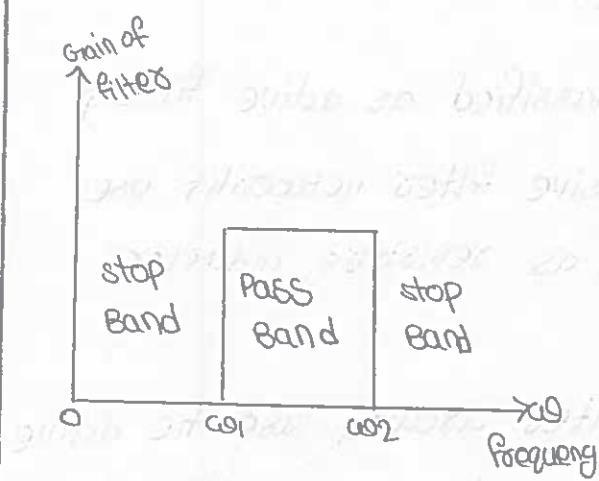
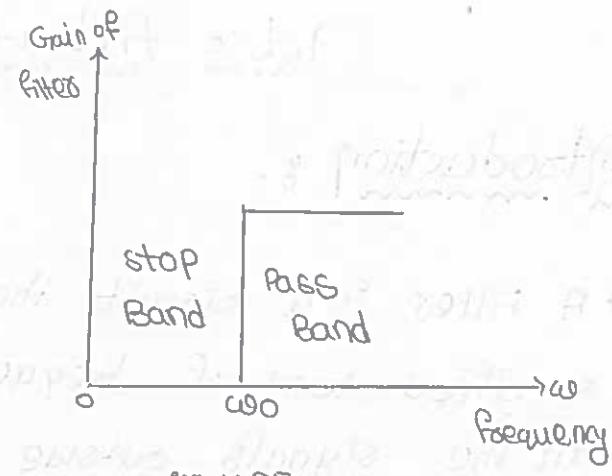
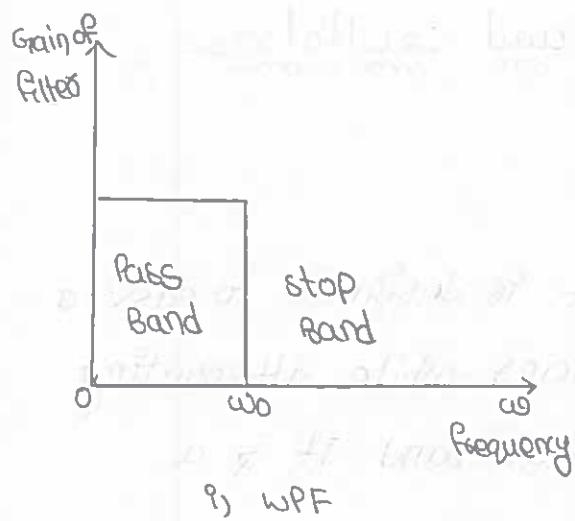
- ⇒ A Filter is a circuit that is designed to pass a specified band of frequencies while attenuating all the signals outside that band. It is a frequency selective circuit.
- ⇒ The filters are basically classified as active filters and passive filters. The passive filter networks use only passive elements such as resistors, inductors and capacitors.
- ⇒ On the other hand, active filter circuits use the active elements such as op-amps, transistors along with the resistors, inductors and capacitors.
- ⇒ Modern active filters do not use inductors as the inductors are bulky, heavy and nonlinear. The inductors generate the stray magnetic fields. The inductors dissipate considerable amount of power.

Filters are two types :- i, Active filter  
ii, Passive filter

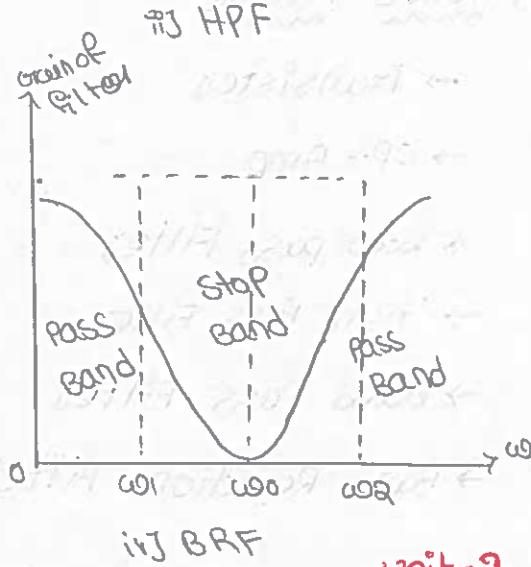
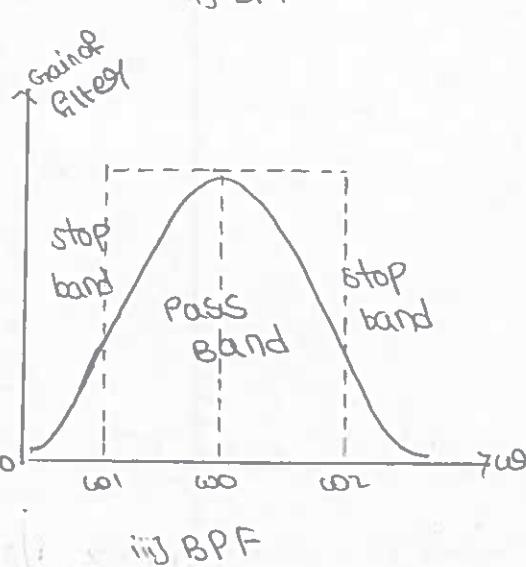
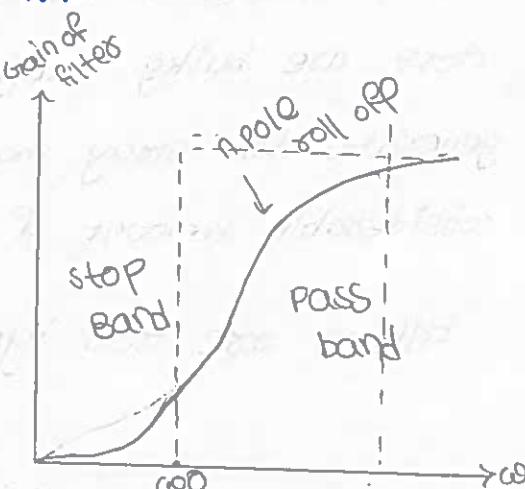
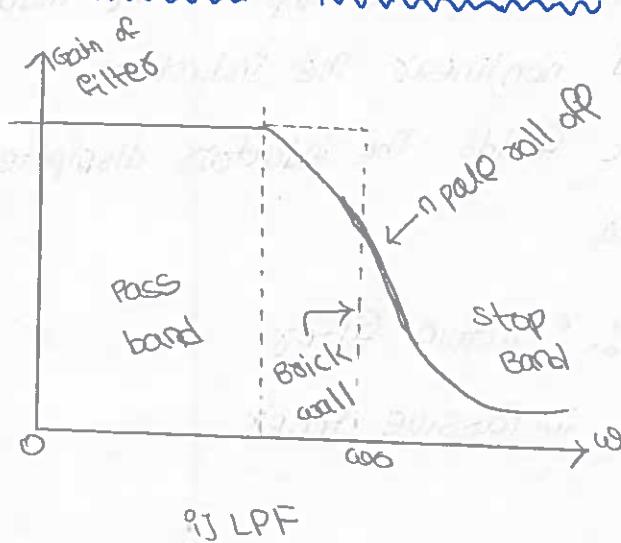
### i) Active Filters

- Transistor
- OP - Amp
- Low Pass Filter
- High Pass Filter
- Band Pass Filter
- Band Rejection Filter

## i) Ideal characteristics of Active Filters :-



## ii) Practical characteristics of Active Filters :-



## First Order Low Pass Filter

- \* The first order low pass filter is realised by R-C circuit used along with an op-amp, used in the non-inverting configuration.
- \* This also called one pole low pass filter.
- \* The resistance  $R_F$  and  $R_i$  decide the gain of the filter in the pass band.

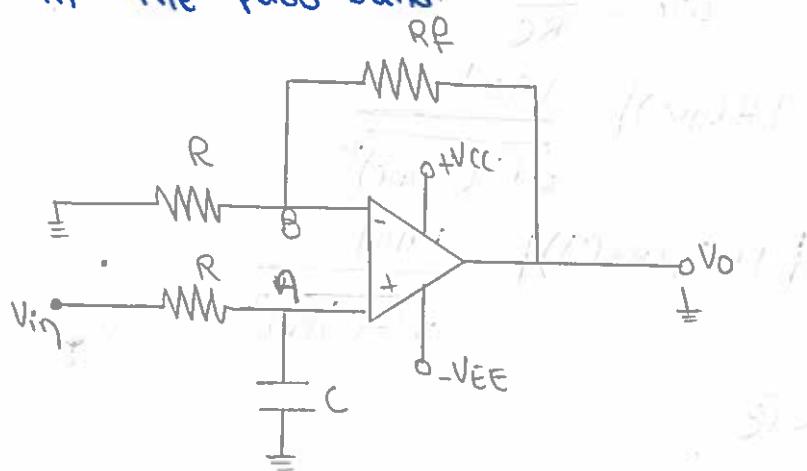


Fig :- First order LPF.

$$V_1(t) = \frac{1}{R + X_C} \cdot V_{in}(t) \quad \text{--- (1)}$$

Apply L.T to above equation

$$V_1(s) = \frac{1/sC}{R + 1/sC} \cdot V_{in}(s)$$

$$V_1(s) = \frac{1}{1 + s(RC)} \quad \text{--- (2)}$$

$\omega K T$

$$A_{CL} = 1 + \frac{R_F}{R_i}$$

$$\frac{V_o(s)}{V_{in}(s)} = \frac{1}{1 + s(RC)} \quad \text{--- (3)}$$

$$\frac{V_o(s)}{V_{in}(s)} = 1 + \frac{R_F}{R_i} \quad \text{--- (4)}$$

$$\frac{V_o(s)}{V_{in}(s)} = \frac{V_o(s)}{V_{in}(s)} \times \frac{V_1(s)}{V_{in}(s)}$$

$$= \left(1 + \frac{R_F}{R_i}\right) \left(\frac{1}{1 + s(RC)}\right)$$

we get  $A_{CL} = 1 + \frac{R_F}{R_i}$

$$H(s) = \frac{A_0}{1+s(RC)} \quad \text{--- (4)}$$

\* To find frequency response take  $s=j\omega$

$$H(j\omega) = \frac{A_0}{1+j\omega RC}$$

$$|H(j\omega)| = \frac{|A_0|}{\sqrt{1+(\omega RC)^2}}$$

$$\omega_C = \frac{1}{RC}$$

$$|H(j\omega)| = \frac{|A_0|}{\sqrt{1+(\omega/\omega_C)^2}}$$

$$|1 + (j(\omega/\omega_C))| = \frac{|A_0|}{\sqrt{1+(\omega/\omega_C)^2}}$$

\* If  $\omega < \omega_C$

$$|H(\omega)| = |A_0|$$

\* If  $\omega = \omega_C$

$$|H(\omega)| = 0.707 |A_0|$$

\* If  $\omega > \omega_C$

$$|H(\omega)| \approx 0$$

$$\phi = -\tan^{-1}(\omega/\omega_C)$$

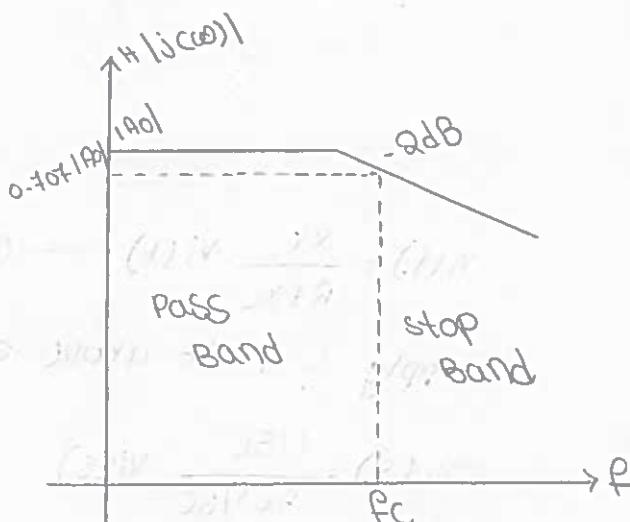


Fig :- Frequency response

### High Pass Filter for First order

\* As mentioned earlier, a high pass filter is a circuit that attenuates all the signals below a specified cut off frequency denoted as  $f_L$ .

\* Thus, a high pass filter performs the opposite function to that of low pass filter. Hence, the high pass filter circuit can be obtained by interchanging frequency determining resistances and capacitors in low pass filter circuit.

\* The first order high pass filter can be obtained by interchanging the elements R and C in a first order low pass filter circuit.

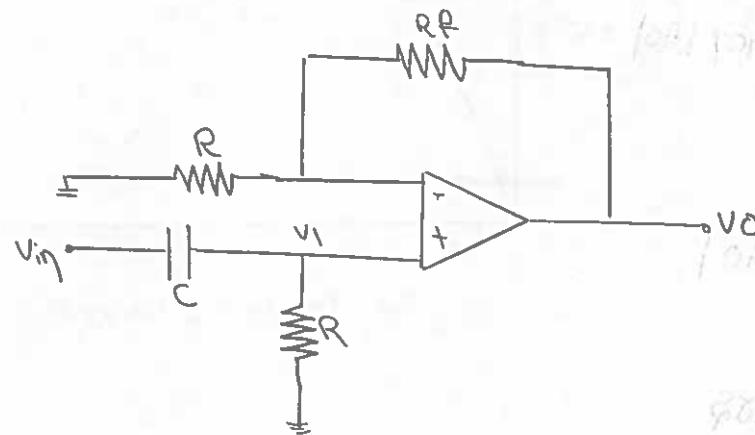


Fig.: First order HPF

$$V_1(s) = \frac{R}{R + 1/sC} * V_i(s)$$

$$V_1(s) = \frac{R}{\frac{R}{sC} + 1} * V_i(s)$$

$$\frac{V_1(s)}{V_i(s)} = \frac{R(sC)}{1 + R(sC)}$$

$$A_{CL} = 1 + \frac{R_P}{R_1}$$

$$\frac{V_o(s)}{V_i(s)} = \frac{V_o(s)}{V_1(s)} * \frac{V_1(s)}{V_i(s)}$$

$$= \left(1 + \frac{R_P}{R_1}\right) \left(\frac{R(sC)}{1 + R(sC)}\right)$$

$$\text{Let } 1 + \frac{R_P}{R_1} = A_0$$

$$H(s) = \frac{A_0 R(sC)}{1 + R(sC)} \quad \text{--- (1)}$$

$$H(j\omega) = \frac{A_0 R j\omega C}{1 + R j\omega C} - \frac{j\omega C R (A_0)}{j\omega C (1/j\omega C + 1)}$$

$$|H(j\omega)| = \frac{|A_0|}{\sqrt{1 + (1/\omega C)^2}} \quad (\omega_C = 1/RC)$$

$$|H(j\omega)| = \frac{|A_0|}{\sqrt{1 + (\omega/\omega_C)^2}}$$

$$|1 + j(\omega \pi f)| = \frac{|A_0|}{\sqrt{1 + (\omega/\omega_C)^2}}$$

If  $f \ll f_c$

$$H(s) = H(2\pi f) = 0$$

If  $f = f_c$

$$H(s) = \frac{|A_0|}{\sqrt{2}} = 0.707 |A_0|$$

If  $f > f_c$

$$H(s) = \frac{|A_0|}{\sqrt{1}} = |A_0|$$

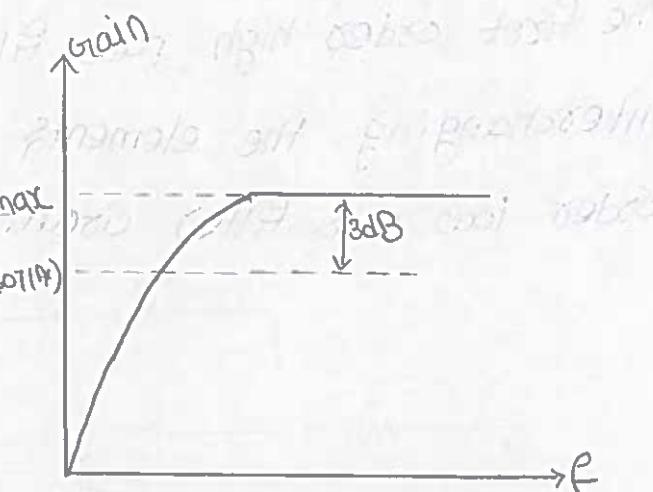


fig. Frequency Response.

### Band pass Filters

- \* A band pass filter is basically a frequency selector. It allows one particular band of frequencies to pass.
- \* Thus, the passband is between the two cut-off frequencies  $f_H$  and  $f_L$  where  $f_H > f_L$ .
- \* Any frequency outside this band gets attenuated.
- \* The pass band which is between  $f_L$  and  $f_H$  is called bandwidth of the filter denoted as B.W.

$$\text{B.W} = f_H - f_L$$

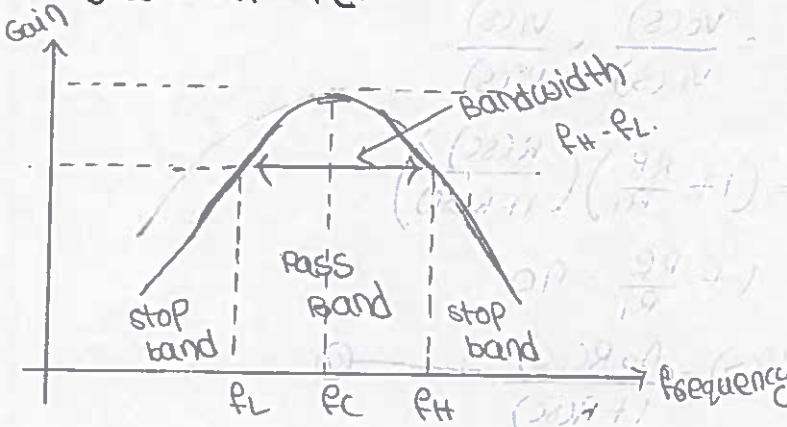


fig :- Bandpass Filter.

Based upon the quality factor BPF are classified into 2 types.

1. narrow Band BPF  $Q > 10$

2. wide Band BPF  $Q < 10$

## 1. Narrow Band BPF :-

- The narrow band pass filter uses only op-amp as against two by wide band pass filter. It has following features.

- It has two feedback paths.
- The op-amp is in the inverting configuration.

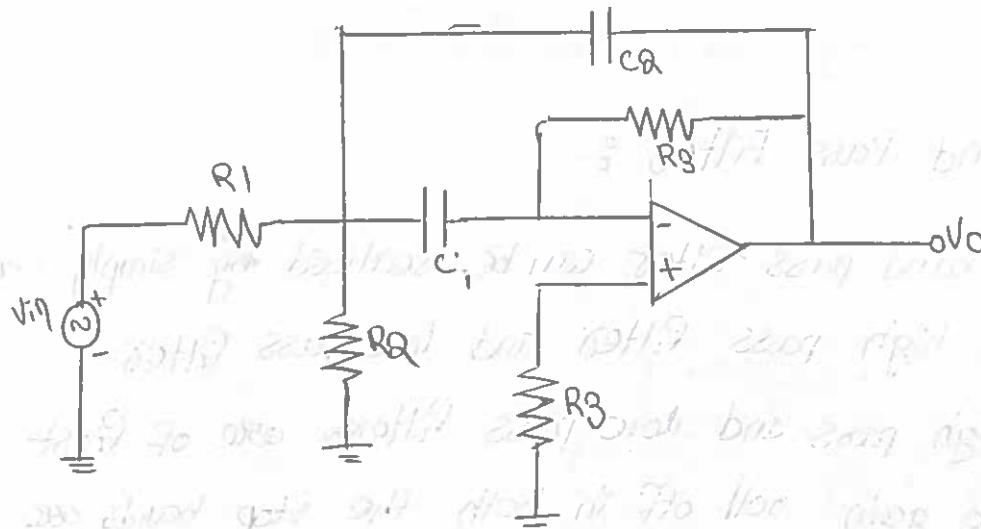


Fig. - Narrow band pass filter

- The important parameters of the narrow band pass filter are  $f_L$ ,  $f_H$  the center frequency  $f_c$ , the gain at the center frequency  $A_F$  and the quality factor  $Q$ .
- The relationship of components with the various parameters are given by the following equations.

For simplifying the calculation choose

$$C_1 = C_2 = C$$

$$R_1 = \frac{Q}{2\pi f_c C A_F}$$

$$R_2 = \frac{Q}{2\pi f_c C (Q^2 - A_F)}$$

$$R_g = \frac{Q}{\pi f_c Q}$$

$$\text{Add } A_F = \frac{R_3}{2R_1} = \text{gain at } f_c.$$

The AF must satisfy the equation  $A_F < 2Q^2$ .

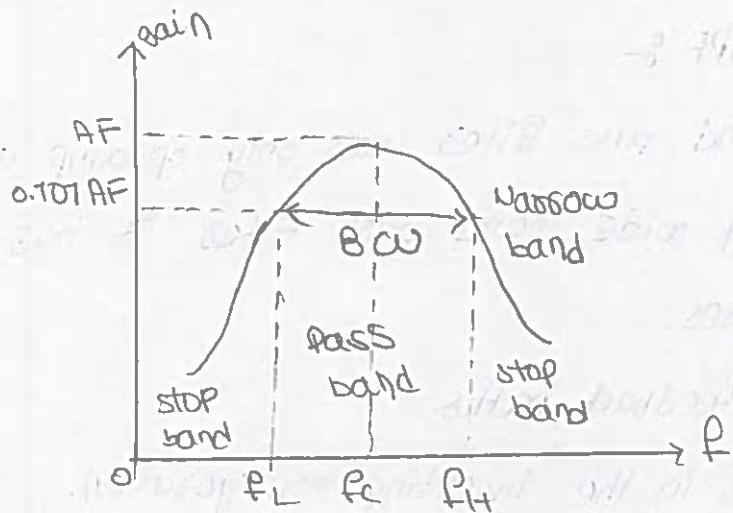


Fig : narrow Band pass filter.

### 2. Wide Band Pass Filter :-

- \* The wide band pass filter can be realised by simply cascading a high pass filter and low pass filters.
- \* If both high pass and low pass filters are of first order, the gain roll off in both the stop bands are  $\pm 20\text{dB/decade}$  and wide band pass filter is of first order.
- \* To get gain roll off  $\pm 40\text{dB/decade}$  and second order wide band pass filter, both high pass and low pass filters must be of second order and so on.
- \* The first order wide band pass filter obtained by cascading first order high pass and low pass filter sections.

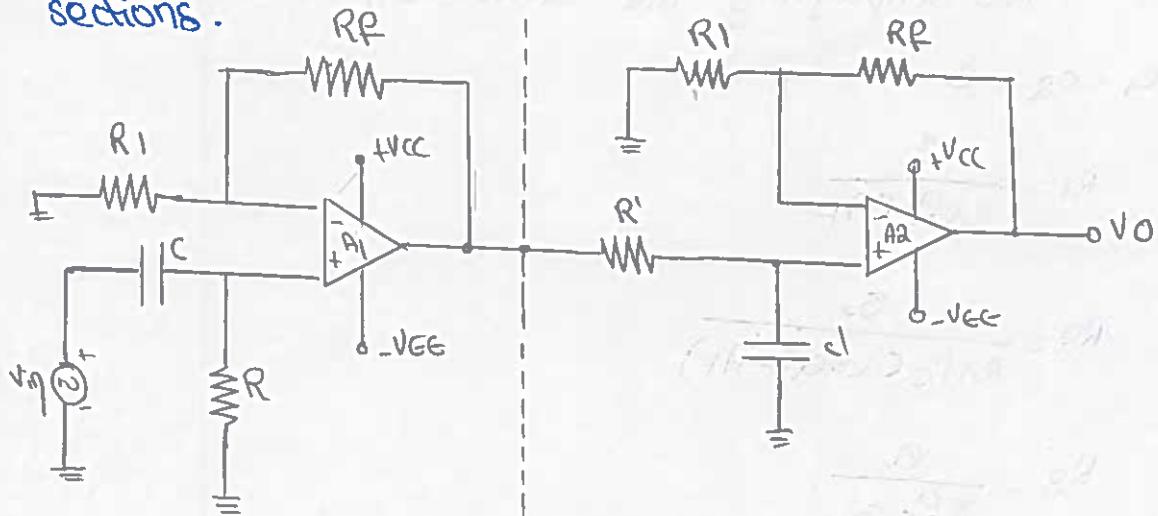


Fig :- wide Band Pass Filter.

## Band Reject Filter

5

⇒ Band Reject filter used to reject the certain band of frequencies. This is also certain band of frequencies. This is also called as band elimination filter.

⇒ This band rejection filter is classified into 2 types based upon the quality factor.

1. Narrow Band BRF  $Q > 10$

2. wide Band BRF  $Q < 10$

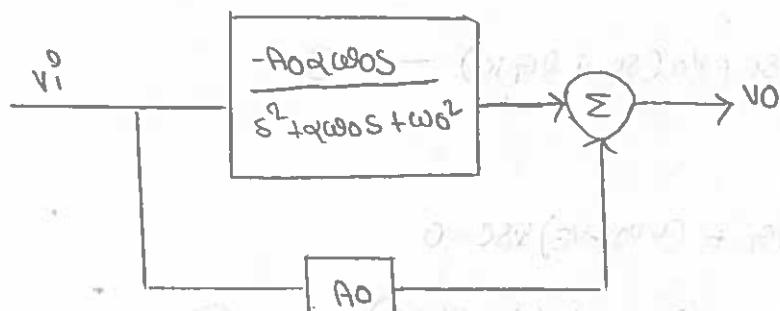
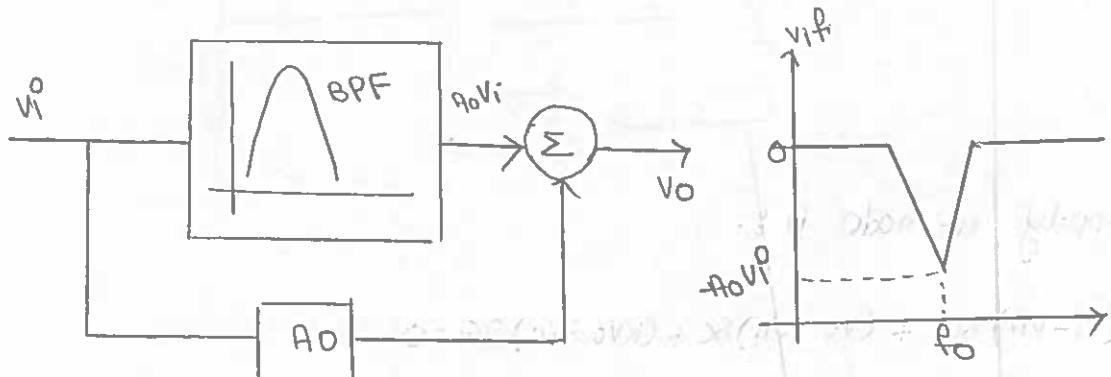
1. Narrow Band BRF :-

i) Notch Filter

ii) Twin T network Filter

1. Notch Filter :-

- By using notch filter we can classified eliminate or reject a sudden frequency.
- In this notch filter we can subtract the BPF output of response from input signal.

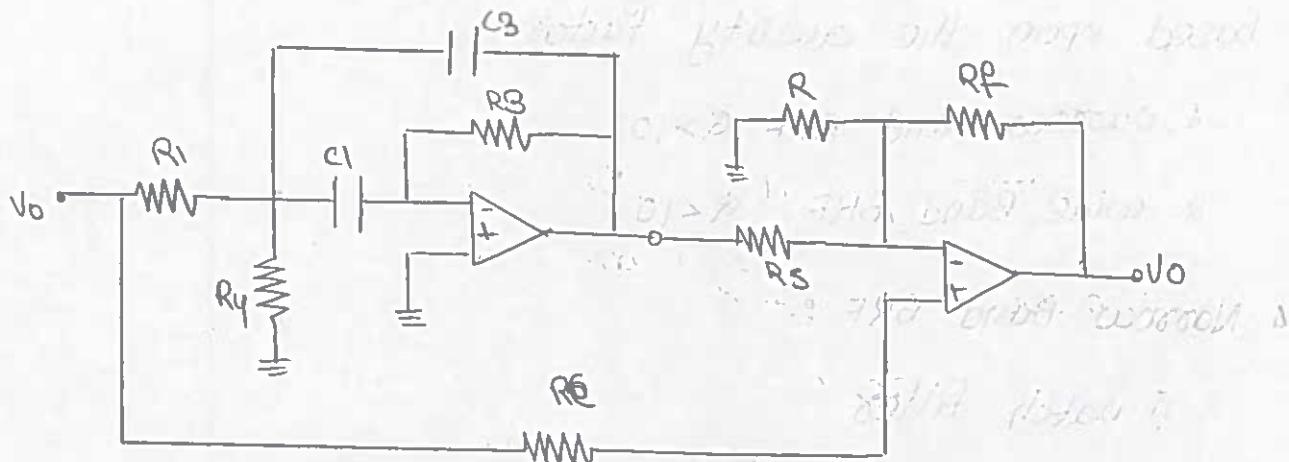


$$V_{o(s)} = A_0 V_i(s) + V_i(s) \left[ -\frac{A_0 \omega_0 s}{s^2 + \omega_0 s + \omega_0^2} \right]$$

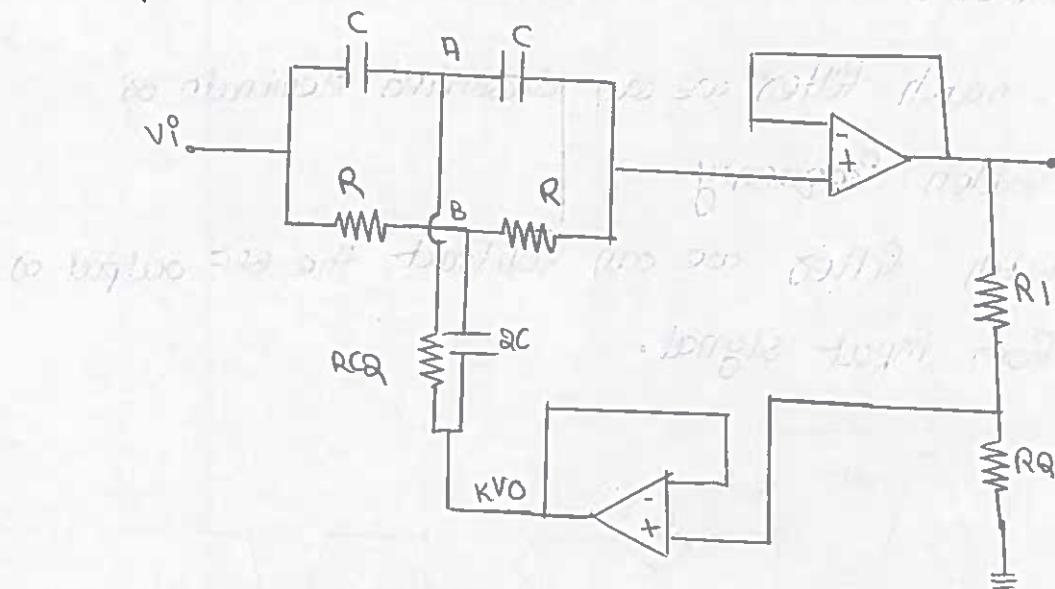
$$V_{o(s)} = A_0 V_i(s) \left[ 1 - \frac{\omega_0 s}{s^2 + \omega_0 s + \omega_0^2} \right]$$

$$\frac{V_o(s)}{V_i(s)} \rightarrow A_0 \left[ \frac{s^2 + \omega_0^2}{s^2 + \omega_0 s + \omega_0^2} \right]$$

Schematic circuit for the notch filter



b. Twin T network Filter :-



Apply at node A :-

$$(V_i - V_A) S_C + (V_o - V_A) S_C + (K_V O - V_A) 2G_1 = 0$$

$$V_A (2S_C + 2G_1) = V_i S_C + V_o S_C + 2G_1 + V_o$$

$$V_A^2 (S_C + G_1) = V_i S_C + V_o (S_C + 2G_1) \quad \text{--- (1)}$$

At node B :-

$$(V_i - V_B) G_1 + (V_o - V_B) G_1 + (K_V O - V_B) 2S_C = 0$$

$$2V_B (G_1 + S_C) = V_i G_1 + V_o (G_1 + 2K_S C) \quad \text{--- (2)}$$

at node P :-

$$(V_A - V_0)S_C + (V_B - V_0)G_I = 0$$

$$V_A S_C + V_B G_I = V_0 (S_C + G_I) \quad \text{--- (1)}$$

From equation (1)

$$V_A = \frac{V_0 S_C + V_0 (S_C + G_I)}{S_C + G_I}$$

From equation (2)

$$V_B = \frac{V_0 G_I + V_0 (G_I + S_C G_I)}{G_I + S_C}$$

$$\frac{(V_0 S_C + V_0 G_I) S_C}{S_C + G_I} + \frac{(V_0 G_I + V_0 G_I + S_C G_I) G_I}{S_C + G_I} = V_0 (S_C + G_I)$$

$$\frac{V_0 S_C^2 + V_0 S_C G_I + S_C G_I K_S C}{S_C + G_I} + \frac{V_0 G_I^2 + V_0 G_I G_I + V_0 S_C G_I}{S_C + G_I} = V_0 (S_C + G_I)$$

$$\frac{V_0}{V_i} = \frac{s^2 + (G_I/c)^2}{s^2 + (G_I/c)^2 + 4(1-K) s(G_I/c)}$$

Assume  $\omega_0 = G_I/c$

$$H(s) = \frac{V_i(s)}{V_o(s)} = \frac{s^2 + \omega_0^2}{s^2 + \omega_0^2 + 4(1-K)s\omega_0}$$

Let  $s = j\omega$

$$H(j\omega) = \frac{-\omega^2 + \omega_0^2}{-\omega^2 + \omega_0^2 + 4(1-K)j\omega\omega_0}$$

$$= \frac{\omega^2 - \omega_0^2}{\omega^2 - \omega_0^2 - 4j(1-K)\omega\omega_0}$$

$$|H(j\omega)| = \frac{|\omega^2 - \omega_0^2|}{\sqrt{(\omega^2 - \omega_0^2)^2 + 16(1-K)^2(\omega\omega_0)^2}}$$

$\omega \cdot K \cdot T$  at  $\omega = \omega_0$

$$H(j\omega) = 0$$

At 3dB Frequency

$$A = \frac{1}{\sigma \alpha} = 0.407$$

$$\frac{1}{\omega} = \frac{\omega^2 - \omega_0^2}{\sqrt{(\omega^2 - \omega_0^2)^2 + 16(1-k)^2(\omega\omega_0)^2}}$$

$$\sqrt{(\omega^2 - \omega_0^2)^2 + 16(1-k)^2(\omega\omega_0)^2} = \sqrt{\omega^2 - \omega_0^2}$$

$$(\omega^2 - \omega_0^2)^2 + 16(1-k)^2(\omega\omega_0)^2 = 2(\omega^2 - \omega_0^2)^2$$

$$16(1-k^2)^2(\omega\omega_0)^2 = 2(\omega^2 - \omega_0^2)^2 - (\omega^2 - \omega_0^2)^2$$

$$16(1-k^2)^2(\omega\omega_0) = (\omega^2 - \omega_0^2)^2$$

Square root on both sides

$$\omega^2 - \omega_0^2 = \pm 4(1-k)(\omega\omega_0)$$

$$\omega^2 - \omega_0^2 \pm 4(1-k)\omega\omega_0 = 0$$

$$\left(\frac{\omega}{\omega_0}\right)^2 - 1 \pm 4(1-k)\left(\frac{\omega}{\omega_0}\right) = 0$$

$$\left(\frac{\omega}{\omega_0}\right) = \frac{\pm 4(1-k) \pm \sqrt{16(1-k)^2 + 1}}{2}$$

$$= \pm 2(1-k) \pm \sqrt{4(1-k)^2 + 1}$$

$$\left(\frac{\omega}{\omega_0}\right) = -2(1-k) + \sqrt{4(1-k)^2 + 1}$$

$$f_H = \left(\frac{\omega}{\omega_0}\right), \quad f_L = \left(\frac{\omega_0}{\omega_0}\right)_2$$

$$\left(\frac{\omega}{\omega_0}\right) = 2(1-k) + \sqrt{4(1-k)^2 + 1}$$

$$f_H = f_0 [2(1-k) + \sqrt{4(1-k)^2 + 1}]$$

$$\begin{aligned} \text{Band width} &= f_H - f_L \\ &= 4f_0(1-k) \end{aligned}$$

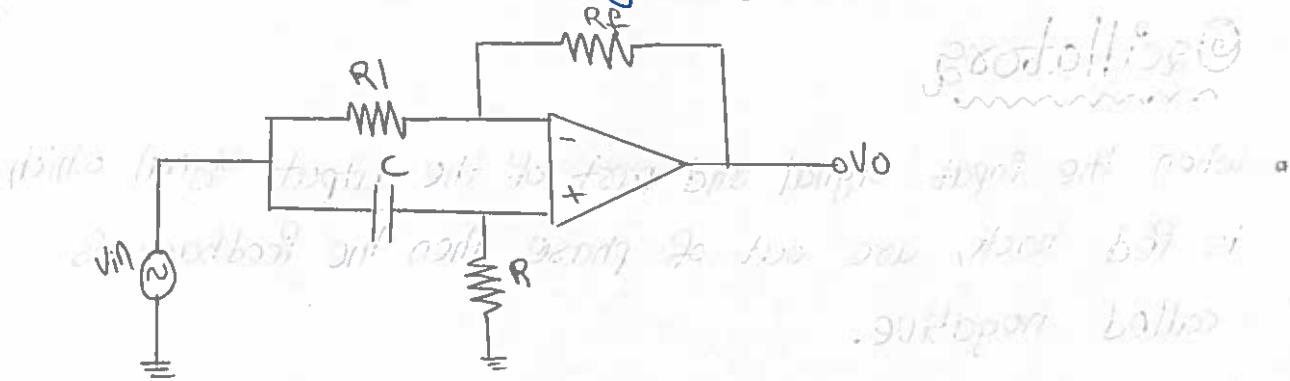
$$Q = \frac{f_0}{B \cdot \omega}$$

$$= \frac{f_0}{4f_0(1-k)}$$

$$Q = \frac{1}{4(1-k)}$$

All Pass Filter :-

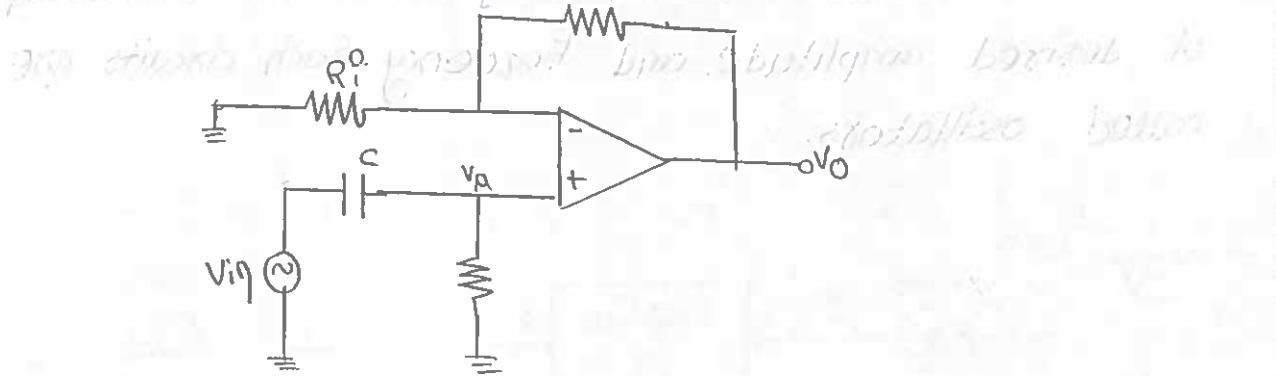
- To find the phase differences between the signals : use
- It allows all frequency signals.



case (i) :-  $V_{in}$  is connected to -ve terminal of op-amp

case (ii) :-  $V_{in}$  is connected to +ve terminal of op-Amp

$$V_{o1} = -\frac{R_F}{R_i} \times V_{in}$$



$$V_{o1} = -\frac{R_F}{R_i} \times V_{in} \quad \text{--- (1)}$$

$$A = 1 + \frac{R_F}{R_i}$$

$$V_{o2} = (1 + \frac{R_F}{R_i}) V_A$$

$$V_{o2} = \left(1 + \frac{R_F}{R_i}\right) \left(\frac{X_C}{R + X_C}\right)$$

$$V_{o2} = \left(1 + \frac{R_F}{R_i}\right) \left(\frac{1}{1 + SCR}\right)$$

$$\frac{|V_{o1}|}{|V_{in}|} = \frac{\sqrt{1 + (2\pi FRC)^2}}{\sqrt{1 + (2\pi FRC)^2}}$$

$$|V_o| = |V_{in}|$$

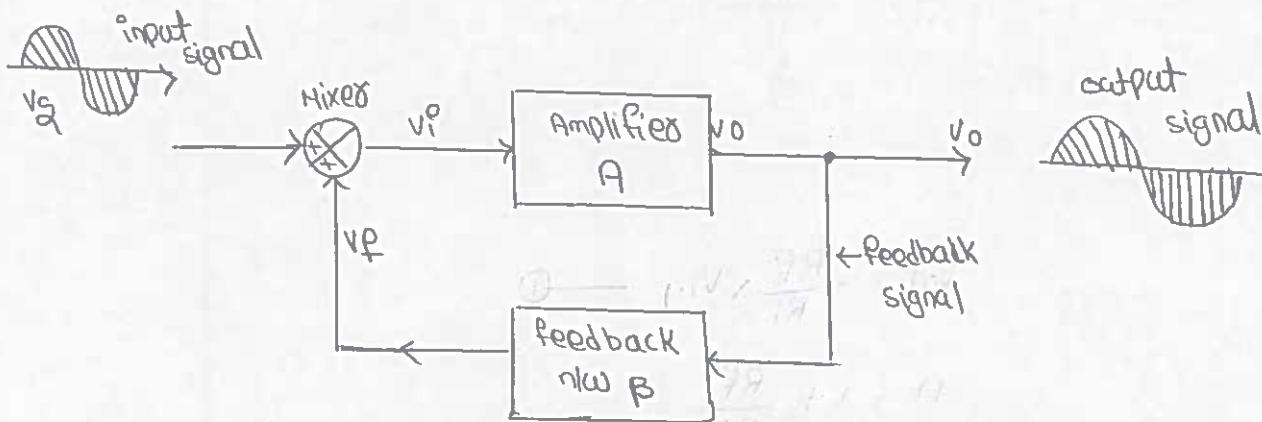
$$V_o = V_{o1} + V_{o2}$$

$$V_o = -\frac{R_f}{R_i} V_{in} + \left(1 + \frac{R_f}{R_i}\right) \left(\frac{1}{1+sCR}\right)$$

$$V_o = \sqrt{1 + (2\pi f R C)^2}$$

## Oscillators

- when the input signal and part of the output signal which is fed back, are out of phase then the feedback is called negative.
- when the input signal and part of the output signal which is fed back, are in phase with each other then the feedback is called positive.
- The +ve feedback results into oscillations and hence hence used in electronic circuits to generate the oscillations of desired amplitude and frequency. Such circuits are called oscillators.



- The expressions for the gains are

$$A = \frac{V_o}{V_i} \text{ - open loop gain } \& \quad A_F = \frac{V_o}{V_s} = \text{closed loop gain}$$

From Fig

$$V_i = V_s + V_F \quad \& \quad V_F = \beta V_o \text{ hence } V_i = V_s + \beta V_o$$

$$V_s = V_i - \beta V_o \text{ hence } A_F = \frac{V_o}{V_i - \beta V_o}$$

$$A_F = \frac{V_o}{V_i - \beta V_o}$$

- Dividing both numerators and denominators by  $V_p$

$$A_f = \frac{V_o/V_p}{1 - \beta \frac{V_o}{V_p}} \quad \text{i.e.,}$$

$$A_f = \frac{A}{1 - AB}$$

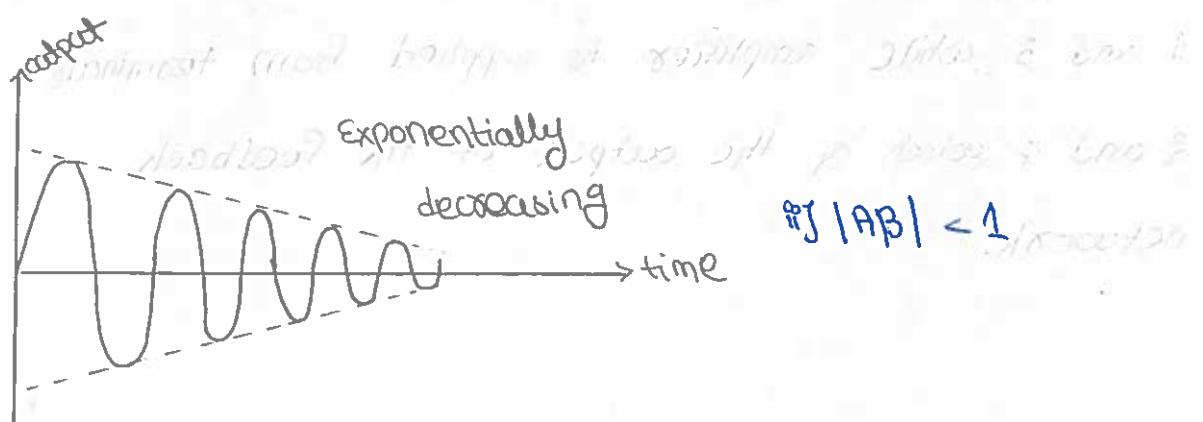
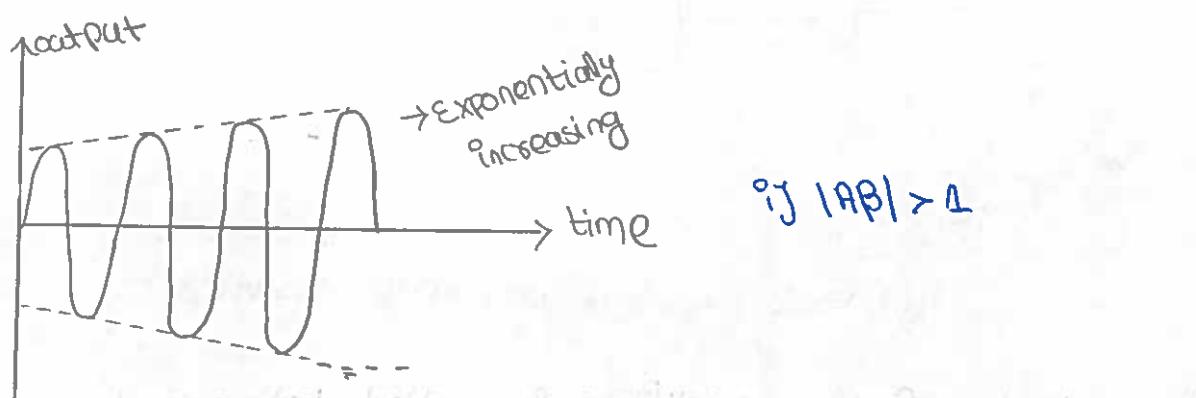
- $V_o = AV_p$  while  $V_p = -BV_o$  where negative indicates  $180^\circ$  phase shift between  $V_o$  and  $V_p$

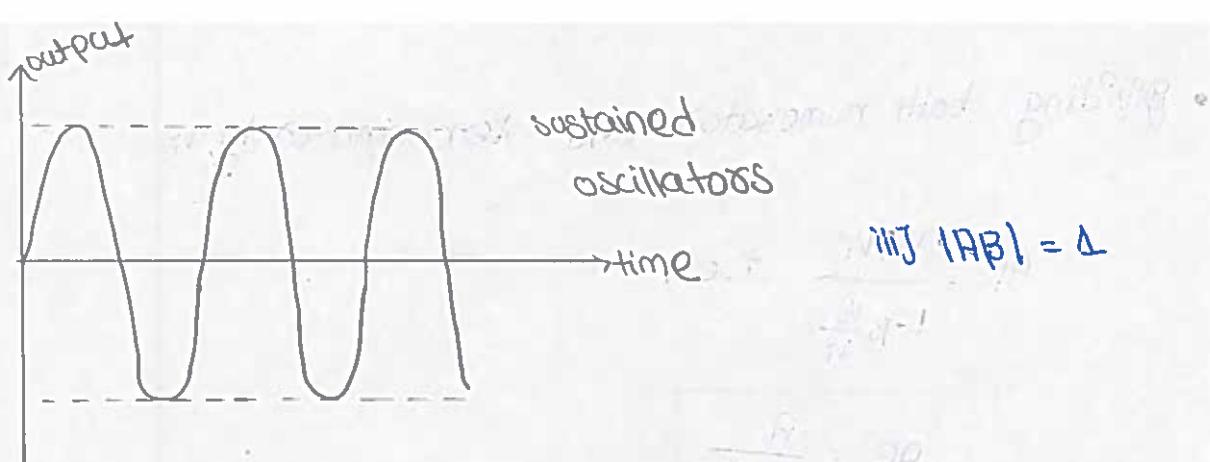
$$V_p = -ABV_o$$

- For oscillator,  $V_p = 0$  and  $V_p$  must drive the circuit hence  $V_p = V$
- $V_o = -ABV_i$  i.e.,  $-AB = 1$
- The condition  $-AB = 1$  is called Barkhausen condition
- From equation we can write,  $AB = -1 + j0$  hence equating magnitudes,

$$|AB| = 1$$

### Effect of $|AB|$ on oscillations





## Wien Bridge Oscillator

- The Wien bridge oscillator is also an RC oscillator which uses Wien bridge circuit as its feedback network.
- The amplifier used in this oscillator is a non inverting amplifier which does not introduce any phase shift.
- The feedback network which is a Wien bridge circuit also does not introduce any phase shift.
- Thus phase shift around a loop in a Wien bridge oscillator is  $0^\circ$ .

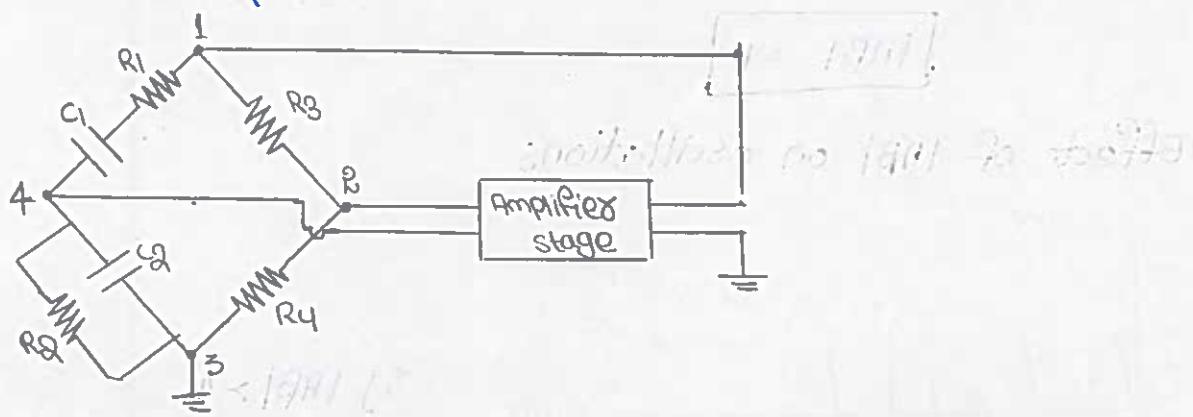


Fig :- Basic circuit of Wien Bridge oscillator

- The output of the amplifier is applied between terminals 1 and 3 while amplifier is supplied from terminals 2 and 4 which is the output of the feedback network.

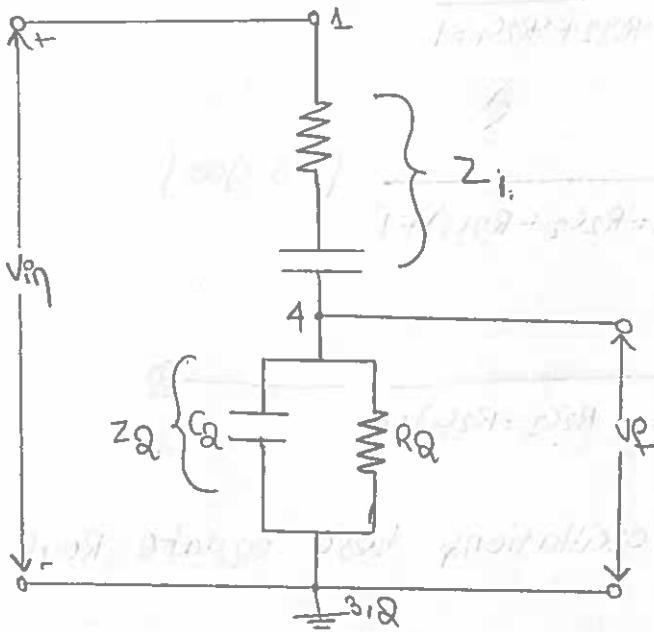


fig :- Feedback network of Wein  
Bridge oscillator

$\rightarrow$  in phase with each other (non-inverting)

$$A = 1 + \frac{R_f}{R_1}$$

$$A = 1 + \frac{R_3}{R_4} \quad \text{---} \textcircled{1}$$

$$V_f = \left( \frac{z_2}{z_1 + z_2} \right) V_o$$

$$z_1 = R_1 + \frac{1}{sC_1}$$

$$z_2 = \frac{R_2}{sC_2 R_2}$$

$$V_f = \left( \frac{R_2 / sC_2 R_2}{R_1 + \frac{1}{sC_1} + R_2 / sC_2 R_2} \right) V_o$$

$$\frac{V_f}{V_o} = B = \frac{R_2 / sC_2 R_2}{\frac{R_1 sC_1 + 1}{sC_1} + \frac{R_2}{sC_2 R_2}}$$

$$B = \frac{R_2 / sC_2 R_2}{C_2 R_2 (R_1 sC_1 + 1) + C_1 R_2}$$

$$= \frac{R_2 sC_1}{R_1 (1 + sR_2 C_2) sC_1 + (1 + sR_2 C_2) + R_2 sC_1}$$

$$= \frac{sC_1 R_2}{(R_1 + sR_1 R_2 C_2) sC_1 + 1 + sR_2 C_2 + sR_2 C_1}$$

$$= \frac{SC_1 R_2}{S R_1 C_1 + S^2 R_1 R_2 C_1 C_2 + S R_2 C_2 + S R_2 C_1 + 1}$$

$$B = \frac{SC_1 R_2}{j(C_1 R_2 C_1 C_2) + (R_1 C_1 + R_2 C_2 + R_2 C_1) + 1} \quad [S = j\omega]$$

$$B = \frac{j\omega R_2 C_1}{-\omega^2 R_1 R_2 C_1 C_2 + j\omega (C_1 C_1 + R_2 C_2 + R_2 C_1) + 1} \rightarrow ⑤$$

→ To get the sustained oscillations here equate Real part = 0

$$B = \frac{j\omega R_2 C_1}{j\omega (C_1 C_1 + R_2 C_2 + R_2 C_1)}$$

$$\text{if } R_1 = R_2 = R \quad \& \quad C_1 = C_2 = C$$

$$B = \frac{RC}{RC + RC + RC}$$

$$B = \frac{RC}{3RC} = \frac{1}{3}$$

$$|AB| \geq 1$$

$$|A| \geq 3$$

$$B = 1/3$$

From equation ①

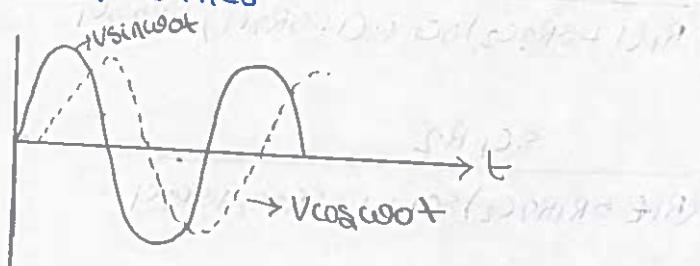
$$A = 1 + \frac{R_3}{R_4} = 3 \Rightarrow \frac{R_3}{R_4} = 2$$

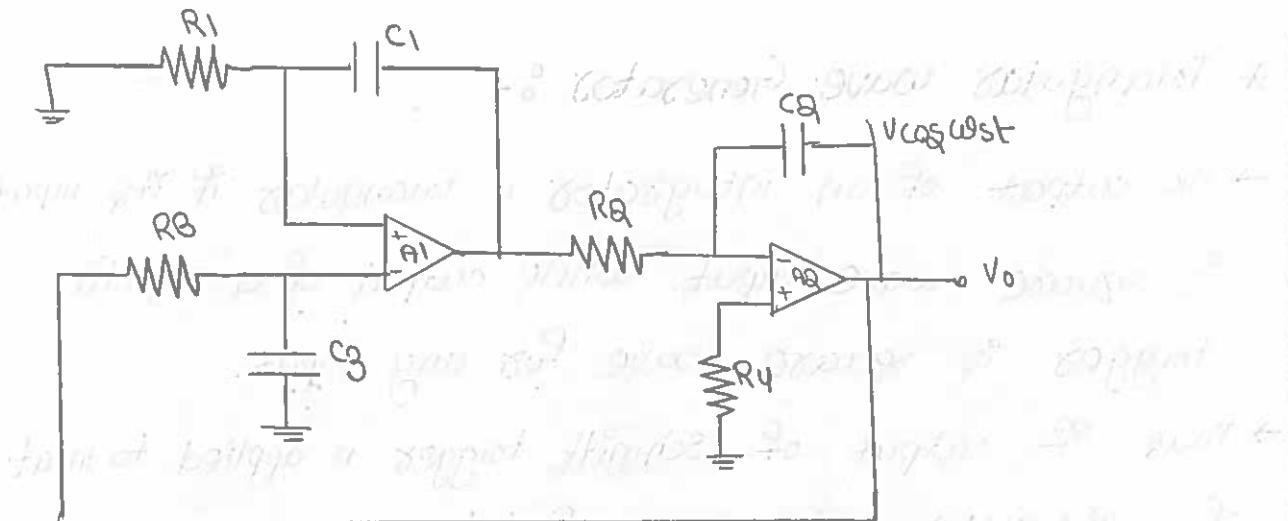
$$R_3 = 2 R_4$$

## Quadrature Oscillator

- \* This oscillator generates two signals which is having the same frequency but a  $90^\circ$  phase shift with respect to each other.

Eg :-





⇒ The  $A_1$  is a non inverting op-amp it can generate a sinusoidal signal as output.

$$\text{i.e., } V_{O1} = V \sin \omega t$$

⇒ Now this  $V_{O1}$  act as a input signal to the  $A_2$ .

This AB section act as a integrator circuit that means it integrates the input signal.

$$V_{O2} = V \cos \omega t$$

Here  $A_2$  is a inverting op-amp.

⇒ The  $90^\circ$  phase shift is provided by the  $R_3$  and  $C_2$ .

⇒ This circuit provides the sustain oscillations at 8dB frequency

$$\text{so, } B = \frac{1}{R_3} \text{ and } AB = 1$$

$$A = \sqrt{2} = 1.414$$

$$f = \frac{1}{2\pi RC} \text{ when } R_1 = R_2 = R_3 = R$$

$$\& C_1 = C_2 = C_3 = C$$

$$\therefore f_0 = \frac{1}{2\pi RC}$$

## Waveform Generators

A waveform generator is a classification of a signal generator used to generate electrical waveforms over a wide range of signals.

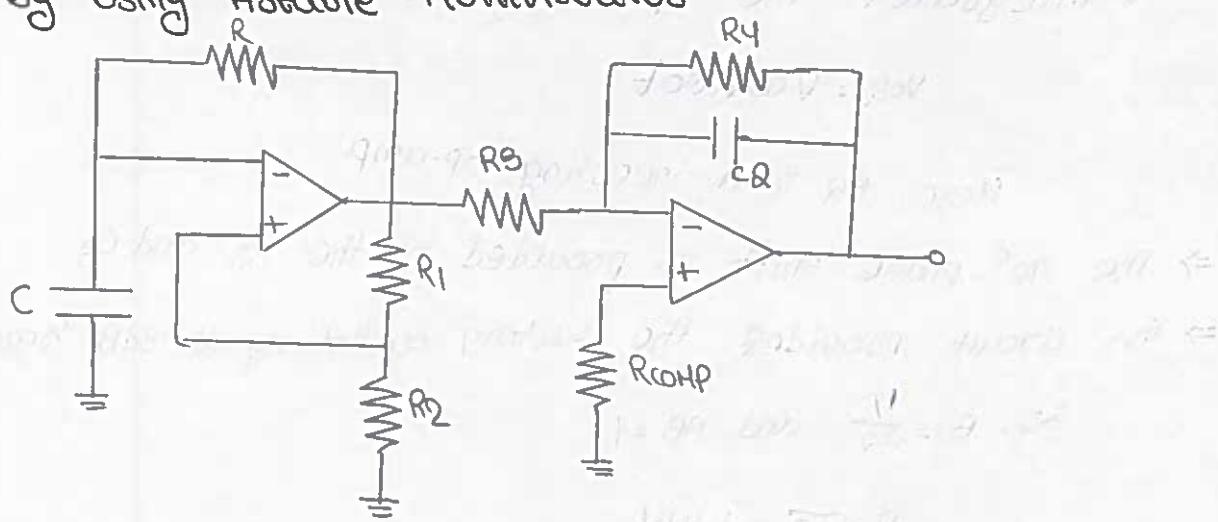
## \* Triangular wave Generator :-

- The output of an integrator is triangular if its input is square wave input. While output of a schmitt trigger is square wave for any input.
- Thus if output of schmitt trigger is applied to input of integrator and output of integrator as input to schmitt trigger then the circuit works as a triangular / rectangular wave generator.
- \* To generate a triangular wave generator it has 2 ways.

i, By using Astable multivibrator.

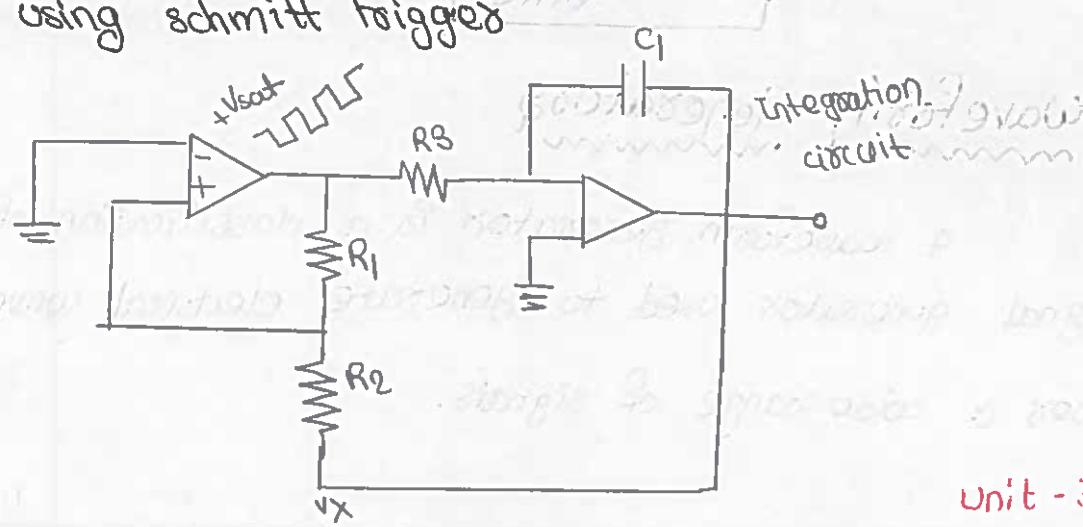
ii, By using schmitt trigger.

i, By using Astable Multivibrator



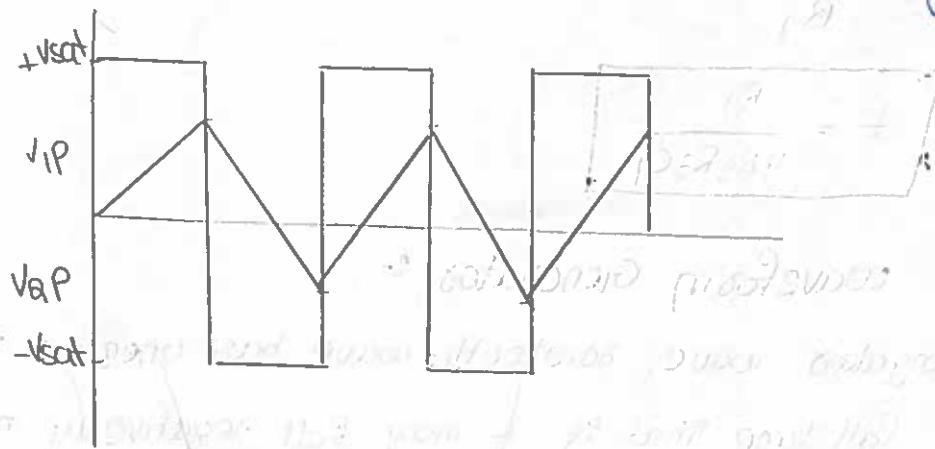
⇒ By using above circuit we are having so many components so we are going to schmitt trigger approach.

ii, By using schmitt trigger



$$V_P = \left( \frac{R_2}{R_1+R_2} \right) V_{sat} + \left( \frac{R_1}{R_1+R_2} \right) V_X \quad \text{--- (1)}$$

To find the threshold levels we are doing analysis.



According virtual ground concept  $V_P = 0$

$$\left( \frac{R_2}{R_1+R_2} \right) V_{sat} + \left( \frac{R_1}{R_1+R_2} \right) V_X = 0$$

$$R_2 V_{sat} + R_1 V_X = 0$$

$$R_2 V_{sat} = -R_1 V_X$$

$$V_{2P} = V_{X_1} = -\frac{R_2}{R_1} V_{sat} \quad \text{--- (2)}$$

From equation (2)

$$V_{2P} = V_{X_2} = \frac{R_1}{R_1} V_{sat} \quad \text{--- (3)}$$

From the waveform  $V_{P-P} = V_{UP} - V_{LP}$

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

$$V_{P-P} = \frac{2R_2}{R_1} V_{sat} \quad \text{--- (4)}$$

initially  $v_i(t) = -V_{sat}$

$$V_{P-P} = -\frac{1}{RC} \int_0^{T/2} v_i(t) dt$$

$$V_{P-P} = -\frac{1}{RC} (-V_{sat}) \cdot \frac{T}{2}$$

Equate equation (3) & (4)

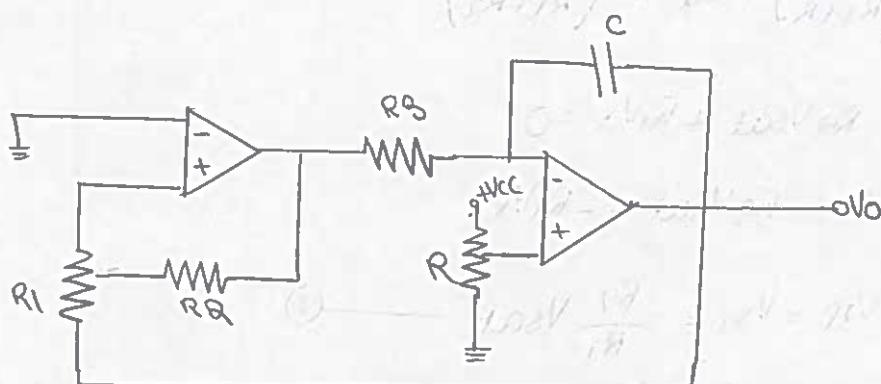
$$\frac{2R_2}{R_1} V_{sat} = \frac{1}{R_2 C_1} V_{sat} \frac{T}{2}$$

$$\frac{4R_2 R_3 C_1}{R_1} = T$$

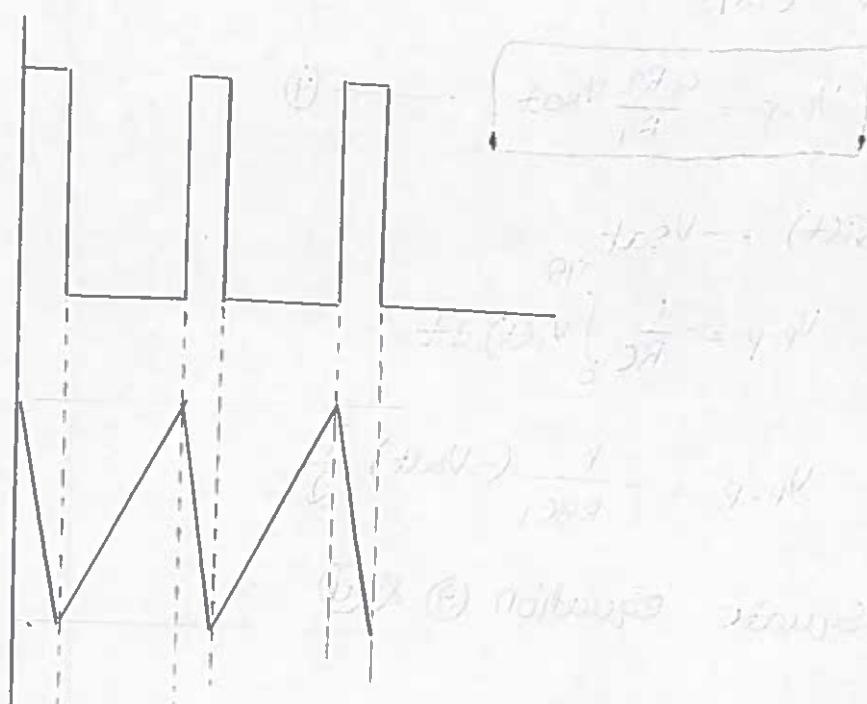
$$f = \frac{R_1}{4R_2 R_3 C_1}$$

### \* Sawtooth waveform Generator :-

- ⇒ Unlike triangular wave, sawtooth wave has unequal rise time and fall time. That is it may fall negatively many times faster than it rises positively or vice versa.
- ⇒ The sawtooth wave generators can be implemented by slightly modifying the triangular wave generator.



- ⇒ when  $-V_{EE}$  is applied to non-inverting terminal the rise time is more.
- ⇒ when  $+V_{CC}$  is applied to non-inverting terminal the risetime is less



## \* Square Wave Generator :-

The square wave generator is defined as an oscillator that gives the output without any input. without any input in the sense we should give input within zero seconds that means it must be an impulse input. This generator is used in digital signal processing and electronic applications. The square wave generator is also known as Astable Multivibrator.

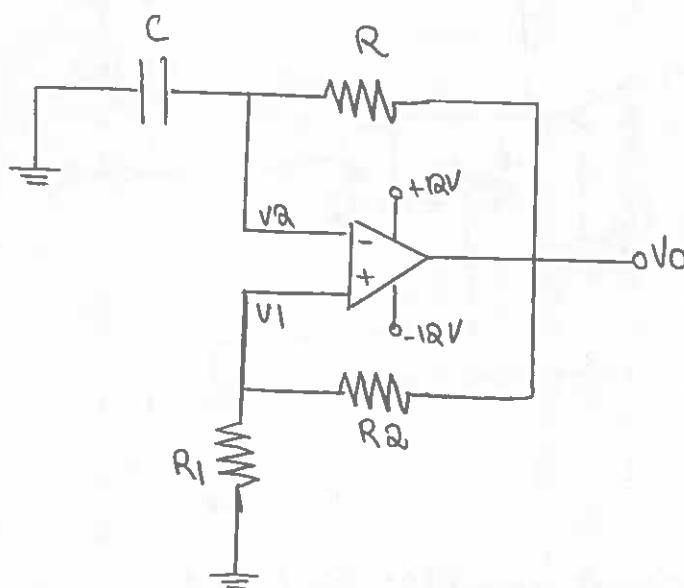


Fig 8- Square wave Generator

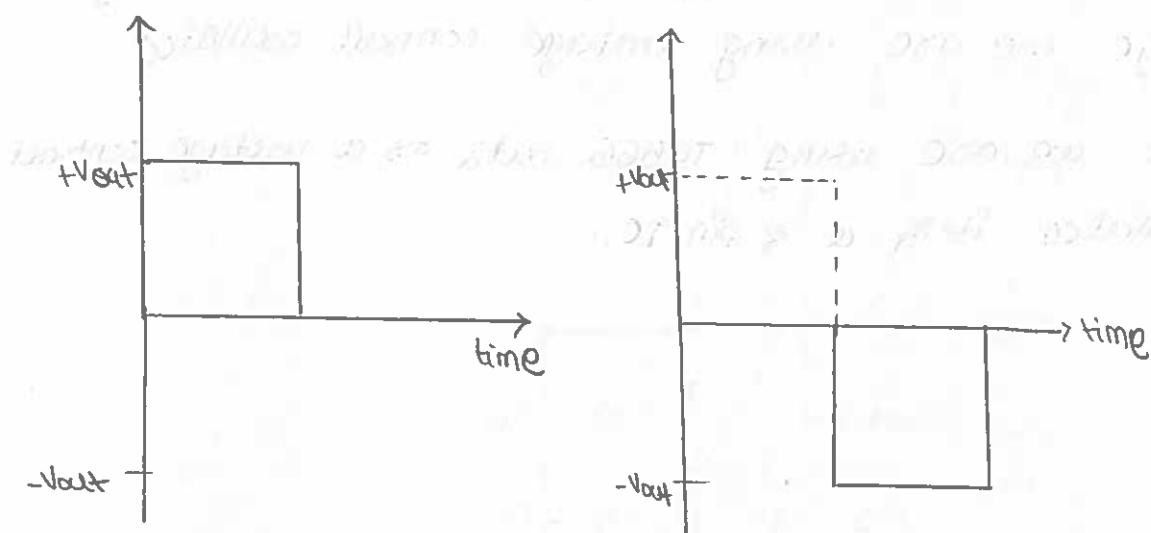


Fig 8- waveforms of square wave.

# Voltage Controlled Oscillator

A voltage controlled oscillator is an oscillator circuit in which the frequency of oscillations can be controlled by an externally applied voltage. The VCO provides the linear relationship between the applied voltage and the oscillation frequency. Applied voltage is called control voltage.

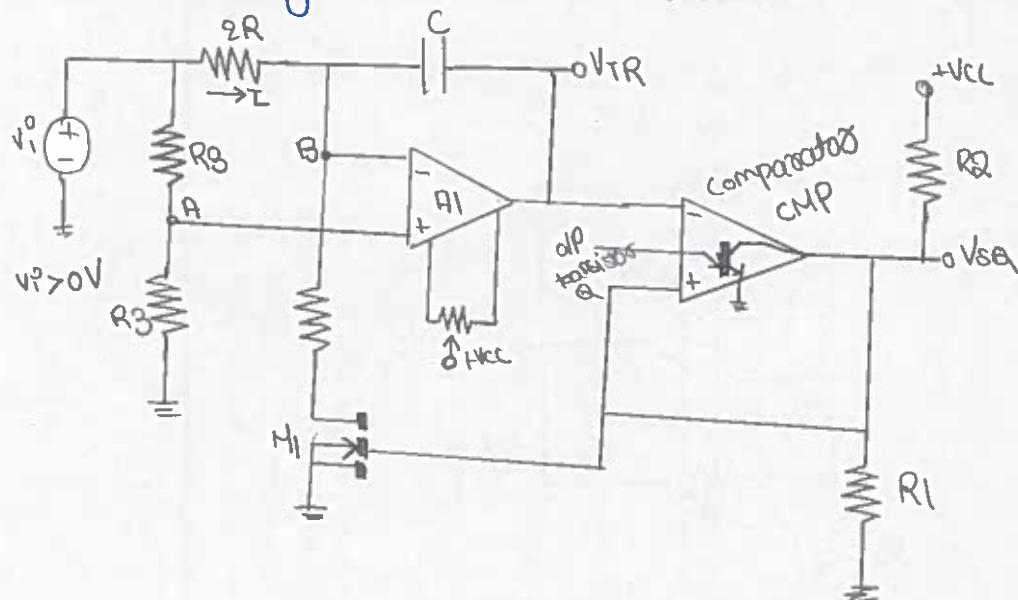
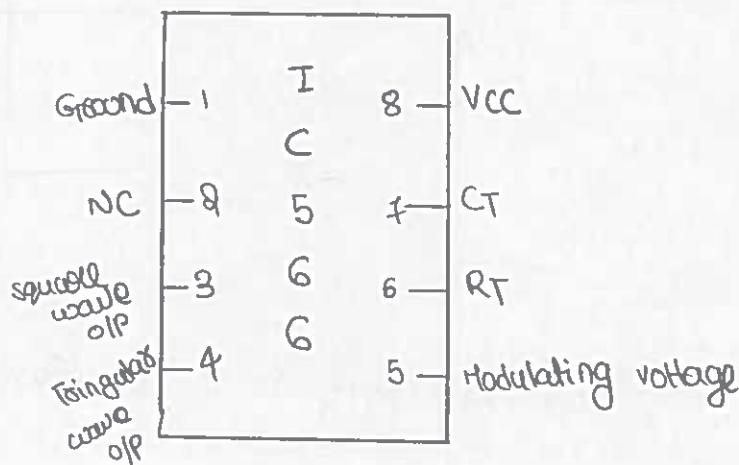


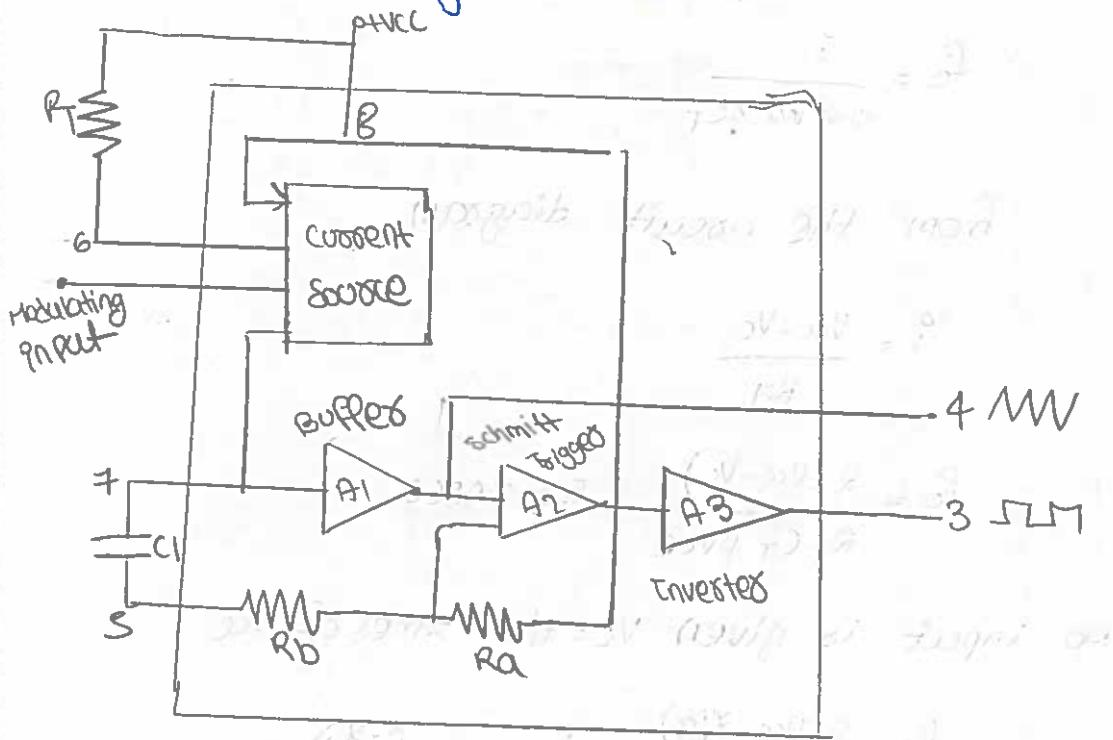
Fig :- Voltage controlled oscillator.

- \* To convert low frequency signal to audio frequency signal range we are using voltage controlled oscillator
- \* Here we are using IC566 chips as a voltage controlled oscillator it is a 8 pin IC.



# Block Diagram for IC566

- \* It consists of 3 operational amplifiers A<sub>1</sub>, A<sub>2</sub>, A<sub>3</sub>. A<sub>1</sub> acts as a buffer circuit, A<sub>2</sub> acts as a schmitt trigger, A<sub>3</sub> acts as an inverting circuit.



→ The output consists of V<sub>OT</sub>, V<sub>LT</sub>

$$V_{OT} = \frac{R_b}{R_a + R_b} \times V_{CC}$$

$$V_{OT} = 0.5 V_{CC}$$

$$V_{LT} = \frac{R_b}{R_a + R_b} \times 0.5 V_{CC}$$

$$V_{LT} = 0.25 V_{CC}$$

$$\Delta V = V_{OT} - V_{LT}$$

$$= 0.25 V_{CC} \quad \text{--- (1)}$$

$$V_{OT}(t) = \frac{1}{C_T} \int idt$$

$$\frac{\Delta V(t)}{\Delta t} = \frac{q}{C_T} \quad \text{--- (2)}$$

Substitute equation (1) in eqn (2)

$$\frac{0.25V_{CC} \times C_T}{i} = \Delta t$$

→ For Full cycle  $T = 2\Delta t$

$$T = \frac{0.25V_{CC} \times C_T}{i}$$

$$f_0 = \frac{i}{0.25V_{CC} \times C_T}$$

From the circuit diagram

$$i = \frac{V_{CC} - V_C}{R_T}$$

$$f_0 = \frac{Q(V_{CC} - V_C)}{R_T C_T + V_{CC}} \quad \text{For TCS66}$$

No input is given  $V_C = \pm 1/8$  times of  $V_{CC}$

$$f_0 = \frac{Q(V_{CC} - \pm 1/8)}{R_T V_{CC} C_T} = \frac{1}{4R_T C_T} = \frac{0.25}{R_T C_T}$$

Voltage to Frequency Conversion Factor :-

$$K_V = \frac{\Delta f}{\Delta V_C} = \frac{\text{change in frequency}}{\text{change in modulating voltage}}$$

$$\Delta f = f_1 - f_0$$

$$f_1 = \frac{Q(V_{CC} - V_C + \Delta V_C)}{V_{CC} R_T C_T}$$

$$f_0 = \frac{Q(V_{CC} - V_C)}{V_{CC} R_T C_T}$$

$$\Delta f = \frac{Q(V_{CC} - V_C + \Delta V_C)}{V_{CC} R_T C_T} - \frac{Q(V_{CC} - V_C)}{V_{CC} R_T C_T}$$

$$\Delta f = \frac{Q \Delta V_C}{V_{CC} R_T C_T} \Rightarrow K_V = \frac{\Delta f}{\Delta V_C} = \frac{Q}{V_{CC} R_T C_T}$$

$K_V$  in terms of  $f_0$  :-

$$K_V = \frac{Q f_0}{V_{CC}}$$

## Problems :-

1. Design a low pass filter using op-amp at a cut-off frequency of 1kHz with pass gain of 2.

Soln

Step 1 :-  $f_H = \text{cut-off frequency} = 1\text{kHz}$

Step 2 :- choose  $C = 0.01\text{ mF}$

Step 3 :-  $f_H = \frac{1}{2\pi RC}$  i.e.,  $1 \times 10^3 = \frac{1}{2\pi R \times 0.01 \times 10^{-6}}$

$$\therefore R = 15.91\text{ k}\Omega$$

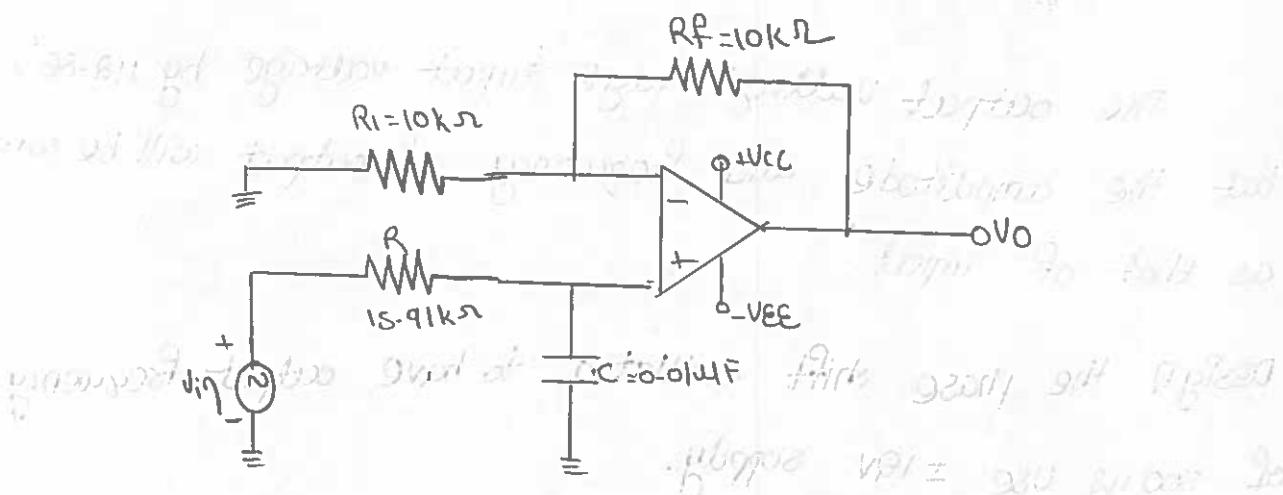
use a pot of  $20\text{k}\Omega$  for frequency scaling.

Step 4 :-  $A_F = 1 + \frac{R_F}{R_1} = 2$

$$\therefore \frac{R_F}{R_1} = 1$$

$$\therefore R_F = R_1 = 10\text{ k}\Omega$$

The designed circuit is shown in below figure.



2. For a low pass filter, a cut-off frequency is  $80\text{ rad/s}$  & the capacitor selected is  $0.01\text{ mF}$ . Determine the corresponding value of the resistance required.

Soln

The given values are,

$$C = 0.01 \mu F \text{ and } \omega_H = 80 \text{ rad/s}$$

$$\text{Now, } \omega_H = 2\pi f_H \text{ and } f_H = \frac{1}{2\pi RC}$$

$$\therefore 80 \times 10^3 = 2\pi \times \frac{1}{2\pi R \times 0.01 \times 10^{-6}}$$

$$\therefore R = 8.83 k\Omega$$

- 3) For the all pass filters, the values of  $R$  &  $C$  are  $7.45 k\Omega$  and  $0.02 \mu F$  respectively. If the input frequency is  $1.5 \text{ kHz}$ , calculate the phase shift.

Soln

$$R = 7.45 k\Omega, C = 0.02 \mu F$$

$$f = 1.5 \text{ kHz}$$

$$\therefore \phi = -2 \tan^{-1} \left( \frac{2\pi f R C}{1} \right)$$

$$= -2 \tan^{-1} \left( \frac{2\pi \times 1.5 \times 10^3 \times 7.45 \times 10^3 \times 0.02 \times 10^{-6}}{1} \right)$$

$$\phi = -112.56^\circ$$

The output voltage lags input voltage by  $112.56^\circ$ , but the amplitude and frequency of output will be same as that of input.

4. Design the phase shift oscillator to have output frequency of  $500 \text{ Hz}$ . Use  $\pm 12V$  supply.

Soln

As  $f$  is less than  $1 \text{ kHz}$ , use op-amp 741 with  $\pm 50 \text{ mA}$

$$I_1 = 100 I_b (\max) = 5 \mu A$$

$$R_F = \frac{V_{O(sat)}}{I_1} \text{ where } V_{O(sat)} = 12 - 1 = 11V$$

$$= \frac{11}{50 \times 10^{-6}} = 2.2 \text{ M}\Omega \text{ (standard value)}$$

$$A_{CL} = \frac{R_F}{R_I} = 29$$

$$R_I = \frac{R_F}{29} = \frac{220 \times 10^3}{29} = 7.586 \text{ k}\Omega$$

use standard of  $7.5 \text{ k}\Omega$

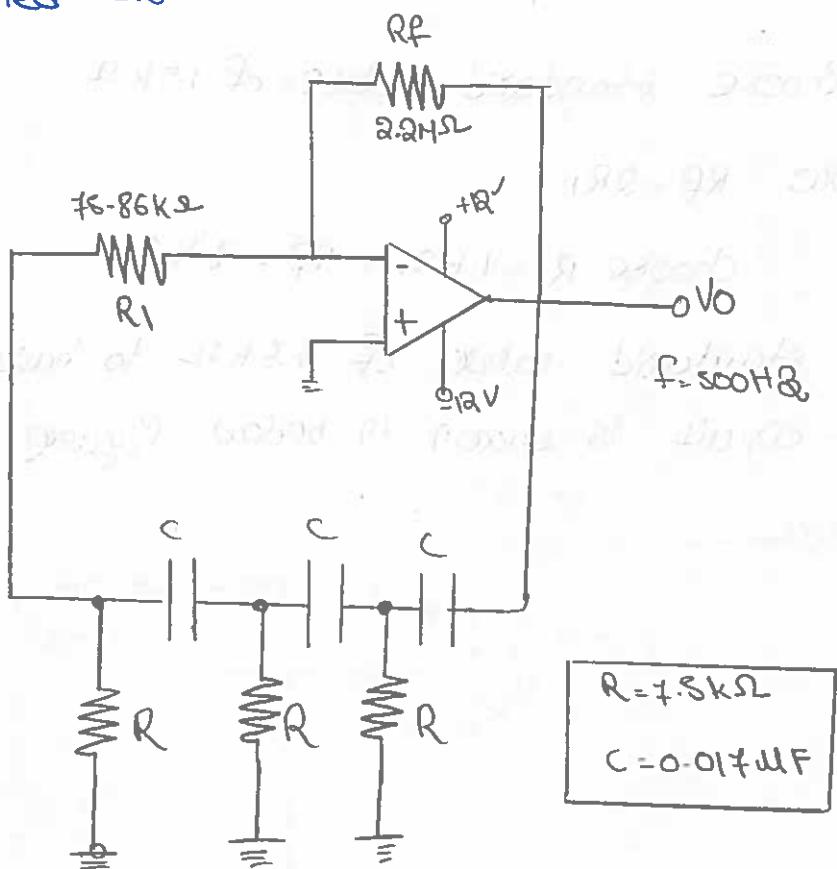
$$R = \frac{R_I}{10} = \frac{7.586 \times 10^3}{10} = 7.5 \text{ k}\Omega \text{ (standard value)}$$

$$\therefore C = \frac{1}{2\pi f R}$$

$$= \frac{1}{2\pi \times 500 \times 7500} = 0.017 \mu\text{F}$$

use standard value of  $0.017 \mu\text{F}$

The designed circuit as shown in the below figure.



5. For the RC phase shift oscillator circuit three identical phase-shifting networks of  $R = 10 \text{ k}\Omega$  &  $C = 0.00141 \mu\text{F}$  are used. Determine the frequency of oscillations.

Sol

$$R = 10k\Omega, C = 0.001\mu F$$

$$\therefore f = \frac{1}{2\pi f_0 R C}$$

$$= \frac{1}{2\pi f_0 \times 10 \times 10^3 \times 0.001 \times 10^{-6}}$$

$$f = 6.497 \text{ kHz}$$

- 6 Design the Wein bridge oscillator circuit to have output frequency of 10 kHz.

Sol

$$\text{choose } C = 0.01\mu F$$

$$\therefore R = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 10 \times 10^3 \times 0.01 \times 10^{-6}}$$

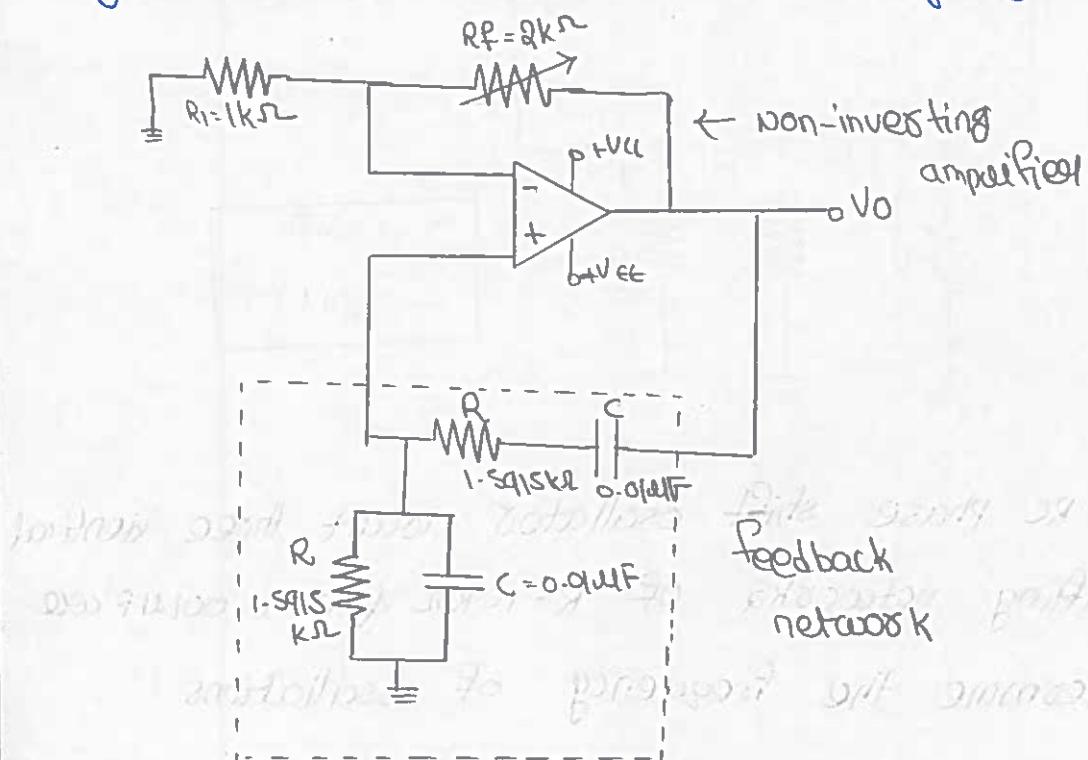
$$R = 1.5915 \text{ k}\Omega$$

- choose standard value of  $1.5 \text{ k}\Omega$

$$\text{now } R_F = 2R_1$$

$$\text{choose } R_1 = 1 \text{ k}\Omega, R_F = 2 \text{ k}\Omega$$

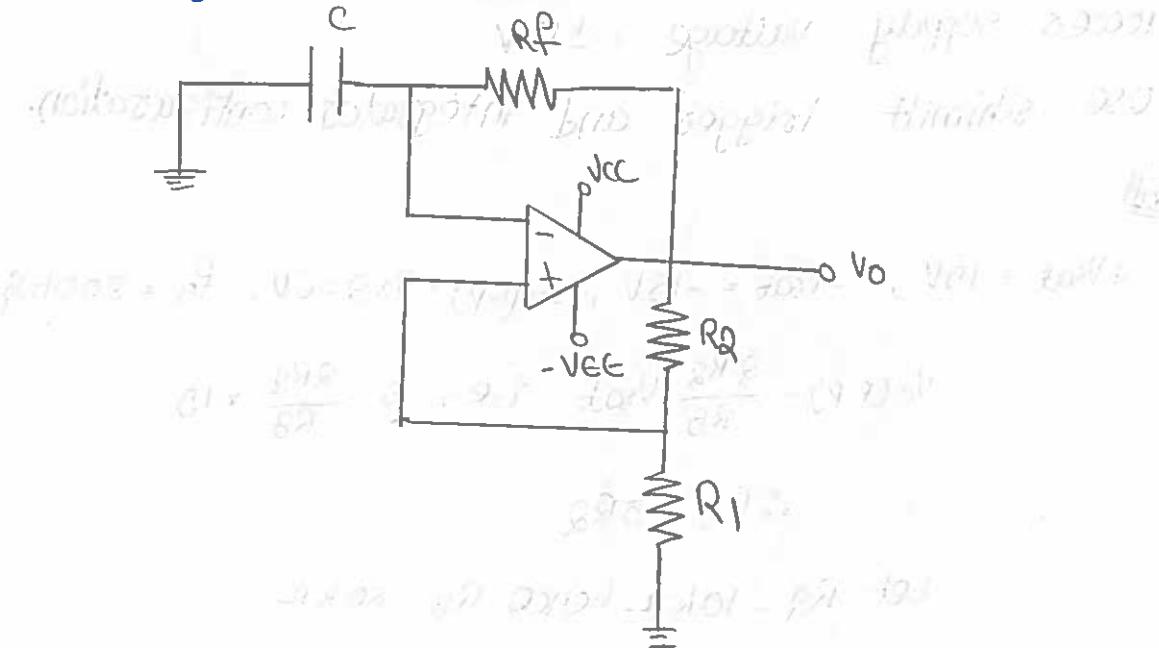
use standard value of  $2.2 \text{ k}\Omega$  to have  $A_{cl} > 8$ . The designed circuit is shown in below figure



7. Design an astable multivibrator using op-amp IC 141 with frequency of 10kHz and using  $C=0.1\mu F$

Soln

The supply is  $\pm 15V$ . The magnitudes of  $+V_{sat}$  and  $-V_{sat}$  are equal.



$$f = \frac{1}{2R_f C \ln \left[ \frac{2R_1 + R_2}{R_2} \right]}$$

choose  $R_1$  and  $R_2$  such that,

$$\ln \left[ \frac{2R_1 + R_2}{R_2} \right] = 1$$

$$\therefore \frac{2R_1 + R_2}{R_2} = 2.7183 \quad \text{i.e., } R_1 = 0.86 R_2$$

$$\therefore R_2 = 100k\Omega \text{ and } R_1 = 86k\Omega$$

$$\therefore f = \frac{1}{2R_1 C} \quad \text{i.e.,}$$

$$10 \times 10^3 = \frac{1}{2R_f \times 0.1 \times 10^{-6}}$$

$$\therefore R_f = 500 \Omega$$

- 8) Design the triangular waveform generated using op-amp for following specifications
- Amplitude of square wave =  $\pm V_{sat}$
- Amplitude of triangular wave =  $\pm 8V$
- Frequency of output waveform =  $800\text{Hz}$
- Power supply voltage =  $\pm 15V$
- Use schmitt trigger and integrator configuration.

Soln

$$+V_{sat} = 15V, -V_{sat} = -15V, V_{O(P-P)} = 8 \times 2 = 6V, f_0 = 800\text{Hz}$$

$$V_{O(P-P)} = \frac{2R_2}{R_8} V_{sat} \text{ i.e., } 6 = \frac{2R_2}{R_8} \times 15$$

$$\therefore R_8 = 5R_2$$

$$\text{Let } R_2 = 10\text{k}\Omega \text{ hence } R_8 = 50\text{k}\Omega$$

$$f_0 = \frac{R_3}{4R_1C_1R_2}$$

$$\text{choose } C_1 = 0.1\mu\text{F}$$

$$800 = \frac{50 \times 10^3}{4 \times R_1 \times 0.1 \times 10^{-6} \times 10 \times 10^3}$$

$$R_1 = 15.625\text{k}\Omega$$

The designed circuit is shown in the figure.

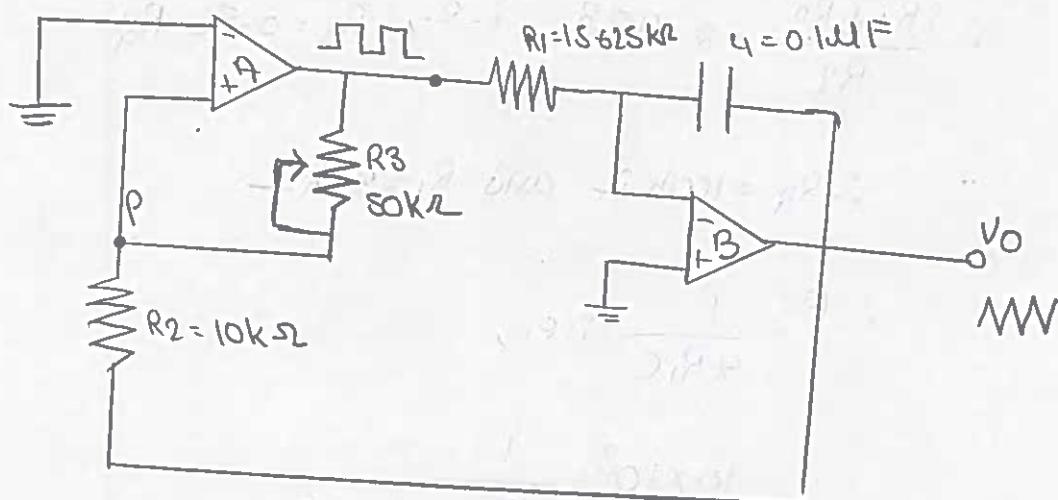


Fig:- Triangular wave generator