UNIT-4

FILTERS & MULTIPLIERS

classification

① passive filter

② Active filter

① passive filters uses only passive elements such as R, L, C

② Active filters uses Active components such as op-amps, Transistors along with R, L, C.

The most commonly used Active filters

i) LPF (Low pass filter)

ii) HPF (High " ")

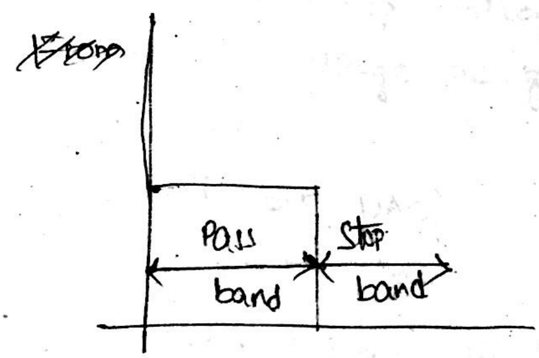
iii) BPF (Band " ")

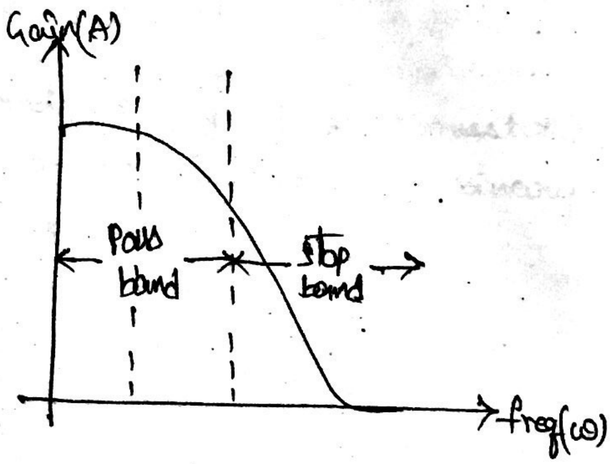
iv) BRF (or) BEF (Band reject (or) Band elimination filter)

v) APF (All pass filter)

Frequency response of Active filters:

LPF (Low pass filter):

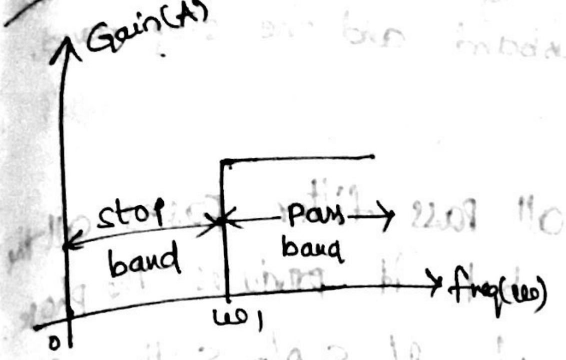


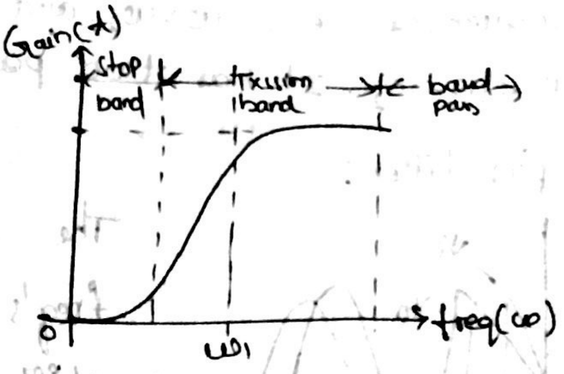


From LPF it passes all frequencies below ω_1 and rejects frequencies above ω_1 i.e. it allows only low frequency signals and rejects high freq signals.

It has one stop and one pass bands.

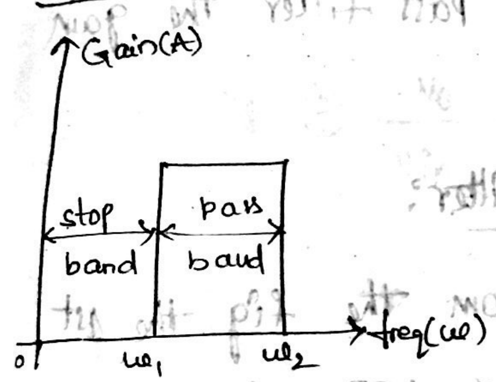
HPF (High pass filter)

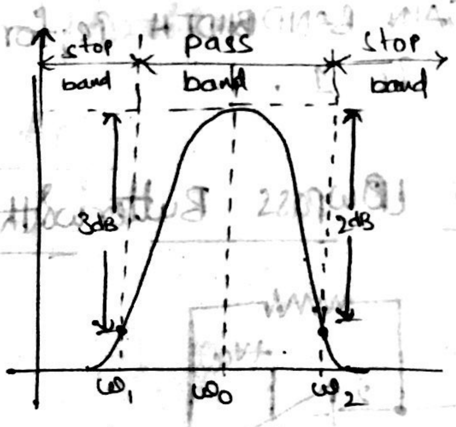




From HPF it allows high frequency signals and rejects low freq signals $0 < \omega < \omega_1$. It has one stop band and one pass band.

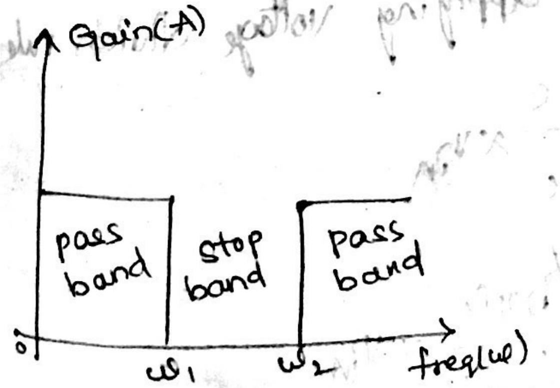
Band pass filter :-

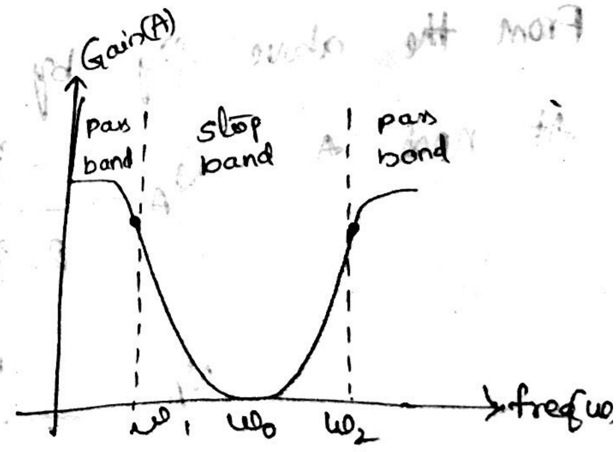




BPF is a combination of LPF & HPF. It has two stop bands and one pass band. From band pass filter, it rejects the freq's less than ω_1, i.e., $0 < \omega < \omega_1$ And higher than ω_2 i.e., $\omega > \omega_2$ & allows the freq b/w ω_1 & ω_2 i.e., $\omega_1 < \omega < \omega_2$. It has the BW is equal to $\omega_2 - \omega_1$ i.e., equal to higher frequency. lower frequency.

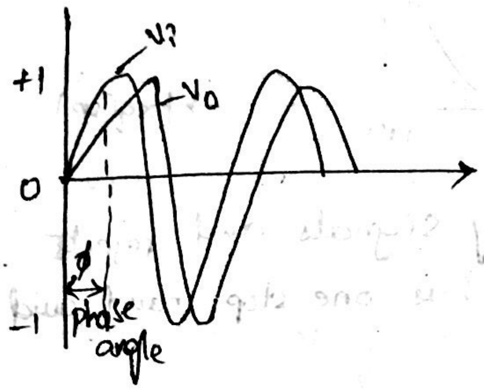
Band reject filter :-





This allows lower frequencies i.e., $0<\omega<\omega_1$ and higher frequencies i.e., $\omega>\omega_2$ and rejects the frequencies b/w $\omega_1<\omega<\omega_2$. It has two passband and one stop band.

All pass filter:



The all pass filter passes all the freq's but it produces the phase shift b/w i/p & o/p & the voltages are equally magnitude but opposite in phase. This is all pass filter is also called as UNITY GAIN BANDWIDTH i.e; for all pass filter the gain response is 1.

1st order Lowpass Butterworth filter:

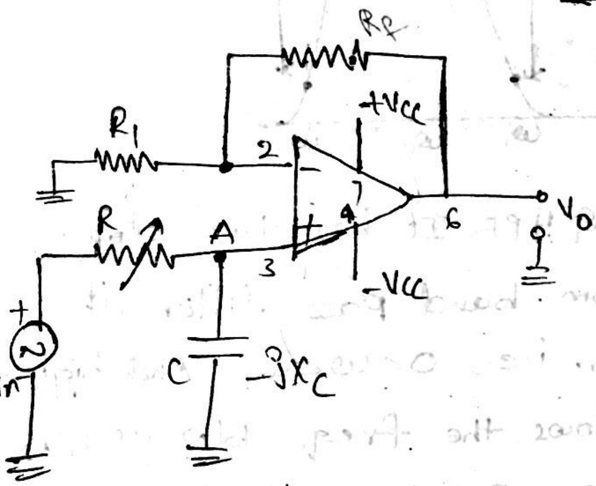


fig: 1st order low pass filter

From the fig the 1st order LPF butterworth filter is having an op-amp with non-inverting configuration. This is also called as SINGLE POLE LOWPASS BUTTERWORTH FILTER.

From the above fig by applying voltage divider rule

At node A
$$V_A = \frac{-jX_C}{R-jX_C} \times V_{in}$$

$$V_A = \frac{1/j2\pi fc}{R+1/j2\pi fc} \times V_{in}$$

$$v_A = \frac{1}{1+j2\pi fRC} \times v_{in} \quad \text{—— (1)}$$

from the fig by using non-inv confriguration.

$$v_0 = \left(1+\frac{R_f}{R_1}\right) v_A \quad \text{—— (2)}$$

Sub (1) in (2) $v_0 = \left(1+\frac{R_f}{R_1}\right)\left(\frac{1}{1+j2\pi fRC}\right) v_{in}$

$$\frac{v_0}{v_{in}} = A_F\left(\frac{1}{1+j2\pi fRC}\right) \quad \text{—— (3)}$$

from eq (3) $\frac{v_0}{v_{in}} = \frac{A_F}{1+j\left(\frac{f}{f_H}\right)}$ $\therefore f_H = \frac{1}{2\pi RC}$

$$\left|\frac{v_0}{v_{in}}\right| = \frac{A_F}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}} \quad \text{—— (4)}, \quad \phi = -\tan^{-1}\left(\frac{f}{f_H}\right) \quad \text{—— (5)}$$

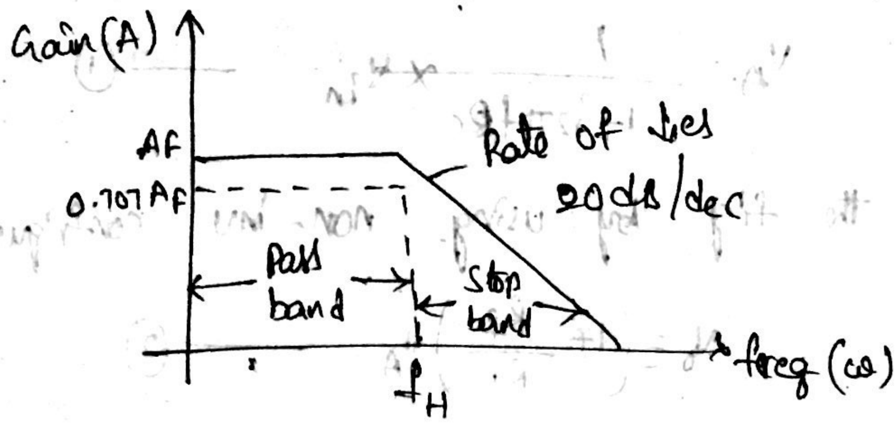
from eq (4) LPF describes the behaviour of filter.

1. At very low freq's ie; $f < f_H$ then $\left|\frac{v_0}{v_{in}}\right| = A_F$.

2. At very high freq's ie; $f > f_H$ then $\left|\frac{v_0}{v_{in}}\right| < A_F$.

3. At $f = f_H$ then $\left|\frac{v_0}{v_{in}}\right| = \frac{A_F}{\sqrt{2}} = 0.707A_F$.

from the freq response of $0 < f < f_H$ the gain is almost constant upto f_H. At $f = f_H$ the gain reduces to 3dB down freq & as freq ↑es more than f_H then gain ↓es at a rate of 20dB/dec.



Designing steps

1. choose the cutt-off freq as f_H.

2. By selecting the capacitance, c is usually in b/w $0.001\mu f - 1\mu f$.

3. For the RC ckt $f_H = \frac{1}{2\pi RC}$ if f_H & C values are known then R will be calculated.

4. the resistance of R_f & R_1 can be selected depending on the required gain in the pass band ie,

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

Prblms

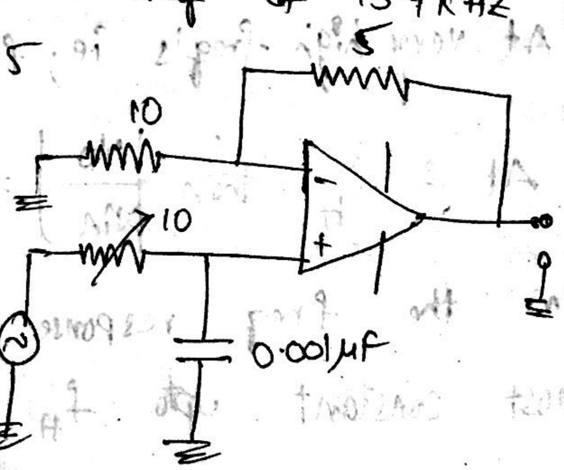
Design a LPF with cutt-off freq of 15.9 kHZ with a pass band gain of 1.5

$f_H = 15.9$ KHZ

$C = 0.001\mu f$

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

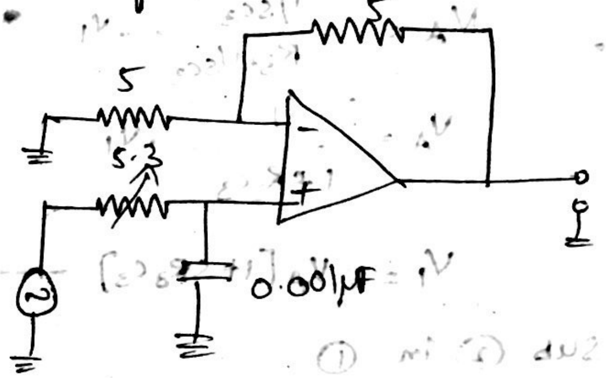
$$R = \frac{1}{2\pi \times 0.001 \times 10^{-6} \times 15.9 \times 10^3} = 10K\Omega$$



$$A_F = 1 + \frac{R_f}{R_1} \qquad \text{Assume } R_1 = 10k\Omega$$

$$1.5 = 1 + \frac{R_f}{10\times10^3} \Rightarrow R_f = 5k\Omega$$

Design a LPF with a freq of 30KHZ with a gain of 2.



$f_H = 30KHZ$

$C = 0.001\mu F$

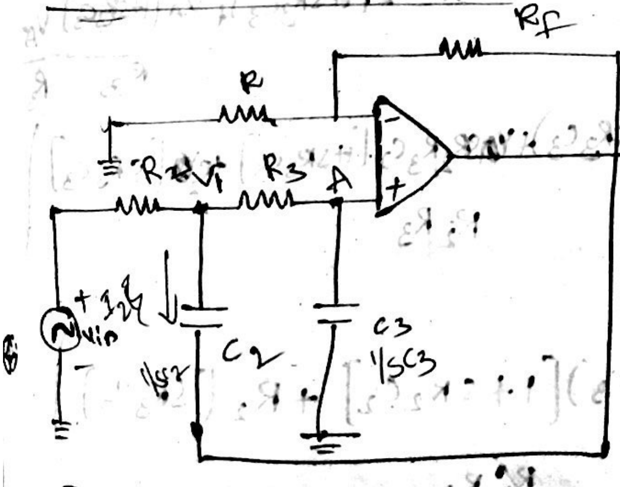
$$f_H = \frac{1}{2\pi RC}$$

$$R = \frac{1}{2\pi \times 30\times10^3 \times 0.001\times10^{-6}} = 5.3K\Omega$$

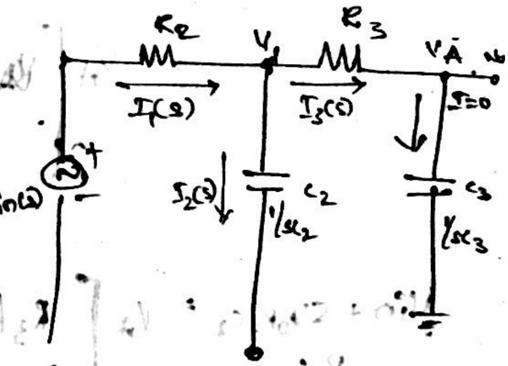
$$A_F = 1 + \frac{R_f}{R_1} \qquad \text{Assume } R_1 = 5K\Omega$$

$$2 = 1 + \frac{R_f}{5\times10^3} \Rightarrow \cancel{R_f} \quad R_f = 10$$

Second order low pass filter



ⓐ second order LPF



ⓑ RC network represented in laplace Transform.

From Second order LPF the roll rate decreases for every 40dB/dec the cutt-off freq f_H is decided by R_2, C_2, R_3 & C_3 and the gain of the filter is decided by R_1 & R_2 from fig ⓐ. Now by using laplace Transform.

apply KCL eq^n from fig (b)

$$I_1 = I_2 + I_3$$

$$\frac{V_{in} - V_1}{R_2} = \frac{V_1 - V_0}{1/sC_2} + \frac{V_1 - V_A}{R_3} \quad \text{--- (1)}$$

From fig (b) by using voltage divider rule

$$V_A = \frac{1/sC_3}{R_3 + 1/sC_3} \cdot V_1$$

$$V_A = \frac{1}{1 + sR_3C_3} \cdot V_1$$

$$V_1 = V_A[1 + sR_3C_3] \quad \text{--- (2)}$$

sub (2) in (1)

$$(1) \Rightarrow \frac{V_{in} - V_A[1+sR_3C_3]}{R_2} = \frac{V_A[1+sR_3C_3] - V_0}{1/sC_2} + \frac{V_A[1+sR_3C_3] - V_A}{R_3}$$

$$\frac{V_{in}}{R_2} - \frac{V_A[1+sR_3C_3]}{R_2} = V_A sC_2[1+sR_3C_3] - V_0 sC_2 + \frac{V_A[1+sR_3C_3] - V_A}{R_3}$$

$$\frac{V_{in}}{R_2} + sV_0C_2 = \frac{V_A(1+sR_3C_3)}{R_2} + V_A sC_2[1+sR_3C_3] + \frac{V_A[1+sR_3C_3]}{R_3} - \frac{V_A}{R_3}$$

$$= V_A\left[\frac{R_3(1+sR_3C_3) + R_2R_3C_2[1+sR_3C_3] + R_2[sR_3C_3]}{R_2R_3}\right]$$

$$\frac{V_{in} + sV_0R_2C_2}{\cancel{R_2}} = V_A\left[\frac{R_3(1+sR_3C_3)[1+sR_2C_2] + R_2[sR_3C_3]}{\cancel{R_2}R_3}\right]$$

$$V_{in} + sV_0R_2C_2 =$$

From fig the op amp is non-inv Configuration then

$$V_0 = \left(1 + \frac{R_f}{R_1}\right) V_A$$

$$\boxed{V_0 = A_F \cdot V_A} \text{ --- } (4)$$

sub (3) in (4)

$$V_0 = A_F \left[\frac{V_{in} + SV_0R_2C_2}{SR_2C_3 + (1 + SR_3C_3)(1 + SR_2C_2)} \right]$$

$$= \frac{A_F V_{in} + A_F SV_0R_2C_2}{SR_2C_3 + (1 + SR_3C_3)(1 + SR_2C_2)}$$

$$= \frac{A_F V_{in}}{SR_2C_3 + (1 + SR_3C_3)(1 + SR_2C_2)} + \frac{A_F SV_0R_2C_2}{SR_2C_3 + (1 + SR_3C_3)(1 + SR_2C_2)}$$

By deriving above equation the overall transfer function

$$\frac{V_0}{V_{in}} = \frac{A}{s^2 + 2\xi\omega_n + \omega_n^2} \text{ --- } (5)$$

A = overall gain

ξ = second order damping s/m

ω_n is the natural frequency of oscellations

From eqn (5) $\omega_n^2 = \frac{1}{R_2R_3C_2C_3}$

In case of low pass filter the frequency is nothing but the cutt off frequency.

i.e., $\omega_H^2 = \frac{1}{R_2 R_3 C_2 C_3}$

$$(2\pi f_H)^2 = \frac{1}{R_2 R_3 C_2 C_3}$$

$$f_H = \frac{1}{2\pi\sqrt{R_2 R_3 C_2 C_3}} \quad \text{--- (6)}$$

This is required cutoff frequency and from eq (5) replace $\frac{s}{j\omega}$ the Transfer function can be written in the frequency domain and the overall magnitude response can be written as

$$\left|\frac{V_0}{V_{in}}\right| = \frac{A_F}{\sqrt{1+\left(\frac{f}{f_H}\right)^4}}$$

Note: If order is increased for every time its order is also doubled.

Designing steps

(1) choose the cutt-off frequency as f_H

(2) By selecting the value of capacitor C in b/w $0.001\mu F$ to $1\mu F$ and for the simplification of designing select $R_2 = R_3 = R$ & $C_2 = C_3 = C$

(3) Calculating the value of resistor R from

$$f_H = \frac{1}{2\pi\sqrt{R_2 R_3 C_2 C_3}} = \frac{1}{2\pi RC}$$

(4) By selecting $R_2 = R_3 = R$, $C_2 = C_3 = C$ the pass band gain $A_F = 1 + \frac{R_f}{R_1}$ of the second order LPF is equal to 1.586

Note: By selecting $R_2 = R_3 = R$, $C_2 = C_3 = C$. The Transfer function from the above derivation we are producing

$$\frac{V_o}{V_{in}} = \frac{A_F}{s^2 \frac{(RC+RC+RC-A_FRC)}{R^2C^2} + \frac{1}{R^2C^2}}$$

$$= \frac{A_F}{s^2 \frac{(3RC-A_FRC)}{R^2C^2} + \frac{1}{R^2C^2}}$$

From this eq^n the damping factor $(\xi) = \frac{3-A_F}{RC}$ then for the second order low pass filter the middle term is required as $\sqrt{2} = 1.414$ then $3-A_F = \sqrt{2} \Rightarrow A_F = 3-\sqrt{2} = 1.586$

From this $A_F = 1 + \frac{R_F}{R_1}$

$1.586 = 1 + \frac{R_F}{R_1}$

$$\boxed{R_F = 0.586R_1}$$

problems

* Design a second order low pass filter with a cutt-off frequency 1kHz and draw its frequency response.

① cutt-off frequency = 1KHZ = f_H

② $C = 0.001\,\mu F$

③ $f_H = \frac{1}{2\pi RC}$

$R = \frac{1}{2\pi f_H C} = \frac{1}{2\pi \times 1\times10^3 \times 0.001\times10^{-6}}$

$$\boxed{R = 159.83\,k\Omega}$$

④ $A_F = 1 + \frac{R_f}{R_1}$

$R_1 = 10k\Omega$

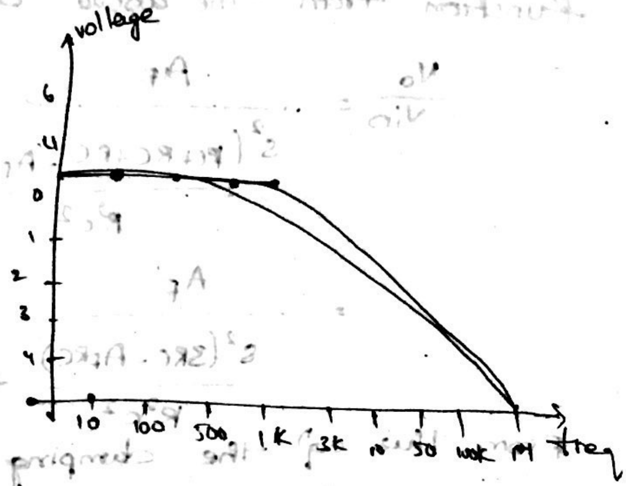
$R_f = 0.586 R_1$

$$\boxed{R_f = 5.86\,k\Omega}$$

For second order low pass filter $\frac{V_o}{V_{in}} = \frac{A_F}{\sqrt{1+\left(\frac{f}{f_H}\right)^4}}$

$$= \frac{1.586}{\sqrt{1+\left(\frac{10}{1\times10^3}\right)^4}}$$

Frequency	$\frac{V_o}{V_{in}}$	$\frac{V_o}{V_{in}}$ (dB)
10Hz	1.586	4.005
100Hz	1.586	4.006
500Hz	1.586	4.006
1k	1.121	0.991
3k	0.175	-15.132
10k	0.015	-35.994
50k	0.0006	-63.994
100k	0.0002	-75.9
1M	1.585×10^{-4}	-75.911



* Design a LPF with cutt-off frequency 5kHz

① $f_H = 5KHz$

② $C = 0.001\mu F$

③ $R = \frac{1}{2\pi f_H C}$

$= \frac{1}{2\pi\times5\times10^3\times0.001\times10^{-6}}$

$\boxed{R = 21.84\ k\Omega}$

Assume $R_1 = 10k\Omega$

$R_f = 0.586\times R_1$

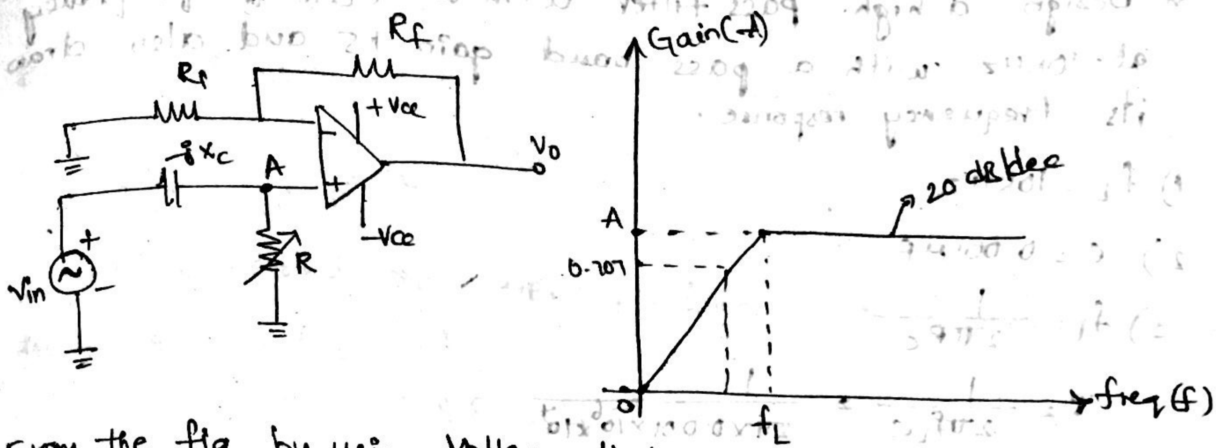
$= 0.586\times10k\Omega$

$= 5.86k\Omega$

$$\frac{V_o}{V_{in}} = \frac{A_F}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}} = \frac{1.586}{\sqrt{1+\left(\frac{10}{5000}\right)^4}}$$

frequency	$\frac{V_o}{V_{in}}$	$\frac{V_o}{V_{in}}$ (dB)
10	1.586	4.005
100		
500		
1k		
3k		
10k		
50k		
100k		
1M		

First order HPF :



From the fig by using voltage divider rule

$$V_A = \frac{R}{R - jx_{c_1}} \cdot V_{in}$$

$$V_A = \frac{R}{R + \frac{1}{j2\pi fC}} \cdot V_{in}$$

$$V_A = \left[\frac{j2\pi fRC}{1 + j2\pi fRC}\right] V_{in}$$

$$V_A = \left[\frac{j\left(\frac{f}{f_L}\right)}{1 + j\left(\frac{f}{f_L}\right)}\right] V_{in} \quad \left[\because f_L = \frac{1}{2\pi RC}\right] \text{ --- (1)}$$

From the fig wrt the non-inv configuration o/p voltage

$$V_0 = \left(1 + \frac{R_f}{R_1}\right) V_A \text{ --- (2)}$$

$$V_0 = A_f V_A$$

Sub (1) in (2)

$$V_0 = A_f \left[\frac{j\left(\frac{f}{f_L}\right)}{1 + j\left(\frac{f}{f_L}\right)}\right] V_{in}$$

$$\frac{V_0}{V_{in}} = A_f \left[\frac{j\left(\frac{f}{f_L}\right)}{1 + j\left(\frac{f}{f_L}\right)}\right] \text{ --- (3)}$$

From eq^n (3) the magnitude response is

$$\left|\frac{V_0}{V_{in}}\right| = \frac{A_f\left(\frac{f}{f_L}\right)}{\sqrt{1 + \left(\frac{f}{f_L}\right)^2}} \text{ --- (4)}$$

From eq^n (4) the ckt behaviour describes that
1. At very low frequencies i.e., $f < f_L$ then $\left|\frac{V_0}{V_{in}}\right| < A_f$
2. At very high " i.e., $f > f_L$ then $\left|\frac{V_0}{V_{in}}\right| > A_f$
3. At $f = f_L$ then $\left|\frac{V_0}{V_{in}}\right| = \frac{A_f}{\sqrt{2}} = 0.707 A_f$

problem

* Design a high pass filter with a cut-off frequency at 10kHz with a pass band gain 1.5 and also draw its frequency response.

1) $f_L = 10kHz$

2) $C = 0.001\mu F$

3) $f_L = \frac{1}{2\pi RC}$

$R = \frac{1}{2\pi f_L C} = \frac{1}{2\pi \times 0.001 \times 10^{-6} \times 10^4}$

$= 15.9k\Omega$

4) $A_F = 1 + \frac{R_f}{R_1}$

$R_1 = 10k\Omega$

$R_f = 0.5 R_1$

$R_f = 0.5 \times 10 k\Omega$

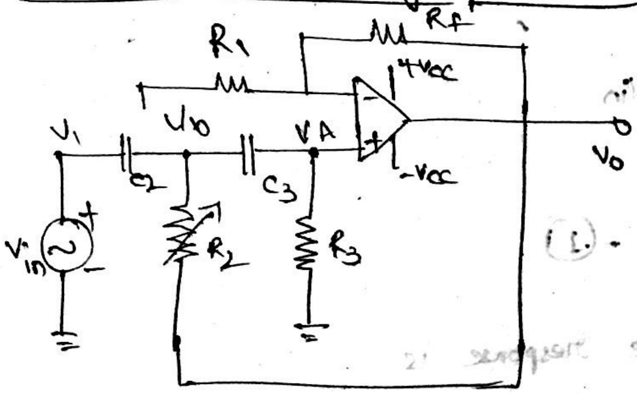
$\boxed{R_f = 5k\Omega}$

$\left|\frac{V_o}{V_{in}}\right| = \left|\frac{A_F\left(\frac{f}{f_L}\right)}{\sqrt{1+\left(\frac{f}{f_L}\right)^2}}\right|$

$= \frac{1.5\left(\frac{10}{1.59 \times 10^3}\right)}{\sqrt{1+\left(\frac{10}{1.59\times10^3}\right)^2}}$

freq	$\frac{V_o}{V_{in}}$	$20\log\left(\frac{V_o}{V_{in}}\right)$
10	0.014	-36.47
100	0.0149	-36.47
500	0.074	-22.5
1k	0.1491	-16.54
5k	0.67	-3.47
10k	1.06	0.506
100k	1.49	3.47
500k	1.52	3.5
1M	1.67	3.67

Second order High pass filter:-



It is same as second order LPF whose expression is derived upto

$$\frac{V_o}{V_{in}} = \frac{A_F}{s^2 + \frac{(R_3C_3 + R_2C_3 + R_2C_2 - A_F R_2 C_2)}{R_2R_3C_2C_3} s + \frac{1}{R_2R_3C_2C_3}}$$

$$= \frac{A_F}{s^2 + 2\xi_g \omega_n + \omega_n^2}$$

For second order HPF whose magnitude response is

$$\left|\frac{V_0}{V_{in}}\right| = \frac{A_F}{\sqrt{1+\left(\frac{f_L}{f}\right)^4}} \quad \text{—①}$$

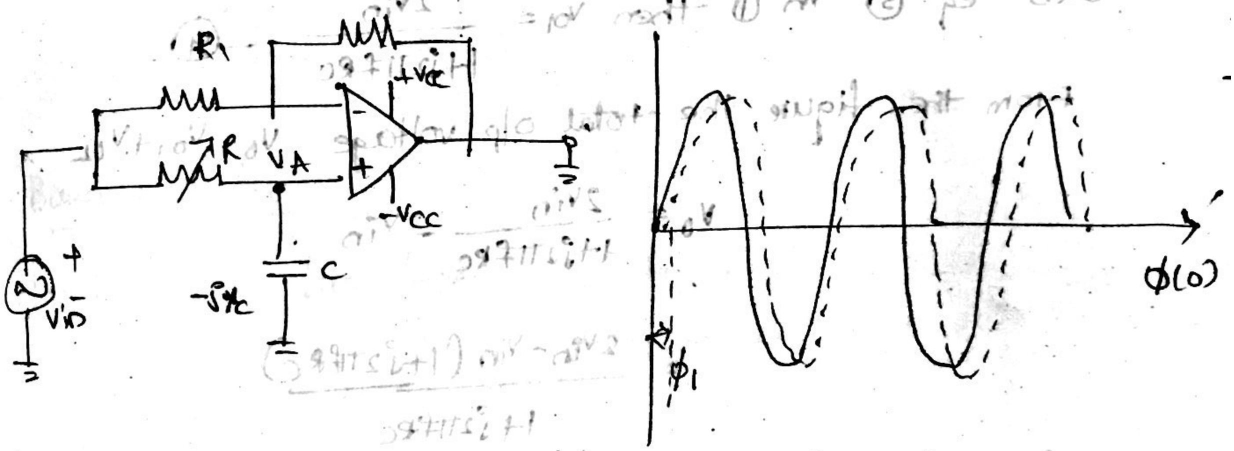
and the second order HPF produces with a gain of 40dB/dec

from eqⁿ ① $f_L = \frac{1}{2\pi\sqrt{R_2R_3C_2C_3}}$

if $R_2 = R_3 = R$, $C_2 = C_3 = C$

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

All pass filter (APF)



For the APF ckt all i/p's are applied from the inv and non-inv terminals.

Let us assume i/p is applied to the non-inv terminal and inv terminal is gnded. then

$$V_{01} = \left(1 + \frac{R_F}{R_1}\right) V_A$$

If $R_f = R_1$ then

$$\boxed{V_{01} = (2V_A)} \quad \text{—①}$$

Let us assume i/p is applied to the inv terminal and non-inv is gnded then $V_{O_2} = -\frac{R_f}{R_1} V_{in}$

If $R_f = R_1$, then

$$\boxed{V_{O2} = -V_{in}} \quad \text{--- (2)}$$

Now from fig by applying voltage divider rule at node A is

$$V_A = \frac{-jX_C}{R - jX_C} V_{in}$$

If $-j = 1/j$ and $X_C = \frac{1}{2\pi f C}$

$$V_A = \frac{\frac{1}{j2\pi f C}}{R + \frac{1}{j2\pi f C}} V_{in}$$

$$\boxed{V_A = \frac{1}{1 + j2\pi f RC} \cdot V_{in}} \quad \text{--- (3)}$$

sub eq^n (3) in (1) then $V_{O1} = \frac{2V_{in}}{1 + j2\pi f RC}$ --- (4)

From the figure the ~~total~~ o/p voltage $V_O = V_{O1} + V_{O2}$

$$V_O = \frac{2V_{in}}{1 + j2\pi f RC} - V_{in}$$

$$= \frac{2V_{in} - V_{in}(1 + j2\pi f RC)}{1 + j2\pi f RC}$$

$$V_O = V_{in}\left(\frac{2}{1 + j2\pi f RC} - 1\right)$$

$$\boxed{\frac{V_O}{V_{in}} = \frac{1 - j2\pi f RC}{1 + j2\pi f RC}} \quad \text{--- (5)}$$

From eq^n (5) the magnitude response is

$$\left|\frac{V_O}{V_{in}}\right| = \sqrt{\left(\frac{1 + j2\pi f RC}{1 + j2\pi f RC}\right)^2} = 1$$

$$\boxed{\left|\frac{V_O}{V_{in}}\right| = 1}$$

So "all pass filter" is also called as "unity gain BW amplifier" and the phase response of the above eqn

is $\phi = -2\tan^{-1}\left(\frac{2\pi f RC}{1}\right)$

$\phi = -2\tan^{-1}(2\pi f RC)$

problem

For all pass filter the resistor and capacitor values are 7.95 K-Ω and 0.02 μF. If the i/p frequency is 1.5 KHz then calculate the phase value of APF.

$R = 7.95\times10^{3}$

$C = 0.02\times10^{-6}$

$f = 1.5\times10^{3}$

$\phi = -2\tan^{-1}\left(2\pi(1.5\times10^{3})(7.95\times10^{3})(0.02\times10^{-6})\right)$

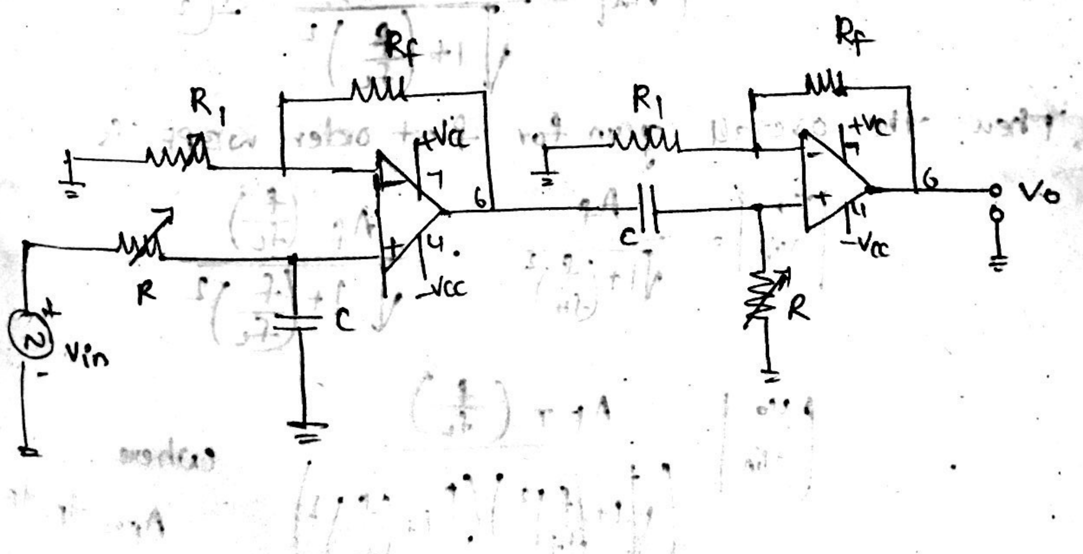
$\boxed{\phi = 112.5}$

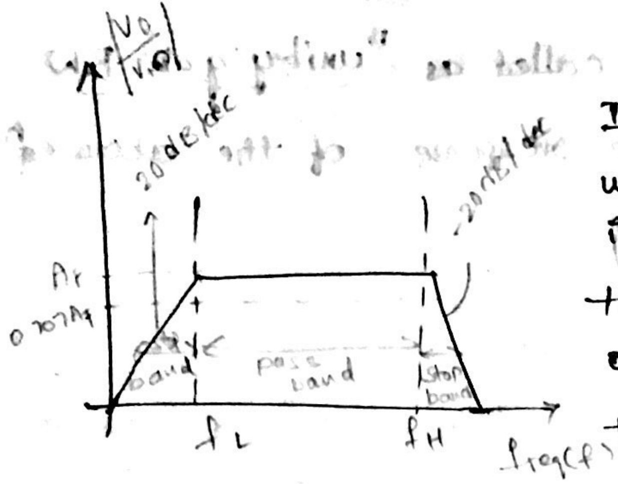
Band pass filter :-

classified into two types i) wide BPF

ii) Narrow BPF

wide BPF :-





If the filter whose BW is wide and quality factor(Q) is less than 10 (Q < 10) i.e., the quality factor is the ratio of cutt-off frequency f_c to the Bandwidth ($f_H - f_L$) i.e.,

$$\boxed{Q = \frac{f_c}{BW} = \frac{f_c}{f_H - f_L}}$$

Such filter is called as wide band pass filter. By using the wide BPF ckt it is the combination of first order LPF and first order HPF. then the roll rate of first order wide BPF is ± 20 dB/dec and if it is Second order the roll rate is ± 40dB/dec

The overall gain expression of first order WBPF is given by using first order LPF & HPF. we know that first order LPF gain is

$$\left|\frac{V_0}{V_{in}}\right| = \frac{A_f}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}} \quad \text{— (1)}$$

slly first order HPF gain is

$$\left|\frac{V_0}{V_{in}}\right| = \frac{A_f\left(\frac{f}{f_L}\right)}{\sqrt{1+\left(\frac{f}{f_L}\right)^2}} \quad \text{— (2)}$$

Then the overall gain for first order WBPF is

$$\left|\frac{V_0}{V_{in}}\right| = \frac{A_f}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}} \cdot \frac{A_f\left(\frac{f}{f_L}\right)}{\sqrt{1+\left(\frac{f}{f_L}\right)^2}}$$

$$\left|\frac{V_0}{V_{in}}\right| = \frac{A_{FT}\left(\frac{f}{f_L}\right)}{\left(\sqrt{1+\left(\frac{f}{f_H}\right)^2}\right)\left(\sqrt{1+\left(\frac{f}{f_L}\right)^2}\right)}$$

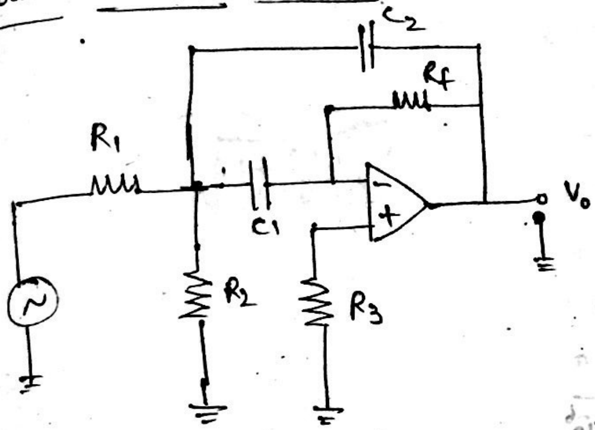
where $A_{FT} = A_F \cdot A_F$

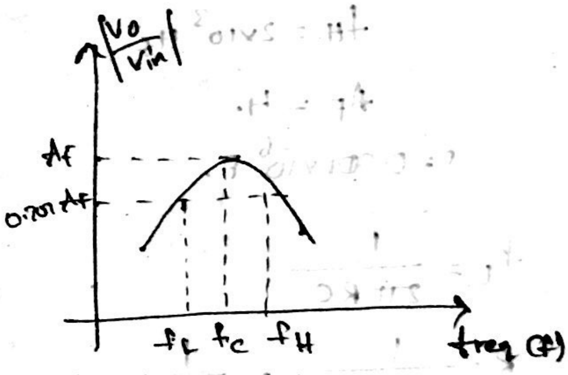
Note
If second order wide BPF gain expression is

$$A_1 = \frac{A_F}{\sqrt{1+\left(\frac{f}{f_H}\right)^4}} \text{ (LPF)} ; \quad A_2 = \frac{A_F}{\sqrt{1+\left(\frac{f_L}{f}\right)^4}} \text{ (HPF)}$$

$$\left|\frac{V_o}{V_{in}}\right| = \frac{A_{FT}}{\left(\sqrt{1+\left(\frac{f}{f_H}\right)^4}\right)\left(\sqrt{1+\left(\frac{f_L}{f}\right)^4}\right)}.$$

Narrow Band pass filter :-





Narrow BPF is defined as whose BW is very small and the quality factor is greater than 10 $(Q > 10)$ such filter is called Narrow BPF. It uses only one op-amp not like Wide BPF. This filter is having two properties

1. It is having two feedback paths
2. The ckt is operating as inv configuration. From the fig the designing of NBPF its elements is designed as following.

If $C_1 = C_2 = C$ then from the figure $R_1 = \dfrac{Q}{2\pi f_c \cdot C \cdot A_F}$

$$R_2 = \frac{Q}{2\pi f_c C\left[2Q^2 - A_F\right]}$$

$$R_3 = \frac{Q}{\pi f_c \cdot C}$$

$\xi \; A_F = \frac{R_3}{2R_1}$

For suppose if the components are changed then simply by replacing and the new resistances component

$$\boxed{R_2' = R_2\left[\frac{f_c}{f_c'}\right]^2}$$

where f_c is the original cutt-off frequency and f_c' is the new cutt-off frequency.

<u>problem:</u>

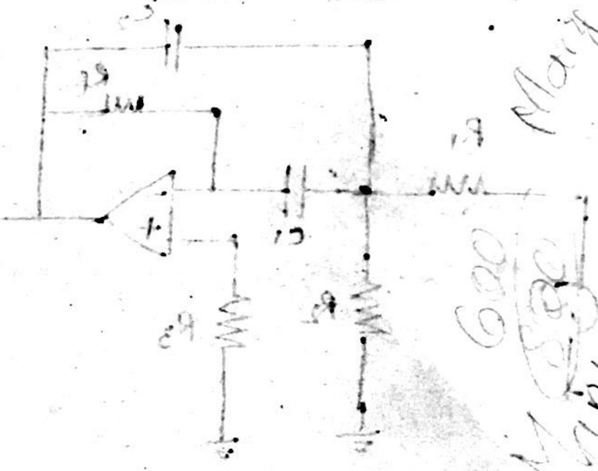
→ Design a WBPF having $f_L = 400Hz$, $f_H = 2KHz$ and a pass band gain of 4 draw the frequency response of filter and also calculate the quality factor of the filter.

Sol) Given $f_L = 400Hz$

$f_H = 2\times10^3 Hz$

$A_F = 4.$

$C = 0.001\times10^{-6} F.$



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

$$R = \frac{1}{2\pi f_L C} = \frac{1}{2\pi\times400\times0.001\times10^{-6}}$$

$$= 0.39 M\Omega$$

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

$$R = \frac{1}{2\pi f_H C} = \frac{1}{2\pi\times2\times10^3\times0.001\times10^{-6}}$$

$$= \frac{1}{4\pi\times0.001\times10^{-3}}$$

we know that the overall gain $A_{FT} = A_1 \cdot A_2$. But the pass band gain is given as '4' i.e., $A_{FT} = 4$ then $A_1 = A_2 = 2$

W.K.T the non-inv operation of an op-amp $A_1 = A_2 = 1 + \frac{R_F}{R_1} = 2$

$R_1 = 10k\Omega$

$R_F = 10k\Omega$.

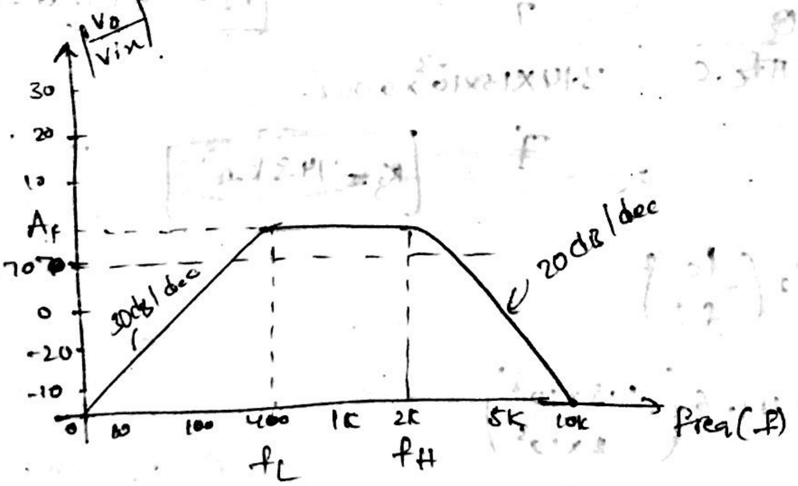
$$\frac{V_o}{V_{in}} = \frac{A_{FT}\left(\frac{f}{f_L}\right)}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}\sqrt{1+\left(\frac{f}{f_L}\right)^2}}$$

$$\frac{V_o}{V_{in}} = \frac{4\left(\frac{10}{400}\right)}{\sqrt{1+\left(\frac{10}{400}\right)^2}\sqrt{1+\left(\frac{10}{2\times10^3}\right)^2}}$$

$$= \frac{10}{\sqrt{1+\frac{1}{1600}}\sqrt{1+\left(\frac{10}{2\times10^3}\right)^2}}$$

$= 0.099$

freq (f)	$\frac{V_o}{V_{in}}$	$20\log\left(\frac{V_o}{V_{in}}\right)$
10 Hz	0.0999	−20.07
50 Hz	0.4	−6.09
100 Hz	0.9689	−0.27 dB
200 Hz		
400 Hz	2.72	8.86
800 Hz		
1k	3.82	10.42
2k	~~2.72~~	8.66
5k	1.48	3.41
10k	0.783	−2.11
500k		
1M		



$$Q = \frac{f_c}{BW}$$

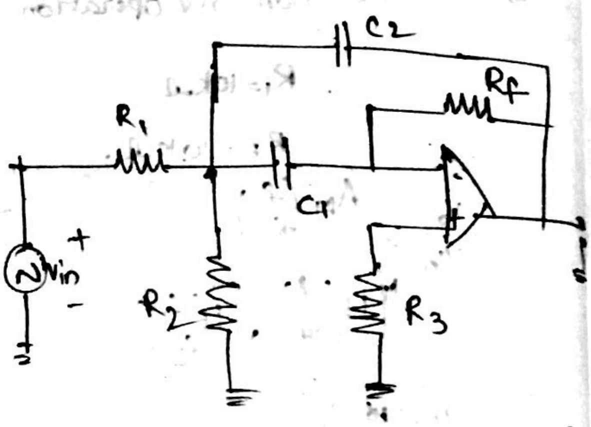
where $f_c = \sqrt{f_L \times f_H}$ $\Rightarrow$ $f_c = \sqrt{400 \times 2\times10^3}$

$BW = f_H - f_L$ $\qquad$ $BW = 2\times10^3 - 400$

$BW = 1600$

$Q = 0.556$

→ Design a narrow band pass filter with two feed back paths with $f_c = 1.5$ KHZ, $Q = 7$, $A_F = 15$. Calculate the new value of the resistance in the ckt which will change f_c to 2KHZ



$f_c = 1.5 \times 10^3$

$Q = 7$ $\quad C_1 = $

$A_F = 15$ $\quad C_1 = 0.02\,\mu F$

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

$$= \frac{7}{2 \times 3.14 \times 1.5 \times 10^3 \times 0.002 \times 10^{-6} \times 15}$$

$$= \frac{7}{30 \times 3.14 \times 1.5 \times 0.002 \times 10^{-3}}$$

$$\boxed{R_1 = 2.447\ k\Omega}$$

$$R_2 = \frac{Q}{2\pi f_c \cdot C\,[2Q^2 - A_F]}$$

$$= \frac{7}{2 \times 3.14 \times 1.5 \times 10^3 \times 0.002 \times 10^{-6}\,[2(49) - 15]}$$

$$\boxed{R_2 = 447.6\ \Omega}$$

$$R_3 = \frac{Q}{\pi f_c \cdot C} = \frac{7}{3.14 \times 15 \times 10^{-3} \times 0.002}$$

$$= \boxed{R_3 = 743\ k\Omega}$$

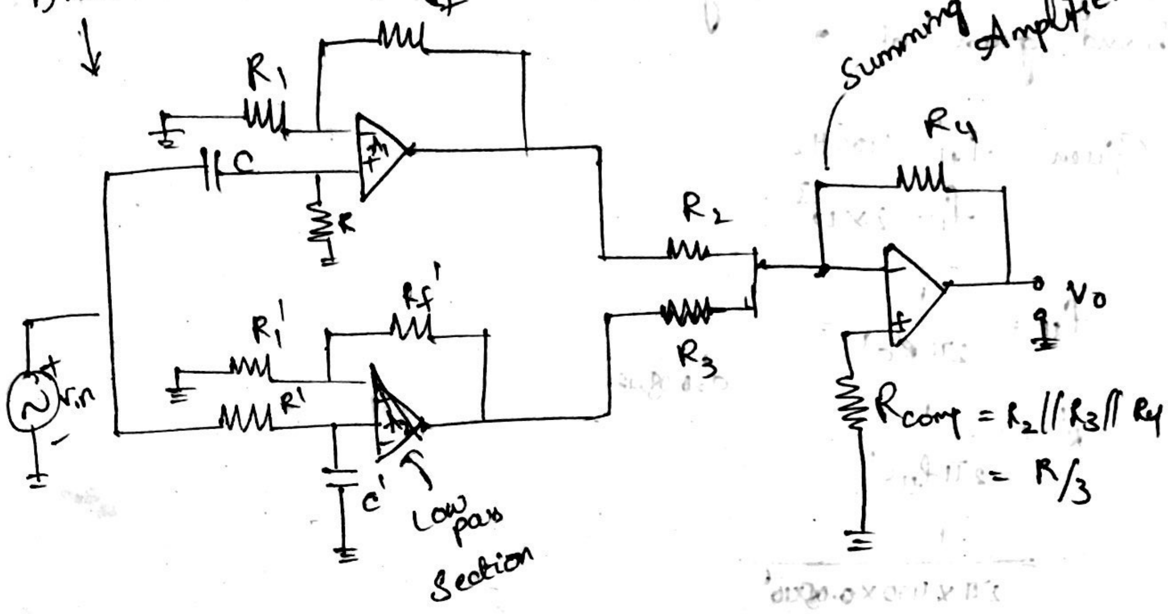
$$R^2 = R_2 \left(\frac{f_c}{f_c'}\right)^2$$

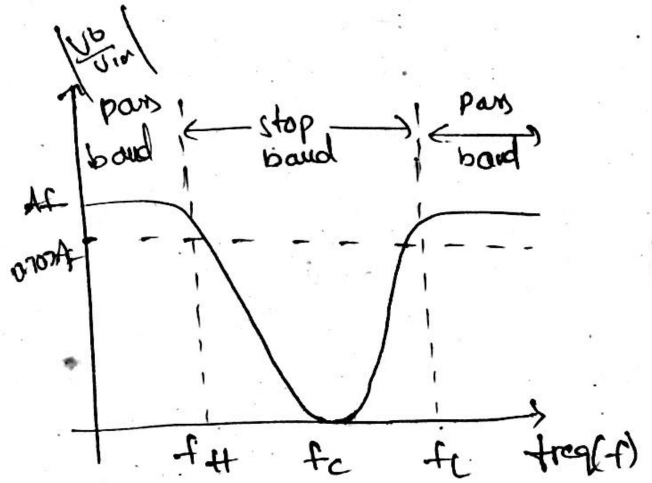
$$= 447.6 \left(\frac{1.5 \times 10^3}{2 \times 10^3}\right)^2$$

$$\boxed{R^2 = 251.7\ \Omega}$$

Band Elimination filter :

i) WBEF . 2) NBEF.





This wide band reject filter is same as wide band pass filter. This filter consists of a high pass and low pass filter section aditionally it consists of summing Amplifier. To satisfying this operation of the filter it is existing following two conditions.

① The lower cutt-off frequency f_L is greater than higher cutt-off frequency f_H ($f_L > f_H$)

② The pass band gain of high and low pass sections must be equal. The design of the overall filter is based on the individual design of the various sections.

i) For low pass filter $f_H = \frac{1}{2\pi R'C'}$

ii) For High pass Section $f_L = \frac{1}{2\pi RC}$

iii) The gain of the summing Amplifier can be adjusted to unity for simplification and thus $R_2 = R_3 = R_4 = R$ then $R_{comp} = R/3 = R_2||R_3||R_4$ and the centre cutt-off frequency $f_c = \sqrt{f_H \cdot f_L}$.

problem

→ Design a WBEF having $f_H = 400Hz$, $f_L = 2kHz$ with a pass band gain of 2

Given $f_H = 400Hz$

$f_L = 2\times10^3$

$$f_H = \frac{1}{2\pi R'C'}$$

$C' = 0.05\mu F$

$$R' = \frac{1}{2\pi f_H C'}$$

$$\frac{1}{2\pi\times400\times0.05\times10^{-6}}$$

$R' = 7.95$

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

$$R = \frac{1}{2\pi f_L C}$$

$$R = \frac{1}{2\pi\times2\times0.01\times10^{-3}}$$

$R = 7.95\,k\Omega$

The gain of both LP and HP sections must be equal i.e., $A_1 = A_2 = A_F = 2$

$$A_f = 1 + \frac{R_f}{R_1} \qquad R_f = R_1 = 10k\Omega.$$

$$2 = 1 + \frac{R_f}{R_1} \qquad R_f = 10k\Omega$$

For Summing Amplifier $R_{comp} = R_2 \| R_3 \| R_4 = \frac{R}{3}$

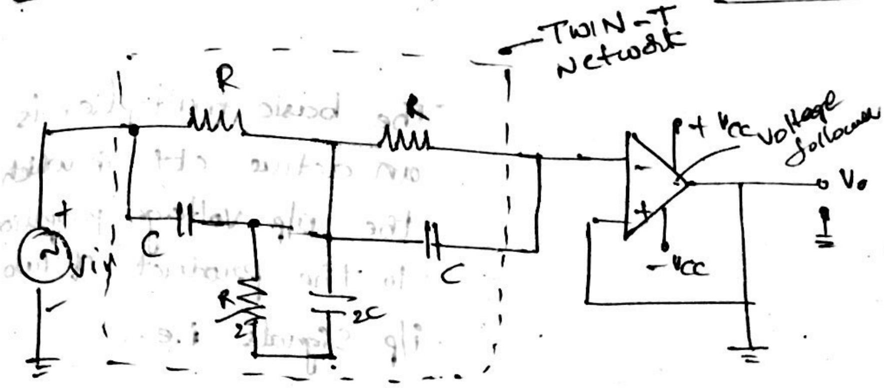
$$= 10k \| 10k \| 10k = \frac{10k}{3} = 3.3k\Omega$$

$$f_C = \sqrt{f_H \cdot f_L}$$

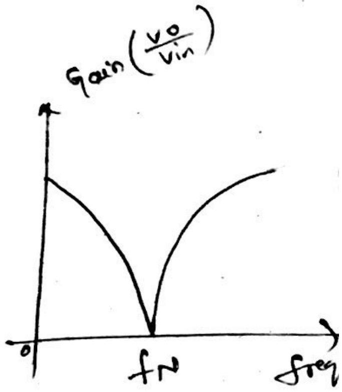
$$= \sqrt{400\times2000}$$

$$= \sqrt{800000} = 894.4Hz.$$

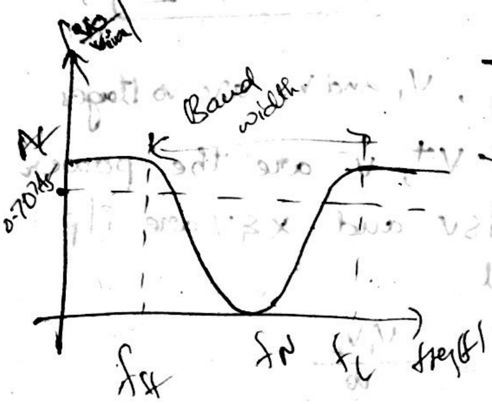
Narrow Band Elimination (or) Reject filter (Notch-filter) :-



(a) Active Notch filter



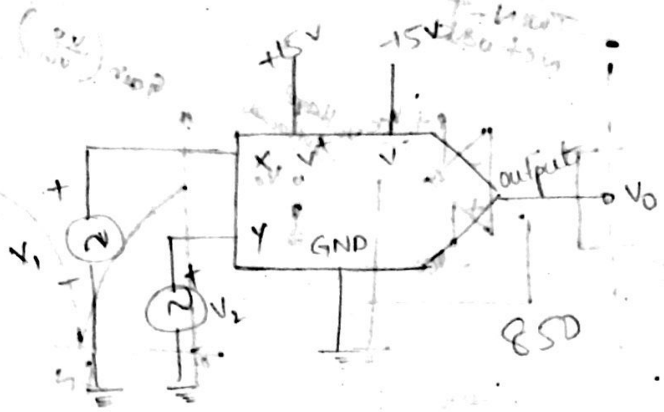
(b) Ideal Response



(c) practical response

This NBEF, is used in bio-medical instrumentation Application. It consists of two T networks one consists of two resistors and a capacitor and another one two capacitors & resistors. The Notch frequency f_N is the max frequency which is given as $f_N = \frac{1}{2\pi RC}$. To design a Notch filter choose the capacitor $C \leq 1\mu F$.

Multiplier :-



a) Multiplier IC symbol

The basic multiplier is an active ckt in which the o/p voltage propotional to the product of two i/p signals i.e.,

$V_0 \propto V_1 . V_2$

$\boxed{V_0 = K V_1 . V_2}$

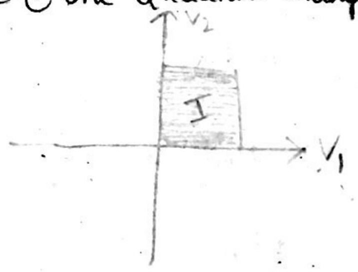
where k is constant i.e., $K = \frac{1}{V_{ref}}$, V_1 and V_2 are voltages

from the multiplier Symbol V^+, V^- are the power Supply terminals. generally it is $\pm 15V$ and X & Y are i/p terminals and V_0 is the o/p terminal

If $V_{ref} = 10V$ then $V_0 = \frac{V_1 V_2}{V_{ref}} = \frac{V_1 V_2}{10}$

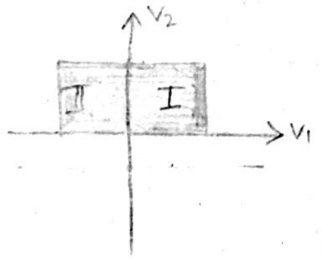
Depending on the use of the basic multiplier it is restricted to the polarity of one or both i/p's. Depending on the Quadrant it is classified into 3 types ① one quadrant multiplier

① One Quadrant multiplier



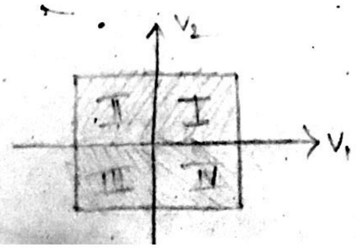
If the polarities of both i/p's are always positive such multiplier is called as one quadrant multiplier.

② Two Quadrant multiplier



If one i/p is positive and another i/p is swinging b/w +ve and -ve such multiplier is called as two Quadrant mul.

③ Four Quadrant multiplier



If both i/p's are allowed to swing in both +ve & -ve directions such multiplier is called as four quadrant multiplier

performance parameters of multiplier

Accuracy :- It is the max deviation of the actual o/p level from the ideal one. i.e., $V_0 = KV_1 \cdot V_2$ for any choice of V_1 & V_2 within the dynamic range of multiplier. It is generally specified in terms of percentage of full Scale o/p.

Linearity : It is the max o/p deviation from the st. line at the o/p, where one i/p is varied while other is fixed. usually. $\pm 10V$. It is also expressed as full scale o/p.

Bandwidth : It is the range upto the frequency where the o/p is 3dB below its lower frequency value.

1% Absolute Error Bandwidth :- It represents the frequency where the o/p magnitude starts to deviate from its low frequency value by 1%.

feed through voltage :- It is the V_{p-p} at the o/p when one of the two i/p's is grounded. But practically the ~~o/p~~ multiplication of o/p voltage is zero.

Zero trim voltage :- It is the ability of the multiplier to set the feed through Voltage at the o/p to zero.

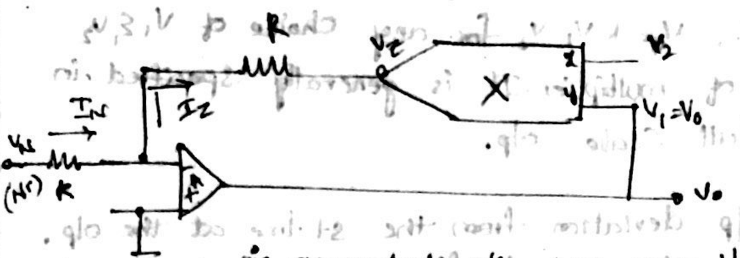
scale factor : It is the proportionality constant K relating to the o/p Voltage i.e., $\boxed{K = \frac{V_0}{V_1 V_2}}$

Quadrant : It is restricted to the polarities of the two i/p Voltages. ~~Fore~~ for one Quad mul both are +ve. For two Quad mul one is +ve & one is swinging b/w +ve and -ve. For Four Quad mul is both swinging in +ve & -ve directions.

Applications:

- In Communication for the amplitude modulation, frequency modulation phase detection & supressed carry detection etc.
- In Instrumentation to control the velocity, acceleration & power etc.
- For voltage Control attenuators & for voltage control amplification.
- used for voltage divider, RMS calculation, Rectifiers phase shift detection
- used for freq convertors, frequency doubling, freq shifting.
- It is used for squaring & square root ckt.
- used to solve non-linear eq's
- used in oscillations to generate the waveforms and also square wave generators.

Voltage divider using Multipliers :-



From the voltage divider ckt by using virtual gnd concept node A is gnded then automatically ~~node B~~ is grounded then op-amp i/p current is 0.

$$I_N = I_Z = \frac{V_N}{R} = \frac{-V_Z}{R} \quad \text{—(1)}$$

W.K.T from the multiplier $V_Z = K.V_1 V_2$

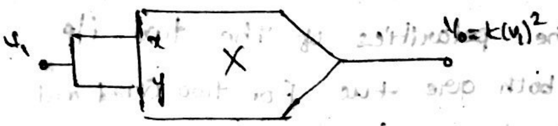
$$V_Z = K V_0 . V_2 \quad \text{—(2)} \quad [\because V_1 = V_0]$$

$$\therefore (1) \Rightarrow -V_N = K V_0 V_2$$

$$\boxed{V_0 = \frac{-V_N}{K V_2}}$$

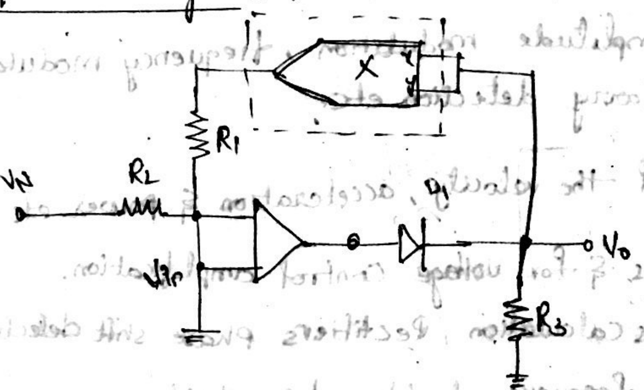
This eq^n gives that the o/p voltage is proportional to two voltages division.

Squaring ckt using Multiplier :-



From the fig the both i/p voltages are applied as equally i.e., $V_1 = V_2$ then the o/p $V_0 = K(V_1)^2$. This eq^n tells that o/p is proportional to the square of i/p voltage.

Square rooting ckt :-



From the fig the operational Amp whose inv and non-inv terminals voltages is applied b/w these two terminals then the op-amp o/p

$$V_0 = -V_{in} A$$

From the fig the voltage V_{in} is applied b/w the voltages V_N & V_Z then we can write as

$$V_{in} = \frac{-V_0}{A} \quad \text{—(1)}$$

$$V_{in} = V_N . \frac{R_1}{R_1+R_2} + V_2 . \frac{R_2}{R_1+R_2}$$

But $V_Z = kV_0^2$

$$\therefore \boxed{V_{in} = V_N \frac{R_1}{R_1+R_2} + kV_0^2 \frac{R_2}{R_1+R_2}} \rightarrow (2)$$

By equating eq^n (1) and eq^n (2)

$$\frac{-V_0}{A} = V_N \frac{R_1}{R_1+R_2} + kV_0^2 \frac{R_2}{R_1+R_2}$$

$$V_0^2 = \frac{-V_N R_1}{kR_2} - \frac{V_0(R_1+R_2)}{AkR_2}$$

By neglecting Second term

$$\boxed{V_0 = \sqrt{\frac{-V_N \cdot R_1}{kR_2}}}$$

This gives that o/p voltage is proportional to square root of V_N and V_N should always be negative.

1M

<u>Frequency doubler using multiplier</u> :