ACTIVE FILTERS :

An electric filter is often a frequency selective circuit that passes a specified band of frequencies and blocks or alternates signal and frequencies outside this band. Filters may be classified as

- Analog or digital.
- Active or passive
- Audio (AF) or Radio Frequency (RF)

- Analog or digital filters:

Analog filters are designed to process analog signals, while digital filters process analog signals using digital technique.

- Active or Passive:

Depending on the type of elements used in their construction, filter may be classified as passive or Active elements used in passive filters are Resistors, capacitors, inductors. Elements used in active filters are transistor, or op-amp.

- Audio (AF) or Radio Frequency (RF)

Audio Frequency (AF) refers to acoustic signals in the human hearing range while Radio Frequency (RF) refers to high-frequency electromagnetic waves used for wireless communication. AF represents the information (sound), and RF acts as the carrier wave that propagates through space to transmit that information.

ACTIVE FILTERS OFFER THE FOLLOWING ADVANTAGES OVER PASSIVE FILTERS

✓ **Gain and Frequency adjustment flexibility:**

Since the op-amp is capable of providing gain, the i/p signal is not attenuated as it is in a passive filter. [Active filter is easier to tune or adjust].

✓ **No loading problem:**

Because of the high input resistance and low o/p resistance of the op-amp, the active filter does not cause loading of the source or load.

✓ **Cost:**

Active filters are more economical than passive filter. This is because of the variety of cheaper op-amps and the absence of inductors.

The most commonly used filters are these:

1. Low pass Filters
2. High pass Filters
3. Band pass filters
4. Band –reject filters

Frequency response of the active filters:

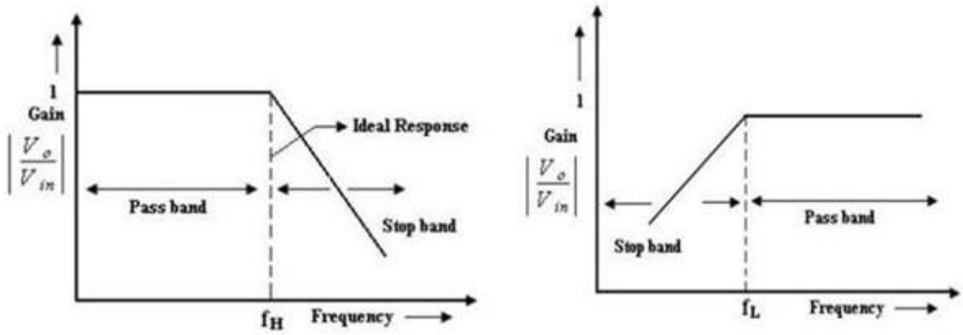


Figure 2.9.1 a).Frequency response of LPF and HPF

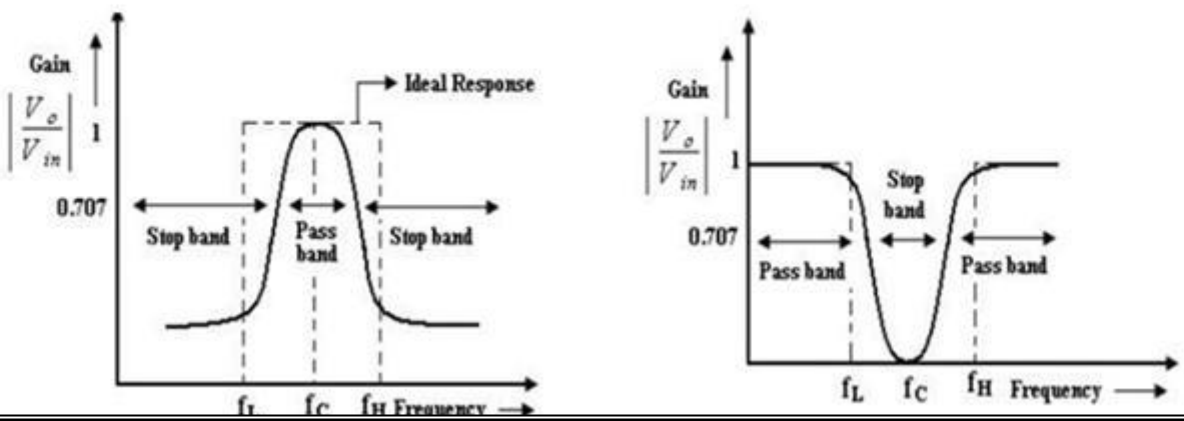


Figure 2.9.1 b) Frequency response of BPF and Band reject filter

LOW PASS FILTERS

- It has a constant gain from 0 Hz to a high cutoff frequency f_1.
- At f_H the gain in down by 3db.
- The frequency between 0 Hz and f_H are known as the pass band frequencies where as the range of frequencies those beyond f_H, that are attenuated includes the stop band frequencies.

HIGH PASS FILTER

High pass filter with a stop band $0 < f < f_{L\ and}$ a pass band $f > f_L$

f_L -> low cut off frequency

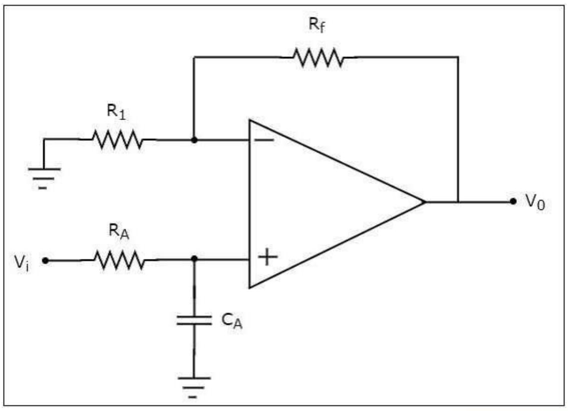
f -> operating frequency.

BAND PASS FILTER

It has a pass band between 2 cut off frequencies f_H and f_L where $f_H > f_L$ and two, stop bands: $0 < f < f_L$ and $f > f_H$ between the band pass filter (equal to $f_H - f_L$). Band –reject filter: (Band stop or Band elimination). It performs exactly opposite to the band pass.It has a band stop between 2 cut-off frequency f_L and f_H and 2 pass bands: $0 < f < f_L$ and $f > f_H$ f_C -> center frequency.

<u>FIRST ORDER LPF FILTER :</u>

First order LPF that uses an RC for filtering op-amp shown in figure 2.9.2a) is used in the non-inverting configuration. Figure 2.9.2 b) shows the frequency response of first order LPF. Resistor R_1 & R_f determine the gain of the filter. According to the voltage –divider rule, the voltage at the non-inverting terminal (across capacitor) C is,



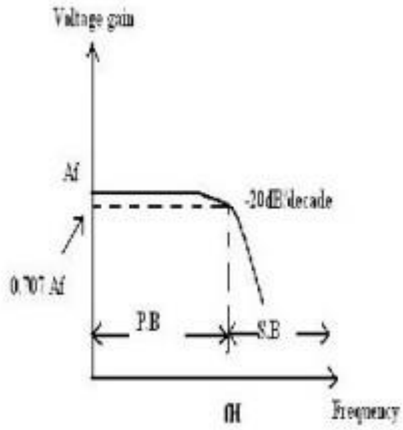


Figure 2.9.2 a) First order low pass filter figure 2.9.2 b)frequency response

Gain $A= (1+R_f/R_1)$

Voltage across capacitor $V_1= V_i / (1+j2\pi fRC)$

Output voltage V_0 for non inverting amplifier $=A\ V_1$

$= (1+R_f/R_1)\ Vi/(1+j2\pi fRC)$

Overall gain $V_0/V_i = (1+R_f/R_1)\ Vi/(1+j2\pi fRC)$

Transfer function $H(s) =A/(jf/f_h+1)$

if $f_h =1/2\pi RC$

$H (j\omega) = A/(j\omega RC+1) = A/(j\omega RC+1)$.

The gain magnitude and phase angle of the equation of the LPF can be obtained by converting eqn. (1) b into its equivalent polar form as follows.

1. At very lowω)|frequency, $f < f_H$

   $|H (j\omega) =A$

2. At $f =f_H$

   $|H (j\omega)|$

3. At $f> f_H$

   $=A/\sqrt{2}=0.707A$

   $|H (j\omega)|<<A \cong 0$

When the frequency increases by tenfold (one decade), the volt gain is divided by 10. The gain falls by 20 dB (=20log10) each time the frequency is reduces by 10. Hence the rate at which the gain rolls off f_H = 20 dB or 6dB/octave (twofold R_{in} frequency). The frequency $f = f_H$ is called the cut off frequency because the gain of the filter at this frequency is down by 3 dB (=20 log 0.707).

SECOND ORDER LP FILTER :

A second order LPF having a gain 40dB/decade in stop band. A First order LPF can be converted into a II order type simply by using an additional RC network shown in figure 2.9.3

- An improved filter response can be obtained by using a second order active filter.
- A second order active filter consists of two RC pairs & has roll off rate of -40db/decade.
- The op-amp is connected as non-inverting amplifier hence

$$V_o = \left(1+\frac{R_f}{R_1}\right)V_B = A_o V_B$$

$$where, A_o = \left(1+\frac{R_f}{R_1}\right)$$

$$and\ V_B \rightarrow voltage\ at\ node\ B$$

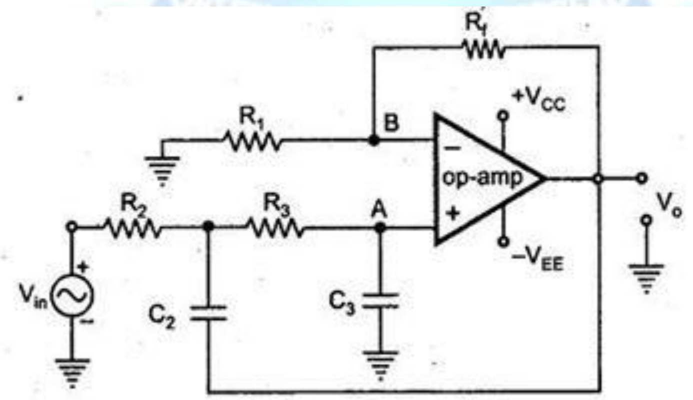


Figure 2.9.3.Second order low pass butterworth filter

Let us consider the General prototype second order filter circuit as in figure 2.9.4.

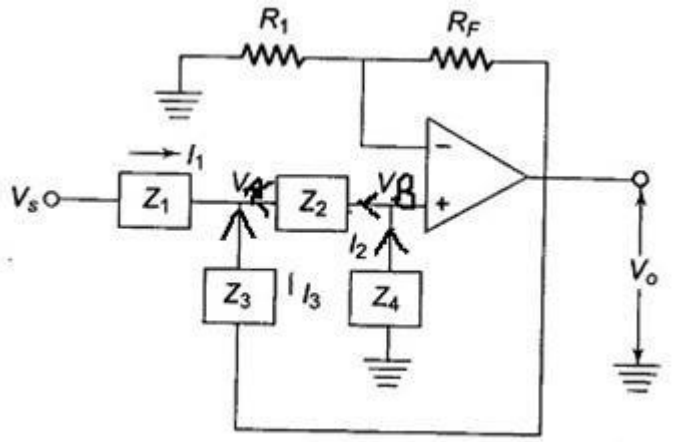


Figure 2.9.4 General prototype second order filter circuit

KCL at node A,

$$(V_i - V_A)Z_1 + (V_0 - V_A)Z_3 + (V_B - V_A)Z_2 = 0$$

$$V_iZ_1 + V_oZ_3 + V_BZ_2 - V_A(Z_1 + Z_2 + Z_3) = 0$$

$$V_iZ_1 = V_A(Z_1 + Z_2 + Z_3) - V_BZ_2 - V_oZ_3$$

$$A_o = \frac{V_o}{V_B}$$

$$V_B = \frac{V_o}{A_o}$$

$$V_iZ_1 = V_A(Z_1 + Z_2 + Z_3) - V_BZ_2 - \frac{V_o}{A_o}Z_3 \text{ ----(1)}$$

$KCL\ at\ node\ B$,

$$(V_B - V_A)Z_2 + V_BZ_4 = 0$$

$$V_AZ_2 = V_B(Z_4 + Z_2)$$

$$V_AZ_2 = \frac{V_o}{A_o}(Z_4 + Z_2) \text{----- (2)}$$

$$V_A = \frac{V_o}{A_o}\frac{(Z_2 + Z_4)}{Z_2}$$

$$Sub\ V_A\ (2)\ in\ (1)$$

$$V_iZ_1 = \frac{V_o}{A_o}\frac{(Z_2 + Z_4)}{Z_2}(Z_1 + Z_2 + Z_3) - V_BZ_2 - \frac{V_o}{A_o}Z_3$$

$$V_i Z_1 = V_o \left(\frac{(Z_2 + Z_4)(Z_1 + Z_2 + Z_3) - Z_3(A_o Z_2) - Z^2{}_2}{A_o Z_2} \right)$$

$$\frac{V_o}{V_i} = \frac{A_o Z_1 Z_2}{Z_1 Z_2 + Z^2{}_2 + Z_2 Z_3 + Z_1 Z_4 + Z_2 Z_4 + Z_3 Z_4 - A_o Z_2 Z_3 - Z^2{}_2}$$

$$\frac{V_o}{V_i} = \frac{A_o Z_1 Z_2}{Z_1 Z_2 + Z_4(Z_1 + Z_2 + Z_3) + Z_2 Z_3(1 - A_0)} \quad --(3)$$

To make a low pass filter, choose $Z_1 = Z_2 = \frac{1}{R}$ And $Z_3 = Z_4 =$ SC *from first fig.*

From (3), *we get the transfer function* $H(s)$ *of a low pass filter as*

$$H(S) = \frac{\frac{A_o}{R^2}}{\left(\frac{1}{R^2} + SC\left(\frac{1}{R} + \frac{1}{R} + SC\right) + \frac{SC}{R}(1 - A_o)\right)}$$

$$After\ simplifying,\ we\ get \qquad \text{-----(4)}$$

$$H(S) = \frac{A_o}{S^2C^2R^2+SCR(3-A_o)+1}$$

$$From\ (4),$$

$$H(s) = A_o,\ for\ S = 0$$

$$H(s) = \infty\ ,for\ S = \infty$$

The transfer function of the low pass second order system can be written as

$$H(s) = \frac{A_o \omega_n^2}{S^2+\alpha\omega_n S+\omega_n^2} \quad \text{------ (5)}$$

Where, $A_o \rightarrow the\ gain$

$\omega_n \rightarrow upper\ cutoff\ frequency\ in\ rad/\sec$

$\alpha \rightarrow sampling\ coefficient$

$comparing\ equ\ (4)\&(5)$

$$\omega_n = \frac{1}{RC} \quad ,\alpha = (3 - A_o)$$

The value of the damping coefficient α *for low pass active RC filter can be determined by the value of* A_o *chosen*

$$Sub\ S = j\omega\ in\ (5)$$

$$H(j\omega) = \frac{A_o \omega_n^2}{(j\omega)^2+\alpha\omega_n j\omega+\omega_n^2}$$

$$H(j\omega) = \frac{A_o}{\left(\frac{j\omega}{\omega_n}\right)^2 + j\alpha\frac{\omega}{\omega_n} + 1}$$

The normalised expression for lowpass filter is

$$H(j\omega) = \frac{A_o}{S_n^2 + \alpha S_n + 1}$$

$$Where,\ normalised\ frequency\ S_n = j\left(\frac{\omega}{\omega_n}\right)$$

The expression of magnitude in db of the transfer function is

$$20\ log|H(j\omega)| = 20\ l0g\left(\frac{A_o}{1+j\alpha\left(\frac{\omega}{\omega_n}\right)+\left(\frac{j\omega}{\omega_n}\right)^2}\right)$$

$$= 20\ log\ \left(\frac{Ao}{\left(1-\frac{\omega^2}{\omega_n^2}\right)2+\left(\alpha\frac{\omega}{\omega_n}^2\right)}\right)$$