Analog and Digital Systems (UEE505)

Lecture # 9
Butterworth filters using op amp -I

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Filter Introduction

- A filter is a circuit that passes some frequency signals without any attenuation (Reduction in amplitude) or with some amplification and attenuate other frequency depending on the types of the filter.
- Filters can be used to attenuate unwanted signals such as interference or noise or to isolate desired signals from unwanted.
- A common instrumentation filter application is the attenuation of high frequencies to avoid frequency aliasing in the sampled data.

Classification of Filters

- Classification of filters based on their frequency response and construction:
  - Analog and Digital Filter (depending on type of techniques used in the process of analog signals)
  - Passive and Active filters (depending on type of elements used in their construction)
  - (According to operating frequency range) Audio or Radio Frequency Filters

Filter Classification according to Frequency Response

i) Low Pass Filter ii) High Pass Filter

iii) Bandpass Filter iv) Band Stop Filter

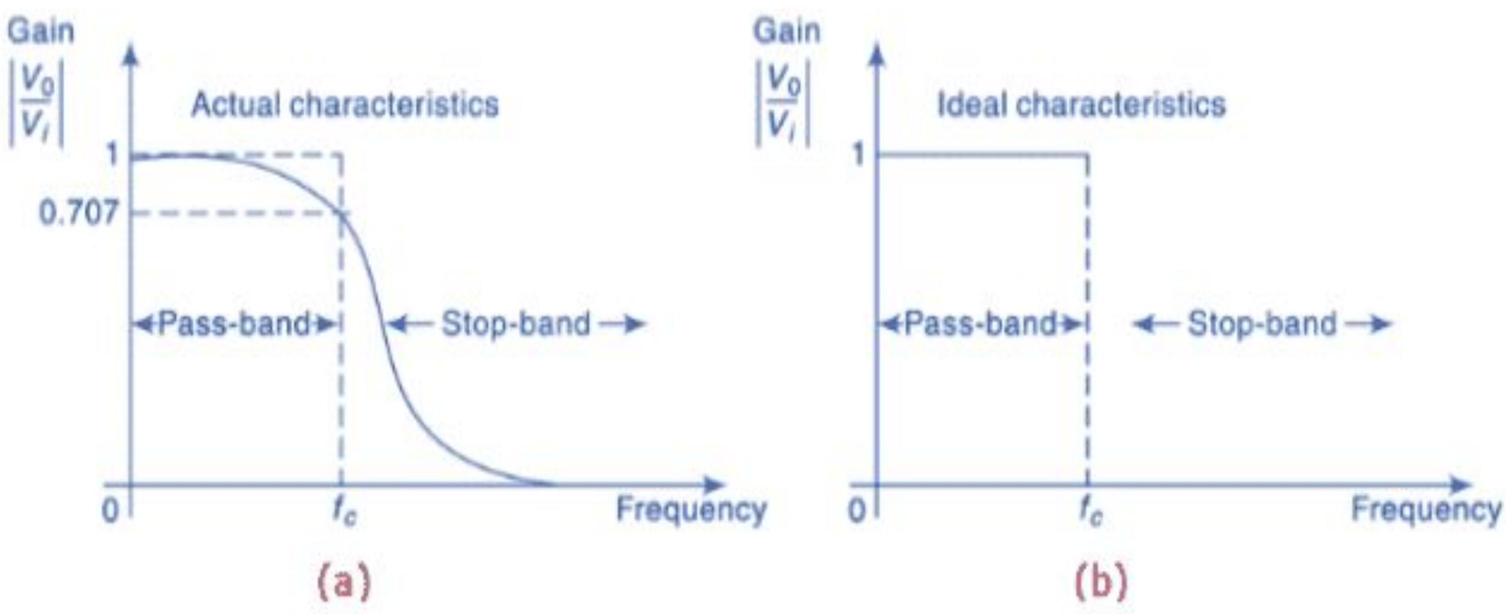
- Butterworth, Chebyshev, and Elliptical Filters are some of most widely used practical filters for approximating the ideal response.

❑ Key Characteristics:

- Butterworth : Flat passband as well as flat stop band (flat flat filter).
- Chebyshev : Ripple passband and flat stop band.
- Elliptical : Ripple passband as well as Ripple stop band (Provide best stopband response)

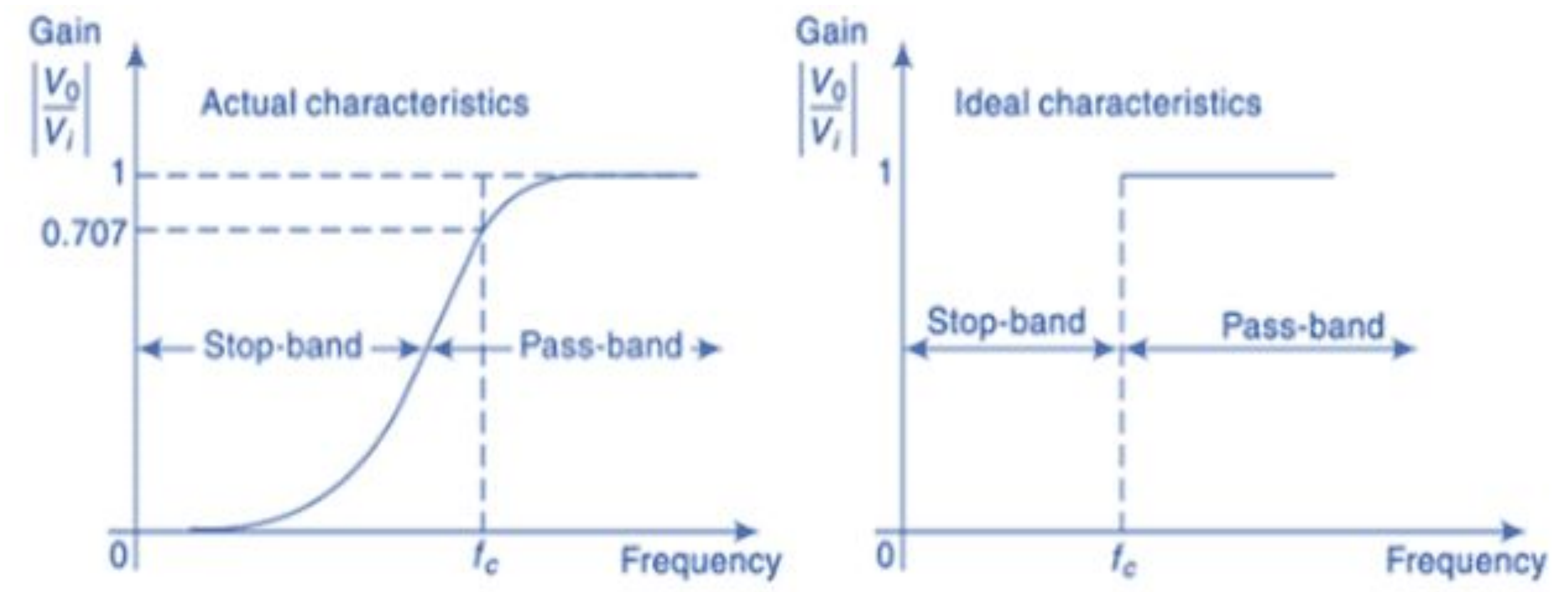
Low Pass Filter

- It is a type of Filter which attenuates all the frequencies above the cut-off frequencies.
- It provides a constant output (gain) from zero to cut-off frequency.



High Pass Filter

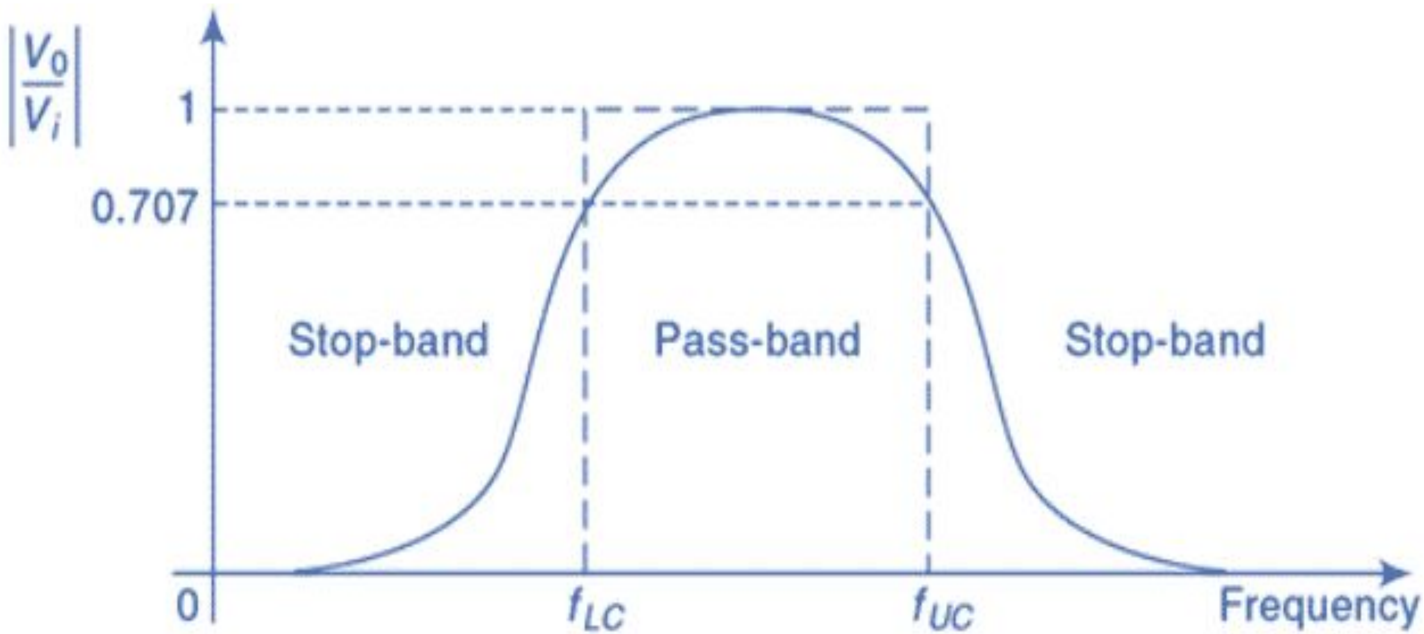
- It is a type of Filter which attenuates all the frequencies below the cut-off frequencies.
- It provides a constant output (gain) above the cut-off frequency.



(a) (b)

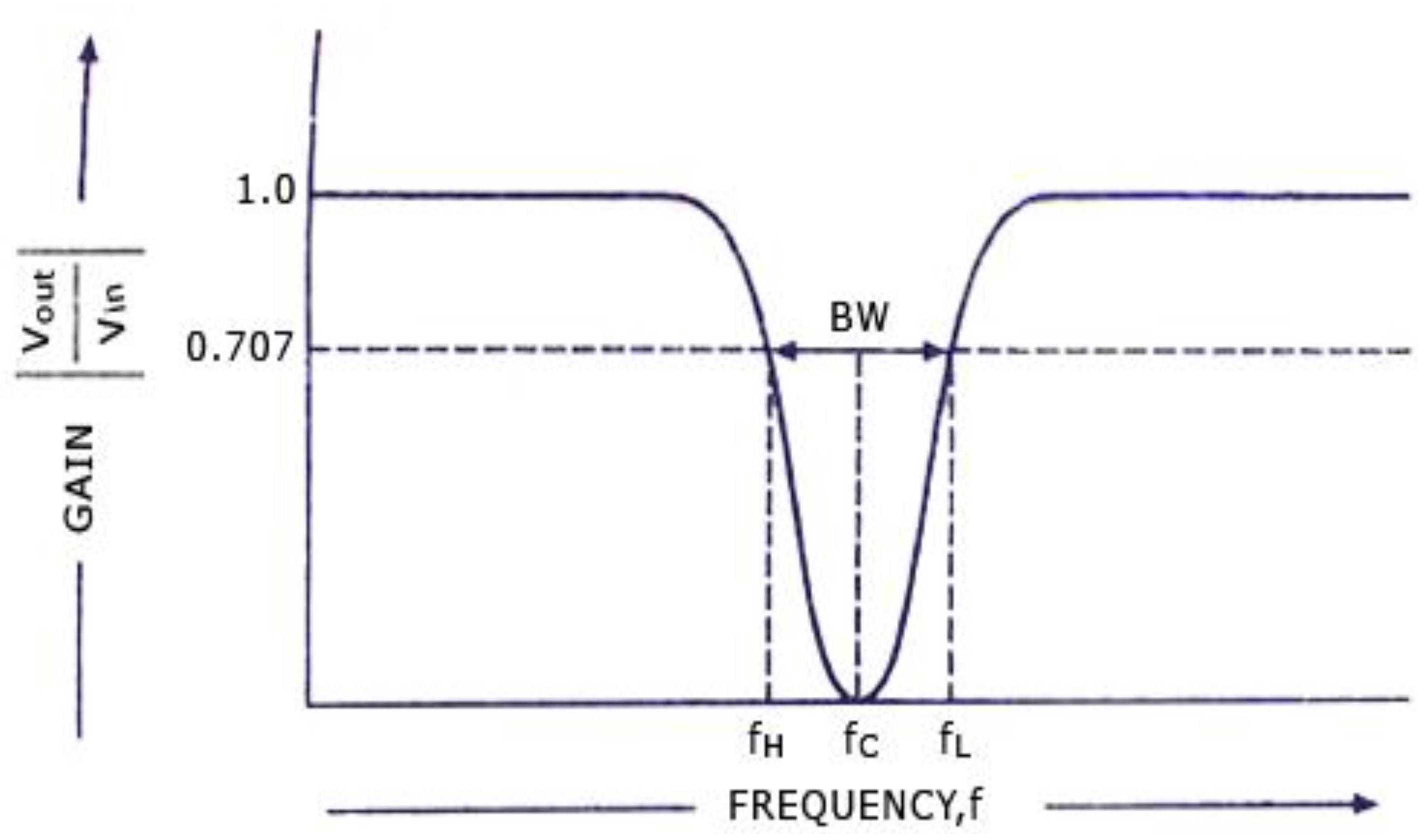
Bandpass Filter

- It is a type of filter which allows specific band of frequencies to pass through and all other frequencies outside the band are attenuated.



Band Stop Filters

- Specific Band of frequencies gets rejected and allows passing of frequencies outside the Band.



Applications of Filters

- Filter Circuits are used to eliminate background Noise
- They are used in Radio tuning to a specific frequency and in signal processing circuits
- Filter Circuits are extensively used in Medical Electronic Systems

Designing of Low Pass Filter

Voltage at non inverting input terminal(voltage across the capacitor) is :

$V_1 = [\ -j\, Xc\ /\ (R - j\, Xc)\ ]\ V_{in}$

Here, $-j\, Xc = 1/2\pi fc$

$V_1 = V_{in}\ /\ (1 + j2\pi fRC)$

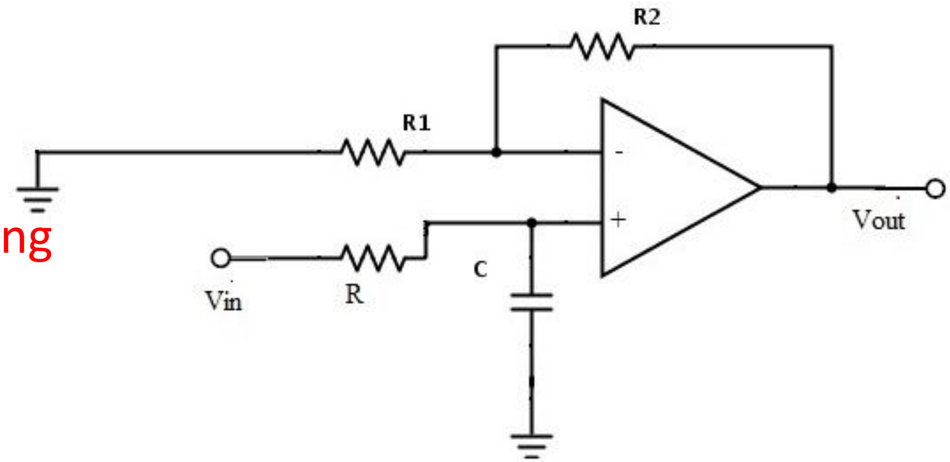
Now the op-amp here used in non inverting configuration, thus

$V_o = (\ 1 + R_2\ /\ R_1\ )\ V_1$.

$V_o = (1 + R_F\ /\ R_1)\ [V_{in}\ /\ (1 + j2\pi fRC)\ ]$

$V_o\ /\ V_{in} = A_F\ /\ (\ 1 + j\ (f/\ f_L)\ )$

Ist order Butterworth LPF



Here,

$V_{out}\ /\ V_{in}$: gain of the filter as a function of frequency

$AF = (1 + R_F\ /\ R_1)$: passband gain of the filter

f : frequency of the input signal

$f_L = 1\ /\ 2\pi RC$: cutoff frequency of the filter.

Frequency Response of Low Pass Filter

$V_o / V_{in} = A_F / (1 + j (f/ f_L))$

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

Now to observe the change in gain magnitude with the change in the frequency of the input signal, consider three cases:

Case1: $f<<f_L$,

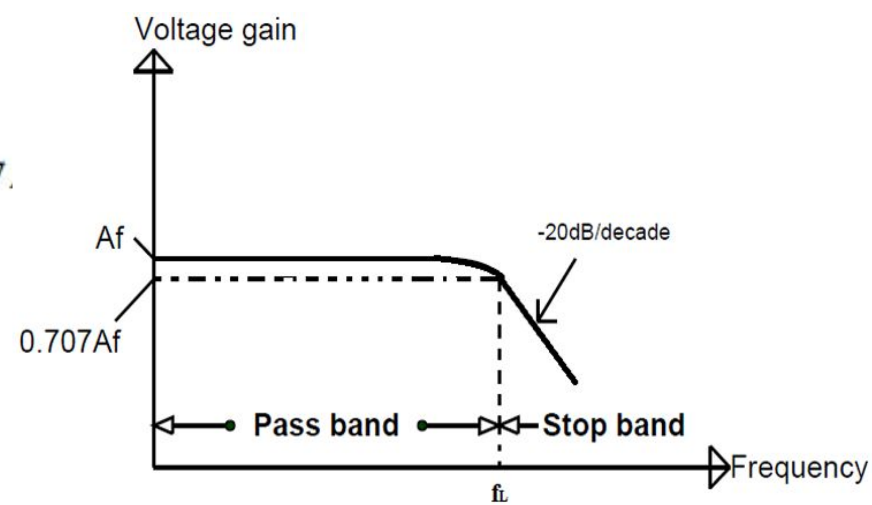
$$\left|\frac{V_o}{V_{in}}\right| = \frac{A_F}{\sqrt{1+(0)^2}} = A_F$$

Case2: $f = f_L$,

$$\left|\frac{V_o}{V_{in}}\right| = \frac{A_F}{\sqrt{1+(1)^2}} = \frac{A_F}{\sqrt{2}} = 0.707.$$

Case3: $f >f_L$,

$$\left|\frac{V_o}{V_{in}}\right| < A_F$$



References

❖ For more details, refer to:

-- *Boylestad R. L., Electronic Devices and Circuit Theory, Pearson Education*

-- *Op-Amps and Linear Intergrated Circuits , Ramakant A. Gayakwad*

-- *Neamen, Donald A., Electronic Circuit Analysis and Design, McGraw Hill*