For M.Sc. 2nd Semester-2020

Paper: EST 201

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Active bandpass filter

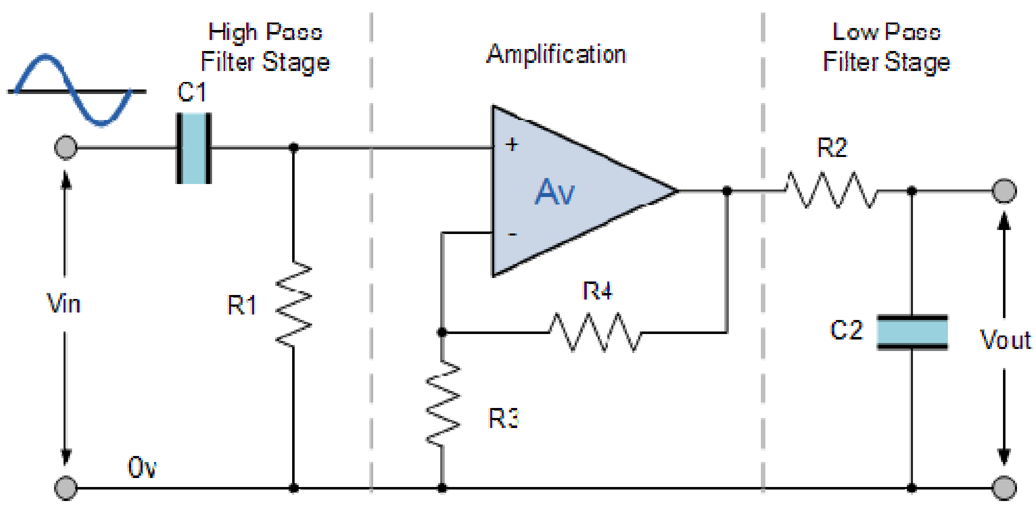
For a low pass filter this pass band starts from 0Hz or DC and continues up to the specified cut-off frequency point at -3dB down from the maximum pass band gain. Equally, for a high pass filter the pass band starts from this -3dB cut-off frequency and continues up to infinity or the maximum open loop gain for an active filter.

However, the **Active Band Pass Filter** is slightly different in that it is a frequency selective filter circuit used in electronic systems to separate a signal at one particular frequency, or a range of signals that lie within a certain "band" of frequencies from signals at all other frequencies. This band or range of frequencies is set between two cut-off or corner frequency points labelled the "lower frequency" (f_L) and the "higher frequency" (f_H) while attenuating any signals outside of these two points.

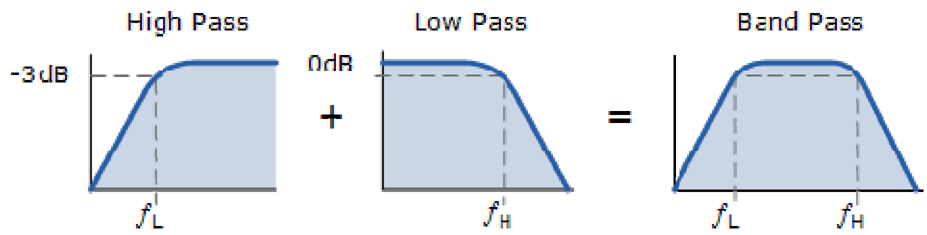
Simple **Active Band Pass Filter** can be easily made by cascading together a single Low Pass Filter with a single High Pass Filter as shown.

The cut-off or corner frequency of the low pass filter (LPF) is higher than the cut-off frequency of the high pass filter (HPF) and the difference between the frequencies at the -3dB point will determine the "bandwidth" of the band pass filter while attenuating any signals outside of these points. One way of making a very simple **Active Band Pass Filter** is to connect the basic passive high and low pass filters we look at previously to an amplifying op-amp circuit as shown.

Active Band Pass Filter Circuit



This cascading together of the individual low and high pass passive filters produces a low "Q-factor" type filter circuit which has a wide pass band. The first stage of the filter will be the high pass stage that uses the capacitor to block any DC biasing from the source. This design has the advantage of producing a relatively flat asymmetrical pass band frequency response with one half representing the low pass response and the other half representing high pass response as shown.

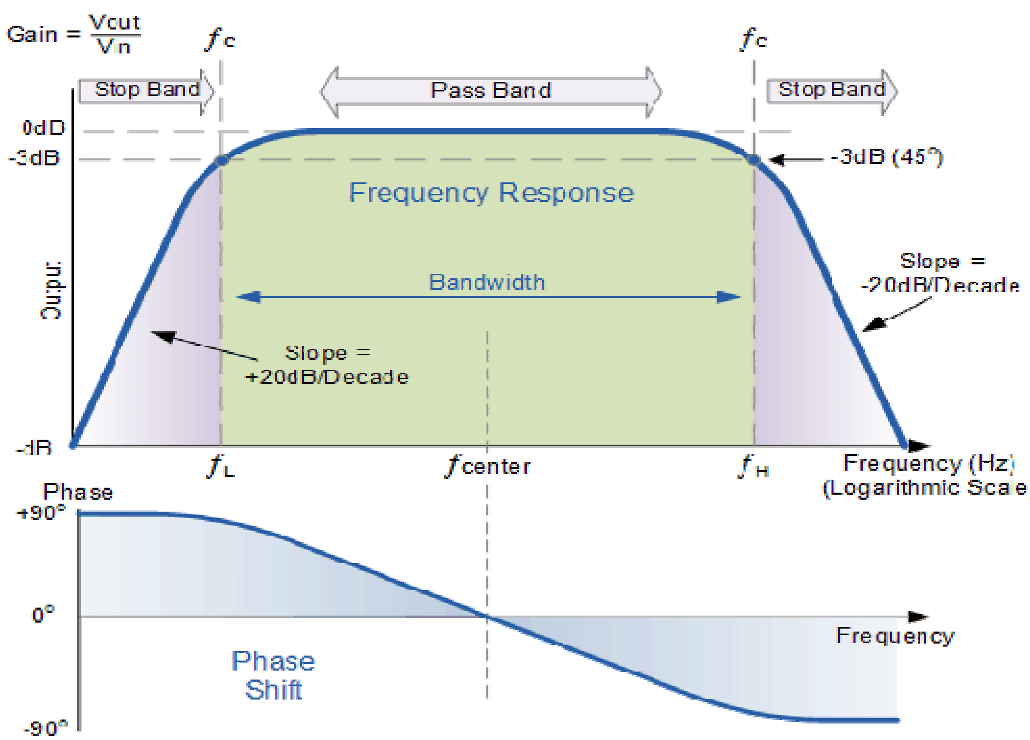


The higher corner point (f_H) as well as the lower corner frequency cut-off point (f_L) are calculated the same as before in the standard first-order low and high pass filter circuits. Obviously, a reasonable separation is required between the two cut-off points to prevent any interaction between the low pass and high pass stages. The amplifier also provides isolation between the two stages and defines the overall voltage gain of the circuit.

The bandwidth of the filter is therefore the difference between these upper and lower -3dB points. For example, suppose we have a band pass filter whose -3dB cut-off points are set at 200Hz and 600Hz. Then the bandwidth of the filter would be given as: Bandwidth (BW) = 600 – 200 = 400Hz.

The normalised frequency response and phase shift for an active band pass filter will be as follows.

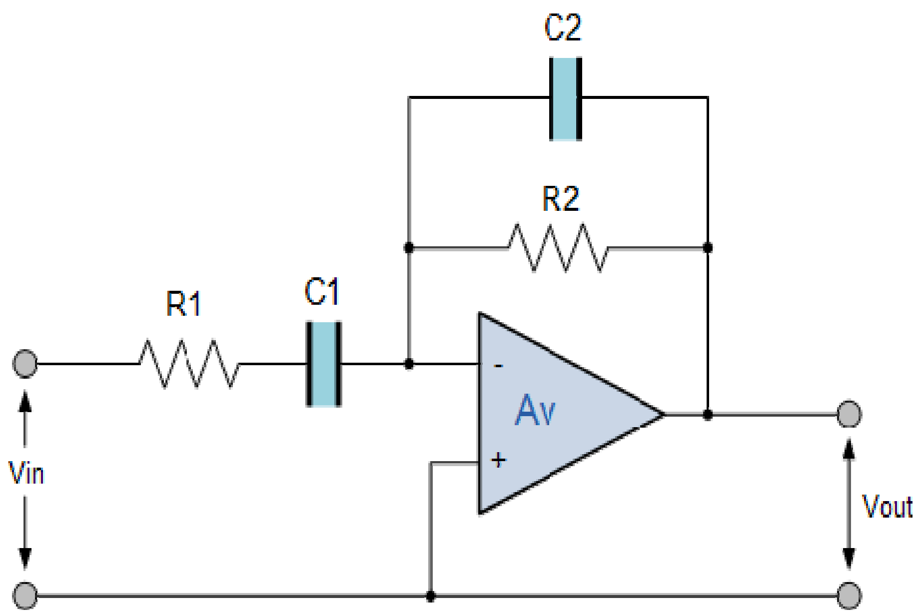
Active Band Pass Frequency Response



While the above passive tuned filter circuit will work as a band pass filter, the pass band (bandwidth) can be quite wide and this may be a problem if we want to isolate a small band of frequencies. Active band pass filter can also be made using inverting operational amplifier.

So by rearranging the positions of the resistors and capacitors within the filter we can produce a much better filter circuit as shown below. For an active band pass filter, the lower cut-off -3dB point is given by f_{C1} while the upper cut-off -3dB point is given by f_{C2}.

Inverting Band Pass Filter Circuit



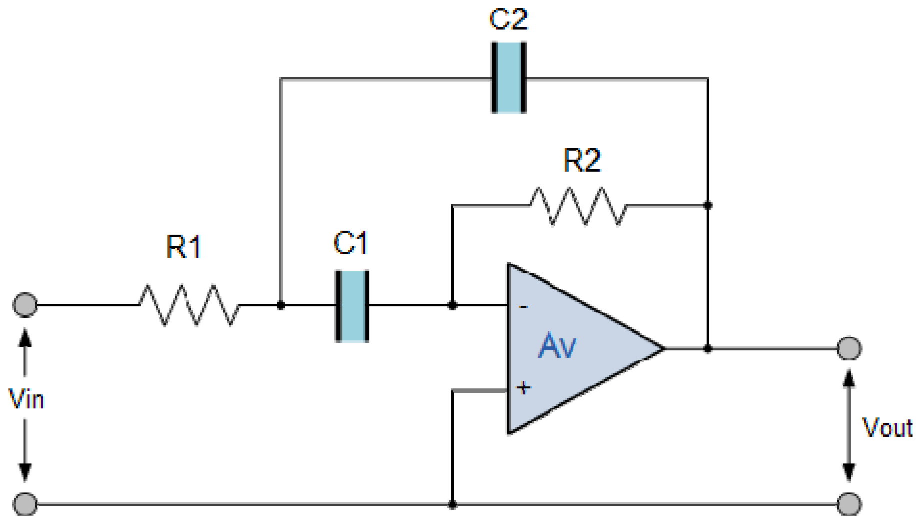
$$\text{Voltage Gain} = -\frac{R_2}{R_1}, \quad fc_1 = \frac{1}{2\pi R_1 C_1}, \quad fc_2 = \frac{1}{2\pi R_2 C_2}$$

This type of band pass filter is designed to have a much narrower pass band. The centre frequency and bandwidth of the filter is related to the values of R1, R2, C1 and C2. The output of the filter is again taken from the output of the op-amp.

Multiple Feedback Band Pass Active Filter

We can improve the band pass response of the above circuit by rearranging the components again to produce an infinite-gain multiple-feedback (IGMF) band pass filter. This type of active band pass design produces a "tuned" circuit based around a negative feedback active filter giving it a high "Q-factor" (up to 25) amplitude response and steep roll-off on either side of its centre frequency. Because the frequency response of the circuit is similar to a resonance circuit, this center frequency is referred to as the resonant frequency, (fr). Consider the circuit below.

Infinite Gain Multiple Feedback Active Filter



This active band pass filter circuit uses the full gain of the operational amplifier, with multiple negative feedback applied via resistor, R_2 and capacitor C_2. Then we can define the characteristics of the IGMF filter as follows:

$$f_r = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \qquad Q_{BP} = \frac{f_r}{BW_{(3dB)}} = \frac{1}{2}\sqrt{\frac{R_2}{R_1}}$$

$$\text{Maximum Gain, }(Av) = -\frac{R_2}{2R_1} = -2Q^2$$

We can see then that the relationship between resistors, R_1 and R_2 determines the band pass "Q-factor" and the frequency at which the maximum amplitude occurs, the gain of the circuit will be equal to $-2Q^2$. Then as the gain increases so to does the selectivity. In other words, high gain – high selectivity.

Active Band Pass Filter Example No1

An active band pass filter that has a voltage gain Av of one (1) and a resonant frequency, fr of 1kHz is constructed using an infinite gain multiple feedback filter circuit. Calculate the values of the components required to implement the circuit.

Firstly, we can determine the values of the two resistors, R_1 and R_2 required for the active filter using the gain of the circuit to find Q as follows.

$$Av = 1 = -2Q^2 \qquad \therefore\ Q_{BP} = \sqrt{\frac{1}{2}} = 0.7071$$

$$Q = 0.7071 = \frac{1}{2}\sqrt{\frac{R_2}{R_1}} \qquad \therefore\ \frac{R_2}{R_1} = \left(\frac{0.7071}{\frac{1}{2}}\right)^2 = 2$$

Then we can see that a value of Q = 0.7071 gives a relationship of resistor, R_2 being twice the value of resistor R_1. Then we can choose any suitable value of resistances to give the required ratio of two. Then resistor R_1 = 10kΩ and R_2 = 20kΩ.

The center or resonant frequency is given as 1kHz. Using the new resistor values obtained, we can determine the value of the capacitors required assuming that $C = C_1 = C_2$.

$$f_r = 1{,}000\text{Hz} = \frac{1}{2\pi C\sqrt{R_1 R_2}}$$

$$\therefore\ C = \frac{1}{2\pi f_r\sqrt{R_1 R_2}} = \frac{1}{2\pi 1000\sqrt{10{,}000 \times 20{,}000}} = 11.2\text{nF}$$

The closest standard value is 10nF.

Resonant Frequency Point

The actual shape of the frequency response curve for any passive or active band pass filter will depend upon the characteristics of the filter circuit with the curve above being defined as an "ideal" band pass response. An active band pass filter is a **2nd Order** type filter because it has "two" reactive components (two capacitors) within its circuit design.

As a result of these two reactive components, the filter will have a peak response or **Resonant Frequency** (*f*r) at its "center frequency", *f*c. The center frequency is generally calculated as being the geometric mean of the two -3dB frequencies between the upper and the lower cut-off points with the resonant frequency (point of oscillation) being given as:

$$fr = \sqrt{f_L \ x \ f_H}$$

- Where:
- f_r is the resonant or Center Frequency
- f_L is the lower -3dB cut-off frequency point
- f_H is the upper -3db cut-off frequency point

and in our simple example in the text above of a filters lower and upper -3dB cut-off points being at 200Hz and 600Hz respectively, then the resonant center frequency of the active band pass filter would be:

$$fr = \sqrt{200 \times 600} = \sqrt{120{,}000} = 346\,Hz$$

The "Q" or Quality Factor

In a **Band Pass Filter** circuit, the overall width of the actual pass band between the upper and lower -3dB corner points of the filter determines the **Quality Factor** or **Q-point** of the circuit. This **Q Factor** is a measure of how "Selective" or "Un-selective" the band pass filter is towards a given spread of frequencies. The lower the value of the Q factor the wider is the bandwidth of the filter and consequently the higher the Q factor the narrower and more "selective" is the filter.

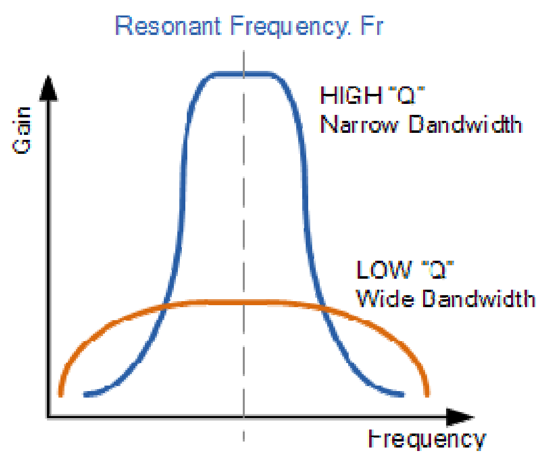
The **Quality Factor, Q** of the filter is sometimes given the Greek symbol of **Alpha**, (α) and is known as the **alpha-peak frequency** where:

$$\alpha = \frac{1}{Q}$$

As the quality factor of an active band pass filter (Second-order System) relates to the "sharpness" of the filters response around its centre resonant frequency (fr) it can also be thought of as the "Damping Factor" or "Damping Coefficient" because the more damping the filter has the flatter is its response and likewise, the less damping the filter has the sharper is its response. The damping ratio is given the Greek symbol of **Xi**, (ξ) where:

$$\xi = \frac{\alpha}{2}$$

The "Q" of a band pass filter is the ratio of the **Resonant Frequency**, (fr) to the **Bandwidth**, (BW) between the upper and lower -3dB frequencies and is given as:



$$Q = \frac{Resonant\ frequency}{Bandwidth}$$

Then for our simple example above the quality factor "**Q**" of the band pass filter is given as:

346Hz / 400Hz = **0.865**. Note that **Q** is a ratio and has no units.

When analysing active filters, generally a normalised circuit is considered which produces an “ideal” frequency response having a rectangular shape, and a transition between the pass band and the stop band that has an abrupt or very steep roll-off slope. However, these ideal responses are not possible in the real world so we use approximations to give us the best frequency response possible for the type of filter we are trying to design.

Probably the best known filter approximation for doing this is the Butterworth or maximally-flat response filter. In the next tutorial we will look at higher order filters and use Butterworth approximations to produce filters that have a frequency response which is as flat as mathematically possible in the pass band and a smooth transition or roll-off rate.