Filter

An electrical filter is a circuit which can be designed to modify, reshape or reject all the undesired frequencies of an electrical signal and pass only the desired signals.

In other words we can say that an electrical filter is an AC circuit that passes a specified band of frequencies and blocks signals of frequencies outside this band.

Classification of Filters

Depending on the type of element used in their construction, filters are classified into two types, such as:

I. **Passive Filters:** A passive filter is built with passive components such as resistors, capacitors and inductors. Passive filters have no amplifying elements (transistors, op-amps, etc) so have no signal gain, therefore their output level is always less than the input.

II. **Active Filters:** An active filter makes use of active elements such as transistors, op-amps in addition to resistor and capacitors. Since the op-amp is capable of providing a gain (which may also be variable), the input signal is not attenuated as it is in a passive filter. Active filters also provide an excellent isolation between the individual stages due to the high input impedence and low output impedence. So, the active filter does not cause loading effect. Besides, active filters are small in size and easier to tune or adjust.

According to the operating frequency range, the filters may be classified as audio frequency (AF) or radio frequency (RF) filters.

Filters may also be classified as:

I. **Low Pass Filter:** The low pass filter only allows low frequency signals from 0 Hz to its cut-off frequency, f_c point to pass while blocking any higher frequency signals.

II. **High Pass Filter:** The high pass filter only allows high frequency signals from its cut-off frequency, f_c point and higher to infinity to pass through while blocking those any lower.

III. **Band Pass Filter:** The band pass filter allows signals falling within a certain frequency band set up between two points to pass through while blocking both the lower and higher frequencies either side of this frequency band.

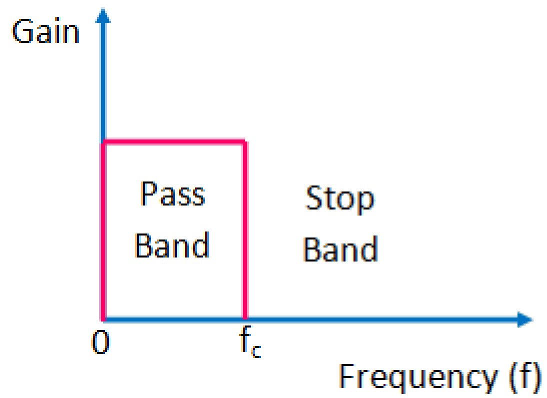
IV. **Band Stop Filter:** The band stop filter blocks signals falling within a certain frequency band set up between two points while allowing both the lower and higher frequencies either side of this frequency band.

Fig. below shows the frequency responses of the four types of filters mentioned above. These are ideal responses and cannot be achieved in actual practice.

Cutoff frequency: A cutoff frequency or corner frequency is a boundary in a system's frequency response at which energy flowing through the system begins to be reduced (attenuated or reflected) rather than passing through. Cutoff frequency also referred as the –3dB frequency, i.e., the frequency at which the magnitude response is 3 dB lower than the value at 0 Hz. At cutoff frequency signal amplitude reduced to 70%.

Ideal Low Pass Filter

A filter that provides a constant output from d.c. (0 Hz) upto a cutoff frequency fc and then passes no signal above that frequency is called an ideal low pass filter.



The ideal response of a low pass filter is shown in fig. above.

The voltage gain i.e. the ratio of output voltage to input voltage is constant over a frequency range from zero to cutoff frequency f_c.

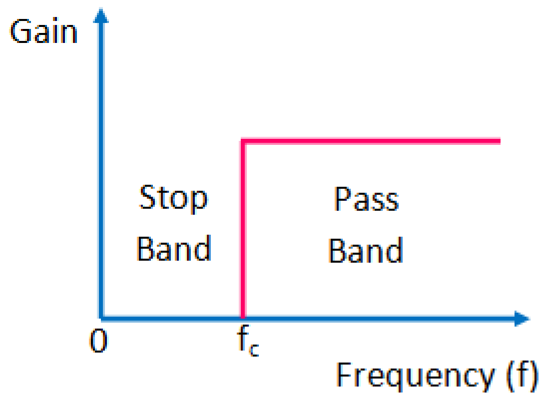
Hence, the output will be available faithfully from 0 to f_c with constant gain.

The frequencies between 0 and f_c, are called passband frequencies, while the frequencies above f_c are called as stopband frequencies.

Therefore the bandwidth is f_c.

Ideal High Pass Filter

A filter that passes signals above a cutoff frequency f_c is a high pass filter.



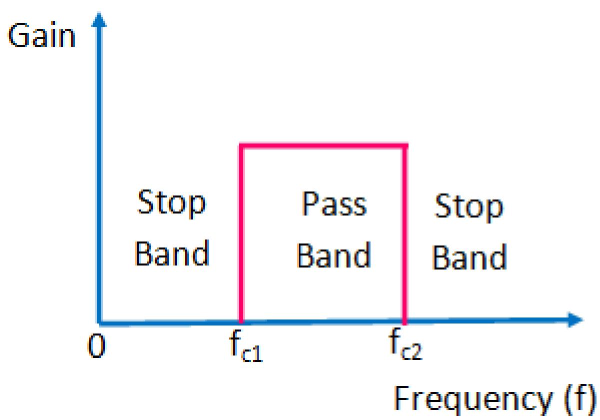
The frequency response of an ideal high pass filter is shown in fig. above.

The high pass filter has a zero gain starting from zero to a frequency f_c, called the cutoff frequency, and above this frequency, the gain is constant.

Hence, signal of any frequency beyond f_c is faithfully reproduced with a constant gain, and frequencies from 0 to f_c will be blocked.

Ideal Band Pass Filter

When the filter circuit passes signals that are above one cutoff frequency and below a second cutoff frequency, it is called a band pass filter.



The frequency response of an ideal band pass filter is shown in fig. above.

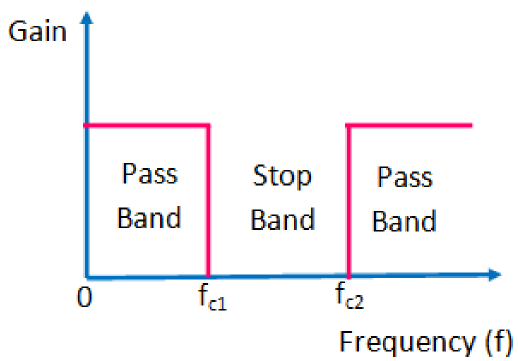
As we can see from the above fig., the band pass filter has a pass band between two cutoff frequencies f_{c2} and f_{c1}, where $f_{c2} > f_{c1}$ and two stop bands: $0<f<f_c1$ and $f>f_{c2}$.

The bandwidth of the band pass filter is therefore, equal to $f_{c2}-f_{c1}$, where f_{c1} and f_{c2} are lower and higher cutoff frequencies respectively.

Ideal Band Stop Filter

The band stop or band reject filter performs exactly opposite to the band pass filter.

It has a band stop between two cut off frequencies f_{c2} and f_{c1} and two pass bands: $0<f<f_{c1}$ and $f>f_{c2}$.



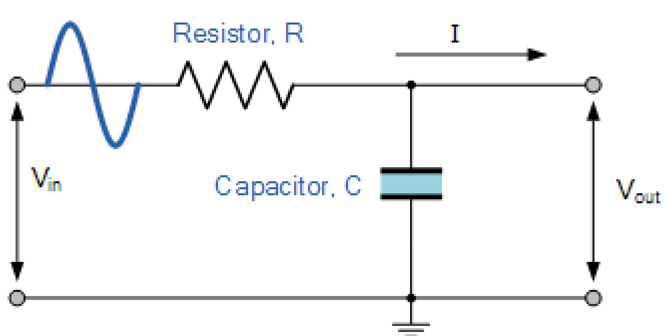
The frequency response of an ideal band stop filter is shown in fig. above.

This is also called as band elimination or notch filter.

In our next articles we will study about each type of passive and active filters in detail.

Design of Passive Low Pass Filter

A simple passive RC Low Pass Filter or LPF, can be easily made by connecting together in series a single Resistor with a single Capacitor as shown below. In this type of filter arrangement the input signal (VIN) is applied to the series combination (both the Resistor and Capacitor together) but the output signal (VOUT) is taken across the capacitor only.



This type of filter is known generally as a first-order filter.

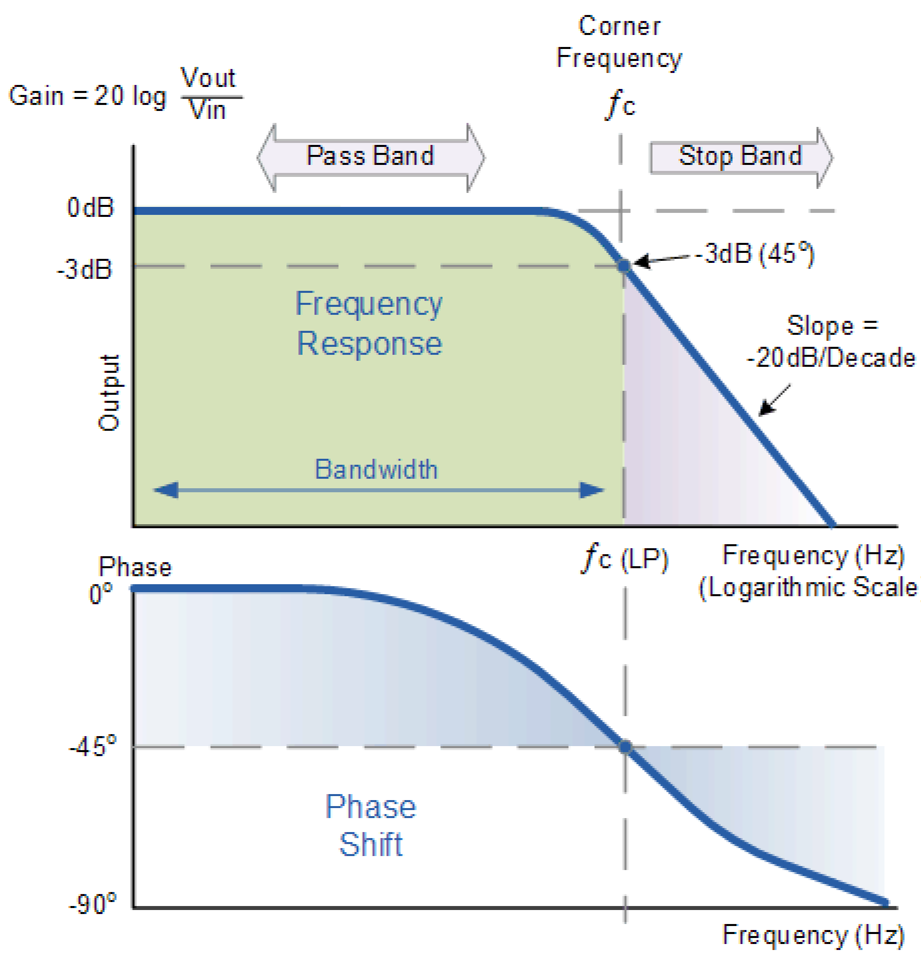
All low-pass filters are rated at a certain cutoff frequency. That is, the frequency above which the output voltage falls below 70.7% of the input voltage. This cutoff percentage of 70.7 is not really arbitrary, all though it may seem so at first glance. In a simple capacitive/resistive low-pass filter, it is the frequency at which capacitive reactance in ohms equals resistance in ohms. In a simple capacitive low-pass filter (one resistor, one capacitor), the cutoff frequency is given as:

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

Frequency Response

By plotting the networks output voltage against different values of input frequency, the Frequency Response Curve or Bode Plot function of the low pass filter circuit can be found, as shown below.

Frequency Response of a 1st-order Low Pass Filter



The Bode Plot shows the Frequency Response of the filter to be nearly flat for low frequencies and all of the input signal is passed directly to the output, resulting in a gain of nearly 1, called unity, until it reaches its Cut-off Frequency point (f_c). This is because the reactance of the capacitor is high at low frequencies and blocks any current flow through the capacitor.

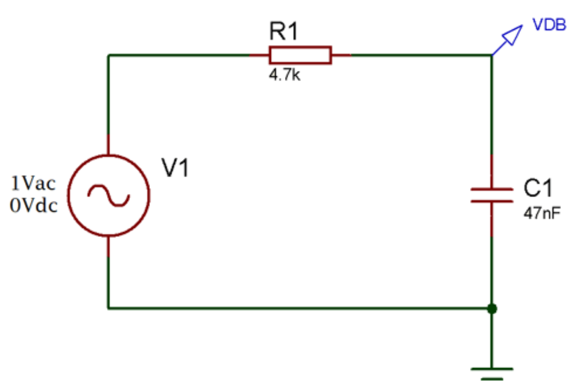
After this cut-off frequency point the response of the circuit decreases to zero at a slope of -20dB/ Decade.

Any high frequency signals applied to the low pass filter circuit above this cut-off frequency point will become greatly attenuated, that is they rapidly decrease. This happens because at very high frequencies the reactance of the capacitor becomes so low that it gives the effect of a short circuit condition on the output terminals resulting in zero output.

Then by carefully selecting the correct resistor-capacitor combination, we can create a RC circuit that allows a range of frequencies below a certain value to pass through the circuit unaffected while any frequencies applied to the circuit above this cut-off point to be attenuated, creating what is commonly called a Low Pass Filter.

Low Pass Filter Example

A Low Pass Filter circuit consisting of a resistor of 4k7Ω in series with a capacitor of 47nFis connected across a 1v sinusoidal supply. Calculate the cutoff frequency. Also calculate the output voltage (V_{OUT}) at a frequency of 1kHz.



We know,

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 4700 \times 47 \times 10^{-9}} = 720 \text{ Hz}$$

At a frequency 10kHz

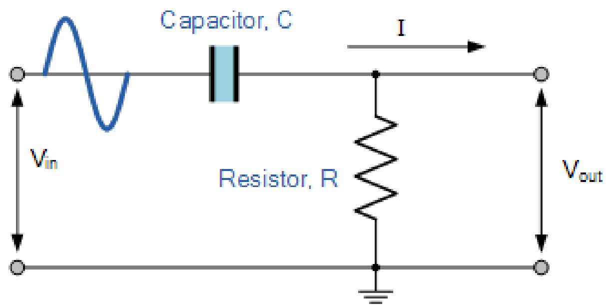
Capacitive reactance $x_c = \frac{1}{2\pi f c} = \frac{1}{2\pi \times 1000 \times 47 \times 10^{-9}} = 3386.27\ \Omega$

Output voltage $V_{out} = V_{in} \times \frac{x_c}{\sqrt{R^2 + {x_c}^2}} = 1 \times \frac{3386.37}{\sqrt{4700^2 + 3386.27^2}} = 0.548\ V$

Design of Passive Low Pass Filter

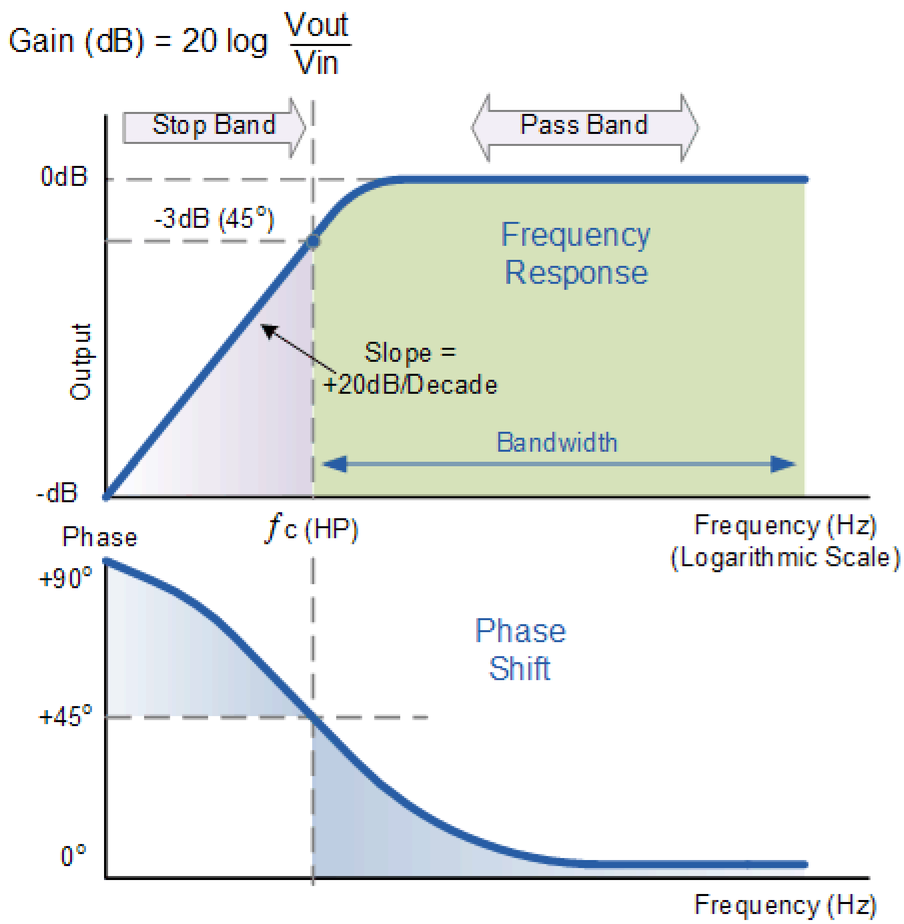
A High Pass Filter is the exact opposite to the low pass filter circuit as the two components have been interchanged with the filters output signal now being taken from across the resistor

Where as the low pass filter only allowed signals to pass below its cut-off frequency point, f_c, the passive high pass filter circuit as its name implies, only passes signals above the selected cut-off point, f_c eliminating any low frequency signals from the waveform. Consider the circuit below.



In this circuit arrangement, the reactance of the capacitor is very high at low frequencies so the capacitor acts like an open circuit and blocks any input signals at V_{IN} until the cut-off frequency point (f_C) is reached. Above this cut-off frequency point the reactance of the capacitor has reduced sufficiently as to now act more like a short circuit allowing all of the input signal to pass directly to the output as shown below in the filters response curve.

Frequency Response



In a simple capacitive high-pass filter (one resistor, one capacitor), the cutoff frequency is given as:

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

High Pass Filter Example

Calculate the cut-off or "breakpoint" frequency (fc) for a simple passive high pass filter consisting of an 82pF capacitor connected in series with a 240kΩ resistor.

We know,

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 240000 \times 82 \times 10^{-9}} = 8087 \text{ Hz or } 8\text{kHz}$$

Example 2: Design a passive low pass filter circuit that has a cut-off or corner frequency of 159Hz.

The cut-off or corner frequency (fc) is given as being 159Hz. This cut-off frequency can be found by using the formula:

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

Choosing R = 10kΩ, by rearranging the above formula we can find the value for capacitor C as:

$$c = \frac{1}{2\pi \times 159 \times 10000} = 100nF$$

Active Low Pass Filter

By combining a basic RC Low Pass Filter circuit with an operational amplifier we can create an Active Low Pass Filter circuit complete with amplification

We noticed that the main disadvantage of passive filters is that the amplitude of the output signal is less than that of the input signal, ie, the gain is never greater than unity and that the load impedance affects the filters characteristics.

With passive filter circuits containing multiple stages, this loss in signal amplitude called “Attenuation” can become quiet severe. One way of restoring or controlling this loss of signal is by using amplification through the use of Active Filters.

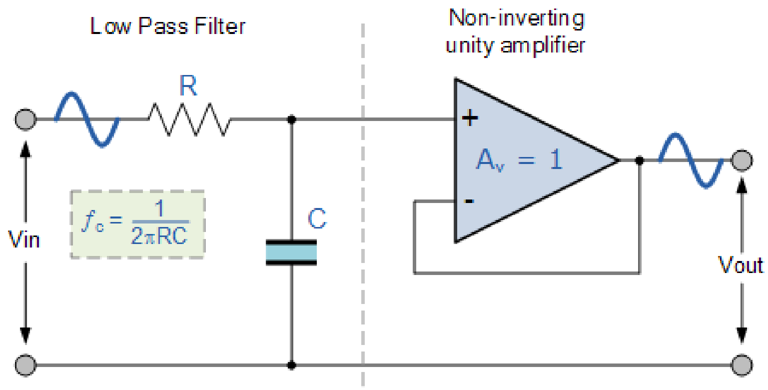
As their name implies, Active Filters contain active components such as operational amplifiers, transistors or FET’s within their circuit design. They draw their power from an external power source and use it to boost or amplify the output signal.

Filter amplification can also be used to either shape or alter the frequency response of the filter circuit by producing a more selective output response, making the output bandwidth of the filter more narrower or even wider. Then the main difference between a “passive filter” and an “active filter” is amplification.

An active filter generally uses an operational amplifier (op-amp) within its design and in the Operational Amplifier tutorial we saw that an Op-amp has a high input impedance, a low output impedance and a voltage gain determined by the resistor network within its feedback loop.

Active filters are generally much easier to design than passive filters, they produce good performance characteristics, very good accuracy with a steep roll-off and low noise when used with a good circuit design.

First Order Low Pass Filter



This first-order low pass active filter, consists simply of a passive RC filter stage providing a low frequency path to the input of a non-inverting operational amplifier. The amplifier is configured as a voltage-follower (Buffer) giving it a DC gain of one, Av = +1 or unity gain as opposed to the previous passive RC filter which has a DC gain of less than unity.

The advantage of this configuration is that the op-amps high input impedance prevents excessive loading on the filters output while its low output impedance prevents the filters cut-off frequency point from being affected by changes in the impedance of the load.

While this configuration provides good stability to the filter, its main disadvantage is that it has no voltage gain above one. However, although the voltage gain is unity the power gain is very high as its output impedance is much lower than its input impedance. If a voltage gain greater than one is required we can use the following filter circuit.

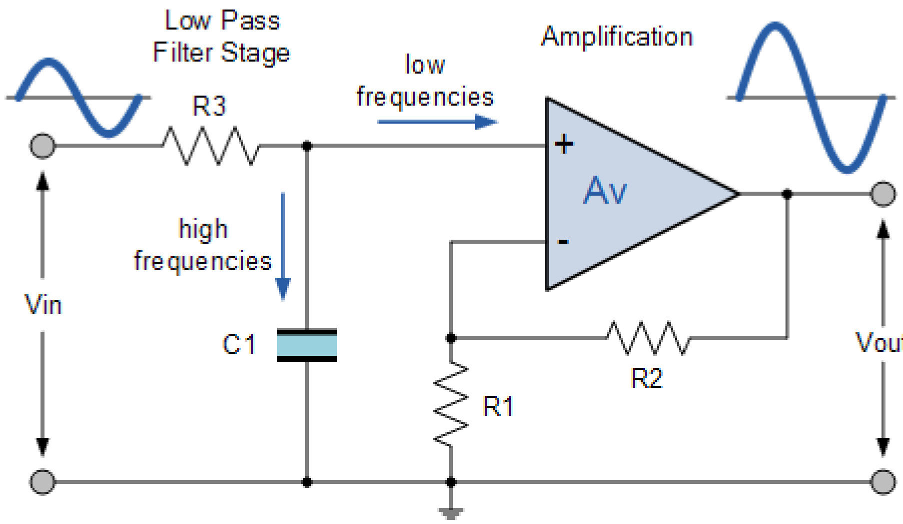
Active Low Pass Filter with Amplification

The frequency response of the circuit will be the same as that for the passive RC filter, except that the amplitude of the output is increased by the pass band gain, AF of the amplifier. For a non-inverting amplifier circuit, the magnitude of the voltage gain for the filter is given as a function of the feedback resistor (R2) divided by its corresponding input resistor (R1) value and is given as:

$$DC\ Gain = 1 + \frac{R_2}{R_1}$$

The cut-off frequency can be found by using the formula:

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



Active Low Pass Filter Example

Design a non-inverting active low pass filter circuit that has a gain of ten at low frequencies, a high frequency cut-off or corner frequency of 159Hz and an input impedance of 10KΩ.

Solution: The voltage gain of a non-inverting operational amplifier is given as:

$$DC\ Gain\ A = 1 + \frac{R_2}{R_1}$$

Assume a value for resistor R_1 of 1kΩ rearranging the formula above gives a value for R_2 of:

$$R_2 = (10 - 1) \times R_1 = 9k\Omega$$

then, for a voltage gain of 10, R_1 = 1kΩ and R_2 = 9kΩ. However, a 9kΩ resistor does not exist so the next preferred value of 9k1Ω is used instead.

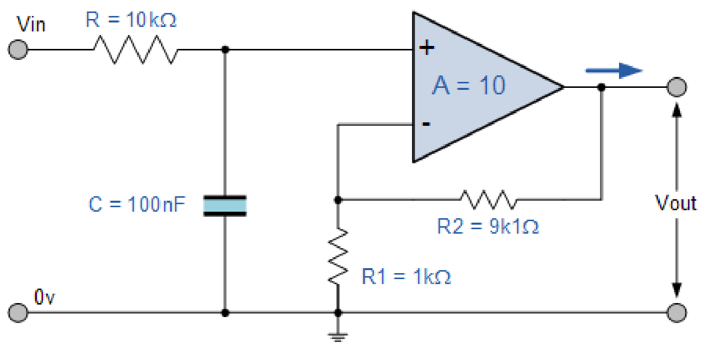
The cut-off or corner frequency (f_c) is given as being 159Hz with an input impedance of 10kΩ. This cut-off frequency can be found by using the formula:

$f_c = \frac{1}{2\pi RC}$ where, $f_c = 159Hz\ and\ R = 10k\Omega$

then, by rearranging the above formula we can find the value for capacitor C as:

$$c = \frac{1}{2\pi \times f_c \times R} = \frac{1}{2\pi \times 159 \times 10k\Omega} = 100nF$$

Then the final circuit will be as following:

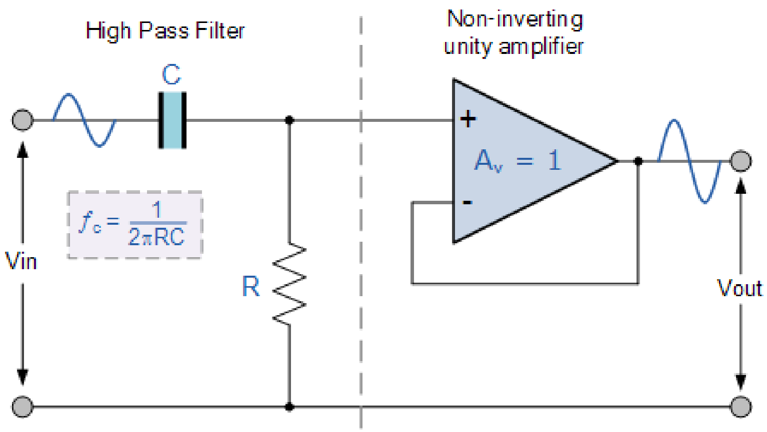


Active High Pass Filter

An Active High Pass Filter can be created by combining a passive RC filter network with an operational amplifier to produce a high pass filter with amplification.

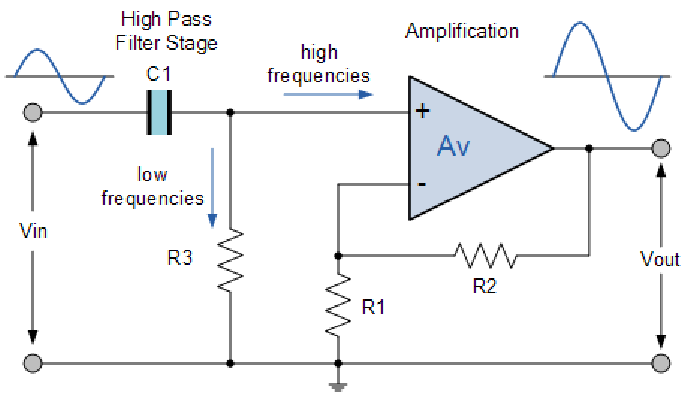
The basic operation of an Active High Pass Filter (HPF) is the same as for its equivalent RC passive high pass filter circuit, except this time the circuit has an operational amplifier or included within its design providing amplification and gain control.

Like the previous active low pass filter circuit, the simplest form of an active high pass filteris to connect a standard inverting or non-inverting operational amplifier to the basic RC high pass passive filter circuit as shown.



A first-order Active High Pass Filter as its name implies, attenuates low frequencies and passes high frequency signals. It consists simply of a passive filter section followed by a non-inverting operational amplifier. The frequency response of the circuit is the same as that of the passive filter, except that the amplitude of the signal is increased by the gain of the amplifier and for a non-inverting amplifier the value of the pass band voltage gain is given as 1 + R2/R1, the same as for the low pass filter circuit.

Active High Pass Filter with Amplification



This first-order high pass filter, consists simply of a passive filter followed by a non-inverting amplifier. The frequency response of the circuit is the same as that of the passive filter, except that the amplitude of the signal is increased by the gain of the amplifier.

As with the previous filter circuits, the cut-off or corner frequency (fc) can be found by using the same formula:

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

Active High Pass Filter Example

A first order active high pass filter has a pass band gain of two and a cut-off corner frequency of 1kHz. If the input capacitor has a value of 10nF, calculate the value of the cut-off frequency determining resistor and the gain resistors in the feedback network.

Solution: With a cut-off corner frequency given as 1kHz and a capacitor of 10nF, the value of R will therefore be:

$$R = \frac{1}{2\pi\, f_c \;\; C} = \frac{1}{2\pi \times 1000 \;\times 10 \;\times 10^{-9}} = 15.92k\Omega$$

or 16kΩ to the nearest preferred value.

Thus the pass band gain of the filter, AF is therefore given as being: 2.

$$A = 1 + \frac{R_2}{R_1}$$

So,

$$\frac{R_2}{R_1} = 1$$

As the value of resistor, R2 divided by resistor, R1 gives a value of one. Then, resistor R1must be equal to resistor R2, since the pass band gain, AF = 2. We can therefore select a suitable value for the two resistors of say, 10kΩ each for both feedback resistors.

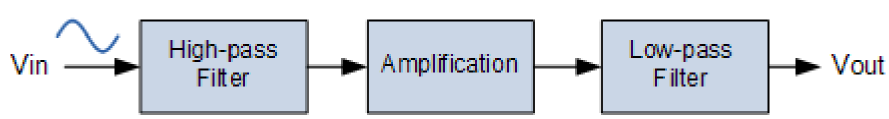
Active Band Pass Filter

The principal characteristic of a Band Pass Filter or any filter for that matter, is its ability to pass frequencies relatively unattenuated over a specified band or spread of frequencies called the "Pass Band".

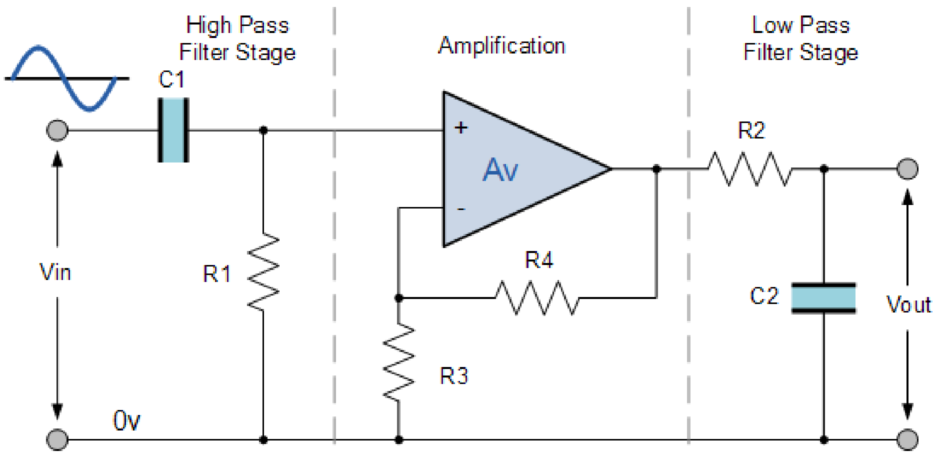
For a low pass filter this pass band starts from 0Hz or DC and continues up to the specified cut-off frequency point at -3dB down from the maximum pass band gain. Equally, for a high pass filter the pass band starts from this -3dB cut-off frequency and continues up to infinity or the maximum open loop 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 labeled the "lower frequency" (f_L) and the "higher frequency" (f_H) while attenuating any signals outside of these two points.

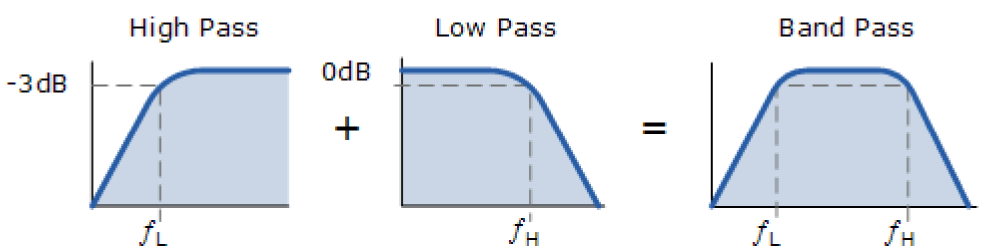
Simple Active Band Pass Filter can be easily made by cascading together a single Low Pass Filter with a single High Pass Filter as shown.



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.



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.

Example: A signal contains frequencies 150Hz, 300Hz and 500Hz. Design an appropriate filter which will pass 300Hz with an amplification of 10.

Do it yourself.