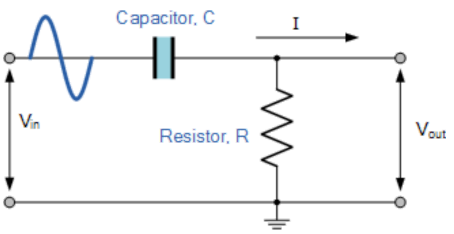
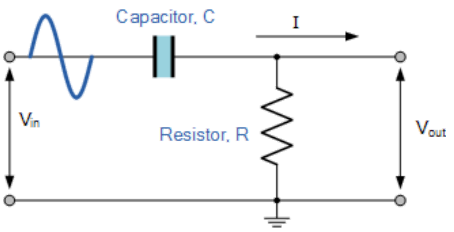


Passive High Pass Filter

A **High Pass Filter** or **HPF**, is the exact opposite to that of the previously seen low pass filter circuit as the two components have been interchanged with the filters output signal (Vout) being taken from across the resistor.

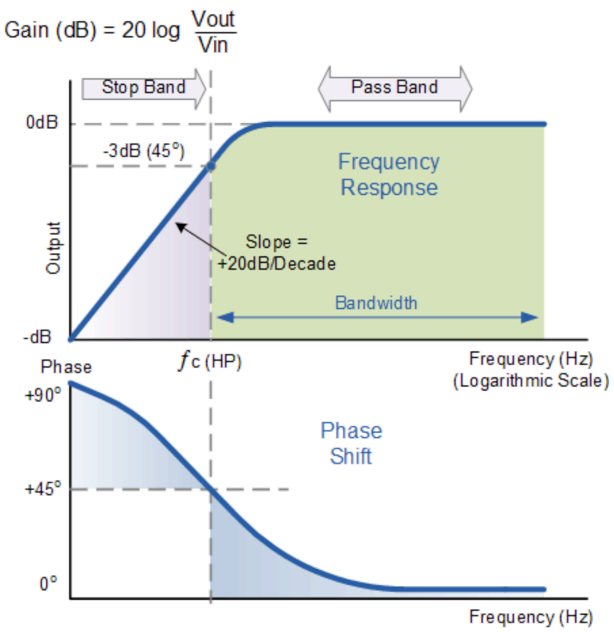
Where as the low pass filter only allowed signals to pass below its cut-off frequency point, *ƒc*, the passive high pass filter circuit as its name implies, only passes signals above the selected cut-off point, *ƒc* eliminating any low frequency signals from the waveform. Consider the circuit below.

The High Pass Filter Circuit



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 Vin until the cut-off frequency point (*ƒc*) 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 of a 1st Order High Pass Filter.



The **Bode Plot** or Frequency Response Curve above for a passive high pass filter is the exact opposite to that of a low pass filter. Here the signal is attenuated or damped at low frequencies with the output increasing at +20dB/Decade (6dB/Octave) until the frequency reaches the cut-off point (fc) where again R = Xc. It has a response curve that extends down from infinity to the cut-off frequency, where the output voltage amplitude is $1/\sqrt{2}$ = 70.7% of the input signal value or -3dB (20 log (Vout/Vin)) of the input value.

Also we can see that the phase angle (Φ) of the output signal **LEADS** that of the input and is equal to **+45°** at frequency fc. The frequency response curve for this filter implies that the filter can pass all signals out to infinity. However in practice, the filter response does not extend to infinity but is limited by the electrical characteristics of the components used.

The cut-off frequency point for a first order high pass filter can be found using the same equation as that of the low pass filter, but the equation for the phase shift is modified slightly to account for the positive phase angle as shown below.

Cut-off Frequency and Phase Shift

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

$$\text{Phase Shift } \phi = \arctan \frac{1}{2\pi fRC}$$

The circuit gain, Av which is given as Vout/Vin (magnitude) and is calculated as:

$$A_V = \frac{V_{OUT}}{V_{IN}} = \frac{R}{\sqrt{R^2 + Xc^2}} = \frac{R}{Z}$$

$$\text{at low } f: \ Xc \to \infty, \ \text{Vout} = 0$$
$$\text{at high } f: \ Xc \to 0, \ \text{Vout} = \text{Vin}$$

High Pass Filter Example No1

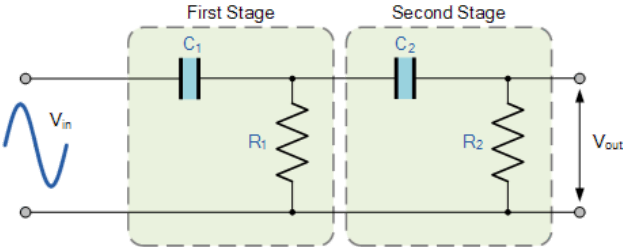
Calculate the cut-off or "breakpoint" frequency (fc) for a simple passive high pass filter consisting of an 82pF capacitor connected in series with a 240kΩ resistor.

$$fc = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 240{,}000 \times 82 \times 10^{-12}} = 8{,}087\ Hz \text{ or } 8kHz$$

Second-order High Pass Filter

Again as with low pass filters, high pass filter stages can be cascaded together to form a second order (two-pole) filter as shown.

Second-order High Pass Filter



The above circuit uses two first-order filters connected or cascaded together to form a second-order or two-pole high pass network. Then a first-order filter stage can be converted into a second-order type by simply using an additional RC network, the same as for the 2nd-order low pass filter. The resulting second-order high pass filter circuit will have a slope of 40dB/decade (12dB/octave).

As with the low pass filter, the cut-off frequency, fc is determined by both the resistors and capacitors as follows.

$$f_C = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}\ \text{Hz}$$

High Pass Filter Summary

We have seen that the **Passive High Pass Filter** is the exact opposite to the low pass filter. This filter has no output voltage from DC (0Hz), up to a specified cut-off frequency (fc) point. This lower cut-off frequency point is 70.7% or **-3dB** (dB = -20log Vout/Vin) of the voltage gain allowed to pass.

The frequency range "below" this cut-off point fc is generally known as the **Stop Band** while the frequency range "above" this cut-off point is generally known as the **Pass Band**.

The cut-off frequency, corner frequency or -3dB point of a high pass filter can be found using the standard formula of: fc = 1/(2πRC). The phase angle of the resulting output signal at fc is **+45°**. Generally, the high pass filter is less distorting than its equivalent low pass filter due to the higher operating frequencies.

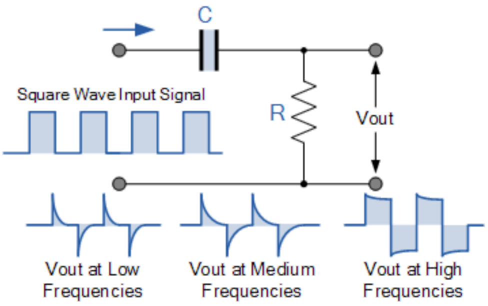
A very common application of this type of passive filter, is in audio amplifiers as a coupling capacitor between two audio amplifier stages and in speaker systems to direct the higher frequency signals to the smaller "tweeter" type speakers while blocking the lower bass signals or are also used as filters to reduce any low frequency noise or "rumble" type distortion. When used like this in audio applications the high pass filter is sometimes called a "low-cut", or "bass cut" filter.

The output voltage Vout depends upon the time constant and the frequency of the input signal as seen previously. With an AC sinusoidal signal applied to the circuit it behaves as a simple 1st Order high pass filter. But if we change the input signal to that of a "square wave" shaped signal that has an almost vertical step input, the response of the circuit changes dramatically and produces a circuit known commonly as an **Differentiator**.

The RC Differentiator

Up until now the input waveform to the filter has been assumed to be sinusoidal or that of a sine wave consisting of a fundamental signal and some harmonics operating in the frequency domain giving us a frequency domain response for the filter. However, if we feed the **High Pass Filter** with a **Square Wave** signal operating in the time domain giving an impulse or step response input, the output waveform will consist of short duration pulse or spikes as shown.

The RC Differentiator Circuit



Each cycle of the square wave input waveform produces two spikes at the output, one positive and one negative and whose amplitude is equal to that of the input. The rate of decay of the spikes depends upon the time constant, (RC) value of both components, (t = R x C) and the value of the input frequency. The output pulses resemble more and more the shape of the input signal as the frequency increases.

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