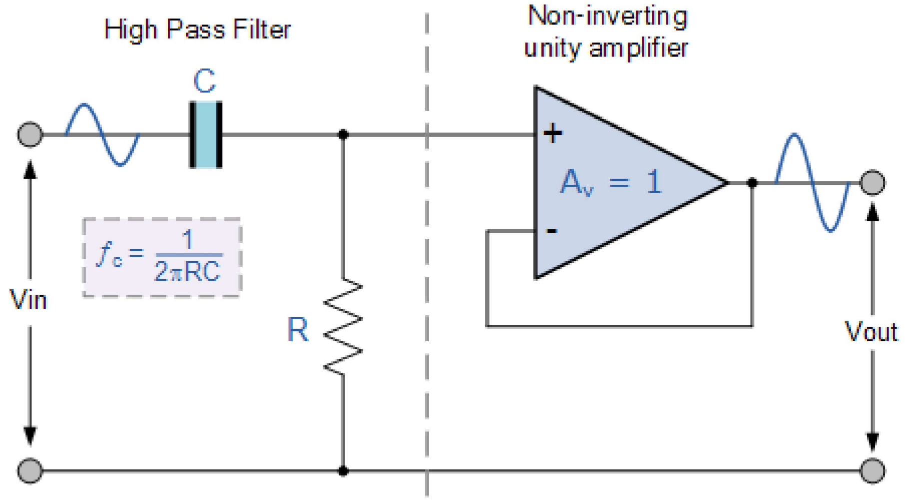


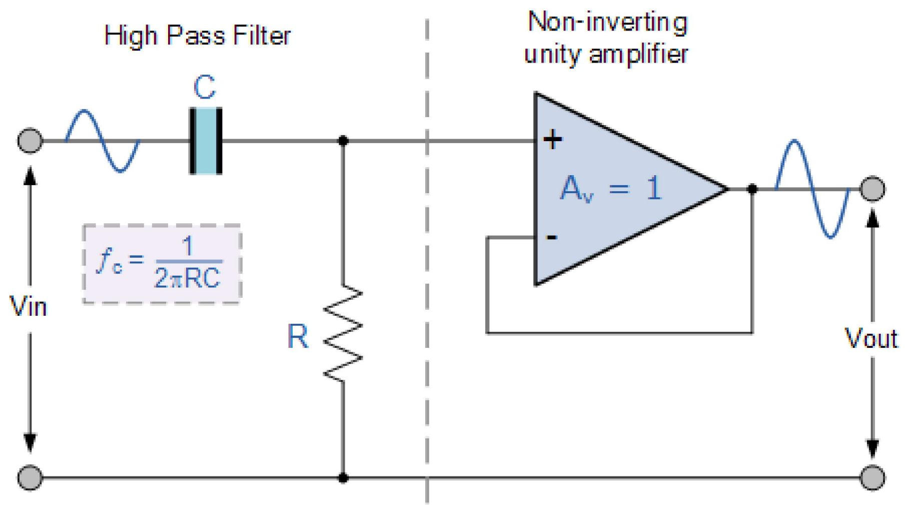
Active High Pass Filter

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 filter* is to connect a standard inverting or non-inverting operational amplifier to the basic RC high pass passive filter circuit as shown.

First Order High Pass Filter

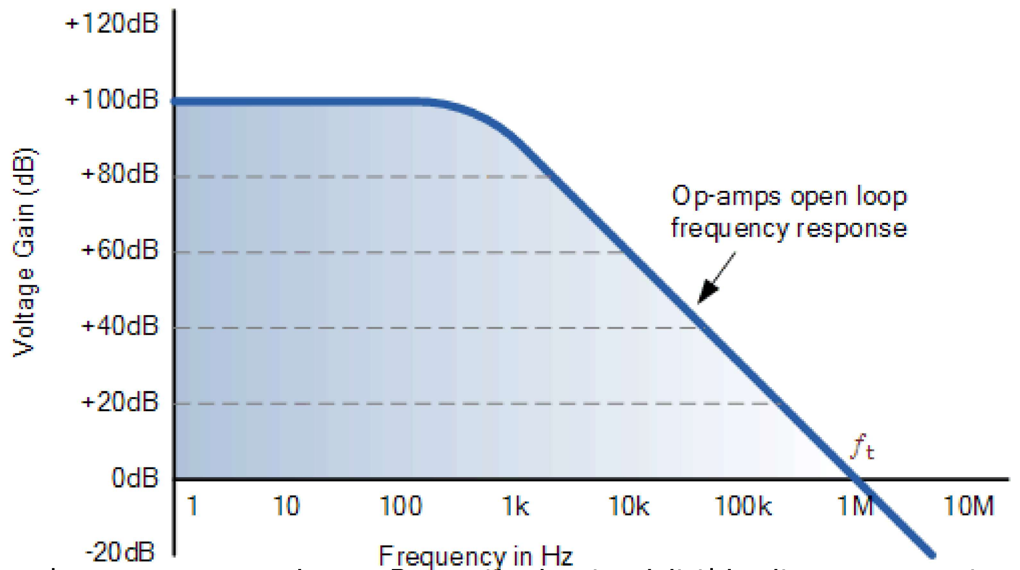


Technically, there is no such thing as an **active high pass filter**. Unlike Passive High Pass Filters which have an "infinite" frequency response, the maximum pass band frequency response of an active high pass filter is limited by the open-loop characteristics or bandwidth of the operational amplifier being used, making them appear as if they are band pass filters with a high frequency cut-off determined by the selection of op-amp and gain.

In the Operational Amplifier tutorial we saw that the maximum frequency response of an op-amp is limited to the Gain/Bandwidth product or open loop voltage gain (A_V) of the operational amplifier being used giving it a bandwidth limitation, where the closed loop response of the op amp intersects the open loop response.

A commonly available operational amplifier such as the uA741 has a typical "open-loop" (without any feedback) DC voltage gain of about 100dB maximum reducing at a roll off rate of -20dB/Decade (-6db/Octave) as the input frequency increases. The gain of the uA741 reduces until it reaches unity gain, (0dB) or its "transition frequency" ($ƒt$) which is about 1MHz. This causes the op-amp to have a frequency response curve very similar to that of a first-order low pass filter and this is shown below.

Frequency response curve of a typical Operational Amplifier.



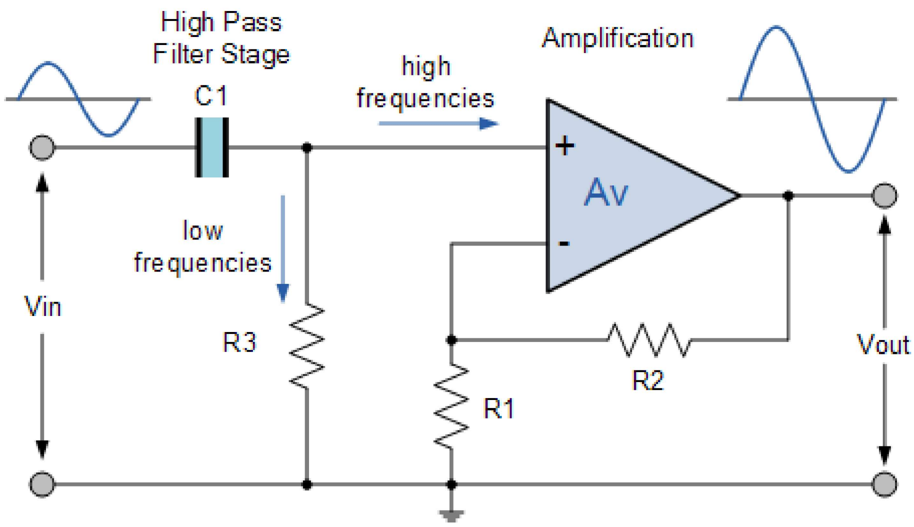
Then the performance of a "high pass filter" at high frequencies is limited by this unity gain crossover frequency which determines the overall bandwidth of the open-loop amplifier. The gain-bandwidth product of the op-amp starts from around 100kHz for small signal amplifiers up to about 1GHz for high-speed digital video amplifiers and op-amp based active filters can achieve very good accuracy and performance provided that low tolerance resistors and capacitors are used.

Under normal circumstances the maximum pass band required for a closed loop active high pass or band pass filter is well below that of the maximum open-loop transition frequency. However, when designing active filter circuits it is important to choose the correct op-amp for the circuit as the loss of high frequency signals may result in signal distortion.

Active High Pass Filter

A first-order (single-pole) **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.

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:

Gain for an Active High Pass Filter

$$\text{Voltage Gain, }(Av) = \frac{Vout}{Vin} = \frac{A_F\left(\frac{f}{fc}\right)}{\sqrt{1+\left(\frac{f}{fc}\right)^2}}$$

Where:

A_F = the Pass band Gain of the filter, (1 + R2/R1)

f = the Frequency of the Input Signal in Hertz, (Hz)

fc = the Cut-off Frequency in Hertz, (Hz)

Just like the low pass filter, the operation of a high pass active filter can be verified from the frequency gain equation above as:

1. At very low frequencies, $f < fc$ $\quad \frac{Vout}{Vin} < A_F$
2. At the cut-off frequency, $f = fc$ $\quad \frac{Vout}{Vin} = \frac{A_F}{\sqrt{2}} = 0.707\,A_F$
3. At very high frequencies, $f > fc$ $\quad \frac{Vout}{Vin} \cong A_F$

Then, the **Active High Pass Filter** has a gain A_F that increases from 0Hz to the low frequency cut-off point, f_C at 20dB/decade as the frequency increases. At f_C the gain is $0.707A_F$, and after f_C all frequencies are pass band frequencies so the filter has a constant gain A_F with the highest frequency being determined by the closed loop bandwidth of the op-amp.

When dealing with filter circuits the magnitude of the pass band gain of the circuit is generally expressed in *decibels* or *dB* as a function of the voltage gain, and this is defined as:

Magnitude of Voltage Gain in (dB)

$$Av(dB) = 20\log_{10}\left(\frac{Vout}{Vin}\right)$$

$$\therefore\ -3dB = 20\log_{10}\left(0.707\frac{Vout}{Vin}\right)$$

For a first-order filter the frequency response curve of the filter increases by 20dB/decade or 6dB/octave up to the determined cut-off frequency point which is always at -3dB below the maximum gain value. As with the previous filter circuits, the lower cut-off or corner frequency ($ƒc$) can be found by using the same formula:

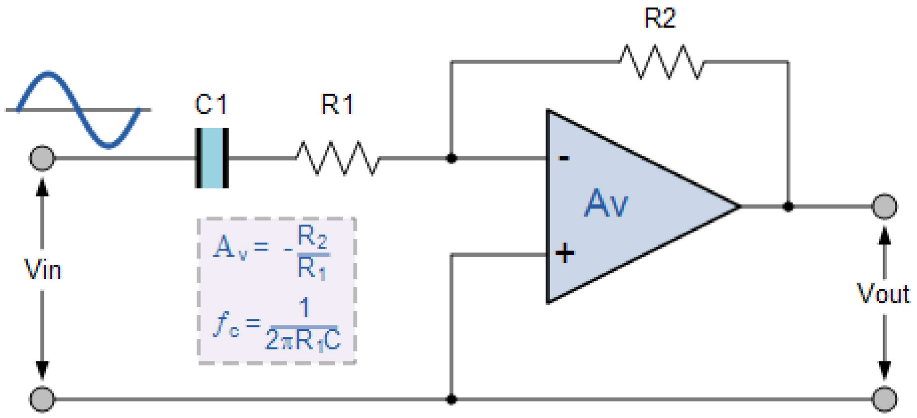
$$fc = \frac{1}{2\pi RC}\ Hz$$

The corresponding phase angle or phase shift of the output signal is the same as that given for the passive RC filter and **leads** that of the input signal. It is equal to **+45°** at the cut-off frequency $ƒc$ value and is given as:

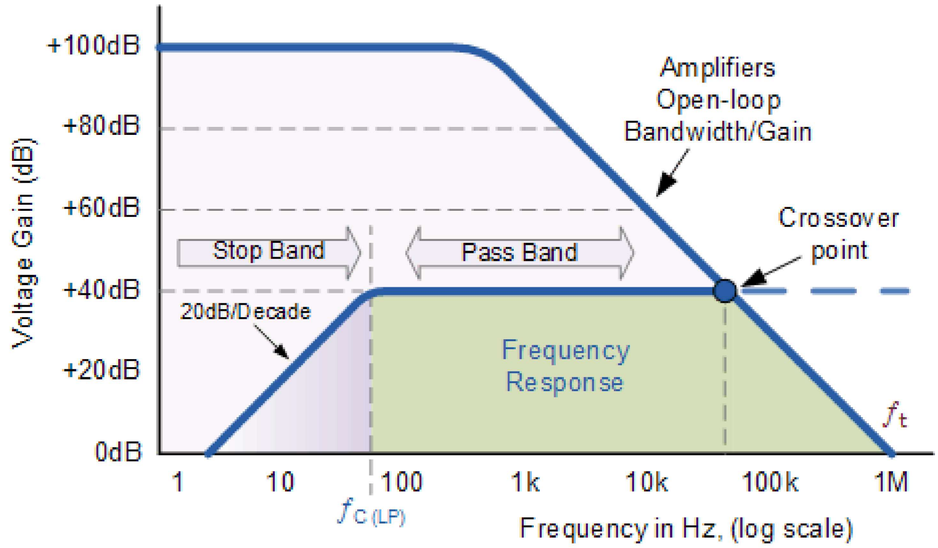
$$Phase\ Shift\ \phi = tan^{-1}\left(\frac{1}{2\pi fRC}\right)$$

A simple first-order active high pass filter can also be made using an inverting operational amplifier configuration as well, and an example of this circuit design is given along with its corresponding frequency response curve. A gain of 40dB has been assumed for the circuit.

Inverting Operational Amplifier Circuit



Frequency Response Curve



Active High Pass Filter Example No1

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. Also, plot the expected frequency response of the filter.

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

$$R = \frac{1}{2\pi f_C C} = \frac{1}{2\pi.1000.10\times10^{-9}} = 15.92\text{k}\Omega$$

or 16kΩ's to the nearest preferred value.

The pass band gain of the filter, A_F is given as being, 2.

$$A_F = 1 + \frac{R_2}{R_1}, \quad \therefore 2 = 1 + \frac{R_2}{R_1} \quad \text{and} \quad \frac{R_2}{R_1} = 1$$

As the value of resistor, R_2 divided by resistor, R_1 gives a value of one. Then, resistor R_1 must be equal to resistor R_2, since the pass band gain, A_F = 2. We can therefore select a suitable value for the two resistors of say, 10kΩ's each for both feedback resistors.

So for a high pass filter with a cut-off corner frequency of 1kHz, the values of R and C will be, 10kΩ's and 10nF respectively. The values of the two feedback resistors to produce a pass band gain of two are given as: $R_1 = R_2 = 10\text{k}\Omega$'s

The data for the frequency response bode plot can be obtained by substituting the values obtained above over a frequency range from 100Hz to 100kHz into the equation for voltage gain:

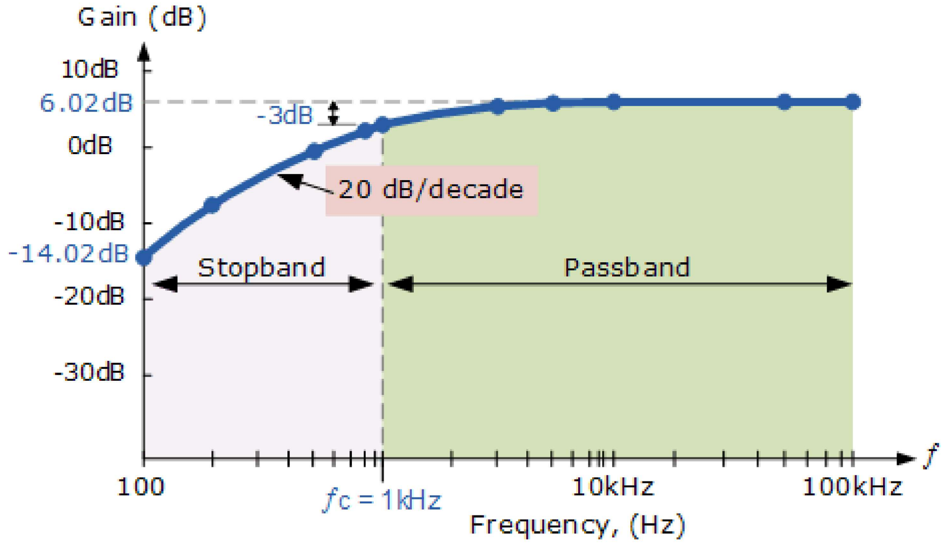
$$\text{Voltage Gain, }(Av) = \frac{Vout}{Vin} = \frac{A_F\left(\frac{f}{fc}\right)}{\sqrt{1+\left(\frac{f}{fc}\right)^2}}$$

This then will give us the following table of data.

Frequency, *ƒ* (Hz)	Voltage Gain (*Vo / Vin*)	Gain, (dB) 20log(*Vo / Vin*)
100	0.20	-14.02
200	0.39	-8.13
500	0.89	-0.97
800	1.25	1.93
1,000	1.41	3.01
3,000	1.90	5.56
5,000	1.96	5.85
10,000	1.99	5.98
50,000	2.00	6.02
100,000	2.00	6.02

The frequency response data from the table above can now be plotted as shown below. In the stop band (from 100Hz to 1kHz), the gain increases at a rate of 20dB/decade. However, in the pass band after the cut-off frequency, f_C = 1kHz, the gain remains constant at 6.02dB. The upper-frequency limit of the pass band is determined by the open loop bandwidth of the operational amplifier used as we discussed earlier. Then the bode plot of the filter circuit will look like this.

The Frequency Response Bode-plot for our example.

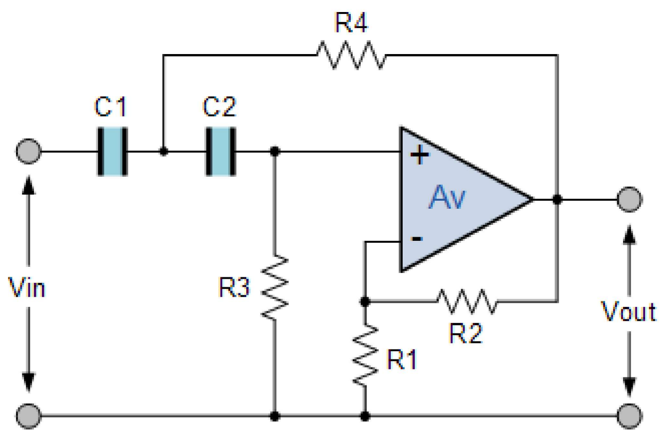


Applications of **Active High Pass Filters** are in audio amplifiers, equalizers or speaker systems to direct the high frequency signals to the smaller tweeter speakers or to reduce any low frequency noise or "rumble" type distortion. When used like this in audio applications the active high pass filter is sometimes called a "Treble Boost" filter.

Second-order High Pass Active Filter

As with the passive filter, a first-order high pass active filter can be converted into a second-order high pass filter simply by using an additional RC network in the input path. The frequency response of the second-order high pass filter is identical to that of the first-order type except that the stop band roll-off will be twice the first-order filters at 40dB/decade (12dB/octave). Therefore, the design steps required of the second-order active high pass filter are the same.

Second-order Active High Pass Filter Circuit



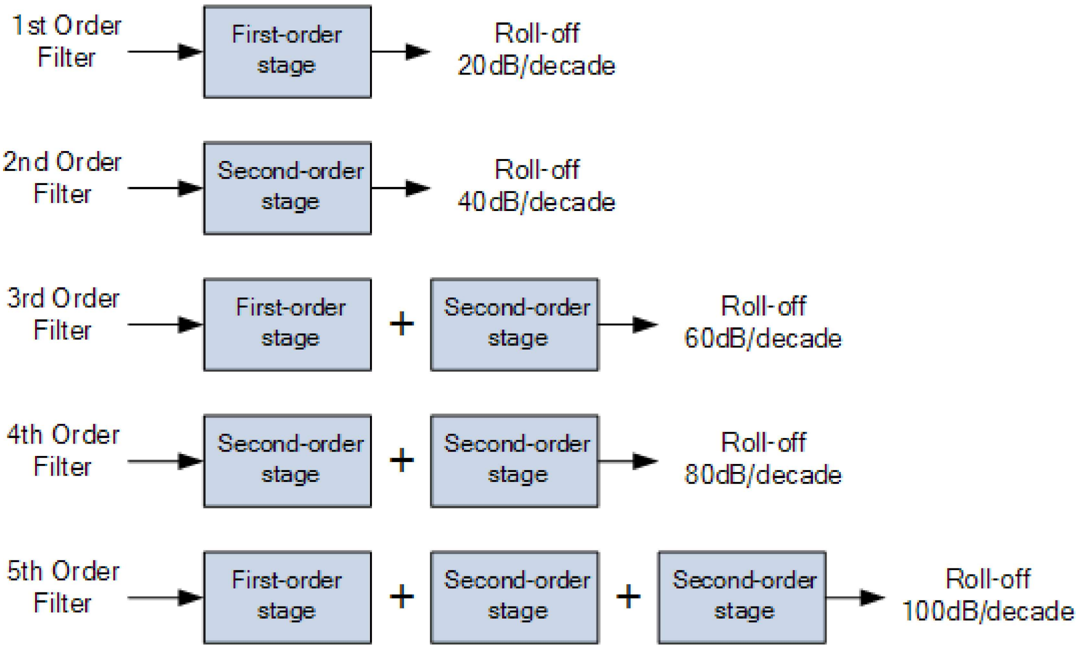
$$A_V = 1 + \frac{R_2}{R_1}$$

$$f_C = \frac{1}{2\pi\sqrt{R_3R_4C_1C_2}}$$

Higher-order high pass active filters, such as third, fourth, fifth, etc are formed simply by cascading together first and second-order filters. For example, a third order high pass filter is formed by cascading in series first and second order filters, a fourth-order high pass filter by cascading two second-order filters together and so on.

Then an **Active High Pass Filter** with an even order number will consist of only second-order filters, while an odd order number will start with a first-order filter at the beginning as shown.

Cascading Active High Pass Filters



Although there is no limit to the order of a filter that can be formed, as the order of the filter increases so to does its size. Also, its accuracy declines, that is the difference between the actual stop band response and the theoretical stop band response also increases.

If the frequency determining resistors are all equal, R1 = R2 = R3 etc, and the frequency determining capacitors are all equal, C1 = C2 = C3 etc, then the cut-off frequency for any order of filter will be exactly the same. However, the overall gain of the higher-order filter is fixed because all the frequency determining components are equal.

In the next tutorial about filters, we will see that Active Band Pass Filters, can be constructed by cascading together a high pass and a low pass filter.

31 Comments

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Your Name.

Email Address

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SUBMIT

m

maitha

hi can you solve it with the percent error and I checked mine is there any possibilities to be the percent error 99.4? because I think it's impossible. and thanks for the helpful information.

Posted on January 26th 2018 | 3:14 pm

Reply

A

Arafat

How can I get DC gain of high pass filter?

Posted on November 27th 2017 | 4:57 pm

Reply

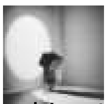
P

Peter

What about 0, DC is blocked by the capacitor at the input.

Posted on February 15th 2018 | 7:23 am

Reply



Eddie

(1 + R2/R1)

Posted on December 20th 2017 | 3:21 am

Reply

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r

rashi

worth reading

Posted on July 28th 2017 | 1:11 pm

Reply

M

Max

Can you please explain where the equation for the Gain for an Active High Pass Filter comes from? I understand that Af comes from the non-inverting op-amp, but where does everything else come from? Thank you

Posted on June 26th 2017 | 8:16 pm

Reply

A

Antony Deffrin J

Good!!

Posted on April 06th 2017 | 2:25 pm

Reply

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y

yosef

that's really nice.but would you mind if you give us the proof how to drive the expressions?

Posted on November 25th 2016 | 5:37 pm

Reply

B

Benjamin

How can i Implement first-order high-pass filter that has cut-off frequency of 30 Hz.

a. Explain how you selected values for R and C.

b. Compute amplitude and phase response of the filter in frequency domain

Posted on September 19th 2016 | 5:07 am

Reply

J

Joseph Colletti

Is there an ideal range for the pass-band gain, A_F?

In you example you use the value of 2, I need to have very high gains ~5K (75dB)

This can be done, in your example, by simply changing the A_F value to ~6000 (this obviously changes the size of the gain resistors, i.e. the resistors end up being not equal but very different). Is this okay?

I am a civil engineer not an EE sorry for this question.

Posted on September 08th 2016 | 10:41 pm

Reply

R

R.

Hi Wayne! Regarding the “Inverting Operational Amplifier Circuit” you write A(v)=-R2/R1 – can we use instead the equation A(v)=-R2/(R1+X(C1)) for some given frequency above the stop-band range?

Posted on August 03rd 2016 | 12:14 pm

Reply

More

---

g

gamn

tell*

Posted on April 06th 2016 | 11:28 am

Reply
