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StudentZone—ADALM2000 Activity: Active Filtering—Part 1

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Objective

The objective of this lab activity is to examine active filtering using different active filter circuit configurations.

The notion of filter is one of the most common terms found in circuit theory, used to configure signal characteristics like phase or amplitude. Besides passive components (that is, resistors, capacitors, inductors), active filters involve one or more active components, usually amplifiers, that can significantly improve the performance, cost, and predictability of the filter. Another advantage that active filters present is that the load impedance of the next circuit stages will not affect the filter characteristics and the high input impedance of the amplifier prevents excessive loading on the filter's output.

The usage of filters covers a wide area of applications including:

- Cut DC offset of high gain amplifiers
- Separate signals, passing only those which are of interest (that is, radio receiver, where the signal of interest, required for processing, is passed through while the rest of the signals are attenuated)
- Eliminate aliases in analog-to-digital systems
- Reconstruction of the signal at the output of a digital-to-analog system, eliminating higher frequency components (harmonics, sampling frequency)

An ideal filter has an amplitude response that is unity or gain dependent for the frequencies that are of interest and zero for other frequencies. The frequency at which the response changes from the fixed gain to zero is called cutoff frequency.

Figure 1 shows the idealized responses of the main types of filters.

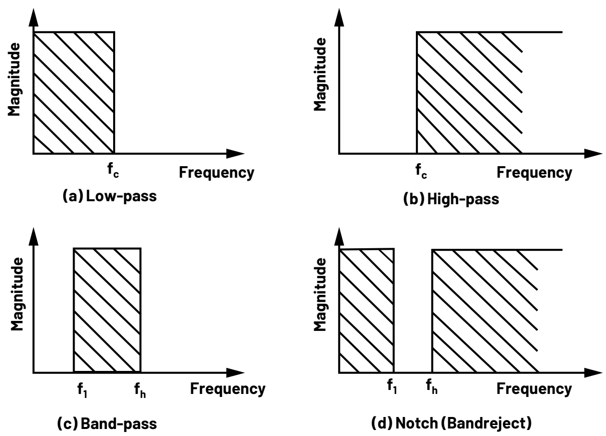


Figure 1. Idealized filter responses.

Materials

- ADALM2000 Active Learning Module
- Solderless breadboard
- Four 1 kΩ resistors
- Three 10 kΩ resistors
- One 470 Ω resistor
- One 9 kΩ resistor (series 6.8 kΩ and 2.2 kΩ)
- One 2 kΩ resistor (series two 1 kΩ)
- Two 1 nF capacitors
- Two 10 nF capacitors
- One 1 µF capacitor
- Five precision op amps (OP37, OP27)

Active Low-Pass Filter with Gain Control

Consider the circuit presented in Figure 2.

The frequency response of the filter is the same as the simple passive low-pass filter with the addition of the op amp for gain control and amplification. The basic RC low-pass filter provides a low frequency path by connecting it at the noninverting input of the operational amplifier.

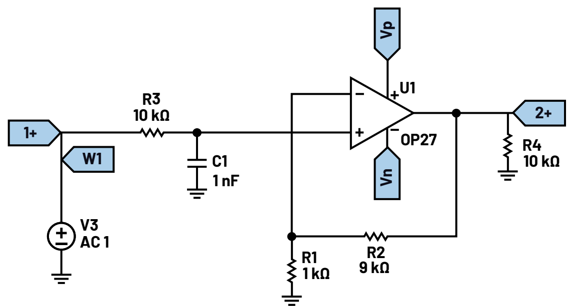


Figure 2. Active low-pass filter with gain control circuit.

The amplitude of the output signal is increased in the pass-band with gain A, which is given as a function dependent on the input resistor (R1) and feedback resistor (R2).

$$A = \left(1 + \frac{R2}{R1}\right) \quad (1)$$

Therefore, the gain of the first-order low-pass filter as a function of frequency will be:

$$V_{GAIN} = \frac{V_{OUT}}{V_{INPUT}} = \frac{A}{\sqrt{1 + \left(\frac{f}{f_c}\right)^2}} \quad (2)$$

Where:

A = voltage gain

f = frequency of the input signal

f_c = cutoff frequency

$$f_c = \frac{1}{(2\pi\ RC)} \quad (3)$$

Following the above formula, we can observe that the frequency-dependent gain of the circuit provides an output close to A when the frequencies are below the cutoff frequency, a value of $A/\sqrt{2}$ when the frequency of the signal is equal to the cutoff frequency, and for frequencies larger than the cutoff frequency the output voltage is decreasing proportionally to the increase of the signal frequency.

Hardware Setup

On your solderless breadboard, construct the active low-pass filter shown in Figure 3. Use the positive and negative power supply from the ADALM2000, set +5 V for the positive supply and –5 V for the negative supply.

Procedure

Open the Scopy Network Analyzer and set Channel 1 as the reference. Configure the sweep to start at 10 Hz and stop at 1 MHz. Set the amplitude to 200 mV and the offset to 0 V. Under the display settings, set the maximum magnitude to 30 dB and minimum magnitude to –30 dB. Set the phase top to +90° and bottom to –270°. Set the sample count to 100. Turn on the power supplies and run a single frequency sweep. You should see amplitude and phase vs. frequency plots that look very similar to your simulation results.

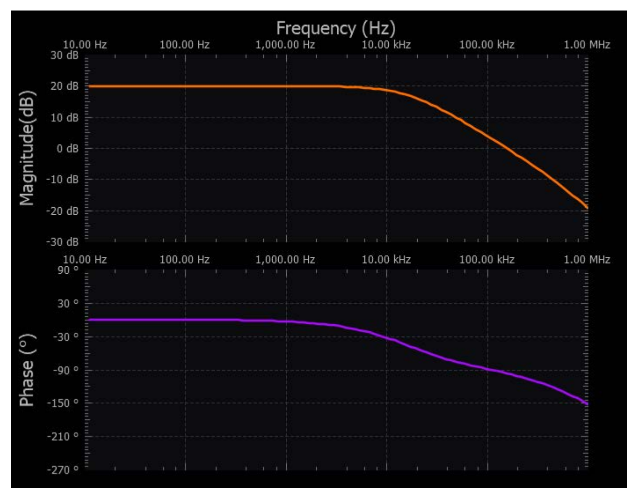


Figure 4. Active low-pass filter with gain control frequency response.

Inverting Amplifier Low-Pass Filter Circuit

The circuit present in Figure 5 is an inverting active low-pass filter. Unlike the previous filter configuration, the low frequency input is fed at the inverting input of the operational amplifier.

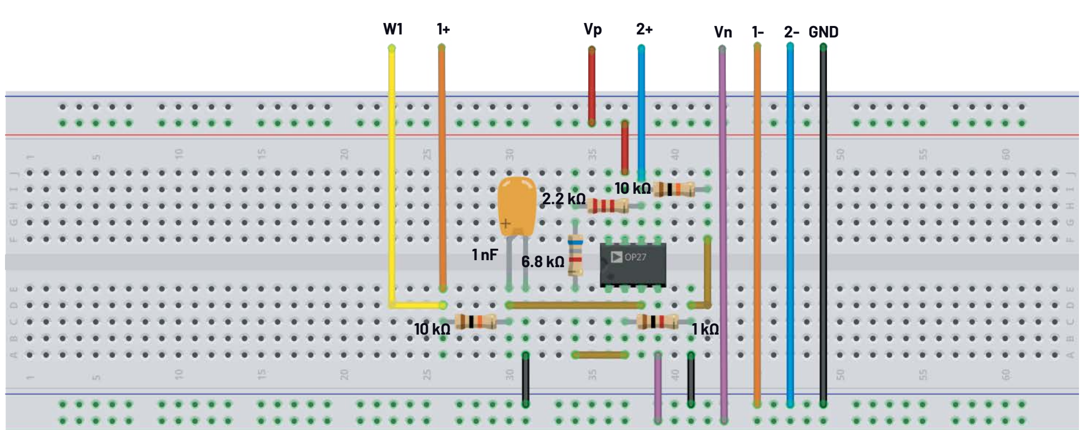


Figure 3. Active low-pass filter with gain control breadboard connection.

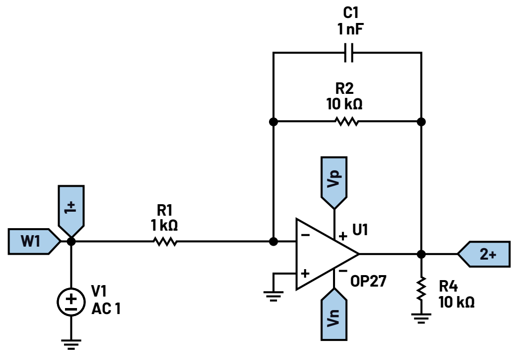


Figure 5. Inverting amplifier low-pass filter circuit.

The filter acts as an inverting amplifier in the pass-band with gain A, which is a function equal to the negative quotient of the feedback resistor (R2) and the input resistor (R1).

$$A = -\frac{R2}{R1} \tag{4}$$

Calculating the cutoff frequency for this circuit is the same as the noninverting active low-pass filter circuit.

Hardware Setup

Build the breadboard circuit presented in Figure 6. Set +5 V for the positive supply and –5 V for the negative supply.

Procedure

Open the Network Analyzer and set Channel 1 as the reference. Configure the sweep to start at 1 kHz and stop at 500 kHz and set the sample count to 100. Set the amplitude to 200 mV and the offset to 0 V. Under the display settings, set the maximum magnitude to 30 dB and minimum magnitude to –30 dB. Set the maximum phase to 180° and minimum phase to 0°. Turn on the power supplies and run a single frequency sweep. You should see amplitude and phase vs. frequency plots that look very similar to your simulation results.

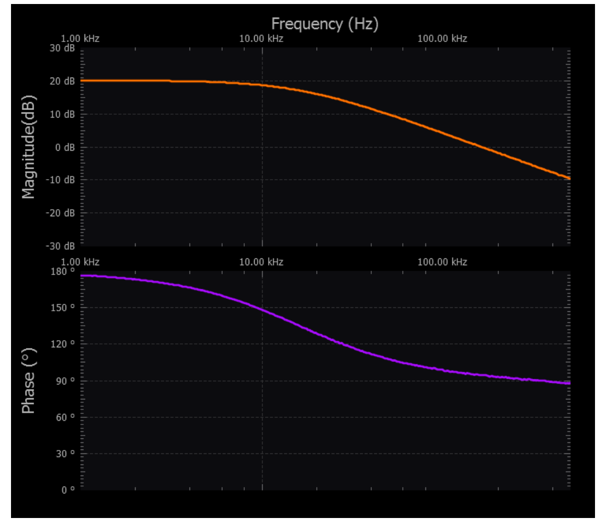


Figure 7. Inverting amplifier low-pass circuit frequency response.

Active High-Pass Filter with Gain Control

Now consider the next circuit in Figure 8.

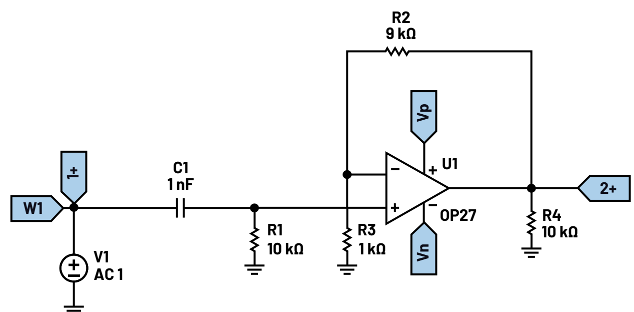


Figure 8. Active high-pass filter with gain control circuit.

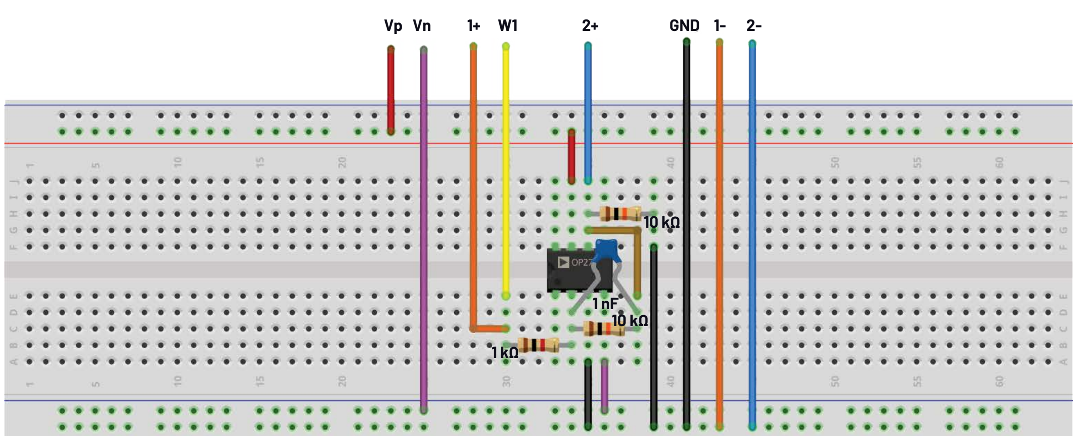


Figure 6. Inverting amplifier low-pass circuit breadboard connection.

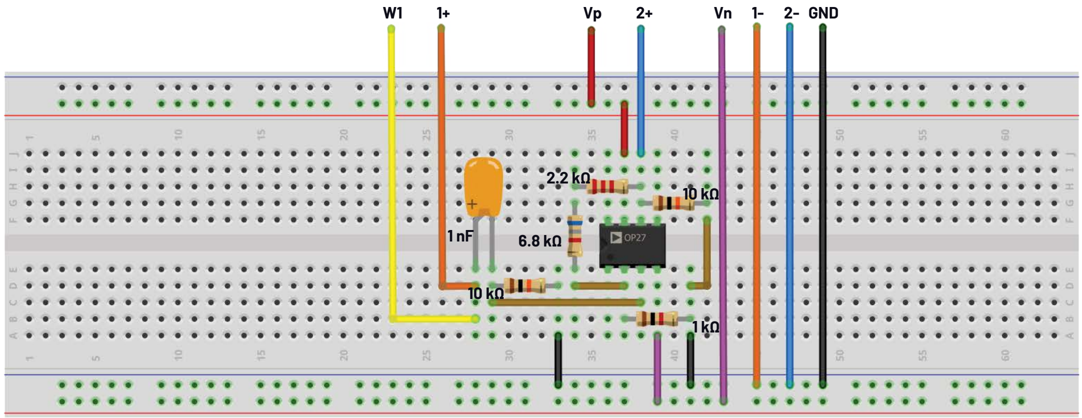


Figure 9. Active high-pass filter with gain control circuit.

The filter circuit is an active high-pass filter, which basically passes and amplifies high frequency. The circuit is composed of an RC high-pass filter providing a high frequency pass with the addition of the op amp for gain control and amplification. The frequency response of the filter is the same compared to a passive high-pass filter. The gain, A, of the output signal is dependent on the input resistor (R3) and feedback resistor (R2), the same as that in a noninverting active low-pass filter.

The gain of the first-order high-pass filter as a function of frequency will be:

$$V_{GAIN} = \frac{V_{OUT}}{V_{INPUT}} = \frac{A \times \left(\frac{f}{f_C}\right)}{\sqrt{1 + \left(\frac{f}{f_C}\right)^2}} \tag{5}$$

Where:

- A = voltage gain
- f = frequency of the input signal
- f_c = cutoff frequency

Hardware Setup

Construct the active high-pass filter circuit shown in Figure 9. Use the positive and negative positive supply from the ADALM2000.

Procedure

On the Scopy Network Analyzer, set Channel 1 as the reference. Set the amplitude to 200 mV, 0 V offset. Under the display settings, set the maximum magnitude to 30 dB and minimum magnitude to –25 dB. Set the phase from –180° to +180°. Set the sample count to 100.

Turn on the power supplies and run a single frequency sweep from 500 Hz to 1 MHz.

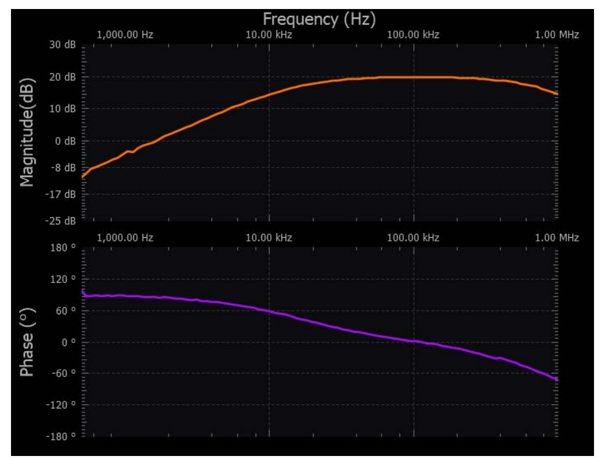


Figure 10. Active high-pass filter with gain control circuit.

Comparing the result to an ideal frequency response of a passive high-pass filter, the frequency response of an active high-pass filter is limited to the op amp's bandwidth or open loop characteristics. There comes a point on the spectrum where the gain decreases as the frequency increases making the whole response look like a band-pass filter. See Figure 10.

Active Band-Pass Filter

Unlike the previous filter configurations shown above in which the pass band is determined only by one cutoff frequency (DC up to the cutoff frequency for the low-pass filter and cutoff frequency onward for the high-pass filter), the active band-pass filter has two cutoff frequencies that define the selected frequency range. A simple configuration of the active band-pass filter is shown in Figure 11.

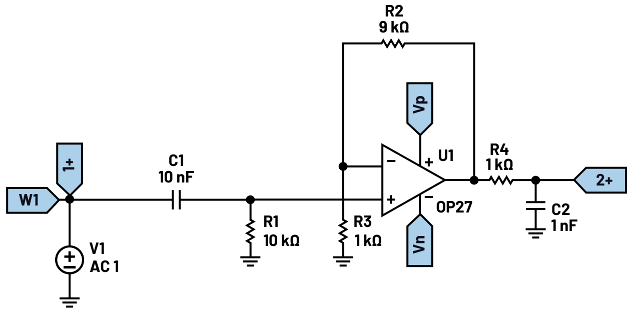


Figure 11. Active band-pass filter.

The circuit is composed of three stages. The first stage is the RC high-pass filter that defines the lower cutoff frequency, f_L, and attenuates signals below this defined frequency. Then the next stage is the amplification stage, which basically is the op amp amplifying the signals passed by the high-pass filter stage. And lastly, the RC low-pass filter stage, which defines the higher cutoff frequency, f_H, and attenuates signals falling above this defined frequency. The difference between the higher cutoff frequency and lower cutoff frequency determines the bandwidth of the band-pass filter.

$$\mathrm{BW} = f_{\mathrm{H}} - f_{\mathrm{L}} \tag{6}$$

The voltage gain of this filter is given by the expression:

$$\mathrm{V_{GAIN}} = \frac{\mathrm{V_{OUT}}}{\mathrm{V_{INPUT}}} = \frac{\mathrm{A_{max}} \times \left(\frac{f}{f_{\mathrm{L}}}\right)}{\sqrt{[1 + \left(\frac{f}{f_{\mathrm{L}}}\right)^2][1 + \left(\frac{f}{f_{\mathrm{H}}}\right)^2]}} \tag{7}$$

Where:

- A_{max} = total voltage gain, can be determined by multiplying the gain of the high-pass stage to the gain of the low-pass stage
- f = frequency of the input signal
- f_L = lower cutoff frequency
- f_H = higher cutoff frequency

Taking a closer look at the circuit, the presented active band pass filter is basically a second-order system. Cascading one low-pass filter and one high-pass filter gives us a second-order band-pass filter. Having two reactive components, capacitors, the filter will have a peak response, resonant frequency, f_r, which is the geometric mean of the two cut-off frequencies. The resonant frequency is also called the center frequency, but in this activity the term resonant frequency is used.

$$f_{\mathrm{r}} = \sqrt{f_{\mathrm{L}} \times f_{\mathrm{H}}} \tag{8}$$

Aside from the cutoff frequencies defining the resonant frequency, it also determines the quality factor of the filter. This quality factor, Q, is a measure of selectivity of the filter and is defined as the quotient of the resonant frequency with regards to the bandwidth. The Q factor, along with the gain and resonant frequency, characterizes the frequency response of the second-order filter.

$$\mathrm{Q} = \frac{f_{\mathrm{r}}}{\mathrm{BW}} \tag{9}$$

When Q is greater than 1, the band-pass filter has a much narrower pass band, whereas when Q is lesser than 1, a wider pass band.

Hardware Setup

Build the breadboard circuit presented in Figure 12. Use the positive and negative power supply from the ADALM2000.

Procedure

On the Scopy Network Analyzer, set Channel 1 as the reference. Set the amplitude to 200 mV, 0 V offset. Under display settings, set the magnitude from –10 dB to +25 dB and the phase from –150° to +100°. Set the sample count to +100.

Turn on the power supplies and run a frequency sweep from 100 Hz to 500 kHz.

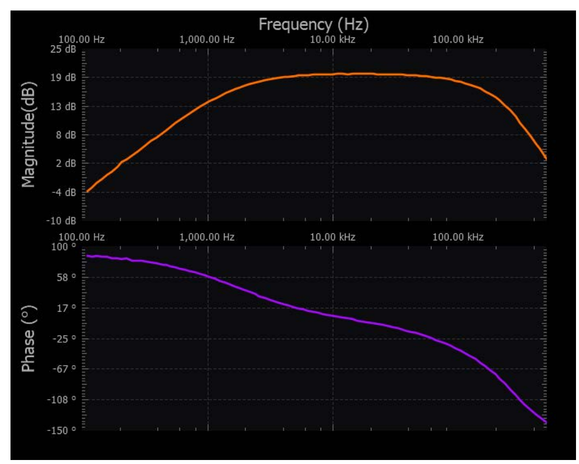


Figure 13. Active high-pass filter frequency response.

Active Band-Stop Filter Circuit

Another type of filter can be made by combining a low-pass filter and a high-pass filter. Such filter configuration is a band-stop filter.

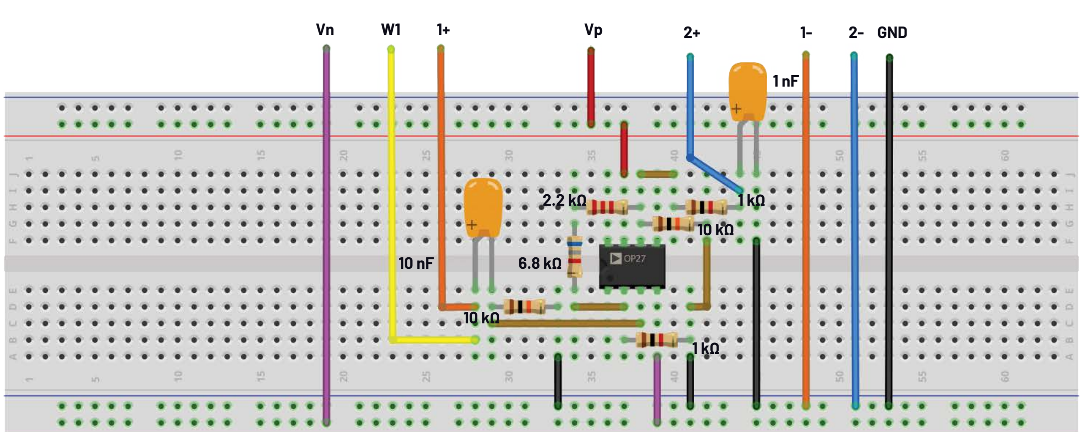


Figure 12. Active band-pass filter breadboard connection.

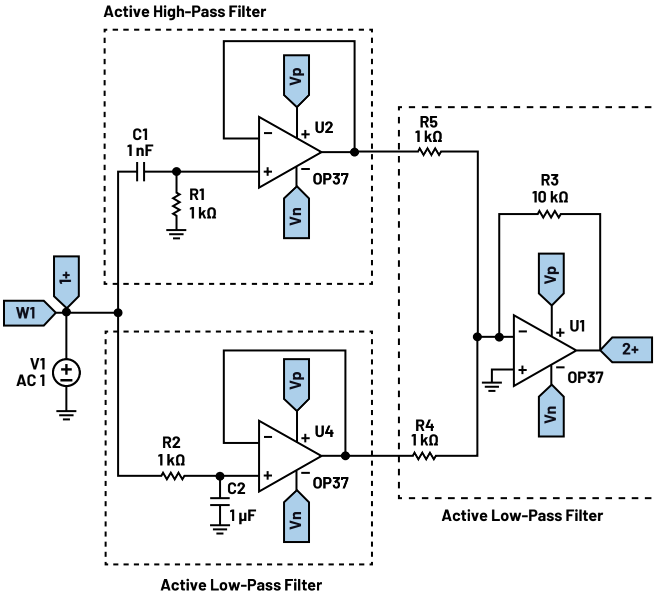


Figure 14. Active band-stop filter circuit.

The filter circuit shown in Figure 14 is an active band-stop or active band-reject filter circuit. It operates exactly the opposite of the active band-pass filter. This filter blocks and attenuates the frequencies between the lower and higher cutoff frequencies but passes signals from DC to the lower cutoff frequency and all the frequencies above the higher cutoff frequency.

The circuit is composed of combined high-pass and low-pass filters. The input signal is simultaneously fed to both the inputs of the high-pass and low-pass filters. The output of each filter then becomes the input to the summing amplifier and is amplified. By summing the low-pass and the high-pass filters, their frequency responses do not overlap. Similarly, like the band-pass filter, the band-stop filter is a second-order system.

The band-stop filter's definition for bandwidth, quality factor, and the resonant frequency is the same as the band-pass filter.

Like the band-pass filter, the band-stop filter has a wider stop band when Q is less than 1 and a much narrower stop band when Q is greater than 1. A narrow-band band-stop filter is referred to as a notch filter. The band stop filter in Figure 14 is an example of a notch filter.

Hardware Setup

On your breadboard, build the circuit shown in Figure 15. Set +5 V for the positive supply and –5 V for the negative supply.

Procedure

On the Network Analyzer instrument, set Channel 1 as a reference and set the sweep logarithmic from 10 Hz to 500 kHz with a sample count of 250. Under the waveform settings, set the amplitude to 200 mV and 0 V offset. Set the display from –30 dB to +30 dB and –180° to +180°. Turn on the power supplies and observe the waveform.

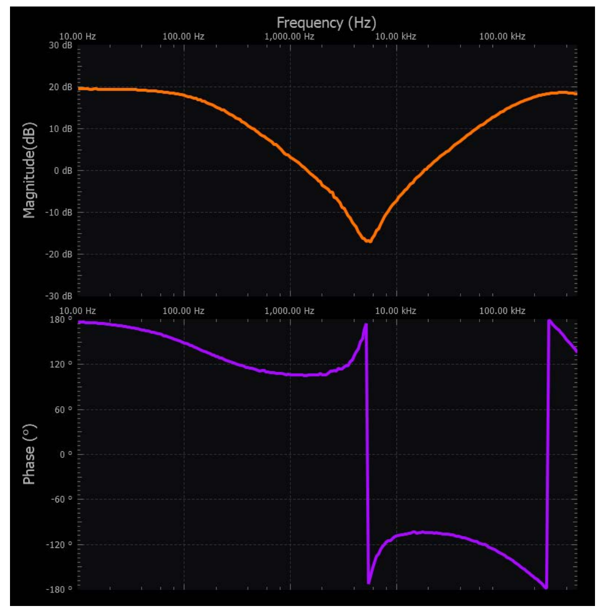


Figure 16. Active band-stop filter circuit frequency response.

Question:

What are the advantages of using active filters over the passive ones?

You can find the answers at the StudentZone blog.

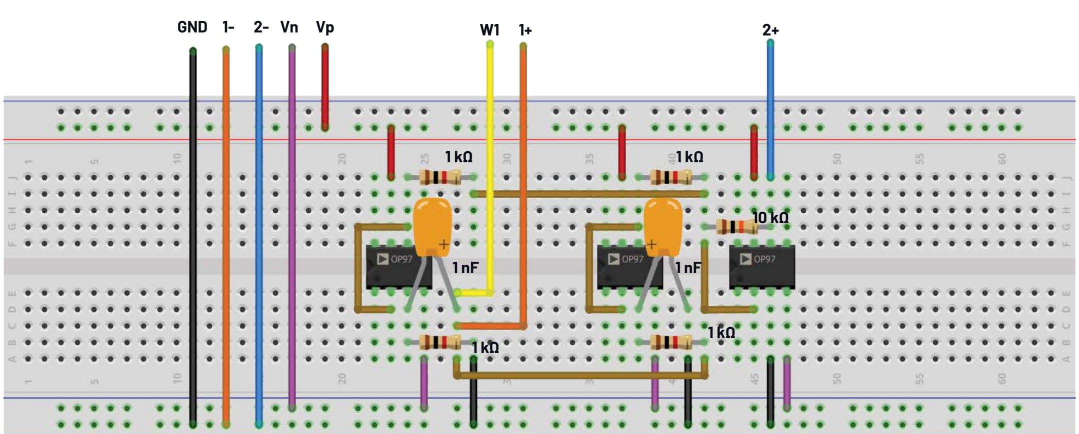
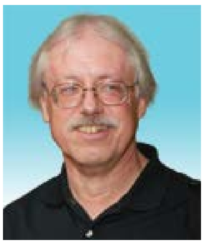


Figure 15. Active band-stop filter circuit breadboard connection.

About the Author

Antoniu Miclaus is a system applications engineer at Analog Devices, where he works on ADI academic programs, as well as embedded software for Circuits from the Lab®, QA automation, and process management. He started working at ADI in February 2017 in Cluj-Napoca, Romania. He currently holds an M.Sc. degree in software engineering from the Babes-Bolyai University and a B.Eng. degree in electronics and telecommunications from the Technical University of Cluj-Napoca.



About the Author

Doug Mercer received his B.S.E.E. degree from Rensselaer Polytechnic Institute (RPI) in 1977. Since joining Analog Devices in 1977, he has contributed directly or indirectly to more than 30 data converter products and holds 13 patents. He was appointed to the position of ADI Fellow in 1995. In 2009, he transitioned from full-time work and has continued consulting at ADI as a fellow emeritus contributing to the Active Learning Program. In 2016, he was named engineer in residence within the ECSE department at RPI.