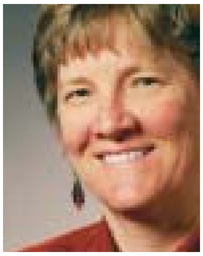

BY BONNIE BAKER

Sallen-Key lowpass-filter stopband limitations

When you design an analog, lowpass, antialiasing filter, you would expect its gain amplitude to continuously decrease beyond the filter's cutoff frequency. For the most part, this assumption is a safe one, but it's not necessarily true with the classic Sallen-Key lowpass-filter design. The Sallen-Key filter attenuates any signals in the frequency range above the cutoff frequency to a point, and then the response turns around and starts to increase in gain with frequency.

Figure 1 illustrates the behavior of three Sallen-Key lowpass filters using signal-supply amplifiers. In the top three curves, the diagram captures the open-loop gain of each amplifier as the response crosses 0 dB. During this test, the configuration for all three amplifiers is a dc noise gain of 1000V/V, or 60 dB. In the diagram, the bandwidth of op amps A, B, and C are 38 MHz, 2 MHz, and 300 kHz, respectively.

A second set of three curves in this figure shows the frequency response of second-order, Sallen-Key lowpass filters for each amplifier. The data indicates that the lowpass filters are performing as you would expect for a little more than a decade after the cutoff frequency of 1 kHz. Although the approximation method does not impact or correct this unexpected behavior, these filters use a Butterworth design. After the cutoff frequency, all three of the filter's responses show a slope of −40 dB/decade. You would expect this response from a second-order lowpass filter. Then, at some point, the filter gain begins to increase at a rate of 20 dB/decade. The difference in the frequency response at the point at which the three amplifiers change to a positive slope depends on the amplifier's output impedance. As the amplifier's open-loop gain decreases, its closed-loop output resistance increases. Eventually, each filter's response flattens at the 0-dB crossing frequency of the op amp's open-loop gain. It is no coincidence that the "flattening" of the filter response occurs at this crossing. As the frequency increases beyond this point, the amplifier's gain is less than 0 dB.

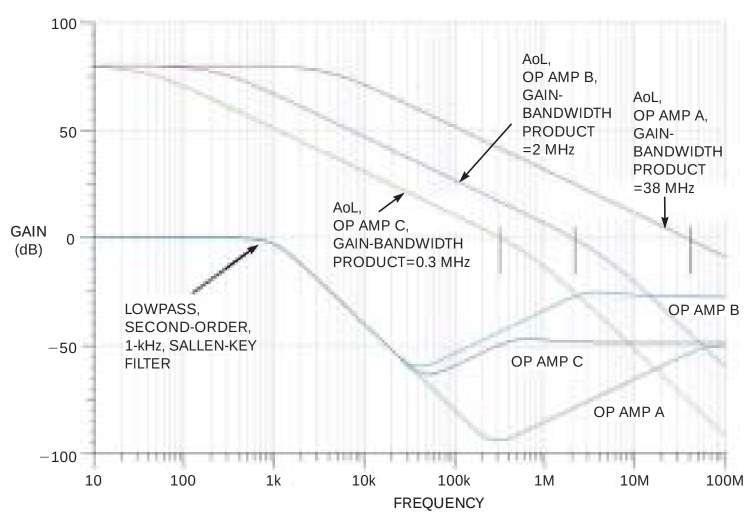

Figure 1 Note the frequency response of three Butterworth, second-order lowpass filters, along with the amplifier gain of each amplifier. The configuration for all three filters is Sallen-Key. The amplifier-gain curves start at the top of the diagram at 60 dB, and the filter curves start at 0 dB.

If you use a Sallen-Key lowpass filter, some characterization is in order. You can reduce the impact of the upward trend in the filter's response by following the offending active filter with a passive RC lowpass filter. The caveat to this action is that the following filter may interfere with the phase response of your intended filter, which may cause additional ringing in the time domain. Further, this action also creates a stage whose output is not low-impedance.

Alternative filters can solve the problem without adding an RC filter. When an inverting filter is an acceptable alternative, you can use a multiple-feedback circuit,which does not display this reversal in the gain response at higher frequencies and does not swing the input stage's common-mode voltage.EDN

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