They say a low-pass filter will rid you of noise in the higher frequencies. Well, this is not entirely true. It will succeed to a certain degree, but let’s take a closer look.

The classical approach to arranging an odd-order, low-pass active filter is to place the single pole of the odd-ordered filter at the front-end of the circuit. Following this first stage there are the remaining second-order stages. Figure 1 illustrates this fifth-order low-pass filter example.

As shown in Figure 1, the first stage is in an active first-order configuration. This first-order stage uses an R/C pair at the input followed by a buffered amplifier. Following this simple first-order stage are two second-order stages.

It is curious to look at the cumulative noise above the corner frequency of this fifth-order filter. With an operational amplifier (op amp) like the OPA350, the cumulative output noise from these three amplifiers and five resistors becomes approximately 3.9 µVrms at 10 kHz. If you use this circuit as an anti-aliasing filter, it reduces higher frequency signals above 1 kHz. However, some of the noise continues to sing through.

The 10 kHz noise density of this op amp is 7 nV / sqrtHz (where sqrt is equivalent to square root). The resistor’s noise density at 10 kHz is equal to sqrt(4 * k * T * R) (where k = 1.38 e-23, T = temperature in Kelvins, and R = resistance in Ohms).

Let’s break away from the classics and place the first-order stage at the end of the circuit (Figure 2).
The components and amplifiers between **Figure 1** and **Figure 2** are identical, but the order of each stage is changed. One would expect identical performance between these two circuits, which is true with the AC and transient step response - but that is where the similarity stops. The cumulative noise at 10 kHz of the circuit in **Figure 2** is approximately 3.0 µVrms. This is approximately a 23 percent improvement \((1 - 3.0 \, \text{µVrms} / 3.9 \, \text{µVrms})\).

This configuration can avoid peaking due to high Q sections. Peaking can occur because of possible overloaded internal nodes.

This is good news but let’s take it a little further. In **Figure 3**, the first-order filter is again at the end of the signal path, but it has been changed to an R/C pair (minus the amplifier). The values of the resistor and capacitor in this stage are the same as in **Figure 2**.

Once again, the components and amplifiers have not changed between the three figures. The
difference in Figure 3 is that the implementation of the first-order low-pass filter now uses a resistor to the output of the filter and capacitor to ground.

There is another reduction in noise with this circuit because one of the noise generators (OPA350) has been removed. The cumulative noise at 10 kHz for the circuit in Figure 3 is 2.8 µVrms. This improvement is not as dramatic as the difference between Figure 1 and 2. However, there is a distinct benefit to this configuration from Figure 1 to Figure 3 with approximately 28 percent improvement.

Figure 4 shows the noise performance of these three Sallen-key low-pass circuits.

![Figure 4](image)

Figure 4 Simulated noise response of Figure 1 (first-order, first stage), Figure 2 (first-order, last stage), and Figure 3 (first-order last RC stage).

So, will a low-pass filter reduce noise in your system? It will to a certain extent in the frequencies beyond the filter’s cut-off frequency. But, as always in the case of noise, there are techniques that you can use to further reduce noise after your filter. The beauty of this idea is that it is easy to make a few minor changes to your circuit architect, and voila! A 28 percent improvement is as easy as one, two, three.

References
1. “Analog filters and specifications swimming: What … I thought I was getting rid of the noise?” On Board with Bonnie, TI, 1-22-14
2. “Noise from Active Filters: An Unwelcome Surprise,” Caldwell, John, Precision Hub, TI, 3-24-14
3. Download the OPA350 datasheet

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