Delta-sigma ADC digital filter types: sinc filters

In my last post, I talked about the different types of digital filters commonly used in delta-sigma analog-to-digital converters (ADCs). In this post, let's focus on the most common type of digital filter used in delta-sigma ADCs: the sinc filter.

So what is a sinc filter, exactly? And why is it used so often in delta-sigma ADCs? Well, like I mentioned in my last blog post, the name "sinc" comes from its frequency response, which takes the form of the sin(x)/x function. The reason the filter has this response is actually tied closely with why it is so often used in delta-sigma ADCs.

The digital filter creates a digital output code by summing the 1s output by the modulator over a certain number of modulator clock periods (remember: the ratio of the delta-sigma ADC's modulator rate [f_{MOD}] to its output data rate [f_{DR}] is known as the "oversampling ratio," or OSR). This is equivalent to taking a moving average of those samples over the sampling period. Taking the moving average in the time domain translates to a first-order sinc response in the frequency domain. The sinc response is equal to zero at integer multiples of the data rate, which appear at notches in the filter's magnitude response plot.

The amount of averaging increases when cascading multiple sinc filters in series. In the spectrum, this corresponds to a lower cutoff frequency and a higher stopband attenuation, which in turn reduces noise. Figure 1 shows the difference in the frequency responses of a first-order sinc filter ($sinc^1$), three sinc filters in series (a third-order sinc, $sinc^3$) and five sinc filters in series ($sinc^5$).

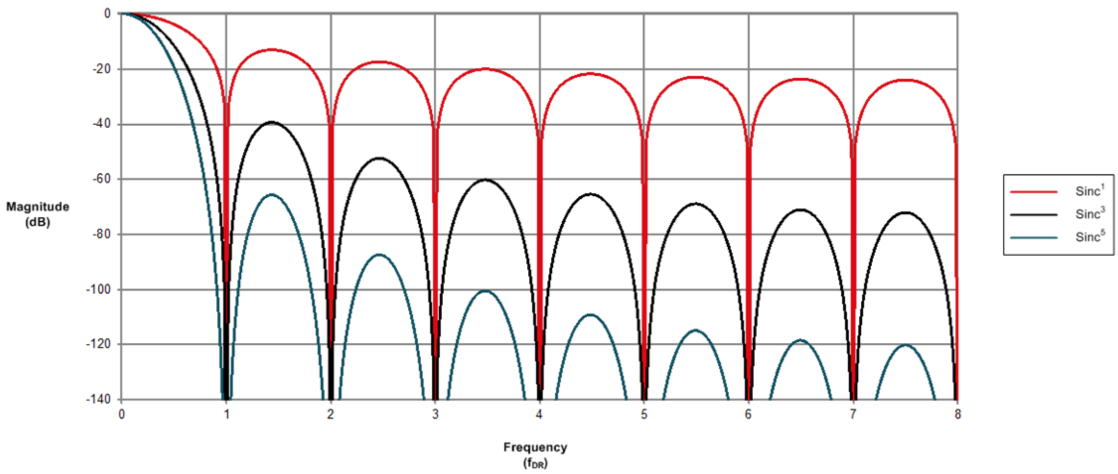

Figure 1: Frequency response of $sinc^1$, $sinc^3$ and $sinc^5$ digital filters

Looking at these responses, there doesn't seem to be very much bandwidth in the digital-filter output, limiting the measurable signal content. This is not as big of a deal as you might think, though. Some precision-sensor applications, like temperature and pressure sensors, don't require all that much bandwidth for measurement, but do need a good low-pass filter to keep the noise low. The sinc filter is great for this.

Given the application, you may wish to multiplex between multiple sensor inputs relatively quickly. To do this, you will need a digital filter that can respond to an input change and settle just as quickly. It turns out that the sinc filter is great for this too! As I mentioned briefly in my last post, sinc filters offer much faster settling times relative to other digital filters with more finely tuned frequency responses. In many cases, you can build these filters to settle to a step input in a single conversion cycle. That being said, trade-offs do exist between the types of sinc filters. The higher order the sinc filter, the longer it will take to settle – but with the bonus of better stop-band attenuation. Figure 2 shows how the $sinc^1$, $sinc^3$ and $sinc^5$ filters respond to a unit step input. Note that the order of the sinc filter matches the number of samples it takes to settle to the input.

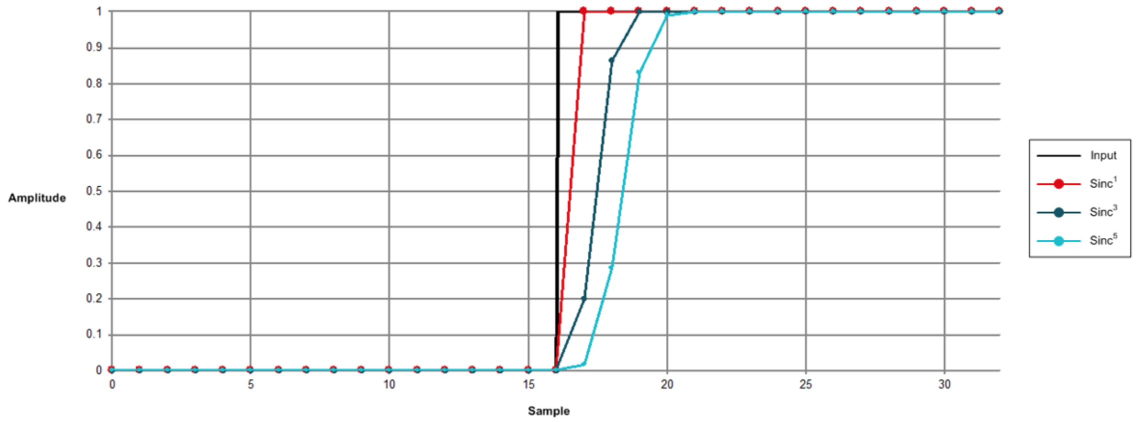

Figure 2: Step response for $sinc^1$, $sinc^3$ and $sinc^5$ digital filters

Some data converters have slightly modified sinc filters. In some industrial applications, power utility interference pollutes the equipment's environment at 50 or 60Hz. A digital filter that has notches in its frequency response at 50 or 60Hz helps reject the utility frequency and maintain system power-supply rejection (PSR).

In many cases, you can build these filters to settle to a step input in a single conversion cycle. However, a filter that settles within a single cycle will not have out-of-band rejection that's as good as an unmodified higher-order sinc filter. Figure 3 shows the magnitude response of the digital filter on the ADS1248 24-bit delta-sigma ADC when the data rate is set to 20SPS. Note that this filter simultaneously rejects both 50Hz and 60Hz. A normal sinc filter would require a data rate at some integer divisor of 10SPS to achieve this, since filter notches would occur at multiples of 10Hz.

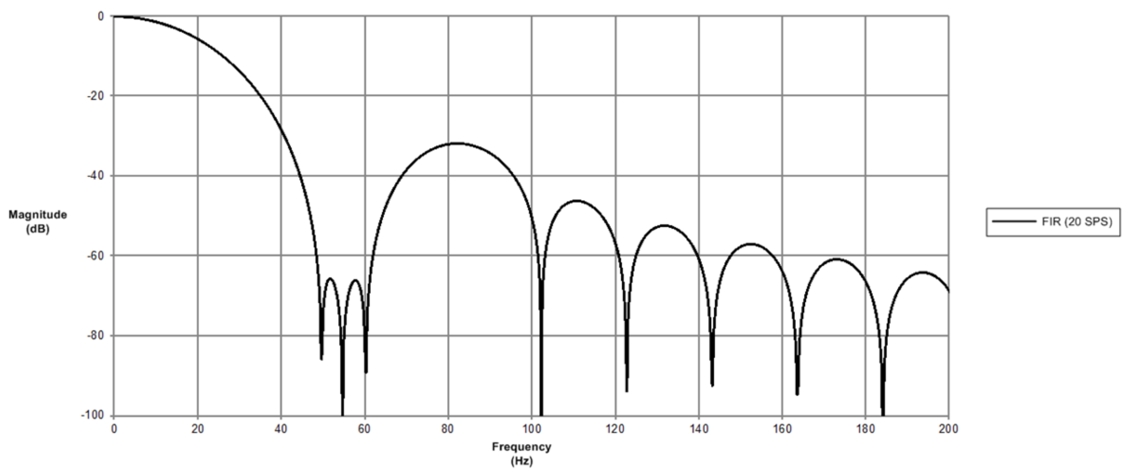

Figure 3: Magnitude response of the ADS1248 digital filter, f_{DR} = 20SPS

In summary, the sinc filter is used as a basic low-pass filter in delta-sigma ADCs. Their reasonable stopband attenuation, combined with their quick-step response make them ideal for DC measurement applications, especially when you are multiplexing between several sensors. Keep a lookout for the final installment in this three-part series about digital filters in delta-sigma ADCs. The next topic will be a detailed discussion of wide-bandwidth, flat pass-band style digital filters. In the