# When is a 24-bit ADC really a 2-bit ADC?

Developed for the high-volume and cost-conscious digital audio marketplace, 24-bit Sigma-Delta converters offer the potential for high resolution at a very low cost compared to traditional Successive Approximation Register (SAR) type A/D converters…often 1/10th the component cost for similar frequency ranges. If Sigma-Delta converters are so much less expensive, why wouldn't we see them in every application? To understand both the benefits and drawbacks, you first need to understand a little bit of how they work.
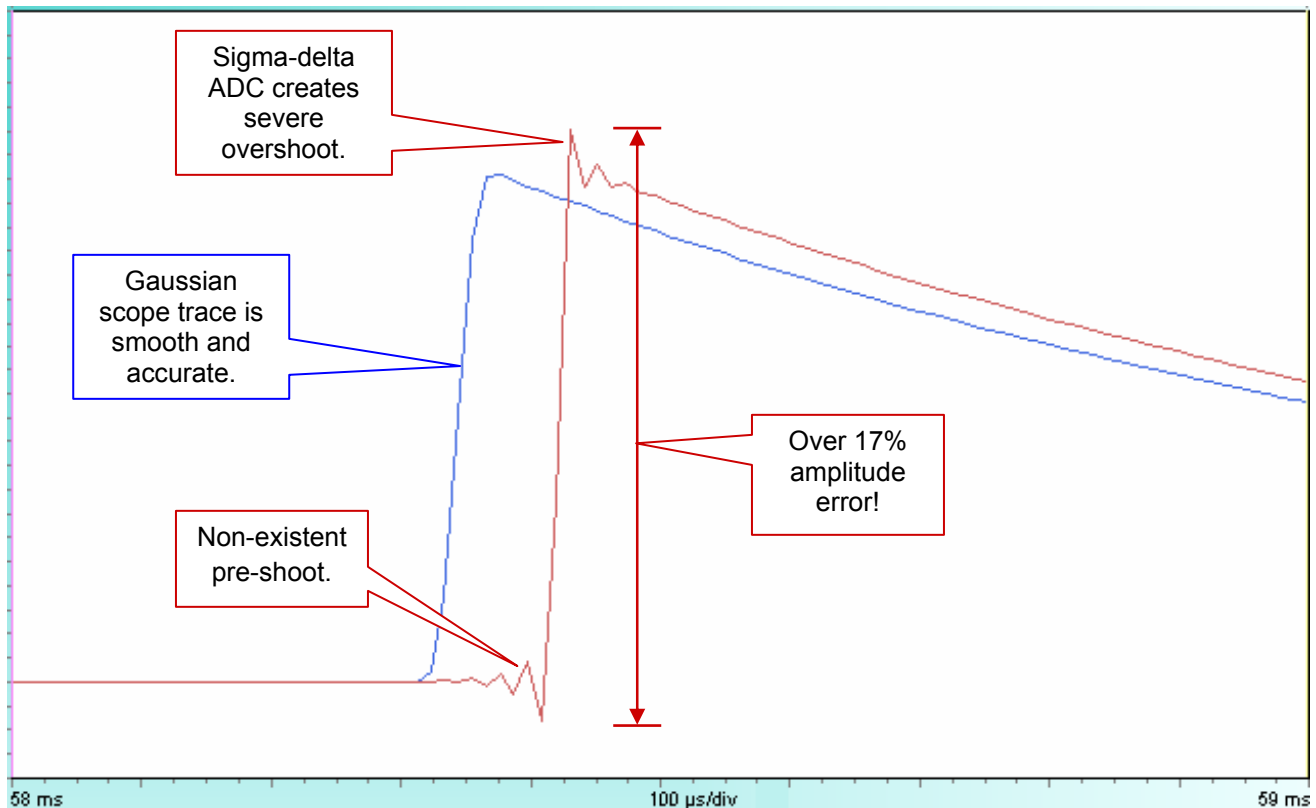
The analog portion of a sigma-delta converter, a 1-bit ADC, is a very simple comparator circuit. Most of the work is done on the digital side by oversampling filter logic, which makes the chip inexpensive to produce. The sigma-delta performs repetitive filtering and decimation on the over-sampled 1-bit data stream to "build up" a higher 24-bit resolution waveform. This filtering and decimation takes place within the chip itself. The internal digital filter has a very flat passband and sharp filter cutoff characteristics. The steep filter allows the bandwidth of the system to be very near the Nyquist frequency (e.g. 90 kHz for a 200 kS/s digitizer) while rejecting alias frequencies above the cutoff. In addition to consumer audio, these characteristics make sigma-delta ADCs attractive for frequency-domain instruments such as FFT analyzers, where the flattest frequency response is the most important factor.
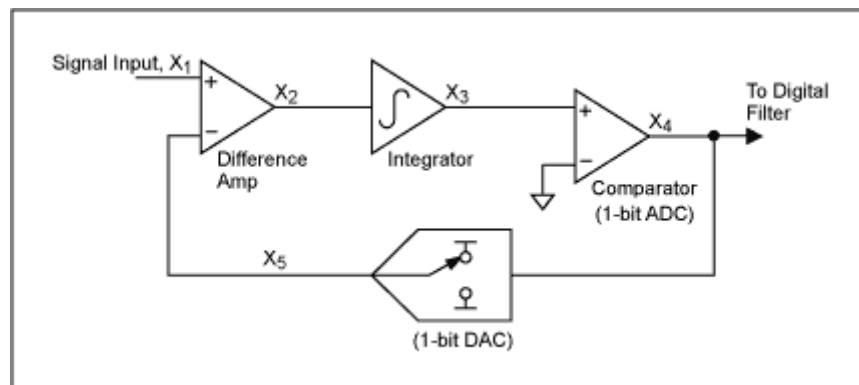
Block Diagram of Sigma Delta Converter

Despite good performance in frequency domain and audio applications, the steep internal filtering of a sigma delta converter makes it unsuitable for traditional oscilloscope and data acquisition applications where step response is important. Physics dictates that a steep filter unavoidably creates a large amount of overshoot and undershoot on a time domain step. This overshoot is referred to as Gibbs phenomenon and can result in a measurement error of up to 22% on a fast voltage step. Unfortunately, measuring fast voltage changes describes exactly the job of an oscilloscope! Examples below on a typical transient waveform illustrate why a sigma-delta ADC should NOT be used for general-purpose data acquisition or as a scope.

The figure shows an example pulse waveform with the following annotations:
- Sigma-delta ADC creates severe overshoot.
- Gaussian scope trace is smooth and accurate.
- Non-existent pre-shoot.
- Over 17% amplitude error!

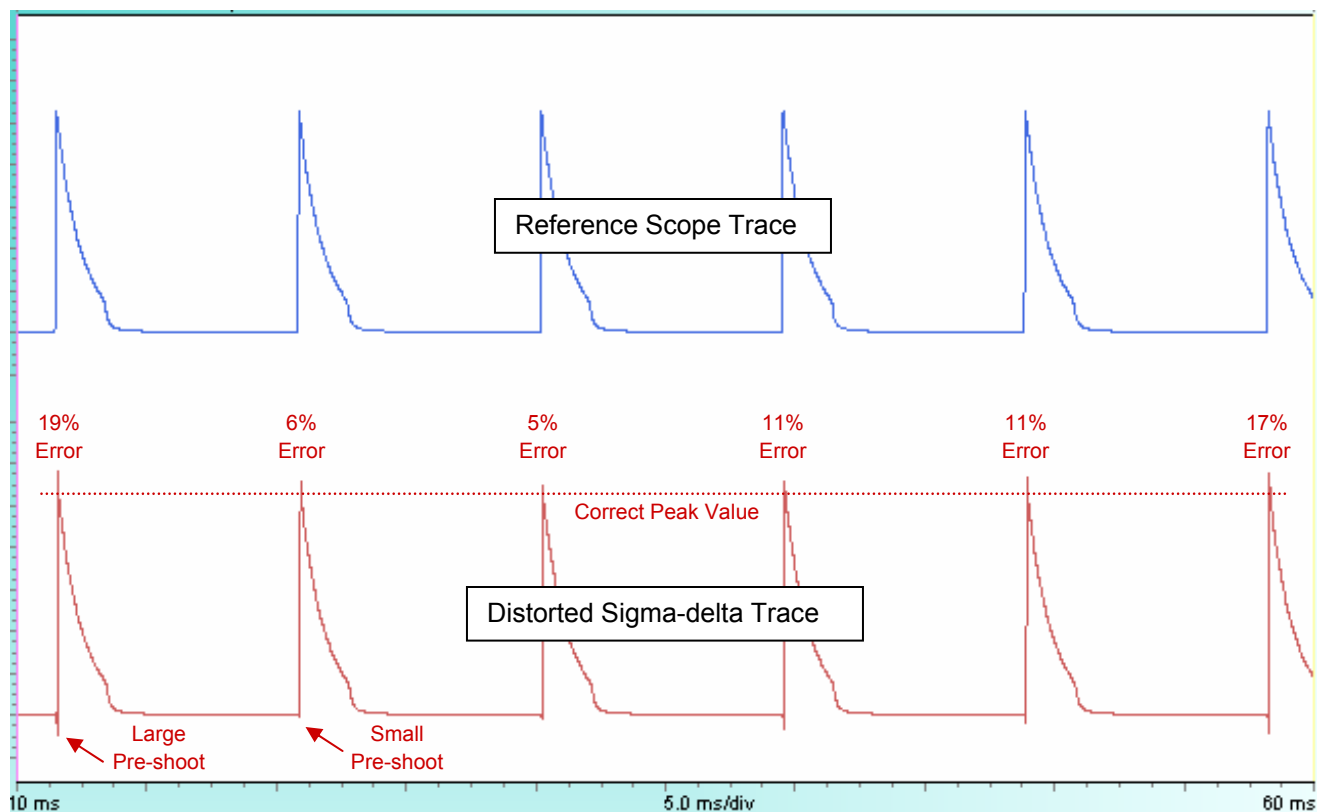Time axis: 58 ms (left), 100 µs/div, 59 ms (right)

The waveform above is an example pulse with a fast rise and slower fall. It is used as an example because a fast rise time is typical of many measurements in materials testing, ballistics, impact, switchgear, mechatronic and electronic applications. The left (blue) reference trace is captured with a normal oscilloscope-type input amplifier. It is tuned for the best rise time without overshoot, a traditional oscilloscope measure of quality. The badly distorted (red) trace on the right is the same signal as digitized by a sigma-delta ADC or by using a Steep filter. Notice the severe overshoot as well as pre-shoot on the baseline which did not physically exist. Clearly any peak and amplitude measurements on the red wave are wholly unreliable: no engineer could accept an error that can exceed 20%!

Not only is the sigma-delta distortion and amplitude error unacceptably large, it is highly variable. The peak error on a voltage step can range from near zero to over 20% depending on its rise time and the precise timing of the edge within the sigma-delta oversampling period. The false pre-shoot can unpredictably be as little as a few percent or as much as 17%.

Reference Scope Trace

| 19% Error | 6% Error | 5% Error | 11% Error | 11% Error | 17% Error |

Correct Peak Value

Distorted Sigma-delta Trace

Large Pre-shoot   Small Pre-shoot

10 ms   5.0 ms/div   60 ms

The above plot shows a string of identical pulses digitized by a Gaussian-response oscilloscope (blue reference) and a sigma-delta ADC (red trace.) Note the sigma-delta error is not only extreme, but also highly variable from cycle to cycle. Therefore there is no way of knowing how much error is contained in your waveforms. Although a sigma-delta can offer high resolution, its unknown amplitude errors of up to 22% mean you may have only 2 bits of actual accuracy! Similar to an economic forecast, more digits of resolution are meaningless when the data is unreliable and variable.

Amplitude Error on 100 Consecutive Pulses

— Sigma-Delta
— Gaussian
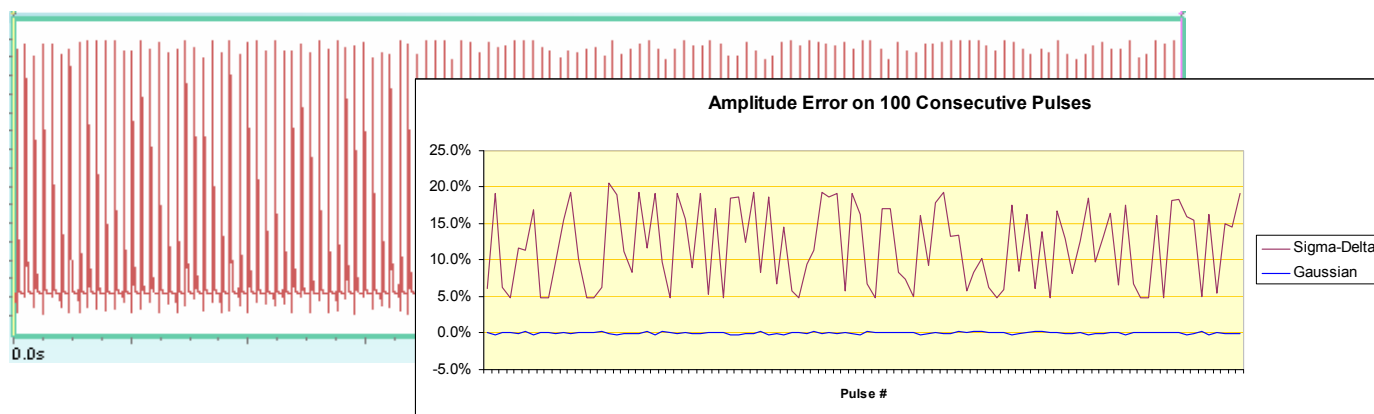
Pulse #

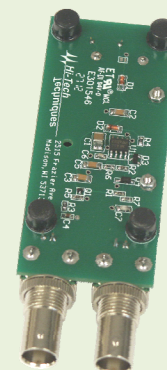Sigma-delta ADC shows wide variations in amplitude on identical pulses.

Since many engineers need to make both frequency-domain AND time-domain measurements, any instrument using a sigma-delta ADC type is overly restrictive: its poor and unpredictable signal fidelity means it cannot be trusted to measure a peak on any fast edge. On the other hand, a wideband oscilloscope will suffer from aliasing if used for FFT measurements. To overcome this contradiction, the best instruments provide software selection between Gaussian filters for the best time response, Steep filters for the best frequency response and a filter bypass for band-limited signals. One instrument can then be used for all purposes, saving time, money and frustration as well as simplifying calibration.

The filter effect can also be demonstrated on the Hi-Techniques Synergy Data Acquisition System simply by viewing a square wave while toggling between the Frequency Domain friendly "Steep" filter shape and the Time Domain friendly "Gaussian" filter shape. (The Synergy "Steep" setting is almost identical to a sigma-delta style filter.) If the Synergy contains two or more input modules, set one to each setting and tee the signal to observe the filter effects side-by-side. They will be similar to the sketch below.
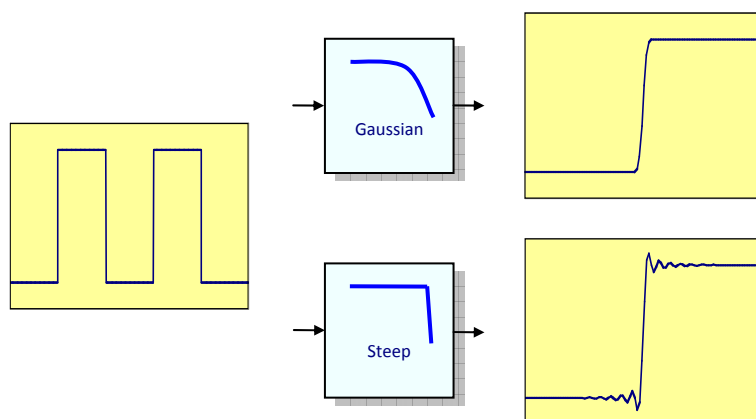
Square wave output using Synergy's Steep and Gaussian Filters.

To easily demonstrate the effect of different filter methods, a small battery-powered signal generator is available on request from Hi-Techniques. The signals used in this Tech Note were generated from the signal generator. See for yourself how different systems respond and determine your best choice. Please visit our website for a video demonstration of filter effects, or download our Filters Tech Note for more technical information.

www.hi-techniques.com

As we have discussed, the low cost and high resolution of a sigma delta type 24-bit A/D converter make it a great choice for frequency domain or audio applications where they provide excellent dynamic range and performance. For time domain applications, however, the traditional 16-bit SAR converter provides a much better solution for accurate representation of the waveform with over ten times lower uncertainty.