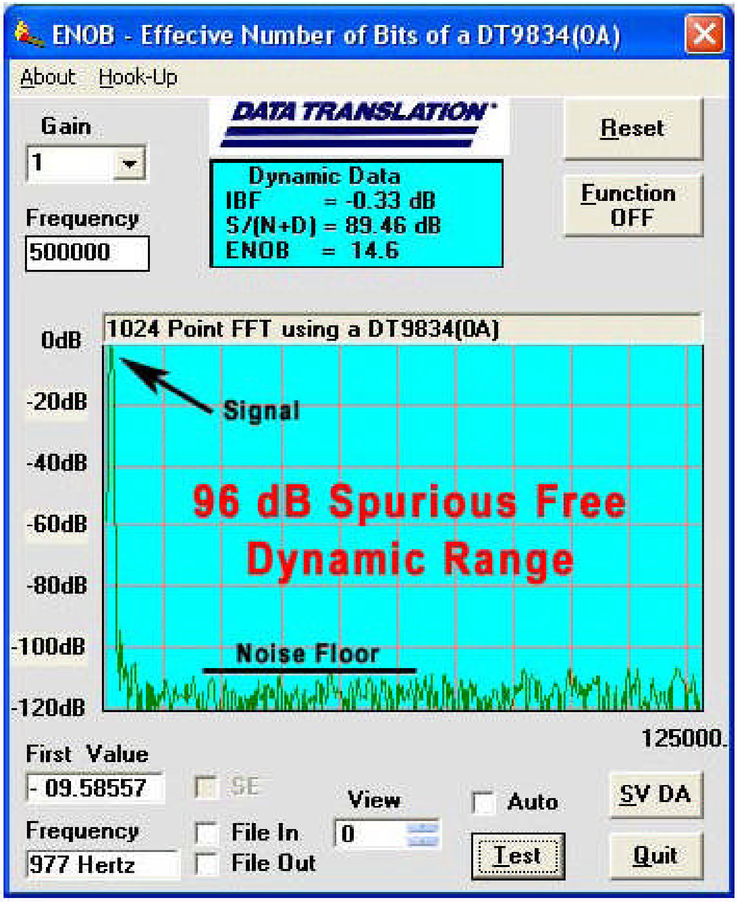
DATA TRANSLATION®

The Battle for Data Fidelity:Understanding the SFDR Spec

As A/D converters (ADC) and data acquisition boards increase their bandwidth, more and more are including the spurious free dynamic range (SFDR) specification as an indicator of their fidelity. The converter is not the only source of spurious signals; however, because of complex interactions between the ADC and the signal conditioning circuits that invariably precede it. The key to properly interpreting this specification lies in understanding the sources of spurious signals and how SFDR is measured.

Like everything else in the world of electronics, the speed and bandwidth of data acquisition (DAQ) systems and their key components, the ADCs, are increasing. And they don’t show any signs of stopping. The need for speed in applications such as high-speed data acquisition is continually pushing the limits of ADCs. At the same time, the need for precision and accuracy in the DAQs and ADCs remains high. One of the specifications that ADC and DAQ board vendors have begun touting is the spurious free dynamic range (SFDR). They often quote the SFDR specification as an indicator of the digital output’s fidelity to the original signal. While there is an element of truth in that implication, the SFDR specification can be misleading if not properly interpreted.



ENOB - Effecive Number of Bits of a DT9834(0A)

Gain: 1

Frequency: 500000

Dynamic Data
IBF = -0.33 dB
S/(N+D) = 89.46 dB
ENOB = 14.6

1024 Point FFT using a DT9834(0A)

96 dB Spurious Free Dynamic Range

First Value: - 09.58557

Frequency: 977 Hertz

View: 0

The basic definition of the SFDR specification is simple. It is the strength ratio of the fundamental signal to the strongest spurious signal in the output. In many cases, the spurious signal is the result of non-linearity in the A/D conversion, hence the interpretation of SFDR as an indicator of fidelity. But a number of other sources of strong spurious signals may be present in the DAQ system, so the SFDR specification requires a closer look.

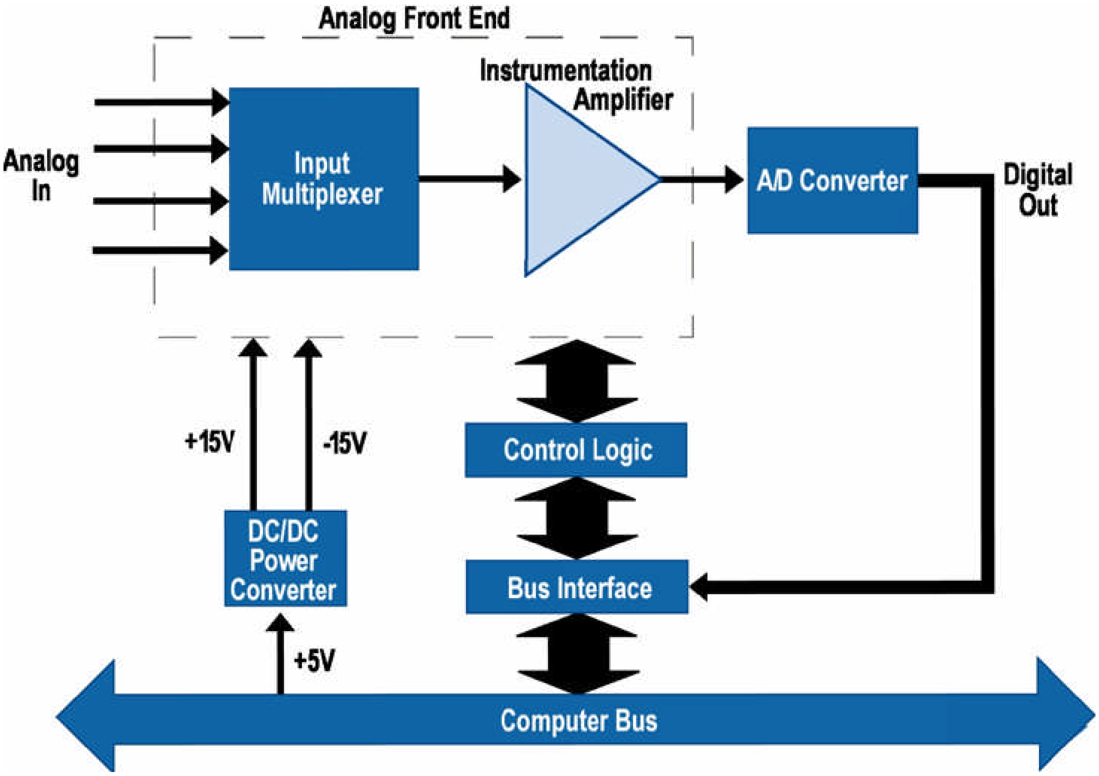


Figure 1: Components commonly found in a data acquisition system, input multiplexer, instrumentation amplifier, A/D converter, power supply control logic and bus interface.

Because ADCs are never used as the only element between the input signal and the digital output, the place to begin this closer look is by considering all of the elements in a DAQ system. As shown in Figure 1, a DAQ module contains several key functions, including a signal-conditioning filter, a sample-and-hold circuit, and in many cases an analog multiplexer to make one ADC handle multiple input signals. Non-linearity in any of these elements can generate spurious signals that can affect the achievable SFDR.

Another source of spurious signals occurs within the anti-aliasing filter as a result of the high signal bandwidth available in today's ADCs. The purpose of an anti-aliasing filter is to limit the input signal's bandwidth to eliminate high-frequency components. A rule of sampled data systems is that the input signal's spectrum gets folded around a frequency one-half that of the sample clock. An ideal anti-aliasing filter would pass all signals in the band of interest and block all signals outside of that band.

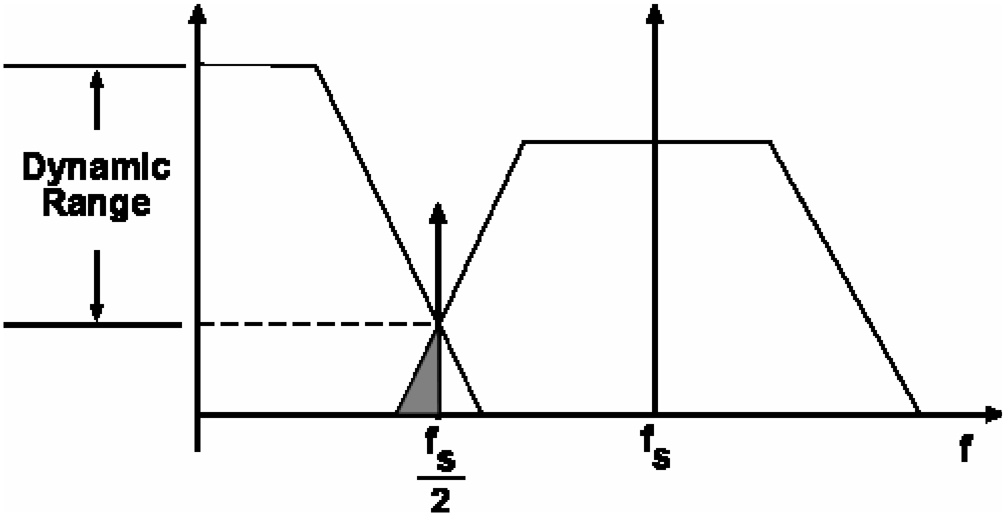


Figure 2: Spurious Signals From a Non-ideal Anti-Alias Filter

The reality is, however, that filters are not perfect. As shown in Figure 2, the roll-off characteristics of a practical filter mean that it will still pass some of the signals above the filter's cutoff frequency. Depending on where that cutoff occurs relative to the sampling frequency, the folded signal spectrum may overlap the input signal spectrum. If the filtered signal contains any energy in this overlap band, that energy appears as spurious signals in the output, affecting the SFDR.

As a result of these numerous spurious sources, the significance of SFDR in many systems is not the converted signal's fidelity, but the impact of the spurious signal as a noise source. In effect, SFDR indicates the lowest-energy input signal that can be distinguished from spurious signals.

Any signal below the SFDR cannot be reliably identified as a true signal instead of as a spurious one. The practical ramification of this ambiguity is that the spurious signals can mask desired signals.

In a motor maintenance application, for example, the DAQ is looking for harmonics of the motor rotation rate in the motor's vibration spectrum. The presence of growing harmonics is an indication of motor wear and the need for replacement. When the DAQ itself creates spurious signals, those harmonics may be masked until they become stronger, reducing the system's ability to make an early prediction of motor failure.

In another example, the presence of spurious signals in digitized audio reduces a system's effectiveness. In the audio case, these signals manifest as "hiss" in the audio signal, reducing the signal quality.

The anti-aliasing filter is only one example of spurious signal sources. A more complete list includes:

- Sample-hold non-linearity
- ADC non-linearity
- Signal multiplexing
- System clock noise
- DC/DC converter noise
- Adjacent channel noise
- Channel overload (driving op-amp to rails)

Because of the many sources of spurious signals, SFDR of the ADC alone is not a sufficient measurement of the achievable signal dynamic range. The measurement must be made in the context of a full DAQ system.

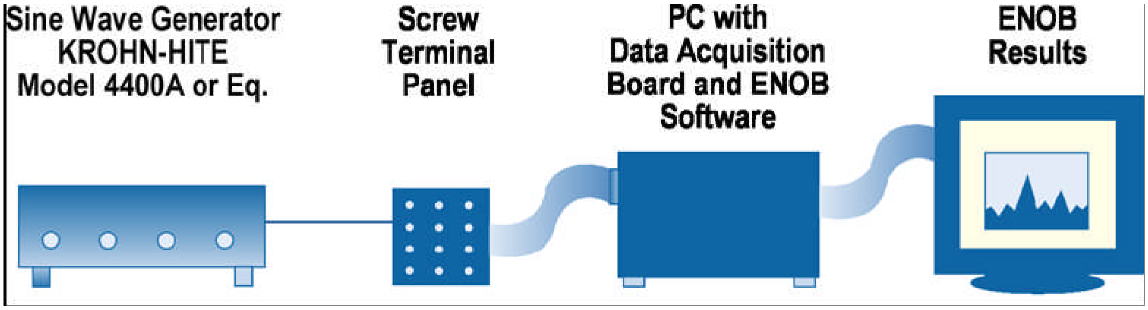


Figure 3: Krohn-Hite model 4400A sine wave generator used to produce 1kHz sine wave into data acquisition module test.

The test setup for measuring SFDR, shown in Figure 3, involves generating a pure sinusoidal input signal (accurate to at least 0.001%) with strength within 1 dB of the DAQ system's maximum input range. Then, perform an FFT (Fast Fourier Transform) on the output. The frequency spectrum that the FFT produces allows direct measurement of the SFDR. In addition, performing the FFT on the output of an adjacent channel, which has its input grounded, provides a measure of the spurious signals coming from the rest of the system as well as coupling of signals from other inputs.

Comparing the two measurements will also provide a metric known as the effective number of bits (ENOB). The ENOB tells users how many of the system's output bits will contain useful information, typically a value lower than the resolution of the ADC. It is a particularly useful metric, as it measures the performance of the entire DAQ system, not just the ADC, and it does so under dynamic, real-world conditions.

As a metric, the ENOB is a more useful measure of a DAQ system's performance. For the analog front end, for instance, it will detect such things as interactions between the over-voltage protection circuits and EMI filters. Noise from gain-setting resistors within the instrumentation amplifier, amplifier and sample-and-hold bandwidth errors, and the effects of acquisition time, channel-to-channel offset, and channel crosstalk in the input multiplexer all contribute to ENOB. So do system electrical noise, distortions that the ADC introduces (a component of SFDR) and the effects of over-driving the filter op amps when the input signal is over-range.

The ENOB metric includes the effects of SFDR, but provides a more accurate overall picture of a DAQ system's potential performance. This does not mean that the SFDR specification has no value, however. Because it focuses specifically on spurious signals rather than random noise, it provides some guidance as to where improvements can be made to the DAQ system.

When spurious signals are large relative to random noise, the frequency of the spurious signal helps identify the source. Pure harmonics of the input frequency, for instance, can be due to non-linearity in the signal conditioning chain as well as the ADC. If the ADC's specified linearity does not account for all of the harmonic energy, the front-end should be checked.

The spurious signals introduced by folding of the anti-aliasing filter's output around the frequency at half the sample clock rate can be identified by their concentration at the high end of the filter bandwidth. When those signals set the SFDR limit, they can be reduced in two ways. One is to use a filter with a sharper roll-off, which generally implies a more complex filter. The other is to increase the sample clock frequency, so that the folding involves signal components further out in the filter's roll-off curve.

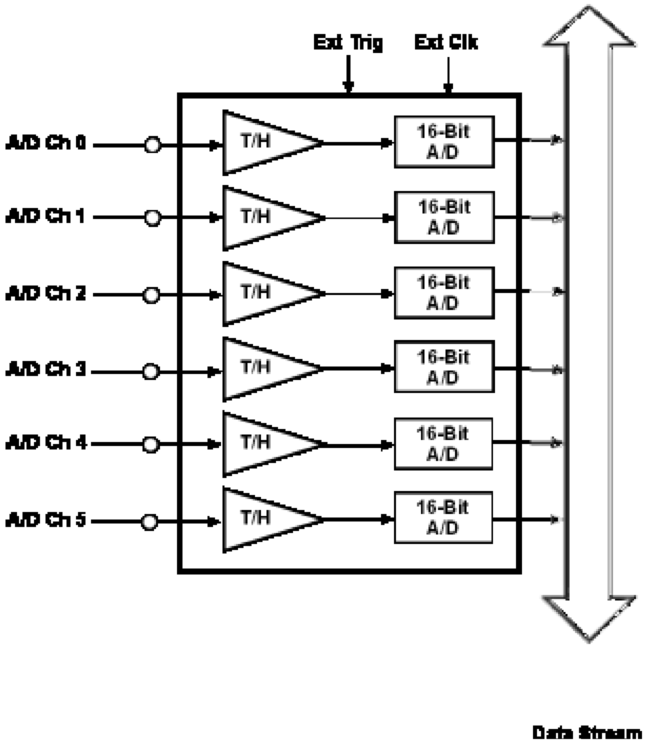


Figure 4: Six independent, successive-approximation A/D converters with track-and-hold circuitry.

Each converter uses a common clock and trigger for simultaneous sampling of all analog inputs.

When the spurious appear tied to the channel switching frequency of a multiple-input ADC, designers can look for noise in the multiplexer. They can also look at the slew rate and settling time of the sample-hold circuit, making sure that converted signals are not being affected by the values on adjacent channels. An alternative, increasingly available due to semiconductor process improvements, is to eliminate the use of a multiplexer and use one ADC for each channel. This allows a simultaneous sample-and-hold for each input signal, eliminating cross-talk and switching noise, and ensures that those signals can utilize the full sample rate of the ADCs rather than just a fraction. This increase also helps move the folding point for the anti-aliasing filter.

Thus, the SFDR specification has value for the DAQ system designer and user, but as a metric of data fidelity it has limits. In its place, the ENOB metric provides a more complete picture of a DAQ system’s performance. The ENOB value incorporates the effects that SFDR aims to measure, as well as virtually every other noise source and distortion in the system

To properly utilize the SFDR specification, designers need to consider how SFDR has been measured, and whether it applies to an entire DAQ module or just the ADC. If it is just the ADC, they should realize that the analog front-end design may degrade the achievable DAQ performance below the values indicated by SFDR. The SFDR specification can then serve as a pointer to problems within the front-end, and help designers maximize the fidelity of their DAQ system.