Measuring Dynamic Performance

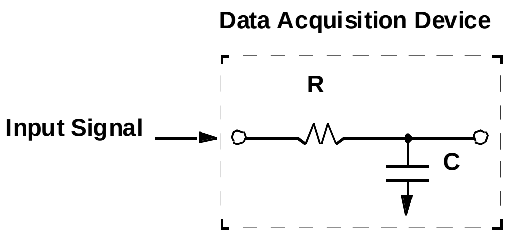
Despite claims from some manufacturers, all data acquisition devices are not created equal. Learning to distinguish a few important specifications can make all the difference. This white paper describes the importance of AC specifications when measuring dynamic performance.

DC versus AC Specifications

DC specifications, which provide information on the accuracy of the A/D converter (ADC), are most important in applications where you want to measure slowly changing signals, such as temperature, or low-frequency signals as compared to the sampling frequency of the ADC.

In applications where you want to measure rapidly changing and/or high frequency signals, however, AC specifications are more significant. AC specifications tell you how much noise and distortion have been introduced into the sampled data to affect the accuracy of the data for a given input signal and sampling frequency. *Just knowing the DC specifications of a device cannot predict its AC performance, so it is important that you know the AC specifications of your device!*

One of the factors that determines AC performance is the effect of the analog front-end circuitry on the input signal. From the simplest perspective, the data acquisition device acts as a low-pass filter that passes low frequencies and attenuates (or reduces) high frequencies. The range of frequencies from DC to the cut-off frequency (70.7% of the input signal) is called the 3 dB bandwidth of the filter. The bandwidth is determined by the resistance and capacitance of the circuit, as shown in Figure 1.



$$F = \frac{1}{2\pi RC}$$

Figure 1. The data acquisition device acts as a low-pass filter that passes low frequencies and attenuates high frequencies. The 3 dB bandwidth is determined by the resistance (R) and capacitance (C) of the circuit.

SideBar 1- Bandwidth

Bandwidth is affected by overvoltage protection (which acts like a resistor in the channel's circuit), EMI protection (which acts like a capacitor in the channel's circuit), and the bandwidth of the operational amplifier (which affects the power that is used and the cost of the device).

For example, assume that you want to measure a +/-10 V (20 V peak-to-peak) signal whose frequency increases over time. The analog front-end circuitry, acting as a low-pass filter, attenuates the input signal, as shown in Figure 2.

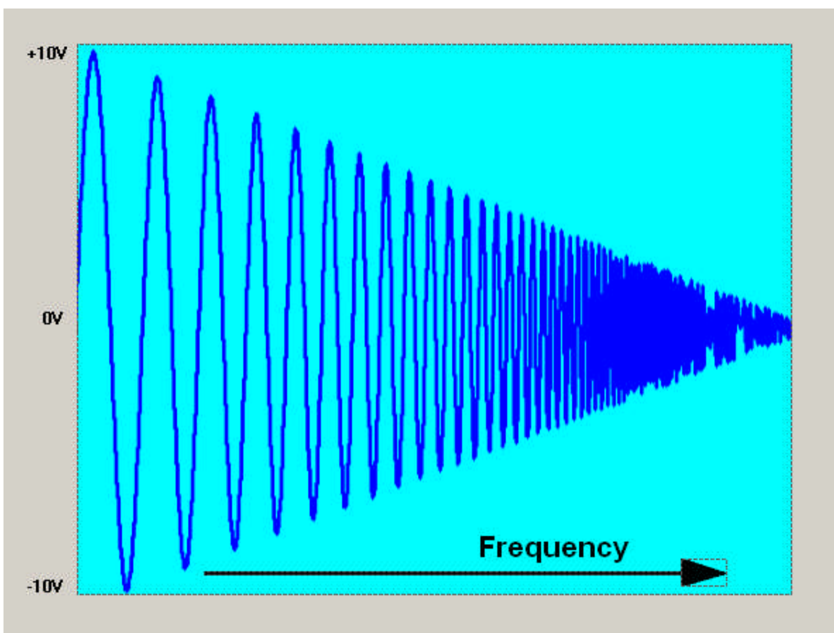


Figure 2. A +/- 10 V (20 Vp-p) input signal is applied. The analog front-end circuitry, acting as a low-pass filter, attenuates the input signal as the frequency increases.

The design of the analog input circuitry determines the bandwidth of the device, which in turn, determines whether your sampled data is distorted by signal attenuation or other errors. For example, the DT9832A module, shown in Figure 3, provides a wide bandwidth, where the 3 dB point is at 10 times the Nyquist limit, or greater than 10 MHz. This wide bandwidth guarantees a very flat response through the Nyquist range (0 to 1 MHz), ensuring that your data is accurate at the maximum sampling frequency of the device (2 MHz) with virtually no attenuation or phase distortion of the input signal.

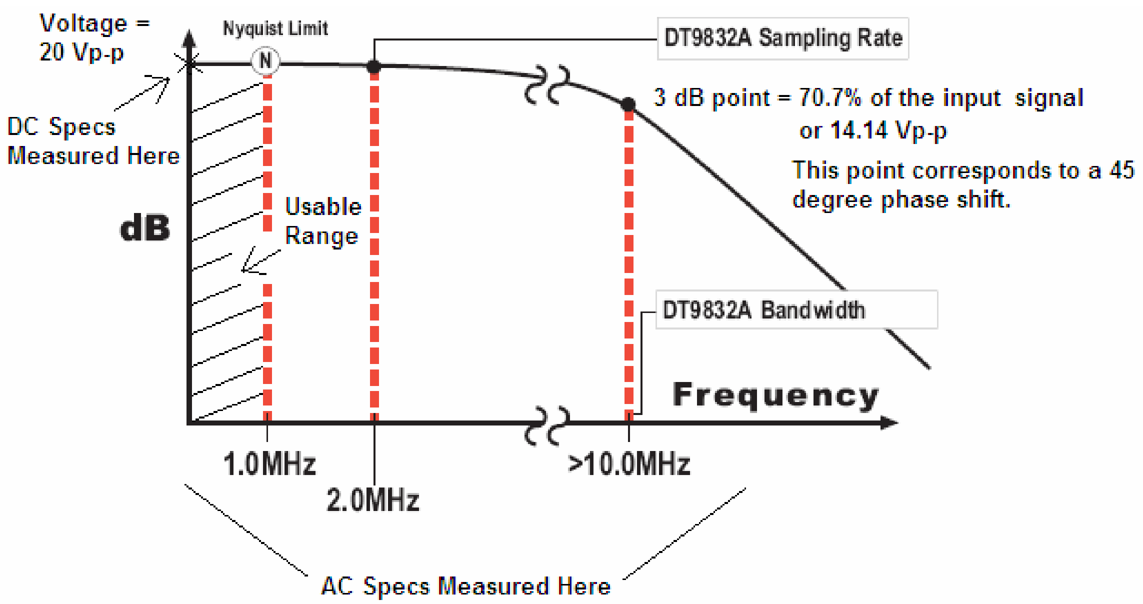


Figure 3. AC specifications tell you how much noise and distortion have been introduced into the sampled data over the entire frequency range of the device. The 3 dB bandwidth of your device determines how well your sampled data reflects the real-world signal that you are trying to measure.

As you can see, AC specifications are critical when characterizing the signal bandwidth and other design features of your device under dynamic conditions. The next section describes two AC specifications that are particularly useful when measuring dynamic performance.

SideBar 2- Nyquist

According to the Nyquist sampling theorem, you must specify a frequency that is at least twice as fast as the input's highest frequency component to avoid aliasing —a condition in which unwanted frequency signals appear within the bandwidth of interest. For example, to accurately sample a 20 kHz signal, you must specify a sampling frequency of at least 40 kHz.

Understanding Two Important AC Specifications - ENOB and SFDR

When you want to measure dynamic signals, pay particular attention to the following AC specifications: ENOB (Effective Number of Bits) and SFDR (Spurious Free Dynamic Range).

The ENOB specification tells you how accurate your device is as a function of the input signal and the chosen sampling rate. *It is a particularly useful metric, as it measures the performance of the entire data acquisition device, not just the ADC, and it does so under dynamic, real-world conditions*. It detects such things as interactions between the over-voltage protection circuits and EMI filters. All of the following errors, which are not reflected in DC specifications, contribute to the ENOB specification:

- Noise from gain-setting resistors within the instrumentation amplifier
- Amplifier and sample-and-hold bandwidth errors
- The effects of acquisition time, channel-to-channel offset, and channel crosstalk in the input multiplexer
- System electrical noise
- Distortions that the ADC introduces
- The effects of over-driving the filter op-amps when the input signal is over-range

The SFDR specification is the ratio of the level of the input signal to the level of the largest distortion component in the FFT spectrum. This specification is important because it determines the minimum signal level that can be distinguished from distortion components of your data acquisition device. In many cases, the significance of SFDR is not merely the converted signal's fidelity, but the impact of the spurious signal as a noise source in your measurement.

ENOB and SFDR specifications are determined by performing an FFT (Fast Fourier Transform) on data that is acquired from two adjacent channels. Measuring two adjacent channels allows you to characterize your input signal as well as spurious signals coming from the rest of the system and from the coupling of signals on other inputs.

Figure 4 shows the ENOB and SFDR specifications for a DT9834 module, which has a 16-bit multiplexed architecture and a maximum sampling frequency of 500 kHz.

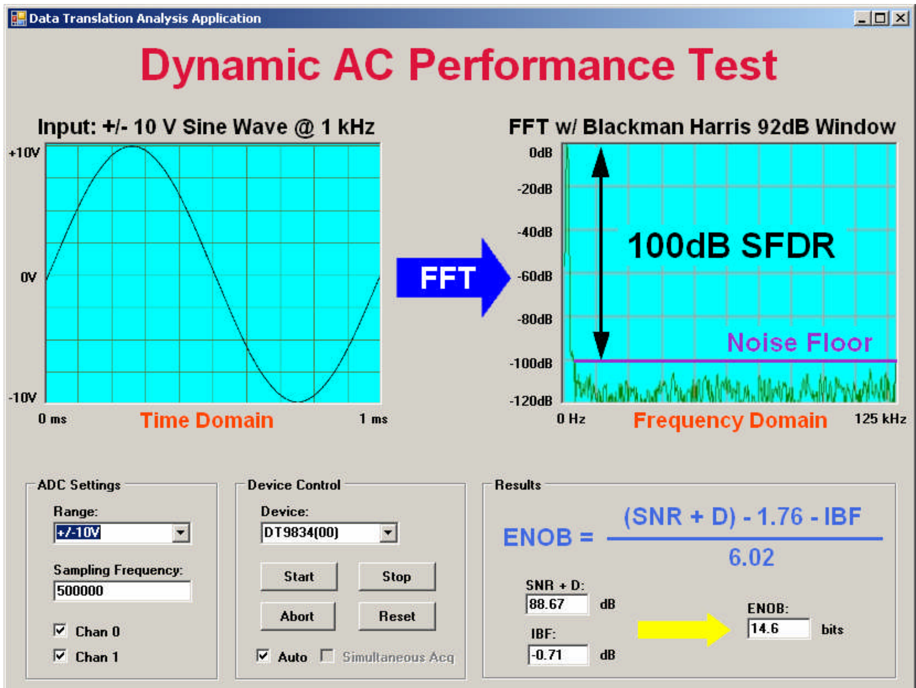


Figure 4. ENOB and SFDR specifications tell you the accuracy of the A/D front-end on your device under dynamic, worse-case conditions when switching between two channels at high speed.

Note the following when looking at Figure 4:

- A +/-10 V input signal with a frequency of 1 kHz is applied
- 1024 samples are acquired from two adjacent channels at the Nyquist limit of 125 kHz per channel
- An FFT is performed on the acquired data using a Blackman Harris 92 dB windowing function

Multiplexed architecture; SNR = signal-to-noise ration; D = distortion; IBF = input below full-scale)

The output spectrum shows the fundamental signal and all harmonics below the noise floor. The ENOB and SFDR specifications are calculated directly from this output spectrum.

For the DT9834 device, the ENOB specification, or the accuracy of the A/D front end at the maximum sampling frequency, is 14.6 bits. The SFDR, or the ratio of the level of the input signal to the level of the largest distortion component in the FFT spectrum, is 100 dB. These specifications characterize the **worse-case performance** of the DT9834 when switching between two channels at high speed.

SideBar 2 – FFT

An FFT (Fast Fourier Transform) is an algorithm that transforms data from the time domain to the frequency domain. The input signal is "decomposed" into its constituent frequency and corresponding amplitude components, allowing a wide range of signal processing techniques to be used. The number of "bins" or size of the FFT determines how many frequencies are available in the output spectrum.

When a signal is observed for a finite interval of time, spectral information may be distorted. To avoid or minimize this distortion, specifically designed filtering functions called "windows" are used. A number of windowing functions are available. In this discussion, a Blackman Harris 92 dB window is used.

Measure Accuracy at Full-Scale

For accurate measurements, ensure that the A/D performance of your data acquisition device has been characterized with a full-scale signal applied, or as close to 0 dB as possible.

For example, assume that you want to measure a signal using a data acquisition device with a +/-10 V input signal range. Table 1 shows how dB relates to full-scale voltage.

Table 1. How dB relates to Voltage for a +/-10 V Input Signal Range

dB	% of Full-Scale	Voltage
0	100	+/-10 V
-6	50	+/-5 V
-20	10	+/-1 V
-40	.1	+/-0.1 V
-60	.01	+/-0.01 V

Let’s look at the output spectrum of a 1 kHz signal at -0.5 dB and -20 dB.

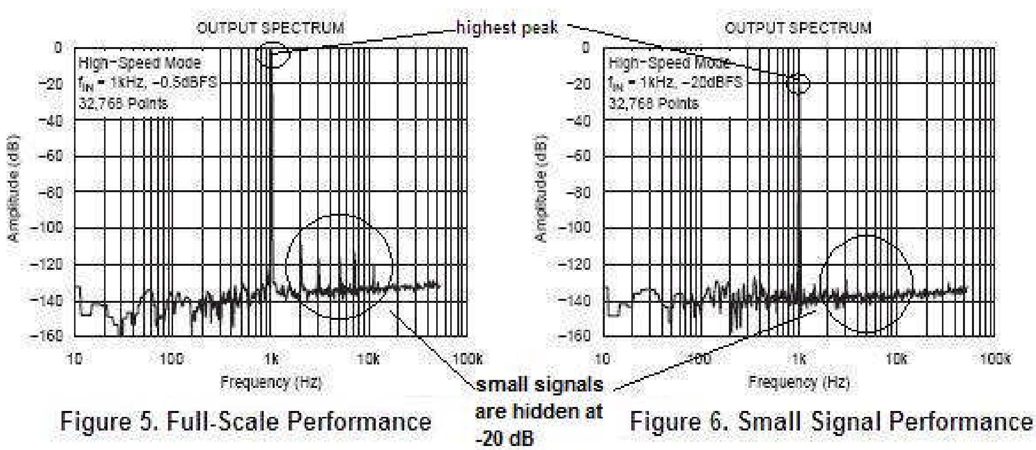


Figure 5. Full-Scale Performance

Figure 6. Small Signal Performance

Since the peak frequency in Figure 5 occurs at -0.5 dB, you know that a +/-10 V signal was applied to the input. You can clearly see how noise and other low frequency components affect your data.

In Figure 6, however, the peak frequency occurs at -20 dB; therefore, according to Table 1, you know that the applied signal was only +/- 1 V. As you can see, if you measure a small signal, the full dynamic range of the converter is not exercised and it is impossible to tell how noise and other low-frequency components affect your data.

Measure Performance at the Frequency of Interest

Since AC performance typically degrades as the input signal frequency increases, it is important to check the AC performance at the frequency of interest.

For example, assume that you want to measure a +/- 10 V signal whose frequency (the frequency of interest) is 10 kHz. To properly characterize the dynamic performance of your device, ensure that the ENOB and SFDR specifications are measured using this 10 kHz input signal.

Figure 7 shows the ENOB and SFDR specifications for the DT9832A module using a +/- 10 V, 10 kHz input signal. The DT9832A module has two 16-bit simultaneous ADCs and a maximum sampling frequency of 2 MHz.

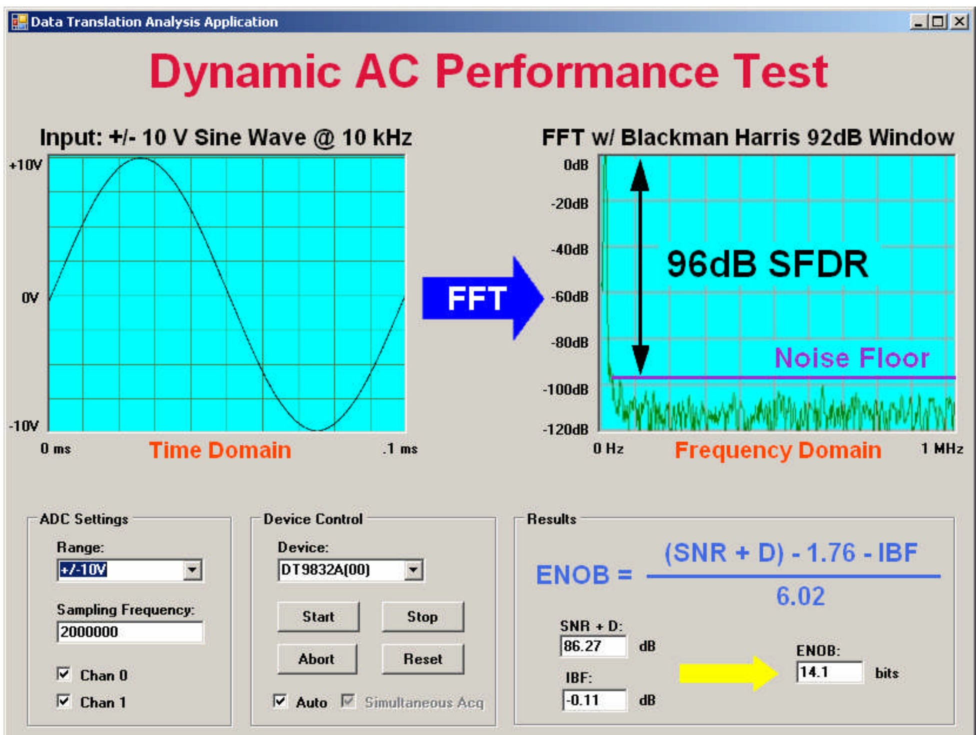


Figure 7. ENOB and SFDR specifications for the DT9832A are taken at the frequency of interest, allowing you to characterize the dynamic performance of your device.

As you can see, at the frequency of interest on the DT9832A, the ENOB specification is 14.1 bits and the SFDR specification is 96 dB. Note that due to the wide signal bandwidth of this device, you can see virtually all signal frequencies, including any noise, that may be in your data.

Verify the Accuracy of Your Device

If you're uncertain about the AC performance of your device, you can measure the ENOB and SFDR specifications yourself.

To measure SFDR and ENOB, generate a pure sinusoidal input signal (accurate to at least 0.001%) with strength within 1 dB of the device's maximum input range on one channel. Then with the input grounded on an adjacent channel, acquire the data on both channels.

Once the data has been acquired, perform an FFT on the output using a Blackman Harris 92 dB windowing function. Once you have the output spectrum of the FFT, determine the SFDR and ENOB specifications.

Summary

In applications where you want to measure rapidly changing and/or high frequency signals, ENOB and SFDR specifications can help you characterize dynamic performance.