Overall Accuracy = ENOB (Effective Number of Bits)

In choosing a data acquisition board, there is probably no more important specification than its overall accuracy – that is, how closely the output data reflects the input signal. Your vibration analysis, sensor readings, audio recording, and temperature measurements can be no more accurate than your data acquisition board. Each data point you measure occurs only once: It is unique and irreplaceable and you have only one chance to capture it.

But overall accuracy can be one of the most difficult specifications to determine by reading a data sheet. You may pay a premium for a 16-bit board thinking that it will measure to one part in 65,536. But factoring in all sources of error and operating under real-world conditions, a good 16-bit board is at most about 14 bits accurate! And a poorly designed 16-bit board may be 12 bits accurate or less!

Heresy? While the A/D converters used on most 16-bit boards are extremely accurate, other circuitry is usually not. 16-bit accuracy in analog circuits is very hard to achieve. Gains greater than one, high sampling rates, and input signals that change rapidly from zero volts to full-scale all tend to reduce the accuracy of the board's analog circuitry. In handling real-world signals, analog circuitry sometimes becomes the limiting element on overall accuracy. But it isn't just the circuitry. Layout of the critical circuit etch, spacing between noise-generating and noise-sensitive devices as well as analog and digital etch patterns, and thermal effects from one circuit to another are all culprits in degrading accuracy. Components CANNOT just be laid out on a printed circuit board. Doing so almost guarantees poor performance.

A dynamic test is needed to show exactly what you can expect from your data acquisition system. Static (dc) measurements are almost useless. Most applications involve switching between multiple channels and measuring varying input signals. Some signals have high-frequency components that contain critical information. A dynamic test specification is needed to determine how the measurement system will perform under real-world conditions.

Examining a board's specifications won't help you much. Measurements like integral and differential nonlinearity drift over time or temperature, and channel-to-channel crosstalk are important. Good data acquisition boards must perform well in all these areas. But taken by themselves, they can be misleading. Crosstalk errors from a data acquisition system's channel-selecting multiplexer interact with the A/D converter's nonlinearities and the overall system's drift in accuracy over time. Interpreting how these specifications affect overall accuracy is something you probably shouldn't attempt unless you're a data acquisition guru.

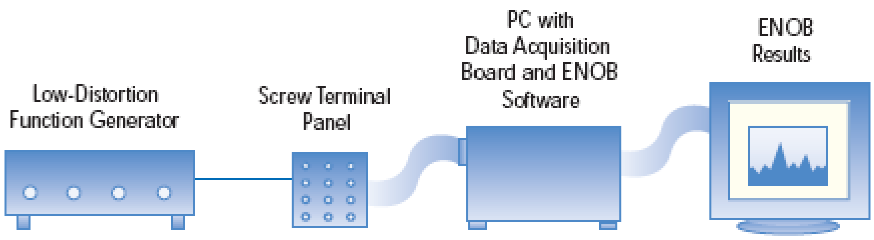
All too often these specifications simply tell you the performance of the components the board manufacturer bought and assembled into a system. High-performance multiplexers, amplifiers, and A/D converters are readily available, and are found on many products. But only the best boards combine these pieces into a precision data acquisition system that stays accurate and stable when installed in your computer measuring your data. Among other things, the board must reject digital noise inside the computer that can contaminate the analog signals you're trying to measure. It must preserve accuracy when instantaneously switching from a signal that is only a few millivolts to one that is hundreds of times larger. And it must do all this at any speed up to its maximum rated sampling rate.

Experienced designers have long understood the need to treat the data acquisition board as a system. They routinely test their products beyond traditional specifications, to assure that they perform accurately under real-world conditions. But doing so has often been a source of frustration. Customers who bought the boards and used them would come back and buy more. But first-time users, comparing only price and data sheet specifications, all too often selected a lesser product because there was no meaningful specification of overall system performance.

Enter ENOB (Effective Number of Bits): A measure of Overall Accuracy under Real-world Conditions

After developing dozens of data acquisition boards over more then two decades, a single test has emerged to meaningfully quantify the overall performance of a data acquisition system. Termed ENOB (Effective Number of Bits), this test measures the entire data acquisition system from the signal input to the resulting data values. It measures the board under real-world conditions – the conditions you are likely to use it in yourself. And it measures the board at full rated throughput, using more than one channel and measuring dynamic signal.

Equipment Needed to Measure ENOB



How to Measure ENOB:

1. Install or plug the data acquisition module to be tested into a computer. Because tests involve the entire board, not just IC-level subsystems purchased from other vendors, everything that can affect performance is covered, including configuration of the subsystems, how they are interconnected and operated.

2. Connect a test signal to one of the modules analog input channels. This signal should come from a precision generator, accurate to at least .001%, and providing a very low noise, very low distortion sine wave. Any noise or distortion detected after the signal is acquired is contributed by the board or module itself. Set the test signal’s voltage level to within 1 dB of the maximum input range of the board. Set the frequency to a known value, typically 1kHz, providing a reference point when comparing different modules.

3. Ground a second input channel on the module. This represents the lowest signal level the module will see.

4. Make connections to the module using the cables and screw terminal panels recommended by the manufacturer. Circuitry on the module to assure

compliance with CE and FCC noise regulations is therefore not bypassed. In short, the tests occur under real-world conditions, just as you might do it if you bought and installed the module yourself.

5. Run a testing program that represents the most demanding input conditions the module is designed to see:

A. Operate the module at full rated throughput.

B. Alternate between sampling the test signal and the grounded input.

C. Going rapidly from no input to full-scale input at full rated throughput exposes slewing, bandwidth, and distortion errors, and fully exercises the analog input circuitry on the module.

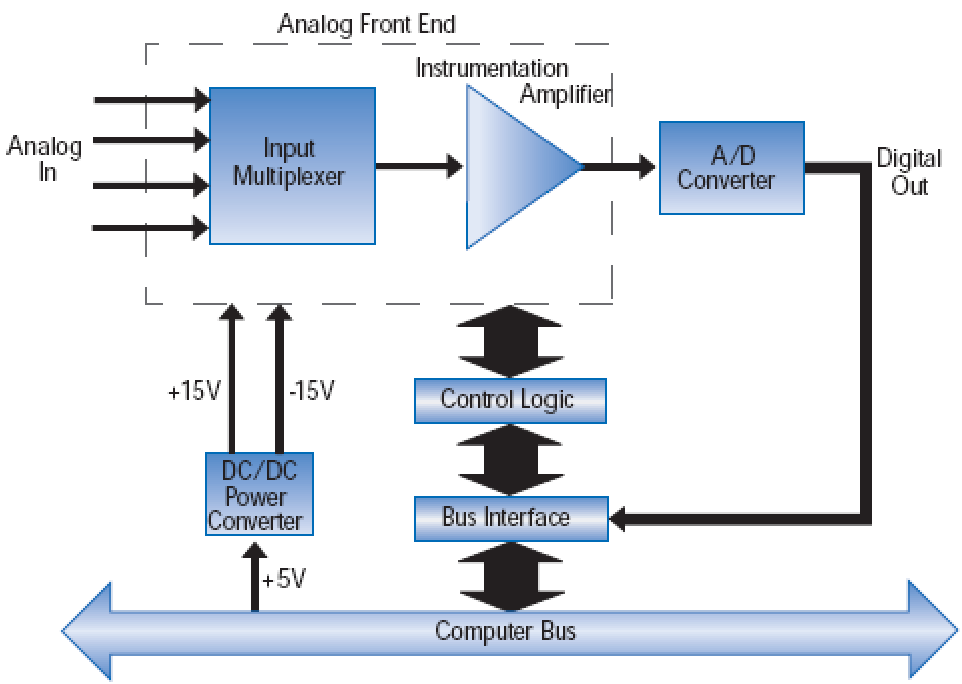
D. Capture 1024 samples on each input channel. The large number of samples is required so the sophisticated FFT algorithm in the test program can compute ENOB with statistical accuracy.

E. Calculate and display ENOB – the number of bits of effective accuracy.

ENOB Measures: The Analog Front End

The analog circuitry on a data acquisition module, its so-called analog "front end", is an area where performance is often compromised. ENOB measurements can be helpful in uncovering performance limitations. The module's channel-selecting multiplexer, for example, interacts with over voltage protection circuits and filters that reduce CE and FCC noise sensitivity. These can form dynamically changing low pass filters that reduce input bandwidth. Resistors that set gain in instrumentation amplifiers can be a source of noise and bandwidth limitation. Bad instrumentation amplifier design can reduce full-scale bandwidth. An instrumentation amplifier of limited bandwidth or too slow a sample-and-hold can lead to errors and distortion when switching at high speed between a low-level and a high-level input. Conventional input specifications, such as channel acquisition time, channel-to-channel offset, and channel crosstalk, do not stress the entire front end dynamically and do not expose these faults. ENOB, however, makes analog circuit limitations strikingly clear.

Because it is a dynamic test that measures performance of a rapidly changing ac signal at full-scale input, sampled at maximum throughput, it is a very useful tool for assessing the module's ability to deal with real-world analog signals.



ENOB Measures: Overall Noise picked up by the System

Electrical noise can significantly reduce the accuracy of data acquisition measurements. It can be directly induced in leads, etch, or components themselves, or picked up indirectly through bus power connections.

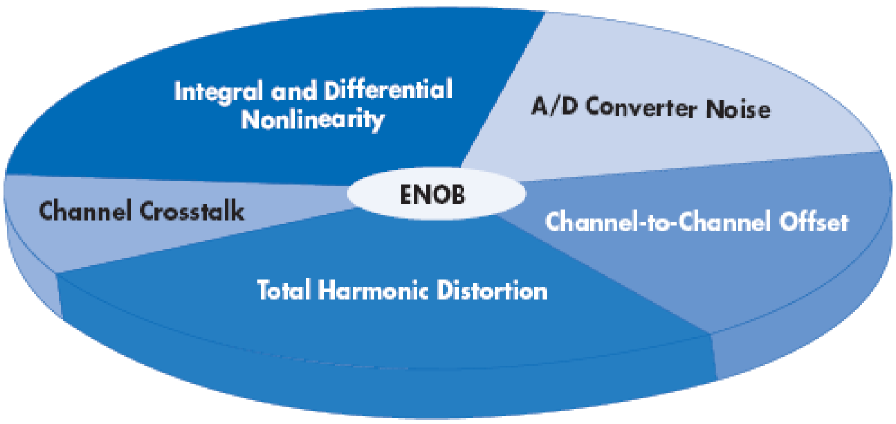
An experienced board designer can do much to minimize this noise. The actual layout of analog components on the board is key, as is the use of ground planes in the boards etch to shield sensitive circuits. Analog circuits perform better if decoupled from the computer's power bus and any onboard power converters.

A board's signal-to-noise ratio is a good indicator of this performance, if measured under conditions that represent real-world operation. ENOB is also extremely sensitive to errors caused by noise in analog circuitry.

ENOB Measures: The Combined Effects of Multiple Sources of Noise and Distortion

Because ENOB measures the entire data acquisition system at once - from analog input to digital output – it is one of the few measurements that shows the interaction of different distortion sources on the measurements you're taking. In a single specification, ENOB provides a figure of merit for the performance of the entire board.

ENOB Measures the Combined Effects of Multiple Sources of Noise and Distortion



Traditionally, accuracy in data acquisition systems is specified in a number of ways. While each specification provides key information, none tells the whole story. Understanding a few key specifications can help you decide what's important and what's not.

DC:

Integral and Differential Nonlinearity are errors between an A/D converter's ideal, "straight line" response to small change sine input voltage and its actual performance. It is considered an "irreducible" form of distortion because an A/D converter's output is not continuously variable, but quantized as small, LSB-sized voltage steps.

Even perfect A/D converters exhibit some integral and differential nonlinearity.

A/D Converter Noise comes from two main sources: Quantization error that is inherent in the data conversion process and noise generated within the converter itself.

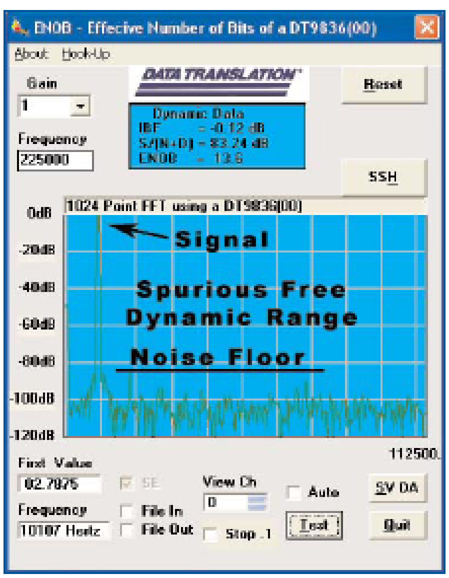
Channel-to-Channel Offset is a difference in the characteristics of analog input channels which causes measurement error, as if a small voltage were added to or subtracted from the input signal.

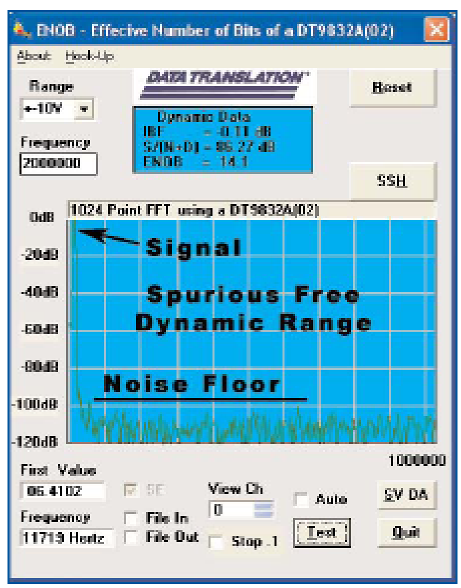
AC:

Total Harmonic Distortion is a form of distortion in analog circuits in which harmonics (signals whose frequency is an integer multiple of the input signal) are generated. Measured in decibels (dB), harmonic distortion is calculated as the ration of the level of the harmonic to the level of the original frequency. Total harmonic distortion is the ratio of all harmonics generated to the original signal frequency.

Channel Crosstalk is the leakage of signals between analog input channels in a data acquisition system.

ENOB Measurement of High-Quality 16-bit Data Acquisition Boards





These graphs show the outstanding quality of the DT9836 and DT9832A modules for all error sources...with ENOB (Effective Number of Bits) ratings of 13.6 and 14.1 bits respectively.

How ENOB Is Measured

The ENOB test procedure captures 1024 data values from the data acquisition module being tested. These values are then processed to calculate a value for equivalent numbers of bits. An FFT is used to determine the actual ENOB specification value. The FFT converts data point from the time domain to the frequency domain, effectively operating as a spectrum analyzer. The original 1024 data values captured over time are thus transformed into 1024 separate frequency values.

Since the input signal consisted of only a single frequency value with no detectable noise or distortion, all other frequency values are noise or distortion contributed by the board. ENOB is simply the ratio of the number of data points with the correct (original) frequency to the number of data points with other frequency values. The ratio is expressed in bits – the effective number of bits of accuracy characterizing the data acquisition board.

Equivalent Expressions

Another way of expressing ENOB is as a signal-to-noise-plus-distortion ratio (SNR), given in dB:

SNR = ((ENOB) x 6.02) + 1.76) dB

Thus an ENOB rating of 14.1 is equivalent to an SNR of over 86 dB.

ENOB can also be expressed as a percent of full-scale error:

Error = ((1/2 ENOB) x 100)%

Therefore, an ENOB rating of 13.5 is also equivalent to an error of .0086% of the data acquisition module’s full-scale range. Note: ENBO measurements should not be confused with the SNR and error measurements provided for many data acquisition modules. ENOB is not just a specification, but a set of conditions under which the specification was measured. SNR and error measurements between products can only be compared if they were taken under the same circumstances: at maximum throughput, on alternating full-scale and zero-scale measurements, measured from the module’s input connectors using data output to the computer’s bus. If measurement conditions are not specified, you should not trust the specification.