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Data Acquisition Systems

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92

Data Acquisition Systems

92.1 Introduction ................................................................. 92-1
92.2 Signals ........................................................................ 92-1
92.3 Plug-In DAQ Boards ...................................................... 92-3
92.4 Types of ADCs ............................................................... 92-4
92.5 Analog Input Architecture ............................................... 92-4
   Basic Analog Specifications
92.6 Data Acquisition Software ............................................... 92-6
   Board Register-Level Programming • Driver Software • What Is
   Digital Sampling? • Real-Time Sampling Techniques • Preventing
   Aliasing • Soft ware Polling • External Sampling
92.7 Scanning ....................................................................... 92-10
   Continuous Scanning • Multirate Scanning • Simultaneous
   Sampling • Interval Scanning
92.8 Factors Influencing the Accuracy of Measurements .......... 92-12
   Defining Terms ................................................................. 92-12
   Further Information .......................................................... 92-13

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92.1 Introduction

The fundamental task of a data acquisition system is the measurement or generation of real-world physical signals. Before a physical signal can be measured by a computer-based system, a sensor or transducer is used to convert the physical signal into an electrical signal, such as voltage or current. Often only a plug-in data acquisition (DAQ) board is considered the data acquisition system; however, a board is only one of the components in the system. A complete DAQ system consists of sensors, signal conditioning, interface hardware, and software. Unlike stand-alone instruments, signals of en cannot be directly connected to the DAQ board. The signals may need to be conditioned by some signal-conditioning accessory before they are converted to digital information by the plug-in DAQ board. Soft ware controls the data acquisition system—acquiring the raw data, analyzing the data, and presenting the results. The components are shown in Figure 92.1.

92.2 Signals

Signals are physical events whose magnitude or time variation contains information. DAQ systems measure various aspects of a signal in order to monitor and control the physical events. Users of DAQ systems need to know the relation of the signal to the physical event and what information is available in the signal. Generally, information is conveyed by a signal through one or more of the following signal parameters: state, rate, level, shape, or frequency content. The physical characteristics of the measured signals and the related information help determine the design of a DAQ system.

All signals are, fundamentally, analog, time-varying signals. For the purpose of discussing the methods of signal measurement using a plug-in DAQ board, a given signal should be classified as one of five
signal types. Because the method of signal measurement is determined by the way the signal conveys the needed information, a classification based on this criterion is useful in understanding the fundamental building blocks of a DAQ system.

As shown in Figure 92.2, any signal can generally be classified as analog or digital. A digital, or binary, signal has only two possible discrete levels of interest—a high (on) level and a low (off) level. The two digital signal types are on–off signals and pulse train signals. An analog signal, on the other hand, contains information in the continuous variation of the signal with time. Analog signals are described in the time or frequency domains depending upon the information of interest. A dc-type signal is a low-frequency signal, and if the phase information of a signal is presented with the frequency information, then there is no difference between the time or frequency domain representations. The category to which a signal belongs depends on the characteristic of the signal to be measured. The five types of signals can be closely paralleled with the five basic types of signal information—state, rate, level, shape, and frequency content.

Basic understanding of the signal representing the physical event being measured and controlled assists in the selection of the appropriate DAQ system.

![Diagram of DAQ system](image)

**FIGURE 92.1** Components of a DAQ system.

![Diagram of signal types](image)

**FIGURE 92.2** Classes of analog and digital signals.
92.3 Plug-In DAQ Boards

The fundamental component of a DAQ system is the plug-in DAQ board. These boards plug directly into a slot in a PC and are available with analog, digital, and timing inputs and outputs (I/O). The most versatile of the plug-in DAQ boards is the multifunction I/O board. As the name implies, this board typically contains various combinations of analog-to-digital converters (ADCs), digital-to-analog converters (DACs), digital I/O lines, and counters/timers. ADCs and DACs measure and generate analog voltage signals, respectively. The digital I/O lines sense and control digital signals. Counters/timers measure pulse rates, widths, delays, and generate timing signals. These many features make the multifunction DAQ board useful for a wide range of applications.

Multifunction boards are commonly used to measure analog signals. This is done by the ADC, which converts the analog voltage level into a digital number that the computer can interpret. The analog multiplexer (MUX), the instrumentation amplifier, the sample-and-hold (S/H) circuitry, and the ADC compose the analog input section of a multifunction board (see Figure 92.3).

Typically, multifunction DAQ boards have one ADC. Multiplexing is a common technique for measuring multiple channels (generally 16 single-ended or 8 differentials) with a single ADC. The analog MUX switches between channels and passes the signal to the instrumentation amplifier and the S/H circuitry. The MUX architecture is the most common approach taken with plug-in DAQ boards. While plug-in boards typically include up to only 16 single-ended or 8 differential inputs, the number of analog input channels can be further expanded with external MUX accessories.

Instrumentation amplifiers typically provide a differential input and selectable gain by jumpers or software. The differential input rejects small common-mode voltages. The gain is often software programmable. In addition, many DAQ boards also include the capability to change the amplifier gain while scanning channels at high rates. Therefore, one can easily monitor signals with different ranges of amplitudes. The output of the amplifier is sampled, or held at a constant voltage, by the S/H device at measurement time so that voltage does not change during digitization.

The ADC transforms the analog signal into a digital value which is ultimately sent to computer memory. There are several important parameters of A/D conversion. The fundamental parameter of an ADC is the number of bits. The number of bits of an A/D determines the range of values for the binary output of the ADC conversion. For example, many ADCs are of 12 bits, so a voltage within the input range of the ADC will produce a binary value that has one of \(2^{12} = 4096\) different values. The more bits an ADC has, the higher the resolution of the measurement. The resolution determines the smallest amount of change that can be detected by the ADC. Resolution is expressed as the number of digits of a voltmeter or dynamic range in decibels, rather than with bits. Table 92.1 shows the relation among bits, number of digits, and dynamic range in decibels.

The resolution of the A/D conversion is also determined by the input range of the ADC and the gain. DAQ boards usually include an instrumentation amplifier that amplifies the analog signal by

![Figure 92.3](image-url)
a gain factor prior to the conversion. This gain amplifies low-level signals so that more accurate measurements can be made.

Together, the input range of the ADC, the gain, and the number of bits of the board determine the minimum resolution of the measurement. For example, suppose a low-level ±30 mV signal is acquired using a 12-bit ADC that has a ±5 V input range. If the system includes an amplifier with a gain of 100, the resulting resolution of the measurement will be range/(gain × 2 bits) = resolution, or 10 V/(100 × 2^{12}) = 0.0244 mV.

Finally, an important parameter of digitization is the rate at which A/D conversions are made, referred to as the sampling rate. The A/D system must be able to sample the input signal fast enough to measure the important waveform attributes accurately. In order to meet this criterion, the ADC must be able to convert the analog signal to digital form quickly enough.

When scanning multiple channels with a multiplexing DAQ system, other factors can affect the throughput of the system. Specifically, the instrumentation amplifier must be able to settle to the needed accuracy before the A/D conversion occurs. With multiplexed signals, multiple signals are being switched into one instrumentation amplifier. Most amplifiers, especially when amplifying the signals with larger gains, will not be able to settle to the full accuracy of the ADC when scanning channels at high rates. To avoid this situation, consult the specified settling times of the DAQ board for the gains and sampling rates required by the application.

### 92.4 Types of ADCs

Different DAQ boards use different types of ADCs to digitize the signal. The most popular type of ADC on plug-in DAQ boards is the successive approximation ADC, because it offers high speed and high resolution at a modest cost.

Subranging (also called half-flash) ADCs offer very high-speed conversion with sampling speeds up to several million samples per second.

The state-of-the-art technology in ADCs is sigma–delta modulating ADCs. These ADCs sample at high rates, are able to achieve high resolution, and offer the best linearity of all ADCs.

Integrating and flash ADCs are mature technologies still used on DAQ boards today. Integrating ADCs are able to digitize with high resolution but must sacrifice sampling speed to obtain it. Flash ADCs are able to achieve the highest sampling rate (gigahertz) but are available only with low resolution. The different types of ADCs are summarized in Table 92.2.

### 92.5 Analog Input Architecture

With a typical DAQ board, the multiplexer switches among analog input channels. The analog signal on the channel selected by the multiplexer then passes to the programmable gain instrumentation amplifier (PGA), which amplifies the signal. After the signal is amplified, the S/H keeps the analog signal constant so that the ADC can determine the digital representation of the analog signal. A good DAQ board will then place the digital signal in a first-in first-out (FIFO) buffer, so that no data will be lost if the sample cannot transfer immediately over the PC I/O channel to computer memory.
TABLE 92.2 Types of ADCs

<table>
<thead>
<tr>
<th>Type of ADC</th>
<th>Advantages</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Successive</td>
<td>High resolution</td>
<td>1.25 M S/s sampling rate</td>
</tr>
<tr>
<td>approximation</td>
<td>High speed</td>
<td>12 bit resolution</td>
</tr>
<tr>
<td></td>
<td>Easily multiplexed</td>
<td>200 kS/s sampling rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16 bit resolution</td>
</tr>
<tr>
<td>Subranging</td>
<td>Higher speed</td>
<td>1 M Hz sampling rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12 bit resolution</td>
</tr>
<tr>
<td>Sigma-delta</td>
<td>High resolution</td>
<td>48 kHz sampling rate</td>
</tr>
<tr>
<td></td>
<td>Excellent linearity</td>
<td>16 bit resolution</td>
</tr>
<tr>
<td></td>
<td>Built-in antialiasing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>State-of-the-art technology</td>
<td></td>
</tr>
<tr>
<td>Integrated</td>
<td>High resolution</td>
<td>15 kHz sampling rate</td>
</tr>
<tr>
<td></td>
<td>Good noise rejection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mature technology</td>
<td></td>
</tr>
<tr>
<td>Flash</td>
<td>Highest speed</td>
<td>125 M Hz sampling rate</td>
</tr>
<tr>
<td></td>
<td>Mature technology</td>
<td></td>
</tr>
</tbody>
</table>

Having a FIFO becomes especially important when the board is run under operating systems that have large interrupt latencies, such as Microsoft Windows.

92.5.1 Basic Analog Specifications

Almost every DAQ board data sheet specifies the number of channels, the maximum sampling rate, the resolution, and the input range and gain.

The number of channels, which is determined by the multiplexer, is usually specified in two forms—differential and single-ended. Differential inputs are inputs that have different reference points for each channel, none of which is grounded by the board. Differential inputs are the best way to connect signals to the DAQ board because they provide the best noise immunity.

Single-ended inputs are inputs that are referenced to a common ground point. Because single-ended inputs are referenced to a common ground, they are not as good as differential inputs for rejecting noise. They do have a larger number of channels, however. Single-ended inputs are used when the input signals are high level (greater than 1 V), the leads from the signal source to the analog input hardware are short (less than 5 m), and all input signals share a common reference.

Some boards have pseudo-differential inputs which have all inputs referenced to the same common—like single-ended inputs—but the common is not referenced to ground. These boards have the benefit of a large number of input channels, like single-ended inputs, and the ability to remove some common-mode noise, especially if the common-mode noise is consistent across all channels. Differential inputs are still preferable to pseudo-differential, however, because differential is more immune to magnetic noise.

Sampling rate determines how fast the analog signal is converted to a digital signal. When measuring ac signals, sample must be at least twice faster than the highest frequency of the input signal. Even when measuring dc signals, the oversample and average the data increase the accuracy of the signal by reducing the effects of noise.

If the physical event consists of multiple dc-class signals, a DAQ board with interval scanning should be used. With interval scanning, all channels are scanned at one sample interval (usually the fastest rate of the board), with a second interval (usually slow) determining the time before repeating the scan. Interval scanning gives the effects of simultaneously sampling for slowly varying signals without requiring the additional cost of input circuitry for true simultaneous sampling.
Resolution is the number of bits that are used to represent the analog signal. The higher the resolution, the higher the number of divisions the input range is broken into, and therefore the smaller the possible detectable voltage. Unfortunately, some DAQ specifications are misleading when they specify the resolution associated with the DAQ board. Many DAQ board specifications state the resolution of the ADC without stating the linearity and noise, and therefore do not give the information needed to determine the resolution of the entire board. Resolution of the ADC, combined with the settling time, integral nonlinearity (INL), differential nonlinearity (DNL), and noise will give an understanding of the accuracy of the board.

Input range and gain determine the level of signal that should be connected to the board. Usually, the range and gain are specified separately, so the two must be combined to determine the actual signal input range as

\[
\text{Signal input range} = \frac{\text{range}}{\text{gain}}
\]

For example, a board using an input range of \pm 10 V with a gain of 2 will have a signal input range of \pm 5 V. The closer the signal input range is to the range of the signal, the more accurate the readings from the DAQ board will be. If the signals have different input ranges, use a DAQ board with the feature of different gains per channel.

### 92.6 Data Acquisition Software

The software is often the most critical component of the DAQ system. Users of DAQ systems usually program the hardware in one of two ways—through register programming or through high-level device drivers.

#### 92.6.1 Board Register-Level Programming

The first option is not to use vendor-supplied software and program the DAQ board at the hardware level. DAQ boards are typically register-based; that is, they include a number of digital registers that control the operation of the board. The developer may use any standard programming language, such as C, C++, or Visual Basic, to write series of binary codes to the DAQ board to control its operation. Although this method affords the highest level of flexibility, it is also the most difficult and time-consuming, especially for the inexperienced programmer. The programmer must know the details of programming all hardware, including the board, the PC interrupt controller, the DMA controller, and PC memory.

#### 92.6.2 Driver Software

Driver software typically consists of a library of function calls usable from a standard programming language. These function calls provide a high-level interface to control the standard functions of the plug-in board. For example, a function called SCAN_OP may configure, initiate, and complete a multiple-channel scanning DAQ operation of a predetermined number of points. The function call would include parameters to indicate the channels to be scanned, the amplifier gains to be used, the sampling rate, and the total number of data points to be collected. The driver responds to this one function call by programming the plug-in board, the DMA controller, the interrupt controller, and CPU to scan the channels as requested.

#### 92.6.3 What Is Digital Sampling?

Every DAQ system has the task of gathering information about analog signals. To do this, the system captures a series of instantaneous “snapshots” or samples of the signal at definite time intervals. Each sample contains information about the signal at a specific instant. Knowing the exact time of each conversion and the value of the sample, one can reconstruct, analyze, and display the digitized waveform.
92.6.4 Real-Time Sampling Techniques

In real-time sampling, the DAQ board digitizes consecutive samples along the signal (Figure 92.4). According to the Nyquist sampling theorem, the ADC must sample at least twice the rate of the maximum frequency component in that signal to prevent aliasing. Aliasing is a false lower-frequency component that appears in sampled data acquired at too low a sampling rate. The frequency at one-half the sampling frequency is referred to as the Nyquist frequency. Theoretically, it is possible to recover information about those signals with frequencies at or below the Nyquist frequency. Frequencies above the Nyquist frequency will alias to appear between dc and the Nyquist frequency.

For example, assume the sampling frequency, \( f_s \), is 100 Hz. Also assume the input signal to be sampled contains the following frequencies—25, 70, 160, and 510 Hz. Figure 92.5 shows a spectral representation of the input signal.

The mathematics of sampling theory show us that a sampled signal is shifted in the frequency domain by an amount equal to integer multiples of the sampling frequency, \( f_s \). Figure 92.6 shows the spectral content of the input signal after sampling. Frequencies below 50 Hz, the Nyquist frequency (\( f_s/2 \)), appear correctly. However, frequencies above the Nyquist appear as aliases below the Nyquist frequency. For example, F1 appears correctly; however, F2, F3, and F4 have aliases at 30, 40, and 10 Hz, respectively.

The resulting frequency of aliased signals can be calculated with the following formula:

\[
\text{Apparent (Alias) Frequency} = \text{ABS (Closest Integer Multiple of Sampling Frequency – Input Frequency)}
\]

![Figure 92.4](https://example.com/figure92_4.png)

**FIGURE 92.4** Consecutive discrete samples recreate the input signal.

![Figure 92.5](https://example.com/figure92_5.png)

**FIGURE 92.5** Spectral of signal with multiple frequencies.
Alias F2 = |100 – 70| = 30 Hz
Alias F3 = |(2)100 – 160| = 40 Hz
Alias F4 = |(5)100 – 510| = 10 Hz

FIGURE 92.6 Spectral of signal with multiple frequencies after sampling at \( f_s = 100 \) Hz.

For the example of Figures 92.5 and 92.6:

\[
\begin{align*}
\text{Alias F2} &= |100 - 70| = 30 \text{ Hz} \\
\text{Alias F3} &= |(2)100 - 160| = 40 \text{ Hz} \\
\text{Alias F4} &= |(5)100 - 510| = 10 \text{ Hz}
\end{align*}
\]

92.6.5 Preventing Aliasing

Aliasing can be prevented by using filters on the front end of the DAQ system. These antialiasing filters are set to cut off any frequencies above the Nyquist frequency (half the sampling rate). The perfect filter would reject all frequencies above the Nyquist; however, because perfect filters exist only in textbooks, one must compromise between sampling rate and selecting filters. In many applications, one- or two-pole passive filters are satisfactory. The rule of thumb is to oversample (5-10 times) and use these antialiasing filters when frequency information is crucial.

Alternatively, active antialiasing filters with programmable cutoff frequencies and very sharp attenuation of frequencies above the cutoff can be used. Because these filters exhibit a very steep roll-off, the DAQ system can sample at two to three times the filter cutoff frequency. Figure 92.7 shows a transfer function of a high-quality antialiasing filter.

The computer uses digital values to recreate or to analyze the waveform. Because the signal could be anything between each sample, the DAQ board may be unaware of any changes in the signal between samples. There are several sampling methods optimized for the different classes of data; they include software polling, external sampling, continuous scanning, multirate scanning, simultaneous sampling, interval scanning, and seamless changing of the sample rate.

92.6.6 Software Polling

A software loop polls a timing signal and starts the A/D conversion via a software command when the edge of the timing signal is detected. The timing signal may originate from the internal clock of the computer or from a clock on the DAQ board. Software polling is useful in simple, low-speed applications, such as temperature measurements.

The software loop must be fast enough to detect the timing signal and trigger a conversion. Otherwise, a window of uncertainty, also known as jitter, will exist between two successive samples. Within the window of uncertainty, the input waveform could change enough to reduce the accuracy of the ADC drastically.
92.6.7 External Sampling

Some DAQ applications must perform a conversion based on another physical event that triggers the data conversion. The event could be a pulse from an optical encoder measuring the rotation of a cylinder. A sample would be taken every time the encoder generates a pulse corresponding to \( n \) degrees of rotation. External triggering is advantageous when trying to measure signals whose occurrence is relative to another physical phenomenon.
92.7 Scanning

92.7.1 Continuous Scanning

When a DAQ board acquires data, several components on the board convert the analog signal to a digital value. These components include the analog MUX, the instrumentation amplifier, the S/H circuitry, and the ADC. When acquiring data from several input channels, the analog MUX connects each signal to the ADC at a constant rate. This method, known as continuous scanning, is significantly less expensive than having a separate amplifier and ADC for each input channel.

Continuous scanning is advantageous because it eliminates jitter and is easy to implement. However, it is not possible to sample multiple channels simultaneously. Because the MUX switches between channels, a timeskew occurs between any two successive channel samples. Continuous scanning is appropriate for applications where the time relationship between each sampled point is unimportant or where the skew is relatively negligible compared with the speed of the channel scan.

If samples from two signals are used to generate a third value, then continuous scanning can lead to significant errors if the time skew is large. In Figure 92.9, two channels are continuously sampled and added together to produce a third value. Because the two sine waves are 90° out of phase, the sum of the signals should always be zero. Because of the skew time between the samples, an erroneous sawtooth signal will result.

92.7.2 Multirate Scanning

Multirate scanning, a method of scanning multiple channels at different rates, is a special form of continuous scanning. Applications that digitize multiple signals with a variety of frequencies use multirate scanning to minimize the amount of buffer space needed to store the sampled signals. Channel-independent ADCs are used to implement hardware multirate scanning; however, this method is extremely expensive. Instead of multiple ADCs, only one ADC is used. A channel/gain configuration register stores the scan rate per channel and software divides down the scan clock based on the per-channel scan rate. Software-controlled multirate scanning works by sampling each input channel at a rate that is a fraction of the specified scan rate.

Suppose the system scans channels 0 through 3 at 10 kS/s, channel 4 at 5 kS/s, and channels 5 through 7 at 1 kS/s. A base scan rate of 10 kS/s should be used. Channels 0 through 3 are acquired at the base scan rate. Software and hardware divide the base scan rate by 2 to sample channel 4 at 5 kS/s, and by 10 to sample channels 5 through 7 at 1 kS/s.

![Figure 92.9](image)

**FIGURE 92.9** If the channel skew is large compared with the signal, then erroneous conclusions may result.
92.7.3 Simultaneous Sampling

For applications where the time relationship between the input signals is important, such as phase analysis of ac signals, simultaneous sampling must be used. DAQ boards capable of simultaneous sampling typically use independent instrumentation amplifiers and S/H circuitry for each input channel, along with an analog MUX, which routes the input signals to the ADC for conversion (as shown in Figure 92.10).

To demonstrate the need for a simultaneous-sampling DAQ board, consider a system consisting of four 50 kHz input signals sampled at 200 kS/s. If the DAQ board uses continuous scanning, the skew between each channel is 5 μs (15/200 kS/s) which represents a 270° ([15 μs/20 μs] × 360°) phase shift in phase between the first channel and fourth channel. Alternatively, with a simultaneous-sampling board with a maximum 5 ns interchannel time of set, the phase shift is only 0.09° ([5 μs/20 μs] × 360°). This phenomenon is illustrated in Figure 92.11.

92.7.4 Interval Scanning

For low-frequency signals, interval scanning creates the effect of simultaneous sampling, yet maintains the cost benefits of a continuous-scan system. This method scans the input channels at one rate and uses a second rate to control when the next scan begins. If the input channels are scanned at the fastest rate of the ADC, the effect of simultaneously sampling the channels is created. Interval scanning is

FIGURE 92.10 Block diagram of DAQ components used to sample multiple channels simultaneously.

FIGURE 92.11 Comparison of continuous scanning and simultaneous sampling.
FIGURE 92.12 Interval scanning—all 10 channels are scanned within 45 μs; this is insignificant relative to the overall acquisition rate of 1 S/s.

Appropriate for slow-moving signals, such as temperature and pressure. Interval scanning results in a jitter-free sample rate and minimal skew time between channel samples. For example, consider a DAQ system with 10 temperature signals. By using interval scanning, a DAQ board can be set up to scan all channels with an interchannel delay of 5 μs, and then repeat the scan every second. This method creates the effect of simultaneously sampling 10 channels at 1 S/s, as shown in Figure 92.12.

To illustrate the difference between continuous and interval scanning, consider an application that monitors the torque and RPMs of an automobile engine and computes the engine horsepower. Two signals, proportional to torque and RPM, are easily sampled by a DAQ board at a rate of 1000 S/s. The values are multiplied together to determine the horsepower as a function of time.

A continuously scanning DAQ board must sample at an aggregate rate of 2000 S/s. The time between which the torque signal is sampled and the RPM signal is sampled will always be 0.5 ms (1/2000). If either signals change within 0.5 ms, then the calculated horsepower is incorrect. But using interval scanning at a rate of 1000 S/s, the DAQ board samples the torque signal every 1 ms, and the RPM signal is sampled as quickly as possible after the torque is sampled. If a 5 μs interchannel delay exists between the torque and RPM samples, then the time skew is reduced by 99% [(0.5 ms – 5 μs)/0.5 ms], and the chance of an incorrect calculation is reduced.

92.8 Factors Influencing the Accuracy of Measurements

How does one determine if a plug-in DAQ will deliver the required measurement results? With a sophisticated measuring device like a plug-in DAQ board, signifi cantly different accuracies can be obtained depending on the type of board used. For example, one can purchase DAQ products on the market today with 16 bit ADCs and get <12 bits of useful data, or one can purchase a product with a 16 bit ADC and actually get 16 bits of useful data. The difference in accuracies causes confusion in the PC industry where everyone is used to switching out PCs, video cards, printers, and so on, and experiencing similar results between equipment.

The most important thing to do is to scrutinize more speci cations than the resolution of the ADC that is used on the DAQ board. For dc-class measurements, one should at least consider the settling time of the instrumentation amplifier, DNL, relative accuracy, INL, and noise. If the manufacturer of the board under consideration does not supply these speci cations in the data sheets, ask the vendor to provide them or run tests to determine these speci cations.

Defining Terms

Alias: A false lower-frequency component that appears in sampled data acquired at too low a sampling rate.

Asynchronous: (1) Hardware—a property of an event that occurs at an arbitrary time, without synchronization to a reference clock. (2) Software—a property of a function that begins an operation and returns prior to the completion or termination of the operation.
Conversion time: The time required, in an analog input or output system, from the moment a channel is interrogated (such as with a read instruction) to the moment that accurate data are available.

DAQ (data acquisition): (1) Collecting and measuring electric signals from sensors, transducers, and test probes or fixtures and inputting them to a computer for processing. (2) Collecting and measuring the same kind of electric signals with ADC and/or DIO boards plugged into a PC, and possibly generating control signals with DAC and/or DIO boards in the same PC.

DNL (differential nonlinearity): A measure in LSB of the worst-case deviation of code widths from their ideal value of 1 LSB.

INL (integral nonlinearity): A measure in LSB of the worst-case deviation from the ideal A/D or D/A transfer characteristic of the analog I/O circuitry.

Nyquist sampling theorem: A law of sampling theory stating that if a continuous bandwidth-limited signal contains no frequency components higher than half the frequency at which it is sampled, then the original signal can be recovered without distortion.

Relative accuracy: A measure in LSB of the accuracy of an ADC. It includes all nonlinearity and quantization errors. It does not include of set and gain errors of the circuitry feeding the ADC.

Further Information

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