Noise, Digital Resolution, and Accuracy in Digital Telemetry Systems

Noise and measurement resolution can be a confusing topic when dealing with digital telemetry systems or with any high performance data acquisition process. In establishing the ultimate accuracy and resolution of a measurement system, we must consider various factors.

Transducers

Any measurement starts with a transducer, which typically converts a physical stimulus to an electrical signal. The fidelity of this process is limited by a variety of effects: linearity (or deviation from a pre-defined nonlinear curve), hysteresis and cross sensitivity to other physical stimulus. For example, a torque transducer will produce an output proportional to shaft torque, but will typically have some cross sensitivity to shaft bending or to changes in the temperature of the transducer. These effects are generally small, but may limit the accuracy of the measurement. Transducers may also generate noise, that is, random variations in their output. Fortunately, these noise effects are often small compared to the noise effects of the electronics to which they are connected.

Signal Conditioners

Digital telemetry systems, like any data acquisition system must first condition transducer signals before these signals may be digitized. Signal conditioning usually involves amplification of low level signals to the levels required for digitizing. But in addition, other processes are often required. For example, bridge type transducers require an electrical excitation source and piezoelectric transducers require a charge amplifier that converts charge to voltage. All signal conditions contribute some amount of electrical noise to the measurement signal. For transducers that produce high level electrical outputs, these noise contributions are insignificant. But when the transducer signals are very small, amplifier noise can be a limiting factor. Noise levels introduced by signal conditioning amplifiers are also a function of bandwidth. For measurements that require greater bandwidth, the noise levels are generally larger. When the noise is uniformly distributed over the frequency spectrum (white noise), it may be characterized by a noise spectral density. The noise spectral density of a signal conditioning amplifier is typically specified in units of volts per square root Hertz. This is because the noise power is uniformly distributed over the frequency spectrum, not the noise voltage. The total noise contribution from a signal conditioner may be determined by multiplying the noise spectral density by the square root of the measurement bandwidth.

Digitizers

Once the sensor signal has been properly conditioned, it may be digitized by an Analog to Digital Converter (ADC). The voltage range of the ADC is divided into 2^n discrete steps, where n is the bit resolution of the converter and each measurement sample is transmitted as a binary number. For a 12 bit converter, 2^n is 4096, so the digital resolution is 1/4096 or about 0.025% of the full scale range. When the measurement range is bipolar, one bit must be reserved for sign so a 12 bit converter will produce a digital resolution of 2^{11}, or 0.05% of the unipolar range.

Putting It All Together: An Example using the Accumetrics AT-4400/ AT-4500

The Accumetrics AT-4400 and AT-4500's are 16 bit digital telemetry systems used for wireless torque measurements. Absolute accuracy of steady state transducer measurements will generally be limited by the linearity and hysteresis capabilities of the transducer, but resolution of the measurement is determined by the telemetry system.

The standard input range of this system is ±1.51mV/V (other ranges available) and the typical input noise spectral density is: $< 0.0005\% FS / \sqrt{Hz}$

The maximum bandwidth of is determined by the anti-alias filtering that occurs before the signal is digitized. This filter removes signal and noise content above 2000 Hz. The signal is then digitized with 16 bit resolution at a very conservative sample rate of 26484 samples/second, or about 13 times the bandwidth.

Using the Noise Spectral Density specification (above), the typical noise level, referred to the input of the system would be:

$$\text{Input Noise} = [0.0005\% / \sqrt{Hz} * 1.51 mV/V] * \sqrt{2000 Hz} = 0.000338 mV/V\ RMS$$

This level may be compared to the digital resolution for the system. The unipolar measurement range of 1.51 mV/V is divided into 2^{15} =32768 steps. Therefore:

Digital Resolution = (1.51mV/V)/ 32768= 0.046 microvolts/V

In this case the input noise is substantially greater than the digital resolution and the overall measurement resolution is limited by noise.

Does this imply that the 16 bit resolution is not useful? Not really! The receiver has selectable filters, allowing the users to limit the bandwidth and thereby limit the noise. Moreover, the means by which the data is subsequently processed has a big impact upon measurement resolution. For example, if the user wishes to measure the signal response at a particular frequency (perhaps a multiple of the machine's running speed), he can use spectral analysis. Here the noise bandwidth becomes the width of the frequency bin of interest within the spectral results. That bandwidth can be arbitrarily low, thereby reducing the effective noise considerably. Now the bit resolution becomes very significant.

Careful consideration of factors related to resolution and accuracy will insure optimal results. Accumetrics' products are designed to provide the best performance and flexibility to meet user's needs.

Contact us: Telemetry@Accumetrix.com
www.Accumetrix.com
Phone:518-393-2200 Fax: 518-393-3622
409 Front Street, Schenectady NY 12305