AN-22: The Need for Speed:

Understanding Conversion Rates in Industrial Multiplexed Data Acquisition Systems

January 6, 2004 David Fitzgerald

There is some confusion concerning conversion rates in modern data acquisition systems used for industrial control. The Gigahertz race leads us to believe that “faster is better” in every aspect of modern technology. Current marketing trends for industrial data acquisition products from many manufactures follow that mindset. The product definition process for the end user, unfortunately, usually comes down to the fastest, highest channel count card for the lowest price. Many other factors affect the actual usable conversion rate for multiplexed applications and should be considered before purchasing the hardware.

While there are many types of high resolution analog to digital converters used in industrial control applications, multiplexed successive approximation converters are prevalent because of their comparatively low per channel cost for resolutions up to about 16 bits, relatively high speed, and small form factor. So how fast is fast enough in terms of analog to digital conversion for a typical industrial control application? To answer this, it is important to understand both how multiplexed data acquisition systems function and what types of signals are being digitized.

Conversion rates in multiplexed data acquisition systems generally determine the channel scan rate, not the actual ability of the converter to digitize a specific maximum frequency. Channel scanning essentially divides the conversion rate by the number of channels. At a rate of 100khz, scanning across 16 channels yields an effective conversion rate of 100,000/16 or 6250 samples per second for each channel. This does not account for other factors like channel to channel settling time, conversion and multiplexer control overhead, data bus bandwidth to the host, as well as other factors that must be addressed to ensure accurate data from the converter. The following examples highlight some of these considerations.

Assuming we are only going to use one single ended input channel, high speed acquisition of a repetitive signal could be converted at a rate of 100khz. Nyquist suggests we can accurately determine the frequency of any repetitive signal at or less than one-half of the conversion rate. To accurately represent the waveform itself, not just the frequency of the signal, or to accurately digitize a non-repetitive signal, we need a much higher sample rate for the same maximum frequency we would like to digitize. In either case, an anti-aliasing filter must also be included to prevent out of band noise, harmonics, etc. from corrupting the digital representation of the signal of interest. This simply means that using the 100khz sample rate, we could accurately digitize 4 points per cycle on a 25khz repetitive waveform, 8 points per cycle on a on a 12.5khz repetitive waveform, etc. The higher the ratio of sample rate to input frequency, the more accurately we can digitally represent the waveform (rise time, fall time, waveform shape, etc). Many modern digitizing oscilloscopes use several thousand times the frequency of interest to deliver the most accurate picture possible. This example suggests that, at least for complex waveforms sampled at this rate, practical digitization of anything more than a few kilohertz is unreasonable.

Another example might use 4 single ended input channels each with a 1hz ~20khz repetitive sinewave waveform who's frequency and peak to peak amplitude only are of interest. Digitizing 100,000 samples on each channel taken at 100khz, continuously performing the same series of conversions on each channel sequentially theoretically allows us to discern the pertinent information from each channel, although not simultaneously. Assuming we can sustain the ~200k bytes/second transfer rate across the bus, there are some basic pitfalls that can affect the accuracy of the data.

First, any analog to digital converter's inherent signal to noise performance degrades with frequency, reducing the effective resolution of the converter. This will affect the accuracy of the data regardless of whether or not there is a multiplexer in front of the converter. And in a multiplexed system, channel to channel cross talk also increases with frequency. For example, at 100hz, a typical multiplexer built with industry standard 408/409 devices might have a channel to channel cross talk number of –110 db, which is quite good. At 1khz, it is more like -100 db. At 10khz it is likely around -80db, and at 20khz, it might be –40 db. The possibility exists for any of the channels to affect the others by as much as half of our converters resolution (16 bits is equivalent to 96db). Multiplexed Analog to digital converter products do not lend themselves well to even moderately high frequency waveform capture across multiple channels.

A more realistic example might use the same data acquisition product to sample 16 channels sequentially. If we assume that the inputs are various sensors that monitor pressure, temperature, torque, light levels, or any other industrial process variable that is represented by a very low frequency (effectively DC) signal up to perhaps one hundred hertz, then the digitization process is much more forgiving. Since most of the inputs monitor conditions that change comparatively very slowly, and even the fastest of the signals are on the order of tens of hertz, we can use a much more realistic 1khz per channel data sample rate and still derive meaningful data from all of the channels. The slower 16khz conversion rate could also allow additional settling time between channels, which is commonly necessary to allow the multiplexer itself to settle after changing channels.

The final example has only a couple of limiting factors that are common for most of the data acquisition products commercially available today.

First, all channels are assumed to be the same input voltage range. If there is a sensor that is nominally 0-1.0 volt, and one that is 0-5.0 volts, they are both sampled using the 0-5.0 volt range. Changing input voltage ranges usually involves changing configuration settings and calibration values, which, even if automated, cannot normally be performed easily between channels during a sequential conversion process. Additional time is also required for the new calibration values to settle before the next conversion can begin.

Second, one input channel may change at a rate that would itself dictate a conversion rate of 1 sample per second, while another might need a 1khz rate. In most sequential scanning data acquisition products, the sample rate must be set to that of the highest rate necessary. To make the point clear, a system with 10 channels that require a 1hz sample rate and 6 channels that require 1khz sample rate, wastes about 63% of the bandwidth used because all channels must be sampled at the 1khz per channel rate, or 16khz overall. You simply throw away 999 out of every 1000 samples for each of the 10 channels because the data is essentially the same.

The WinSystems PCM-ADIO addresses all of the issues highlighted in the last example through a unique, intelligent conversion control processor built onto the most advanced industrial data acquisition design available in the PC/104 format. Any single input channel can be programmed independently of any other channel to any combination of voltage range, polarity, conversion rate, buffer size, and either single ended or differential input modes. It also includes 4 channels of independently software programmable 12 bit Digital to Analog output and 16 bits of general propose digital I/O.

More information is available at www.winsystems.com, or, contact the WinSystems Application Engineering department at (817) 274-7553