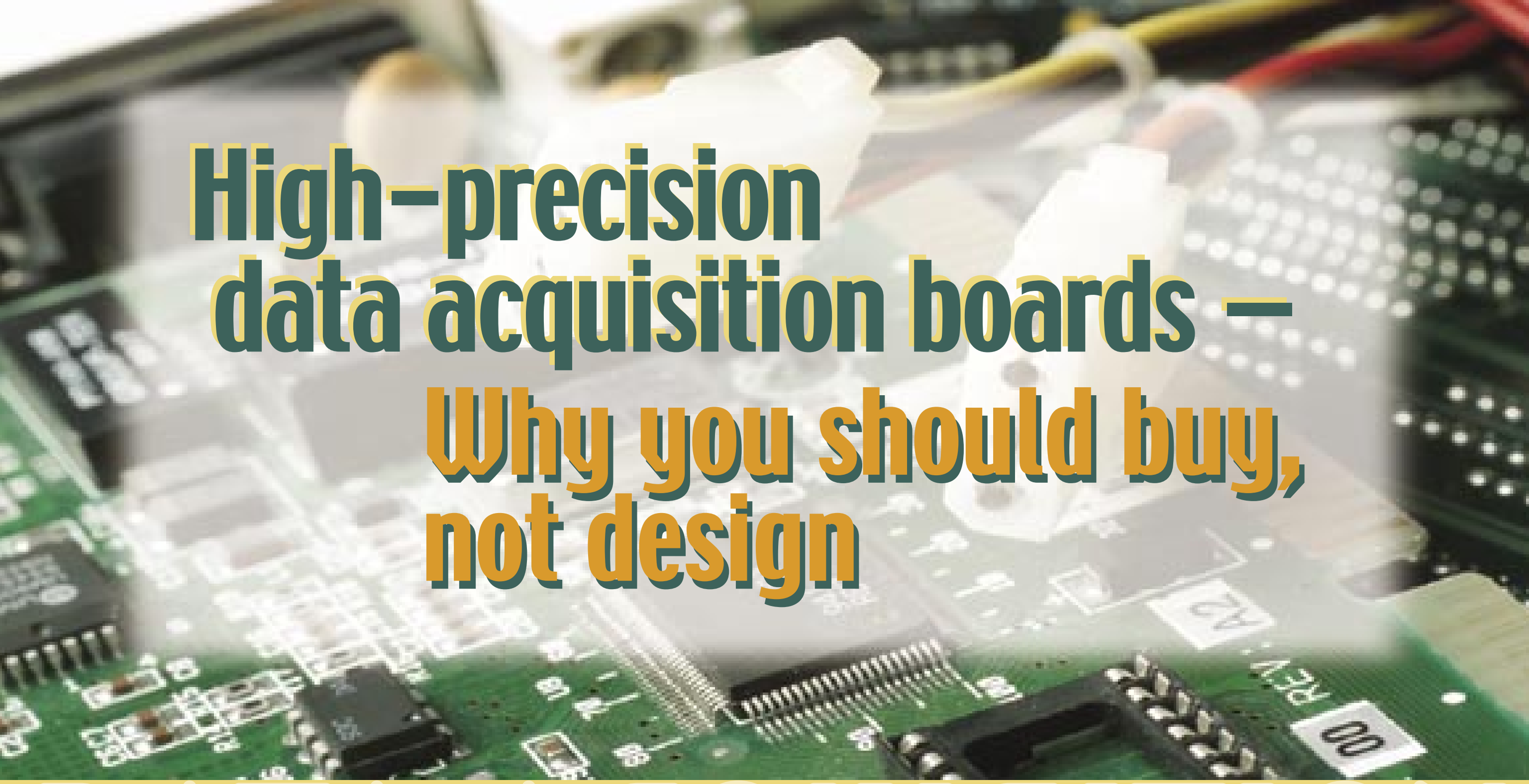

High-precision data acquisition boards – Why you should buy, not design

DATA ACQUISITION

By Greg Boyle

Designing a data acquisition system (DAS) is like learning to play golf. Anyone can hit the ball from day one but then may spend the rest of their life refining the game. Anyone can design a system with an analog-to-digital converter (ADC) and take a sample, but they will spend an immense amount of time refining the circuits to achieve a level equivalent to a high-performance instrument. Buying the board aids in the performance of the final system because the engineer does not have to design the heart of the analog circuit, which includes accuracy, drift, low noise, temperature, AC response to full power bandwidth, slew rate, filtering, cable loading, and so on. The engineer only has to interface to the board to get all the benefits of the core analog system.

This article will delineate the required parameters for a multi-channel, 16-bit, high-precision DAS board suitable for industrial applications from DC to 100 KHz. For the vast majority of engineers, buying the core analog board allows more time for systems engineering, interfacing the custom machine/instrument to the DAS board, and achieving quicker time to market for a successful product.

Power supply system

All analog and digital functions sit on top of the power supply system. The power supply system consists of all voltages including references that will provide voltages to the entire board. In an ideal power supply system, all voltages should provide perfect line/load regulation, zero oscillation, zero noise, and infinitely quick adaptation to dynamic load changes. In order for those functions to work, a good sourcing/grounding scheme must be implemented in the copper, often with a mix of careful trace and plane layout, as well as differential and common-mode filtering. The goal is to account for all current flow, how each individual circuit will receive its current, and how each returns the current back to the source without causing ground loops, oscillations, and voltage drops around other sensitive components. This goes beyond lumping together the analog section and digital section.

The best way to drive the above copper for the minimal amount of noise is with external linear supplies, which by design have noise of <5mV p-p. However, getting the +5VDC and ±12VDC for the digital and analog functions will add to the difficulty of the wiring scheme for the user, thus making it easier to introduce ground loops. This, in turn, will introduce system noise of >75mV p-p.

With the advances in DC/DC control ICs running at higher frequencies such as 400 KHz, taking up less room, and costing less, it is now feasible to develop the voltages needed right on the board from a single input supply, i.e., +5VDC. This allows the DAS board engineer to control the source/grounding scheme and to keep the details away from the user. The compromise is a little more board noise, 10mV p-p @ 400 KHz, but often the system level noise will be lower, <20mV p-p, because of the reduced grounding loops.

Although the DC/DCs provide the positive and negative analog voltage, this voltage is not good enough for an instrumentation grade design due to the poor line/load regulation of the DC/DCs. Therefore, the DC/DCs are followed with low drop-out regulators (LDOs) to achieve the line/load regulation required. There is also a benefit of reduced low-frequency noise from the DC/DCs by regulating it out with the LDOs. The reference is normally then driven from the positive LDO. Since the line regulation gets better with items in a series, i.e., DC/DC + LDO + reference, the line regulation of what the electronics sees is rock solid, <10uVDC. This will affect how well the board holds its calibration. If you have an unlimited budget, using linear supplies with the above scheme can achieve system noise levels of <2mV p-p.

A 6.5-digit multimeter can test the above items and the 20 MHz oscilloscope. To measure line regulation, the meter is placed at each DC voltage while the input voltage is varied. A system with good line regulation will not budge. To measure load regulation, watch the output as the board goes through its different functions. This should be stable. To look for noise/spikes/oscillation, use the oscilloscope and place the probe at all locations of interest, i.e., all supplies and references. At all points look for noise or spikes with the scope

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adjusted to DC coupling at time bases of both 1 usec and 1 msec. Repeat this with the scope set for AC coupling. The high frequency spikes will be the frequency of the converter. However, do make sure there is not a lower frequency oscillation happening, such as 1 msec. This process will give you a good snapshot of what to expect from the board.

Input interfacing

This is where the DAS board connects to external sensors and voltages. The multichannel inputs can be either single-ended or differential. Channel 1 in Figure 1, showing the input modes, is set up to read a differential voltage (notice the ± inputs each have a common voltage on them), while Channel 2 is reading in the single-ended mode (its " - " input is common to ground). Channel 1 will read 100mVDC on the output of the instrument amp (INA), and Channel 2 will read 10VDC. It is important that the channels be selectable between single-ended/differential, allowing the design to handle either type of input. For the differential circuit to work correctly and subtract away the common-mode voltage, 5VDC, the inputs must always be within the common-mode voltage range of the input circuit, usually ±10VDC.

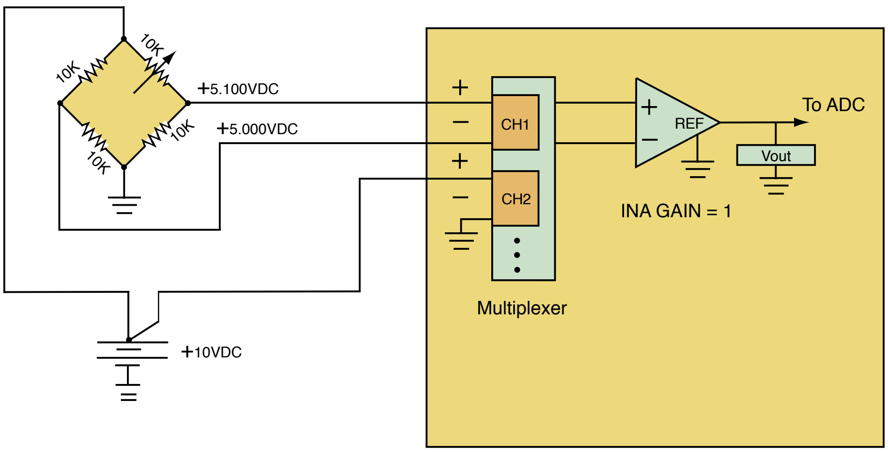

Figure 1

The next feature of the input circuit is to not load down the circuit being measured. This is usually straightforward if an instrument amp follows the multiplexer on multichannel systems. However, what happens when the power is turned off from the DAS board? The DAS board still must not load down the input. If it did, it could cause the sensor to blow a fuse or the DAS board to burn up an input channel. This problem is solved with fault-tolerant multiplexer ICs that can handle the voltage being removed while still having the sensor voltage present. Having the multiplexer go into a high-impedance state allows for an easy system design where the engineer doesn't have to worry about power sequencing of a system, blowing sensor fuses, shorted sensors, and so on.

Lastly, it is important to talk about *charge injection*. Since each input channel of the multiplexer is a switch, it contains a certain amount of capacitance. When a channel is switched from one channel to another channel, it dumps this charge, or glitch, into the circuit it is trying to measure. This can have devastating effects if the circuit being measured is a closed-loop system. To minimize this effect, series resistors are placed between the inputs of the DAS board and the multiplexer.

Input signal conditioning

The input signal conditioning is the circuit that starts with the INA, converting differential inputs to single-ended outputs, and ends at the front door of the analog-to-digital converter (ADC). In order for the ADC to use its full dynamic range, it is up to this conditioning circuit to have different gain settings, e.g., 1, 2, and 10. If the input signal is too small, i.e., millivolts from a strain gauge, the sensor will need to have a pre-amplifier before coming into the DAS board.

The DAS must have a low-pass filter, anti-aliasing, before the ADC to filter out unwanted frequencies. Without this filter, the ADC aliasing will digitize the frequencies above the sampling rate, and once in the data set, they cannot be removed. This is often called the Nyquist frequency. A way to see this effect is to turn the filter off and write software that samples the ADC reading for example, 1 msec, and sends it straight to the digital-to-analog converter (DAC). With an oscilloscope on the DAC, put a sine-wave generator on the input of the DAS and sweep the frequency from a low frequency, Hz, to a high frequency, KHz. The DAC will output the sine wave up to 1 msec. As the signal generator keeps sweeping up in frequency, i.e., 10 KHz, the scope will reproduce the 1 KHz sine wave again. This will keep on happening over again as the frequency on the generator keeps increasing. Digital oscilloscopes use this to benefit from repetitive sampling, but it creates havoc for users trying to do signal analysis or digital closed-loop control. See Figure 2 for a diagram of the aliasing process.

The signal conditioning circuit is where all the high-precision work is done to determine how well the DAS can process signals. These circuits must be thought out for the performance issues they must handle. However, they must be very simple to keep the noise level down. The circuits must be very stable over temperature, introduce insignificant amounts of noise, have minimal DC drift, and also provide high slew-rates to handle higher frequency/

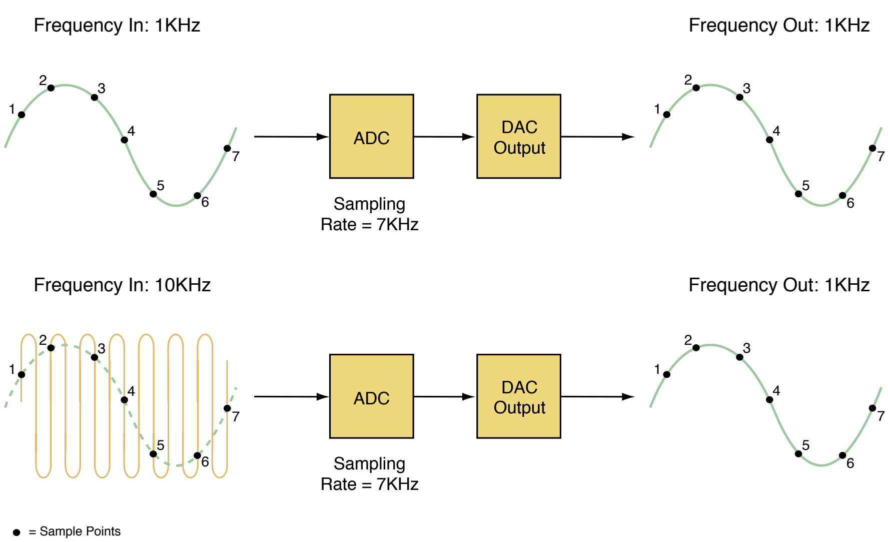

Figure 2

higher voltage signals, ±10VDC, termed full-power bandwidth. Many DAS boards will leave this entire section off. Do not be fooled by the amount of work and effort that goes into this section.

Analog-to-digital converter

By taking the gains from the above section and using a 16-bit ADC, one can achieve a very good total dynamic range. In the past, 12-bit systems with more gain settings on the front end met this total dynamic range. The more gain settings on the front end, the more noise that is introduced. With 16-bits one can get the same dynamic range and decrease the noise.

The ADC functions by taking a snapshot of its input signal, a sample. This is then held while the converter compares it to a reference and then kicks out the value in a digital format. With advances in ADCs, very good sample and hold circuits are now contained in the device. The ADCs also have internal references. However, to achieve 16-bit accuracies, the internal reference can hardly ever be used. Most internal references have a temperature coefficient (TC) of 20-30ppm/C. Most external references have TCs of 3-7ppm/C. Of course, an external reference will cost more and is harder to use, but if done properly, it will benefit the accuracy and drift parameters of the DAS.

It is important for the ADC digital bus to be buffered from the high-speed digital bus of the processor. This is usually done with transceivers and is termed a *Faraday shield*. This setup prevents the processor's high-speed digital bus from bombarding the *die* of the ADC while the ADC is trying to convert an analog signal.

The ADC can have a number of different ways to get the digital information to the processor. The easiest method is for the processor to start a conversion and poll the ADC for a tone signal, and then the processor reads the data. The next method is for the processor to start the conversion, and when the conversion is finished, the ADC generates an interrupt, which the software then services. The last technique is more of an automated process, where the DAS is set up and waiting for an external trigger to occur. Upon the trigger, a pacer clock causes the ADC to start a conversion, and when the conversion is finished, the ADC signals the direct memory access (DMA) controller to take the digital data and place it into the system memory. The pacer clock then goes to the next channel and the process is repeated. When all the channels have been read at the desired number of times, the DMA controller will generate an interrupt telling the processor it is finished.

To test the entire input circuit along with the ADC, input a sine wave into the system and sample this for approximately 20 cycles. Doing a Discrete Fourier Transform (DFT) and histogram on the data will produce the effective number of bits for the system. Any major jitter in the pacer clock will show up as noise, any non-linearities will show up as peaks in the spectrum, and missing codes will show up in the histogram. The C-code/Mathcad that performs the above functions on a data set is available for purchase. Mathcad is a registered trademark of MathSoft Engineering and Education, Inc. Visit www.mathcad.com for further information.

Digital-to-analog converter

The DAC is usually made up of multiple channels from two to four. For industrial electronics, an output of ±10VDC is required. This range will drive motors, valves, 4-20mA transmitters, and so on. The DAC should be protected from the rest of the system with a Faraday shield, to prevent digital feed-through noise from the processor to the outside world and also to prevent the DAC from inadvertently changing values.

It is also very important that the DAC is monotonic if it is operating in a digital control loop. Monotonic means that if the digital value of the DAC is increased, the analog output will increase or stay the same. If it drops due to offsets inside the DAC, then it is termed non-monotonic. This is important in digital control systems because it can cause oscillations leading to instabilities. Imagine if you are trying to run a motor in a control loop and the ADC senses that you need to speed up the motor. In a non-monotonic system, the motor will actually decrease its speed. This can lead to oscillations in the system.

Most good systems have a low-pass filter following the DAC to remove segment-to-segment transition noise from getting to the output. Before the signal leaves the board, it should go through a very robust buffer amp that is capable of driving the capacitance of a cable without ringing or oscillating. The buffer amp also protects the internal *die* of the DAC from the external noise bombarding the cable.

To test how well the output circuit works, connect some long instrumentation cable with an oscilloscope on the end. Have the software pulse the cable and look for excessive ringing at the end of the cable. If the system is designed without output buffers, it is possible to see the pulsing from one channel show up on the cable of another channel.

Digital input/output (I/O)

The digital input and output functions are very straightforward. If a programmable logic device is used for this function, it must be 5VDC tolerant. It must also be immune from ESD coming from operators pressing buttons and must limit switches with moving parts and such. This is accomplished with series resistors and protection diodes.

It is best if outputs come up, out of reset, with a logic-low level for fail-safe. This way, on power up, the outputs are low and stay low. If outputs come up with a logic-high, there is an unknown transition time when the logic is low and then goes high. In multi-board systems this can bang relays/solenoids around and so forth. Normally, all I/O will have pull downs on each pin. Additionally, the DAS board should be able to be powered down without burning up inputs/outputs from mating I/O boards.

Advanced features for the I/O will be individual bit control of direction, with high-current output drive capabilities, external trigger, external pacer clock, clock/timer, and interrupt generation from selectable digital inputs.

Calibration

Calibration is the act of taking all the electronics pieces from above and calibrating them to read or output traceable voltages. Calibration once used potentiometers to adjust slope and offsets of all of these op-amps. Each potentiometer had to be padded on each side with resistors so mechanical shock would have less of an effect on the setting of the potentiometer. The next evolution was to control the slope and offsets with DACs, R2R ladders, and trim DACs. This procedure had the advantage of not having to worry about mechanical shock. However, adding all these trim DACs just added more noise, both digital and analog, to the system.

With advances in single-board computers becoming smaller and faster, all of the potentiometers and trim DACs can be left off the board, and the slope and offsets can be corrected in the software. This reduces circuitry and keeps the noise down. Often the slope and offset values will be held onboard with an EEPROM.

Upon receiving a DAS board, it may or may not be calibrated. It is helpful if it is calibrated to test the accuracy of the board. However, if it is going into a system, the board will normally have to be recalibrated with the system using external meters and voltage sources. The best way to test a board is to put it in an environmental chamber, have it read a constant voltage source outside the chamber, and have it print to a file every so often. The readings should be within the limits of the manufacturer's claims. The DACs can be tested by putting out a constant voltage and verifying they hold their values over temperature.

Micro/sys MPC560

One example of a DAS board that incorporates all of the items discussed in this article is the Micro/sys MPC560 board, shown in Figure 3. The 16-bit DAS

Figure 3

board has been designed to handle harsh environmental conditions but still yield high-precision results. With its built-in fault protection, ultra-low noise design, and solid calibration, any user will be able to set it up and forget it. The MPC560 is ideal for process control, automation, and spectral analysis.

The design considerations that go into an instrument-grade data acquisition system are significant. As time to market for design projects continues to shrink, it generally makes more sense to buy the DAS board and to spend more time on the interfacing to the system.

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