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Application Note

Care and Feeding of Inputs to High-Resolution, High-Speed A/D Converters
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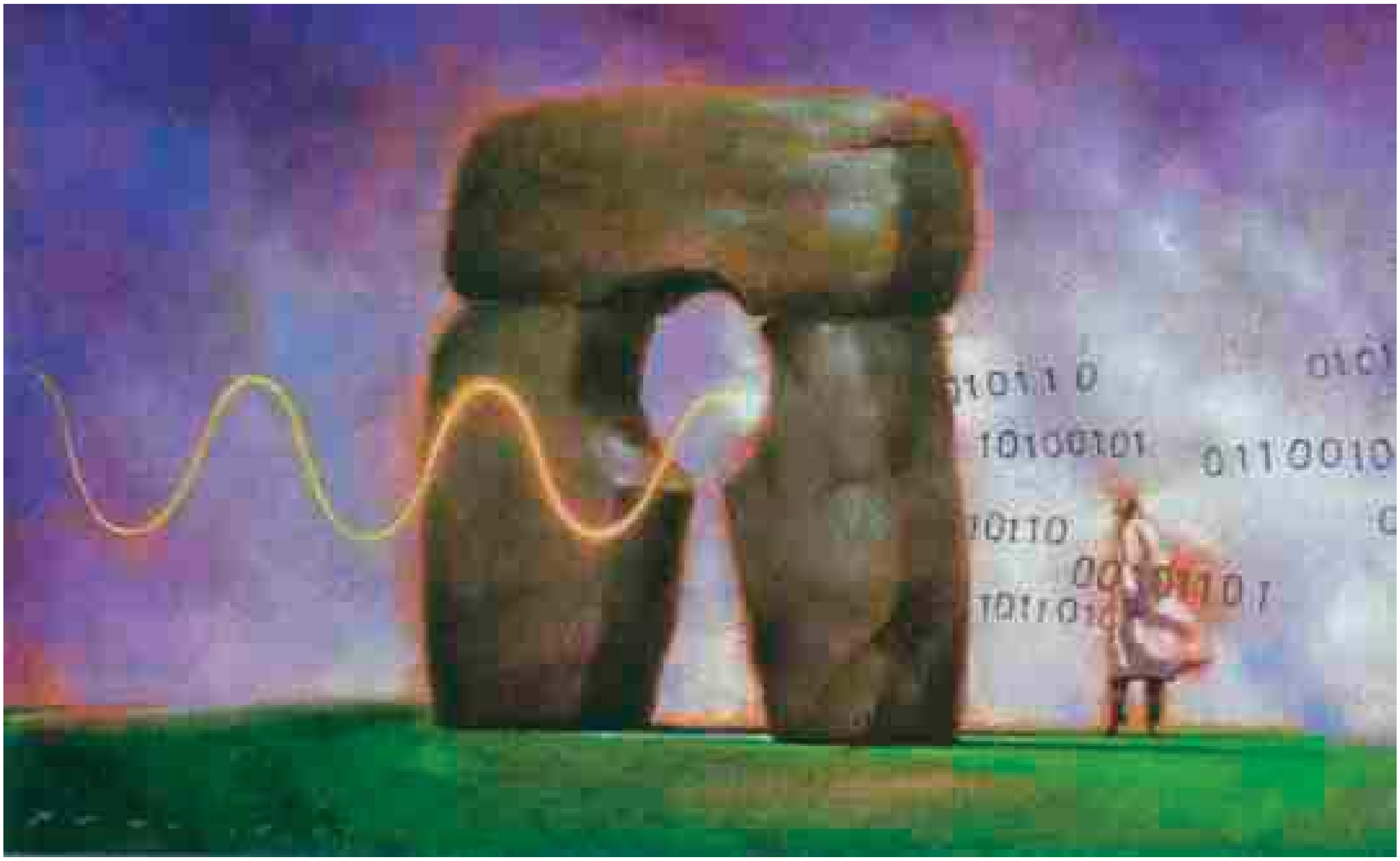
by Bob Leonard



Signal generators, filters, drive amplifiers, interfacing logic and layouts . . . the performance is in the details!

Many spread-spectrum systems utilize high-resolution, high-speed A/D converters to digitize their input frequency spectrum. The performance goal is to achieve system frequency domain specifications as close to those (equivalent?—better?) specified in the high-resolution A/D converter data sheet. Signal generators, filters, drive amplifiers, interfacing logic and layouts demand special attention for an overall successful system. This article looks to explore the design aspects the user controls in obtaining the desired frequency domain performance from high-resolution, high-speed sampling A/D converters (14 to 16-bit A/Ds, 500kHz to 10MSPS sampling rates, for the purposes of this article — yet many of the topics are relevant for all system accuracies and speed).

Frequency Domain

Frequency domain applications may differ from one another in that any particular system may want to optimize a particular specification of the frequency domain. One application may dictate the widest dynamic range of operation before incurring any artifact such as a harmonic or spurious signal. Yet another may be much more interested in the noise floor and Signal-to- Noise Ratios. The “subranging A/D” architecture used for high-resolution, high-speed A/D Converters plays the major role in defining the performance (16-bit, 2MSPS sampling A/D shown in figure 1). Yet, while the A/D converter manufacturer may set the ultimate limit on what specifications can be achieved, the user plays no less an important role.

Signal Generators

Testing high-resolution, high-speed sampling A/D converters over a particular frequency spectru begins with a clean input test signal. The “clean” definition gets very demanding, as harmonics below 90 to 100dB are required from the test signal. The noise performance of the signal generator is also important.

As a general rule, even the best available available signal generator will need an external passive filter to achieve performance sufficient for a high-resolution

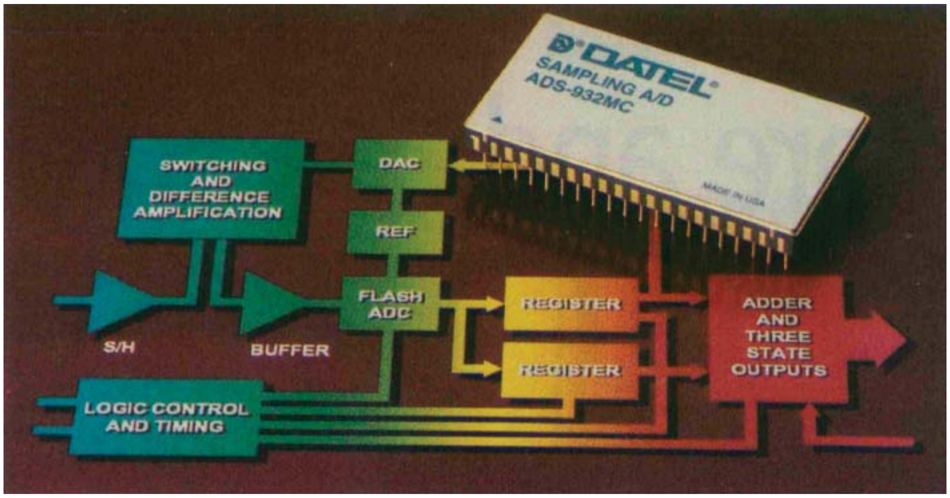


Figure 1. Subranging architecture for high-resolution, high-speed Sampling A/Ds

sampling A/D. The exception to this would be some signal generators may give acceptable performance close to dc (< 5 kHz). However, low frequency performance is no guarantee of higher frequency performance! Slew rate limitations and noise aspects are very demanding as input frequencies push into the 100's of kHz to MHz spectrum.

An engineer integrating a sampling A/D into his design, may not have the resources to test every component to its limits. DATEL uses the Hewlett Packard Model #8644B (we still need external filters!), however, the price can exceed $25K (please check with the vendors for exact pricing information) and therefore may not be practical for many users. Khron-Hite Model 4400A (approximate $1,250) can have 2nd & 3rd harmonics past 100 dB with the noise floor higher than some. Using bandpass filters at exact test frequencies helps in making the noise acceptable. The Bruel & Kjaer Model 1051 (about $15K) and the Fluke 6080A have all been reported as giving good results by users. Check your signal generator listings for additional sources.

Note our focus is on testing operation over a particular frequency spectrum (frequency domain specifications). Timedomain, static specifications, such as integral nonlinearity will require other approaches. For instance, DATEL uses a Dynamic Test Systems instrument with an internal 18-bit D/A converter, for integral nonlinearity testing.

Filters

Having established that even the best signal generators will require a filter, let's turn our focus to them. There are two basic filter types of filter construction, active (op amps with resistors and capacitors) and passive (discrete resistors, capacitors and inductors).

A user of filters may first hope that an active filter could meet his requirement. Active filters feature relatively small size, low cost and "cookbook" approaches for tuning the filter type and performance required. As a rule of thumb though, the techology border between active and passive filters has been at 12-bits, with frequencies to 200kHz, although now targeting 1 MHz performance. For high-resolution, high-speed A/D converters we'll find the large and expensive passive filters are required.

Observing the well known Nyquist theorem, namely digitizing at a sampling rate that is twice the highest signal frequency to be seen, is a first criteria for the filter. Trying to detect an unknown signal would suggest a low pass filter good through half the sampling rate is needed. Sampling rates of 4x to 10X the highest frequency are often used in practice to lessen the stringent filter demands of pure Nyquist sampling.

It's also possible that an application knows the center frequency of the signal and just requires a bandpass filter for the spectrum around the center frequency. The Nyquist sampling criteria would still be observed, unless alias signals (of a particular bandwidth) from an undersampling application were involved. Testing a sampling A/D with a bandpass filter is also recommended for high-resolution, high-speed sampling A/Ds. This will limit the noise from the full input spectrum.

It's not unusual to require large (we're talking multiple inches, modular type packages here), expensive ($400 to $500 price range) passive filters. Normally you would specify the filter (low-pass, bandpass), type (Butterworth, Checybshev, Cauer ellyptical, etc.) for your application, impedance and voltage range. It's quite common to utilize an available filter that had been used for a prior application - but beware of the design differences! If the input voltage range exceeds the prior design's limits, third order harmonics can surface as the inductor core saturates. Also the impedance matching may need tweaking to avoid gain loss that could hurt the distortion specifications. Consider adding an external amplifier to drive the A/D properly if impedance matching is the issue. The overall performance may improve, even though you've just added another distortion source!

DATEL uses many passive , seventh order bandpass filters from Allen Avionics of Mineola, NY (now their F4202 Series) in testing our high-resolution A/Ds. We also utilize DATEL's own active filters when testing our lower resolution A/Ds and have used some passives from TTE (Los Angeles, CA). Frequency Devices (Haverhill, MA) is another popular source for filters.

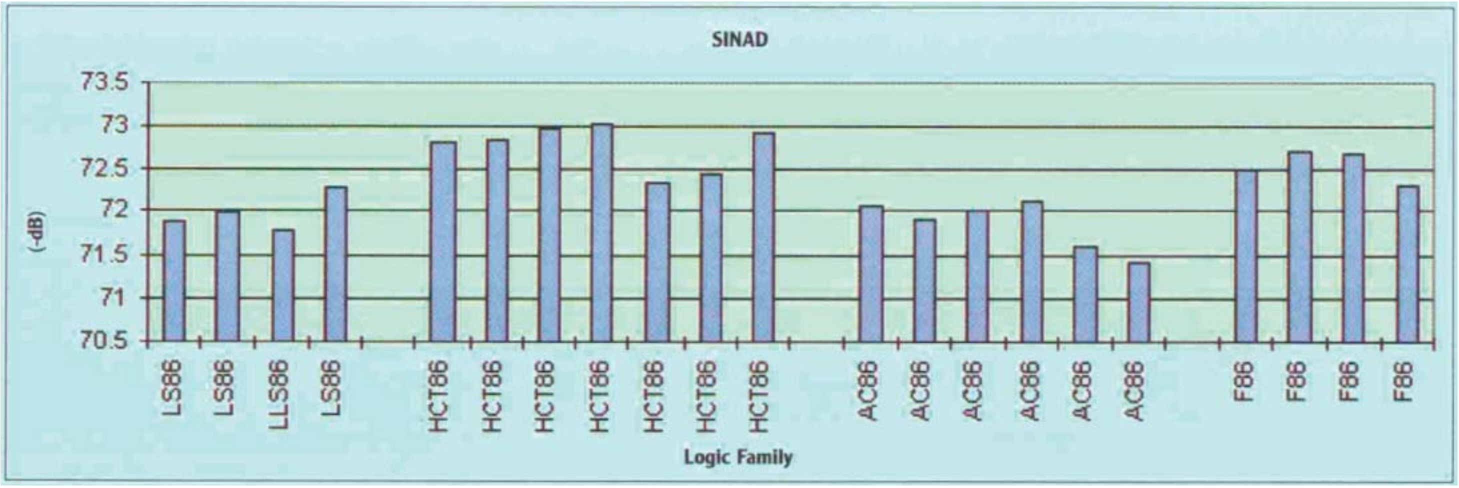


Figure 2. Effects of various logic families on Signal-to-Noise Ratios

Drive Amplifier

Choosing a drive amplifier for a high-resolution, high-speed sampling A/D is dependent on the overall system design goal. Choices will need to be made between whether the harmonics, noise or power or combination thereof, in a system are most important. As a manufacturer, we try to optimize all of these aspects into one standard product and choose the particular drive amplifier for these virtures also. Any particular application may be more focused and want to optimize just one of these parameters.

The first surprise for anyone chartering for the first time into the unknown waters of high-resolution A/D drive amplifiers, is that most amplifiers on the market are only characterized for 0.01% settling time performance (1/2 LSB at 12-bits). You are on your own in qualifying these parts to 14 and 16-bit accuracies and usage. Questions include: Will the device settle to higher accuracies with some additional settling time, or will it exhibit lengthy "settling tails"? Over temperature, are there some surprise "thermal tails" impacting performance? And just where is the noise floor of the device before it impacts the application?

Some of the old "rules of thumb" can be thrown out the window when it comes to analyzing today's drive amplifiers. Historically, FET based amps were known for having good linearity over a wide operation range, therefore exhibiting good distortion performance in the frequency domain. Low noise goals may have suggested a bipolar amplifier for their low noise spectral density figures. This all seems a blur today, with degenerative feedback stages being used to improve noise performance and with differential second stages to improve linearity, etc. Nothing short of your own testing, querying the amplifier manufacturer and the manufacturer of the sampling A/D converter for a recommendation will do. Inverting configurations are still the best for power supply rejection and common mode rejection.

Tradeoffs of distortion, noise and power start with the amplifier's power supply rails and input voltage range. To minimize the noise impact as a function of the Least Significant Bit (LSB), ideally you want as large a signal range as possible, improving the overall Signal-to-Noise Ration (SNR) Conversely though, for good distortion performance, you need the amplifier to be very high-speed, slewing fast to keep up with the changing signal, i.e., avoid large signal swings! At 100kHz to MHz input frequencies, 1 V to 2 V signal ranges make optimizing the distortion issue a much easier task. Any slew rate limitations or nonlinearities in tracking the input signal result in distortion in the frequency domain. A designer must consider these issues when selecting the drive amplifier. The good news is that amplifiers with a choice of ±15 Volt supplies or ±5 Volt supplies are available.

There are many manufacturers whose amplifiers will qualify upon further inspection for high-resolution, high-speed sampling A/Ds. Analog Devices' AD8XX series or newer AD96XX series are utilized for many of the DATEL sampling A/D converter's evaluation boards. The FET type AD845, offers good distortion and noise performance for input frequencies from 100 kHz to 400 kHz, settling to 14-bits in about 400/500 nanoseconds. The bipolar AD843 may offer faster settling times. The AD9631 is utilized for our 16-bit, 1 MSPS and 2 MSPS sampling A/Ds. This device offers low distortion specifications up to 5MHz input frequencies, although note its settling time is only specified as 16 nsec to 0.01% on the data sheet.

Burr Brown also has devices found suitable for 14 to 16-bit sampling A/Ds. The OPA628 and OP642 (good performance at 14-bit, 5 MHz input frequency) come to mind. Their OP627 provides good performance at 16-bits up to the 100 to 200 kHz frequencies. Comlinear's 4XX/5XX series of products offers high-resolution performance, with some models able to clamp the input.

Logic Interfacing

As a data converter manufacturer, we participate in many discussions where our customers are trying to wring additional tenths of a dB of performance out of their competitive spread spectrum system. Therefore no rock can be left unturned in improving performance. This pursuit includes investigating the interface logic utilized for generating sampling A/D start convert pulses and buffering the parallel outputs. Looking at Figure 2, you'll see a chart fo the variation of Signal-to-Noise Ratio and Distortion (SINAD) for DATEL's ADS-944, 14-bit, 5MSPS sampling A/D when utilizing various logic familes just for generating the start convert pulse. Figure 3 shows an FFT (Fast Fourier Transform) for the ADS-944.

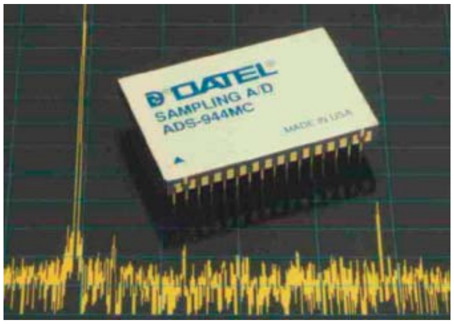


Figure 3. Fast Fourier Transform for a 14-bit, 5 MSPS sampling A/D

Here, the same sampling A/D converter was used with different logic families and multiple devices to simulate what a production variation within the family might be like. The HCT logic family turned in the best results, follwed by FAST logic, AC logic and finally LS logic. The Total Harmonic Distortion (THD) performance was basically the same, but SINAD and SNR w/o distortion showed 0.5 dB to 1 dB improvements with HCT logic.

Layouts

A 14-bit A/D with a 2.5 Volt full scale input range has just 153µV representing the LSB, and 16-bit devices may push below 100µVolts for an LSB. Considering these high-resolution, high-speed A/Ds are often paired with high-performance processors in the 100MHz range, then proper layout can be critical.

There are high-performance digital design seminars that advise how to avoid compromising the logic families' noise immunity. They're talking about ground movements in the 100mV area, whereas a high-resolution A/D paired with these devices has to be safeguarded by 3 orders of magnitude or more!

A/D manufacturers often define their device's grounds as "these are analog and those are digital ground". And it is true that our own internal layouts manage these grounds. However, the technical notes of the data sheets often recommend that the grounds come together at the ground plane beneath the converter. What this means is that your digital supplies and digital ground returns better be as clean as your analog equivalents or you'll contaminate your overall ground reference. Manufacturers for most applications might as well call every ground "analog ground".

What to do for high-resolution, highspeed sampling A/Ds. The subject certainly deserves a treatise, but let's cover some helpful tips. First, consider the use of local isolated dc/dc converters to power your converters. This will break any ground loops and associated ground currents/noise. New dc/dc converters are often "switchers" and the use of an LC filter should be considered, based upon the switching frequency and tolerable noise level. Practically speaking, this often works out to a 1µH inductor and 33µF tantalum capacitor (with short leads) for our own analog I/O boards and dc/dc converters.

As the analog and digital ground planes get connected beneath the converter, its often convenient to "split the groundplanes" beneath the parallel output buffer registers. Although many of our sampling A/Ds have output latches, we'll use external latches to drive the capacitance of the I/O bus, and to help keep those digital ground currents from getting into the analog paths. It never hurts to have a back-up plan with complex layouts, and utilizing solder gaps across the split can become helpful. If some ground contamination is taking place, then lowering the overall ground impedance may be the best compromise. The analog and digital grounds should be returned separately to their respective power supplies, with thick ground buses to lower their impedance.

Summary

Sampling A/D converters that live up to their specifications (and in some cases become optimized to exceed them) are highly dependent upon the external components and layouts chosen for their usage and test. Giving the proper attention to these details will result in a rewarding, successful design.

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