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Speed Considerations for A/D Converters

In an earlier newsletter, we looked at techniques to ensure a good quality signal at the input to an analog-to-digital (A/D) converter. In this article, we will consider the basic conversion methods that are commonly implemented on commercially available boards and how these methods affect the throughput and accuracy of the data.

Some Important Terms

Resolution – The number of discrete values that a converter can produce over the range of analog values. A 12-bit A/D converter can produce 4096 (2^{12}) values in binary form. For example, if the range of the conversion is 0 to +5V, each single binary digit increment is equivalent to approximately 1.2 mV.

Table 1 shows some of the most common resolution A/D converters and the equivalent voltage change per single binary increment for several voltage ranges.

Table 1: A/D Converter Resolutions

Bit Width	Maximum Binary Value (Unsigned)	Voltage Range				
		-3.3V to +3.3V	-5V to +5V	-10V to +10V	0 to +5V	0 to +10V
10-bit	1023	6.4mV	9.7mV	19mV	4.8mV	9.7mV
12-bit	4095	1.6mV	2.4mV	4.8mV	1.2mV	2.4mV
14-bit	16383	0.4mV	0.6mV	1.2mV	0.3mV	0.61mV
16-bit	65535	0.1mV	0.15mV	0.3mV	0.07mV	0.15mV

Conversion Rate – The amount of time that is required from the beginning of one conversion to the time the converted value is available to read from the A/D converter. It is usually stated in microseconds. The specified conversion rate is often an ideal condition. Conversion time should take into consideration settling to a stable condition to allow conversion to the stated accuracy. Data sheets will often state “throughput”, which is the inverse of conversion rate. For example, an A/D converter that has a conversion rate of 8µS will have an ideal throughput of 125 KHz ($10^6 \div 8$). Throughput is an important consideration when trying to sample a continuous waveform that must be reproduced. Sampling theory requires that the sampling rate be greater than 2X the maximum frequency to be reproduced.

Accuracy – Accuracy is not the same as resolution, which is discussed above. Accuracy is usually stated in terms of the uncertainty for a number of low order bits. For example, an accuracy of 2 LSB in a 16-bit A/D converter is approximately 0.0046% (3 ÷ 65534). However, this is not the only consideration. Signal quality factors like A/D quantization, input signal linearity, and calibration signal accuracy will contribute to the theoretical maximum error. Common A/D converters with selectable ranges will generally have theoretical maximum accumulated errors from 0.05% to 0.10% of the conversion voltage range with typical accuracies significantly better.

Conversion Technology

Successive Approximation Conversion (SAC) – A method of conversion that makes use of a paired digital voltage generator and a digital-to-analog (D/A) converter. In simple terms, a digital value is converted to an analog value and compared with the target signal. The measured difference is fed back to the digital value generator which makes a second and more accurate "guess". The process continues until the difference is sufficiently small. This method is most common for low cost converters because it can be implemented on a relatively small and inexpensive component. The approximation iterations are actually very fast. Current technology SAC converters are pushing 200KHz throughput. On the software side, Successive Approximation Conversion is sometimes called an SAR – Successive Approximation Register.

Pipeline Conversion – A method of conversion that takes advantage of the fact that the higher the frequency of sampling, the smaller the change of voltage from one sample to the next. A pipeline converter will have several low resolution A/D converters, usually 3-bits each, which can very quickly approximate the change in a signal from one sample to the next. Rather than zeroing in on the value by iterations, the value is determined by a cascade of converters which narrows the range very quickly. An added advantage is that while one sample is being approximated at the "back-end" of the circuit, the "front-end" is already free to begin converting the next sample. Current technology pipeline converters can achieve 20MHz to 200MHz at the cost of more expensive components.

Delta-Sigma Conversion – A method of conversion that is in its simplest sense a voltage controlled oscillator combined with a counter. The input voltage is the signal to be converted and the output frequency is proportional to the input which can be made highly linear with an elegant feedback loop using a low-resolution D/A converter. The principle of the Δ-Σ architecture is to make rough evaluations of the signal, measure the error, integrate it, and then compensate for that error. This method is currently used in applications that need to accurately extract and reproduce frequency components in the audio range and competes with older oversampling techniques.

Table 2 shows the various A/D converter options within Acromag's line of embedded computing products.

The throughput of an A/D converter in a real application is affected by system considerations. Until the advent of FPGA boards (which are covered in another series of Tech Notes), most A/D boards were used to convert signals and transfer the result as binary numbers to a computer for further processing. Considerations for using A/D converters in a system will be covered in the next article.

Table 2: Acromag A/D Converter Modules

Form Factor and Models	Input*	Resolution	Conversion rate	Throughput	Memory	Technology	Comments
Industry Pack Modules							
IP320A	20DI / 40SE	12-bit	4.5µS	200KHz		Successive Approximation	Three dip switch-selectable input ranges: -5 to 5V, -10 to 10V, and 0 to 10V. Programmable gains of 1, 2, 4, and 8.
IP330A	16DI / 32SE	16-bit	5µS	200KHz	I per channel	Successive Approximation	Three dip switch-selectable input ranges: -5 to 5V, -10 to 10V, and 0 to 10V. Programmable gains of 1, 2, 4, and 8.
!P340	16DI	12-bit	8µS	125KHz per 8-channel bank	512	Successive Approximation	16 differential inputs. A/D converters in 2 banks of 8. Range -10V to +10V.
IP341	16DI / 32SE	14-bit	8µS	125KHz per 8-channel bank	512	Successive Approximation	16 differential A/D converters in 2 banks of 8. Range -10V to +10V.
PMC/PCI/cPCI Modules							
PMC330/APC330/AcPC330	16DI / 32SE	16-bit	15µs	125KHz	I per channel	Successive Approximation	Switch selectable input ranges -5V to +5V, -10V to +10V, 0 to 5V and 0 to 10V. Programmable Gains of 1, 2, 4 and 8.
PMC341/APC341/AcPC341	16DI	14-bit	8µS		512	Successive Approximation	16 differential A/D converters in 2 banks of 8. Range -10V to +10V.
PMC730/APC730/AcPC730	16DI / 32SE	16-bit	10µS	100KHz	512	Successive Approximation	Range selection (±3.3V, ±5V, ±10V, 0-5V, and 0-10V ranges).
PMC FPGA Modules							
PMC-AX1020/2020/3020	4DI	14-bit		20MHz		Pipeline	Range -1V to +1V.
PMC-AX1065/2065/3065	4DI	14-bit		65MHz		Pipeline	Range -1V to +1V.
FPGA Extension Module							
AXM-A30	2DI	16-bit		105MHz		Pipeline	Range -1.6V to +1.6V.