A case study on Analog to Digital signal converters and their types

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Abstract — *A signal is an electric current or electromagnetic field used to convey data from one place to another. Signal converters are electronic devices that receive one type of signal and output another type of signal. They can be found in many industrial and commercial applications. This paper aims to list down the different types of Analog to Digital signal converters that are available in the market.*
Keywords *— Signals, Signal converters, Signal Processing*

I. Introduction

There are several types of signal converters. Analog-to-digital converters (ADCs) sample analog signals and convert them to a series of digital values. Digital-to-analog converters (DACs) convert digital numbers into corresponding voltage or current levels. Frequency converters or translators convert or scale input frequencies to specific output frequencies. Along with this, there are a lot of other signal converters such as Frequency converters (Translators), Voltage converters, and many others

II. Results and Discussions

Analog-to-digital converters (ADC) sample an analog signal and convert it to a series of digital values. Most data packages in real-world applications are transmitted using analog signals. In order to be read, manipulated, and analyzed by microprocessors, these signals must be converted to digital information. Analog-to-digital converters exist to accomplish this process.

Analog signals tend to take the form of a continuous wave, while digital ones are purely numerical and, when graphed, take the form of a square wave. Therefore, digital signals may be mapped to analog ones using sampling, the process of measuring the signal at predetermined times.

There are two important parameters related to sampling:

- The sampling rate, fs, determines the number of samples taken per second.
- Sampling precision, N, determines the gradations for the sampling process.

Generally, sampling as quickly as possible with a reasonably fast converter produces the best signal reproduction.

Analog-to-digital converter precision is determined by the number of bits the device possesses. The number of bits, n, is directly related to the number of sampling gradations, N, so that N = 2^n.

Device precision can be defined as 1/N, with smaller values indicating greater precision. For example, a 4-bit converter has a precision 1/16 that of the analog signal, while a 10-bit one is 1/1024 as precise.

A) Flash ADC

A flash ADC (also known as a direct-conversion ADC) is a type of analog-to-digital converter that uses a linear voltage ladder with a comparator at each "rung" of the ladder to compare the input voltage to successive reference voltages. Often these reference ladders are constructed of many resistors; however, modern implementations show that capacitive voltage division is also possible. The output of these comparators is generally fed into a digital encoder, which converts the inputs into a binary value (the collected outputs from the comparators can be thought of as a unary value).

Flash converters are extremely fast compared to many other types of ADCs, which usually narrow in on the "correct" answer over a series of stages. Compared to these, a flash converter is also quite simple and, apart from the analog comparators, only requires logic for the final conversion to binary.

For best accuracy, often a track-and-hold circuit is inserted in front of the ADC input. This is needed for many ADC types (like successive approximation ADC), but for flash ADCs there is no real need for this, because the comparators are the sampling devices.

A flash converter requires a huge number of comparators compared to other ADCs, especially as the precision increases. A flash converter requires $2^n - 1$ comparators for an n-bit conversion. The size, power consumption, and cost of all those comparators make flash converters generally impractical for precisions much greater than 8 bits (255 comparators). In place of these comparators, most other ADCs substitute more complex logic and/or analog circuitry that can be scaled more easily for increased precision.

B) Successive approximation ADC

A successive-approximation ADC is a type of analog-to-digital converter that converts a continuous analog waveform into a discrete digital representation using a binary search through all possible quantization levels before finally converging upon a digital output for each conversion.

The successive-approximation analog-to-digital converter circuit typically consists of four chief subcircuits:

- A sample-and-hold circuit to acquire the input voltage Vin.
- An analog voltage comparator that compares Vin to the output of the internal DAC and outputs the result of the comparison to the successive-approximation register (SAR).
- A successive-approximation register subcircuit designed to supply an approximate digital code of Vin to the internal DAC.
- An internal reference DAC that, for comparison with Vref, supplies the comparator with an analog voltage equal to the digital code output of the SARin.

Since SARs have been around for a long time, SAR designs are stable and reliable, and the chips are relatively inexpensive. They can be configured for both low-end A/D cards, where a single ADC chip is "shared" by multiple input channels (multiplexed A/D boards), or in configurations where each input channel has its own ADC for true simultaneous sampling.

C) Sigma-Delta ADC

A sigma-delta ADC (also known as a delta-sigma ADC) oversamples the incoming signal by a large factor using a smaller number of bits than required are converted using a flash ADC and filters the desired signal band. The resulting signal, along with the error generated by the discrete levels of the flash, is fed back and subtracted from the input to the filter. This negative feedback has the effect of noise shaping the quantization error that it does not appear in the desired signal frequencies. A digital filter (decimation filter) follows the ADC which reduces the sampling rate, filters off unwanted noise signal and increases the resolution of the output. The name comes from integrating or summing differences, which, in mathematics, are operations usually associated with Greek letters sigma and delta respectively.

D) Dual Sloped ADC

In a dual-slope ADC, the input signal is applied to an integrator. At the same time, a counter begins counting clock pulses. After a predetermined amount of time (T), a reference voltage with opposite polarity is applied to the integrator. At that instant, the accumulated charge on the integrating capacitor is proportional to the average value of the input over the interval T. The integral of the reference is an opposing ramp with a slope of VREF/RC. Simultaneously, the counter is again counting from zero. When the integrator output reaches zero, the counter stops, and the analog circuitry is reset. Since the charge gained is proportional to VIN × T, and the equal amount of charge lost is proportional to VREF × tx, then the number of counts relative to the full-scale count is proportional to tx/T, or VIN/VREF. If the output of the counter is a binary number, it will therefore be a binary representation of the input voltage.

The dual-slope ADC architecture was a breakthrough in ADCs for high-resolution applications such as digital voltmeters (DVMs). The dual-slope ADC has the following advantages:

- Noise present on the input voltage is reduced by averaging
- The values of the capacitor and conversion clock do not affect conversion accuracy since they act equivalently on the up-slope and down-slope
- Linearity is very good and extremely high-resolution measurements can be obtained

Its main disadvantage is a slow conversion rate, often in the range of 10 samples/second. In applications where this is not a problem, such as in measuring temperature transducers, a dual-slope ADC is a good choice.

E) Pipelined ADC

For applications that require higher sample rates than SAR and delta-sigma ADCs can provide, but which do not require the ultra-high-speed of the Flash ADCs, we have Pipelined ADCs.

As discussed in the previous section, in a Flash ADC, the comparators are all latched simultaneously, hence the lack of latency. But this requires a lot of energy - especially when more and more comparators are used to achieve higher bit resolution. However, in a Pipelined ADC, the analog signal is not latched by all comparators at the same time, spreading out the energy required to convert the analog to a digital value. Hence the flash comparators are "pipelined" into a quasi-serial process of 2-3 cycles. This has the benefit of allowing higher resolutions to be achieved without huge energy, but it imposes two penalties: sample rates cannot be as high as a pure Flash approach, and there is a latency of typically of 3 cycles. This can be mitigated somewhat but can never be completely eliminated.

These ADCs are a popular architecture for applications from 2-3 MS/s to 100 MS/s (1 GS/s is possible). For sample rates beyond this, Flash ADC technology is typically employed. The resolution of Pipelined ADCs can be as high as 16-bits at the lower sample rates but are typically 8-bits at the highest sample rates. Again, there is always a trade-off between speed and resolution.

III. CONCLUSION

The following table puts summarizes the discussion:

ADC Type	**Pros**	**Cons**	**Max Resolution**	**Max Sample Rate**	**Main Applications**
Successive Approximation (SAR)	Good speed/resolution ratio	No inherent anti-aliasing protection	18 bits	10 MHz	Data Acquisition
Delta-sigma (ΔΣ)	High dynamic performance, inherent anti-aliasing protection	Hysteresis on unnatural signals	32 bits	1 MHz	Data Acquisition, Noise & Vibration, Audio
Dual Slope	Accurate, inexpensive	Low speed	20 bits	100 Hz	Voltmeters
Pipelined	Very fast	Limited resolution	16 bits	1 GHz	Oscilloscopes
Flash	Fastest	Low bit resolution	12 bits	10 GHz	Oscilloscopes

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