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A to D Converters used in Microsystems

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Abstract

There is strong interest in the development of very small integrated microsystems capable precision measurements of environmental parameters and yet able to operate by scavenging energy from their surroundings. The measurement of environmental temperature, pressure, and humidity using solar power or the measurement of blood pressure using kinetic energy derived from the beating heart are possible examples. In order to realize such microsystems, a number of circuit blocks will be needed, including the sensors themselves, the readout and control electronics, a suitable power source, and some means of storing the information and/or reporting it to the outside world.

In a microsystem, using capacitive devices, sensing can be accomplished with virtually no expenditure of energy. On-board data storage in static RAM can also be accomplished with modest energy use. The use of oscillators for reading out capacitive sensors can be done with very little energy. Data conversion can be accomplished using ultra low power Analog to Digital Converters (ADC). This paper discusses the application of ADCs in a microsystem and four common ways of implementing the ADC function. The four common ways are sigma delta, successive approximation, sub ranging and flash. The advantages and disadvantages of each ADC circuit and the interplay between accuracy, resolution, sampling rate, size, and power are discussed in the paper also.

Operation of an A to D Converter in a Microsystem

A microsystem is a unit capable of gathering electronic data from the physical world, processing and acting on the information and transferring the data to other electronic systems which gain intelligence from this process. Capacitive sensors are widely used in application areas for measurement of physical quantities such as pressure. They offer high sensitivity, yet consume no power and can be readout rapidly using low power techniques. In the block diagrams of the readout circuitry in a microsystem is shown in Figure 1. An integrator is used to convert the changes in pressure to an electrical parameter. Pressure changes are detected by a capacitive transducer. The integrator serves as a capacitance to voltage converter. The amplitude of the integrator's output voltage changes as the capacitance changes on the capacitive transducer. The voltage output of the inverter is sent to an analog to digital converter. The output voltage of the integrator is then converted to a digital signal by the analog to digital converter and stored in the memory or sent to a microcontroller.

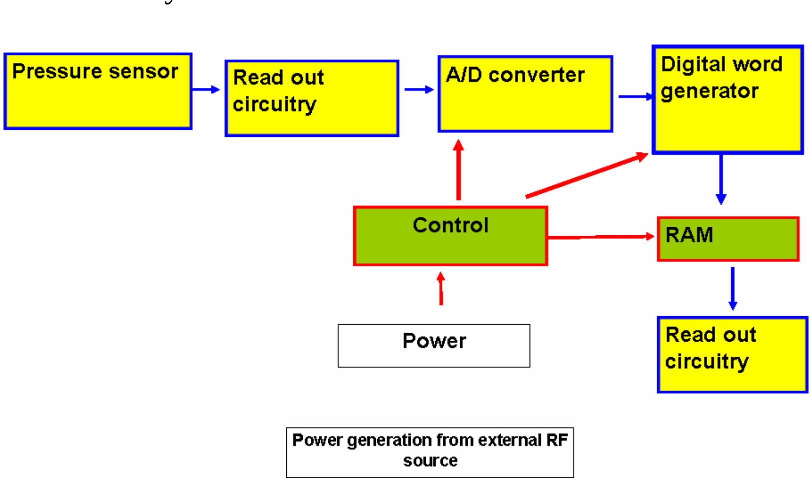

Figure 1: Block Diagram of Readout Circuitry in a Microsystem

Operation of an A to D Converter

An A to D converter is a device that converts an analog (continuous) signal to discrete digital numbers. These devices vary in resolutions, bandwidths, accuracies, architectures, packaging, power requirements, and temperature ranges, as well as hosts of specifications and requirements, covering an expansive range of performance needs. Consequently, with the varying application in data-acquisition, instrumentation, communications, and interfacing for signal processing, it is important that the right A to D device is used for a specific application.

The Analog to Digital Converter (ADC) is the popular way of introducing analog inputs into a microprocessor. The analog-to-digital converter (ADC) accepts an analog input, be it a voltage or a current, and converts it to a digital value that can be read by a microprocessor. Figure 2, shows a block diagram of a typical ADC.

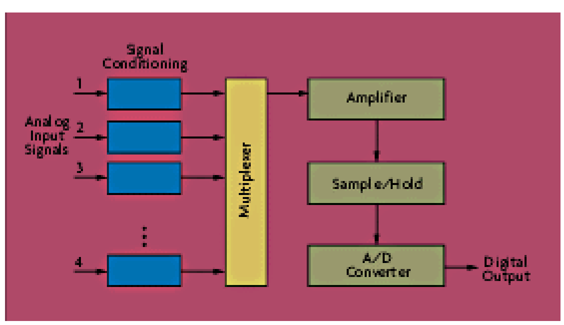

Figure 2: Block Diagram of an Analog to Digital Converter

The resolution, accuracy, sampling rate, size, and power all play a significant role in all A to D converters. The resolution of an A to D converter is specified in bits and determines how many distinct codes (2^N) a converter is capable of producing. For this research a 4-bit converter will be used. A 4 bit converter is capable of 2^4 or 16 output codes. The accuracy of an ADC has to do with the number of bits of an output code which represents useful information about the input signal. Useless information is considered an error. There are two factors in errors: quantization and non- linearity (only if the ADC is intended to be linear). Quantization error is due to the finite resolution of the ADC, and is an unavoidable imperfection in all types of ADC. The magnitude of the quantization error at the sampling instant is between zero and half of one LSB. The analog signal is continuous in time and is necessary to convert to a flow of digital values. It is therefore required to define the rate at which new digital values are sampled from the analog signal. The rate of new values is called the sampling rate of the converter.

Different Types of Analog to Digital Converters

As shown above in Figure 3, ADCs differ in resolution and bandwidth. Bandwidth is the numerical difference between the upper and lower frequencies of a band of electromagnetic radiation or the amount of data that can be passed along a

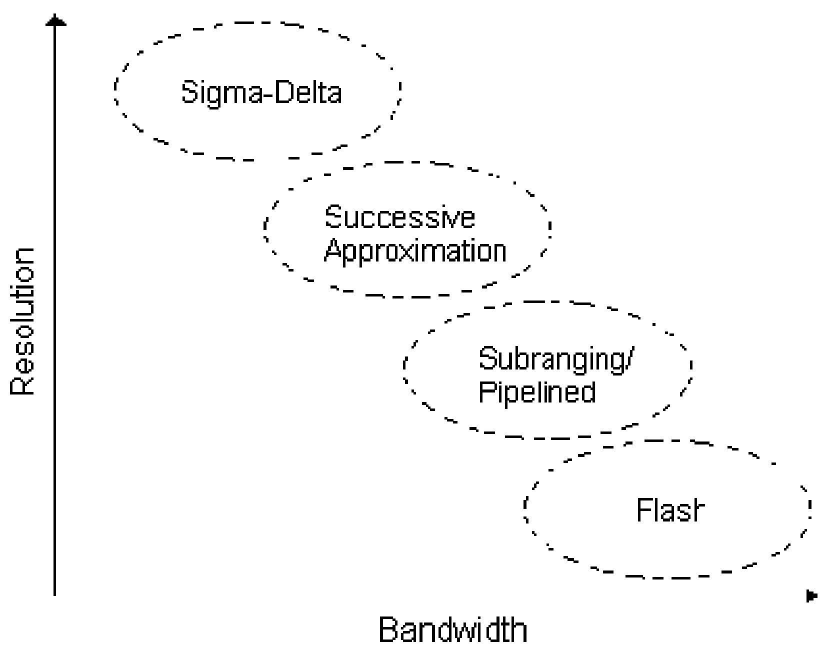

Figure 3 - A/D Converter technologies, resolution and bandwidth

communications channel in a given period of time. Each ADC has advantages and disadvantages. The Sigma-Delta converter provides as much as 24-bits of resolution at the price of speed. Due to its capability of such high resolutions, it is used in weighing systems and temperature-based applications. The Successive Approximation (SAR) ADC uses a comparator to reject ranges of voltages and eventually finds a voltage range. A comparator is a device which compares two voltages or currents, and switches its output to indicate which is larger. More generally, the term is also used to refer to a device that compares two items of data. SARs have good resolution, decent bandwidth but the design is a little more complex. The Sub-Ranging ADC uses two or more steps of sub ranging. First, the ADC does a coarse conversion and next, the difference of the input signal is found by a digital analog converter. Finally, the differences are converted and the results are found. The Flash Converter usually has a low resolution which is only as high as 8-bits. It is the fastest ADC but it needs a very expensive circuit to operate. They are ideal for applications that need large bandwidths but they consume more power than most ADCs. Flash ADCs are also more prone to glitches and are not the most accurate.

When selecting the best ADC for your situation, it all depends on what you need. For example: if temperature measurements are needed, then an ADC with a high resolution would be need because temperatures are usually measured in small increments. One the other hand, anything that can be measured in large increments could use an ADC with low resolution like Flash ADC. As stated before, accuracy, resolution, sampling rate, size, and power are always going to have an effect on your decision as to which ADC to use. For our research the SAR was selected because power was the major concern. Table 1 with summarizes the advantages and disadvantages of each ADC mentioned.

Table 1: ADC Summary

Type	Resolution (bit)	Sample rate (MSPS)	SNR (dB)	Power	Advantages	Disadvantages
SAR Converter	14	3	78	85mW	Low power, Low circuit complexity, Comparator offset does not affect the linearity of the overall converter; high degree of performance; compared to cost; because lower power dissipation leads to a lower temperature rise, greater reliability , and fewer problems with warm-up and temperature drift; low power, accuracy and high resolution	Low sampling rate, parasitic capacitance affects the linearity, capacitor array consumes area; sample rates limited t 1MHz;dependent of sample and hold and an anti-alias filter is required
Sigma-Delta Converters Maxim (1402)	18	480	110	Low power	They are inherently linear and present little differential non linearity, they do not require and external sample and hold circuit; high resolution	Most of the circuitry in sigma-delta converts is digital, they are inherently monotonic

Flash	8	120	46	1.4W	Fastest way to convert and analog signal to a digital signal; suitable for applications requiring very large bandwidths.	Consumes more power than other ADCs, limited to 8 bits, limited to high frequency applications that typically cannot be addressed any other way, very expensive
Sub Ranging (pipeline) combination between SAR and Flash converters	8	40	45	150mW	Reduces the number of comparators and logic complexity, used when higher resolution or smaller die size and power is needed	Slower conversion speed; errors can occur due to settling time

The Successive Approximation Register (SAR)

Our research group has chosen to investigate the Successive Approximation Register (SAR). The SAR has a high resolution, and accuracy (18 bits); it is easy to multiplex, has few external components and is low cost. Its disadvantages are that its sample rate is limited to approximately 1 MHz. The SAR's conversion process is relatively faster than the delta-sigma converter's. The clock pulses required to implement a complete conversion by the SAR converter are typically no more than two pulses plus the number of converter bits. For example, a 12-bit converter typically requires 14 clock pulses. This method of conversion presents significant advantages if the SAR converter is integrated with the microcontroller. Some of these advantages that the SAR has over other ADC are: speed, noise reduction, and reduced chip count. In terms of speed, the SAR converter completes its task quickly so the microcontroller can execute other tasks in the applications. In terms of noise reduction, the quick conversion time reduces opportunities for noise to get into the conversion system. The control unit of a microprocessor directs the operation of the other units by providing timing and control signals.

References

1. http://www.rmsinst.com/dt3.htm
2. http://en.wikipedia.org/wiki/Analog_to_digital_converter
3. http://ww1.microchip.com/downloads/en/appnotes/00693a.pdf

4. http://www.omega.com/literature/transactions/volume2/analogio2.html

5. K. Kundert, et al., "Design of Mixed-Signal Systems on Chip, "IEEE Trans. On CAD, vol.19, no. 12, pp.1561-1572, Dec. 2000.

6. A. Doboli, et al., "Behavioral Synthesis of Analog Systems using Two Layered Design Space Exploration," IDDD/ACM DAC, June 1999.

7. K. Kundert, "A Formal Top-Down Design Process for Mixed-Signal Circuits," Advances in Analog Circuit Design, April 2000.

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