The Real World Versus Your ADC

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Sensors that measure real-world variables seldom have output signals that can be directly connected to a data converter in a system. Typically, there are requirements to amplify, filter, shift offset, and perform other conditioning functions. Various device families perform these analog signal processing functions, each with unique strengths and application requirements.

Where The Real-World Lies

Real-world phenomena that we sense in a variety of applications occur in different frequency ranges (Fig. 1). Low-frequency entities such as temperature and pressure produce low-level output signals. As a result, these sensor signal paths require high-resolution converters.

Additionally, temperature and pressure changes occur at slower speeds, so the accompanying converter can have a lower conversion rate. Resistance temperature detector (RTD), thermocouple, thermistor, diode, thermopile, and silicon temperature sensors all are common.

The pressure sensor construction usually is modeled with a diamond shaped, four-element resistive network. Additionally, pressure systems often require temperature sensors to help maintain accurate readings. Generally, these sensors use successive approximation register (SAR) analog-to-digital converters (ADCs) or sigma-delta ADCs in their signal path.

Flow sensors are temperature sensors, pressure sensors, or audio sensors (microphones). Physical changes in the flow of gases or liquids are relatively slow, and the measurement bandwidth complements that speed.

Among the higher bandwidths, displacement, proximity, and photo-sensing circuits have lower precision requirements. These photo-based sensors require higher-frequency converters, such as SAR converters or high-speed sigma-delta converters. At higher frequencies, imaging and test measurements require lower levels of precision. Pipeline or high-speed SARs are best suited for these applications.

There is a variety of ADC architectures on the market today in addition to SAR, sigma-delta, and pipeline. The SAR and sigma-delta converters usually operate in dc to low-frequency applications where accuracy is more important than speed. Pipeline converters are most appropriate for high-speed application circuits.

The sigma-delta ADC determines its digital word by oversampling the analog input signal. The sigma-delta input modulator stage converts the analog input signal to a 1-bit digital data stream. A following digital filter collects the data from this 1-bit data stream and converts it to a multibit output word. The output resolutions of delta-sigma ADCs typically range from 16 to 24 bits.

In contrast, the SAR ADC acquires a snapshot of the analog signal. After acquiring this sample, the SAR converter uses an internal iterative process to finally determine the equivalent digital output value. The output resolutions of SAR ADCs typically range from 8 to 18 bits.

The sampling speed of pipeline converters allows for undersampling activities. In an undersampling system, the input-signal bandwidth’s center is at a higher frequency than the sampling frequency of the converter. With pipeline ADCs, the conversion occurs with the use of a sample/gain ladder.

There are multiple stages in the pipeline converter, which causes a cycle-latency. For ADCs, cycle-latency is equal to the number of complete data cycles between the initiation of the input-signal conversion and the initiation of the next signal conversion. The unit of measure for this definition of latency is (n)-cycle latency, where n is a whole number.

Mapping The Real World

The different converter architectures have their own ranges of converter resolution and conversion rate (Fig. 2). In general, sigma-delta converters are used for high resolution at low data rates. The sigma-delta’s advantages include low power, high resolution, and high stability at a low cost. These advantages are obtained mostly in the digital portion of the circuit. Disadvantages usually include low speed and, in some converters, non-zero cycle-latency.
2. Converter resolution and conversion rate favor different kinds of applications.

These devices can produce output bit ranges from 16 to 24 bits, which in and of itself is impressive. This overall performance of the sigma-delta ADC reduces the number of analog signal-conditioning chips prior to the input of the ADC. Delta-sigma converters are used in many high-accuracy sensor applications.

Sigma-delta converters in development today are working toward higher and higher resolutions at low speeds as well as higher speeds. The oversampling nature of the sigma-delta converter now allows for greater accuracy at higher speeds with less analog front-end circuitry, saving the designer debug (test) time, space, and money.

SAR converters are used for moderate speed at medium to high resolutions. They’re the backbone of general-purpose application circuits that need analog signals to be changed to digital. The resolution generally is lower than the sigma-delta converter.

However, the SAR converter has a zero-cycle latency (or single cycle settling) while operating at higher speeds. SAR converters are used in many data-acquisition applications like control loops, power monitoring, and low- to medium-frequency analysis.

Also, SAR converters boast high dc and ac accuracy. Typically, you can use SAR converters in low-power applications because, when they aren’t in use, they automatically power down. The sampling rates of SAR converters peak at 5 MHz, though. Still, SAR converters fill the gap in resolution and speed between the sigma-delta converter and pipeline converter.

Pipeline converters are very fast and often are used in undersampling applications. Undersampling is a sampling technique that occurs above the signal frequency bandwidth, but still obeys the Nyquist criterion for sampling twice the signal bandwidth of interest. Generally, the pipeline converter has lower resolution than the SAR or sigma-delta converter. It requires more power, and there’s a greater than zero-cycle latency. In most applications where a pipeline converter is in use, this cycle latency has no impact on the system.

When selecting an ADC for a particular application, first look at the ADC’s architecture. There are three main ADC architectures: SAR, sigma-delta, and pipeline (Table 1).

<table>
<thead>
<tr>
<th>Topology</th>
<th>Conversion rate</th>
<th>Resolution</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAR</td>
<td>&lt;5 Msamples/s</td>
<td>Up to 18 bits</td>
<td>Simple operation, low cost, low power</td>
</tr>
<tr>
<td>Sigma-delta</td>
<td>&lt;625 ksamples/s</td>
<td>Up to 24 bits</td>
<td>Slow, moderate cost</td>
</tr>
<tr>
<td></td>
<td>&lt;250 Msamples/s</td>
<td>Up to 16 to 18 bits</td>
<td></td>
</tr>
<tr>
<td>Pipeline</td>
<td>&lt;500 Msamples/s</td>
<td>Up to 16 bits</td>
<td>Fast, expensive, high power requirements</td>
</tr>
</tbody>
</table>

The SAR converter is a great general-purpose converter. Users can trigger sampling at their discretion and power down. It’s low cost and simple to use as well. The sigma-delta converter offers much higher resolutions than the SAR and less complex front-end signal conditioning requirements. For very high resolution (24 bits), sigma-delta is the only choice (at a sample rate of less than 625 Hz). The pipeline converter is very fast, offering up to 16 bits of resolution.

This invites a comparison among these three architectures for throughput, resolution, latency, and power consumption (Table 2). As technology improves and the three architectures start overlapping each other’s application spaces, designers will be able to choose between the three based on priorities like power, latency, accuracy, and cost.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Pipeline</th>
<th>SAR</th>
<th>Sigma-delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput (samples/s)</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Resolution (effective number of bits)</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Latency (sample-to-output)</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Able to convert non-periodic, multiplexed inputs</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Power consumption</td>
<td>Constant</td>
<td>Scales with sample rate</td>
<td>Constant</td>
</tr>
</tbody>
</table>
References