baker's**best** *By Bonnie Baker, Microchip Technology Inc*

Is your converter accurate?

WHAT DOES ADC ACCURACY really mean? You might say that it means that the ADC output code represents the actual analog-input voltage minus the quantization error. This scenario makes sense, but do you see a precise determination of the analog input?

Does accuracy also mean that the A/D-conversion results are repeatable? Is the converter output code repeatable from transition to transition, with everything remaining unchanged in the circuit during successive conversions?

Theoretically, an ADC code-to-code transition may be sharp, occurring at a unique input voltage. Actually, the transition regions in the ADC-transfer function may be wide. In fact, these regions may span several digital-output codes. In **Figure 1**, a transition point occurs where the digital output switches from one code to the next with respect to a specific analog-input voltage. But, because of ADC internal noise, the transition point is typically not a single threshold, but rather a small region of uncertainty. Consequently, you need to define the transition point as the statistical average of many conversions. In other words, the voltage-input value is the point at which half the conversions produce one digital code and the other half produce the adjoining digital code. Upon closer inspection, the conversions you collect appear to be noisy, with a Gaussian probability curve.

Assuming that you are using good layout techniques, bypass capacitors, and so on in your circuit, one quick converter experiment grounds the input of a good 16-bit ADC. Next, collect 1024 samples at the converter's specified conversion rate. Multiple codes in the output data exist. Witness the converter's transition noise. Some manufacturers indicate the rms transition noise for their ADCs. Multiply the rms-transition-noise specification by 6.6 to obtain a peak-to-peak value.

Taking this discussion a step further, the offset, gain, differential nonlinearity, and integral nonlinearity are the accuracy specifications for ADCs. Some manufacturers also call these characteristics the dc specifications, because these device tests use a dc-input voltage for the conversions. But these specifications do not indicate how repeatable the results are from conversion to conversion. They indicate only that, on the average, these errors are no more or no less than the minimum and maximum in your ADC manufacturer's data sheet. To precisely describe your converter's accuracy, you need to combine the ac specifications with the dc specifications.

Three types of ac specifications exist, but one is particularly interesting for this discussion: the SINAD (signal-to-noise-plus-distortion) ratio. The counterpart of this specification is ENOB (effective number of bits). ENOB=(SINAD-1.76 dB)/6.02. Combining this specification with the dc specifications gives you a stronger feel for how accurate your converter really is.□

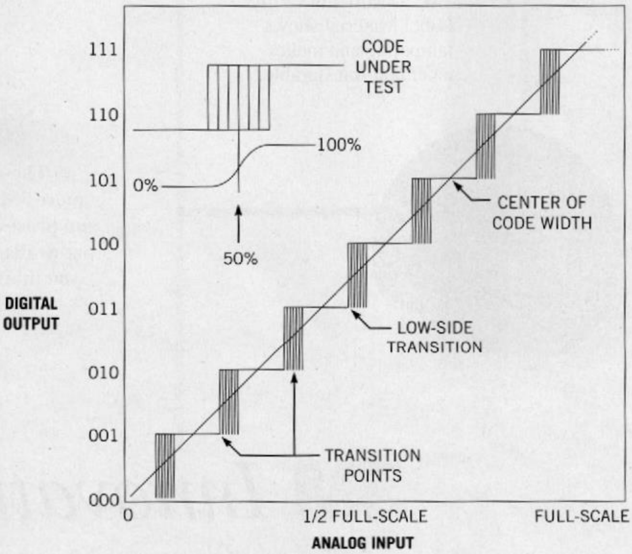

Figure 1 **This 3-bit ADC's nonideal transfer function illustrates the transition noise of every code.**

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Accuracy comes in many flavors

MOST PROCESS-CONTROL APPLICATIONS require digital results that have resolution of one part in 4096. By definition, the digital output of a 12-bit ADC has 4096 digital combinations. This feature makes the ADC look like a perfect fit. So, why do these applications use ADCs with a higher number of bits? Pay no attention to the number of digital codes or the full-scale input range of the ADC. Instead, look at the system-accuracy requirements or analog-voltage LSB size.

Designing circuits around the ADC's LSB is easy (full-scale range/2^n). Using the system-LSB size in your design is a different story. Take, for instance, an RTD (resistive-temperature-detector) temperature-sensing circuit. A platinum RTD sensor, such as the PR-100, equals 100Ω at 0°C and increases 38.5Ω every 100°C. A 1-mA current source excites the sensor. You can capture, condition, and convert the voltage drop across the sensor. With a 400°C change in the environment, the RTD resistance has a delta change of 154Ω. If the desired system-LSB size is 0.1°C over 40°C, the granularity of the voltage across the RTD sensor is one part in 4000, or 4000 38.5-μV steps. So, with the system-LSB size of 0.1°C and the full-scale range of 400°C, it is easy to see that you can implement the design with a 12-bit converter, right?

For a temperature range of 0 to 400°C, the voltage range across the RTD element is 90.375 to 244.375 mV. If you use a 12-bit, single-supply ADC, you need an analog-gain stage. In reviewing the gain, input swing, output swing, and precision limitations, you can solve this gain problem with a dual, single-supply operational amplifier. In this application, the gain of the analog amplifier stage should be ~20V/V. This fix sounds easy, but the subtleties may take you by surprise. With a gain of 20V/V, the amplifier's output swing is 1.8075 to 4.8875V. With this voltage range, you underuse your 12-bit ADC. You can work around this problem. One possible option uses a 12-bit A/D SAR (successive-approximation-register) converter that has the combination of differential inputs and adjustable-input ranges.

But now it's time to regroup. The LSB size of the measurement is 0.1°C. The measurement's full-scale range is 400°C. The RTD's LSB size is 38.5 mΩ, and its full-scale range is 154Ω. If you excite the RTD with 1 mA, the analog system's LSB size is 38.5 μV, and the full-scale range is 154 mV.

PAY NO ATTENTION TO THE NUMBER OF DIGITAL CODES OR THE FULL-SCALE INPUT RANGE OF THE ADC. INSTEAD, LOOK AT THE SYSTEM-ACCURACY REQUIREMENTS OR ANALOG-VOLTAGE LSB SIZE.

Forget the analog-gain stage. Find a converter that can reliably digitize the analog signal to as little as the 38.5 μV divided by two, or 19.25 μV. If you use a high-resolution converter, such as a delta sigma, you can not only throw away your analog-gain stage, but also ignore unused bits.

How does this scenario work? If you find a converter with a full-scale range of 5V and a high-resolution ADC with peak-to-peak noise accuracy of 18 bits, you will receive the desired results. You calculate this step with the following formula: Number of bits=1.44*ln (full-scale range/LSB).

You need to apply some specmanship when using high-resolution converters. For instance, if you expect a reliable, repeatable result with every digital output word, understanding the terms "rms" and "peak to peak" is critical. The units of rms imply a calculated value that is within one standard deviation, based on several hundred samples. A peak-to-peak specification predicts the probability that one conversion result will fall into an expected range. If you use a crest factor of 3.3 to calculate the peak-to-peak LSB size, or effective number of bits, your converter's results will fall within a 99.9% window of the expected result (peak to peak=2×crest factor×rms). Imagine that the system you are designing needs a repeatable output resolution of 18 bits. This scenario implies that the rms resolution of the converter is 20.723 bits. Industrial-quality delta-sigma ADCs have this type of performance.

A 12-bit application may not always need a 12-bit converter. The system actually dictates the real dynamic range. Throwing away unused codes may give you heartburn, because you are throwing away the full dynamic range. But don't worry. You make up for it with your reduced chip count. And in this market, bits and dynamic range are like memory: They are getting less expensive as time goes on.□

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