Predict the Repeatability of Your ADC to the BIT

By Bonnie C. Baker, Microchip Technology Inc.

ANALOG DESIGN NOTE



One of the more common A/D Converter (ADC) questions design engineers ask is, "How do I know that an ADC will give me good, reliable code and can I determine this from the converter's data sheet?" Of course, this depends on your definition of "reliable". If you are looking for a repeatable output from conversion to conversion, you should refer to AC domain specifications. The AC domain specifications are Signal-to-Noise Ratio (SNR), Effective Resolution (ER), Signal-to-(Noise + distortion) (SINAD) and Effective Number of Bits (ENOB). These specs will give you the information you need so that you can determine the level of repeatability of our ADC. This is true even when you perform DC conversions, because you are looking for repeatability, not accuracy!

You will notice that this list does not include offset, gain, Differential Non-linearity (DNL) or Integral Non-linearity (INL), which are DC specifications. These specifications refer to the accuracy of the converter, not the repeatability.

AC domain specifications provide information about ADC repeatability. All four specifications are derived from taking a large amount of clocked samples out of the converter. When you are interested in getting fairly repeatable result, a 12-bit converter requires 4096 samples that are collected at a predetermined data rate. The actual number of samples that are required for all four of these measurements can be calculated using the formula:

FFT Accuracy =
$$\pm 4 \text{ dB/(n}\sqrt{\bullet} \text{ N)}$$

Where,

FFT Accuracy =
$$\pm 4 \text{ dB/(nv \bullet N)}$$

n is the number of bits for the converter, and N is the number of samples in the sample set The SNR is a measurement of the quantization noise combined with the other internal ADC noise from the transistors. The unit of measure for SNR is dB. Signal-to-Noise ratio measurements are best suited for SAR, Pipeline and Flash converters, to name a few. A SNR measurement does not make sense for the Delta Sigma ADC. This is because an AC input signal is required and the Delta Sigma ADC is designed for DC inputs.

Ideally, the SNR of a converter is equal to 6.02n + 1.76 dB, where n is equal to the number of converter bits. This theoretical, RMS noise is caused by the quantization error of the ideal converter. The quantization error in an ADC occurs because each output conversion code can occur across a small range of the input voltage signal, hence the error.

In practice, SNR is equal to 20 log (RMS Signal)/(RMS noise). The real SNR of an ADC is calculated using the fundamental and noise bins in a Fast Fourier Transform (FFT) plot. The FFT plot of a 12-bit ADC with an input signal of 9.9 kHz is shown in Figure 1. With the actual test, the sinusoidal input signal noise should be more than three times lower than the ideal noise of the ADC. If this is true, the RMS signal is equal to the signal magnitude divided by $\sqrt{2}$.

The noise from the converter is calculated using the measured magnitude of the bins in this FFT graph. The bins that are excluded in the denominator of the SNR calculation are DC, the fundamental, and harmonics of the input fundamental, such as 19.8 kHz, 29.7 kHz, etc. The RMS noise from the converter is calculated by taking the magnitude of each of these bins, squaring them, adding all of the squared bins together and then calculating the square-root of that summation (the square-root of the sum-ofthe-squares). The calculated SNR of the data ("C") from this 12-bit converter is shown in the graph.



This is the FFT plot of 4096 samples taken from the MCP3201, 12-bit ADC at a data rate of 100k samples-Figure 1. per-second. During this test, the sinusoidal input signal frequency was 9.985 kHz.

The RMS input signal is sinusoidal and about 0.5 dB smaller than the full-scale input range of the converter. In order to determine the RMS noise, many conversion results need to be collected and then converted to a FFT representation. Remember, the samples for this type of test are taken at a defined data rate in order to capture the appropriate frequency information.

The ER is a counterpart of SNR in that it refers to the noise of the converter; where SNR units are in decibels and ER units are bits or volts. SNR requires an input signal for comparison and ER is measured with a DC input signal, which is half-way between the power supply rails. ER measurements are more appropriate for integrating converters such as Delta Sigma ADCs. ER can be changed from volts to bits with the following formula:

$$ER(bits) = ln \left(\frac{FSR}{ER (in volts)}\right) / ln(2)$$

Where FSR is the full-scale range of the converter in volts.

While SNR or ER provides information about the device noise of the converter, SINAD and ENOB specifications provide more information about ADC frequency distortions. SINAD is the ratio of the RMS amplitude of the fundamental input frequency of the input signal to the RMS sum of all the other spectral components below one half of the sampling frequency (excluding DC). This includes noise, as well as the harmonics. The theoretical minimum for SINAD is equal to the SNR or 6.02n + 1.76 dB. In practice, an ADC will create some harmonic distortion of this input signal. This distortion is generated inside the converter. It is customary to use at least nine harmonics in this calculation.

The SINAD is a measure of the resulting distortion of a sinusoidal input signal plus the same noise that was measured with SNR. With this test, the input signal is "distortion-free". The distortion in this measurement is generated by the ADC through the conversion process. The units of SINAD are decibels.

The complementary specification to SINAD is ENOB. The unit of measure for SINAD is dB and the unit of measure for ENOB is bits. SINAD can be converted to ENOB with the calculation:

ENOB = (SINAD - 1.76)/6.02

Both SINAD and ENOB measurements require an input sinusoidal input. Therefore, these specifications are best suited for SAR, Pipeline and Flash converters (to name a few) and not sampling converters such as the Delta Sigma ADC.

These two measurements quantify not only the noise generated by the converter, but also the distortion of the input signal as it travels through the converter. Once again, reliable measurements require a large sample size with the sample taken at a constant clock rate. The MCP3201 is a successive approximation 12-bit ADC from Microchip Technology Inc. The device provides a single pseudodifferential input. The performance of this device is shown in Figure 1.

Signal-to-Noise Ratio of the MCP3201 is specified at 72 dB (typ). The SINAD and ENOB is 72 dB (typ) and 11.67 bits (typ), respectively. The conditions of these specifications are $V_{DD} = 5V$, $V_{REF} = 5V$, $f_{SAMPLE} = 100$ ksps and the ambient temperature equals 25°C. Since this device is a sampling converter, as opposed to an integrating converter, ER is not specified.

Communication with this device is done using a simple serial interface compatible with the SPITM protocol. The device is capable of sample rates of up to 100 ksps at a clock rate of 1.6 MHz. The MCP3201 operates over a broad voltage range (2.7V - 5.5V). Low current design permits operation with typical standby and active currents of only 500 nA and 300 μ A, respectively.

So, the answer to the question, "How do I know that an ADC will give me a good, repeatable code?", can be found in the converter product data sheet by looking at the SNR, ER, SINAD and ENOB specifications. Once again, if you know the behavior of your converter, you can confidently convert at any data rate and should know that your results will fall within a specified boundary. With this information, you are now armed to tackle your DC and ac ADC repeatability challenges.

References:

"Anticipate the Accuracy of Your Converter", Baker, Bonnie C., EDN Magazine, March 18, 2004

"Reading and Using Fast Fourier Transforms", Baker, Bonnie C., AN681, DS00681, Microchip Technology Inc.

"Understanding Data Converters' Frequency Domain Specifications", Leonard, Bob, AN-4, Datel



For more information, please visit <u>www.microchip.com</u>

The Microchip name and logo and the Microchip logo are registered trademarks of Microchip Technology Inc. in the U.S.A. and other countries. SPI is a trademark of Motorola Inc. All other trademarks mentioned herein are the property of their respective owners. Information subject to change.
© 2004 Microchip Technology Inc. 5/2004