BY BONNIE BAKER

Where did all the bits go?

Theoretically, the SNR (signal-to-noise ratio) of an ADC is equal to (6.02N+1.76) dB, where N equals the number of ADC bits. Although I'm a little rusty with my algebra skills, I think that the SNR for any 16-bit converter should be 98.08 dB. However, I see something different when I read converter data sheets. For instance, the specification for a 16-bit SAR (successive-approximation-register) converter can typically be as low as 84 dB and as high as 95 dB. Manufacturers proudly advertise these values on the front page of their data sheets, and, frankly, an SNR of 95 dB for a 16-bit SAR converter is competitive. Unless I am wrong, the 98.08 dB I calculate is higher than the 95-dB specification that I find with the best of the 16-bit-converter data sheets. So, where did the bits go?

Let's start by finding out where this ideal formula, 6.02N+1.76, comes from. The SNR of any system, in decibels, is equal to 20 $\log_{10}$ (rms signal/rms noise). When you derive the ideal SNR formula, you first define the rms signal. If you change a peak-to-peak signal to rms, you divide it by the 2$\sqrt{2}$. The ADC rms signal in bits is equal $(2^{(N-1)} \times q)/2\sqrt{2}$, where q is the LSB (least-significant bit).

All ADCs generate quantization noise as a consequence of dividing the input signal into discrete "buckets." The ideal width of these buckets is equal to the converter's LSB size. The uncertainty of any ADC bit is $\pm 1/2$ LSB. If you assume that this error's response is triangular across each bit, the rms value equals this LSB signal's magnitude divided by $\sqrt{3}$: rms noise = $\pm$(LSB/2)/$\sqrt{3}$=q/$\sqrt{12}$.

Combining the rms-signal and rms-noise terms, the ideal ADC SNR in decibels is:

$$SNR = 20 \log_{10} \left(\frac{\left(2^{(N-1)} \times q/2\sqrt{2} \right)}{q/\sqrt{12}} \right)$$
$$= 6.02N + 1.76.$$

Again, where did the bits go? The ADC vendors enthusiastically explain the missing-bits phenomenon, because they bench-test their devices to see how good the SNR is. Fundamentally, they find that the device noise from resistors and transistors creeps into the results. Vendors test their ADC SNR by inputting their data into the following formula:

$$SNR = 20 \log_{10} \frac{RMS\ SIGNAL}{RMS\ NOISE}.$$

These theoretical and tested SNR formulas are complete, but they provide only part of what you need to know about how many bits your converter is truly giving you. THD (total harmonic distortion), another ADC specification you need to watch, is the ratio of the rms sum of the powers of the harmonic components, or spurs, to the input-signal power: THD_{RMS}=20 $\log_{10}\sqrt{((10^{HD2/20})^2+(10^{HD3/20})^2+(10^{HD4/20})^2+ ...)}$, or

$$THD_{RMS} = 10 \log_{10} \left(\frac{P_S}{P_O} \right),$$

where HDx is the magnitude of distortion at the Xth harmonic, P_S is the signal power of the first harmonic, and P_O is the power of harmonics two through eight. Significant ADC INL (integral-nonlinearity) errors typically appear in the THD results.

Finally, SINAD (signal-to-noise and distortion) is the ratio of the fundamental input signal's rms amplitude to the rms sum of all other spectral components below half of the sampling frequency, excluding dc. The theoretical minimum for SINAD is equal to the ideal SNR, or 6.02N+1.76 dB, with SAR and pipeline converters. For delta-sigma converters, the ideal SINAD equals 6.02N+1.76 dB+10 $\log_{10}(f_S/(2BW))$, where f_S is the converter sampling frequency and BW is the maximum bandwidth of interest. The not-so-ideal value of SINAD is $-20 \log_{10}\sqrt{(10^{-SNR/10}+10^{+THD/10})}$, or

$$SINAD = 10 \log_{10} \frac{P_S}{P_N + P_D},$$

where P_S is the fundametal signal power, P_N is the power of all the noise spectral components, and P_D is the power of all the distortion spectral components.

So, the next time you're looking for lost bits, remember that it is the combination of SNR, THD, and SINAD that gives you the complete picture of the real bits in your ADC—regardless of whether it's SAR, pipeline, or delta-sigma technology and regardless of the number of bits that the first page of the data sheet mentions. EDN

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