BY BONNIE BAKER

Delta-sigma ADCs in a nutshell, part 2: the modulator

A delta-sigma converter uses many samples from the modulator to produce a stream of 1-bit codes. The delta-sigma ADC accomplishes this task by using an input-signal quantizer running at a high sample rate. Like all quantizers, the delta-sigma modulator takes an input and produces a stream of digital values that represents the voltage of the input. You can look at the delta-sigma modulator in the time or in the frequency domain. If you look at a time-domain representation, you can see the mechanics of a first-order modulator (**Figure 1**).

The modulator measures the difference between the analog-input signal and the analog output of a feedback DAC. An integrator then measures the analog-voltage output of the summing junction and presents a sloping signal to the 1-bit ADC. The 1-bit ADC converts the integrator's output signal to a digital one or zero. Using the system clock, the ADC sends the 1-bit digital signal to the modulator's output, as well as back through the feedback loop, where a 1-bit DAC is waiting.

The 1-bit ADC digitizes the signal to a coarse output code that has the quantization noise (e_i) of the converter. The modulator output is equal to the input plus the quantization noise, (e_i-e_{i-1}). As this formula shows, the quantization noise is the difference of the current error (e_i) minus the previous error (e_{i-1}) of the modulator. The time-domain output signal is a pulse-wave representation of the input signal at the sampling frequency, f_S. If you average the output-pulse train, it equals the value of the input signal.

The frequency-domain diagram tells a different story (**Figure 2**). The time-domain output pulses in the frequency domain appear as the input signal (or spur) and shaped noise. The noise characteristic in **Figure 2** is the key to the modulator's frequency operation.

Unlike most quantizers, the delta-sigma modulator includes an integrator that shapes the quantization noise. The noise spectrum at the modulator output is not flat. More important, in a frequency analysis, you can see how the modulator shapes the noise to higher frequencies, facilitating the production of a higher resolution result.

The modulator output in **Figure 2** shows that the quantization noise of the modulator starts low at 0 Hz, rises rapidly, and then levels off at a maximum value at the modulator sampling frequency.

Integrating twice with a second-order modulator, instead of just once, is a great way to minimize low-frequency quantization noise. Most delta-sigma modulators are of a higher order. For instance, the designs of the more popular delta-sigma converters include second-, third-, fourth-, fifth, or sixth-order modulators. Multi-order modulators shape the quantization noise even harder to higher frequencies. **EDN**

REFERENCES

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2 Baker, RJ, *CMOS mixed-signal circuit design*, Wiley & Sons, ISBN 0471227544, May 2002.

Bonnie Baker is a senior applications engineer at Texas Instruments. You can reach her at bonnie@ti.com.

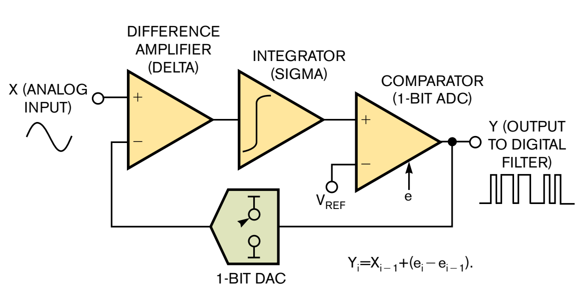

Figure 1 A time-domain representation shows the mechanics of a first-order modulator.

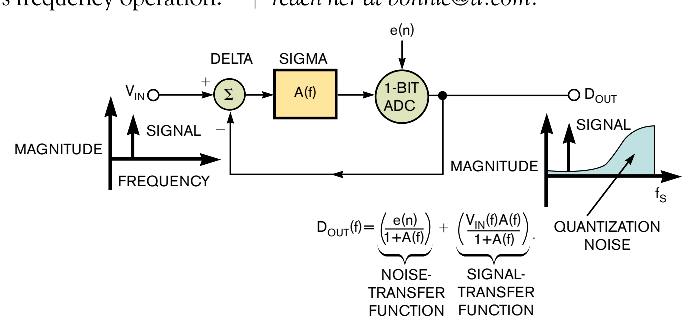

Figure 2 In a frequency-domain representation, the noise characteristic is key to the modulator's frequency operation.