OmniDesign

DAC Performance Parameters

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Abstract

Digital-to-digital converters (DACs) are widely used in audio/video devices, ADAS, wireless communication, and wireline networking. DACs convert digital bits of ones and zeros to an equivalent analog signal in current or voltage form. In the real world, the conversion from digital bits to an analog signal introduces errors that affect the performance of the DAC. DAC performance is measured by static and dynamic parameters. This document details commonly used parameters to specify DAC.

DAC Parameters

Resolution is the number of bits in the converter and is a well-known specification that goes along with speed. Resolution determines the size of the least significant bit (LSB) and the quantization noise.

Full-Scale Output is defined as the maximum voltage or current range of the DAC.

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Offset-Error is defined as the deviation of the linearized transfer curve of the DAC output from the ideal output at the linear region of the transfer function. The offset error is typically measured at a code greater than zero so that a positive or negative value can be obtained.

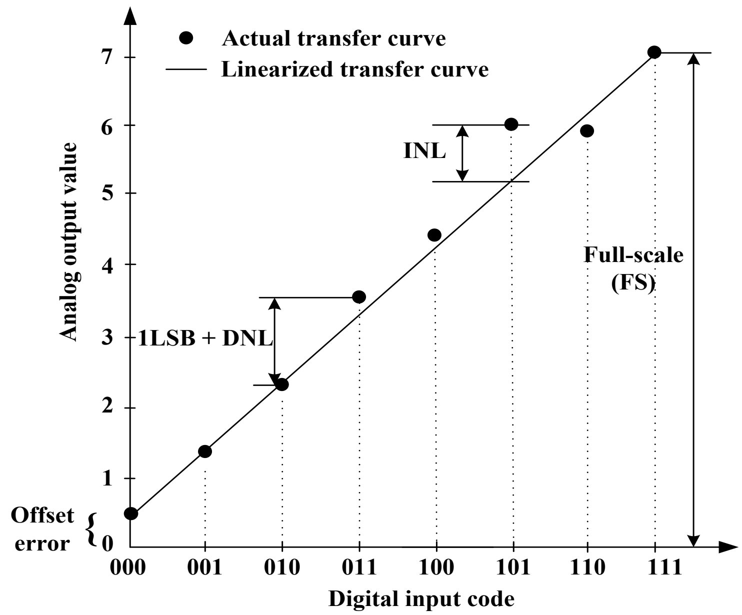

Figure 1: Diagram showing offset error between actual and ideal T/F for a 3-bit ADC.

Gain Error is expressed as percent of Full Scale error and is defined as the ratio between the actual full-scale (FS) signal to the ideal FS output range. The gain error is diagrammatically shown in Figure 1. The gain error can be stated as

$$Gain\ error = 1 - \frac{FS_{actual}}{FS_{ideal}}$$

Differential-Nonlinearity (DNL) is the difference between an actual step size and the ideal value of 1LSB which is shown in Figure 1. A DNL of greater than -1LSB will guarantees monotonicity and no missing code. DNL for an N-bit DAC can be calculated for the input-code position as

$$DNL(code) = \frac{Out_{DAC}(code) - Out_{DAC}(code - 1)}{LSB_{avg}} - 1$$

where,

$$LSB_{avg} = \frac{Full\ scale\ output}{2^N - 1}.$$

Integral-Nonlinearity (INL) The INL is defined as the deviation of the actual DAC output from its ideal transfer curve at every digital code input. Generally, INL is a measure of the deviation of the DAC output values from a straight line drawn between its endpoints. The INL can be expressed as

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$$INL(code) = \frac{Out_{DAC}(code) - Out_{DAC}(0)}{LSB_{avg}} - code.$$

Monotonicity A DAC is termed monotonic if the analog output always increases or remains constant as the digital input increases. If the DNL is less than -1LSB, the DACs transfer function is non-monotonic. As shown in Figure 1, the actual DAC transfer function is non-monotonic at code input 110.

Settling Time is the amount of time required from the start of a transition until the DAC output settles its new output value to within the specified accuracy.

Signal-to-Noise Ratio (SNR) is defined as the ratio of the power of the fundamental signal to the integrated noise power of the noise floor over the Nyquist band (dc to $\boldsymbol{F_s/2}$) excluding power at dc and in the harmonics. Here, the noise floor only consists of the quantization noise produced by the converter. SNR in dBs is expressed as follows

$$SNR_{dB} = 10log_{10}\left(\frac{v_1^2}{v_n^2}\right).$$

Here, v_1 is the fundamental signal root-mean-square (RMS) value and the v_n is the RMS noise voltage.

Spurious Free Dynamic Range (SFDR) is the ratio of the RMS voltage of the fundamental signal tone to the largest spurious spectral component within the Nyquist band and it is specified relative to full-scale input (dBFS) or the actual input level (dBc). The spurs are generated at harmonics of the input frequency, and at frequencies related to the clock, subsampling clocks, and interleaving frequencies. SFDR can be specified with or without HD2 and HD3 terms. SFDR is a very important metric in communication systems since the spurs frequently occur within the bandwidth of interest and cannot be distinguished from a real signal.

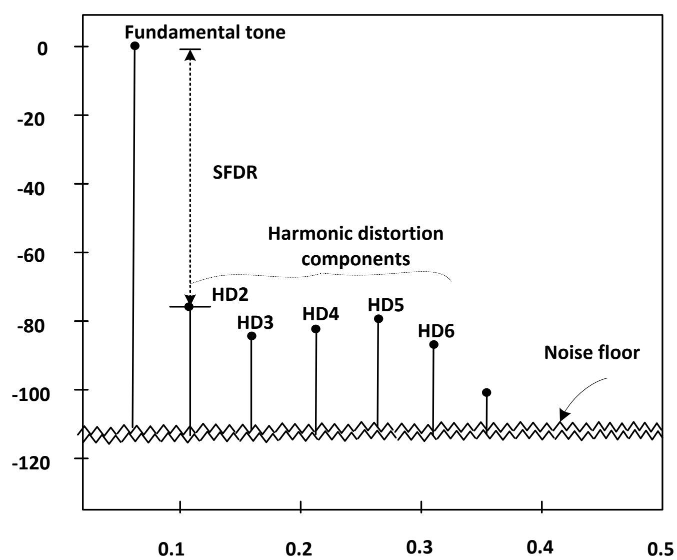

Figure 2: A spectrum showing fundamental tone and distortion components.

Second-Harmonic Distortion (HD2) spur falls at twice the frequency of the fundamental (see Figure 2).

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Third-Harmonic Distortion (HD3) spur falls at thrice the frequency of the fundamental (see Figure 2).

Total Harmonic Distortion (THD) is the ratio of the sum of powers of harmonics to the fundamental signal power. Typically, the first six harmonics are considered for the THD (see Figure 2). THD equation is stated as follows

$$THD_{dB} = 10log_{10}\left(\frac{v_2^2 + v_3^2 + v_4^2 + v_5^2 + v_6^2}{v_1^2}\right).$$

The terms in the numerator indicate distortion from the harmonics where v_2, v_3, v_4, v_5, and v_6 are the RMS voltage of the 2^{nd}, 3^{rd}, 4^{th}, 5^{th}, and the 6^{th} harmonics, respectively. The term in the denominator, v_1, is the RMS voltage of the fundamental signal.

Signal-to-Noise Distortions (SNDR) measure the signal power relative to all spectral components that come from noise and distortion power.

$$SNDR_{dB} = 10log_{10}\left(\frac{v_1^2}{v_n^2 + v_d^2}\right)$$

The RMS noise voltage, v_n, includes the thermal noise and the quantization noise as discussed in the SNR metric. The RMS distortion noise voltage, v_d, includes distortion from all harmonics, time-interleaving spurs, and any other distortion spectral components.

Noise Spectral Density (NSD) is the noise power in a 1Hz bandwidth. The DAC output noise is the sum of the quantization noise and other noise sources.

Intermodulation Distortion (IMD) of the two-tone is the ratio expressed in dBc (or dBFS) of the worst 3rd-order IMD products to any output tone.

Adjacent Channel Power (ACP) is commonly used in combination with DOCSIS-compliant QAM signals. ACP is the ratio in dB between the power in a channel at a specified frequency offset from the edge of the transmitted channel block, and power in the lowest frequency channel of the transmitted block. ACP provides a quantifiable method of determining out-of-band spectral energy and its influence on an adjacent channel when a bandwidth-limited RF signal passes through a nonlinear device.

Adjacent Channel Leakage Power Ratio (ACLR) is commonly used in combination with wideband code-division multiple access (WCDMA). ACLR reflects the leakage power ratio in dB between the measured powers within a channel relative to its adjacent channel. ACLR provides a quantifiable method of determining out-of-band spectral energy and its influence on an adjacent channel when a bandwidth-limited RF signal passes through a nonlinear device.

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