Robert T. Short, Ph.D.
rtshort@PhaseLockedSystems.com
www.PhaseLockedSystems.com

Quantization and Clipping Noise in Data Converters

In this white paper we will show that the degradation induced by A/D quantization and clipping noise in a DSP system is heavily dependent on the signal level and signal type presented to the A/D converter. Standard formulas for computing the degradation do not include the signal level, nor do they account for clipping distortion.

In most DSP systems, including wireless and audio systems, data converters are used to convert analog signals to digital and back. Selection of the data converter is a critical component of system design and it is almost always advantageous to use the smallest converter (least number of bits) that will meet the performance requirements. It is generally understood that data converters contribute to signal distortion by adding quantization noise and other degradations. There are some widely-used formulas for computing the degradations. For example most engineers are familiar with the formula for signal to quantization noise ratio contributed by quantization

$$SQNR = 6.02N_b + 1.74(dB) \tag{1}$$

where N_b is the number of bits used in the conversion process. This formula leads many to believe that the SQNR is a constant, but in fact the constant factor $1.74dB$ is valid only for a sinusoid that occupies the full range of the converter. In practice, a better formula is

$$SQNR = 6.02N_b + C(dB) \tag{2}$$

where the value of C depends on both the *type* of signal and the *range* of the converter that the signal occupies.

As an example, if the input signal is a zero-mean random signal and the converter clipping level is set at $3\sqrt{P}$ where P is the average signal power, then $C = 1.25$. Many authors assume clipping is a serious problem and set the converter level to avoid clipping whenever possible. In fact, clipping distortion may be reasonably treated as just another form of noise. This is particularly true in audio and many types of wireless systems. If we input a noisy signal, such as those found in wireless receiver systems, into an A/D converter and plot the total SNR due to clipping, quantization, and input noise we obtain curves like those shown in the Figure below. It becomes clear that arbitrarily selecting a clipping level may not yield the best SNR, especially at lower quantization levels. In fact, if the level is set below the "standard" $3\sqrt{P}$ level, a four bit converter will provide reasonable results where the standard formulas would lead to the selection of a 5 or 6 bit converter.

The Figure was generated using analytic approximations that closely match simulated and actual measured results. The analytic formulas are important since design may be done without complex and time-consuming simulations. Different waveforms produce different results, but with the same general characteristics.

Obtaining the maximum performance from a data converter takes experience and knowledge. For more information email rtshort@phaselockedsystems.com.