ADC Guide, Part 11: ADC Noise – 2, SINAD, ENoB

In the previous part of this series, we discussed about noise basics and how they affect an ADC’s output. We will continue this discussion about noise and cover Signal-to-Noise and Distortion ratio and ENoB, all commonly used specifications of an ADC.

Peak-to-peak noise is important for a very limited set of applications where the accuracy of analog to digital conversion is of utmost importance. One such example is precise weighing scales where the ADC has to measure very small analog voltages extremely accurately.

For most of the general applications of an ADC, RMS noise is the parameter considered as the measure for DC noise performance of the ADC. It is apparent in Figure 3 from the previous part of this series that the typical distribution of a grounded input histogram approximately assumes the shape of a Gaussian curve. This Gaussian curve is marked in red in Figure 3. The difference between the actual distribution and perfect Gaussian arises from the DNL of the ADC. As we have already seen in part 5 of this series, if DNL is more than -1 LSB, missing codes can result which will make this distribution go far off from an ideal Gaussian.

We can compute the RMS noise by statistical methods. As a rule of thumb, peak-to-peak noise is around 6 to 8 times the RMS noise of the ADC, assuming an approximate Gaussian distribution. RMS noise can be expressed in terms of number of counts or number of LSBs, similar to peak-to-peak noise.

The Signal-to-Noise Ratio (SNR) is the parameter of an ADC which accounts for the noise in the ADC. As it was derived in the first part of this series, the SNR of an ideal ADC is given by equation (4) below:

\[ SNR_{db} \text{ (Ideal)} = 6.02 \times N + 1.76 \]

; where \( N \) is the resolution of ADC.

The SNR of an ideal ADC is also known as signal-to-quantization noise ratio (SQNR) for obvious reasons.

For a practical ADC, the signal-to-noise ratio is always less than the SNR value of an ideal ADC of the same resolution due to added noise from the noise sources mentioned previously. The SNR for a practical ADC can be calculated from the FFT of the output of the ADC. It depends upon the power of the fundamental signal and noise. The noise power can be estimated by removing the power of fundamental and harmonic components from the total signal power. The RMS noise voltage is marked as \( v_{noise} \) in Figure 1. Therefore, the SNR of practical ADC is given by equation (5) as below:

\[ SNR_{db} = 20 \log \left( \frac{V_1}{v_{noise}} \right) \]

; where \( V_1 \) is the fundamental voltage.

Although we do not consider the power content of the harmonics frequencies when calculating the SNR of an ADC, harmonics are in fact equally important when selecting an ADC for a particular application. ‘THD+N’ is the parameter which adds up the effect of noise and harmonics. It is defined as the power of harmonics and noise with respect to power of fundamental frequency component and is given by Equation (6) below:
Using this parameter, we can define the Signal-to-Noise and Distortion ratio or SINAD. SINAD can be considered as a parameter similar to SNR but includes adding the effect of distortion and the noise in the output of the ADC. SINAD is given by equation (7):

\[
SINAD_{dB} = 20 \log \left( \frac{V_1}{\sqrt{V_2^2 + V_3^2 + V_4^2 + \ldots + V_n^2 + v_{\text{noise}}^2}} \right) \quad \text{... Equation (7)}
\]

The term SINAD leads us to one of the most important parameters in the dynamic characteristics of an ADC. It is known as the effective number of bits (ENoB) of an ADC. ENoB is given by equation (8) below:

\[
ENoB = \frac{SINAD - 1.76}{6.02} \quad \text{... Equation (8)}
\]

Note that equation (8) assumes that the test signal used to calculate the SINAD value spanned over the full scale input voltage range of the ADC. In this condition, it gives a true representation of effective number of bits in the output of ADC.

SINAD and ENoB are very important parameters for analysing the noise performance of an ADC. Other parameters such as THD and SNR give the individual impact of harmonics and noise on the output of an ADC. However, for all practical applications, both of these factors are equally important. Therefore, ENoB or SINAD, which consider the combined effect of noise and distortion together, is the parameter to look for when comparing the noise performance of an ADC for general-purpose applications.

As the name suggests, ENoB gives the effective number of bits of the ADC output. This number is always less than the resolution of ADC. The difference between ENoB and resolution of ADC will represent the amount of noise and distortion added by the ADC. The closer the ENoB is to the resolution of an ADC, the better the noise performance of the ADC.

In this part, we concentrated on the noise which is present inherently in an ADC. In other words, an ADC would add this noise on its own to the analog signal while converting it to a digital signal. Practically, the ADC would add more noise than the noise figures indicate. A very common source of such noise is the ADC reference. Overall, ADC noise cannot be less than the reference noise. So, if an internal reference is being used in an ADC, its specifications must be examined carefully to ensure that the overall noise does not cause the required ENoB to go drop below the system’s requirements.

In upcoming parts of this series, we will talk about single-ended vs differential ADCs, input impedance specifications followed by various ADC architectures, and how to select an ADC based on the application.

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