

## Translating System Level Protection and Measurement Requirements to ADC Specifications

by Aileen Ritchie and Claire Croke

### INTRODUCTION

This application note provides guidelines on how to translate system level requirements for transmission and distribution applications to analog-to-digital converter (ADC) specifications provided in Analog Devices, Inc., data sheets. These guidelines show the effect of measurement and protection devices on system level performance. The AD7779 is used as a reference in this application note. However, the general principles described in this application note can be applied across all Analog Devices ADCs.

### SYSTEM LEVEL REQUIREMENTS

Although system level specifications can vary from application to application, a few key requirements apply across most applications, including a maximum and minimum nominal operating current ( $I_{\text{NOM}}$ ) and an accuracy specification. The accuracy is often driven by a measurement or protection standard that requires a particular percentage error in the resulting current, voltage, or energy measurement.

### KEY SPECIFICATIONS

The ac or dynamic performance of an ADC or data acquisition system (DAQ) is specified in terms of the SNR, SINAD, and THD at a given input frequency and sampling rate ( $f_s$ ) or an output data rate (ODR). These key specifications and descriptions are stated as follows:

- Signal-to-noise ratio (SNR) is the ratio of the rms value of the actual input signal to the ratio of all other spectral components below the Nyquist frequency, excluding harmonics and dc. SNR is expressed in dB.
- Dynamic range (DR) is the ratio of the maximum input signal to the smallest input signal the DAQ/ADC can produce. DR is expressed in dB.
- Signal-to-noise and distortion ratio (SINAD) is the ratio of the rms value of the actual input signal to the ratio of all other spectral components below the Nyquist frequency, including harmonics but excluding dc. SINAD traditionally measures the measurement resolution of an ADC or DAQ signal chain. SINAD is expressed in dB.
- Total harmonic distortion (THD) is the ratio of the rms sum of the first five harmonic components to the rms value of a full-scale input signal. THD is expressed in dB.

See [MT-003](#), *Understand SINAD, ENOB, SNR, THD, THD + N, and SFDR so You Don't Get Lost in the Noise Floor*, for more details on the key specifications.

Two scenarios can result in the need for high DR:

- A need to resolve a signal in the input range to a high degree of accuracy.
- A need to measure a signal with a wide range of varying to modest accuracy.

Achieve the DR through different signal chain designs, discussed further in the Signal Chain Implementation section.

### TRANSLATING THE SPECIFICATIONS

To determine what performance level is required from the DAQ or the ADC, analyze the following requirements:

- The input range the DAQ/ADC operates over.
- The accuracy requirements over the input range.

The Input Range section demonstrates how the effect of these two components is calculated.

#### Input Range

Calculate the DR required to measure the input range span by using the ratio of the maximum and minimum current (or voltage) the ADC must measure. The DR for the input range ( $DR_{\text{Input Range}}$ ) is calculated as shown in the following equation:

$$DR_{\text{Input Range}} = \frac{\text{Maximum Current (A)}}{\text{Minimum Current (A)}}$$

A design margin is typically required at the upper limit of this input range to allow uncertainties.

Use the same procedure to calculate the DR of a voltage channel using the maximum and minimum voltage inputs. The following equation converts the DR for the input range into a value expressed in dB ( $DR_{\text{Input Range (dB)}}$ ).

$$DR_{\text{Input Range (dB)}} = 20 \times \log_{10} (DR)$$

Note that the previous equation assumes the maximum current scales directly to the maximum ADC input voltage.

If this is not the case, additional margins on the DR are required to compensate for not utilizing the full input range of the ADC.

## Accuracy

System accuracy refers to the allowable error in the resulting measurement. Typically, system accuracy is described in terms of percentage error with respect to the measured signal, for example, 0.5% error over the entire operating range.

Alternatively, accuracy can be described as a percentage error with respect to the nominal signal or as an absolute value. To translate this requirement into a DR value, the percentage error at the minimum input used is shown in the following equation:

$$DR_{Accuracy (dB)} = 20 \times \log_{10} \left( \frac{1}{Percentage\ Error} \right)$$

where  $DR_{Accuracy (dB)}$  is the DR required to meet the specified accuracy.

It is important to note, however, that the desired accuracy must be achieved over a specified measurement time and not necessarily in each output sample from the DAQ/ADC. For example, in a protection application, the algorithms may use all the samples collected from the [AD7779](#) and average the samples over a half power line cycle period to generate the result. In a metering application, the measurement period may be significantly longer. For example, an rms reading may update after a period of 10 power line cycles. As the ADC, in this case the [AD7779](#), produces multiple samples over this time period, these samples can be averaged. The result of this averaging, or oversampling process, is a reduction in the noise floor. The amount by which the noise floor is reduced depends on how many ADC samples are available over the measurement time period, as described in the following equation:

$$DR_{Averaging (dB)} = 20 \times \log_{10} \sqrt{No\_Samples}$$

where:

$DR_{Averaging (dB)}$  is the DR reduction (dB) achieved from averaging over  $No\_Samples$  (dB).

$No\_Samples$  is the number of ADC output samples produced during the measurement time.

To calculate the number of samples ( $No\_Samples$ ), the [AD7779](#) ODR is required. The [AD7779](#) can achieve output data rates up to 16 kSPS. See the following equation:

$$No\_Samples = ODR (SPS) \times Measurement\ Time (sec)$$

A net positive DR from averaging results in a reduction in the  $DR_{Accuracy (dB)}$  specification and therefore must be recalculated by considering the averaging DR.

$$DR_{Accuracy (dB)} = DR_{Accuracy (dB)} - DR_{Averaging (dB)}$$

## Resulting DAQ/ADC Performance Requirement

The final DAQ/ADC DR specification is determined by adding the DR contribution from the input range to the DR from the accuracy.

$$DR_{Final} = DR_{Input\ Range (dB)} + DR_{Accuracy (dB)}$$

## Effect of Total Harmonic Distortion (THD)

The averaging calculations assume that the noise from the [AD7779](#) is random and spread evenly across the spectrum. In reality, however, a certain level of harmonic noise also exists in the system. Because harmonic content is present at the same frequency in every ADC output sample, simple averaging does not reduce this noise. The amount by which averaging can benefit a system is limited by the THD. It is important, therefore, to be aware of the THD specification when selecting an ADC. THD is a measurement of the harmonic content and is defined as the ratio of the rms sum of the first five harmonic components to the rms value of a full-scale input signal. The THD specification of the ADC must be lower than the SNR/ $DR_{Final}$  value to meet the system requirements. If the THD is higher, the system performance is limited to the value of the THD. In the case of the [AD7779](#), the THD is  $-108$  dB for a  $-0.5$  dB signal. THD improves if the amplitude of the input signal to the ADC is reduced, which is usually the case in a protection and measurement application.

## PROTECTION AND MEASUREMENT

Most transmission and distribution applications incorporate both a protection and a measurement function. These functions may each have a different requirement in terms of the accuracy and the range over which they are specified. When determining the correct DAQ/ADC to meet these requirements, both sets of requirements are evaluated separately. Use the highest resulting specification to select the appropriate ADC, as demonstrated in the Air Circuit Breaker Example section.

## AIR CIRCUIT BREAKER EXAMPLE

The following example demonstrates the process of translating the system level specification of an air circuit breaker (ACB) into requirements from an ADC. In this particular example, there is a metering unit included in the ACB; therefore, there is a separate set of metering and protection specifications.

### System Level Specifications Example

Table 1 shows examples of metering and protection specifications.

**Table 1**

Parameter	Metering	Protection
Accuracy	0.5%	2%
Minimum Current	5 A	40 A
Maximum Current	6300 A	150 kA
Measurement Time	200 ms	0.1 ms

## EXAMPLE OF CALCULATING THE ADC REQUIREMENTS

### Dynamic Range (DR)

The maximum input signal must be scaled to match the maximum ADC input range; therefore, use the largest maximum current to calculate the DR. In this example, 150 kA is required for protection. The minimum signal is driven by 5 A, required for measurement.

$$\text{Input Range} = \frac{150,000}{5} = 30,000$$

$$\text{DR Input Range} = 20 \times \log_{10}(30,000) = 89.5 \text{ dB}$$

### Accuracy

There are two accuracy requirements in this example:

- Measurement: 0.5% at 5 A over 200 ms.
- Protection: 2% at 40 A over 0.1 ms.

Evaluate each of these requirements individually and use the highest requirement to select the appropriate ADC.

### Measurement Requirement

The measurement accuracy of 0.5% is required at the minimum input of 5 A and, therefore, the additional SNR/DR can be calculated as follows:

$$\text{DR}_{\text{Accuracy}} = 20 \times \log_{10}\left(\frac{1}{0.005}\right) = 46 \text{ dB}$$

$$\text{No\_Samples} = 8 \text{ kSPS} \times 0.2 \text{ sec} = 1600 \text{ samples}$$

$$\text{DR}_{\text{Averaging}} = 20 \times \log_{10}\sqrt{1600} = 32 \text{ dB}$$

$$\text{DR}_{\text{Measurement Accuracy}} = 46 \text{ dB} - 32 \text{ dB} = 14 \text{ dB}$$

where  $\text{DR}_{\text{Measurement Accuracy}}$  is the DR for accuracy relative to measurement.

### Protection Requirement

The protection requirement states that a maximum of 2% error is required at 40 A. To determine the effect this requirement has over the total DR, first calculate the accuracy at the minimum current of 5 A. This allows the protection and measurement requirements to be compared directly:

$$\text{Error (\%)} \text{ at } 5 \text{ A} = \frac{40 \text{ A}}{5 \text{ A}} \times 2\% = 16\%$$

The SNR/DR contribution is calculated as follows:

$$\text{DR}_{\text{Accuracy}} = 20 \times \log_{10}\left(\frac{1}{0.16}\right) = 15.9 \text{ dB}$$

$$\text{No\_Samples} = 8 \text{ kSPS} \times 0.001 \text{ sec} = 8 \text{ samples}$$

$$\text{DR}_{\text{Averaging}} = 20 \times \log_{10}\sqrt{8} = 9 \text{ dB}$$

$$\text{DR}_{\text{Protection Accuracy}} = 15.9 \text{ dB} - 9 \text{ dB} = 6.9 \text{ dB}$$

where  $\text{DR}_{\text{Protection Accuracy}}$  is the DR for accuracy relative to protection.

After evaluating both the protection and measurement requirements, it is clear that the measurement requirement results in a higher SNR accuracy specification of 14 dB. Therefore, base the ADC selection the following equation:

$$\text{DR}_{\text{Final}} = 89.5 \text{ dB} + 14 \text{ dB} = 103.5 \text{ dB}$$

## SIGNAL CHAIN IMPLEMENTATION

As previously mentioned, DR can be achieved through a combination of different analog signal chain designs and digital processing means.

Figure 1 to Figure 3 show top level block diagrams of how to achieve system DR.

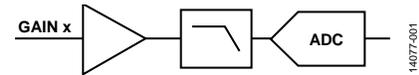


Figure 1. Analog Gain and Moderate Resolution ADC

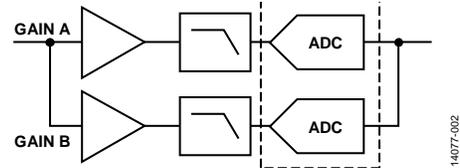


Figure 2. Dual ADC with Split Gain Paths

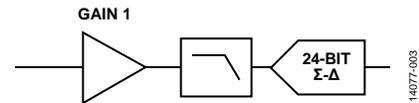


Figure 3. High Resolution ADC with Unity Gain Driver (Traditionally  $\Sigma$ - $\Delta$  Solution)

Depending on the ratio between the ADC sampling rate and the measurement bandwidth of interest, additional digital filtering on the ADC samples can be performed to further increase the DR of the signal chain.

The [AD7779](#) is an 8-channel, 24-bit, sigma-delta ( $\Sigma$ - $\Delta$ ) ADC. The [AD7779](#) can achieve sample rates/output data rates up to 16 kSPS. The THD of the [AD7779](#) is  $-108 \text{ dB}$  up to an input frequency of 1 kHz.

The SINAD is the ratio of a full-scale rms input signal to the ratio of all other spectral components below the Nyquist frequency including harmonics. SINAD often determines the measurement resolution of a signal chain as it contains both the SNR and THD contributions from the signal chain.

After the SNR and the THD of the signal chain is known, the resultant SINAD can be calculated as follows:

$$SINAD = -10 \times \log \left( 10^{\frac{-SNR}{10}} + 10^{\frac{-THD}{10}} \right)$$

Therefore, at 8 kSPS with an SNR of 112 dB and THD of -108 dB, the resultant SINAD is 106.54 dB, meeting the DR requirements outlined in the Air Circuit Breaker Example.

The [AD7779](#) provides a fully integrated signal chain solution with integrated PGA and 24-bit  $\Sigma$ - $\Delta$  ADCs. See the [AD7779](#) data sheet for more details about the device.

Additional examples of systems that measure signals with a wide DR can be found in the *Analog Dialogue* article, "[Oversampled ADC and PGA Combine to Provide 127-dB Dynamic Range](#)."