Data Converter Drifts

Version 1.2

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Revision History

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July 27, 2016	1.0	Initial Release
August 18, 2016	1.1	Added equations representing the effect of each drift.
January 31, 2017	1.2	Added section on calibrating out drifts

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1. Introduction

Data Converters are devices that convert data from one type to another. They are more commonly used to refer to Analog to Digital Converters (ADCs) and Digital to Analog Converters (DACs).

Used in nearly all instrumentation systems, data converters suffer from a variety of errors that can impact measurement or control dependent systems. As such, it is required that these errors be identified and compensated for in the appropriate manner.

2. Types of Data Converters

The main two types of Data Converters are:

2.1. Analog to Digital Converters (ADCs)

An ADC is an electronic device that converts a continuous physical quantity (usually voltage) to a digital number that represents the quantity's amplitude. The conversion involves quantization of the input. Due to the nature of quantization, it introduces a small amount of error dependent on the quantization resolution. Instead of continuously performing the conversion, an ADC samples the input periodically. The result is a sequence of digital values that have been converted from a continuous-time and continuous-amplitude analog signal to a discrete-time and discrete-amplitude digital signal that can then be utilized by embedded systems.

An ADC is defined by its bandwidth and its signal to noise ratio. The actual bandwidth of an ADC is characterized primarily by its sampling rate. The dynamic range of an ADC is influenced by many factors, including the resolution, linearity and accuracy and jitter. ADCs are chosen to match the bandwidth and required signal to noise ratio of the signal to be quantized. If an ADC operates at a sampling rate greater than twice the bandwidth of the signal, then in theory, perfect reconstruction is possible.

The common types of ADCs are:

- Flash ADC: A bank of comparators sampling the input signal in parallel, each firing for their decoded voltage range.
- SAR ADC: Uses a comparator to successively narrow a range that contains the input voltage.
- Delta-Sigma ADC: Oversamples the desired signal by a large factor and filters the desired signal band

2.2. Digital to Analog Converters (DACs)

A DAC is an electronic device that converts digital data into an analog signal (current, voltage, or electric charge). It performs the reverse operation of an ADC. DACs are typically used to convert finite-precision time series data to a continually varying physical signal. The suitability of a DAC for a particular application is determined by six main parameters: physical size, power consumption, resolution, speed, accuracy, cost.

An ideal DAC converts a fixed-point binary number into a conceptual sequence of impulses that are then processed using some form of interpolation to fill in data between the impulses. A typical practical DAC converts the numbers into a piecewise constant function made up of a sequence of rectangular functions that is modeled with the zero-order hold. Other DAC methods produce a pulse-density modulated signal that can then be filtered in a similar way to produce a smoothly varying signal. In theory, a DAC can reconstruct the original signal from the sampled data provided that its bandwidth meets certain requirements. Quantization errors manifest as low-level noise added to the reconstructed signal.

The common types of DACs are:

- PWM: A stable current or voltage is switched into a low-pass analog filter with a duration determined by the digital input code.
- Delta-Sigma DAC: Uses oversampling and a pulse density conversion technique.
- Binary-Weighted DAC: Contains individual electrical components for each bit of the DAC connected to a summing point

3. Drifts in Data Converters

This section covers the various types of drifts that have been identified to be present in data converters.

3.1. Offset Error

This error changes all the outputs by an equal amount. Figure 1 shows such an error for an ADC.

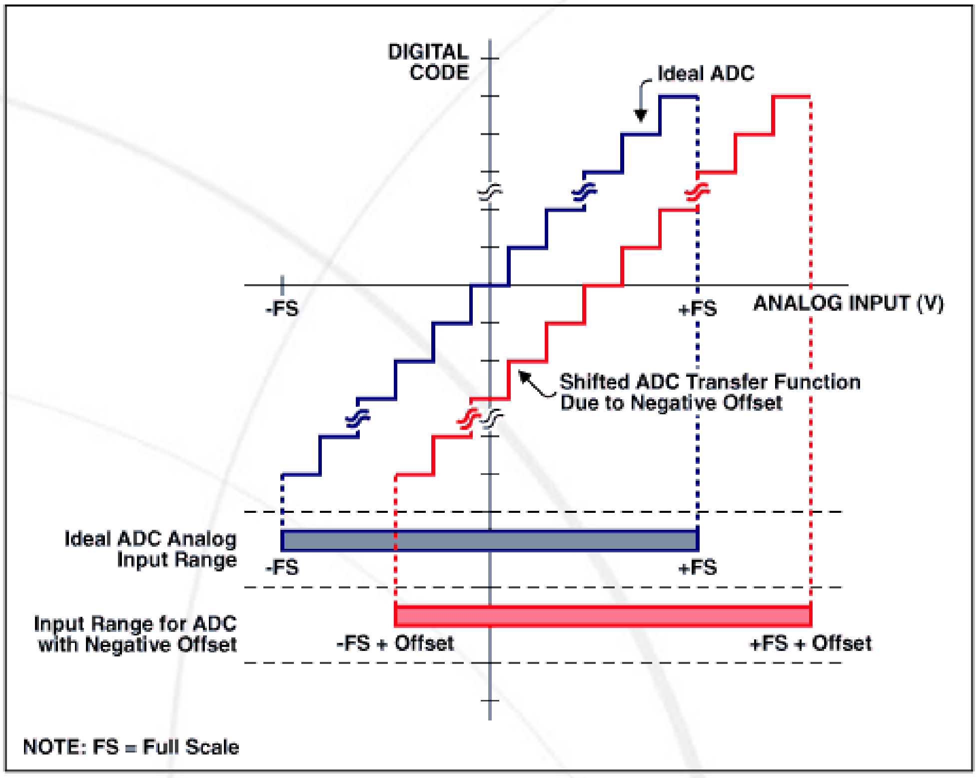

FIGURE 1: BIPOLAR OFFSET ERROR IN AN ADC

If the equation $y = mx + c$ represents the ideal performance of an ADC, then the offset error can be expressed as below, where e_{offset} is a constant:

$$y = mx + c + e_{offset}$$

Offset errors are mainly attributed to drifting of the data converter's voltage reference. When dealing with unipolar data converters, this error ends up moving the input out of range of the available quantization levels thus degrading the converters performance. This is not the case for bipolar converters.

Offset errors can be prevented by using voltage references resistant to drift or by considering temperature compensation in design. Offset errors can be easily calibrated out using the connected microcontroller.

3.2. Gain Error

This error causes the transfer function of the data converter to be rotated on its axis, thus effecting each output by the same percentage. Figure 2 shows such an error for an ADC.

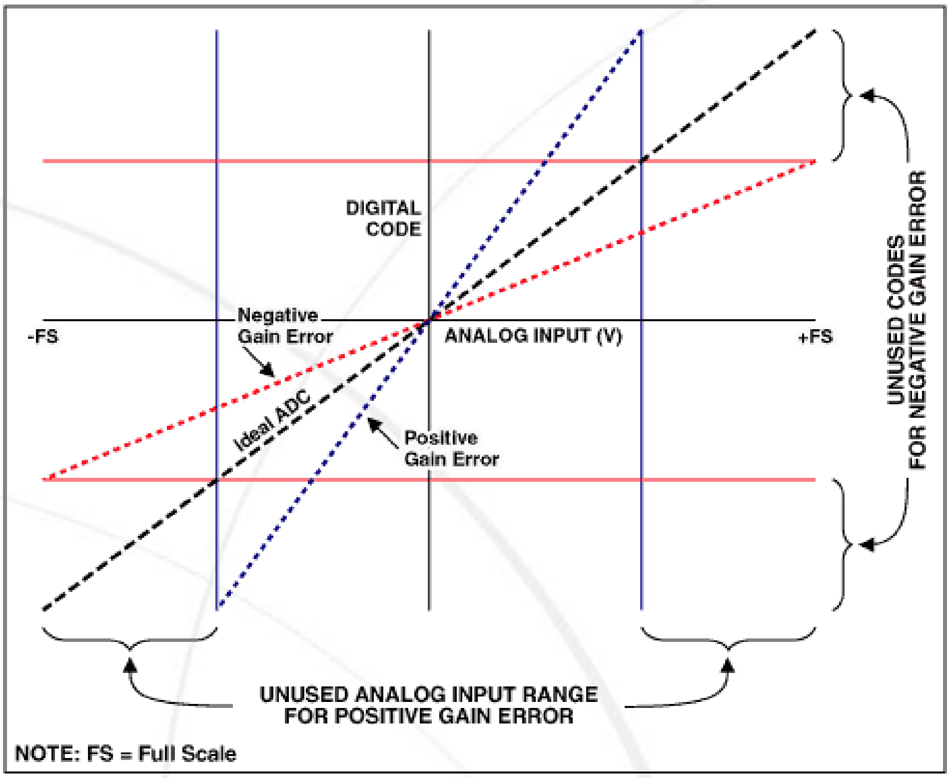

FIGURE 2: GAIN ERROR IN ADCS

If the equation $y = mx + c$ represents the ideal performance of an ADC, then the gain error can be expressed as below, where e_{gain} is a constant:

$$y = e_{gain} \cdot mx + c$$

As with the offset error, the gain error is mainly caused by drift in voltage reference input to the data converter, particularly with temperature variation. Gain errors can be also prevented by using voltage references resistant to drift or by considering temperature compensation in design and be easily calibrated out using the connected microcontroller.

Due to the similarity between the Offset and Gain errors, they are grouped together and called the full scale drift.

3.3. Linearity Drift

Linearity drift is deviation of the converters performance from the typical straight line performance (shown in Figures 1 and 2). This deviation is due to varying effect of temperature on the various resistances part of the data conversion circuit.

Compared to the offset and gain errors, drift due to linearity is much smaller. It is typically defined by the data converter's manufacturer as a maximum limit over the operating temperature range and needs to be considered in the instrumentation's design to be sufficiently low.

3.4. Bipolar Zero Drift

This error causes a **random** variation in the data converter's performance around the origin. This error is not caused by temperature or reference drift but instead due to bad tracking in the data converter's design.

As with the linearity error, due to its randomness, the bipolar zero error needs to be considered as during design as per the applications requirements to be sufficiently small.

3.5. Aging Drift

This is a problem present with all electronic devices. It is the deviation from the device's typical performance due to natural degradation with time. The effect of aging drift is only prominent with newer analog and digital designs where the push for smaller technology has pushed transistor lengths to below 200 nm. These negative impacts due to this drift can include slower speeds, irregular-timing characteristics, and increased power consumption. In extreme cases, circuit aging may even cause functional failures to occur over time.

To address this issue, data converters and other circuits are typically designed targeting a specific lifetime. This lifetime must be considered during the instrumentation's design. There is no specific manifestation of an aging drift but should be minimized with periodic calibration based on the device.

4. Calibrating Out Data Converter Errors

The maximum drift for a data converter is typically defined in the converter's specification. Therefore, the system using the data converter must be designed to perform with these errors without requiring calibration or they must be calibrated. Typically, the higher the accuracy requirement, the more often calibration in required. Calibration can be done using either digital or analog methods.

Digital calibration methods are typically preferred since the vast majority of system employing data converters already have some form of digital processing on board. Therefore, digital calibration requires little to no additional hardware. Digital calibration is typically done with the use of a look-up table. The table would contain codes for counters the gain and the offset errors for each input. Populating the look-up table is typically done by automated test equipment at time of final test. A larger table results in a more accurate conversion but is more time and thus cost intensive. The arithmetic operation required to obtain the calibrated data converter output is shown in Figure 3.

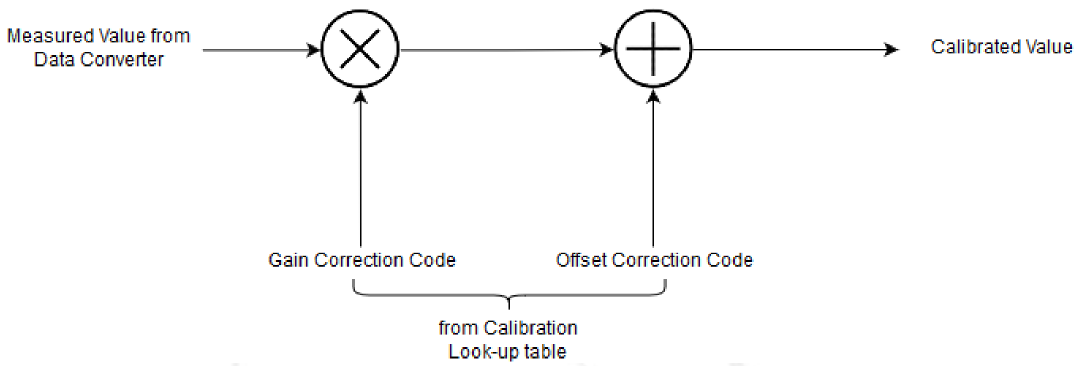

FIGURE 3: THE ARITHMETIC PROCESS TO DIGITALLY CALIBRATE OUT DATA CONVERTER ERRORS

Digital calibration can introduce an error of up to half of the least significant bit. Using Analog calibration can avoid this.

Analog calibration typically involves usage of high-tap count potentiometers to adjust the voltage reference input of the data converter and associated op-amps. This implementation is typically not practical unless being implemented onto the IC using passive components for programmability.

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5. References

Kester, W. (2005). *Data conversion handbook*. Amsterdam: Elsevier.
http://www.analog.com/library/analogDialogue/archives/39-06/data_conversion_handbook.html

Analog-to-digital converter. In *Wikipedia, The Free Encyclopedia*.
https://en.wikipedia.org/w/index.php?title=Analog-to-digital_converter&oldid=726273712

Digital-to-analog converter. In *Wikipedia, The Free Encyclopedia*.
https://en.wikipedia.org/w/index.php?title=Digital-to-analog_converter&oldid=720913100

ADC and DAC Glossary, Maxim.
https://www.maximintegrated.com/en/app-notes/index.mvp/id/641

The ABCs of ADCs: Understanding How ADC Errors Affect System Performance
https://www.maximintegrated.com/en/app-notes/index.mvp/id/748

What Designers Should Know About Data Converter Drift
http://www.ti.com/lit/an/sbaa046/sbaa046.pdf

Circuit Aging: A New Phenomenon For SoC Designs
http://electronicdesign.com/products/circuit-aging-new-phenomenon-soc-designs

Adjusting and Calibrating Out Offset and Gain Error in a Precision DAC
https://www.maximintegrated.com/en/app-notes/index.mvp/id/4602#

Methods for Calibrating Gain Error in Data-Converter Systems https://www.maximintegrated.com/en/app-notes/index.mvp/id/4494