AN-1352
APPLICATION NOTE

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Calibration Procedures for the ADA4571

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INTRODUCTION

The ADA4571 is an analog anisotropic magnetoresistive (AMR) angle sensor consisting of a sensing element and a conditioning analog instrumentation amplifier. This application note discusses various simple calibration procedures to reduce the angle linearity error from the sensor. The AMR angle sensor element consists of two resistive Wheatstone bridges. Each Wheatstone bridge is completely independent within the sensor. Resistive mismatches occur due to minor process variations. These mismatches appear as electrical offsets and amplitude variations between the two bridges. To achieve the most accurate result from the AMR sensor, it is important to perform simple calibration routines.

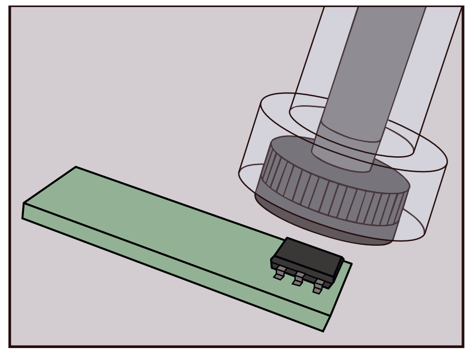

Figure 1. Typical Measurement Configuration for an AMR Angle Sensor

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4/15—Revision 0: Initial Version

CALIBRATING THE ADA4571

SINGLE POINT, END OF LINE (EOL) CALIBRATION PROCEDURE FOR THE ADA4571

Figure 2 and Figure 3 show the typical accuracy over temperature that can be achieved with a room temperature calibration with gain control (GC) mode enabled and GC mode disabled.

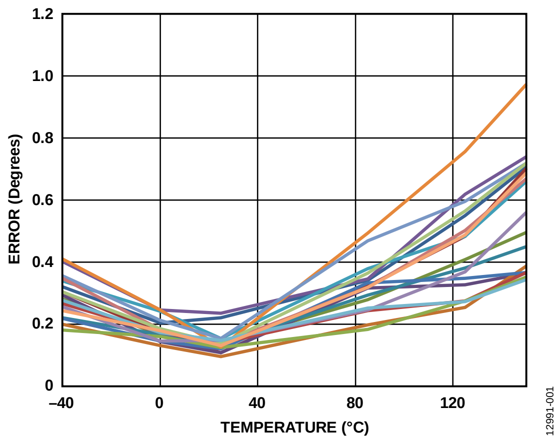

Figure 2. Angular Error over Temperature After Calibration at Room Temperature, GC Enabled

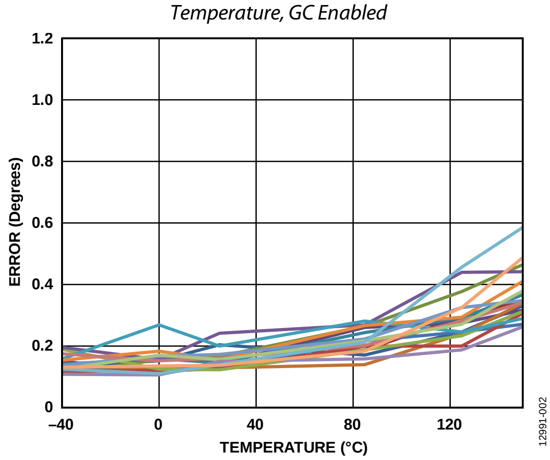

Figure 3. Angular Error over Temperature After Calibration at Room Temperature, GC Disabled

The two angle relevant output voltages for the ADA4571 AMR magnetic field angle are V_{SIN} and V_{COS}. The following equations represent these two outputs throughout an entire magnetic field rotation when referenced to $V_{DD}/2$:

$$V_{SIN} = A_S \times \sin(2 \times \alpha + \theta_S) + O_S$$

where:

A_S is the amplitude of V_{SIN}.
α is the current magnetic field angle.
θ_S is the phase of V_{SIN}
O_S is the offset of V_{SIN}.

$$V_{COS} = A_C \times \cos(2 \times \alpha + \theta_C) + O_C$$

where:

A_C is the amplitude of V_{COS}.
α is the current magnetic field angle.
θ_C is the phase of V_{COS}
O_C is the offset of V_{COS}.

Typical output signals are shown in Figure 4.

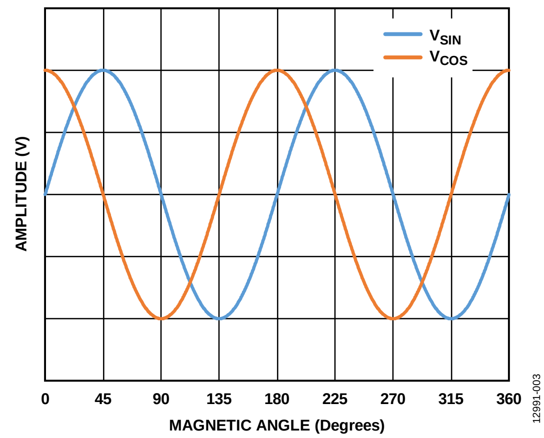

Figure 4. Typical Output Signals over a Single Mechanical Revolution

The amplitude mismatch (k) between the V_{SIN} and V_{COS} channels is production tested and specified as ±1% maximum. However, typically, this mismatch is much lower. Figure 5 shows the distribution of the amplitude mismatch over a sample of devices.

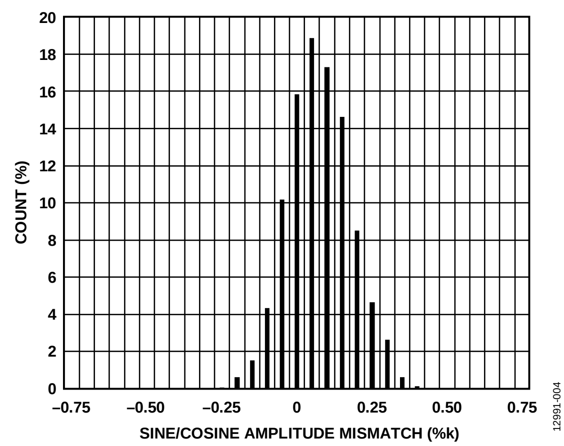

Figure 5. Sample Test Distribution of Sine/Cosine Amplitude Mismatch

Figure 6 shows the theoretical error contribution from amplitude mismatch.

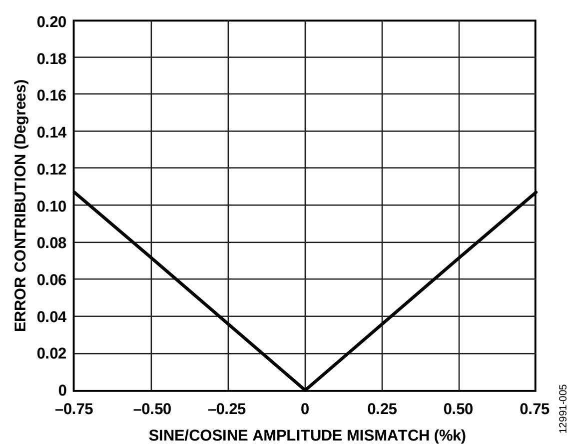

Figure 6. Theoretical Error Contribution due to Amplitude Mismatch of Sine/Cosine Outputs

This error is typically much smaller than other errors in the system. In addition, any miscalculation in an attempt to correct for amplitude mismatch can result in extra error added to the system. Therefore, ignore amplitude mismatch correction.

The orthogonality error between the V_{SIN} and V_{COS} channel is specified at 0.05° maximum though typically is much lower. Therefore, negligible error contribution is the result of orthogonality error; therefore, ignore this factor also.

Because of ignoring the amplitude mismatch and phase errors from the respective channels, the representative equations simplify to

$$V_{SIN} = A \times \sin(2 \times \alpha) + O_S$$

where A is the amplitude of the sine and cosine channels.

$$V_{COS} = A \times \cos(2 \times \alpha) + O_C$$

Offset only remains as the primary error contributor to the end angle.

SINGLE-TEMPERATURE CALIBRATION FOR THE ADA4571

Complete the following steps to calibrate the device through an entire 360° rotation. Note, if possible, it is recommended to complete the following routine as close as possible to the final application temperature:

1. Turn the magnetic stimulus through an entire 360° revolution in either direction while continuously monitoring the V_{SIN} and V_{COS} outputs of the device.
2. Calculate the offset of V_{SIN} and V_{COS} independently. Calculate the offset either by the maximum and minimum or by the mean of the respective output as shown in the following equations:

$$O_S = \frac{V_{SIN\_MAX} - V_{SIN\_MIN}}{2} = \sum_{\alpha = 0°}^{\alpha = 360°} V_{SIN}$$

$$O_C = \frac{V_{COS\_MAX} - V_{COS\_MIN}}{2} = \sum_{\alpha = 0°}^{\alpha = 360°} V_{COS}$$

Final Angle

To calculate the final electrical angle using the arctangent2 function.

$$\alpha = \arctan 2\left(\frac{V_{SIN} - O_S}{V_{COS} - O_C}\right)$$

The result repeats twice for each full 360^0 magnetic rotation (see Figure 7). This is a function of the AMR technology.

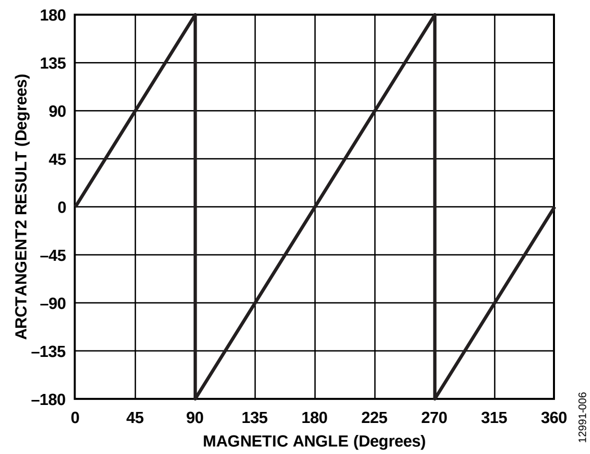

Figure 7. Calculated Angle over an Entire Mechanical Revolution

TWO-TEMPERATURE EOL CALIBRATION FOR THE ADA4571

To reduce further the error across the wide temperature span of the device, complete a two-temperature EOL calibration. Use the on-board temperature sensor to monitor the temperature at the device under test (DUT).

Because this calibration procedure uses the temperature sensor integrated into the ADA4571, the two-temperature calibration procedure does not require an accurate temperature forcing system to complete or any other temperature monitoring device during operation. As long as the system can go into a hot and cold temperature relative to the operating temperature range of the end application, this type of calibration performs well.

Figure 8 shows typical data of both the sine and cosine outputs for the remaining offset due to the offset drift of the ADA4571 after the single point calibration scheme at 25°C. For the two-temperature calibration procedure, this data set was examined.

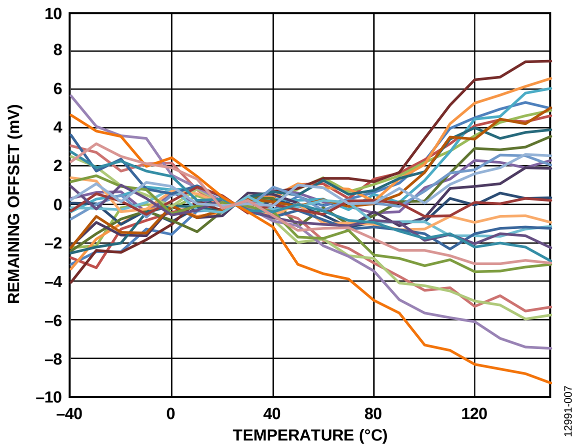

Figure 8. Sine and Cosine Remaining Offset After a Single Point Calibration at 25°C

With a single point calibration scheme at room temperature, the device achieves typical angular error results (see Figure 3). However, a two-temperature calibration increases accuracy over the entire operating temperature.

Figure 9, Figure 10, and Figure 11 show the remaining offset of the ADA4571 after a two-point calibration at a few different chosen temperature points. If these temperatures are altered, a different remaining offset profile is the result. To reduce the effect of the offset drift, it is best to choose two calibration temperatures that span nearly the entire operating temperature range in the final application. A lower magnitude of the remaining offset over the entire operating temperature range results in a more accurate angle calculation.

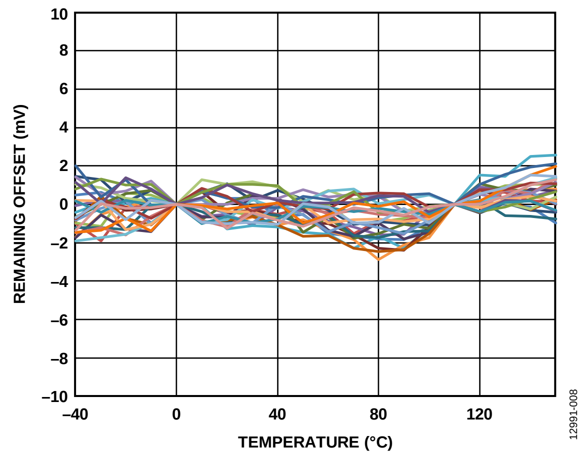

Figure 9. Sine and Cosine Remaining Offset After a Two-Point Calibration at 0°C and 110°C

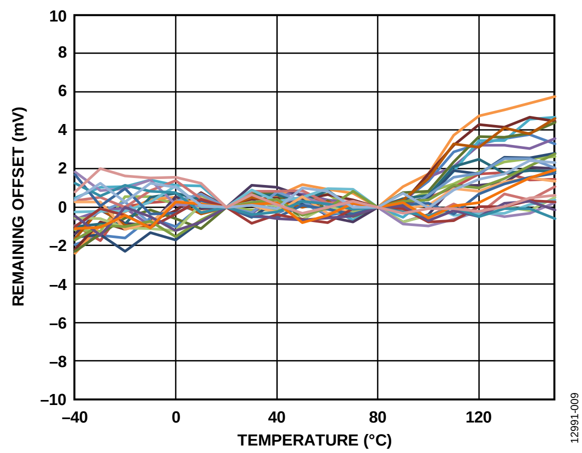

Figure 10. Sine and Cosine Remaining Offset After a Two-Point Calibration at 20°C and 80°C

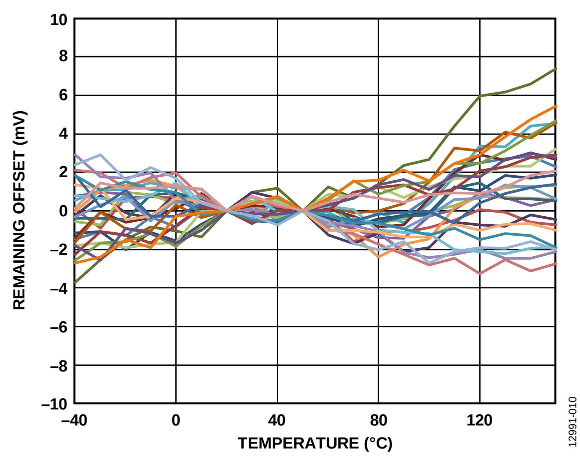

Figure 11. Sine and Cosine Remaining Offset After a Two-Point Calibration at 20°C and 50°C

Using the same analysis to reduce the output terms as described in in the Single Point, End of Line (EOL) Calibration Procedure for the section, the two outputs terms reduce to

$$V_{SIN} = A \times \sin(2 \times \alpha) + O_S$$

$$V_{COS} = A \times \cos(2 \times \alpha) + O_C$$

However, a correction factor for the offset drift over temperature must be considered. Add this correction factor to the end of the V_{SIN} and V_{COS} equations as follows:

$$V_{SIN} = A \times \sin(2 \times \alpha) + O_{S1} + TC_S \times (V_{TEMP\_CUR} - V_{TEMP1})$$

where:
O_{S1} is the sine channel offset at Temperature 1 (T1).
V_{TEMP_CUR} is the VTEMP output voltage at the current operating temperature.
V_{TEMP1} is the VTEMP output voltage at T1.
TC_S is the temperature coefficient of the sine channel and equals

$$\left(\frac{O_{S1} - O_{S2}}{V_{TEMP1} - V_{TEMP2}}\right)$$

where:
O_{S2} is the sine channel offset at Temperature 2 (T2).
V_{TEMP2} is the VTEMP output voltage at T2.

$$V_{COS} = A \times \cos(2 \times \alpha) + O_{C1} + TC_C \times (V_{TEMP\_CUR} - V_{TEMP1})$$

where:
O_{C1} is the sine channel offset at T1.
TC_C is the temperature coefficient of the cosine channel and equals

$$\left(\frac{O_{C1} - O_{C2}}{V_{TEMP1} - V_{TEMP2}}\right)$$

where:
O_{C2} is the cosine channel offset at Temperature 2.

To achieve the following ideal equations, both the initial calibrated offset as well as the drift must be subtracted from the previous equations:

$$V_{SIN} = A \times \sin(2 \times \alpha)$$

$$V_{COS} = A \times \cos(2 \times \alpha)$$

The routine for a two-temperature calibration requires monitoring one additional pin on the device, the VTEMP pin.

Procedure for Two-Temperature Calibration

Complete the following steps for proper two-temperature calibration for the ADA4571:

1. Bring the system to T1 and hold the temperature steady during Step 2.
2. Turn the magnetic stimulus through an entire 360° revolution in either direction while continuously monitoring the V_{SIN} and V_{COS} outputs of the device. Monitor the VTEMP output to record temperature information for V_{TEMP1}.
3. Calculate the offset of V_{SIN} (O_{S1}) and V_{COS} (O_{C1}) independently using the same scheme as described in the Single-Temperature Calibration for the ADA4571 section.
4. Bring the system to T2 and hold the temperature steady during Step 5.
5. Turn the magnetic stimulus through an entire 360° revolution in either direction while continuously monitoring the V_{SIN} and V_{COS} outputs of the device. Monitor the VTEMP output to record temperature information for V_{TEMP2}.
6. Calculate the offset of V_{SIN} (O_{S2}) and V_{COS} (O_{C2}) independently using the same scheme as described in the Single-Temperature Calibration for the ADA4571 section.
7. Calculate the offset temperature coefficient for each channel by using the following equations:

$$TC_S = \left(\frac{O_{S1} - O_{S2}}{V_{TEMP1} - V_{TEMP2}}\right)$$

$$TC_C = \left(\frac{O_{C1} - O_{C2}}{V_{TEMP1} - V_{TEMP2}}\right)$$

Final Angle

To correct for offset drift during operation of the device, monitor the VTEMP pin channel. Calculate the final angle by

$$\alpha = \frac{\arctan 2\left(\dfrac{V_{SIN} - O_{S1} - TC_S \times (V_{TEMP\_CUR} - V_{TEMP1})}{V_{COS} - O_{C1} - TC_C \times (V_{TEMP\_CUR} - V_{TEMP1})}\right)}{2}$$

DYNAMIC CALIBRATION PROCEDURE FOR THE ADA4571

Dynamic calibration only performs in a free running application where the sensor goes through entire electrical rotations faster than the environment is changing. In general, this condition requires an electrical revolution faster than 1 Hz. For an end of shaft magnetic configuration, an electrical revolution of 1 Hz equates to a motor spinning at 30 rpm. Dynamic calibration in slower motors are possible; however, the accuracy of the dynamic calibration depends on the motor speed relative to the speed of temperature change in the system.

Dynamic calibration is similar to a single point calibration in that only offset correction is needed to achieve the desired accuracy. However, the offset correction factor constantly updates to increase the accuracy. It is recommended to use the ADA4571 with its GC mode enabled when performing a dynamic calibration because it increases the signal-to-noise ratio (SNR), thereby decreasing the angular error of the device.

Using the simplified equations from the Single Point, End of Line (EOL) Calibration Procedure for the section, the only two factors that must be calculated are the offsets of the sine and cosine channels.

$$V_{SIN} = A \times \sin(2 \times \alpha) + O_S$$

$$V_{COS} = A \times \cos(2 \times \alpha) + O_C$$

During the first full rotation of the device, the offsets of the sine and cosine channels are unknown; therefore, use either a single point EOL calibration scheme or let $O_S = O_C = 0$. Setting $O_S = O_C = 0$ results in a start-up accuracy that is specified by the uncorrected error section and uncorrected error typical performance characteristics found in the ADA4571 data sheet until it is adjusted for offset in future mechanical rotations.

The external controller must save the maximum and the minimum values for both the sine and cosine channels during the first full revolution. Use these values to determine the offset of each channel independently. It is important that the sensor go through an entire mechanical revolution, not only a single electrical revolution for the purpose of offset correction. For a single dipole magnet in the end of shaft mounting configuration, one mechanical revolution produces two sinusoidal cycles for both the V_{SIN} and V_{COS} outputs. Each cycle has a slightly different offset; therefore, capturing the minimum and maximum values over two cycles results in the average offset for each channel, resulting in the most accurate value to use in dynamic calibration.

Figure 12 shows the difference between the AMR electrical angle and the mechanical angle for the end of shaft magnet configuration.

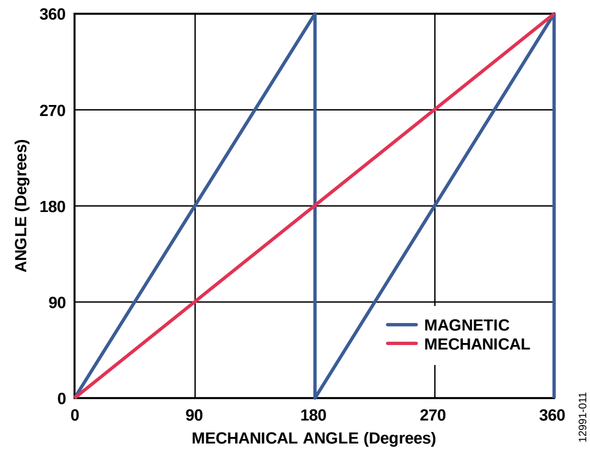

Figure 12. Magnetic vs. Mechanical Angle for End of Shaft Magnet Configuration

$$O_S = \frac{V_{SIN\_MAX} - V_{SIN\_MIN}}{2}$$

$$O_C = \frac{V_{COS\_MAX} - V_{COS\_MIN}}{2}$$

The accuracy of a dynamic calibration depends on how accurately the offset of each channel was calculated. When a motor is spinning quickly, at 1000 rpm or more, it is best to use dynamic calibration. At 1000 rpm, the electrical cycles are orders of magnitude faster than the temperature change in environment. In this case, the minimum and maximum values used to calculate the offset were taken from multiple mechanical cycles to ensure that an accurate offset was calculated.

In calculating the final electrical angle calculation, complete the same procedure as used for the single point calibration; however, O_S and O_C update continuously as follows:

$$\alpha = \arctan2\left(\frac{V_{SIN} - O_S}{V_{COS} - O_C}\right)$$

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