Application Information

Calculating Temperature Compensation Using A1342 Linear Hall-Effect Sensor ICs

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Introduction

Numerous applications in industries spanning automotive, industrial automation, and robotics require the monitoring of mechanical position or rotation. Linear Hall-effect sensor integrated circuits (ICs) provide a cost-effective solution for non-contacting measurements in such applications.

Linear Hall-effect systems design involves a mechanical system that modulates magnet flux density measured by a Hall-effect sensor IC. The sensor IC converts the magnetic input to an electrical output. The end result is an electrical output proportional to the magnetic input; it is also proportional to the movement of the mechanical system. (For more information on applications using linear Hall-effect sensor ICs, visit www.allegromicro.com.)

A successful system design takes into account various error contributors. Typical major system errors for linear Hall-effect sensor IC applications include:

- Non-ideal variations in magnetic flux density
- Parametric temperature drift
- Noise

Non-ideal variations in magnetic flux density occur as a result of several common factors. Some of these include: changes to the magnetic field strength as a result of ambient temperature changes; assembly tolerances; dynamic and static mechanical tolerances; and mechanical variation as a result of temperature changes. Parametric temperature drift errors occur as a result of non-ideal behaviors of the sensor IC. Noise error is derived from a combination of the magnetic input signal strength and sensor IC noise performance.

The sensor IC, magnet material, and mechanical system are key contributors to the system design. It is desirable to select components to optimize cost and achieve the required accuracy. Lower cost magnet materials tend to have larger variation over temperature and/or lower field strength. Selecting a higher performance sensor IC may allow for use of a less expensive magnet or allow for larger mechanical tolerances.

The Allegro MicroSystems A1342 linear Hall-effect sensor IC is highly advanced and designed with several features to reduce or eliminate the aforementioned systems errors and give greater flexibility in the system design. The scope of this document provides information on how to use A1342 customer-adjustable compensation parameters to reduce systems errors as a result of ambient temperature changes.

Device Features

The A1342 contains several features for reducing temperature-induced systems errors. Note all temperatures refer to ambient temperature conditions of the sensor IC.

Features applied from –40°C to 25°C:

- 1st-order Sensitivity temperature compensation
- 2nd-order Sensitivity temperature compensation
- 1st-order Offset temperature compensation

Features applied from 25°C to 150°C:

- 1st-order Sensitivity temperature compensation
- 2nd-order Sensitivity temperature compensation
- 1st-order Offset temperature compensation

Definitions

The following terms are used within this document. It is recommended to review the A1342 datasheet along with this document.

Ambient Temperature, T_A

The symbol T_A is used to represent the term ambient temperature of the sensor IC.

Sensitivity

Sensitivity is defined as the change in output versus the change in input. At the sensor IC level, Sensitivity is ΔLSB / ΔB, where B is the applied magnet flux density perpendicular to the Hall sensing element. At the system level, the input may be defined in units of distance, rotation, or other, depending on the application. For this document, Sensitivity is a function of temperature and is defined by the following formula:

$$SENS(T_A) = \Delta Output(LSB) / \Delta Input$$

Offset

Offset is defined as the output at zero input. At the sensor IC level, the Offset is the output when the applied magnetic flux density is zero gauss. This point is also referred to as the Quiescent Output, Q_O. At the system level, the Offset is the output at zero input. For example, the output when at 0 mm of travel:

$$Output(x=0,T_A) = SENS(T_A) \times x + OFFSET(T_A)$$

Sensitivity Error

Sensitivity Error is the percent change in Sensitivity from the ideal value. For this document, Sensitivity Error is a function of temperature and is defined by the following formula:

$$SENS_{ERR}(T_A)\ \% = [SENS(T_A) / SENS(T_A)(Ideal) - 1] \times 100$$

Offset Error

Offset Error is the change in Offset from the ideal value. For this document, Offset Error is a function of temperature and defined by the following formula:

$$OFFSET_{ERR}(T_A) = OFFSET(T_A) - OFFSET(T_A)(Ideal)$$

Temperature Characterization Data

To determine the temperature drift error, it is first necessary to collect some characterization data. The characterization data consists of the sensor IC output, recorded at a minimum of two input points, taken over the various ambient temperature readings. At a minimum, data is recorded at T_A = 25°C, two temperatures where T_A < 25°C (cold data), and two temperatures where T_A > 25°C (hot data). The temperature points and input points should give an accurate representation of the output error versus temperature. Prior to collecting the characterization, it is assumed the sensor IC is calibrated correctly at 25°C and is not clipping at the input points over the operating range. Also, the linearization features of the A1342 must be disabled to collect the temperature characterization data.

A sample dataset was created to demonstrate the procedures outlined in this document. For the sample dataset, an application measuring position was chosen. The application has an operating temperature range of T_A = –40°C to 150°C. The example input points were chosen at Position 1 = –5 mm and Position 2 = 5 mm. The example includes characterization data recorded across the ambient temperature range, at intervals between 20°C and 25°C. The number of temperature points selected in the example provides adequate resolution to demonstrate first- and second-order drift errors at hot and cold temperatures. The datapoint at 25°C is taken as the room temperature value. This point serves as the reference value for calculating temperature drift. The characterization data for the example is listed in Table 1. The example output data is in units of LSB. The A1342 can also have output data in units of percent duty cycle. For easier calculation, output units of LSB are recommended.

Table 1: Example Temperature Characterization Data

T_A (°C)	Output @ Position 1 (LSB)	Output @ Position 2 (LSB)
–40	290	3726
–20	323	3713
0	356	3698
25	410	3687
50	447	3671
75	503	3653
100	568	3627
125	647	3599
150	723	3557

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Calculating Sensitivity and Offset

After collecting the temperature characterization data, some basic calculations are required to analyze the data and apply the correct sensor IC compensation. The A1342 features include temperature compensation for both the Sensitivity and Offset parameters. It is important to derive how much of the temperature-induced error affects each of these independently to ensure the compensation is applied to the appropriate parameter. First, calculations are made to determine the Sensitivity and Offset at each temperature point. For data with two inputs, as shown in the example, Sensitivity and Offset are derived using equations 1 and 2. Note if the characterization data contains more than two inputs, a least squares linear regression is recommended to calculate Sensitivity and Offset. Table 2 shows the Sensitivity and Offset derived from the data in Table 1. The data from Table 2 is plotted in Figure 1 and Figure 2.

Equation 1:

$$SENS(T_A) = (Output(T_A)\ @\ Position\ 2 - Output(T_A)\ @\ Position\ 1) / (Input\ 2 - Input\ 1)$$

Example Sensitivity Calculation:

$T_A = 25°C$

$SENS(25) = (3687 - 410) / (5 + 5) = 327.7$ LSB/mm

Equation 2:

$$OFFSET(T_A) = Output(T_A)\ @\ Position\ 1 - SENS(T_A) \times Input\ 1$$

Example Offset Calculation:

$T_A = 25°C$

$OFFSET(25) = 410 - (327.7 \times -5) = 2048.5$ LSB

Table 2: Example Calculated Sensitivity and Offset

T_A (°C)	Sensitivity (LSB/mm)	Offset (LSB)
–40	343.6	2008
–20	339	2018
0	334.2	2027
25	327.7	2048.5
50	322.4	2059
75	315	2078
100	305.9	2097.5
125	295.2	2123
150	283.4	2140

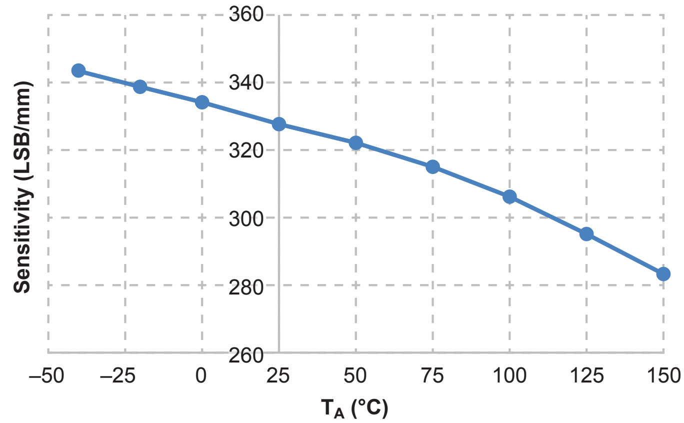

Figure 1: Example Data Plot of Sensitivity vs. Temperature

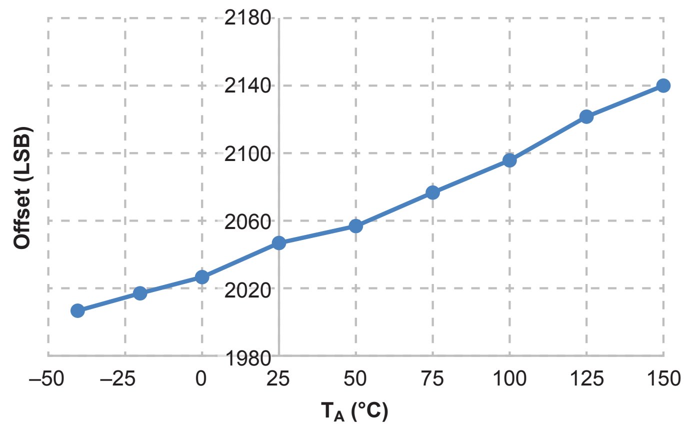

Figure 2: Example Data Plot of Offset vs. Temperature

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Formatting the Data

After calculating the Sensitivity and Offset from the characterization data, it is necessary to format the data. The Sensitivity data is formatted as a normalized ratio using 25°C as the reference, while the Offset data is formatted as a delta change from the 25°C value. The equations to calculate Normalized Sensitivity and Delta Offset are shown in equations 3 and 4. In addition to formatting Sensitivity and Offset data, the ambient temperature, T_A, is adjusted from an absolute value to a change from the reference temperature. The formula for adjusting T_A is shown in equation 4. The formatted example data from Table 2 is shown in Table 3. The results of Table 3 are plotted in Figure 3 and Figure 4. The example data results show, at 150°C, the Normalized Sensitivity is at 0.865 or 13.5% lower than the reference, and the Offset is 91.5 LSB higher than the reference.

Equation 3:

$$\mathit{Normalized\ SENS}(T_A) = \mathit{SENS}(T_A) / \mathit{SENS}(25)$$

Example Normalized Sensitivity Calculation:

$$\mathit{Normalized\ SENS}(150) = 283.4 / 327.7 = 0.865$$

Equation 4:

$$\mathit{Delta\ OFFSET}(T_A) = \mathit{OFFSET}(T_A) - \mathit{OFFSET}(25)$$

Example Delta Offset Calculation:

$$\mathit{Delta\ OFFSET}(150) = 2140 - 2048.5 = 91.5 \text{ LSB}$$

Equation 5:

$$\Delta T_A = T_A - 25$$

Example ΔT_A Calculation:

$$\Delta T_A = 100 - 25 = 75°C$$

Table 3: Example Data of Normalized Sensitivity and Offset

T_A (°C)	Normalized Sensitivity	Delta Offset (LSB)
–65	1.049	-40.5
–45	1.034	-30.5
–25	1.020	-21.5
0	1.000	0
25	0.984	10.5
50	0.961	29.5
75	0.933	49
100	0.901	74.5
125	0.865	91.5

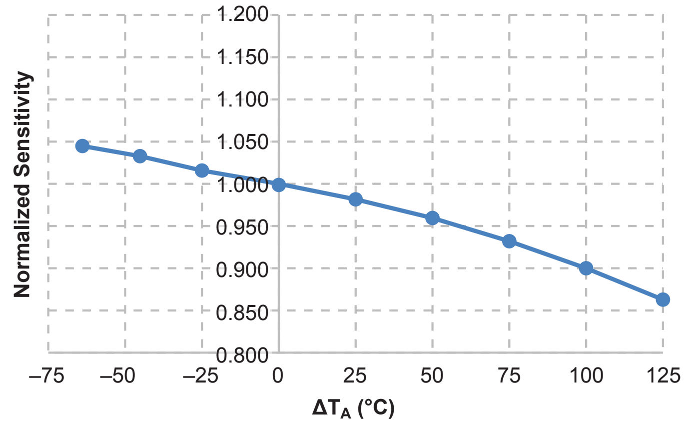

Figure 3: Example Data Plot of Normalized Sensitivity vs. Temperature

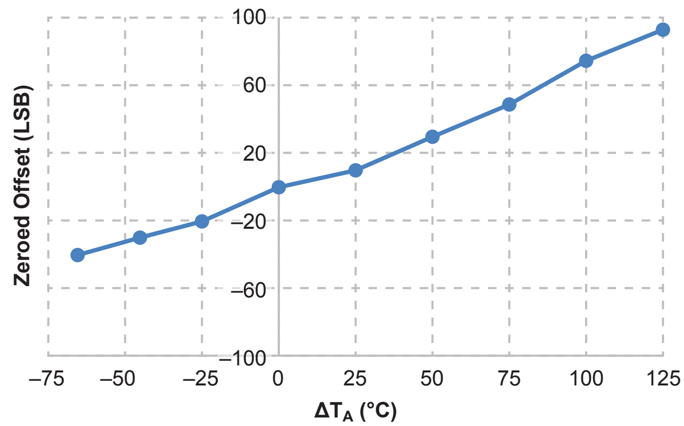

Figure 4: Example Data Plot of Delta Offset vs. Temperature

Note, the example data displayed in Figure 3 and Figure 4 represent total system error including the sensor, magnet material, and mechanical system. The sensor error is typically much lower than total system error. For more information on sensor error, refer to the sensor datasheet.

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Calculate the Temperature Compensation Coefficients

To this point, the characterization data is formatted to show the temperature-induced errors on Sensitivity and Offset. The next step is to calculate the compensation to apply to the A1342.

Before making additional calculations, it is important to stop and analyze the data. Look at the Sensitivity change over temperature—are there any strange discontinuities in the data? Typical temperature-induced Sensitivity errors appears as a first- or second-order function and may have different curves at hot and cold temperatures.

In addition, check the minimum and maximum percentage change in Sensitivity—is this value within A1342 datasheet specifications? Similarly, check the Offset change over temperature. Typical temperature-induced Offset errors appear as a first-order function. Check if the minimum and maximum Offset change is within datasheet specifications. The A1342 is designed with a large temperature compensation range suitable for most applications, including applications with ferrite magnets. If the temperature data exceeds the compensation range or appears abnormal, contact your local Allegro FAE for additional support.

The A1342 temperature compensation features include first- and second-order Sensitivity compensation and first-order Offset compensation. In addition, the Sensitivity and Offset compensation applies independently to two segments, hot and cold. The hot segment applies compensation when the change in ambient temperature, ΔT_A, is greater than zero. The cold segment applies compensation when ΔT_A is less than zero. To follow the temperature compensation features available on the A1342, the formatted data is separated into four groups: Normalized Sensitivity Hot, Normalized Sensitivity Cold, Delta Offset Hot, and Delta Offset Cold.

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Sensitivity Compensation

The Sensitivity temperature compensation feature adjusts the reference value, at 25°C, by a compensating scale factor to minimize the temperature-induced errors. For perfect Sensitivity correction, the Sensitivity compensation feature multiplies Sensitivity by the inverse of the temperature-induced error at the applied temperature. For example, the data in Table 3 shows the Sensitivity at ΔT_A = 125°C is 0.865. Otherwise stated, the Sensitivity has an error of –13.5% at a temperature of 150°C. The ideal compensation factor is the inverse of this value, 1/0.865 or 1.156. When the ideal compensation factor is applied, the end result is a value of one or no Sensitivity temperature-induced error.

To determine the best-fit Sensitivity compensation, calculate the inverse of the normalized sensitivity data and apply a 2nd-order best fit curve. To calculate the inverse data, take the reciprocal of the normalized Sensitivity data, equation 6. Then, separate the inverse data into the two defined segments for hot and cold. Next, determine the best fit 2nd-order curve to each segment independently. The end result is a 2nd-order polynomial for each segment that best represents the Sensitivity compensation, equations 7 and 8. The inverse Sensitivity for the example data is shown in Table 4 and is plotted in Figure 5. The Sensitivity compensation polynomials are shown in Figure 6 and in the examples under equations 7 and 8.

Equation 6:

$$\textit{Inverse Normalized SENS}(\Delta TA) = 1 \,/\, \textit{Normalized SENS}(\Delta T_A)$$

Equation 7:

$$\textit{Sensitivity Compensation Polynomial, } 0 \le \Delta T_A \le 125$$

$$a_1 \times (\Delta T_A)^2 + b_1 \times (\Delta T_A) + 1$$

Example Data: Compensation Polynomial

$$a_1 = 5.963 \times 10^{-6}$$

$$b_1 = 5.043 \times 10^{-4}$$

Equation 8:

$$\textit{Sensitivity Compensation Polynomial, } -65 \le \Delta T_A \le 0$$

$$a_2 \times (\Delta T_A)^2 + b_2 \times (\Delta T_A) + 1$$

Example Data: Compensation Polynomial

$$a_2 = 1.564 \times 10^{-6}$$

$$b_2 = 8.127 \times 10^{-4}$$

Table 4: Example Data Temperature Compensation

	ΔT_A (°C)	Inverse Normalized Sensitivity	Opposite Delta Offset (LSB)
◆ (cold)	–65	0.954	–40.5
	–45	0.967	–30.5
	–25	0.981	–21.5
	0	1.000	0
■ (hot)	25	1.016	10.5
	50	1.040	29.5
	75	1.071	49
	100	1.110	74.5
	125	1.156	91.5

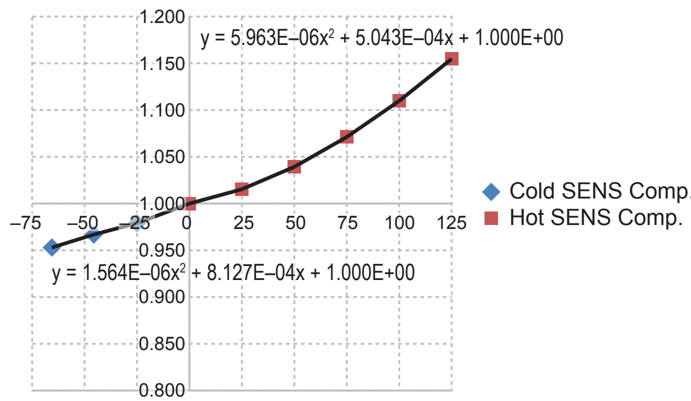

Figure 5: Example Data Sensitivity Compensation Data

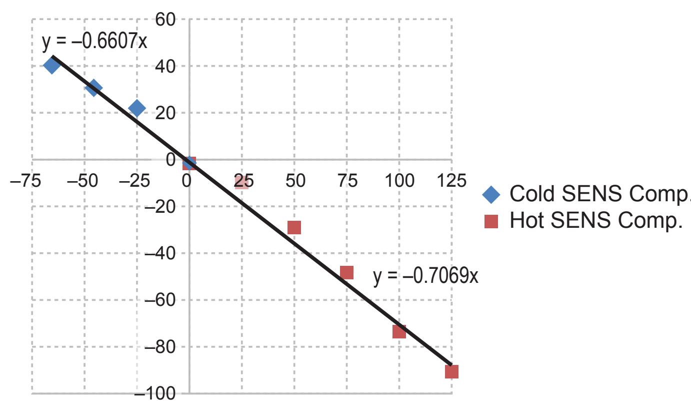

Figure 6: Example Data Offset Compensation Data

Offset Compensation

The Offset temperature compensation feature adjusts the reference value, at 25°C, by adding a compensating offset factor to minimize temperature-induced errors. For perfect Offset correction, the Offset compensation feature sums the additive inverse of the temperature-induced Offset error at the applied temperature. For example, the data in Table 3 shows the delta Offset at ΔT_A = 125°C is 91.5 LSB. The ideal compensation factor is the additive inverse of this value, –91.5 LSB. When the ideal compensation factor is applied, the end result is a value of zero, or no Offset temperature-induced error.

To determine the best-fit Offset compensation, calculate the additive inverse of the delta Offset data and apply a 1st-order best-fit curve. To calculate, multiply the delta Offset data by negative one, equation 9. Then, separate the data into the two defined segments for hot and cold. Next, determine the best-fit 1st-order curve to each segment independently. The end result is a 1st-order polynomial for each segment that best represents the Offset compensation, equations 10 and 11. The Offset compensation for the example data is shown in Table 4 and is plotted in Figure 7. The Offset compensation polynomials are shown in Figure 7 and in the examples under equations 10 and 11.

Equation 9:

$$Negative\ Delta\ OFFSET(\Delta T_A) = -1 \times Delta\ OFFSET(\Delta T_A)$$

Equation 10:

Offset Compensation Polynomial, $25 \le T_A \le 150$

$$c_1 \times (\Delta T_A) + 1$$

Example Data: Compensation Polynomial

$$c_1 = -0.707 \text{ LSB/°C}$$

Equation 11:

Sensitivity Compensation Polynomial, $-40 \le T_A \le 25$

$$c_2 \times (\Delta T_A) + 1$$

Example Data: Compensation Polynomial

$$c_2 = -0.661 \text{ LSB/°C}$$

Apply Temperature Compensation Parameters

The coefficients, a_1 and a_2, represent the values for the 2nd-order Sensitivity temperature compensation. These values convert to a digital code corresponding to the A1342 parameters senstc2_hot_c and senstc2_cld_c, respectively. The calculations for senstc2_hot_c and senstc2_cld_c are shown in equations 12 and 13.

Equation 12:

$$senstc2\_hot\_c = a_1 \times 2^{25}$$

where senstc2_hot_c is a signed integer between –512 and 511.

Equation 13:

$$senstc2\_cld\_c = a_2 \times 2^{23}$$

where: senstc2_hot_c is a signed integer between –512 and 511.

The coefficients, b_1 and b_2, represent the values for the 1st-order Sensitivity temperature compensation. These values convert to a digital code corresponding to the A1342 parameters senstc1_hot_c and senstc1_cld_c, respectively. The calculations for senstc1_hot_c and senstc1_cld_c are shown in equations 14 and 15.

Equation 14:

$$senstc1\_hot\_c = b_1 \times 2^{18}$$

where senstc1_hot_c is a signed integer between –1024 and 1023.

Equation 15:

$$senstc1\_cld\_c = b_2 \times 2^{17}$$

where senstc1_hot_c is a signed integer between –1024 and 1023.

The coefficients, c_1 and c_2, represent the values for the 1st-order Offset temperature compensation. These values convert to a digital code corresponding to the A1342 parameters qotc_hot_c and qotc_cld_c, respectively. The calculations for qotc_hot_c and qotc_cld_c are shown in equations 16 and 17.

Equation 16:

$$qotc\_hot\_c = c_1 \times 2^{6}$$

where qotc_hot_c is a signed integer between –2048 and 2047.

Equation 17:

$$qotc\_cld\_c = c_2 \times 2^{5}$$

where qotc_hot_c is a signed integer between –2048 and 2047.

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Allegro MicroSystems provides hardware and software tools to support development of applications using the A1342. The programming tools may be utilized to configure device parameters. Figure 7 shows a small excerpt of the temperature compensation parameters within the A1342 programming software tool. The parameters may be set by entering the calculated codes or the calculated values. Note when entering the calculated values, ensure the units are correct. For example, the units of a_1 and a_2 are 1/°C^2. To adjust the units of a_1 and a_2 to m%/°C^2, multiply each coefficient by 10^5. Also, the units of b_1 and b_2 are 1/°C. To adjust the units of b_1 and b_2 to %/°C, multiply each coefficient by 100. For more information on support tools and software, visit www.allegromicro.com or contact your local FAE.

☑	senstc1_hot_c	131	0.050	%/°C
☑	senstc1_cld_c	106	0.081	%/°C
☑	senstc2_hot_c	200	0.596	m%/°C2
☑	senstc2_cld_c	13	0.155	m%/°C2
☐	qo_c			
☑	qotc_hot_c	4051	-0.703	LSB/°C
☑	qotc_cld_c	4075	-0.656	LSB/°C

Figure 7

The example data Sensitivity and Offset errors versus ambient temperature are shown in Figure 8 and Figure 9. The graphs display errors before and after applying the compensation parameters. The Sensitivity error reduces from ±13%, before compensation, to less than ±0.1% after compensation. The Offset error reduces from ±92 LSB, before compensation, to less than ±8 LSB after compensation. Offset values are based on a 12-bit, 0 to 4095, LSB range. The results in Figure 8 and Figure 9 do not include latent error sources, such as lifetime drift, drift from mechanical wear, or other sources.

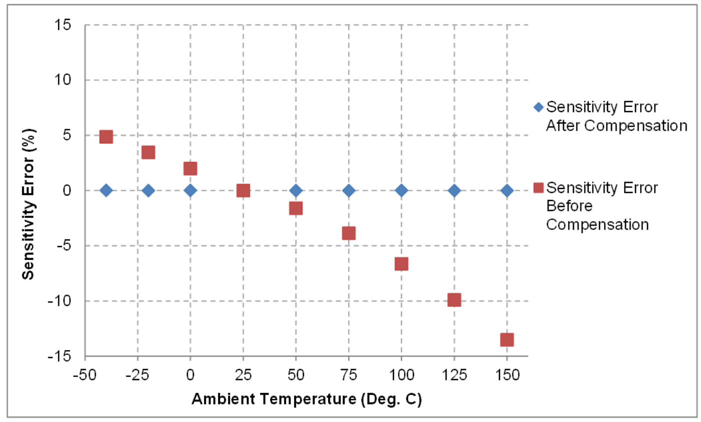

Figure 8: Example Data Sensitivity Error versus Ambient Temperature

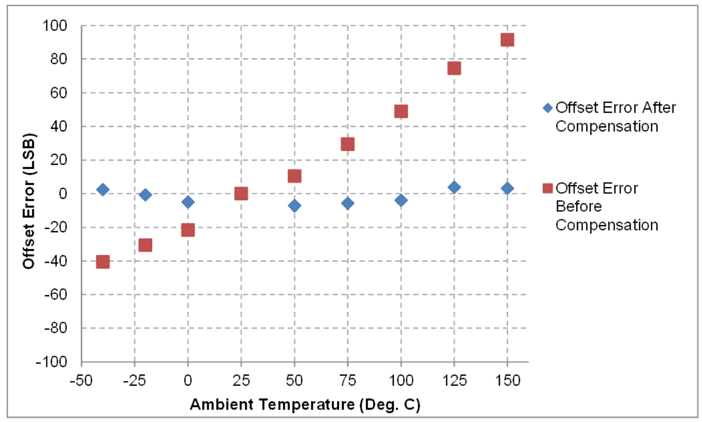

Figure 9: Example Data Offset Error versus Ambient Temperature

Revision History

Number	Date	Description
–	January 4, 2017	Initial release
1	April 23, 2021	Addition to Formatting the Data section (page 4); addition to Apply Temperature Compensation Parameters section (page 8); removed A1346 part; and other minor editorial updates.

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