A1340, A1341, and A1343 Sensor Temperature Compensation

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Introduction

Sensor output can change over temperature due to sensor imperfections or temperature-dependent properties of the magnetic system. The purpose of applying temperature compensation inside the sensor is to keep the sensor output value independent of the temperature and only dependent on the input magnetic field strength.

Implementation

Allegro sensors allow the customer to change how the sensor responds to temperature deviations through the use of sensor temperature compensation coefficients. These coefficients are part of the sensor temperature algorithm implemented in the Temperature Compensation Block shown in Figure 1.

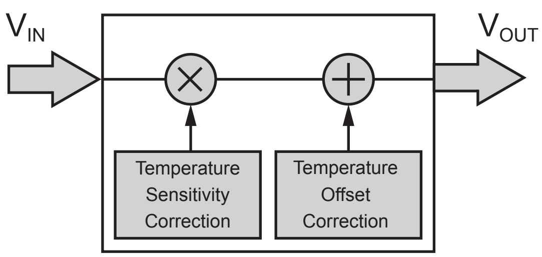

Figure 1: Temperature Compensation Block (Offset and Sensitivity Adjustment)

The transfer function of the temperature compensation block is given as the following equation:

$$V_{OUT}\ (\text{V}) = SENS(\Delta T_A) \times V_{IN}\ (\text{V}) + OFFSET(\Delta T_A) \quad (1)$$

where T_A is ambient temperature, and $\Delta T_A = T_A - 25°C$.

The *Sensitivity Temperature Compensation*, labeled as $SENS(\Delta T_A)$, is used to manipulate the effect of temperature on the gain that the sensor applies on the input magnetic signal. The Sensitivity Temperature Compensation is described as a polynomial function of second order:

$$SENS(\Delta T_A) = [TC1\_SENS\ (\text{m\%/°C}) \times \Delta T_A\ (°\text{C}) + TC2\_SENS\ (\text{m\%/°C}^2) \times (\Delta T_A)^2\ (°\text{C}) + 1\ ] \quad (2)$$

where $SENS(\Delta T_A)$ at some temperature T is actually calculated as:

$$(SENS\ at\ 25°C)\ /\ (Recorded\ SENS\ @\ T°C) \quad (3)$$

The user-programmable parameters are described in the following table:

Table 1: Input Variables of Sensitivity Compensation

Parameter	Definition	Unit
TC1_SENS	First-order gain temperature coefficient. Coefficient applied to the first order term of the sensitivity change over temperature.	m%/°C
TC2_SENS	Second-order gain temperature coefficient. Coefficient applied to the second order term of the sensitivity change over temperature.	m%/°C^2

Applying Compensation Coefficients, TC1_SENS and TC2_SENS, as calculated will result in a temperature-independent gain applied to the sensor's input signal. It is important to keep in mind that there two sets of these parameters—one to compensate for temperatures below 25°C and one for temperatures above 25°C.

The *Offset Temperature Compensation*, labeled as $OFFSET(\Delta T_A)$, is used to change the temperature behavior of the offset that the sensor applies on the input magnetic signal. The equation for $OFFSET(\Delta T_A)$ is described as a linear first-order function:

$$OFFSET(\Delta T_A) = TC1\_OFFSET\ (\text{mG/°C}) \times \Delta T_A\ (°\text{C}) \times DIV\_SENS\_COARSE\ (\text{mV/G}) \quad (4)$$

where $OFFSET(\Delta T_A)$ at some temperature T is actually calculated as:

$$OFFSET(\Delta T_A) = (OFFSET\ @\ 25°C) - (Recorded\ OFFSET\ @\ T°C) \quad (5)$$

Applying the coefficient TC1_OFFSET as calculated would result in temperature-independent offset behavior.

In the case of the A1343 device, parameter DIV_SENS_COARSE is not applicable since the temperature compensation algorithm is not accounting for this parameter.

Table 2: Input Variables of Offset Compensation

Parameter	Definition	Unit
TC1_OFFSET	First-order offset temperature coefficient. Coefficient applied to the first-order term of the offset change over temperature.	mG/°C
DIV_SENS_COARSE	Offset Compensation coefficient for different magnetic ranges. It changes respectively to the change of magnetic field. It is equal to 1 for value of ±500 G. For example if field range changed to ±300 G, coefficient value will be 3/5.	mV/G

Calculating Sensitivity Compensation

Allegro sensors are often used with permanent magnets of unknown field strength at the specific operating positions. Therefore exact calculation of the system Sensitivity per gauss is impossible. However, Sensitivity can be calculated with respect to device position.

In the example below, the user collects device output at two different points in the movement range. Position 1 is at –10 degrees and Position 2 is at +10 degrees.

Table 3: Example of Device Output

Temperature (°C)	Sensor with Analog Output		Sensor with PWM Output		Sensor with SENT Output	
	Sensor Output @ Position 1 (V)	Sensor Output @ Position 2 (V)	Sensor Output @ Position 1 (%D)	Sensor Output @ Position 2 (%D)	Sensor Output @ Position 1 (LSB)	Sensor Output @ Position 2 (LSB)
–40	0.354	4.548	8.0	91.9	139	3955
–20	0.394	4.532	8.6	91.3	165	3929
0	0.435	4.514	9.2	90.8	191	3902
25	0.500	4.501	10	90	227	3867
50	0.546	4.481	10.7	89.4	257	3837
75	0.614	4.459	11.6	88.5	298	3796
100	0.693	4.427	12.7	87.4	349	3746
125	0.790	4.393	14.1	86.1	408	3686
150	0.883	4.342	15.5	84.7	474	3621

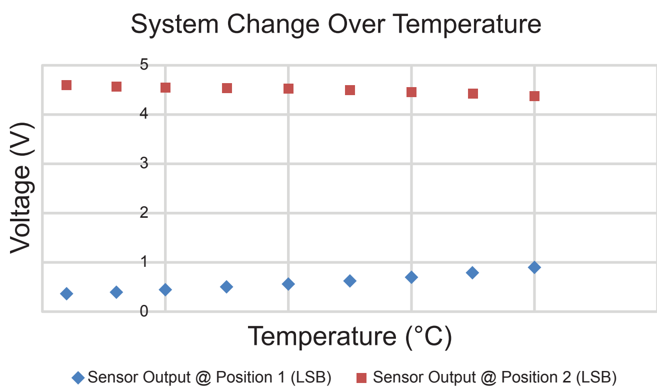

Figure 2: Output Voltages Changing with Temperature

The Sensitivity throughout the temperature range can be calculated as:

$$SENS = (V_{OUT} @ Position\ 2 - V_{OUT} @ Position\ 1) / (Position\ 2 - Position\ 1) \quad (6)$$

Table 4

Temperature (°C)	Sensitivity (V/°C)	Sensitivity (%D/°C)	Sensitivity (LSB/°C)
–40	0.210	4.19	190.78
–20	0.207	4.14	188.23
0	0.204	4.08	185.55
25	0.200	4	182.00
50	0.197	3.93	179.00
75	0.192	3.84	174.90
100	0.187	3.73	169.85
125	0.180	3.60	163.90
150	0.173	3.46	157.35

In order to calculate the compensation function SENS(ΔT_A) versus ΔT_A values, apply equation 3 on the recorded data in Table 4. The equation effectively performs an inverted normalization with respect to 25°C. The resulting data is presented in the table below (note that the temperature values now appear as ΔT_A values, representing deviation from 25°C):

Table 5: Normalized Inverse Sensitivity vs. Temperature

	ΔT_A (°C)	Normalized Inverse Sensitivity
◆ (cold)	–65	0.954
	–45	0.967
	–25	0.981
	0	1.000
■ (hot)	25	1.017
	50	1.041
	75	1.072
	100	1.110
	125	1.157

The graphical representation of Table 5 is given in Figure 3:

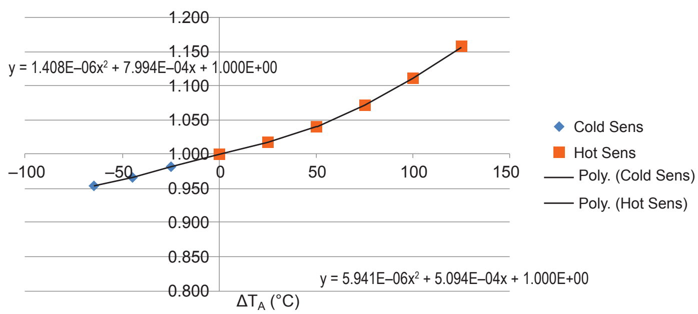

Figure 3: Normalized Inverse Sensitivity over Temperature

Since Allegro sensors have different temperature coefficient codes for compensation at hot and cold temperatures, the above curve is divided into two regions. The hot region, from ΔT_A of 0°C and above, is described with the following equation: SENS(ΔT_A) = 1.408E-06x^2 + 7.994E-04x + 1.000. The cold region, below ΔT_A of 0°C on the *x*-axis, is governed by the equation: SENS(ΔT_A) = 5.941E-06x^2 + 5.094E-04x + 1.000.

The programmable coefficients can now be calculated from the above equations. Note that to convert to m%, a factor of 10^5 should be introduced.

Table 6: Calculated Temperature Compensation Coefficients

Coefficients Hot	Value	Coefficients Cold	Value
TC1_SENS_HOT (m%/°C)	79.94	TC1_SENS_CLD (m%/°C)	50.94
TC2_SENS_HOT (m%/°C2)	0.1408	TC2_SENS_CLD (m%/°C2)	0.5941

Programming Sensitivity Coefficients

Calculated values for the temperature adjustment can be entered in the software directly under the "Value" column, or the user can calculate the code manually and enter it under the "Code" column.

If the user enters the desired coefficient under the "Value" column, then the software will round the actual number to the closest discrete value offered in the device. For example, TC2_SENS_CLD is calculated as 0.5941 m%/°C^2, but the program rounded to the 0.593 m%/°C^2. The software automatically calculates the code based on the TC2_SENS_CLD value, the step size of that register, and also the transfer function between the value and the code.

Select	Name	Code	Value	Units
☑	TC2_SENS_CLD	99	0.593	m% / (°C^2)
☑	TC2_SENS_HOT	24	0.144	m% / (°C^2)

Figure 4: Second-Order Temperature Parameter Entries in Programmer

Select	Name	Code	Value	Units
☑	TC1_SENS_CLD	33	50.531	m% / °C
☑	TC1_SENS_HOT	52	79.625	m% / °C

Figure 5: First-Order Temperature Parameter Entries in Programmer

In the case that the user would like to calculate the necessary codes, the table below, extracted from the datasheet, can be used as a guideline. The needed value of 0.5941 m%/°C^2 would be divided by 0.00596 m%/°C^2, the typical step size, to get to the needed code of 99.

TC2_SENS_CLD (Register Address: 0x08, bits 14:6)
TC2_SENS_HOT (Register Address: 0x08, bits 23:15)

Function	2nd Order Sensitivity Temperature Coefficient. Specifies a compensation factor for drift in device Sensitivity resulting from changes in ambient temperature during operation. Applies a 2nd order, quadratic compensation algorithm. Two different parameters are set, one for increasing values relative to T_A = 25°C, and the other for decreasing values, as follows: • TC2_SENS_HOT: ΔT (from 25°C) > 0 • TC2_SENS_CLD: ΔT (from 25°C) < 0
Syntax	Quantity of bits: 9 (each parameter)
Related Commands	SENS_MULT, TC1_SENS_HOT, TC1_SENS_CLD
Values	1 0000 0000: –1.53 m% / °C 0 1111 1111: +1.53 m% / °C Increments (step size) of ±0.00596 m% / °C
Options	Set all bits to 0 if TC2_SENS_HOT and TC2_SENS_CLD are not used.
Examples	Refer to Temperature Compensation section.

Figure 6: Second-Order TC Parameter Description from Datasheet

Calculating Offset Compensation

In the application, linear sensors often see a magnetic field in all positions or often the customer cannot determine in which position the field will be equal to 0. However, reading the device output in two application positions can help to determine the needed sensitivity of the sensor which then helps to calculate the offset as: (V_{OUT} @ Position 2 – Position 2 × Sensitivity). This is shown in Table 7 below:

Table 7: Voltage Offset Over Temperature

Temperature (°C)	Offset (V)	Offset (%)	Offset (LSB)
–40	2.45	49.95	2047
–20	2.46	49.96	2047
0	2.47	49.97	2047
25	2.5	50.00	2047
50	2.51	50.01	2047
75	2.53	50.04	2047
100	2.56	50.06	2047
125	2.6	50.09	2047
150	2.61	50.11	2047

Once the offset at each temperature is obtained, the correction curve is calculated using equation 5.

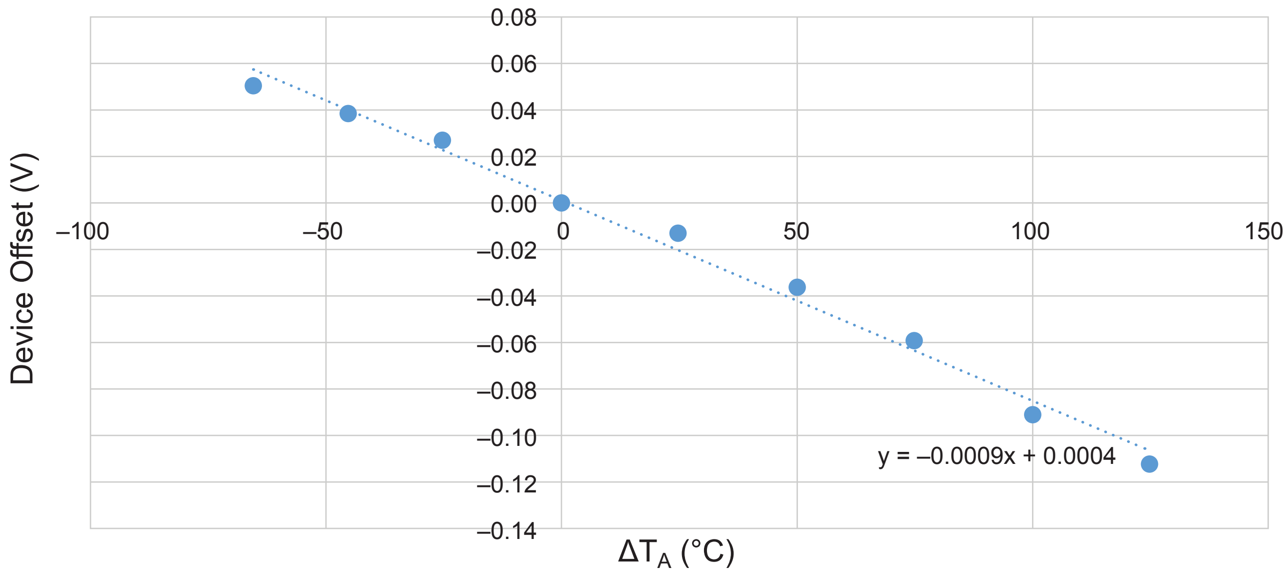

Figure 7: Negative Offset Correction Curve

From Figure 7, it can be seen that offset over temperature can be calculated as:

$$OFFSET(\Delta T_A) = -0.0009 \times \Delta T_A + 0.0004.$$

The recorded behavior is in mV/°C and represents the formula:

$$OFFSET(\Delta T_A) = TC1\_OFFSET\ (\text{mG/°C}) \times \Delta T_A\ (\text{°C}) \times DIV\_SENS\_COARSE\ (\text{mV/G}).$$

The constant term of 0.0004 is close to zero, so it can be ignored. The function gain of 0.0009 is the product of TC1_OFFSET (mG/°C) × DIV_SENS_COARSE (mV/G), so it is necessary to divide the gain number with DIV_SENS_COARSE (mV/G), which depends on the chosen magnetic coarse range. If the chosen range were 250 G, then the parameter DIV_SENS_COARSE (mV/G) has value of 0.5.

Table 8: Offset Coefficient Value

Offset Coefficient	Value
TC1_OFFSET (mG/°C) for +/-250 G range	0.0009 / 0.5 = –0.002

Programming Sensitivity Coefficients

Calculated values for the temperature adjustment can be entered in the software directly under the "Value" column, or the user can calculate the code manually and enter it under the "Code" column.

Select	Name	Code	Value	Units
☑	TC1_OFFSET	255	-0.004	mG/°C

Figure 8: Negative Offset Correction Curve

In the case that the user would like to calculate the necessary codes, the table below, extracted from the datasheet, can be used as a guideline.

TC1_OFFSET (Register Address: 0x09, bits 7:0)

Function	1st-Order Magnetic Offset Temperature Compensation coefficient.
Syntax	Quantity of bits: 8 Code stored in two's complement format.
Related Commands	SIG_OFFSET, TC1_SENS_CLD, TC1_SENS_HOT, TC2_SENS_CLD, TC2_SENS_HOT
Values	0000 0000: Default 0111 1111: +0.48 G/°C 1000 0000: –0.48 G/°C
Options	No fine magnetic offset is applied if this parameter is not set.
Examples	–

Figure 9: TC1_OFFSET Parameter Description from Datasheet

REVISION HISTORY

Number	Date	Description
–	May 3, 2016	Initial release

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