



APPLICATION NOTE 4261

## Measuring and Calibrating for Product-Dependent Temperature Offsets

*Abstract: This application note presents a procedure for optimizing the accuracy of the MAX1358/MAX1359/MAX1360 data acquisition system temperature reading when the temperature to be measured is external to the chip.*

### Introduction

The [MAX1358/MAX1359/MAX1360](#) data acquisition system has an on-board diode junction. The diode's intrinsic i-v characteristics are used to measure the temperature. To improve the measurement accuracy, Maxim stores calibration coefficients inside each part to correct for small errors in the reading and achieve the best possible accuracy.

A temperature reading corresponds to the actual temperature of the junction. In applications where the change in temperature is being monitored, the reading can be used directly. In other applications where the desired temperature is, for example, outside a plastic enclosure, the temperature will be more accurate if the reading is offset by a few degrees.

Measuring this offset for your product and using that offset is described in this application note. Using the calibration coefficient data stored inside the part is described in application note 4296, "[Measuring Temperature with the MAX1358 Data Acquisition System](#)."

### Temperature Measurement Model

The MAX1358/MAX1359/MAX1360's on-board temperature sensor measures temperature with either an on-chip diode junction or a customer-provided external temperature sensor. Two constants (m, b) are stored in calibration registers on the chip to correct for measurement errors caused by variation of the on-chip diode and other circuitry from ideal. A four-current procedure for measuring, calculating, and removing errors due to nonidealities that vary from part-to-part or with temperature is described in application note 4296 noted above. This four-current procedure is applicable to both on-chip and off-chip diode junction temperature sensors.

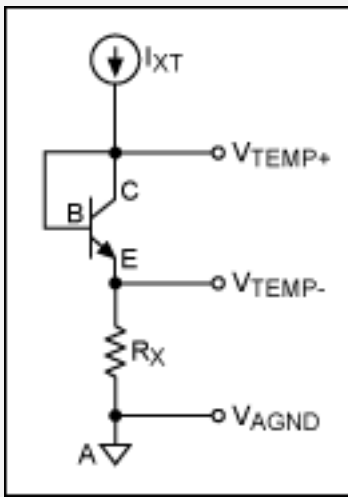


Figure 1. Temperature measurement with a diode junction.

The temperature measured by the MAX1358/MAX1359/MAX1360 is the junction temperature (**Figure 1**). A familiar model for relating junction temperature,  $T_J$ , to the ambient temperature,  $T_A$ , and the case temperature,  $T_C$ , is shown in **Figure 2**.

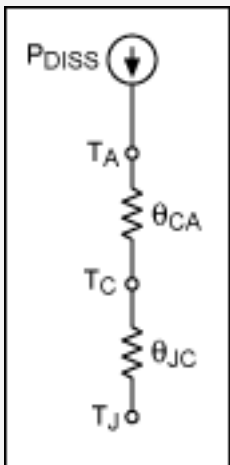


Figure 2. Junction temperature and ambient temperature.

In this model the thermal properties are translated into an equivalent circuit. (Note that when the chip is calibrated at Maxim, the case temperature  $T_C$  and the ambient temperature  $T_A$  are forced to be the same by the oil bath.)

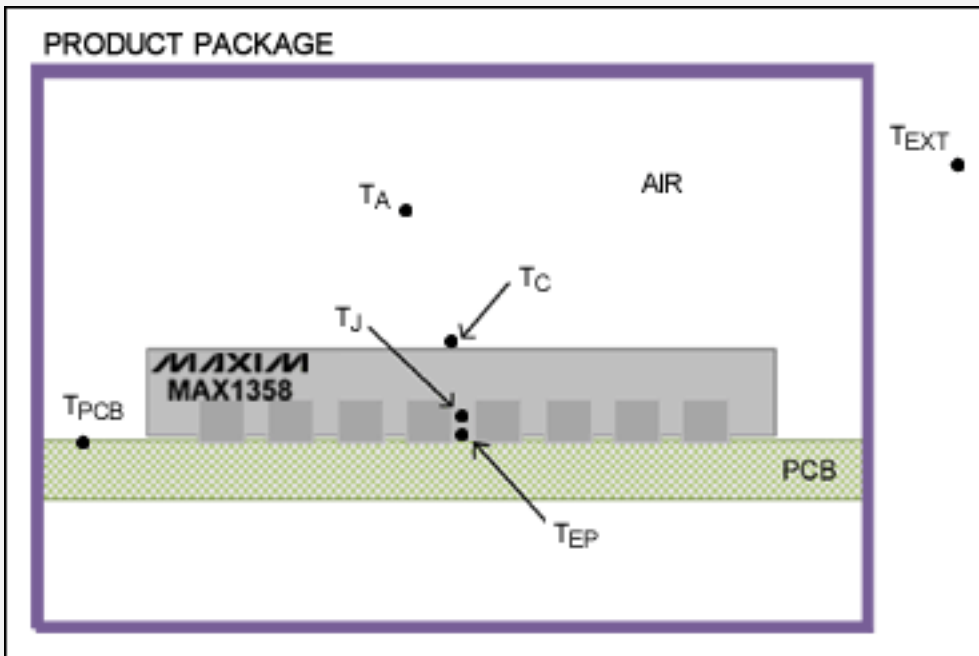


Figure 3. Thermal model of a product.

When the chip is installed on your circuit board (**Figure 3**), the value of  $T_J$  seen by the MAX1358/MAX1359/MAX1360 will depend on a number of product-specific factors:

- The temperature of the PCB
- The air temperature around the PCB
- The thermal connection of the EP to the PCB
- The power dissipated by the MAX1358/MAX1359/MAX1360
- The power dissipated by circuitry on the PCB
- The temperature of the air surrounding the product
- Packaging that insulates the product from the ambient temperature

The above factors create a difference between the temperature  $T_J$  seen inside the MAX1358/MAX1359/MAX1360 and the point outside MAX1358/MAX1359/MAX1360 where you wish to measure. This means that the  $T_J$  you measure with the devices is an estimate,  $T_{EST}$ , of the actual  $T_{EXT}$ .

Fortunately, for a fixed setup, the largest part of the difference between  $T_J$  and  $T_{EXT}$  is a small, constant, product-dependent offset that can be determined with some simple measurements.

## Procedure for Calculating the Temperature Offset

A simple procedure can be used to correct for the product-specific offset. A worksheet is shown below (**Figure 4**) to illustrate the procedure.

"Silver" coefficients refer to the values of the calibration coefficients that are stored inside the MAX1358/MAX1359/MAX1360 (the TEMP\_CAL register). You read these values from the chip over the SPI™ bus. The values are used as follows:

$$T_{ESTIMATE} (^{\circ}C) = T_{MEAS} (^{\circ}C) \times G_S + O_S (^{\circ}C)$$

Product	Temperature	Offset
MAX1358	25.0	0.0
MAX1358	30.0	0.5
MAX1358	35.0	1.0
MAX1358	40.0	1.5
MAX1358	45.0	2.0
MAX1358	50.0	2.5
MAX1358	55.0	3.0
MAX1358	60.0	3.5
MAX1358	65.0	4.0
MAX1358	70.0	4.5
MAX1358	75.0	5.0
MAX1358	80.0	5.5
MAX1358	85.0	6.0
MAX1358	90.0	6.5
MAX1358	95.0	7.0
MAX1358	100.0	7.5
MAX1358	105.0	8.0
MAX1358	110.0	8.5
MAX1358	115.0	9.0
MAX1358	120.0	9.5
MAX1358	125.0	10.0
MAX1358	130.0	10.5
MAX1358	135.0	11.0
MAX1358	140.0	11.5
MAX1358	145.0	12.0
MAX1358	150.0	12.5
MAX1358	155.0	13.0
MAX1358	160.0	13.5
MAX1358	165.0	14.0
MAX1358	170.0	14.5
MAX1358	175.0	15.0
MAX1358	180.0	15.5
MAX1358	185.0	16.0
MAX1358	190.0	16.5
MAX1358	195.0	17.0
MAX1358	200.0	17.5
MAX1358	205.0	18.0
MAX1358	210.0	18.5
MAX1358	215.0	19.0
MAX1358	220.0	19.5
MAX1358	225.0	20.0
MAX1358	230.0	20.5
MAX1358	235.0	21.0
MAX1358	240.0	21.5
MAX1358	245.0	22.0
MAX1358	250.0	22.5
MAX1358	255.0	23.0
MAX1358	260.0	23.5
MAX1358	265.0	24.0
MAX1358	270.0	24.5
MAX1358	275.0	25.0
MAX1358	280.0	25.5
MAX1358	285.0	26.0
MAX1358	290.0	26.5
MAX1358	295.0	27.0
MAX1358	300.0	27.5
MAX1358	305.0	28.0
MAX1358	310.0	28.5
MAX1358	315.0	29.0
MAX1358	320.0	29.5
MAX1358	325.0	30.0
MAX1358	330.0	30.5
MAX1358	335.0	31.0
MAX1358	340.0	31.5
MAX1358	345.0	32.0
MAX1358	350.0	32.5
MAX1358	355.0	33.0
MAX1358	360.0	33.5
MAX1358	365.0	34.0
MAX1358	370.0	34.5
MAX1358	375.0	35.0
MAX1358	380.0	35.5
MAX1358	385.0	36.0
MAX1358	390.0	36.5
MAX1358	395.0	37.0
MAX1358	400.0	37.5
MAX1358	405.0	38.0
MAX1358	410.0	38.5
MAX1358	415.0	39.0
MAX1358	420.0	39.5
MAX1358	425.0	40.0
MAX1358	430.0	40.5
MAX1358	435.0	41.0
MAX1358	440.0	41.5
MAX1358	445.0	42.0
MAX1358	450.0	42.5
MAX1358	455.0	43.0
MAX1358	460.0	43.5
MAX1358	465.0	44.0
MAX1358	470.0	44.5
MAX1358	475.0	45.0
MAX1358	480.0	45.5
MAX1358	485.0	46.0
MAX1358	490.0	46.5
MAX1358	495.0	47.0
MAX1358	500.0	47.5
MAX1358	505.0	48.0
MAX1358	510.0	48.5
MAX1358	515.0	49.0
MAX1358	520.0	49.5
MAX1358	525.0	50.0
MAX1358	530.0	50.5
MAX1358	535.0	51.0
MAX1358	540.0	51.5
MAX1358	545.0	52.0
MAX1358	550.0	52.5
MAX1358	555.0	53.0
MAX1358	560.0	53.5
MAX1358	565.0	54.0
MAX1358	570.0	54.5
MAX1358	575.0	55.0
MAX1358	580.0	55.5
MAX1358	585.0	56.0
MAX1358	590.0	56.5
MAX1358	595.0	57.0
MAX1358	600.0	57.5
MAX1358	605.0	58.0
MAX1358	610.0	58.5
MAX1358	615.0	59.0
MAX1358	620.0	59.5
MAX1358	625.0	60.0
MAX1358	630.0	60.5
MAX1358	635.0	61.0
MAX1358	640.0	61.5
MAX1358	645.0	62.0
MAX1358	650.0	62.5
MAX1358	655.0	63.0
MAX1358	660.0	63.5
MAX1358	665.0	64.0
MAX1358	670.0	64.5
MAX1358	675.0	65.0
MAX1358	680.0	65.5
MAX1358	685.0	66.0
MAX1358	690.0	66.5
MAX1358	695.0	67.0
MAX1358	700.0	67.5
MAX1358	705.0	68.0
MAX1358	710.0	68.5
MAX1358	715.0	69.0
MAX1358	720.0	69.5
MAX1358	725.0	70.0
MAX1358	730.0	70.5
MAX1358	735.0	71.0
MAX1358	740.0	71.5
MAX1358	745.0	72.0
MAX1358	750.0	72.5
MAX1358	755.0	73.0
MAX1358	760.0	73.5
MAX1358	765.0	74.0
MAX1358	770.0	74.5
MAX1358	775.0	75.0
MAX1358	780.0	75.5
MAX1358	785.0	76.0
MAX1358	790.0	76.5
MAX1358	795.0	77.0
MAX1358	800.0	77.5
MAX1358	805.0	78.0
MAX1358	810.0	78.5
MAX1358	815.0	79.0
MAX1358	820.0	79.5
MAX1358	825.0	80.0
MAX1358	830.0	80.5
MAX1358	835.0	81.0
MAX1358	840.0	81.5
MAX1358	845.0	82.0
MAX1358	850.0	82.5
MAX1358	855.0	83.0
MAX1358	860.0	83.5
MAX1358	865.0	84.0
MAX1358	870.0	84.5
MAX1358	875.0	85.0
MAX1358	880.0	85.5
MAX1358	885.0	86.0
MAX1358	890.0	86.5
MAX1358	895.0	87.0
MAX1358	900.0	87.5
MAX1358	905.0	88.0
MAX1358	910.0	88.5
MAX1358	915.0	89.0
MAX1358	920.0	89.5
MAX1358	925.0	90.0
MAX1358	930.0	90.5
MAX1358	935.0	91.0
MAX1358	940.0	91.5
MAX1358	945.0	92.0
MAX1358	950.0	92.5
MAX1358	955.0	93.0
MAX1358	960.0	93.5
MAX1358	965.0	94.0
MAX1358	970.0	94.5
MAX1358	975.0	95.0
MAX1358	980.0	95.5
MAX1358	985.0	96.0
MAX1358	990.0	96.5
MAX1358	995.0	97.0
MAX1358	1000.0	97.5

[Download Excel file](#)

Figure 4. Product-specific temperature offset removal.

The silver coefficients are used whenever you wish to convert from the measured  $T_J$  to an estimate of the actual temperature.

To measure your temperature offset during engineering characterization of your product, you need two numbers: the temperature estimated by the MAX1358/MAX1359/MAX1360 (**C** in the equation above), and the actual temperature outside your product (**A** in the equation above). The actual temperature should be measured with a known accurate sensor, meter, and procedure. With these two numbers you can calculate the value of **D**, the product-specific temperature offset. Typical values for **D** lie between 0°C and +6°C.

This procedure should be repeated during engineering characterization to determine if the value is stable enough to hard-code for all copies that you build, or if you need to apply it to each product that you build. A value that is stable from copy to copy can be hard-coded into your firmware. A value which is not stable from copy to copy should be stored per-copy in nonvolatile memory during manufacturing.

Finally, the value of **D** is used at runtime as shown in the equation for **K**. The result is a calibrated and offset reading which estimates the desired temperature external to your product.

## Summary

A simple procedure has been described which improves the accuracy of the temperature reading seen by the MAX1358/MAX1359/MAX1360 family's internal temperature sensor.

Note that this procedure is not necessary if your product is only looking at changes in temperature. For example, if you simply wish to trigger another operation when the temperature rises or falls. In that case, any offset terms drop out.

Also note that a similar procedure may be used with an external temperature sensor if it is not immersed in  $T_{EXT}$ .

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Application note 4261: [www.maxim-ic.com/an4261](http://www.maxim-ic.com/an4261)

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AN4261, AN 4261, APP4261, Appnote4261, Appnote 4261

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