# TMP007 Calibration Guide

The TMP007 is a thermal infrared (IR) sensor sensitive to radiation in the IR spectrum from approximately 4- to 16-µm wavelength. The TMP007 measures the temperature of an object by sensing the infrared radiation emitted by the object and converting the voltage generated to a digital reading of the temperature.

Calibration is the process of correlating the radiation emitted by the object to the digital value in the object temperature register based the sensor voltage and the die temperature generated by the TMP007.

This guide covers the basic principles of calibration: generating a data set for calibration, common errors in calibration, generating the calibration coefficients and verifying the calibration coefficients. While intended for the TMP007, many of the principles and techniques can be applied to the TMP006 thermopile sensor.

This guide is intended to be used with the TMP007 data sheet (SBOS685).

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# 1 Introduction

The TMP007 can estimate the temperature of an object based on the thermal radiation received from the object and the die temperature. To calculate the temperature, the TMP007 must first be calibrated for the specific object and the system geometry.

*Calibration is the process of correlating the radiation emitted by the object to the digital value in the object temperature register based the sensor voltage and the die temperature generated by the TMP007.*

This document discusses calibration for three distinct operating modes:

1. Temperature range – Measuring the temperature across a predetermined range
2. Interrupt mode – Enabling an ALERT when the temperature is outside a set band
3. Comparator mode – Enabling an ALERT when the temperature exceeds a set threshold

While each mode does have unique features, they all share a common set of concepts and principles which are discussed first.

## 1.1 How to Use This Guide

The basic steps in the calibration procedure are:

1. Define the function used in calibration (Section 1.2)
2. Define object and die temperatures for calibration, accuracy required (Section 2.2). At this point the object size, distance, and material are also defined and fixed for the remainder of the calibration.
3. Collect data and use NETD to estimate the quality of calibration (Section 2.2, Section 2.3)
   (a) Common errors in data sets (Section 6)
4. Calibration and Verification for:
   (a) Calibrating over a temperature range (Section 3)
   (b) Calibrating in INTERRUPT mode – maintaining a temperature band (Section 4)
   (c) Calibrating in COMP mode – exceeding a threshold and recovery (Section 5)
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7. Section 8 contains code examples for converting register values to decimal

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The calibration procedure and key decision points are represented graphically in Figure 1. The calibration is dependent on system factors, if these change then re-calibration may be required.

- The object emissivity, ε, dependent on the material
- Object position in the sensor field of view (FOV), related to object size and distance
- Background scene temperature if in the sensor FOV
- Presence of convection from air and/or thermal conductance from nearby components

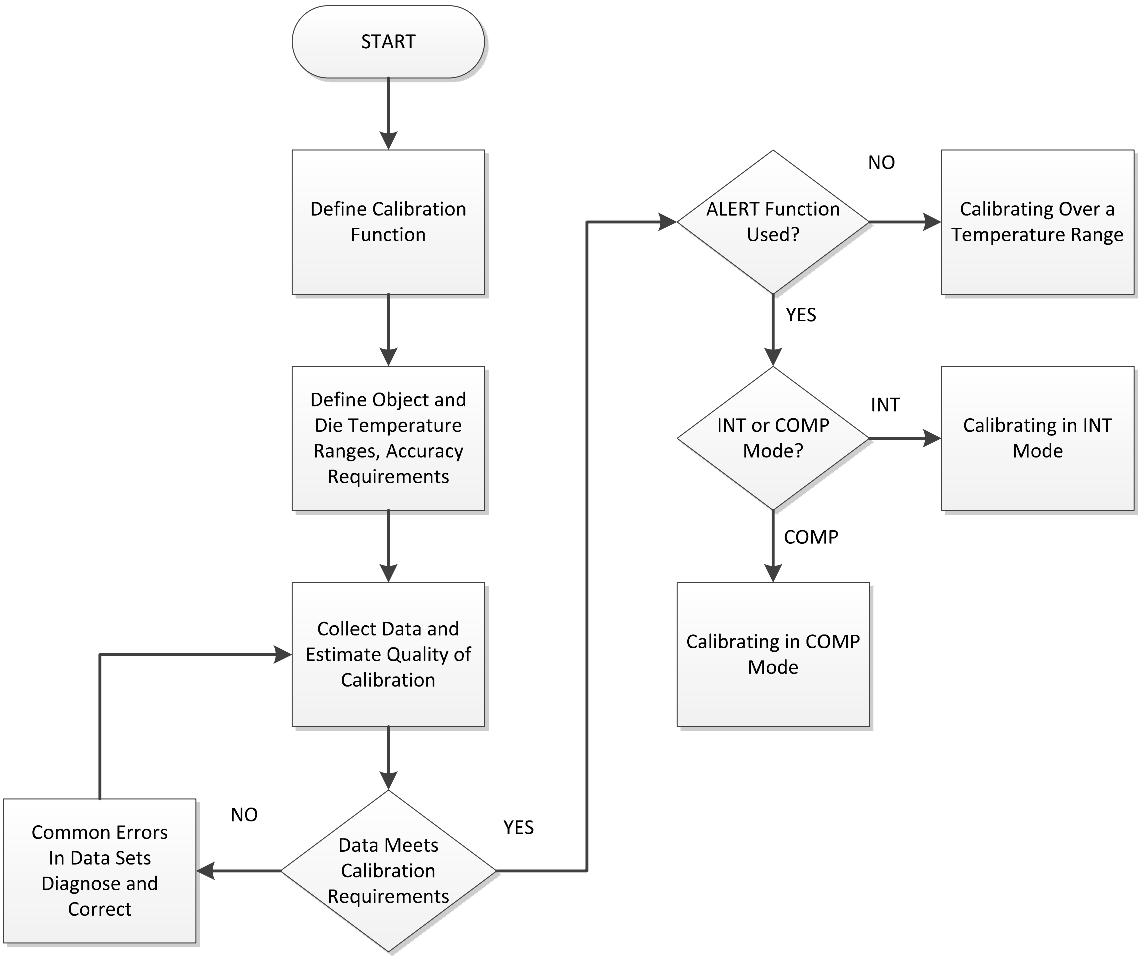


**Figure 1. Calibration Procedure Flow Chart**

## *1.2 Principles of Calibration*

The key data required for calibration are the sensor voltage, the die temperature, and the object temperature. In addition, the engineer must decide on the upper limit (UL) and lower limit (LL) for temperature accuracy required by the application. Any measurement within these limits is considered an accurate measurement of the object temperature. As an example, if the application requires measuring a 25°C temperature to within 1°C, then the UL = 25 + 1 = 26°C and the LL = 25 – 1 = 24°C.

The thermal radiation is converted to a sensor voltage by the TMP007 thermopile which can be read from a register. The die temperature is calculated from an integrated pn junction on the TMP007. The object temperature is measured with an external reference sensor (for example, a thermocouple, pn junction, thermistor),

The principles of operation of the TMP007 are described in the *TMP007 Data Sheet* (SBOS685), including the operation of the math engine. TI recommends becoming familiar with the contents of the TMP007 data sheet. In the data sheet, the ideal relationship between the sensor voltage and the object temperature is given as:

$$T_{OBJECT} = \sqrt[4]{T_{DIE}^4 + \frac{V_{SENSOR}}{\varepsilon\sigma}} \quad (1)$$

Where:

σ = Stefan-Boltzman constant = 5.7 x $10^{-12}$ W/cm$^2$/K$^4$
ε = Emissivity, 0 < ε < 1, an object dependent factor, ε = 1 for a perfect emitter
$V_{SENSOR}$ = Sensor voltage in TMP007 sensor voltage register
$T_{DIE}$ = Local die temperature calculated by the TMP007 from integrated pn junction

The ideal relationship assumes that the radiation is well-described by the black body spectrum, that there is no absorption or other restrictions in the optical path, that the sensor absorbs radiation equally well across the entire spectrum, and most importantly, that radiation from the object is the only source of energy reaching the thermal sensor. In practice, these ideal conditions rarely occur, hence the relationship as implemented in the TMP007 is modified to allow for compensation.

$$T_{OBJECT} = \sqrt[4]{T_{DIE}^4 + \frac{f(V_{OBJECT})}{S}} \quad (2)$$

Where:

S is a system dependent parameter incorporating the object emissivity (ε), optical FOV and transmission characteristics, and sensor characteristics. The parameters S0, A1 and A2 are used in estimating S as described in the following section.
$f(V_{OBJECT})$ is a function that compensates for heat flow from sources other than thermal radiation from the object, such as convection or heat conduction from nearby objects.

### 1.2.1 Definition of S Parameter

S modifies the ideal emissivity of the object to compensate for the practical features of the thermal spectrum of the object, the transmission of the thermal radiation to the sensor as it may be modified by windows, lenses, or other effects and the non-ideal absorption of the sensor itself. The functional form implemented in the TMP007 math engine is:

$$S = S0\left(1 + A1(T_{DIE} - T_{REF}) + A2(T_{DIE} - T_{REF})^2\right) \quad (3)$$

Where:

S0 is the material emissivity × the Stefan-Boltzman constant, εσ
$T_{DIE}$ = Local die temperature calculated by the TMP007 from the integrated pn junction
$T_{REF}$ = 25.0°C
A1 and A2 are experimentally derived parameters from the calibration process to obtain a best fit

### 1.2.2 Definition of $f(V_{OBJECT})$

$f(V_{OBJECT})$ compensates for heat flows to the sensor other than from thermal radiation. These non-ideal effects are observed primarily as an offset to the ideal sensor voltage from thermal radiation alone. The compensation is done in two stages, first as an offset voltage estimate, $V_{OS}$ :

$$V_{OS} = B0 + B1(T_{DIE} - T_{REF}) + B2(T_{DIE} - T_{REF})^2 \quad (4)$$

Where:

$T_{DIE}$ = Local die temperature calculated by the TMP007 from integrated pn junction
$T_{REF}$ = 25.0°C
B0, B1, and B2 are experimentally derived parameters from the calibration process to obtain a best fit.

Now, a modified sensor voltage, $f(V_{OBJECT})$, is calculated as:

$$f(V_{OBJECT}) = (V_{SENSOR} - V_{OS}) + C(V_{SENSOR} - V_{OS})^2 \quad (5)$$

All parameters are as previously defined and C is an optional fitting parameter.

### 1.2.3 Calibration with Transient Correction Enabled

The TMP007 has a transient correction mode to compensate for rapid changes in the die temperature. With transient correction turned on, the sensor voltage is modified before the arithmetic in Section 1.2 is performed. The values for $T_{DIE}$ and $V_{SENSOR}$ are modified with a filter to reduce the effects of the transient.

The n[th] sample of $T_{die}$ is modified by the relationship:

$$T_{DIE\_FILT}[n] = (T_{DIE}[n] + T_{DIE}[n-1]) \times 0.2 + T_{DIE\_FILT}[n-1] \times 0.6$$
$$T_{DIE\_SLOPE} = \frac{T_{DIE}[n] - T_{DIE\_FILT}[n]}{2} \qquad (6)$$

Note this introduces a time constant of approximately 5 times the sample rate as set in the Configuration Conversion Rate bits, (CR2, CR1, CR0).

Similarly, the sensor voltage is modified by the relationship:

$$V_{SENSOR\_FILT}[n] = (V_{SENSOR}[n] + V_{SENSOR}[n-1]) \times 0.2 + V_{SENSOR\_FILT}[n-1] \times 0.6$$
$$V_{SENSOR\_SLOPE} = \frac{V_{SENSOR}[n] - V_{SENSOR\_FILT}[n]}{2} \qquad (7)$$

The two slope estimates are then used to modify the sensor voltage to obtain:

$$V_{SENSOR\_FINAL} = V_{SENSOR} + TC0 \times T_{DIE\_SLOPE} + TC1 \times V_{SENSOR\_SLOPE} \qquad (8)$$

$V_{SENSOR\_FINAL}$ is then used in calculating the object temperature as described in Section 1.2. The parameters TC0 and TC1 are experimentally determined based on the specific system and environment to minimize the effects of the temperature transient.

It is recommended to consider using the transient correction mode when the change in $T_{DIE}$ is greater than 5°C/minute. Note this applies to $T_{DIE}$ transients only; the thermopile response to changes in object temperature is set by the conversion bits CR2, CR1, and CR0 in the configuration register. Transient correction can also be used as a filter, though with the consequence of increasing the system time constant.

## *1.3 Accuracy and Precision*

It is useful to distinguish the terms *accuracy* and *precision* as used in the calibration process. The measurement process generates a distribution of values characterized by a mean (average) value and a random variation (usually estimated as the standard deviation). The temperature limits for an acceptable measurement are defined in terms of a high and low temperature.

As an example, suppose we wish to measure the temperature of an object at 25°C to an accuracy of ±1°C. Then the lower limit for an acceptable measurement is 24°C and the upper limit is 26°C. Figure 2 shows the mean and distribution of the measurement values before calibration (black) and after calibration. Prior to calibration, the mean of the measurements is 23°C when the object temperature is 25°C and only a small proportion of the measurements fall into the acceptable range.

After calibration, the mean changed from 23°C to 24.7°C, and a much larger proportion of the measurements (red) fall within the limits of 24–26°C. This calibration procedure improved the accuracy of the measurements since the mean is now closer to the desired value. However, note that the calibration does not affect the random error. If the random error is large compared to the limits set, then some measurements still fall outside the upper and low limits.

**NOTE:** **ACCURACY:** The difference in the mean (average) value of the measurements and the reference value.

**PRECISION:** The random variation in measurement, for a normal distribution the standard deviation.

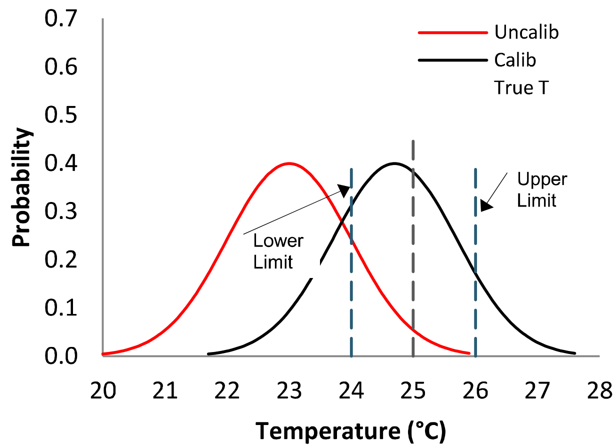


**Figure 2. Definition of Accuracy and Precision**

In summary, the calibration process improves the accuracy by modifying the mean of the measurements; calibration does not directly impact the random variations. When planning the calibration procedure, it is important to consider the accuracy of the calibration in regards to the high and low limits, as well as the precision obtainable under application conditions.

# 2 Good Calibration Requires Good Data

The quality of the calibration is directly correlated to the quality of the data used in the calibration. This section discusses guidelines for designing a calibration procedure, testing the data and collecting a suitable data set. These are guidelines only and must be adapted to the specific application using sound engineering judgment.

## 2.1 Defining the Calibration Environment

The calibration is only valid for a defined environment. In particular, the calibration is valid only for the device in the final product configuration with any windows, lenses, or other enclosures present. At a minimum, the environment definition must include:

- Object material
- Object size
- Object distance

These parameters must remain fixed for the remainder of the calibration procedure.

## 2.2 Defining the Calibration Data Set

The next step is to define the temperature range for both object and die temperature over which the calibration is expected to be valid. Figure 3 shows the basic concepts for defining the calibration data range. The actual object temperature as measured by a reference (thermistor, thermocouple, IC device) is plotted on the x-axis; the predicted temperature after calibration is shown on the y-axis. In this example, data has been taken at three object temperatures.

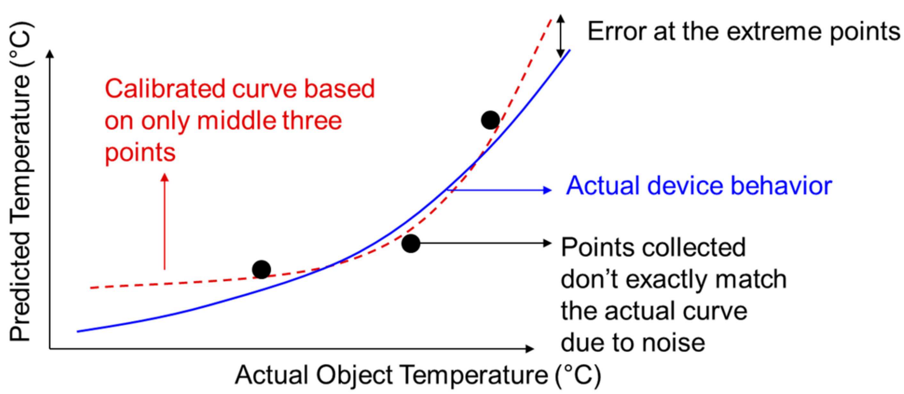


**Figure 3. Calibration Curve Concepts**

Note that the calibration is only valid in the range covered by the three object temperatures; outside this range the predicted temperatures may vary significantly from the actual device behavior. The first step then is to define the range of temperatures in which the application operates and for which the calibration is valid. In mathematical terms, calibration is best used as an interpolation procedure, not an extrapolation procedure.

**1. Select object temperatures to include the entire range of operation.**

Recall from Section 1.2 that the temperature reading also depends on the die temperature. If the die temperature is expected to vary in the application, then it is also necessary to select a set of die temperatures over which to calibrate.

**2. Select die temperatures to include the entire range of operation.**

Based on these two criteria, it is now possible to define a table of the object and die temperatures for the calibration. Here $T1_{OBJ}$ is the lowest object temperature for which the calibration is valid; $T4_{OBJ}$ is the highest object temperature for which the calibration is valid. Similar considerations apply for $T_{DIE}$. The number of object temperatures and die temperatures selected will depend on the application. Generally, the more data points in the region of interest, the better the results. It is often not necessary to take data at every combination; in Table 1, the cells marked with an X are chosen for those conditions where calibration data is taken. This data set emphasizes calibration at the extremes of the temperature ranges.

**Table 1. Example Calibration Data Set**

| | $T_{OBJ}$ | | | |
|---|---|---|---|---|
| $T_{DIE}$ | $T1_{OBJ}$ | $T2_{OBJ}$ | $T3_{OBJ}$ | $T4_{OBJ}$ |
| $T1_{DIE}$ | X | X | X | X |
| $T2_{DIE}$ | | X | X | |
| $T3_{DIE}$ | X | X | X | X |

Alternatively, a different data set covering the same range can be chosen as shown in Table 2. The difference is that in the second set, the calibration process emphasizes a good fit to the conditions in the center of the table. The data set selected should be chosen to cover the entire range of $T_{OBJ}$ and $T_{DIE}$ for which the calibration is to be valid, with additional point in regions where the best accuracy is required. Remember that the calibration process in interpolative, not extrapolative. The calibration is only valid within the limits of the calibration data set; behavior outside the limits is undefined.

**Table 2. Alternative Calibration Data Set**

| | $T_{OBJ}$ | | | |
|---|---|---|---|---|
| $T_{DIE}$ | $T1_{OBJ}$ | $T2_{OBJ}$ | $T3_{OBJ}$ | $T4_{OBJ}$ |
| $T1_{DIE}$ | | X | X | |
| $T2_{DIE}$ | X | X | X | X |
| $T3_{DIE}$ | | X | X | |

Conclusion: *The choice of data set conditions influence the accuracy of the calibration process in different regions of the applications operating range.*

## *2.3 Understanding the Effect of Noise on Calibration*

For purposes of this section, noise is defined as random variations; systemic errors of various types are addressed separately. Referring to Figure 3, note that the data points that are used for the calibration may not reflect the actual device behavior if the data points contain too much noise. *The calibration curve is correlated to the data points collected; not the actual device behavior.* For good calibration results, it is necessary that the data points used for calibration reflect the actual device behavior as closely as possible.

Before undertaking a calibration, it is recommended to first understand the noise characteristics of the device in the application. The noise is most often characterized by the standard deviation. *Prior to calibration, the contents of the object temperature register (03h) are invalid. Therefore, all noise measurements should be made using the sensor voltage register, (00h).* As an example, for four devices at a die temperature of 0°C and object temperature of 50°C, twenty (20) measurements were taken. The mean (average) and standard deviation of the measurements were then estimated as shown in Figure 4. The x-axis is the number of samples and the y-axis is the estimate for the mean (or standard deviation) based on that number of samples.

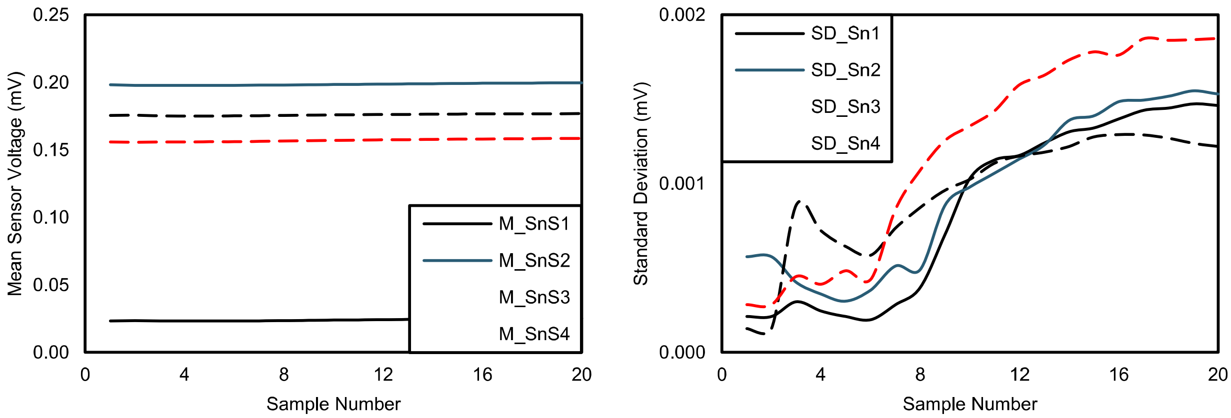


**Figure 4. Estimate of Mean and Standard Deviation vs Number of Samples**

Note that as the number of samples increases, the estimate of the mean and standard deviation improves. This is particularly true for the estimate of the standard deviation. Also, note that the means of devices SnS2, SnS3, and SnS4 are relatively close together; that of SnS1 is significantly lower. Depending on the accuracy desired, then it may be necessary to use a different set of calibration coefficients or to understand and correct any issues in the system

**Table 3. Example Values for Calibration**

| Device | SnS1 | SnS2 | SnS3 | SnS4 | Batch Calibration |
|---|---|---|---|---|---|
| Mean (mV) | 0.025 | 0.199 | 0.176 | 0.158 | 0.1395 |
| StDev (mV) | 0.001463 | 0.001532 | 0.00122 | 0.001863 | 0.068 [(1)] |

(1) For batch calibration, the standard deviation is estimated based on the standard deviation of the measurements from all devices at a given experimental condition. This is required to include device-to-device variation.

Table 3 shows the possible values that would be used for calibration at the data point ($T_{DIE}$ = 0°C, $T_{OBJECT}$ = 50°C). There are two calibration strategies possible – unit calibration and batch calibration. In unit calibration, each device uses a unique set of coefficients with the mean value for each device used in the calibration process (SnS1 = 0.025 mV, SnS2 = 0.199 mV, and so forth). The advantage of unit calibration is that greater accuracy is achievable as reflected in the lower standard deviations, because device-to-device variation is eliminated; the disadvantage is the effort required is increased. An alternative is batch calibration, in which case the value listed for the mean under batch calibration is used. However, note that the standard deviation is larger so the accuracy is lower.

Reducing the noise as measured by the standard deviation will depend on the source of the noise. The sensor noise limit is about 200–300 µV at a 1 second sample time (see TMP007 data sheet, Typical Characteristics). If the noise is sensor limited, The simplest method to reduce noise is to increase the sample time. If the noise is not sensor limited, then other actions may be required. Common sources of excess noise are convection, conduction, and thermal instability of the object being measured. Alternatively, the signal can be increased by increasing the FOV the object covers, lowering the die temperature, or increasing the object emissivity.

## *2.4 NETD: Estimating Temperature Precision Based on Sensor Voltage Noise*

Before proceeding with the calibration procedure, it is often useful to estimate the potential accuracy of the calibration based on the means and standard deviations of the data set. The procedure described in this section is an estimate of precision, those errors due to random variations.

The precision is quantified as the Noise Equivalent Temperature Difference (NETD) and is measured in degrees K. Typically, the quantity is presented as mK, or degrees Kelvin/1000. The NETD is calculated from the thermal responsivity, $R_{TH}$ which has units of µV/°C. The thermal responsivity is a non-linear function, but for purposes of estimation it can calculated as the slope of sensor voltage vs change in temperature:

$$R_{TH} = \frac{\left(V_{T2} - V_{T1}\right)}{\left(T_2 - T_1\right)} \mu V / °C \quad (9)$$

Where:

$V_{T2}$, $V_{T1}$ are the mean sensor voltages at object temperatures $T_2$ and $T_1$

$T_2$, $T_1$ are the two object temperatures

The NETD is then simply the standard deviation of the sensor voltage, $\sigma_{VSENSOR}$, divided by $R_{TH}$. Note that NETD and all subsequent procedures in this section are based on the standard deviation of the sensor voltage; it is therefore critical to have taken enough samples to estimate it reliably.

$$NETD = \frac{\sigma_{VSENSOR}}{R_{TH}} mK \quad (10)$$

As an example, consider the following data set with $T_{DIE}$ = 20°C. and $T_2 > T_1$.

**Table 4. Example Data Set to Estimate Calibration Accuracy**

| $T_{OBJ}$ | 0°C | 20°C | 40°C | 60°C | 75°C | Comments |
|---|---|---|---|---|---|---|
| $V_{SENSOR}$ (µV) | –87.4 | –27.4 | 45.9 | 133 | 208 | |
| $\sigma_{VSENSOR}$ (µV) | 0.267 | 0.208 | 0.225 | 0.202 | 0.196 | |
| $R_{TH}$ (µV/°C) | 3.0 | 3.7 | 4.4 | 5 | N/A | Equation 7 |
| NETD (mK) | 89 | 56 | 51 | 40 | | Equation 8 |

Example calculation for 20°C point:

$$R_{TH} = \frac{45.9\mu V - (27.4\mu V)}{40°C - 20°C} = 3.7\mu V / °C \quad NETD = \frac{0.208\mu V}{3.7\mu V / °C} = 56mK \quad (11)$$

Note that in Table 5, as the object temperature increases, $R_{TH}$ also increases. This is because the radiation emitted by the object scales as $T^4$ so a one degree temperature change at a higher temperature has a larger energy difference than at a lower temperature. Also note, that if the noise, $\sigma_{VSENSOR}$, remains constant as the object temperature increases, then the precision also increases, that is NETD becomes smaller. However, it is *strongly recommended* to verify this behavior for each point of the data set; it is possible that as the temperature differential between the die and the object increases, thermal convection from air or conductance from components on the PCB may increase the observed noise.

The NETD can be used to estimate the potential accuracy of the calibration. The estimated accuracy is related to the confidence level necessary for the application, that is, what percentage of the measurements must lie within the upper and lower limits desired.

**Table 5. Accuracy from NETD**

| $T_{OBJ}$ | 0°C | 20°C | 40°C | 60°C | 75°C | Comments |
|---|---|---|---|---|---|---|
| NETD (°C) | 0.089 | 0.056 | 0.051 | 0.040 | | NETD = 1σ, Converted to °C from mK |
| 2σ limit (°C) | 0.18 | 0.11 | 0.10 | 0.08 | | 68% of measurements within limits |
| 4σ limit (°C) | 0.36 | 0.22 | 0.20 | 0.16 | | 95% of measurements within limits |
| 6σ limit (°C) | 0.53 | 0.34 | 0.31 | 0.24 | | 99% of measurements within limits |

The confidence level chosen is a matter of engineering judgment based on the application requirements. For the remainder of this discussion, we will discuss accuracy using the 6σ criterion, or in other words requiring 99% of measurements to fall within the upper and lower limit. As an example, based on Table 5, we predict that at 20°C and a confidence level of 99%, the accuracy obtainable is 0.34°C.

Note that this estimate sets a lower bound on the calibration accuracy, essentially assuming that after curve fitting, the difference between the predicted value and the mean of the measurements is zero (see Figure 2 and Figure 3). In practice, there is often some error in the curve fit. However, if the accuracy requirements are not met at this stage, they will not be met after calibration. If the accuracy requirements are met, then proceed to the next step of calibration – generating the coefficients to predict the object temperature.

# 3 Calibrating Over a Temperature Range

One of the most common requirements is to calibrate the thermal sensor over a specified temperature range. Calibration across a specified temperature range requires the following information.

- Defining the temperature range for both $T_{DIE}$ and $T_{OBJECT}$
- Defining the required accuracy at each point in the range, in this example < 1°C
- The means and standard deviations of the sensor voltage at each point as described in Section 2

In principle, there are a number of curve fitting techniques that could be used – polynomial, table look-up and interpolation, cubic splines, and so forth. In practice, we will fit to the function described in Section 1.1, since this is the function implemented in the TMP007 math engine. Prior to implementing the curve fitting process, it is recommended that the procedures described in Section 2 be followed to verify the feasibility of the calibration given the desired accuracy.

## 3.1 Calibration for Multiple Object Temperatures at Constant Die Temperature

The simplest case is calibration for a constant die temperature and a varying object temperature. As an example, we use the data set from Table 3. There are a number of mathematical techniques to generate coefficients using various optimization criteria. For this example, to obtain the coefficients, we use the EASYCAL™ Calibration Software, with the option to minimize the average error selected. Alternatively, many commercial and public interpolation routines are available.

The coefficients obtained are:

| Coefficient Name | s0 | a1 | a2 | b0 | b1 | b2 | c2 |
|---|---|---|---|---|---|---|---|
| **Calibrated Coefficient** | 3.287E-14 | 1.750E-03 | –1.680E-05 | –1.178E-05 | 0.000E+00 | 0.000E+00 | 0.000E+00 |

The mean error is shown as the difference between the mean of the observed temperatures and predicted temperatures. However, to estimate the accuracy, the NETD or precision also needs to be included.

**Table 6. Example Calibration Results – Mean Error**

| $T_{OBJ}$ | 0°C | 20°C | 40°C | 60°C | 75°C | Comments |
|---|---|---|---|---|---|---|
| $V_{SENSOR}$ (μV) | –87.4 | –27.4 | 45.9 | 133 | 208 | Measured |
| $V_{SENSOR}$ (μV) | –75.6 | –15.6 | 57.7 | 144 | 219 | Predicted |
| $T_{PREDICTED}$ | 0.4 | 20.4 | 40.3 | 59.9 | 74.4 | Equation 2, Equation 3, Equation 4 |
| Mean Error | –0.4 | -0.4 | –0.3 | 0.1 | 0.6 | $T_{OBJ} – T_{PREDicted}$ |
| NETD (6σ) °C | 0.53 | 0.34 | 0.31 | 0.24 | 0.24 | Assumed $NETD_{75} = NETD_{60}$ |
| Accuracy (6σ) °C | **0.93** | **0.74** | **0.61** | **0.34** | **0.84** | = ABS(Mean Error) + NETD |

Based on this data set and the calibration coefficients generated, the accuracy at 20°C equals the absolute value of the mean error (0.4°C) + NETD (0.34°C) = 0.74°C. Figure 5 illustrates graphically the contribution of mean error and NETD to the accuracy at each object temperature. There is some flexibility in choosing the coefficients so as to minimize the error at a particular object temperature, however, it is generally accompanied by a loss of accuracy at other object temperatures.

The data set was taken with a sample rate of 1 sample/sec; changing the sample rate to 1 sample every 4 seconds would reduce the NETD portion of the error by a factor of two in Figure 5. However, it would not affect the mean error at all. Similarly, changing the calibration coefficients or the number and pacing of the data points alters the mean error, but does not affect the NETD factor.

The calibration in the example is considered a success under the criterion that the accuracy is less than 1°C across the temperature range.

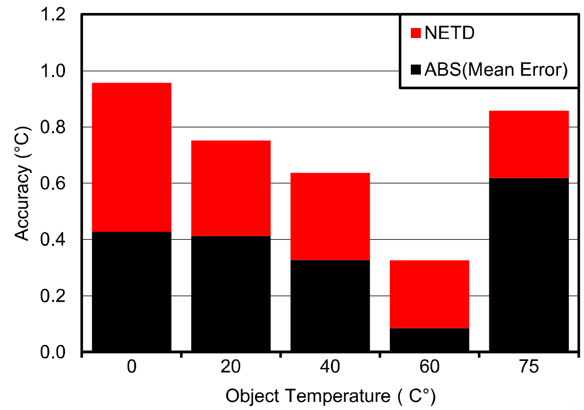


**Figure 5. Effect of Mean Error and NETD on Accuracy**

### 3.2 Calibration for Multiple Object Temperatures at Multiple Die Temperatures

The same principles apply when multiple die temperatures are to be included in the calibration. The primary modification is that when calculating the thermal responsivity and NETD, always use the difference between two object temperatures that are *at the same* die temperature.

For the case of multiple die temperatures, the primary effect is that the b-coefficients become more important. These coefficients account for heat flows to the device other than radiative transfer from the object such as radiation from the scene, conduction from other components on the PCB, and so forth.

# 4 Calibrating in INTERRUPT Mode – Maintaining a Temperature Band

After calibration, enable this mode by ALRTEN (bit 8) = 1 and INT/COMP (bit 5) = 0 in the configuration register (02h).

INTERRUPT mode enables an ALERT when the temperature is outside a preset band. The band is defined by the value in the object high-limit temperature register (06h) and object low-limit temperature register (07h) [see the TMP007 data sheet (SBOS685)]. Calibration across a specified temperature range requires the following information with values for the example calibration:

- Defining both object high limit (27°C) and object low limit (23°C)
- Defining the required accuracy for enabling the ALERT function (0.5°C)
- The means and standard deviations of the sensor voltage at each point as described in Section 2.

## *4.1 Calibration for Maintaining a Temperature Band*

For a calibration involving setting a temperature band, it is only necessary to collect a data set which spans the band of interest and the immediate region around it. Data points outside this region are of no interest.

The data set was constructed to sample the region around the edges of the temperature band more densely as shown in Figure 6. In this example, because the object temperature range is smaller, the thermal responsivity can be well approximated as a linear relationship. The thermal responsivity is the slope of the line, in this example 3.47 µV/°C. Similarly, when measured the standard deviation of the sensor voltage had little variation across this range, so a single value of $\sigma_{VSENSOR}$ = 0.3 µV is used for all calculations. If the temperature range of interest is sufficiently small, it is often feasible to make these simplifying assumptions in the calibration process.

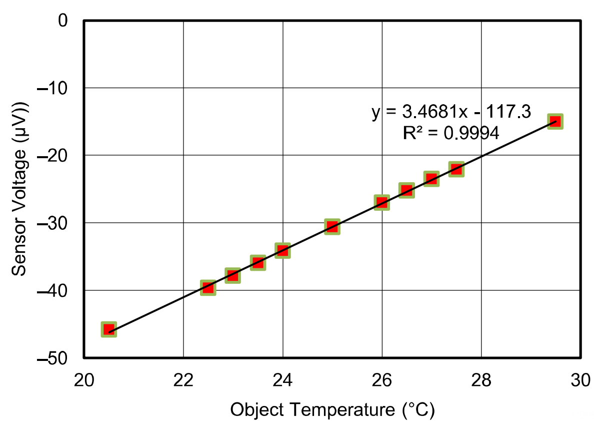


**Figure 6. INTERRUPT Mode Data Set Example**

With the simplifying assumptions concerning $R_{TH}$ and $\sigma_{VSENSOR}$, the NETD can be quickly estimated as:

$$NETD = \frac{\sigma_{VSENSOR}}{R_{TH}} = \frac{0.3\,\mu V}{3.47\,\mu V/°C} = 0.086°C \text{ which for } 6\sigma \text{ becomes } 0.52°C \quad (12)$$

The data set is summarized in Table 7, for mean error, NETD and accuracy. Recall that accuracy is defined as:

Accuracy = Mean Error + 6 × NETD

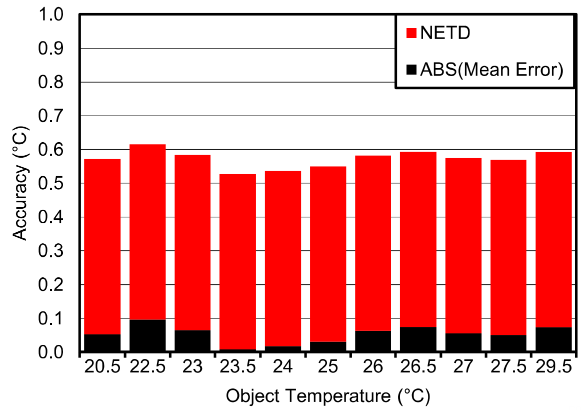


**Figure 7. INTERRUPT Mode Accuracy Example**

The accuracy is dominated by the NETD component, the random noise component as shown in Figure 7.

**Table 7. Example Data for INTERRUPT Mode Calibration**

| OBJ | $V_{SENSOR}$ (µV) Measured | NETD (6σ) (°C) | $T_{OBJ}$ Pred | Mean Error (°C) | Accuracy (°C) |
|---|---|---|---|---|---|
| 20.5 | –45.8 | 0.52 | 20.55 | -0.05 | 0.57 |
| 22.5 | –39.6 | 0.52 | 22.4 | 0.1 | 0.61 |
| 23 | –37.8 | 0.52 | 22.93 | 0.07 | 0.58 |
| 23.5 | –35.9 | 0.52 | 23.49 | 0.01 | 0.53 |
| 24 | –34.1 | 0.52 | 24.02 | –0.02 | 0.54 |
| 25 | –30.6 | 0.52 | 25.03 | –0.03 | 0.55 |
| 26 | –27 | 0.52 | 26.06 | –0.06 | 0.58 |
| 26.5 | –25.2 | 0.52 | 26.57 | –0.07 | 0.59 |
| 27 | –23.5 | 0.52 | 27.06 | –0.06 | 0.57 |
| 27.5 | –22.1 | 0.52 | 27.45 | 0.05 | 0.57 |
| 29.5 | –15 | 0.52 | 29.43 | 0.07 | 0.59 |

## 4.2 *Choosing Threshold Values for INTERRUPT Mode*

Choosing the threshold values for interrupt mode is based on the desired confidence levels for the application, If the calculated temperature is above the high limit or below the low limit at the end of a conversion, its respective flag is asserted; if enabled the ALERT pin is also asserted. Because of random noise and mean error, there is some uncertainty of when an ALERT is enabled relative to the set point.

As an aid to the discussion, consider the graph in Figure 8. The black line, P(x), gives the probability that a value a given number of standard deviations away from the mean will occur. In terms of calibration, this is the probability that a value that is a given number of standard deviations from the predicted mean will occur. The red line is the probability that the observed value is greater than the mean, or in terms of calibration that the observed value is greater than the threshold.

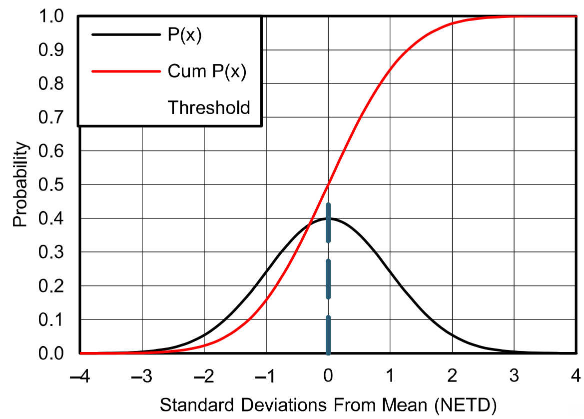


**Figure 8. Normal Distribution and Cumulative Probability**

Choosing the ALERT value is equivalent to choosing the confidence level that the threshold limit has been exceeded. Recalling that for the example, NETD – 0.086°C, low limit = 23°C and high limit = 27°C, then the effect of the register settings is summarized in Table 8.

In each case, the limit settings for the registers are calculated as:

$$\text{Reg Setting} = \text{Threshold} \pm n \times \text{NETD} \tag{13}$$

**Table 8. INT Mode – Choosing the Threshold Value vs Confidence Level**

| σ | Prob $T > T_{TH}$ | Prob $T < T_{TH}$ | Example σxNETD | Obj High Limit Reg Setting | Obj Low Limit Reg Setting |
|---|---|---|---|---|---|
| –3 | 0.1% | 99.9% | –0.258 | 26.74 | 22.74 |
| –2 | 2% | 98% | –0.172 | 26.82 | 22.82 |
| –1 | 16% | 84% | –0.086 | 26.91 | 22.91 |
| 0 | 50% | 50% | 0 | 27 | 23 |
| 1 | 84% | 16% | 0.086 | 27.09 | 23.09 |
| 2 | 98% | 2% | 0,172 | 27.12 | 23.12 |
| 3 | 99.9% | 0.1% | 0.258 | 27.258 | 23.258 |

In the example shown, because the NETD is small, the impact on confidence level is small relative to the threshold value. However, in cases where the NETD, or the NETD plus mean error is large, it may be advisable to bias the register setting relative to the desired threshold. In those cases, one would bias the object low-limit register to a lower value to ensure the threshold had been exceeded and the object high limit register to a higher value to ensure the threshold had been exceeded. Conversely, if the consequences of exceeding the threshold are high, then the register settings would be biased in the opposite direction.

**CAUTION**

The difference between the upper and lower limits should be at least 6X the NETD to avoid unstable behavior.

# 5 Calibrating in COMP Mode – Thermostat Mode

After calibration, enable this mode by ALRTEN (bit 8) = 1 and INT/COMP (bit 5) = 1 in the configuration register (02h)

COMPARE mode enables an ALERT when the temperature exceeds a preset threshold, the high limit, and removes the ALERT when the temperature falls below a second threshold, the low limit, the high limit threshold is defined by the value in the object high-limit temperature register (06h) and the reset temperature in the object low-limit temperature register (07h), [see TMP007 Data Sheet (SBOS685)]. The reset temperature (lower limit) provides hysteresis for system stability. Calibration in COMP mode is very similar in principle to that for INT mode. Calibration across a specified temperature range requires the following information with values for the example calibration:

- Defining both object high limit (27°C) and object low limit (23°C)
- Defining the required hysteresis for disabling the ALERT Function (0.5°C)
- The means and standard deviations of the sensor voltage at each point as described in Section 2

## 5.1 *Calibration for Exceeding a Threshold*

For a calibration involving setting a temperature band it is only necessary to collect a data set which spans the band of interest and the immediate region around it. Data points outside this region are of no interest.

The data set was constructed to sample the region around the threshold and reset temperatures more densely as shown in Figure 9. In this example, because the object temperature range is smaller, the thermal responsivity can be well approximated as a linear relationship. The thermal responsivity is the slope of the line, in this example 3.47 μV/°C. Similarly, when measured the standard deviation of the sensor voltage had little variation across this range, so a single value of $\sigma_{VSENSOR}$ = 0.3 μV is used for all calculations. If the temperature range of interest is sufficiently small, it is often feasible to make these simplifying assumptions in the calibration process.

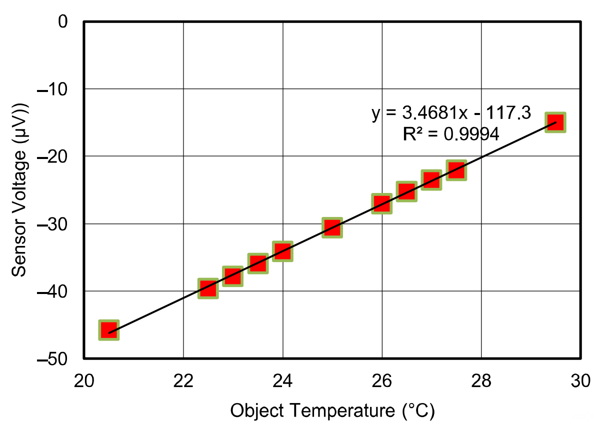


**Figure 9. COMP Mode Data Set Example**

With the simplifying assumptions concerning $R_{TH}$ and $\sigma_{VSENSOR}$, the NETD can be quickly estimated as:

$$\text{NETD} = \frac{\sigma_{VSENSOR}}{R_{TH}} = \frac{0.3\mu V}{3.47\mu V/^{\circ}C} = 0.086^{\circ}C \quad \text{which for } 6\sigma \text{ becomes } 0.52^{\circ}C \tag{14}$$

The data set is summarized in Table 9 for mean error, NETD, and accuracy. Recall that accuracy is defined as:

$$\text{Accuracy} = \text{Mean Error} + 6 \times \text{NETD} \tag{15}$$

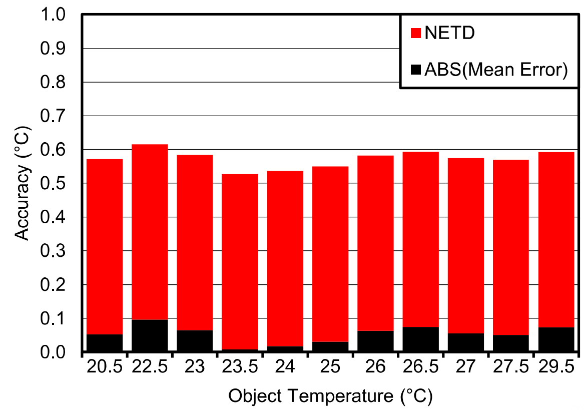


**Figure 10. COMP Mode Accuracy Example**

The accuracy is dominated by the NETD component, the random noise component as shown in Figure 10.

**Table 9. Example Data for COMP Mode Calibration**

| OBJ | $V_{SENSOR}$ (µV) Measured | NETD (6σ) (°C) | $T_{OBJ}$ Pred | Mean Error (°C) | Accuracy (°C) |
|---|---|---|---|---|---|
| 20.5 | –45.8 | 0.52 | 20.55 | –0.05 | 0.57 |
| 22.5 | –39.6 | 0.52 | 22.4 | 0.1 | 0.61 |
| 23 | –37.8 | 0.52 | 22.93 | 0.07 | 0.58 |
| 23.5 | –35.9 | 0.52 | 23.49 | 0.01 | 0.53 |
| 24 | –34.1 | 0.52 | 24.02 | –0.02 | 0.54 |
| 25 | –30.6 | 0.52 | 25.03 | –0.03 | 0.55 |
| 26 | –27 | 0.52 | 26.06 | –0.06 | 0.58 |
| 26.5 | –25.2 | 0.52 | 26.57 | –0.07 | 0.59 |
| 27 | –23.5 | 0.52 | 27.06 | –0.06 | 0.57 |
| 27.5 | –22.1 | 0.52 | 27.45 | 0.05 | 0.57 |
| 29.5 | –15 | 0.52 | 29.43 | 0.07 | 0.59 |

## 5.2 Choosing Threshold Values for COMP Mode

Choosing the threshold values for interrupt mode is based on the desired confidence levels for the application, If the calculated temperature is above the high limit, the flag is asserted; if enabled the ALERT pin will also be asserted. Because of random noise and mean error, there is some uncertainty of when an ALERT is enabled relative to the set point. When the calculated temperature falls below the reset, or lower limit, the ALERT pin is disabled, though flags will remain set. In contrast to the INT mode, there is a bias to the settings in COMP mode.

As an aid to the discussion, consider the graph in Figure 11. The black line, P(x), gives the probability that a value a given number of standard deviations away from the mean will occur. In terms of calibration, this is the probability that a value that is a given number of standard deviations from the predicted mean will occur. The red line is the probability that the observed value is greater than the mean, or in terms of calibration that the observed value is greater than the threshold.

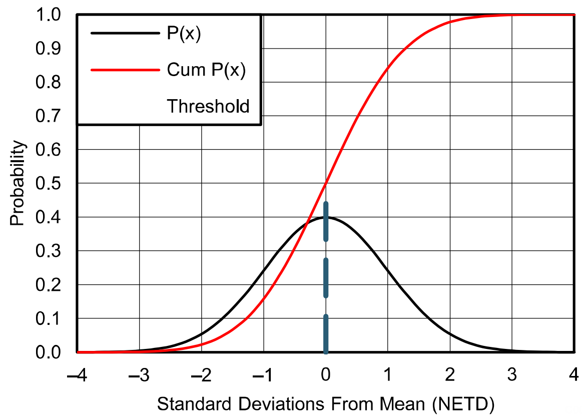


**Figure 11. Normal Distribution and Cumulative Probability**

Choosing the object high-limit temperature register value is equivalent to choosing the confidence level that the threshold limit has been exceeded. Choosing the object low-limit temperature register setting is equivalent to choosing the hysteresis, or the probability that the ALERT condition is no longer valid. Recalling that for the example, NETD – 0.086°C, low limit = 23°C and high limit = 27°C, then the effect of the register settings is summarized in Table 7.

In each case, the limit settings for the registers are calculated as

$$\text{Reg Setting} = \text{Threshold} \pm n \times \text{NETD} \quad (16)$$

**Table 10. COMP Mode –Choosing the Threshold Value vs Confidence Level**

| σ | Prob $T > T_{TH}$ | Prob $T < T_{TH}$ | Example σxNETD | Obj High Limit Reg Setting | Obj Low Limit Reg Setting |
|---|---|---|---|---|---|
| –3 | 0.1% | 99.9% | –0.258 | 26.74 | 22.74 |
| –2 | 2% | 98% | –0.172 | 26.82 | 22.82 |
| –1 | 16% | 84% | –0.086 | 26.91 | 22.91 |
| 0 | 50% | 50% | 0 | 27 | 23 |
| 1 | 84% | 16% | 0.086 | 27.09 | 23.09 |
| 2 | 98% | 2% | 0,172 | 27.12 | 23.12 |
| 3 | 99.9% | 0.1% | 0.258 | 27.258 | 23.258 |

In the example shown, because the NETD is small, the impact on confidence level is small relative to the threshold value. However, in cases where the NETD, or the NETD plus mean error is large, it may be advisable to bias the register setting relative to the desired threshold.

In those cases, one would bias the object low-limit register to a lower value to ensure the threshold had been exceeded and the object high limit register to a higher value to ensure the threshold had been exceeded. Conversely, if the consequences of exceeding the threshold are high, then the register settings would be biased in the opposite direction.

**CAUTION**

The difference between the upper and lower limits should be at least 6X the NETD to avoid unstable behavior. If these limits are too close together, the device may cycle unpredictably in and out of ALERT state.

# 6 Common Issues in Data Sets

The calibration can only be as good as the data which is used. This section will briefly discuss common errors seen in data sets and potential remedies. This section does not cover all possible data set issues, only the more common issues.

## *6.1 The Sensor Voltage Data is Too Noisy*

As discussed in Section 2, standard deviation of the sensor voltage data sets a lower limit on the achievable accuracy. If the noise level is too high for the desired accuracy, then a noise analysis is required to determine if a reduction in noise is feasible and potential steps to reduce the noise.

First, verify that a sufficient number of samples were taken to obtain a good estimate of the standard deviation. A minimum of 25 samples is recommended. Compare the sensor voltage noise value to the sensor limited noise. This value is found in the product data sheet. For TMP007 at a die temperature of 25°C, the standard deviation of the sensor voltage reading should be < 1 µV.

### 6.1.1 Vary the Sample Time

The sampling time is controlled by bits CR2–CR0 (b11:b9) of the configuration register (02h). The sensor limited noise scales as the square root of the sampling time. If the sampling time is quadrupled (for example, from 1 to 4 seconds), the standard deviation should decrease by a factor of two. Similarly, if the sampling time is reduced by a factor of 4, then the noise will double. Vary the sample time and verify that the noise, as measured by the standard deviation, scales as expected. If not, then the noise source is most likely external to the sensor.

## *6.2 Temperature Drift*

A common occurrence in taking calibration data is the object temperature will drift during the measurement. This is often apparent when the sensor voltage is plotted against the sample number as in Figure 12. $V_{MEAS}$ is the original data and clearly shows a trend over time. A first-order correction is performed using a linear fit. The corrected data is calculated as:

$$V_{CORR} = (V_{MEAS} - SLOPE \times SampleNo) - (INTERCEPT - MEAN_{VMEAS}) \quad (17)$$

Where:

SLOPE = Slope of the best fit line to the measured data
INTERCEPT = Intercept of the best fit line to the measured data
MEAN = Average of the measured data

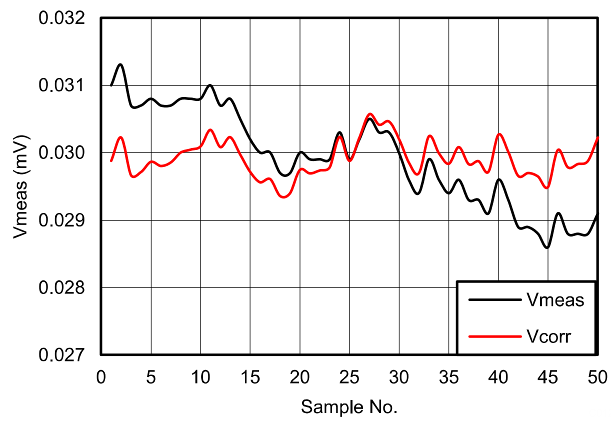


**Figure 12. Compensating for Temperature Drift**

The means and standard deviations before and after correction are shown in Table 11. Note the true standard deviation has decreased by two-thirds from the original value. This indicates the primary source of the *noise* was thermal drift, not device performance.

**Table 11. Correction for Temperature Drift**

| | $V_{MEAS}$ | $V_{CORR}$ |
|---|---|---|
| Mean = | 0.02942 | 0.02942 |
| StDev = | 0.00072 | 0.00027 |
| | | |
| Slope = | 4.58007E-05 | |
| Intercept | 0.030 | |

## *6.3 Effects of Other Heat Sources: Scene Radiation, PCB Components, and Others*

The thermal sensor will detect thermal energy not only from the object, but from the environment surrounding the object as well. The die temperature measurement can compensate for some of these sources, but not all. As a first-order test, it is useful to plot the thermal radiation versus the sensor voltage for different die temperatures.

Recall from the TMP007 product data sheet that the thermal radiation impinging on the sensor from the object is ideally given by:

$$E(\text{watts}) = \sigma \sin^2 \theta A_{ABS} \left(T_{OBJ}^4 - T_{DIE}^4\right) \quad (18)$$

Where

σ, Stefan-Boltzmann Constant = $5.7 \times 10^{-12}$ W/cm²/K⁴
$A_{ABS}$, is the sensor absorber area = 0.0009 $cm^2$

Sinθ, for an object at distance d and of radius r, is approximately: $\sin\theta = d / \sqrt{d^2 + r^2}$

An example set of data is shown in Table 12. In this example, the value of $T_{DIE}$ is varied over a very large range from 0°C to 100°C.

**Table 12. Example Data For Heat Source Effects**

| $T_{DIE}$(°C) | $T_{OBJ}$(°C) | E (µW) | Sensor V (µV) |
|---|---|---|---|
| 0 | –15 | –1.8 | –40.2 |
| | 0 | 0 | –40.3 |
| | 50 | 8.4 | 143.9 |
| | 100 | 21.8 | 317.5 |
| 50 | –15 | –10.2 | –350.4 |
| | 0 | -8.4 | –289.8 |
| | 50 | 0 | –26.5 |
| | 100 | 13.4 | 370 |
| 100 | 0 | –23.6 | –754.6 |
| | 50 | –21.8 | –675.9 |
| | 100 | –13.4 | –400.9 |

When the thermal radiation is plotted against the sensor voltage as a function of $T_{DIE}$, the results are shown in Figure 13. The three data sets are for $T_{DIE}$ = 0°C, 50°C and 100°C.

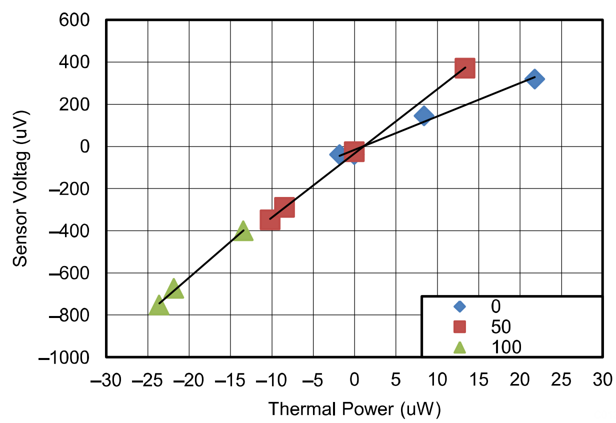


**Figure 13. Effects of Heat Sources**

Ideally, all three lines for the different values of $T_{DIE}$ should have the same slope and be collinear. The B coefficients can compensate for this to some degree. Identifying and minimizing the interfering sources of thermal energy is the root-cause solution. This may be radiation form the scene background, air convection, conduction from other components on the PCB, and so forth, If that does not achieve the desired accuracy, then one option is to have a separate set of coefficients for a subrange of $T_{DIE}$.

Note that the sensor voltage will be negative when the energy outflow form the thermopile exceeds the energy inflow to the thermopile. In the case of purely radiant energy transfer, if $T_{OBJ}$ > $T_{DIE}$; then the radiation from the thermopile exceeds the radiant energy arriving at the thermopile. In addition, other sources such as convection and/or conduction may cause a net offset in the sensor reading.

# 7 Appendix A: FAQs

This section addresses frequently asked questions (FAQs).

**Is calibration required?**

For the best accuracy, the system should be calibrated to the actual measurement environment to properly account for the material of the target object and the placement of the sensor in relationship to the target (distance, angle). The factory-loaded coefficients are only valid for a black body with emissivity, ε = 0.94, and a 110°FOV with scene radiation.

For most systems, only a one-time system characterization is needed to determine the calibration value (S0) used for mass production. Higher accuracies may be obtained by calibrating each individual unit to determine that particular unit's calibration value (S0).

**Can I use this guide for the TMP006?**

The general procedures and concepts described in this guide apply to the TMP006. However, note there are some specific functions (the ALERT function, for example) not supported by the TMP006.

**What is the accuracy?**

The TMP007 is typically capable of measuring on object to an accuracy of ±1°C, post calibration.

- The accuracy can effected by changes in the measurement system since calibration. (changes in distance, angle, and/or the emissivity of the target object).
- As with all thermopiles, as the difference in temperature between the object and the sensor increases, so will the error.

**How can I improve accuracy beyond data sheet specs?**

The data sheet specs are defined to account for variations in process from unit to unit, is valid over a given temperature range and assumes a onetime calibration is performed to determine the calibration value (S0) for a particular measurement environment. Thereafter, the same set of coefficients are used for all units.

Higher accuracies may be obtained by calibrating each individual unit to determine that particular unit's calibration value (S0). Also, defining a narrower temperature range for calibration or increasing the sample time will improve accuracy.

**Is the accuracy affected by airflow?**

The object temperature results are impacted by changes in airflow directly across the device. The effects of airflow can be somewhat mitigated by implementing the transient correction algorithm. Shields or windows often provide a more robust solution.

**Is the accuracy affected by PCB components generating heat?**

The object temperature and local temperature are impacted by heat flows from PCB components. For steady state heat flows, the thermal sensors measure the local die temperature and can compensate. If there are transient heating conditions caused by power cycling of the components, then implementation of the transient correction feature on the TMP007 should be considered.

**What is the maximum and minimum object temperature I can measure?**

The thermal sensor can measure any object temperature provided it can receive thermal radiation from the object. Note that the object temperature register (03h) is limited to ±256°C, due to the finite number of bits. However, readings outside this range can be accommodated by reading the sensor voltage register (00h) and local temperature register (01h), then performing the calculation on an external processor.

Ensure that the die temperature remains within the operating range specified by the data sheet. At lower object temperatures, ensure that liquid or vapor does not condense on the device.

### How far away can I read an object temperature?

The distance an object can be measured is dependent upon the size of the target object. The object should cover at least 90° of the FOV of the sensor. See the TMP007 Product Data Sheet for a discussion of the effect of FOV on measurement.

Should the target object being measured not encompass the full FOV, the sensor will include the background temperature behind the target object in the measurement.

### Sometimes $V_{OBJ}$ is negative, what does this mean?

Whether $V_{OBJ}$ is positive or negative is dependent on whether the die is colder or hotter than the object. If $T_{OBJ} > T_{DIE}$, then the thermopile absorbs more energy from the object than it radiates and $V_{OBJ} > 0$. If $T_{OBJ} < T_{DIE}$, then the thermopile absorbs less energy from the object than it radiates and $V_{OBJ} < 0$.

### How can I change the Field of View (FOV)?

The FOV can be altered by using additional optical lenses or by limiting the FOV through the use of an aperture. A simple low-cost method to restrict the FOV is with the use of a metal aperture over the device with an opening over the sensor.

Should a lens be used, the material must allow for transmission of IR radiation in the band the device detects [see TMP007 product data sheet (SBOS685)]. Polyethylene and polypropylene are low costs materials with good transmissive properties to IR. Germanium is a higher-performance, higher-cost option.

Calibration **must** be performed with the window or lens present and in the final system configuration.

### What are the processing resources required to calculate the temperature?

The TMP007 includes an onboard math engine to perform the required calculations, allowing for simple read back of the temperatures across the I2C interface. In addition, because of the math engine, the TMP007 has ALERT functions to notify a host of out-of-bounds temperature conditions. Note the TMP007 can operate at 0.27 mA at 2.5 V for low-power applications. The calculation time is < 50 µs. Energy required is < 1 µJ.

The TMP006 requires the host processor to perform the calculations from the sensors and ADC output to correctly determine the object temperature. To accomplish this, the processor must be able to handle 10 addition and 17 multiplying operations within 250 ms. Word length is 16 bits. The following image shows an example for an MSP430 processor.

Example using a MSP430F5526

| | |
|---|---|
| Device | MSP430F5526 |
| Cycles counts | 21064 |
| Memory Size (bytes) | 4516 |

| | | | | | |
|---|---|---|---|---|---|
| Vcc (V) | 3 | 3 | 3 | 3 | 3 |
| CPU Speed (MHz) | 25 | 20 | 12 | 8 | 1 |
| Current (mA) | 10.1 | 7.1 | 4 | 2.32 | 0.36 |
| Power (mW) | 30.3 | 21.3 | 12 | 6.96 | 1.08 |

| | | | | | |
|---|---|---|---|---|---|
| Time to execute (ms) | 0.84256 | 1.0532 | 1.755333 | 2.633 | 21.064 |
| Energy (uJ) | **25.530** | **22.433** | **21.064** | **18.326** | **22.749** |

### What is the sensor response time?

The sensor response time is approximately 20 ms. The internal ADC has a minimum measurement time of 250 ms which sets the data rate. Since the ADC is an integrating converter, thermal response as fast as 20 ms are captured.

### For calibration, how can I measure the object temperature?

For the initial calibration process, the thermal sensor requires a known object temperature for correlation. The temperature sensor used to measure the object must be in good thermal contact with the object. Thermocouples, thermistors, high accuracy IC temperature sensors (for example, TMP112) or pn junction remote are all options. For temperature sensors without a digital output, ensure that the digitized data is sufficiently accurate for use.

### Can I use the local temperature sensor on the thermal sensor to measure object temperature for calibration?

Yes, you can use the local temperature sensor (register 01h) on a separate thermal sensor to measure the object temperature for calibration.

### Can the local temperature of the PCB be measured?

Yes, A 14-bit local temperature sensor is integrated into the device allowing for ±1°C accuracy across a range of 0° to 60°C or ±1.5°C across a range of –40°C to 125°C

### Can air temperature be measured?

Air is transparent to IR. Air temperature can be measured indirectly, by measuring an object which is at the temperature of the air. For example: aiming the TMP006 at a painted metal vent in the air flow or a thin metal sheet in the air flow. Ensure the target object in the air flow has a high emissivity for best results.

### Are there other package options available?

Currently, the only package option is a 1.9 mm x 1.9 mm WCSP (TMP007) or 1.6 mm x 1.6 mm WCSP (TMP006). Note the devices have identical PCB footprints. Additional package options may be available in the future.

### PCB material impact on calibration

The PCB board material does not have a significant effect on the sensor sensitivity to thermal gradients unless the material has significantly lower thermal resistance than FR4.

Any board material may be used. Special attention to the layout is required.

### Reliability and Environmental Considerations

- **Moisture Sensitivity:** The TMP006/007 meets moisture sensitive level 1 requirements
- **ESD:** The TMP006/007 meets 4-kV HBM
- **RoHS:** Yes, the TMP006/007 is RoHS compliant.

### Is an SPI version available?

An SPI version is not available at this time. Please contact your local TI representative for current availability.

### Can the TMP006/TMP007 be used for gas detection?

Yes: The thermal sensors are sensitive to the spectral region typically used for this purpose and can work for gases with high light absorption in this range. See the TMP007 Product Data Sheet (SBOS685) for further information on the spectral response.

### Is software or example code available?

Source code is available in the product folder. As an example, source code to the TMP006 EVM is available on the TMP006 EVM product folder on TI.com. For further information, contact your local TI representative.

# 8 Appendix B: Setting Coefficient Register Values

## 8.1 Converting 2's Complement Coefficient Values to Decimal Format

The coefficients in the registers are in hex format. However, for purposes of validating a calibration or checking calculations, it is convenient to have the coefficients in decimal format. For ease of conversion, the code for a spreadsheet is given here.

**Table 13. Code Example For 2's Complement to Decimal Coefficient Conversion**

```
Code For Sensor Voltage Register 00h 2's Complement to Decimal
      ( IF(HEX2DEC(A1) < 2^15, HEX2DEC(A1), HEX2DEC(A1)-2^16) ) * (0.00000015625)

Code For Tdie Temperature Register 01h 2's Complement to Decimal
         HEX2DEC(A1)/4*0.03125

Code For Object Temperature Register 03h 2's Complement to Decimal
      ( IF(HEX2DEC(A1) < 2^14, HEX2DEC(A1), HEX2DEC(A1)-2^16) ) * (0.03125)

Code For Temperature Limit Registers 06h-09h 2's Complement to Decimal
      ( IF(HEX2DEC(A1) < 2^10, HEX2DEC(A1), HEX2DEC(A1)-2^16) ) * (0.5)

Code For S0 Coefficient Registers 0Ah 2's Complement to Decimal
     HEX2DEC(A1)*4.5475E-18

Code For Coefficient Registers 0Bh-10h 2's Complement to Decimal
     ( IF(HEX2DEC(A1) < 2^16, HEX2DEC(A1), HEX2DEC(A1)-2^16) ) * (LSB)
     A1              0Bh                   3.8150E-6
     A2              0Ch                   5.9600E-8
     B0              0Dh                   1.5625E-7
     B1              0Eh                   6.1035E-10
     B2              0Fh                   9.5367E-12
     C0              10h                   4.7680E-02

Code For Transient Correction Coefficient Registers 01h-12h 2's Complement to Decimal
     ( IF(HEX2DEC(A1) <1 2^16, HEX2DEC(A1), HEX2DEC(A1)-2^16) ) * (LSB)
     TC0             11h                   5.0000E-6
     TC1             12h                   3.1250E-2
```

## 8.2 Converting Decimal Co-efficient Values to 2's Complement

The coefficients derived from the curve fitting process are usually in decimal format. However, the TMP007 requires the coefficients to be in 2's complement format. For ease of conversion, the code for a spreadsheet is given here.

**Table 14. Code Example For DEC to 2's Complement Coefficient Conversion**

```
Code For S0 Co-efficient Registers 0Ah Decimal to 2's Complement
        RIGHT(DEC2HEX(A1/4.547119E-18),4)

Code For Co-efficient Registers 0Bh-10h Decimal to 2's Complement
        RIGHT(DEC2HEX(A1/LSB),4)  (LSB for each register given in table below)
        A1             0Bh                3.8150E-6
        A2             0Ch                5.9600E-8
        B0             0Dh                1.5625E-7
        B1             0Eh                6.1035E-10
        B2             0Fh                9.5367E-12
        C0             10h                4.7680E-02

Code For Transient Correction Co-efficient Registers 01h-12h Decimal to 2's Complement
        RIGHT(DEC2HEX(A1/LSB),4)  (LSB for each register given in table below
        TC0            11h                5.0000E-6
        TC1            12h                3.1250E-2
```

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