User's Guide
SBOU107 – May 2011

TMP006

This user's guide describes the function and operation of the TMP006, a non-contact infrared (IR) sensor with a digital interface. This document discusses the most important application-related design considerations to achieve optimal performance when using the TMP006 for surface temperature measurements.

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1 Introduction

1.1 Terms and Definitions

The following list summarizes many of the terms and abbreviations used in this document.

- PCB: Printed circuit board; specifically refers to the printed circuit board that the TMP006 is mounted on.
- IR: Infrared, or radiation that occurs in the infrared wavelengths (0.7 µm to 1000 µm). The TMP006 uses IR wavelengths from 4 µm to 8 µm.
- IR sensor, Sensor: The IR sensor within the TMP006 integrated circuit device.
- Target object, Target: The object for which the TMP006 measures the temperature.

1.2 If You Need Assistance

If you have questions about the TMP006, join the discussion with the Linear Amplifiers Temperature Sensors Applications Team in the e2e™ forum at e2e.ti.com. Include ***TMP006*** as the subject heading of your posting.

1.3 Information About Cautions and Warnings

This document contains caution statements.

CAUTION

This is an example of a caution statement. A caution statement describes a situation that could potentially damage your software or equipment.

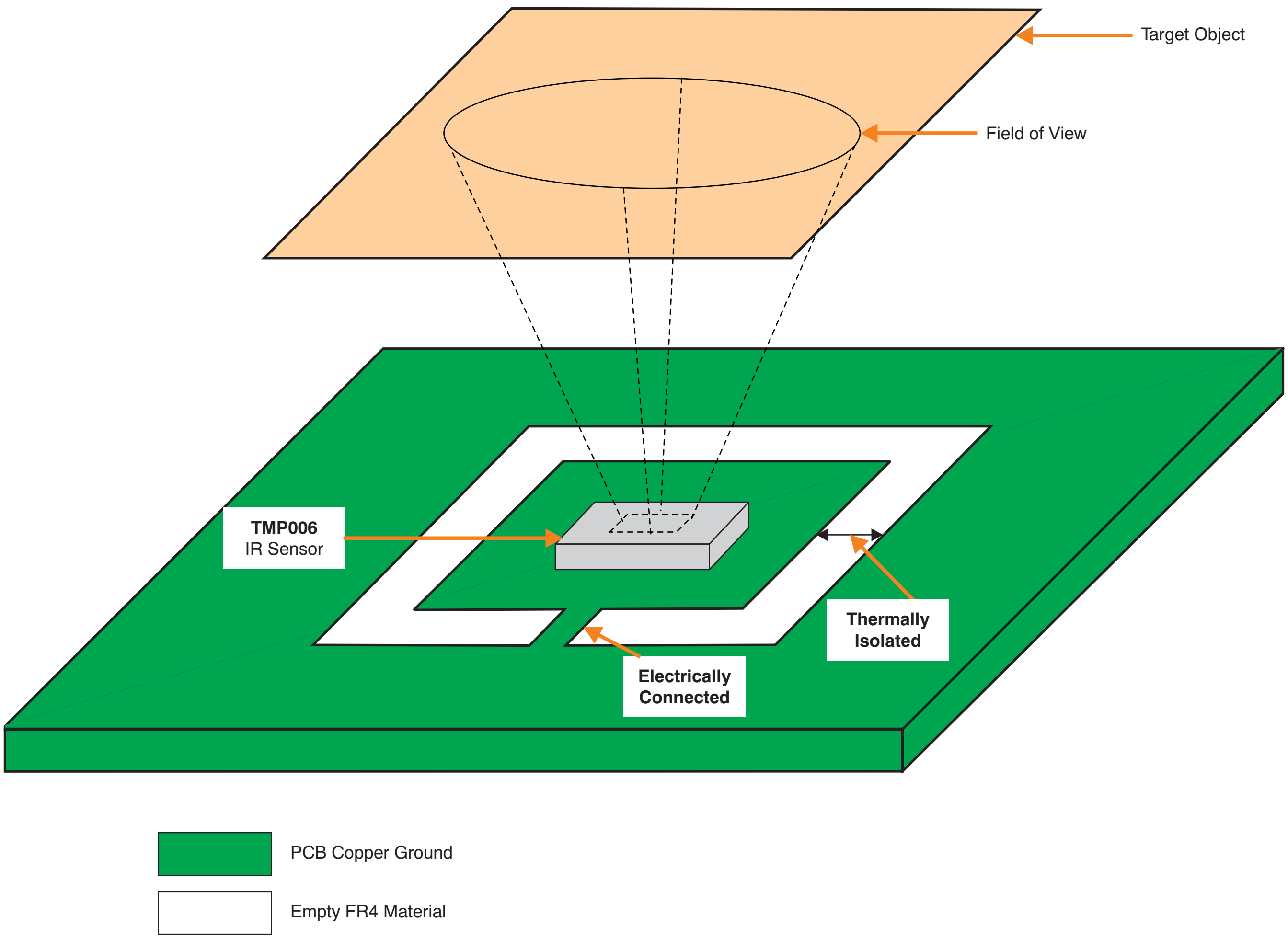
The information in a caution or a warning is provided for your protection. Please read each caution and warning carefully.

1.4 FCC Warning

This equipment is intended for use in a laboratory test environment only. It generates, uses, and can radiate radio frequency energy and has not been tested for compliance with the limits of computing devices pursuant to subpart J of part 15 of FCC rules, which are designed to provide reasonable protection against radio frequency interference. Operation of this equipment in other environments may cause interference with radio communications, in which case the user at his own expense is required to take whatever measures may be required to correct this interference.

2 System Overview

Figure 1 shows an example of the TMP006 in a typical target object surface temperature measurement setup.



NOTE: Drawing not to scale; for illustration purposes only. The TMP006 field of view is much wider than shown here.

Figure 1. TMP006 in a Target Object Temperature Measurement Setup

The TMP006 must be mounted on a printed circuit board (PCB). Section 4 reviews the details of the PCB construction.

> **CAUTION**
>
> Many of the components mounted on a PCB (including the TMP006) are susceptible to damage by electrostatic discharge (ESD). Customers are advised to observe proper ESD handling precautions when handling the TMP as configured on a PCB, including the use of a grounded wrist strap at an approved ESD workstation.

3 TMP006 Object Temperature Measurement Setup

When measuring the temperature of an object using the TMP006, there are several fundamental measurement constraints that must be followed to ensure the accuracy of the object temperature calculation. The two primary constraints are:

- The surface emissivity of the target object; and
- The placement of the TMP006, relative to the size of the target.

The next two subsections examine these constraints in particular.

3.1 Target Object Emissivity Guidelines

The *emissivity* of an object is defined as the ability of an object surface to radiate energy relative to an ideal emitter. An ideal emitter, also called a *black body*, has an emissivity value of 1. When using the TMP006 for target object surface temperature calculations, it is essential that the surface of the target object be able to emit sufficient IR radiation to be accurately detected by the IR sensor in the TMP006. Targets with very low emissivity values emit less IR radiation, and therefore produce smaller signals, which are harder for the TMP006 to capture and measure. Polished and shiny metal objects have surface emissivity values that are typically too low for use with the TMP006.

To measure the surface temperature of an object with a very low emissivity, it can be painted with lampblack paint which has an emissivity of 0.96.

As a design guideline, the TMP006 should only be used to calculate the surface temperature of target objects with emissivity values greater than 0.7, and preferably greater than 0.9. The emissivity values of common objects are listed in Table 1.

Table 1. Emissivity Values for Common Objects

Object or Material	Emissivity		Object or Material	Emissivity
Aluminum, commercial sheet	0.09		Nickel, electroplated	0.03
Aluminum, polished	0.039 to 0.057		Porcelain, glazed	0.92
Aluminum, anodized	0.77		Paper	0.93
Brass, dull plate	0.22		Paint	0.8-0.96
Brass, polished	0.03		Plaster	0.92
Brick, red rough	0.90		Plastics	0.91
Cast Iron, turned and heated	0.6 to 0.7		Sand	0.76
Chromium, polished	0.08 to 0.36		Sawdust	0.75
Concrete	0.85		Silver, polished	0.02 to 0.03
Cotton, cloth	0.77		Steel, mild	0.2 to 0.32
Copper, polished	0.08 to 0.036		Steel, oxidized	0.79
Glass	0.92		Steel, polished	0.07
Gold, pure and polished	0.018 to 0.035		Steel, galvanized old	0.88
Granite	0.45		Steel, galvanized new	0.23
Gypsum	0.85		Stainless steel, weathered	0.85
Ice	0.97		Stainless steel, polished	0.075
Iron, polished	0.14 to 0.38		Tile	0.97
Iron, plate rusted red	0.61		Water	0.95
Lampblack paint	0.96		Wood, oak	0.91
Marble, white	0.95		Wrought iron	0.94

3.2 Measurement Geometry Setup

The TMP006 can accurately detect signals in almost the entire 180° field of view of the sensor. The final calculated target object temperature is an integration of all of the signals present in the sensor field of view. Therefore, the ability of the TMP006 to accurately calculate the temperature of a target depends on ability of the IR sensor to capture the majority of its signal from the target. This capture effectiveness, in turn, depends on two factors: the angle of incidence and the distance of the TMP006 from the target.

Figure 2 illustrates the dependence of the TMP006 on the angle of incidence compared to the IR signal absorption. For this test, the intensity of an input signal was held constant and was moved throughout the sensor field of view. This figure shows that the majority of the received signal comes from IR sources located at 0° angles of incidence.

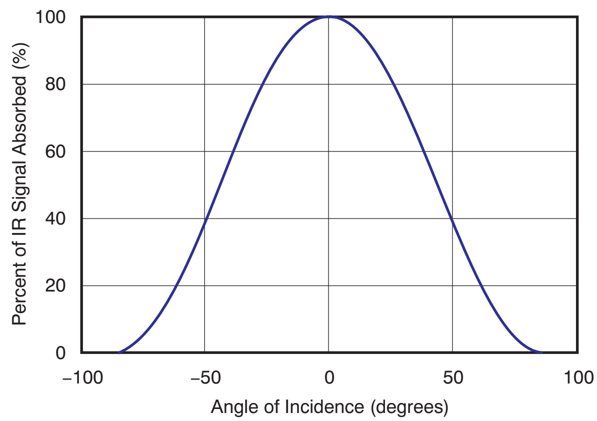


Figure 2. Percentage of IR Signal Absorbed by Sensor versus Angle of Incidence

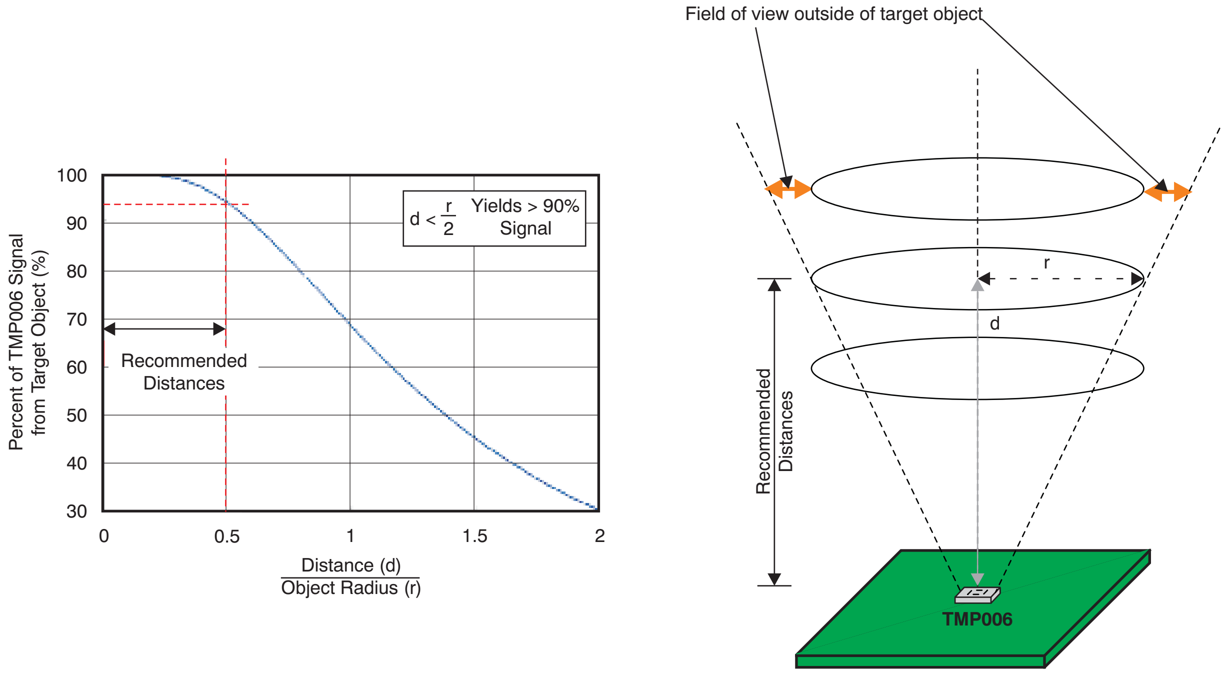
As a design guideline, place the TMP006 directly underneath the target object with the surface of the target parallel to the TMP006, so the angle of incidence between them is 0°.

The distance that the TMP006 should be placed from the target is largely dictated by the size of the target. Smaller targets must be placed closer to the TMP006 to ensure that the majority of the IR signal captured by the sensor is emitted from the target. A circular target should be placed at a distance less than one-half of the radius of the target to ensure at least 90% of the IR signal that the sensor captures is from the target.

As the sensor is moved away from the target, other objects or surfaces enter into the device field of view. Because the final result is an integration of the entire field of view of the sensor, it is not possible to determine which captured signals come from the target and which captued signals come from the other objects (or surfaces).

As a design guideline, then, the target object should be placed at a distance no further than one-half of the radius of the target from the TMP006.

Figure 3 shows how the percentage of the final IR signal captured by the TMP006 depends on the radius of the target and its distance from the TMP006.



NOTE: Drawing not to scale; for illustration purposes only. The TMP006 field of view is much wider than shown here.

Figure 3. Relationship Between Target Object Size and Distance from the TMP006

4 TMP006 Layout Guidelines

The IR thermopile sensor in the TMP006 is as susceptible to conducted and radiant IR energy from below the sensor on the PCB as it is to the IR energy from objects in its forward-looking field of view. When the area of PCB below the TMP006 is at the same temperature as the die or substrate of the TMP006, heat is not transferred between the IR sensor and the PCB. However, temperature changes on a closely-placed target object or other events that lead to changes in system temperature can cause the PCB temperature and the TMP006 temperature to drift apart from each other. This drift in temperatures can cause a heat transfer between the IR sensor and the PCB to occur. Because of the small distance between the PCB and the bottom of the sensor, this heat energy will be conducted (as opposed to radiated) through the thin layer of air between the IR sensor and the PCB below it. This heat conduction causes offsets in the IR sensor voltage readings and ultimately leads to temperature calculation errors. To prevent and minimize these errors, the TMP006 layout must address three critical factors:

1. Match the thermal time constant of the PCB below the TMP006 IR sensor with the TMP006 sensor itself.
2. Thermally isolate the TMP006 from the rest of the PCB and any heat sources on it.
3. Provide a stable thermal environment to reduce the noise in the measurement readings.

Guidelines for creating a PCB that has been used and tested extensively by Texas Instruments are shown in Figure 4 through Figure 6. These PCB layout guidelines are based on a simplified two-layer design for the TMP006 that has no significant performance reductions from the four-layer design used on the TMP006EVM. For a more complete understanding of the TMP006 layout requirements as well as detailed layout design guidelines used for the TMP006EVM, refer to the related document *TMP006 Layout and Assembly Guide* (SBOU108), available for download from the TI website.

4.1 Layer 1: Top Layer

Figure 4 shows the top layer of the TMP006 two-layer PCB.

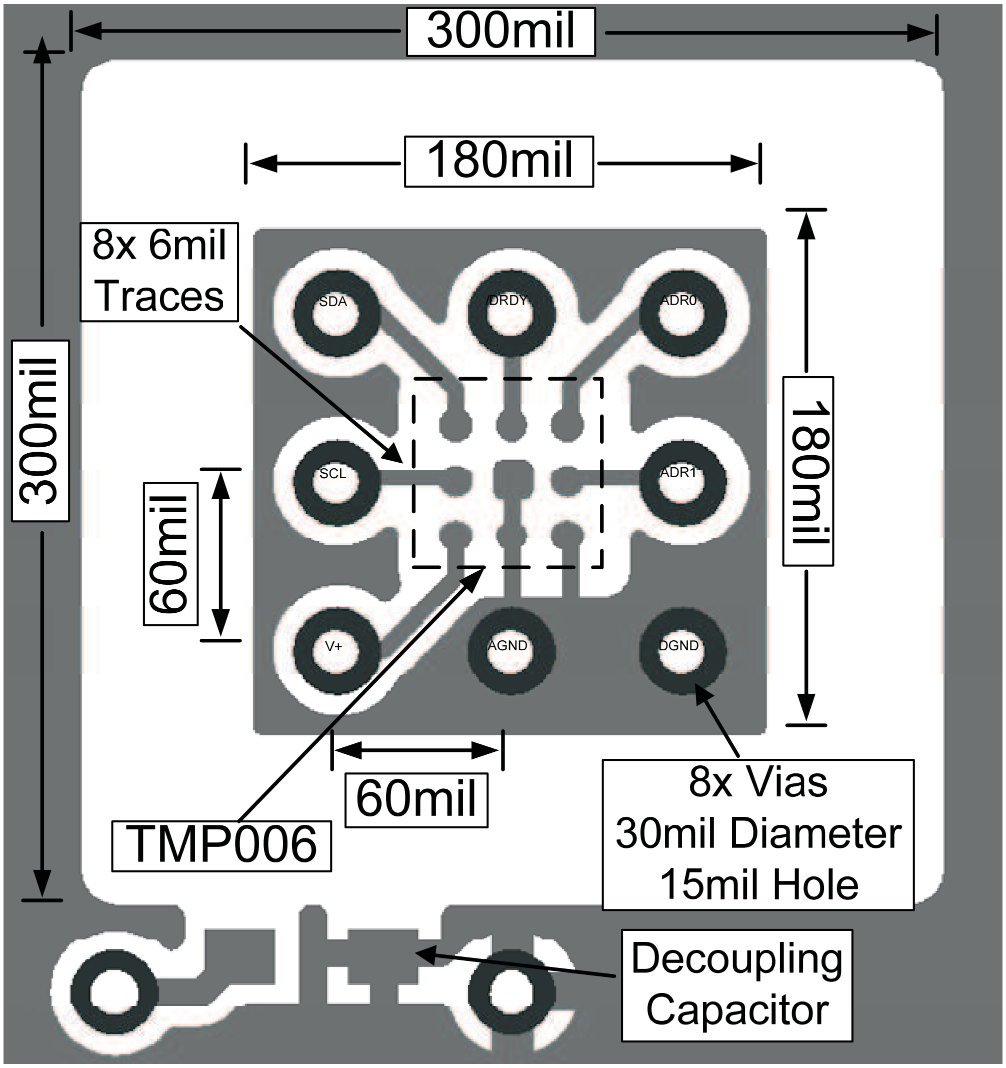


Figure 4. TMP006 Two-Layer PCB: Top Layer

Figure 5 shows an enlarged view of Layer 1 to clearly indicate the TMP006 land pattern and 15-mil x15-mil (.015-in x .015-in) copper fill.

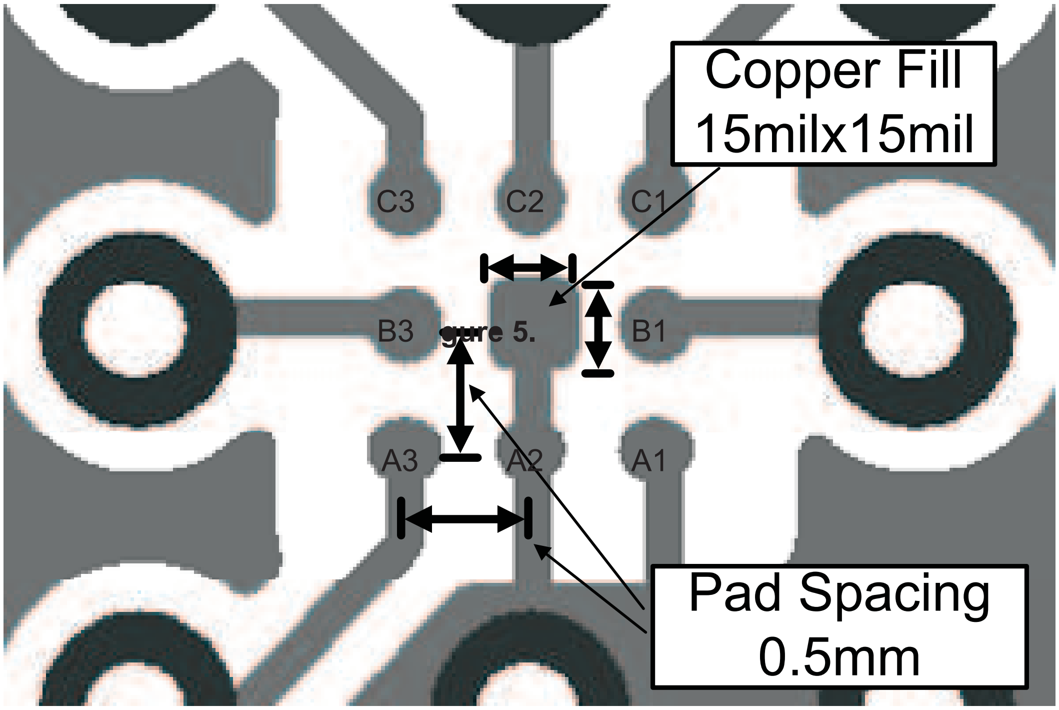


Figure 5. Enlarged View of Layer 1: TMP006 Land Pattern and Copper Fill

4.2 Layer 2: Bottom Layer

The bottom layer of the TMP006 two-layer PCB is shown in Figure 6.

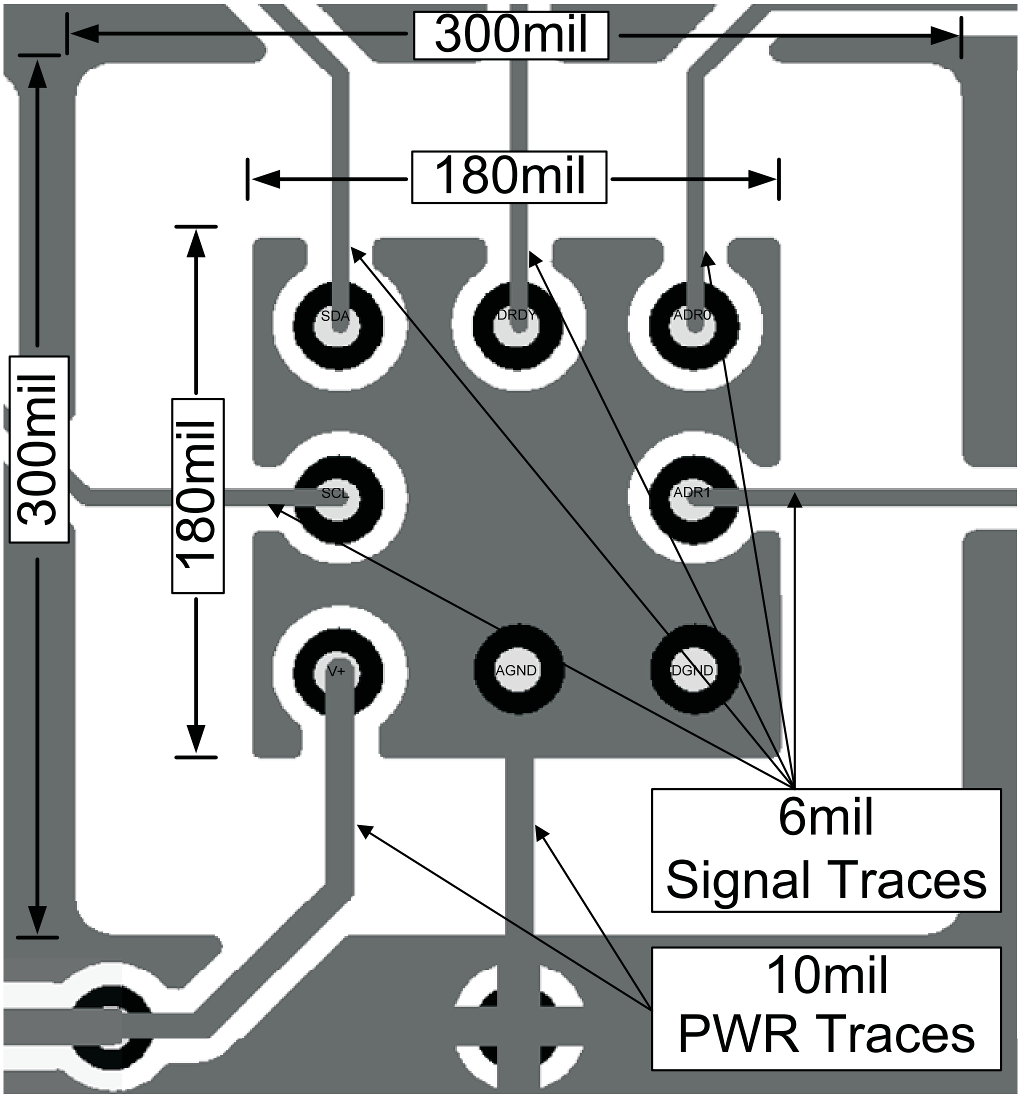


Figure 6. TMP006 Two-Layer PCB: Bottom Layer

5 Object Temperature Calculation

Once the TMP006 has been installed in a system, measurements of the local temperature and object voltage can be made with the TMP006 through the digital interface. Using these two measurements, the target object temperature can be calculated. Section 5.1 presents the calculations required to solve for a target object temperature. V_{OBJ} and T_{DIE} are the readings from the object voltage (Register 0) and local temperature (Register 1) registers in the TMP006, respectively.

5.1 Equations for Calculating Target Object Temperatures

The target object temperature calculations consist of a series of equations that can be used to solve for the target object temperature (T_{OBJ}) in Kelvins. Equation 1 represents the sensitivity of the thermopile sensor and how it changes over temperature:

$$S = S_0 \left[1 + a_1(T_{DIE} - T_{REF}) + a_2(T_{DIE} - T_{REF})^2\right] \quad (1)$$

Equation 1 also contains the primary calibration factor, S_0, which is discussed more in Section 6.

Equation 2 describes an offset voltage that arises because of the slight self-heating of the TMP006, caused by the non-zero thermal resistance of the package and the small operational power dissipation (1 mW) in the device:

$$V_{OS} = b_0 + b_1(T_{DIE} - T_{REF}) + b_2(T_{DIE} - T_{REF})^2 \quad (2)$$

Equation 3 models the Seebeck coefficients of the thermopile and how these coefficients change over temperature.

$$f(V_{OBJ}) = (V_{OBJ} - V_{OS}) + c_2(V_{OBJ} - V_{OS})^2 \quad (3)$$

Equation 4 relates the radiant transfer of IR energy between the target object and the TMP006 and the conducted heat in the thermopile in the TMP006.

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

Solve the system of equations to calculate the temperature of the target object in Kelvins.

The terms used in these formulas are:

- V_{OBJ}: Voltage in TMP006, Register 0
- T_{DIE}: Temperature in TMP006, Register 1
- S_0: Calibration factor (should be calibrated)
- a_1: 1.75×10^{-3}
- a_2: -1.678×10^{-5}
- T_{REF}: 298.15 K
- b_0: -2.94×10^{-5}
- b_1: -5.7×10^{-7}
- b_2: 4.63×10^{-9}
- c_2: 13.4

6 Calibrating the System

The final step to calculate the temperature of the target object is to calibrate the system by calculating the appropriate sensitivity factor, S_0. The term S_0 is unique to a given system and can be determined with a simple two-point calibration performed on one or several devices. S_0 is an accumulation of the system-related signal reductions that can occur when using the TMP006/ This value is part of Equation 1 in the object temperature calculations. This series of equations (for the object temperature calculations) are derived in a way that reduces all application-related factors to a single gain error term. Because the errors only create a gain error, the S_0 term can be determined with a simple two-point calibration. The primary contributors to S_0 are the field of view and emissivity of the target object (refer to Section 3 for additional discussion of these two factors).

To determine S_0, plot the Calibration Function as shown in Equation 2 versus $T_{OBJ}{}^4 - T_{DIE}{}^4$. S_0 is equal to the slope of a linear approximation of the plotted data.

$$\text{Calibration Function} = \frac{f(V_{OBJ})}{\left[1 + a_1(T_{DIE} - T_{REF}) + a_2(T_{DIE} - T_{REF})^2\right]} \quad (5)$$

Typical values for S_0 are between 5×10^{-14} and 7×10^{-14}.

In order to plot the Calibration Function versus $T_{OBJ}{}^4 - T_{DIE}{}^4$, the actual temperature of the object (T_{OBJ}) must first be measured using an accurate temperature probe. The local die temperature measurement should be taken from the TMP006 local temperature sensor (Register 1). Ideally, the two points used for the linear slope-fit represent two extreme temperature points in the system. For example, the first temperature measurement point could be taken with the main system in standby mode, and the second temperature measured with the system running at full power.

Figure 7 shows a plot of the calibration function for several TMP006 devices tested in the same system. The calibration functions for the TMP006 devices were plotted over many temperatures by accurately controlling the local temperature and the object temperature using test equipment. Figure 7 shows that all errors are only gain errors; device-to-device variation is limited, meaning that the calibration can be performed on only a single device. This plot features many measurement points for each device; although only two points are required for calibration, using more data points produces a more accurate curve fit.

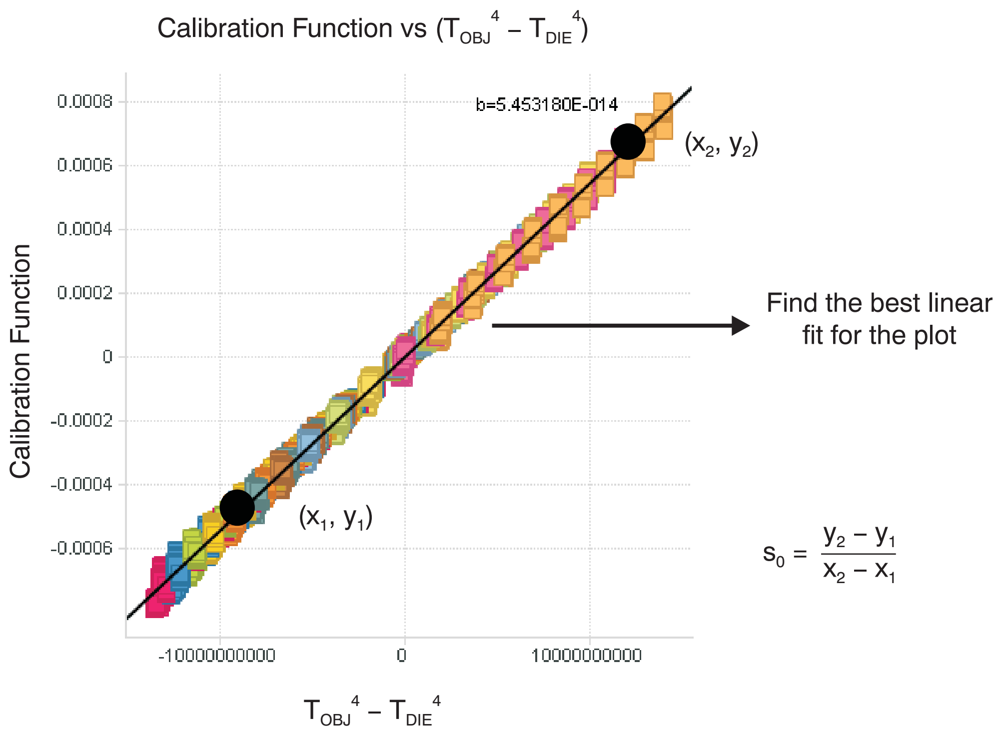


Figure 7. Finding the Slope of the Calibration Function vs $T_{OBJ}{}^4 - T_{DIE}{}^4$ to Calculate S_0