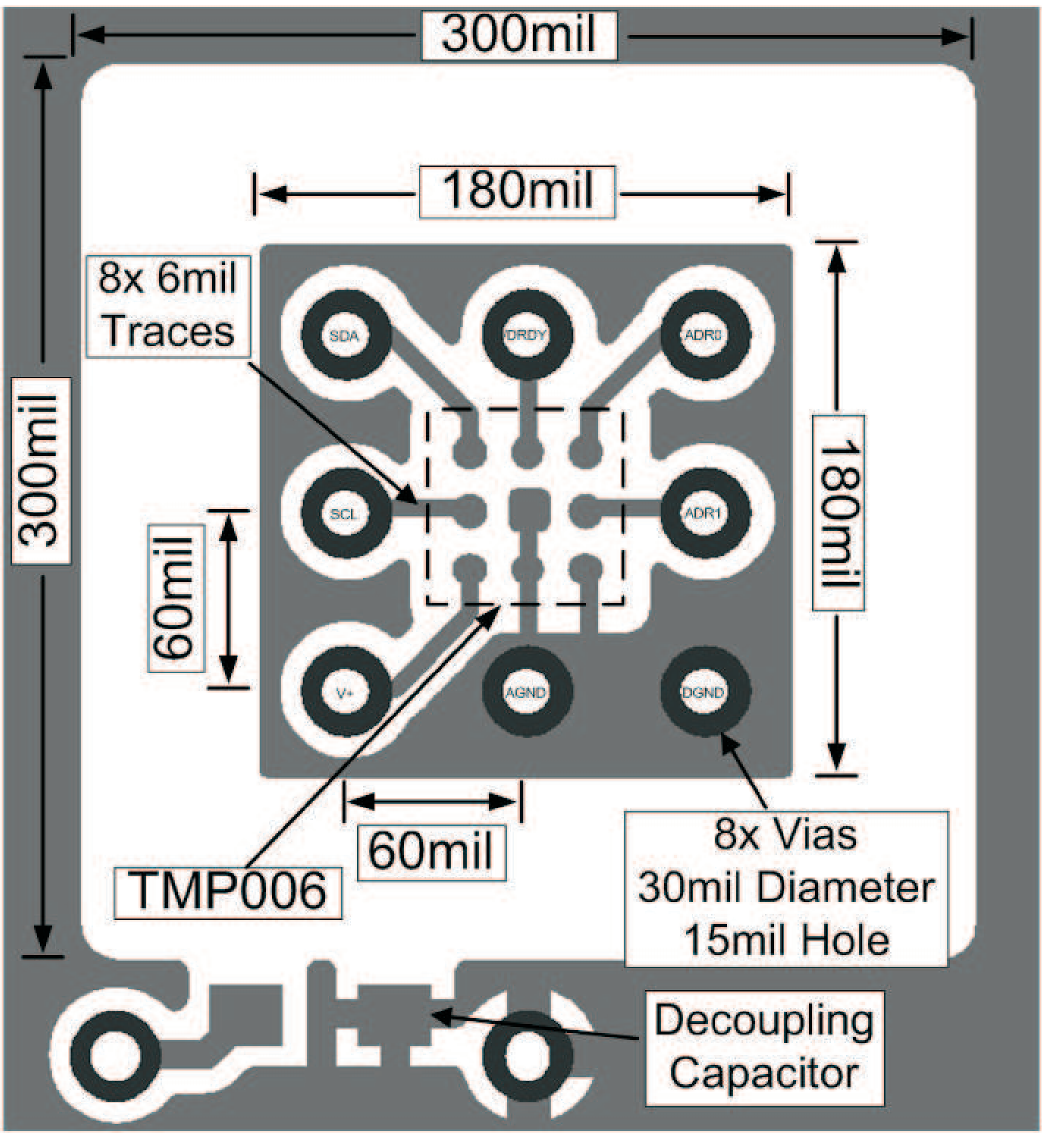
TEXAS INSTRUMENTS

Reference Guide
SBOU108–May 2011

TMP006 Layout and Assembly Guidelines

A specific printed circuit board (PCB) layout is required for the TMP006, a non-contact infrared (IR) sensor, in order for the device to achieve optimal performance when calculating object temperatures. This document explains the theory behind the board layout as well as measurement guidelines for constructing the PCB. Additionally, guidelines for properly assembling the TMP006 on the evaluation module PCB are discussed.



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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.

- EVM: Evaluation module. The TMP006EVM demonstrates characteristics of the TMP006 integrated circuit.
- 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.
- k_X: Coefficient of thermal conductivity of a given material. This coefficient is defined as the rate at which heat flows through a given material. k_X is measured by heating a material through transients and then measuring the change in temperature over time. This coefficient can be understood as a *thermal time constant* because it is analogous to an RC time constant in electronics. Materials with larger *k* values have smaller thermal time constants and tend to settle faster with regard to changes in system temperature than do materials with smaller values of *k*. Figure 1 shows an example of three materials with different *k* values and the respective reaction to a step increase in system temperature.

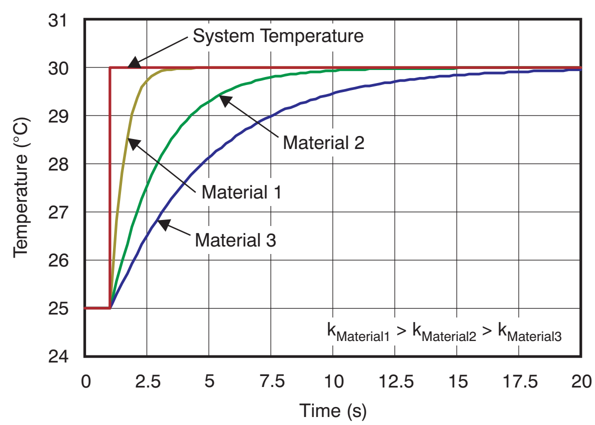

Figure 1. Example of Materials with Different Coefficients of Thermal Conductivity and Corresponding Reactions to a Step Input in Temperature

- k_{TMP006}: Coefficient of thermal conductivity of the entire TMP006 integrated circuit.
- k_{SENSOR_PCB}: Coefficient of thermal conductivity of the area of the board directly under the TMP006 IR sensor.
- k_{BOARD}: Coefficient of thermal conductivity of the entire board. See Table 1 for a list of the coefficients of thermal conductivity for common PCB materials.
- PCB: Printed circuit board. Specifically refers to the printed circuit board that the TMP006 is mounted on.
- Target object, Target: The object for which the TMP006 measures the temperature.

Table 1. Coefficients of Thermal Conductivity (k) for Common PCB Materials

Material	Coefficient of Thermal Conductivity (k) at +25°C
Air	0.024
Aluminum	250
Copper	400
FR-4	0.27
Gold	310
Lead	35
Silver	430
Tin	67

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.

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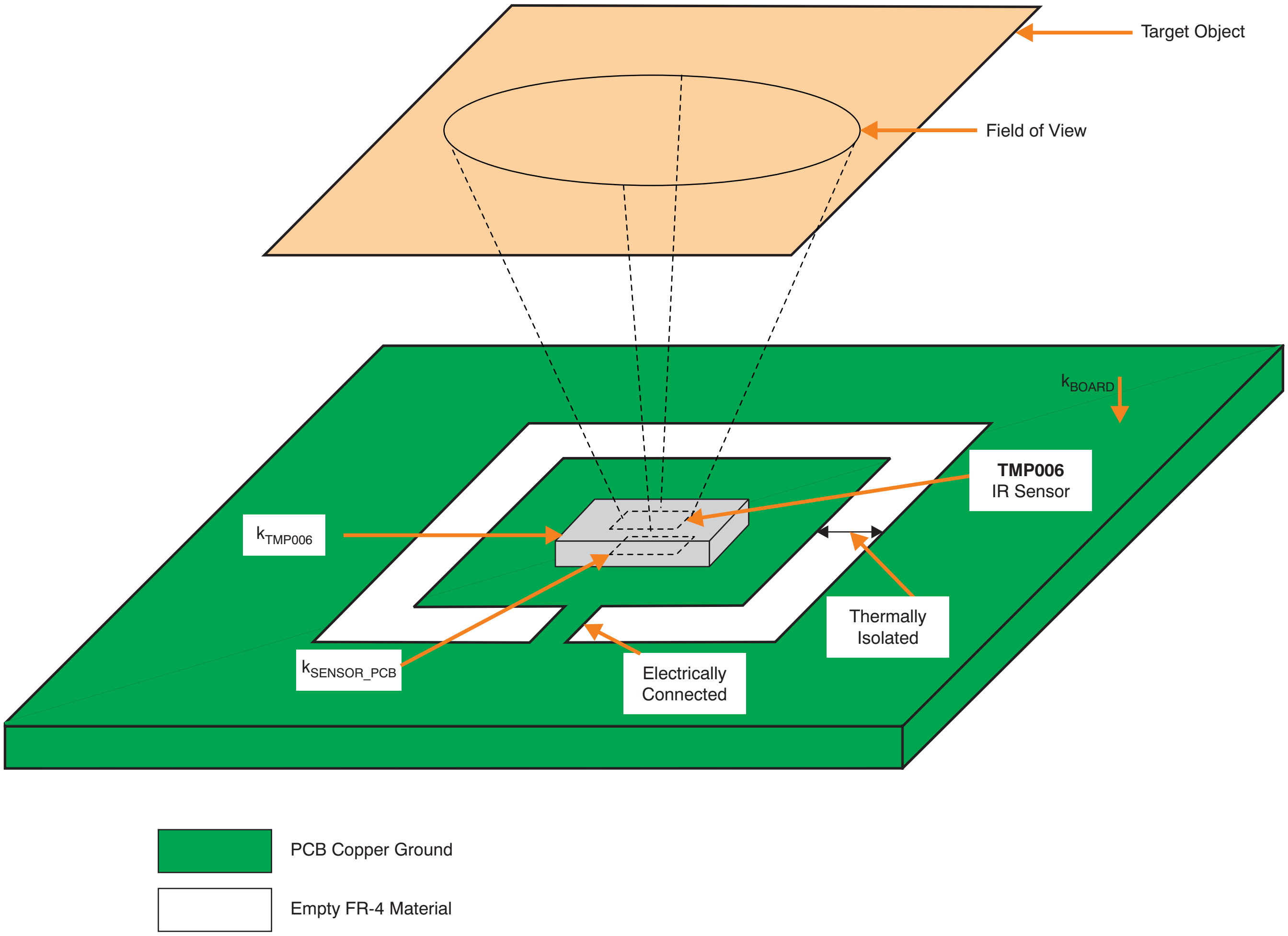
This equipment is intended for use in a laboratory test environment only. It generates, uses, and can radiate radio frequency energy and has not been tested for compliance with the limits of computing devices pursuant to subpart J of part 15 of FCC rules, which are designed to provide reasonable protection 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 2 shows an example of the TMP006 in a typical target object surface temperature measurement setup. The coefficients of thermal conductivity for the key areas of the design are indicated.



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

Figure 2. TMP006 Target Object Temperature Measurement Overview

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 TMP006 as configured on a PCB, including the use of a grounded wrist strap at an approved ESD workstation.

3 TMP006 Layout Theory

3.1 *IR Sensor Interaction with PCBs*

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. That is:
   - $k_{TMP006} \cong k_{SENSOR\_PCB}$
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.

For a more complete understanding of the TMP006 device itself, refer to the related document *TMP006 User Guide* (SBOU107), available for download from the TI website.

3.1.1 Matching the Thermal Time Constants ($k_{TMP006} \cong k_{SENSOR\_PCB}$)

If the thermal time constant of the TMP006 is different than that of the PCB area directly below the device, then changes in the system temperature generate mismatches in temperature between the TMP006 and the PCB underneath it until both temperatures stabilize. During the time where these mismatches occur, all target object temperature calculations are invalid. Changes in system temperature can occur because of a number of factors: a sudden change in the system ambient temperature from a fan turning on or off, for example; a processor of another high-power-consuming device turning on or off; or an increase in the target object temperature if it is located close to the TMP006.

Figure 3 illustrates an example with a 5°C increase in temperature in a system where the thermal time constant of the PCB area below the TMP006 is larger than that of the TMP006. The increase in system temperature causes the two thermal masses to heat at different rates as a result of the different thermal time constants. Again, note that until both the device and the PCB are settled at the same final temperature, any target object temperature calculations are invalid.

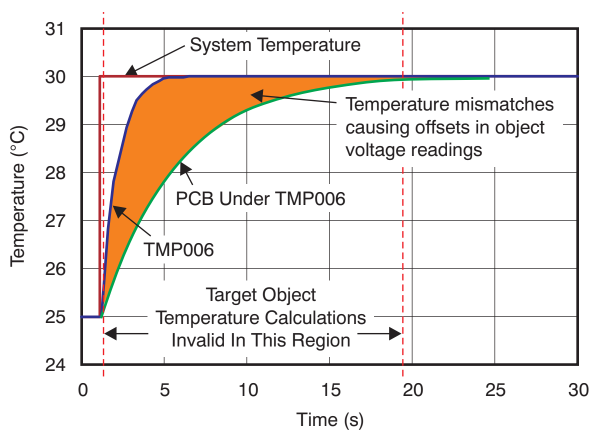


Figure 3. Effects of Thermal Time Constant Mismatches Between the TMP006 and PCB Area

Achieving thermal equilibrium between the two thermal time constants requires the die (specifically, the substrate) of the TMP006 to be thermally coupled to the PCB area below it through a high-*k* material. This PCB area should have the correct amount of copper mass to match its thermal time constant with the

TMP006. In the recommended layout discussed here, the coupling is achieved with a 15-mils × 15-mils (3.81-mm × 3.81-mm) copper fill directly below the sensor (k_{COPPER} = 400). This copper fill is electrically connected to the GND pins of the TMP006. The GND pins provide the best thermal path to the die/substrate of the TMP006, so this small copper fill provides the required high-*k* connection to keep the PCB area below the TMP006 at a temperature very close to that of the TMP006. A larger 180-mils × 180-mils (4.572-mm × 4.572-mm) copper GND island that the TMP006 and copper fill reside on has been sized appropriately to match the thermal time constant of the TMP006. Images of this area of the PCB can be seen in Figure 6 and Figure 7.

Leaving FR-4 material exposed below the sensor produces one of the worst conditions for the TMP006. FR-4 material is an insulator with a very low *k* ($k_{FR\text{-}4} \approx 0.27$), and prevents the temperature between the TMP006 and the PCB from achieving equilibrium unless the entire measurement setup has been in thermal equilibrium for an extended time. Similarly, connecting the GND pins and the small copper fill to a very large copper plane (much larger than 180 mils x 180 mil, or 4.572 -mm × 4.572 mm) produces similar undesirable effects because the very large GND plane has too much copper mass, and therefore a large thermal time constant.

3.1.2 Isolating the TMP006

The second factor that the TMP006 layout must address is to thermally isolate the TMP006 and the PCB area below it from the effects of other heat sources on the PCB. Consider the effects of a high-power-consuming component near the TMP006, for example. As this second component becomes active or inactive, the amount of heat that is being dissipated into the GND plane changes greatly. If the TMP006 is connected to the same GND plane as this component, then the TMP006 die temperature is affected by the change in temperature of the nearby device. This configuration could lead to the same type of temperature gradients that cause the problems described in Section 3.1.1 and also cause the TMP006 to experience transient related issues as discussed in the TMP006 User's Guide. The same 180-mils × 180-mils (4.572-mm × 4.572-mm) copper island that is used to match the thermal time constants described earlier was also used to help isolate the TMP006 from the rest of the board by increasing the area that separates the island from the rest of the PCB GND plane to 60 mils (1.524 mm) on all sides. Additionally, eight equally-spaced PCB vias were placed around the outside of the isolated copper island to create low-*k* air gaps (k_{AIR} = 0.024) between the island and the rest of the PCB. An example of how this approach helps prevent unwanted thermal interactions is shown in Figure 4.

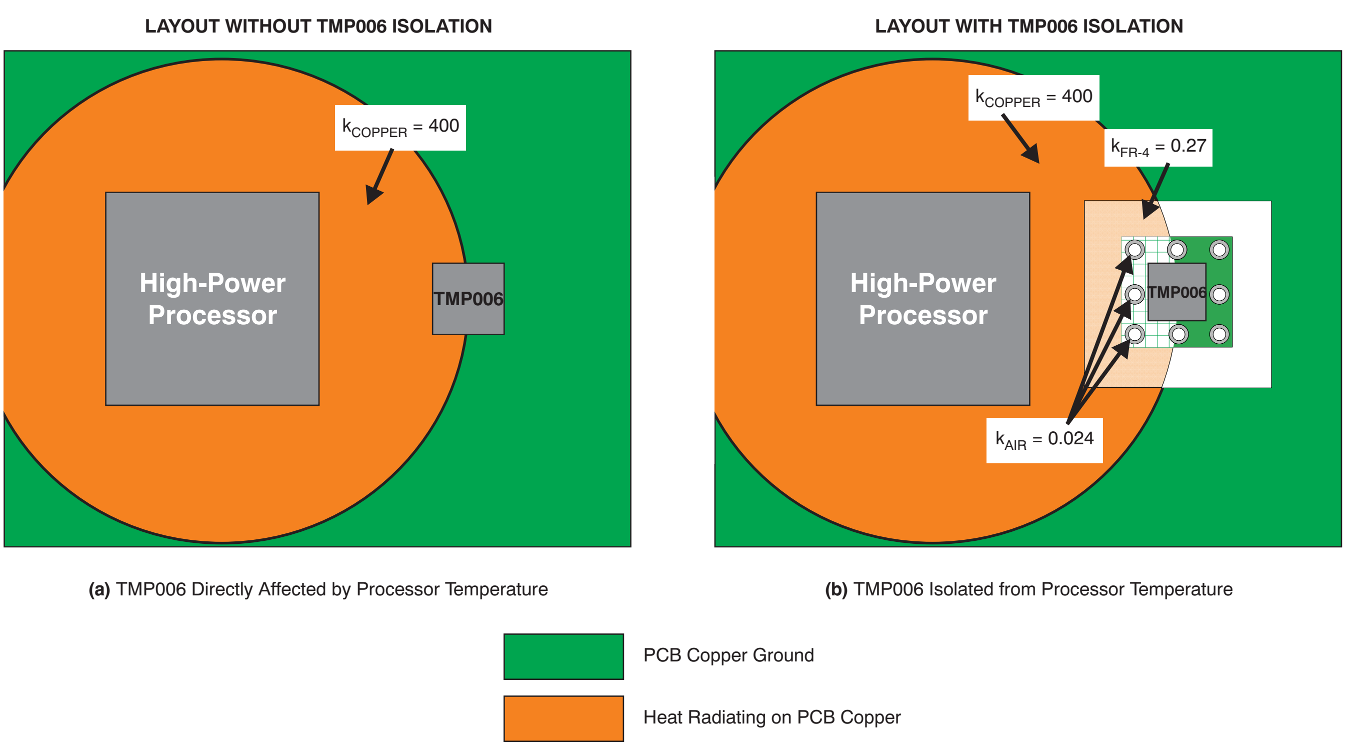


Figure 4. Isolating the TMP006 from Interaction with Other Devices on the PCB

The 60 mils (1.524 mm) of empty FR-4 between the primary GND plane and the island, as well as the air gaps noted previously, have proven to provide sufficient isolation to achieve accurate target temperature measurements with the TMP006, even with a nearby heat-generating source.

3.1.3 Stabilizing the Thermal Environment

The third issue addressed with the recommended layout for the TMP006 is to lower measurement noise and internal inaccuracies by creating a stable temperature environment for the TMP006. The accuracy of the object temperature calculation depends on the local sensor being at the same temperature when it is measured as it is for the corresponding object voltage measurement. There are design measures taken internal to the TMP006 to minimize effects of temperature drift between measurements, but a stable environment will always produce more accurate results. This goal of temperature stabilization poses a conflict with the first topic (refer to Section 3.1.1) because temperature stability implies larger copper masses and slower thermal time constants. These larger thermal time constants provide immunity to small, quick variations in temperature in a similar fashion to large RC time constants that reject high-frequency voltage inflections. Stabilization is achieved by including a layer (or multiple layers) below the TMP006 with an identically-sized copper cutout and island. Both the top layer and second (or multiple) layer cutouts and islands have been sized to provide the best compromise between the first and third topics, and were selected after testing many designs.

Although the steps described here help minimize measurement noise by helping to stabilize the thermal environment around the TMP006, the best method for achieving stabilization is to prevent drastic changes in system temperature from occurring near the TMP006. This preventive step can mean keeping the TMP006 away from fans or other heat sources on the PCB.

4 TMP006 Layout Guidelines

The PCB layout guidelines and images shown here represent a two-layer PCB that has been tested extensively with the TMP006. Section 4.3 provides the guidelines for the construction of the TMP006EVM; the EVM uses a four-layer PCB. There are no significant performance differences between the two-layer and four-layer PCB designs. The PCB layout was designed on a 1-mil grid (1 mil = .001 in, or 0.0254 mm). The TMP006 dimensions are shown in millimeters (mm). The copper weight of the PCB is 1 oz. The PCB via size does not vary between layers, and all vias go through the entire board from the top to the bottom layer (that is, there are no blind or buried vias). The recommended PCB layer stack is shown in Figure 5.

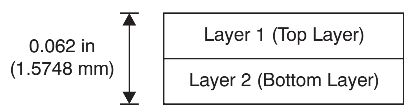


Figure 5. TMP006 Two-Layer PCB Layer Stack

4.1 TMP006 PCB

4.1.1 Layer 1: Top Layer

The TMP006 device is mounted on the top layer of the PCB (layer 1). This layer also contains the PCB landing pattern for the TMP006 wafer chip-scale package, an isolated island of copper around the TMP006 device, and the TMP006 decoupling capacitor. Figure 6 shows the full image and the dimensions of the first layer PCB layout around the TMP006.

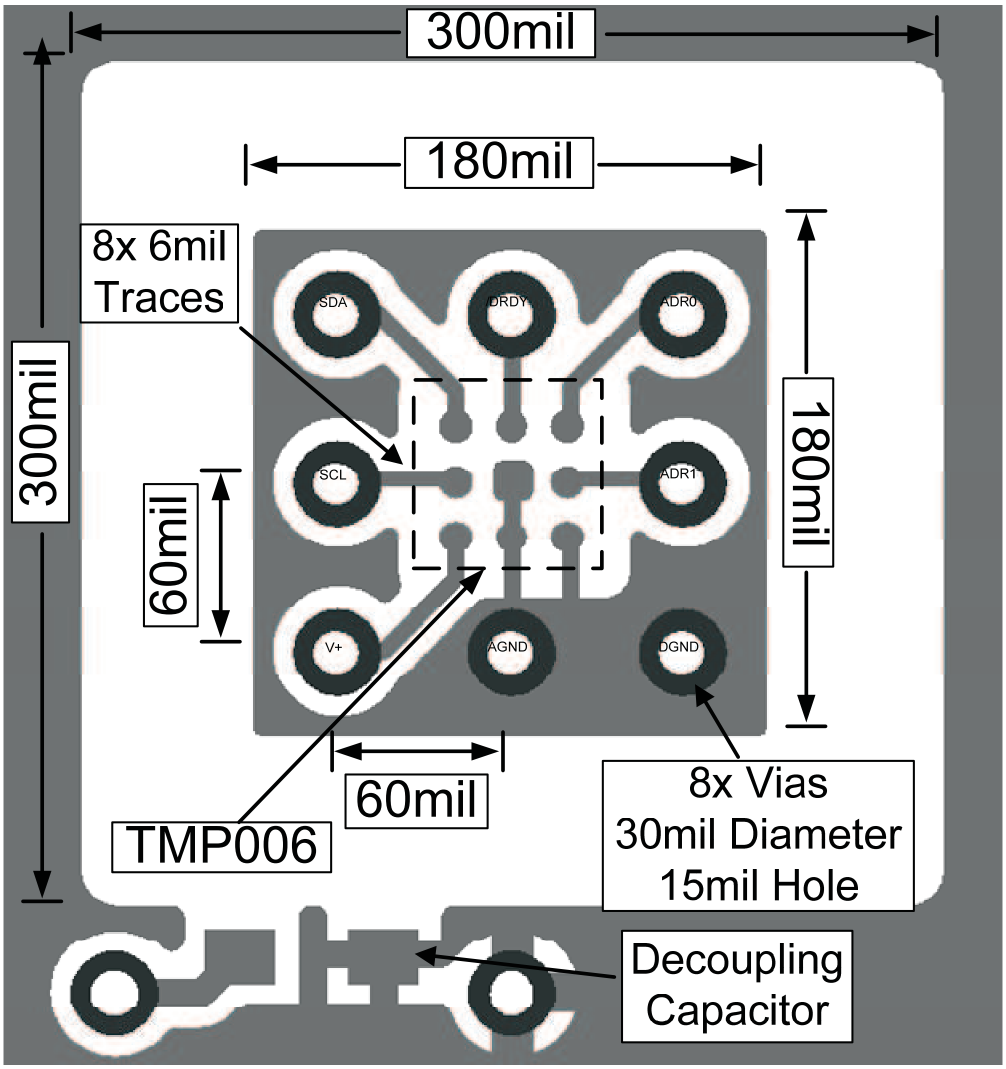


Figure 6. TMP006 Two-Layer PCB: Top Layer

A large opening (300 mils × 300 mils, or 7.62 mm × 7.62 mm) in the primary copper GND plane. A copper island is centered in this opening with dimensions of 180 mils × 180 mils (4.572 mm × 4.572 mm). The TMP006 PCB land pattern is centered in the copper island. Eight vias surround the TMP006 on the copper island that connect the TMP006 signals to the traces on the third layer (see Section 4.3.3). The vias have a diameter of 30 mils (that is, 0.762 mm), a hole size of 15 mils (or 0.381 mm) are equally spaced 60 mils (1.524 mm) apart, and are located with the TMP006 in the center of the pattern. These vias help to further isolate the temperature of the copper island from the rest of the PCB by using the air gap in the via holes as an insulator.

A critical part of the TMP006 top layer design is a copper fill placed directly under the IR sensor in the center of the PCB land pattern for the TMP006. This copper fill has dimensions of 15 mils × 15 mils (0.381 mm × 0.381 mm). The fill is covered with the top layer solder-mask. Figure 7 shows an enlarged view of Layer 1 to clearly indicate the TMP006 land pattern and 15-mils x15-mils (.015-in x .015-in) copper fill.

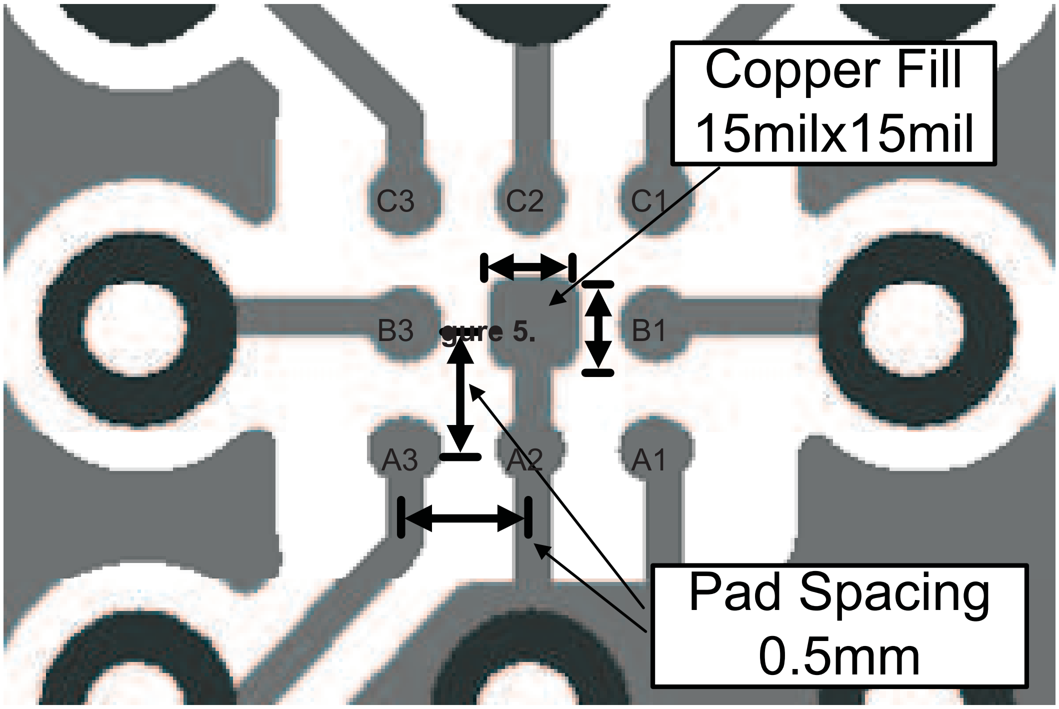


Figure 7. Enlarged View of Layer 1: TMP006 Land Pattern and Copper Fill

4.1.2 Layer 2: Bottom Layer

The bottom layer of the TMP006 two-layer PCB is shown in Figure 8.

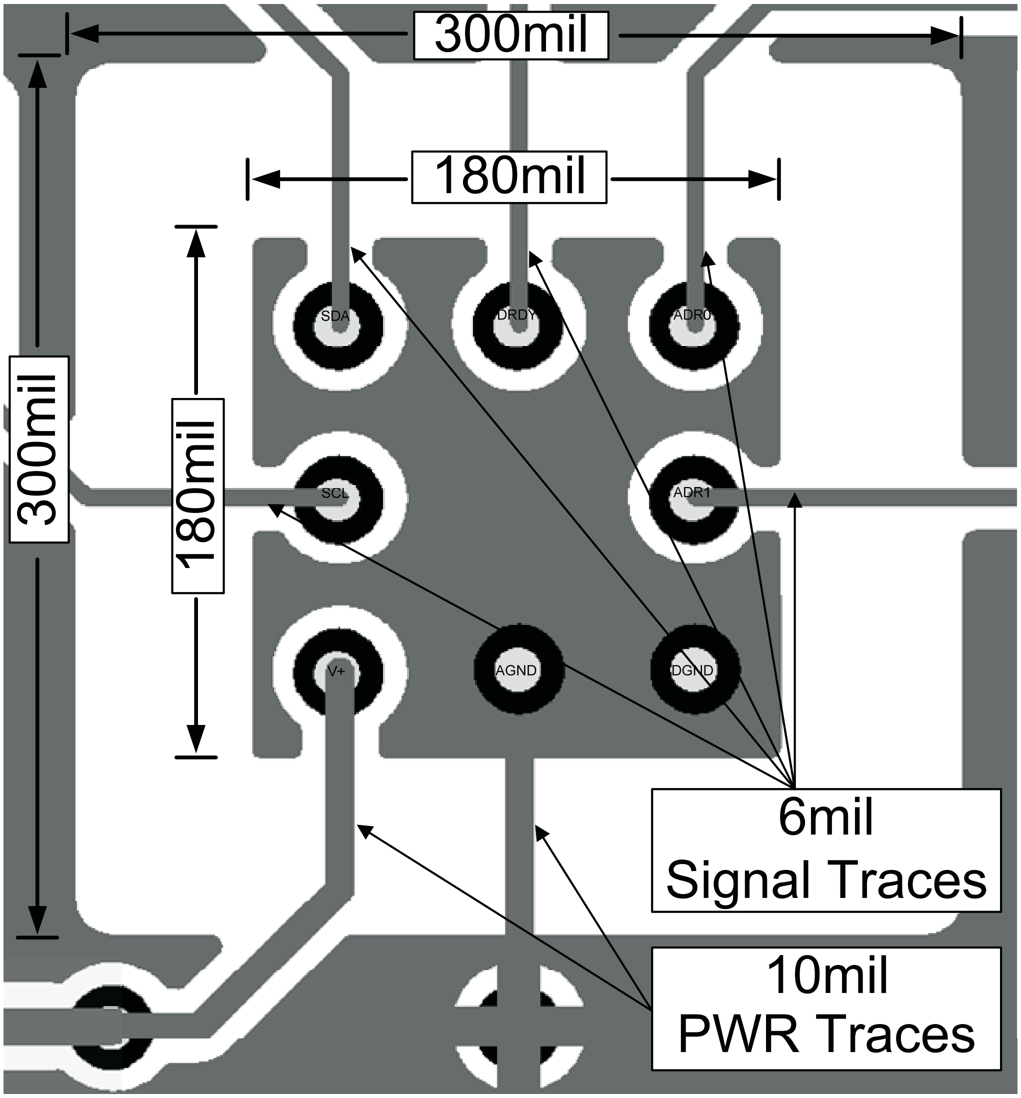


Figure 8. TMP006 Two-Layer PCB: Bottom Layer

4.2 TMP600EVM Four-Layer PCB Layout

The four-layer TMP006EVM PCB layout guidelines were also developed on a 1-mil grid (1 mil = .001 in, or 0.0254 mm). The copper weight of the PCB was 1 oz. The PCB via size does not vary between layers, and all vias go through the entire board from the top to the bottom layer (there are no blind or buried vias). The PCB layer stack for the TMP006EVM is illustrated in Figure 9.

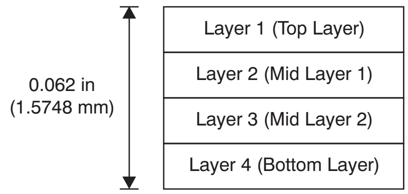


Figure 9. TMP006EVM PCB Layer Stack

The first layer of the TMP006EVM is the same as the first layer of the two-layer design. The third layer of the TMP006EVM is very similar to the second layer of the two-layer design. The second and fourth layers of the TMP006EVM are used for additional GND plane islands that are not included in the two-layer design; these additional layers do not result in any significant improvements in measurement stability. Figure 10 shows the correlation between the two- and four-layer designs.

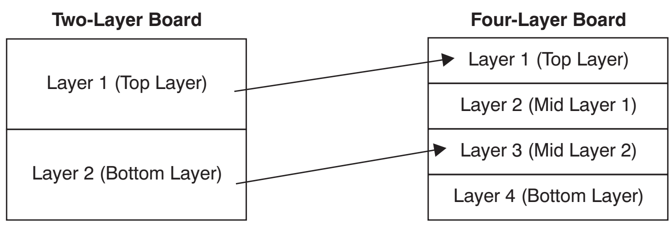


Figure 10. Correlation of Two-Layer and Four-Layer TMP006 PCB Designs

4.3 TMP006EVM PCB

4.3.1 Layer 1: Top Layer

The top layer of the TMP006EVM is identical to the top layer of the two-layer TMP006 PCB layout described in Section 4.1. An image of the TMP006EVM top layer is shown in Figure 11.

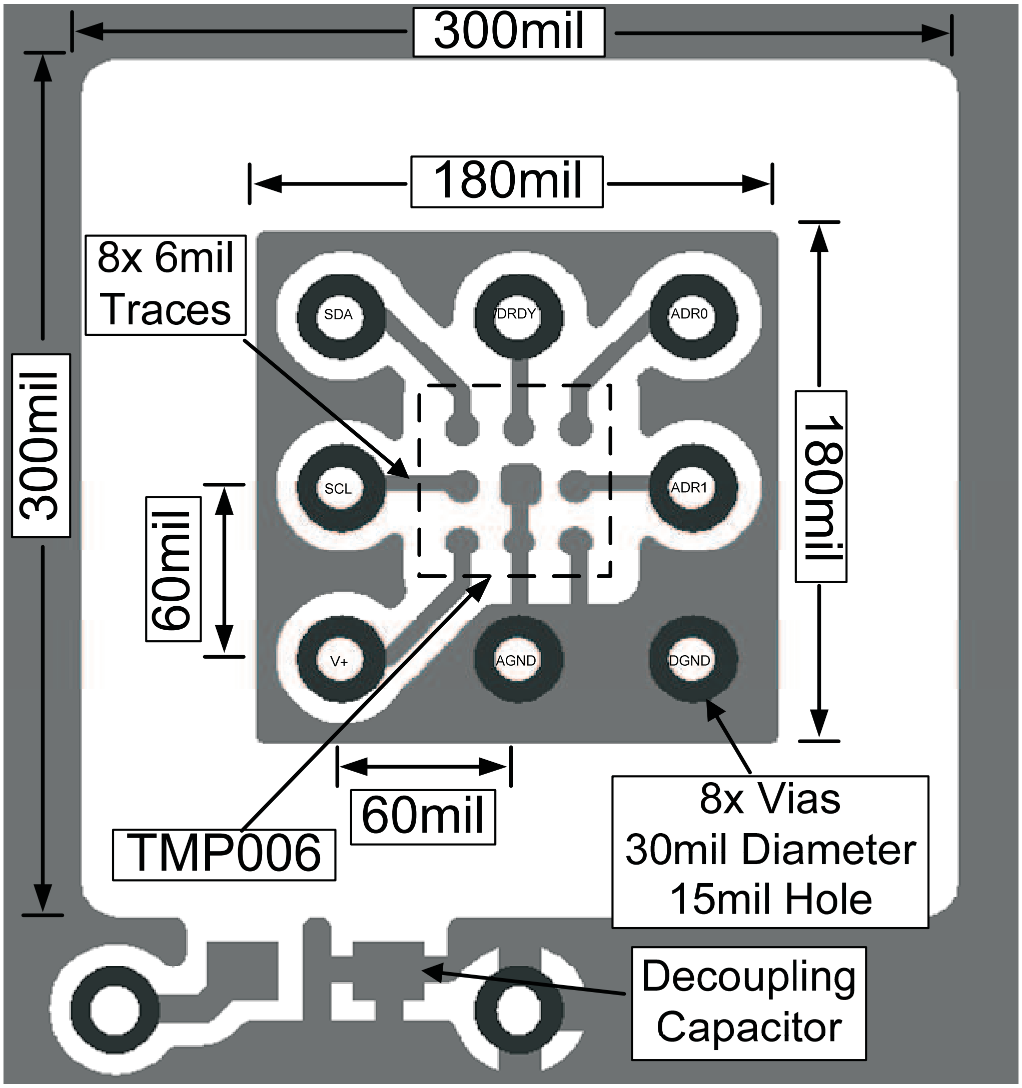


Figure 11. TMP006EVM Four-Layer PCB: Top Layer

Figure 12 shows an enlarged view of Layer 1 to clearly indicate the TMP006 land pattern and 15-mils x15-mils (.015-in x .015-in) copper fill on the TMP006EVM. This region is the same as the two-layer board.

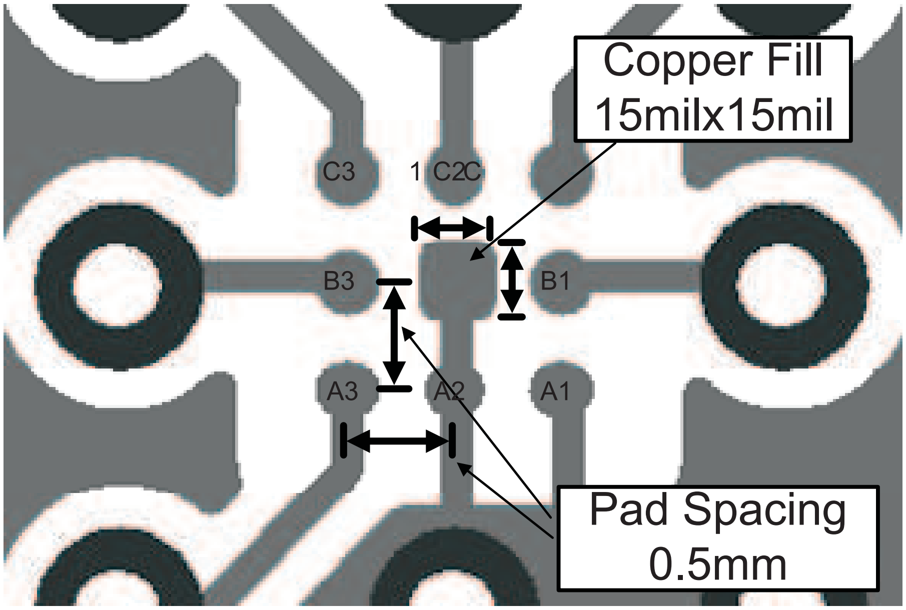


Figure 12. Enlarged View of Layer 1: TMP006EVM Land Pattern and Copper Fill

4.3.2 Layer 2: Mid Layer 1

The second layer of the TMP006EVM contains an isolated island of copper connected to the TMP006 GND. It is sized the same as the first layer copper island and located directly below it. On the TMP006EVM, the second layer is also used to route the V+ power signals for the EVM. This layer could have been used to route the signals that have been routed on layer 3. Figure 13 shows the second layer.

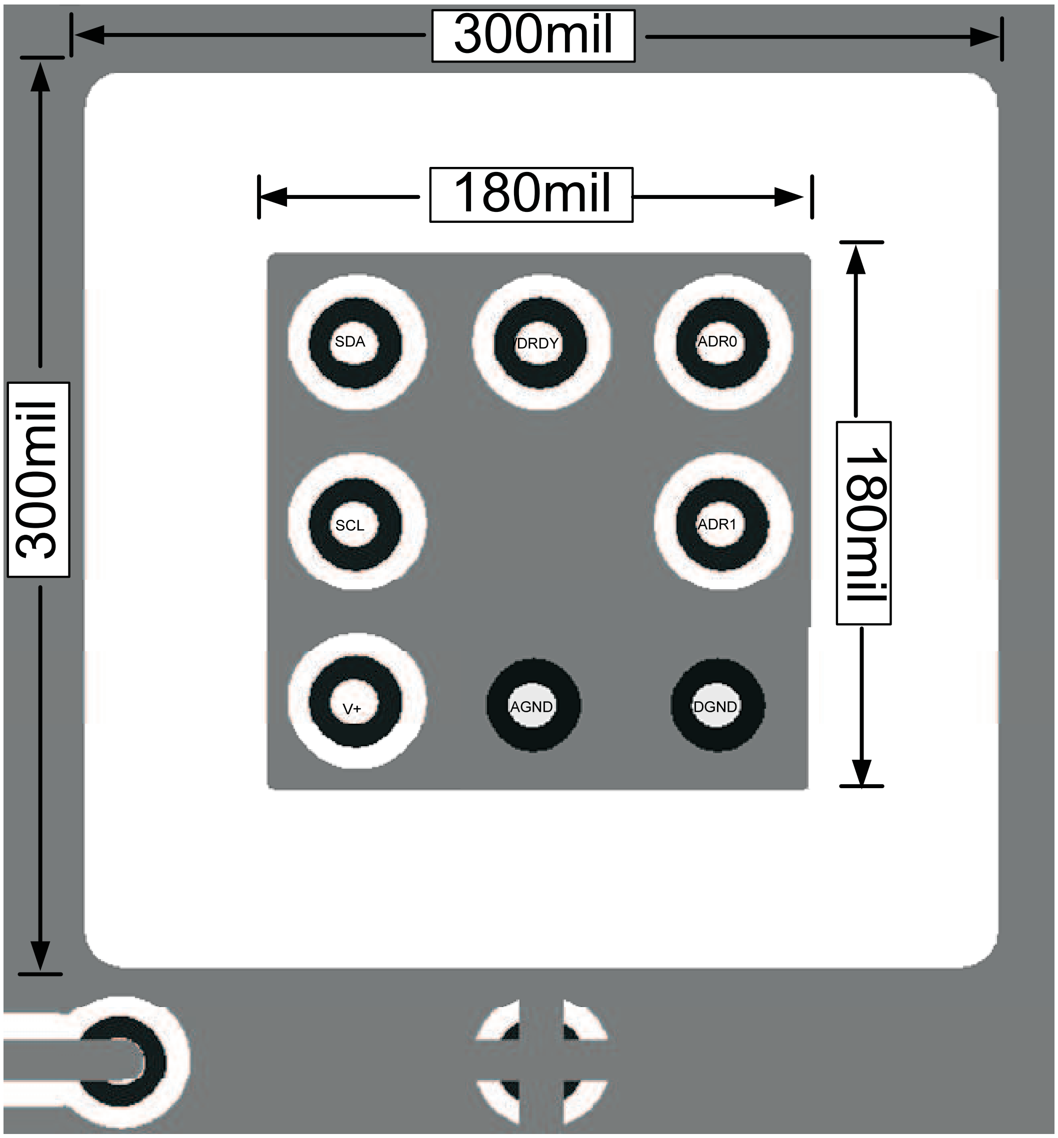


Figure 13. TMP006EVM Four-Layer PCB: Mid Layer 1

4.3.3 Layer 3: Mid Layer 2

The third layer of the TMP006EVM is nearly identical to the second layer of the two-layer design. The third layer contains the same copper island as the first two layers of the TMP006EVM, and was also used to route the TMP006 digital and power signals to the rest of the PCB. The power signals, V_{CC} and GND, were routed with 10-mil (0.254-mm) traces, and the remaining digital signals were routed with 6-mil (0.1524-mm) traces. Figure 14 shows the third layer of the EVM board. The signals routed on this layer could have been routed on layer 2 or layer 4 as well, with no impact on the design performance.

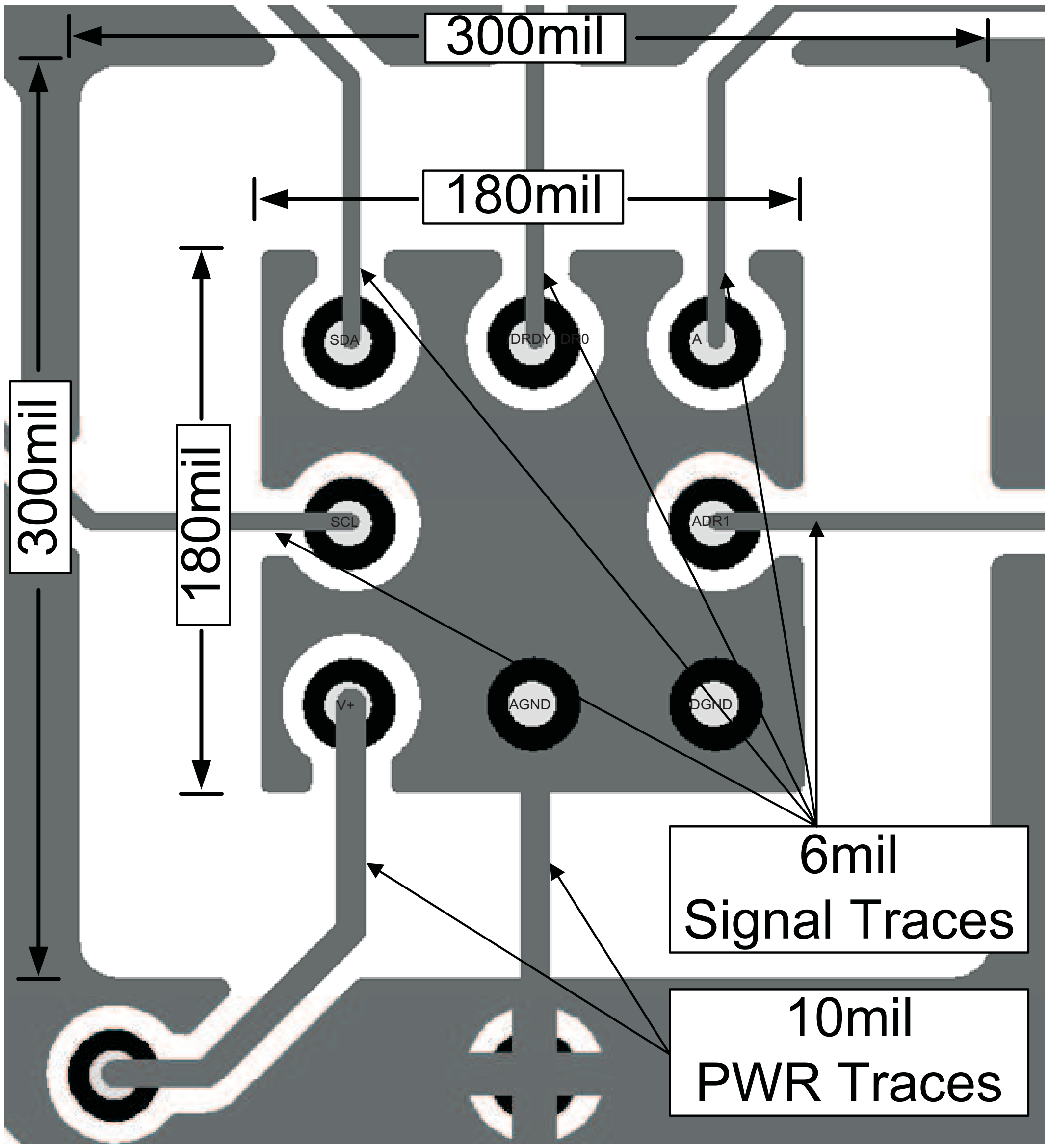


Figure 14. TMP006EVM Four-Layer PCB: Mid Layer 2

4.3.4 Layer 4: Bottom Layer

The fourth and bottom layer of the TMP006EVM contains another copper island connected to the GND plane. Layer 4 could have been used to route the signals located on layer 2 and layer 3 with no impact to design performance. Figure 15 shows the fourth layer.

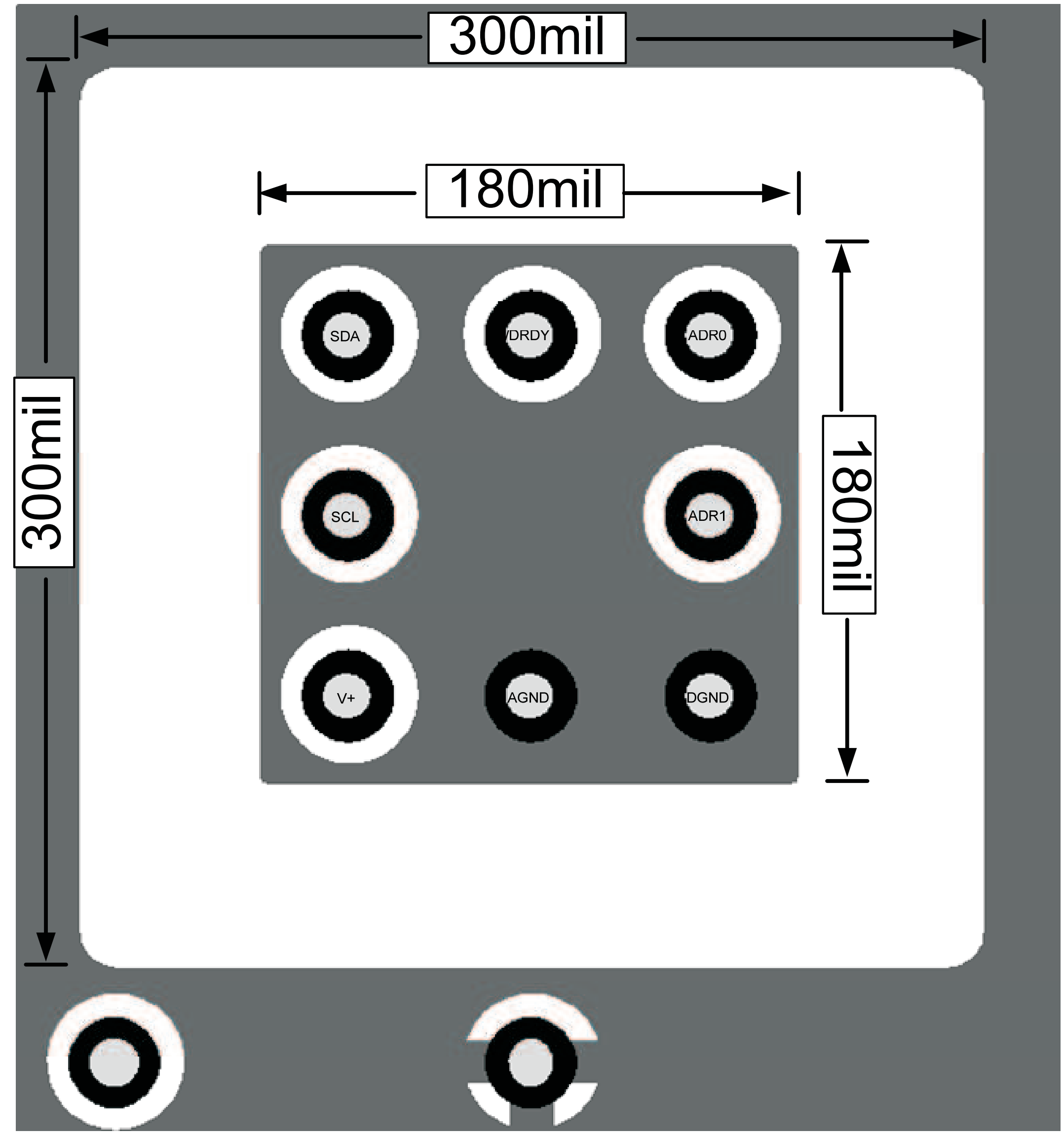


Figure 15. TMP006EVM Four-Layer PCB: Bottom

5 TMP006 Assembly Guidelines

This section presents several key steps in the assembly process for the TMP006. Follow these guidelines to ensure correct performance when using the TMP006.

5.1 Solder Flux

Applying flux to the PCB before placing the board into an IR reflow oven is required to ensure that the solder balls on the TMP006 wafer chip-scale package flow appropriately. The recommended flux type is an organic water-soluble liquid flux. Kester 2331-ZX is an example of the type of flux that has been used and tested by Texas Instruments.

5.2 Device Placement

CAUTION

Always be sure to use plastic tweezers or vacuum pencils to handle the TMP006. Do not scratch or damage the top of the TMP006 device. Be especially sure not to touch or damage the TMP006 sensor membrane that lies in the center of the bottom of the TMP006 between the solder balls.

5.3 Reflow Oven Thermal Profile

To prevent damage to the TMP006, the appropriate thermal profile must be followed during the reflow process in the PCB assembly. The thermal profile used by Texas Instruments is illustrated in Figure 16.

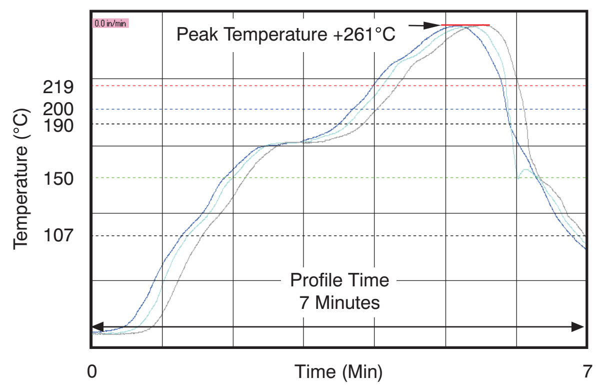


Figure 16. Thermal Profile for TMP006 IR Reflow Oven

5.4 PCB Cleaning

After assembly, the TMP006 PCB must be thoroughly cleaned to remove any flux or other residue remaining underneath the TMP006 device that could interact with the sensor. Cleaning with an ultrasonic PCB cleaner is the recommended method to ensure all residue is removed from under the TMP006. If Kester 2331-ZX flux is used, then the ultrasonic cleaner should be filled with de-ionized (DI) water. If a different brand of flux is used, contact the flux vendor for specific information regarding an appropriate cleaning solution.

Place the TMP006 board into the ultrasonic cleaner and clean the board with the transducers for at least five minutes. Remove the boards from the cleaner and use an air-gun or other drying method to remove all excess cleaning solution from the PCB.

Any fingerprints or other residue on the surface of the TMP006 can interfere with measurement accuracy. Therefore, the final step in the cleaning process is to inspect the surface of the TMP006; use cotton swabs or other cleaning devices to remove anything remaining on the surface of the TMP006.

5.5 Underfill

Do not insert any underfill material underneath the TMP006. Underfill materials short the hot and cold junctions of the IR sensor together and render it unable to measure object temperatures accurately.

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