User's Guide
SBOU143B–October 2014–Revised June 2015

TMP006 and TMP007 Layout and Assembly Guide

The TMP006 and TMP007 are infrared (IR) thermopile sensors that are sensitive to radiation in the IR spectrum with a wavelength of approximately 4 µm to 16 µm. The thermopile also responds to other sources of heat, such as convection and conduction. To obtain the best performance, use proper layout and assembly techniques to control the effects of other heat sources. Ideally, the only energy reaching the thermopile is the IR radiation.

This guide covers the basic principles of thermal isolation, optical effects, printed circuit board (PCB) layout, and assembly. The specific application conditions determine the optimal layout and assembly implementation.

This guide is used together with the TMP006 or TMP007 data sheet, and the TMP006 and TMP007 calibration guide, as listed in the following table.

Related Documentation

Device	Literature Number
TMP006 Product Data Sheet	SBOS518
TMP007 Product Data Sheet	SBOS685
TMP007 Calibration Guide	SBOU142

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1 Introduction

The TMP006 and TMP007 estimate the temperature of an object based on the thermal radiation received from the object and the die temperature. To calculate the temperature, the TMP006 and TMP007 must receive thermal energy primarily from the target object with minimal contributions from other sources, such as background scene objects, air convection, or thermal conduction from adjacent components on the PCB. It is possible to compensate for these effects to some degree in the calibration process; however, the less compensation required, the greater the accuracy that is obtained.

Layout and assembly is the process of defining and implementing the TMP006 and TMP007 environment to control the field of view (FOV) and extraneous sources of heat to maximize the device performance for a given application.

This document discusses layout and for three common application classes:

- The end-equipment (EE) design provides the field of view (FOV) and thermal isolation.
- The EE design does not provide proper isolation and heat conduction is a significant effect.
- The EE design does not provide proper isolation and heat convection is a significant effect.

While each application does have unique features, they all share a common set of concepts and principles that are discussed first. In cases where conduction and convection are both present, it may be necessary to combine techniques to control both types of sources.

NOTE: PCB fabrication, materials, and assembly techniques can vary substantially from one fabricator to another. The contents of this guide are meant only as guidelines and any particular layout and PCB assembly must be verified by the user as regards performance, reliability and suitability.

1.1 How to Use This Guide

The basic steps in the layout and assembly procedure are:

1. Define Object size and distance relative to the location of the TMP006 or TMP007 on the PCB. This would include any windows, lenses or other material between the TMP006 or TMP007 and the object.
2. Understand the TMP006 or TMP007 environment with regard to all energy sources (Section 2.1 to Section 2.3).
   - Thermal radiation path
   - Background scene radiation
   - Conduction from other objects, especially those on the PCB (Section 2.4)
   - Convection from fluids: gas and liquids (Section 2.5)
3. Select a layout and assembly strategy based on the TMP006 or TMP007 thermal environment and the relative potential heat flows from IR radiation, conduction, and convection.
   - Standard footprint for maximum isolation from thermal conduction (Section 3.1)
   - Small footprint recommended for most applications (Section 3.3)
   - Laser-cut micro footprint for applications requiring densest layouts (Section 3.4)
4. If the FOV definition is required, select a shield strategy based on the TMP006 or TMP007 thermal convection environment. If it is uncertain whether convection effects will be significant at the time of design, then place the shield footprint on the PCB.
   - If the object is on the same side of the PCB as the TMP006 or TMP007 (Section 4.1)
   - If the object is on the opposite side of the PCB as the TMP006 or TMP007 (Section 4.2)

Common issues in layout and assembly are addressed in Section 5. Appendix A contains a set of FAQs. Appendix B contains a more accurate formula for window performance with additional parameters.

The layout and assembly procedure and key decision points are represented graphically in Figure 1. The selection of a PCB layout depends on the following factors:

- Object position in the sensor FOV, related to object size and distance
- Background scene temperature, if in the sensor FOV
- Presence of convection from air, or thermal conductance from nearby components

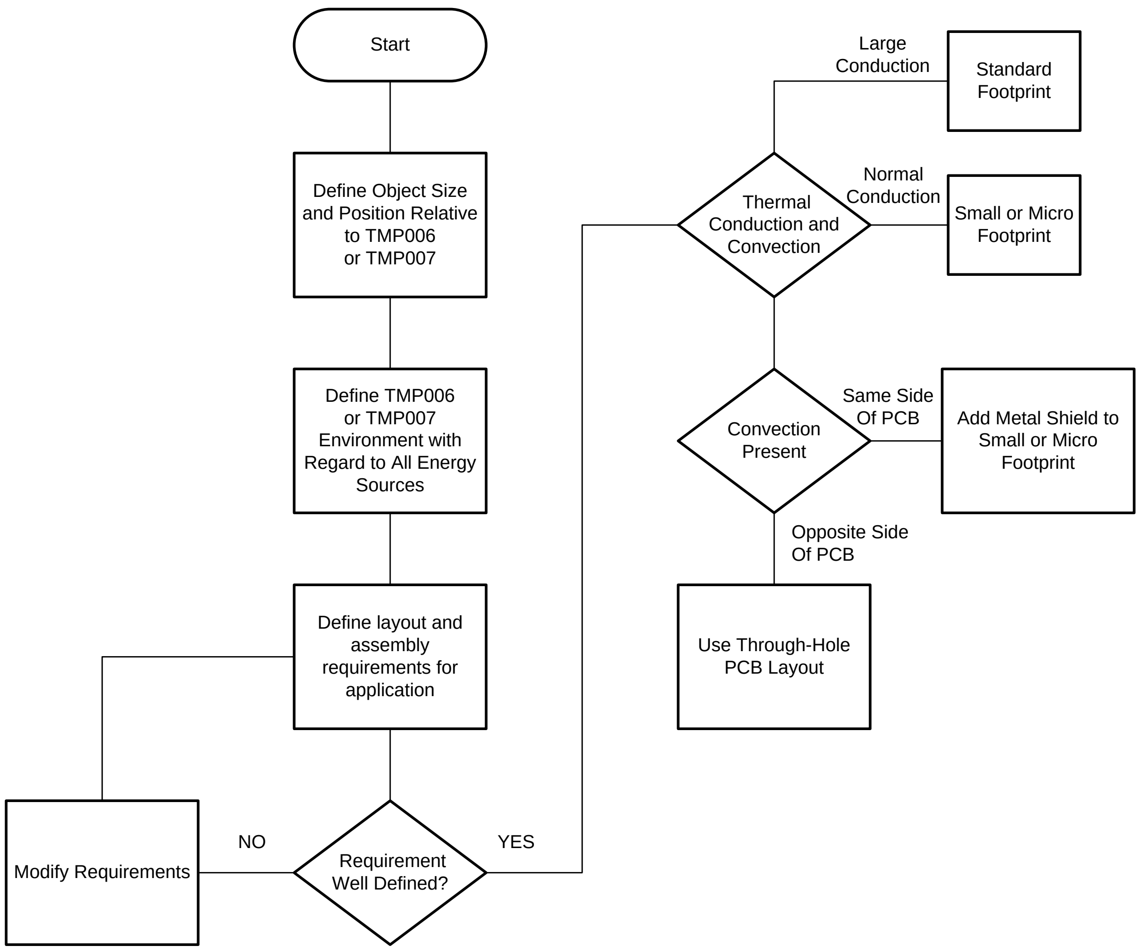


Figure 1. Layout and Assembly Procedure Flow Chart

1.2 Principles of Layout and Assembly

This section briefly reviews the impact of layout and assembly on device performance before deciding on a specific implementation. A detailed explanation of the principles presented here is found in the *TMP006 and TMP007 Calibration Guide* (SBOU142).

Thermal radiation is converted to a sensor voltage by the TMP006 or TMP007 thermopile and can be read from a register. The sensor voltage is also affected by sources of heat other than thermal radiation, such as convection and conduction. The die temperature is calculated from an integrated p-n junction on the TMP006 or TMP007. If a temperature gradient exists across the die (for example, when a thermal source on the PCB causes a temperature gradient on the PCB), then the p-n junction does not accurately reflect the cold junction temperature of the thermopile.

The principles of operation of the TMP006 (SBOS518) and TMP007 (SBOS685) are described in the respective product data sheets. The equations within this section apply to both the TMP006 and TMP007. However, the math engine embedded within the TMP007 must be implemented in software or firmware for use with the TMP006. It is assumed that the reader is familiar with the contents of the data sheets. In the data sheet, the ideal relationship between the sensor voltage and the object temperature is given as:

$$T_{OBJ} = \sqrt[4]{T_{DIE}^4 + \frac{V_{SENSOR}}{\varepsilon\sigma}}$$

where

- σ = Stefan-Boltzman constant = 5.7×10^{-12} W × cm^{-2} × K^{-4}
- ε = Emissivity, $0 < \varepsilon < 1$, an object dependent factor, $\varepsilon = 1$ for a perfect emitter
- V_{SENSOR} = sensor voltage in TMP006 or TMP007 sensor voltage register
- T_{DIE} = Local die temperature calculated by the TMP006 or TMP007 from integrated p-n junction (1)

The ideal relationship has an object that emits radiation described by the black body spectrum, with no absorption or other restrictions in the optical path, where the sensor absorbs radiation equally well across the entire spectrum, and most importantly, where radiation from the object is the only source of energy reaching the thermal sensor. In practice, these ideal conditions rarely occur; therefore, the relationship as implemented in the TMP006 or TMP007 is modified to allow the user to compensate for these nonidealities.

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

where

- S is a system-dependent parameter described in Section 1.2.1. The parameters S0, A1, and A2 are used in estimating S.
- $f(V_{OBJ})$ compensates for heat flow from sources other than thermal radiation, and is described in Section 1.2.2. (2)

1.2.1 Definition of S Parameter

S is a system-dependent parameter incorporating the object emissivity (ε), optical FOV and transmission characteristics, and sensor characteristics. The S parameter 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 nonideal absorption of the sensor itself. The functional form implemented only in the TMP007 math engine is:

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

where

- S0 is the ideal emissivity times the Stefan-Boltzman constant, εσ
- A1 and A2 are experimentally-derived parameters from the calibration process to obtain a best fit
- T_{DIE} = local die temperature calculated by the TMP007 from integrated p-n junction
- T_{REF} = 25°C (3)

Better defined and more stable IR transmission path and object emissivity lead to a better defined and more stable system.

1.2.2 Definition of f(V_{OBJ})

f(V_{OBJ}) compensates for heat flows to the sensor other than from thermal radiation. These nonideal 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}

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

where

- T_{DIE} = local die temperature calculated by the TMP006 or TMP007 from integrated p-n junction
- T_{REF} = 25°C
- B0, B1, and B2 are experimentally-derived parameters from the calibration process to obtain a best fit. (4)

From which a modified sensor voltage, f(V_{OBJ}), is calculated as shown in Equation 5

$$f\left(V_{OBJ}\right) = \left(V_{SENSOR} - V_{OS}\right) + C\left(V_{SENSOR} - V_{OS}\right)^2$$

where

- C is an optional fitting parameter
- All other parameters are as previously defined (5)

The more stable the non-IR sources of heat, then the more stable the measurement system. Non-IR heat sources appear as an offset in the sensor voltage.

In general, it is possible to compensate for nonidealities in calibration; however, a system with less required compensation is more stable and has a broader range of operation.

2 Understanding the TMP006 and TMP007 Environment

Better defined and more stable TMP006 and TMP007 environments lead to better defined and more stable systems, and result in higher accuracy. This section describes critical aspects of the environment and the impact on device performance. Apply these principles to select the correct assembly and layout implementation for a given application.

2.1 *Case 1: IR Radiation From Object*

In the simplest case, the only energy source is the IR radiation from the object of interest, as shown in Figure 2.

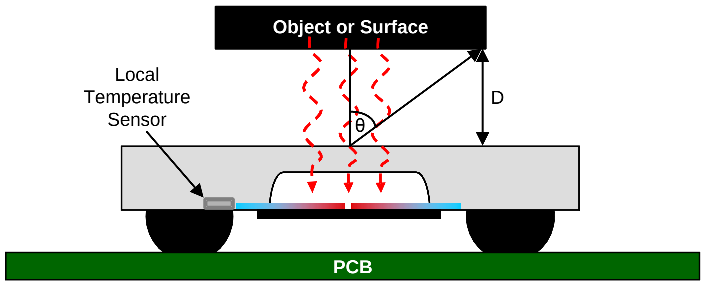


Figure 2. IR Radiation From Object

The object covers the field of view defined by the angle θ. The TMP006 and TMP007 product data sheets describe the process to calculate the FOV based on the object size and the distance from the object to the sensor (D). For an object with a radius of 6 inches (150 mm), a typical value of D is 4 in to 6 in (100 mm to 150 mm). Case 1 is valid when:

- θ is large, approximately 55° or greater, and
- the environment of TMP006 or TMP007 is at the same temperature as the die, as measured by the local temp sensor, and
- there is no significant convection or air flow across the device, and
- there is no significant heat transfer from other devices on the PCB

2.2 *Case 2: IR Radiation from Object with a Window*

The second simplest case is when the only energy source is the IR radiation from the object, but the radiation passes through a window or lens. For this case, a window is used. The case of a lens is beyond the scope of this user guide; consult a qualified IR optical designer for more information.Figure 3 shows the mechanisms involved when a window is present; reflection at the interface, and absorption in the window material.

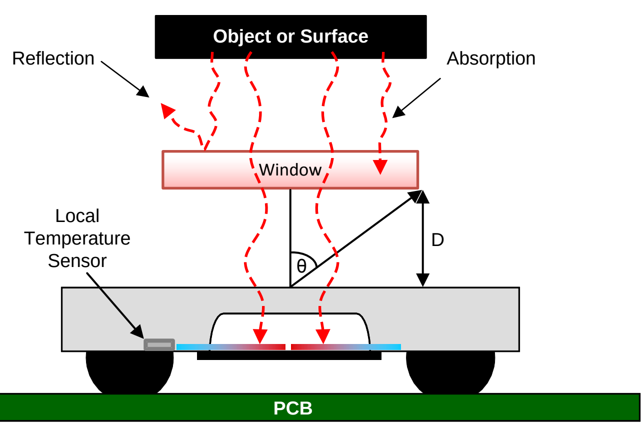


Figure 3. IR Radiation From Object with Window

The reflection and refraction are determined by the refractive index of the materials on each side of the interface, as described by Fresnel's law. The absorption in the bulk is described by a material-dependent property, absorption coefficient, described by the Beer-Lambert law (see Section 2.2.2).

In determining the transmitted power through the window, account for both mechanisms. The reflection at the interface is considered first because this reflection determines the intensity of the radiation that is transferred to the bulk material.

2.2.1 Fresnel Relations—Transmission and Reflection at an Interface

The change in refractive incidence at a boundary between two materials causes a reflection; the larger the difference in refractive index between the two materials, the more energy is reflected. The amount of energy reflected also depends on the angle of incidence with respect to the interface. Appendix B contains information on the angular dependence, if required.

At normal incidence, for two materials with refractive indices n_1 and n_2, the reflectance is given by Equation 6:

$$R = \left|\frac{n_1 - n_2}{n_1 + n_2}\right|^2 \tag{6}$$

The transmitted power (T = 1 – R) gives an estimate of the ratio of power transmitted, as shown in Equation 7:

$$T = 1 - \left|\frac{n_1 - n_2}{n_1 + n_2}\right|^2 \tag{7}$$

Table 1 lists some common example materials and the relative transmissions, where R is the proportion reflected, and T is the proportion of the incident radiation transmitted into the material.

Table 1. IR Transmission at an Interface (10-µm Reference Wavelength)

Medium 1	n_1	Medium 2	n_2	Reflectance, R	Transmission, T
Air	1	Silicon	3.44	30%	70%
Air	1	SiO_2	1.43	3%	97%
Air	1	Germanium	4.06	37%	63%
Air	1	Polyethylene	1.49	4%	96%
Air	1	Polypropylene	1.49	4%	96%

In the event of large optical losses at the interface, use an antireflective (AR) coating on the optical surface. Note that the AR coating must be applied to each interface experiencing a significant loss. The materials and techniques used for AR coating are specific to each material.

2.2.2 Beer-Lambert Law—Absorption and Scattering in a Material

After the radiation enters the second medium, a portion of the radiation may be absorbed or scattered. For purposes of this discussion, consider absorption to be the primary loss mechanism. The intensity at distance z in a medium, I(z), is a function of the intensity at the surface, I_0, and the absorption coefficient, α, described by the Beer-Lambert law shown in Equation 8:

$$I(z) = I_0 e^{-\alpha z} \tag{8}$$

The absorption coefficient (α) is given in terms of cm^{-1}. The absorption coefficient is the distance at which the intensity has fallen to a value of e^{-1} = 37% of the initial value. The relative intensity as a function of several thicknesses is shown in Table 2. These values are approximate because only the absorption for a single wavelength is considered and some of the materials have significant changes in absorption versus wavelength. In addition, Equation 8 does not take into account multiple reflections that may occur between the surfaces of a material. Appendix B contains further information to account for cases of multiple reflections, if needed.

Table 2. IR Transmission as a Function of Material Thickness

Medium	α(cm^{-1})	0.5 mm	1 mm	2 mm	5 mm
Silicon	0.82	96.0%	92.1%	84.9%	66.4%
SIO_2	0.50	97.5%	95.1%	90.5%	77.9%
Germanium	0.029	99.9%	99.7%	99.4%	98.6%
Polyethylene	8.1	66.7%	44.5%	19.8%	1.7%

Germanium has very high transmission, making it suitable for thicker windows. Conversely, polyethylene is suitable for thinner windows and low-cost applications.

2.2.3 Estimating IR Performance of a Window

To obtain the overall transmission, account for both the reflection at the interface and the thickness of the material. Obtain a first-order estimate by combining the equations for transmission at an interface and absorption, as shown in Equation 9:

$$\frac{I(z)}{I} = T \times I(z) = \left[1 - \left|\frac{n_1 - n_2}{n_1 + n_2}\right|^2\right] \times e^{-\alpha z} \tag{9}$$

Figure 4 shows the results of this simple model for IR transmission through a material as a function of thickness. The initial transmission for thin windows is dominated by the effects of refractive index. The refractive index is shown in parentheses in the legend.

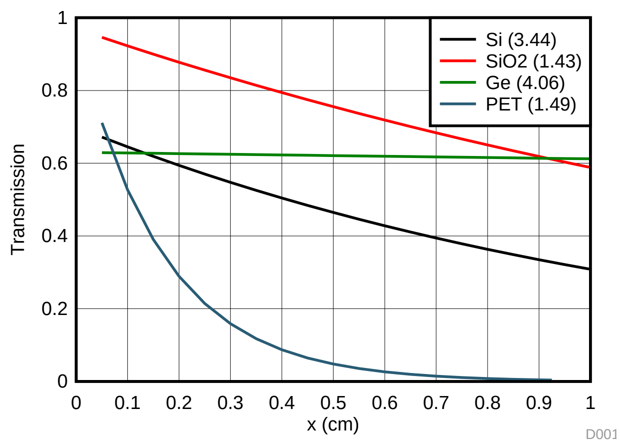


Figure 4. IR Transmission for Selected Materials vs Thickness (x)

The decrease in intensity as a function of thickness then depends on the absorption. Both the refractive index (n) and absorption (α) are wavelength-dependent properties of the material. For some materials, such as polyethylene, processing also affects the material properties.

NOTE: The information on reflection and absorption is provided for illustrative purposes only. Prior to committing to a design, simulation of the IR performance based on the actual window and lens properties is strongly recommended.

2.3 Case 3: IR Radiation from an Object and Background Scene Radiation

If the object does not fill the entire FOV of the TMP006 or TMP007, then IR radiation from the background scene is also detected by the thermopile. In Figure 5, the detector receives IR radiation from the object over an angle defined by θ, and also receives IR radiation from an angle defined by (φ – θ). If the background scene is at a constant temperature, then the scene causes a constant offset in thermal radiation received by the detector as the object temperature varies. Conversely, if the scene temperature varies while the object temperature remains constant, the detector also interprets this variation as a change in temperature.

Because the TMP006 or TMP007 detects all radiation in the FOV, the temperature estimate is based on a weighted average of the object and scene radiation. The less radiation received from the scene, determined by the angle (φ – θ), the more accurate the estimate for object temperature. The one exception to this rule is *if the scene temperature is equal to the die temperature, then the IR radiation to and from the scene cancels and leaves only the net radiation from the object in order to determine the object temperature*.

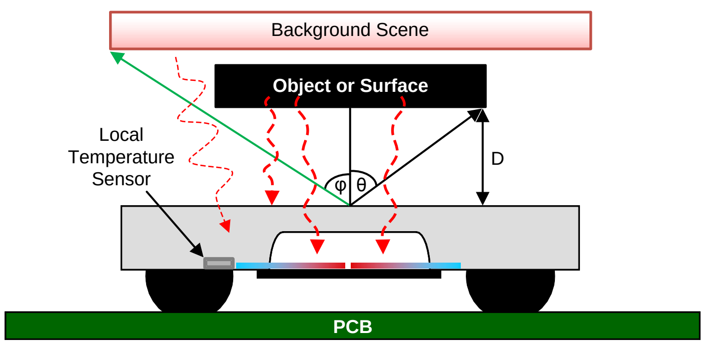


Figure 5. IR Radiation From Object and Background

For this reason, enclose the TMP006 or TMP007 in a thermally-grounded enclosure so that the scene background temperature is approximately the same as the local die temperature.

2.4 Case 4: Convection as a Heat Source

The TMP006 or TMP007 is responsive to all forms of heat that can transfer energy to the thermopile. Convection is the motion in a fluid driven by temperature differences across that fluid that can transport heat energy. In the case of the TMP006 or TMP007, if there are significant temperature differences in the air around the device, or if there is a fan in the system causing air flow, then convection occurs. The air contacts the TMP006 or TMP007, exchanges heat with the device (absorbs heat if colder than the TMP006 or TMP007, or releases heat if warmer) and induces a signal on the thermopile. This signal is added to the sensor voltage caused by other heat sources.

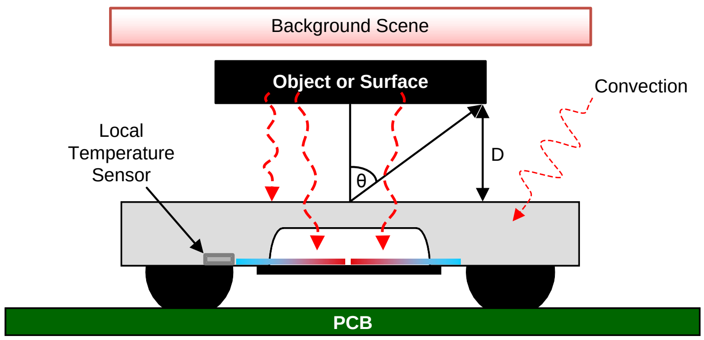


Figure 6. Energy Transfer by Convection

Make sure to distinguish convection effects from conduction effects. Air, in particular, is a rather good insulator, and if undisturbed, has minimal impact on TMP006 or TMP007 operation. *The primary effect of convection is that the phenomenon is chaotic; therefore, the sensor voltage variations induced are highly variable and impossible to calibrate out. Depending on the intensity of convection, these signal variations can be quite substantial.*

The only feasible method of addressing convective effects is by eliminating the effect. This elimination entails either minimizing the temperature difference across the air surrounding the TMP006 or TMP007, or providing a shield around the device. The use of shields is particularly important in cases where fans are blowing air across the device.

2.5 Case 5: Conduction as a Heat Source

The TMP006 or TMP007 is responsive to all forms of heat that can transfer energy to the thermopile. In contrast to convection, conduction is the transport of energy through a material as a result of temperature differences without movement of the material. The heat source is typically another component such as an FPGA, CPU, or power supply (PS) on the same PCB placed near the TMP006 or TMP007, as shown in Figure 7. Heat transfer by conduction occurs from the heat source, through the PCB (both the FR-4 and any copper traces) to the TMP006 or TMP007 solder balls, and then up to the thermopile sensor.

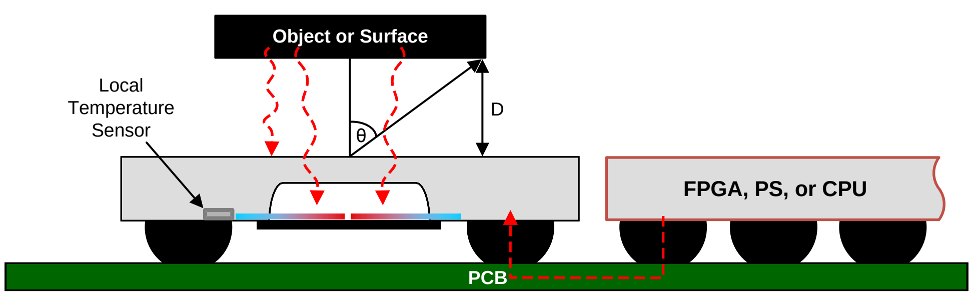


Figure 7. Energy Transfer by Conduction

Heat from conduction impacts sensor performance by two mechanisms. The first mechanism is transferring heat directly to the thermopile itself, causing the sensor voltage to change. The second mechanism is, in extreme cases, a temperature gradient created across the TMP006 or TMP007 so that the local temperature sensor and the thermopile cold junction are at different temperatures. As discussed in the TMP006 (SBOS518) and TMP007 (SBOS685) product data sheets, all object temperatures are measured relative to the die temperature. If there is an error in die temperature, this error appears as an offset error in object temperature.

Table 3 lists the coefficients of thermal conductivity (k) for selected materials. Higher coefficients imply faster or more efficient heat conduction, whereas lower coefficients imply lower heat conduction or insulators. Copper is a good heat conductor, whereas air (without convection) is a good insulator.

Table 3. Coefficients of Thermal Conductivity (k) For Common PCB Materials

Material	Coefficient of Thermal Conductivity (k) ($W \times m^{-1} \times K^{-1}$)
Air	0.024
Aluminum	250
Copper	400
FR-4	0.27
Gold	310
Lead	35
Silver	430
Tin	67

As with convection, errors caused by conduction are difficult if not impossible to address with calibration after the fact. This difficulty arises because the heat source usually cycles through a series of different power states during system operation. The only effective method of addressing conduction is by placing high-power components away from the TMP006 or TMP007, and by using proper layout techniques to provide thermal isolation, as discussed in later sections.

Do not route power or ground planes under the TMP006 or TMP007 if these planes are connected to devices dissipating significant power. Though the IR drop in the plane itself may be low, the heat generated by the device often dissipates through the power and ground planes, and can then transfer heat through the PCB to the TMP006 or TMP007.

3 Layout Guidelines: IR radiation From Object and Scene Is Dominant

This section applies to applications where IR radiation from the object and the scene are the dominant heat sources. In these cases, the layout is designed to provide some degree of thermal isolation from the surrounding PCB; in some cases, the end equipment may include a window.

3.1 Standard Footprint: Two-Layer PCB Guidelines

There are no significant performance differences between the two-layer and four-layer PCB designs. The PCB layout is designed on a 1-mil grid (1 mil = 0.001 in, or 0.0254 mm). The TMP006 and TMP007 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).

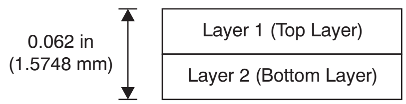


Figure 8. Two-Layer PCB Stack

3.1.1 Detailed Layout Considerations

A consideration for the recommended layout is to match thermal time constants of the TMP006 or TMP007 to the underlying PCB. Achieving thermal equilibrium between the two thermal time constants requires the die (specifically, the substrate) of the TMP006 or TMP007 to be thermally coupled to the PCB area below it through a high-*k* material. Make sure this PCB area has the correct amount of copper mass to match its thermal time constant with the TMP006 or TMP007. In the recommended layout, as shown in Figure 9, the coupling is achieved with a 15-mil × 15-mil (0.381-mm × 0.381-mm) copper fill directly below the sensor (k_{COPPER} = 400 W/m/K).

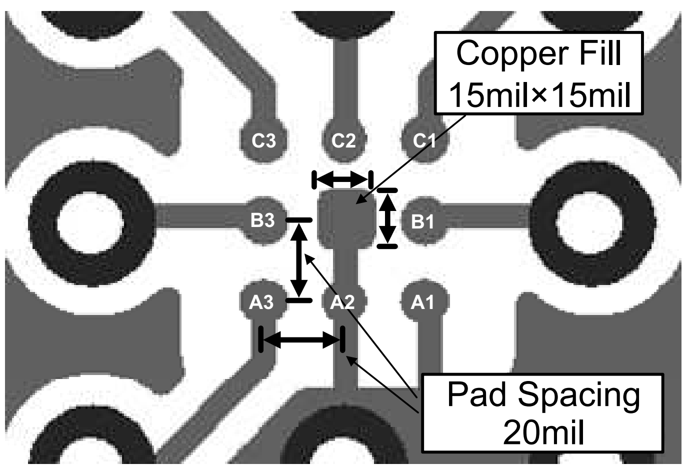


Figure 9. Detail of PCB Top-Layer Layout

This copper fill is electrically connected to the GND pins of the TMP006 or TMP007. The GND pins provide the best thermal path to the die and substrate of the TMP006 or TMP007, so this small copper fill provides the required high-k connection to keep the PCB area below the TMP006 or TMP007 at a temperature very close to that of the TMP006 or TMP007. A larger 180-mil ×180-mil (4.572-mm × 4.572-mm) copper GND island where the TMP006 or TMP007 and copper fill reside has been sized appropriately to match the thermal time constant of the TMP006 or TMP007. Images of this area of the PCB can be seen in Figure 10.

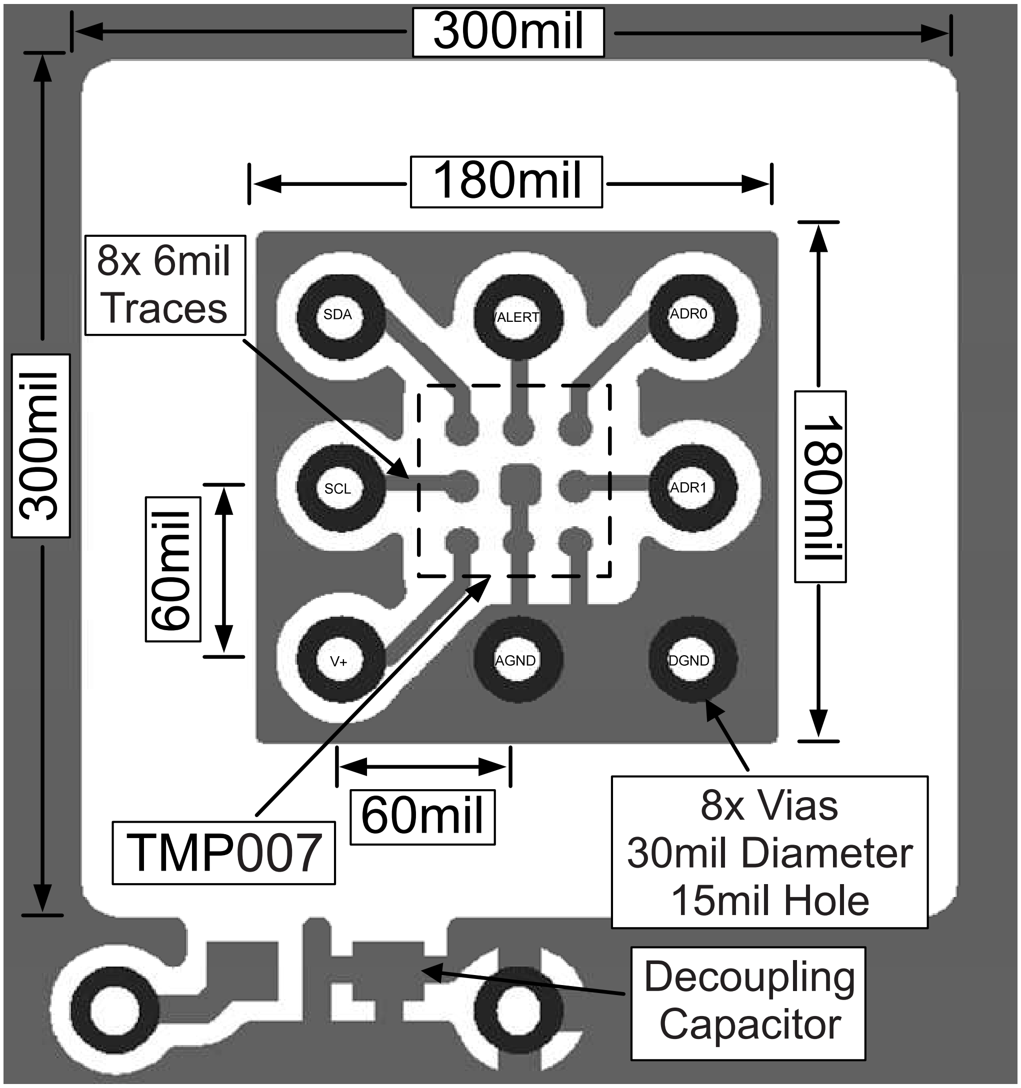
The same 180-mil × 180-mil (4.572-mm × 4.572-mm) copper island that is used to match the thermal time constants described earlier is also used to help isolate the TMP006 or TMP007 from the rest of the board by increasing the area that separates the island from the rest of the PCB GND plane to 60 mils (1.524 mm) on all sides. Additionally, eight equally-spaced PCB vias are 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.

Leaving FR-4 material exposed below the sensor produces one of the worst conditions for the TMP006 or TMP007. FR-4 material is an insulator with a very low *k* (k_{FR-4} ≈ 0.27), and prevents the temperature between the TMP006 or TMP007 and the PCB from achieving equilibrium unless the entire measurement setup has been in thermal equilibrium for an extended time. Connecting the GND pins and the small copper fill to a very large copper plane (much larger than 180 mil × 180 mil, or 4.572 mm × 4.572 mm) produces similarly undesirable effects because the very large GND plane has too much copper mass, and therefore, a large thermal time constant. 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.

Stabilize the sensor by including a layer (or multiple layers) below the TMP006 or TMP007 with an identically-sized copper cutout and island. Both the top layer and second (or multiple) layer cutouts and islands are sized to provide the best performance.

3.1.2 Layer 1: Top Layer

The TMP006 or TMP007 device is mounted on the top layer of the PCB (layer 1), Figure 10. This layer also contains the PCB landing pattern for the TMP006 or TMP007 wafer chip-scale package (WCSP), an isolated island of copper around the TMP006 or TMP007 device, and the TMP006 or TMP007 decoupling capacitor. Note that WCSP is also known as a die size ball grid array (DSBGA) package.



NOTE: The TMP007 is used in this figure; the TMP006 layout is identical.

Figure 10. Two-Layer PCB, Top Layer

3.1.3 Layer 2: Bottom Layer

The bottom layer is shown in Figure 11.

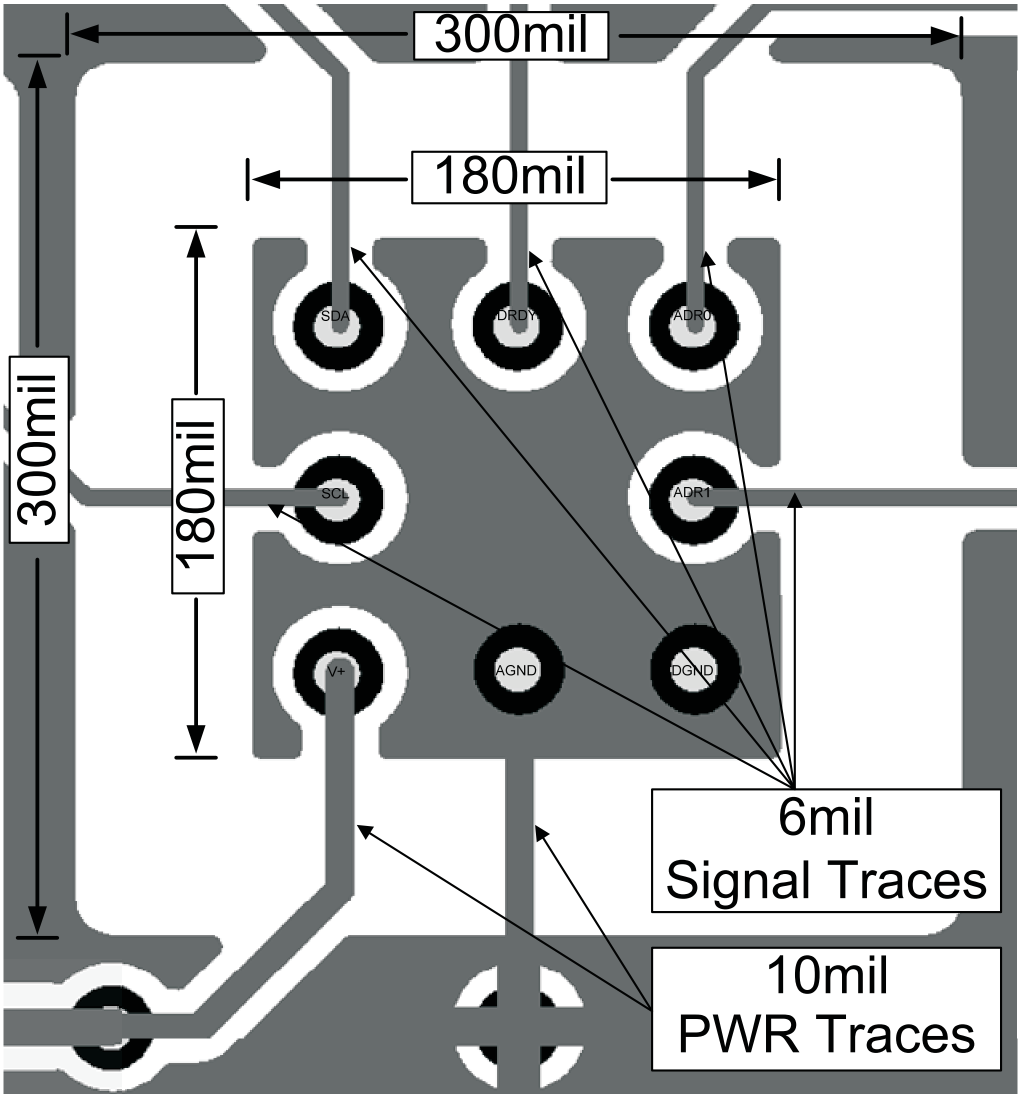


Figure 11. Two-Layer PCB, Bottom Layer

3.2 Standard Footprint: Four-Layer (or More) PCB Layout Guidelines

The four-layer PCB layout guidelines are also developed on a 1-mil grid (1 mil = 0.001 in, or 0.0254 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 first layer of the four-layer design is the same as the first layer of the two-layer design. The third layer is very similar to the second layer of the two-layer design. The second and fourth layers 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 changes in performance versus the two-layer design.

The PCB layer stack for the four-layer PCB is illustrated in Figure 12.

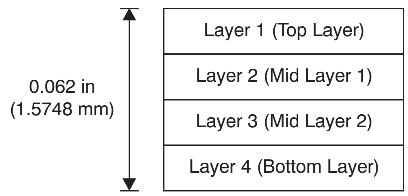


Figure 12. Four-Layer PCB Stack

Figure 13 shows the correlation between the two- and four-layer designs.

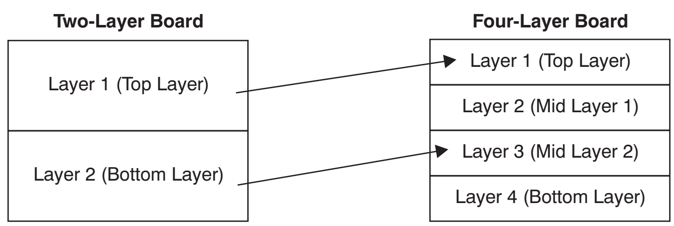


Figure 13. Correlation of Two-Layer and Four-Layer PCB Designs

3.2.1 Layer One: Top Layer

Layer 1 is identical to the top layer described previously (see Figure 10).

3.2.2 Layer Two: Mid Layer One

The second layer contains an isolated island of copper connected to the TMP006 or TMP007 GND. It is sized the same as the first-layer copper island and located directly below it. In the example, the second layer is also used to route the V+ power signals for the device. This layer can be used to route the signals that have been routed on layer three.

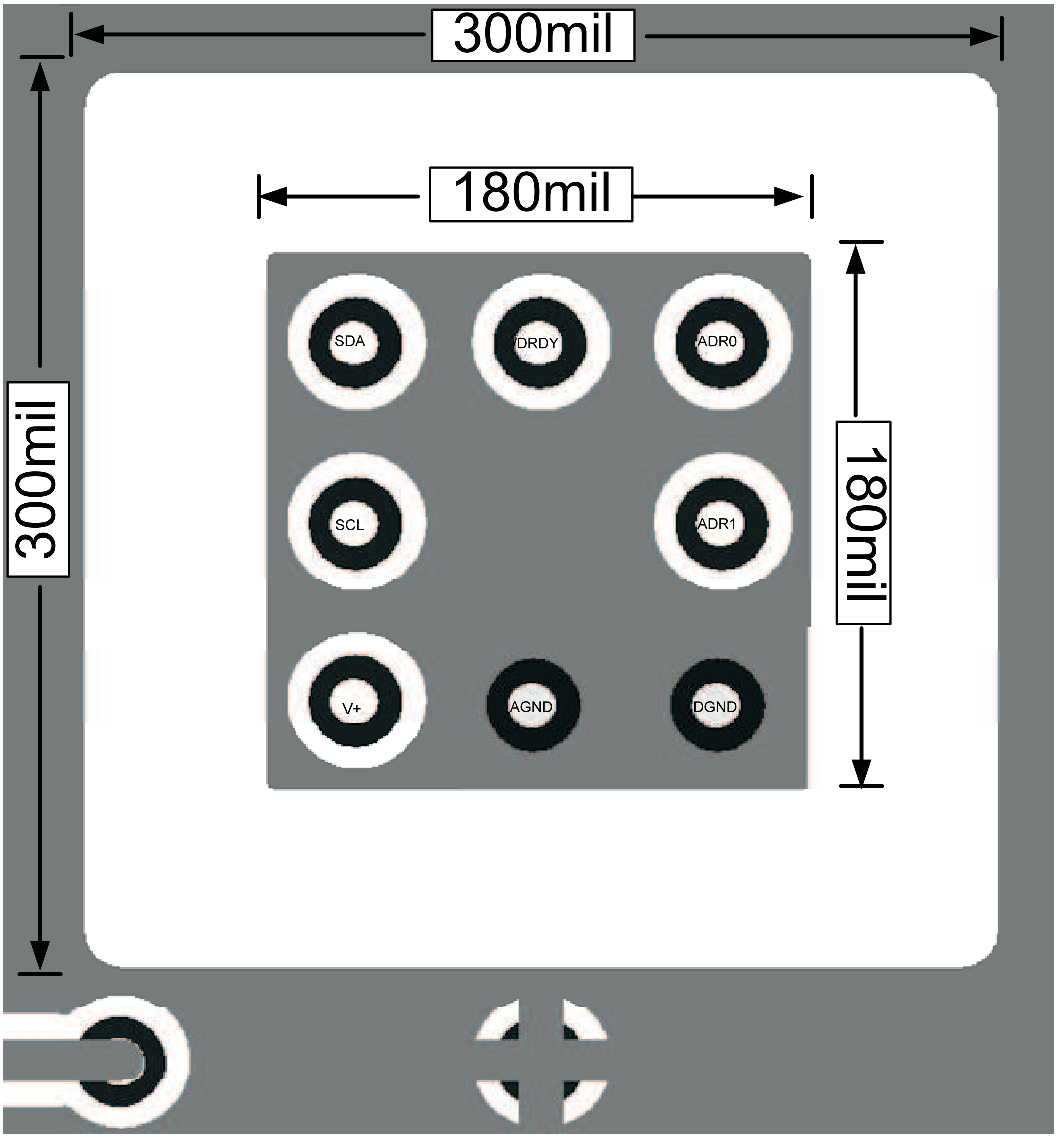


Figure 14. Layer Two: Mid Layer One

3.2.3 Layer Three: Mid Layer Two

The third layer 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, and is also used to route the TMP006 or TMP007 digital and power signals to the rest of the PCB. The power signals (VCC and GND) are routed with 10-mil (0.254-mm) traces, and the remaining digital signals are routed with 6-mil (0.1524-mm) traces. Figure 15 shows the third layer. The signals routed on this layer can be routed on layer two or layer four with no impact on the design performance.

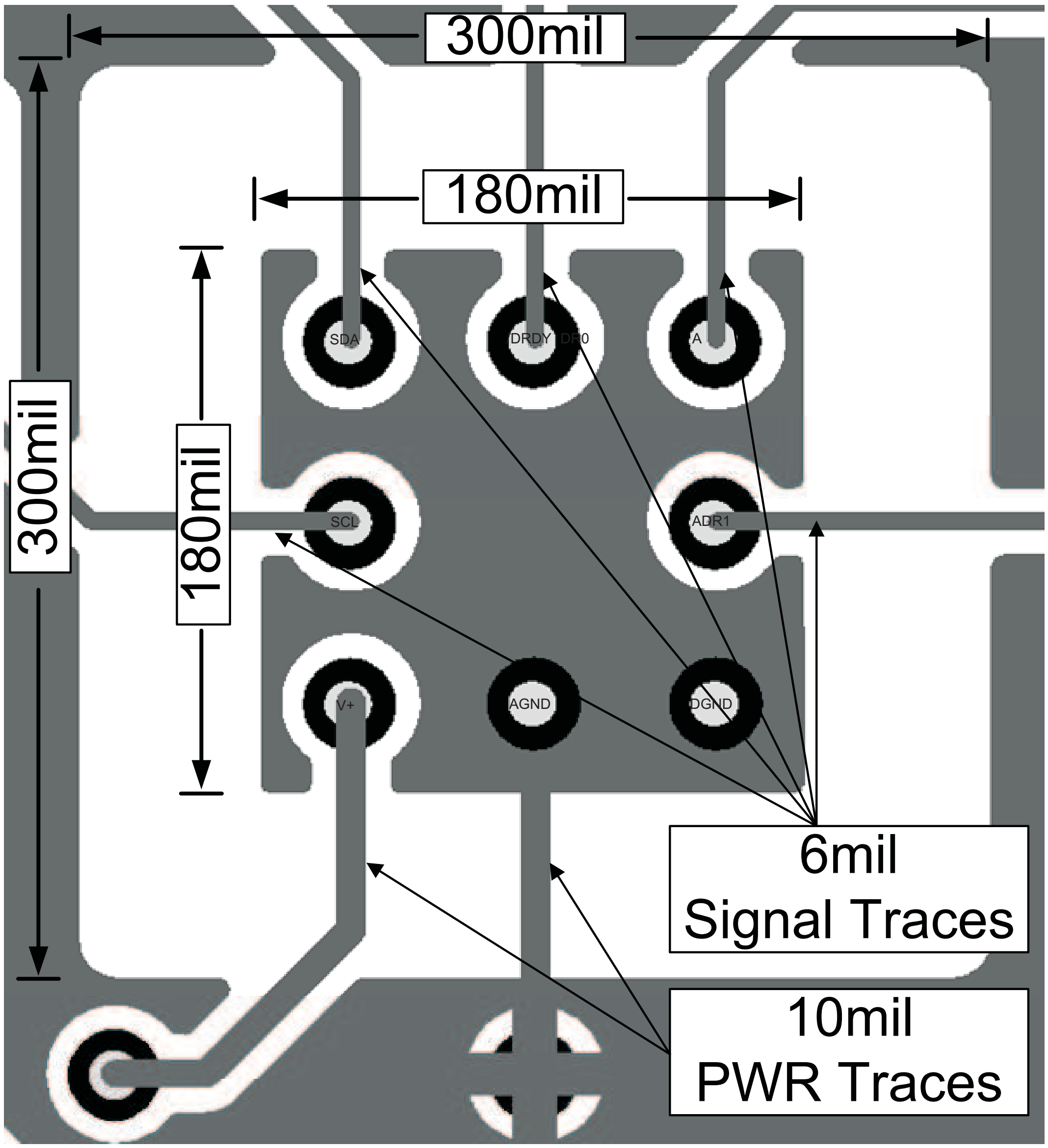


Figure 15. Layer Three: Mid Layer Two

3.2.4 Layer Four: Bottom Layer

The fourth and bottom layer contains another copper island connected to the GND plane. Layer four can be used to route the signals located on layer two and layer three with no impact to design performance.

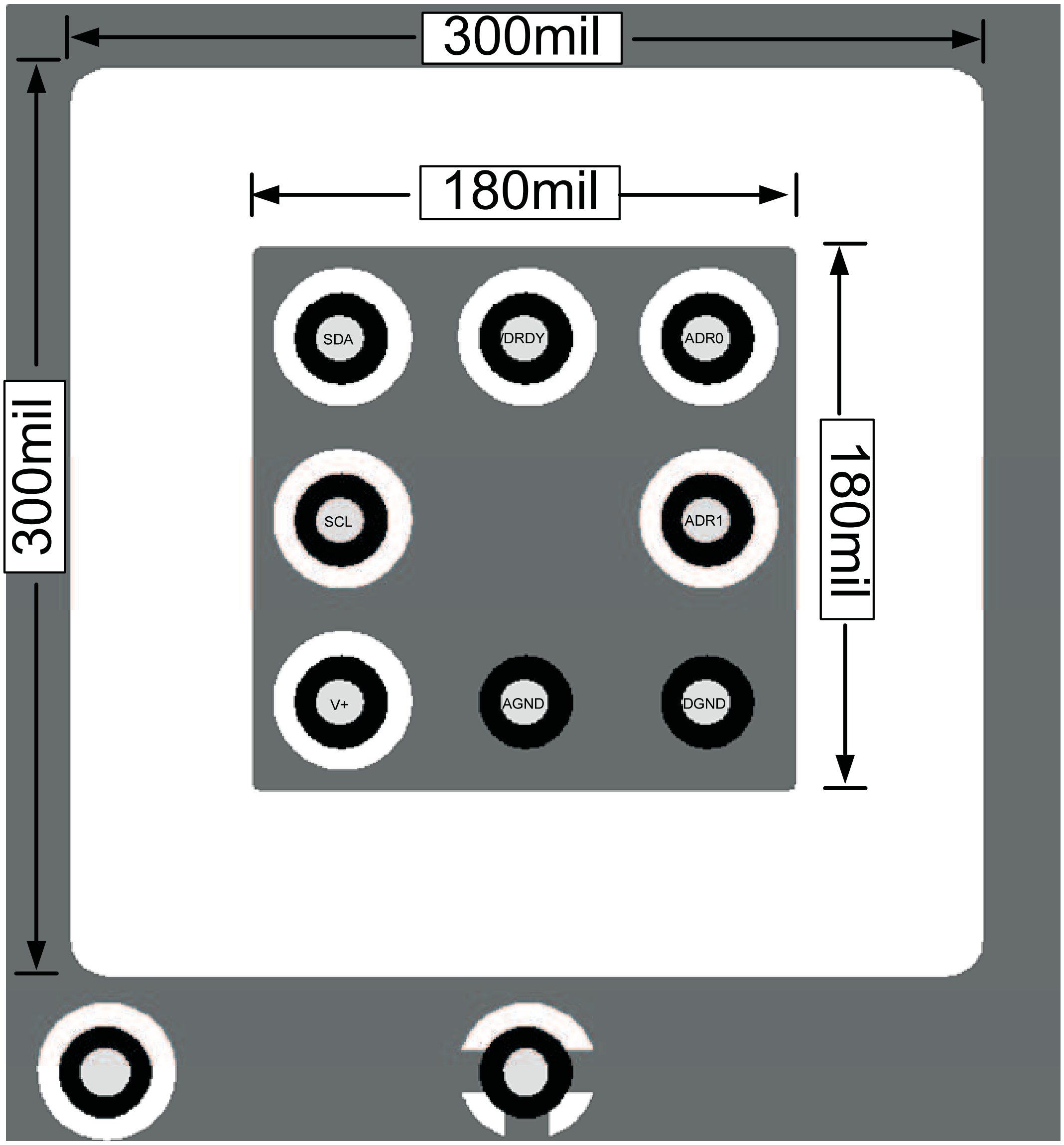


Figure 16. Layer Four: Bottom Layer

3.3 Small Footprint: Two-Layer Layout Guidelines

Some applications require a smaller footprint than the standard footprint. If the surrounding components are low power or well isolated, then it is possible to reduce the footprint; however, with a trade-off of reduced thermal isolation from conductive sources.

The reduced footprint layout reduced the footprint from 300 mil × 300 mil (7.62 mm × 7.62 mm) to 200 mil × 200 mil (5.1 mm × 5.1 mm). The small footprint requires 44% of the standard footprint PCB area. The reduction is attained, as shown in Figure 17, by:

- Reducing the via sizes from a 30-mil diameter with a 15-mil drill to a 25-mil diameter with a 10-mil drill in standard footprint
- Reducing the copper surrounding the vias to 130 mils (compared to 180 mils in the standard layout)
- Reducing the FR-4 spacing used for thermal isolation to 30 mils from adjacent components (compared to 60 mils in the standard layout)

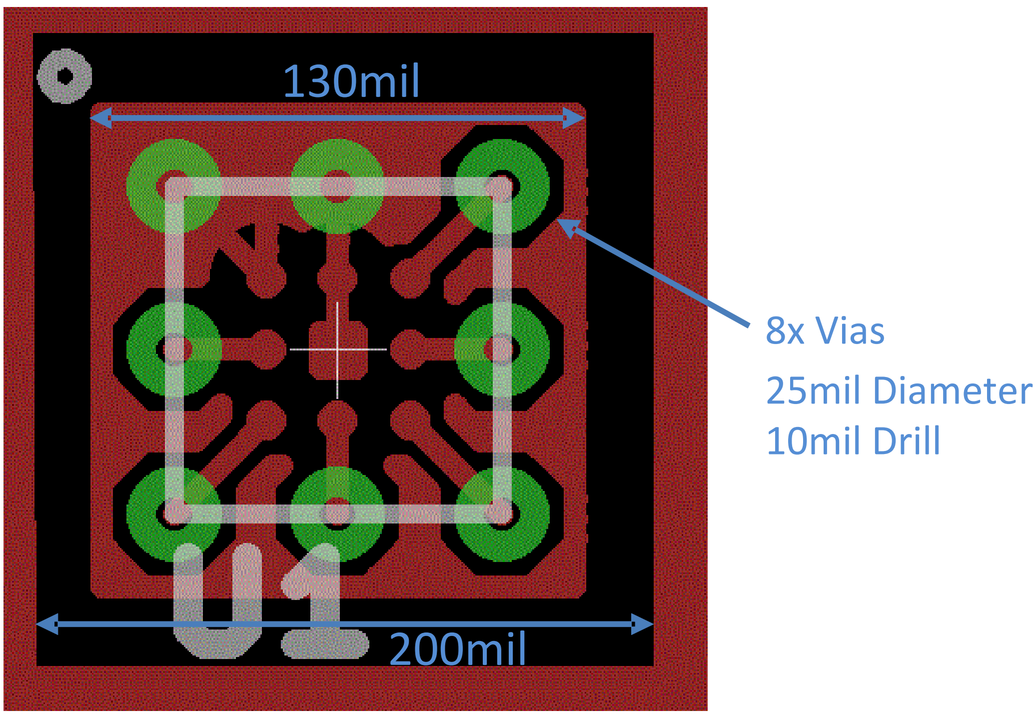


Figure 17. Small Footprint Layout: Top Layer

The same principles that are used for the standard layout apply to the bottom layer.

3.4 Laser Cut Micro Footprint: Two-Layer Layout Guidelines

In applications requiring extremely dense layout in aggressive thermal environments, laser-cut techniques can be used on the PCB to provide thermal isolation, as shown in Figure 18.

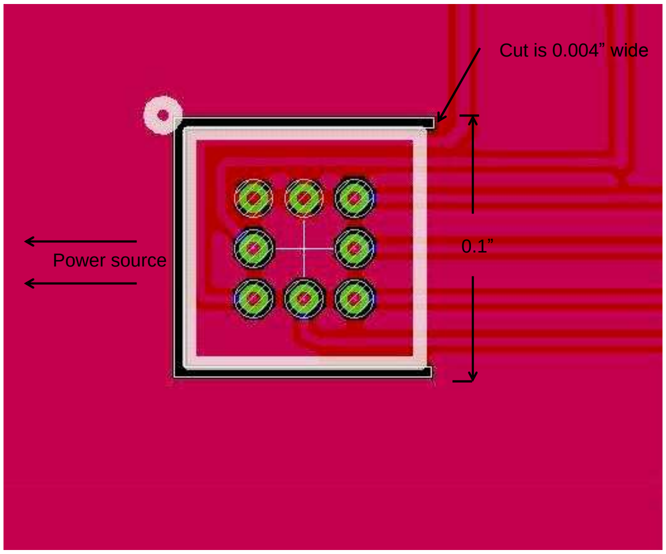


Figure 18. Micro Footprint Layout Overview

A laser or similar technique is used to remove PCB material from three sides of the board to provide an air gap for thermal isolation. The footprint measures 100 mil × 100 mil (2.5 mm × 2.5 mm), and requires just 6.25 mm^2 of PCB area, as shown in Figure 19.

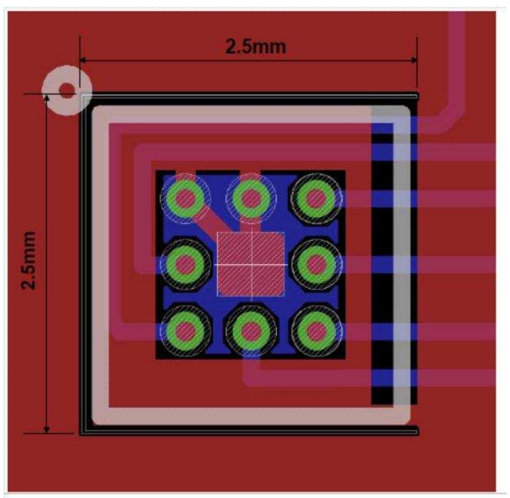


Figure 19. Micro Footprint Layout: All Layers

The top pads have an 11-mil diameter and a 6-mil drill, as shown in Figure 20. The 4-mil vias are filled for backside routing of the signals, all of which exit the layout on the opposite side of the dominant heat source on the PCB. The top side is the ground plane and is used for thermal isolation for any radiation coming from the side of the PCB opposite the TMP006 or TMP007.

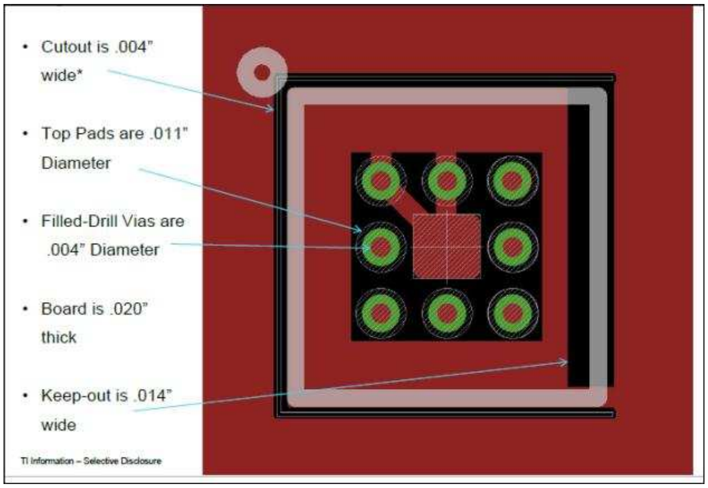


Figure 20. Micro Footprint Layout: Top Layer

Routing is performed on the bottom layer, as shown in Figure 21. Note that all signals exit from the opposite side of the dominant heat source.

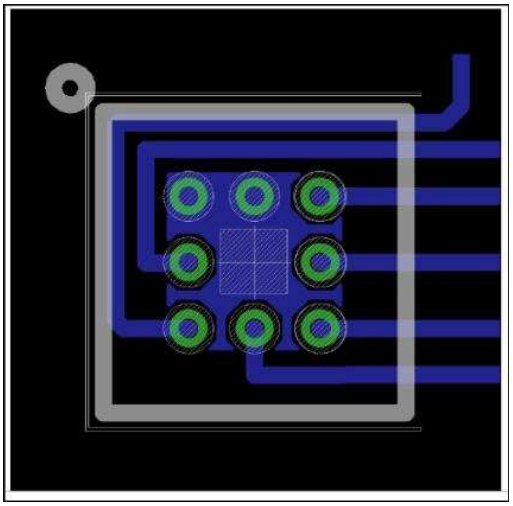


Figure 21. Micro Footprint Layout: Bottom Layer

The width of the cut and the thickness of the PCB are related and depend on the process used to make the slot. Some guidelines are given in Table 4.

Table 4. Micro Footprint Typical Slot Guidelines

Slot Width (mil)	4	5	6
Maximum PCB Thickness (mil)	20	25	30

4 Layout with Metal Shield Guidelines: Convection or FOV Definition Required

Significant errors and noise can be introduced in the presence of convection, whether driven by temperature differences across the fluid or by forced convection from a fan. If the end equipment does not provide protection from convective effects, then take additional measures in the layout and assembly process. If defining the FOV to make sure only the object of interest is measured, then follow the guidelines described in this section.

NOTE: Implementing a shield with a FOV definition substantially improves the accuracy and stability of the TMP006 or TMP007 device performance, and greatly simplifies the calibration process. This procedure simplifies the environment to that described in Section 2.1. If unsure of the effects of conduction and convection in your design, the best practice is to use the small footprint with provisions for a metal shield during prototyping, and perform testing before finalizing the production design.

4.1 Object and Sensor on Same Side of PCB

Use a shield that is fabricated from a high thermal conductivity material that does not transmit significantly in the IR region detected by the TMP006 or TMP007. Any material with significant thermal conductivity is suitable. Typically, metals work well, and are easily fabricated and assembled onto the PCB. Some common examples are given in Table 3.

Figure 22 shows the concept of a shield. A shield eliminates any convection effects. In addition, the aperture in the shield defines the field of view. Finally, the shield helps equalize the temperature distribution across the PCB if it is thermally grounded, and greatly increases TMP006 or TMP007 immunity from other components generating heat.

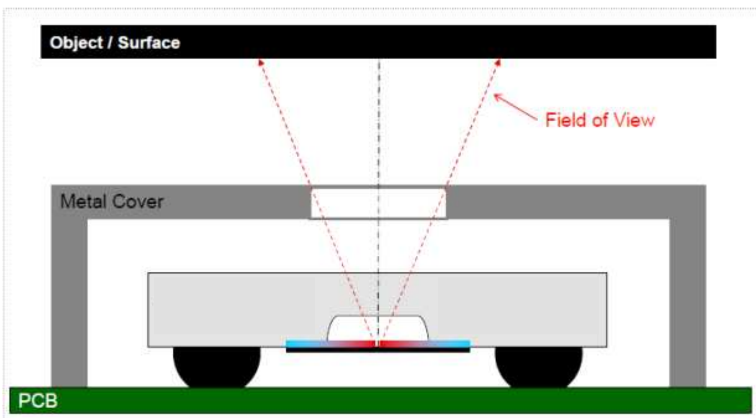


Figure 22. Metal Shield Eliminates Convection

Optimize the dimensions of the shield for the application requirements in terms of FOV and available space. Typical dimensions are shown in Figure 23. As detailed in the TMP006 (SBOS518) or TMP007 (SBOS685) product data sheets, a 90° to 120° FOV provides sufficient signal for most applications. This requirement translates into an aperture of 1 mm to 2 mm in the shield. Center the aperture in the shield to align with the thermopile.

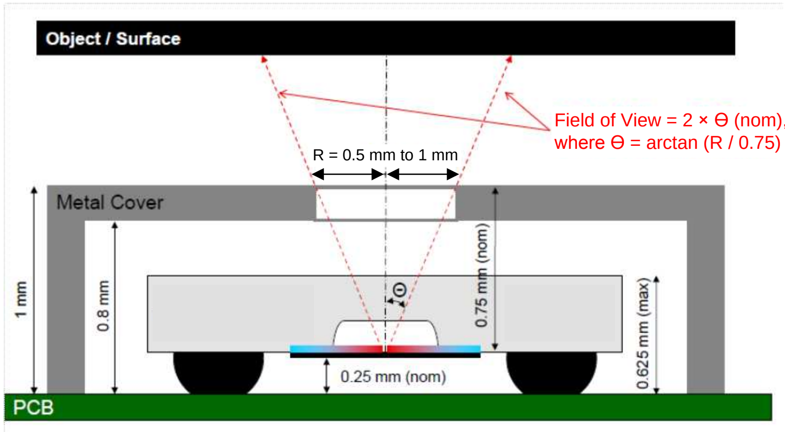


Figure 23. Nominal Shield Dimensions

Figure 24 shows an example of the small-footprint layout modified to accommodate a metal shield. The copper area on the top layer is extended to provide a solder-mask frame for mounting. In this example, a wall thickness for the shield of 0.2 mm (8 mil) is assumed; therefore, the solder mask frame is 0.25-mm (10-mil) wide. The copper surround is electrically and thermally grounded to the TMP006 or TMP007 ground pins, as shown, and ensures that the metal shield is in electrical and thermal equilibrium with respect to the TMP006 or TMP007 device. Optionally, the shield may include pegs that align with vias in the solder mask to aid in alignment. For suggested sources, see the TI E2E community website at http://e2e.ti.com/.

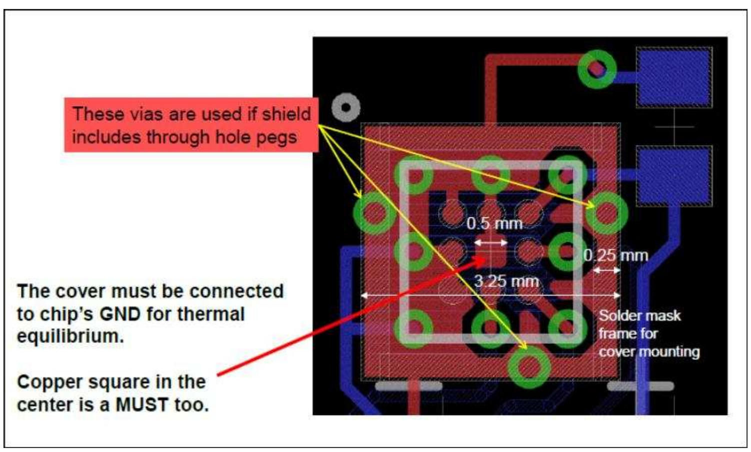


Figure 24. Layout Modified For Metal Shield

To estimate the FOV for a shield with a hole of a given size, first calculate the distance from the top of the shield to the thermopile location. In this example, cover height (1 mm) – thermopile offset from PCB (0.25 mm) = 0.75 mm. For a hole of radius R, angle θ (by geometry) is shown in Equation 10:

$$\Theta = \arctan\left(\frac{R}{0.75}\right) \tag{10}$$

Table 5 shows an example of the FOV calculation for the case of a 1-mm shield height.

Table 5. Example of Shield FOV Estimation

Radius, R (mm)	Distance, D (mm)	Sinθ	θ (deg)	FOV = 2θ (deg)
0.75	0.75	0.71	45	90
1.00	0.75	0.80	53	106
1.25	0.75	0.86	59	118
1.50	0.75	0.89	63	127
2.00	0.75	0.94	69	139

Figure 25 shows a mechanical sketch of a metal shield with features to aid in the assembly process. Final design and fabrication of a shield is the responsibility of the user.

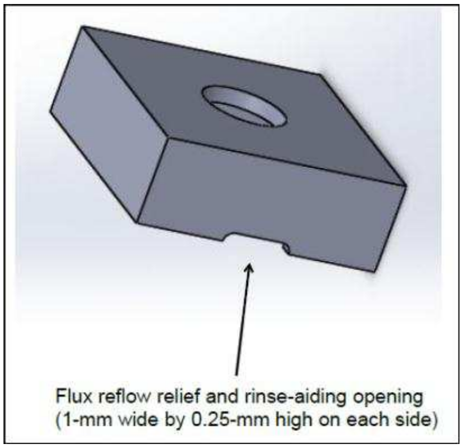


Figure 25. Schematic of Metal Shield Construction

4.2 Object and Sensor on Opposite Side of PCB

In specialized applications, the object to be measured may be on the opposite side of the board on which the TMP006 or TMP007 is mounted. Whenever feasible, place the TMP006 or TMP007 and the object on the same side of the board; if for some reason this placement is not feasible, then use a through-hole layout.

NOTE: This technique is very dependent on the details of fabrication and PCB processing. It is difficult to predict the performance without testing fabricated devices.

Figure 26 shows the modification required for the through-hole layout. In place of the copper square in the center used in all other layouts, a plated drilled hole is used to admit radiation from beneath the PCB. In principle, the plated via hole forms a reflecting set of optics using the plating material to guide radiation to the thermopile detector. Therefore, the performance greatly depends on the details of the via structure and plating. Refer to literature on Winston cones for further information.

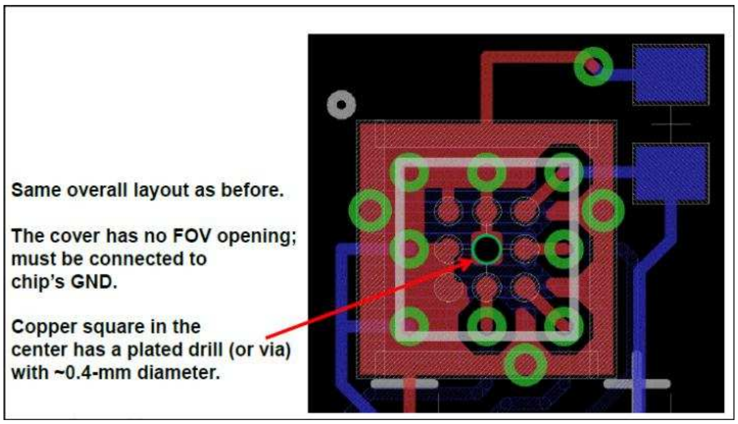


Figure 26. Through-Hole Layout Modification

Note that this layout *must* have a shield with no aperture to block thermal radiation from objects on the top side of the PCB from affecting the thermopile operation.

5 Assembly Guidelines

This section contains assembly guidelines that apply to all the layout options discussed in the previous sections.

5.1 Handling Assembly Forces

The TMP006 and TMP007 are microelectromechanical systems (MEMS) devices and require special care in handling to avoid damage.

CAUTION

Be especially careful not to touch or damage the thermopile membrane that lies in the center of the bottom of the TMP006 or TMP007 between the solder balls.

Observe the following handling recommendations for best results:

- Pick-up and place-down force = 125 gf to 200 gf
- Use a compliant tip. Make sure total contact is smaller than package outline.
- Make sure tip contact area is rectangular with ~0.7-mm circular diameter vacuum opening; an 0201 tip works well.

5.2 Underfill and Overcoat Warning

CAUTION

Underfill is strictly forbidden. Underfill contacts the thermopile membrane, causes a thermal short, and renders the device inoperative.

In general, overcoats are discouraged without extensive user testing for impact on device performance and reliability. However, overcoats are permitted only if there is no underfill, and the material is well characterized in the IR spectrum detected by the TMP006 or TMP007.

5.3 Coplanarity

The TMP006 and TMP007 meet a coplanarity specification of 0.05 mm, as shown in Figure 27. Coplanarity is defined as a unilateral tolerance zone measured upward from the seating plane (reference ASME Y14.5M - 1994).

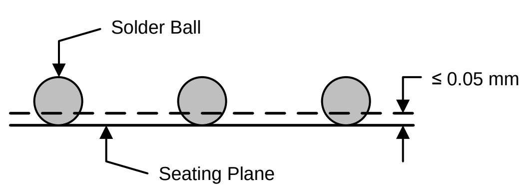


Figure 27. Coplanarity of Solder Ball Assembly

5.4 Self-Alignment During Reflow

When using a shield to mitigate convection effects, alignment of the shield and the TMP006 or TMP007 thermopile is critical. WCSPs are very forgiving to placement errors. About 50% ball-to-paste overlap is sufficient for self-alignment during reflow.

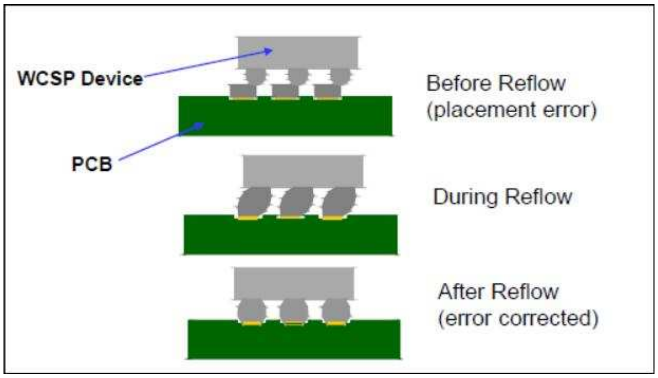


Figure 28. WCSP Self-Alignment During Reflow

5.5 Solder Flux

Apply flux to the PCB before placing the board into an IR reflow oven to make sure that the solder balls on the TMP006 or TMP007 WCSP 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.

5.6 Solder Paste

Use type-3 solder paste. Type-3 solder paste facilitates wetting of the solder ball to the PCB land better than the use of flux alone. The adhesive properties of the paste also hold the component in place during reflow. The recommended stencil thickness is 100 µm to 103 µm (3.9 mil to 4.06 mil).

5.7 Solder-Mask Trace Detail

To reduce solder-flow starvation, follow the guideline shown in Figure 29.

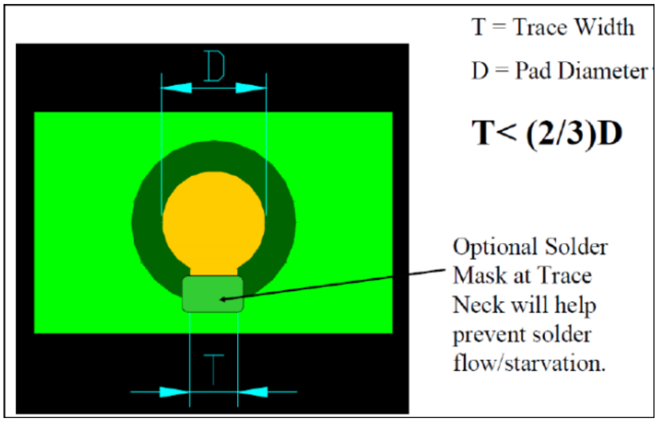


Figure 29. Solder-Mask Trace Detail

5.8 Reflow Oven Thermal Profile

To prevent damage to the TMP006 or TMP007, follow the appropriate thermal profile during the reflow process in the PCB assembly. These are approximate profiles, and actual conditions obtained in any specific reflow oven can vary. These profiles are based on convection or IR plus forced convection heating. Table 6 shows a sample reflow profile.

Table 6. Reflow Oven Profile

	Pb Free Assembly
Ramp rate	< 3°C/min
Preheat	160°C to 180°C 60 s to 120 s
Time above liquidus	220°C 30 s to 90 s
Peak temperature	245°C to 260°C
Time within 5°C of peak	10 s to 40 s
Ramp down	< 6°C/s

A thermal profile used by Texas Instruments is shown in Figure 30.

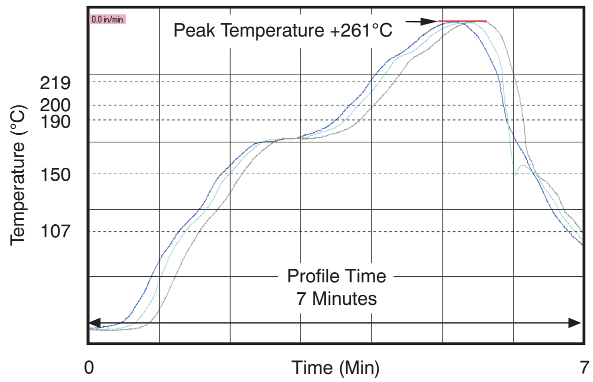


Figure 30. Reflow Oven Profile Example

5.9 PCB Cleaning

After assembly, thoroughly clean the TMP007 PCB to remove any flux or other residue remaining underneath the TMP006 or TMP007 device that can interact with the sensor. Use an ultrasonic PCB cleaner to ensure all residue is removed from under the TMP006 or TMP007. If Kester 2331-ZX flux is used, then fill the ultrasonic cleaner with deionized (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 or TMP007 board into the ultrasonic cleaner and clean the board with the transducers for at least five minutes. Remove the board 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 or TMP007 can interfere with measurement accuracy. Therefore, the final step in the cleaning process is to inspect the surface of the TMP006 or TMP007; use cotton swabs or other cleaning devices to remove anything remaining on the surface of the TMP006 or TMP007.

5.10 TMP006 and TMP007 Rework Procedures

A MEMS structure such as the TMP006 and TMP007 requires careful handling during rework as described in Section 5.1.

Acceptable methods for rework are:

- Hot gas conduction nozzle
- Electrical conduction nozzle
- Hot gas convection nozzle

Exhaust venting prevents adjacent component reflow. The TMP006 die size is 1.6 mm × 1.6 mm, and the TMP007 die size is 1.9 mm × 1.9 mm.

Presented here are generic guidelines to rework Pb-free bumped WCSPs assembled on a 0.056-inch thick FR4 board. Modify the heating profiles for different board thicknesses and equipment used. Do not reuse the part after it is removed. Use the assembly process in the following subsections with a new device.

5.10.1 Pb-Free Ball Removal

1. Apply flux paste to component.
2. Align nozzle over part to be removed.
3. Maintain nozzle at 0.05" over device. Care must be taken to prevent overtravel of the vacuum tip so that neither the tip nor the device are damaged when measuring this distance.
4. Preheat board to 90ºC, warm up nozzle to 20% air flow at 125°C.
5. Soak stage: 20% air flow, 225°C, 90 s.
6. Ramp stage: 20% air flow, 335°C, 30 s.
7. Reflow stage: 25% air flow, 370°C, 65 s.
8. Enable vacuum at the end of the reflow cycle, lower vacuum nozzle, and remove device.
9. Cool down stage: 40% air flow, 25°C, 50 s.
10. Turn off the vacuum and remove device from nozzle.
11. Using any metal tweezers or rough handling can damage the device and not allow for analyzing.

5.10.2 Pb-Free Ball Placement

1. Apply flux paste to component.
2. Align device over pads.
3. Place device on board. Take care to prevent overtravel during placement so that neither the device nor the vacuum tip are damaged.
4. Raise nozzle 0.050"
5. Preheat board to 90°C, warm up nozzle to 20% air flow at 125°C
6. Soak Stage—20% air flow, 225°C, 90 s
7. Ramp Stage—20% air flow, 335°C, 30 s
8. Reflow Stage—25% air flow, 370°C, 65 s
9. Cool down Stage—40% air flow, 25°C, 50 s

Frequently-Asked Questions (FAQ)

A.1 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.

A.2 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 compensate any variations. If there are transient heating conditions caused by power cycling of the components, then consider implementation of the transient correction feature on the TMP006 or TMP007.

Windows: Improving Performance Estimates

This section contains procedures to improve the predicted performance of a window by including additional effects, such as multiple reflections and angular dependence.

B.1 Window Transmission with Multiple Reflections

In Section 2.2.3, a 1st-order formula for estimating window performance is presented. In this section, a formula including multiple reflections is presented.

The transmittance through a thick [(1)] plate, taking into account losses at the surfaces and in the bulk, is shown in Equation 11:

$$T = \frac{(1-\rho_s)^2 e^{-ax}}{1-\rho_s^2 e^{-2ax}}$$

where

- $$\rho_s = \frac{(n-1)^2 + \left(\frac{\lambda a}{4\pi}\right)^2}{(n+1)^2 + \left(\frac{\lambda a}{4\pi}\right)^2}$$ is the surface reflectance, and where *a* is the absorption coefficient (11)

Typically, the $(\lambda a/4\pi)^2$ term is much smaller than the $(n\text{-}1)^2$ term, and can be ignored. Under this model, some typical performance estimates are shown in Table 7. The transmission is given for both uncoated surfaces and assumes an antireflective (AR) coating is applied.

(1) *Thick* means significantly thicker than the coherence length, so that interference effects can be ignored.

Table 7. Typical Performance Estimates

Symbol	Silicon	SiO_2	Polyethylene	Description
a =	0.82 cm^{-1}	0.50 cm^{-1}	8.10 cm^{-1}	Absorption coefficient
λ =	10.00 µm	10.00 µm	10.00 µm	Nominal wavelength
n =	3.415	1.430	1.490	Refractive index
x =	1.00 mm	1.00 mm	0.25 mm	Thickness
k =	6.53E-05	3.98E-05	6.45E-04	Imaginary part of refractive index
ρs =	29.92%	3.13%	3.87%	Single-surface reflectance
τ_s =	70.08%	96.87%	96.13%	Single-surface transmittance
T =	49.0%	89.3%	75.5%	Transmittance with uncoated surfaces
T_0 =	92.1%	95.1%	81.7%	Transmittance with ideal AR coatings on both surfaces

B.2 Fresnel Equation: Transmission with Angle Dependence

In Section 2.2.1, the transmission and reflection at an interface of two materials is described for the special case of normal incidence (that is, θ = 0°). In practice, the reflected and transmitted energy depends on the angle of incidence. The reflection at the interface is polarization dependent, conventionally referred to as *s* and *p* polarization.

The reflection relations are shown in Equation 12:

$$R_S = \left| \frac{n_1 \cos\theta_i - n_2 \cos\theta_t}{n_1 \cos\theta_i + n_2 \cos\theta_t} \right|^2 \quad \text{and} \quad R_P = \left| \frac{n_1 \cos\theta_t - n_2 \cos\theta_i}{n_1 \cos\theta_t + n_2 \cos\theta_i} \right|^2$$

where

- i and t refer to the incident and transmitted angles, respectively
- n_1 and n_2 are the refractive indices of the first and second material (12)

In principle, the integration must be carried out over the entire range of θ = 0 to π/2.

Note that for certain combinations of the parameters, the numerator of the fraction becomes zero. This result corresponds to a condition of total transmission with no reflective loses, also known as total internal reflection.

Revision History

Changes from A Revision (April 2015) to B Revision **Page**

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

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      3.1.1 *Notice applicable to EVMs not FCC-Approved:*

      This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

      3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

      CAUTION

      This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

      Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

      FCC Interference Statement for Class A EVM devices

      NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d’usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。
http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page

3.3.2 *Notice for Users of EVMs Considered “Radio Frequency Products” in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required by Radio Law of Japan to follow the instructions below with respect to EVMs:

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry’s Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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2. 実験局の免許を取得後ご使用いただく。
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4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. *Disclaimers:*

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