

## APPLICATION NOTE PRD-05652

# MOUNTING RECOMMENDATIONS AND THERMAL MEASUREMENT FOR WOLFSPEED® SiC POWER DEVICES IN THROUGH-HOLE PACKAGES



# INTRODUCTION

The trend of current power electronics systems is towards high efficiency and high-power density designs. Silicon Carbide (SiC) has a unique combination of critical electric field and electron velocity, enabling low on-state resistance at the device level. Compared to its Silicon-based counterpart, SiC MOSFETs have a smaller capacitance and much better reverse recovery on the body diode, resulting in low switching losses. The low on-state resistance and low switching losses provided by Silicon Carbide enables higher power density and higher switching frequencies in a wide variety of power electronics applications. High power density systems impose new challenges towards the thermal management of SiC power devices, the basics of which will be covered in this application note.

The mounting method of Wolfspeed through-hole device (THD) packages can have a significant impact on the overall performance of the device and should be performed following the guidelines in this document. Thermal performance, mechanical reliability, and electrical isolation are a few of the factors that can be affected by the mounting method used to attach the device to the PCB assembly and heatsink. This application note will detail the recommended lead bending and mounting procedures for Wolfspeed® Silicon Carbide (SiC) through-hole devices, along with typical thermal measurement and management techniques for proper device functionality.

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## 1. PACKAGE DESCRIPTION

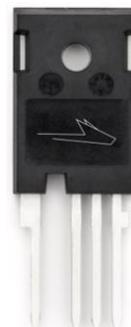
Through-hole device packages have long straight leads that are placed into drilled holes on a PCB and soldered, often by wave soldering, into place. This differs from surface mount device (SMD) packages, which are mounted directly to one side of the PCB. Depending on the application, the leads of a THD package can be carefully bent to various angles prior to soldering to allow better fit into the assembly or to provide increased lead spacing on the PCB. Figure 1 below shows various types of Wolfspeed power through-hole packages:



TO-247-2



TO-247-3



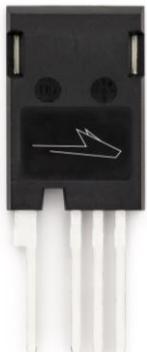
TO-247-4



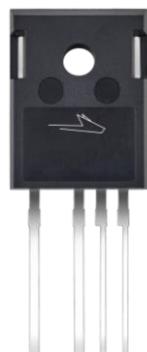
TO-220-2



TO-3PF-3L



TO-247-4 Plus



TO-247-4L LP



TO-220-F2

Figure 1: Through-Hole Package Examples

To aid in the dissipation of heat from the device, an additional heat sink can be attached to the package body or can be shared by multiple devices. Depending on the application, the heat sink can be applied to the package before or after the lead soldering has occurred. Please refer to section 4 of this application note for heat sink mounting recommendations. Two of the THD package offerings from Wolfspeed, the TO-3PF-3L and TO-220-F2, are fully molded packages where there is no exposed drain metal on the backside of the package. These packages are suitable for low-power applications where heat dissipation performance is not as critical,

but savings in assembly cost and time through the removal of the need of a TIM material in the system is desired.

## 2. THERMAL RELATED PARAMETERS IN THE DATASHEET

To create a proper thermal design, we first need to understand the datasheet of the device. Here, we use the datasheet of a 1200V 40mohm SiC MOSFET, C3M0040120D, as an example to introduce the key parameters:

### A. JUNCTION TEMPERATURE

$T_J, T_{stg}$	Operating Junction and Storage Temperature	-40 to +175	°C
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Table 1: Junction Temperature ( $T_J$ ) and Storage Temperature ( $T_{stg}$ ) [1]

Table 1 defines the maximum device junction temperature ( $T_J$ ) and storage temperature ( $T_{stg}$ ) of the through-hole package. In other words, operation is not guaranteed below -40°C or over 175 °C. If the temperature is exceeded, this may cause permanent damage to the device.

### B. THERMAL RESISTANCE

#### Thermal Characteristics

Symbol	Parameter	Typ.	Unit	Test Conditions	Note
$R_{\theta,JC}$	Thermal Resistance from Junction to Case	0.46	°C/W		
$R_{\theta,JA}$	Thermal Resistance From Junction to Ambient	40			Fig. 21

Table 2: Thermal Characteristics [1]

$R_{\theta,JC}$  ( $R_{\theta}$ junction – case) is the thermal resistance from the junction to the case of the package and is a very important parameter for junction temperature evaluation. Junction refers to the semiconductor die of the device and case refers to the copper lead frame of the device. The thermal dissipation path of the heat generated by the device is shown in Figure 2 below.  $R_{\theta,JA}$  is the thermal resistance from junction to ambient when there is no heatsink equipped for the device. and is usually much higher than  $R_{\theta,JC}$ . In high power applications with a heatsink,  $R_{\theta,JC}$  can be used in conjunction with the heatsink temperature or heatsink thermal impedance and power dissipation for engineering calculation of the junction temperature.

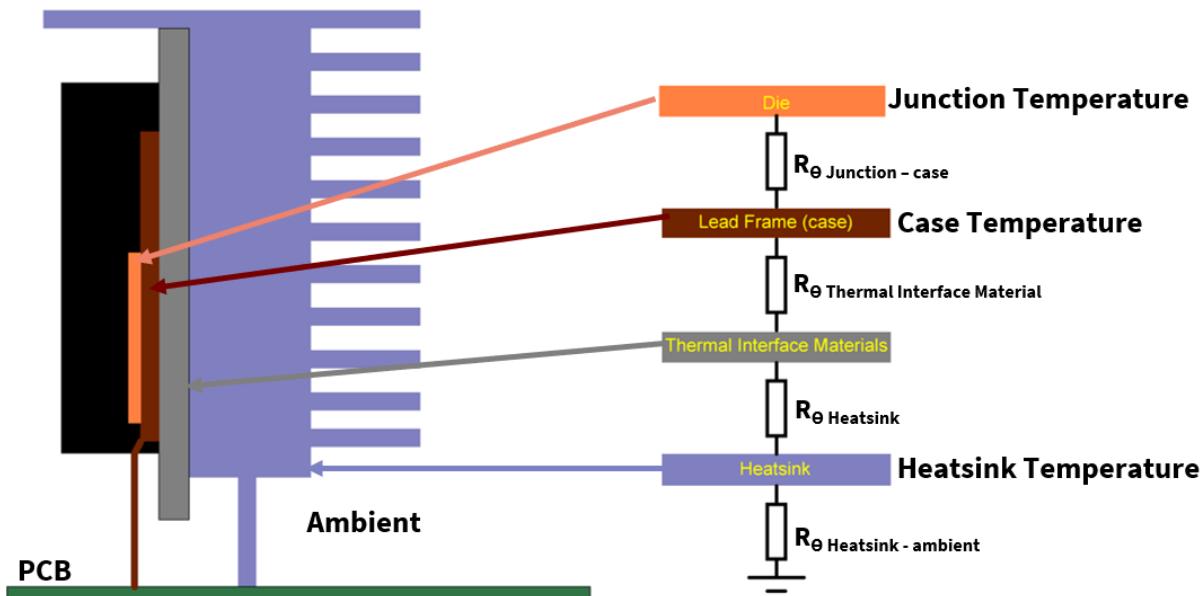


Figure 2: Thermal Path of a TO-247 Device

The transient thermal impedance from junction to case from the C3M0040120D datasheet is shown in Figure 3. This plot includes the transient thermal impedance for different duty cycles as indicated by the label on each curve. The pulse duration is indicated at the X-axis, and the junction to case thermal resistance is shown at the Y-axis. This plot shows that for very short pulses, the thermal impedance is lower than the  $R_{\theta}JC$  shown in the Thermal Characteristics table, which represents a steady-state value.

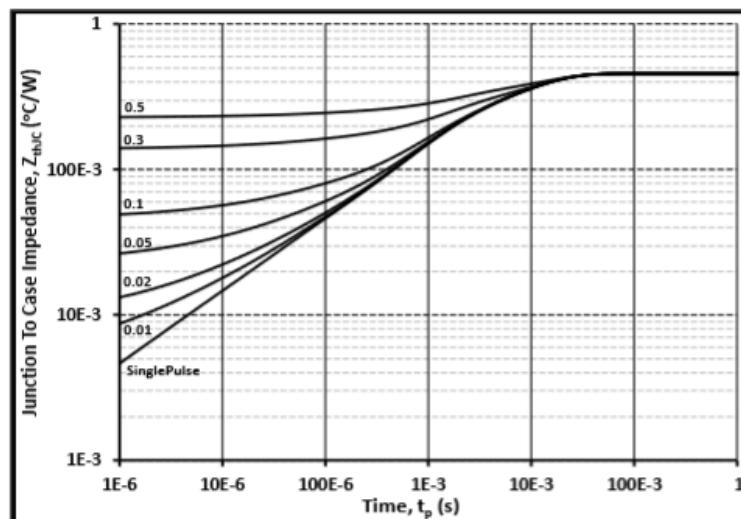


Figure 3: The Transient Thermal Resistance from Junction to Case of C3M0040120D [1]

### 3. LEAD CUTTING AND FORMING

Numerous manufacturing processes can be performed on the THD packages prior to soldering to the PCB to better fit the package into the assembly. This includes lead cutting and lead bending, which must be done carefully to avoid damage to the package or device itself. The following guidelines can be used for proper lead cutting and bending of THD devices:

## **Lead Cutting**

Wolfspeed through-hole devices are built with relatively long leads to allow for use in a variety of applications. In many instances, the leads will be longer than needed and must be trimmed either before or after mounting to the PCB. In fact, the electrical performance of the device is optimized when the leads are as short as possible because this will minimize the parasitic inductance between the PCB and the SiC die inside the package. When cutting the leads prior to mounting, leads should be clamped to limit any stress potentially transferring to the package body. Clamping methods should follow the same guidelines as presented in the next section “Lead Bending”. Careful consideration must be taken if lead cutting is being performed after the package is soldered to the PCB, so as to not damage the solder joint integrity from excess mechanical force. Generally, this excess force will not damage the component body.

## **Lead Bending**

In some instances, the package leads must be bent when mounting the device to a heatsink surface that is not perpendicular to the PCB. When lead bending is necessary, these general guidelines should be followed:

- A suitable clamp on the leads between the package body and the bend is required to eliminate any mechanical stresses from being transferred to the package body.
- Clamping force should be enough to ensure no movement of the clamp on the lead during the bending process.
- Clamping force should not be excessive which can cause lead deformation or weakening.
- The clamp must not contact the body of the device under any circumstances during the bending process. This can transfer stress into the mold compound and result in damage to the part.
- The minimum recommended spacing between the body and the clamp is 0.5mm, however it is recommended to perform the bend after the narrowing of the lead (seating plane).
- Bending the leads at the package is not allowed. A clamp must always be used on the leads.

- Bending leads laterally (parallel to the body plane) is not allowed.
- Leads may be bent a maximum of 90° up or down. Do not unbend or repetitively bend the same location as this may result in weakening the lead.
- If the package being used has mold compound extending onto package leads, the 0.5mm spacing should still be held between the end of the mold compound and the clamp location

Clamp, fixturing, and bend process must be designed to not apply any stress between the body and the leads of the device. Considerations should be made for part tolerances and tool wear-out to ensure this under all conditions.

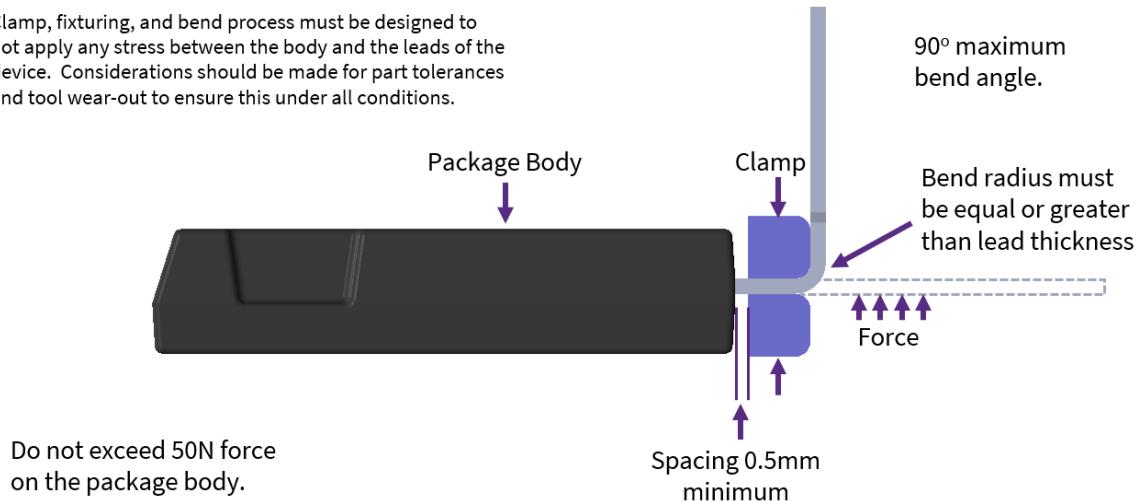


Figure 4: Clamping Requirements for Lead Bending

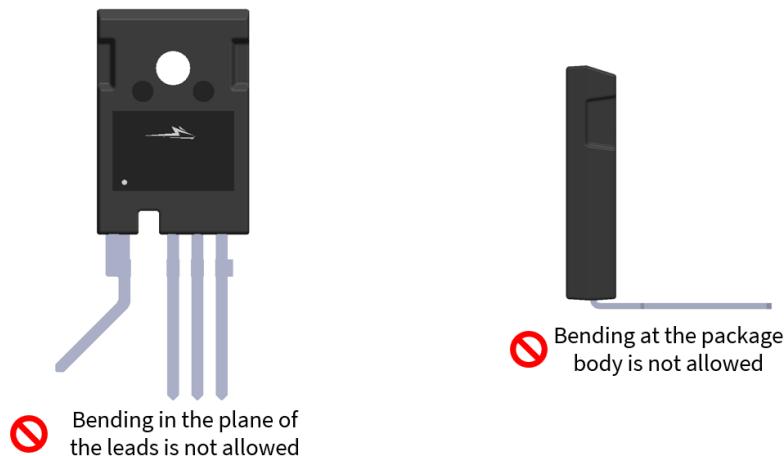


Figure 5: Poor Lead Bending Examples

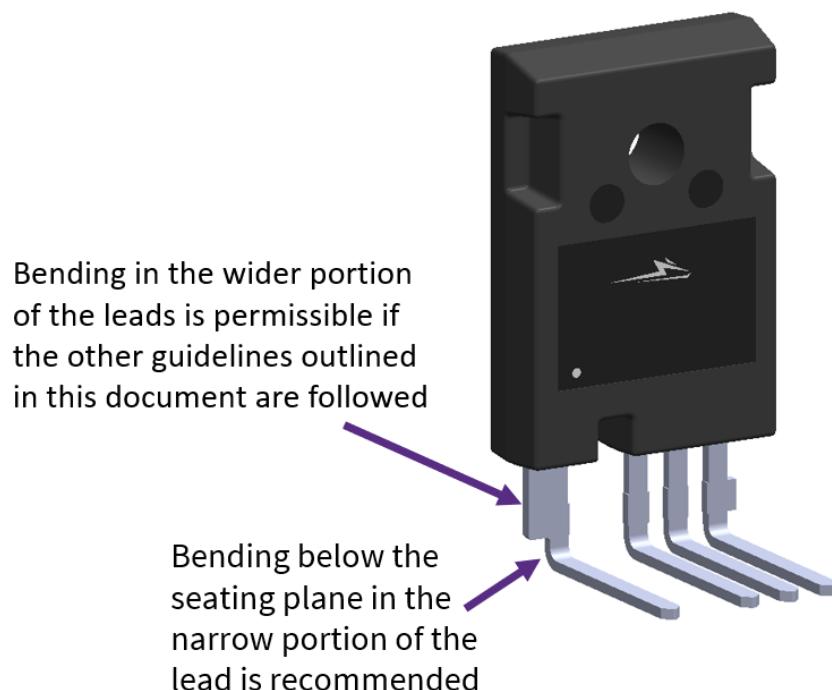


Figure 6: Recommended Bending Position

These lead bending guidelines must be followed to avoid damage to the device. The lead bending and cutting procedure should be qualified and tested to ensure the process is repeatable and does not damage the device or leads

## 4. MOUNTING OF TO-247 PACKAGES

Many different factors contribute to the assembly quality of a THD package, including:

- Hardware
- Thermal interface materials
- Heatsink and PCB quality
- Insulating material (if necessary)
- Mounting torque
- Soldering method

Any of these individual factors can cause less than ideal performance in an assembly if attention to detail is not prioritized. THD parts are typically inserted into the PCB with automated placement equipment or manually by a technician. Avoiding any damage or additional bending to the leads is critical during this step of the assembly process. Appropriate design of the PCB is needed to account for any tolerances in the package leads including lead diameter and pitch and the properties of the solder being used. For more details about the recommended soldering process please see PRD-05653 “Soldering Recommendations for Wolfspeed Power Devices”.

### Heat Sink Mounting

Through-hole packages are typically attached to a heat sink to improve the thermal performance of the device using either a screw, clip, or pressure bar depending on the application. The first method of attachment is using a screw through the hole in the middle of the package body. A basic diagram of this setup can be seen below:

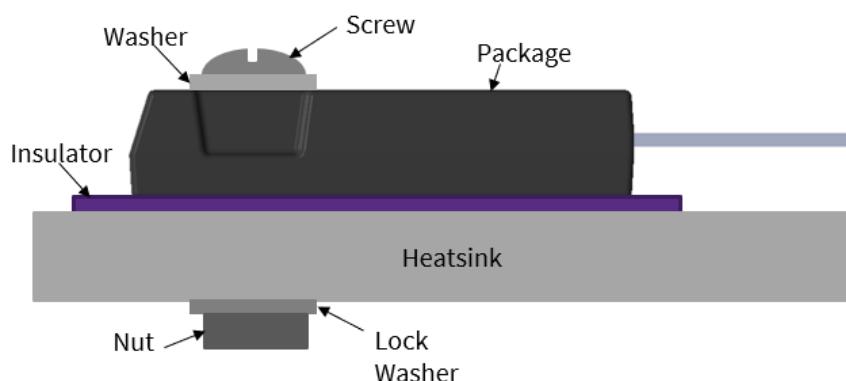


Figure 7: Screw Mounting of a Through-Hole Package

It is recommended that a washer is used between the screw head and the package body to distribute the clamping force and prevent damage to the package body. A compression washer and nut are also recommended for use, although a tapped heat sink is acceptable. In the case of a tapped hole in the heatsink, a compression washer should be added between the screw head and the flat washer. The compression washer should be designed and tested to maintain consistent clamping force between the package and heatsink over time accounting for any thermal cycling and vibration that may occur in the application.

For the best thermal performance possible, adequate and consistent contact pressure between the package and heat sink is critical to minimize contact resistance. Proper torqueing of the screw will lead to the desired contact between the two surfaces, but care must be taken not to over-torque. Over-torqueing can lead to damage to the package body as well as deformation of the isolation foil which can cause tilting of the package and reduced thermal performance. In general, Wolfspeed recommends a screw torque of 0.7Nm for through-hole packages with a maximum torque of 1Nm. The process and tools used to torque the screws should be accurate and repeatable to prevent damage. Self-tapping screws can have inconsistent clamping forces and should not be used for these applications. The design of the heat sink and insulation are also important and should be as flat and clean as possible to allow good thermal contact to occur. For best results, the heat sink should be manufactured with the following characteristics:

- Surface roughness of 10µm
- Flatness of less than 20µm per 100mm
- Machined using proper tools and quality control methods
- Assembled in a clean environment

One disadvantage of the screw mounting method is the reduced electrical creepage distance from the back tab of the device to the heatsink through the screw. This often limits the application of a screw mount to lower voltage applications.

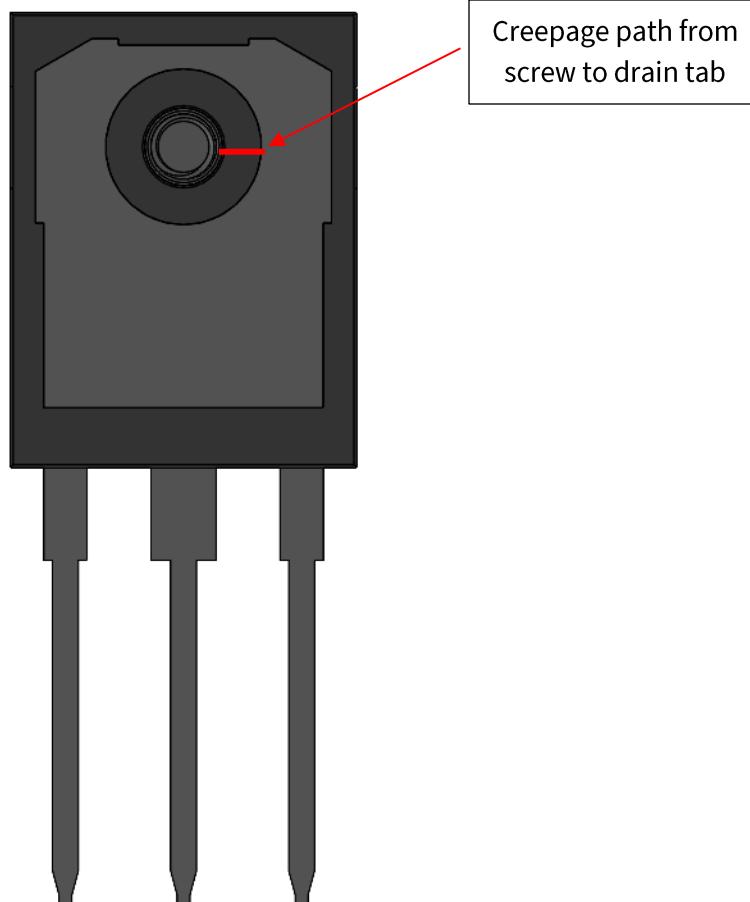


Figure 8. Creepage on Screw Mounting TO-247

Spring clips can also be used to mount through-hole packages to the heat sink. This attachment method has become popular due to its straightforward and reliable assembly which is suitable for mass production. Two basic diagrams of popular clip mounting designs can be seen below, a retaining clip and a Maxclip style:

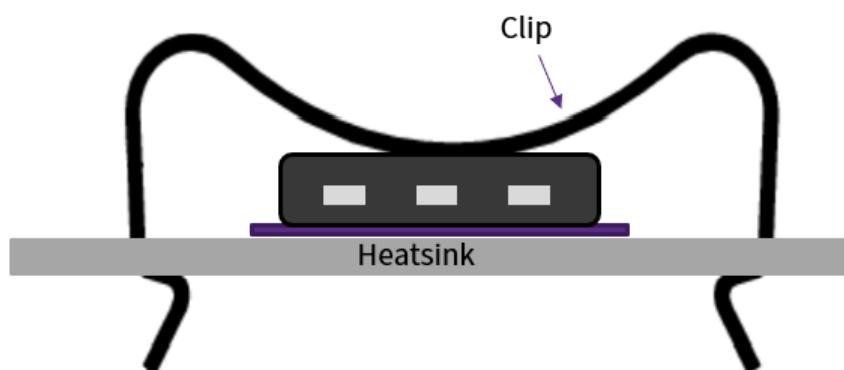


Figure 9: Retaining Style Spring Clip

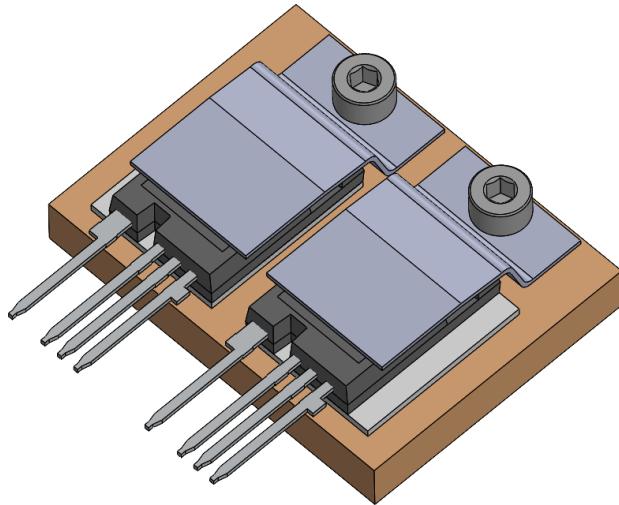


Figure 10. Maxclip Style Spring Clip

Clip mounting provides a uniform contact pressure across the package body which reduces the chances of the package tilting and mitigates the concern for over or under tightening. When using a clip to mount the package to the heatsink, a 15N minimum clamping force is suggested to provide adequate thermal contact with a maximum pressure of 150 N/mm<sup>2</sup>. The clips used should be rounded with a smooth finish where it contacts the package to reduce concentrated loads. Adequate contact on the package is important to prevent potentially damaging or cracking the mold compound. The contact area for the clip should be located between the screw hole and the bottom of the package where the leads exit. This will provide the maximum clamping force in the area where the die is located in the package. There are numerous clip solutions available that can be used to mount a through-hole package to a heat sink including saddle clips, U clips, heatsink anchored clips, and clips with a screw.

Pressure bars are also another common mounting method used on through hole packages in the power industry. A pressure bar sits across numerous packages and applies equal pressure to each by way of screws through the bars into the heat sink. The metal bar used must be designed to be flat and have little to no bow to prevent unequal pressure distribution among packages and to reduce stress on package edges. Failure to do this may result in increased thermal contact resistance or damaged package molding. A basic diagram of a pressure bar set up can be seen in Figure 11 below:

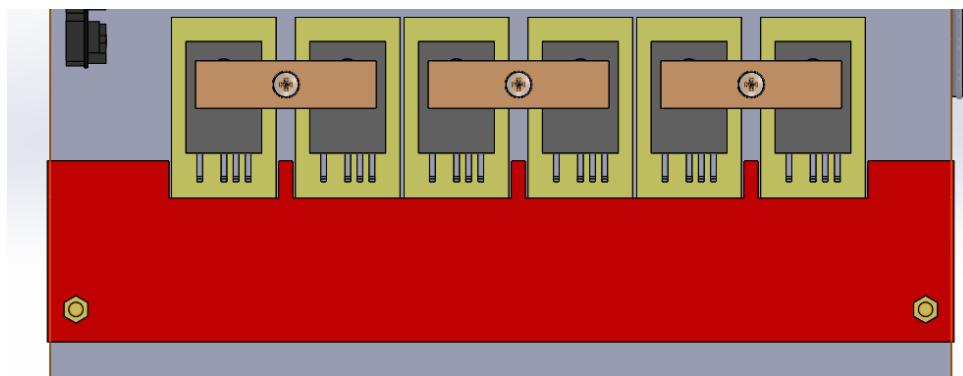


Figure 11: Heatsink/Baseplate Assembly with Insulator and Pressure Bars.

Isolation is another factor that should be considered in the heatsink assembly design. For many applications with 650V devices where only functional isolation is required, mounting the device to the heatsink with a screw and shoulder washer is a cost-effective solution. Figure 12 shows a typical assembly using this method:

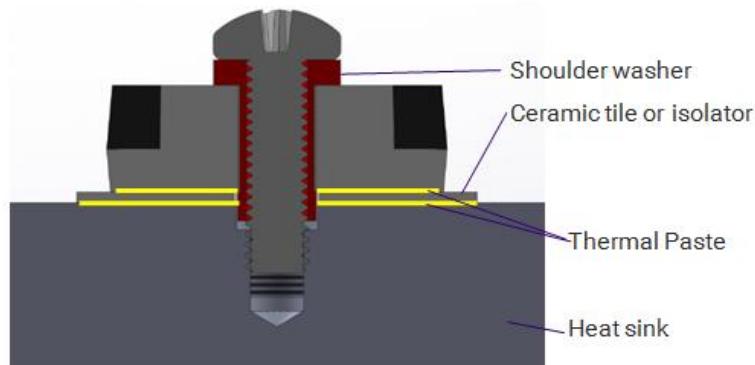


Figure 12: Cross Section Mounting View with the Insulating Shoulder Washer.

With 1200V or higher devices, a clip or pressing bar solution is more cost effective since the screw mounting often cannot meet the requirement for creepage.

For applications requiring basic safety isolation, an isolating thermal interface material needs to be used between the package and the heat sink. The TIM material should extend beyond the package, exposed drain ears, and leads sufficiently to meet the minimum creepage per the applicable safety requirement for the system and account for the maximum assembly tolerance in manufacturing. Typically, a distance greater than 4mm is required for 800V systems.

## 5. THERMAL MANAGEMENT TECHNIQUES

This section of the document discusses mounting and isolation methods in general. It is the customer's responsibility to ensure that the design conforms to all required isolation, safety, and mechanical standards or practices for their application.

There are two general ways to design the heatsink into a system with SiC through-hole devices. The first method is to have the heatsink either electrically floating or connected to one of the high-voltage rails (usually -BUS) in the system. In this case, only functional isolation is required for the heatsink assembly. The second method is to ground the heatsink to protected earth (PE) or chassis in the system. In this case, the requirements of the isolation between device and cooling plate will be related to the safety standard requirements, such as IEC-60664-1, which may require basic or reinforced isolation.

The difference between functional isolation and safety isolation is that safety isolation has clear requirements for creepage and clearance, while functional isolation has no formal third-party requirements in most applications.

In many cases, isolation will be required between the power device and heatsink, since the mounting surface of the THD package is connected to the drain terminal for a MOSFET, or the cathode for a Schottky diode. Adding isolation will increase the thermal resistance of the case-to-heatsink interface, so it is important to understand the different thermal interface materials and mounting methods available to find the optimal solution for each design. Without proper thermal management, the design may require a lower  $R_{DS(on)}$  MOSFET (or higher  $I_F$  diode) to reduce the power loss and junction to case thermal resistance to meet the thermal requirements, potentially resulting in higher system cost.

As shown in Figure 13, the actual junction temperature is not only related to the power loss and the junction to case thermal resistance of the device, but it is also related to the Case-to-Heatsink thermal resistance and temperature of the heatsink.

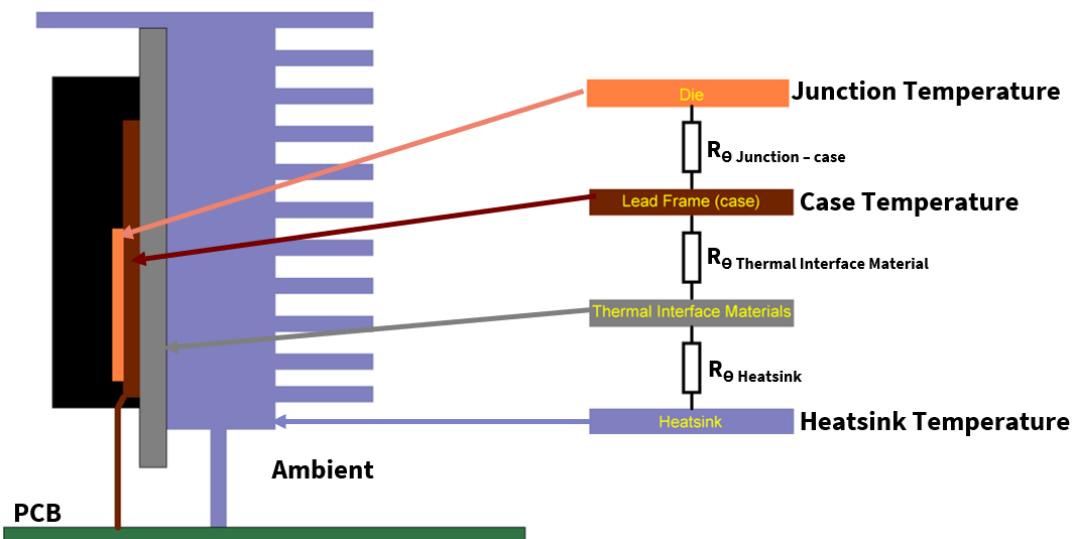


Figure 13: Thermal Resistance From Junction to Heatsink

The Case-to-Heatsink thermal resistance depends on the area of the drain tab of the devices, the thermal interface material (TIM) selection, and the mechanical pressure to mount the device on the heatsink. There are numerous isolating TIM materials available, including silicone rubber [2], ceramic pads (Aluminum Oxide or Aluminum Nitride Ceramic) [3], and Kapton® tape coated with a phase change or grease material – among others.

Ceramic pads generally have better thermal conductivity than the other solutions, even though they tend to be significantly thicker than the other options. The thermal resistance of ceramic pads is lower due to the material's much higher thermal conductivity. When using a ceramic pad, both sides of the pad need to have thermal grease applied to provide a good interface between the device and heatsink. For a TO-247 package, the case-to-heatsink thermal resistance can be 0.2~0.5 K/W, depending on which ceramic material is used, the thermal grease, and the flatness of the heatsink. With a typical 1mm thickness, the parasitic capacitance from the drain to the heatsink is also much smaller compared to thermal pads, which will reduce common mode noise coupling. Ceramic pads are brittle and require careful handling and assembly to avoid cracking. Ceramic pads are well suited for high-power applications where the requirements for thermal performance and EMI are very demanding. Flexible pads are better suited for lower power ratings, large sizes, or complex mechanical structures due to their flexibility. Figure 14 shows the thermal resistance of different isolating thermal pads from Bergquist with different pressure on a TO-220 power device [2].

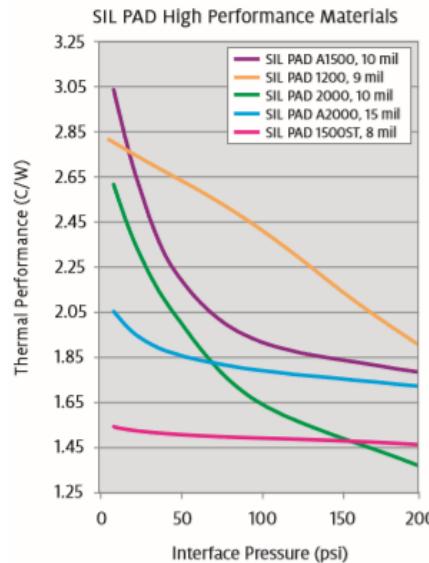


Figure 14: Thermal Resistance of Different Sil-Pad® Insulators with Different Pressure.

Table 3 shows the thermal resistance, breakdown voltage, and temperature range of some Sil-Pad® insulators from Bergquist [2]. Sil-Pad® 1500ST is the best-in-class thermal material to meet basic isolation. AlN and Al<sub>2</sub>O<sub>3</sub> are the most common ceramic pad materials. The thermal conductivity of AlN is approximately 170W/m·K, and for Al<sub>2</sub>O<sub>3</sub> it is 25 W/m·K.

	SIL PAD 1500ST	SIL PAD 2000	SIL PAD A2000	SIL PAD K-4	SIL PAD K-6	SIL PAD K-10
COLOR	BLUE	WHITE	WHITE	GREY	BLUE-GREEN	BEIGE
Thickness (in./mm)	.008 ± .001 (.20 ± .025)	.010 ± .001 (.25 ± .025)	.015 ± .001 (.38 ± .025)	.006 ± .001 (.15 ± .025)	.006 ± .001 (.15 ± .025)	.006 ± .001 (.15 ± .025)
Thermal Performance TO-220 Test @ 50 psi °C/W	1.51	2.02	1.86	3.13	2.76	2.01
Thermal Impedance (°C-in. <sup>2</sup> /W)	0.23	0.33	0.32	0.62	0.64	0.41
Thermal Conductivity (W/m·K nominal)	1.8	3.5	3.0	0.9	1.1	1.3
Voltage Breakdown (Vac.)	3,000	4,000	4,000	6,000	6,000	6,000
Continuous Use Temperature (°C)	-60 to 180	-60 to 200	-60 to 200	-60 to 180	-60 to 180	-60 to 180
Construction	Silicone/Fiberglass	Silicone/Fiberglass	Silicone/Fiberglass	Silicone/Film	Silicone/Film	Silicone/Film

Table 3: Thermal Resistance, Isolation and Temperature Range of Different Sil-Pad® Insulators

When analyzing the thermal requirements of a system, it is important to consider all of the tradeoffs in order to optimize the system. Selecting a smaller heatsink or fan may save cost on those components, but it could result in the design requiring a lower  $R_{DS(on)}$  MOSFET (or higher  $I_F$  diode), or a better thermal interface material

in order to meet the design targets, which will add cost. An optimized design seeks to minimize the total cost by looking at several different thermal solutions.

## 6. THERMAL MEASUREMENT OF DISCRETE SiC DEVICES

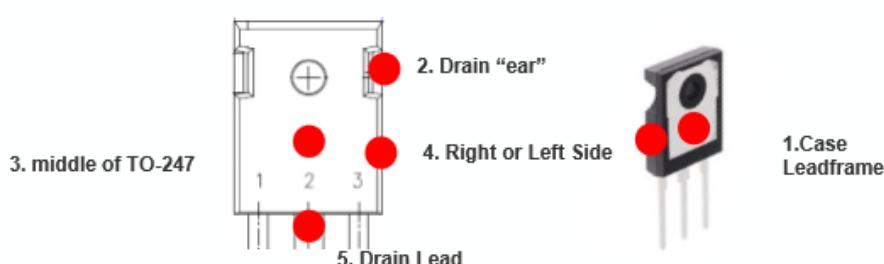
For semiconductor devices, the junction temperature is one of the key parameters to be evaluated in the qualification procedure. However, since the die is protected by the device package, normally the junction is not accessible for a direct thermal measurement. As an alternative, case temperature ( $T_c$ ) based junction temperature estimation is a reasonable approach and is shown in Equation 1 below. Power dissipation ( $P_d$ ) in the device is required in the calculation and must be calculated or measured separately. This method is verified and commonly adopted in engineering practice.

$$T_J = T_c + P_d * R_{\theta JC} \quad (1)$$

*Equation 1: Estimating junction temperature using case temperature*

However, normally the case of a power device (See Figure 2) is attached to a heatsink and is not accessible for a direct thermal measurement. Therefore, an alternative measurement position is needed for the case temperature. Alternative measurement locations were identified and verified through testing which is described below.

As shown in Figure 15, some alternative points can be considered for case temperature measurement. The drain “ear” is part of the lead frame, so it can be representative of case temperature. The mold compound is very thin at the left or right side of the package, making it very close to the lead frame so it can also be considered as a testing point. The other two options that were investigated are a point in the center of the TO-247 package face and the drain lead right at the point where it emerges from the package body.



*Figure 15: Possible Thermal Measurement Points for TO-247 SiC Devices*

To identify the relationship between the temperature of alternative points and the junction temperature, a special setup was designed. The schematic of the setup is as shown in Figure 16.

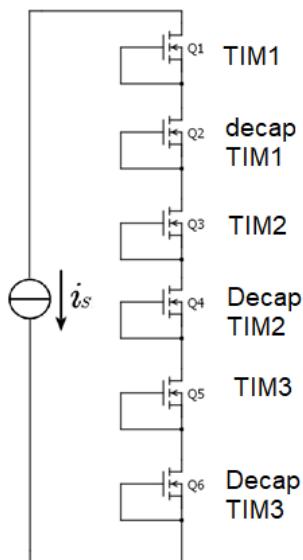


Figure 16: Schematics of the Thermal Setup for Wolfspeed® THD SiC Packages

The actual setup for thermal measurement of Wolfspeed THD Silicon Carbide packages is shown in Figure 17. Here, six packages of C3M0065090D SiC MOSFETs were connected in series and mounted to a large heatsink. The gate of each device was short circuited to its source to make sure the channels were off. As shown in Figure 17, three different thermal interface materials (TIM) were used in the test. Q1 and Q2 were equipped with Sil-Pad® 2000 from The Bergquist Company, Q3 and Q4 were equipped with 1mm AlN ceramic TIM, and Q5 and Q6 were equipped with Sil-Pad® 1500ST from Bergquist. To expose the die for thermal measurement, partial-decapped devices were used for Q2, Q4 and Q6. Decapped parts have the mold compound removed to expose the die and lead frame. In this case, only a portion of the mold compound was removed to allow for thermal imaging of the die, but still maintain a surface for clamping the package to the heatsink.

A constant DC current of 9.24A was applied to the devices through the body diode. The power loss on each device is the result of the voltage drop of the body diode and the source current. In this test, all devices have exactly the same source current and similar voltage drops, resulting in power loss on the devices being very similar to each other. As shown in Figure 17, the drain ear, middle of molding compound, side of molding compound, drain lead, the die (for the decapped devices) and the heatsink (close to each DUT) are painted in black before conducting the test to enable infrared thermal measurements on the different surfaces.

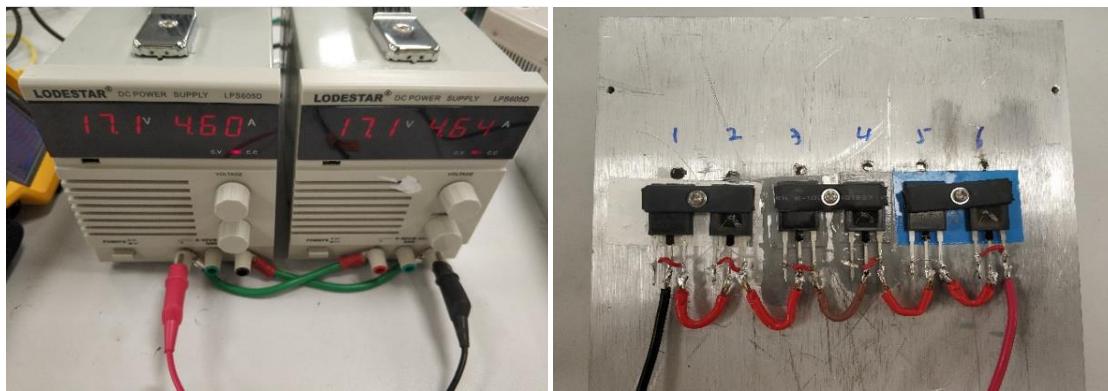


Figure 17: Actual Setup for Thermal Measurement of Wolfspeed® TO-247 SiC Devices

The first portion of the test was to simulate convection cooled situations in outdoor applications, with no air flow at all applied to the heatsink and devices. The temperature of the heatsink, drain ear, middle of molding compound, side of molding compound, drain lead and  $T_J$  (for the decapped devices) were measured with a thermal camera. Figure 18 shows the measurement of  $T_J$  directly using a thermal camera. The voltage drops on each device were also recorded to allow for calculating the actual power loss in each device. Table 4 on the next page shows the results of this test. The drain lead has a slightly lower temperature than drain ear, while the middle and side of the package have higher temperatures.

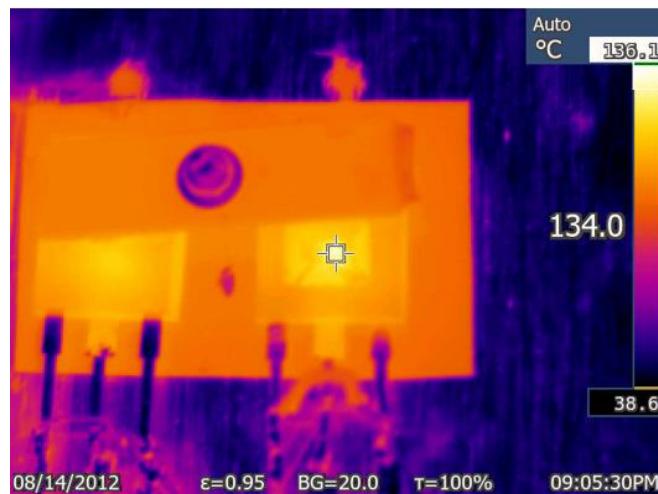


Figure 18: Thermal Measurement of Wolfspeed® TO-247 SiC Devices

Description	Q1	Q2 Decap	Q3	Q4 Decap	Q5	Q6 Decap
<b>TIM</b>	Sil-Pad® 2000		AlN 1mm		Sil-Pad® 1500ST	
<b>Drain Ear (°C)</b>	114.6	115.5	102.6	102.7	110	109.4
<b>Middle of package (°C)</b>	121.1	--	108	--	116.8	--
<b>Right side of package (°C)</b>	118.2	119.5	106.2	107.4	112.9	113.9
<b>Drain Lead (°C)</b>	112	113.4	99.5	101.5	107.6	107.1
<b>Die Temperature <math>T_J</math> (°C)</b>	--	140	--	127.2	--	134
<b>Heatsink (°C)</b>	88.5	89.1	91.6	91.8	91.4	91.1
<b>Power loss on the device (W)</b>	27.07	26.31	26.48	26.21	25.87	26.80
<b>Heatsink to Drain Ear (case) Rise(°C)</b>	26.1	26.4	11	10.9	18.6	18.3
<b>Junction to Case Rise(°C)</b>	--	24.5	--	24.5	--	24.6
<b>TIM Thermal resistance(°C/W)</b>	0.964	1.004	0.415	0.416	0.719	0.683
<b>Measured Junction to Case Thermal Resistance (°C/W)</b>	--	0.931	--	0.935	--	0.918

Table 4: Thermal Test Results on Wolfspeed® C3M0065090D TO-247 SiC Devices with Different TIM

Table 5 shows the resulting estimated junction temperature using each of the possible measurement points on Q3 and the  $R_{\theta JC}$  value (1°C/W) from the datasheet according to Equation 1. The result is then compared to the measured  $T_J$  on Q4 (127.2°C), which should be very similar to Q3  $T_J$ . These results show that the drain ear and the drain lead can be used to estimate  $T_J$  with good accuracy in this condition.

Description	Q3 Measured	T <sub>J</sub> Calculated	T <sub>J</sub> Estimation Error
<b>Drain Ear (°C)</b>	102.6	129.1	+1.9
<b>Middle of package (°C)</b>	108	134.5	+7.3
<b>Right side of package (°C)</b>	106.2	132.7	+5.5
<b>Drain Lead (°C)</b>	99.5	126	-1.2

Table 5: Using Various Package Temperatures to Estimate  $T_J$

In addition, to simulate indoor applications with forced air cooling, air flow was applied to the surface of devices with varying fan power, which represents varying air flow speeds. Airflow over the top of the package can impact the temperature readings because there will be a larger temperature gradient between the die and the package in this scenario. For this test, only Q3 and Q4 were analyzed, and the results are shown in Table 6. The result is similar to the previous case without air flow as the temperature of the middle of the package, side of the package, and drain lead are close to drain ear measurement. However, the equivalent thermal resistance  $R_{\theta JC}$  and the thermal resistance case-to-heatsink becomes smaller since more power dissipation has gone through the top side molding compound and leads. If the datasheet  $R_{\theta JC}$  is used to estimate  $T_J$  by applying Equation 1 under forced air condition, the estimated  $T_J$  will be higher than actual value.

Description	Q3	Q4	Q3	Q4	Q3	Q4
	Decap		Decap		Decap	
<b>Air Flow</b>		None		4W cooling fan		15W cooling fan
<b>TIM</b>		AlN 1mm		AlN 1mm		AlN 1mm
<b>Drain Ear (°C)</b>	102.6	102.7	72.2	72.5	58.8	59.9
<b>Middle of package (°C)</b>	108	--	75.1	--	61.2	--
<b>Right side of package (°C)</b>	106.2	107.4	73	74.1	59.4	60.4
<b>Drain Lead (°C)</b>	99.5	101.5	72.9	72.1	60.8	60.3
<b>Die Temperature <math>T_J</math> (°C)</b>	--	127.2	--	96.4	--	82.5
<b>Heatsink (°C)</b>	91.6	91.8	61.5	61.7	50.2	50.5
<b>Power loss on the device (W)</b>	26.482	26.205	26.24	25.96	26.15	25.87
<b>Heatsink to Drain Ear (case) Rise(°C)</b>	11	10.9	10.7	10.8	8.6	9.4
<b>Junction to Case Rise(°C)</b>	--	24.5	--	23.9	--	22.6
<b>TIM Thermal resistance(°C/W)</b>	0.415	0.416	0.408	0.416	0.329	0.363
<b>Measured Junction to Case Thermal Resistance (°C/W)</b>	--	0.935	--	0.920	--	0.874

Table 6: Thermal Test Results on Wolfspeed® TO-247 SiC Devices at Different Air Flow Conditions

Table 7 shows the error in  $T_J$  estimates for the 4W and 15W cooling fan scenarios. These results show that when there is airflow over the surface of the package, the resulting  $T_J$  estimate will be slightly high since the effective thermal impedance of the device will be lower than what is stated in the datasheet.

Description	$T_J$ Estimation Error	$T_J$ Estimation Error
<b>Fan Power</b>	4W	15W
<b>Drain Ear (°C)</b>	+2.0	+2.4
<b>Middle of package (°C)</b>	+4.9	+4.8
<b>Right side of package (°C)</b>	+2.8	+3.1
<b>Drain Lead (°C)</b>	+2.7	+4.4

Table 7: Using Various Package Temperatures to Estimate  $T_J$

Depending on how the device is mounted in the application, some parts of the package may be more accessible for thermal measurement. If the drain ear is not available, the center or side of the package, or the drain lead can be used to estimate case temperature. This test data shows that several points on the device package can be used to estimate the junction temperature of the device with reasonably good accuracy when the devices are mounted to an air cooled heatsink.

## 7. SUMMARY

Following the mounting guidelines stated here in conjunction with other assembly best practices, such as a proper thermal design and thermal measurement, will help the customer create a robust and effective assembly that optimizes system-level performance when utilizing Wolfspeed through-hole devices.

Understanding how to properly measure case temperature and estimate junction temperature are critical for designing highly reliable systems. Developing a thermal solution requires careful consideration of the heatsink, TIM, grease and assembly of these components to keep the power device in a safe temperature range of operation. This guideline is applicable to all Wolfspeed THD discrete devices.

## References

- [1] Datasheet of C3M0040120D, [www.wolfspeed.com](http://www.wolfspeed.com)
- [2] Selection Guide Thermal Interface Materials from Bergquist
- [3] Digikey, <https://www.digikey.com/catalog/en/partgroup/aluminum-oxide-ceramic/51058>
- [4] Ref Design, “22kW Bi-directional High Efficiency DC/DC Converter”,  
<https://www.wolfspeed.com/power/products/reference-designs/crd-22dd12n>

## Revision History

Date	Revision	Changes
Feb. 2022	1	First issue
May. 2023	2	Added Mounting Sections
February. 2025	3	Added TO-3PF-3L, TO-220-F2, TO-247-4 Plus, and TO-247-4L LP package images and note