

Mounting and Cooling Solutions for SMPD Packages

Objectives

This application note discusses various mounting solutions for Surface Mount Power Device (SMPD) packages. Mounting instructions are provided for single- and multi-device mounting respectively. A view into tolerances explains important detail when designing around the SMPD. A brief explanation of a procedure is given to determine the thermal resistance with a given design by conducting a simple experiment.

Applications

- Motor drives
- PV inverters
- UPS systems
- DC-DC converters

Target Audience

This document is intended for potential adopters of power semiconductors in the SMPD package who want to determine the appropriate mounting and cooling solution to ensure proper package mounting and thermal performance.

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1. Introduction

The Surface Mounted Power Device (SMPD) package is an innovative solution that was introduced by IXYS (A Littelfuse Technology) in January 2013. SMPD expands the ISOPLUSTM package family for power semiconductor devices. It features Direct Copper Bonded (DCB) substrate with copper lead frame, aluminum bond wires, and a plastic molding compound. The DCB substrate inherently offers electrical insulation and allows multiple semiconductor chips on one substrate to form different circuit topologies. Combining a copper lead frame with aluminum bond-wires results in a surface mounting type of device for simplified soldering and assembly. The plastic mold compound provides excellent sealing and semiconductor protection. The backside copper of the DCB substrate is exposed and acts as large-area connection between the semiconductor and a heat sink. An illustration of the SMPD package is shown in **Figure 1**.

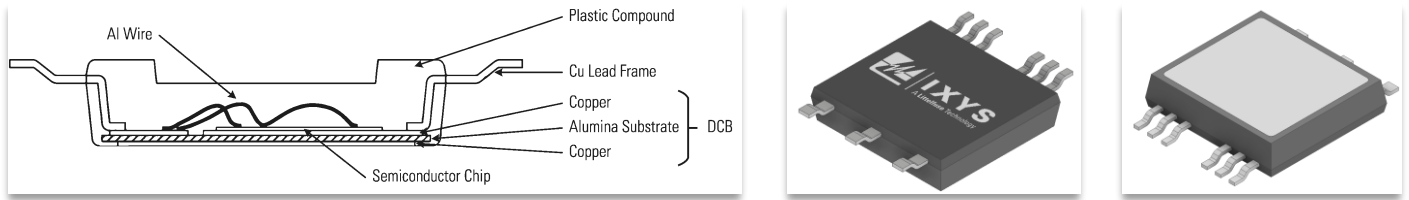


Figure 1. SMPD Package Illustration

The SMPD package provides unique features for power electronic applications. These include:

- High electric insulation strength of 2500 V
- Lower thermal resistance compared to standard packages like TO-247 or TO-264
- Enhanced flexibility regarding customized topologies
- Higher current carrying capability compared to TO-style packages
- Internal construction is designed to reduce parasitic effects like stray inductance and parasitic capacitances, leading to improved EMI-performance

All these advantages make the SMPD package an exceptional candidate for both Si and SiC power semiconductors.

2. Recommended PCB and Heat Sink Assembly

The SMPD package is a surface mounted package. The devices are soldered to PCB in state-of-the-art processes. A layer of Thermal Interface Material (TIM) is needed to ensure a high thermal conductivity from the thermal pad to the heatsink. After soldering and applying TIM is completed, the assembly can be mounted to a heatsink by mounting screws. An example of heat sink assembly is shown in **Figure 2**.

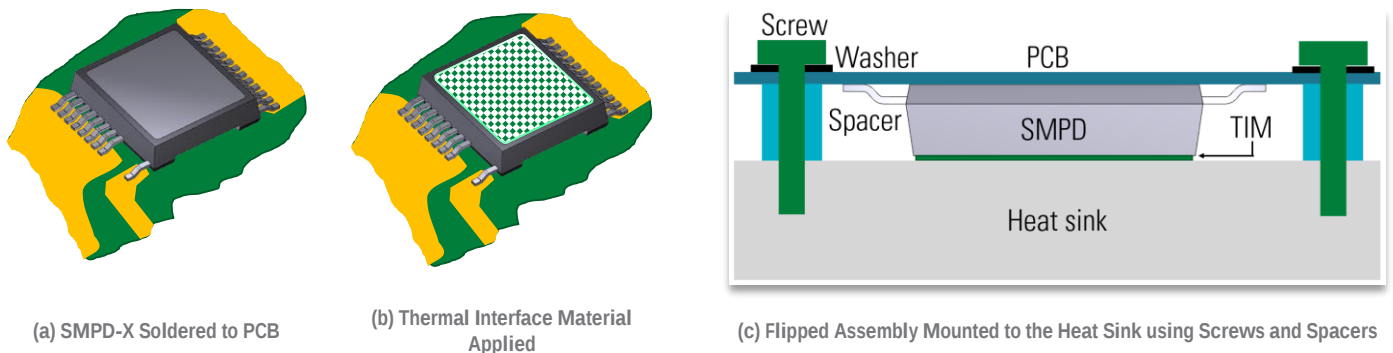


Figure 2. Sequence of Mounting the SMPD to a Heat Sink

2.1. Soldering Instructions

As SMD-components, all SMPD-packages can be soldered using three different approaches:

- Selective soldering with a soldering iron set to 260-287°C -- Take care to ensure that heating power and thermal capacity of the soldering iron are suitable for the size of the component. Apply heat to the pins for no longer than 10 seconds.
- Wave-soldering using a temperature profile according to IEN61760-1 -- Protect the DCB-area from capturing solder alloy. Kapton-style tape can be attached to prevent contamination.
- Reflow-soldering using a temperature profile as described in IPC/JEDEC J-STD-020E

Littelfuse strongly recommends using lead-free soldering alloys that are RoHS and REACH compliant.

2.2. SMPD Layout Recommendations

The SMPD-B package can carry a variety of topologies including single switches, co-packs of switch and freewheeling diodes, and more complex topologies like booster-stages or half bridges. As an example, **Figure 3** displays the SMPD-B with an integrated 1200V IGBT-based half-bridge. The SMPD-B-package is designed for applications with a working voltage up to 630V_{rms}.

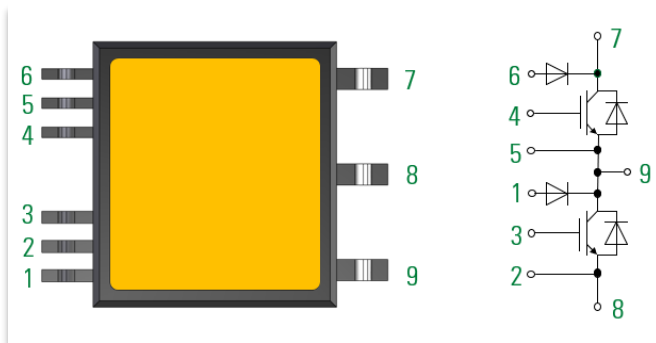
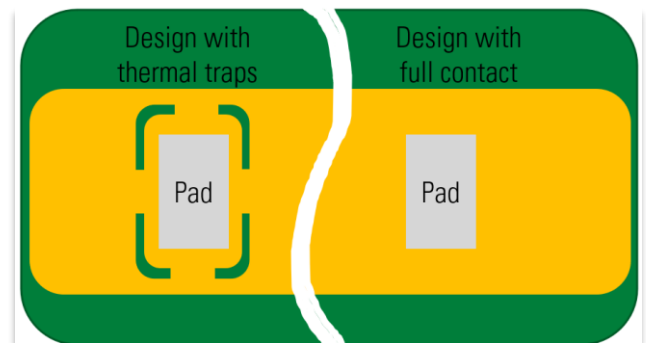


Figure 3. SMPD-B Package Outline and Topology, IXA40PG1200HGLB



(a) With thermal traps

(b) With full contact

Figure 4. Solder Area

Using shapes with rounded corners as soldering pads is considered good practice. As the SMPD-B package is used in high voltage applications, rounded corners help reduce the electric field stress seen on rectangular corners. The high voltage pads are pins 7, 8, and 9. A corner radius of 0.6mm or 25mil is recommended. The same practice is advised for the angles of PCB traces and copper polygons.

A common approach involves applying thermal traps in larger copper areas to improve the soldering process. These traps, as seen in **Figure 4**, prevent the heat from soldering to escape into larger copper areas and thus help to prevent the formation of cold solder spots. Inherently, the cross section available to carry electric current is reduced.

Care has to be taken to design the thermal traps large enough to efficiently block the heat during soldering and at the same time small enough to keep a sufficient cross section to carry current.

The SMPD's internal construction is designed to also carry heat to the pins during operation to enhance cooling. Thermal traps at the pins may prevent this heat from being dissipated properly; therefore, a design with a full contact area is preferred.

2.3. Isolation Management

Two major parameters require to be considered when PCB-layouts are designed:

- Clearance – the shortest possible distance between two points, and
- Creepage distance – the shortest path from one point to another point along an uninterrupted line on solid material

In high-voltage environments, arcing between different voltage levels has to be prevented. Arcing takes place over air-gaps – clearance distances – so the voltage level expected in the final system defines the distance between pads and traces as well as between active areas and heat sinks or other grounded parts. Even if the clearance between two points is chosen to be high enough, the insulation strength can be reduced by conductive particles over a longer period. This depends on the degree of pollution, which relates to the ambient conditions the device is used in.

IEC60664-1 gives an insight about the relevant conditions that need to be considered to determine the creepage and clearance distances in a targeted design.

2.4. Use of Thermal Interface Materials

The use of Thermal Interface Materials (TIM) is mandatory to achieve a suitable contact between the device's base and the heat sink surface. It reduces the thermal resistance case-to-heatsink, R_{thch} . Thermal interface materials are available as thermal pad and thermal grease/compound. Unlike the discrete packages where the copper cooling pad is usually electrically active, SMPD packages feature a DCB structure which uses a layer of ceramic as electrical isolation. With up to 2500 V isolation voltage, the package provides the option to use electrically non-isolated thermal interface materials. It is not recommended to use an interface material with isolation such as silicone-pads used for discrete packaged devices. These materials inherently exhibit a higher thermal resistance compared to thermal grease/compound or conductive thermal pads.

The thermal interface materials should be applied evenly to the device base plate or the heat sink surface. Ideally, screen printing is used to achieve accurate and reproduceable results.

As no electrical isolation is required from the TIM layer, it is recommended to have a very thin layer of TIM so that the material just fills the gaps and voids between the device's copper pad and the heatsink, as seen in **Figure 5**.



Figure 5. Improving Thermal Transfer by using Thermal Interface Material (TIM)

If a solid thermal pad is considered, softer materials with high thermal conductivity are preferred to better fill the gaps. The thermal pad should be as thin as possible to provide the lowest possible thermal resistance. The mounting mechanism also needs to provide proper pressure on the thermal interface material to ensure a low value of thermal resistance.

2.5. Heat Sink Preparation

When the SMPD package is soldered to PCB, the copper side of the DCB substrate remains exposed for better thermal management. A heatsink needs to be mounted for heat dissipation, as shown in **Figure 6**. There are no mounting holes in the SMPD package; therefore, the heatsink should be mounted using screws or similar mechanical ways close to the package. Corresponding holes in the PCB need to be part of the layout.

To ensure a low value of thermal resistance, the contact surface of the heat sink must be flat, even, and clean. For the mounting area, the surface quality has to achieve or exceed the values given in **Figure 6**.

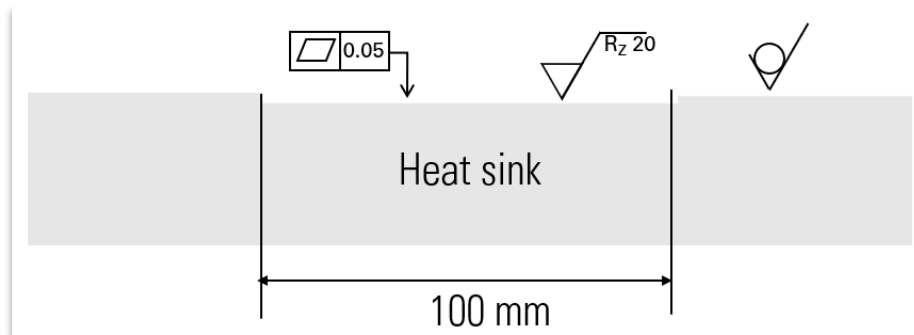


Figure 6. Heat Sink's Surface Requirements to Mount an SMPD

Prior to mounting, cleaning the surface with a suitable cleaning agent is advised.

3. Recommended Mounting Methods

Mounting an SMPD can conveniently be done in a multitude of ways using well-established methods. Screws, rivets, or clamps can be used as long as the pressure needed to obtain low thermal resistance is achieved.

3.1. Mounting a Single Device using a Clamp

A single device, as used in DC-DC-converters, can be attached to a heat sink using a suitable clamp. The design is drafted in **Figure 7**.

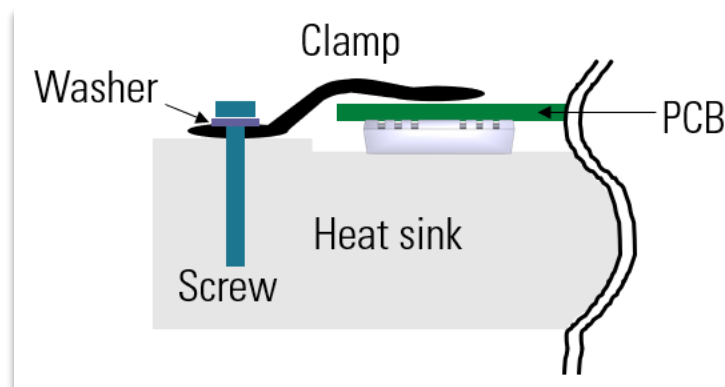


Figure 7. SMPD Mounted using a Clamp

Several manufacturers offer clamps in a wide variety of materials, shapes, and sizes that might be considered. The force applied to the module needs to safely exceed 50 Newtons. This minimum force is necessary to achieve a proper thermal connection, as the diagram in **Figure 8** reveals.

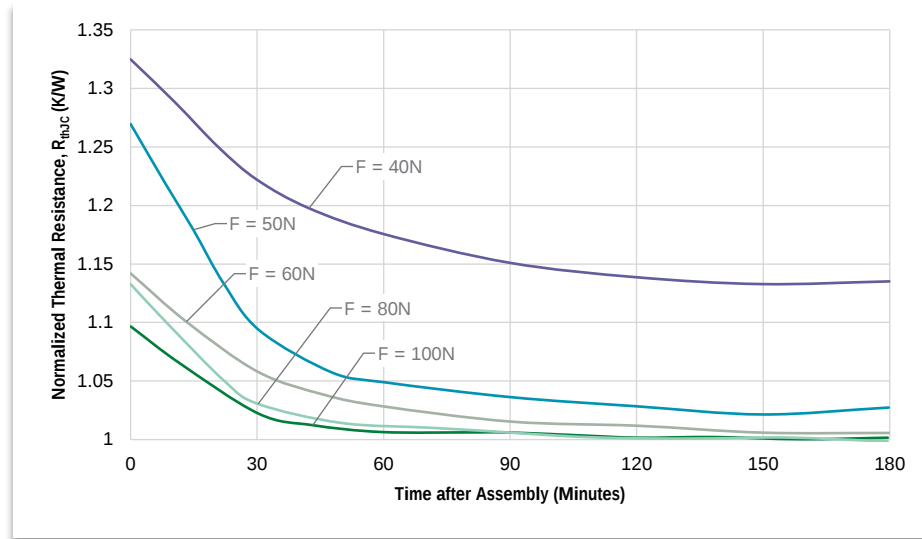


Figure 8. Correlation between Force Applied and Thermal Resistance, R_{thJC}

3.2. Mounting the SMPD using Screws

Generally, mounting the SMPD with screws, using the PCB to apply the necessary pressure is an option. When doing so, two important details need to be considered:

- an even distribution of pressure needs to be achieved to establish a suitable thermal contact
- spacers need to be in place that prevent bending the PCB too much while at the same time guarantee that the necessary pressure is applied.

Not implementing spacers can lead to unwanted bending of the PCB, as demonstrated in **Figure 9**. This needs to be prevented as the mechanical stress to the PCB and components mounted in the bent area can lead to instant defects or early failure in the field.

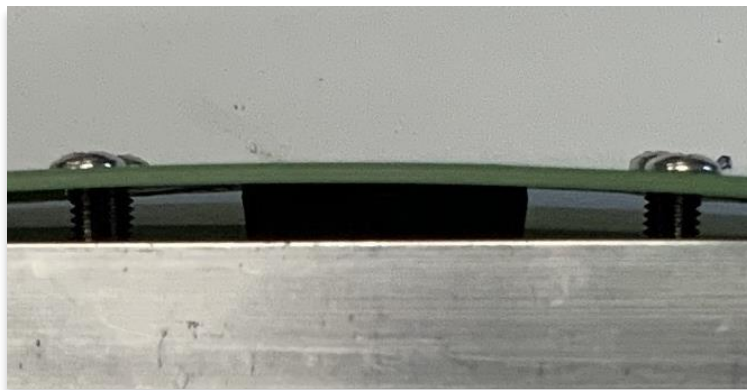


Figure 9. Bending of PCB due to Missing Spacers

In **Figure 10**, two examples are provided that are considered good practice.



Figure 10. Mounting the SMPD using Cylindrical Spacers or Screw-type Spacer Studs

While mounting a single device with just two cylindrical spacers is a simple task, aligning spacers for a PCB that holds multiple devices can be challenging. In this case, spacer studs that are screwed into the heat sink and thus remain in place, pose a good solution. Such studs are available in male/female or male/male configuration and the selection depends upon the designer's preference.

In addition, the spacer studs can be made of non-conductive material. This keeps the heat sink isolated from the PCB. Thus, a metal screw or nut holding the PCB is not galvanically connected to the heat sink. This can be a helpful feature with regards to clearance and creepage distances during PCB-routing.

This sort of consideration becomes obsolete if all parts for the assembly are electrically non-conductive. Using plastic parts for mounting still requires that the mounting forces for each device are achieved.

A detailed look into the package and spacer tolerances is necessary to guarantee a force F in the direction shown in **Figure 11**. The drawing given in the datasheets includes the package height and the correlated tolerances. For SMPD-B, SMPD-X, and miniSMPD, the details are displayed in **Figure 11**.

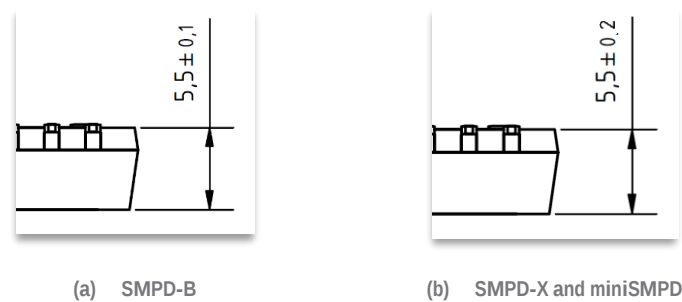


Figure 11. Package Height and Tolerances

A suitable spacer must guarantee a height which is always slightly below that of the SMPD-package. As the spacer itself has a tolerance, care has to be taken that any possible combination of package and spacer remains in a valid range.

With a SMPD-B package's height of 5.5 ± 0.1 mm, a spacer must remain below 5.4 mm, including its own tolerances. A suitable part could be a cylinder with a nominal height of 5.4 mm and a tolerance of -0.1 mm. In a worst-case scenario, this could lead to a combination of a package with 5.6 mm height and a spacer of 5.3 mm, with a difference in height of 0.3 mm. This difference grows to 0.5 mm in case of the SMPD-X and miniSMPD due to the larger tolerances of these packages.

By moving the spacer away from the package, the bending angle of the PCB can be adjusted to remain within reasonable limits. This correlation is summarized in the diagram in **Figure 12**.

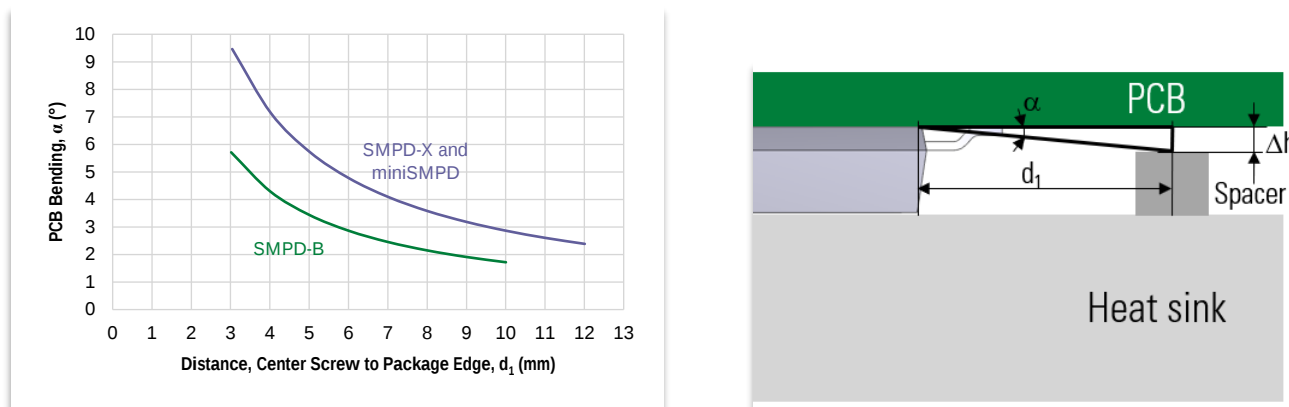


Figure 12. Impact of Spacer Distance to PCB Bending

The diagram is based on the worst-case assumption that Δh results from combining a package with a maximum thickness and a spacer of minimum length. To keep the mechanical stress low, both packages are well-served with a minimum distance of $d_1=8\text{mm}$ between the module's edge and the center of the mounting screw. As a precaution, placing sensitive components like ceramic capacitors in the stressed area should be prevented.

Note: It is not considered best practice to compensate the tolerances by adding a compressible sheet or pad of thermal interface material. If it were thick enough to compensate a gap of 0.1mm or more, the thermal transfer, and therefore performance, of the component would be reduced.

Thermal pads that are not compressible need to be considered as an additional height and add a further tolerance to the setup that needs to be accounted for.

Multiple SMPDs in a variety of topologies can be used within an individual design. A typical topology of a converter in drives applications and the correlating power semiconductors can be seen in **Figure 13**.

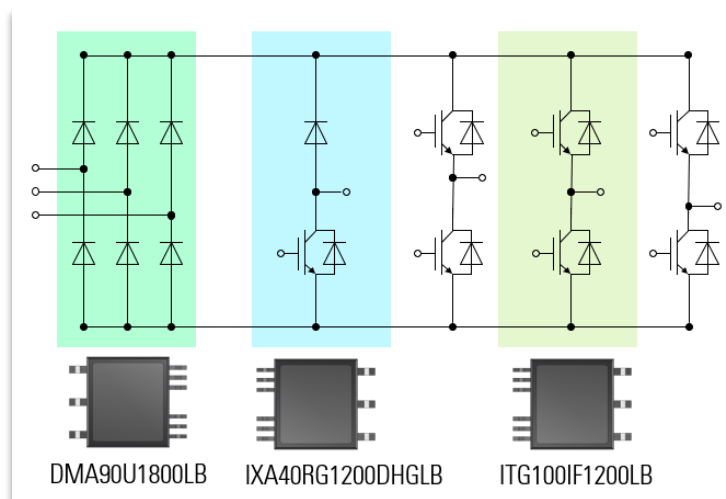


Figure 13. Power Section of an Inverter for Drives Application, Built by SMPD Devices

When mounting multiple devices, care has to be taken that the DCBs of the modules are as well aligned to the same plane as possible. Minor misalignments between the devices will be equalized due to the flexibility of the PCB.

The three power semiconductors that form the output stage in the example given in **Figure 13** are usually mounted close to each other, while the input rectifier and brake-chopper can be positioned in a location convenient for routing the PCB.

Parts aligned in a row can be fixed using screws along their center line, as shown in **Figure 14**. This can also be extended to a larger number of modules.

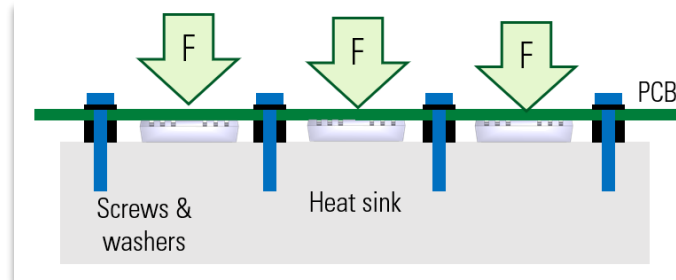


Figure 14. Mounting n Devices in a Row using $n+1$ Screws

Using a counter bracket to apply pressure to several devices is a further option when mounting multiple devices aligned in one row, as seen in **Figure 15**.

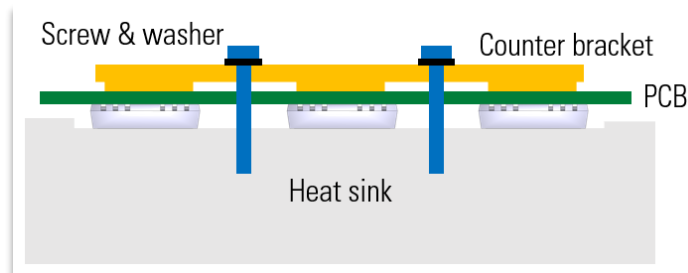


Figure 15. Multiple SMPDs Mounted using a Counter Bracket

A well-designed counter bracket applies a force only to the area covered by the module. The space between the modules remains free of pressure. Therefore, no bending of the PCB occurs, and spacers or supports are not needed.

The bracket is preferably made from non-conductive materials. Industrial thermoplastics like PBT, ASA, or ABS can be considered and first parts for evaluation can easily be created by 3D-printing. Milling brackets from solid material like paper-based plastics is another option. In mass production, customized injection-molded parts remain an option.

To keep the hole for the screws small, metric screws as small as M3 have proven to be sufficient. The use of washers and spring-lock washers is recommended to prevent loosening over time.

One suitable combination consists of:

- a metric screw M3 according to ISO 4672 / DIN 912 in a suitable length, reaching into the heat sink's thread by at least 3mm
- a washer according to ISO 7092 / DIN 433
- spring-lock washer as described in ISO 7090 / DIN 127.

For the screw, property class 6.8 or higher is recommended with a torque applied of 0.9Nm. If imperial screws are preferred, a screw 4-32 is closest to 3mm and a torque of 8lb-in is recommended.

3.3. Holistic Approach Built around the SMPD

In designs that are newly built, one further option is available. A housing, designed with suitable spring elements, can hold the PCB in place while at the same time have mechanical features that apply the desired pressure. Simultaneously, the encapsulation acts as the heat sink. **Figure 16** displays the idea in general.

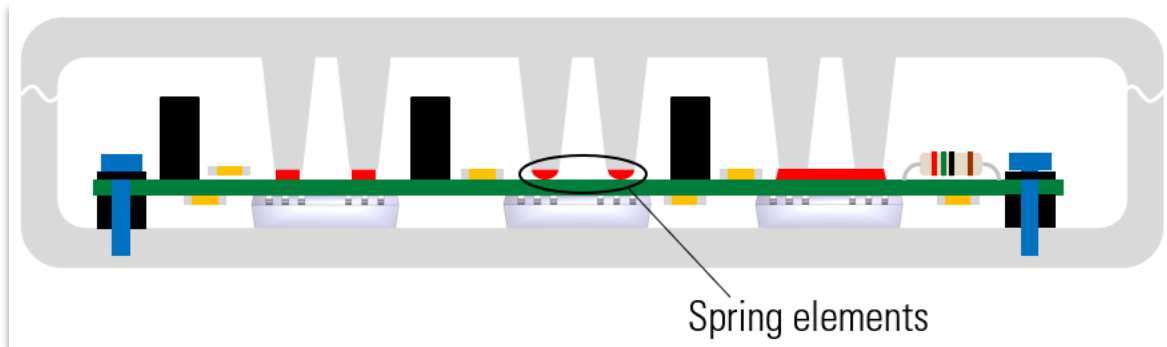


Figure 16. Multi-functional Encapsulation to Fix the PCB in Place and Apply Pressure where needed

The spring elements can be made of helical metal springs or they can be softer materials like rubber or suitable thermoplastics like TPU.

4. Thermal Performance Verification

In any application or setup, the thermal conditions are a major consideration for the semiconductor. It is important to verify that thermal interface material performs as predicted and that the semiconductor's junction temperature remains within the expected limits. To substantiate estimations based on simulations, a measurement within the given setup is needed.

As the chips within the SMPD are not accessible from outside, an indirect measurement is an appropriate way to get an insight about the thermal performance.

The procedure is about measuring the resulting sum of thermal resistances R_{thja} from the semiconductor's junction to the surrounding ambient, including thermal interface and the heat sink that is chosen for the setup. Once this value is known precisely, the chips' junction temperatures T_{vj} can be calculated from the following linear equation:

$$T_{vj} = T_{amb} + P_v \cdot \sum R_{th} = T_{amb} + P_v \cdot R_{thja}$$

In this equation, P_v represents the losses in the chip and T_{amb} is the ambient temperature.

4.1. Preparation and Calibration

First, the correlation of a die's forward voltage as a function of temperature, using a constant current, needs to be determined. The current needs to remain constant to reduce the number of variables, as the forward voltage depends on both, current and temperature.

As an example, the MCB20P1200LB featuring two MOSFETs in a half bridge configuration in an SMPD-B package is considered.

For the calibration, the device is mounted to a heat plate to precisely control the temperature. In steady state, the chip temperature and the heat plate's temperature reach the same value. Losses that heat up the chip are compensated by the heat plate's control, so that in steady state the two temperatures are the same again. Steady state is typically reached within a matter of minutes.

The MOSFETs feature body diodes as inherent part of the die. These are well-suited for the proposed procedure as their forward voltage for a given current linearly depends on the temperature. Safely turning off the MOSFET during the measurement is necessary to prevent current flowing through the MOSFET's channel as this will reduce the final result's accuracy. Applying a gate-source voltage of -5V is sufficient. **Figure 17.** includes the schematic used for calibration and the thermal dependance determined. For the measurement, the temperature was increased in steps of 10°K.

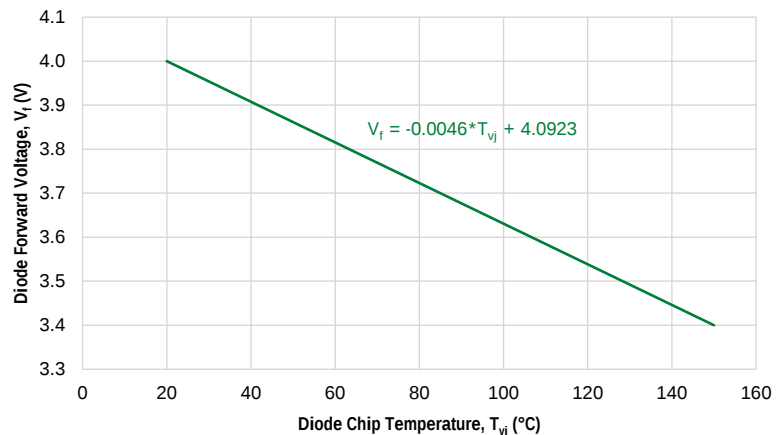
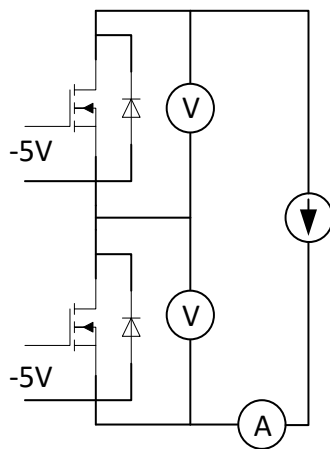


Figure 17. Schematic for the Test Setup and the Thermal Dependence Determined

The linear correlation $V_f = f(T_{vj}, I_D = 5A)$ can be rewritten into $T_{vj} = f(V_f, I_D = 5A)$.

4.2. Determining the Thermal Resistance in the Final Setup

This measurement can only be done within the final setup consisting of the mounted PCB, thermal interface material, and heat sink in place, mounted with the final technique. The process is now repeated at a known and measured ambient temperature T_{amb} . The same constant current as used for the calibration is injected into the power semiconductor and the voltage across the diode is observed until steady state is reached. This is achieved when the voltage across the diodes remains constant. Depending on the cooling conditions, this again can take several minutes.

In steady state, the losses result in $P_v = V_f \cdot I_D$. Given the linear correlation between thermal resistance, temperature swing and losses, the resulting thermal resistance R_{thja} can be calculated as:

$$P_v = \frac{\Delta T}{R_{thja}} = \frac{T_{vj} - T_{amb}}{R_{thja}} \Leftrightarrow R_{thja} = \frac{T_{vj} - T_{amb}}{P_v}$$

In applications that use the MOSFETs and the body diode, this procedure returns the value for one die that serves the function of the switch as well as the function of the freewheeling diode. This procedure can also be used on other chip technologies like IGBTs. In that case, conducting two measurements is advised as the thermal resistances of the diodes and the switches are independent.

Once the thermal resistance of the final design is known, calculations for operating points different from the calibration conditions can be done.

5. Conclusion

With the SMPD-package, Littelfuse has enlarged the ISOPLUSTM family. This portfolio of power semiconductor components allows a modular approach to set up a wide variety of power electronic applications.

Spreading the heat to larger areas enhances the thermal performance while at the same time releasing the designer from unwanted proximities, often seen in CBI-style power modules.

The isolated architecture and the combination of DCB and lead frame are key to building most compact designs in challenging applications like industrial drives or off-board EV-chargers.

The package can easily be mounted in a variety of ways, giving the designer further degrees of freedom in setting up their layouts.

For additional information please visit www.Littelfuse.com/powersemi

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