VE-Trac™ B2 SiC - Assembly Guide

AND90135/D

This document is intended to be a guide to assemble VE−Trac B2 SiC family of power modules. It covers the specifications and requirements for integrating B2 SiC modules with the major sub−components of a traction inverter, including printed circuit board assemblies (PCBA), heatsink, capacitors, sensors and bussing.

Applies to The Following Parts

− NVVRxxAxxxMxWSx

INTRODUCTION

In order to get the optimal performance from the B2−SiC power module and avoid unnecessary mechanical stress on the module, its signal leads or power terminals, it is important to follow the recommended specifications and assembly order to install the power module into the end application power converter. Proper assembly also ensures reliable operation over the designed life of the product.

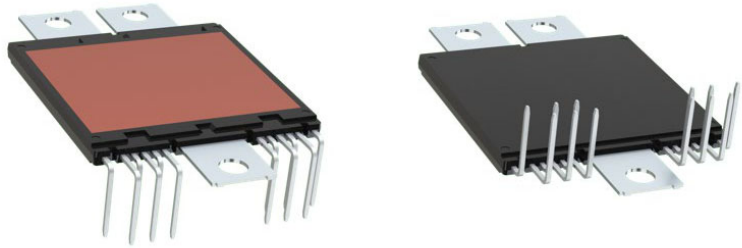


Figure 1. VE−Trac B2 SiC Power Module Referencing the Top and Bottom View

Since the product itself is only the power module, it should be noted that this guide will use an example cooler design and Printed Circuit Board Assembly to explain the assembly process. The user has the freedom to design their own coolers and other sub−components within a traction drive to meet their specific end application requirements. But the assembly order and certain specific requirements should be followed to ensure optimal performance.

Recommended mounting order for the assembly:

1. Application of Thermal Interface Material (TIM) to the cooler or the module in a controlled manner.
2. Align and place power modules on the cooler with TIM contacting the cooling side.
3. Align and place the spring pads on the modules.
4. Align, place and loosely secure the clamps on each module.
5. Secure each clamp according to the defined clamping and torqueing sequence.
6. Cure the assembly at the defined settings by the TIM manufacturer.
7. Re−torque the screws to the correct settings.

HEATSINK/COOLER REQUIREMENTS

Power dissipated in the module must be effectively removed from the module without exceeding the maximum rated operating temperature of the module as specified in its data sheet. In this section the general requirements for the cooler is explained.

General Specifications for the Cooler

- Liquid cooling is necessary to enable the full capability of the power module.
- It is necessary to use a thermal interface material between the Direct Bond Copper (DBC) to the cooler surface. It’s necessary to ensure full coverage of the DBCs to the cooler.
- The specified flatness for the module clamping area (see Figure 2) is specified as Max. Surface flatness ⏥ 50 μm, Rz ≤ 10 μm.
- Mating alignment feature must be included on the cooler (see Figure 3) to ensure the modules are properly aligned during the assembly process.
- The clamp contact area, shape, distance to module center and number of clamping points must be followed as specified.

Table 1. CLAMPING FORCE LIMITS

Clamping Area	Max. Cooler Roughness RZ [μM] Per ISO 4287	Min. Cooler Flatness [Per 100 mm] Per ISO 1101	Max. Step [μM] Per ISO 4287	Minimum Clamping Force [N]	Maximum Clamping Force [kN]
RED + BLUE AREA	10	50	10	760	7
BLUE AREA	10	50	10	760	5.4

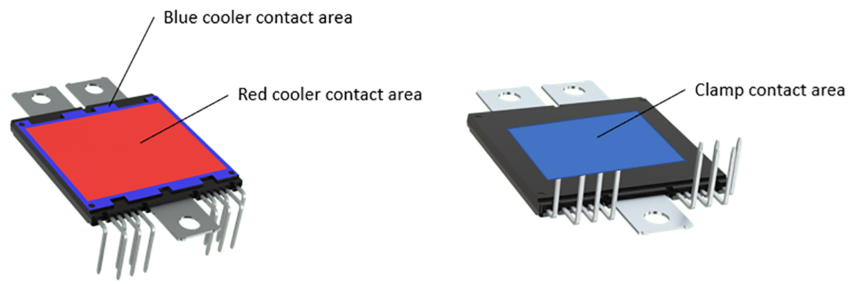


Figure 2. Illustration of the Red and Blue Cooler Contact Area on the Bottom and the Clamp Contact Area on the Top

Cooler Contact Area – In Figure 2 the area to be contacted by the cooler is shown in two shaded colors. Red color indicates the Cu area of the DBC, and the Blue area indicates the mold compound area. Both areas (Red & Blue) will be in contact with the cooler if the cooler is flat and large enough to cover the module. It is possible to design a cooler with a raised area to only contact the red area of the module or it is also acceptable to have a flat cooler and contact the red + blue contact areas. As a minimum, the module must be in contact with all the red cooler contact area. The maximum force that can be applied to the module depending on which area is contacted with the cooler is defined in Table 1. The reference cooler as shown in Figure 3 is designed to only contact the red area. Detail D in the drawing shows the raised cooler contact area.

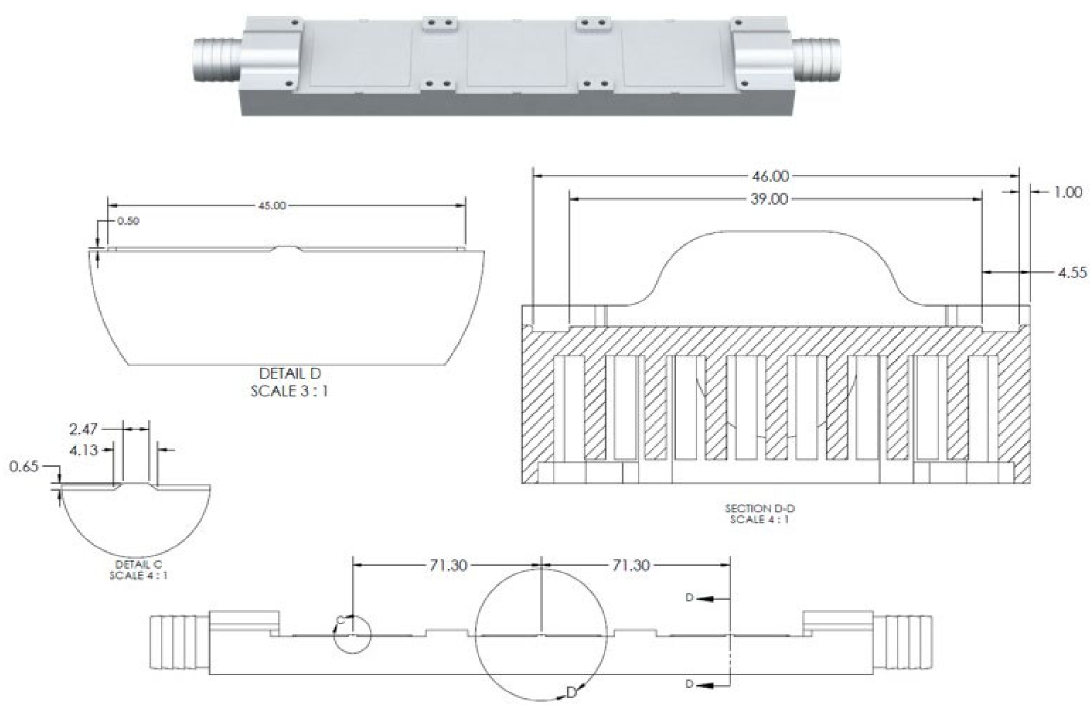


Figure 3. Alignment Feature to be Included on the Bottom Half of the Cooler

Thermal Interface Material (TIM) – Use of an effective Thermal Interface Material is crucial to achieving the best thermal performance. For VE−Trac B2 SiC assemblies we recommend using the Honeywell PTM7000 die cut Phase Change Material at 200 μm thickness. This material has been tested with the product and used in all thermal measurements shown on the product data sheet.

Table 2. CRITICAL PROPERTIES OF THE RECOMMENDED THERMAL INTERFACE MATERIAL (TIM)

Physical Properties	Unit	Honeywell PTM7000
Thermal Conductivity	W/m·K	6.5
Thermal Impedance @ No Shim	°C.cm^2/W	0.06
Specific Gravity	g/cm^3	2.7
Volume Resistivity	Ω·cm	2.1 x 10

The PTM7000 is also available in paste form to be used with automated dispensing machines. Please refer to the supplier for additional information on its handling and use. Figure 4 shows the size and positioning of the die cut PTM7000 pad placement on the bottom cooling area of the VE−Trac™ B2 SiC power module.

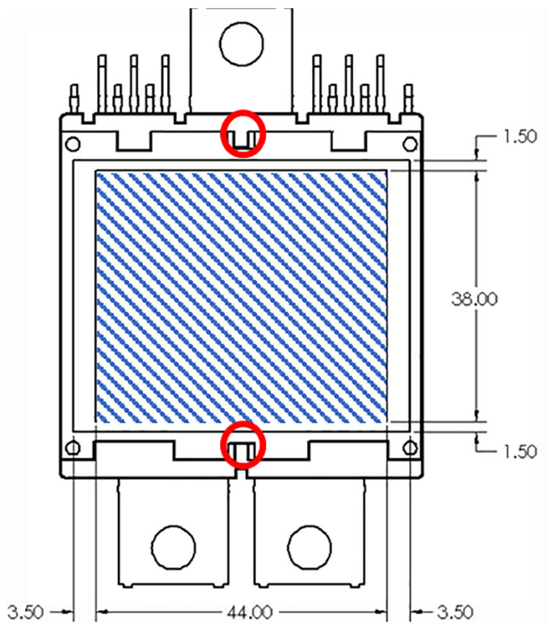


Figure 4. Recommended Size and Location of the TIM Pad (Hatched) and Module Alignment Features (Red)

It is possible to use other TIM materials from other suppliers in either pad or paste form. However, the new material will have to be characterized to determine its performance and optimal method of use in assembly. Users should do this in consultation with their preferred TIM supplier.

Alignment Feature – The power modules are designed with alignment indents as shown in red circles in Figure 4. The indents in the mold compound of the module are designed to help align the modules properly during assembly. The mating protrusions as shown in Figure 3, Detail C must be included on the cooler.

Spring Pad – One of the key elements in the assembly process is the use of a spring pad between the module top side and the clamp (see Figure 7). The constant thermal expansion and contraction of the module in the stack up creates a pumping action on the TIM and results in TIM pump out. Loss of TIM in critical areas at the module/cooler interface can result in uneven cooling and early module failures or degraded performance. See recommended specifications for the pad and stack up below:

Table 3. RECOMMENDED SPECIFICATIONS FOR THE SPRING PAD

Description	Value	Units	Tolerance
Material Type	Silicone	–	–
Thickness	5.8	mm	±0.5
Footprint	41 x 51	mm	±0.5
Durometer	40 A	–	±5
Temperature	−40 to 175	°C	–

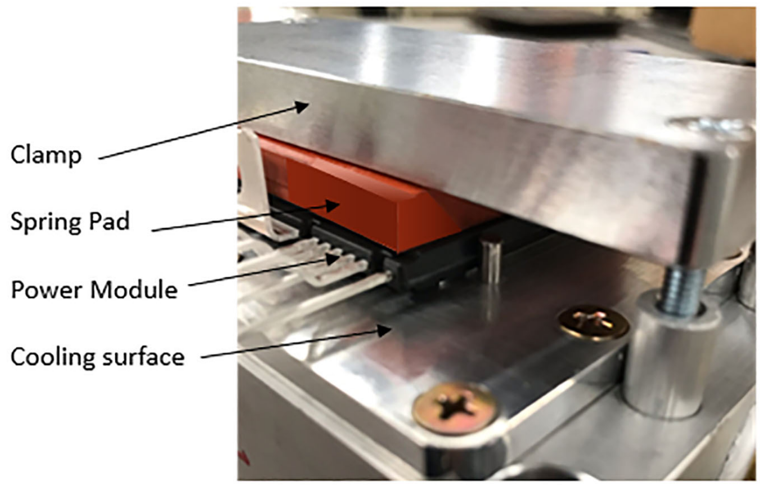


Figure 5. Example Module Stack with Spring Pad

Clamp – A clamp is needed to secure the stack together. The purpose of the clamp is to provide even and constant downward force on the modules over time. An example clamp is shown in the figure below. It not necessary that the clamp design be exactly as shown, the critical parameters are the clamp contact area and the 4−point mounting at the locations shown in the drawing.

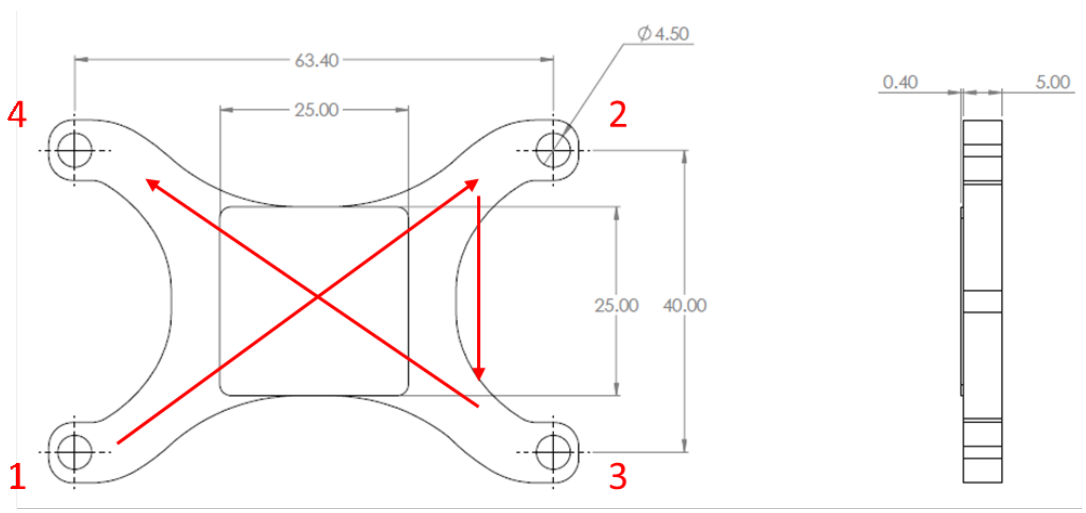


Figure 6. Example Single Clamp for the B2−SiC Module

A three−step torqueing sequence is recommended if relying on the clamp, as opposed to an external force, to apply even pressure during assembly. The figure above and the table below summarizes the process.

Table 4. TORQUE SET VALUES

	Torque Set Value [N]	Tolerance
Step 1	0.4	±0.1
Step 2	1.0	±0.1
Step 3	1.5	±0.1

Curing and Re−torque − Once the stack assembly is fully assembled the TIM should be cured according to the supplier recommendation for time and ambient temperature. For the recommended PTM7000 the phase change occurs at 50°C and is typically cured @ 60°C for 15 min. After curing the stack is re−torqued to the final values shown in Table 4. Use of serrated locking washers with the clamp hardware is highly recommended.

Alternatively, it is possible to use a steel pressure distribution bar and a hydraulic press to apply the required force across all three modules before securing them with the screws. In this case the assembly can be done in a single step. However, the curing and re−torque step is still needed.

The complete stack up with the cooler, TIM, modules, spring pad and clamp is shown in Figure 7. It may be possible to make the clamp and spring pad large enough to cover all three modules, thus reducing the number of components in the stack. However, this concept has not been tested.

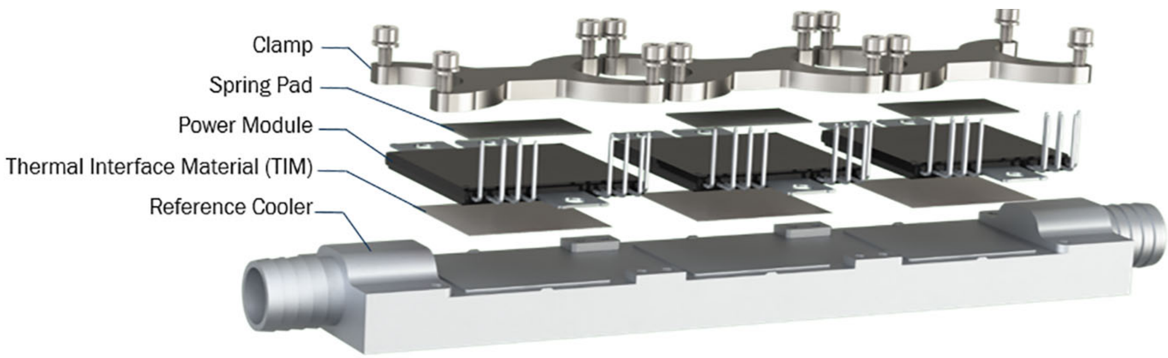


Figure 7. Exploded View of the Cooler Stack for the VE−Trac B2 SiC

DBC Appearance

The red cooler contact surface as shown in Figure 2 can sometimes appear to be discolored before assembly. The discoloration is due to the copper on the DBC getting oxidized due to prolonged exposure to air. The oxide layer is thin (1.8 nm – 14 nm) and forms non−uniformly, resulting in various shades of colors. The contribution of the copper oxide layer to the thermal performance of the module is so small that it has no effect on the Rth.j−f (junction to fluid) of the module stack up with the cooler.

Other common issues seen on the DBC include scratches and pitting. This can occur due to handling during assembly or assembly rework. Figure 8 shows some examples of these common issues and acceptable criteria for each type. Copper oxide layer, scratches and pits within the acceptable criteria have no impact on the electrical, thermal or isolation voltage capability of the power module.

Any visible cracks in the DBC, especially around the corners near the mold compound, can be serious. Such modules with cracked DBCs should not be used as they likely have degraded isolation capability.

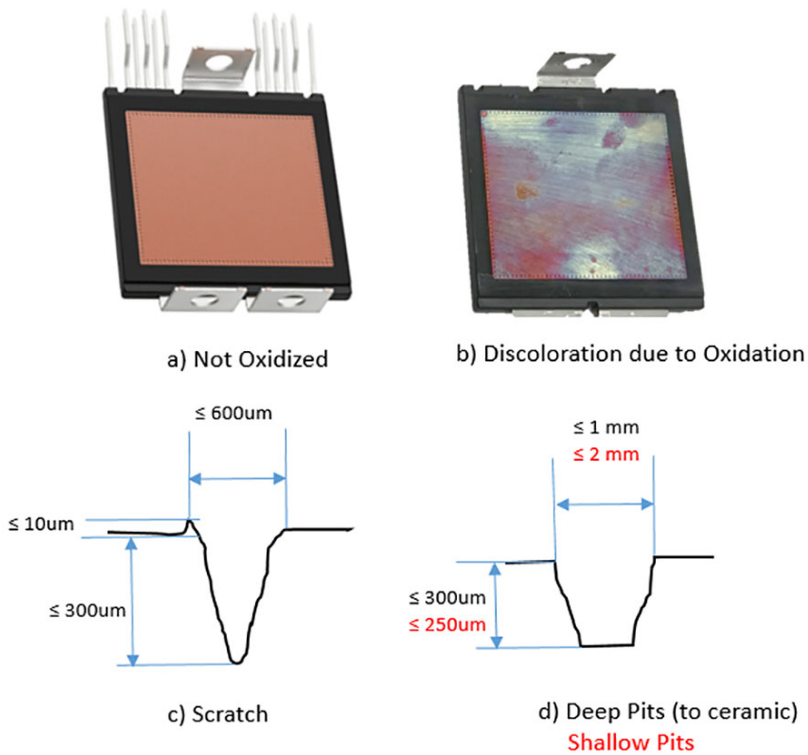


Figure 8. Different Acceptable Criteria of the Module DBC

Reference Cooler Design and Performance

The reference cooler design can be used as a guide by customers to develop their own cooler designs. There is no specific requirement to use this design for the cooler. The thermal data shown in the data sheet for VE−Trac B2 SiC products are all measured using this reference cooler. The cooler can be designed in different ways as long as the minimum requirements described in the previous section are met and the proper trade−off consideration is given to the thermal resistance/impedance, pressure drop and flow rates.

The reference cooler uses a pin−fin design and is optimized for thermal performance, pressure drop and cost. The data shown below in Figure 9 and Figure 10 should be considered as typical performance of the cooler with VE−Trac B2 SiC modules assembled using the recommended thermal interface material and the assembly process described earlier in the document. All measurements were performed using 50/50 Ethylene Water Glycol mix at 65°C as the coolant. The maximum static with−stand pressure of the reference heatsink is 4 Bar.

CAD models can be made available for the reference heatsinks upon request and must be requested via onsemi sales team.

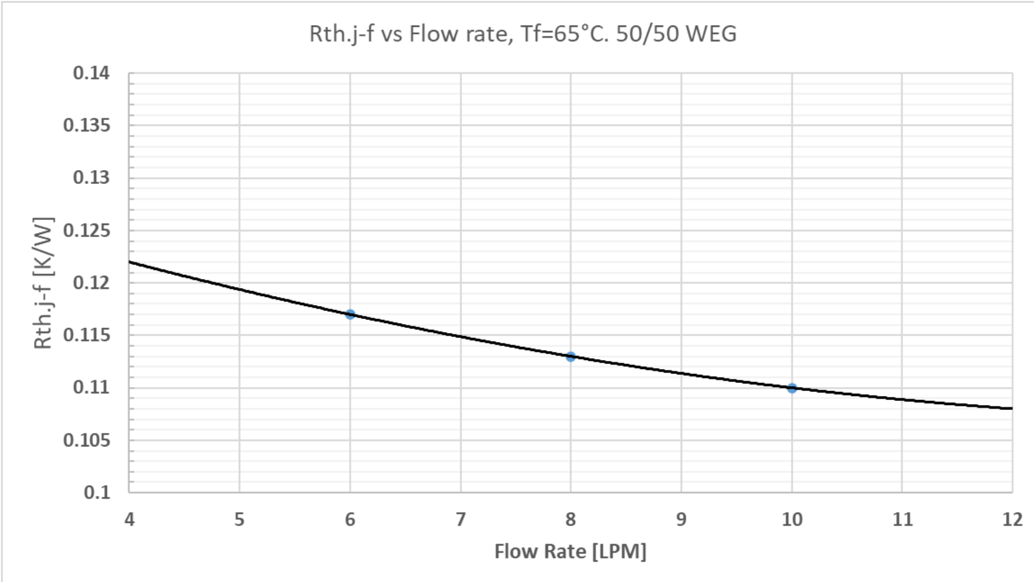


Figure 9. Thermal Performance Rth.j–f for NVVR26A120M1WSB at Coolant Temperature of 65°C

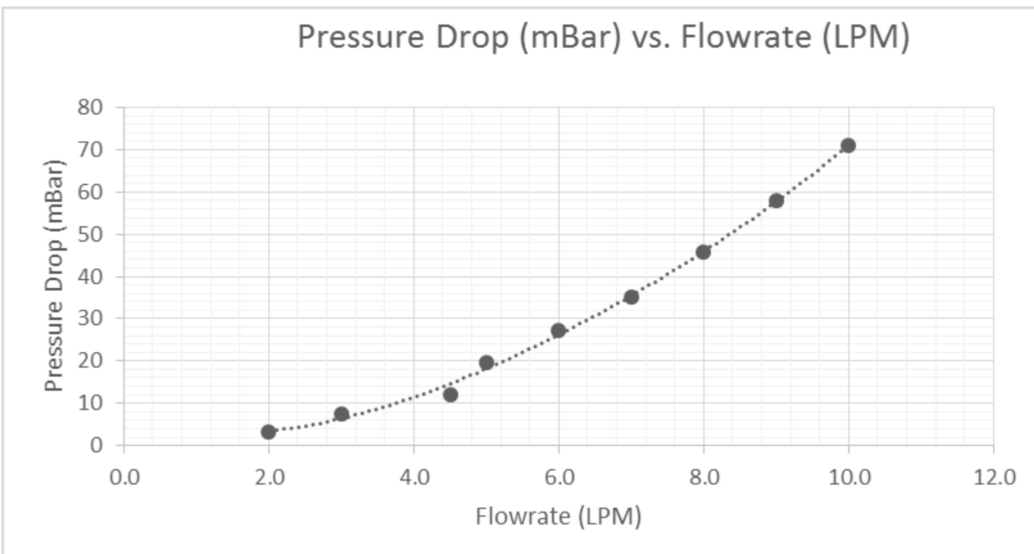


Figure 10. Pressure Drop versus Flow Rate for the Reference Heatsink Coolant @ 65°C

INTEGRATION WITH OTHER COMPONENTS

Besides the cooler, the power module must interface with other key components in the traction drive. Some concepts are discussed below for integration with the following components:

1. DC Link Capacitor / AC bussing
2. Gate driver PCBA
3. Current sensors

Terminal Connection Options

The B2 SiC modules are available in different terminal configurations. Some common examples are shown below. There are two main methods to connect the module power terminals to bus bars. The oxygen free copper power terminals are tin plated and well suited for screw type fastening. Other available option is a terminal with no holes in it without tin plating and suitable for welding.

WSB version WST version

Figure 11. Terminal Options for B2 SiC

When designing the interconnection on the DC or AC terminals one of the most important area of concern is maintaining creep and clearance as required by the application. The creepage and clearance distances are summarized in the table below for the VE−Trac™ B2 SiC package attached to the reference cooler. The module offers basic isolation, pollution degree 2 and a Comparative Tracking Index (CTI) value > 600.

Table 5. CREEPAGE AND CLEARANCE

Parameter	WSB	WST
Clearance Power Terminal – Power Terminal	3.8 mm	3.8 mm
Clearance Power Terminal – Signal Pin	3.1 mm	3.1 mm
Clearance Signal Pin – Signal Pin	3.0 mm	3.0 mm
Clearance Signal Pin – Ref. Cooler	8.0 mm	8.0 mm
Clearance Power Terminal – Ref. Cooler	8.0 mm	8.0 mm
Creepage Power Terminal – Power Terminal	6.4 mm	6.2 mm
Creepage Signal Pin – Signal Pin	5.8 mm	5.8 mm
Creepage Power Terminal – Signal Pin	5.9 mm	5.9 mm
Creepage Power Terminal – Ref. Cooler	10.9 mm	10.9 mm
Creepage Signal Pin – Ref. Cooler	10.9 mm	10.9 mm

Table 5 summarizes the creepage and clearance distances between the various pins of the module and between the reference cooler to the different module pins. The measurement assumes no other components are nearby and only assumes the presence of the module and the reference cooler. Figure 12 illustrates the various distances noted in Table 5. However, the actual minimum requirements for creepage and clearance should be calculated based on the maximum operating voltage and the required specifications in the compliance standard. In some cases, the spacing may not be enough to meet a certain standard and it may be necessary to achieve a higher level of creepage and clearance. This is a common issue for WST option in the B2 package and when using screws and nuts to fasten the power terminals to external bus bars.

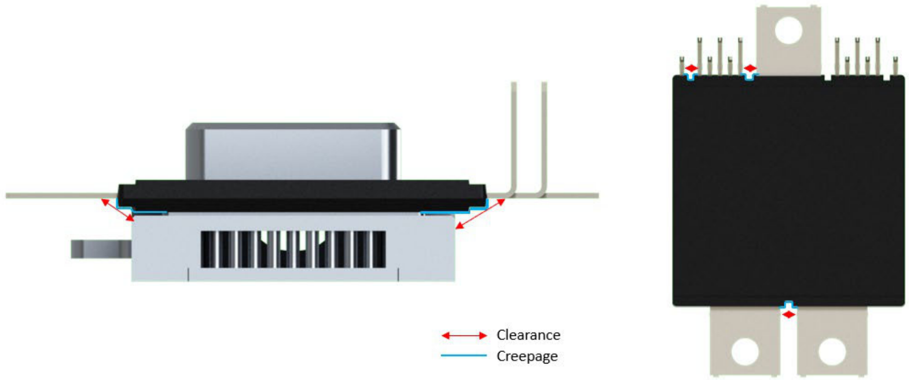


Figure 12. Illustration of Creepage and Clearance Distances in the WSB Version of the Module

In order to increase the creepage and clearance between the cooler and the pins it is necessary to use an isolator. The issue is illustrated in Figure 13. The addition of the screw and nut has reduced the distance between the high potential power terminal and the grounded metal cooler.

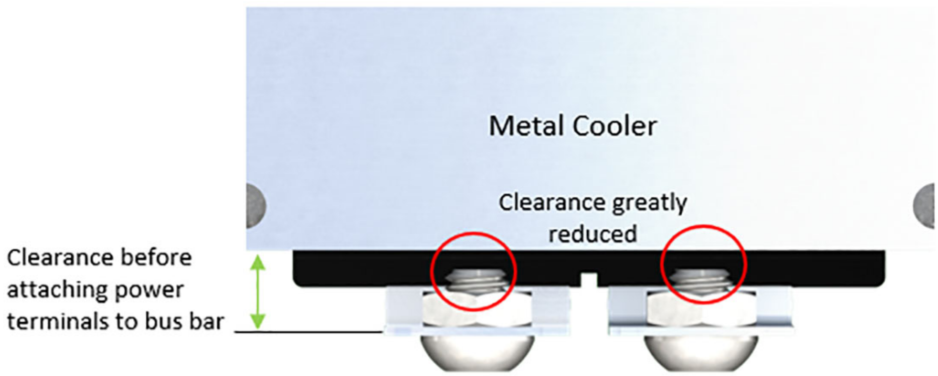


Figure 13. Illustration of the Clearance Issue when Using Fasteners to Secure the Power Module Terminals

There are several methods to overcome this clearance issue depending on your cooler design. One of the methods is shown below as an example. This method captures the nuts in a floating isolator as shown in the figure below. However, it up to the user to ensure that the module interconnections meet the required clearance and creep requirements of the end application.

Figure 14. Using a Floating Isolator with Captured Nuts is a Potential Solution

Example of connecting the DC or AC terminals to bus bars with specific hardware is shown below. There are many other feasible methods for making the interconnection. Including laser or ultrasonic welding process. The non−plated copper terminal version is recommended for welding.

Hardware shown:
Screw – DIN 439B M6 x 1mm thread Thin Hex nut
Nut – ISO 7380 M6 x 1mm thread x 8mm long

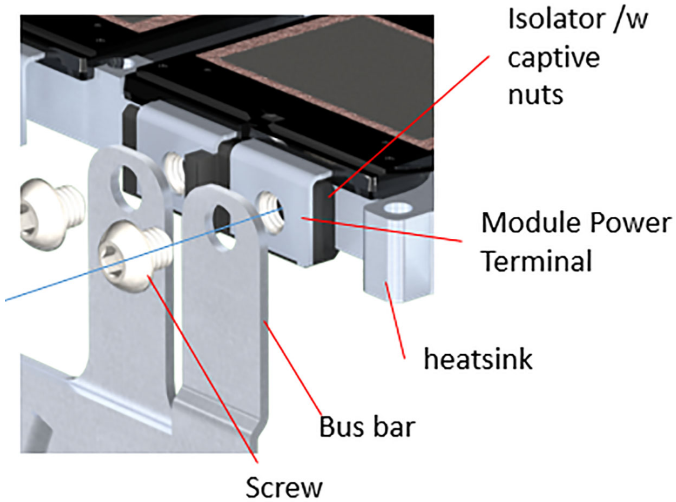


Figure 15. Recommended Stack Up for Module Power Terminal Connections

The mounting process should result in a system that will limit the forces acting on the power terminals when secured to the bus bars. Figure 16 shows the maximum allowed forces and their axis on the module power terminal.

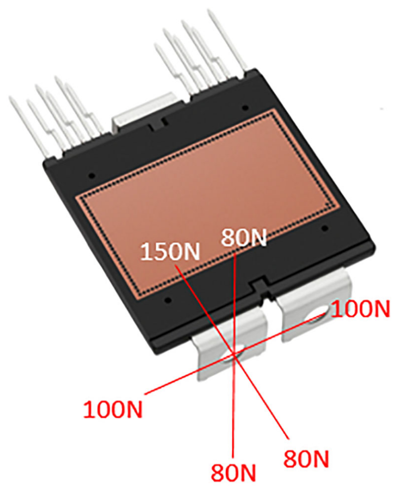


Figure 16. Force Limitations on the Power Terminal in All Axis

DC Link Capacitor

The DC link capacitor is the largest sub−component by volume in a traction drive. The selection and design of the DC link capacitor is crucial in SiC module based traction drives and this topic is covered in the technical guide. However, for the assembly guide the focus will be on the actual integration of the DC link capacitor assembly to the power modules. Several key parameters must be considered:

1. *Mechanical stress* – The capacitor bank is likely the largest and often the heaviest sub−component attached to the power modules, it is critical that the shock and vibration on the capacitor bank do not transfer to the power module terminal tabs beyond the limits of the tabs.
2. *Heat dissipation* – If capacitor bank is not adequately cooled, then the heat build−up within the capacitors will likely create a heat flow from the capacitor terminals to the module terminals. The module terminals will then act as a heat sink and this becomes an additional heat source for the module and may not be accounted for in the cooling design.
3. *Electrical contact* – Poor contact or inadequate contact area between the capacitor terminals and

the module terminals can also lead to increased power dissipation on the terminals and can result in similar issues as described in the previous paragraph.

4. *Parasitic inductance* – To maximize performance of the power module it is important to minimize the power loop inductance between the capacitor and the power modules. In order to minimize the inductance it is necessary to minimize the loop area (see Figure 17) between the module and capacitor terminals. This is a trade−off between several mechanical and electrical considerations.

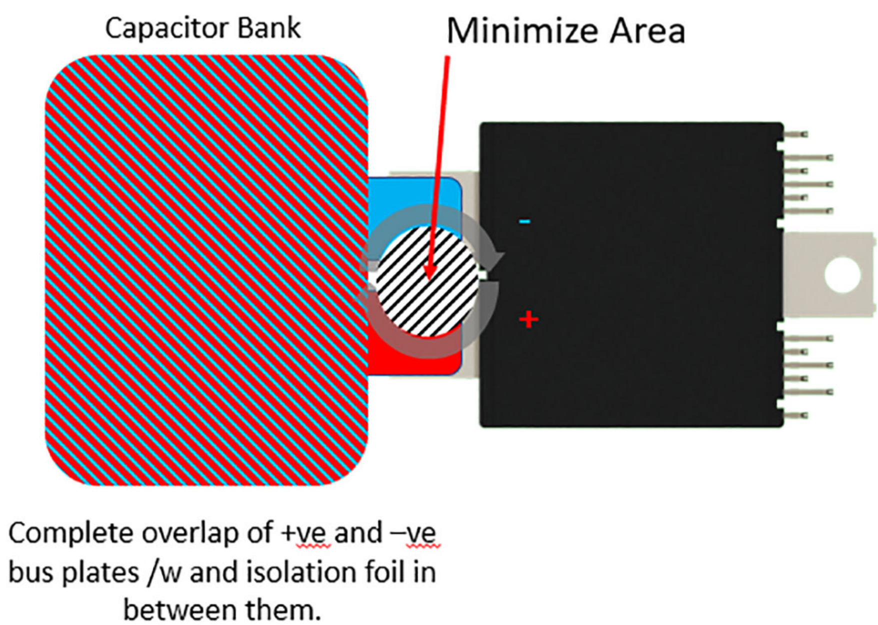


Figure 17. Critical to Minimize Parasitic Inductance in the Power Loop

PRINTED CIRCUIT BOARD (PCB) GUIDELINES

The general recommendation for the plated through holes for the control pins are shown in Table 6 and Figure 18 shows the recommended drill hole pattern. Depending on the design of the PCB there are different methods to solder the control pins to the PCB. Wave soldering or hand soldering are the general practice for through−hole type (THT) components.

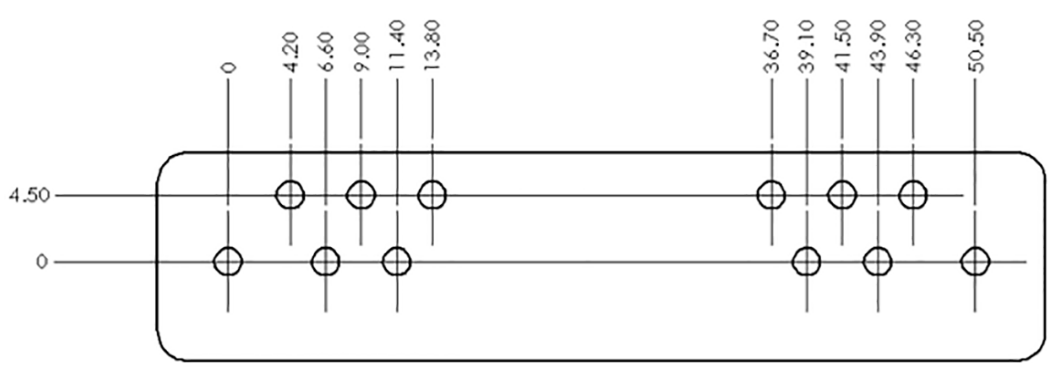
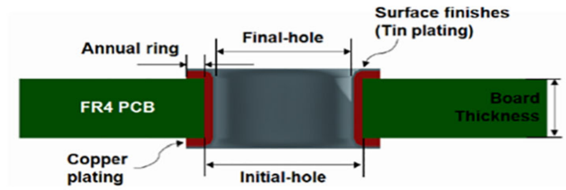


Figure 18. Recommended Drill−Hole Pattern for the PCB

Table 6. SPECIFICATIONS FOR PLATED THROUGH HOLES ON PCB FOR THE SOLDERABLE MODULE SIGNAL PINS

#	Description	Min	Typ	Max
1	Initial hole diameter (mm)	1.95	2.00	2.15
2	Copper thickness in via (μm)	25	–	–
3	Metallization (Sn) in via (μm)	10	–	–
4	Final hole diameter (mm)	–	1.85	–
5	Annular ring (μm)	200	–	–
6	PCB Thickness (mm)	0.8	1.6	–



Manual / Robotic Soldering

The recommended conditions for manual soldering are listed in Table 7. Considering the glass transition temperature (Tg) of the package mold resin and the thermal withstand capability of internal chips, the temperature of the terminal root part should be kept below 150°C. Iron tip should touch the lead terminal keeping certain distance from the package mold body. Manual soldering is not recommended for mass production as it may be difficult to control the amount of solder applied and the time and temperature of the soldering step.

Table 7. SPECIFICATION FOR MANUAL SOLDERING CONDITIONS

Parameter	Single Side Circuit Board	Double/Multi−Layer Circuit Board
Iron Tip Temperature	385 ±10°C	420 ±10°C
Soldering Time	2 s – 6 s	4 s – 10 s

Wave Soldering

Assemblies are placed on a carrier belt and go into the soldering process to contact the wave solder. The wave soldering process typically uses a thermal profile which consists of four stages: solder fluxing, preheating zone, solder wave and cooling zone. Solder flux is either sprayed or foamed into the components. Then it goes to the preheating zones, normally by convention, where the flux is activated. The assembly then goes to wave soldering and is slowly cooled down. Key elements such as preheat ramp rate, conveyor speed, peak temperature and time forms a wave solder profile. Wave soldering profile should be optimized in the assembly site since it strongly depends on the equipment condition and the material type used in application. A typical soldering profile and conditions are shown in Figure 19 and recommended specifications are shown in Table 8 for the SnPb and Pb free solder types.

Preheat:

Preheat is required to avoid any possible thermal stress due to overheating. Preheat temperatures and the preheating time should be set according to the flux specification. Too high a temperature and too long a duration may break down the flux activation systems which can cause unintentional shorts. On the other hand, too low a preheat temperature setting may cause skips or unwanted residues left on the PCB. Ramp up rate between 1~4 °C per second is suggested in the preheat zone.

Wave soldering:

Dual−wave soldering is the most common method. The 1st wave which has turbulent wave crest ensures wetting of all the landing pads, allowing the molten solder to find its way to all joints on the PCB. The 2nd wave, which has a laminar flow, drains the excess solder from the board after the 1st wave thus removing the solder bridges. It is recommended that maximum soldering temperature up to 260°C for 10 sec is maintained to establish a good quality of the solder joint and to avoid package damage by thermal shock.

Cooling:

Gradually cool the processed board down. A cool down rate between 1°C/s – 5°C/s is recommended in general.

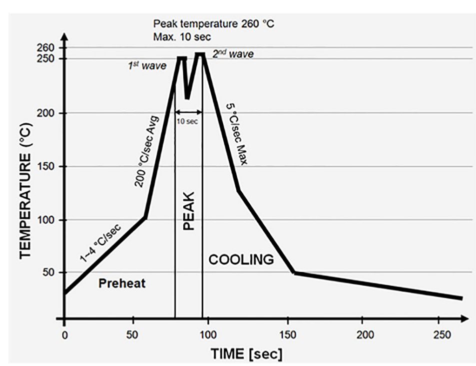


Figure 19. Typical Dual Solder Profile

Table 8. RECOMMENDED WAVE SOLDERING CONDITIONS

Profile Feature	SnPb Eutectic Assembly	Pb−Free Assembly
Average Ramp Up Rate	~200°C/s	~200°C/s
Preheat Ramp Up Rate	Typical 1−2, max 4°C/s	Typical 1−2, max 4°C/s
Final Preheat Temperature	~130°C	~130°C
Peak Wave Soldering Temperature	Max 235°C, max 10 s	Max 260°C, max 10 s
Ramp Down Rate	5°C/s max	5°C/s max

Solder Inspection

Monitoring the soldering quality is essential, since abnormal solder joints are potential risks for failures. IPC−A−610 (DE) standard specifies the soldering quality criteria for soft soldering. For the examination of a solder joint, visual or X−ray inspection and automatic optical inspection are suitable evaluation methods.

Figure 20 shows the recommended final position of a 4−layer PCB (1.6mm) relative to the edge of the power module. The minimum recommended space from the edge of the module mold compound to the PCB surface is 10mm spacing. Moving it closer will likely bend the control pins. Likewise, the maximum distance between the module edge and PCB surface should be 18.38 mm. It is generally recommended that the distance between the PCB and the module edge be kept as short as possible for optimal performance.

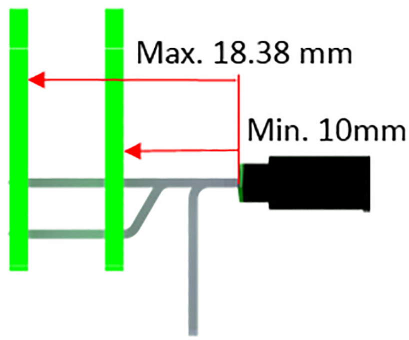


Figure 20. PCB Position to Module

PCB and Signal Pins Alignment

Each power module has 12 signal pins and if the modules are not handled correctly during assembly there is the possibility of getting the signal pins bent and misaligned, making it challenging to insert all the signal pins into the PCBA for soldering. It is recommended that a plastic tray be designed to align all the signal pins for easier assembly. The concept is illustrated below in Figure 21. The plastic tray (shown in red) is attached to the cooler and it consists of conical guide holes, as can be seen in the cross section view, to help guide all the signal pins to their final position for insertion into the PCBA for soldering.

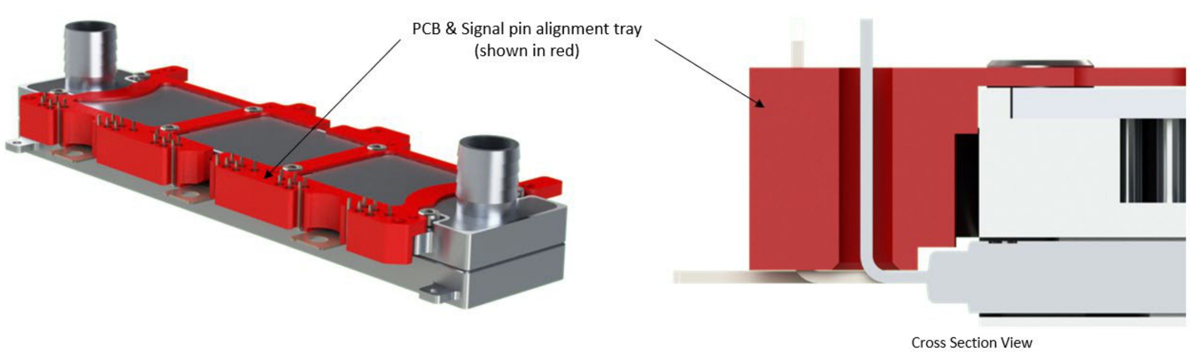


Figure 21. Use of a Signal Pin Alignment Tray Can Make Integration Easier

Load Current Sensor Integration

Integration of high accuracy load or phase current sensors is needed for motor control. There are different ways to integrate the sensors, but the two most common method is to either integrate the sensors into the plastic signal pin alignment tray discussed in the previous section or to integrate them into the PCBA assembly itself.

Figure 22 is an example that shows how the current sensors are integrated into the bottom side of the PCBA. In this case the plastic signal pin alignment tray is shown in white and the three hall effect sensors for measuring the phase current is shown in black attached to the PCBA. The AC bus bars could slide through the holes in the center of the sensors, without contacting the plastic sensor case and thus make accurate phase current measurements.

This is only a suggestion on how current sensors maybe integrated with the power modules. There are many application specific factors to consider when selecting and integrating phase current sensors.

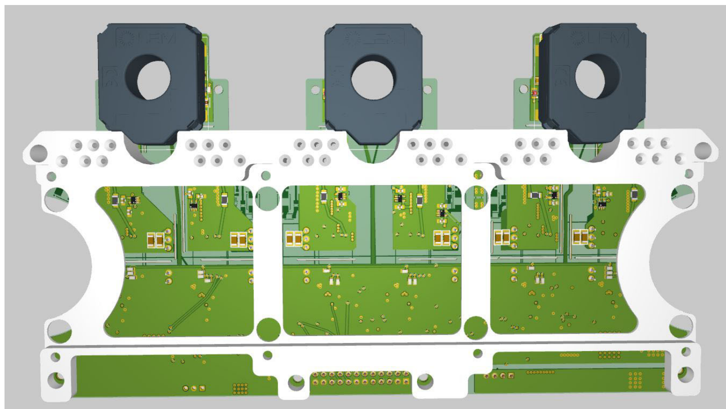


Figure 22. Example PCBA Shown with Integrated Hall Effect Current Sensors to Sense the Phase Current

VISUAL MARKINGS

The product has several visual identification markings to enable traceability. It’s important to maintain a robust traceability chain from a vehicle in the field all the way back to the individual chips in the module. This helps with root cause analysis and containment actions in case of failures. It is part of the automotive quality plan.

Traceability and Identification

Figure 23 and Table 9 together describe all the visual markings on the module and provide an explanation of the markers. Sometimes additional information may be added to the 2D matrix code at customer request.

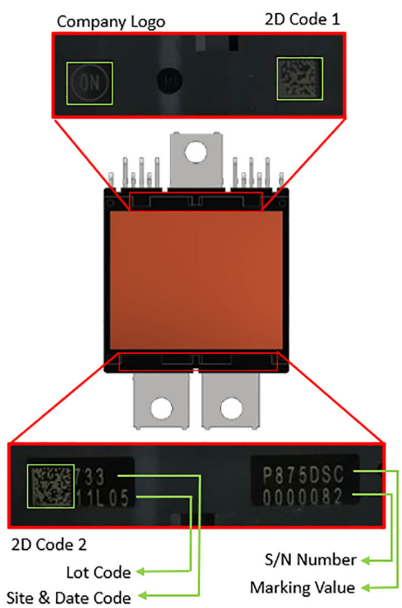


Figure 23. Traceability Markings on the Power Module

Table 9. EXPLANATION OF MARKINGS

Marker	Description
Company Logo	**onsemi** Logo
2D Code 1	Assembly Lot Number + S/N
2D Code 2	P/N + Assy. Lot Number + Site & Date Code + Tool ID + S/N
Site and Date Code	Assembly Location (XX) and Date Code (YWW)
Lot Code	Last 3 Digits of Lot Number
S/N Number	7 Digit Serial Number
Marking Value	7 Character Product Number

Storage and Shipping

Transporting and storing the modules requires care to avoid extreme shock, vibration and environments. The recommended storage conditions for the module according to IEC 60721−3−1, class 1K2 should be followed and storage time should not exceed two years from manufactured date code. Below is a summary of the recommended storage parameters:

Table 10. STORAGE SPECIFICATIONS

Parameter	Value	Unit
Maximum Air Temperature	40	°C
Minimum Air Temperature	+5	°C
Maximum Relative Humidity	85	%
Minimum Relative Humidity	5	%
Condensation	Not Allowed	–
Precipitation	Not Allowed	–
Icing	Not Allowed	–

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