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Application note 5SYA 2159-00

Mounting and applying RoadPak modules

E-Mobility is one of the fastest growing market segments and, at the same time, silicon carbide (SiC) devices are introduced in many inverters in this market segment. Silicon (Si) and SiC are different in many aspects and RoadPak as an e-mobility power module is also different to typical industrial or even traction modules.

Furthermore, RoadPak addresses the medium to high power segment with voltages up to 1200 V and currents up to > 1000 A, which drives some changes, creates requests for additional information and requires other measures to be considered during design-in.

1. Introduction

This application note is not only summarizing the main technical key values of the RoadPak but is also summarizing additional external effects to be considered, e.g., on the gate unit, the mounting on the cooler or the connection to PCB. The last aspect considered in the application note is the connection to the busbars. In SiC electric circuits, low stray inductance is essential. The RoadPak module is as low as 5 nH, and it is, therefore, crucial to follow low stray inductance design principles on the busbars and the related busbar connections.
Data sheets and the related simulation tool are available at www.hitachienergy.com/semiconductors. Even though the MOSFET is a non-latching device it has been designed for switching operation and should not be used in its linear operation mode. This application note does not cover any direct semiconductor physics. For a systematic introduction to the operation principle and physics of power semiconductor devices, including the MOSFET, we recommend the book «Power Semiconductors» from Stefan Linder (ISBN 0-8247-2569-7).

2. ESD considerations

The MOSFET is an electrostatic sensitive device and must be handled properly to avoid damage from electrostatic discharge (ESD). For further details on this topic, please refer to the international standard IEC 60747-1:2006 ch.8.
The RoadPak product family has been designed and qualified for automotive and industrial level. Ensure that the RoadPak is left as long as possible in the conducting packaging and is only removed to assemble immediately afterward.

3. Climatic conditions

The RoadPak is a molded power module with excellent environmental protection. However, semiconductors housed in plastic packaging are non-hermetic. This means the housings can be permeated by humidity and gases in both directions. Once water molecules are inside the housing, they can reduce the blocking voltage or initiate corrosion. Condensation must be avoided.
Due to the importance of climatic conditions, these parameters are highlighted separately in the document 5SZK 9118 “General environmental conditions for high power semiconductors”, where the environmental conditions for storage, transportation and handling, and operation of the RoadPak module is described.

Hitachi Energy

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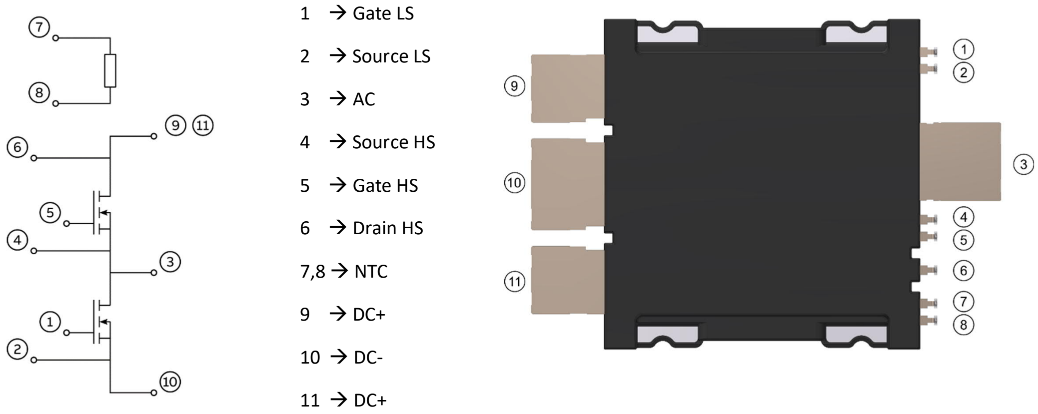


01 Electrical connections of the RoadPak module

4. Electrical connection

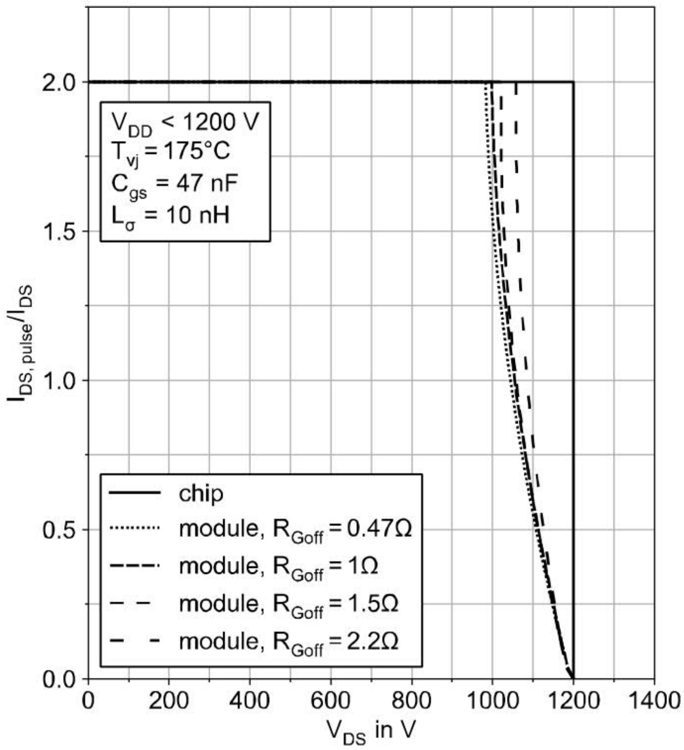
The RoadPak module has been designed for ultra-low stray inductance and fast switching in a compact design. Figure 1 shows the device circuit schematics of the RoadPak. The electrical connections of the main terminals (3, 9, 10, 11) are designed to implement a low stray inductance connection to the DC link capacitor. The complete procedure for the mounting of the terminals is described in chapter 10. The auxiliary terminals (1,2 and 4 ... 8) are used to connect to the high side and low side Gate – Source contacts of the module, as well as the NTC resistor for temperature sensing. We recommend using a PCB with a low inductive gate connection in order to take advantage of the full potential of the device and avoid unwanted effect such as oscillations. For the design considerations of the auxiliary PCB, refer to chapter 9.

5. Safe operating area

In order to prevent failure on the internal module chips, the peak voltage between Drain and Source (V_{DSM}) of each switch side must be kept below the maximum rated Drain – Source voltage (V_{DSS}), on chip level. The formula to calculate the maximum Drain – Source voltage is given by:

$$V_{DSM} = \left|\frac{dI}{dt}\right| \left(L_{\sigma,DS} + L_{\sigma}\right) + V_{DC}$$

Where $\frac{dI}{dt}$ is the switching speed, adjustable by the gate drive resistors, $L_{\sigma,DS}$ is the stray inductance contribution of the internal circuit of the module (typically 5 nH) and L_{σ} is the stray inductance contribution of the components external to the module, i.e. DC link capacitor and connections to the module main terminals. Figure 2 shows the limitation of the Drain – Source voltage on the main terminals and on the chip in function of the switched current and for various turn-off gate resistor values, for a design of overall loop stray inductance of 10 nH.



02 Turn off SOA diagram of the 5SFG 0780B120000 module

6. Gate drive

It is recommended to drive the gates of the RoadPak SiC module with a turn-on gate voltage of +15 V, in order to benefit from the low on-state resistance of the module. For the turn-off voltage, a value of -4 V is recommended to provide enough margin at the positive side against parasitic turn-on effects, as well as at the negative side to avoid violating the minimum allowed chip gate voltage.

Hitachi Energy Ltd.
Semiconductors
Fabrikstrasse 3
5600 Lenzburg, Switzerland
Tel: +41 58 588 68 68
salesdesksem@hitachienergy.com

In any case, care must be taken that the maximum Gate – Source values mentioned in the data sheet are not violated during short transients of the switching, otherwise the lifetime of the module might be dramatically decreased. Additionally, the current output capability of the gate drive unit should be carefully selected to be able to switch the high number of paralleled devices in the RoadPak module.

6.1. Gate drive circuit

As mentioned in chapter 4, it is necessary to maintain the gate drive circuit as close to the auxiliary pins as practically possible, in order to have a low gate inductance. This is achieved by using a PCB which is directly pressed on the auxiliary pins of the RoadPak module, as explained in chapter 9.

6.2. Tuning of the switching

The operation of a SiC module is similar to an IGBT-diode module, however the limitations for each type of module are different, so the tuning process of the gate drive unit, specifically the switching speed through the gate resistors and capacitances, is slightly different. Because of the nature of the SiC MOSFETs, the switching behavior is sensitive to the external component setup, so tuning the switching of the module with the final converter layout is recommended. Using temporary test setups might lead to unpredicted parasitics which will unfavorably affect the switching.
The tuning should be performed with standard double pulse tests on the modules. The following procedure is recommended for tuning the gate parameters:

- Set the initial values of the R_{goff} to 1 Ohm and the R_{gon} to 0.47 Ohm. An initial small gate capacitance of C_{gs} = 2.2 .. 4.7 nF might also be beneficial for reducing the gate oscillations.
- Start by tuning the turn-off of the modules, performing switching events and gradually increasing the turn-off current up to the maximum predicted current of the inverter, as defined by the specific application. Since the turn-on has not been tuned yet, it is recommended to perform only single pulses at this stage. Make sure that the Drain – Source voltage does not exceed the specified V_{DSS} of the module, according to the SOA diagram of the data sheet; if it does, the switching speed can be reduced by increasing the R_{gon}. If at any point excessive oscillations are observed at the gate voltage (> 5·Vpp), increasing the gate capacitance might provide some relief to the effect.
- Repeat this process for both high side and low side. Different values for the resistors might be needed for the high side and the low side switches, according to the application, so both sides should be tuned separately.
- The turn-off at this point should be stable, so the tuning of the turn-on/ body diode turn-off can be also tuned. For this measurement, it is crucial to monitor both the high side and low side voltages of the module. When one of the sides performs a turn-on, the opposite side will perform a diode turn-off. At this point, the gate voltage of the device which is performing the diode turn-off should be closely observed for parasitic turn-on effects.
- For the tuning process, start by performing double pulse tests with gradually increasing current. The Drain – Source voltage of the device performing the diode turn-off should not exceed the maximum drain voltage at any point. If it does, increase the R_{gon} value and repeat the process.
- Additionally, the gate voltage during diode turn-off might be subject to parasitic dI/dt and dV/dt effects which will cause oscillations during switching. If the gate voltage exceeds the threshold value during these oscillations, there might be a parasitic turn-on of the switch. In order to avoid this, increasing the C_{gs} might help, however taking into account the current capability of the gate drive unit is advised in this case. Furthermore, the switching speed of the devices might be affected by increasing the gate capacitances, so it might be needed to examine the MOSFET turn-off again and compensate for the speed loss. If the gate drive unit has an active Miller clamping option, it might be also useful to enable it and observe if it improves the oscillations.
- Perform the same process for the high side and low side switch.
- Because of the operation of SiC MOSFETs, the diode turn-off reverse recovery is practically nonexistent at low temperatures, but it is affecting the diode turn-off at high temperatures. The recovery current in this case is higher and the diode turn-off might present snappiness in combination with high values of stray inductance and parasitic effects due to application design. Therefore, when the tuning of the turn-on/ diode turn-off is complete, it is strongly recommended to repeat it on a high temperature (>100°C). A heating plate can be used to achieve the required temperature on the module, and it can be confirmed with the use of the integrated NTC resistor.

During the tuning process, the devices may temporarily exceed the maximum limit of V_{DSS}. This is not expected to damage the module directly and can be allowed for the purpose of experimenting on the gate resistor values. However, it may reduce the lifetime of the module and therefore in the final application care must be taken that the worst switching conditions are not causing overvoltage on the Drain – Source contacts of the chip.
At the end of this process, the devices should have stable gate drive unit conditions, taking advantage of both the high speed and the low on-state resistor of the SiC MOSFETs.

6.3. Gate drive protection features

The following features are recommended in order to achieve clean switching, low losses and increased protection against failure conditions:

- Short circuit protection: Contrary to the well-known short circuit capability of IGBT-diode modules, the short circuit capability of a

SiC device is very short (~1.2 μs). Protecting the module against a short circuit event requires fast and reliable short circuit detection. When selecting an appropriate gate drive unit, it is recommended to ensure that the unit can safely detect and turn off the short circuit event within the given time frame.

- Active Miller clamp: This feature can protect the module against parasitic turn on when performing a diode turn-off, as explained in section 6.2. The system designer may decide if the use of an active Miller clamp is beneficial for the system and use it as required.
- NTC sensor: The RoadPak integrates an NTC resistor for sensing the temperature of the module. A circuit for sensing the resistor value may be integrated in the gate drive unit IC and can be useful for the application.

Additional features like high CMTI (Common Mode Transient Immunity), interlock protection, glitch protection, etc., are typical for commercial gate drive units and are also recommended to ensure proper operation of the system.
As well established and tested gate unit, we recommend the NXP GD3160.

7. Recommended mounting sequence

The following recommended mounting sequence was applied during RoadPak qualification. In the described sequence, the modules are first mounted to the cooler, then the PCB is mounted to the press-fit pins (on a fixture outside of the inverter), to have better accessibility for the press-pin alignment and support tool. Afterwards, the PCB is fixed to the cooler by a PCB support (9.3), close to the press-fit connections. The PCB needs to be designed in a way that allows access to the main terminal connections of the power modules in the next step. Either the PCB does not overlap the main terminals, or has corresponding openings, to have access for welding or screwing tools.

Recommended mounting sequence (as done during RoadPak qualification):

1. Module mounting to cooler (8)
2. PCB mounting (press-fit connection) and fixation (9)
3. Placing the assembly in the inverter and connecting main terminals to busbar (10)

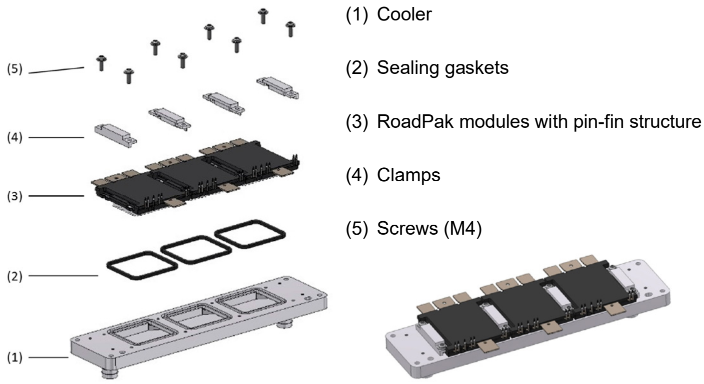
Depending on the inverter design, another mounting sequence might be necessary. Alternative mounting sequences have not been tested by Hitachi Energy.

8. Module mounting to cooler

8.1. Components used for mounting modules to cooler

RoadPak modules have a pin fin structure on the bottom side of the base plate to enhance heat transfer in a direct liquid cooling application. During RoadPak qualification, the power modules were mounted to the cooler using clamps and screws. For sealing purposes, sealing gaskets were used between the cooler and the base plate.

The image below (figure 3) shows an example of 3 RoadPak modules mounted on a cooler (6Pak), with all needed components as used during RoadPak qualification.



03 Components used for module mounting to cooler (left) / Final assembly after mounting process (right)

8.1.1. Cooler

During operation, the power module produces losses in the form of heat, which must be dissipated to avoid junction temperatures to overpass the maximum allowed temperature in the data sheet.
The cooling cavities and the internal cooling structure of the open cooler must be designed in a way that makes it possible to reach the desired heat transfer with the lowest pressure drop possible for a given flow rate. It is to be noted that each final application can be different and may require different cooling conditions. As a result, the optimal cooling cavity structure may vary.
The pin fin structure of the power module as well as the cooler (as shown in figure 5) were designed and optimized for a cooling mixture of water and ethylene glycol (1:1). Note that the pin fin located at the bottom of the power module is coated with a thin layer of nickel. As a result, it is critical to mount the modules in a way that the coating is not scratched, which could expose the copper and cause corrosion. Operation with other fluid mixtures or types is also possible if the nickel coating of the pin fin is resistant to it.
The cooler design must also consider the operating pressure to be withstood. The cooler (as shown in figure 5) was designed for operation at maximum 3.5 bar (absolute), while several tests confirmed no noticeable deformation of the bottom side of the cooler up to 6 bar.
All values provided in the data sheet correspond to the first and the third modules in the direction of the flow, for the cooler (as shown in figure 5) and for a cooling mixture of water and ethylene glycol (1:1). The values may differ for different cooler designs and cooling fluids.
It is recommended to operate the cooler under local flow velocities of 2 m/s to avoid long-term abrasion caused by small particles located in the fluid, which correspond to a flow rate of 14 L/min.
To ensure a proper mounting process of the RoadPak modules to the cooler, there are several alignment and mounting features needed, as

Hitachi Energy Ltd.
Semiconductors
Fabrikstrasse 3
5600 Lenzburg, Switzerland
Tel: +41 58 588 68 68
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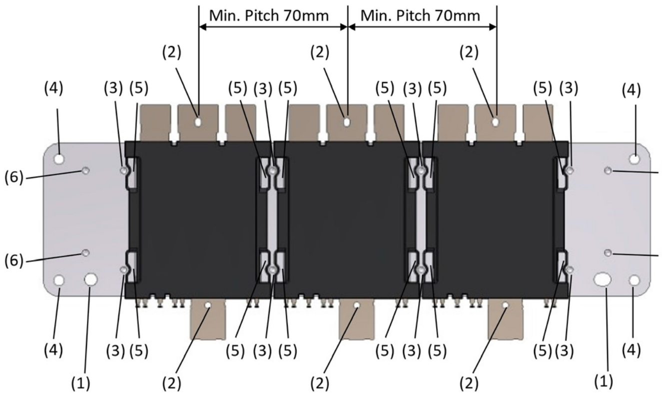
shown in figure 4. The minimum and recommended pitch from module to module is 70 mm. Missing dimensions can be taken from the RoadPak module outline drawing (data sheet) and from the cooler drawing (figure 5).



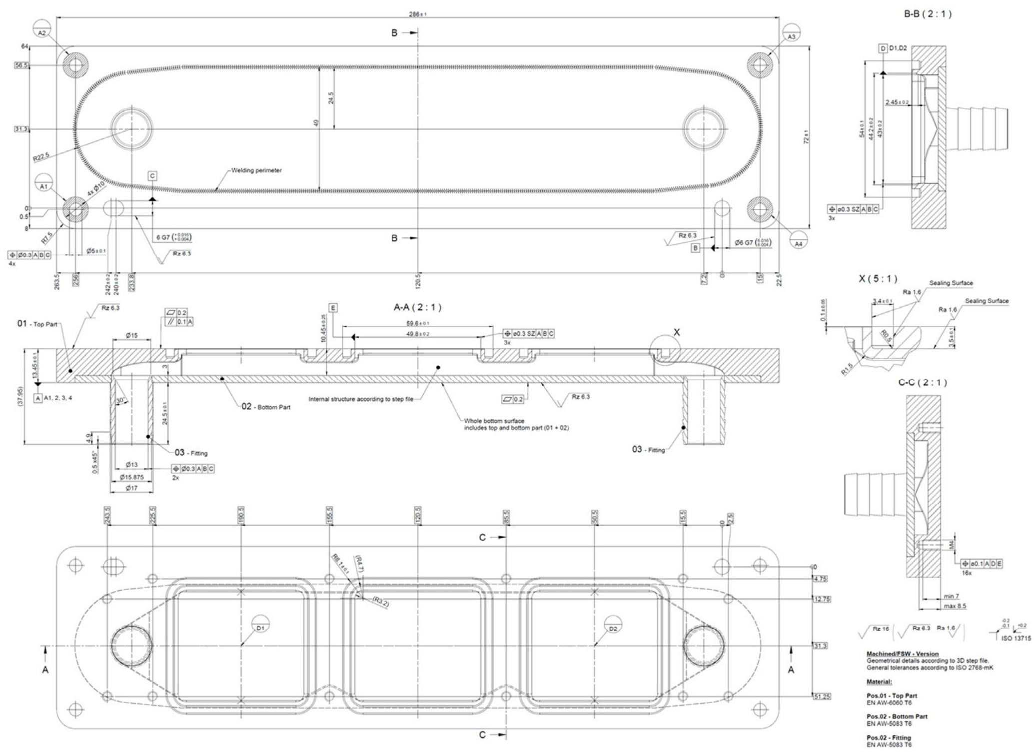
(1) Cooler alignment holes
(2) Module alignment holes (Ø3.05 ±0.05)
(3) Threads for module fixation (M4)
(4) Holes for cooler fixation (Ø5)
(5) Clamping surface on base plate
(6) Threads recommended for PCB support (M4)

04 Alignment and mounting features

The drawing below (figure 5) shows an example of a cooler design, as used during RoadPak qualification, with all cooler features mentioned in figure 4. It does also match to the designs of the sealing gasket (section 8.1.2), clamp designs (section 8.1.3) and screws (section 8.1.4), described in a later stage. The design of the cooler outline and the fittings can be customized as needed. The in- and outlet diameter of the fittings of the described cooler is Ø 13mm.

8.1.2. Sealing gasket and sealing groove

The sealing gasket is strictly needed for module operation, as it prevents the cooling fluid to leak and provides certain damping between power modules and cooler during vibration cycles. It is placed inside a groove in the cooler body and pressed down by the modules during mounting. For a long-lasting and optimal functionality, the surface roughness of the walls of the groove must not exceed Ra 1.6. The sealing gasket is designed for operation with a cooling mixture of water and ethylene glycol (1:1), or water. For different fluid types, please refer to the sealing gasket supplier.
With regards to operating pressure, it is recommended to stay below 3.5 bar (absolute pressure) in the interior of the cooling cavity to avoid any damage in the sealing gasket.
Figure 6 shows the sealing gasket design (Material: EPDM E8556) and the corresponding sealing groove design in the cooler, as used during RoadPak qualification.



05 Example of a cooler design as used during qualification at Hitachi Energy

Hitachi Energy Ltd.
Semiconductors
Fabrikstrasse 3
5600 Lenzburg, Switzerland
Tel: +41 58 588 68 68
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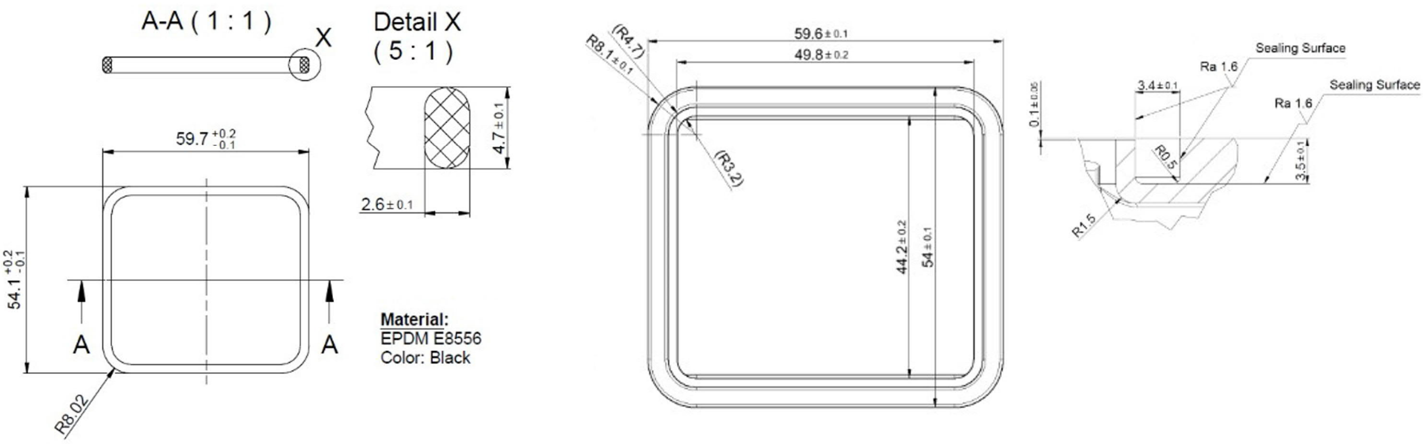
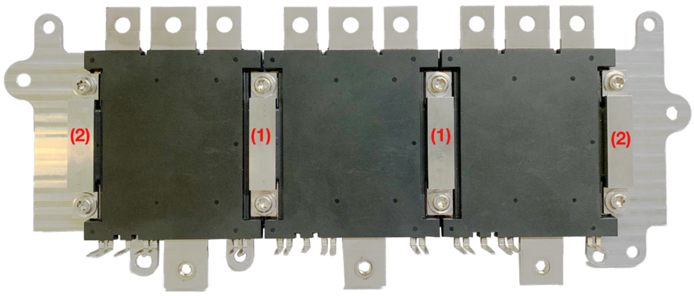


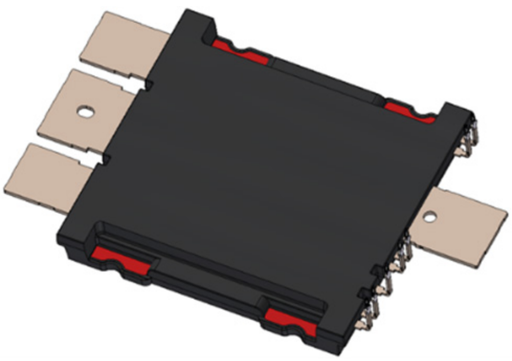
06 Sealing gasket - Material: EPDM E8556 (left) + Sealing groove design in cooler (right)

8.1.3. Clamps

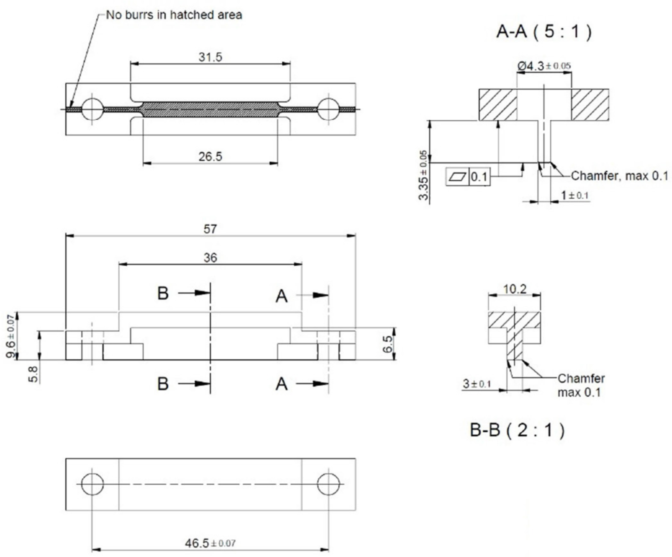
Two different clamp designs are needed to build an assembly with 3 RoadPak modules on a cooler. The center clamps (figure 7 (1) / figure 9) are located between the modules and the outer clamps (figure 7 (2) / figure 10) are located at the external sides (left / right module). The clamps are designed to avoid any load to the mold body of the RoadPak module and only press on the exposed clamping surfaces of the base plate (figure 8).



07 (1) Center clamps / (2) Outer clamps

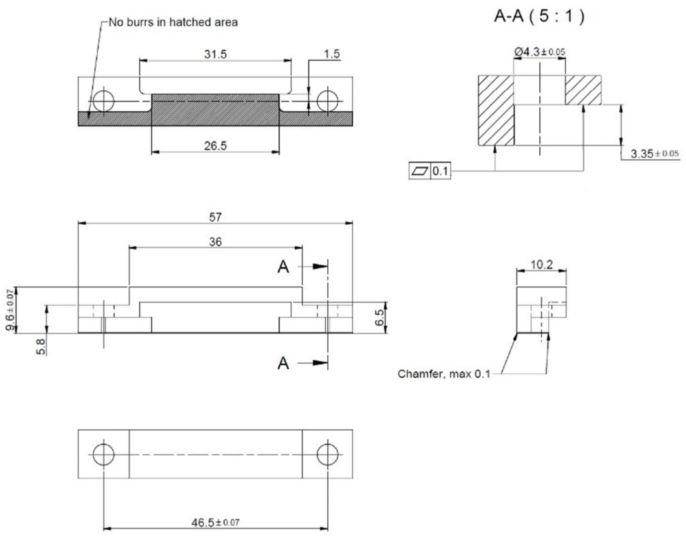


08 Exposed clamping surfaces on the base plate (red marked) of the RoadPak module



09 Center clamp – Material: Aluminum alloy EN AW-6082 T6 (as used during qualification of RoadPak)

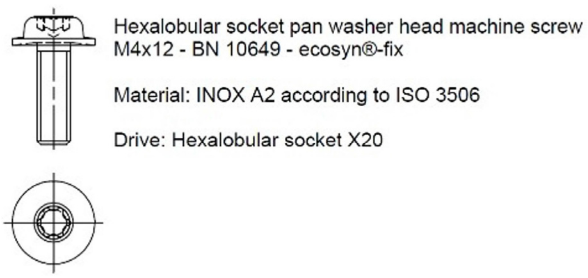
Hitachi Energy Ltd.
Semiconductors
Fabrikstrasse 3
5600 Lenzburg, Switzerland
Tel: +41 58 588 68 68
salesdesksem@hitachienergy.com



10 Outer clamp - Material: Aluminum alloy EN AW-6082 T6 (as used during qualification of RoadPak)

8.1.4. Screws

To mount the RoadPak modules to the cooler, M4 screws are needed. During RoadPak qualification, ecosyn®-fix screws (screw with integrated pan washer) supplied by the company Bossard AG have been used (figure 11). Torque values for the proposed screws, according to section 8.2.3. Other screws in combination with separate helical springs and/or flat washers are possible to use but have not been tested at Hitachi Energy. It is strongly recommended to secure the screws against loosening, due to vibrations in application and thermal cycles.



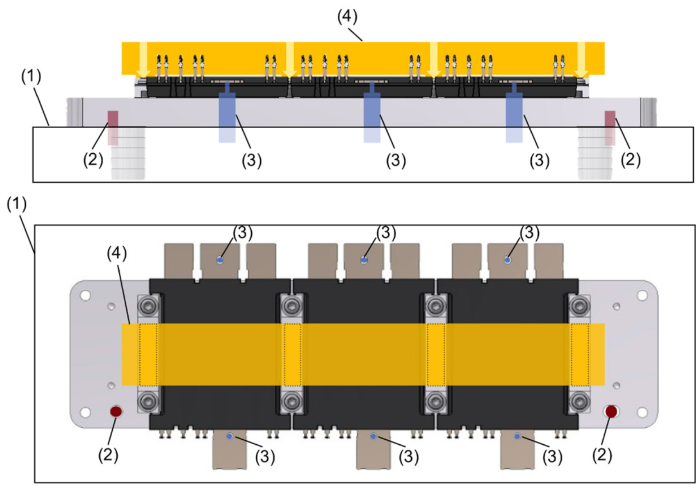
11 M4 ecosyn®-fix stainless steel (A2-70) screws (as used during RoadPak qualification)

8.2. Mounting process (module to cooler)

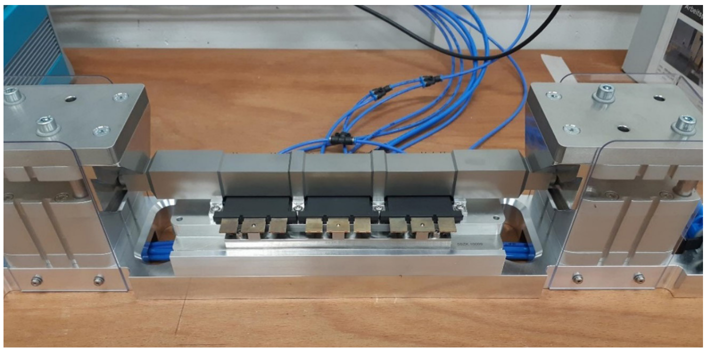
To align the RoadPak modules to the cooler, a mounting fixture (figure 12) is needed. Before applying the final torque to the screws, all sealing gaskets (module-cooler interface) must be compressed into the final stage to cancel any forces of the compressed sealing gasket before applying a torque to the screws. A pressure bar is needed to press on all clamps at the same time and bring the clamps and modules to the final position. This will avoid any tilt of modules and clamps during tightening of the screws and ensures the control of the final torque of the screws. The pressure bar needs to be designed in such a way, to only press on the clamps and avoid any load on the epoxy mold body of the modules.

8.2.1. Mounting fixture setup

The images below (figures 12 and 13) show examples of a possible fixture to mount RoadPak modules to the cooler, including all necessary features.



12 Module mounting fixture and features



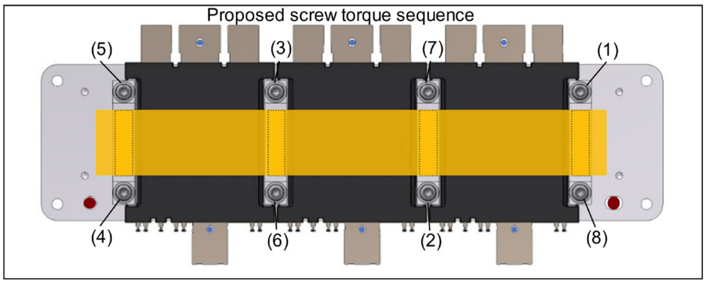
13 Image of a possible mounting fixture setup (with 2 pneumatic cylinders)

8.2.2. Mounting sequence (module to cooler)

1. Align the cooler (including sealing gaskets) over the cooler alignment pins (figure 12 - 2)
2. Align the RoadPak modules over the module alignment pins (figure 12 - 3)
3. Bring all clamps in position – placing all screws by one turn (manually or with a low torque of <0.5 Nm)
4. Press the pressure bar (figure 12 - 4) down, until all clamps are in

Hitachi Energy Ltd.
Semiconductors
Fabrikstrasse 3
5600 Lenzburg, Switzerland
Tel: +41 58 588 68 68
salesdesksem@hitachienergy.com

contact with the cooler top surface and hold this position. Compression force for 3 sealing gaskets (according to section 8.1.2): roughly 3 x 650 N = 1950 N, applied with a press or pneumatic cylinders.
5. Apply the final torque (according to section 8.2.3) to all screws, according to the recommended screw torque sequence (figure 14) while pressing down with pressure bar.



14 Recommended screw torque sequence (1 – 8), recommended torque values according to section 8.2.3

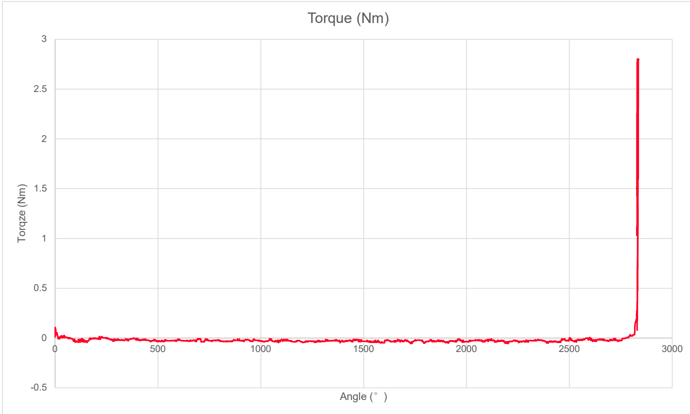
8.2.3. Recommended torque values for screws (M4 A2-70)

In RoadPak qualification M4 screws (stainless steel A2-70), according to section 8.1.4, were used to mount the modules to the cooler. The torque value recommendation (table 1) is only valid for this screw type in combination with the cooler design (figure 5), sealing gasket (figure 6) and the clamps (figures 9 and 10), with the assumption of the maximum internal cooler pressure of 3.5 bar. For any other combination which differs from the described specification (cooler material, sealing gasket design, clamp designs, screw type, or different internal cooler pressure), the final screw torque must be adjusted accordingly.

Description	Min.	Typ	Max.	Remarks
Mounting torque (final)	2.5 Nm	2.8 Nm	3.1 Nm	M4 screw (stainless steel A2), according to section 8.1.4
Threshold torque (during process)	0.4 Nm		1.5 Nm	Set a lower threshold torque value, to check for jamming of screw during process
Screwing speed	100 rpm		300 rpm	
Recommended length of screw in cooler	6 mm			Cooler material: Aluminum alloy EN AW-6060 T6 (figure 5)

Table 1: Recommended torque values M4 screws, stainless steel A2-70

The use of electronic torque wrenches with automatic release, including control of screwing speed and screw-in angle, is highly recommended to avoid any damage of the screws during mounting process and better control of final torque (figure 15). It is strongly recommended to avoid faster screwing speeds than specified, as this might yield too high torque values or jamming of the screws.



15 Angle controlled screwing process

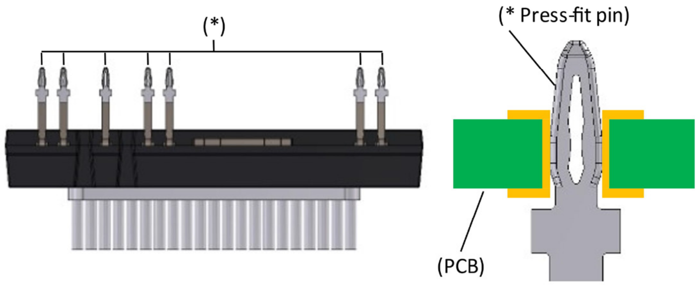
8.2.4. Leakage test

After mounting the RoadPak modules to the cooler, a leakage test (between in- and outlet) with the final assembly is highly recommended to ensure that the product is leak tight. The leakage test can be made according to the following proposal:

- Pressure test: 3 bar (air, relative) - measure pressure drop, over a certain holding time.
- Vacuum test: -0.5 bar (air, relative) – measure pressure increase, over a certain holding time.
- Suggested holding time 10 – 20 s:
  - Additional filling and stabilization phase should be considered.
  - Limits depend on the volume in the whole system.

9. PCB mounting (press-fit connection)

The 7 auxiliary terminals on the RoadPak module have press-fit pins for directly pressing into corresponding plated through holes in the PCB (figure 16). This will generate a reliable electrical contact by cold welding, without the need of an additional soldering process. This press-fit connection has been used during RoadPak qualification. Soldering of the pins to the PCB, is also possible, but this has not been qualified at Hitachi Energy.



16 Press-fit connection

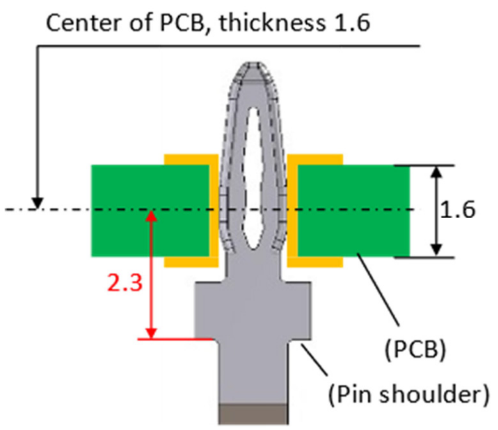
Hitachi Energy Ltd.
Semiconductors
Fabrikstrasse 3
5600 Lenzburg, Switzerland
Tel: +41 58 588 68 68
salesdesksem@hitachienergy.com

The requirements for the press-fit connection area (pin and hole) are according to IEC 60352-5. Details about the press-fit pin design are shown in section 9.1 and requirements for the PCB and the plated through holes are shown in section 9.2.
Please note that the press-fit connection can only be done once. Any disassembly of the PCB from the press-fit pins will lead to a damage of the PCB hole and press-fit pin and after re-assembly, and a reliable connection can no longer be guaranteed. A possible rework, for testing purposes only, could be re-soldering of the pins (rework not qualified).
It is highly recommended to support and fix the PCB in its final position close to the press-fit connections, as described in section 9.3, to avoid any damage of the connections due to shock and vibration in application.
A description of a possible PCB mounting process, including fixtures and tools for pin alignment and support is shown in section 9.4.

9.1. Press-fit pin specification

The press-fit pins (auxiliary terminals) of the RoadPak module are designed for a PCB, with a thickness of 1.6 mm.

- Press-fit type: Inovan 06-10
  - According to INOVAN 40 2187 01
  - According to IEC 60352-5
  - Material: CuNiSi R580
  - Plating: 0.5 - 2.5 µm Sn over 0.5 – 2.5 µm Ni
- PCB material and hole specification, for this press-fit pin are described in section 9.2.
- The pins are very flexible in all directions (X/Y/Z) and must be handled with care, to avoid any deformation due to handling.
- All pins must be aligned and supported over the pin shoulders (figure 17) during press-in process with a corresponding tool, as described in section 9.4. The pin shoulders are 2.3 mm below the nominal center of the PCB with a thickness of 1.6 mm. For the missing dimensions (center of PCB and shoulder position relative to module features), please refer to the module outline drawing in the RoadPak data sheet.



17 Pin with pin shoulder for alignment and support

9.2. PCB specification

The press-fit pin (as specified in section 9.1) has been qualified with the following PCB specification (material and plated through holes), according to IEC 60352-5. Alternative PCB specifications have not been tested.
PCB specification for Inovan 06-10 press-fit (as specified in 9.1):

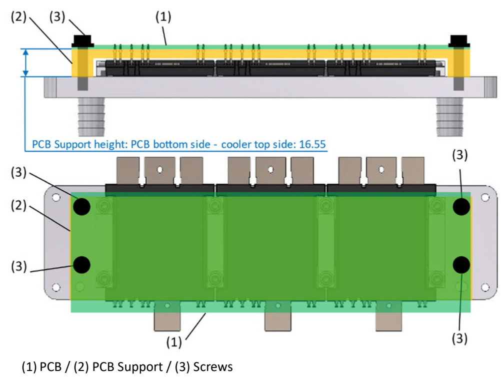
- PCB material and thickness: FR4 ISOLA IS 410 - 1.6mm ±10%
- Dimensions and plating according to IEC 60352-5 (proposal see Table 2)

Description	Unit	Min.	Typ	Max.	Remarks
Drill tool diameter	mm		1.15		
Copper thickness in hole	µm	25		50	To avoid cracks in the Cu metallization, the minimum copper thickness should not be lower than 25 µm
Tin thickness in hole (Sn chemical)	µm	1		5	Other metallization types, such as HAL + ENIG plating are not recommended, they have a negative impact on press-fit connection and have not been tested
End diameter of plated trough hole	mm	0.94	1.06	1.09	Recommended end diameter of plated through hole according to IEC 60352-5 is 1.06 mm

Table 2: Dimensions and plating of hole (proposal)

9.3. PCB support and fixation in final position

It is highly recommended to support and fix the PCB in its final position close to the press-fit connection position to ensure a reliable auxiliary connection during operation (shock and vibration). Ideally, the PCB is directly fixed to the cooler by an additional PCB support (figure 18 - 2). The usage of a PCB support is also beneficial during the PCB mounting process (see section 9.4), where it acts as a z-direction block for height control of the PCB. The recommended PCB support height for an FR4 PCB (thickness 1.6 mm) mounted on top of the cooler is: 16.55 mm, measured from cooler top side to PCB bottom side (figure 18).



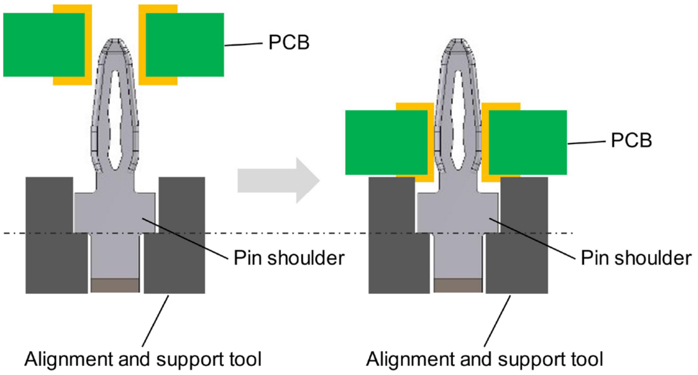
(1) PCB
(2) PCB Support
(3) Screws

18 Fixation of PCB to cooler, with additional PCB support

Hitachi Energy Ltd.
Semiconductors
Fabrikstrasse 3
5600 Lenzburg, Switzerland
Tel: +41 58 588 68 68
salesdesksem@hitachienergy.com

9.4. PCB mounting process (press-fit connection)

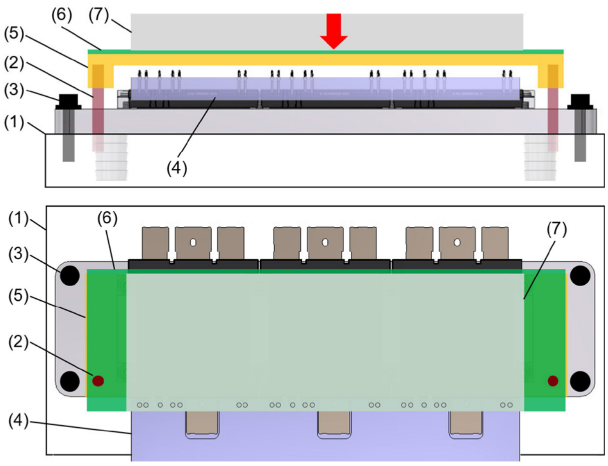
To press the press-fit pins into the PCB, a PCB mounting fixture (section 9.4.1) has been designed, mounted on a press. This fixture setup has been used for RoadPak qualification. The fixture concept is based on the assumption that a PCB support (see section 9.3) is used for the PCB positioning and fixation in its final position. The usage of a PCB support is very beneficial during the PCB mounting process, as it acts as a blocker in z-direction during pressing the pins into the PCB. A description of the PCB mounting process sequence can be next found under section 9.4.2.
The press-fit pins (auxiliary pins) of the RoadPak module are very flexible and need to be aligned and supported over the pin shoulder (figure 19) during press-fit connection process with an alignment and support tool (section 9.4.3).



19 Pin shoulder for alignment and support during press-fit connection

9.4.1. PCB mounting fixture setup

The image below shows a PCB mounting fixture setup, as used during qualification of RoadPak. The fixture was mounted on a pneumatic press (not shown), with force, travel, and speed measurement for process control.

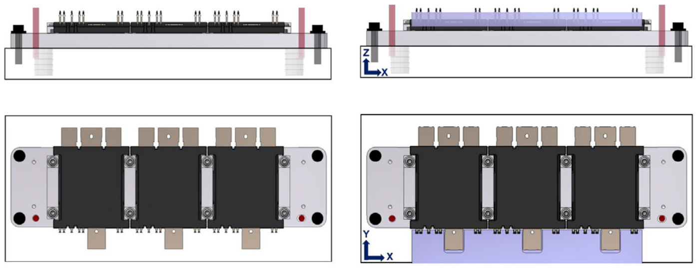


(1) Fixture plate
(2) Alignment pins (cooler + PCB)
(3) Screws or any other fixation
(4) Pin alignment and support tool (**Error! Reference source not found.**)
(5) PCB support (**Error! Reference source not found.**)
(6) PCB (**Error! Reference source not found.**)
(7) Press block

20 PCB mounting fixture setup (as used during qualification)

9.4.2. PCB mounting sequence

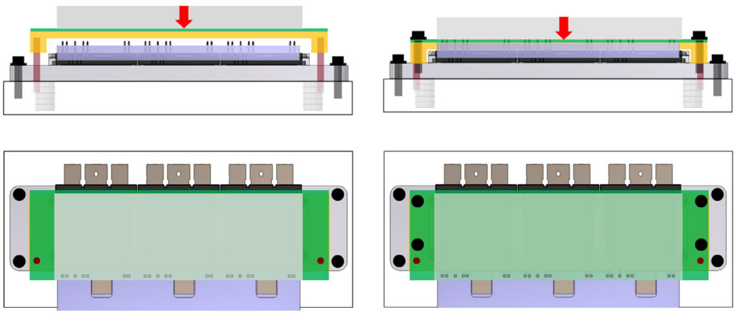
1. Provide PCB mounting fixture (section 9.4.1) attached on a press setup.
2. Align the assembly (module mounted to cooler) over the two alignment pins (figure 20 - 2).
3. Fix the assembly in the fixture with screws (figure 20 - 3) or any other fixation method, to avoid upwards tilting of the assembly during press-in process.
4. Align and support the press-fit pins with the alignment and support tool (figure 20 - 4) in two steps (y- and z-direction separate) as described in section 9.4.3.



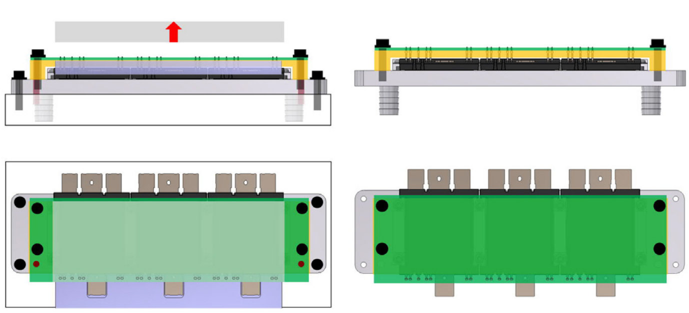
21 PCB Mounting sequence illustration (step 1 - 4)

5. Align and fix the PCB (figure 20 - 6) to the PCB support (figure 20 - 5), align this pre-assembly over the alignment pins (figure 20 - 2), attach it to the press block (figure 20 - 7), for instance by vacuum, and hold it above the press-fit pins.
6. Moving the press block down towards the press-fit pins until the PCB support (figure 20 - 5) blocks on the cooler top surface and control and track the press-in speed and force (section 9.4.4) during press-in process.
7. Fix the PCB support (figure 20 - 5) including PCB (figure 20 - 6) to the cooler, by additional screws.
8. Detach the PCB from the press block (figure 20 - 7), by releasing the vacuum.

Hitachi Energy Ltd.
Semiconductors
Fabrikstrasse 3
5600 Lenzburg, Switzerland
Tel: +41 58 588 68 68
salesdesksem@hitachienergy.com



22 PCB Mounting sequence illustration (step 5 - 7)



23 Mounting sequence illustration (step 8 -10)

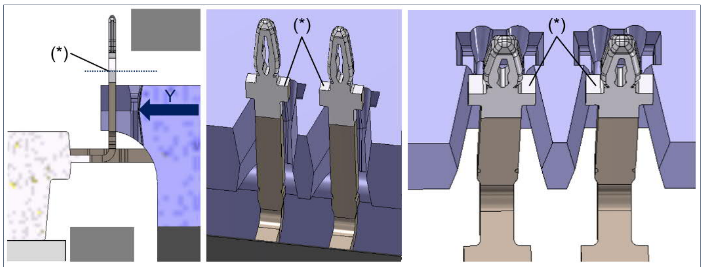
9. Move away the pin alignment and support tool (figure 20 - 4) and remove the screws for assembly fixation (figure 20 - 3).
10. Move the press upwards and take the final assembly (PCB mounted) out of the fixture.

9.4.3. Pin alignment and support tool

For RoadPak qualification, a pin alignment and support tool which was part of the PCB mounting fixture (section 9.4.1) has been designed. The tool was designed in such a way to do the alignment in 2 steps (y + z-directions in separate steps). The 2-step approach guarantees a secure alignment of the 21 pins and due to the chamfers in the openings of the tool, it allows to control positions tolerances of the very flexible pins. In the final tool position, all pins will be perfectly aligned in x- and y- directions and supported in z-direction for the PCB press-in process. If a pin position is still too high in z-direction, it will be pressed down by the PCB to the final position (pin shoulder block). The alignment and support tool needs to be designed in such a way, to withstand the press-in forces described in section 9.4.4. Alternative methods for alignment and support of the pins, might be possible, but have not been tested.

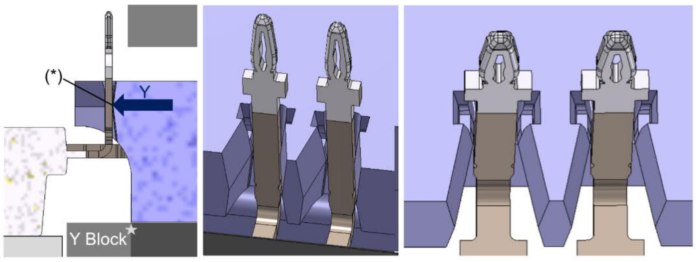
Aligning and supporting the pins in 2 steps (y- and z-direction)

1. Moving the alignment tool in y-direction (figures 24 and 25).



Move the pin alignment tool in y-direction towards pins. Keep the tool below the pin shoulders (*).	All pins will be pre-aligned in x-direction.	Due to slots with chamfers, positioning tolerances of the pins can be controlled.

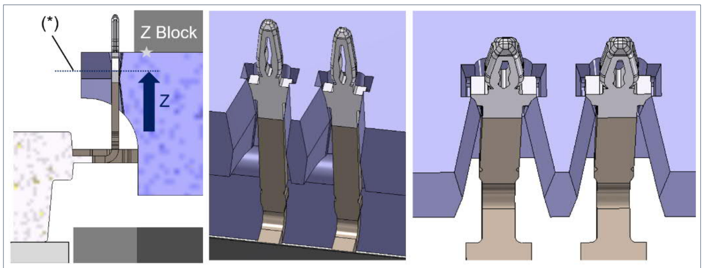
24 Moving tool in y-direction below pin shoulders



Move the tool in y-direction until the theoretical y-zero point of the pins (*). Block and fix the tool in y-direction (Y Block). The tool must still be moveable in z-direction.	All pins are now well aligned in x-direction. y-direction is pre-aligned.	At y-zero position the alignment tool, has a tight alignment opening in x-direction.

25 Block the tool in y-direction in its final position

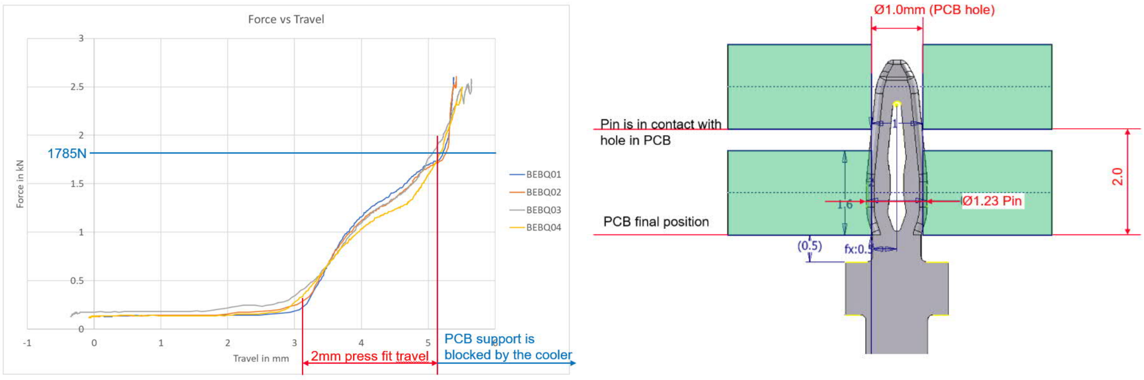
2. Moving the alignment tool in z-direction (figure 26).



Move the tool in z-direction until the theoretical z-zero point of the pin (*) – the pin shoulder. Block and fix the tool in z-direction (Z Block).	All pins are now well aligned in x + y-direction over pin shoulder.	At z-zero position the alignment tool, has a tight alignment opening in x + y-direction . The pin shoulder will be supported by the tool in z-direction. If a pin is too high, it will be pressed down to the right z-zero point during PCB mounting.

26 Moving the tool in z-direction and block it in final position

Hitachi Energy Ltd.
Semiconductors
Fabrikstrasse 3
5600 Lenzburg, Switzerland
Tel: +41 58 588 68 68
salesdesksem@hitachienergy.com



27 Press-in force vs. travel for 3 modules (21 pins: 1785 N), measured on 4 assemblies – force increase over roughly 2 mm travel distance, after first contact of pins with PCB until the final position (PCB support blocks on cooler top surface)

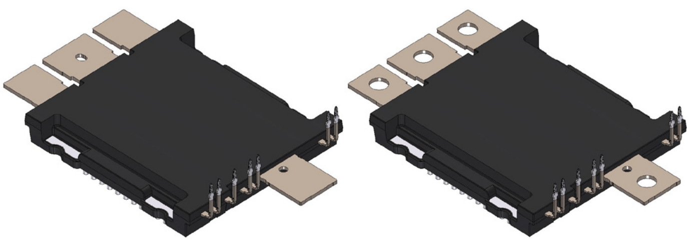
9.4.4. Press-in speed and forces

The following specification regarding press-in speed and the estimated press-in forces, according to INOVAN 40 2187 01, must be considered during the press-fit connection process. For process control reasons, the force, travel, and speed during the process should be controlled and tracked.
As shown in figure 27 the press fit travel distance for a pin is roughly 2 mm, after the conical tip of the pin touches the PCB hole the first time, until the final position (PCB support blocks on the cooler top surface).

- Recommended press-in speed: 25 mm/min (0.42 mm/sec)
- Estimated press-in force per pin: approx. 85 N
  - For 1 RoadPak module (7 pins): approx. 595 N
  - For 3 RoadPak modules (21 pins): approx. 1785 N

10. Connecting main terminals to busbar

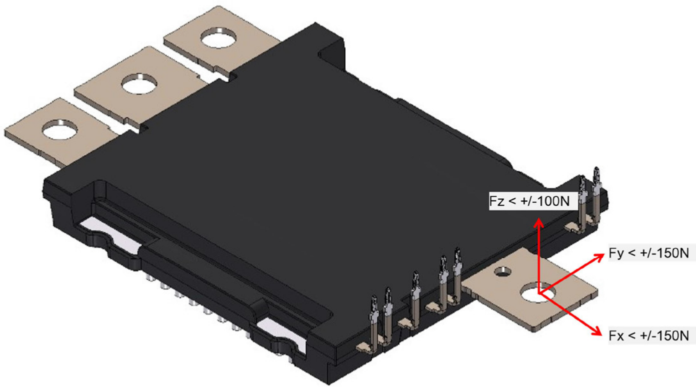
There are two versions of the RoadPak modules available with different main terminal designs, which allows to contact the main terminals to the busbar, with either welding or screwing process (figure 28). Laser welding is the preferred method for high volume manufacturing, but for lower volumes also a screwing connection is possible. While connecting the main terminals to the busbar in the inverter, the maximum forces on main terminals, defined in section 10.1 must not be exceeded.



28 Two different versions of RoadPak main terminals (left: designed for welding connection + right: designed for screwing connection).

10.1. Maximum forces allowed on main terminals

While connecting the main terminals to the busbar, or in operation, the maximum forces to the main terminals in all directions must not be exceeded. The main terminals are not designed to be bent in any direction for tolerance compensation. Plastic deformation of the main terminals must be avoided and height tolerances in the inverter assembly must be compensated in a different way. Higher forces than specified in (figure 29), could lead to cracks in the epoxy mold body of the RoadPak module and must be avoided, to guarantee the function of the RoadPak module.

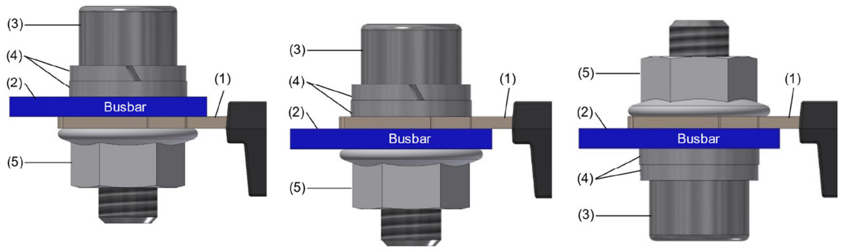


29 Maximum allowed forces on main terminals, to avoid cracks in the epoxy mold body

10.2. Connecting the main terminals with welding

Laser welding is the preferred method to connect the main terminals to the busbar, especially for high volume manufacturing. The laser welding process, including all process parameters, must be evaluated by the customer with support of a welding equipment supplier. Please consider enough space in the inverter design for the welding process and note that before and during the welding process, the maximum allowed forces to the terminals, defined in

Hitachi Energy Ltd.
Semiconductors
Fabrikstrasse 3
5600 Lenzburg, Switzerland
Tel: +41 58 588 68 68
salesdesksem@hitachienergy.com



(1) Terminal (RoadPak
(2) Busbar (Inverter)
(3) Screw
(4) Securing elements
(5) Nut

(1) Terminal (RoadPak) / (2) Busbar (Inverter) / (3) Screw / (4) Securing elements / (5) Nut

30 Examples of possible screw connections

section 10.1, must not be exceeded. During laser welding process, the maximum allowed temperature on the epoxy mold body of the RoadPak module is: 150°C.
Main terminal specification:
- Oxygen free copper (Cu-OF R240)
- No additional coating
- Thickness 1.2 mm

10.3. Connecting the main terminals with screws

Screwing is another method, besides welding, to connect the main terminals to the busbar, suitable for small volume manufacturing and engineering. The hole diameter in the main terminals is Ø 6.4 mm and designed for a M6 screws or smaller.
Main terminal specification:
- Oxygen free copper (Cu-OF R240)
- No additional coating
- Thickness 1.2 mm
- Hole diameter: Ø6.4 mm (for M6 screws, or smaller)

There are several possibilities, how to screw the terminals to the busbar, depending on the inverter design. Some possible screw connection examples are shown in figure 30. It is strongly recommended to secure the screws against loosening, due to vibrations in application. The torque applied to the screw connection depends on the chosen screw and nut design and must be evaluated by the customer. Please consider enough space in the inverter design for the tools to apply the torque and counter torque to the screw connection. Please note that during applying the torques to the screw connection, the maximum allowed forces to the terminals, defined in section 10.1, must not be exceeded. Screw and nut type, and securing elements are only listed as examples and must be evaluated during the inverter design.

11. Recycling recommendation

Our power semiconductor devices have built-in chips, which are manufactured with a minute amount of impure substances harmful to a human body. These substances are bound to the chip materials used on a molecular level and will never be drained away. They are also completely sealed by packages and thus have no influence on the environment. However, when disposing our semiconductor devices, please be sure to hire a professional waste disposer to treat them as industrial waste, not to crush or burn them without proper treatment or careful consideration.

12. References

• IEC 60747 "Semiconductor devices"
• IEC 60352-5 "Press-in connections - General requirements, test methods and practical guidance"
• 5SZK 9118 "General environmental conditions for high power semiconductors"
• INOVAN 40 2187 01 "Specification Press Fit Area Inovan 06-10"
• BN 10649 "Bossard - ecosyn®-fix screws"
• ISBN 0-8247-2569-7 "Power Semiconductors» (Stefan Linder)

13. Revision history

Version	Change	Authors
Initial Edition	November 2022	Tobias Keller Dominik Trüssel

Hitachi Energy Ltd.
Semiconductors
Fabrikstrasse 3
5600 Lenzburg, Switzerland
Tel: +41 58 588 68 68
salesdesksem@hitachienergy.com