# XHP™ 2 power modules

## Application and assembly note

## About this document

### Scope and purpose

This document, in combination with the product datasheets, provides application details and assembly instructions for the XHP™ 2 semiconductor module family. More information on Infineon's power module datasheets is available in [1].

An important aspect in the construction of the mechanical layout is the application condition at which the components are operated. This application note should be considered for mechanical, electrical, and thermal designs using Infineon's XHP™ 2 products.

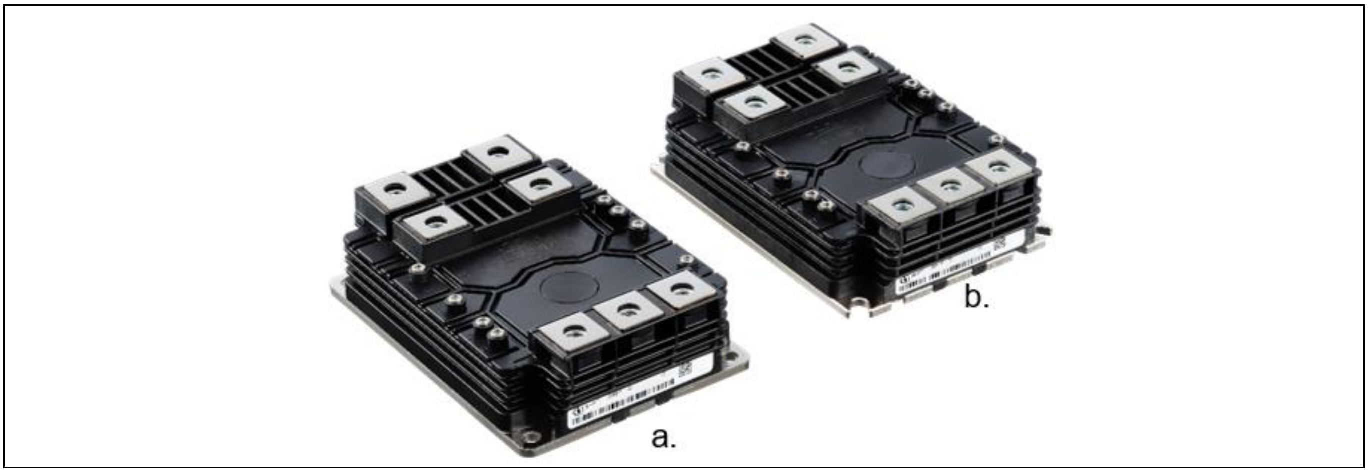


**Figure 1 Typical appearance of the XHP™ 2 product family with:**
**a. Copper (Cu) baseplate**
**b. Aluminum silicon carbide composite (AlSiC) baseplate**

The notes and recommendations in this document cannot cover all applications and not all conditions. It is recommended that users perform a thorough assessment and evaluation of the suitability of this product for the purpose envisaged by their technical departments.

This application note only provides guidelines for the implementation of the XHP™ 2 products and the contents should NOT be regarded as warranty for any functionality, condition, or quality of the product.

### Intended audience

The intended audiences for this document are design engineers, technicians, and developers of electronic systems.

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# 1 Electrostatic protective measures

Power semiconductors components are electrostatic-sensitive devices that require handling according to the electrostatic discharge (ESD) directives. Uncontrolled discharge, voltage from non-earthed operating equipment, personnel, static discharges, or similar effects can destroy the devices.

The gate emitter (IGBT)/gate source (MOSFET) control terminals are electrostatic-sensitive contacts. Users must NOT operate or measure power modules with open-circuit gate-emitter terminals.

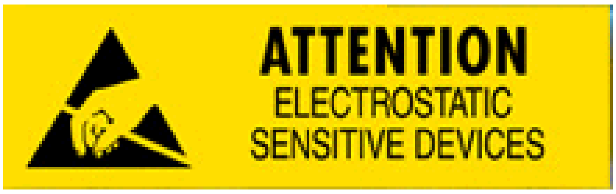


**Figure 2 ESD label**

***Attention:*** ***ESD can partially or even completely damage the power modules. Users must observe all precautions to avoid electrostatic discharge during handling, movement, and packing of these components.***

To avoid destruction or pre-damage to the power semiconductor components by electrostatic discharge, the devices are made using suitable ESD packaging. The module is delivered with an ESD protection at module terminals according to the ESD directives.

***Note:*** *Installing ESD workstations is required for unpacking the module, removing the ESD protection, and for handling the unprotected modules.*

Subsequent work steps must only be carried out at special workstations complying with the following requirements:

- High impedance ground connection
- Conductive workstation surface
- ESD wrist straps

Further information is available in the currently valid standards:

- IEC 61340-5-2: Protection of electronic devices from electrostatic phenomena, general requirements
- ANSI/ESD S2020
- MIL-STD 883C: Method 3015.6 for testing and classification
- DIN VDE 0843 T2: identical to IEC801-2

# 2 Power module material content

The following directives regulate the use of substances classified by legislators as "hazardous in the end products":

- The European directives 2000/53/EC governing end-of-life vehicles (ELV Directive: End-of-Life Vehicles)
- 2015/863/EU that amends Annex II of Directive 2011/65/EU to restrict the use of certain hazardous substances in electrical and electronic devices (RoHS directive)

Infineon's products comply with these requirements and conform to the material restrictions in all applicable statutory regulations.

Material content datasheets (MCDS) are available at www.Infineon.com on the respective product pages.

For detailed RoHS information on specific products, please contact an Infineon sales partner.

# 3 Supply quality

Individual electrical power module characteristics are described in the module datasheet. Maximum values in the product datasheets and additional descriptions, such as those given in application notes, are absolute values that must NOT be exceeded, even for brief periods. It can lead to pre-damage or destruction of the power module.

Each individual power module must pass the end-of-line production test according to IEC60747-9 and IEC60747-15. Inwards goods test of the components at the recipient's site is therefore not required.

Deflection of the base plate in the µm range is permissible within valid Infineon specification limits and bears no influence on the thermal, electrical, or reliability characteristics of the power modules.

After the final visual inspection, the modules are equipped with individual ESD protection and packed in an ESD-protected transport packaging. The transport packaging is sealed with adhesive tape and has an appropriate ESD label.

Product qualification reports (PQR) are available at www.Infineon.com on the respective product pages.

## 3.1 Storage and transportation of power modules

The storage of modules needs be differentiated in two main cases. Storing the modules in the origin packaging, with respect to logistics of shipping goods. The second case is storing the module in the final application when the module is mounted and connected but not operating.

For the first case, storing the modules in the origin packaging the detailed storage conditions and storage time of power modules in the original packaging is defined by Infineon [2]. During transportation and storage of the modules, extreme forces such as shock and/or vibration loads, and extreme environmental influences should be avoided.

The storage time at the recommended storage conditions mentioned in [2] should not be exceeded.

If the modules are properly stored in accordance with the Infineon guidelines given in [2] in the original packaging, a pre-drying process of the modules before assembly will not be necessary.

The XHP™ 2 modules are available in two variants:

- With an advanced pre-applied thermal interface layer on the base plate
- Without a pre-applied thermal interface layer

More information about Infineon's pre-applied thermal interface material (TIM) is available in chapter 6.1.1. Both variants differ in their shipping packages.

- XHP™ 2 modules with the advanced pre-applied TIM at the module base plate are delivered in an expanded polypropylene (EPP) box. The EPP box is made to transport the pre-applied thermal interface material safely.
- XHP™ 2 modules without pre-applied thermal interface material are shipped in a disposable paper box.

Once the modules are removed from the packaging, the pre-applied thermal interface layer is no longer protected. To ensure compliance with the thermal properties specified by Infineon, users must carefully handle the layer until the module is mounted on the heatsink.

After the power module is removed from the ESD-protected transport box, further processing must be carried out in accordance with the guidelines given in Chapter 1. The ESD protection attached to the module's auxiliary contacts can remain on the modules until the gate control board is installed.

For storing the modules in the final application when the module is mounted and connected but not operating, the temperature limits for storing are used in the bare module qualification and defined in the individual module datasheet. If the module is stored under these extreme conditions in an assembled and connected conditions, the user must check and ensure on his own responsibility that no impermissible conditions or loads act on the module. Further information can be found in the notes and recommendations in this Application Note and on the ambient conditions before commissioning in chapter 5.4.

For more information, contact an Infineon sales partner or visit www.Infineon.com.

# 4 Module labeling and type designation

Infineon offers power modules in different configurations, and voltage and current ranges with various optimizations. Each power module variant is described with an individual type-designation.

## 4.1 Power module type designation

Table 1 explains individual digits of a product type name as examples. Further combinations and variations may differ from these examples.

Table 1 **Type designation examples for Infineon power modules**

| **FF** | **1800** | **XT** | **R** | **17** | **T2** | **P** | **5** | **_P** |
|---|---|---|---|---|---|---|---|---|
| FF | | | | | | | | Half-bridge topology – dual switch topology |
| FD | | | | | | | | Chopper-switch configuration, high side system |
| DF | | | | | | | | Chopper-switch configuration, low side system |
| FZ | | | | | | | | Single-switch configuration |
| DD | | | | | | | | Dual diode topology |
| (1) | 1800 | | | | | | | IGBT modules nominal collector current in Amperes |
| (1) | 2000 | | | | | | | CoolSiC™ modules drain-source resistance, $R_{DS(on)}$ |
| | | U | | | | | | CoolSiC™ $R_{DS(on)}$ in µOhm [micro Ohm] |
| | | M | | | | | | CoolSiC™ $R_{DS(on)}$ in mOhm [milli Ohm] |
| | | XT | | | | | | .XT technology for extended high cycling load capability |
| | | | R | | | | | Reverse conducting |
| | | | RB | | | | | Reverse blocking |
| | | | S | | | | | Fast diode |
| | | | | 17 | | | | Blocking voltage in 100 V steps = 1700 V |
| | | | | 33 | | | | Blocking voltage in 100 V steps = 3300 V |
| | | | | | T2 | | | XHP™ 2 package |
| | | | | | T3 | | | XHP™ 3 package |
| | | | | | | P | | TRENCHSTOP™ IGBT: soft turn-off with optimized tail current |
| | | | | | | E | | TRENCHSTOP™ IGBT: fast switching with low tail current |
| | | | | | | M | | CoolSiC™ MOSFET |
| | | | | | | | 1..n | Chip generation |
| | | | | | | | | D enlarged diode |
| | | | | | | | | _P Pre-applied thermal interface material |
| (2) | Optional | | | | | | | _S1..n Marking for additional electrical properties |
| (2) | Optional | | | | | | | _B1..n Marking for additional mechanical properties |

(1) This type designation is described via the Si-IGBT modules nominal collector current, $I_{C,nom}$, value in Ampere (A) or the SiC-CoolSiC™ modules drain-source resistance $R_{DS(on)}$ value (in µΩ or mΩ depending on the following letter), is only shown as an example. The module-specific data is provided in the respective module's product datasheet.

(2) Power module features marked as "optional" in the type-designation are described in the specific power module's datasheet.

## 4.2 Power module labels

All Infineon power modules provide a module-specific label. The position and content of the label corresponds to the module's design and required size. The position of the label in XHP™ 2 modules is shown in Figure 3.

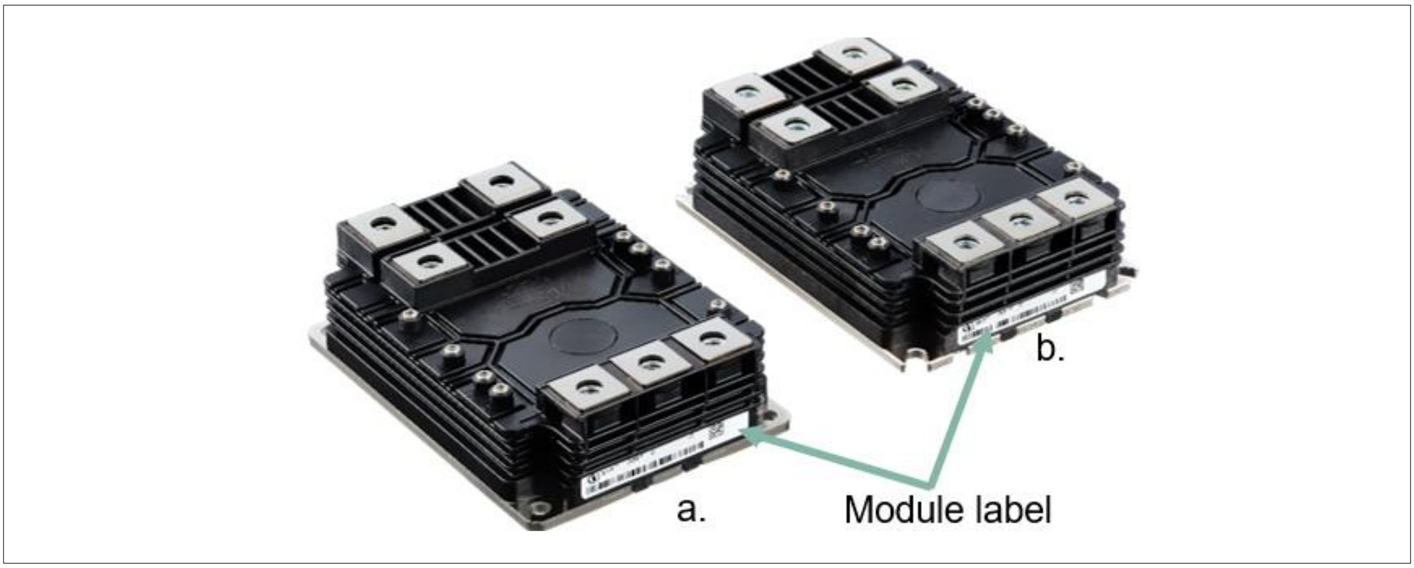


**Figure 3 Typical appearance of the XHP™ 2 with label positions**
**a. Module with copper baseplate**
**b. Module with AlSiC baseplate**

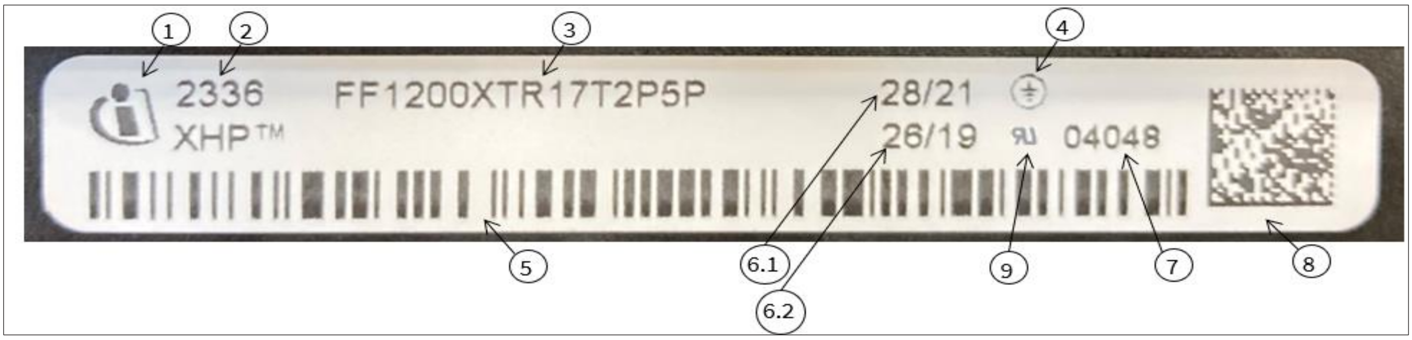


**Figure 4 An exemplary XHP™ 2 product label**

The content of the product label and the machine-readable codes are shown in Table 2.

Table 2 **Exemplary content on the product label:**

| Label Number | Description |
|---|---|
| 1 | Infineon brand logo |
| 2 | Date code:<br>01 - 02 digit: production year (YY)<br>03 - 04 digit: production week (WW) |
| 3 | Type designation as per Table 1 |
| 4 | Grounding symbol; basic insulation acc. EN/IEC 61140 |
| 5 | Barcode type 128<br>01 – 05 digit: module serial number<br>06 – 11 digit: module material number<br>12 – 19 digit: production order number<br>20 – 21 digit: YY - production year date code, e.g., 2023 = 23)<br>22 – 23 digit: WW - production week date code, e.g., week = 36) |
| 6.1 | Optional: IGBT $V_{CEsat}$ class high side/FWD $V_F$ class high side (HS) (3) |
| 6.2 | Optional: IGBT $V_{CEsat}$ class low side/FWD $V_F$ class low side (LS) (3) |
| 7 | Module serial number; 5 digits, unambiguous in combination with date code |
| 8 | 2D data matrix code type ECC200<br>01 – 05 digit: module serial number<br>06 – 11 digit: module material number<br>12 – 19 digit: production order number<br>20 – 21 digit: YY - production year date code, e.g., 2023 = 23)<br>22 - 23 digit: WW - production week date code, e.g., week = 36)<br>24 – 27 digit: 0000<br>28 – 29 digit: IGBT $V_{CEsat}$ class high side switch = 28<br>30 – 31 digit: FWD $V_F$ classes high side diode = 21<br>32 – 33 digit: IGBT $V_{CEsat}$ class low side switch = 26<br>34 – 35 digit: FWD $V_F$ classes low side diode = 19 |
| 9 | Optional: UL component mark according to UL 1557<br>UR is a trademark of UL LLC |

(3) The $V_{CEsat}$ and $V_F$ classes listed on the module label can help select the narrow $V_{CEsat}$ and $V_F$ parameters for paralleling power modules. HS or LS systems in similar classes have the same measured parameters. The class from HS and LS may differ due to different layout design within the module.

# 5 Selecting a power module for the application

Infineon offers power modules in different configurations, and voltage and current ranges with various optimizations.

Various criteria's, depending on the target application of the module, needs to be considered for selecting the most suitable component.

## 5.1 Selecting the module's voltage class

When selecting an appropriate power module, the semiconductor must have a blocking capability appropriate for the operating conditions.

Table 3 shows examples of possible voltage classes for different working voltages. This table can be referred to select the initial voltage class. The maximum blocking voltage of the power module, specified in individual product datasheets, must not be exceeded even for short periods during switching. The maximum blocking voltage shall be considered while selecting a suitable voltage class over the entire temperature range.

Table 3 **Exemplary possible voltage classes for exemplary given different operational voltage**

| **Nominal voltage,**<br>± tolerances according to the application must be considered | **System voltage,**<br>**defined as maximum voltage**<br>e.g. Photovoltaic systems | **Typical power module voltage class**<br>**used in 2 level topologies** |
|---|---|---|
| 300 $V_{DC}$ | n.a. | 600 V / 650 V |
| n.a. | 600 $V_{DC}$ | 1200 V |
| 600 $V_{DC}$ | n.a. | 1200 V |
| 750 $V_{DC}$ | n.a. | 1700 V |
| n.a. | 1000 $V_{DC}$ | 1700 V |
| 1100 $V_{DC}$ | n.a. | 1700 V |
| n.a. | 1500 $V_{DC}$ | 2300 V |
| 1500 $V_{DC}$ ± industrial tolerances | n.a. | 2300 V |
| 1500 $V_{DC}$ ± railway tolerances | n.a. | 3300 V |
| n.a. | 2000 $V_{DC}$ | 3300 V |
| 2800 $V_{DC}$ | n.a. | 4500 V |
| 3000 $V_{DC}$ | n.a. | 6500 V |

Depending on the application for the selection of a proper module voltage classes, the possible voltage tolerances within the application must be taken into account. High value for upper tolerance may require the selection of a higher voltage class power module.

Beside the selection according to the application voltage level, transient overvoltage's effects must be considered for the power module voltage class as well. The transient overvoltage, $\Delta V_L(t)$, at the switch during a turn-off event, affected by the load current slope $(\frac{di}{dt})$ and the complete, module + system setup, stray inductances ($L_\sigma$) must be considered as a further add-on for selecting a suitable voltage class.

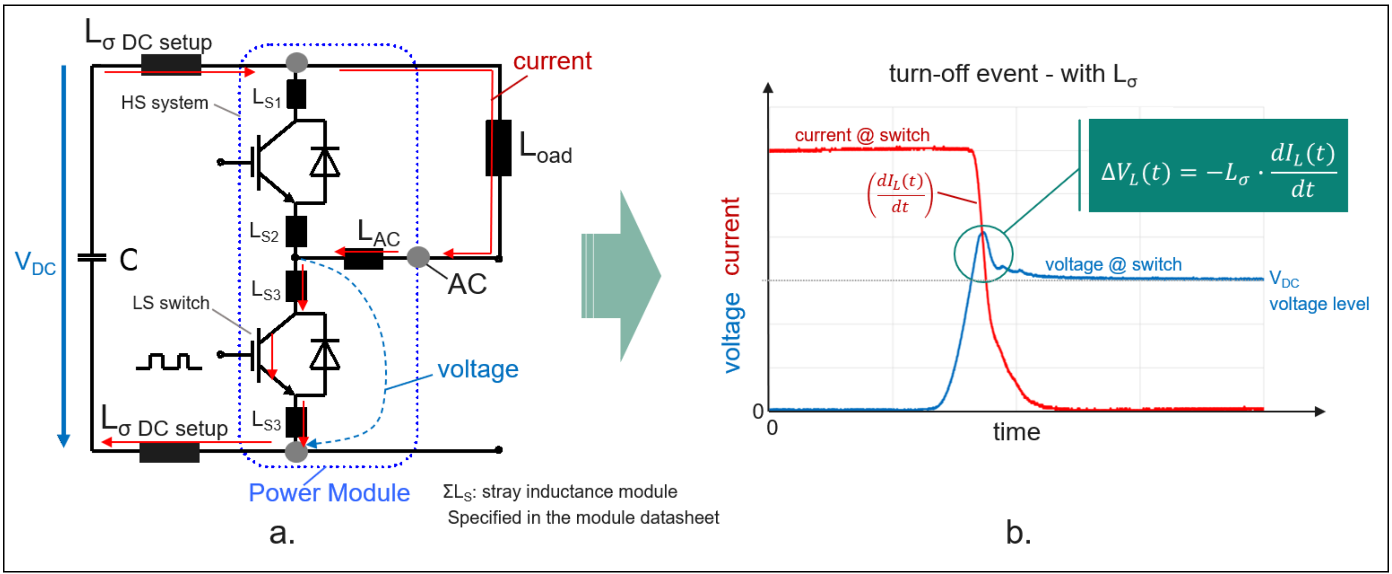


**Figure 5 a. Simplified equivalent circuit diagram of a power module in a test setup**
**b. Simplified example of a turn-off event with the overvoltage influences due to $L_\sigma$**

Total system stray inductance: Lσ = LS, module + Lσ, DC setup **(1)**

Overvoltage: $\Delta V = (-L_\sigma * \frac{di}{dt})$ **(2)**

Total voltage under switching conditions: $\text{Voltage} = (V_{DC} + \Delta V) \leq \text{module voltage class}$ **(3)**

If the operating temperature is T < 25°C, the reduced blocking capability and a steeper current slope should be kept in mind, studied, and considered in the design. The specification of the blocking capability's dependence on the temperature T = - 40°C to T = + 25°C is available on request from Infineon's sales representative for power devices.

Operating the power semiconductor components at elevated geographical levels, e.g., at geographical heights over 2000 m above sea level (>2000 m.a.s.l.) may limit the operating range.

Due to the lower air pressure, the cooling capability of the air-cooling systems may require evaluation.

Insulation properties, especially clearance distances, would require adjustments due to the lower dielectric strength of the air. See also chapter 5.5 on module creepage and clearance distances.

The possible statistical failure rates when operating power semiconductors at elevated heights (cosmic radiation or single burn-out events) should be considered when selecting a suitable voltage class during the design phase.

***Note:*** *The maximum blocking voltage of the power module must not be exceeded even for short periods during switching. Exceeding the specified maximum voltage class of the power module means operating out of the specification. This may lead to a failure of the power module.*

***Note:*** *In addition to selecting the module voltage class that matches the intended DC link voltage range, other insulation coordination requirements must be considered. Insulation test voltage, clearance and creepage distance must be derived from topology, system voltage, overvoltage category and pollution degree according to the standards applicable to the respective design. The product definition for power modules takes into account the most common application requirements. The use of complex topologies or exceptionally harsh environmental conditions may lead to requirements that are not covered by our standard modules. In this case, please contact an Infineon sales partner to discuss further options.*

## 5.2 Selecting the module current class

When selecting a suitable module current class, a thermal simulation supports the initial selection criteria to determine the maximum junction temperature ($T_{vjop}$) under switching conditions.

Infineon´s IPOSIM is an online simulation platform for loss and thermal calculation of Infineon power modules, discrete and disc devices. This Plecs-powered tool supports the user to select the most suitable Infineon high power product according to the application parameters entered in the simulation.

The complete product overview of the selection and the simulation program, IPOSIM, is available at www.Infineon.com.

## 5.3 Power module lifetime under cyclic load conditions

The ability to withstand active cycling loads during their operational lifetime is essential for the reliability of power modules. Especially in demanding applications such as in the traction converters of commercial vehicles, train applications, or converters in wind turbines. To estimate the lifetime of such applications, dedicated power module models are required. Results of investigations in which test parameters are adjusted to determine their influence on aging mechanisms are used as the basis for developing these models. Power cycling (PC) diagrams are based on such models. These diagrams describe a power module's ability to withstand cyclic loads. They are also used to calculate the power module's lifetime. More information on this subject is provided in [2] and [20].

## 5.4 Environmental conditions

XHP™ modules are not hermetically sealed. The housings and the molding compound used for electrical insulation within the housing allow humidity and gases to permeate in both directions. Therefore, humidity differences are equalized in both directions. Corrosive gases must be avoided during storage and operation of the devices.

The climatic conditions for Infineon XHP™ modules in active, current-carrying operations are specified as per IEC60721. Avoid operating these modules in humid conditions created by condensation or in climatic conditions beyond the IEC60721 humidity classes defined for the individual module and/or voltage class, for example beyond class 3K22 or 5K2. Additional protective countermeasures should be taken in such cases.

More information on this subject is provided in [20] or contact your sales partner for Infineon power modules.

## 5.5 Module creepage and clearance distances

For designing and evaluating the insulation characteristics of an application, the application-specific standards, particularly regarding clearance and creepage distances, must be considered.

The given clearance and creepage values are the shortest clearance and creepage distances, considering the minus tolerances of the power module housing.

When selecting bolts and washers, sufficient clearance and creepage distances must be considered.

The module specific XHP™ 2 package drawings (2D), including tolerances, can be taken from the datasheets. The 3D housing model, without tolerance information, can be taken from www.Infineon.com or from your sales partner for Infineon modules.

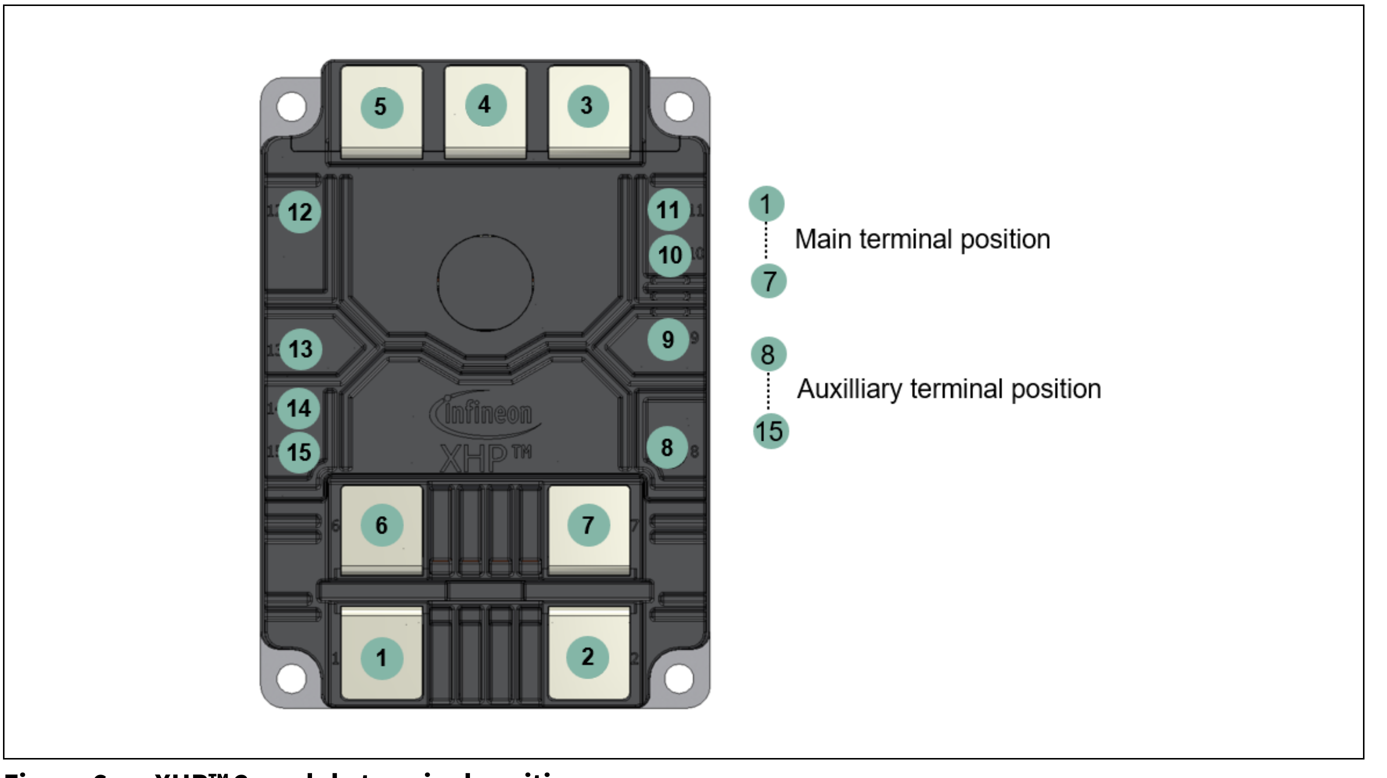


**Figure 6** XHP™ 2 module terminal position

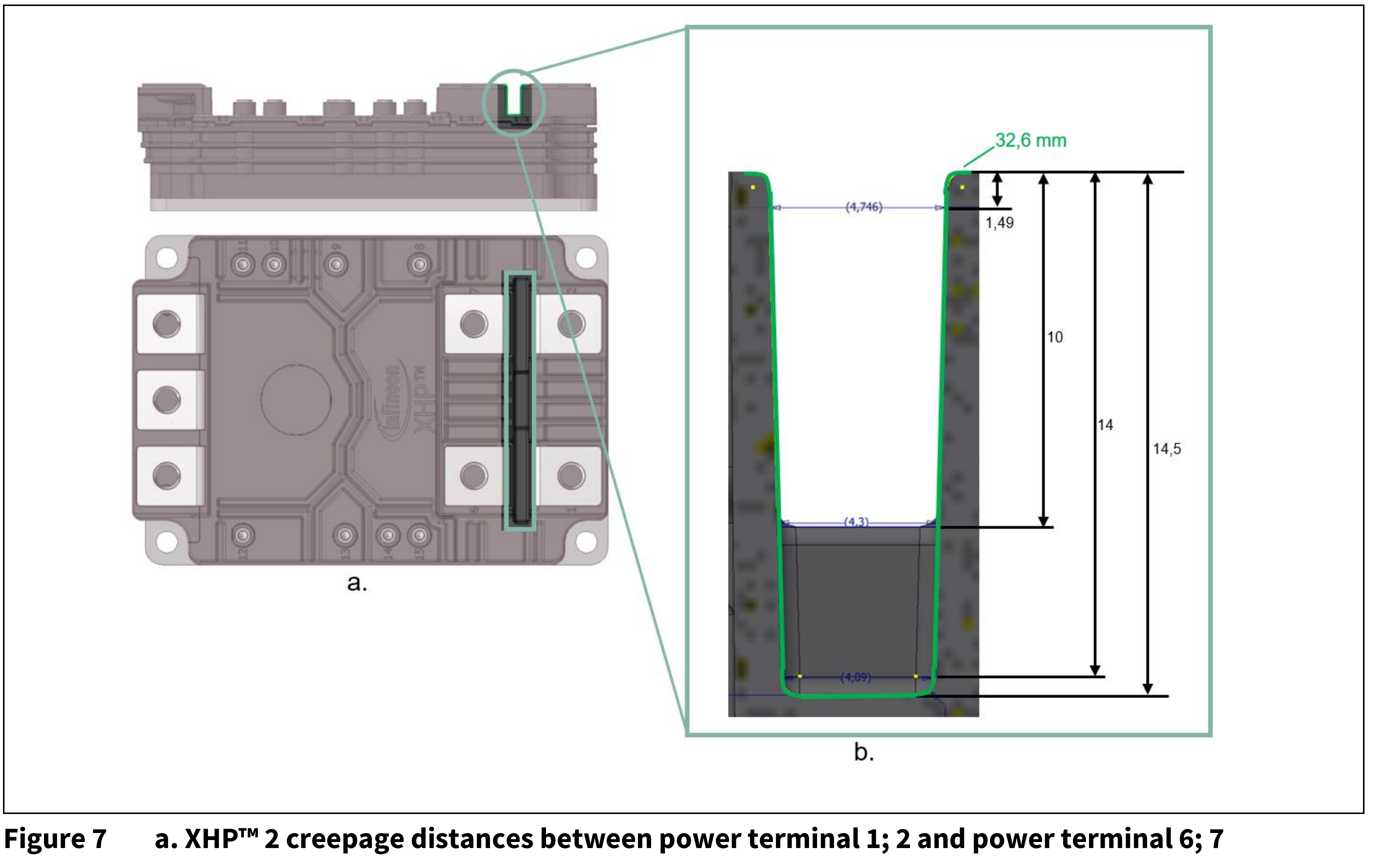


**Figure 7** a. XHP™ 2 creepage distances between power terminal 1; 2 and power terminal 6; 7
b. Exemplary trench drawing between DC(+) and DC(-)

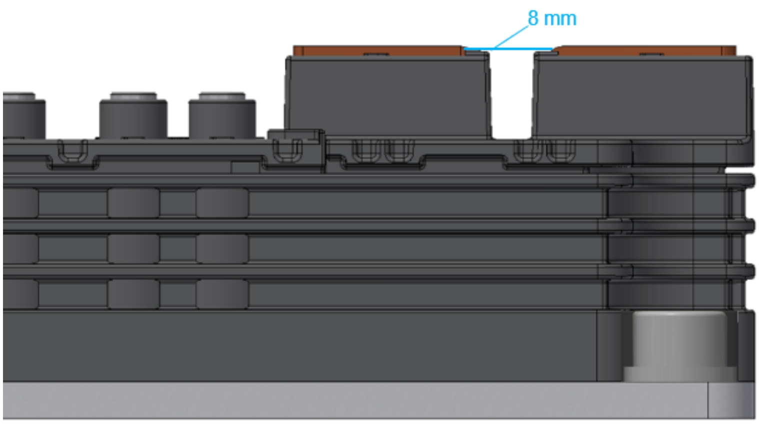


**Figure 8** Clearance distance between power terminal 1; 2 and power terminal 6; 7 in an XHP™ 2 module

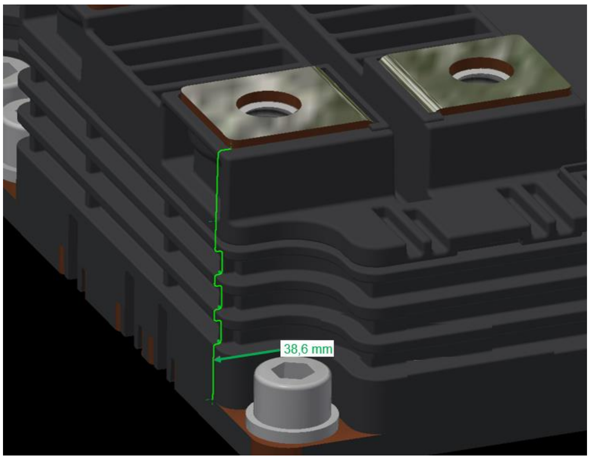


**Figure 9** Creepage distance between power terminal 1; 2 and base plate in an XHP™ 2 module

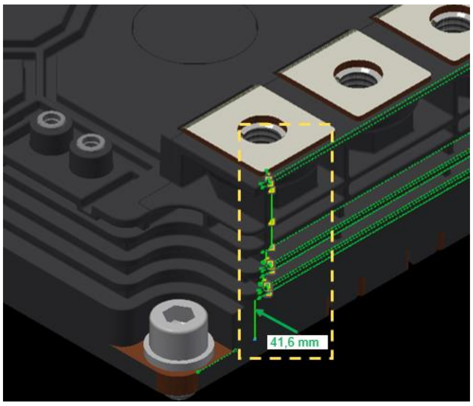


**Figure 10** Creepage distance between power terminal 3; 5 and base plate in an XHP™ 2 module

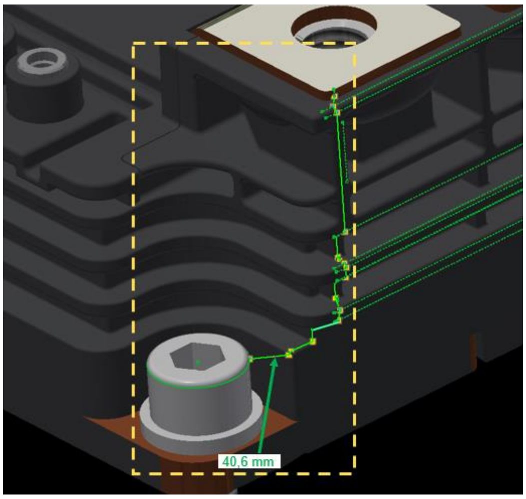


**Figure 11 Creepage distance between power terminal 3; 5 and module mounting screw in an XHP™ 2 module**

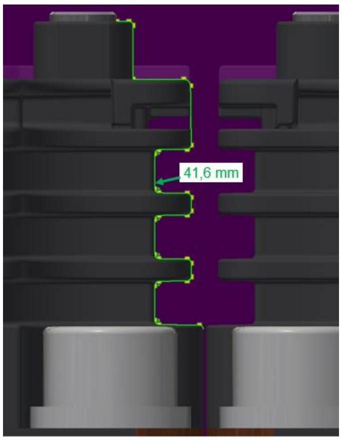


**Figure 12 Creepage distance between Aux terminal 12 and the module base plate in an XHP™ 2 module**

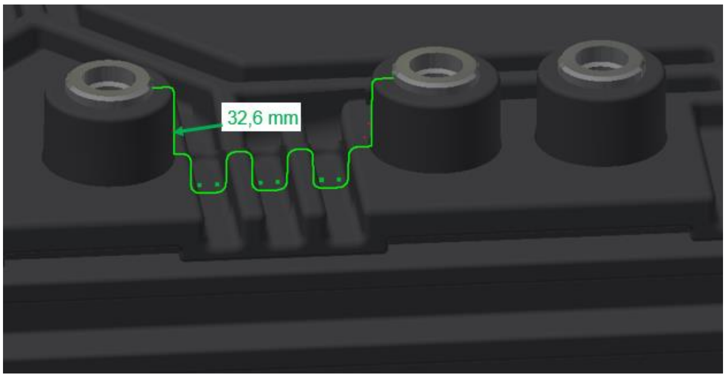


**Figure 13 Creepage distance between Aux terminal 9 and Aux terminal 10 in an XHP™ 2 module**

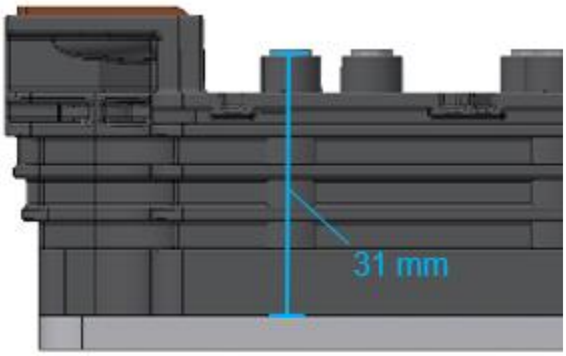


**Figure 14 Clearance distance between a PCB and the baseplate of the XHP™ 2 base plate**

***Note:*** *Clearance and creepage distances for an application must be examined and compared with the requirements of relevant application standards, and, if necessary, must also be verified through design measures.*

Table 4 **Creepage distances in XHP™ 2 modules**

| Creepage distance | Value [mm] | Figure |
|---|---|---|
| Creepage distance between power terminal 1;2 and power terminal 6;7 | 32,6 | Figure 7 |
| Creepage distance between power terminal 1;2 and base plate | 38,6 | Figure 9 |
| Creepage distance between power terminal 3;5 and base plate | 41,6 | Figure 10 |
| Creepage distance between power terminal 3;5 and module mounting screw | 40,6 | Figure 11 |
| Creepage distance between Aux terminal 12 and the module base plate | 41,6 | Figure 12 |
| Creepage distance between Aux terminal 9 and Aux terminal 10 | 32,6 | Figure 13 |

***Note:*** *Operation of power semiconductor components at elevated geographical heights, e.g., at geographical heights >2000 m above sea level (2000 m.a.s.l.) may necessitate in limiting the operating range. The insulation properties, especially the clearance distances, need to be adjusted due to the lower dielectric strength of the air.*

Table 5 **Clearance distances in XHP™ 2 modules**

| Clearance distance | Value [mm] | Figure |
|---|---|---|
| Clearance distance between power terminal 1;2 and power terminal 6;7 | 8 | Figure 8 |
| Clearance distance between a PCB and the baseplate of the XHP™ 2 base plate | 31 | Figure 14 |

# 6 Module mounting

All protective measures against electrostatic discharge during handling and assembly of the power modules have to be properly implemented by users.

The module must be connected within the permissible module tolerances specified in the outline drawings in the respective datasheets.

## 6.1 Thermal interface material (TIM)

Due to the individual surface shapes of the mounted module baseplate and the heatsink, they do not sit solidly across the entire area. Therefore, gaps between them over parts of the contact surface cannot be prevented.

The baseplates of Infineon's power modules are designed in a way to dissipate the losses occurring in the module. To allow a good flow of heat into the heatsink, all the gaps between the baseplate and the heatsink need to be filled with a suitable heat-conducting material. The thermally conductive material should have long-term stability properties appropriate for the application and ensure consistently good thermal-contact resistance. Also, it should be applied such that the mounting holes are not contaminated, which could lead to the falsification of the resulting force pressure force values.

As power densities in power electronics increase, the thermal interface between a power module and a heatsink becomes a larger challenge. A thermal interface material (TIM), especially developed for and pre-applied on Infineon's power modules outperforms other general-purpose materials available in the market.

This pre-applied TIM not only provides an optimized thermal resistance, but also fulfills the highest-quality standards for power modules. This helps in achieving the longest lifetime and highest system reliability.

Using XHP™ 2 modules with the pre-applied TIM enable a reproducible thermal performance in power electronic applications.

### 6.1.1 Modules with pre-applied TIM

XHP™ 2 modules with the recommended pre-applied TIM in an optimized structure can be purchased from your sales partner for Infineon components. More information is provided in [4].

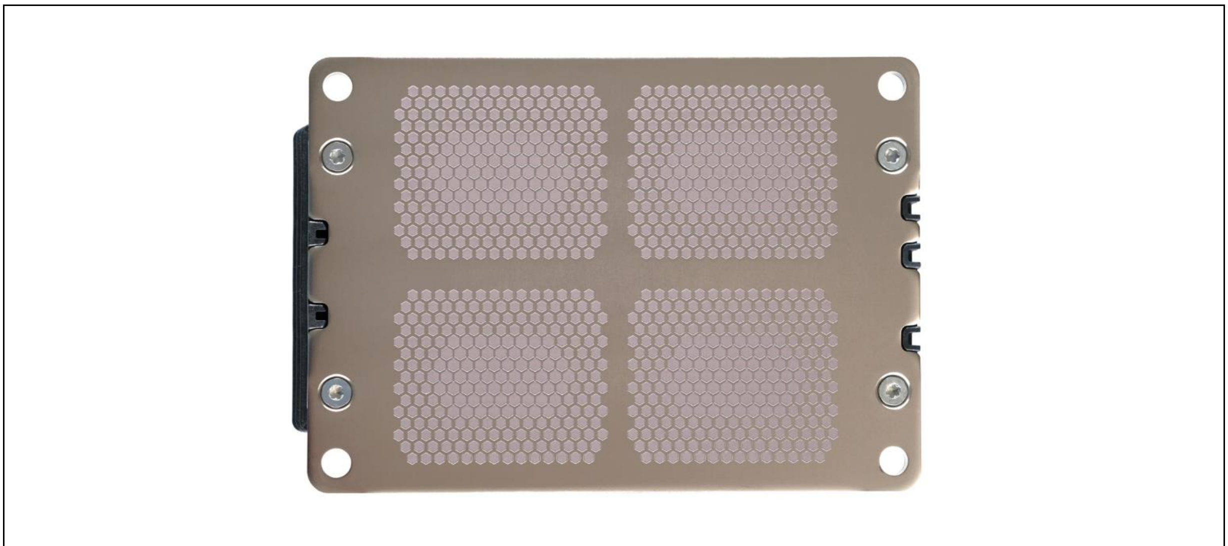

**Figure 15 Exemplary XHP™ 2 power module with Infineon's pre-applied thermal interface material**

TIM is applied using a fully automated stencil printing process to adjust the amount applied on the module locally. Before mounting, checking that the print is undamaged and complete is recommended. A valid example is depicted in Figure 16.

To protect the pre-applied TIM layer, the modules are packed in protective boxes. Each package is also designed to protect the module areas not covered by TIM.

The TIM used by Infineon consists of a substance that changes properties when heated. At about 45°C, it changes from a solid state to a thixotropic state.

"Solid" here refers to a consistency like candle wax, which is the base for the unique mechanical features and thermal abilities of this material. The material is applied using the screen-printing process. The resulting honeycomb shapes and the dedicated areas without any applied TIM are characteristic features of this solution.

> ***Note:*** *The verified long-term robustness of Infineon's pre-applied TIM is an essential aspect of the robustness of Infineon's power modules in an application.*

In case a module needs to be replaced, the heatsink has to be cleaned and leftovers have to be removed. In cold conditions, cleaning does not require any special personal safety care. Cleaning can be done without wearing gloves. Larger particles can be removed using a squeegee or a scraper. Ensure that the heatsink surface is not scratched or otherwise damaged. Using a plastic scraper is recommended. Further cleaning can be done using a dry cloth. The use of liquid solvents or cleaners is not recommended.

Inside the microscopic surface structure, tiny particles might still remain. These are not detrimental to the repairs if the module used for repairing also includes Infineon's pre-applied TIM. During the first-phase transition, the thermal interface forms an interconnection again leading to excellent thermal transfer.

If a module is delivered to the assembly line without the protective packaging, it has to be handled with care. In any case, the TIM layer has to be considered as a functional area and should be protected from mechanical contact, scratching, and touching. Contamination by dirt, dust, moisture, oil, or grease has to be avoided. The stencil design features areas not covered with TIM along the edges of the module. These areas can be used to carry the module in proper carriers.

If an XHP™ 2 module with Infineon's pre-installed thermal interface is used, please proceed to section 6.2.

### 6.1.2 Modules for self-printing thermal paste using a screen-printing process

For power modules without Infineon's pre-applied thermal paste, users must select and qualify a heat-conducting material for suitability and long-term stability.

Investigating and qualifying the thermal properties, especially that of the selected thermal interface and the module mounted on the heatsink, is recommended. Long-term robustness of the selected, self-printed thermal paste is essential for the robustness of the module in an application.

Users must verify the suitability of applying the heat-conducting material, e.g., thermal grease, in combination with the screen-printing process.

> ***Note:*** *Users are responsible for qualifying the thermal properties and long-term robustness of the selected thermal interface material on their own.*

To achieve an optimal result, the module, the contact area of the heatsink, the applied thermal interface material, and the resulting temperatures expected in the application, have to be considered as one unit in the thermal investigation.

Applying thermal paste manually with a layer thickness in the µm-range is inherently problematic because an optimally filled layer should close all gaps between the mounted module and the heatsink surface. However, it should not prevent the metallic contact between the base plate and the heatsink surface where no gaps need to be filled. Therefore, if a thermal paste is used it is recommended that it shall be applied using a stencil printing process. With this method, it is possible to adjust the layer's thickness reproducibly.

When applying the paste with the assistance of a tool, spatula, or squeegee, on the stencil, the possible wear-out of the stencil and the possible concomitant reduction in the layer thickness must be checked at intervals. Stencils must be replaced if they no longer have the predetermined thickness.

In a self-printing screen printing process, the following steps are recommended for applying the thermal paste:

1. Clean the stencil of possible thermal grease residues. This step can be carried out with suitable solvents like isopropanol or ethyl alcohol. Observe the safety regulations when handling these materials.
2. Align stencil and module with a jig holding the module.
3. Lower the stencil onto the module base plate.
4. Apply the thermal paste over the stencil. It is imperative that all stencil holes are filled properly.
5. Lift the template and remove the module.
6. Visually inspect, after application of the material, to ensure that every point of the template is filled.

Manual application of the paste may be affected by poor alignment of the stencil and small variations in the amount of paste. Measuring the thickness of the deposited material is therefore strongly recommended. It ensures that an adequate amount of material was applied. More information can be found in [5].

Trying to derive a correlation between the imprints of a certain thermal grease and its thermal qualities may lead to misjudgments and is therefore not recommended.

## 6.2 Quality of the heatsink surface

Power losses in the module must be dissipated through a suitable heatsink, so as not to exceed the maximum specified temperature, $T_{vjop}$, during a switching operation. More information on junction temperature limits is provided in [4]. The quality of the heatsink surface within the area of the module placement is of great importance. This contact between the heatsink and the module is crucial for heat dissipation.

***Note:*** *The quality of the heatsink surface in the mounting area is of great importance for thermal conductivity and distribution of the thermal energy.*

For optimal heat dissipation, the contact area conditions of the heatsink relative to each XHP™ module should not exceed the following values:

Table 6 **Heatsink surface definition or XHP™ 2 mounting area**

| Roughness/Flatness | [µm] |
|---|---|
| Heatsink surface roughness | ≤ 15 |
| Heatsink surface flatness | ≤ 30 |

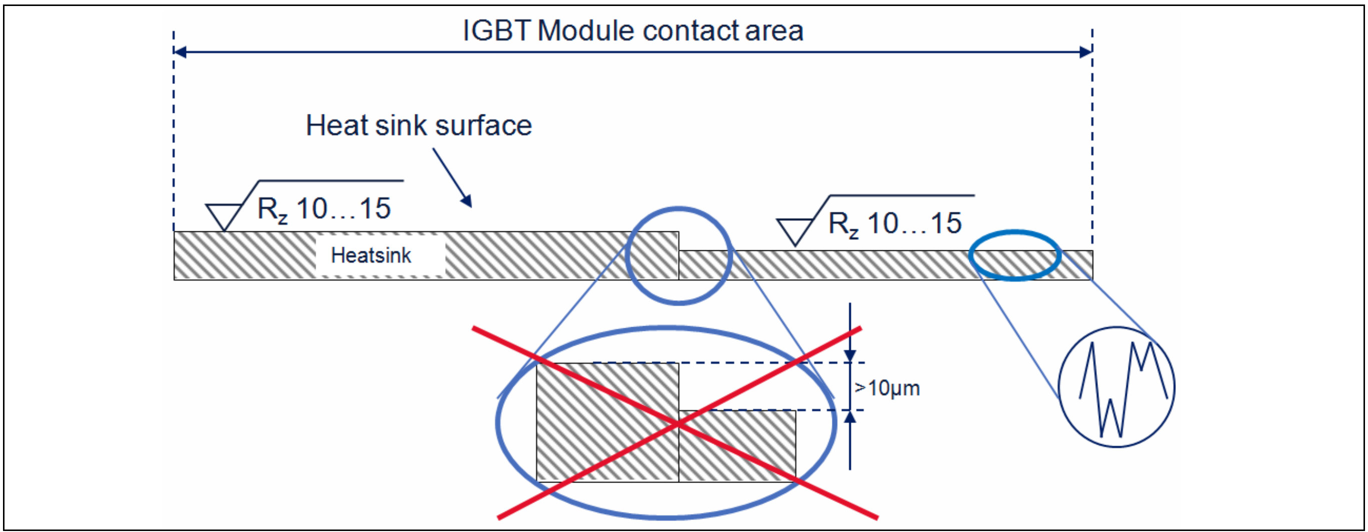


**Figure 16 Simplified drawing of the heatsink surface definition**

> ***Note:*** *The condition of the heatsink surface for the module contact area according to Figure 16 must not be exceeded.*

The contact areas, the base plate of the module, and the surface of the heatsink must be free of damage and contamination that could degrade the thermal contact. Before mounting the module, cleaning the contact areas with a lint-free cloth is recommended.

The heatsink must be of sufficient stiffness for the assembly process and the subsequent transportation to prevent additional mechanical stress on the base plate of the module. For the assembly process, the heatsink must have an anti-twist support, e.g., it should be positioned on a suitable carrier jig.

Operation of power semiconductor components at elevated geographical heights, e.g., at heights > 2000 m above sea level (2000 m.a.s.l.) may necessitate in limiting the operating range. Due to the lower air pressure, the cooling capability of air-cooling systems needs to be evaluated.

## 6.3 Module assembly onto the heatsink

The module assembly must comply with the tolerances specified in the module datasheets. Module-specific outline drawings can be taken from the datasheets. For the nominal dimensions of the module threaded holes in the heat sink, it is recommended to consider a tolerance of ± 0.1 mm.

Bolt mounting of the module onto the heatsink has to be done in such way that the sum of all the occurring forces does not exceed the yield point of the material of the joined parts. Setting devices, such as spring washers, increase the elasticity of the connection and can compensate for the settling effects. Thereby, the pre-tension force is largely retained, and any loosening of the assembly is counteracted.

> ***Note:*** *Loosening of the module screws due to thermo-mechanical load during operation must be avoided.*

Threads have to be clean and not lubricated or contaminated by thermal grease. When screwing to the heatsink, the minimum screw length has to be chosen depending on the heatsink, the thickness of the selected washer, and toothed or spring washers.

All mounting screws have to be uniformly tightened with the specified mounting torque. A preferred tool for this is an electronically controlled, or at least slow moving, electrical screwdriver. The work can also be accomplished manually using a torque wrench. Pneumatic screwdrivers should not be used because of their lack of accuracy and precision.

Table 7 **Technical data of the mounting bolts**

| Description | Value | |
|---|---|---|
| **Mounting bolt** | M6 | (4) |
| **Recommended torque** | Refer to the module datasheet | (5) |
| **Recommended property class of the bolt** | ≥ 8.8 | |
| **Minimal thread length into the heatsink** | 1.6 – 2.2 *d | (6) |

*(4) According to ISO4762, DIN6912, DIN7984, ISO14581, or DIN7991 in combination with a suitable washer and a toothed washer. For example, according to DIN433 or DIN125 or a complete combination bolt according to DIN6900 is recommended for module assembly.*

*(5) Threads should be clean and not lubricated or contaminated by thermal grease.*

*(6) Into aluminum – according to technical literature depending on the material properties of the heatsink and the screw, d = diameter of the bolt.*

Other material combinations of bolts and/or heatsink material may require adjusting the mechanical parameters and evaluating the corrosion stability.

The module mounting bolts are to be tightened evenly crosswise with a torque within the specified limits.

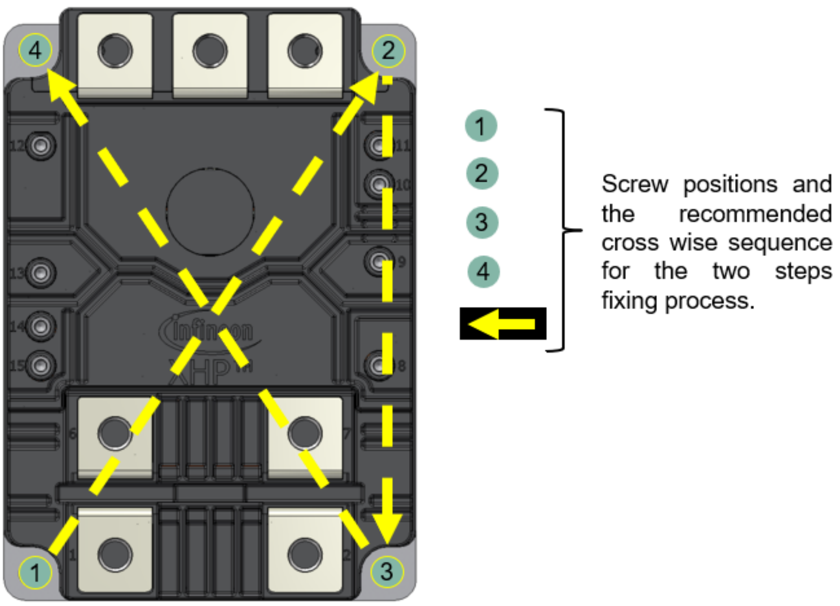


**Figure 17 Exemplary crosswise tightening sequence for the XHP™ 2 modules**

For the best thermal contact between the module and the heatsink, the following procedure is recommended when tightening the bolts:

1. Place the module, with the heat transfer compound applied, onto the clean heatsink and fix it by inserting two screws approximately until half their length.
2. Follow by the other screws also to approximately half their length.
3. Tighten all screws crosswise hand-tight (~0.5 Nm) in the sequence: bolt 1 - 2 - 3 - 4 (see Figure 17).

If using Infineon modules with pre-applied thermal interface material, continue to step 4. If NOT using Infineon modules with the recommended pre-applied thermal interface, then depending on the viscosity of the selected thermal paste material, the following intermediate steps may be necessary:

   a. In the case of a high viscosity TIM, allow the paste to flow and fill the remaining voids. This lets the module baseplate adapt to the heatsink contour.
   b. Tighten the bolts crosswise with 0.5 Nm to 1 Nm torque in the same sequence with subsequent retention time. For example, bolt 1 - 2 - 3 - 4 (see Figure 18).

   The retention time depends on the material used. Users are responsible for determining this value through experiments with the favored material. As a guide for initial investigation during the development phase, a retention time of about 10 to 20 minutes can be expected.

   After completing these steps, continue to step 4.

4. Tighten bolts crosswise with the recommended torque specified in the datasheet in the same sequence. For example, bolt 1 - 2 - 3 - 4 (see Figure 18).

***Note:*** *Use the crosswise tightening sequence for XHP™ 2 modules.*

***Note:*** *If using power modules with non-pre-applied TIM from Infineon it may be necessary, depending on the nature of the thermal paste used, to check the tightening torques for the correct value of the bolts after a burn-in period.*

***Note:*** *Infineon cannot give any recommendations for using other thermal interconnection layers, such as solid foils, due to their significantly different material properties from typical thermal interface materials.*

***Note:*** *For qualifying and verifying the assembly process and the suitability of the thermal design, an investigation by the user in the target design is essential.*

# 7 Main terminal and auxiliary terminal connection

## 7.1 Power losses of the main terminals

For the design-in of a module into a system, note that a minor share of the power semiconductor's power losses and a significant share of the internal busbar losses can be transferred through the power terminals. The terminal losses may result in a rise in the terminal temperature increases. Its effect on the lifetime of the joint, the insulation of the internal and external busbar, and maybe on the connected DC-link capacitors has to be considered. Figure 18 shows a simplified representation of a possible heat transfer.

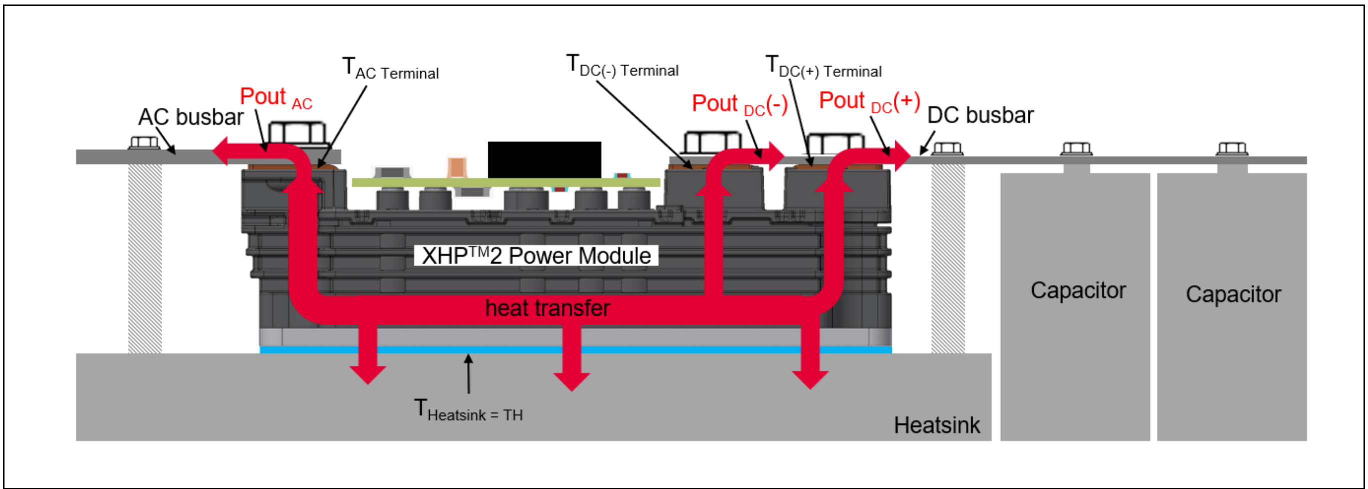


**Figure 18 Simplified heat transfer to the XHP™ 2 power terminal during operation**

An exemplary simulation of the heat flow under defined conditions leads to the results shown in Figure 19. The heatsink temperature and the terminal temperature are defined with constant values. The module components with their current carrying capacity and insulation properties are designed for these conditions. For other operating conditions, the thermal situation needs to be evaluated individually.

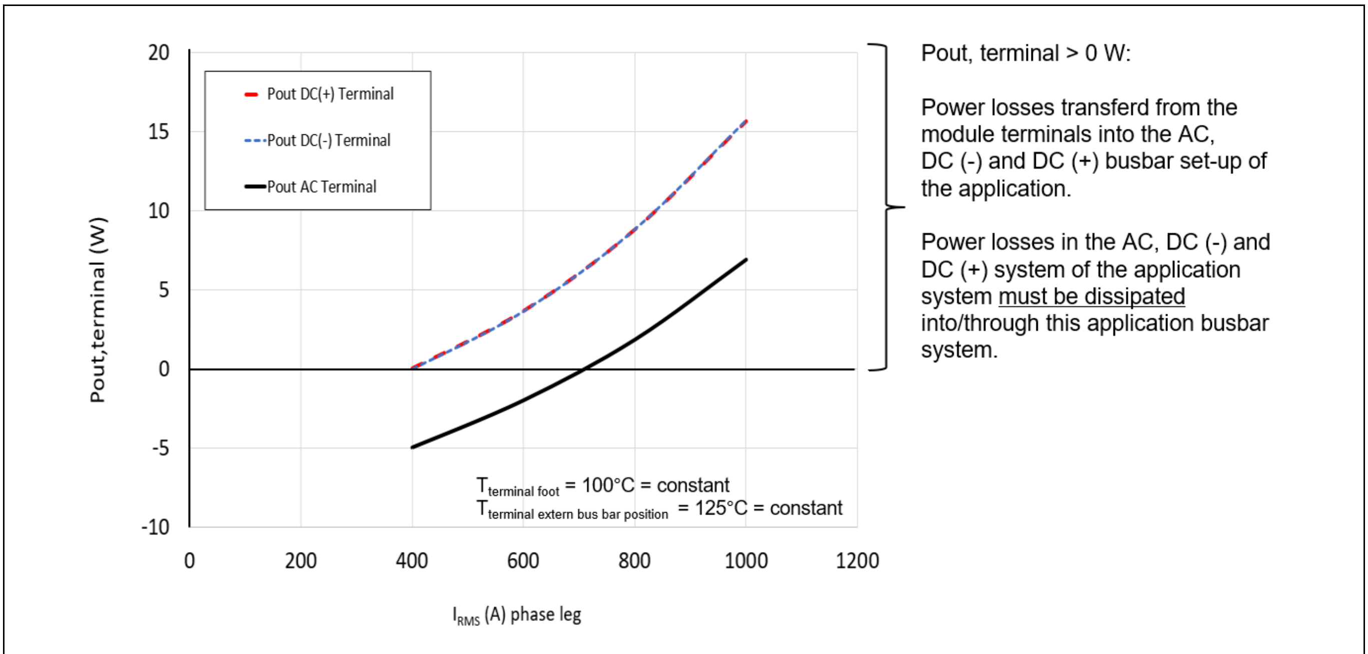


**Figure 19 Simulation results of an XHP™ 2 power terminal losses under various current conditions**

Losses in the busbar must be dissipated into/through the busbars. The insulation of the module terminals within the module may get damaged if the conditions are exceeded. For temperatures above 105°C at the joint spring elements are to be included to maintain the contact pressure even if settling effects take place. As example a conical spring washer according to DIN 6796 or a dented edge washer with Belleville shape can be used. Also, for lower temperatures at the joint this design of the connection is recommended to alleviate the effect of cyclic load.

A more detailed investigation of the physical effects of copper joints beyond 105°C can be found in [19]

## 7.2 Mechanical connections of the main and auxiliary terminals

The module must be connected within the permissible module tolerances specified in the outline drawings given in the respective datasheets. The position and tolerance of adjacent components such as PCBs, DC-bus, mounting bolts, or cables have to be designed in such way that, after the connection, no sustained effect of the static and/or dynamic tensile forces is exerted on the terminals. The power terminals are built using copper with a nickel coating. The following recommendations are valid for copper busbars, bare or with suitable plating.

### 7.2.1 Maximum forces at the terminals during the assembly process

The connecting parts must be mounted onto the electrical contacts such that the specified maximum permissible forces are not exceeded during the assembly process.

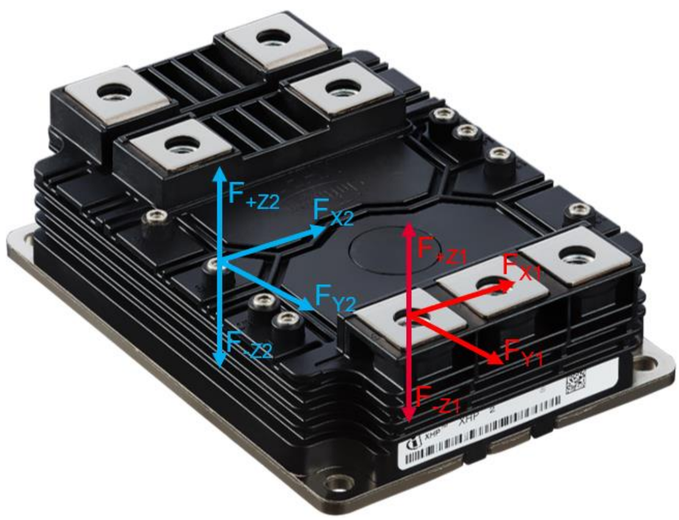


**Figure 20 Direction of the maximum permissible force during the assembly process at the XHP™ 2 module terminals**

The upper limit given in Table 8 assumes the worst-case scenario when the full torque applied to the terminal passes into the nut that is inserted into the plastic housing.

Table 8 **Maximum permissible forces during the assembly process, per terminal, of a XHP™ 2 module**

| Terminal | Terminal number | Force direction | Maximum Force [N] |
|---|---|---|---|
| **Main** | 1; 2; 3; 4; 5; 6; 7 | $F_{+Z1}$ | ≤ 100 |
| **Main** | 1; 2; 3; 4; 5; 6; 7 | $F_{-Z1}$ | ≤ 500 |
| **Main** | 1; 2; 3; 4; 5; 6; 7 | $F_{X1}$ | ≤ 100 |
| **Main** | 1; 2; 3; 4; 5; 6; 7 | $F_{Y1}$ | ≤ 100 |
| **Auxiliary** | 8; 9; 10; 11; 12; 13; 14; 15 | $F_{+Z2}$ | ≤ 100 |
| **Auxiliary** | 8; 9; 10; 11; 12; 13; 14; 15 | $F_{-Z2}$ | ≤ 100 |
| **Auxiliary** | 8; 9; 10; 11; 12; 13; 14; 15 | $F_{X2}$ | ≤ 100 |
| **Auxiliary** | 8; 9; 10; 11; 12; 13; 14; 15 | $F_{Y2}$ | ≤ 100 |

M8 bolts are required to connect the power terminals of XHP™ modules. The bolts should be selected at least according to the property class 8.8, in combination with, for example a conical spring washer according to DIN 6796 or a dented edge washer with Belleville shape. The thread should be clean and not lubricated. The screws are to be tightened with the torque specified in the datasheet. Using a torque value near the maximum torque is recommended.

***Note:*** *Loosening the module screws due to thermo-mechanical load during operation must be avoided.*

The busbar or PCB prevent the direct introduction of excessive forces into the nut and further on into the housing plastic material. The tightening torque must be chosen such that the applied pre-tension force leads to a purely frictional bond between the components. Knowledge of the friction coefficient, μ, is a prerequisite to determine the preload and tightening torque accurately. This friction depends on several different factors, such as material combination, surface, lubrication, temperature, and so on.

The torque values specified in the datasheets assumes the use of galvanized metric steel bolts. If the coefficient of friction in the construction differs from this, adjust the torque value accordingly.

Table 9 **Tightening torque M for the mounting bolts of the electrical connections**

| Terminal | Mounting bolt | Max. screw depth [mm] | Mounting torque |
|---|---|---|---|
| **Main** | M8 | 16.0 | Refer to the module datasheet |
| **Auxiliary** | M3 | 7.0 | Refer to the module datasheet |

The choice of bolt length depends on the maximum thread depth specified for the module and the gauge of the connecting parts. The sum of these values must not be smaller than the selected bolt thread length. The effective thread length of the bolts into the module terminals must not exceed the maximum specified depth in the outline drawing of the datasheet.

### 7.2.2 Mounting recommendation for main terminals with strain relief

Having an assembly that leaves the power terminals permanently free of mechanical stress is recommended. Since such an assembly is inherently difficult over the entire temperature range, the construction should be don in such way that the power terminals exhibit a load bias by means of suitable spacers.

The connecting parts must be mounted onto the electrical contacts such that the specified maximum permissible forces are not exceeded during the assembly process.

It must be ensured that the direction of the bias force always acts in the direction of the base plate. The suitability of the support must be evaluated individually in the structure.

Static forces in other directions and exposure to vibration and/or thermal expansion should be avoided.

Infineon modules have a solid construction that guarantees easy handling and the highest possible robustness in the application.

The impact of additional permanent mechanical load on the module, especially repetitive stress by vibration- and shock, is highly dependent on the mechanical construction and the load profile of the application. Thus, it cannot be generally specified.

Users must qualify the suitability of using these modules under specific mechanical stresses, including transport, in their assembly.

To terminate the power terminals with the best possible strain relief, an assembly similar to the drawings shown in Figure 21 is recommended. This is especially important if the modules or busbars are subjected to vibration. Keeping the terminals in compression rather than in tension (as shown) is recommended. The terminals should not be pulled up.

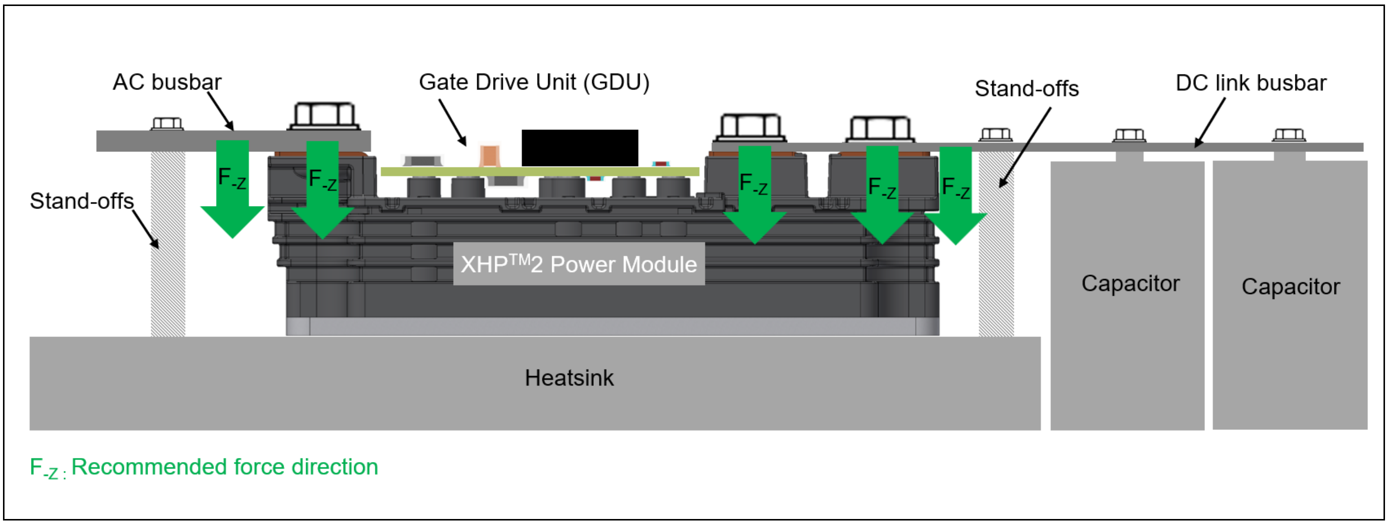


**Figure 21 Simplified representation of a configuration with a proposed strain-relief method**

The mechanical setup should be designed such that the resulting forces (F-Z) keep the main connections, after the complete assembly is done, under compression.
The mechanical setup should be designed to avoid a resulting pull force (F+Z) applied to the main connections.

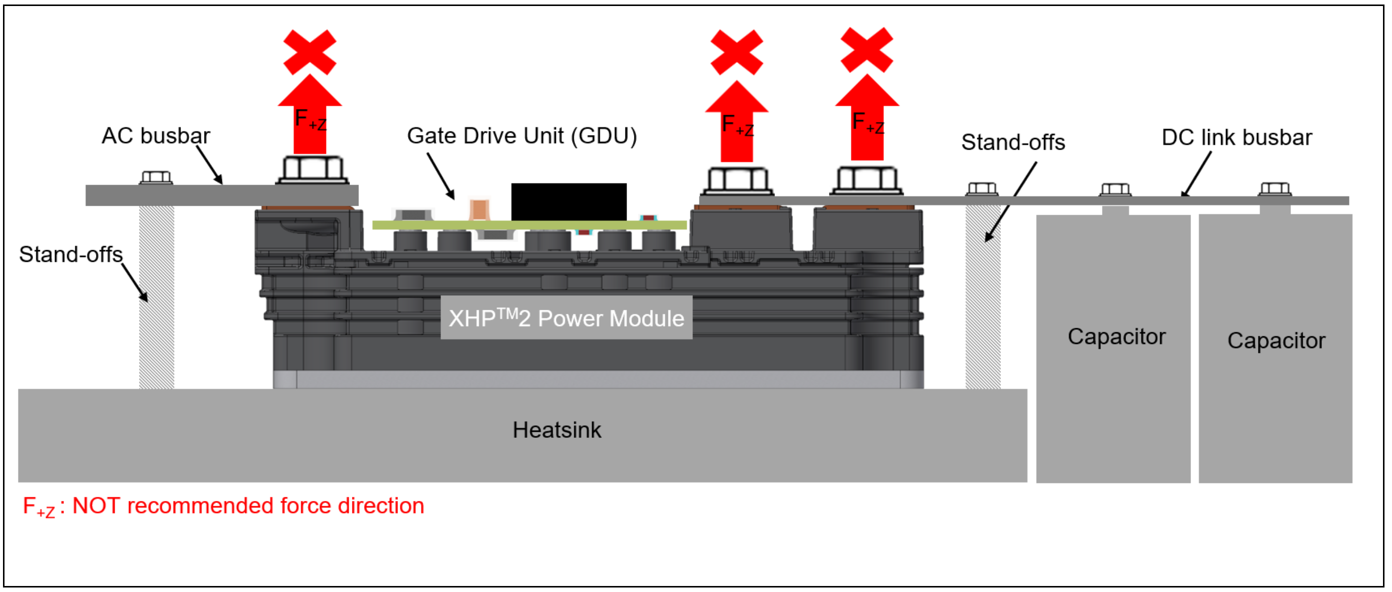


**Figure 22 Simplified representation of a configuration that is NOT recommended**

> ***Note:*** *After complete assembly, the resulting tensile pull forces ($F_{+Z}$) applied to the main terminals, should be avoided in the mechanical design.*

# 8 Application tips and recommendations

## 8.1 General switching tips

Dynamic behavior and thus energy per pulse strongly depend on a variety of application-specific operating conditions such as gate driving circuit, layout, gate resistance, magnitude of voltages and currents to be switched, and the junction temperature. Therefore, the datasheet values provide an indication of the switching performance of the power module under nominal conditions.

For a design-specific loss determination, experimental investigations in the final target setup are necessary.

A simplified equivalent circuit diagram of a power module in a test setup and a simplified example of turn-on and turn-off events are depicted in Figure 23, Figure 24, and Figure 25. The influence of different system stray inductances (Lσ) are illustrated.

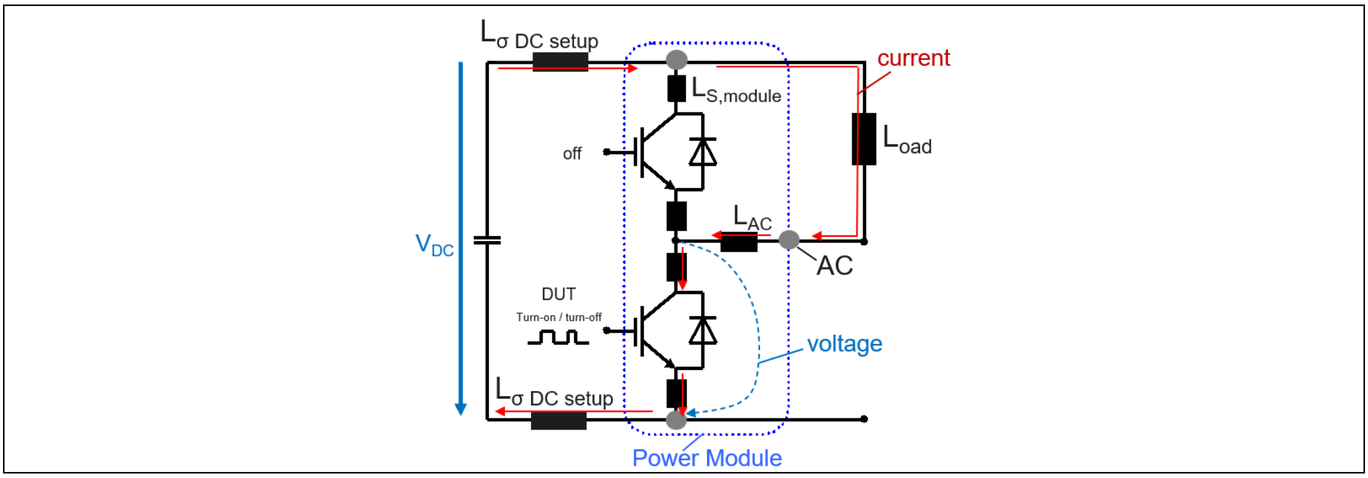


**Figure 23 A simplified equivalent circuit diagram of a power module in a test setup**

$$\text{Total system stray inductance: } L\sigma = L_{S,module} + L_{\sigma,DC\ setup} \quad (4)$$

During a turn-on event, an increased Lσ causes a voltage drop. Due to this reduced voltage across the semiconductor during switching, the resulting $E_{on}$ loss decreases ($E_{rec}$ is neglected) [7].

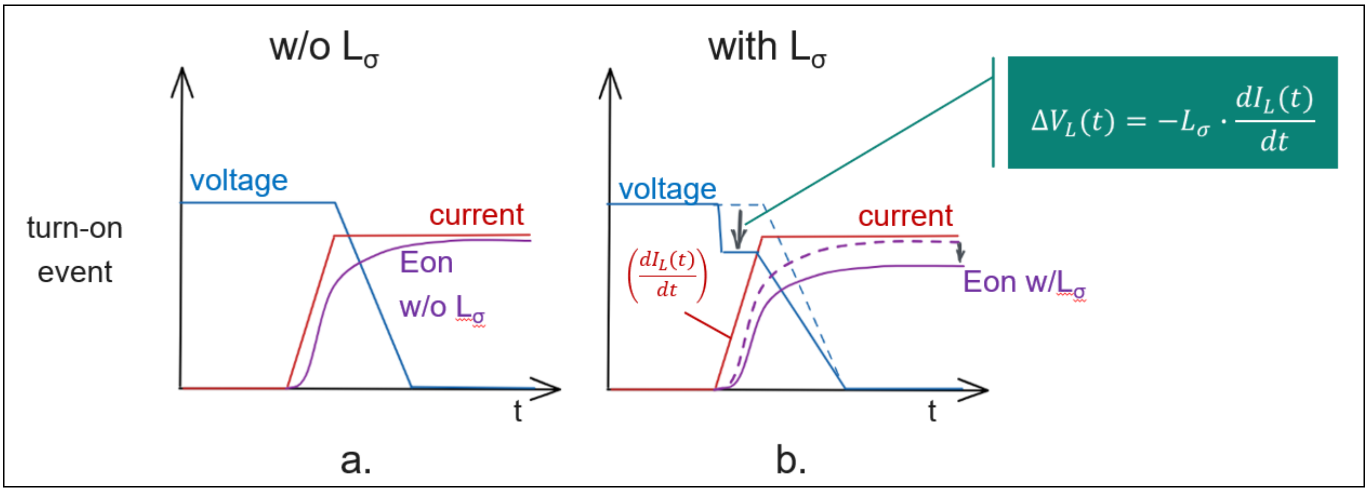


**Figure 24 a. A simplified example of an ideal turn-on event without the influence of Lσ**
**b. A simplified example of a turn-on event with the influence of Lσ**

In a turn-off event, a stray inductance (Lσ), as can be expected in a real setup, causes a voltage overshoot. Due to this increased voltage across the semiconductor during switching, the resulting $E_{off}$ loss is increased ($E_{rec}$ is neglected), [7].

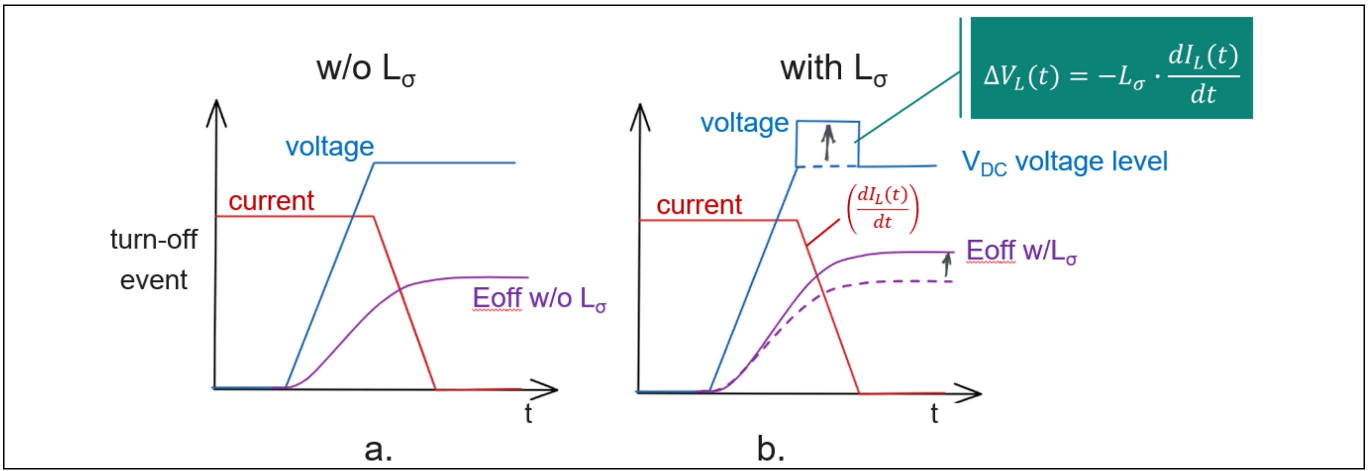


**Figure 25 a. A simplified example of an ideal turn-off event without the influence of Lσ**
**b. A simplified example of a turn-off event with the influence of Lσ**

di/dt in combination with the total leakage inductance reduces the voltage at the switch when turning on but increases the overvoltage at the switch when turning off.

In addition to the influence on switching losses, the speed of switching on and off, the occurrence of the switch-off behavior, and oscillations (EMI) are also becoming increasingly important. Parasitic leakage inductances play an important role.

Module or switch optimizations designed for high system stray inductance are meant to meet higher softness requirements. This function comes at the expense of higher switching losses during the same operation.

Especially when using fast-switching devices such as SiC MOSFETs, a DC link design optimized for low inductivity becomes more important for achieving an optimized setup.

***Note:*** *For the DC link inductance, the lower the better is a simple rule for high-efficiency designs [8].*

***Note:*** *To determine switching losses, measurements in the final DC link design are essential.*

## 8.2 Module lead resistances

The output characteristics, the forward characteristic of the high side (HS) or the low side (LS) system, formed by Infineon power chips are defined in the datasheet diagrams without module-specific ohmic lead resistances.

When selecting a suitable cooling system, total losses must be taken into account. This includes the module-specific lead resistances that contribute to the total losses. In electrical measurements at the module terminals, the module-specific lead resistances are part of the measurement results. Depending on the specific layout within the individual power module, the lead resistance for the HS system and the LS system can be different. In the case of different values, the typical highest value from the module system is specified in the datasheet.

For an IGBT+FWD combination in the HS or LS system, the lead resistances are divided into $R_{AA'+\ EE'}$ for the FWD and $R_{CC'+\ EE'}$ for the IGBT per HS or LS system.

For the HS and LS systems formed by a CoolSiC™ MOSFET switch (with an embedded body diode and without a separate FWD) only one module lead resistance, $R_{CC'+\ EE'}$, per high side or low side system is defined.

The definition is:

C = IGBT collector/MOSFET drain main terminal

C'= IGBT collector/MOSFET drain aux terminal

E = IGBT emitter/MOSFET source main terminal

E' = IGBT emitter/MOSFET source aux terminal

A = Diode-Anode main terminal

A' = Diode-Anode aux terminal

E = IGBT emitter main terminal

E' = IGBT emitter aux terminal

$R_{CC'+\ EE'}$ is the total ohmic lead resistance from DC(+) main connection to AC main connection or vice versa – from AC main connection to DC(-) main connection.

$R_{AA'+CC'}$ is the total ohmic lead resistance from AC main connection to DC(+) main connection or vice versa from DC(-) connection to AC connection.

## 8.3 Gate drive units

To install the gate drive unit (GDU) or an any adapter board, the self-adhesive ESD protection strips on the modules must be removed.

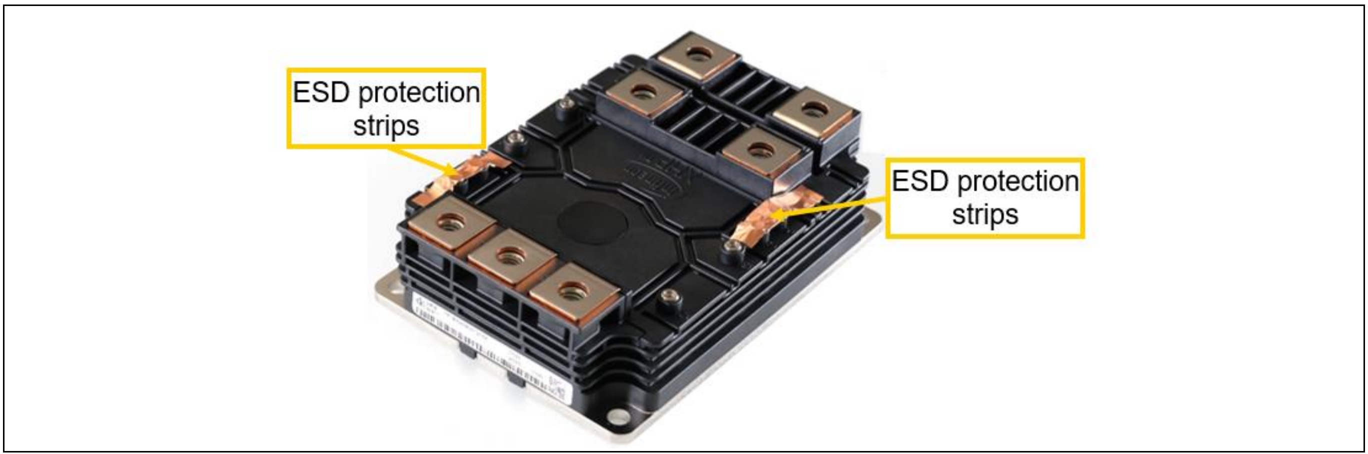


**Figure 26 XHP™ 2 package ESD protection strips**

After removing the module specific ESD protection, users must do further processing according to the guidelines in Chapter 1.

> ***Note:*** *ESD may partially or even completely damage the power modules. The gate-emitter control terminals are electrostatic-sensitive contacts.*

For a PCB or an adapter mounted on the module, the recommended hole pattern for fitting the auxiliary terminal connection of the XHP2 is shown in the individual module datasheet.

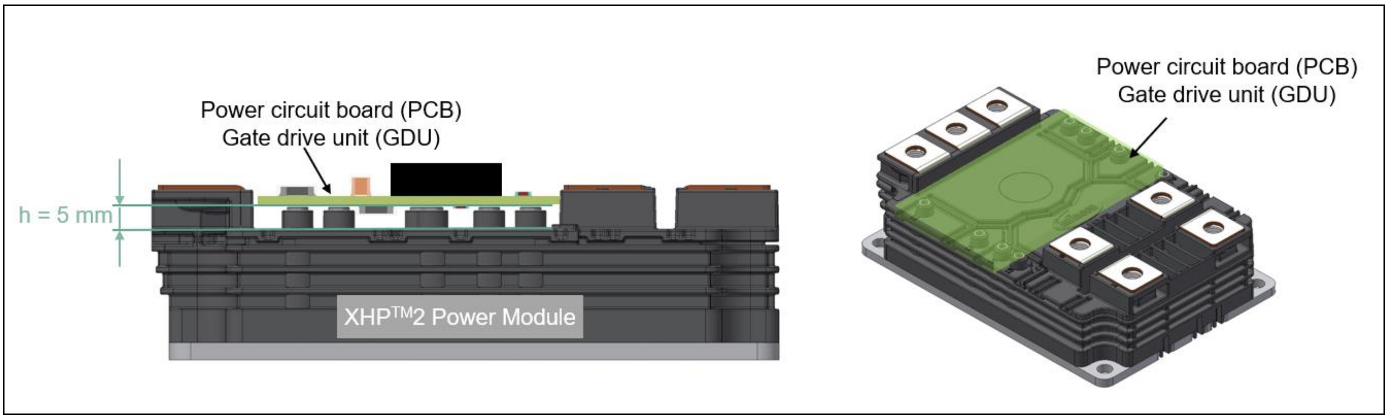


**Figure 27 Simplified representation of the XHP2 module for the gate drive unit (GDU)**

Having an assembly that leaves the power and auxiliary terminals permanently free of mechanical stress is recommended. Such an assembly, however, is inherently problematic mechanically and over the entire temperature range. Especially if the PCB width is the same as the width of the module. In these scenarios, one assembly option can be to have a construction where the auxiliary terminals are supported by suitable spacers for the PCB.

> ***Note:*** *The semiconductors can only be controlled through the terminals designed for the control of the switch like the auxiliary emitter and the auxiliary gate (see Figure 29 and Figure 30). The additional auxiliary emitter's main contacts (terminal 8 and 12) are not suitable for the control for the module.*

The gate driver unit (GDU) has to perform multiple functions, from turning the switch ON and OFF as well as fault protection functions. Chapter 6 in [9] provides a detailed description of the various functions that the gate driver needs to perform. Additional features of the gate driver depend on the system design requirements.

When developing or selecting a gate driver unit (GDU), the following main aspects should be considered:

- $V_{GE}/V_{GS}$ turn-on voltage: A $V_{GE}/V_{GS}$ turn-on voltage of +15 V is recommended. Differing or extended recommendations can be found in the module-specific datasheet. The recommended positive $V_{GS}$ turn-on voltage for SiC-MosFET devices may differ between different technology generations and the recommended voltage can be found in the module-specific datasheet.
- $V_{GE}/V_{GS}$ turn-off voltage: A negative $V_{GE}/V_{GS}$ turn-off voltage is recommended to prevent the risk of parasitic turn-on due to the dv/dt phase. The recommended negative $V_{GE}/V_{GS}$ turn-off voltage differ between different technology generations, and the recommended voltage can be found in the module-specific datasheet.
- Gate resistors: In a voltage-driven gate driver, the gate resistors influence the current and the voltage slopes during the turn-on and turn-off sequences. Based on system specifications of losses and EMI, the gate resistors have to be appropriately selected. The application note [10] provides comprehensive information on selecting gate resistors. Also, the module datasheets provide graphs on loss versus gate resistors and switching time versus gate resistors. Selecting a gate resistor within the range specified in the datasheet is recommended.

> ***Note:*** *If the collector voltage potential is used for monitoring the desaturation of the switch (DSAT) via an auxiliary collector/drain line and returned to the driver, the auxiliary collector/drain line should be as far as possible from the gate-emitter connections to prevent signal interference.*

For safe operation of the components, ensure a sufficiently dimensioned gate driver with respect to gate current and gate driver power. More information can be found in [11].

The XHP™ 2 power module package provides a height distance of h = 5 mm between the module lid and the top side of the auxiliary connections. This height offers additional space for surface-mounted components on the bottom side of the GDU-PCB or for the wired components contacted at the bottom of the GDU-PCB.

The circuit boards used on the module should be supported to minimize the tensile and compressive forces that can act on the module terminals. The driver board should be supported with bolt standoffs near the module.

## 8.4 Gate drive units – Additional auxiliary emitter / source main terminals for advanced gate drive design

For a more sophisticated gate control design, the XHP™ 2 module offers the option of using the leakage inductance through the additional main-emitter-sense, for IGBT modules, or main-source-sense, for MOSFET modules, connectors 8 and 12, marked in Figure 28. These additional auxiliary-emitter-mains are connected to the half-bridge circuit inside the module. The leakage inductance between the auxiliary emitters (11 for HS and 15 for LS) for module control and the auxiliary-emitter-mains (12 for HS and 8 for LS) provides a voltage drop in the di/dt phase. This can be used to control the transient behavior of the switch [11].

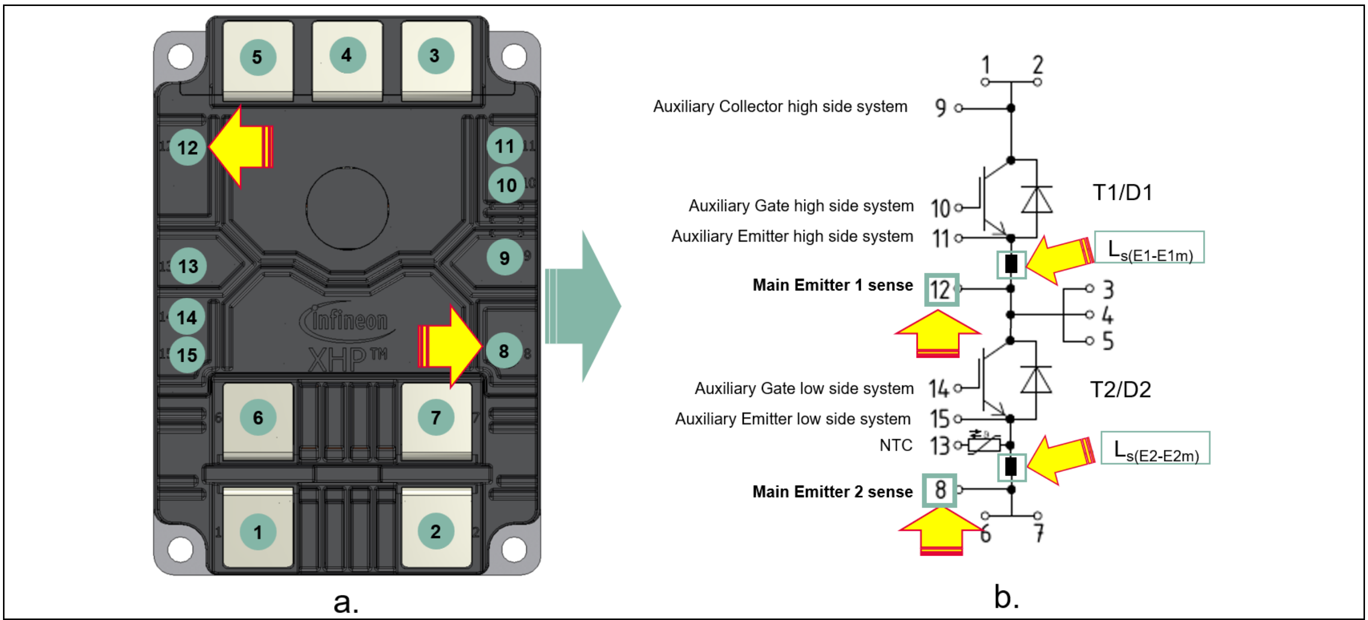


**Figure 28** **a. Typical auxiliary connector positions**
**b. Typically auxiliary connection assignment with a main emitter sense equivalent circuit**

For different module types, the leakage inductance and the ohmic lead resistance between the auxiliary emitter contact, pin 11 or pin 15, and its corresponding main emitter sense contact, pin 12 or pin 8, may differ due to individual layouts designs within the individual modules. Therefore, if the leakage inductance is used for the di/dt monitoring in an advanced gate design, it is recommended to measure the feedback voltage of the individual module types during the development phase of the GDU.

For an IGBT+FWD combination in the HS or LS system of the XHP™ 2 power module, the leakage inductances are divided into:

Main emitter inductance 1 per HS system: $L_{s(E1\text{-}E1m)}$

Main emitter inductance 2 per LS system: $L_{s(E2\text{-}E2m)}$

For an MOSFET switch in the HS or LS system of the XHP™ 2 power module, the leakage inductances are divided into:

Main source inductance 1 per HS system: $L_{s(S1\text{-}S1m)}$

Main source inductance 2 per LS system: $L_{s(S2\text{-}S2m)}$

The nominal values of the individual module main emitter inductance or main source inductances are given in the individual product datasheets.

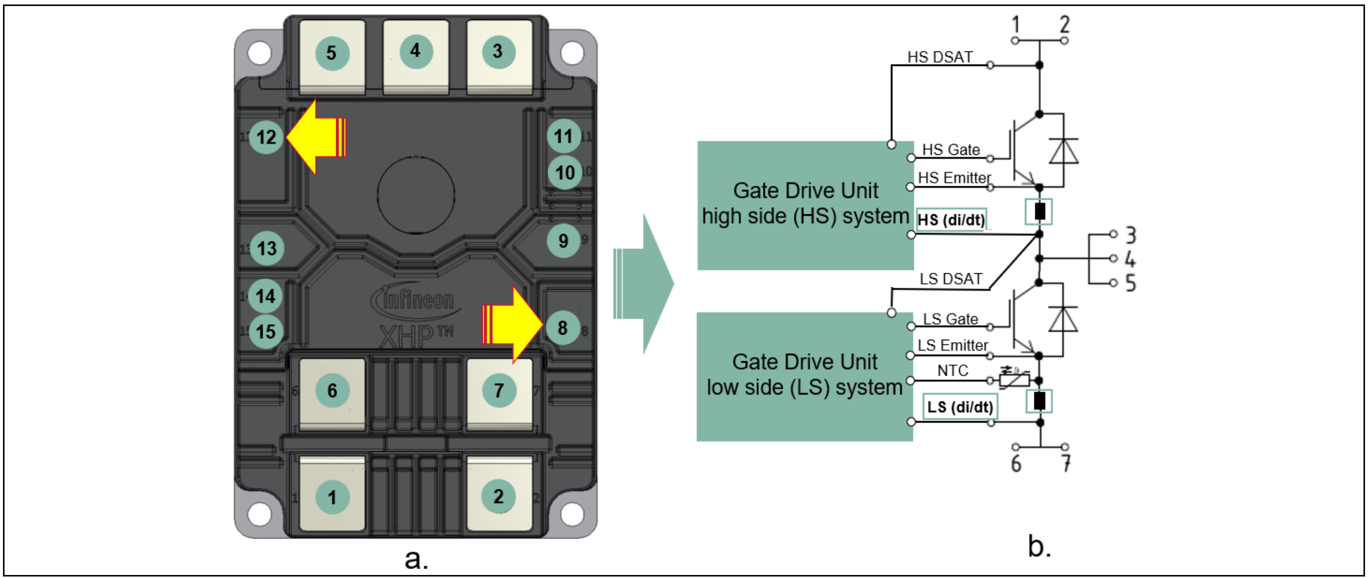


**Figure 29 a. Typical module auxiliary connector positions**
**b. Simplified GDU auxiliary connection with a dedicated (di/dt) detection connection for advanced gate driver design**

If the di/dt detection is not used in the gate-control design, the additional main-emitter-sense connectors 8 and 12, shown in Figure 29, will not be electrically connected. It is essential to avoid electrically connecting these connections to the emitters on the driver board to prevent circulating load currents during the commutation phase.

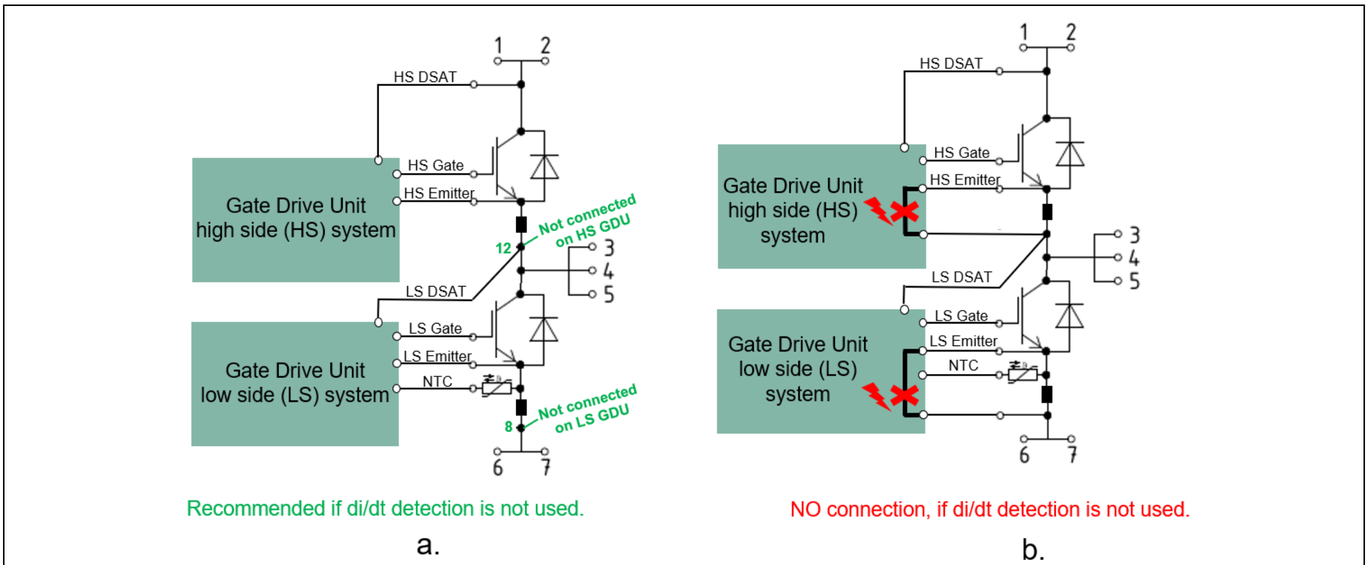


**Figure 30 Simplified GDU auxiliary connection assignment and recommendation if di/dt detection is not used**

***Note:*** *If the di/dt detection is not used, terminals 8 and 12 of the auxiliary terminals should not be connected electrically to the gate driver board but left isolated in the gate drive circuit. Except terminal 12, if this terminal is used for DSAT detection of the LS system.*

## 8.5 Temperature sensor

The XHP 2 module has an implemented temperature sensor. This temperature sensor is a resistor that is dependent on temperature (thermistor). It is implemented as a separate device, not embedded in the power chip. The value of the thermistor has a negative temperature coefficient (NTC) and the resistor value decreases with increased temperature.

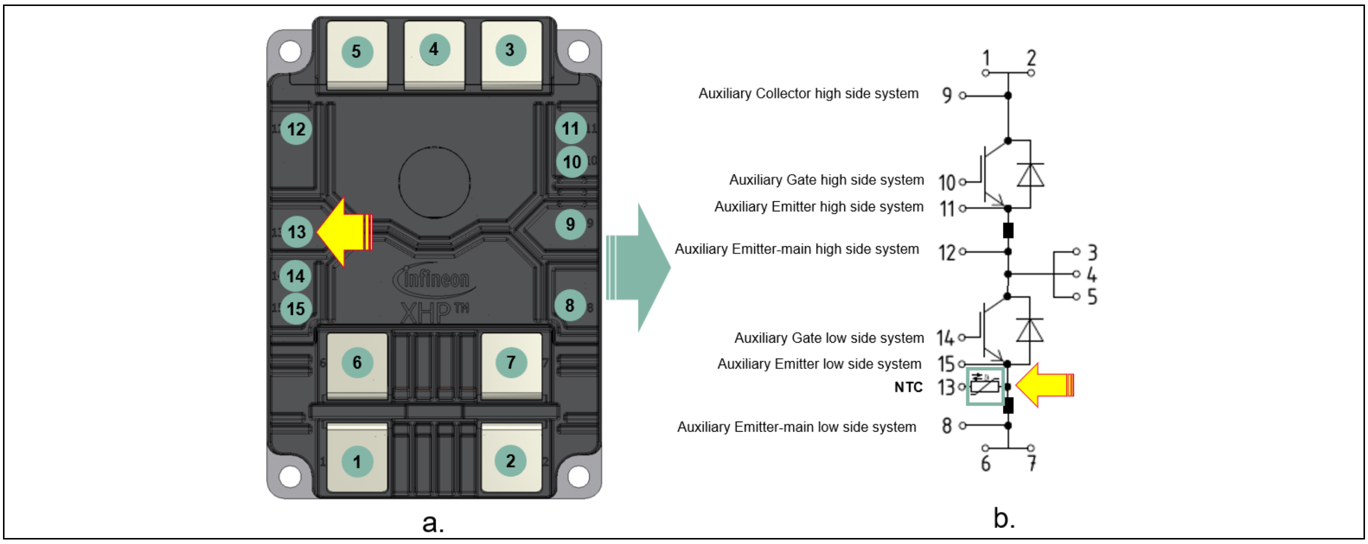


**Figure 31 a. Typical module auxiliary connector positions**
**b. Simplified GDU auxiliary connection with dedicated thermistor position**

***Note:*** *The thermistor in the XHP 2 module is directly connected to the high-voltage DC(-) parts. An insulation barrier must be added externally, and it must be ensured that all insulation requirements for the particular design are met.*

Most of the heat generated in the power modules are generated by the power chips. This heat goes from the chip to the attached heatsink from where it is dissipated to the environment. Some of this heat is also distributed over the upper Cu layer of the composite material (substrate).

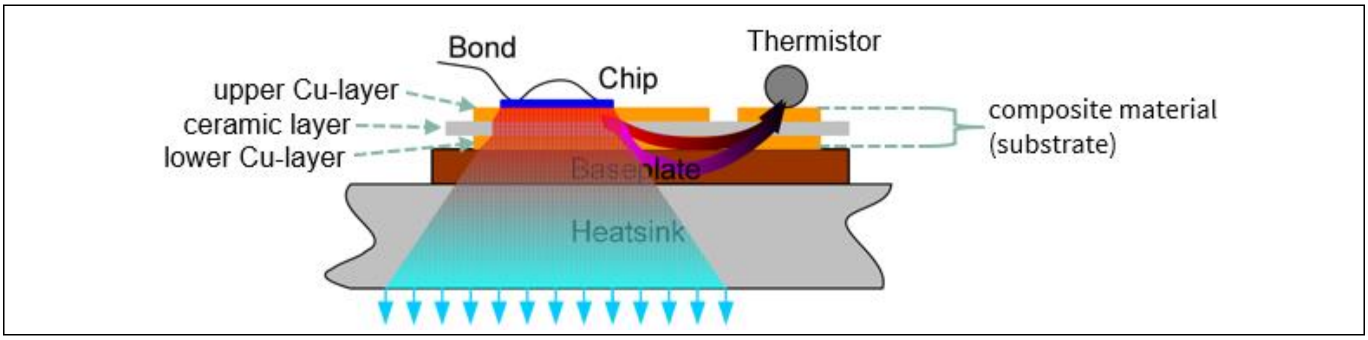


**Figure 32 Flow of thermal energy inside a power electronic module**

As the heat does not flow instantaneously, the thermistor is suitable for representing the temperature at its location in static points of operation. The point of operation can also be used for detecting if the cooling system is functioning properly and the degrading of its performance over a lifetime. To use such thermal monitoring, a corresponding thermal model needs to be evaluated.

The corresponding thermal model must be created by users based on the final heatsink used. Users are responsible for the accuracy of the thermal model.

> ***Note:*** *Transient temperature changes, for example in fast overload or short circuit conditions, cannot be monitored or detected. The correlating time constants of the chip during such events are far too small.*

For the characteristic data of the NTC, please refer to the specific module datasheet. Equation (5) displays the thermistor function from the temperature:

$$R_{T2} = R_N * e^{B\left(\frac{1}{T2}-\frac{1}{TN}\right)} \quad (5)$$

$R_{T2}$ = NTC resistance value at temperature, $T_2$

$R_N$ = NTC resistor value at nominal temperature, $T_N$

$T_N$ = Nominal temperature

$T_2$ = NTC temperature at $T_2$ [K]

B = B-value - material constant of the resistor

The thermistor temperature, $T_2$, can be calculated based on the measured resistance value, $R_{T2}$, with the equation:

$$T_2 = \frac{1}{\frac{\ln\left(\frac{R_{T2}}{R_N}\right)}{B} + \frac{1}{T_N}} \quad (6)$$

More details on the insulation and usage of internal thermistors can be found in 0.

## 8.6 Paralleling operation of power modules

Applications can require multiple modules to be connected in parallel to achieve the rated current required. The challenge when connecting power modules in parallel is the symmetrical and even distribution of current in the modules.

For paralleling modules different configurations are possible, each having different merits and drawbacks. More information can be found in[14], [15], [16] and [17].

One of the most popular configurations is the direct connection or the hard-paralleling configuration of power modules. Here, hard-parallel connected power modules that are not decoupled, for example through separate active module adapters, are used. Different selection criteria exist for selecting these power modules.

The typical selection criteria for a proper sharing of static current are static parameters such as $V_{CEsat}$ and $V_F$. On some IGBT modules, the $V_{CEsat}$ and $V_F$ classes are printed on the label. These can help in selecting tight $V_{CEsat}$ and $V_F$ parameters for connecting the power modules in parallel.

Power module HS or LS systems with the same class have the same measured parameters. The class may differ from HS and LS because of the different layout designs within the module.

A more advanced option for connecting power modules in parallel is the decoupled operation of the parallel-connected modules using a separate active module adapter per module [16].

Separate active module adaptors suppress load currents traveling on auxiliary connections. Other aspects are minimized gate loop inductance, and more sensitive driver parts because insulation and logic parts can be placed further apart. The gate voltage clamping circuit can be applied as close as possible to the individual module. This close connection may provide a proper short circuit current limitation in a failure case. The DESAT diodes can be placed close to the individual module collector/drain connection. This close connection may provide a fast feedback loop for active VCES voltage clamping.

The total gate-drive power required rises with the number of modules. A separate booster stage per module offers the required power, which otherwise must be provided by the GDU core. Additional factors that may influence the static and dynamic current distribution of the modules connected in parallel are the AC connection, the DC-link design, the commutation inductance, the driver circuit, and connection, and the cooling system used.

***Note:*** *Symmetrical and even design of all the module current paths, with identical stray inductances, in DC link and AC connections ensure proper dynamic current sharing [15].*

***Note:*** *Symmetrical design of gate drivers, same driver stage, individual gate resistors, and to select gate resistors within the datasheet specified range is recommended.*

***Note:*** *Symmetrical cooling conditions, identical heatsink temperatures, and flow rates of cooling media below the paralleled devices ensure operation at identical case temperature.*

***Note:*** *Verify that current sharing is even through appropriate investigations of the application design.*

## 8.7 Thermal validation

The junction temperature, $T_{vj}$, in pulsed operation must not exceed the maximum junction temperature specified in the datasheet. The maximum junction temperature occurring under application conditions must be reviewed through thermal measurements.

Temperature, $T_{vjop}$, as given in the datasheet, specifies the limits, the minimum and maximum value, of the junction temperature between which the device may be operated. This includes the switching operation. The maximum values are identical to those specified in the reverse bias safe operating area (RBSOA) diagram of the datasheet.

Current carrying capability at normal load and overload, also for short time duration, should be calculated using the typical ON state, turn-on ($E_{on}$), and turn-off losses ($E_{off}$). If a worst case evaluation is preferred an additional safety margin can be added on the total losses for the temperature evaluation.

For thermal measurements close to the chip, it is necessary to place the sensor probe under the chip position, like the simplified depiction in Figure 33. Knowledge of the exact chip positions is essential. For module-specific drawings of the chip position, contact your sales partner for Infineon products.

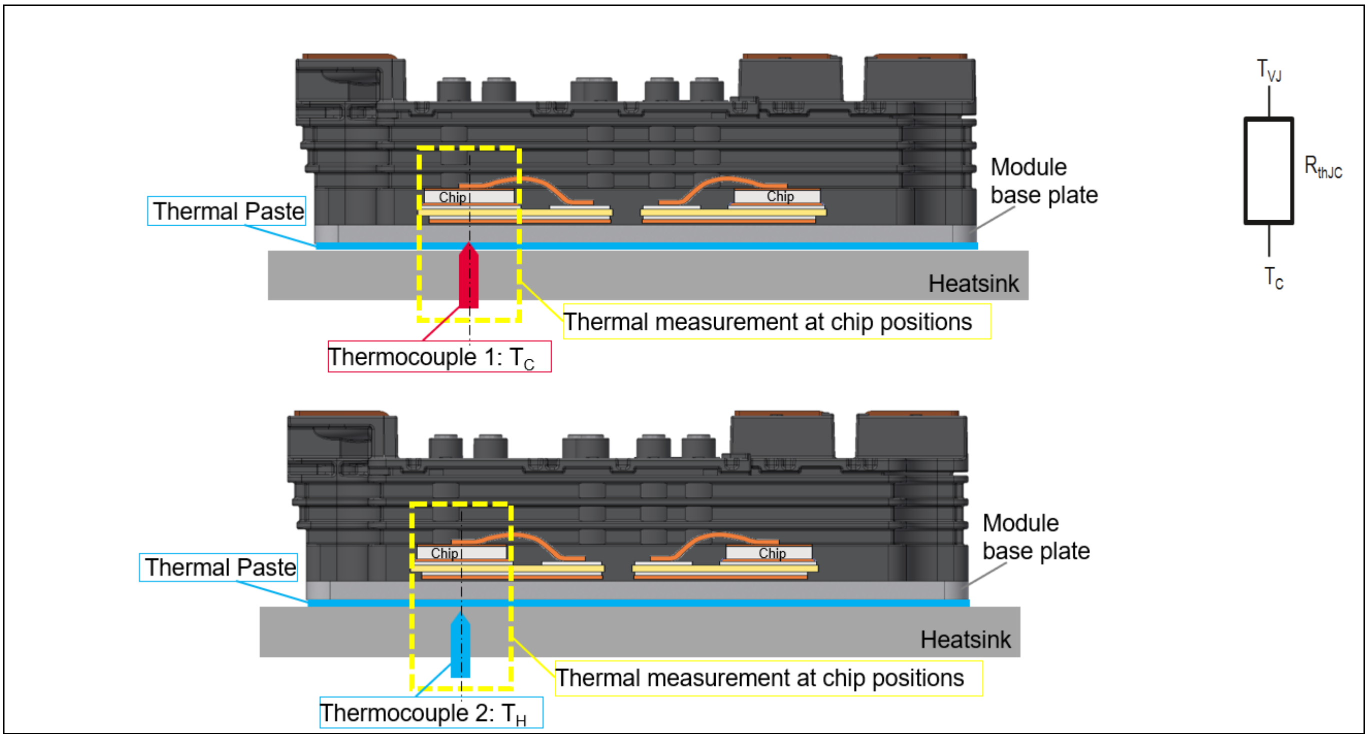


**Figure 33 A simplified example of a temperature measurement setup using:**
**a. A thermocouple for case temperature**
**b. A thermocouple for heatsink temperature**

The junction temperature, $T_{vj}$, can be determined by the formula:

$$Tvj = Tc + Pv * Rthjc \quad (7)$$

The losses ($P_V$) as well as the base plate temperature $T_C$ must be given for the calculation:

$T_{vj}$: The virtual junction temperature under operational conditions

$T_C$: The case temperature

$P_V$: The total power losses per measured system

$R_{thJC}$: The junction (J)-to-case (C) thermal resistance, per switch

The junction temperature (Tvj) under all operation conditions must be within the datasheet specified limits:

$$Tvj \leq Tvj\ max \quad (8)$$

***Note:*** *During operation, the maximum junction temperature, $T_{vj}$, must not exceed the maximum junction temperature specified in the module datasheet.*

For more details, see the application note on transient thermal measurements and thermal equivalent circuit models [18].

# 9 Abbreviations

| | |
|---|---|
| **XHP™ 2** | Infineon's e**X**tended **H**igh-**P**ower module platform, package variant **2** |
| **AlSiC** | Aluminum silicon carbide composite baseplate material |
| **Cu** | Copper |
| **RoHS** | Restriction of hazardous substances |
| **MCDS** | Material content datasheets |
| **NTC** | Resistor with a negative temperature coefficient |
| **FF** | Half bridge circuit, high side and low side system electrically connected in the module |
| **HS** | High side system of the half-bridge circuit |
| **LS** | Low side system of the half-bridge circuit |
| **GDU** | Gate drive unit or a gate control board |
| **PCB** | Power circuit board or a module adapter board |
| **substrates** | composite material: upper Cu layer/ceramic/lower Cu layer |
| **DUT** | Device under test |

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