



MOUNTING INSTRUCTION

安装说明

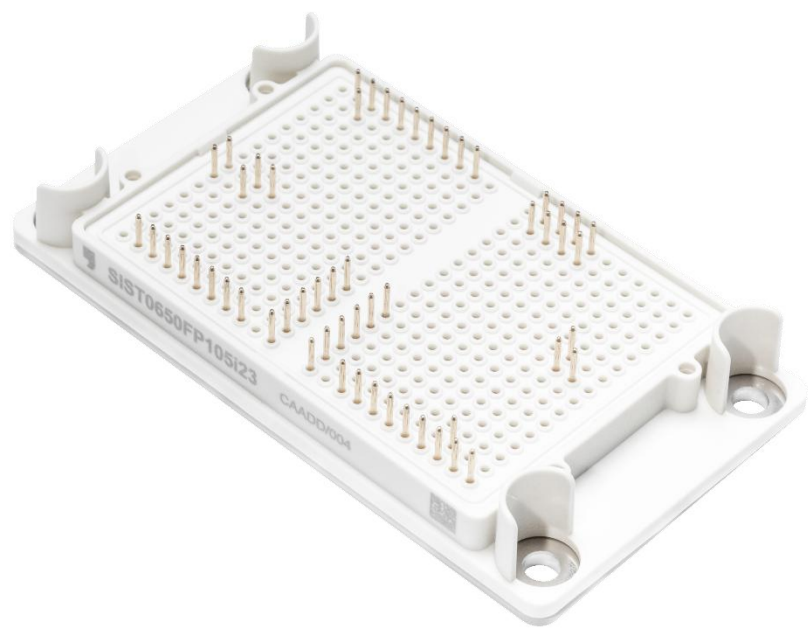
SEM AN 25-0001

Application note for FP-Type modules

FP 模块应用说明

swiss
semicon
ductors.

MOUNTING-INSTRUCTION 安装说明



Basic guidelines for the application, environmental conditions and installation of FP-type product platform are provided within this application note. Obeying these guidelines ensures safe mechanical, electrical and thermal connections which are crucial for a reliable operation of such power modules.

本应用说明提供了 FP 封装产品应用、环境条件和安装的基本指南。依据指南的内容操作，可确保 IGBT 模块在机械、电气和散热方面的可靠性得到保证。

GENERAL REMARKS AND PRECAUTIONS 通用要求和预防措施

The recommendations and guidelines provided here cannot replace a detailed assessment and evaluation of all aspects of the application related to the intended use of the power-module. All FP-type modules pass a final production test-sequence according to IEC60747-9 and IEC60747-15 prior shipment.

本说明中的推荐和指南仅做为参考，并不能涵盖评估模块预期应用的所有方面。所有 FP 封装 IGBT 模块都会依据 IEC60747-9 和 IEC60747-15 标准进行测试并通过。

1.1 ESD 静电放电

IGBT power modules are sensitive to electrostatic discharge (ESD). All FP-type power modules are protected during transportation and storage in the provided packaging. A short circuit with ESD-protection between the gate and the auxiliary terminals of high-side and low-side switch should be guaranteed, when handling the modules, to prevent ESD related damage by static charges (IEC60747-1, chapter VIII). A conductive-

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grounded wrist strap and a conductive-grounded workstation are strongly recommended during the assembly process.

IGBT 模块对静电放电比较敏感。所有 FP 封装 IGBT 模块在运输和存储过程中都会采用特定的包装。根据 IEC60747-1 标准第 8 章要求，在拆装和搬运 IGBT 的过程中，为了防止静电放电引起的损坏，需要在将栅极和高低压侧辅助端子短路的同时也要有静电放电的保护。安装 IGBT 的过程中，强烈建议戴上防静电手环并在具有导电接地的平台上进行操作。

1.2 Climatic conditions 环境条件

During transportation and storage of the FP-type modules, extreme forces such as shock and vibration should be avoided as well as environmental conditions exceeding the recommended limits. The FP-type modules are not hermetically sealed. The housings and the silicone gel used for the electrical isolation within the housing, are permeable by humidity and gases in both directions. Humidity differences will therefore be equalized.

FP 封装 IGBT 模块在运输和存储的过程中，应避免发生冲击和振动，以及超出模块本身允许的外界环境。FP 封装 IGBT 模块并不是完全密封的，外壳和内部用于电气隔离的硅胶对于空气和湿度可以双向渗透，最终会导致模块内外部的湿度差平衡。

1.2.1 Storage 存储

Storing the modules at the specified temperature limits stated in the datasheet is possible, however not recommended. The recommended storage conditions according to Table 1 should be assured for the recommended storage time of maximum two years.

IGBT 模块是可以满足数据表中标示的极限存储温度的，但是通常不建议这样做。如下表格 1 给出的存储条件，可以满足最长 2 年的存储时间。

Table 1 Climatic conditions for storage 储存条件

POS	PARAMETER 参数	VALUE 范围	UNIT
1	Temperature 温度	5 to 40	°C
2	Relative humidity 相对湿度	20 to 75	%
3	Precipitation, condensation, ice, frost and similar 降水、结冰、霜冻及类似情况	Not allowed at any time 任何时候都不允许	

1.2.2 Operation 应用条件

The climate conditions for the non-hermetically sealed FP-type power modules in active, current carrying operation are specified as EN60721-3-3 class 3K3. In the case of a humid atmosphere that causes condensation, or operation in climatic conditions surpassing class 3K3 of EN60721-3-3, appropriate measures must be taken to avoid liquid droplet depositions on the module in all circumstances. Corrosive gases must be avoided during operation and storage of the devices.

非密封 FP 封装 IGBT 模块正常工作的环境条件是标准 EN60721-3-3 中的 3K3 级。如果空气潮湿导致冷凝现象发生，或在超过 EN60721-3-3 中 3K3 级的环境条件下运行，必须采取适当措施，避免在任何情况下模块上出现凝露。模块在储存和使用过程中，禁止与腐蚀性气体接触。

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2 ELECTRICAL 电气特性

2.1 Terminals and circuitry 接线端子和驱动电路

The connection distance between the gate drive circuit and the control terminals of the FP-type IGBT module should be as short as possible. It is mandatory to directly solder the pins of the FP-type IGBT module onto the PCB board. This approach is primarily aimed at preventing any electromagnetic interference (EMI) from the main circuit to the gate drive signals.

FP 封装 IGBT 模块的栅极驱动电路和控制端子之间的连接距离越短越好。建议使用使用焊接的方式直接将 FP 封装 IGBT 模块的引脚焊接在 PCB 板上，这样做的目的主要是防止主回路对栅极驱动信号产生任何的电磁干扰（EMI）。

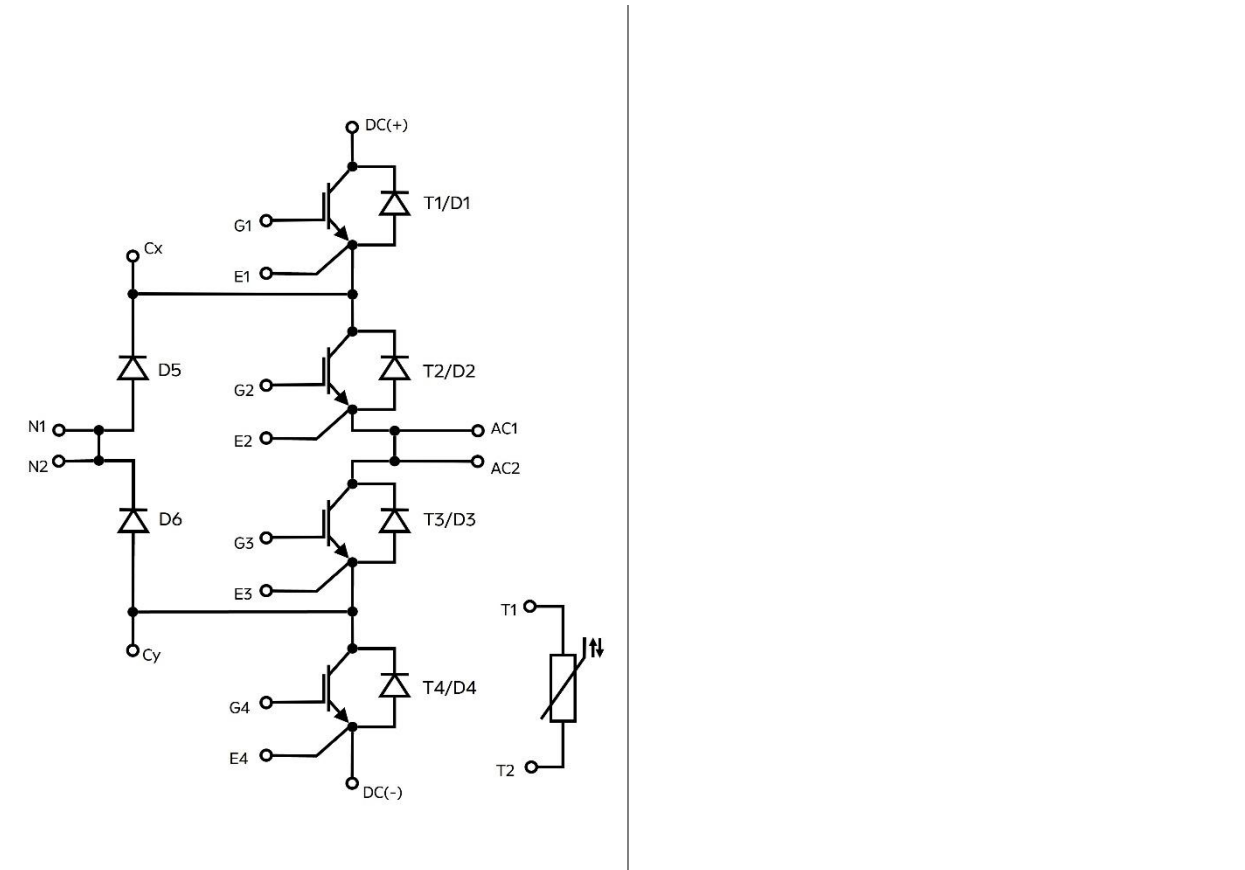


Figure 2-1 Schematic circuit diagram 图 2-1 电路原理图

Figure 2-2 RBSOA diagram IGBT RBSOA 曲线图暂未提供，后期会进行补充。

For all FP-type IGBT modules, all pins on the module are connected to the PCB board through soldering. The layout design of the DC busbars on the PCB should aim to minimize stray inductance.

对于所有 FP 封装的 IGBT 模块，模块上所有的引脚都是通过焊接的方式与 PCB 板进行连接的。PCB 上直流母排的布线设计应尽量使其杂散电感降至最低。

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2.2 Safe operating area / Voltage rating 安全工作区域/额定电压

During the turn-off process of the FP-type IGBT module, it is essential to ensure that the peak of the turn-off overvoltage V_{CEM} remains below the maximum rated collector-emitter voltage V_{CES} . Therefore, it is recommended to minimize the stray inductance of the commutation loop through reasonable layout design. Please refer to the datasheet for the internal stray inductance L_{SCE} of the module.

FP 封装 IGBT 模块在关断的过程中，必须确保关断过电压 V_{CEM} 峰值在最大额定集电极-发射极电压 V_{CES} 以下。因此，建议通过合理的布线设计尽量降低换流回路的杂散电感。请参阅模块内部杂散电感 L_{SCE} 的数据表。

Several factors limit the voltage and operating range of the power module in applications running at altitudes higher than 2000 m above sea level. The lower air pressure will affect the cooling performance; the changed dielectric strength of the air will reduce the clearance distance of the device and the statistical failure rate due to higher cosmic radiation levels will also impact the maximum operating voltage.

在海拔高于 2000m 的应用中，外部因素限制了功率模块的工作特性。较低的空气压力会影响其散热性能，空气介电强度的变化将减小器件的电气间隙，同时高海拔带来的高宇宙射线失效会影响模块的最大工作电压的选择。

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3 INSTALLATION 安装

3.1 Power module mounting 模块安装

There are two installation methods for FP-packaged IGBT modules:

FP 封装 IGBT 模块的安装方法有两种:

- The first method is: First, solder the IGBT module onto the PCB board via the module's pins, then install the PCB-mounted IGBT module onto the heat sink.
第一种方法是: 首先通过模块的引脚将 IGBT 模块焊接在 PCB 板上, 然后将焊接在 PCB 板上的 IGBT 模块模块安装到散热器上。
- The second method is: First, install the IGBT module onto the heat sink, then solder the heat-sink-mounted IGBT module onto the PCB board via the module's pins.
第二种方法是: 首先将 IGBT 模块模块安装到散热器上, 然后通过模块的引脚将安装在散热器上的 IGBT 模块焊接在 PCB 板上。

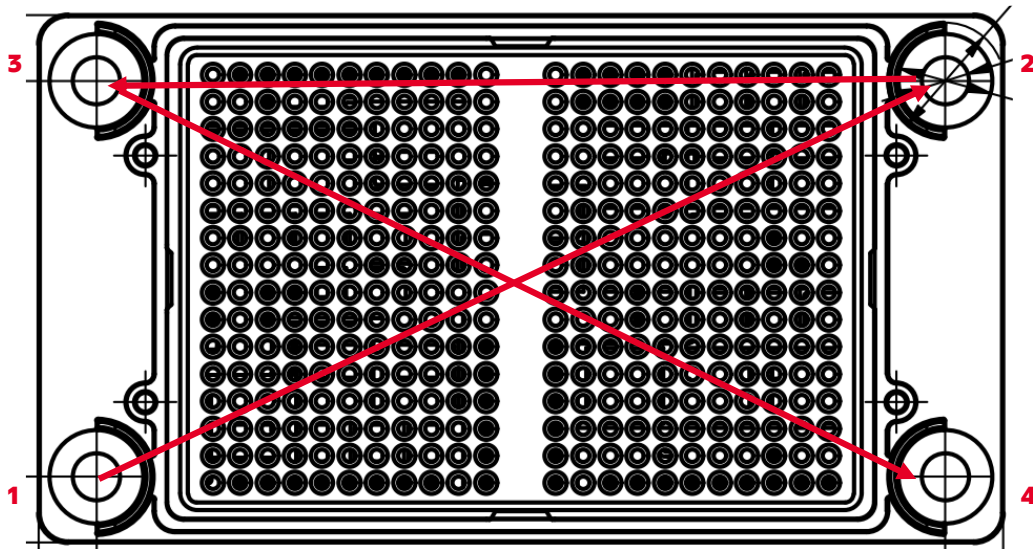


Figure 3-1 Sequence for tightening the FP-type power module to the heatsink; 图 3-1, FP 封装 IGBT 模块螺钉紧固顺序。

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Table 2 The specifications and torque requirements for the screws used to secure the FP-type IGBT module to the heat sink are as follows; 图2, FP 封装 IGBT 模块在散热器上固定的螺丝规格及扭矩要求

POS	DESCRIPTION 参数	VALUE 范围	UNIT 单位
1	Mounting screw 安装螺丝	M5	
2	Recommended mounting torque 推荐的安装扭矩	1.5	Nm
3	Recommended property class of bolt 推荐的螺栓等级	4.6 – 5.6	
4	Minimal thread length into the heat sink 最小的导线长度进入散热器	10	mm
5	Pre-tightening torque 预紧扭矩	0.3 – 0.5	Nm
6	Tightening torque Ma 紧固扭矩	1.3 – 1.5	Nm
7	Screw velocity (pre-tightening) 螺钉速度 (预紧)	≤ 250	RPM
8	Screw velocity (tightening) 螺钉速度 (拧紧)	≤ 20	RPM
9	Recommended washer 推荐的垫圈	M5	

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3.1.1 Installation procedure (Installation Method 1): 安装步骤 (安装方法 1)

- Position the FP-type IGBT module on the PCB according to the pre-arranged plated through-hole locations for the IGBT module pins on the PCB board.
按照 PCB 板上预留的 IGBT 模块引脚的过孔位置将 FP 封装 IGBT 模块放置在 PCB 上。
- (Optional) Use self-tapping screws to secure the module (not recommended if multiple modules are located on the same PCB). If self-tapping screws are used to fix the FP-type IGBT module on the PCB, the PCB must have four self-tapping through-holes with a diameter of 3 mm, according to the specifications of the FP-type IGBT module's self-tapping screw holes. The effective length of the thread in the module's screw holes should be at least 4 mm and no more than 8 mm. Depending on the thickness of the PCB used, metric self-tapping screws such as M2.5×8 or M2.5×10 can be selected. The maximum torque is $M_{max} = 0.4 \text{ Nm} \pm 10\%$. During assembly, to avoid damage or cracking of the studs, the screws must be inserted vertically into the module's screw holes.
(可选) 使用自攻螺钉固定模块 (如果多个模块位于同一 PCB 上, 则不推荐使用)。如果使用自攻螺丝在 PCB 板上固定 FP 封装 IGBT 模块, PCB 板上需要按照 FP 封装 IGBT 模块自攻螺丝孔规格预留 4 个直径为 3 毫米的自攻螺丝通孔。螺纹在模块螺丝孔中的有效长度应至少为 4 毫米, 且最多为 8 毫米。根据所用 PCB 的厚度, 可选用 公制 M2.5×8 或 M2.5×10 等规格的自攻螺丝。最大扭矩: $M_{max} = 0.4 \text{ 牛米} \pm 10\%$ 。在组装过程中, 为避免螺柱受损或开裂, 必须将螺钉垂直插入模块的螺丝孔。
- Solder each pin of the FP-type module onto the PCB board in accordance with the technical requirements specified in section 3.2 of this document.
按照本文 3.2 的技术要求将 FP 封装模块各引脚焊接在 PCB 板上。
- Apply thermal grease to the bottom of the IGBT module in accordance with the requirements specified in Section 3.4 of this document.
按照本文 3.4 的要求为 IGBT 模块底部涂抹导热硅脂。
- Mount the FP-type IGBT module onto the heat sink. The PCB board must include an appropriate fixation at four corners of each FP-type IGBT module to the heat sink to prevent mechanical load to the module pins during transport and operation. During the installation of the IGBT module, lateral movement on the heat sink should be avoided. Secure the module to the heat sink by pre-tightening with a manual, electric, torque wrench at a torque value of 0.5 Nm, following the sequence indicated in Figure 3-1. Then, following the same steps, tighten the screws to the torque requirements specified in the datasheet Table 2. It is recommended to use an automatic torque-release wrench, setting the maximum torque value to that specified in the datasheet.
将 FP 封装 IGBT 模块安装在散热器上。PCB 板必须包含合适的通孔用于 FP 封装 IGBT 模块与散热器的安装固定。孔的大小取决于螺丝刀的尺寸、螺丝头的直径或垫圈的大小。安装 IGBT 模块过程中, 应避免其在散热器上发生横向移动。将模块固定到散热器上, 用手动或电动或气动的力矩扳手以 0.5Nm 的力矩值按照图 3-1 中标明的顺序进行预紧固, 然后按照相同的步骤, 将螺钉紧固至图 3-1 数据表中规定的扭矩要求。建议使用自动释放扭矩的扳手, 将最大扭矩值设置为图 2 数据表中规定的数值。

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3.1.2 Installation procedure (Installation Method 2): 安装步骤 (安装方法 2)

- Apply thermal grease to the bottom of the IGBT module in accordance with the requirements specified in Section 3.4 of this document.
按照本文 3.4 的要求为 IGBT 模块底部涂抹导热硅脂。
- Secure the module to the heat sink by pre-tightening with a manual, electric, torque wrench at a torque value of 0.5 Nm, following the sequence indicated in Figure 3-1. Then, following the same steps, tighten the screws to the torque requirements specified in the Table 2. It is recommended to use an automatic torque-release wrench, setting the maximum torque value to that specified in the datasheet.
将 FP 封装 IGBT 模块安装在散热器上。PCB 板必须包含合适的通孔用于 FP 封装 IGBT 模块与散热器的安装固定。孔的大小取决于螺丝刀的尺寸、螺丝头的直径或垫圈的大小。安装 IGBT 模块过程中，应避免其在散热器上发生横向移动。将模块固定到散热器上，用手动或电动或气动的力矩扳手以 0.5Nm 的力矩值按照图 3-1 中标明的顺序进行预紧固，然后按照相同的步骤，将螺钉紧固至图 2 数据表中规定的扭矩要求。建议使用自动释放扭矩的扳手，将最大扭矩值设置为图 2 数据表中规定的数值。
- Position the PCB on the FP-type IGBT module.
按照 PCB 板上预留的 IGBT 模块引脚的过孔位置将 FP 封装 IGBT 模块放置在 PCB 上。
- (Optional) Use self-tapping screws to secure the module (not recommended if multiple modules are located on the same PCB). If self-tapping screws are used to fix the FP-type IGBT module on the PCB, the PCB must have four self-tapping through-holes with a diameter of 3 mm, according to the specifications of the FP-type IGBT module's self-tapping screw holes. The effective length of the thread in the module's screw holes should be at least 4 mm and no more than 8 mm. Depending on the thickness of the PCB used, metric self-tapping screws such as M2.5×8 or M2.5×10 can be selected. The maximum torque is $M_{\max} = 0.4 \text{ Nm} \pm 10\%$. During assembly, to avoid damage or cracking of the studs, the screws must be inserted vertically into the module's screw holes.
(可选) 使用自攻螺钉固定模块 (如果多个模块位于同一 PCB 上，则不推荐使用)。如果使用自攻螺丝在 PCB 板上固定 FP 封装 IGBT 模块，PCB 板上需要按照 FP 封装 IGBT 模块自攻螺丝孔规格预留 4 个直径为 3 毫米的自攻螺丝通孔。螺纹在模块螺丝孔中的有效长度应至少为 4 毫米，且最多为 8 毫米。根据所用 PCB 的厚度，可选用 公制 M2.5×8 或 M2.5×10 等规格的自攻螺丝。最大扭矩： $M_{\max} = 0.4 \text{ 牛米} \pm 10\%$ 。在组装过程中，为避免螺栓受损或开裂，必须将螺钉垂直插入模块的螺丝孔。
- Solder each pin of the FP-type module onto the PCB board in accordance with the technical requirements specified in section 3.2 of this document.
按照本文 3.2 的技术要求将 FP 封装模块各引脚焊接在 PCB 板上。

Warning Note: 警告说明:

- That the Inverter Stack (Module, Sink, Capacitors etc.) should not be lifted by holding the PCB as this can create unwanted forces to the module (Sink is hanging on the module and pins) and PCB could be damaged (hair-line cuts).
逆变器组件 (模块、散热器、电容器等) 不应通过抓住 PCB 来提起，因为这可能会对模块产生不必要的力 (散热器悬挂在模块和引脚上)，并且 PCB 可能会损坏 (出现细裂纹)。

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3.2 Soldering Requirements 焊接要求

All pins on the FP-type IGBT module are connected to the PCB board through soldering. The pins of the FP-type IGBT module comply with the solderability requirements of IEC standard 60068-2-20, enabling the FP-type IGBT products to be soldered onto the printed circuit board (PCB). To ensure reliable and effective soldering connections between the DC power supply section, the inverter output section, and the gate drive section on the PCB board with the relevant pins of the FP-type IGBT module, the following regulations must be adhered to during the soldering process:

FP 封装 IGBT 模块上所有的引脚都是通过焊接的方式与 PCB 板进行连接的。FP 封装 IGBT 模块引脚符合 IEC 标准 60068-2-20 中的可焊性要求，使得 FP 封装 IGBT 产品能够焊接到印刷电路板（PCB）上。为了保证 PCB 板上的直流电源部分、逆变输出部分、栅极驱动部分能够可靠有效的与 FP 封装 IGBT 模块相关各引脚进行焊接，必须在焊接过程中遵守如下规定：

- It is recommended that the final minimum aperture for soldering the pins of the FP-type IGBT module be 1.25 millimeters.
建议用于焊接 FP 封装 IGBT 模块引脚的最终最小孔径为 1.25 毫米。
- The final aperture of the plated through-holes for the FP-type IGBT module pins is defined as "D = 1.25 mm + X", where the selection of "X" should be in accordance with the IPC2220 series of standards. Due to the interdependence of various factors such as PCB type, thickness, plating, manufacturing tolerances, soldering processes, and solder alloys, the parameter X must be determined by the customer to ensure good soldering results and reliable long-term connections.
FP 封装 IGBT 模块引脚的镀通孔最终孔径定义为“D = 1.25 毫米 + X”，“X”的选择需依照 IPC2220 系列标准。由于 PCB 类型、厚度、镀层、生产公差、焊接工艺以及焊料合金等多种因素相互依存，参数 X 必须由客户确定，以确保良好的焊接效果和可靠的长期连接。
- The final aperture size must be determined with caution. If the aperture is too large, it may be difficult to ensure a secure electrical and mechanical connection between the pin and the circuit board.
最终的孔径尺寸必须谨慎确定。如果孔径过大，可能会难以确保引脚与电路板之间实现牢固的电气和机械连接。
- The soldering pins of the FP-type IGBT module are designed for soldering onto printed circuit boards (PCB) with a thickness not exceeding 2 millimeters. The geometric dimensions of the soldering pins are provided in the module's datasheet.
FP 封装 IGBT 模块焊接引脚的设计用于焊接在厚度不超过 2 毫米的印刷电路板（PCB）上。模块数据表中提供了焊接引脚的几何尺寸。
- The soldering process can be carried out using manual soldering, automated soldering, and wave soldering techniques. According to the stipulations of IEC 68 Part 2, the maximum duration at a soldering temperature of 260°C is 10 seconds. To ensure the reliability of the module, the maximum temperature of the module casing must not exceed 223°C during the soldering process.
焊接工艺可以采用手工焊接、自动焊接和波峰焊接。根据 IEC 68 第 2 部分的规定，260°C 焊接温度的最大持续时间为 10 秒。为确保模块可靠性，在焊接过程中模块外壳的最高温度不得超过 223°C。
- We recommend soldering prior sink mounting to avoid heat loss through the pins and sink.
我们建议在安装散热器之前进行焊接，以避免通过引脚和散热器损失热量。
- Solder pads: The recommended diameter of the solder pads on the PCB is 2 mm. For large area copper layers (power connections) it is mandatory to design a thermal relief to the copper pad (copper spokes) to minimize heat drain from the pad to the large copper area and improve see Figure 3-2.

焊盘：PCB 上焊盘的推荐直径为 2 毫米。对于大面积铜层（功率连接），必须设计热风焊盘连接（辐射状铜条），以最小化从焊盘到大铜面积的热耗散并改善焊接状况 图 3-2。

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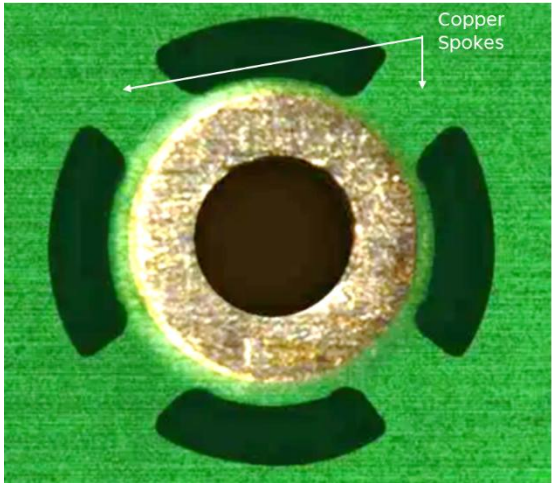


Figure 3-2 Thermal stress relief around the solder pad – referred to as “Copper spokes” in the PCB. 图 3-2 焊盘周围的热应力释放——在电路板中称为“铜辐条”。

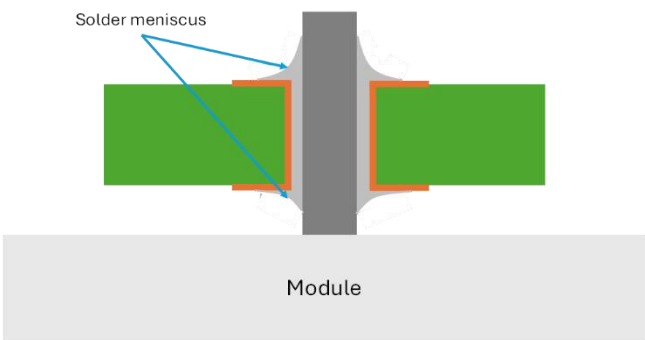


Figure 3-3 Wetting of the solder to the PCB and module Pin. 图 3-3 焊料对 PCB 和模块引脚的润湿。

Good soldering: It is mandatory that the solder wets well on the module pins and the solder pads. The soldering process needs to be qualified to ensure this to have reliable inverter operation. A good soldering process is obtained if there is a proper solder meniscus on both sides of the PCB Figure 3-3.
良好的焊接：焊料必须很好地润湿模块引脚和焊盘。焊接工艺需要经过验证，以确保逆变器能够可靠运行。如果在 PCB 的两侧都有适当的焊料曲面，那么就能获得良好的焊接工艺 图 3-3。

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3.3 Heatsink 散热器

Maximum thermal conductivity between the power module bottom-side and the heatsink must be ensured by using a clean heatsink, being free of any particles or ridges of more than 10 µm. There is a risk that such objects deform the Cu-baseplate and result in cracks of the ceramic layers inside the power module. The following conditions must be obeyed in the application:

安装 IGBT 时，必须使用清洁的散热器，确保 IGBT 底部和散热器表面之间的最大导热系数，散热器表面不得有任何超过 10 µm 颗粒物。因为此类颗粒有可能使 IGBT 的铜基板变形，并导致 IGBT 内部的陶瓷层开裂。使用散热器时必须遵循以下条件：

- Roughness: $R_z \sim 10 \mu\text{m}$ 粗糙度: $R_z \sim 10 \mu\text{m}$
- Flatness: 30 µm (valid for entire contact area) 平整度: 30µm (适用于整个接触面积)

3.4 Applying thermal paste 涂抹导热硅脂

The application of thermal paste is a must to ensure good thermal conductivity between the power module and the heat sink and will prevent “dry” contact and enables a metal-to-metal contact wherever possible. Typical thermal pastes include but are not exclusively limited to: Honeywell PTM6000HV-SP, Wacker P12, Electrolube HTC(P), Dow Corning TC-5121. Please obey the guidelines provided by the manufacturers.

安装 IGBT 的时候，必须涂抹导热硅脂，用于确保 IGBT 模块和散热器之间具有良好的导热性。常见的导热硅脂包含：霍尼韦尔 PTM6000HV-SP、Wacker P12、Electrolube HTC (P)、道康宁 TC-5121。使用时可参考制造商提供的应用指南。

Please ensure the following by applying thermal paste: 使用导热硅脂前请确保如下内容：

- Generate a reproducible, homogeneous, and even layer. Inhomogeneities might result either in dry contacts or act like particles and potentially result in cracked ceramic.
确保涂抹的导热硅脂是均匀的，因为不均匀的涂抹会导致干接触或者生成颗粒，进而导致陶瓷层开裂。
- Cleaning all interfaces the thermal paste will be in contact with prior applying thermal paste (e.g. IPA ethylene glycol etc.)
在涂抹导热硅脂之前，需要清洁导热硅脂的所有接口处（例如：可用乙二醇等清洁）。
- A stencil or screen printer is recommended to ensure an even distribution of the grease
建议使用刮刀和钢网配合涂抹，目的是确保导热硅脂的均匀分布。
- In case of a manual application of the grease a thickness of 50 µm to 100 µm is recommended depending on paste type, its viscosity and stencil thickness.
如果手动涂抹的话，依据导热硅脂的类型、粘度等因素，建议厚度在 50 µm 至 100 µm 之间。
- A subsequent process control (e.g. concerning thickness, volume, pattern etc.) is recommended.
建议在后续涂抹过程中，从厚度、体积、图案等方面进行相应的工艺优化。

SwissSEM provides a stencil mask design Figure 3-4

如图 3-4 所示，SwissSEM 设计了一个涂抹导热硅脂的模具工装。

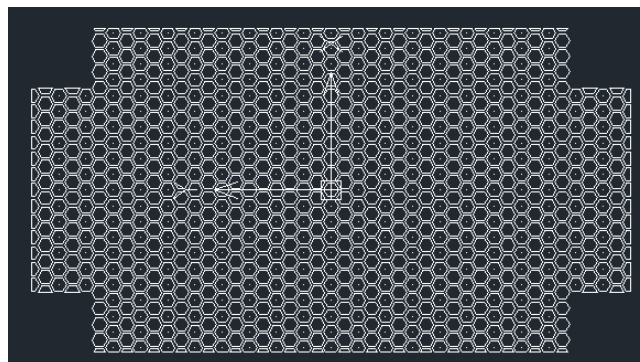


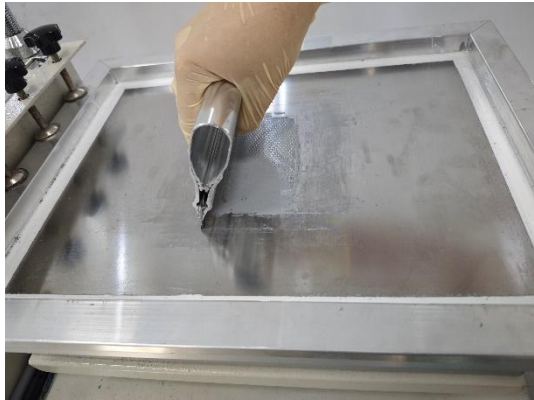
Figure 3-4 SwissSEM can provide corresponding tooling and mold drawings based on the specific requirements of customers. 图 3-4 SwissSEM 可根据客户的需求情况，提供的相应的工装模具图纸。

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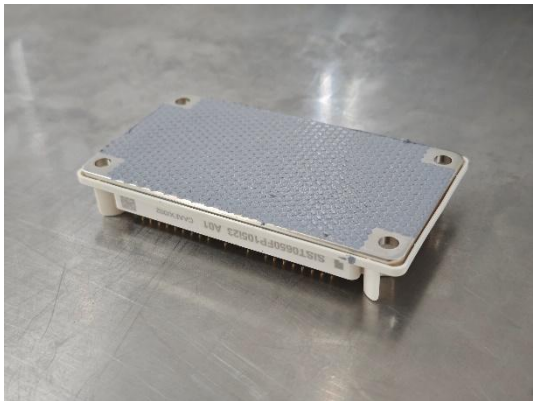
Stencil printing tooling

涂抹工装



Thermal grease application onto the stencil using a scraper (suitable for low viscosity pastes)

使用刮刀在工装上涂抹导热硅脂（适用于低粘度）



Example of an FP-type module after stencil printing

FP 封装 IGBT 模块涂抹完后的示例



Example of good thermal grease coverage (module removed after mounting)

从散热器上拆除后，可以看到导热硅脂均匀覆盖在 IGBT 的基板上。

Figure 3-5 FP-type power module and typical grease application; 图3-5，FP 型 IGBT 模块涂抹导热硅脂示例

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3.5 Gate drive 栅极驱动

The FP-type IGBT module should be operated with a gate drive voltage of +15V to achieve low conduction state and good short-circuit resistance.

A higher gate turn-on voltage reduces conduction losses, but it also decreases the short-circuit SCSOA capability of the IGBT. The gate turn-off voltage is recommended to be between -5V and -15V, which is chosen to ensure that the IGBT can achieve low turn-off losses while withstanding a high dv/dt .

FP 封装 IGBT 模块应在+15V 的栅极驱动电压下开通运行，以实现低导通状态和良好的抗短路能力。虽然较高的栅极开通电压可以降低损耗，但是同时也增大了 IGBT 发生短路的风险。栅极关断电压建议在-5V 至-15 V 之间，这样选取的目的在于 IGBT 实现低关断损耗的同时能够承受较高 dv/dt 的能力。实际应用中，FP 封装 IGBT 模块包括栅极、发射极在内的所有引脚是直接焊接在同一块 PCB 板上的。对于安装在振动环境中运行的模块，强烈建议额外使用 4 个自攻螺钉将 FP 封装 IGBT 模块固定在 PCB 板上。自攻螺钉的紧固力矩必须在 0.41Nm~0.49Nm 之间，模块外壳中的有效螺纹长度必须在 4 到 10 mm 之间。

A schematic of a typical Gate Unit output stage is depicted in Figure 3-6. It is recommended to clamp the gate voltage to V_{GEon} (typically 15 V) for protection against high inductive short-circuit events or short-circuit type II events, with a suppressor diode (D3) mounted close to the module Gate and auxiliary Emitter as well as with fast Schottky diodes (D1 & D2) connected low inductive to the gate-voltage supply. An optional gate-emitter capacitor mounted low inductive to the module can improve the controllability of the IGBT. In case the turn-off overvoltage of the IGBT can't be kept below the allowed V_{CEm} of the IGBT, for instance due to too high stray inductance, an active clamp circuit compromising of suppressor diodes (D4 to Dx) a Schottky Diode D7 and a damping resistor R3 is needed. The total clamp voltage of the suppressor diodes (D4 to Dx) and the value of the damping resistor need to be optimized to the effective power circuit and stray inductance. The clamp circuit must be low inductive connected to the module to be effective. In any case the sum of the V_{BR} of the clamp diodes needs to be above the maximum expected V_{DC} to avoid damage to the IGBT and inverter.

图 3-6 中给出了典型的栅极驱动示意图，在靠近栅极和辅助发射极之间增加一个抑制二极管（D3），同时在栅极驱动回路中增加两个快速肖特基二极管（D1 和 D2），目的是防止高电感引起的短路或者二类短路事件的发生，保持栅极驱动电压钳制在 15V。栅极-发射极之间可选择性的增加一个电容用于提高 IGBT 的可控性。由于系统电路中的杂散电感太高，为了防止 IGBT 关断过程中的过电压超过 V_{CEm} 的最大值，需要增加一个由抑制二极管（D4 至 Dx）、肖特基二极管 D7 以及电阻 R3 组成的有源钳位电路。这里的 R3、总钳位电压（D4 至 Dx）的数值是根据实际电路的情况以及电路中的杂散电感来选取的。钳位电路必须低电感连接到模块才能有效，任何时候钳位二极管的电压总和 V_{BR} 要大于最大预期的 V_{DC} ，从而避免 IGBT 和逆变器损坏。

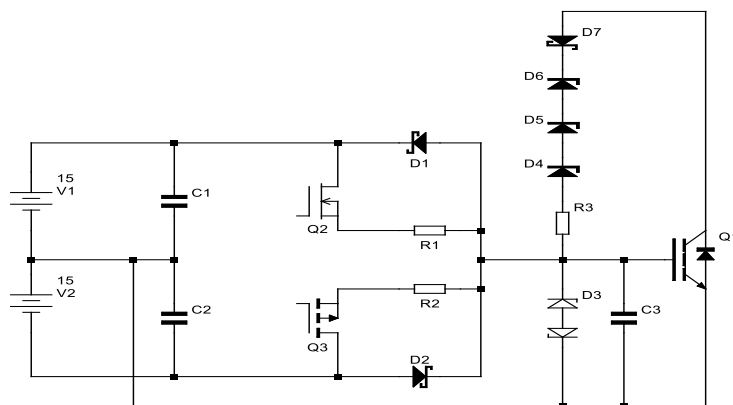


Figure 3-6 Typical Gate-drive output stage; 图 3-6 典型栅极驱动电路

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3.6 General mounting remarks 通用安装要求

Table 3 The industry standards apply for this product as shown in the table below; 表格 3 如下表所示，工业标准同样适用于此类产品。

POS 序号	DO 允许	DON'T 禁止	RISK 存在的风险
1	Apply wrenches with automatic release in case maximum torque is reached 如果达到最大扭矩，则使用带有自动释放功能的扳手	Use impact wrenches 禁止使用冲击类型的扳手	Damage to power module Jamming of screw 损坏 IGBT 模块 螺钉断裂，卡在螺纹里面
2	Limit screw speed to manageable values 将螺钉紧固速度限制在允许的范围之内	Maximize screw speed 最大速度紧固螺钉	Damage to power module Jamming of screw 损坏 IGBT 模块 螺钉断裂，卡在螺纹里面
3	Use screws for module mounting that are tailored to heat sink material 使用适合散热器材料的螺钉安装 IGBT 模块	Compromise 禁止使用不达标准的螺钉	
4	Length of screws must be tailored to application 根据实际情况选取合适长度的螺钉	Compromise 禁止使用不达标准的螺钉	Damage to power module 损坏 IGBT 模块

4 REVISION HISTORY 修订记录

DATE 日期	AUTHOR 修订者	REMARK 修订内容
March, 2025 2025 年 3 月	Xiaoming Meng 孟小明	Initial version 初始版本
September, 2025	Sven Matthias	Major revision and correction

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