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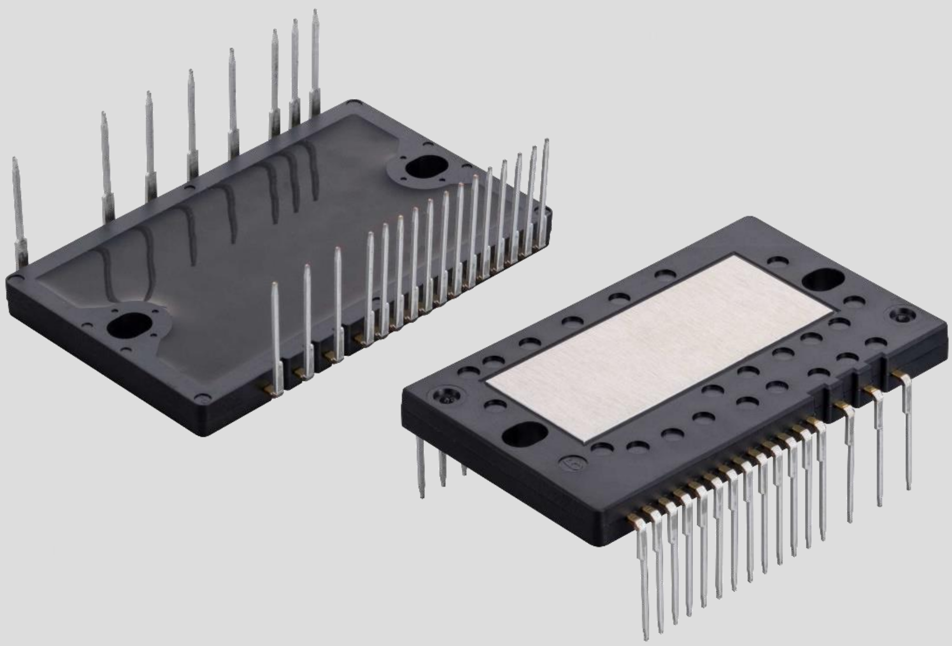

Small IPM (Intelligent Power Module)
P633C Series
6MBP**XS*065-50

Application Manual

August 2023

Fuji Electric Co., Ltd.

MT6M16945

Cautions

This Instruction contains the product specifications, characteristics, data, materials, and structures as of August 2023. The contents are subject to change without notice for specification changes or other reason. When using a product listed in this Instruction be sure to obtain the latest specifications.

The application examples in this note show the typical examples of using Fuji products and this note shall neither assure to enforce the industrial property including some other rights nor grant the license.

Although Fuji Electric Co., Ltd. continually strives to enhance product quality and reliability, a small percentage of semiconductor products may become faulty. When using Fuji Electric semiconductor products in your equipment, be sure to take adequate safety measures such as redundant, flame-retardant and fail-safe design in order to prevent a semiconductor product failure from leading to a physical injury, property damage or other problems.

The products described in this application manual are manufactured with the intention of being used in the following industrial electronic and electrical devices that require normal reliability.

- Compressor motor inverter
- Fan motor inverter for room air conditioner
- Compressor motor inverter for heat pump applications, etc.

If you need to use a semiconductor product in this application note for equipment requiring higher reliability than normal, such as listed below, be sure to contact Fuji Electric Co., Ltd. to obtain prior approval. When using these products, take adequate safety measures such as a backup system to prevent the equipment from malfunctioning when a Fuji Electric’s product incorporated in the equipment becomes faulty.

- Transportation equipment (mounted on vehicles and ships)
- Trunk communications equipment
- Traffic-signal control equipment
- Gas leakage detectors with an auto-shutoff function
- Disaster prevention / security equipment
- Safety devices, etc.

Do not use a product in this application note for equipment requiring extremely high reliability such as:

- Space equipment
- Airborne equipment
- Atomic control equipment
- Submarine repeater equipment
- Medical equipment

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CONTENTS

CONTENTS

Chapter 1 Product Outline

This manual describes the following contents for Fuji IGBT Intelligent Power Module “Small IPM”
- Product outline
- Explanation of terminal symbols and terminology
- Detailed description and design guidelines for control and power terminals
- Recommended wiring and layout, along with mounting guidelines

1. Introduction

<Product overview>
- IGBT modules used in inverters for compressors and air conditioner fans are developing rapidly in response to the growing demand for energy saving, equipment miniaturization and weight reduction.
- IGBTs are devices that combine the high-speed switching performance of power MOSFETs and the high-voltage, high-current capabilities of bipolar transistors, and are expected to further develop in the future.
- Among them, the IPM (Intelligent Power Module) is a 3-phase IGBT inverter bridge circuit with integrated gate drive circuits and protection circuits.

<Product concept>
- 7th gen. IGBT/FWD technology realize low loss and energy saving of equipment.
- Guaranteed T_{vjop}=150^{o}C allows expansion of output current.
- High accuracy short-circuit protection detection expands the overload operation range.
- Compatible pin assignments, footprints, and mounting dimensions with conventional Small IPM.
- Product lineup of 650V/15A to 35A.
- Lower total loss against conventional products by improving the trade-off between Collector-Emitter saturation voltage $V_{CE(sat)}$ and switching loss.
- Achieves low dv/dt and low switching loss compared to conventional products.

<Internal circuit>
- Optimally designed IGBT drive circuit.
- The high-side control IC (HVIC) contains a high-voltage level shift circuit.
- This product can be driven directly by MCU (microcontroller) on both the high-side and low-side arms. The voltage level of the input signals are 3.3V or 5V.
- Since the wiring length between the internal drive circuit and IGBT is short and the impedance of the drive circuit is low, no reverse bias power supply is required.
- Normally, IPM device requires a total of four isolated control power supplies: one for the lower sides and three for the upper sides. However, since this IPM has built-in bootstrap diodes (BSD), isolated power supplies for the high-sides are not needed.

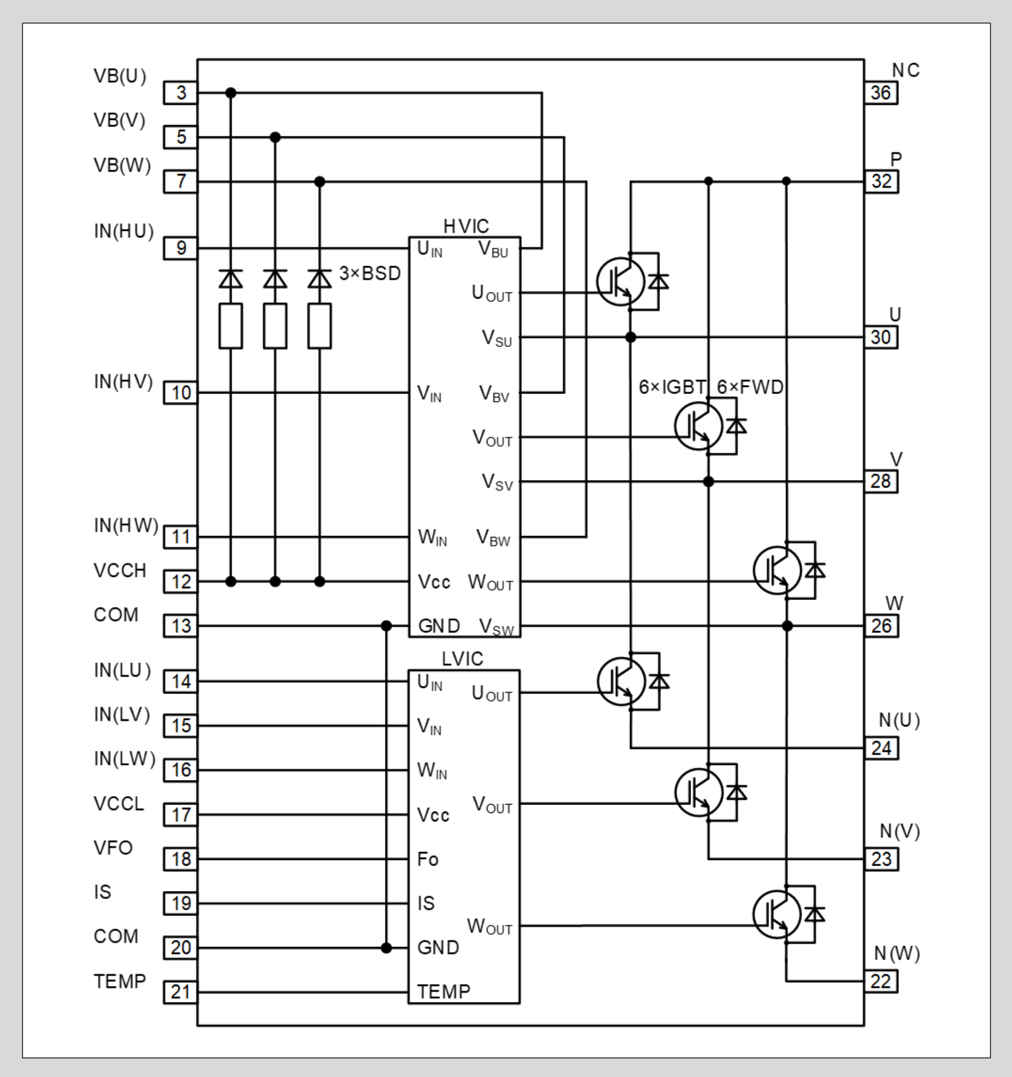


Fig.1-1 Block Diagram of Internal Circuit

<Built-in protection circuits>

- The following built-in protection circuits are incorporated in the product:
  - OC: Over current protection
  - UV: Under voltage protection for power supplies of control IC
  - LT: Temperature sensor output function
  - OH: Overheating protection (only applied to some products)
  - FO: Fault alarm signal output

- The OC protection circuits protect the IGBT against over current, load short-circuit or arm short-circuit.
- The protection circuit can monitor the emitter current using external shunt resistor in each low-side IGBT and thus it can protect the IGBT against arm short-circuit.
- The UV protection circuit operates when the control power supply voltage drops below the trip voltage level. It is built into all of the IGBT drive circuits.
- The OH protection circuit protects the product from overheating. The OH protection circuit is built into the control IC of the low-side arm (LVIC).
- The temperature sensor output function is built into the LVIC and converts the detected temperature into analog voltage output.
- The FO function outputs a fault signal when the circuit detects abnormal conditions, thus making it possible to shut down the system reliably and preventing destruction by outputting the fault signal to the microprocessor unit controlling the product.

<Compact package>

- This product uses high heat dissipation aluminum insulated metal substrate (IMS), which improves the heat radiation.
- The control input terminals have a shrink pitch of 1.778mm (70mil).
- The power terminals have a standard pitch of 2.54mm (100mil).

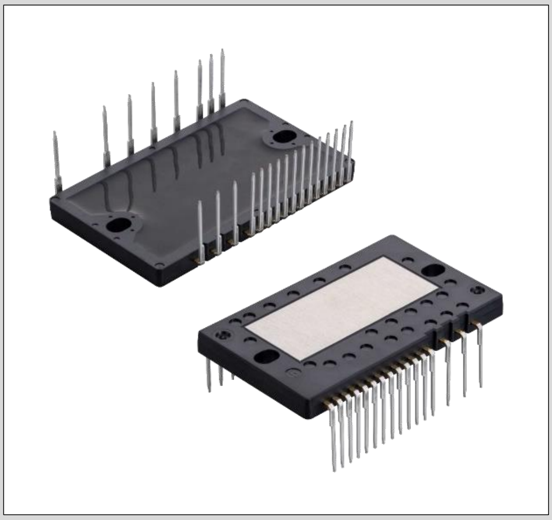


Fig.1-2 Package overview

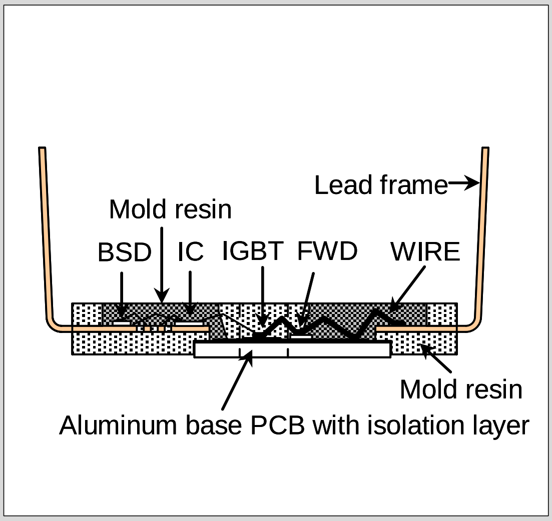


Fig.1-3 Package cross section diagram

2. Product Lineup

Table. 1-1 Lineup

Temperature sensor output (Vtemp, out)
Overheating protection(self shutdown)
Over current protection (External current detection and shutdown)
Under voltage protection (self shutdown)
N-side fault status Output (Alarm)
P-side fault status Output (Alarm)

<table>
<tr><th rowspan="2">Package</th><th rowspan="2"></th><th rowspan="2"></th><th rowspan="2"></th><th rowspan="2"></th><th rowspan="2"></th><th rowspan="2"></th><th colspan="2">Rating of IGBT</th><th rowspan="2">Type name</th><th rowspan="2">Isolation Voltage [Vrms]</th></tr>
<tr><th>Voltage [V]</th><th>Current [A]</th></tr>
<tr><td rowspan="8">P633C</td><td rowspan="8">✓</td><td rowspan="4">-</td><td rowspan="8">✓</td><td rowspan="8">✓</td><td rowspan="8">✓</td><td rowspan="8">-</td><td rowspan="8">650V</td><td>15A</td><td>6MBP15XSJ065-50</td><td rowspan="8">1500Vrms
Sinusoidal 60Hz,
1min. *1</td></tr>
<tr><td>20A</td><td>6MBP20XSJ065-50</td></tr>
<tr><td>30A</td><td>6MBP30XSJ065-50</td></tr>
<tr><td>35A</td><td>6MBP35XSJ065-50</td></tr>
<tr><td rowspan="4">✓</td><td>15A</td><td>6MBP15XSK065-50</td></tr>
<tr><td>20A</td><td>6MBP20XSK065-50</td></tr>
<tr><td>30A</td><td>6MBP30XSK065-50</td></tr>
<tr><td>35A</td><td>6MBP35XSK065-50</td></tr>
</table>

*1 Between all shorted terminals and case

3. Definition of Type Name and Marking Spec

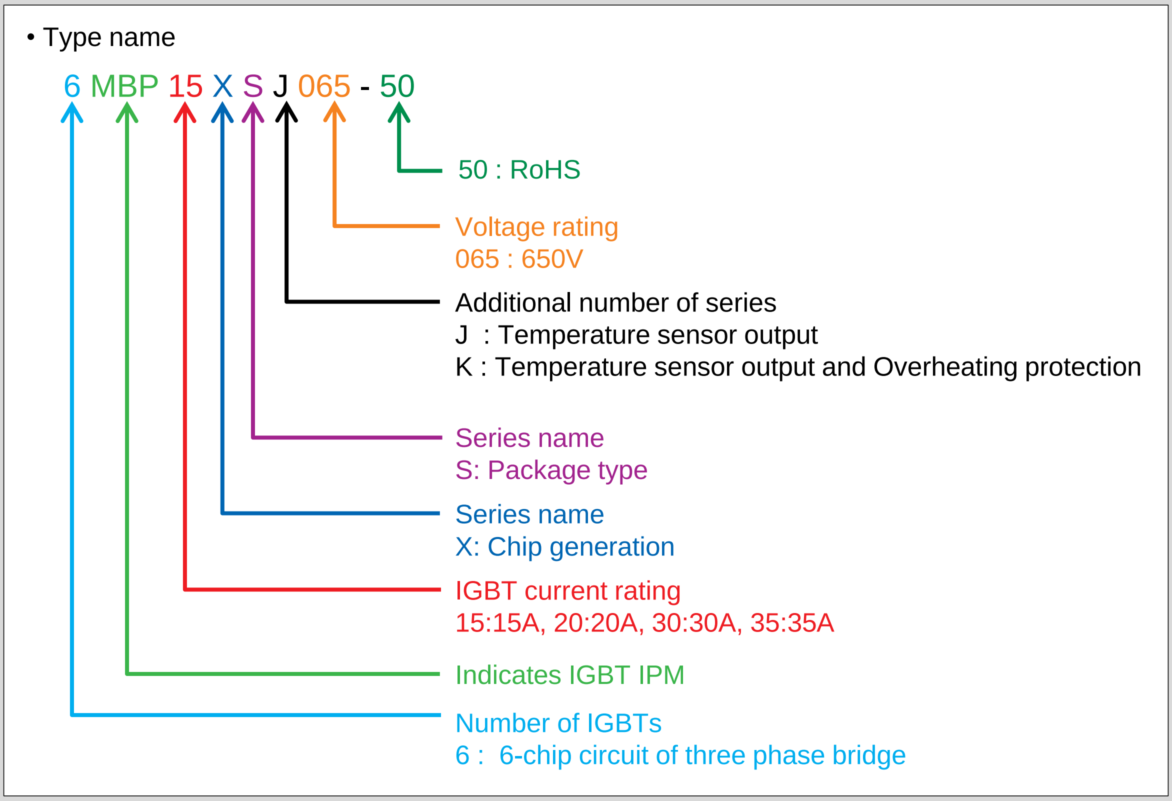


Fig.1-4 Part numbers

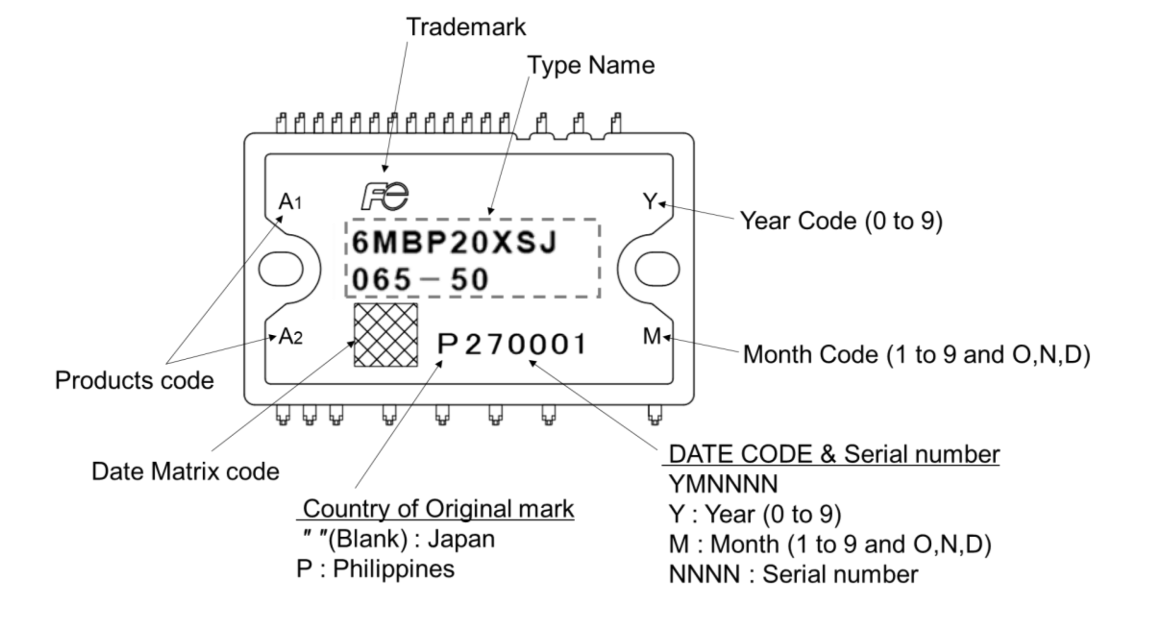
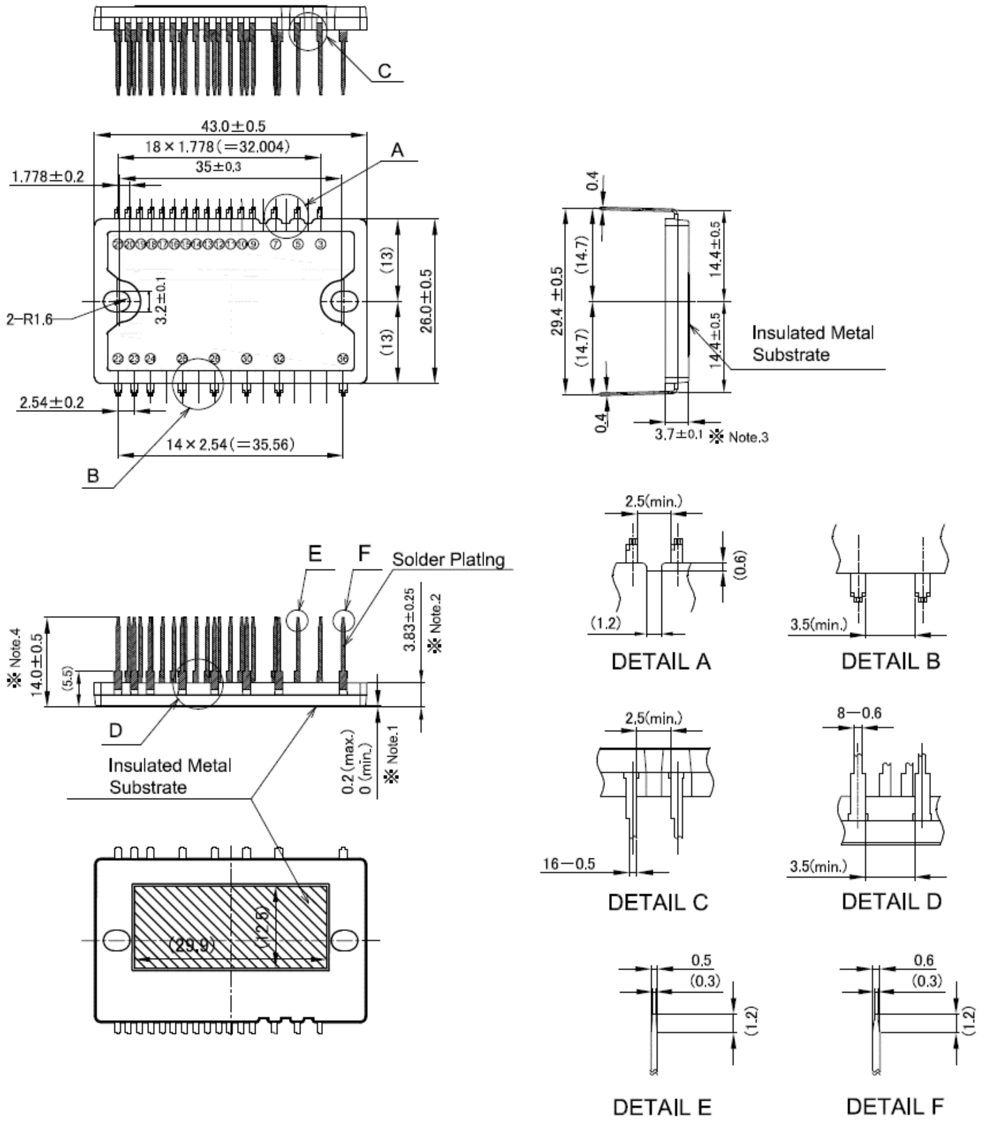


Fig.1-5 Marking Specification

Table. 1-2 Products code

TYPE NAME	PRODUCTS CODE	
	A1	A2
6MBP15XSJ065-50	L	J
6MBP15XSK065-50	L	K
6MBP20XSJ065-50	M	J
6MBP20XSK065-50	M	K
6MBP30XSJ065-50	O	J
6MBP30XSK065-50	O	K
6MBP35XSJ065-50	P	J
6MBP35XSK065-50	P	K

4. Outline Dimensions



Unit: mm

Note.1

IMS(Insulated Metal Substrate) is deliberately protruded to improve the thermal conductivity between IMS and heat-sink.

Note.2

The thickness from the package surface to the back side includes the IMS.

Note.3

Thickness of the case part of the package outer wall. (excluding the IMS and marking surface)

Note.4

Height of the terminal and height of the stopper part including IMS.

Fig.1-6 Case outline drawings

Table. 1-3 Pin assignment

Pin No.	Pin Name	Pin No.	Pin Name
3	VB(U)	22	N(W)
5	VB(V)	23	N(V)
7	VB(W)	24	N(U)
9	IN(HU)	26	W
10	IN(HV)	28	V
11	IN(HW)	30	U
12	VCCH	32	P
13	COM	36	NC
14	IN(LU)		
15	IN(LV)		
16	IN(LW)		
17	VCCL		
18	VFO		
19	IS		
20	COM		
21	TEMP		

5. Absolute Maximum Ratings

An example of the absolute maximum ratings of 6MBP20XSJ065-50 is shown in Table 1-4.

Table 1-4 Absolute Maximum Ratings at T_{vj}=25°C,V_{CC}=15V (unless otherwise specified)

Item	Symbol	Rating	Unit	Description
DC Bus Voltage	$V_{DC(terminal)}$	450	V	DC voltage that can be applied between P-N(U), N(V), N(W) terminals
Bus Voltage (Surge)	$V_{DC(Surge,terminal)}$	500	V	Peak value of the surge voltage that can be applied between P-N(U), N(V), N(W) terminals during switching operation
Collector-Emitter Voltage	$V_{CE(chip)}$	650	V	Maximum collector-emitter voltage of IGBT and repeated peak reverse voltage of FWD.
Collector Current	I_C	20	A	Maximum collector current for the IGBT chip. T_c=25°C
Peak Collector Current	I_{CP}	40	A	Maximum pulse collector current for the IGBT chip. T_c=25°C
Forward Current	I_F	20	A	Maximum forward current for the FWD chip. T_c=25°C
Peak Forward Current	I_{FP}	40	A	Maximum pulse forward current for the FWD chip. T_c=25°C
Collector Power Dissipation	P_{D_IGBT}	41.0	W	Maximum power dissipation for one IGBT element at T_c=25°C
FWD Power Dissipation	P_{D_FWD}	33.9	W	Maximum power dissipation for one FWD element at T_c=25°C
Self operation “DC Bus voltage” of circuit protection between upper-arm and lower-arm	$V_{DC(sc)}$	400	V	$V_{CC}=V_{B(*)}$=13.5~16.5V T_{vj}=125°C, arm short circuit, non-repetitive less than 2us.
Virtual Junction Temperature of Inverter Block	T_{vj}	+150	°C	Maximum virtual junction temperature of the IGBT chips and the FWD chips. Operating life is limited by junction temperature and power cycle.
Operating Virtual Junction Temperature of Inverter Block	T_{vjop}	-40 ~ +150	°C	Junction temperature of the IGBT and FWD chips during continuous operation. Operating life is limited by junction temperature and power cycle.

Table 1-5 Absolute Maximum Ratings at T_{vj}=25°C,V_{CC}=15V (Continued)

Item	Symbol	Rating	Unit	Descriptions
High-side Supply Voltage	V_{CCH}	-0.5 ~ 20	V	Voltage that can be applied between COM and V_{CCH} terminal
Low-side Supply Voltage	V_{CCL}	-0.5 ~ 20	V	Voltage that can be applied between COM and V_{CCL} terminal
High-side Bias Absolute Voltage	$V_{B(U)-COM}$ $V_{B(V)-COM}$ $V_{B(W)-COM}$	-0.5 ~ 670	V	Voltage that can be applied between VB(U)-COM, VB(V)-COM,VB(W)-COM terminal
High-side Bias Voltage for IGBT Gate Driving	$V_{B(U)}$ $V_{B(V)}$ $V_{B(W)}$	-0.5 ~ 20	V	Voltage that can be applied between U-VB(U), V-VB(V), W-VB(W) terminal
High-side Bias offset Voltage	V_U V_V V_W	-5 ~ 650	V	Voltage that can be applied between U-COM, V-COM, W-COM terminals.
Input Signal Voltage	V_{IN}	-0.5 ~ V_{CCH}+0.5 -0.5 ~ V_{CCL}+0.5	V	Voltage that can be applied between IN(*)-COM terminal
Input Signal Current	I_{IN}	3	mA	Maximum input current that flows from IN(*) to COM terminal
Fault Signal Voltage	V_{FO}	-0.5 ~ V_{CCL}+0.5	V	Voltage that can be applied between COM and VFO terminal
Fault Signal Current	I_{FO}	1	mA	Sink current that flows from VFO to COM terminal
Over Current Sensing Input Voltage	V_{IS}	-0.5 ~ V_{CCL}+0.5	V	Voltage that can be applied between IS and COM terminal
Maximum Junction Temperature of Control Circuit Block	T_{vj}	150	°C	Maximum junction temperature of the control circuit block
Operating Case Temperature	T_c	-40 ~ +125	°C	Operating case temperature (temperature of the aluminum plate directly under the IGBT or the FWD)
Storage Temperature	T_{stg}	-40 ~ +125	°C	Range of ambient temperature for storage or transportation, when there is no electrical load
Isolation Voltage	V_{isol}	AC 1500	Vrms	Maximum effective value of the sine-wave voltage between the terminals and the heat sink, when all terminals are shorted simultaneously. (Sine wave = 60Hz / 1min)
Mounting torque of screws	M_S	0.59 ~ 0.98	N・m	Maximum torque value when tightening the product and heat sink with M3 screws.

<Absolute Maximum Rating of Collector-Emitter Voltage>

During operation, the voltage between P-N(U, V, W) is usually applied to high-side or low-side of one phase. Therefore, Use the product with the voltage applied between P-N(*) within the absolute maximum ratings. The collector-emitter voltage absolute maximum rating is described below.

$V_{CE(chip)}$:	Since $V_{CE(chip)}$ cannot be measured directly, use the product with $V_{DC(terminal)}$, $V_{DC(Surge,terminal)}$, which is the voltage between P-N(*) terminals, within the absolute maximum ratings.
$V_{DC(terminal)}$:	DC bus voltage (between P-N(U, V, W) terminals)
$V_{DC(Surge,\ terminal)}$:	DC bus voltage at P-N(U, V, W) terminals including surge voltage generated during switching.

- Fig.1-7 shows the waveforms during short-circuit, IGBT turn-off and FWD reverse recovery. Since $V_{DC(Surge,terminal)}$ is different in each situation, it is necessary to set $V_{DC(terminal)}$ considering these situations.
- $V_{CE(chip)}$ is the collector-emitter voltage absolute maximum rating of the IGBT chip. $V_{DC(Surge,\ terminal)}$ is specified considering the margin of surge voltage generated by the wiring inductance inside the Product.
- Also, VDC(terminal) is specified with margin considering the surge voltage generated by the wiring inductance between the P-N(*) terminal and the bulk capacitor.

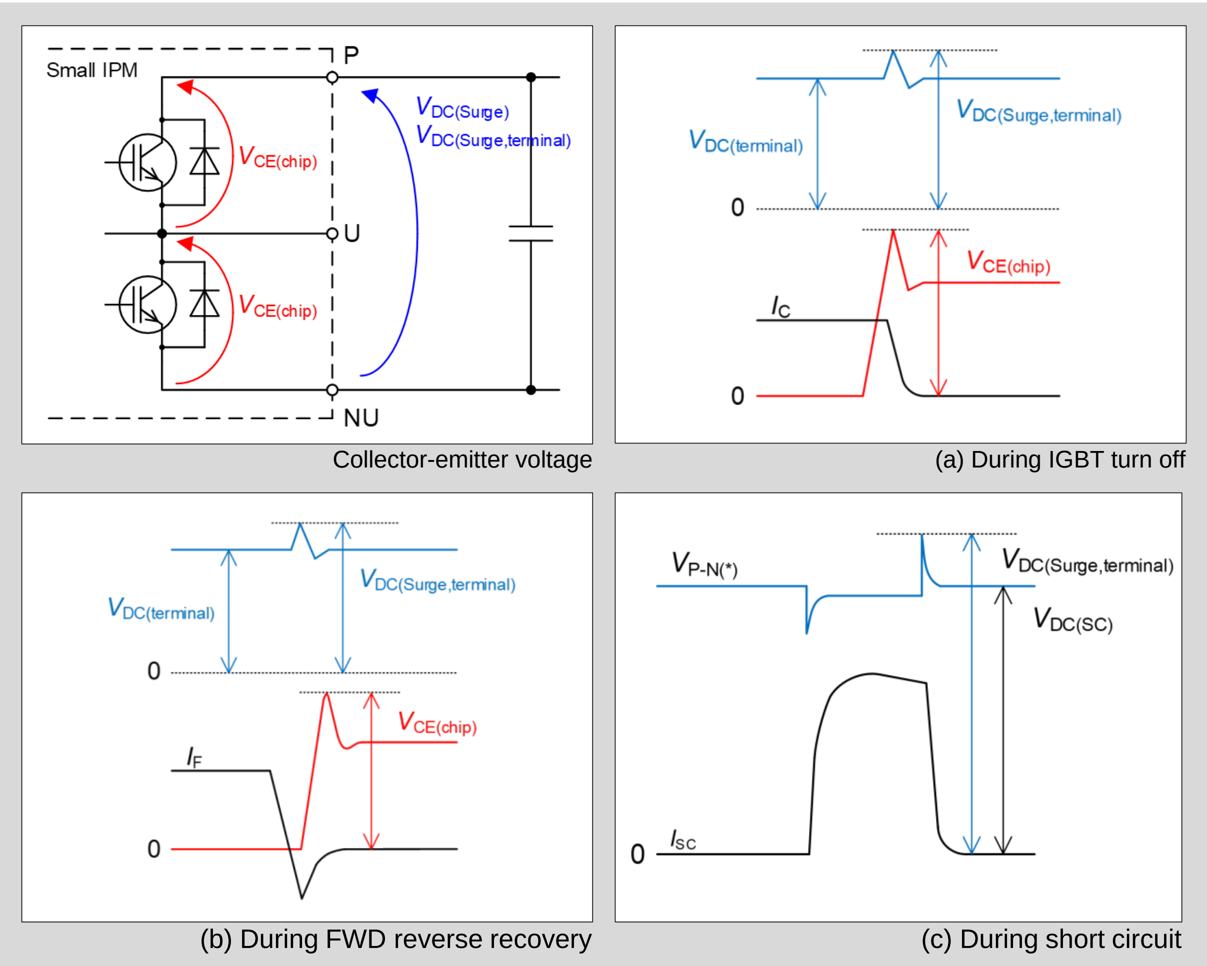


Fig.1-7 Waveforms and Collector-Emitter voltage during IGBT turn-off, FWD reverse recovery, and short-circuit

Chapter 2 Description of Terminal Symbols and Terminology

1. Description of Terminal Symbols

Table 2-1 describes the terminal symbols, and Table 2-2 to 2-6 explain the terminology.

Table 2-1 Description of Terminal Symbols

Pin No.	Pin Name	Pin Description
3	VB(U)	High side bias voltage for U-phase IGBT driving
5	VB(V)	High side bias voltage for V-phase IGBT driving
7	VB(W)	High side bias voltage for W-phase IGBT driving
9	IN(HU)	Signal input for high side U-phase
10	IN(HV)	Signal input for high side V-phase
11	IN(HW)	Signal input for high side W-phase
12	VCCH	High side control supply
13	COM	Common supply ground
14	IN(LU)	Signal input for low side U-phase
15	IN(LV)	Signal input for low side V-phase
16	IN(LW)	Signal input for low side W-phase
17	VCCL	Low side control supply
18	VFO	Fault output
19	IS	Over current sensing voltage input
20	COM	Common supply ground
21	TEMP	Temperature sensor output
22	N(W)	Negative bus voltage input for W-phase
23	N(V)	Negative bus voltage input for V-phase
24	N(U)	Negative bus voltage input for U-phase
26	W	Motor W-phase output
28	V	Motor V-phase output
30	U	Motor U-phase output
32	P	Positive bus voltage input
36	NC	No Connection

2. Description of Terminology

Table 2-2 Description of Terminology(Inverter block)

Item	Symbol	Description
Zero gate Voltage Collector current	I_{CE}	Collector current when a specified voltage is applied between the collector and emitter of an IGBT with all input signals L (=0V)
Collector-Emitter saturation voltage	$V_{CE(sat)}$	Collector-emitter voltage at a specified collector current when the input signal of only the element to be measured is H (= 5V) and the inputs of all other elements are L (=0V)
Forward voltage	V_F	Forward voltage at a specified forward current with all input signals L (=0V)
Turn-on time	t_{on}	The time from the input signal rising above the threshold value until the collector current becomes 90% of the rating. See Fig. 2-1.
Turn-on delay time	$t_{d(on)}$	The time from the input signal rising above the threshold value until the collector current decreases to 10% of the rating. See Fig. 2-1.
Turn-on rise time	t_r	The time from the collector current becoming 10% at the time of IGBT turn-on until the collector current becomes 90%. See Fig. 2-1.
V_{CE}-I_C Cross time of turn-on	$t_{c(on)}$	The time from the collector current becoming 10% at the time of IGBT turn-on until the V_{CE} voltage of IGBT dropping below 10% of the rating. See Fig. 2-1.
Turn-off time	t_{off}	The time from the input signal dropping below the threshold value until the V_{CE} voltage of IGBT becomes 90% of the rating. See Fig. 2-1.
Turn-off delay time	$t_{d(off)}$	The time from the input signal dropping below the threshold value until the collector current decreases to 90%. See Fig. 2-1.
Turn-on fall time	t_f	The time from the collector current becoming 90% at the time of IGBT turn-off until the collector current decreases to 10%. See Fig. 2-1.
V_{CE}-I_C Cross time of turn-off	$t_{c(off)}$	The time from the V_{CE} voltage becoming 10% at the time of IGBT turn-off until the collector current dropping below 10% of the rating. See Fig. 2-1.
Reverse Recovery time	t_{rr}	The time required for the reverse recovery current of the built-in diode to disappear. See Fig. 2-1.

Table 2-3 Description of Terminology(Control circuit block)

Item	Symbol	Description
Circuit current of Low-side drive IC	I_{CCL}	Current flowing between control power supply V_{CCL} and COM
Circuit current of High-side drive IC	I_{CCH}	Current flowing between control power supply V_{CCH} and COM
Circuit current of Bootstrap circuit	I_{CCHB}	Current flowing between upper side IGBT bias voltage supply VB(U) and U,VB(V) and V or VB(W) and W on the P-side (per one unit)

Table 2-3 (Continued)

Item	Symbol	Description
Input Signal threshold voltage	$V_{th(on)}$	Control signal voltage when IGBT changes from OFF to ON
	$V_{th(off)}$	Control signal voltage when IGBT changes from ON to OFF
Input Signal threshold hysteresis voltage	$V_{th(hys)}$	The hysteresis voltage between $V_{th(on)}$ and $V_{th(off)}$.
Operational input pulse width of turn-on	$t_{IN(ON)}$	Control signal pulse width necessary to change IGBT from OFF to ON. Refer to Chapter 3 section 4.
Operational input pulse width of turn-off	$t_{IN(OFF)}$	Control signal pulse width necessary to change IGBT from ON to OFF. Refer to Chapter 3 section 4.
Input current	I_{IN}	Current flowing between signal input IN(HU,HV,HW,LU,LV,LW) and COM.
Input pull-down resistance	R_{IN}	Resistance of resistor connected between each input terminals IN(HU,HV,HW,LU,LV,LW) and COM.
Fault Output voltage	$V_{FO(H)}$	Output voltage level of VFO terminal under the normal operation (The low-side arm protection function is not actuated.) with pull-up resistor 10kW.
	$V_{FO(L)}$	Output voltage level of VFO terminal after the low-side arm protection function is actuated.
Fault Output pulse width	t_{FO}	Period in which an fault status continues to be output (V_{FO}) from the VFO terminal after the low-side arm protection function is actuated. Refer to Chapter 3 section 6.
Over Current Protection voltage level	$V_{IS(ref)}$	Threshold voltage of IS terminal at the over current protection. Refer to Chapter 3 section 5.
Over Current Protection delay time	$t_{d(IS)}$	The time from the Over current protection triggered until the collector current becomes 50% of the rating. Refer to Chapter 3 section 5.
Output Voltage of temperature sensor	$V_{(temp)}$	The output voltage of temp. It is applied to the temperature sensor output model. Refer to Chapter 3 section 7.
LVIC overheating protection	T_{OH}	Tripping temperature of overheating protection. The temperature is monitored by LVIC. All low side IGBTs are shut down when the LVIC temperature exceeds T_{OH}. See Fig.2-2 and refer to Chapter 3 section 8.
LVIC overheating protection hysteresis	$T_{OH(hys)}$	Hysteresis temperature that does not reset the overheating protection operation. See Fig.2-2 and refer to Chapter 3 section 8. T_{OH} and $T_{OH(hys)}$ are applied to the overheating protection model.
V_{CC} Under Voltage Trip Level of Low-side	$V_{CCL(OFF)}$	Tripping voltage of the low-side control IC power supply. All low side IGBTs are shut down when the voltage of V_{CCL} drops below this threshold. Refer to Chapter 3 section 1.
V_{CC} under voltage reset level of Low-side	$V_{CCL(ON)}$	Resetting threshold voltage from under voltage trip status of V_{CCL}. Refer to Chapter 3 section 1.
V_{CC} under voltage hysteresis of Low-side	$V_{CCL(hys)}$	Hysteresis voltage between $V_{CCL(OFF)}$ and $V_{CCL(ON)}$.

Table 2-3 (Continued)

Item	Symbol	Description
V_{CC} Under Voltage Trip Level of High-side	$V_{CCH(OFF)}$	Tripping voltage of high-side control IC power supply. The IGBTs of high-side are shut down when the voltage of V_{CCH} drops below this threshold. Refer to Chapter 3 section 1.
V_{CC} Under Voltage Reset Level of High-side	$V_{CCH(ON)}$	Resetting threshold voltage from under voltage trip status of V_{CCH}. See Fig.3-3 Resetting voltage at which the IGBT performs shut down when the high-side control power supply voltage V_{CCH} drops. Refer to Chapter 3 section 1.
V_{CC} Under Voltage hysteresis of High-side	$V_{CCH(hys)}$	Hysteresis voltage between $V_{CCH(OFF)}$ and $V_{CCH(ON)}$.
V_B Under Voltage Trip Level	$V_{B(OFF)}$	Tripping voltage V_B(*) under voltage. The high-side IGBTs are shut down when the voltage of V_B(*) drops below this threshold. Refer chapter 3 section 2.
V_B Under Voltage Reset Level	$V_{B(ON)}$	Resetting voltage at which the IGBT performs shut down when the upper side arm IGBT bias voltage V_B(*) drops. Refer to Chapter 3 section 2.
V_B Under Voltage hysteresis	$V_{B(hys)}$	Hysteresis voltage between $V_{B(OFF)}$ and $V_{B(ON)}$.
Forward voltage of Bootstrap diode	$V_{F(BSD)}$	Forward voltage when a specified forward current flows through BSD.
Built-in limiting Series Resistance (BSD)	$R_{S(BSD)}$	Built-in current limiting resistor resistance value of bootstrap circuit.

*1 : $V_{B(*)}$ is applied between VB(U)-U, VB(V)-V, VB(W)-W.

Table 2-5 Thermal Characteristics

Item	Symbol	Description
Junction to Case Thermal Resistance (per single IGBT)	$R_{th(j-c)\_IGBT}$	Thermal resistance from the junction to the case of a single IGBT.
Junction to Case Thermal Resistance (per single FWD)	$R_{th(j-c)\_FWD}$	Thermal resistance from the junction to the case of a single FWD.

Table 2-6 Mechanical Characteristics

Item	Symbol	Description
Mounting torque of screws	M_S	Screwing torque when mounting the Small IPM to a heat sink with a specified screw.
Heat-sink side flatness	-	Flatness of a heat sink side. See Fig.2-3.
Weight	-	Weight of this product
Resistance to soldering heat	-	Soldering heat resistance

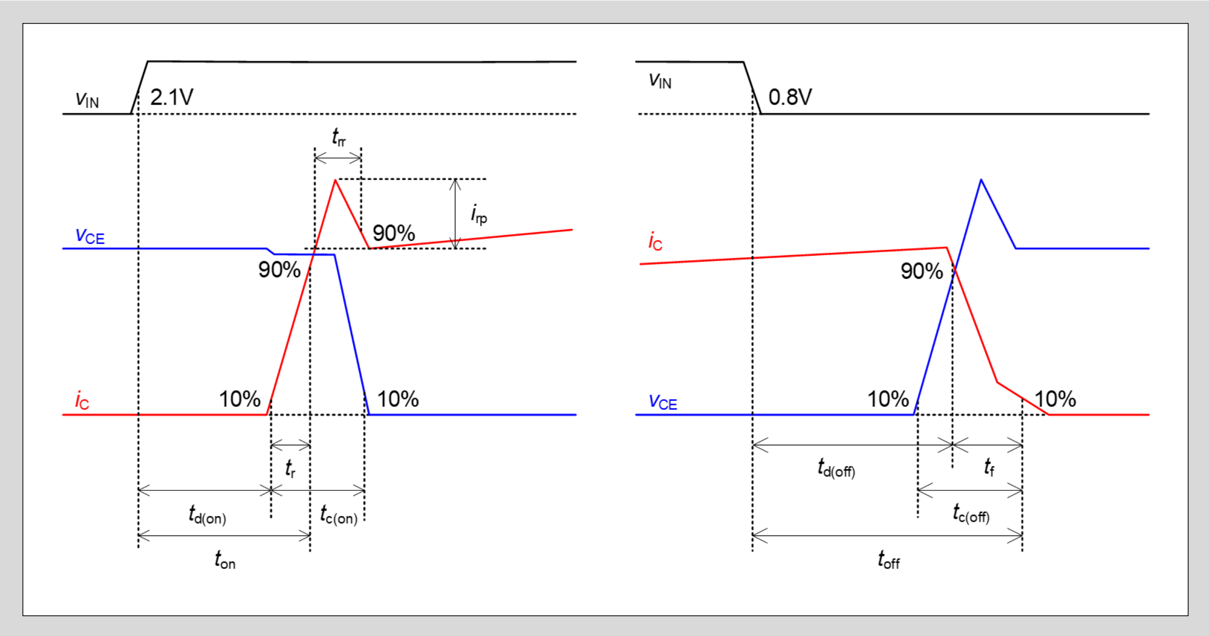


Fig.2-1 Switching waveforms

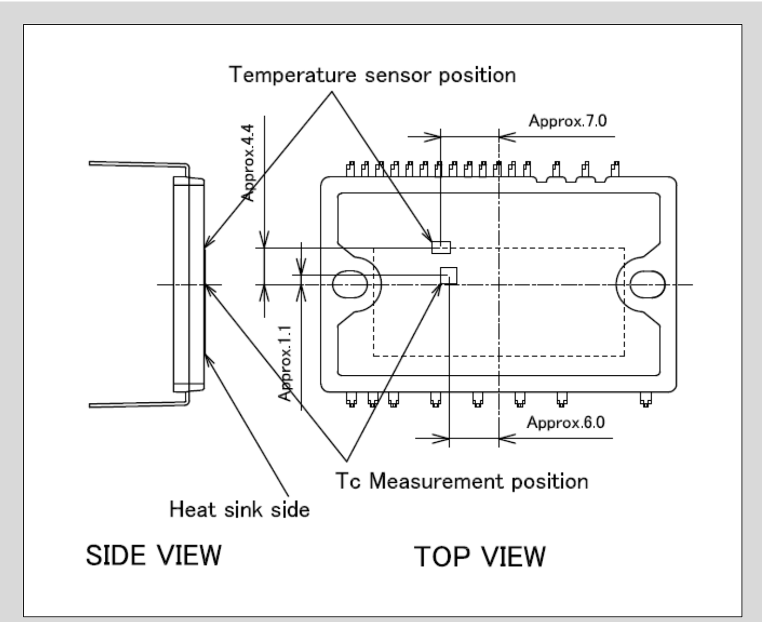


Fig.2-2 The measurement position of temperature sensor and Tc.

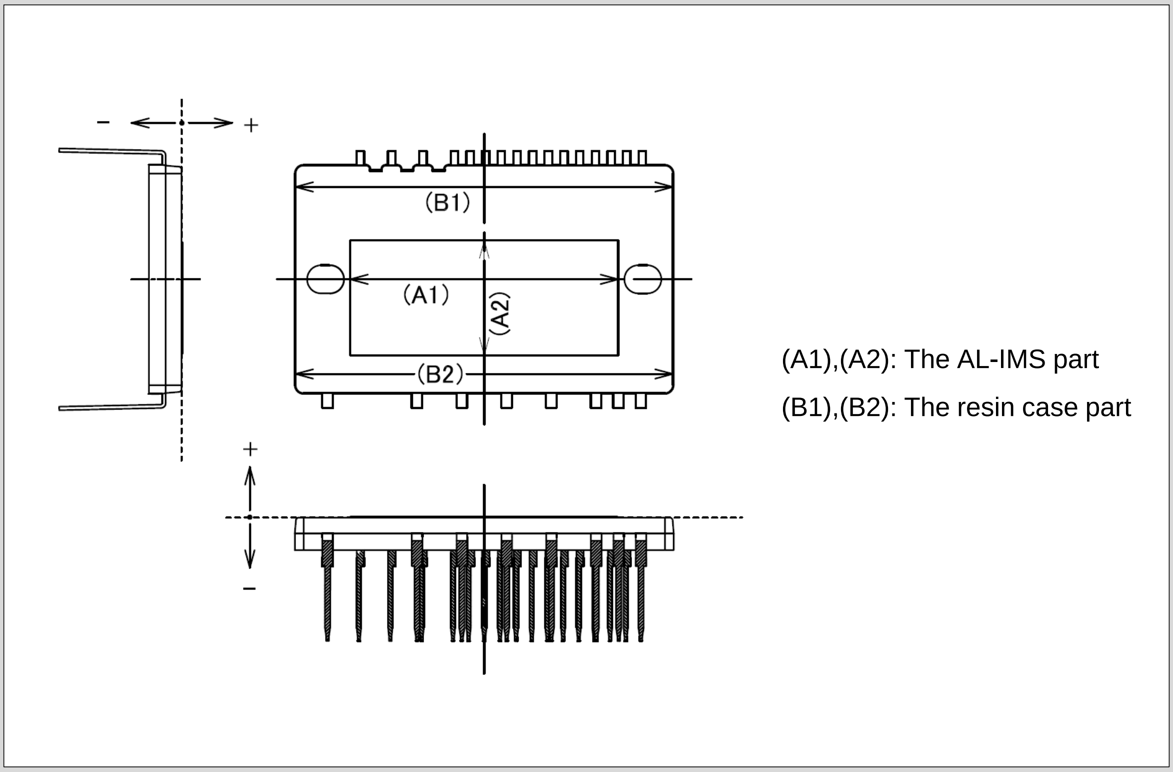


Fig.2-3 The measurement point of heat-sink side flatness.

Chapter 3 Details of Signal Input/Output Terminals

1. Control Power Supply Terminals VCCH, VCCL, COM

<Voltage Range of control power supply terminals VCCH, VCCL>

- For control supply voltage, please connect a 15V±10% DC power supply between VCCH, VCCL and COM terminals.
- Table 3-1 describes the operation of the product for various control supply voltages. A low impedance capacitor and a high frequency decoupling capacitor should be connected close to the terminals of the power supply.
- High frequency noise on the power supply might cause malfunction of the internal control IC or erroneous fault signal output. To avoid these problems, the maximum amplitude of voltage ripple on the power supply should be less than ±1V/μs.
- The potential at the COM terminal is different from that at the N(U, V, W) power terminal. It is very important that all control circuits and power supplies are referred to the COM terminal and not to the N(U, V, W) terminals. If circuits are improperly connected, current might flow through the shunt resistor and cause improper operation of the short-circuit protection function. In general, it is recommended to make the COM terminal as the ground potential in the PCB layout.
- The main control power supply is also connected to the bootstrap circuit which provide floating power supplies for the high-side gate drivers.
- When high-side control supply voltage V_{CCH} falls below $V_{CCH(OFF)}$, only the IGBT which under voltage condition occurred becomes off-state even though input signal is ON condition.
- When low-side control supply voltage V_{CCL} falls below $V_{CCL(OFF)}$, all low-side IGBTs become off-state even though the input signal is ON condition.

Table 3-1 IPM operations versus control supply voltage V_{CCH}, V_{CCL}

Control Voltage Range [V]	Operations and functions
0 ~ 4	The product doesn't operate. UV and fault output are not activated. d*v*/d*t* noise on the main P-N supply might cause malfunction of the IGBTs.
4 ~ 13	The product starts to operate. UV is activated, control input signals are blocked and fault output VFO is generated.
13 ~ 13.5	UV is reset. IGBTs perform switching in accordance to input signal. Drive voltage is below the recommended range, so $V_{CE(sat)}$ and the switching loss will be larger than that under normal condition. High side IGBTs do not switch until $V_{B(*)}$ *1 reaches $V_{B(ON)}$ after initial charging.
13.5 ~ 16.5	Normal operation. This is the recommended operating condition.
16.5 ~ 20	IGBTs perform switching. Because drive voltage is above the recommended range, IGBT's switching is faster and causes an increase in system noise. Even with proper overcurrent protection design, the short-circuit peak current can become very large and might lead to failure.
Over 20	Control circuit in the product might be damaged. It is recommended to insert a Zener diode between each pair of control supply terminals if necessary.

*1 : $V_{B(*)}$ is applied between VB(U)-U, VB(V)-V, VB(W)-W.

<Under Voltage (UV) protection of control power supply terminals VCCH, VCCL>

- Fig.3-1 shows the UV protection circuit of VCCH and VCCL.
- Fig.3-2 and Fig.3-3 shows the operation sequence of UV operation of V_{CCH} and V_{CCL}.
- As shown in Fig.3-1, a diode is connected between VCCH-COM and VCCL-COM terminals. The diode is connected to protect the Small IPM from the input surge voltage. Do not use the diode for voltage clamp purpose otherwise the product might be damaged.

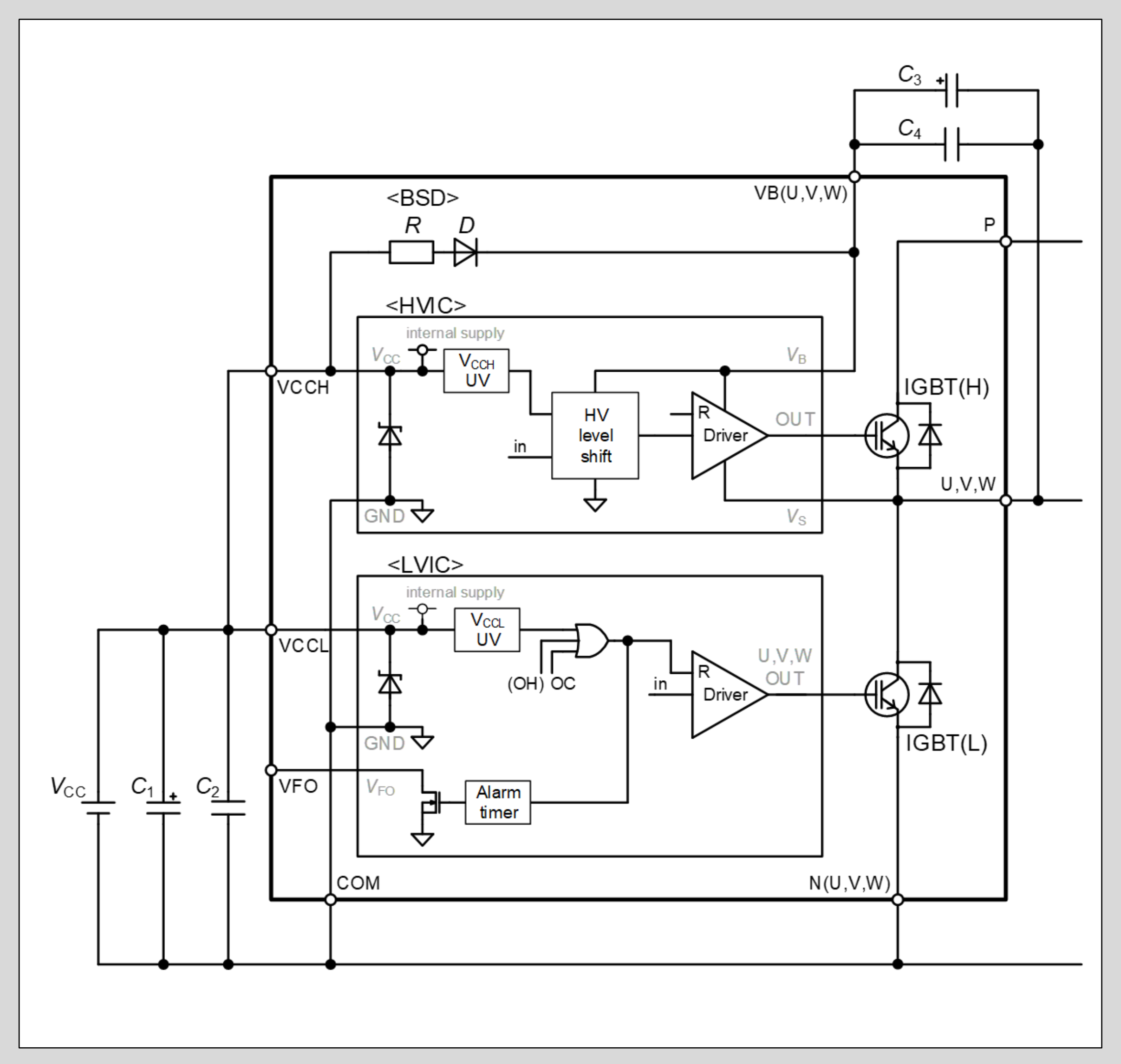


Fig.3-1 UV protection circuit of VCCH, VCCL

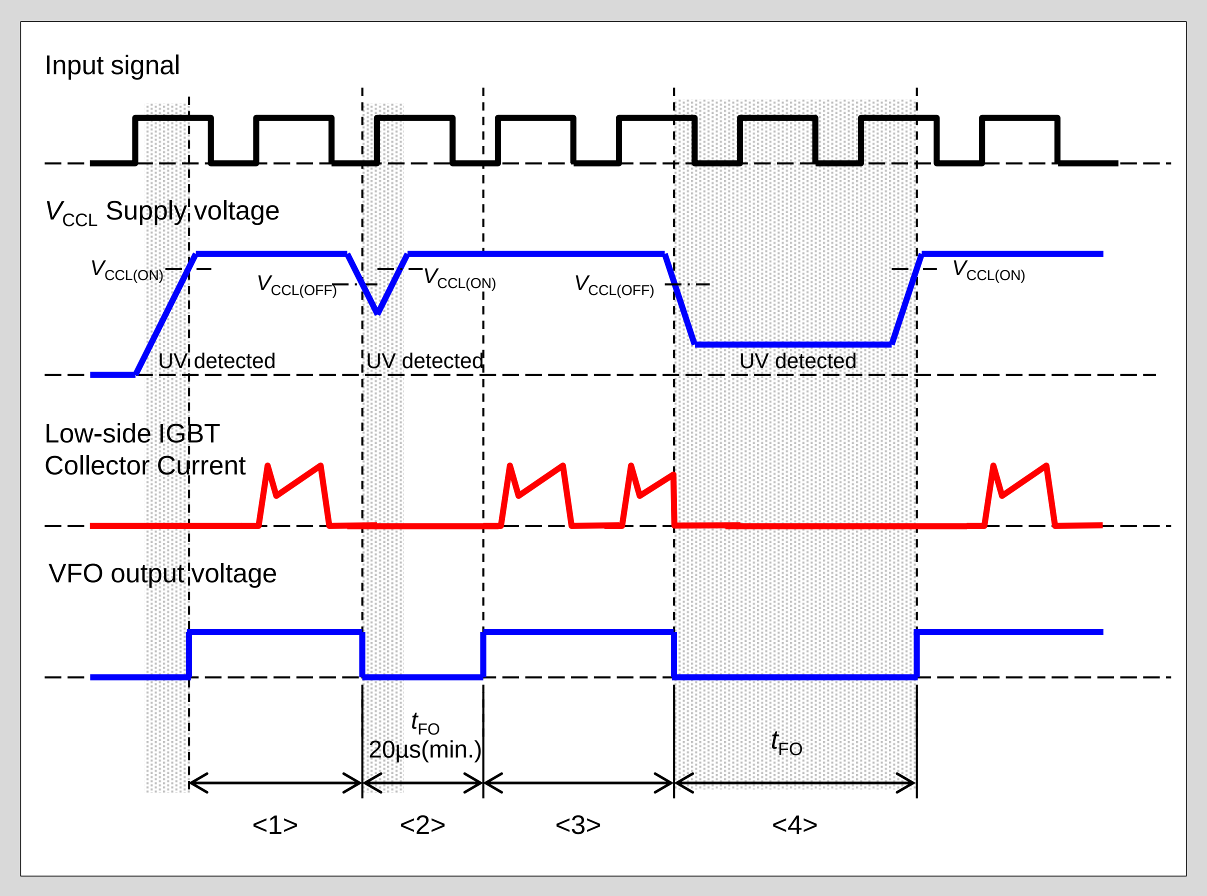


Fig.3-2 Operation sequence of V_{CCL} Under Voltage protection (Low-side)

When V_{CCL} is below 4V, under voltage (UV) protection of low-side and fault output are not activated.

<1> When V_{CCL} is lower than $V_{CCL(ON)}$, all low-side IGBTs are in OFF state. After V_{CCL} exceeds $V_{CCL(ON)}$, the fault output V_{FO} is reset from L level to H level. The low-side IGBTs start switching operation from the next input signal.

<2> The fault output V_{FO} is activated when VCCL falls below $V_{CCL(OFF)}$, and all low-side IGBTs are turned-off. If the voltage drop period is less than 20µs, the minimum pulse width of the fault output is t_{FO}=20µs(min.). During this period, all low-side IGBTs remain in OFF state regardless of the input signal condition.

<3> When V_{CCL} exceeds $V_{CCL(ON)}$ after t_{FO} elapsed, UV protection is reset and the fault output V_{FO} is reset simultaneously. The low-side IGBTs start switching operation from the next input signal.

<4> If the voltage drop period is longer than t_{FO}, the fault output V_{FO} with the same width is generated. During this period, all low-side IGBTs are in OFF state regardless of the input signal condition.

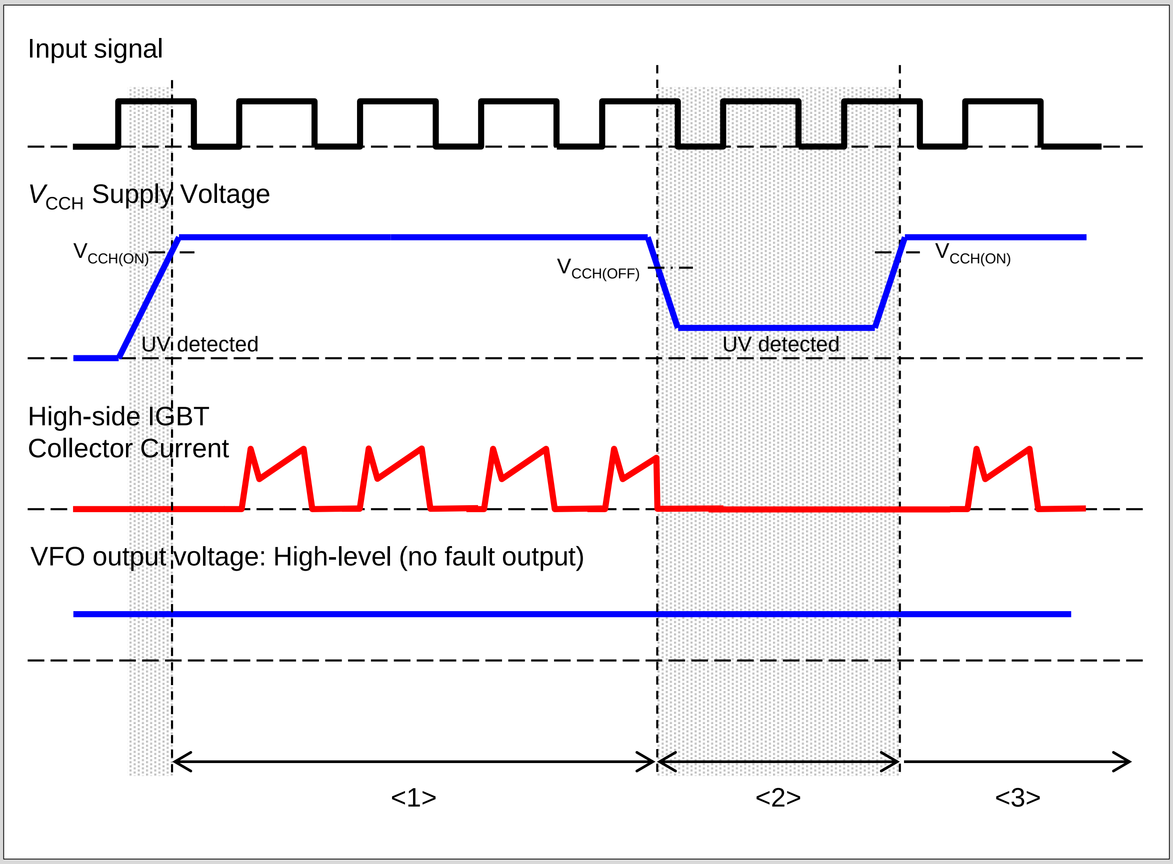


Fig.3-3 Operation sequence of V_{CCH} Under Voltage protection (High-side)

<1> When V_{CCH} is lower than $V_{CCH(ON)}$, the high-side IGBTs is in OFF state. After V_{CCH} exceeds $V_{CCH(ON)}$, the upper side IGBTs start switching operation from the next input signal. The fault output VFO remains at H level regardless of V_{CCH}.*1

<2> When V_{CCH} falls below $V_{CCH(OFF)}$, the high-side IGBTs are turned-off. The fault output V_{FO} remains H level.

<3> After the UV protection operation is reset, the upper side IGBTs start switching operation from the next input signal.

*1: The fault output does not depend on the HVIC bias conditions.

2. Power Supply Terminals of High-Side VB(U,V,W)

<Voltage range of high-side bias voltage for IGBT driving terminals VB(U, V, W)>

- The voltage $V_{B(*)}$, which is the voltage between VB(U,V,W) and U, V, W, provides the power supply to the HVICs within the product. The HVIC can drive the high-side IGBT when this voltage is in the range of 13.0~18.5V.
- The product includes UV protection for $V_{B(*)}$ to ensure that the HVICs do not drive the high-side IGBTs when $V_{B(*)}$ drops below a specified voltage (refer to the datasheet). This function prevents the IGBT from operating in a high dissipation mode. Please note that the UV protection only works on the triggered phase and doesn't generate fault output.
- In the case of using bootstrap circuit, the IGBT drive power supply for high-side can be generated from the high-side/low-side control power supply.
- The power supply of the high-side is charged when the low-side IGBT is turned on or when freewheel current flows through the low-side FWD. Table 3-2 describes the operation of the product for various control supply voltages. The control supply should be well filtered with a low impedance capacitor and a high frequency decoupling capacitor connected close to the terminals in order to prevent malfunction of the internal control IC caused by a high frequency noise on the power supply.
- When $V_{B(*)}$ falls below $V_{B(OFF)}$, only the triggered phase IGBT is off-state even though the input signal is provided.

Table 3-2 IPM operations versus high-side voltage for IGBT driving $V_{B(*)}$

Control Voltage Range [V]	Operations and functions
0 ~ 4	HVICs are not activated. UV does not operate. d*v*/d*t* noise on the main P-N supply might trigger the IGBTs.
4 ~ 12.5	HVICs start to operate. As the UV is activated, control input signals are blocked.
12.5 ~ 13	UV is reset. The high side IGBTs perform switching in accordance to input signal. Driving voltage is below the recommended range, so $V_{CE(sat)}$ and the switching loss will be larger than that under normal condition.
13 ~ 18.5	Normal operation. This is the recommended operating condition.
18.5 ~ 20	The high side IGBTs perform switching. Because drive voltage is above the recommended range, IGBT's switching is faster and causes an increase in system noise. Even with proper overcurrent protection design, the short-circuit peak current can become very large and might lead to failure.
Over 20	Control circuit in the product might be damaged. It is recommended to insert a Zener diode between each pair of high side power supply terminals.

<Under Voltage (UV) protection of high-side power supply terminals VB(U,V,W)>

- Fig.3-4 shows the UV protection circuit of high-side power supply terminals VB(U)-U, VB(V)-V, VB(W)-W, $V_{B(*)}$.
- Fig.3-5 shows the operation sequence of $V_{B(*)}$ UV protection.
- As shown in Fig.3-4, diodes are electrically connected to the VB(U,V,W)-(U,V,W) and VB(U,V,W)-COM terminals. These diodes are built-in to protect the product from surge input. Do not use these diodes as voltage clamp diodes as it might damage the product.

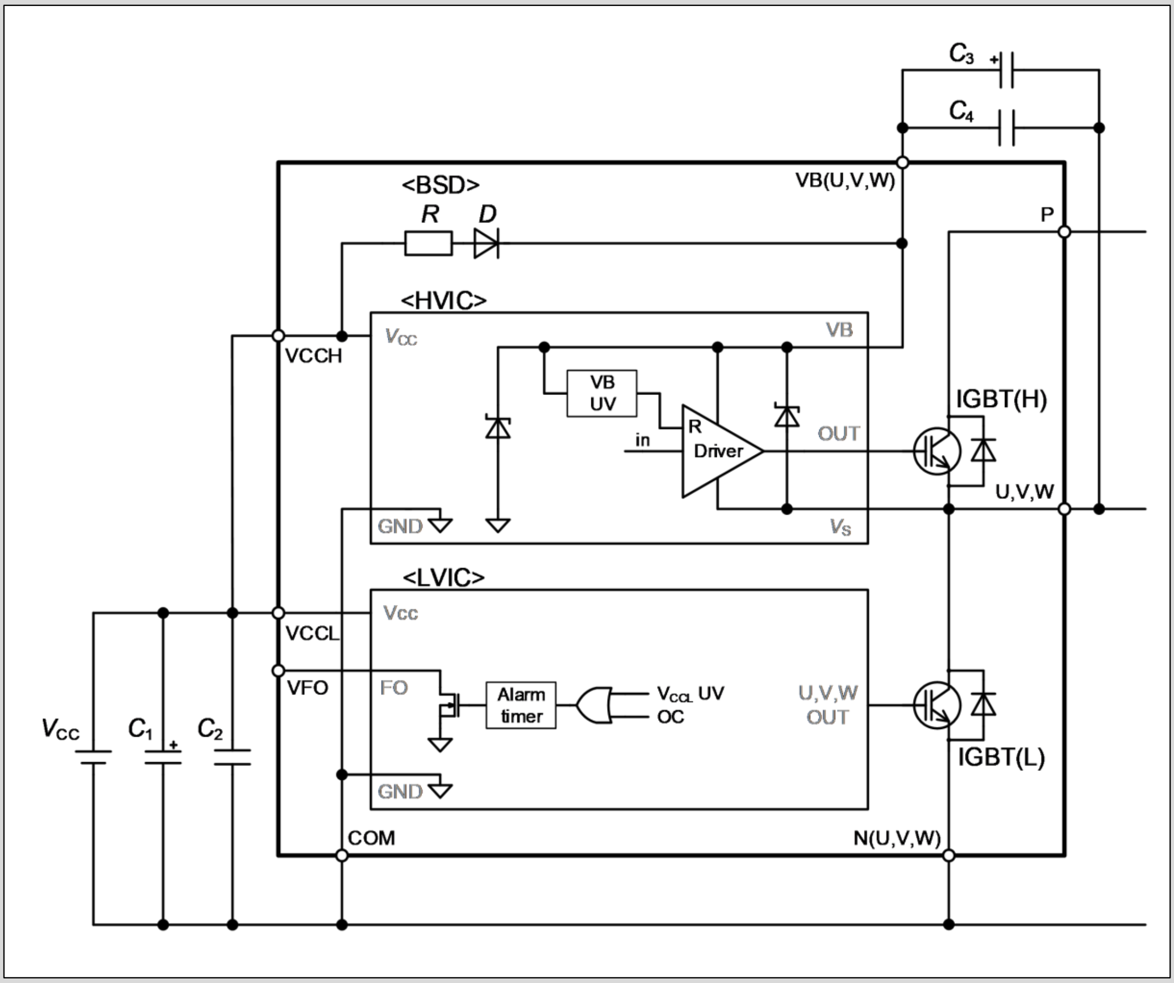


Fig.3-4 UV protection circuit of V_B(U, V, W)

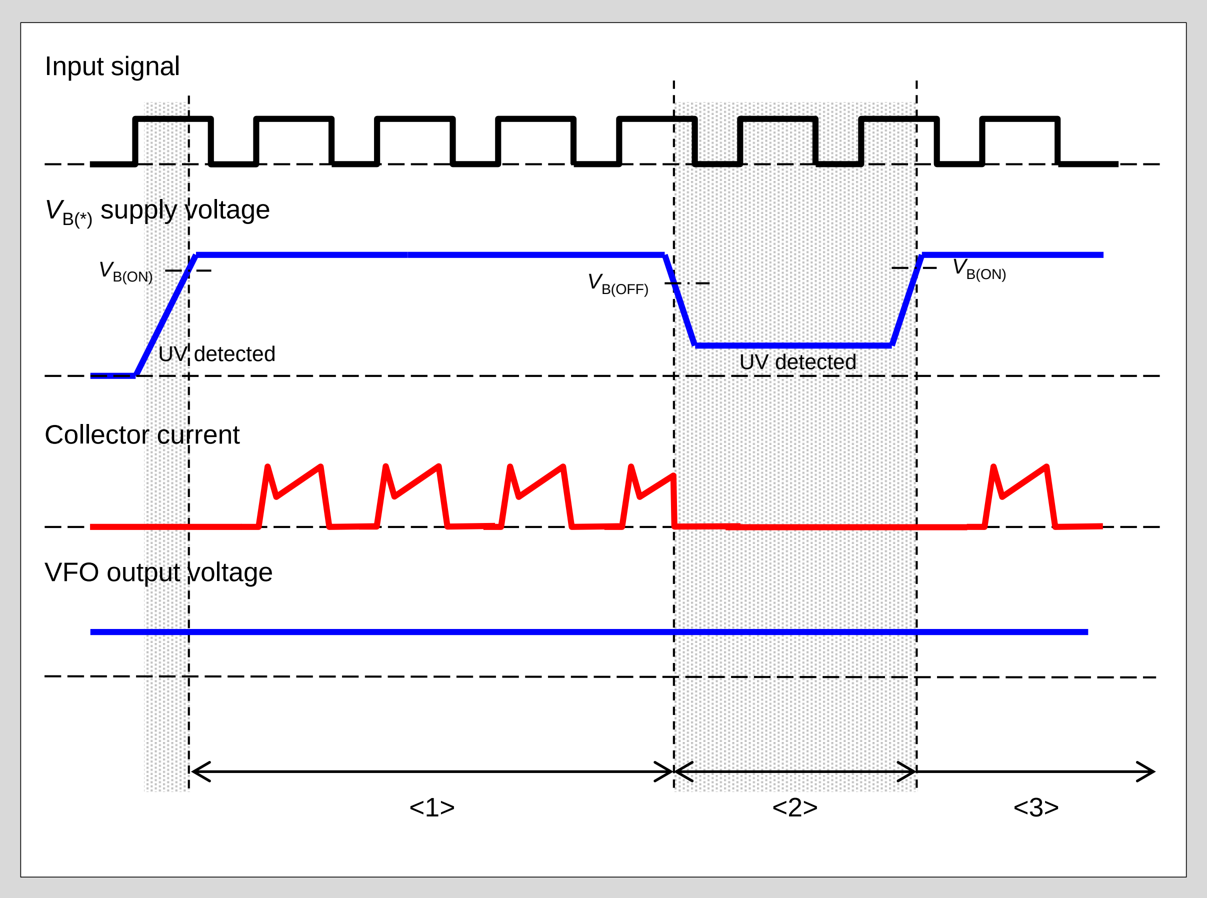


Fig.3-5 Operation sequence of $V_{B(*)}$ Under voltage protection (High-side)

<1> When the voltage between VB(U)-U, VB(V)-V, VB(W)-W, $V_{B(*)}$ is lower than $V_{B(ON)}$, the high-side IGBT is in OFF state. After $V_{B(*)}$ exceeds $V_{B(ON)}$, the high-side IGBT starts switching operation from the next input signal. The fault output VFO does not depend on $V_{B(*)}$ and remains at H level. *1

<2> When $V_{B(*)}$ falls below $V_{B(OFF)}$, the high-side IGBT is turned-off. However, the fault output VFO remains at H level.

<3> After the UV protection operation is reset, the high-side IGBT starts switching operation from the next input signal.

*1: The fault output does not depend on the HVIC bias conditions.

3. Function of Built-in BSDs (bootstrap Diodes)

There are several ways to supply the voltage $V_{B(*)}$ between the high-side drive power supply terminals VB(U)-U, VB(V)-V, VB(W)-W. This product can configure a bootstrap circuit by using the built-in BSD. The bootstrap method is a simple and cheap solution. However, the duty cycle and on-time are limited by the charging operation of the bootstrap capacitor. As shown in Fig. 3-6, Fig. 3-8 and Fig. 3-11, the bootstrap circuit consists of bootstrap diode with current limiting resistor, which are integrated in the Small IPM and an external capacitor.

<Charging and Discharging of Bootstrap Capacitor During Inverter Operation>

When low-side IGBT is ON state, the charging voltage on the bootstrap capacitance $V_{C(t1)}$ is calculated by the following equations. Fig.3-6 shows the circuit diagram of charging operation, and Fig.3-7 shows the timing chart.

$V_{C(t1)} = V_{CC} - V_{F(D)} - V_{CE(sat)} - I_b \cdot R$......Transient state

$V_{C(t1)} \approx V_{CC}$.................................Steady state

$V_{F(D)}$: Forward voltage of Bootstrap diode D

$V_{CE(sat)}$: Saturation voltage of low side IGBT

R : Bootstrap resistance

I_b : Bootstrap charging current

When low-side IGBT is turned off, the freewheeling current flows through the freewheel path of the high-side FWD. Once V_S rises above V_{CC}, the charging of bootstrap capacitor, C stops, and the voltage of C gradually decreases due to current consumption of high-side drive circuit.

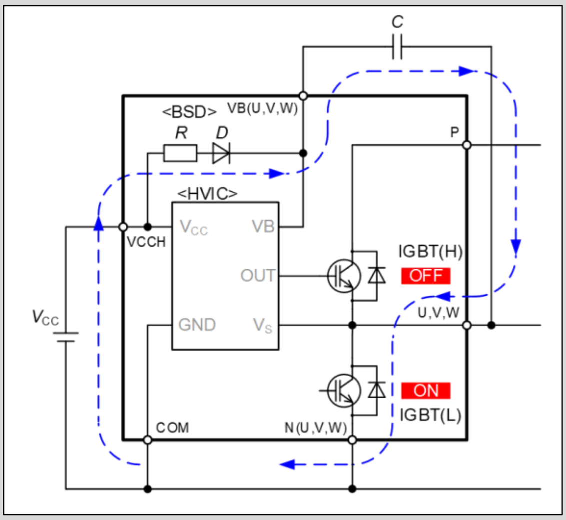


Fig.3-6 Circuit diagram of charging operation

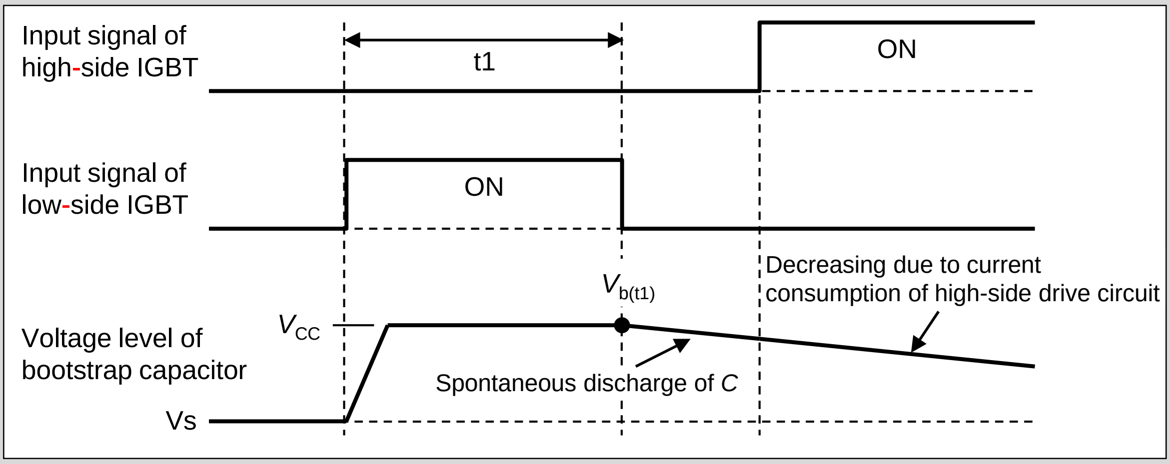


Fig.3-7 Timing chart of charging operation

When the low-side IGBT is OFF and the low-side FWD is ON, freewheeling current flows through the low-side FWD. The voltage on the bootstrap capacitance $V_{C(t2)}$ is calculated by the following equations. Fig.3-8 shows the circuit diagram of charging operation, and Fig.3-9 shows the timing chart.

$V_{C(t2)} = V_{CC} - V_F + V_{F(FWD)} - I_b \cdot R$………Transient state
$V_{C(t2)} \approx V_{CC}$………………………………Steady state

$V_{F(D)}$: Forward voltage of Bootstrap diode D
$V_{F(FWD)}$: Forward voltage of low-side FWD
R : Current limiting resistance
I_b : Bootstrap charging current

When both the low-side and high-side IGBTs are OFF, a regenerative current flows continuously through the low-side FWD. Therefore V_s drops to $-V_F$ of FWD, then the bootstrap capacitor, C is re-charged to restore the declined potential. When the high-side IGBT is turned ON and V_s exceeds V_{CC}, the charging of C stops, and the voltage of C gradually decreases due to current consumption of high-side drive circuit.

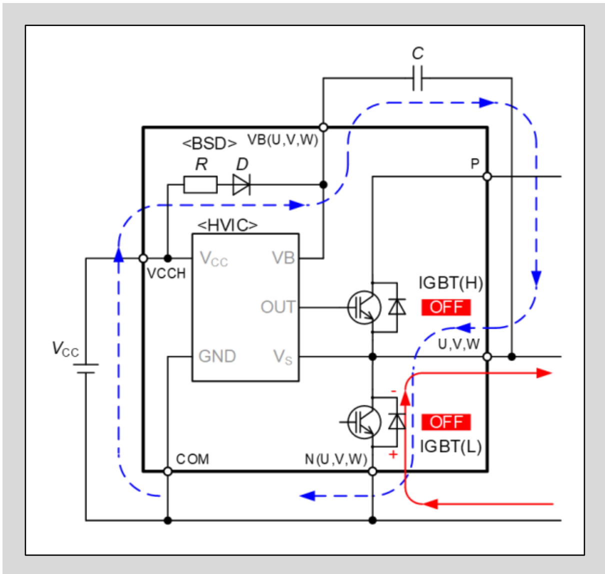


Fig.3-8 Circuit diagram of charging operation when the low-side FWD is ON

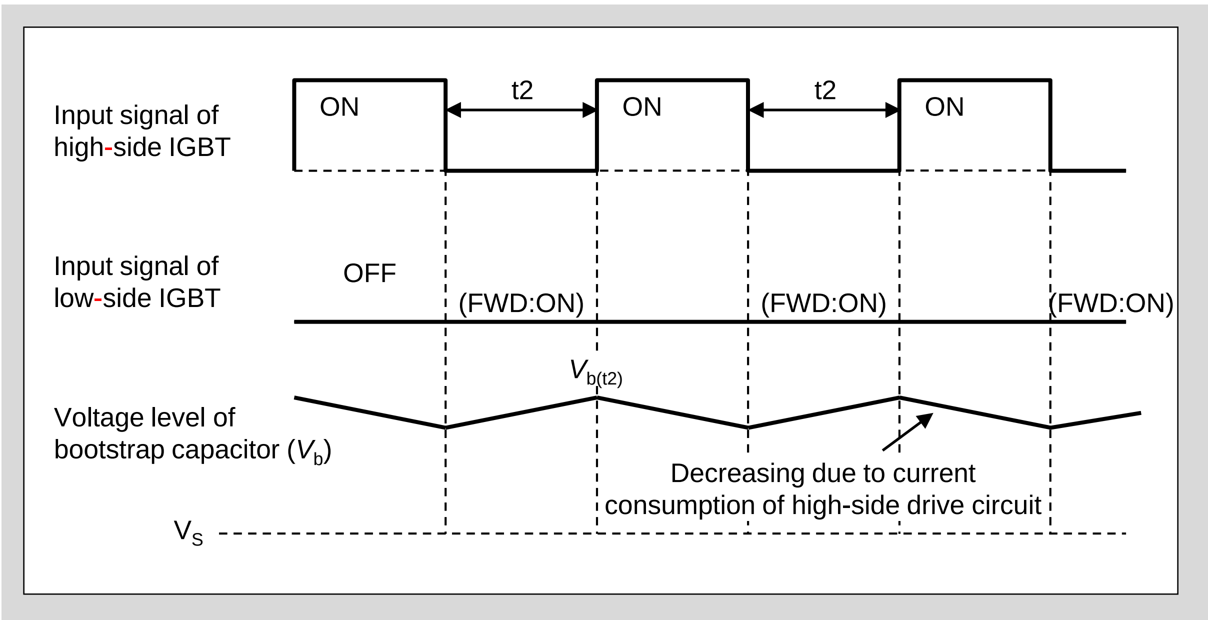


Fig.3-9 Timing chart of charging operation when the low-side FWD is ON

<Setting the bootstrap capacitance and minimum ON/OFF pulse width>

The parameter of bootstrap capacitor can be calculated by the following equation:

$$\mathrm{C} = I_{CCHB} \cdot \frac{t_1}{dV_\mathrm{b}}$$

t_1 Maximum ON pulse width of the high-side IGBT

I_{CCHB}: Drive current of the HVIC (depends on temperature and frequency characteristics)

dV_b: Allowable discharge voltage. (see Fig.3-10)

- A certain margin should be added to the calculated capacitance.
- The bootstrap capacitance is generally selected 2~3 times the value of the calculated result.
- The recommended minimum ON pulse width (t_2) of the low-side IGBT should be determined such that the time constant $C \cdot R$ will enable the discharged voltage (dV) to be fully recharged during the ON period.
- In the operation mode in which the high-side IGBT performs switching operation and charges when the low-side FWD is turned-on (timing chart in Fig. 3-10), the time constant is set so that the power consumed during the ON period of the high-side IGBT can be recharged during the OFF period.
- The minimum pulse width is decided by the minimum ON pulse width of the low-side IGBT or the minimum OFF pulse width of the high-side IGBT, whichever is shorter.

$$t_2 \geq \frac{R \cdot C \cdot \mathrm{d}V_\mathrm{b}}{V_\mathrm{CC} - V_\mathrm{b(min)}}$$

R: Current limiting resistance of Bootstrap diode ΔRF(BSD)

C: Bootstrap capacitance

dV: Allowable discharge voltage.

V_CC Control power supply voltage (ex.15V)

$V_\mathrm{b(min)}$: Minimum voltage of high-side IGBT drive voltage (Added margin to UV. ex. 14V)

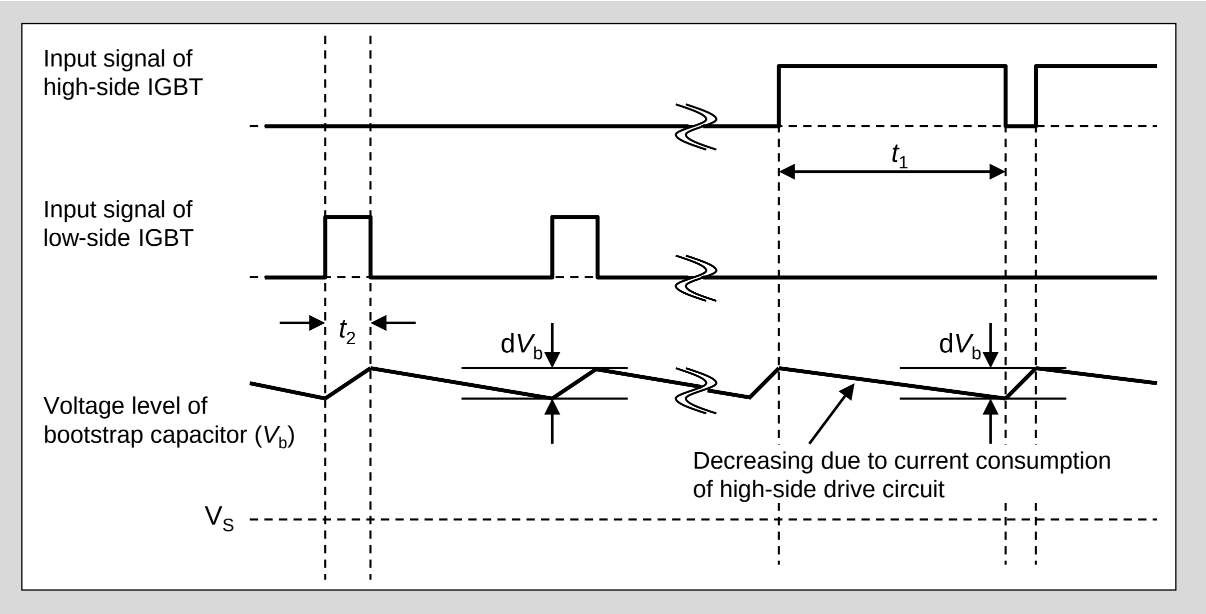


Fig.3-10 Timing chart of charging and discharging operation

<Setting the bootstrap capacitance for Initial charging>

- Initial charging of the bootstrap capacitor is required to start the inverter.
- The pulse width or number of pulses should be long enough to fully charge the bootstrap capacitor.
- For reference, the charging time of a 10μF capacitor through the internal bootstrap diode is about 2ms.

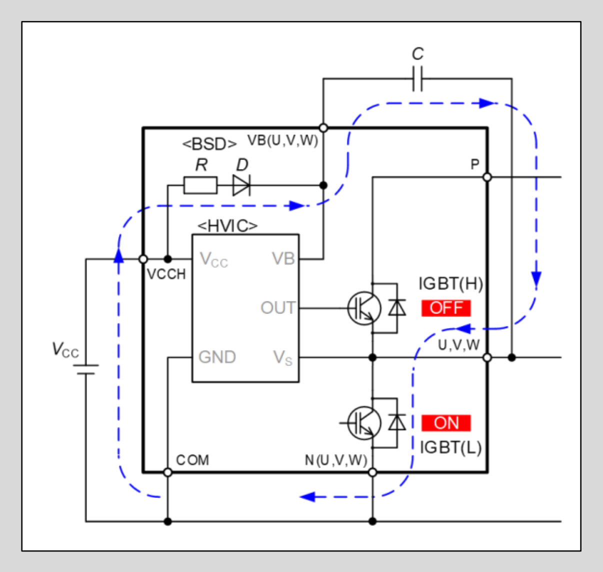


Fig.3-11 Circuit diagram of initial charging operation

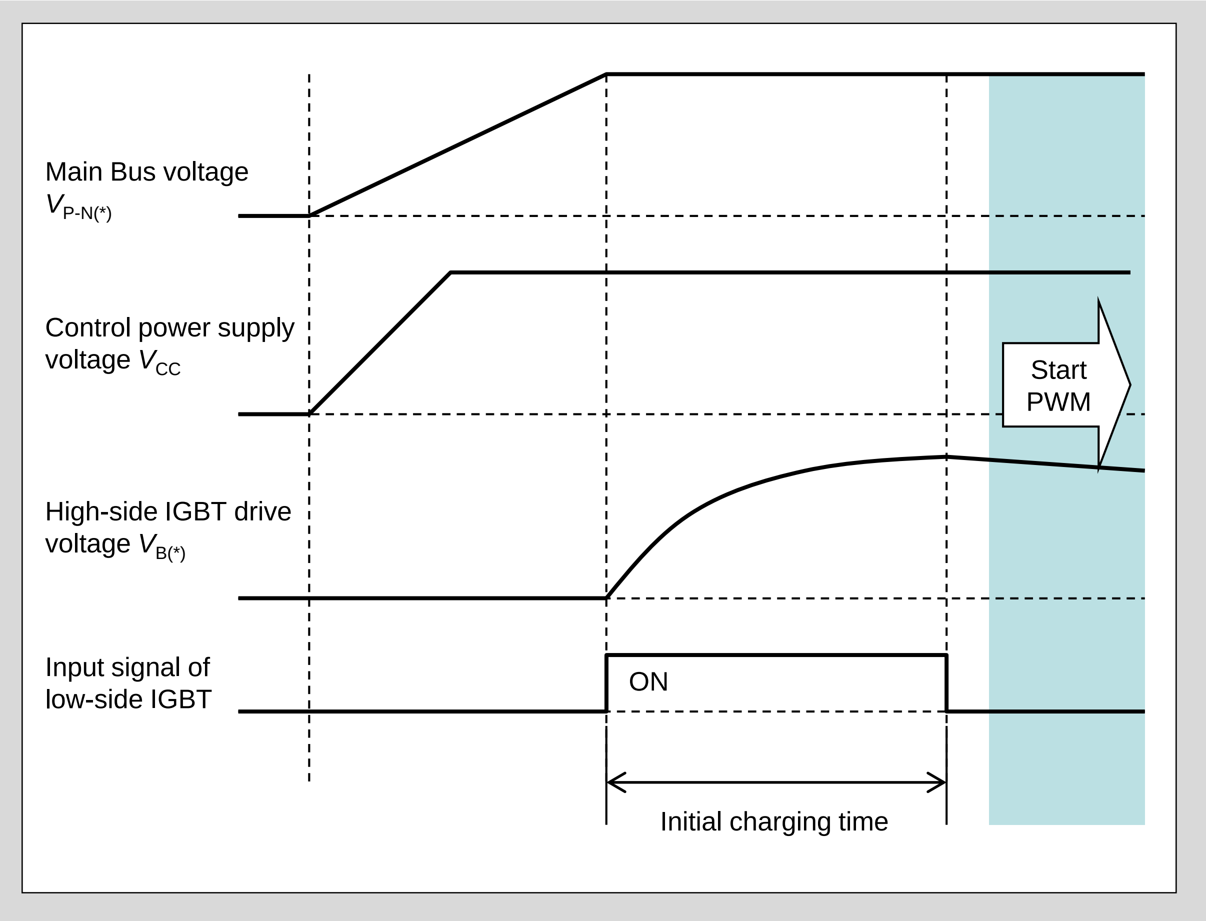


Fig.3-12 Timing chart of initial charging operation

<Resistance characteristics of built-in BSD>

The BSD forms a current limiting resistance of 100Ω (typ.) inside the chip. Fig. 3-13 and 3-14 show the V_F-I_F characteristics of the BSD.

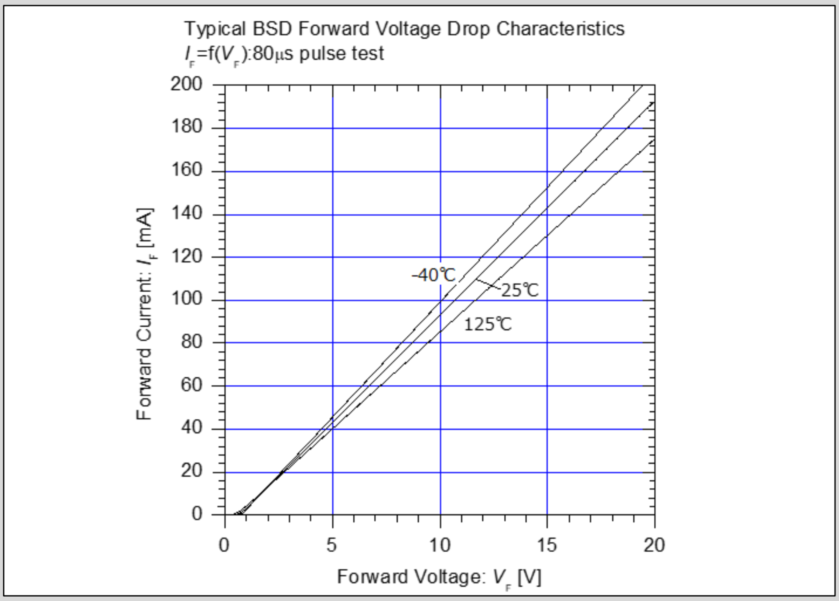


Fig.3-13 V_F-I_F curve of boot strap diode

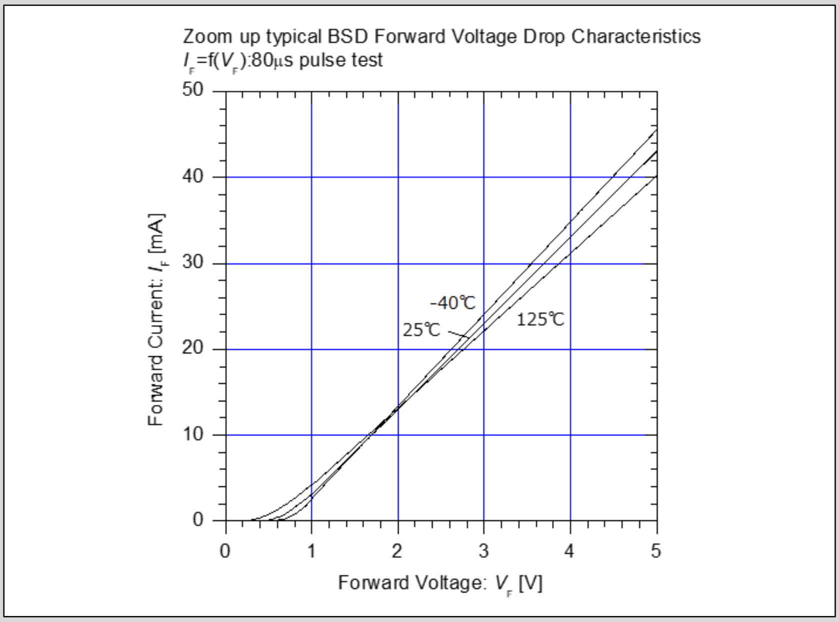


Fig. 3-14 V_F-I_F curve of boot strap diode（Expansion of low current area）

4. Input Terminals IN(HU,HV,HW), IN(LU,LV,LW)

<Input terminals Connection>

- Fig.3-15 shows the input interface circuit between the MPU and the product. The input terminals can be directly connected to the MPU. The input terminals have built-in pull down resistors, thus external pull-down resistors are not required. Also, the input logic is active high, thus external pull-up resistors are not required.
- If the signal wiring is long and noise is superimposed, insert RC filter circuit indicated by the dotted line in Figure 3-15. Adjust the R and C constants according to the PWM control method and wiring pattern of the PCB.

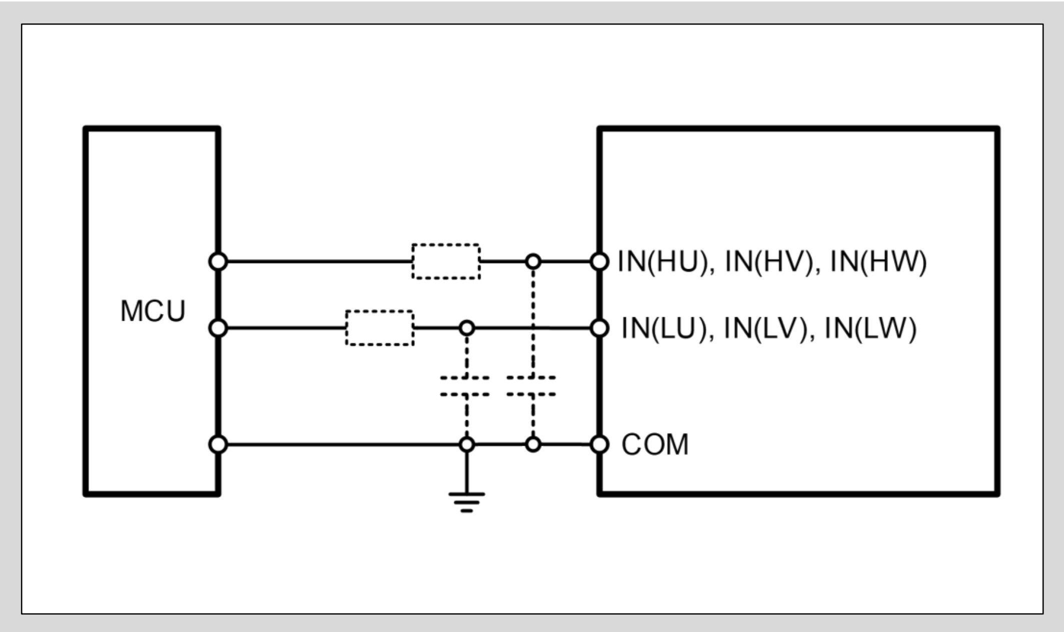


Fig.3-15 Recommended MPU I/O Interface Circuit of IN(HU,HV,HW), IN(LU,LV,LW) terminals

<Input terminal circuit>

- The input logic of this product is active high. This logic has removed the sequence restriction between the control power supply and the input signal during startup or shut down operation. Therefore it makes the system fail safe. In addition, pull-down resistors are built into each input terminals in Fig.3-16. Thus, external pull-down resistors are not needed and reduces the number of system components. Furthermore, by setting the input threshold voltage low,. a 3.3V-class MPU can be connected directly.
- As shown in Fig.3-16, the input circuit integrates a pull-down resistor. Therefore, when using an external filtering resistor between the MPU output and input of the product, please consider the signal voltage drop at the input terminals to satisfy the turn-on threshold voltage requirement. For instance, *R*=100Ω and *C*=1000pF for the parts shown by the dotted line in Fig.3-15.
- Fig.3-16 shows that internal diodes are connected to the VCCL-IN(LU, LV, LW) and IN(HU, HV, HW, LU, LV, LW)-COM terminals. Do not use these diodes for voltage clamp purpose otherwise the product might be damaged.

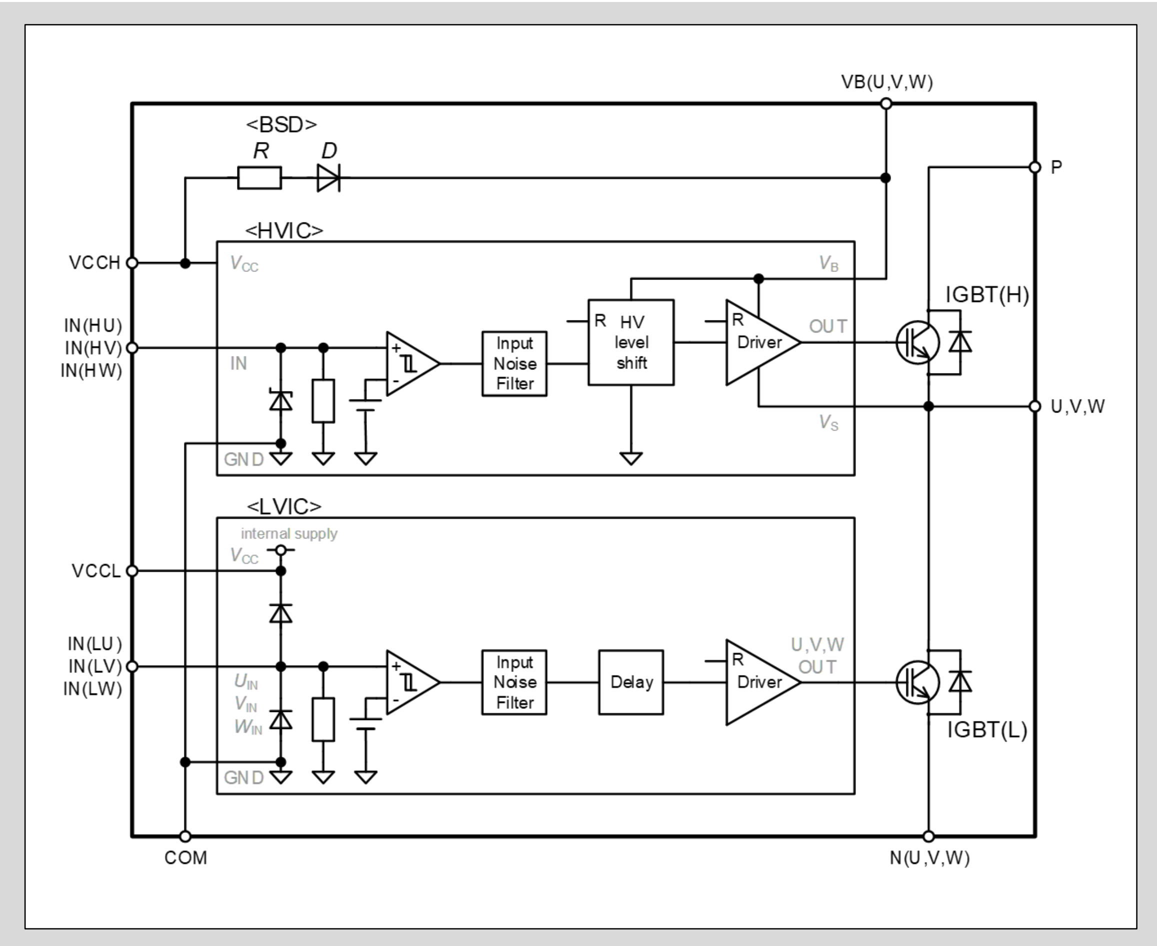


Fig.3-16 Input terminals IN(HU, HV, HW), IN(LU, LV, LW) circuit

<IGBT drive state versus Control signal pulse width>

$t_{IN(ON)}$ is the recommended minimum turn-on pulse width for changing the IGBT state from OFF to ON, and $t_{IN(OFF)}$ is the recommended minimum turn-off pulse width for changing the IGBT state from ON to OFF. Fig.3-17 and Fig.3-18 show the IGBT drive state for various control signal pulse width.

A: IGBT may turn on occasionally, even when the ON pulse width of control signal is less than minimum $t_{IN(ON)}$. Also if the ON pulse width of control signal is less than minimum $t_{IN(ON)}$ and voltage below -5V is applied between U-COM,V-COM,W-COM , it may not turn off due to malfunction of the control circuit.

B: IGBT can turn on operates in the linear region under normal conditions.

C: IGBT may turn off occasionally, even when the OFF pulse width of control signal is less than minimum $t_{IN(OFF)}$. Also if the OFF pulse width of control signal is less than minimum $t_{IN(OFF)}$ and voltage below -5V is applied between U-COM, V-COM, W-COM, it may not turn on due to malfunction of the control circuit.

D: IGBT can turn off fully under normal condition.

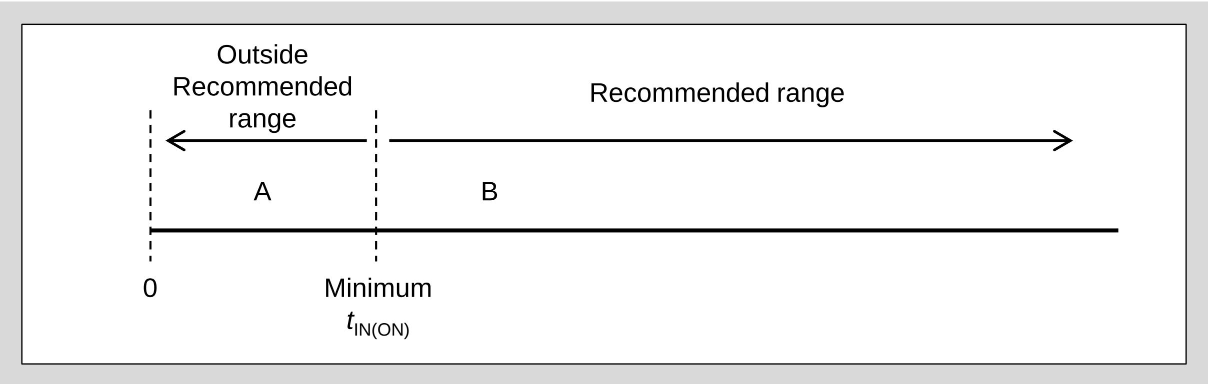


Fig.3-17 IGBT drive state versus ON pulse width of input signal

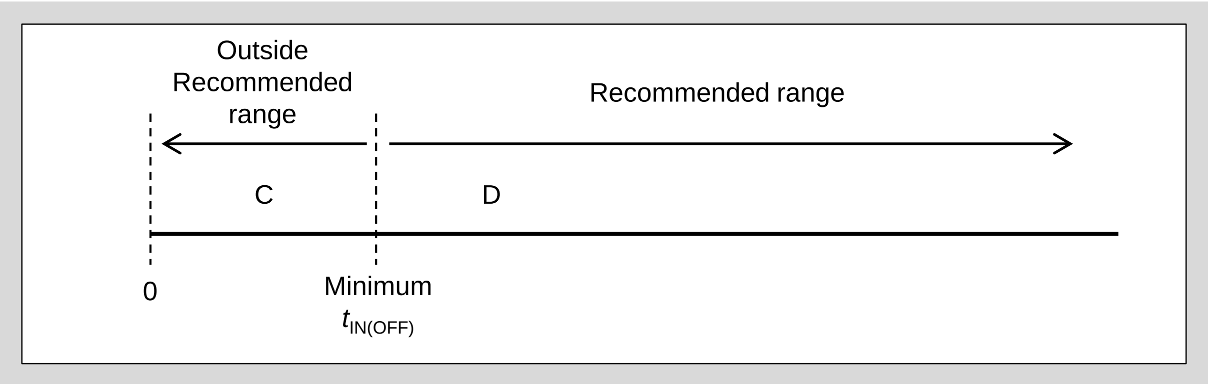


Fig.3-18 IGBT drive state versus OFF pulse width of input signal

5. Over Current Protection Input Terminal IS

- Over current (OC) protection function works by detecting the voltage generated by the external shunt resistor connected between N(U, V, W) and COM at the IS terminal, turn off the IGBTs and output an alarm signal.
- Fig.3-19 shows the over current sensing voltage input IS circuit block, and Fig.3-20 shows the OC operation sequence.
- To prevent the product from unnecessary operations due to normal switching noise or recovery current, it is necessary to apply an external R-C filter (time constant is approximately 0.7μs) to the IS terminal. The shunt resistor should be connected to the product as close as possible.
- Fig.3-19 shows that the diodes in the product are connected to the VCCL-IS and IS-COM terminals. Do not use these diodes for voltage clamp purpose otherwise the product might be damaged.

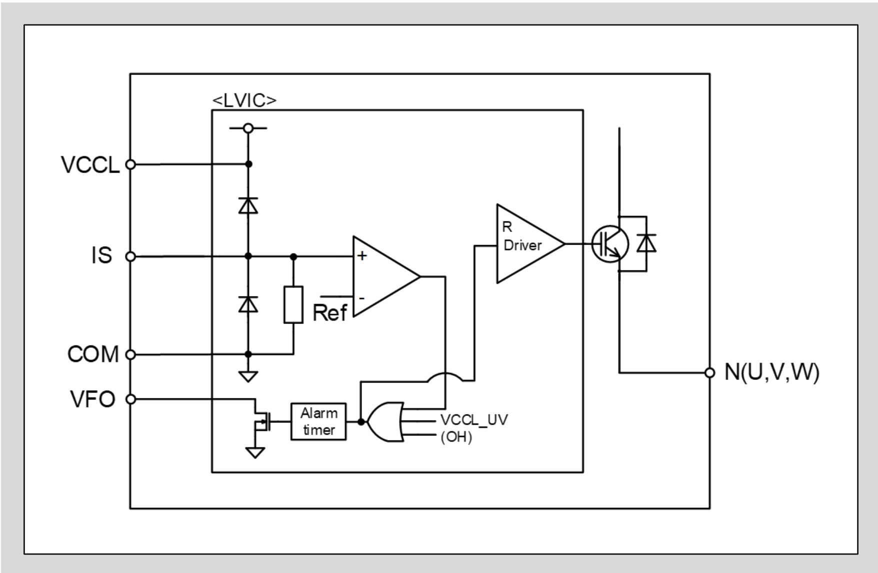


Fig.3-19 Over current sensing voltage input IS circuit

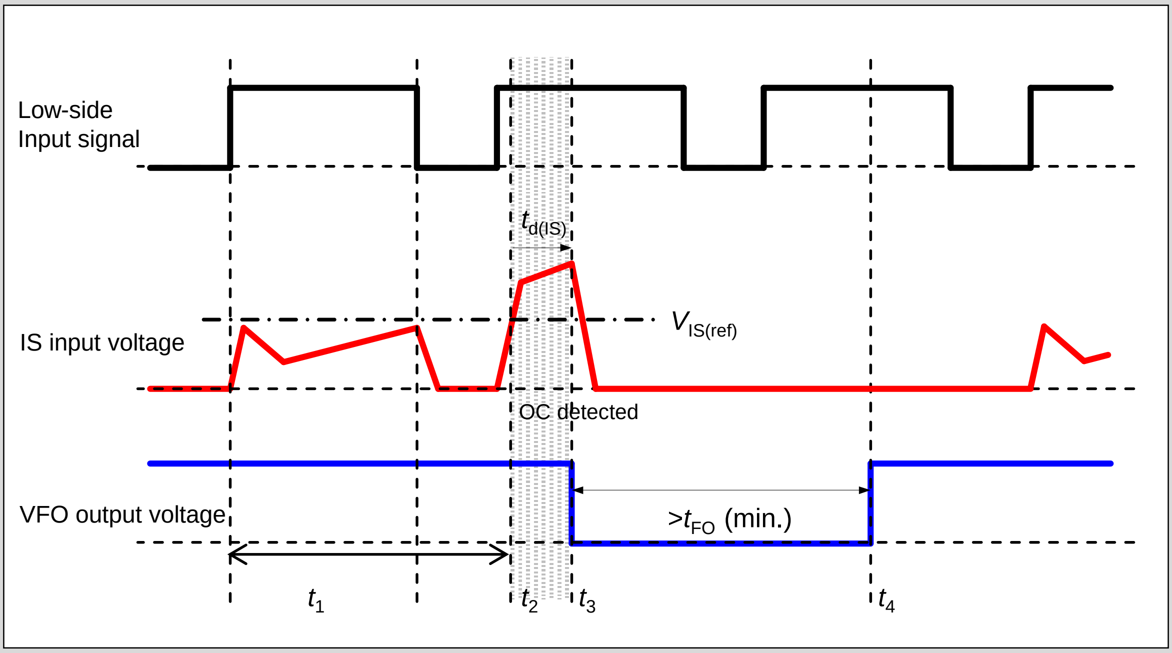


Fig.3-20 Operation sequence of Over Current protection

<*t1*>: IS input voltage does not exceed $V_{IS(ref)}$, while the collector current of the low-side IGBT is under the normal operation.

t2: When IS input voltage exceeds $V_{IS(ref)}$, the OC is detected.

t3: The fault output V_{FO} is activated and all low-side IGBT shut down simultaneously after the over current protection delay time $t_{d(IS)}$. Inherently there is dead time of LVIC in $t_{d(IS)}$.

t4: After the fault output pulse width t_{FO}, the OC is reset. Then next input signal is activated.

6. Fault Status Output Terminal VFO

- As shown in Fig.3-21, it is possible to connect the fault status output VFO terminal directly to the MPU. VFO terminal is open drain configured, thus this terminal should be pulled up by a resistor of approximate 10kΩ to the positive side of the 5V or 3.3V external logic power supply. It is also recommended that the bypass capacitor C1 and the inrush current limitation resistor R1 above 5kΩ, should be connected between the MPU and the VFO terminal. These signal lines should be wired as short as possible.
- Fault status output VFO function is activated by the UV of VCCL, OC and OH. (OH protection function is applied to “6MBP**XSK065-50”.)
- Fig.3-21 shows that the diodes in the IPM are electrically connected to the VCCL-VFO and VCCL-COM terminals. Do not use these diodes for voltage clamp purpose otherwise the product might be damaged.
- Fig.3-22 shows the Voltage-current characteristics of VFO terminal at fault state condition. The I_{FO} is the sink current of the VFO terminal as shown in Fig.3-21.

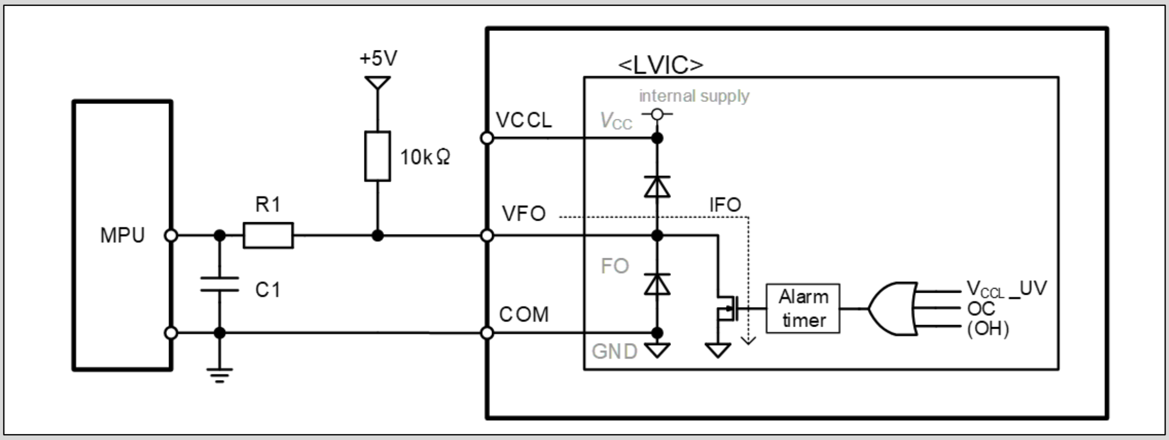


Fig.3-21 Recommended MPU I/O Interface Circuit of VFO terminal

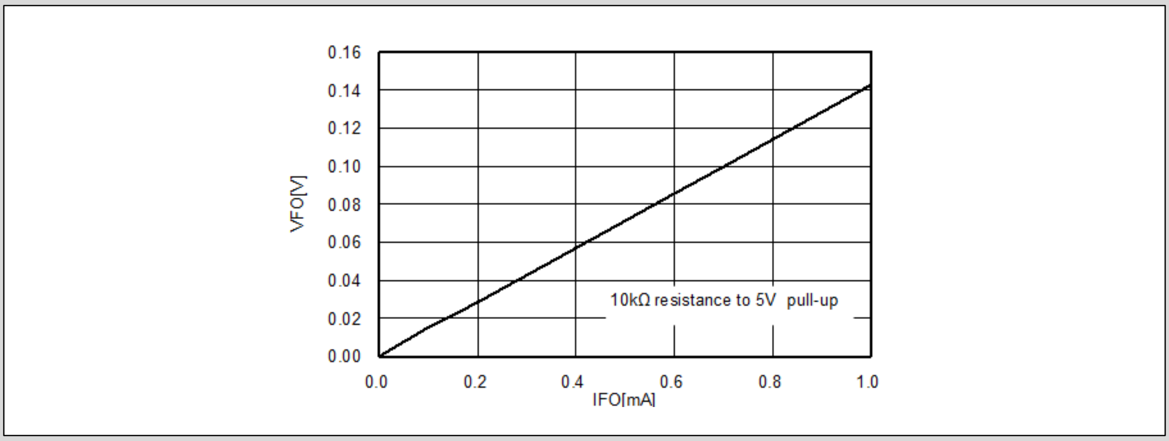


Fig.3-22 Voltage-current Characteristics of VFO terminal at the fault state condition

7. Temperature Sensor Output Terminal TEMP

- As shown in Fig. 3-23, the temperature sensor output TEMP can be connected to MPU directly.
- It is recommended that a by-pass capacitor C_{TEMP} and inrush current limiting resistor R_{TEMP} above 10kΩ is connected between the TEMP terminal and the MPU. These signal lines should be wired as short as possible to each device.
- The product has a built-in temperature sensor, and it can output an analog voltage according to the LVIC temperature. This function doesn't protect the product, and there is no fault signal output.
- "6MBP**XSK065-50" has built-in overheating protection. If the temperature exceeds TOH, fault signal will output due to the overheating protection function.
- Since the position of the IGBT chip and the position of the temperature sensor are different, it is not possible to respond to sudden rise in T_{vj} such as during motor lock and short circuit (see Fig. 2-2).
- A diode is electrically connected between TEMP-COM terminal as shown in Fig. 3-12. The diode protect the product from input surge voltage. Do not use the diode for voltage clamp purpose otherwise the product might be damaged.
- Fig.3-24 shows the LVIC temperature versus TEMP output voltage characteristics. A Zener diode should be connected to the TEMP terminal when the power supply of MPU is 3.3V. The output voltage shows clamp characteristic at below room temperature. Connect a 22kΩ±10% pull-down resistor to the TEMP terminal if linear characteristic is required.
- Fig. 3-25 shows the LVIC temperature versus TEMP output voltage characteristics with 22kΩ pull-down resistor $R_{pulldown}$.
- Fig.3-26 shows the operation sequence of TEMP terminal at during the LVIC startup and shut down conditions.

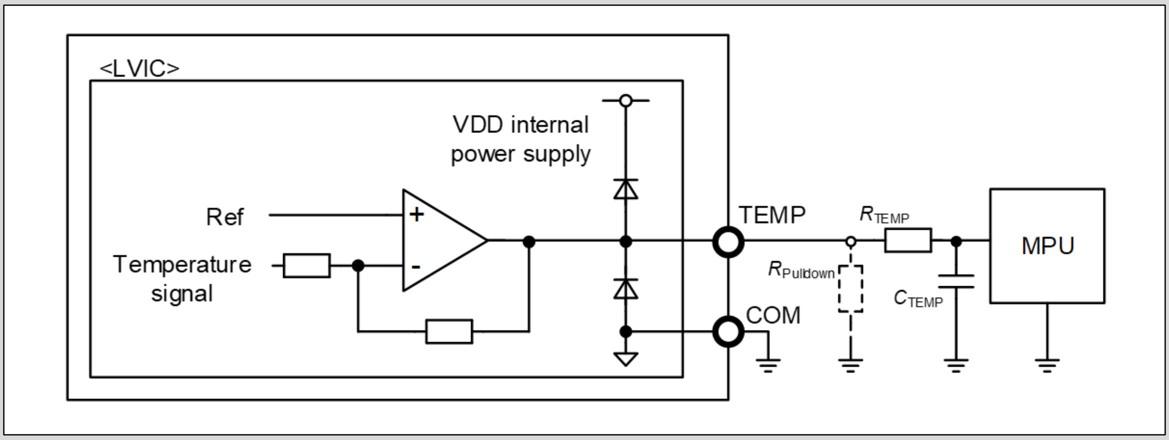


Fig.3-23 Recommended MPU I/O Interface Circuit of TEMP terminal

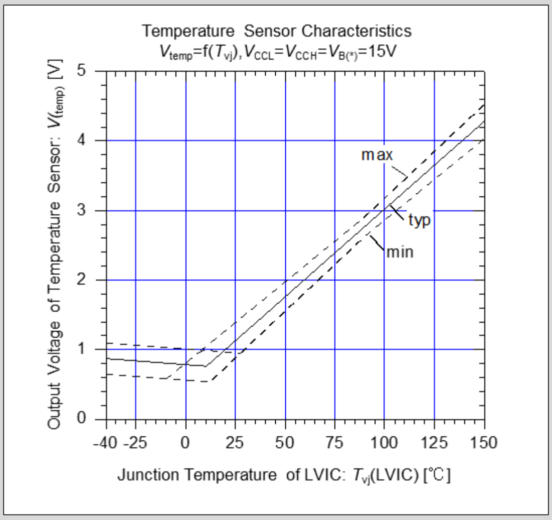


Fig.3-24 LVIC temperature vs. TEMP output voltage characteristics without pull-down resistor

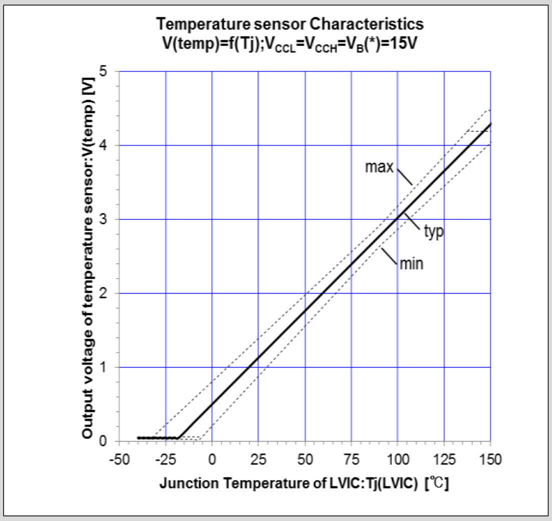


Fig.3-25 LVIC temperature vs. TEMP output voltage characteristics with 22kΩ pull-down resistor

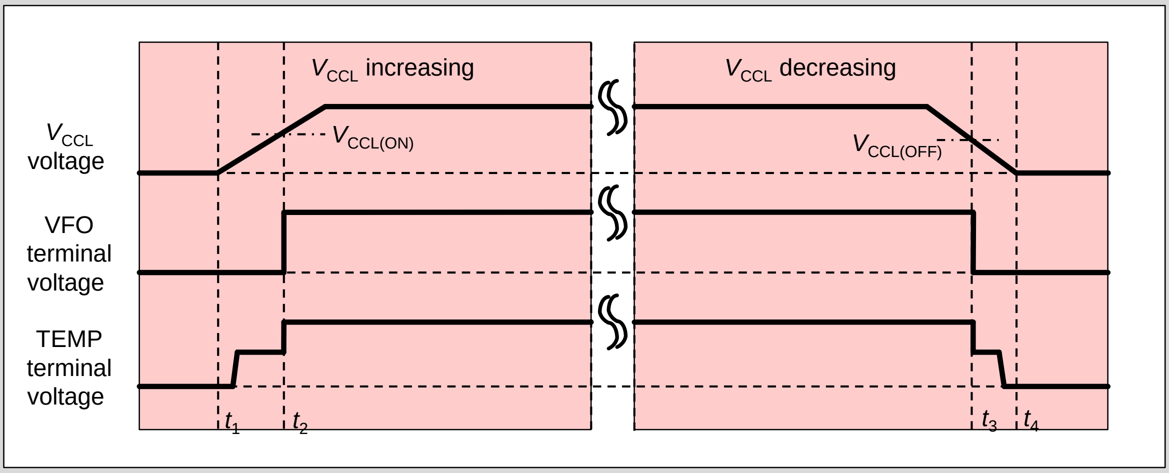


Fig.3-26 Operation sequence of TEMP terminal during LVIC startup and shut down conditions

t_1-t_2 : TEMP function is activated when V_{CCL} exceeds $V_{CCL(ON)}$. If V_{CCL} is lower than $V_{CCL(ON)}$, the TEMP terminal voltage is the same as the clamp voltage.

t_2-t_3 : TEMP terminal voltage rises to the voltage determined by LVIC temperature. In the case that the temperature is under clamping condition, the TEMP terminal voltage is the clamp voltage even though V_{CCL} is above $V_{CCL(ON)}$.

t_3-t_4 : TEMP function is reset when V_{CCL} falls below $V_{CCL(OFF)}$. TEMP terminal voltage is the same as the clamp voltage.

8. Overheating protection

- The Overheating (OH) protection functions is integrated into "6MBP**XSK065-50".
- The OH function monitors the LVIC junction temperature. Since the position of the IGBT chip and the position of the temperature sensor are different, it is not possible to respond to sudden rise in T_{vj} such as during motor lock and short circuit (see Fig. 2-2).
- The T_{OH} sensor position is shown in Fig.2-2.
- As shown in Fig.3-27, the product shuts down all low side IGBTs when the LVIC temperature exceeds T_{OH}. The fault status is reset when the LVIC temperature drops below $T_{OH} - T_{OH(hys)}$.

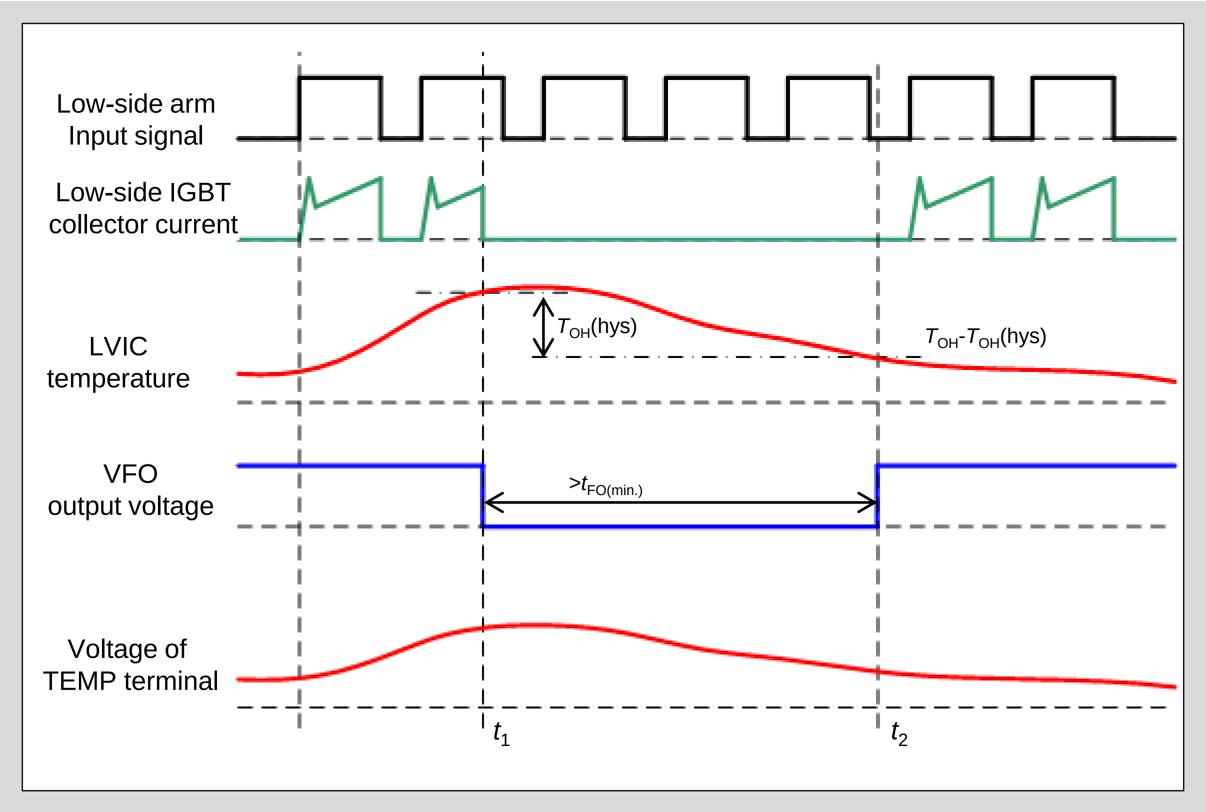


Fig.3-27 Operation sequence of the over heating operation

t_1 : The fault status is activated and all IGBTs of the low-side arm shut down, when LVIC temperature exceeds T_{OH}.

t_2 : When LVIC temperature falls below $T_{OH} - T_{OH(hys)}$, the fault status is reset after t_{FO} and next input signal is activated. $T_{OH(hys)}$ is the over heating protection hysteresis

Chapter 4 Power Terminals

In this chapter, the guideline and precautions in circuit design on the power terminals, such as how to determine the resistance of shunt resistor are explained.

1. Connection of Bus Input terminal and low-side Emitters

<Description of the power terminals>

Table 4-1 shows the details about the power terminals.

Table 4-1 Detailed description of power terminals

Terminal Name	Description
P	Positive bus voltage input terminal It is internally connected to the collector of the high side IGBTs. In order to suppress the surge voltage caused by the wiring or PCB pattern inductance of the bus voltage, connect a snubber capacitor close to this terminal. (Typically metal film capacitors are used)
U, V, W	Inverter output terminals for connecting to motor load.
N(U), N(V), N(W)	Negative bus voltage input terminals These terminals are connected to the low side IGBT emitter of each phase. In order to monitor the current on each phase, shunt resistors are connected between these terminals and the negative bus voltage input (power ground).

<Recommended wiring of shunt resistor and snubber capacitor>

- Connect external shunt resistors to detect over current (OC) condition and phase currents.
- Long wiring patterns between the shunt resistor and the product will cause excessive surge voltage that might damage the internal control IC and current detection components. To reduce the pattern inductance, the wiring between the shunt resistors and the product should be as short as possible.
- As shown in the Fig.4-1, snubber capacitors should be connected at the right location to suppress surge voltage effectively.
- Connecting the snubber capacitor at location "C" is recommended. If the snubber capacitor is connected at location "A" as shown in the Fig.4-1, the snubber capacitor cannot suppress the surge voltage effectively because the wiring inductance is not negligible. If the capacitor is connected at the location "B", the charging and discharging current of snubber capacitor will flow through the shunt resistor. This will impact the current detection signal and the OC protection level will be lower than the design value. Although the surge voltage suppression effect when the snubber capacitor is connected at location "B" is greater than that at location "A" or "C", location "C" is recommended considering the impact to the current detection accuracy.
- Snubber capacity of 0.1 ~ 0.22 μF is recommended.

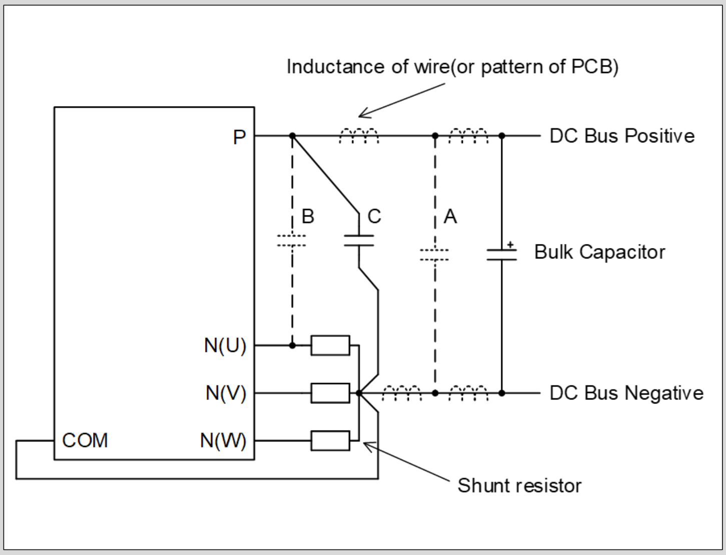


Fig.4-1 Recommended wiring of shunt resistor and snubber capacitor

2. Setting of Shunt Resistor for Over Current Protection

<Selecting current sensing shunt resistor>

The value of current sensing resistor is calculated by the following equation :

$$R_{\mathrm{Sh}} = \frac{V_{\mathrm{IS(ref)}}}{I_{\mathrm{OC}}} \qquad (4.1)$$

- Where $V_{IS(ref)}$ is the over current (OC) protection reference voltage level of the product and I_{OC} is the current of OC detection level. $V_{IS(ref)}$ is 0.455V(min.), 0.48V(typ.) and 0.505V(max.). And R_{Sh} is the Resistance of the shunt resistor.
- The maximum value of OC level should be set lower than the repetitive peak collector current in the specification datasheet of this product, taking into consideration the variation in shunt resistance.
- For example, if OC level is set at 45A, the recommended value of the shunt resistor is calculated as:

$$R_{\mathrm{Sh(min)}} = \frac{V_{\mathrm{IS(ref)(max)}}}{I_{\mathrm{OC}}} = \frac{0.505}{45} = 11.2[\mathrm{m}\Omega] \qquad (4.2)$$

- $R_{Sh(min)}$ is the minimum resistance of the shunt resistor. It should be noted that a proper resistance should be chosen considering OC level required in practical application.

<Filter delay time setting of over current protection>

- An external RC filter is necessary in the over current sensing circuit to prevent unnecessary over current protection caused by noise. The RC time constant is determined by the noise application time noise and the short circuit withstand capability of IGBTs. It is recommended to be set approximately 0.7μs.
- When the voltage across the shunt resistor exceeds the OC level, the filter delay time t_{delay} that delays the rises of input voltage of IS terminal to the OC level is determined by the RC filter time constant and is given by the following equation:

$$t_{\mathrm{delay}} = -\tau \cdot \ln\left(1 - \frac{V_{\mathrm{IS(ref)(max)}}}{R_{\mathrm{Sh}} \cdot I_{\mathrm{p}}}\right) \qquad (4.3)$$

- τ is the RC time constant, I_P is the peak current flowing through the shunt resistor.
  In addition, there is a shut down propagation delay $t_{d(IS)}$ of OC.
- Therefore, the total time t_{total} from OC triggered to shut down of the IGBT is given by:

$$t_{\mathrm{total}} = t_{\mathrm{delay}} + t_{\mathrm{d(IS)}} \qquad (4.4)$$

- The total delay time t_{total} should be shorter than the short circuit withstands capability of IGBT. Please confirm the proper delay time in actual equipment.

Chapter 5 Recommended wiring and layout

In this chapter, recommended wiring and layout are explained. In this section, tips and precautions in PCB design are described with example of application circuit.

1. Examples of Application Circuits

Fig. 5-1 and Fig.5-2 show examples of application circuits and their notes. In these figures, although two types of current detection method are shown, the notes are common.

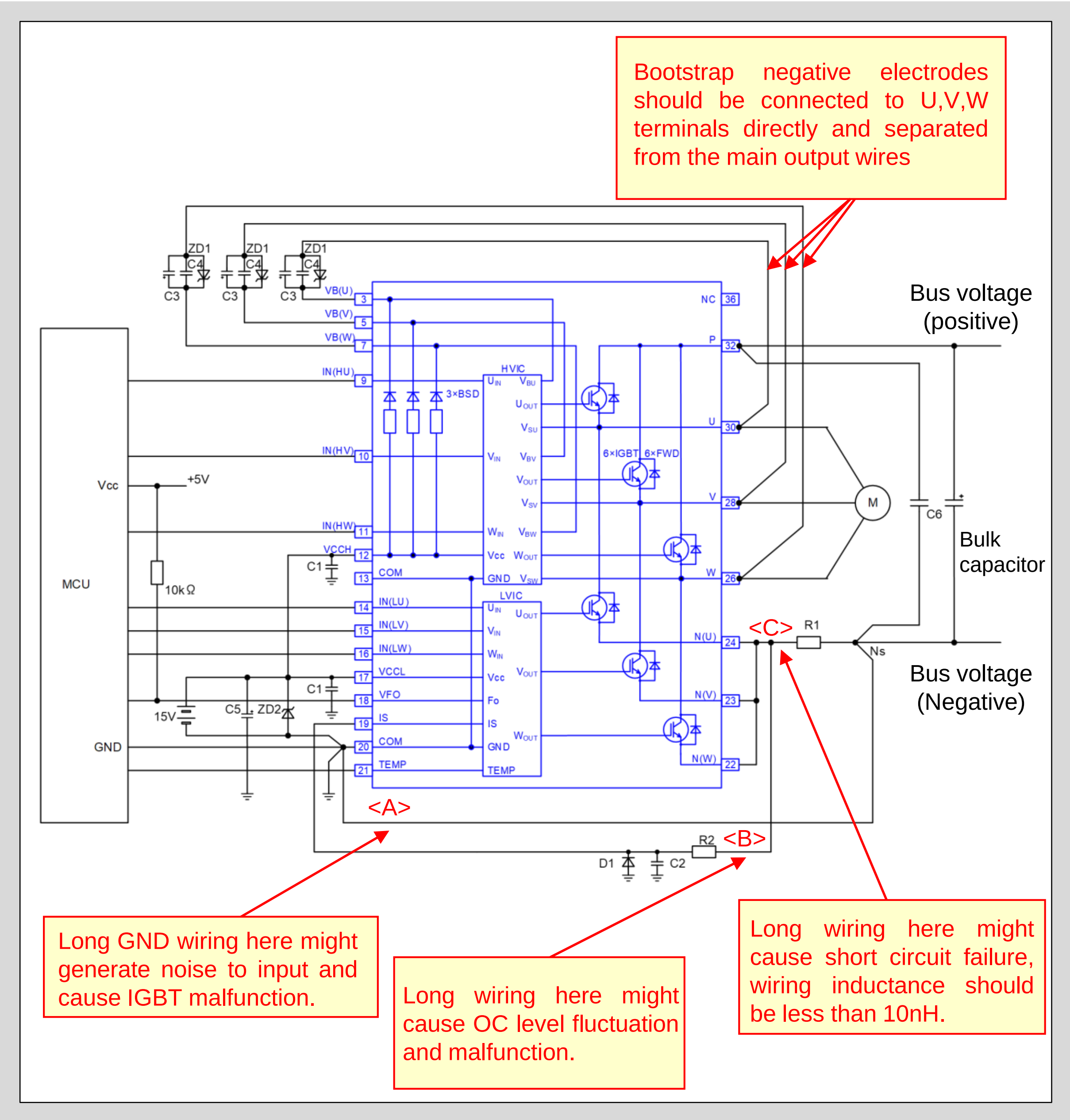


Fig. 5-1 Example of application circuit 1
(In case of sensing all 3 phase currents at once with a single shunt resistor)

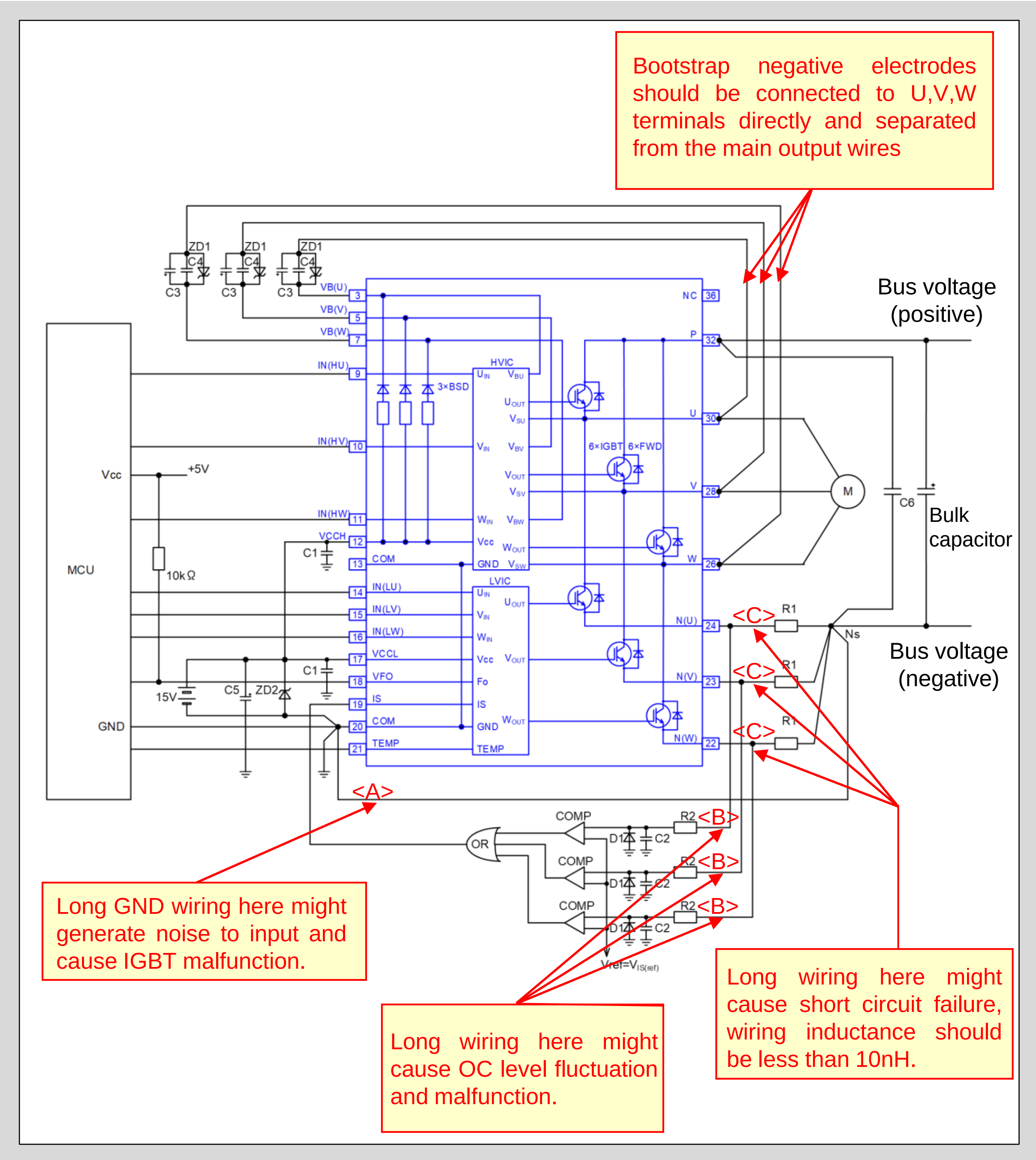


Fig. 5-2 Example of application circuit 2
(In case of sensing each phase current individually)

<Note>

1. Input signal for IGBT driving is High-Active. The input circuit of the IC has a built-in pull-down resistor. To prevent malfunction, the wiring of each input should be as short as possible. When using RC filter, please make sure that the input signal level meets the turn-on and turn-off threshold voltage.
2. The product has built-in HVIC and thus it is possible to be connected to MPU directly without any photocoupler or pulse transformer.
3. VFO output is open drain type. It should be pulled up to the positive side of a 5V power supply by a resistor of about 10kΩ.
4. To prevent erroneous protection, the wiring of (A), (B), (C) should be as short as possible.
5. The time constant R2-C2 of the protection circuit should be selected approximately 0.7μs. Over current (OC) shut down time might vary due to the wiring pattern. Tight tolerance, temp-compensated type is recommended for R2, C2.
6. It is recommended to set the threshold voltage of the comparator reference input to be same level as the product OC trip reference voltage VIS(ref).
7. Please use high speed type comparator and logic IC to detect OC condition quickly.
8. If negative voltage is applied to R1 during switching operation, connecting a Schottky barrier diode D1 is recommended.
9. All capacitors should be connected as close to the terminals of the product as possible. (C1, C4: ceramic capacitors with excellent temperature, frequency and DC bias characteristics are recommended; C3, C5: select an electrolytic capacitor considering the ripple current capability and lifetime.)
10. To prevent destruction caused by surge voltage, the wiring between the snubber capacitor C6 and P terminal, Ns node should be as short as possible. Generally, snubber capacitance of 0.1μF~0.22μF is recommended.
11. Two COM terminals (13 & 20 pin) are connected internally. Please connect either of the terminal to the signal GND and leave the other terminal open.
12. It is recommended to connect a Zener diode (22V) between each pair of control power supply terminals to prevent destruction caused by surge voltage.
13. If signal GND is connected to power GND by board pattern, there is possibility of malfunction due to fluctuations at the power GND. It is recommended to connect signal GND and power GND at a single point.

2. Recommendations and Precautions in PCB design

In this section, the recommended pattern layout and precautions in PCB design are described.
Fig.5-3 to Fig.5-7 show the images of recommended PCB layout (referring to example application circuit in Fig.5-1 and Fig.5-2).
In these figures, the input signals from system control are represented with "IN(HU)".

The recommendations and precautions are as follows,

<Overall design around Small IPM>

- Keep a relevant creepage distance at the boundary. (Place a slit between there if needed.)
- The pattern of the power input (DC bus voltage) part and the power supply for high side drive parts should be separated in order to prevent the increase of conduction noise. In case of crossing these wirings on pattern in multi-layer PCB, please take note of stray capacitance between wires and insulation performance of the PCB.
- The pattern of the power supply for high side drive part and the input circuit of each phase part should be separated to avoid malfunction of the system. In case of using multi-layer PCB, it is strongly recommended not to cross these wirings.

Details of each part are described in next page.

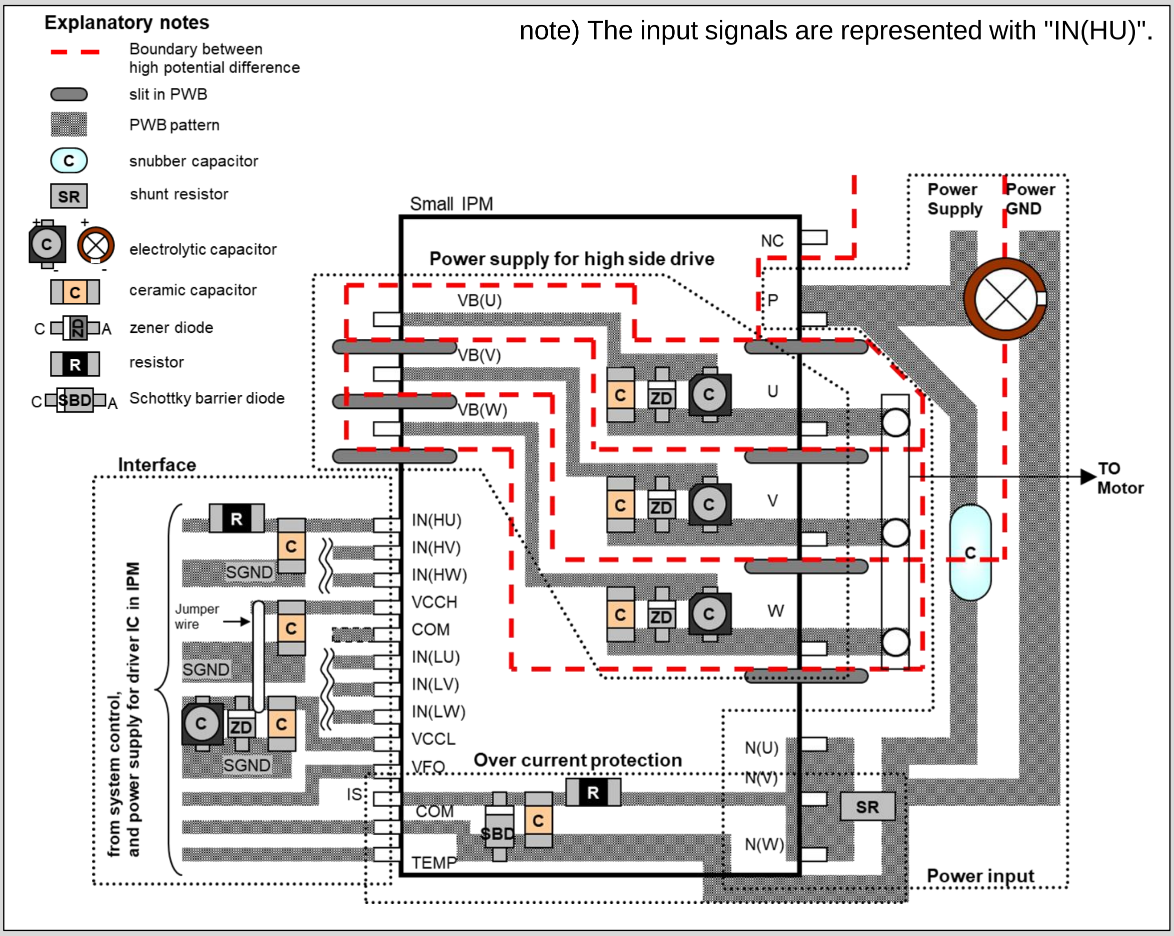


Fig.5-3 Image of recommended PCB layout (Overall design around the Small IPM)

<Power input part>

(A) Connect the snubber capacitor between P terminal and the negative node of the shunt resistor as close as possible. The pattern between the snubber capacitor and P terminal, and shunt resistor should be as short as possible to avoid the influence of pattern inductance.
(B) Pattern of the bulk capacitor and snubber capacitor should be separated near the P terminal and shunt resistor.
(C) The pattern from power GND and COM terminal should be connected as close as possible to the shunt resistor with single-point-grounding.
(D) Please use low inductance shunt resistor.
(E) The pattern between N(U),N(V),N(W) terminals and the shunt resistor should be as short as possible.

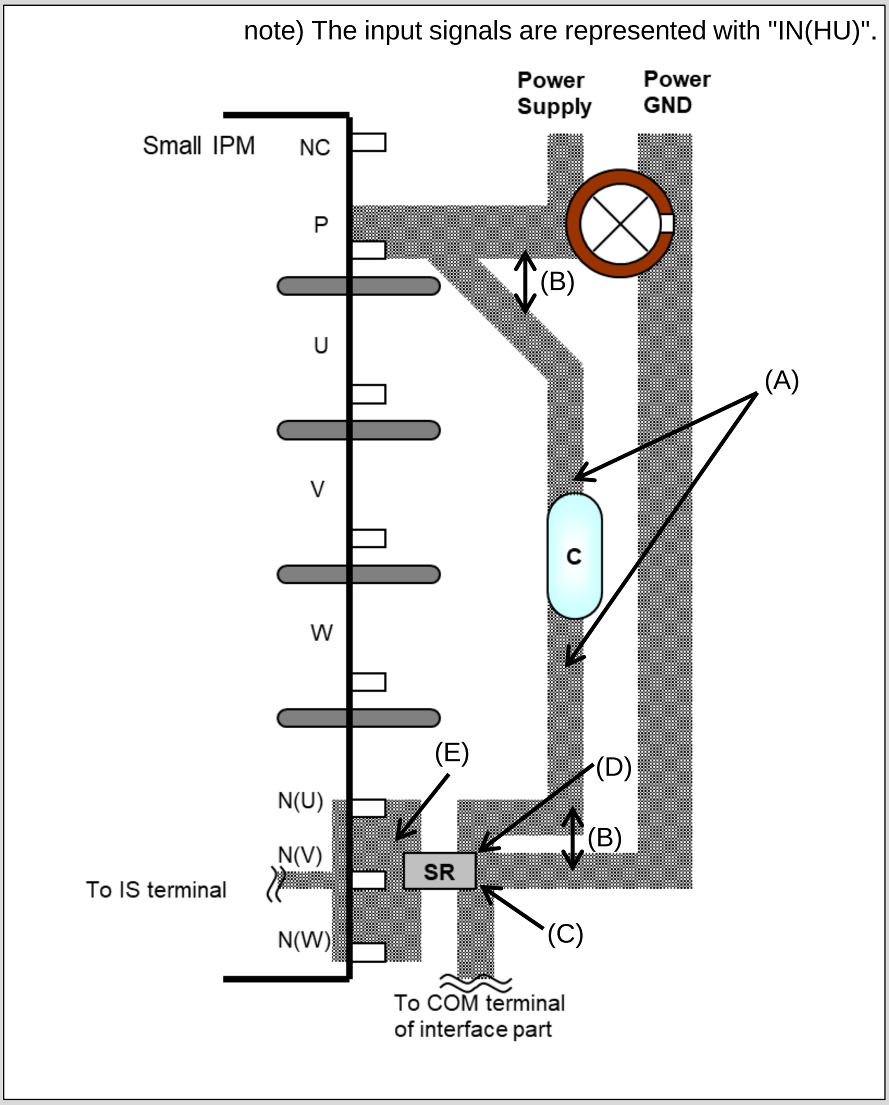


Fig.5-4 Image of recommended PCB layout(Power input part)

<Power supply for high side drive part>

A) The pattern between VB(U), VB(V), VB(W) and the electronic components (ceramic capacitor, electrolytic capacitor and Zener diode) should be as short as possible to avoid the influence of pattern inductance.

B) Please use appropriate capacitor according to applications. Especially, please use ceramic capacitor or low-ESR capacitor close to VB(U), VB(V), VB(W) terminals.

C) The pattern to Motor output and negative pole of the capacitor connected to VB(U), VB(V), VB(W) should be separated close to U,V and W terminals in order to avoid malfunction due to common impedance.

D) If the stray capacitance between VB(U) and power GND (or equal potential) is large, the voltage between VB(U) and U terminals might become overvoltage or negative voltage when IGBT turns on and off with high dV/dt. Therefore, connecting a Zener diode between VB(U) and U are recommended. It should be connected close to VB(U) terminal.

(The same applies to VB(V) and VB(W).)

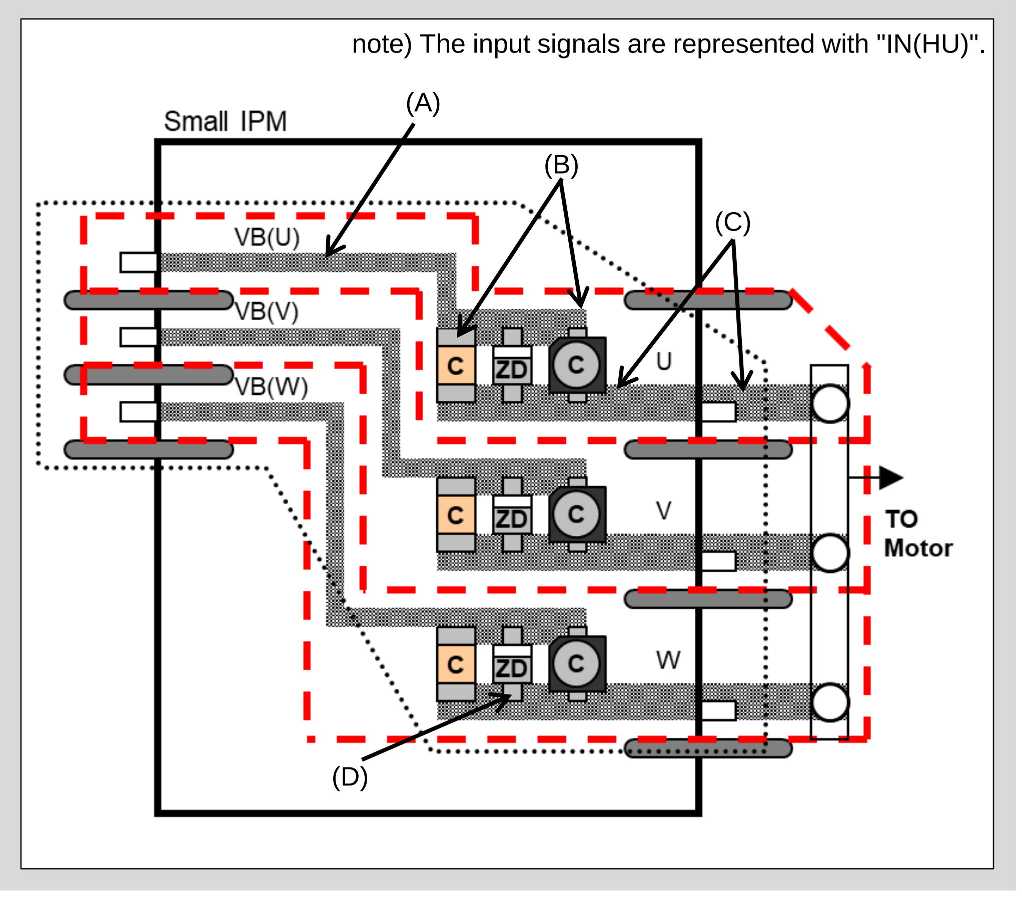


Fig.5-5 Image of recommended PCB layout(Power supply for high side drive part)

<Interface part>

(A) Please connect a capacitor between the input signal and COM terminal if the influence of noise from the power supply for high side drive part (and so forth) are not negligible. The negative pole of the capacitor should be connected as close as possible to the pattern of signal GND near the COM terminal. If filter resistor or capacitor is used, please take into account the internal pull down resistors in this IPM and confirm the signal level in the actual system.

(B) This product has two COM terminals that are connected internally. Please use either one.

(C) Electrolytic capacitor and ceramic capacitor should be connected between VCCL and COM, VCCH and COM. These capacitors should be connected as close to each terminal as possible.

(D) The output signal from TEMP terminal should be parallel with Signal GND in order to minimize the effects of noise.

(E) The pattern of Signal GND from system control and the pattern from COM terminal should be connected at single point ground. The single point ground should be as close to the COM terminal as possible.

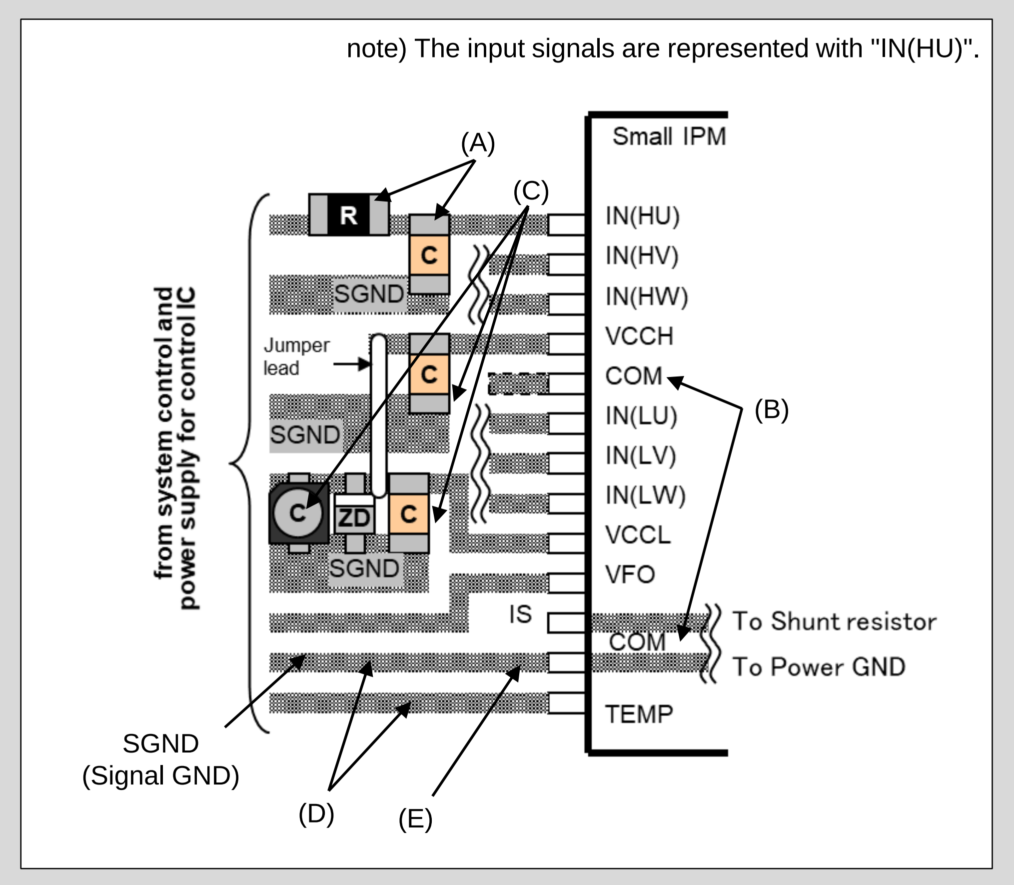


Fig.5-6 Image of recommended PCB layout (Interface part)

<Over Current Protection part>

There are two methods to detect overcurrent (OC). Fig.5-7(a) shows the ‘one-shunt type’, and Fig.5-7(b) shows the ‘3-shunt type’.

Fig.5-7 (a)

(A) The pattern between the negative pole of the shunt resistor and the COM terminal is very important. It is not only the reference zero level of the control IC, but also the current path of bootstrap capacitor charging current and gate driving current of low side IGBTs.Therefore, in order to minimize the impact of common impedance, this pattern should be as short as possible.

(B) The pattern of IS signal should be as short as possible to avoid OC level fluctuation and malfunction.

(C) In order to prevent false detection during switching operation, it is recommended to connect a RC filter to the IS terminal. The negative pole of this capacitor should be connected to the pattern of signal GND near the COM terminal.

(D) If negative voltage is applied to IS terminal during switching operation, please connect a Schottky barrier diode between the IS and COM terminals or in parallel with the shunt resistor .

Fig.5-7 (b)

(A) Please use high speed type comparator and logic IC to detect OC condition quickly.

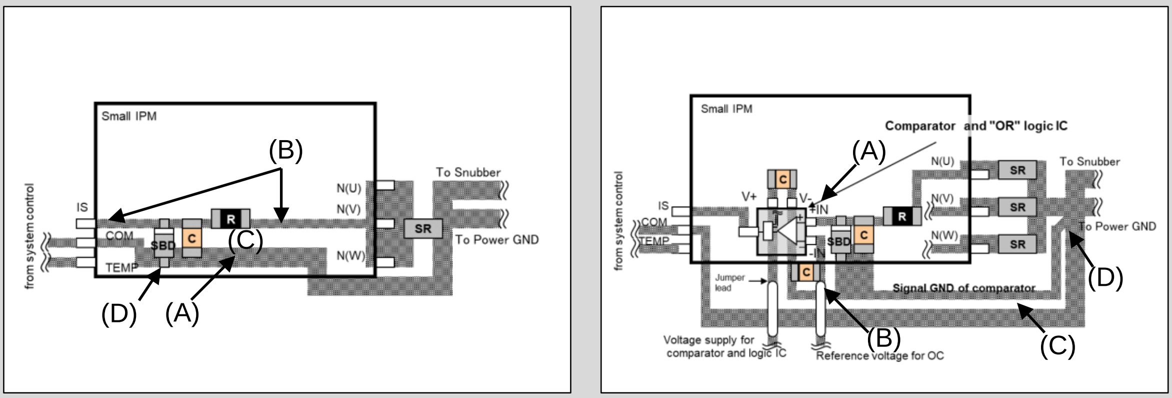
(B) The reference voltage level of OC which is inputted to the comparator should be coupled by a capacitor to signal GND. The capacitor should be as close to the comparator as possible.

(C) The pattern of signal GND for COM terminal and the pattern of signal GND for the comparator should be separated.

(D) The pattern of signal GND from COM and the pattern of signal GND of the comparator should be connected at single point ground. The single point ground should be as close to the shunt resistors as possible.

(E) The other precautions and recommendations are same as Fig.5-7 (a).

Please refer to Chapter 4, Section 2 for more information on determining the circuit constant.



(a) One-shunt type (b) 3-shunt type

Fig.5-7 Image of recommended PCB layout (Over Current Protection part)

note) The input signals are represented with "IN(HU)".

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Chapter 6 Mounting Guideline and Thermal Design

1. Soldering to PCB

- The product's temperature during soldering might exceed the maximum storage temperature. To prevent damage to the product and to ensure reliability, please use the following soldering temperature.

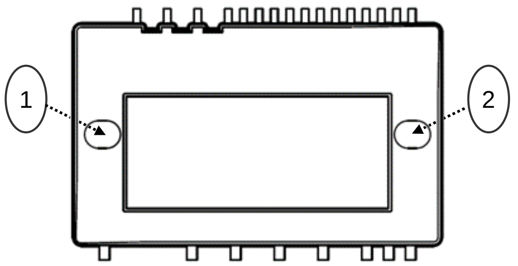
Table 6.1 Soldering temperature and duration

Methods	Soldering Temp. & Time
Dip soldering	260±5°C, 10±1sec

- A stopper is provided on the terminal to prevent the immersion depth of the terminal from coming too close to the product body. Use this stopper to secure the required distance from the printed circuit board and prevent the product body from being immersed in the solder bath during flow soldering.
- It is not recommended to reuse the product after it is removed from the printed circuit board because there is a possibility that the removed product was subjected to thermal or mechanical damage during the removal process.

2. Mounting to Heat Sink

- When mounting the product to a heat sink, please refer to the following recommended fastening order. Uneven fastening due to excessive torque might lead to destruction or degradation of the chip.



Recommended:
Pre-screwing: 1 → 2
Final screwing: 2 → 1

Note) The pre-screwing torque is set to 30% of the final screwing torque rating(0.59～0.98N·m)

Fig.6-1 Recommended screw fastening procedure

- Fig.6-2 shows the measurement position of heat sink flatness.
- The heat sink flatness should be 0μm/100mm to +100μm/100mm, and the surface roughness (Rz) should be less than 10μm.
- If the heat sink surface is concave, a gap occurs between the heat sink and the product, leading to deterioration of cooling efficiency.
- If the flatness is +100μm/100 mm or more, the aluminum base of the product is deformed and cracks could occur in the internal isolating substrates.

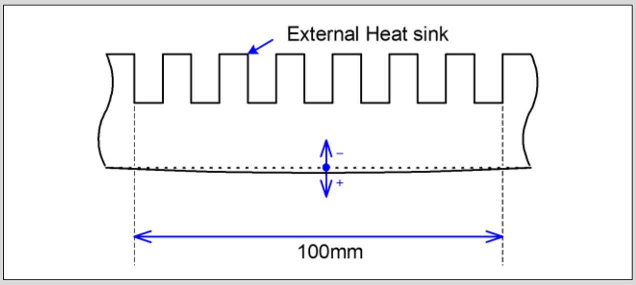


Fig.6-2 The measurement point of heat sink flatness

In order to achieve good heat dissipation, thermal grease with high thermal conductivity should be applied evenly to the contact surface between the product and the heat sink. The stencil mask method (Fig. 6-3) is recommended to control the appropriate thermal grease thickness. Please refer to mounting instruction for the recommended characteristics, amount, stencil mask pattern, etc. of thermal grease.

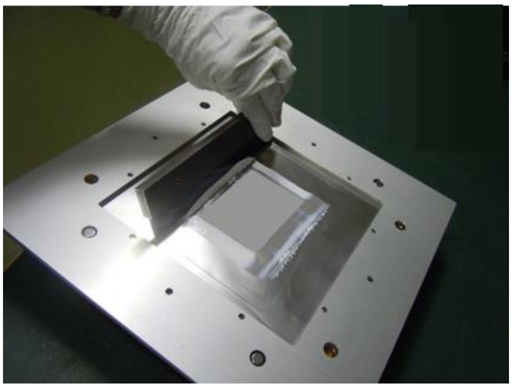


Fig. 6-3 Thermal grease application

3. Heat Sink Selection

- Please make sure that the junction temperature T_{vj} should not exceed the maximum junction temperature rating for safe operation. Heat sink should be designed to ensures that T_{vj} is always below the maximum junction temperature rating even during abnormal conditions such as overload operation as well as during rated load.
- Operating the IGBT above the maximum junction temperature rating can cause damage to the chips. The over heating (OH) protection function works when the IGBT junction temperature exceeds the maximum junction temperature rating. However, if the temperature rises too quickly, the OH protection might not work.
- Please note that the junction temperature of FWD should not exceed the maximum junction temperature rating too.
- When selecting a heat sink, please verify the chip temperature by measuring at the position shown in Fig.2-2.

For more detail about thermal design, please refer to IGBT MODULE APPLICATION MANUAL (REH984)"
Contents:

- Power dissipation loss calculation
- Selecting heat sinks
- Heat sink mounting precautions
- Troubleshooting

Chapter 7 Precautions

1. Precautions for use

- This product shall be used within its maximum rating (voltage, current, temperature, and so on) described in specification. This product may be broken in case of using beyond the maximum ratings. The specified value in the absolute maximum ratings are guaranteed value for the rating, not for any combination of ratings or characteristics. Even if this product is used within absolute maximum ratings, expected product lifetime may not be obtained depending on the temperature or usage environment. Please refer to the absolute maximum rating of this product, and judge the suitability of this product for your system / equipment after evaluation and verification by yourself.
- It shall be confirmed that IGBT's operating locus of the turn-off voltage and current are within the RBSOA specification. If the IGBT is used beyond the range of RBSOA, this product may be destroyed.
- If a voltage exceeding $V_{CE(chip)}$ is applied, avalanche breakdown may occur and this product may be destroyed. Use this product so that $V_{CE(chip)}$ is within the maximum rating.
- FWD of this product is not designed to be used as a diode rectifier (AC-DC conversion circuit).
- If a transient overvoltage that exceeds the voltage rating of the device in this product is propagated from the electric power supply to this product due to a lightning strike, etc., the overvoltage may destroy this product. If any transient overvoltage is expected to be applied from the electric power supply to line-line or line-ground, insert a surge absorber, etc. to suppress the voltage applied to this product in order to avoid damage.
- This product is not designed for use in parallel connection, so it cannot be used in parallel connection.
- If applied Printed Circuit Board is not suitable, the main terminals may have higher temperature than T_c (Case temperature). Also the main pin terminals shall be used within temperature range of T_c (Case temperature).
- This product are made of incombustible material. However, if this product fails, it may emit smoke or flame. Also, operating this product near any flammable place or material may cause this product to emit smoke or flame in case this product become even hotter during operation. Take measures to prevent the spread of fire.
- Install surely an adequate fuse or breaker between the commercial power supply (three-phase line) and this product in case the system / equipment is destroyed by an accident to prevent secondary destruction such as fire, explosion, and fire spread.
- In any environment containing corrosive gases, corrosive liquids, corrosive solids (acids, alkalis, organic substances, etc., ex: hydrogen sulfide, sulfurous acid gas, cutting fluid, cement powder etc.), this product may oxidize or corrode, resulting in poor contact, disconnection, short circuit, ground fault, etc. In such cases, avoid to use this product as it may cause malfunctions. In the unlikely event that a short circuit or ground fault occurs to this product, there is a secondary risk of smoke, fire, or explosion, etc. If this product is used under conditions containing these corrosive substances, Fuji Electric Co., Ltd. is not responsible regardless of the conditions (temperature, humidity, concentration, etc.).
- If this product is used in an environment with sudden temperature changes, it is expected that short circuits and ground faults will occur due to dew condensation. In the unlikely event that a short circuit or ground fault occurs to this product, there is a secondary risk of smoke, fire, or explosion, etc. Fuji Electric Co., Ltd. is not responsible for any use of the product in an environment where condensation may occur.
- If excessive static electricity is applied to the terminals, this product may be broken.

- If the product is used in a high humidity environment or after storage the equipment after assembling, operate the equipment after sufficiently releasing the moisture. If the product is operated in a moisture-absorbed state, it may cause electrical wiring defects or insulation defects inside of this product, and Fuji Electric Co., Ltd. is not responsible for the matters.
- This product is not designed for use in a dusty environment. When used in an environment where dust is generated, heat dissipation may deteriorate due to clogging of the heat sink, and short circuits or ground faults may occur due to leaks between terminals or creeping discharge. (Even if the dust is an insulating material such as fiber, it may leak due to moisture absorption.)
- In general, semiconductor devices have accidental failure modes due to high-speed particles (cosmic rays) derived from space or radiation. The failure rate in this failure mode varies depending on the installation location (latitude, longitude, altitude), installation environment, and operating conditions (voltage). When using the product under high altitude and/or voltage condition, please contact Fuji Electric Co., Ltd.
- Clearance distance and creepage distance of this product are designed for usage in an environment of up to 2000m sea level. Fuji Electric Co., Ltd. is not responsible for the use in an environment where the altitude exceeds 2000 m above sea level or in an environment where the atmospheric pressure is similarly low.
- If this product is used beyond its lifetime, this product performance and quality of the product may deteriorate before the target lifetime of the system / equipment, and in the worst case, this product may be destroyed. Use this product after fully understanding the usage environment of the system / equipment in which this product is installed and considering that this product satisfies the target lifetime.
- Consider the possible temperature rise not only for the junction and case, but also for the outer leads.
- When designing a new equipment, always refer to the latest mounting instructions.
- To prevent high-frequency noise such as switching noise from being applied directly to the VCCH and VCCL terminals, connect an adequate ceramic capacitor close to each control power supply voltage terminal between the VCCH and COM terminals, and between the VCCL and COM terminals.
- When noise is applied to the control terminal of this product, the product may malfunction. Please confirm that neither unstable operation nor malfunction occurs due to noise.
- When $V_{B(*)}$ are less than $V_{B(off)}$ due to noise, the corresponding high-side IGBTs may turn OFF. Please connect an adequate ceramic capacitor near the VB(U)-U terminal, VB(V)-V terminal and VB(W)-W terminal, respectively.
- Use this product below the power cycle lifetime curve (Technical Document No. MT6M14324). Power cycle withstand capability is classified to ΔT_{vj} mode and ΔT_c mode. Since the ΔT_c power cycle lifetime of this product depends on the thermal stress due to the rise and fall of the case temperature (T_c), the lifetime of this product is greatly affected by the cooling design of the equipment installing this product. If the case temperature rises and falls frequently, or if the operating time at high temperature is long, use this product with paying sufficient attention to the product lifetime.
- If excessive stress (tension, pushing, bending) is applied to the main terminal and control terminal, the terminal may be deformed and the case resin may crack, causing poor contact and poor insulation. For the maximum allowable stress of the main terminal and control terminal, refer to the application manual of each package.

- When handling this product, be careful to avoid any breakdown due to the static electricity, take measures against static electricity.
- When handling this product, hold the case (package body) and do not touch the terminals. In case of touching the terminals of this product, discharge static electricity adhering to body or clothing by grounding through a high impedance resistor (approx. 1MΩ) before touching.
- Work on grounded conductive floor or table mat are recommended.
- When soldering, in order to protect this product from static electricity, use antistatic soldering iron or soldering bath to prevent static electricity, and solder with low impedance resistor between soldering iron and ground.
- When soldering the product terminals, soldering at an excessive high temperature may cause deterioration of the package. Please be careful about the soldering process. When used in the reflow soldering process, the solder inside this product may remelt and impair its quality. In this case, Fuji Electric Co., Ltd. is not responsible for this product performance and appearance.
- Use the tightening torque of the screws that mounting the product within the specified values. If the tightening torque is excessive, insulation failure may occur due to cracking of the case, and if the torque is small, the contact thermal resistance may increase and the heat generation of the device may increase. In addition, it is expected that the screws will loosen due to vibrations in the usage environment, so select screws that are difficult to loosen, tighten with appropriate torque, and retighten to prevent loosening.
- The product mounting surface of the heat sink should have flatness of 50 μm or less per 100 mm between the screw mounting positions and surface roughness of 10 μm or less. Excessive convex warpage may cause isolation breakdown of this product, resulting in a serious accident. Excessive concave warpage or distortion may create gaps between the product and the heat sink, resulting in poor heat dissipation and thermal destruction.
- When mounting this product on a heat sink, use thermal grease or equivalent to ensure cooling. In order to spread the thermal grease thinly and evenly, the flatness and surface roughness of the heat sink should be within the recommended values described in this specification. Due to insufficient applied amount or improper spreading method, thermal grease may not spread sufficiently over the entire mounting surface of this product, leading to thermal destruction due to poor heat dissipation. When applying thermal grease, make sure that the thermal grease is spread over the entire surface of the product. (By removing this product after mounting, the spread of thermal grease can be confirmed.)
- If the amount of thermal grease near this product mounting hole is excessive, the thermal grease acts as a spacer, hindering the spread of the thermal grease and causing deterioration of heat dissipation. In addition, depending on the type or application method of thermal grease, deterioration or depletion of thermal grease may occur during high-temperature operation or temperature cycle, which may shorten this product lifetime. Pay close attention to the selection and application method of the thermal grease. Please refer to the mounting instructions of this product for selection and application method of the thermal grease.

2. Precautions on storage

- This product must be stored at a normal temperature of 5 to 35ºC and relative humidity of 45 to 75%. If the storage area is very dry, a humidifier may be required. In such a case, use only deionized water or boiled water, since the chlorine in tap water may corrode the leads.
- This product should not be subjected to rapid changes in temperature to avoid condensation on the surface of this product. Therefore store this product in a place where the temperature is steady.
- This product should not be stored on top of each other, since this may cause excessive external force on the case.
- This product should be stored with the lead terminals remaining unprocessed. Rust may cause presoldered connections to fail during later processing.
- This product should be stored in antistatic containers or antistatic shipping bags.
- Under the above storage condition, use this product within one year.