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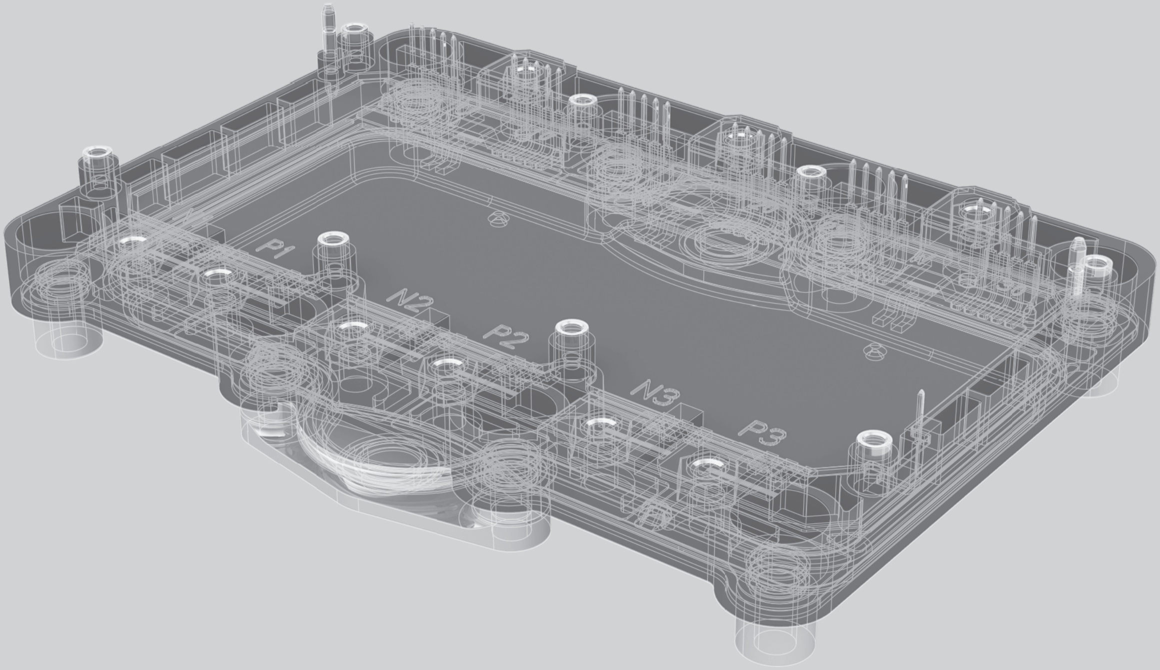

Fuji Automobile IGBT Module
M653 Series
6MBI800XV-075V-01

Application Manual

December 2016 Rev.0

Fuji Electric Co.,Ltd.

MT5F33743

Warning:

This manual contains the product specifications, characteristics, data, materials, and structures as of Nov. 2016.

The contents are subject to change without notice for specification changes or other reasons. When using a product listed in this Catalog, be sure to obtain the latest specifications.

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⚠ Cautions

(1) During transportation and storage

Keep locating the shipping carton boxes to suitable side up. Otherwise, unexpected stress might affect to the boxes. For example, bend the terminal pins, deform the inner resin case, and so on.

When you throw or drop the product, it gives the product damage.

If the product is wet with water, that it may be broken or malfunctions, please subjected to sufficient measures to rain or condensation.

Temperature and humidity of an environment during transportation are described in the specification sheet. There conditions shall be kept under the specification.

(2)Assembly environment

Since this power module device is very weak against electro static discharge, the ESD countermeasure in the assembly environment shall be suitable within the specification described in specification sheet. Especially, when the conducting pad is removed from control pins, the product is most likely to get electrical damage.

(3)Operating environment

If the product had been used in the environment with acid, organic matter, and corrosive gas (hydrogen sulfide, sulfurous acid gas), the product's performance and appearance can not be ensured easily.

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Chapter 1 Basic Concept and Features

This chapter describes the basic concept and features of the automotive IGBT module.

1. Basic Concept of The Automotive IGBT Module

From the viewpoint of protecting the global environment, the reduction of Carbon dioxide (CO_2) emissions has recently been required in the world. In the automotive field, use of hybrid electric vehicles (HEV) and electric vehicles (HV) has been increasing to reduce CO_2 emissions. HEV and EV drive a running motor A driving motor in HEV and EV is driven by converting DC power stored in a high-voltage battery into AC power using a power conversion system. IGBT modules are mainly used for such power conversion system. The IGBT module used for the power conversion system is required to be compact since a high-voltage battery, power conversion system, motor, etc. must be installed within a limited space.

In view of such circumstances, Fuji's automotive IGBT module has been developed based on the concept of "downsizing."

Fig. 1-1 shows the basic needs in the market for IGBT modules, which include the improvement in performance and reliability and reduction in environmental impact. Since characteristics determining performance, reliability, and environmental load are related to one another, it is essential to improve them in good balance to downsize the IGBT module.

The newly developed automotive IGBT module achieves the basic concept "downsizing" by adopting (i) 3rd-generation direct liquid-cooling structure with water jacket, (ii) 7th-generation X-series RC-IGBT*1) chip, and (iii) high-strength soldering material, thus optimizing the performance, reliability and environmental impact. And two on-chip sensors, which are current sensor and temperature sensor, can support high reliability. Additionally, the P-voltage monitor terminal can assist the fine control of the power control system according to the battery voltage.

*1) RC-IGBT: Reverse Conducting Insulated Gate Bipolar Transistor

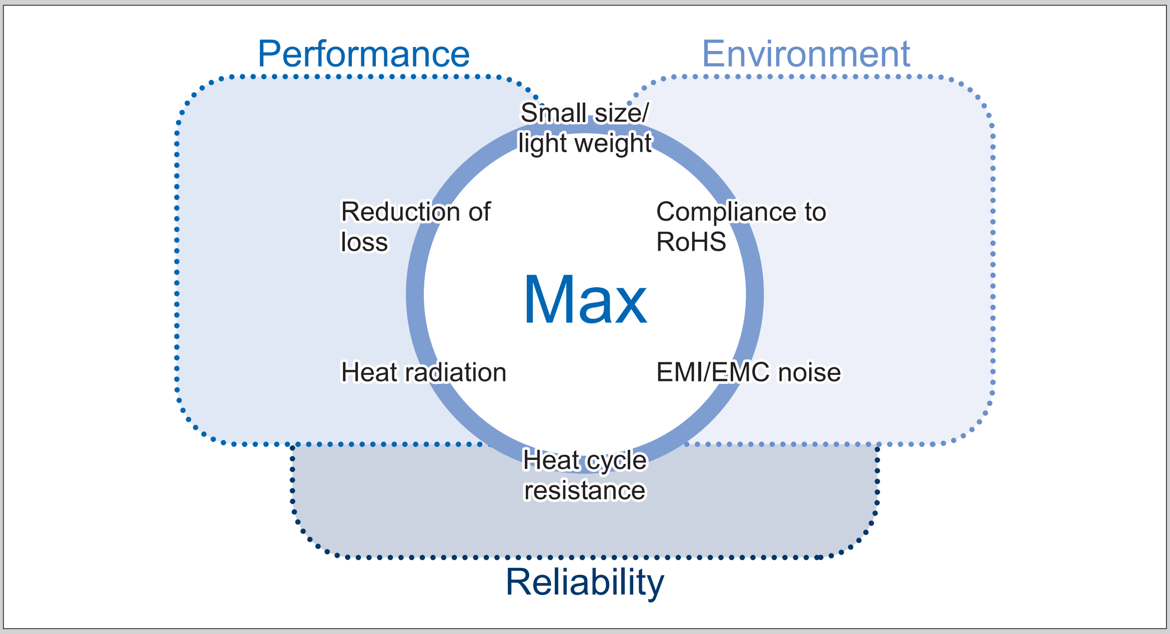


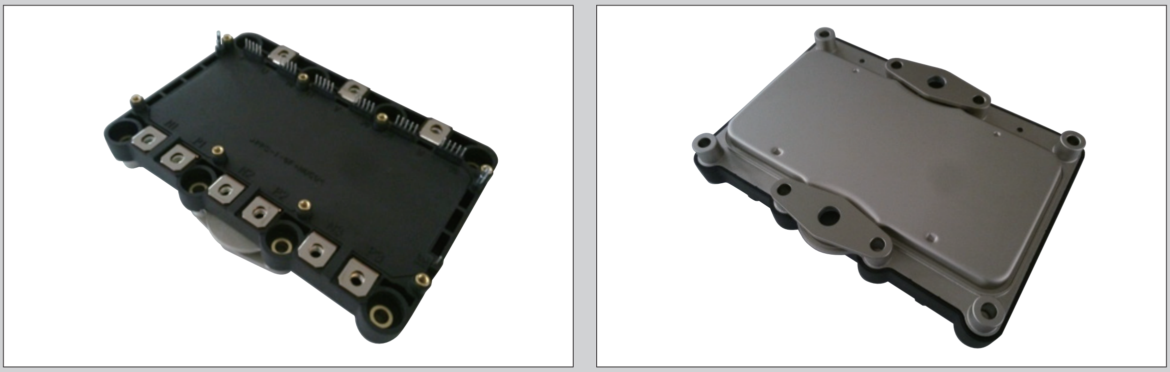
Fig. 1-1 IGBT module development concept targeted by Fuji Electric

2. Direct Liquid-Cooling Structure

The newly developed automotive IGBT module has achieved the decreasing of thermal resistance significantly by adopting 3rd. generation direct water-cooling structure. Although 1st. generation direct cooling system could be achieved 33% of thermal resistance improvement comparing to indirect cooling system, 3rd. generation system can be improved more 30% gain in thermal resistance by integrated base fins and water jacket. This concept can present not only better thermal resistance performance but also water flow design free. And applying flange type water flow connection, it is able to easily design to integrate motor and control module.

Fig. 1-2 shows the appearance of the newly developed automotive IGBT module developed this time.

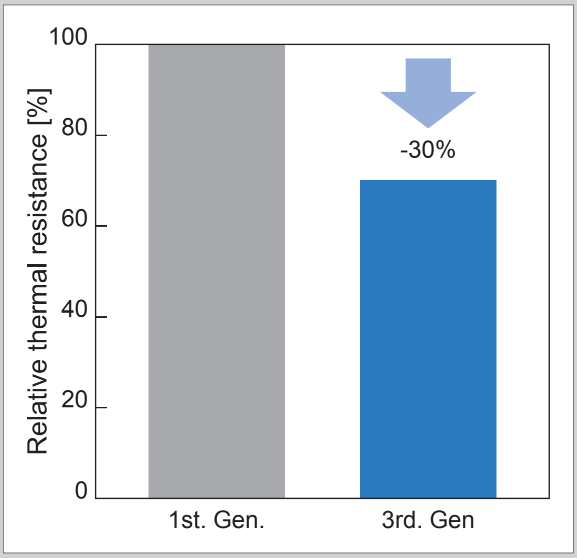
Fig. 1-3 is a comparison of steady-state thermal resistance between the 1st. generation and the 3rd. generation. On 3rd. generation cooling system, a cooling design without clearance increases coolant flow speed between fins, as a result 30% of the thermal resistance is improved.

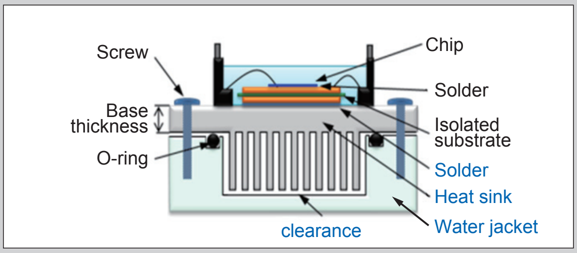


(a) Top face

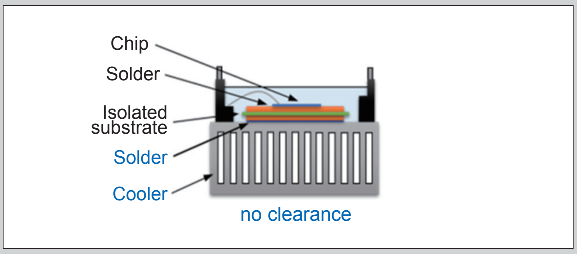
(b) Bottom face

Fig. 1-2 Appearance of 6MBI800XV-075V-01





(a) 1st. generation cooling structure



(b) 3rd. generation cooling structure

Fig. 1-3 Thermal resistance comparison

3. Feature of 7th Generation RC-IGBT Chips

The newly developed model of automotive IGBT module (6MBI800XV-075V) is using 750 V "X-series" RC-IGBTs . The X-series RC-IGBT has decreased on-state voltage and switching loss by optimizing field-stop (FS) structure. Furthermore, switching-speed controllability has also been improved by optimizing trench gate structure.

As shown in below schematic, RC-IGBT has IGBT part and FWD part in the same die like stripe shape.

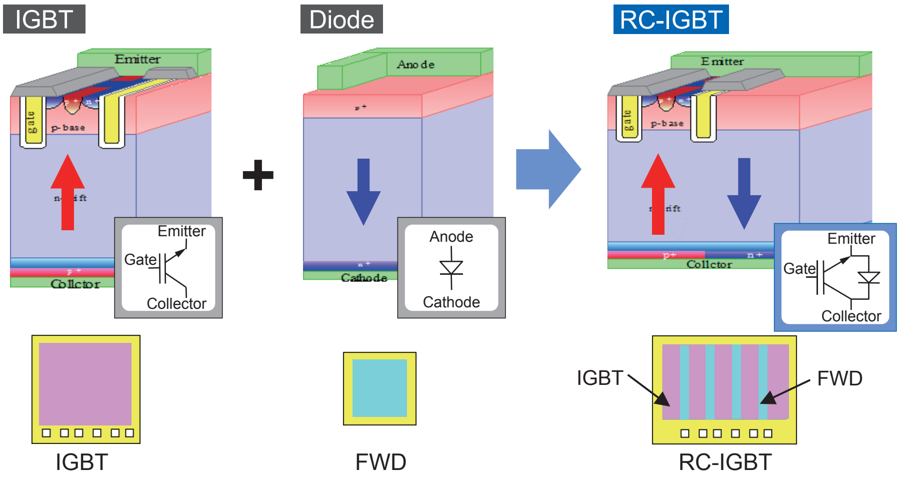


Fig. 1-4 Basic concept of the RC-IGBT

Advantage of the RC-IGBT is better $V_{CE(sat)}$-E_{off} performance than conventional IGBT.

As shown in below image, during the turn-off operation, the electron is easily swept because of corrector-shorted structure on the bottom side.

That is why turn-off loss is improved compare with conventional one.

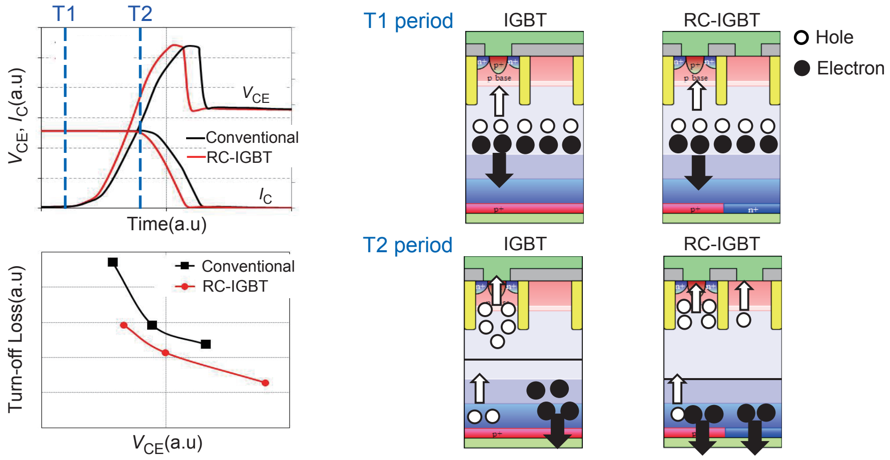


Fig. 1-5 Advantage of the RC-IGBT in loss

As shown in below schematic, IGBT and FWD part are alternately located on the die. Therefore thermal resistance is better than conventional one because the loss from each part are radiated from whole die surface.

Especially, the effect is big on rotor-lock mode, step-up converter and active short circuit operation.

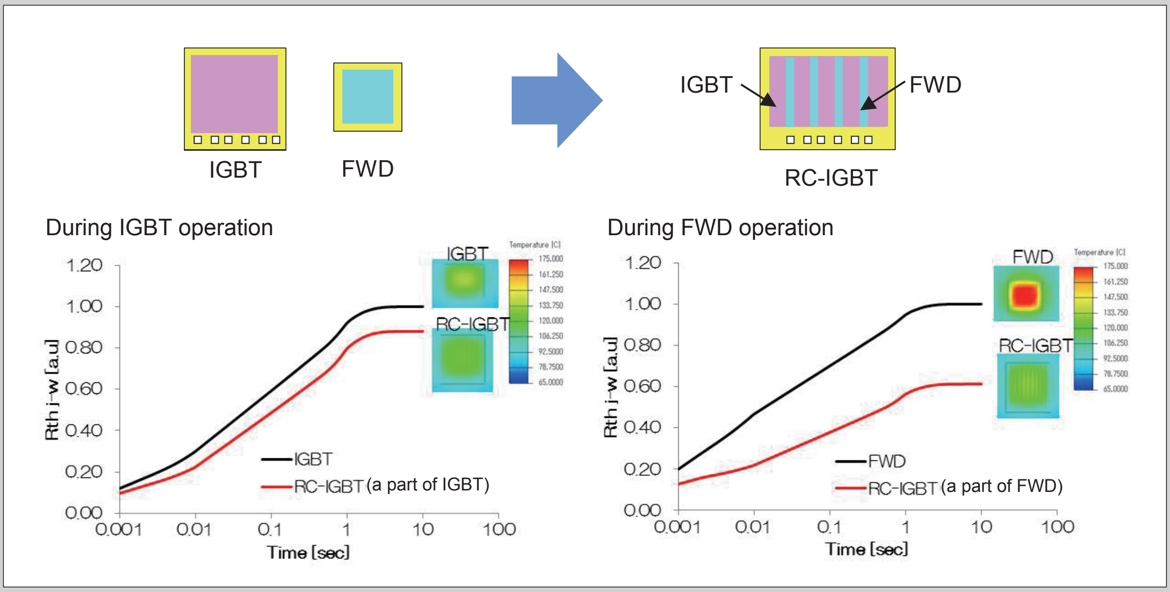
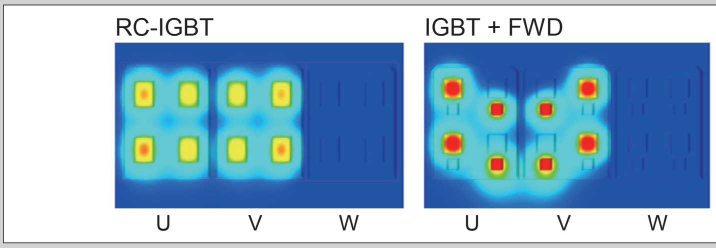


Fig. 1-6 Advantage of the RC-IGBT in thermal resistance

In the case of rotor-lock mode, RC-IGBT can dramatically suppress heating up because of large radiation area.

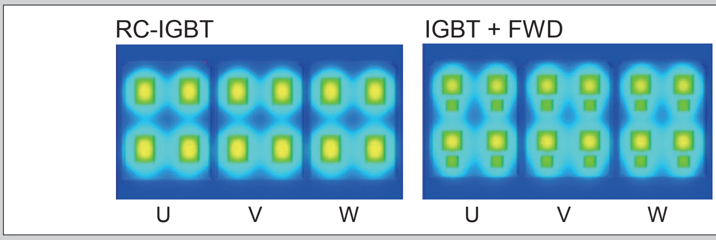
On the other hand, RC-IGBT has a little bit demerit on 3 phase operation since there is thermal interference between IGBT part and FWD part.



Die temperature

RC-IGBT: 146°C
FWD: 219°C
→ RC-IGBT is 73°C lower than FWD.

1) In the case of motor-lock



Die temperature

RC-IGBT: 130°C
Conventional IGBT: 126°C
→ RC-IGBT is 4°C higher than conventional IGBT.

2) In the case of 3 phase operation

Fig. 1-7 Advantage of the RC-IGBT in rotor lock mode

4. On-chip Sensors

As shown in Fig. 1-8, a temperature sensor and a current sensor are integrated on a same IGBT chip. By current source and a shunt resistor, a T_j and a current can be monitored, respectively.

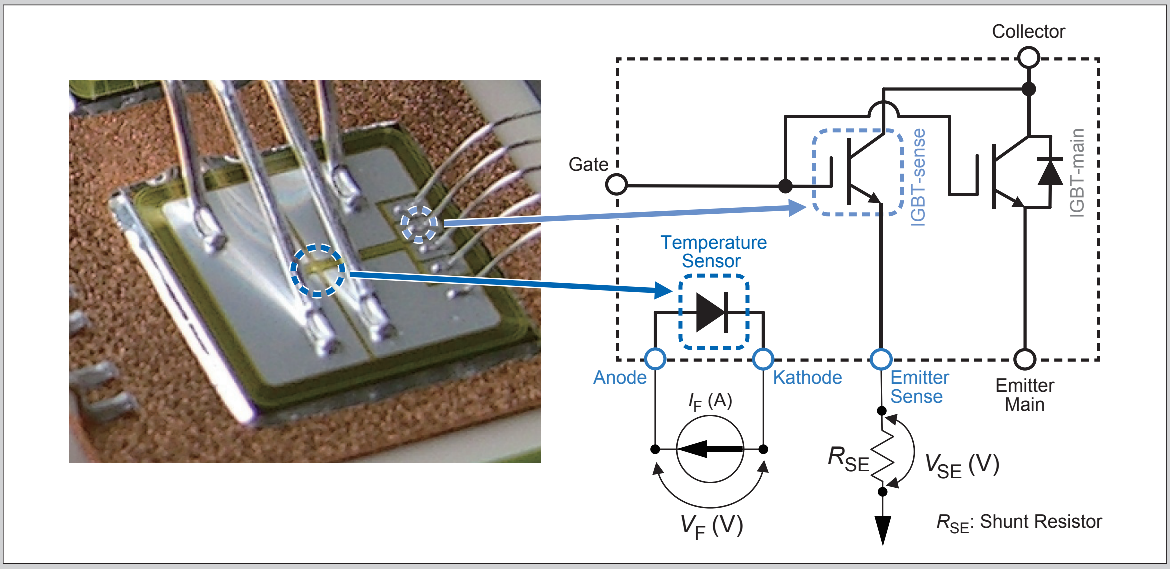
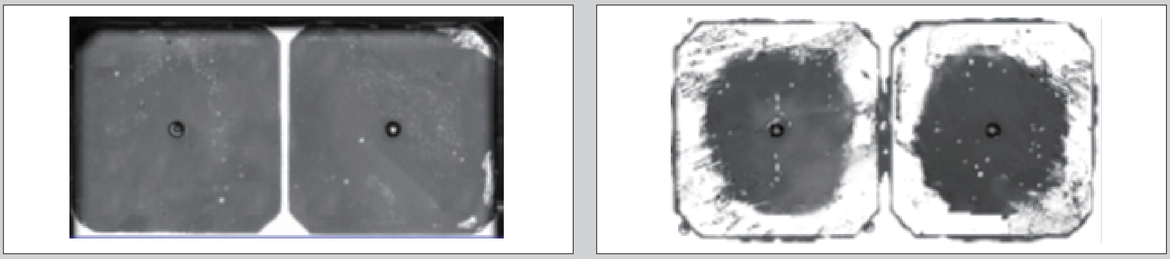


Fig. 1-8 On-chip sensors

5. Application of High-Strength Soldering Material

Since automotive semiconductors are often used in a severe condition compared to industrial or consumer use, higher reliability is required. In particular, if a crack is generated in a solder layer between the insulated substrate and the baseplate due to mechanical stress by temperature cycles, the thermal resistance is increased then abnormal chip heating might be occurred, and it cause a failure of the IGBT module. Fuji's automotive IGBT module suppresses generation of cracks significantly by changing solder material to newly developed SnSb series solder from conventional SnAg-series solder (Fig. 1-9).



(a) SnSb-series solder

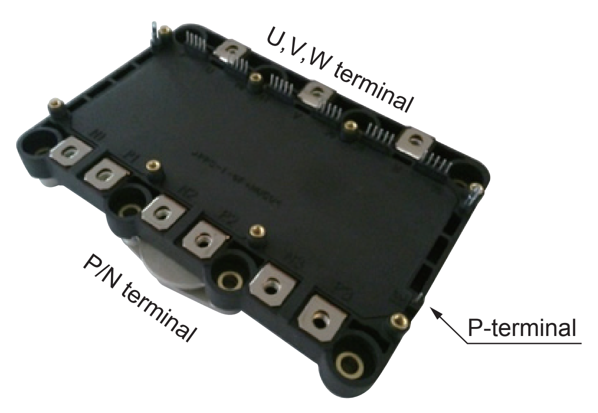
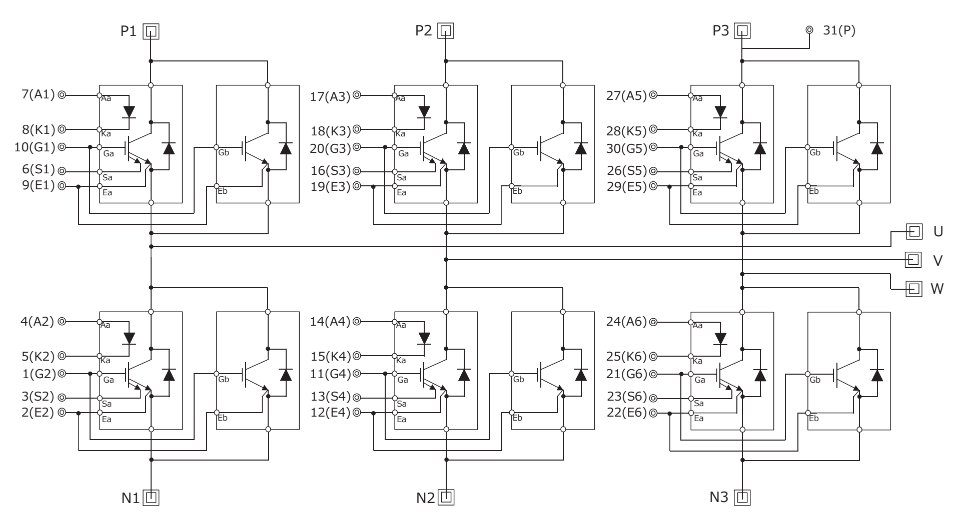
(b) SnAg-series solder

Fig. 1-9 Comparison in progress of cracks after temperature cycle test between SnSb-series solder and SnAg-series solder (Ultrasonic flow detection image after 2,000 temperature cycles)

6. Circuit Configuration

Table 1-1 shows the circuit configuration of the automotive IGBT modules.

Table 1-1 Circuit configuration

Name		6 in 1
Model name		6MBI800XV-075V
Appearance		
Equivalent circuit		
Features		One arm is constituted by two pars of RC-IGBT. Each arm at the outlet side of the cooling water has two on chip sensor. One is temperature sensing diode, and the other is current sensing IGBT.
Function	Temp. sensor	Temperature diode specification is shown in the specification sheet. Typical performance between V_F and T_j is shown in Fig. 7-3(a) of chapter 7.
	Sense IGBT	Sense IGBT specification is described in the specification sheet. And its typical characteristics and the usage examples are explained in the chapter 8.
	P-terminal	P-terminal can monitor the positive voltage of V_{dc} value. Negative voltage shall be taken from the terminal number 22, which is the emitter terminal of the lower arm of the phase W. This terminal voltage is same as voltage of P terminal so please take care of electric shock. An example of the P terminal voltage monitoring is shown in Fig. 7-5 of chapter 7.

7. Numbering System

The numbering system of the automotive IGBT module for 6MBI800XV-075V-01 is shown in Fig. 1-10 below as an example.

6 MB I 800 X V - 075 V - 01
(1) (2) (3) (4) (5) (6) (7) (8) (9)

	Symbol	Description
(1) Number of switch elements	6	6 arms
(2) Model group	MB	IGBT model
(3) Insulation type	I	Insulated type
(4) Maximum current	800	800 A
(5) Chip generation	X	X series
(6) In-house identification No.	V	Identification No.
(7) Element rating	075	Withstand voltage: 750 V
(8) Automotive product	V	Automotive product
(9) In-house identification No.	01	Identification No.

Fig. 1-10 Numbering system

Chapter 2 Terms and Characteristics

This chapter describes the terms related to the automotive IGBT module and its characteristics.

1. Description of Terms

Various terms used in the specification, etc. are described below.

Table 2-1 Maximum ratings

Term	Symbol	Definition explanation (See specifications for test conditions)
Collector-emitter voltage	V_{CES}	Maximum collector-emitter voltage with gate-emitter shorted
Gate-emitter voltage	V_{GES}	Maximum gate-emitter voltage with collector-emitter shorted
Collector current	I_{CN}	Ratings current
	I_{Cnom}	Maximum forward DC collector current
	I_{C}	
	$-I_{\mathrm{Cnom}}$	Maximum reverse DC collector current
	$-I_{\mathrm{C}}$	
Maximum power dissipation	P_{C}	Maximum power dissipation per element
Junction temperature	T_{j}	Maximum chip temperature, at which normal operation is possible. You must not exceed this temperature in the worst condition.
Operation junction temperature	$T_{\mathrm{j(op)}}$	Maximum chip temperature during continuous operation
Case temperature	T_{C}	Temperature of the case of the IGBT module
Storage temperature	T_{stg}	Temperature range for storage or transportation, when there is no electrical load on the terminals
Isolation voltage	V_{iso}	Maximum effective value of the sine-wave voltage between the terminals and the heat sink, when all terminals are shorted simultaneously
Screw torque	Mounting	Maximum torque for specified screws when mounting the IGBT on customer's system
	Main Terminal	Maximum torque for terminal screws when connecting external wires/bus bars to the main terminals
	PCB Mounting	Maximum torque for tightening screws when PCB install on the IGBT module
Control terminal soldering	Number of time	Maximum number of times
	Soldering temperature	Maximum soldering temperature
	Soldering time	Maximum soldering time

Caution: The maximum ratings must not be exceeded under any circumstances.

Table 2-2 Electrical characteristics

Term		Symbol	Definition explanation (See specifications for test conditions)
Static characteristics	Zero gate voltage collector current	I_{CES}	Collector leakage current when a specific voltage is applied between the collector and emitter with gate-emitter shorted
	Gate-emitter leakage current	I_{GES}	Gate leakage current when a specific voltage is applied between the gate and emitter with collector-emitter shorted
	Gate-emitter threshold voltage	$V_{GE(th)}$	Gate-emitter voltage at a specified collector current and collector-emitter voltage (gate-emitter voltage which start to flow a low collector current)
	Collector-emitter saturation voltage	$V_{CE(sat)}$	Collector-emitter voltage at a specified collector current and gate-emitter voltage (Usually V_{GE}=15V)
	Input capacitance	C_{ies}	Gate-emitter capacitance, when a specified voltage is applied between the gate and emitter as well as between the collector and emitter, with the collector and emitter shorted in AC
	Output capacitance	C_{oes}	Gate-emitter capacitance, when a specified voltage is applied between the gate and emitter as well as between the collector and emitter, with gate-emitter shorted in AC
	Reverse transfer capacitance	C_{res}	Collector-gate capacitance, when a specified voltage is applied between the gate and emitter, while the emitter is grounded
	Diode forward on voltage	V_F	Forward voltage when the specified forward current is applied to the internal diode
Dynamic characteristics	Turn-on time	t_{on}	The time interval between when the gate-emitter voltage rises to 0V and when the collector-emitter voltage drops to 10% of the maximum value during IGBT turn on
	Rise time	t_r	The time interval between when the collector current rises to 10% of the maximum value and when collector-emitter voltage drops to 10% of the maximum value during IGBT turn on
		$t_{r(i)}$	The time interval between when the collector current rises to 10% and when the collector current rises to 90% of the maximum value at IGBT turn-on
	Turn-off time	t_{off}	The time interval between when the gate-emitter voltage drops to 90% of the maximum value and when the collector current drops to 10% of the maximum value during IGBT turn off
	Fall time	t_f	Time required for collector current to drop from 90% to 10% of the maximum value
	Reverse recovery time	t_{rr}	Time required for reverse recovery current in the internal diode to decay
	Reverse recovery current	$I_{rr}(I_{rp})$	Peak reverse current during reverse recovery
Reverse bias safe operating area		RBSOA	Current and voltage area when IGBT can be turned off under specified conditions
Gate resistance		R_G	Series gate resistance (See switching time test conditions for standard values)

Table 2-3 Electrical characteristics (cont'd)

Term	Symbol	Definition explanation (See specifications for test conditions)
Gate charge capacity	Q_g	Turn on gate charge between gate and emitter
Electro Static Discharge	HMB	Static electricity tolerance on human body model
	MM	Static electricity tolerance on machine model
Sense emitter voltage	V_{SE}	Sense emitter voltage between specified shunt resistance under ratings corrector current by specified V_{GE}
Temperature sense diode forward on voltage	V_{ak}	Temperature sense diode forward voltage between anode and kathode

Table 2-4 Thermal resistance characteristics

Term	Symbol	Definition explanation (See specifications for test conditions)
Thermal resistance	$R_{th(j\text{-}w)}$	Thermal resistance between the junction and cooling water

2. Cooling Performance of the Automotive IGBT Module

2.1 Cooler (liquid-cooling jacket)

The automotive IGBT module has a direct liquid-cooling structure which has a aluminum base and fins with aluminum water jacket. The cooling efficiency is enhanced by eliminating clearance at the bottom of the cooler in 1st. generation cooling system. Although the 1st. generation direct cooling structure requires a cooler (liquid-cooling jacket) which has a flow path of coolant, it is not necessary to design the liquid-cooling jacket because of integrated both of base fin and water jacket in 3rd. generation cooling system any more.

2.2 Transient thermal resistance characteristics

Fig. 2-1 shows the transient thermal resistance characteristics which is used to calculate temperature increase. (This characteristics curve represents the value of one element of IGBT)

The thermal resistance characteristics are often used for thermal analysis, and defined by a formula similar to the one representing the Ohm’s law for electrical resistance.

Temperature difference ΔT [°C] = Thermal resistance R_{th} [°C/W] × Energy (loss) [W]

The thermal resistance is used for calculation of T_j of IGBT and FWD in the automotive IGBT module. (See Chapter 3 Heat dissipation design method for details.)

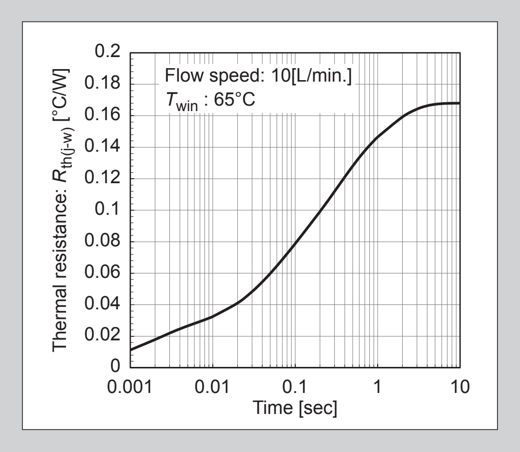


Fig. 2-1 Transient thermal resistance (max.)

2.3 Cooling performance dependence of cooling liquid temperature

The temperature of the cooling liquid (coolant) which is used to cool the automotive IGBT module does not affect the thermal resistance. Meanwhile, the higher the cooling water temperature, the lower the pressure loss, but higher the junction temperature. Due attention should therefore be paid to the above when designing the module.

2.4 Cooling performance and pressure loss

Dependence of flow rate of cooling liquid as well as the cooling liquid temperature, the flow rate of the cooling liquid also affects the cooling performance. The cooling performance increases with an increase of flow rate, but the pressure loss between the inlet and outlet of the flow path also increases. If the pressure loss increases, the variation of chip temperature in the module becomes wide. Therefore it is necessary to optimize the performance of the pump in the system and flow path design.

As a typical example, Fig. 2-2 shows the pressure loss and thermal resistance on the flow rate of coolant. Refer to this figure when designing a module.

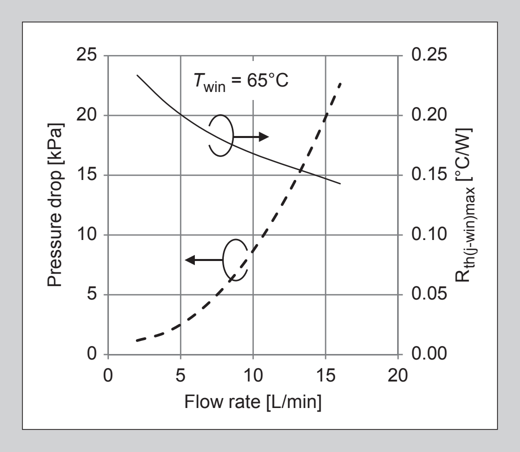


Fig. 2- 2 Pressure drop and R_{th} dependence of flow rate

Chapter 3 Heat Dissipation Design Method

This chapter describes heat dissipation design.

To operate the IGBT safely, it is necessary not to allow the junction temperature (T_j) to exceed $T_{j(max)}$.

Perform thermal design with sufficient allowance in order not for $T_{j(max)}$ to be exceeded not only in the operation under the rated load but also in abnormal situations such as overload operation.

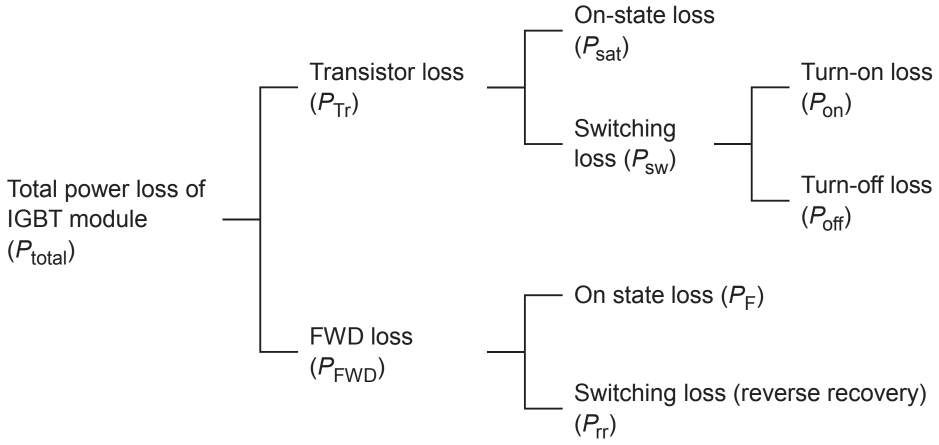
1. Power Dissipation Loss Caluculation

In this section, the simplified method of calculating power dissipation for IGBT modules is explained.

1.1 Types of power loss

The IGBT module consists of several IGBT dies and FWD dies. The sum of the power losses from these dies equals the total power loss for the module. Power loss can be classified as either on-state loss or switching loss. A diagram of the power loss factors is shown as follows.

Power loss factors



The on-state power loss from the IGBT and FWD part can be calculated using the output characteristics, and the switching losses can be calculated from the switching loss vs. collector current characteristics on the datasheet. Use these power loss calculations in order to design a suitable cooling system to keep the junction temperature T_j below the maximum rated value.

The on-state voltage and switching loss values at higher junction temperature (T_j = 175°C) is recommended for the calculation.

Please refer to the module specification sheet for these characteristics data.

1.2 Power dissipation loss calculation for sinusoidal VVVF inverter application

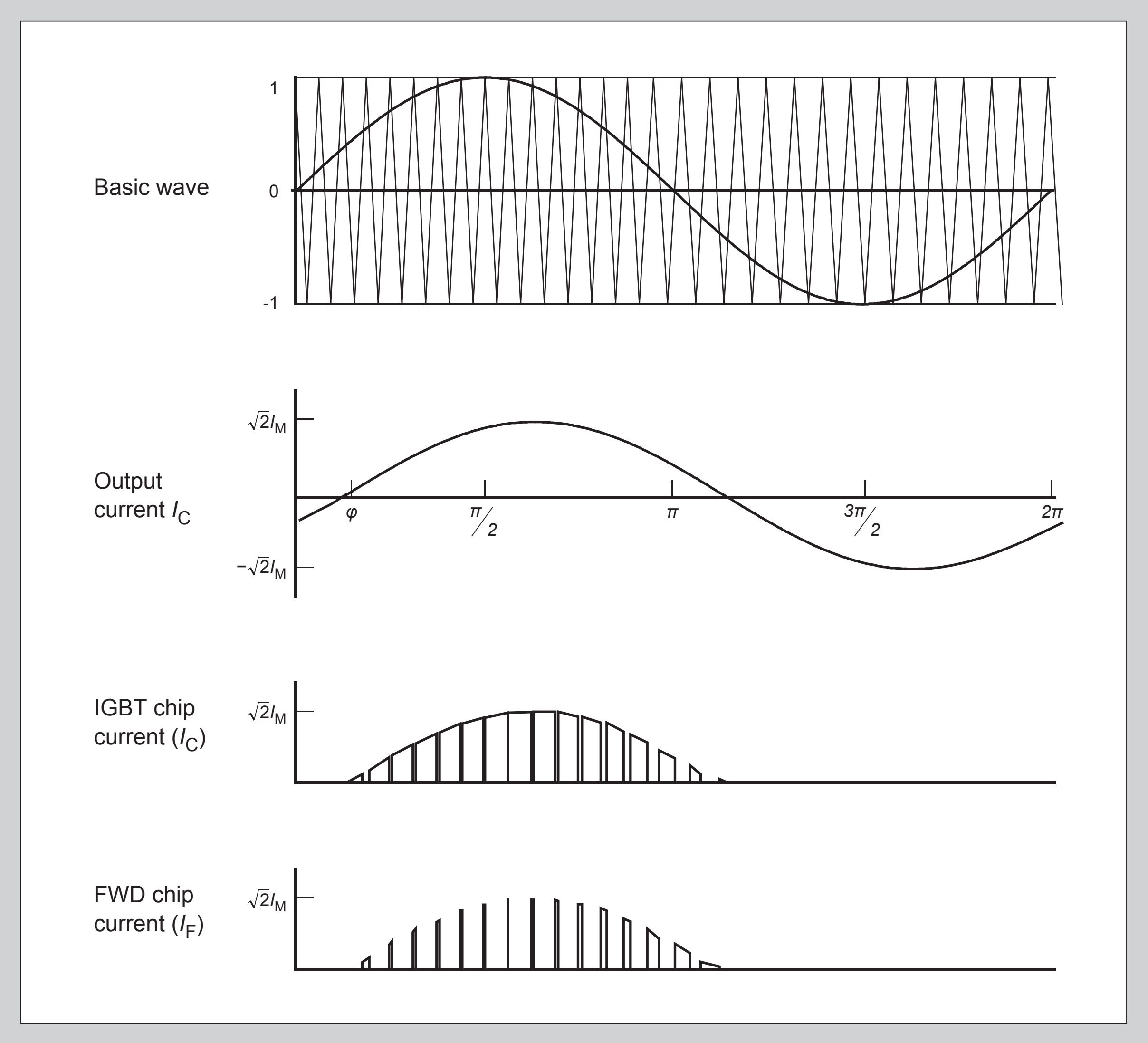


Fig. 3-1 PWM inverter output current

In case of a VVVF inverter with PWM control, the output current and the operation pattern are kept changing as shown in Fig.3-1. Therefore, it is helpful to use a computer calculation for detailed power loss calculation. However, since a computer simulation is very complicated, a simplified loss calculation method using approximate equations is explained in this section.

Prerequisites

For approximate power loss calculations, the following prerequisites are necessary:

- Three-phase PWM-control VVVF inverter for with ideal sinusoidal current output
- PWM control based on the comparison of sinusoidal wave and saw tooth waves

On-state power loss calculation (P_{sat}, P_F)

As displayed in Fig.3-2, the output characteristics of the IGBT and FWD have been approximated based on the data contained in the module specification sheets.

On-state power loss in IGBT chip (P_{sat}) and FWD chip (P_F) can be calculated by following equations:

$$\left(P_{sat}\right) = DT\int_0^x I_C V_{CE(sat)}\,d\theta$$

$$= \frac{1}{2}DT\left[\frac{2\sqrt{2}}{\pi} I_M V_O + I_M{}^2 R\right]$$

$$\left(P_F\right) = \frac{1}{2}DF\left[\frac{2\sqrt{2}}{\pi} I_M V_O + I_M{}^2 R\right]$$

DT, DF: Average on-state ratio of the IGBT and FWD at a half-cycle of the output current. (Refer to Fig.3-3)

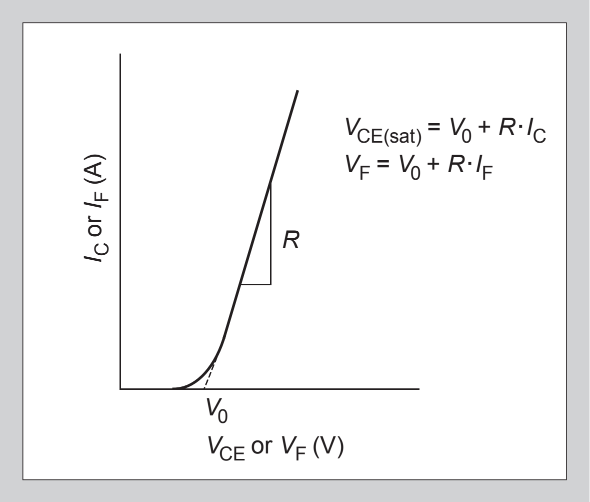


Fig. 3-2 Approximate output characteristic

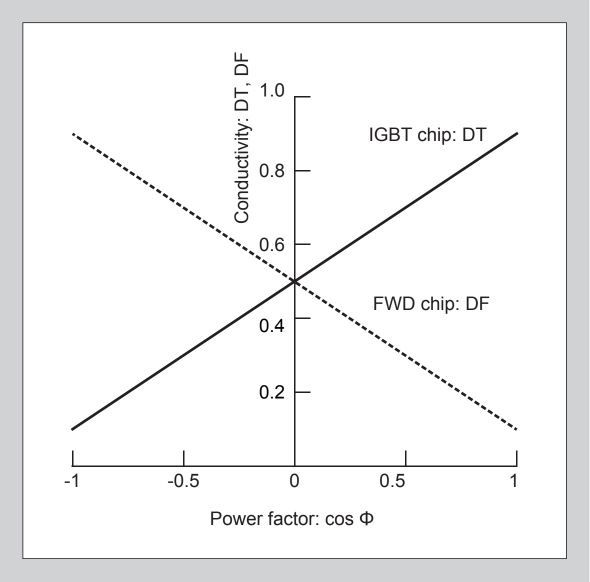


Fig. 3-3 Relationship between power factor sine-wave PWM inverter and conductivity

On-state power loss in IGBT chip (P_{sat}) and FWD chip (P_F) can be calculated by following equations:

$$E_{on} = E_{on'}\left(I_C / \text{rated}\, I_C\right)^a$$

$$E_{off} = E_{off'}\left(I_C / \text{rated}\, I_C\right)^b$$

$$E_{rr} = E_{rr'}\left(I_C / \text{rated}\, I_C\right)^c$$

a, b, c: Multiplier

$E_{on'}$, $E_{off'}$, $E_{rr'}$: Eon, E_{off} and E_{rr} at rated I_C

The switching losses can be represented as follows:

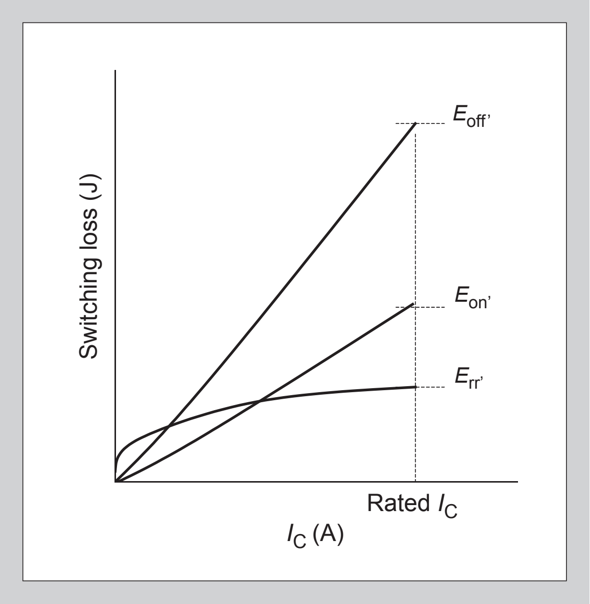


Fig. 3-4 Approximate switching losses

- Turn-on loss (P_{on})

$$P_{on} = f_o \sum_{K=1}^{n} (E_{on})k \qquad \left(\text{n: Half−cycle switching count} = \frac{f_c}{2f_o}\right)$$

$$= f_o E_{on'} \frac{1}{\text{rated}\, I_C{}^a} \sum_{K=1}^{n} (I_C{}^a)k$$

$$= f_o E_{on'} \frac{n}{\text{rated}\, I_C{}^a \times \pi} \int_0^{\pi} \sqrt{2}\, I_M{}^a \sin\theta d\theta$$

$$= f_o E_{on'} \frac{1}{\text{rated}\, I_C{}^a}\, n I_M{}^a$$

$$= \frac{1}{2} f_c E_{on'} \left[\frac{I_M}{\text{rated}\, I_C}\right]^a$$

$$= \frac{1}{2} f_c E_{on} \left(I_M\right)$$

$E_{on}(I_M)$: $I_C = E_{on}$ at I_M

- Turn-off loss (P_{off})

$$P_{off} = \frac{1}{2} f_c E_{off} \left(I_M\right)$$

$E_{\mathrm{off}}\,(I_{\mathrm{M}})$: $I_{\mathrm{C}} = E_{\mathrm{off}}$ at I_{M}

- FWD reverse recovery loss (P_{rr})

$$P_{\mathrm{rr}} \approx \frac{1}{2} f_{\mathrm{c}} E_{\mathrm{rr}} \left(I_{\mathrm{M}} \right)$$

Total power loss
Using the results obtained in section 1.2.

IGBT chip power loss: $P_{T_{\mathrm{r}}} = P_{\mathrm{sat}} + P_{\mathrm{on}} + P_{\mathrm{off}}$

FWD chip power loss: $P_{\mathrm{FWD}} = P_{\mathrm{F}} + P_{\mathrm{rr}}$

The DC supply voltage, gate resistance, and other circuit parameters will differ from the standard values listed in the module specification sheets.

Nevertheless, by applying the instructions of this section, the actual values can easily be calculated.

2. Usage of the Cooler with Water Jacket

Usage of cooling system of this IGBT module is very easy, because a water jacket is already integrated to cooling fin base. So user do not need to design any water jacket comparing to conventional open pin fin type IGBT module.

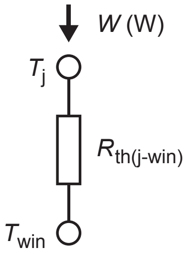
2.1 Thermal equation in steady state

Thermal conduction of IGBT module can be represented by an electrical circuit. In this section, in the case only one IGBT module mounted to a heat sink is considered. This case can be represented by an equivalent circuit as shown in Fig. 3-5 thermally.

From the equivalent circuit shown in Fig. 3-5, the junction temperature (T_j) can be calculated using the following thermal equation:

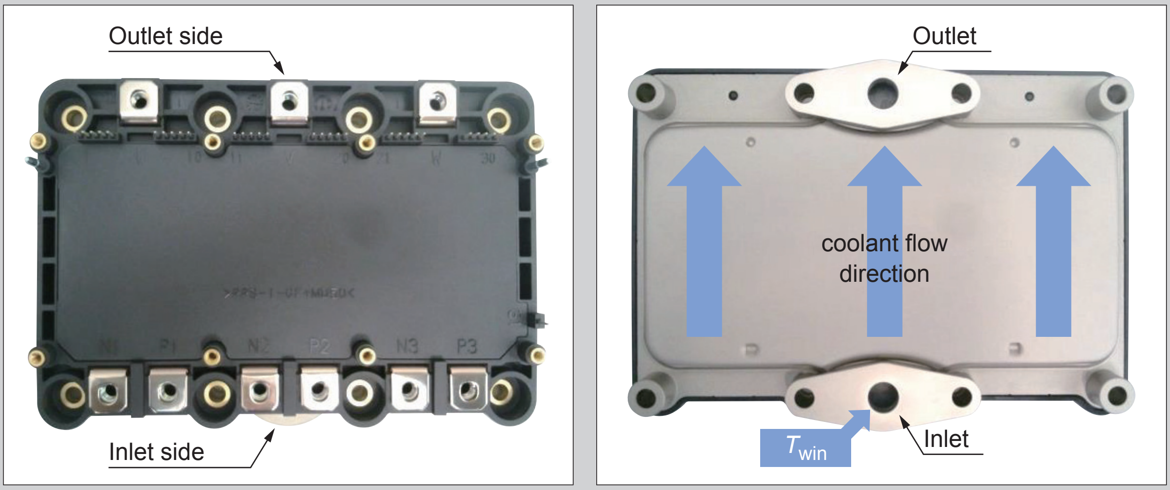
$$T_j = W \times \{R_{th(j\text{-}win)}\} + T_{win}$$

Where, the inlet coolant temperature T_{win} is represents the temperature at the position shown in Fig. 3-6. As shown in Fig. 3-6, the temperature at points other than the relevant point is measured low in actual state, and it depends on the heat dissipation performance of the water jacket. Please be designed to be aware of these.



W: Module power loss
T_j: Junction temperature of IGBT chip
T_{win}: Cooling water temperature
$R_{th(j\text{-}win)}$: Thermal resistance between junction and cooling water

Fig. 3-5 Equivalent circuit of the thermal resistance



(a) Top view

(b) bottom view

Fig. 3-6 An inlet and an outlet of the cooling sytem and the coolantr flow direction

2.2 Thermal equations for transient power loss calculations

Generally, it is enough to calculate T_j in steady state from the average loss calculated as described previous section. In actual situations, however, actual operation has temperature ripples as shown in Fig. 3-7 because repetitive switching produce pulse wave power dissipation and heat generation. In this case, considering the generated loss as a continuous rectangular-wave pulse having a certain cycle and a peak value, the temperature ripple peak value (T_{jp}) can be calculated approximately using a transit thermal resistance curve shown in the specification (Fig. 3-8).

$$T_{jp} - T_{win} = P \times \left[R(\infty) \times \frac{t_1}{t_2} + \left(1 - \frac{t_1}{t_2}\right) \times R(t_1 + t_2) - R(t_2) + R(t_1) \right]$$

Select a water jacket by checking that this T_{jp} does not exceed T_{jmax}.

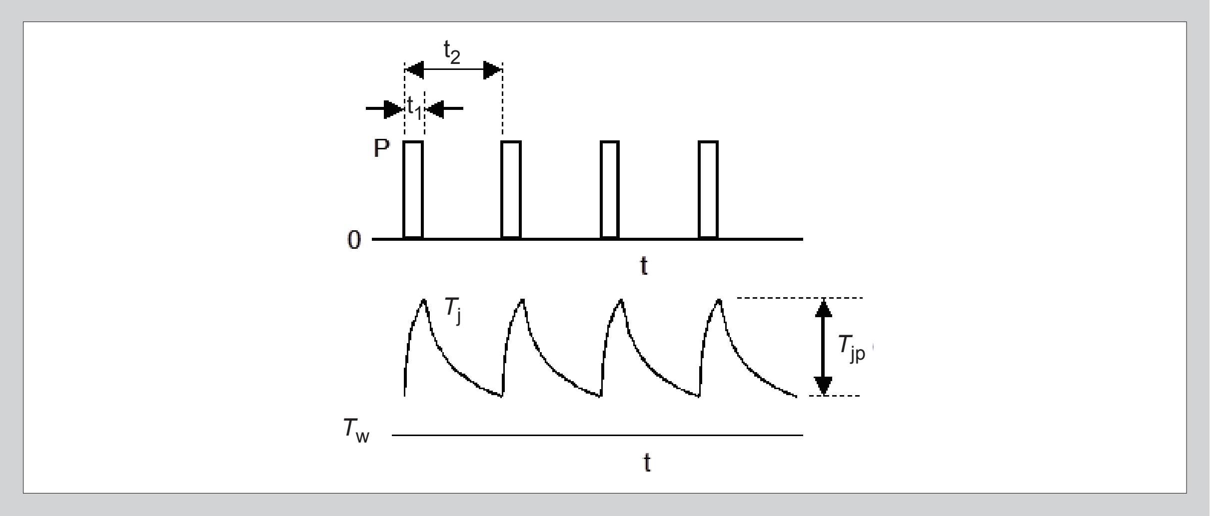


Fig. 3-7 Temperature ripple

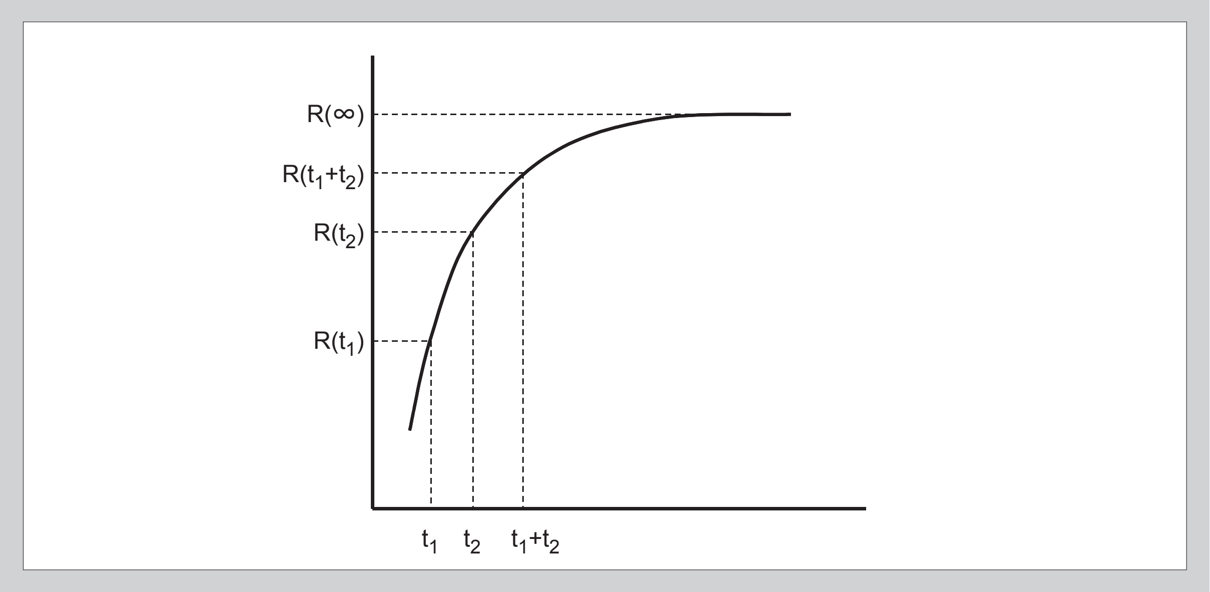


Fig. 3-8 Transit thermal resistance curve

2.3 Flow path and pressure loss

As shown in Fig. 3-6, the direction of cooling water is already designed from inlet to outlet. The pressure loss is almost same, even if the water flow direction were exchanged respectively. However, the water flow direction shall not be exchanged for safety operation, because the location of the junction temperature sensor diode is already fixed to the outlet side of the designed water flow direction.

2.4 Selection of cooling liquid

A mixed liquid of water and ethylene glycol shall be used as a coolant for the direct liquid-cooling system. As cooling liquid, 50% of long life coolant (LLC) aqueous solution is strongly recommended. Impurities contained in the coolant cause a clogging of flow path, and increasing pressure loss and decreasing cooling performance. So eliminating impurities shall be required to avoid performance degradation of the module. In addition, if water which corrosion inhibiter is not including is used, corrosion of aluminum oxide may be produced. To prevent the corrosion of fin base of the IGBT module, it is recommended to monitor the pH buffer solution and the corrosion inhibitor in the coolant periodically to keep these concentrations over the value which recommended by the LLC manufacturer. Replenish or replace the pH buffer agent and the corrosion inhibitor before their concentration decreases to the recommended reference value or lower.

IGBT module operation without coolant shall strictly forbid.

And any particle in the coolant which clog cooling system also shall be eliminated out by a filter.

2.5 Selection of O-ring

When this IGBT is installed to a power control system, certain suitable O-ring is needed. Size and material of O-ring depend on the system design and the operational environment of the system. Therefore, when O-ring is selected, sufficient confirmation about seal performance shall be needed.

There is an example of O-ring in Table 3-1 as the flange adapter kit for IGBT module evaluation.

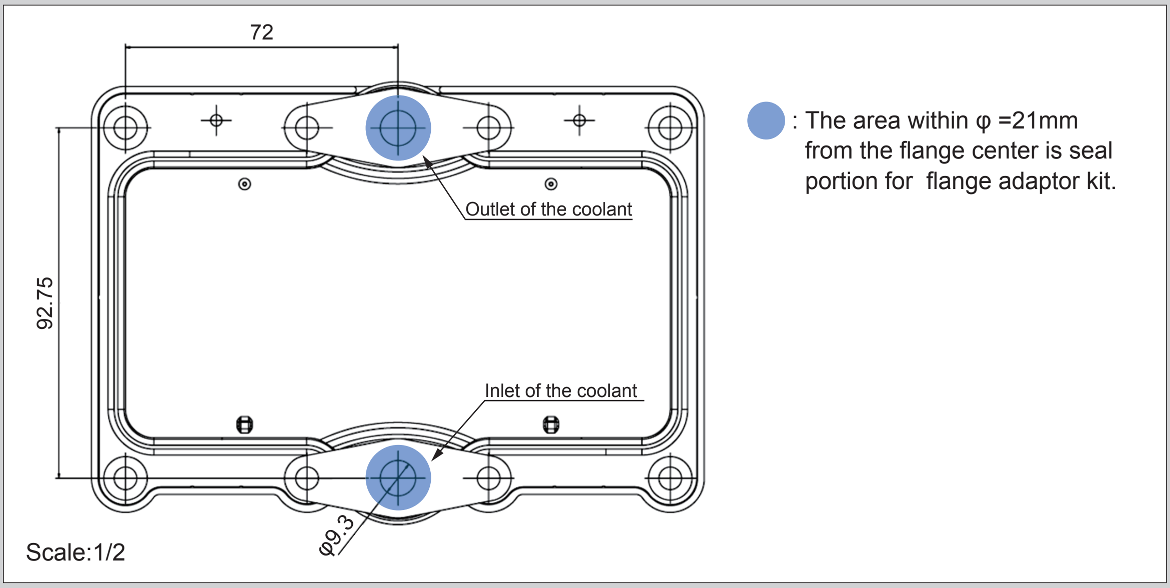
Seal area of the flange for the flange adapter kit is shown in Fig. 3-9.

2.6 Temperature check

After selecting a O-ring and determining the mounting position of the IGBT module, the temperature of each part should be measured to make sure that the junction temperature (T_j) of the IGBT module does not exceed the rating or the designed value.

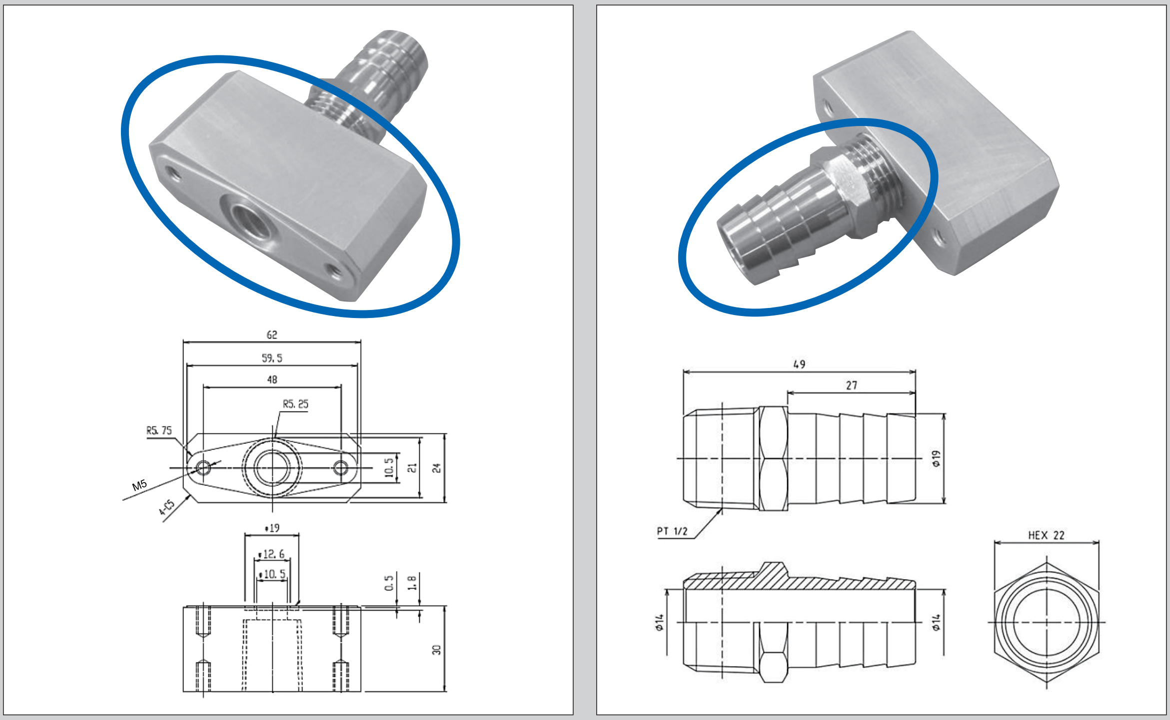
3. Flange Adaptor Kit

Flange adaptor kit is prepared as an optional part.
The kit is including a sealing block with O-ring and a nipple to connect the cooler to the water line.



●: The area within φ =21mm from the flange center is seal portion for flange adaptor kit.

Fig. 3-9 Seal area of the flange



(a) Flange adaptor base

(b) Nipple of flange adaptor

Fig. 3-10 Flange adaptor kit : flange adaptor base and nipple

Reference information of O-ring of the flange adaptor kit

- Size: P15 @JIS standard
- Material: NBR (Nitrile rubber)
- Hardness: 70

Table 5 Size of O-ring

Nominal size (JIS)	Dimension of O-ring			Dimension of grove						
	Thickness W	Inner dimension do		d	D	G (tolerance $^{+0.25}_{0}$)			H	R
						No backup ring	One backup ring	Two backup ring	H±0.05	MAX
P10A		9.8	±0.20	10	14					
P11		10.8	±0.21	11	15					
P11.2		11.0		11.2	15.2					
P12		11.8	±0.22	12	16					
P12.5		12.3		12.5	16.5					
P14		13.8		14	18					
P15	2.4±0.09	14.8	±0.24	$15^{\ 0}_{-0.06}$	$19^{+0.06}_{\ 0}$	3.2	4.4	6.0	1.8	0.4
P16		15.8		16	20					
P18		17.8	±0.25	18	22					
P20		19.8	±0.26	20	24					
P21		20.8	±0.27	21	25					
P22		21.8	±0.28	22	26					

Photo 5 The image of assembled O-ring onto the flange adaptor base

Chapter 4 Troubleshooting

This chapter describes how to deal with troubles that may occur while the automotive IGBT module is handled.

1. Troubleshooting

When the IGBT module is installed in an inverter circuit, etc. a failure of the IGBT module might be occurred due to improper wiring or mounting. Once a failure is occurred, it is important to identify the root cause of the failure. Table 4-1 illustrates how to determine a failure mode as well as the original causes of the failure by observing irregularities outside of the device. First of all, estimate a failure mode of the module by using the table when a failure is happened. If the root cause cannot be identified by using Table 4-1, see Fig. 4-1 as detailed analysis chart for helping your further investigation.

Table 4-1(a) Estimated causes and its device failure modes

External abnormalities		Cause		Device failure mode	Further checkpoints
Short circuit	Arm short-circuit	After short-circuit detection, surge voltage excess SCSO		Outside SCSOA	Integrity waveform of locus and device ruggedness
	Series arm short-circuit	Insufficient dead time	Large t_{off} due to reverse gate bias dead time setting mistakes	Over heating	Integrity device t_{off} and dead time
		dv/dt malfunction	less reverse gate bias too long gate wiring	SCSOA and/or overheat	Faulty turn-on due to dV/dt
		Noise induced	Gate circuit malfunction Logic circuit malfunction		confirm circuit mulfunction
	Output short-circuit	Faulty wiring, abnormal wire contact, load short-circuit			confirm failure phenomenon Integrity between device ruggedness and protection cunction Wiring conditions
	Ground short	Faulty wiring, abnormal wire contact			
Overload		Overcurrent	Logic circuit malfunction	Overheating	Logic signal
			protection function setting fault		Redesign of protecion condition
Overvoltage	Excessive DC voltage	Overvoltage larger than device breakdown voltae apply between Corrector and Emitter	Excessive input voltage	Excess ratings of V_{CE}	Redesign of protecion condition
			Overvoltage protection		
	Excessive spike voltage	Destruction due to excessive surge voltage larger than RBSOA at turn-off		RBSOA	Integrity confirmatiom RBSOA and operating locus at turn-off Redesign of sunubber circuit
		Destruction due to excessive surge voltage larger than device breakdown voltage at reverse recovery		Overvoltage of V_{ces}	Integrity spike voltage and device breakdown voltage sunubber circuit
		Reverse recovery phenomenon at operating with very narrow gate pulse *1)	logic circut or gate circuit malfunction due to noise		Logic circuit and/or gate circuit
			Electomagnetic induction noise from main circuit to gate wiring		Mutual interference between gate circuit and mian circuit
		Destruction by the main circuit wiring is too long, the surge voltage at the time of the turn-off to reach the dynamic avalanche voltage		Destruction due to dynamic avalanche	Redesign of main circuit inductance

*1) Excessive reverse recovery voltage over device breakdown voltage is produced, if gate pulse width is less than few hundrednano second.

Table 4-1(b) causes of device failure modes

External abnormalities		Cause		Device failure mode	Further checkpoints
driver supply voltage drop		V_{CE} is increased by V_{GE} lower than specified value. As a result, power consumption and Jule head are increased.	DC/DC converter malfunction	Overheat	Ecah circuit design
			Too mach time constant of power supply settling		
			Gate wiring break		
Excessive gate voltage		Electro static discharge on V_{GE}		Excessive V_{GES}	Assembly earea environment against ESD
		Spike voltage larger than V_{GES} is produced by too long gate wiring			Gate voltage
Operation under opened gate circuit		Voltage apply to Corrector and Emitter while gate is opened.		Overheat	Gate voltage
Overvoltege on temperature diode, sense IGBT		Temperature diode and/or sense IGBT destruction due to ESD		ESD	Assembly earea environment against ESD
Overheat	Lack of heat dissipation capacity	Anomalous heating due to lack of heat dissipation capacity	Less flow rate	Overheat	Radiation condition or radiation design
			Radiator malfunction		
	Thermal runaway	Total disspation is increased by carrier frequency increased due to logic circuit malfunction.			Logic circuit on gate
Stress	Stress	Soldered portion is broken by stress fatigue	Stress from external wiring	Disconnection of circuit	Mechanical stress due to mounting condition
	Vibration		Stress induced vibration		
Reliability (Life time)		The application condition exceeds the reliability of the module.		Destruction is different in each case.	Refer to Fig. 4-1 (a-f)

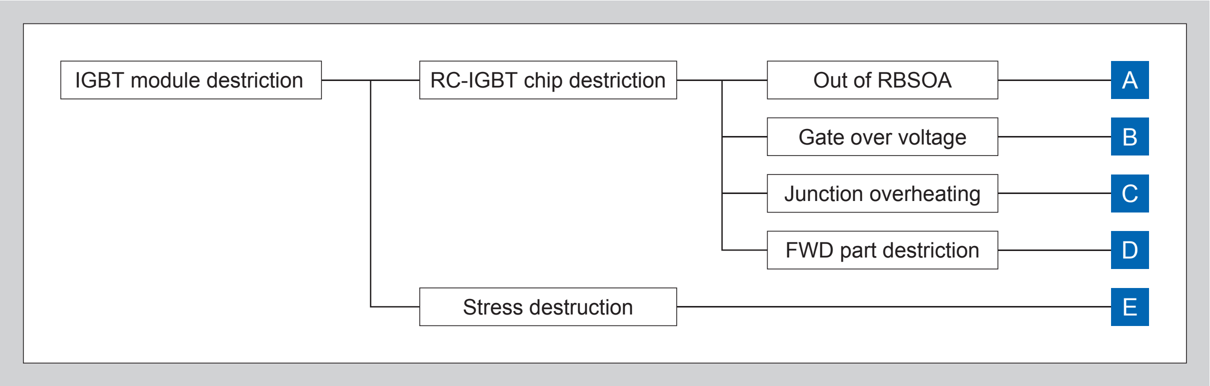


Fig. 4-1(a) IGBT module failure analysis

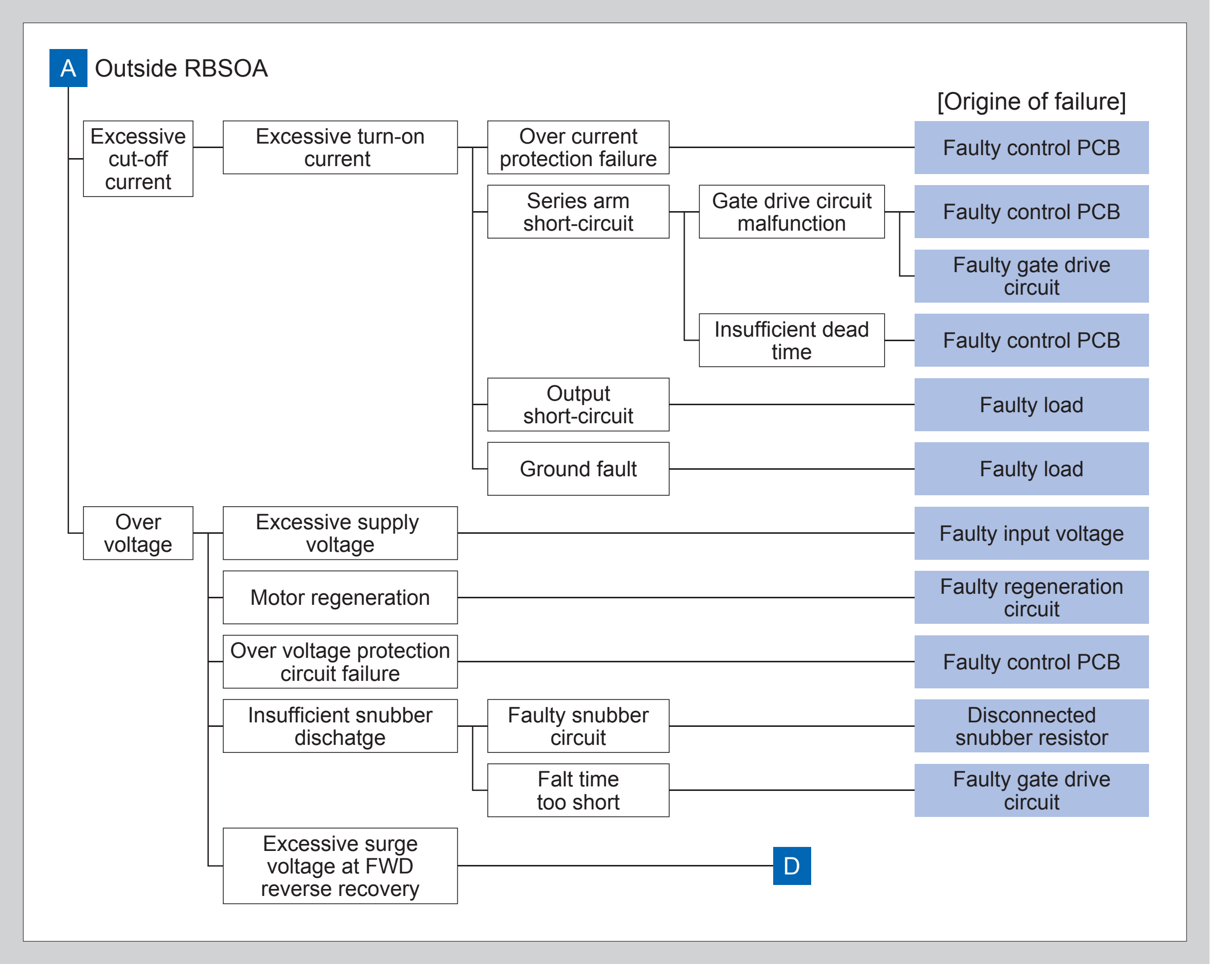


Fig. 4-1(b) Mode A: Outside RBSOA

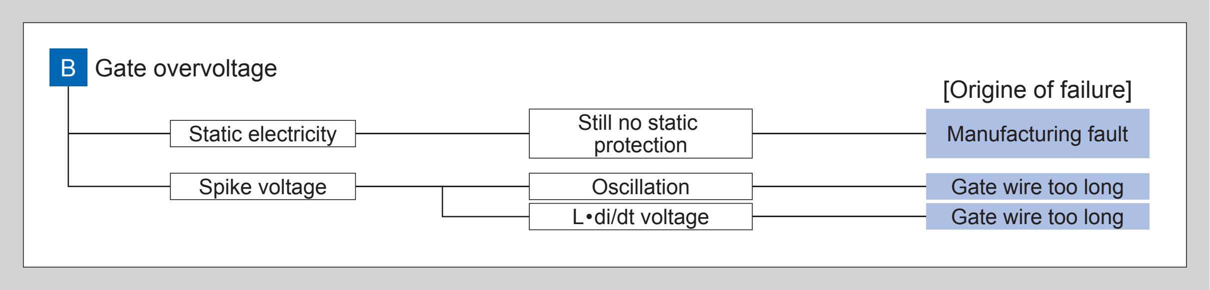


Fig. 4-1(c) Mode B: Gate overvoltage

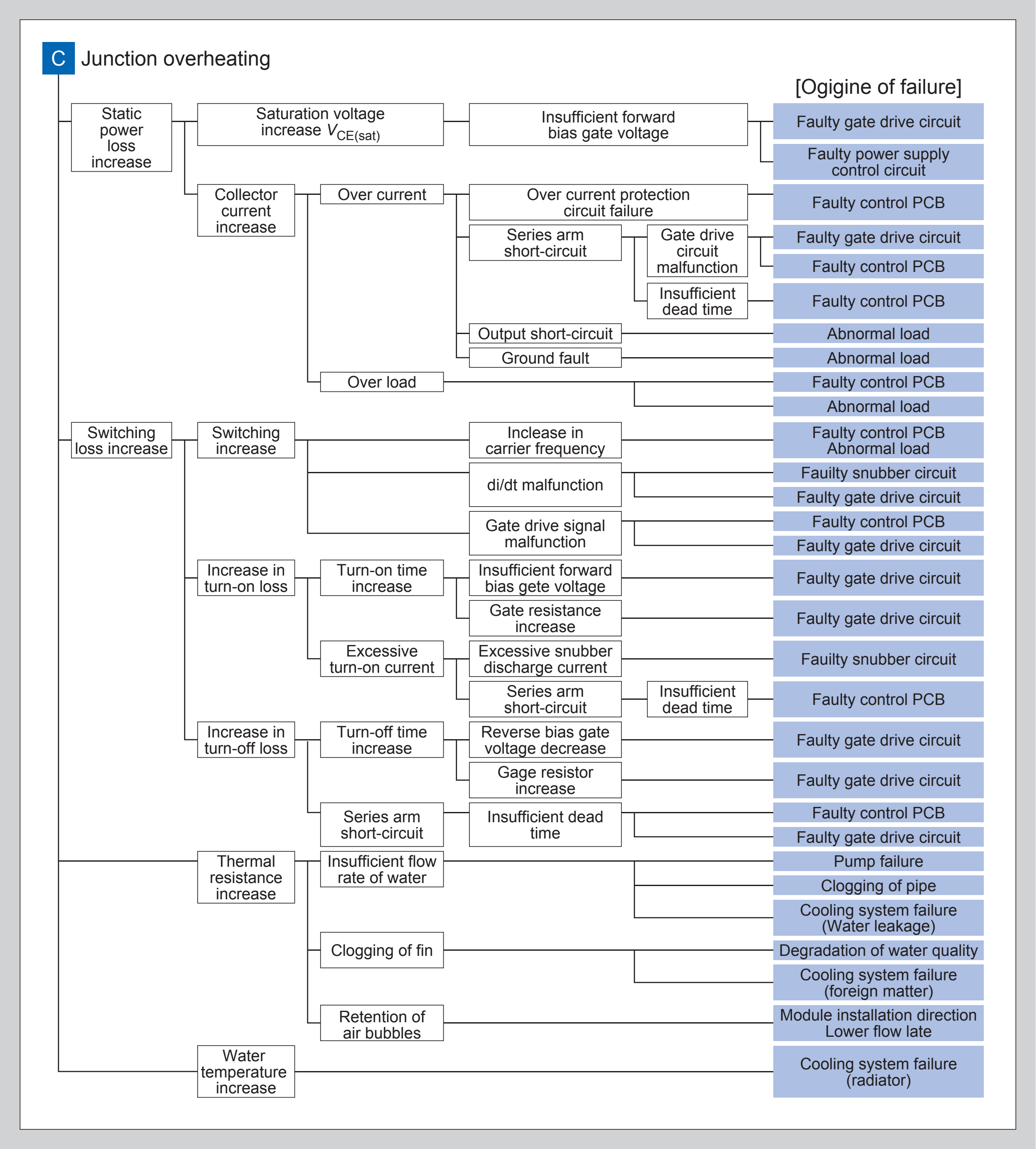
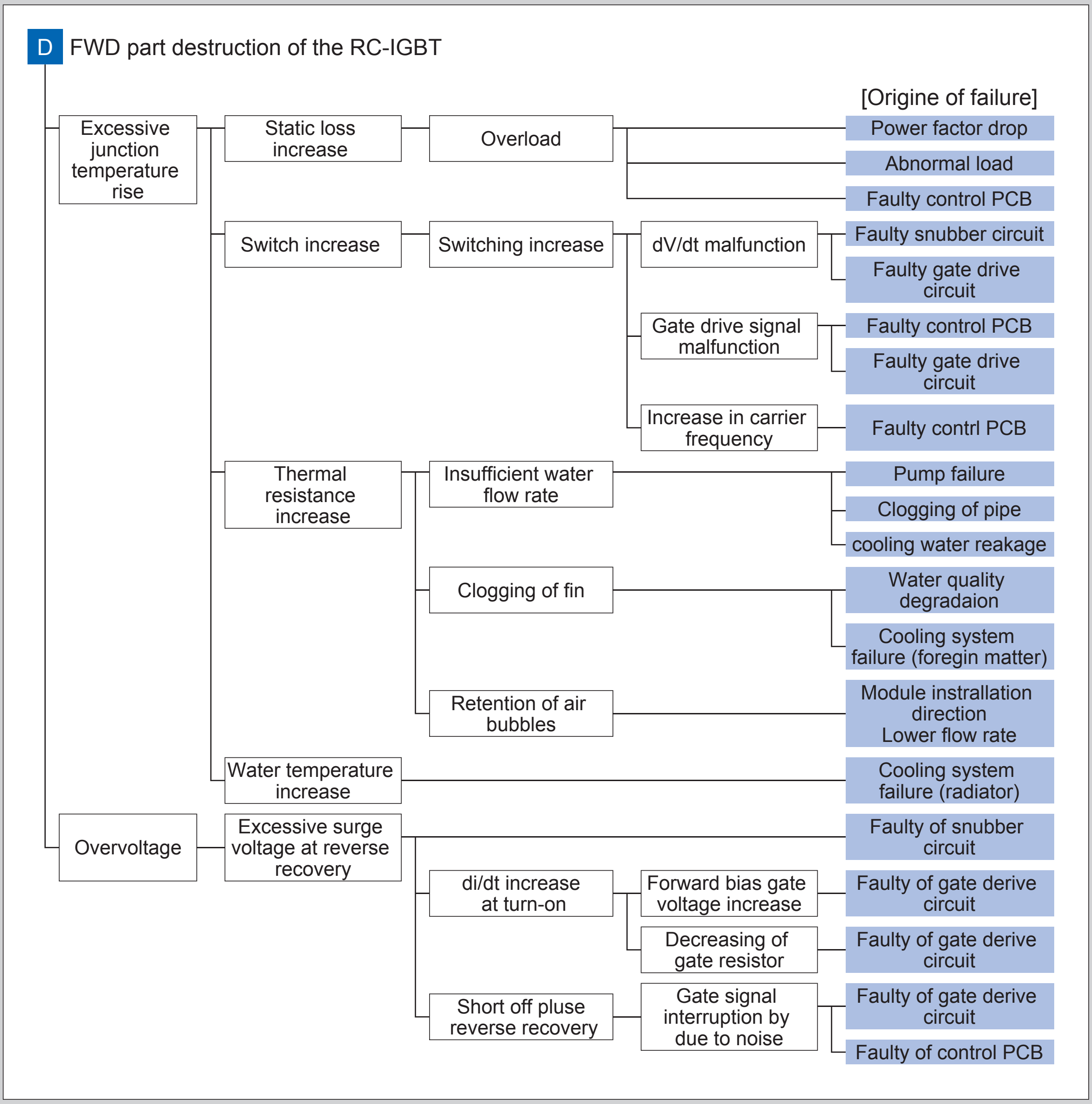


Fig. 4-1(d) Mode C: Junction over heating



D FWD part destruction of the RC-IGBT

[Origine of failure]

- Excessive junction temperature rise
  - Static loss increase
    - Overload
      - Power factor drop
      - Abnormal load
      - Faulty control PCB
  - Switch increase
    - Switching increase
      - dV/dt malfunction
        - Faulty snubber circuit
        - Faulty gate drive circuit
      - Gate drive signal malfunction
        - Faulty control PCB
        - Faulty gate drive circuit
      - Increase in carrier frequency
        - Faulty contrl PCB
  - Thermal resistance increase
    - Insufficient water flow rate
      - Pump failure
      - Clogging of pipe
      - cooling water reakage
    - Clogging of fin
      - Water quality degradaion
      - Cooling system failure (foregin matter)
    - Retention of air bubbles
      - Module installation direction Lower flow rate
  - Water temperature increase
    - Cooling system failure (radiator)
- Overvoltage
  - Excessive surge voltage at reverse recovery
    - Faulty of snubber circuit
    - di/dt increase at turn-on
      - Forward bias gate voltage increase
        - Faulty of gate derive circuit
      - Decreasing of gate resistor
        - Faulty of gate derive circuit
    - Short off pluse reverse recovery
      - Gate signal interruption by due to noise
        - Faulty of gate derive circuit
        - Faulty of control PCB

Fig. 4-1(e) Mode D: FWD destruction

E Destruction due to reliability or product handling

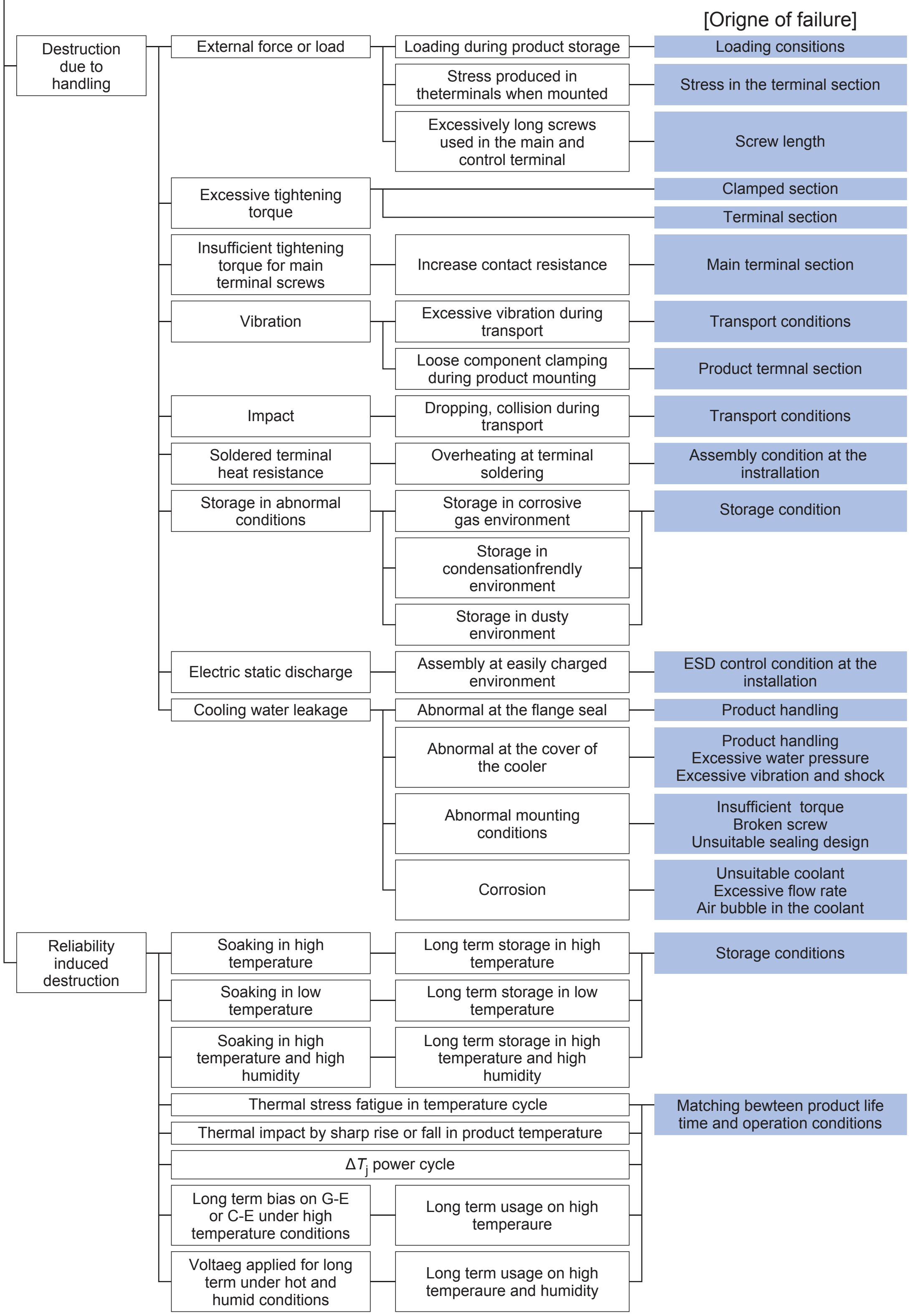


Fig. 4-1(f) Mode E: FWD destruction

Chapter 5 Precautions for Use

This chapter describes precautions for actual operation of the IGBT module.

1. Maximum Junction Temperature $T_{j(max)}$

As described in specification sheet, this automotive IGBT module can be used under T_j=175°C. However, if junction temperature under operation were excessed over the maximum ratings, the products life time degradation might be happened by expediting thermal fatigue destruction. Therefore, to keep safety operation, please use the product under suitable operating conditions.

2. Short-circuit Protection

When IGBT is to be short-circuit state, Collector current is increased and V_{CE} voltage is rapidly increased. From this characteristics, although Collector current is limited certain level under short-circuit state, high power due to high voltage and high current is apply to the IGBT at this moment. Therefore, this severe state should be removed as soon as possible.

An example by using gate driver IC which has short-circuit protection function is shown in chapter 7, please refer it.

As it is explained in chapter 1, this IGBT module has on-chip current detecting sensor. Its function and characteristics are shown in chapter 8.

So please use this on-chip sensor for short-circuit protection function suitably.

On the other, because this IGBT module does not have corrector voltage detecting point on each arm, desaturation type of short-circuit protection method shall not be used to avoid any unexpected trouble.

3. Overvoltage Protection and Safety Operation Area

3.1 Overvoltage protection

Because switching speed of IGBT is very fast, large di/dt is produced in turn-off operation or reverse recovery. So from this large di/dt and inductance component included in this module surge voltage is produced. If this surge voltage is excessed the device breakdown voltage, the device is in overvoltage state and it would be destructed in the worst case. Followings are some examples to avoid this kind of worst case:

1) Add snubber circuit 2) Tune the gate resistance 3) Reduce inductance in the main circuit

Images of turn-off waveform and reverse recovery waveform are shown in Fig. 5-1 and surge voltage is defined.

(a) Turn-off (b) Reverse recovery

Fig. 5-1 Turn-off waveform, reverse recovery waveform and surge voltage

Some examples of actual surge voltage by using 6MBI800XV-075V are explained below.

Fig. 5-2 shows an example of surge voltage dependence of collector current. In generally, the larger collector current makes the larger surge voltage at the turn-off. On the other hand, the larger collector current is produced the smaller surge voltage on reverse recovery.

Fig. 5-3 shows an example of surge voltage of reverse recovery dependence of gate resistor.

As explained above, surge voltage produced by IGBT module is not only depend on circuit inductance but also many of operating conditions like V_{CC} and circuit parameters like gate resistor.

Therefore, when IGBT module is employed to actual equipment, it is need to confirm that surge voltage on all of operating conditions is to be within RBSOA on actual system like invertor. If surge voltage is excess guaranteed RBSOA, surge voltage shall be suppressed by adding snubber circuit, by reducing stray inductance, by tuning gate resistors and so on. In addition, when surge voltage is reduced by gate resistor, it is able to be effective operating condition to independently tune the gate resistor of turn-on and turn-off, respectively.

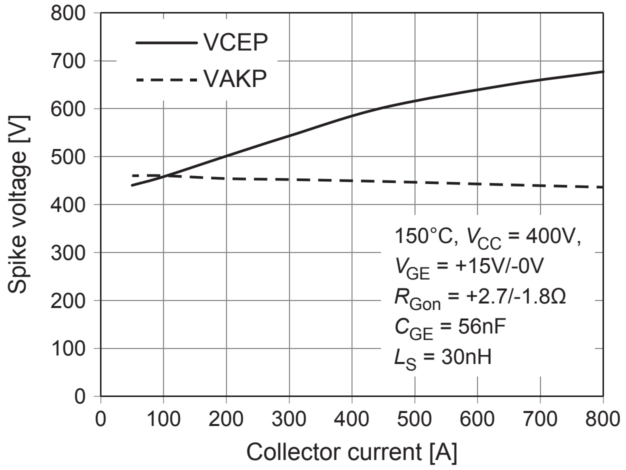


Fig. 5-2 An example of surge voltage dependence of collector current

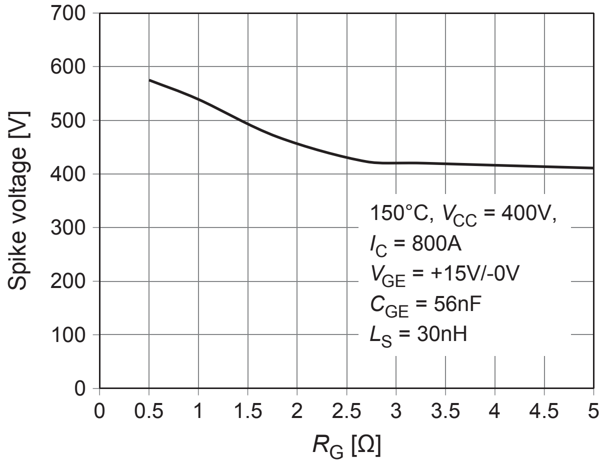


Fig. 5-3 An example of surge voltage of reverse recovery dependence of gate resistor

3.2 Surge voltage of turn-off dependence of gate resistor

Relating to overvoltage protection, an example of the surge voltage dependence of gate resistor is shown in Fig. 5-4.

In generally, a methodology, which the larger resistor is applied to suppress surge voltage, had been used. However, according to generation changing of IGBT chip itself, the surge voltage characteristics is also being changed. Therefore, when gate resisters is tuned, sufficient confirmation on actual system shall be needed.

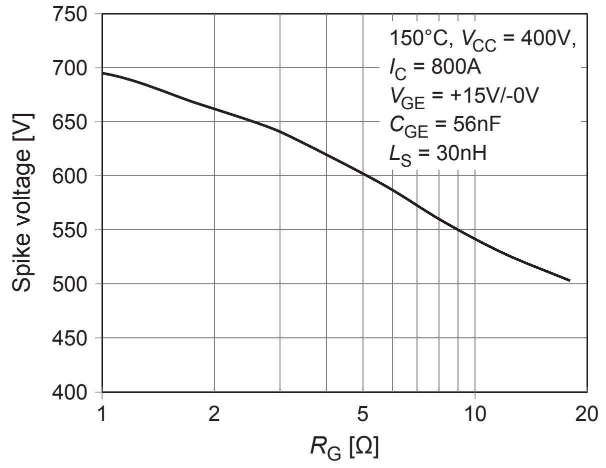


Fig. 5-4 An example of surge voltage of turn-off dependence of gate resistor

3.3 Safety operation area (SOA) of FWD part

As same as RBSOA of IGBT, SOA of FWD part is also defined. SOA of diode is defined as acceptable area of maximum power (P_{max}) which is the product of current and voltage during reverse recovery operation. Therefore, any system shall be designed that locus of current and voltage during reverse recovery should be within SOA.

An example of SOA of FWD part of 6MBI800XV-075V is shown in Fig. 5-5.

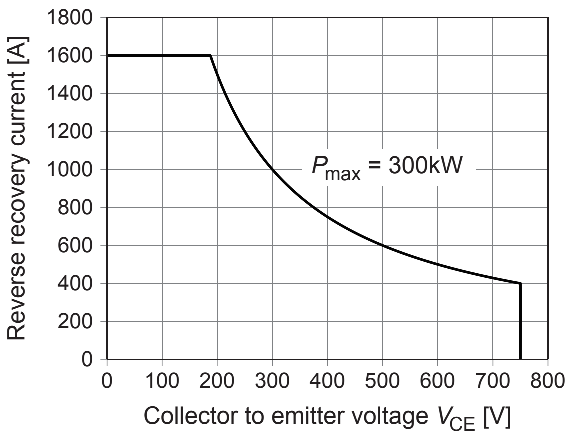


Fig. 5-5 An example of SOA of FWD part

3.4 Dynamic avalanche phenomenon

It is explained in previous section that V_{CE} is increased when turn-off operation is performed. And if V_{CE} is excessed certain voltage, V_{CE} voltage is suppressed. One of typical example of this phenomenon is shown in Fig.5-6. This phenomenon is called Dynamic avalanche.

If this dynamic avalanche is happened, spike voltage of V_{CE} is suppressed by the decreased turn-off current. The certain operating conditions which happen dynamic avalanche shall not be applied because there is possibility of IGBT destruction by turn-off loss increase and latch-up phenomenon. There are many causes of dynamic avalanche like long wiring of main circuit. To prevent this dynamic avalanche, IGBT module shall be used within RBSOA condition, at least.

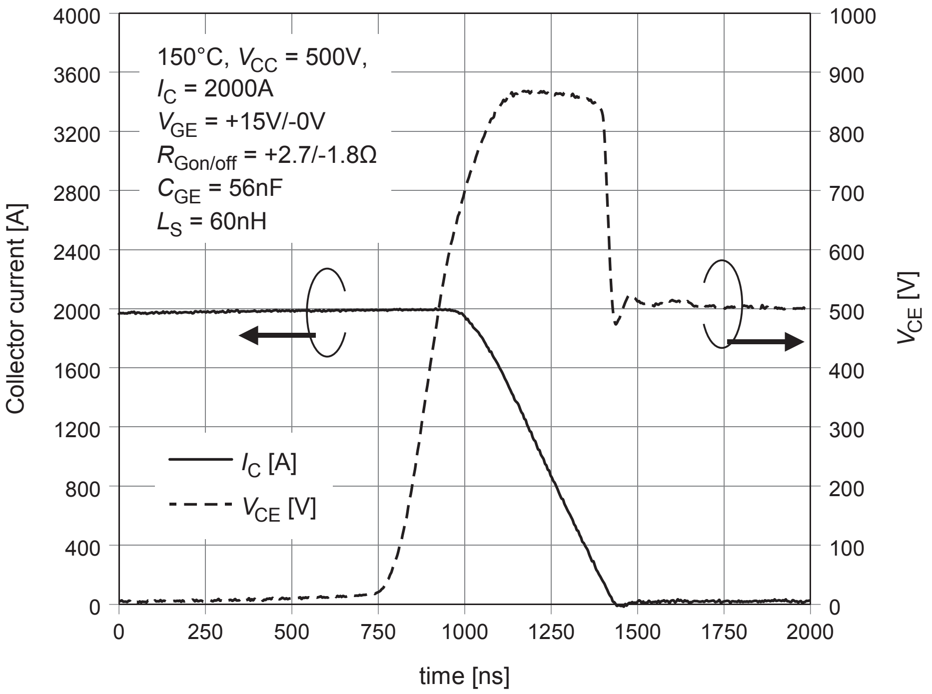


Fig. 5-6 An example of dynamic avalanche waveform

4. Operation Condition and Dead Time Setting

Since principal characteristics of IGBT depend on driving conditions like V_{GE} and R_G , certain setting according to target design is needed. Gate bias condition and dead time setting are described here.

4.1 Forward bias voltage : $+V_{GE}$ (on state)

Notes when $+V_{GE}$ is designed are shown as follows.

(1) Set $+V_{GE}$ so that is remains under the maximum rated G-E voltage, V_{GES} =±20V.

(2) It is recommended that supply voltage fluctuations are kept to within ±10%.

(3) The on-state C-E saturation voltage $V_{CE(sat)}$ is inversely dependent on $+V_{GE}$, so the greater the $+V_{GE}$ the smaller the $V_{CE(sat)}$.

(4) Turn-on switching time and switching loss grow smaller as $+V_{GE}$ rises.

(5) At turn-on (at FWD reverse recovery), the higher the $+V_{GE}$ the greater the likelihood of surge voltages in opposing arms.

(6) Even while the IGBT is in the off-state, there may be malfunctions caused by the dv/dt of the FWD’s reverse recovery and a pulse collector current may cause unnecessary heat generation. This phenomenon is called a dv/dt shoot through and becomes more likely to occur as $+V_{GE}$ rises.

(7) The greater the $+V_{GE}$ the smaller the short circuit withstand capability.

4.2 Reverse bias voltage : $-V_{GE}$ (off state)

Notes when $-V_{GE}$ is designed are shown as follows.

(1) Set $-V_{GE}$ so that it remains under the maximum rated G-E voltage, V_{GES} =±20V .

(2) It is recommended that supply voltage fluctuations are kept to within ±10%.

(3) IGBT turn-off characteristics are heavily dependent on $-V_{GE}$, especially when the collector current is just beginning to switch off. Consequently, the greater the $-V_{GE}$ the shorter, the switching time and the switching loss become smaller.

(4) If the $-V_{GE}$ is too small, dv/dt shoot through currents may occur, so at least set it to a value greater than -5V. If the gate wiring is long, then it is especially important to pay attention to this.

4.3 Avoid the unexpected turn-on by recovery dv/dt

In this section, the way to avoid the unexpected IGBT turn-on by dv/dt at the FWD's reverse recovery will be described.

Fig.5-7 shows the principle of unexpected turn-on caused by dv/dt at reverse recovery. In this figure, it is assumed that IGBT_1 is turned off to on and gate to emitter voltage V_{GE} of IGBT_2 is negative biased. In this condition, when IGBT_1 get turned on from off-state, FWD on its opposite arm, that is, reverse recovery of FWD_2 is occurred. At same time, voltage of IGBT_2 and FWD_2 with off-state is raised. This causes the dv/dt according to switching time of IGBT_1. Because IGBT_1 and IGBT_2 have the mirror capacitance C_{GC}, Current is generated by dv/dt through C_{GC}. This current is expressed by C_{GC} x dv/dt. This current is flowed through the gate resistance R_{G}, results in increasing the gate potential. So, V_{GE} is generated between gate to emitter. If V_{GE} is excess the sum of reverse biased voltage and $V_{\mathrm{GE(th)}}$, IGBT_2 is turned on. Once IGBT_2 is turned on, the short-circuit condition is happened, because both IGBT_1 and IGBT_2 is under turned-on state.

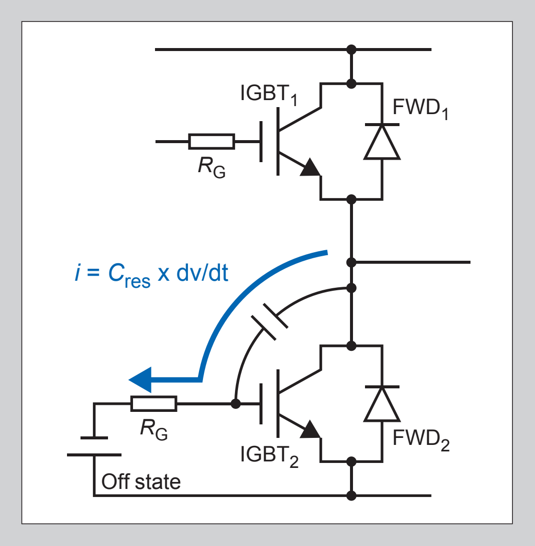


Fig. 5-7 Dead time timing chart

4.4 Dead time setting

For inverter circuits and the like, it is necessary to set an on-off timing "delay" (dead time) in order to prevent short circuits. During the dead time, both the upper and lower arms are in the "off" state. Basically, the dead time (see Fig.5-8) needs to be set longer than the IGBT switching time (t_{off} max.). For example, if R_{G} is increased, switching time also becomes longer, so it would be necessary to lengthen dead time as well. Also, it is necessary to consider other drive conditions and the temperature characteristics.

It is important to be careful with dead times that are too short, because in the event of a short circuit in the upper or lower arms, the heat generated by the short circuit current may destroy the module. Therefore, appropriate dead time should be settled by the confirmation of practical machine.

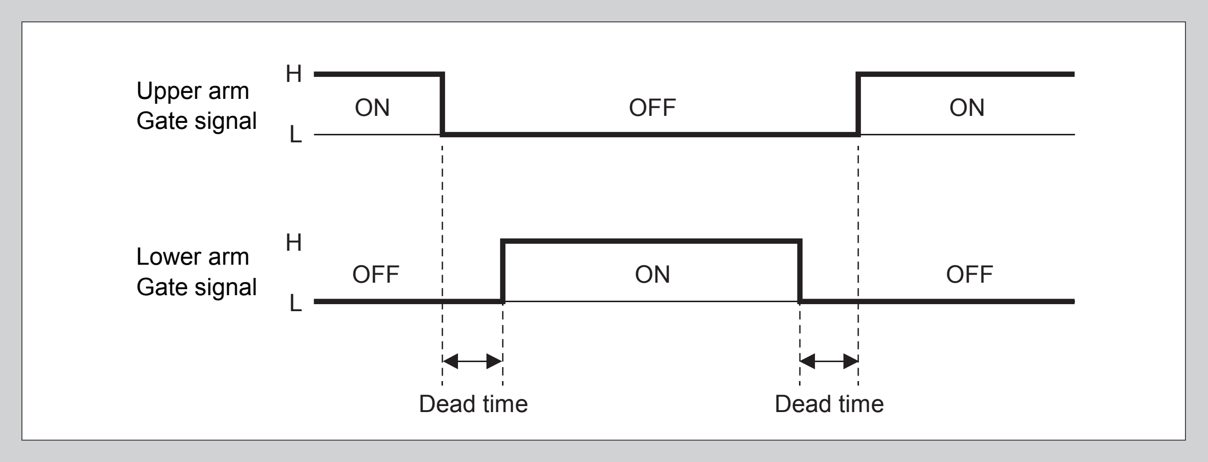


Fig. 5-8 Dead time timing chart

Chapter 6 Recommended Mounting Method

This chapter describes the recommended method of mounting the IGBT module and the PCB.

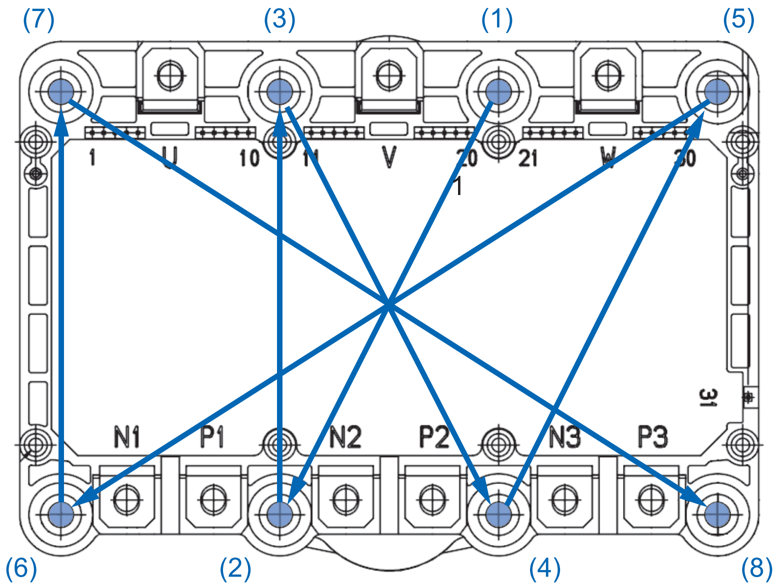
1. Instruction of Mounting the IGBT Module

1.1 Method of fastening the module to customer's system

Figure 6-1 shows the recommended procedure of tightening screws for mounting the IGBT module. The fastening screws should be tightened with the specified torque.
See the specification for the specified torque and screws size to be used.

1.2 Prohibited matters:

(1) Screw has jammed: IGBT module shall not be used anymore.
There is possibility of collapsed threads, producing metal particle and so on.
(2) Excessive tightening torque: IGBT module shall not be used anymore.
Cause of cooling system destruction by flange damage and buckling of the stud.
(3) Insufficient tightening torque:
Liquid leakage from the cooling flange may occur, or the screws may be loosened during operation, cooler destruction due to vibration during operation are expected.
(4) Applying a load onto the cover of the cooler:
Cause of cooling system destruction, cooling water leakage are expected.



	Torque	Sequence
Initial	1/3 of specified torque	(1) → (2) → (3) → (4) → (5) → (6) → (7) → (8)
Final	Full specified torque	(8) → (7) → (6) → (5) → (4) → (3) → (2) → (1)

Fig. 6-1 Screw sequence for IGBT module

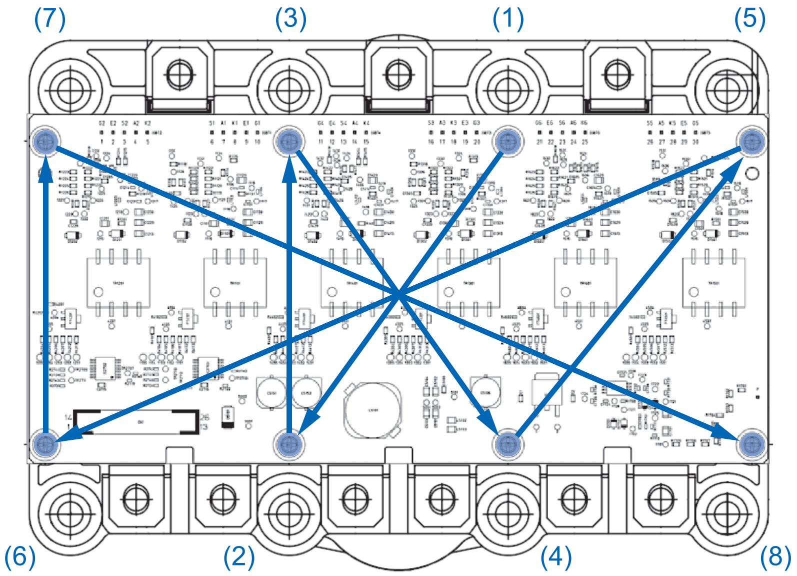
1.3 Installation direction of the IGBT module

The IGBT module shall be installed on horizontal upward direction, but not upside down. If it were inclined or upside down, air bubble would be remained in the cooler when cooling water is flowed. Air bubble might make cavitation phenomenon and it is cause of water leakage.

1.4 Method of mounting the PCB and cautions

(a) As screws to be used at positions (1) to (8), specified screw size and tightening torque described in the specification sheet.
The length of the screw thread for PCB can be considered by the drawings of the module in the specification sheet.
Adjust the length of the screws depending on the types of the screws used if necessary.

(b) Fix the screws temporarily with 1/3 of the final fastening torque and in the sequence from (1) to (8) in Fig. 6-2.



	Torque	Sequence
Initial	1/3 of specified torque	(1) → (2) → (3) → (4) → (5) → (6) → (7) → (8)
Final	Full specified torque	(8) → (7) → (6) → (5) → (4) → (3) → (2) → (1)

Fig. 6-2 Screw sequence for PCB fix

1.5 Electrostatic discharge protection

If excessive static electricity is applied to the control terminal, the module may be damaged. Please take countermeasures against static electricity when handling the module.

Assembly environment relating to ESD shall be within specified value shown in the specification sheet.

1.6 Soldering of the control terminals

Soldering of the control terminals shall be performed based on the condition which is described on the specification sheet. Otherwise, disconnect between them might be happened.

2. Connection of the Main Terminal

2.1 Connection of the main circuit

(a) Screw size: M5

(b) Maximum fastening torque: refer to the specification sheet.

(c) Length of the screw: Check the depth of screw holes on the outline drawing.

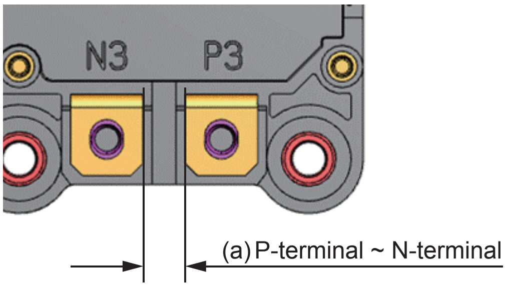
Adjust the length of the screws depending on the types of screws used if necessary.

2.2 Clearance and creepage distance

It is necessary to keep enough clearance distance and the creepage distance (defined as (a) in Fig. 6-3) from the main terminal to secure desirable insulation voltage. The clearance distance and the creepage distance must be longer than the minimum value shown in below.

Suitable insulation distance between a bus-bar and the main terminal screw of the module shall be designed when the module is installed to a power system.

Screws for tightening a control board on the module shall be electrically isolated. And the screws shall be appropriately selected by taking account of insulation distance between the control terminals of the module and the screws.



Position	Creepage distance (mm)	Spatial distance (mm)
(a) P-terminal ~ N-terminal	≥ 11.3	≥ 7.3

Fig. 6-3 Creepage distance and spatial distance at the P/N terminal

Chapter 7 Evaluation Board

1. Abstract

This evaluation board are designed only for Fuji M653 IGBT module.

The board can control the module safely by monitoring two on-chip sensors, which are junction temperature sensor and emitter current sensor.

Gate driver IC ADuM4138 Rev. 1v15 of Analog Devices,Inc. is used in this evaluation board.

And the other test board, which is made by IC ACFJ-3540T of Broadcom Ltd., is also selectable.

Please contact us to understand more detail information according to your choice.

2. Features

- Six channel driver
- 26 pin connector
- Isolated DC/DC converters
- Interface for 5V logic levels
- Active Clamping
- High voltage DC link monitoring
- Short circuit (SC) protect and alarm
- Over temperature protection and alarm

  +15V/0V gate drive voltage (To be applied)

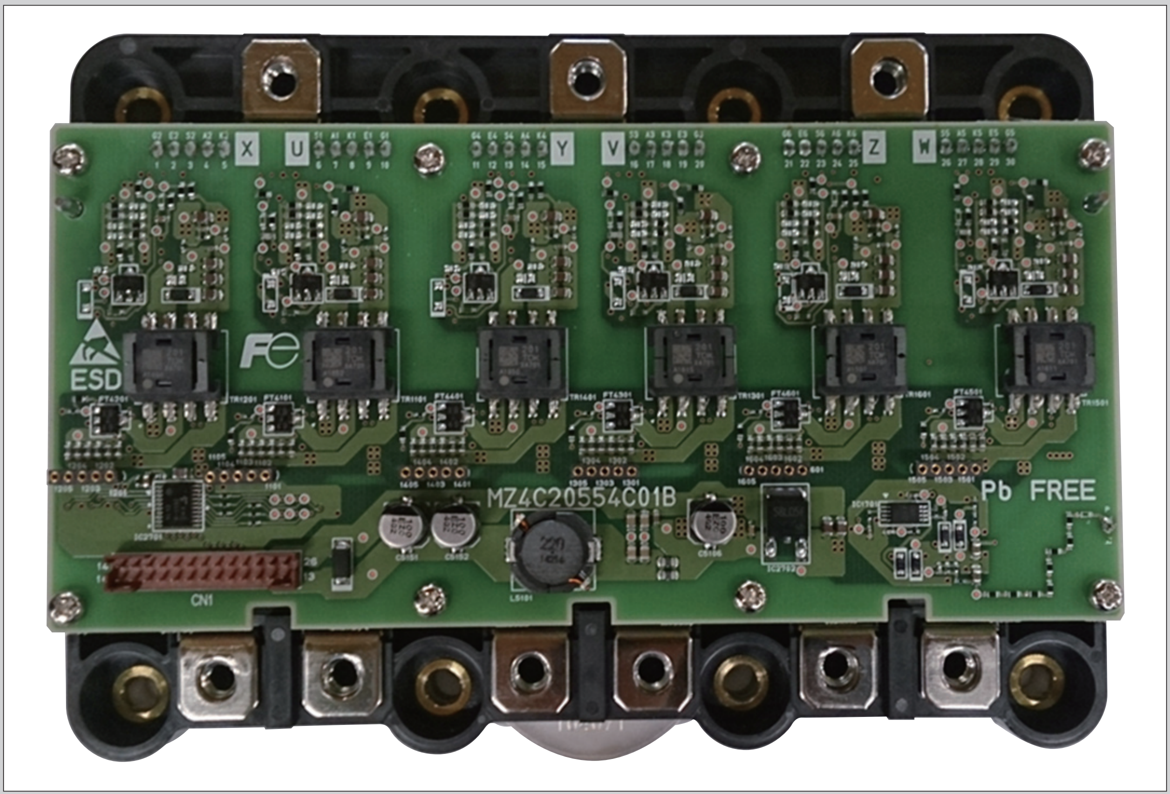


Fig. 7-1 M653 IGBT module evaluation board

3. System Outline

The basic topology of the driver is shown in Fig. 7-2.

Fuji sets the values for gate resistors and other key components based on our evaluation results by using M653 IGBT module.

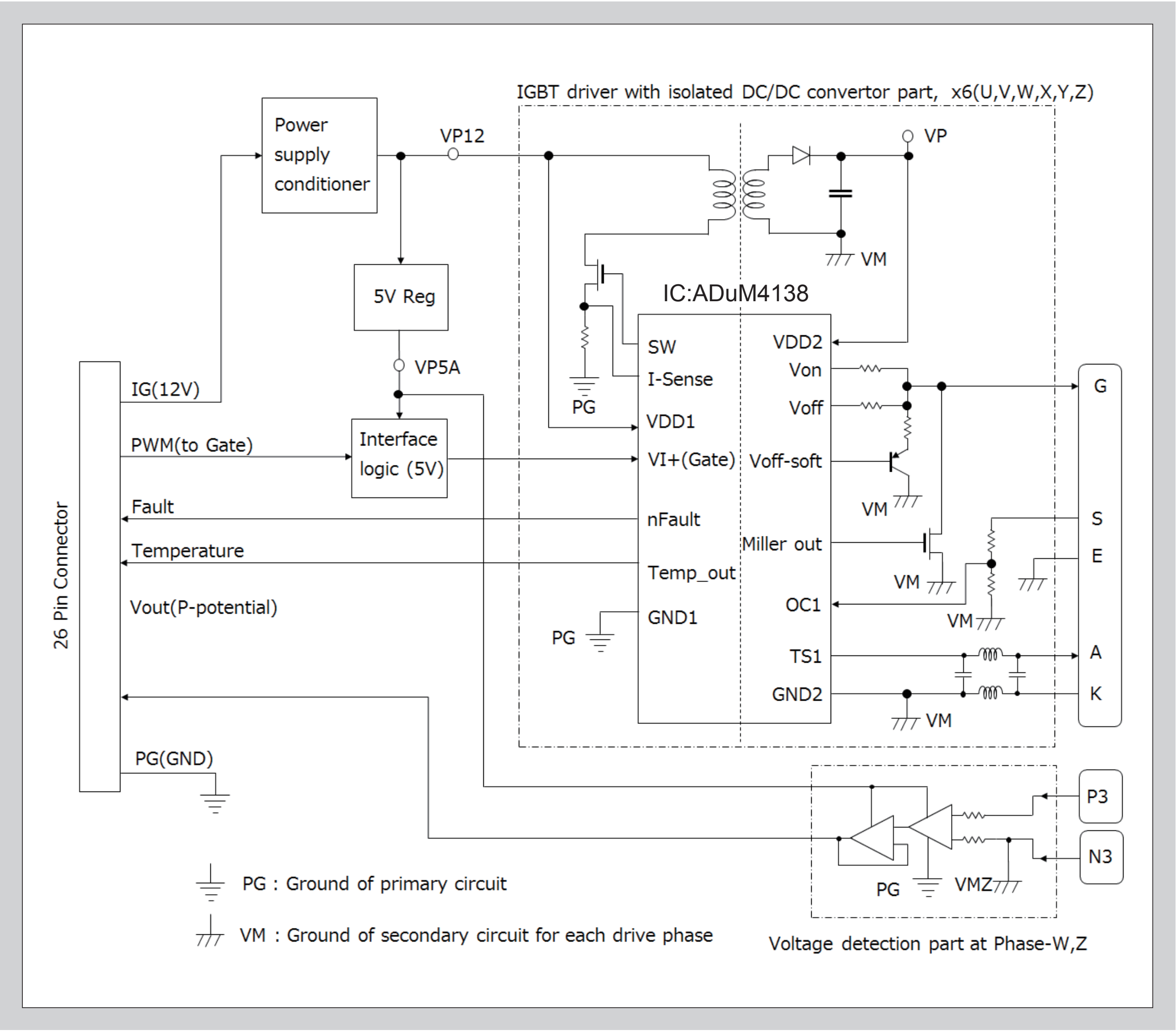


Fig. 7-2 Basic schematic of the M653 IGBT module evaluation board

4. Absolute Maximum Ratings

Table 7-1 Absolute maximum ratings

Parameter	Description	Min	Max	Unit
Supply Voltage	IG Input	-0.3	25	V
Peak Gate Current		-6	6	A
Input Logic Levels	To GND	-0.3	5.3	V
Switching Frequency			20	kHz
Isolation Voltage	Primary to Secondary		2500	Vrms
Operating Temperature		-40	+105	°C
Storage Temperature		-40	+105	°C

* measured under ambient temperature 25°C. unless otherwise specified.

5. Electrical Characteristics

Table 7-2 Electrical characteristics

Power Supply	Description	Min	Typ	Max	Unit
Supply Voltage	IG input	6	12	16	V
Supply Current	Without Load		200		mA
Rush Current	Start up Current		16		A
Average Supply Current	Switching Frequency: 10KHz		600		mA
UVLO Level (Primary Side)	Primary Side low voltage detect fault level		4.3		V
UVLO Level (Secondary Side)	Secondary Side low voltage detect fault level		11.2		V
Secondary Output Voltage	Fly-Back Output Voltage	14	15	16	V

Logic Signal	Description	Min	Typ	Max	Unit
Input Current			1.0		mA
V5 Regulated Voltage		4.85	5.00	5.15	V
Logic High Input Voltage		2.0			V
Logic Low Input Voltage				0.8	V
PWM Pulse On Delay Time	PWM Input to IGBT Gate		0.5		µsec
PWM Pulse Off Delay Time	PWM Input to IGBT Gate		0.45		µsec
Gate Output Voltage Low				0.1	V
Gate Output Voltage High		14	15	16	V
Alarm Output Impedance	Fault pull down		10	30	Ω
Alarm Fault Hold Time			26.2		msec

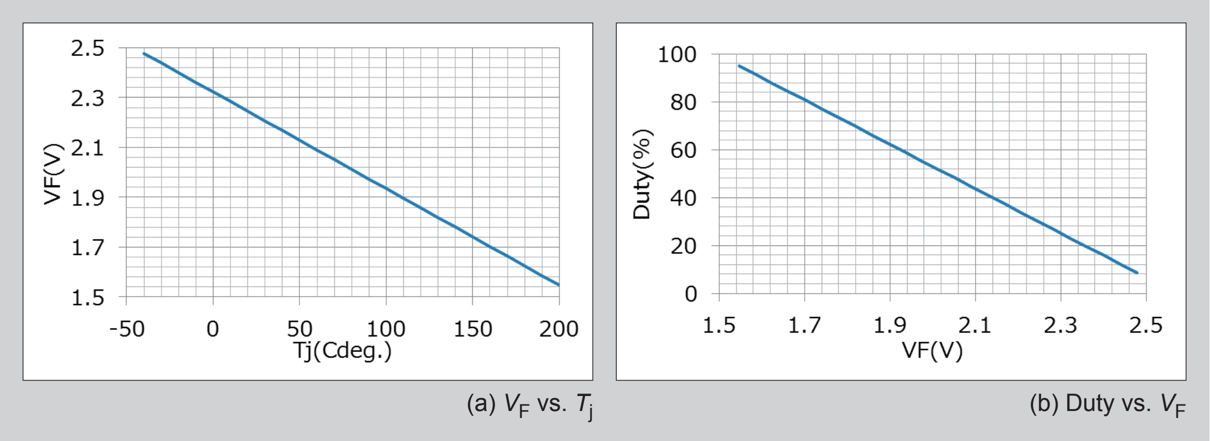
* measured under ambient temperature 25°C. unless otherwise specified.

6. Junction Temperature Monitor Function

Table 7-3 Junction temperature monitoring

IGBT temperature communication	Description	Min	Typ	Max	Unit
Output high voltage		4.85	5.00	5.15	V
Output low voltage				0.1	V
Output frequency			50		KHz
PWM duty	Temp V_F = 2.22V		30		%
PWM duty	Temp V_F = 1.65V		82		%

* measured under ambient temperature 25°C. unless otherwise specified.



(a) V_F vs. T_j

(b) Duty vs. V_F

Fig. 7-3 Relationship among T_j, V_F and Duty

* Note:

I_F current specification on ADuM4138: ±5 %@ I_F = 1(mA) .

→ V_F shift of Temperature Diode under ±5% of I_F (1mA) : ±11 mV.

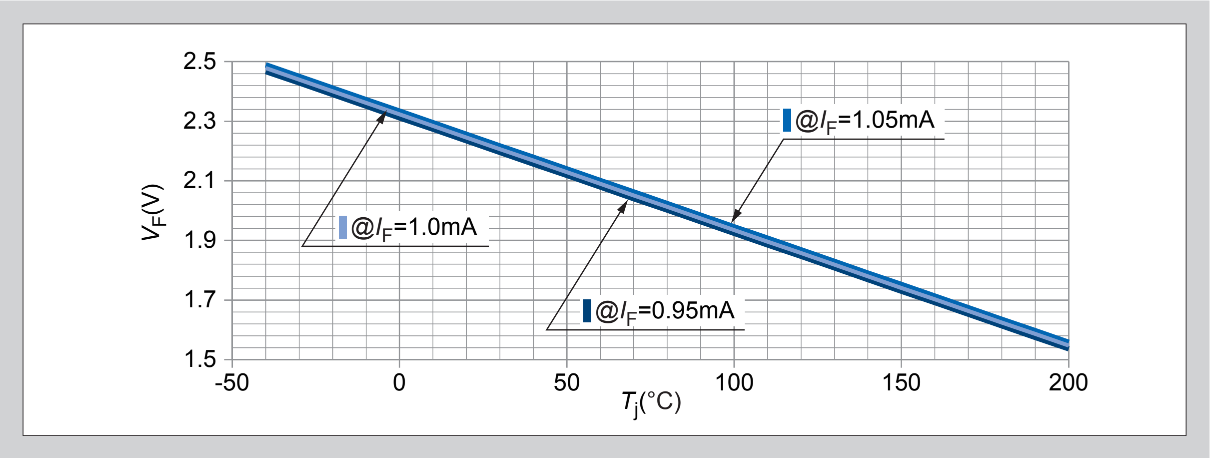


Fig. 7-4 V_F - T_j shift according to I_F@±0.05(mA)

7. PN Voltage Monitoring Function

Table 7-4 PN voltage monitoring

PN Voltage Communication	Description	Min	Typ	Max	Unit
Output Voltage	PN = 100V		0.79		V
Output Voltage	PN = 250V		1.94		V
Output Voltage	PN = 400V		3.09		V

* measured under ambient temperature 25°C. unless otherwise specified.

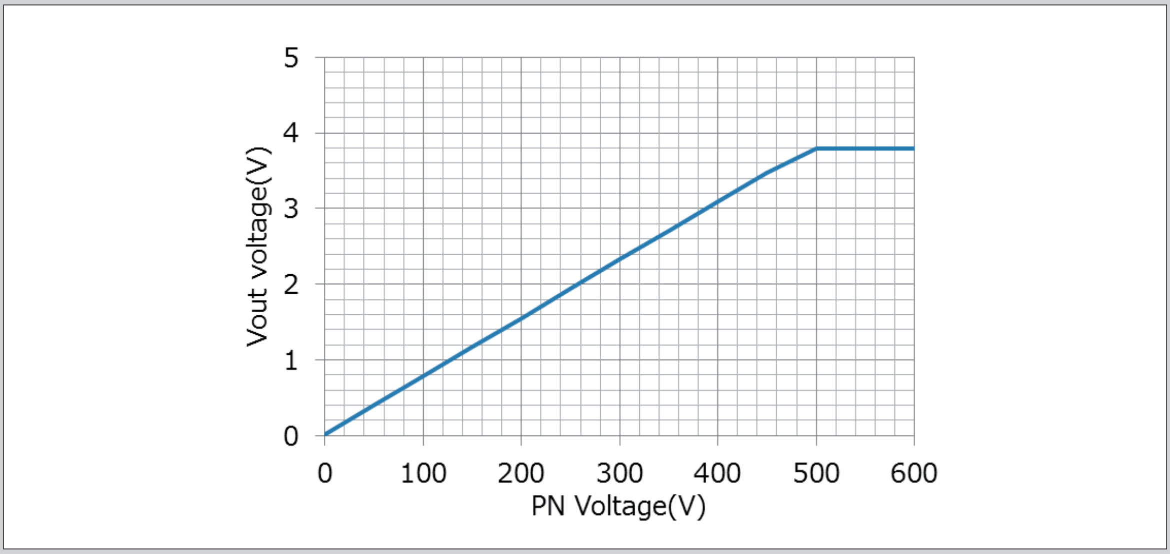


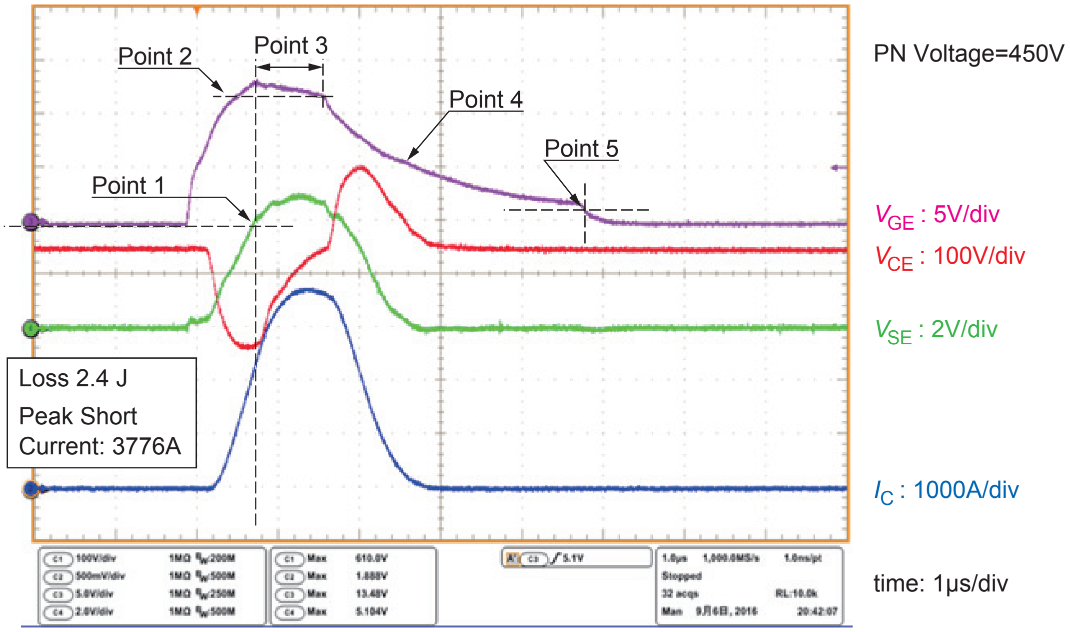
Fig. 7-5 Output voltage vs. PN voltage

8. Short-circuit (SC) Protection Function

Table 7-5 Short-circuit protection conditions

IGBT Short Protection	Description	Min	Typ	Max	Unit
Short Current Detect Voltage	Point 1		3.14		V
Gate Clamp Voltage	Point 2		12		V
Fixation Time	Point 3		800		nsec
Soft-OFF MOS FET Impedance	Point 4		30		Ω
Miller Clamp Gate Voltage Threshold	Point 5	1.75	2.00	2.25	V

* measured under ambient temperature 25°C. unless otherwise specified.

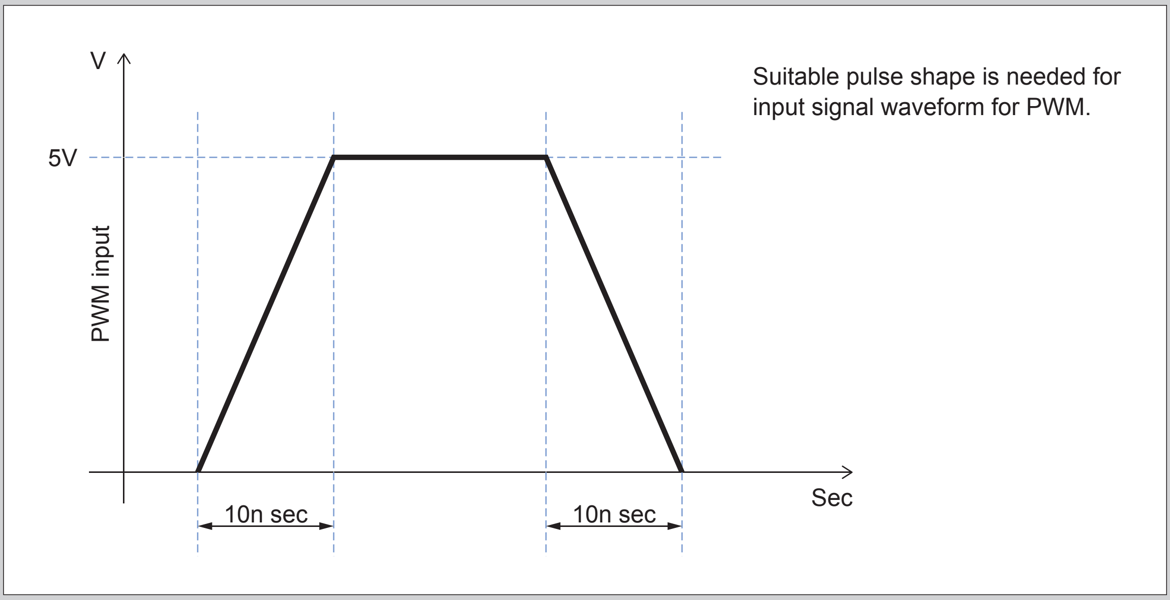


* Point1 : Detect overcurrent by monitoring the V_{SE} voltage
Point2 : Clamp the gate voltage in 12V
Point3 : Settle the abnormal state if V_{SE} > 2.87(V) continues for 800nsec
Point4 : Turn off gently
*If hard cut-off is implemented, IGBT module should be broken by surge voltage during turn-off.
So please take care of gentle turn-off.
Point5 : Turn to miller clamp state if the V_{GE} is less than 2V

Fig. 7-6 Short-circuit protection function

9. Timing Diagrams

Input Waveform to PWM-U, V, W, X, Y, Z (to Gate)



Suitable pulse shape is needed for input signal waveform for PWM.

Fig. 7-7 Input signal waveform for PWM input

10. Generic Sample Factory Settings

The default gate resistor and dividing resistor for current sense function are shown in below Table 7-6.

R_G setting are set by taking account of Short circuit protection and surge voltage which does not exceed 700V at -40°C.

Table 7-6 Default value of the circuit board parameters

	R_{Gon} (Ω) / R_{Goff} (Ω)	C_{GE} (μF)	R_{SENSE} (divider: Ω/Ω)
Upper arm	2.8 / 2.8	0.047	47 / 82
Lower arm	2.8 / 2.8	0.068	47 / 82

11. Recommended Start-Up Testing

Caution: Handling devices with high voltage involves risk to life. It is imperative to comply with all respective precautions and safety regulations.

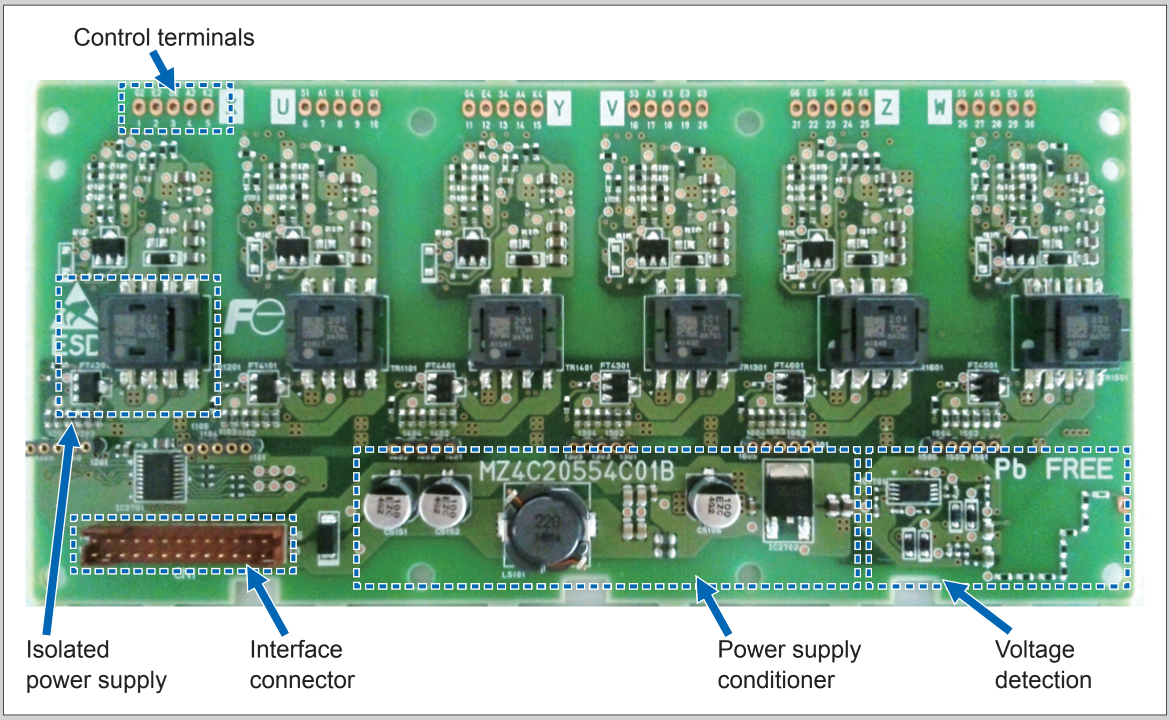
1. Connect the driver through the 26 pin post header to test board and supply +12V through pins 12 and 13.

2. Although there is no fault reset pin, fault function is automatically reset by power-off and power-on sequence.

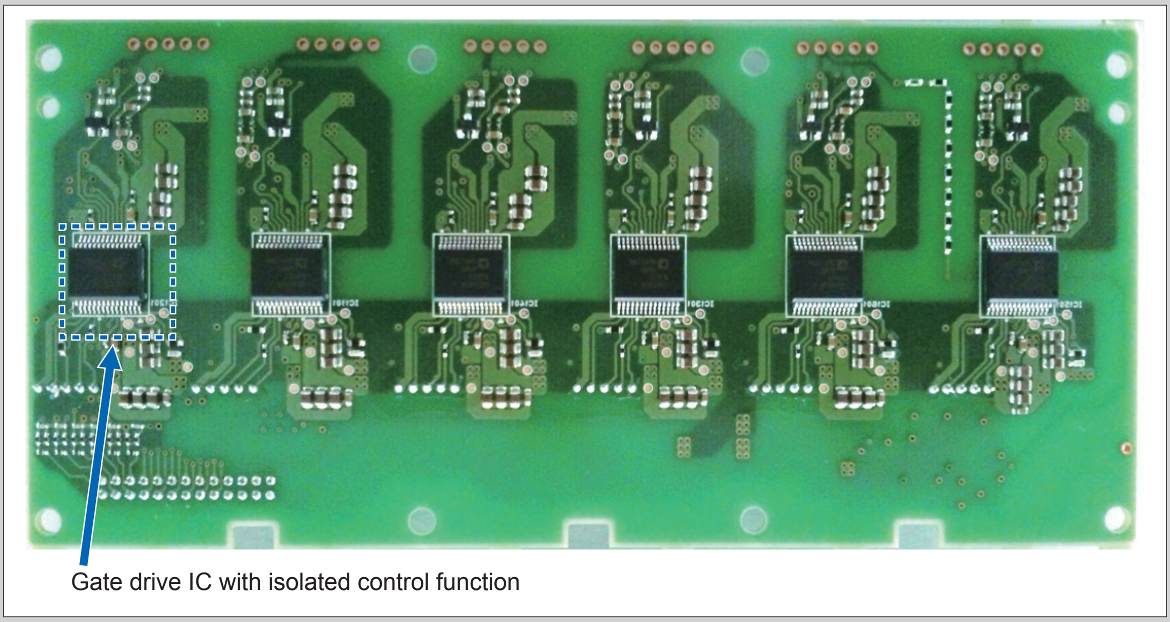
3. Check the gate voltage according to followings:
   a) For the off-state, the nominal gate voltage should be 0V.
   b) For the on-state, it is +14 to +16V
   c) Check the current consumption of the driver without the clock signals and the desired switching frequency driving a capacitive load equivalent to the Gate Capacitance of the IGBT.
   In the case of M653 module, 0.22μF of the capacitance is recommended.
   And its consumption is around 600mA as typical value.
   On the other hand, it is less than 200mA without any load.
   d) Above test should be performed before board installation.

12. Evaluation Board Appearance

IGBT driving part for each phase, which are U, V, W, X, Y and Z, has an isolated power supply. The driver IC has an isolated Input-Output.



(a) Top view

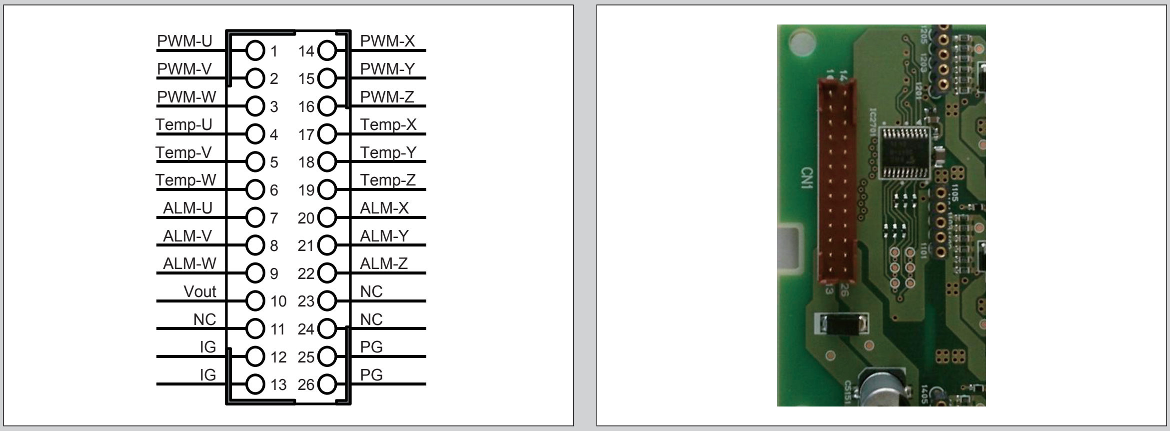


(b) Bottom view (mirror)

Fig. 7-8 Evaluation board appearance

Table 7-7 External connector pin assignment

Pin Number	Pin Name	Type	Description
1	PWM-U	Input	Gate drive PWM signal for phase U
2	PWM-V	Input	Gate drive PWM signal for phase V
3	PWM-W	Input	Gate drive PWM signal for phase W
4	Temp-U	Output	Temerature data output of phase U
5	Temp-V	Output	Temerature data output of phase V
6	Temp-W	Output	Temerature data output of phase W
7	ALM-U	Output	Alarm signal output when any fault is occured on phase U
8	ALM-V	Output	Alarm signal output when any fault is occured on phase V
9	ALM-W	Output	Alarm signal output when any fault is occured on phase W
10	Vout	Output	Potential monitor at P3 which shows Battery voltage
11	NC	NC	Not connected
12	IG	Supply	+12.0V Power Supply
13	IG	Supply	+12.0V Power Supply
14	PWM-X	Input	Gate drive PWM signal for phase X
15	PWM-Y	Input	Gate drive PWM signal for phase Y
16	PWM-Z	Input	Gate drive PWM signal for phase Z
17	Temp-X	Output	Temerature data output of phase X
18	Temp-Y	Output	Temerature data output of phase Y
19	Temp-Z	Output	Temerature data output of phase Z
20	ALM-X	Output	Alarm signal output when any fault is occured on phase X
21	ALM-Y	Output	Alarm signal output when any fault is occured on phase Y
22	ALM-Z	Output	Alarm signal output when any fault is occured on phase Z
23	NC	NC	Not connected
24	NC	NC	Not connected
25	PG	Supply	Ground
26	PG	Supply	Ground



(a) External connector pin assignment

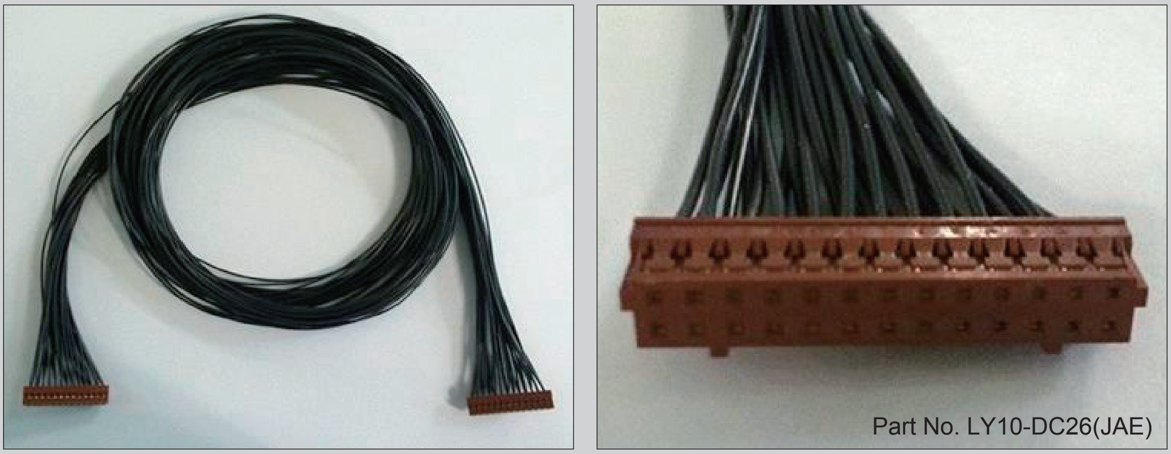
(b) Top view of external connector

Fig. 7-9 Pin assignment and top view of external connector

13. Interface Connector and Harness

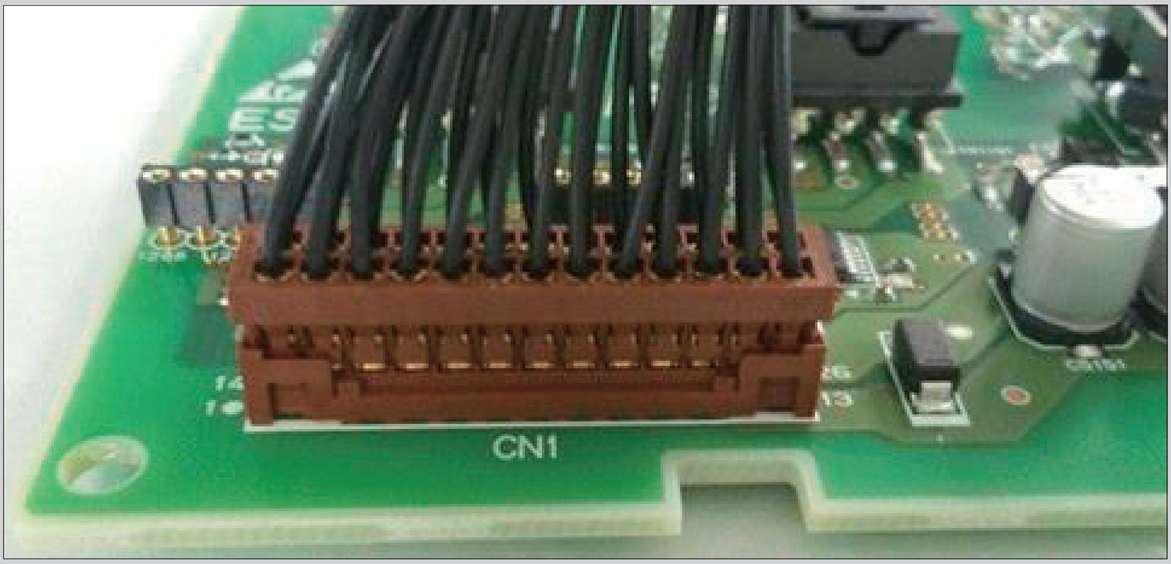
Connection to the evaluation board is performed by an optional interface cable.

As shown in Fig. 7-10–(a), the optional interface cable has 2 socket housings in both ends respectively. So any other interface board preparation might be useful for testing.



(a) Harness for board interface

(b) Socket housing



(c) Connecting the cable to the board

Fig. 7-10 Interface harness and its application

14. Evaluation Board Installation to the Module

Caution: An IGBT module is an electric device and weak against ESD, so please take it with enough countermeasure against electrostatic prior to board installation.

Board installation procedure:

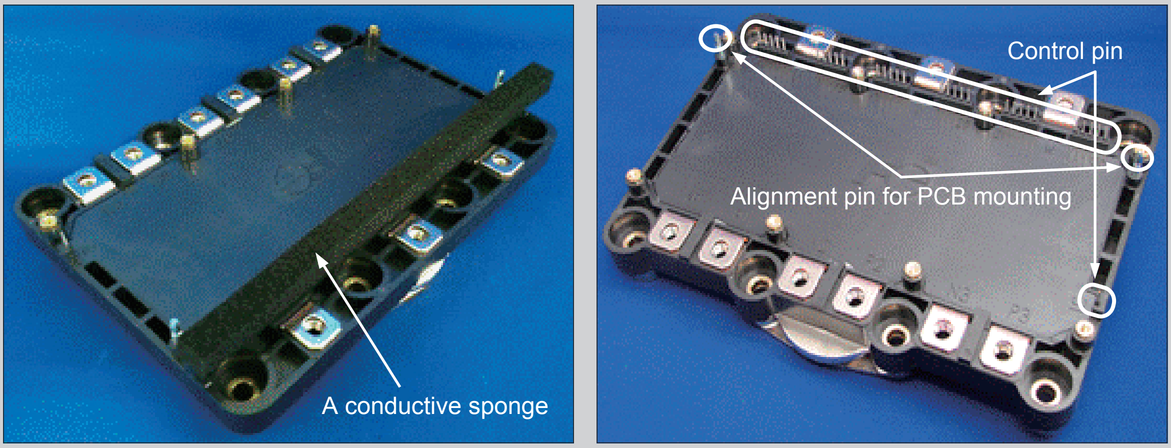
(a) Remove the sponge with take care.
A conductive sponge is attached to protect the module from ESD prior to factory shipment.

(b) Confirm whether there is any vended control pin or not.
There are 30 pcs of control pin and one voltage detection pin, so call P-terminal, all terminals should be confirmed.

(c) Mount the board along the alignment pin at the both side of the module.

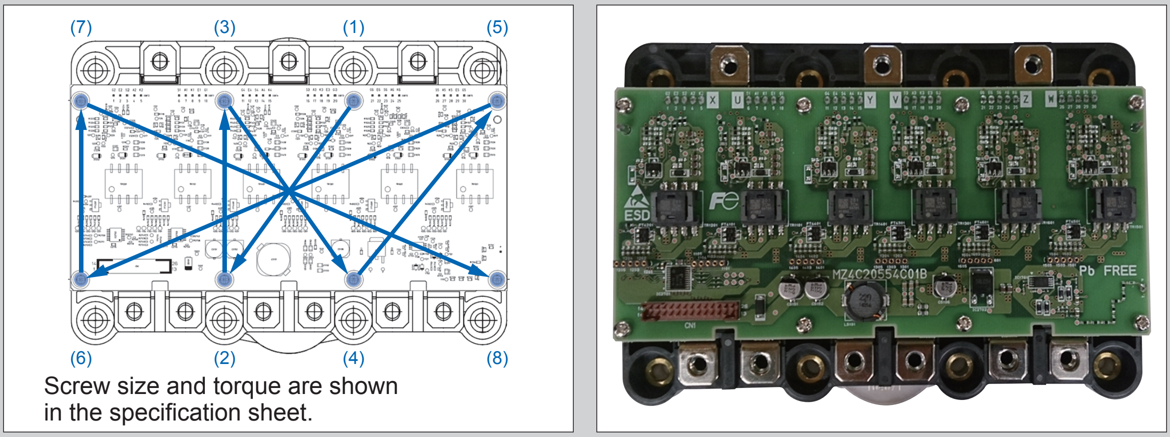
(d) Tighten the screws within specific torque.

(e) Soldering the control pins. Soldering condition is shown in the specification sheet.



(a) protection the module from ESD

(b) Alignment pin for the board installation



Screw size and torque are shown in the specification sheet.

(c) Sequence of tightening screw

(d) The installed board on the module

Fig. 7-11 The board installation

15. Evaluation Board Circuit Diagram

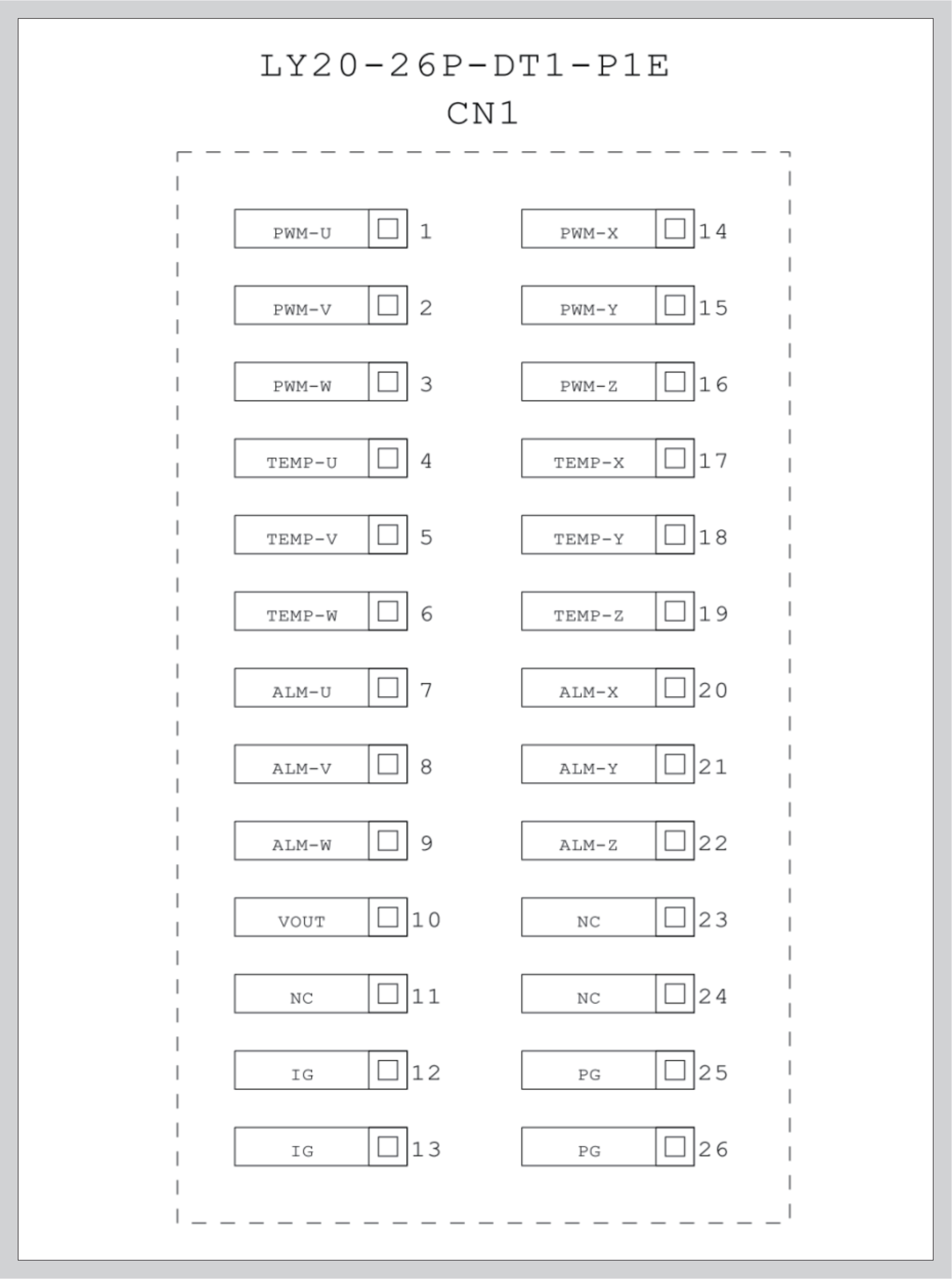


Fig. 7-12 External connector pin assignment

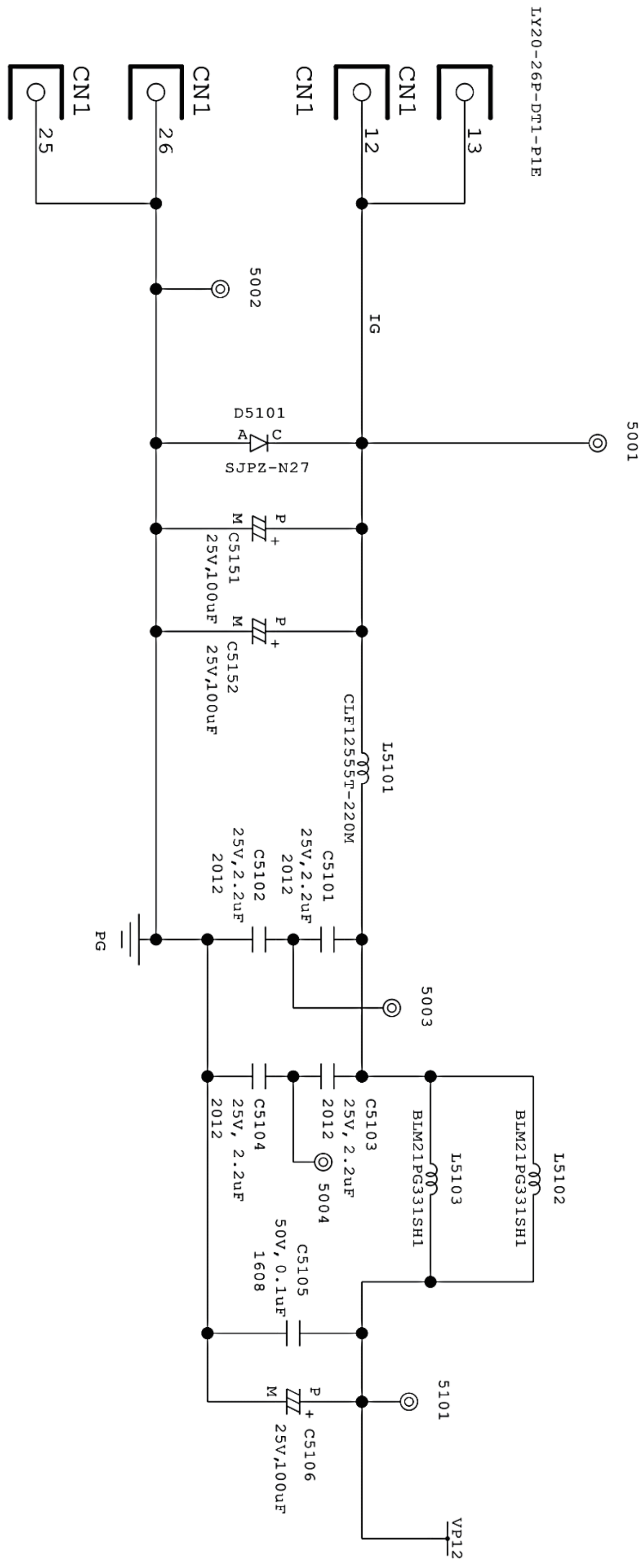


Fig. 7-13 Power supply conditioner

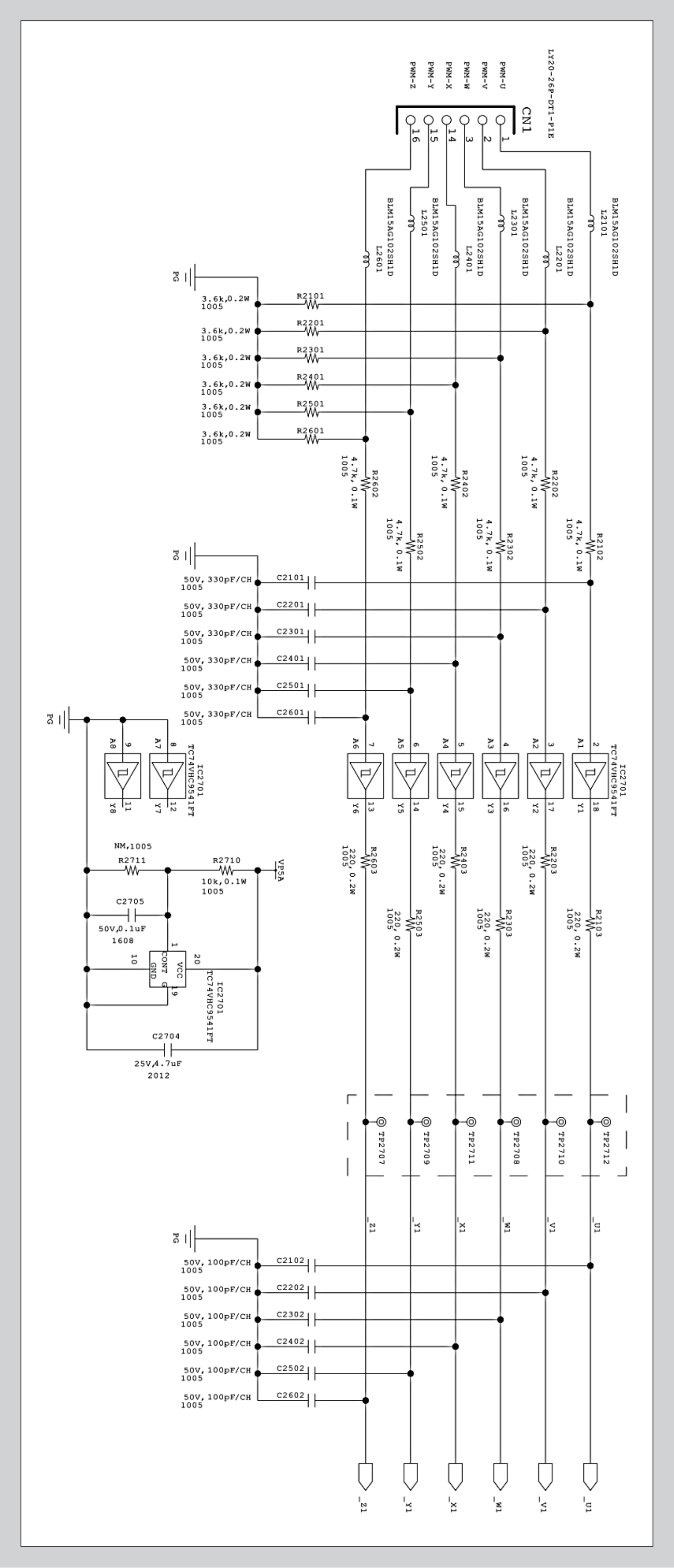


Fig. 7-14 Interface logic

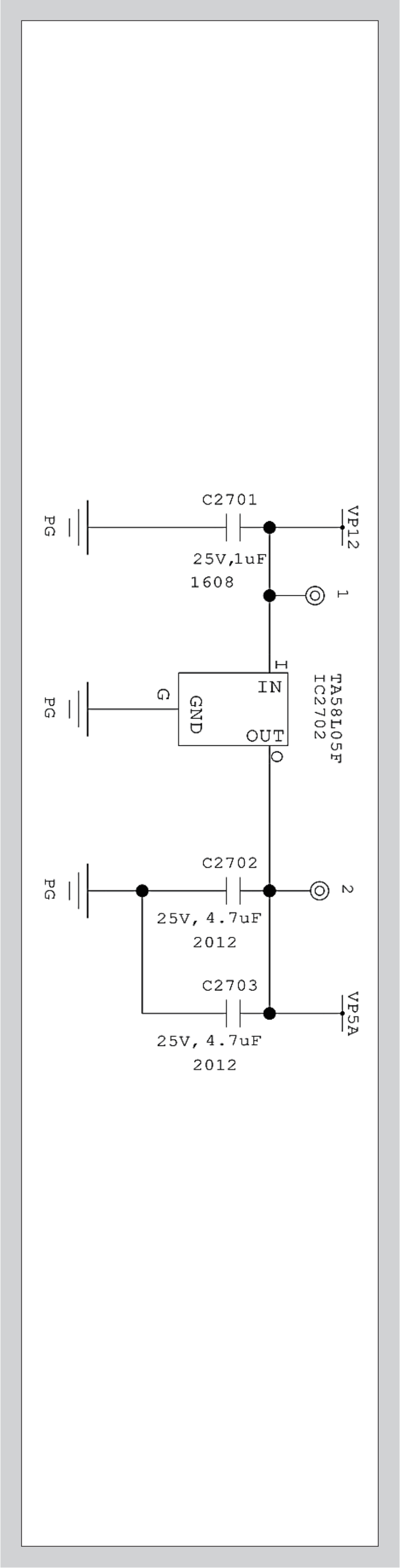


Fig. 7-15 5V power supply

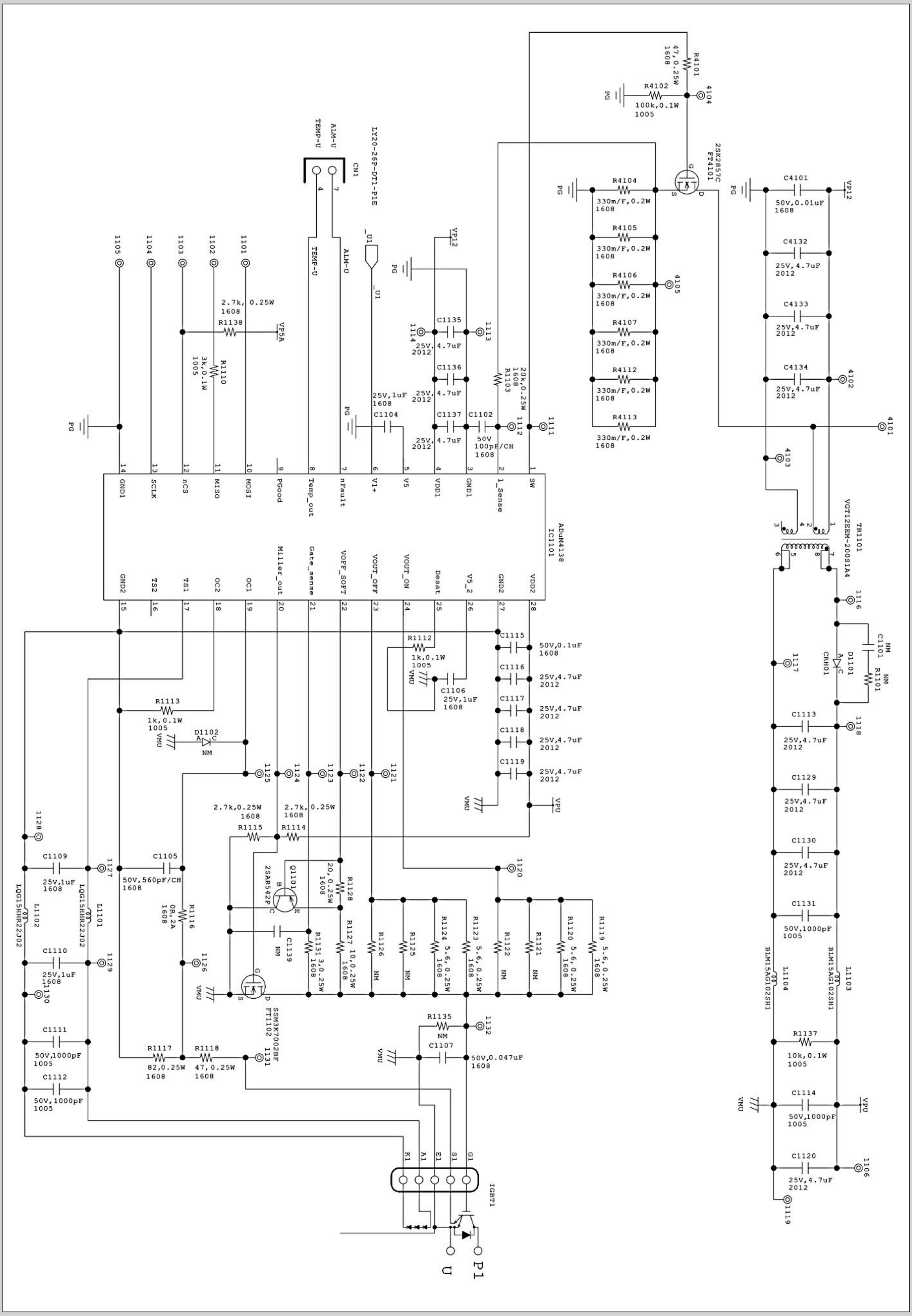


Fig. 7-16 Gate driver for Phase U

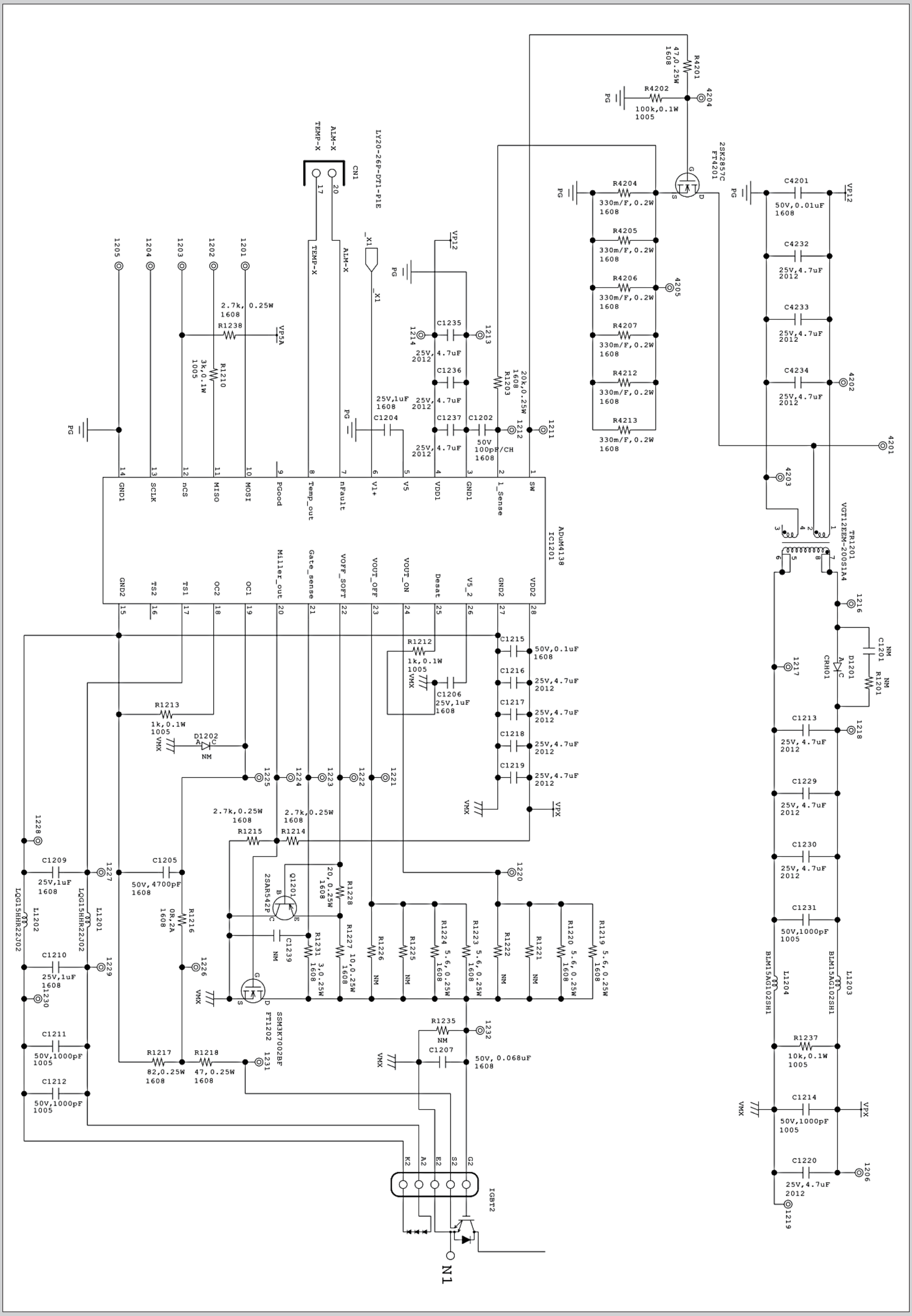


Fig. 7-17 Gate driver for Phase X

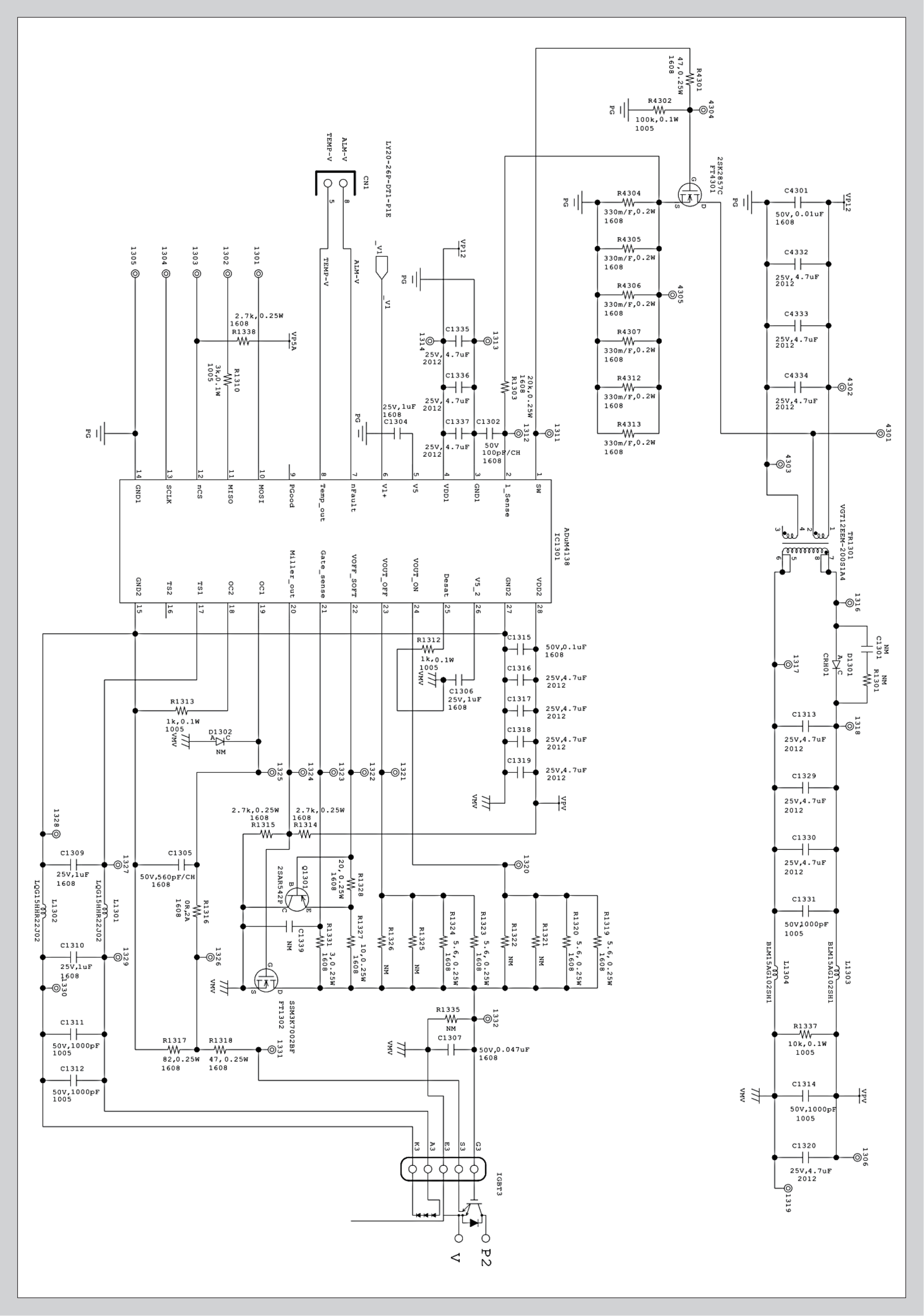


Fig. 7-18 Gate driver for Phase V

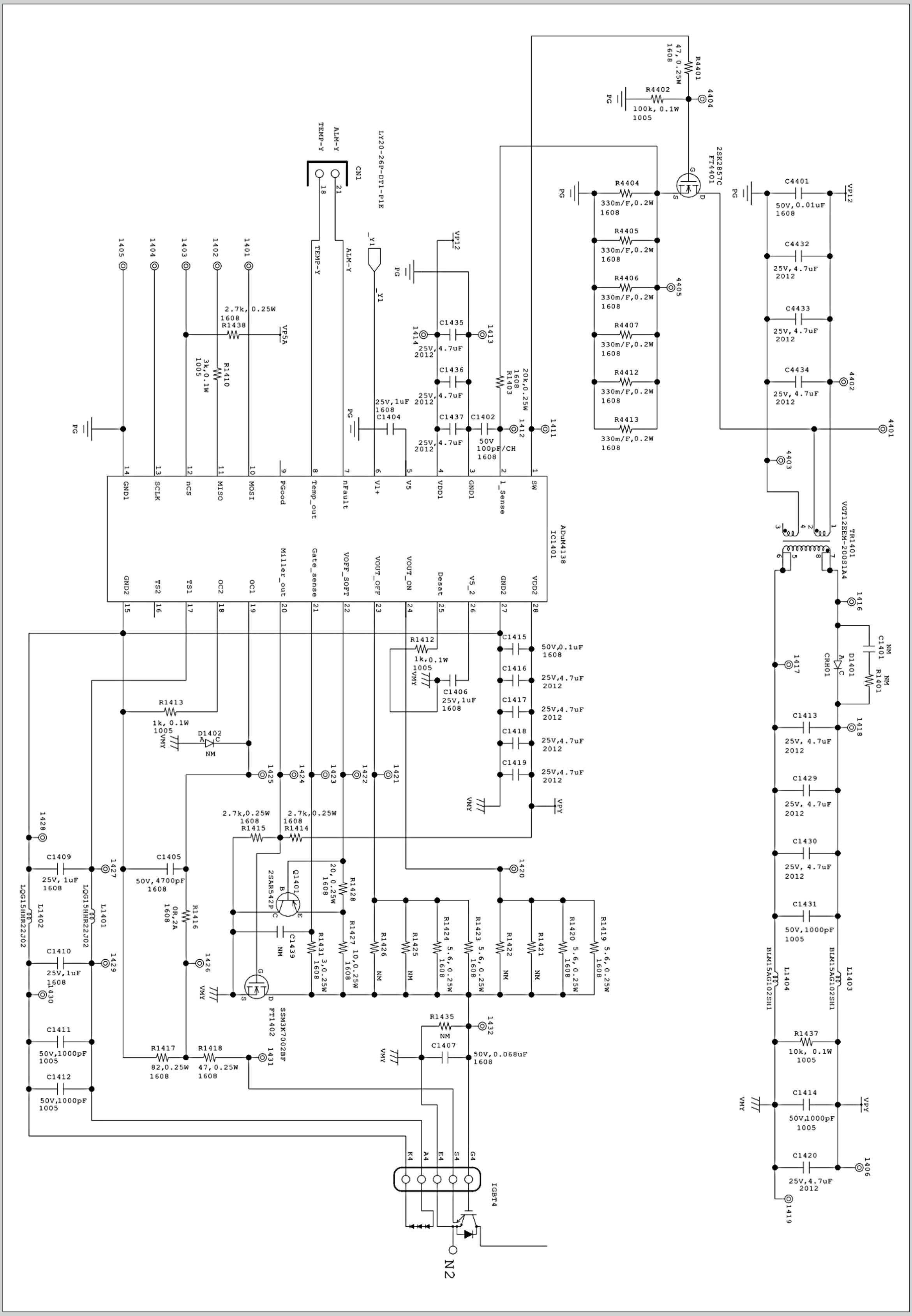


Fig. 7-19 Gate driver for Phase Y

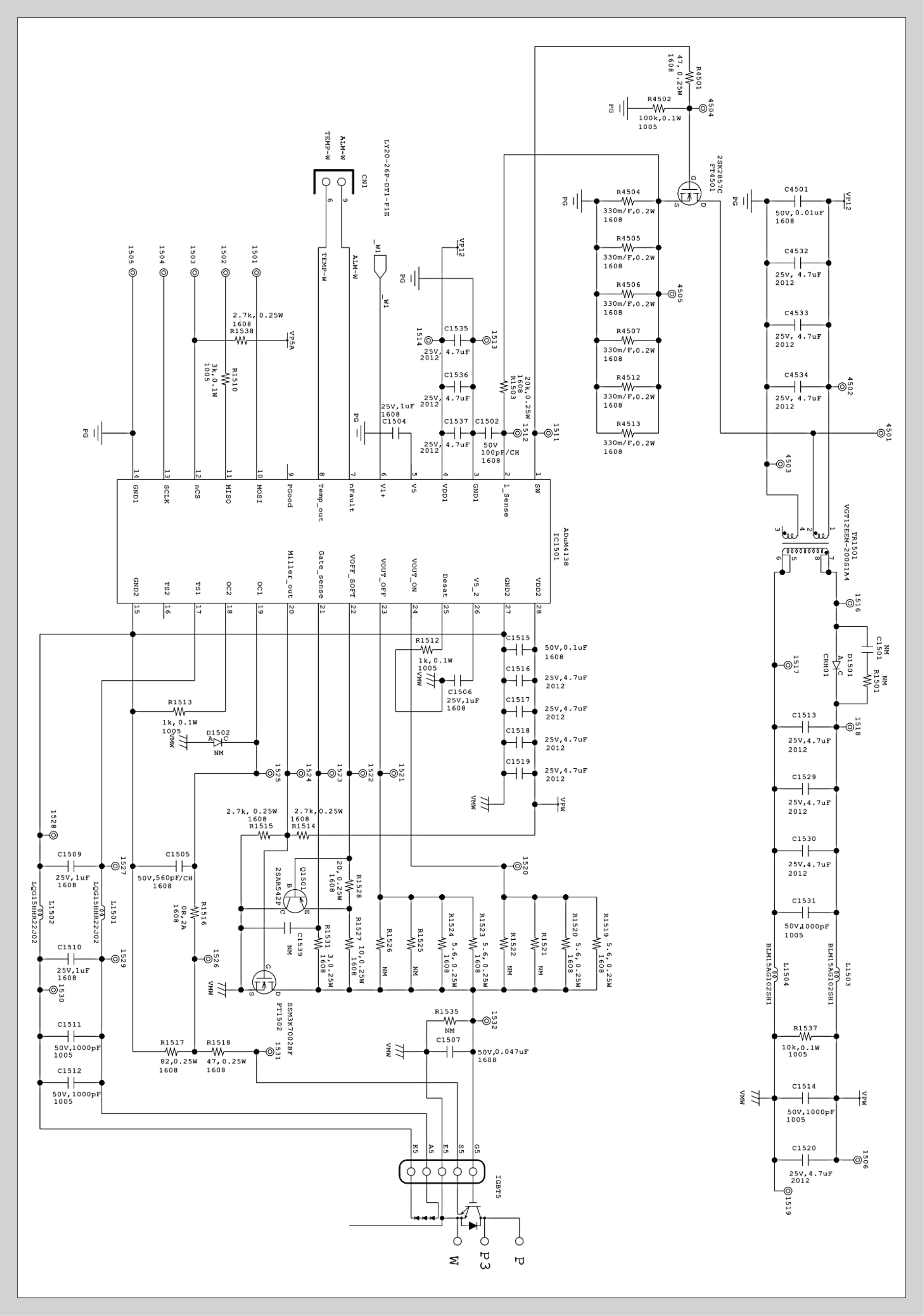


Fig. 7-20 Gate driver for Phase W

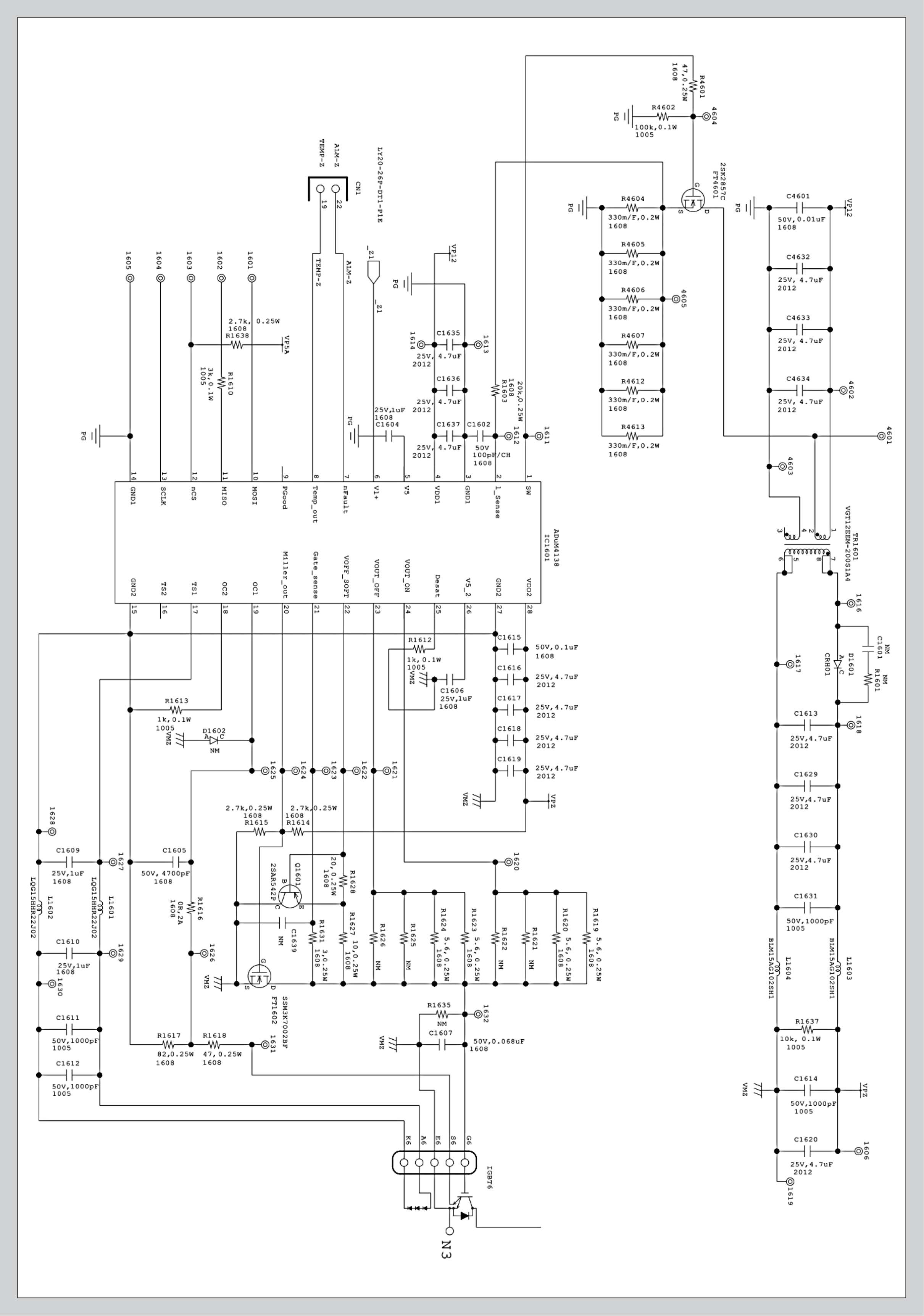


Fig. 7-21 Gate driver for Phase Z

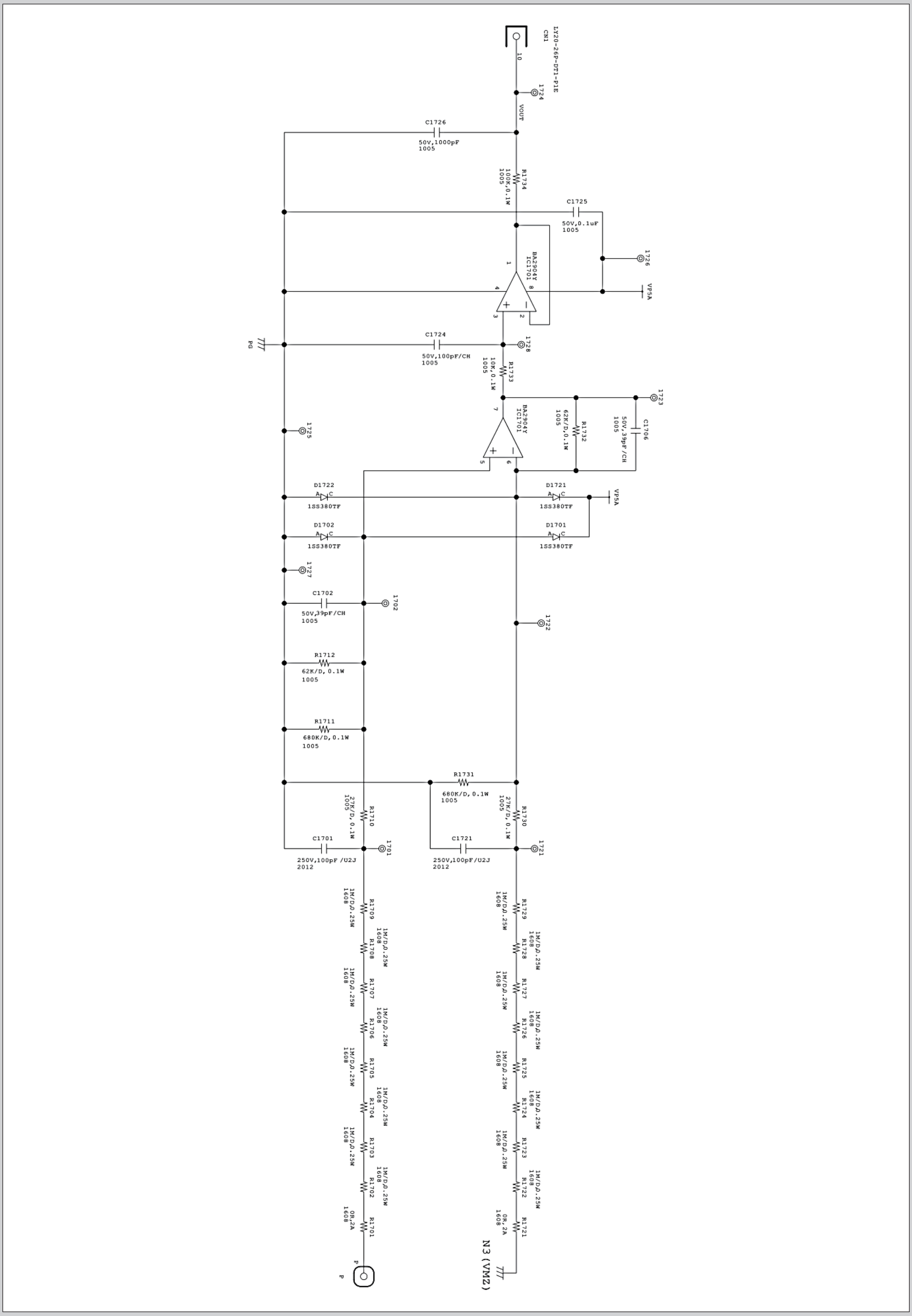
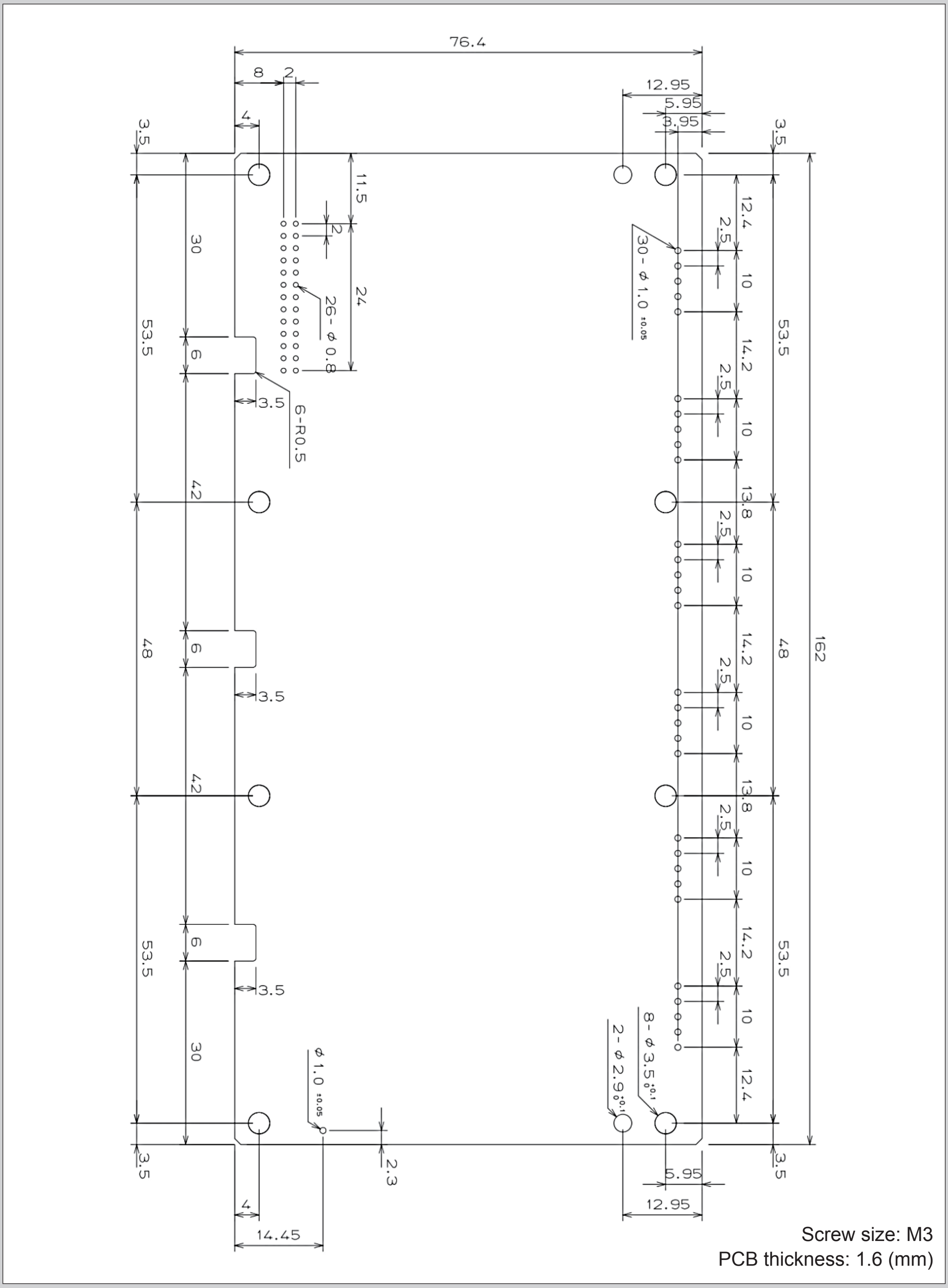


Fig. 7-22 Voltage detection part at Phase W, Z

16. Evaluation Board Dimensions



Screw size: M3
PCB thickness: 1.6 (mm)

Fig. 7-23 Assembly drawing of the driver board (Top)

17. Assembly Drawing

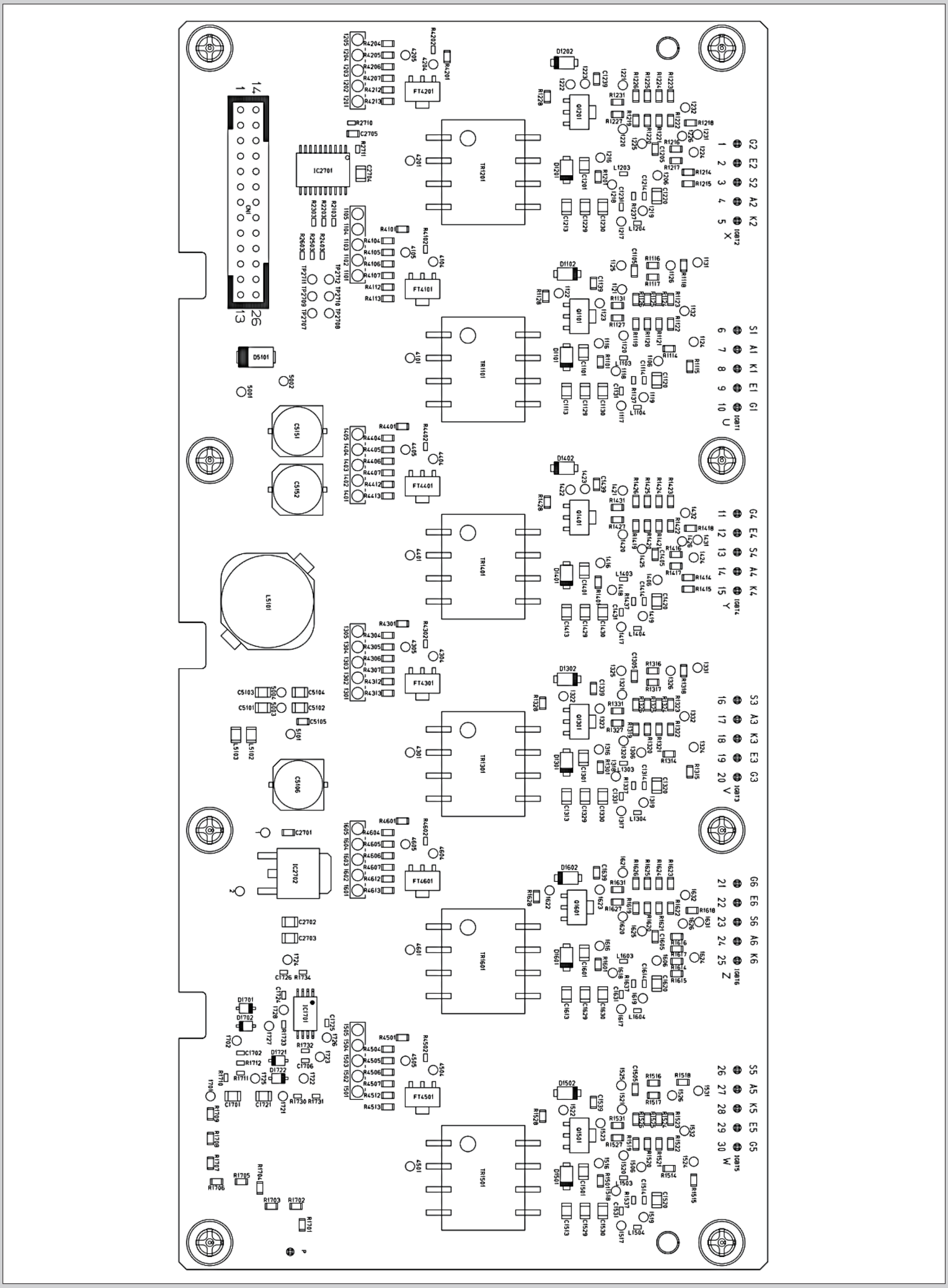


Fig. 7-24 Assembly drawing of the driver board (Top)

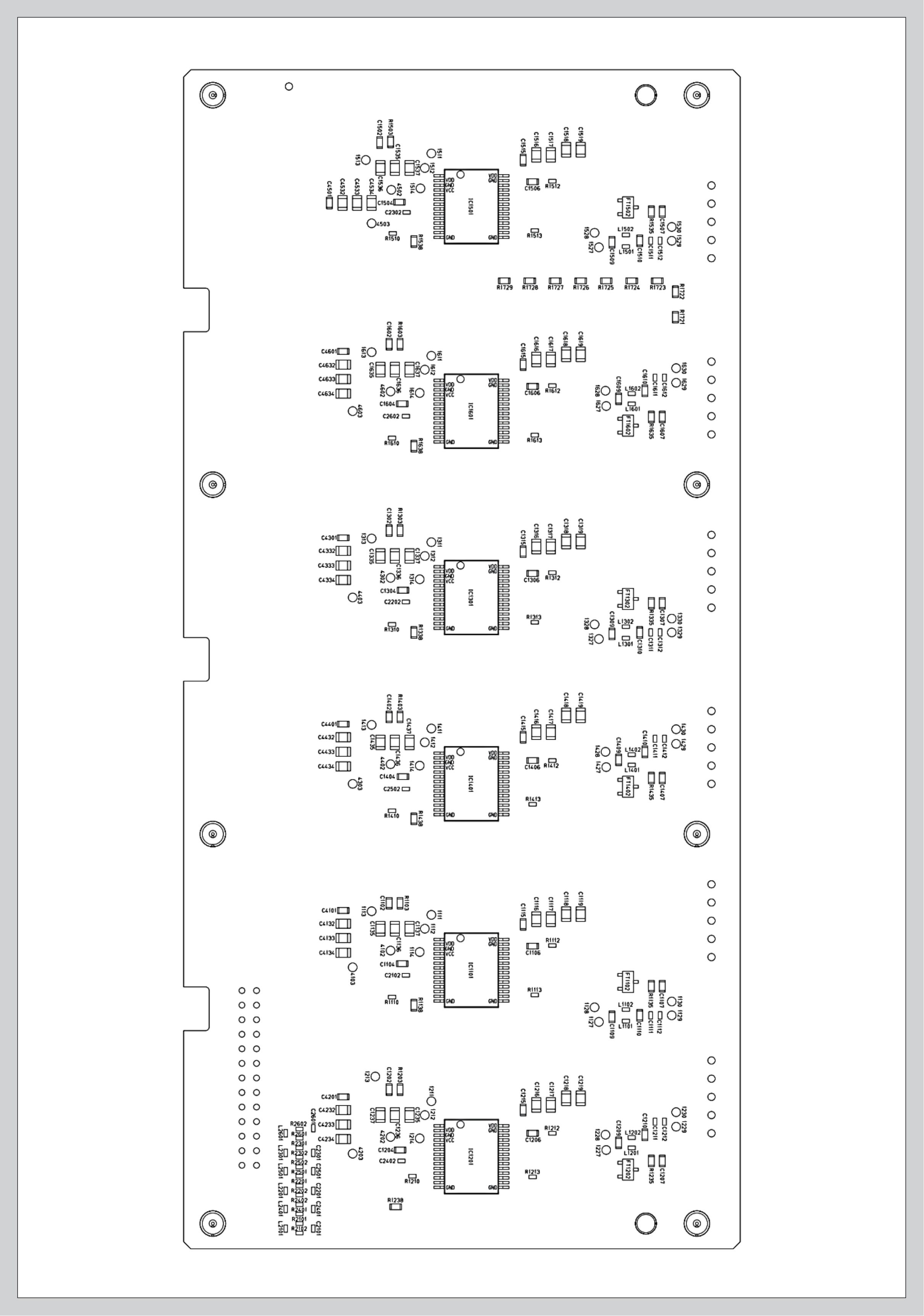


Fig. 7-25 Assembly drawing of the driver board (Bottom)

18. Layout

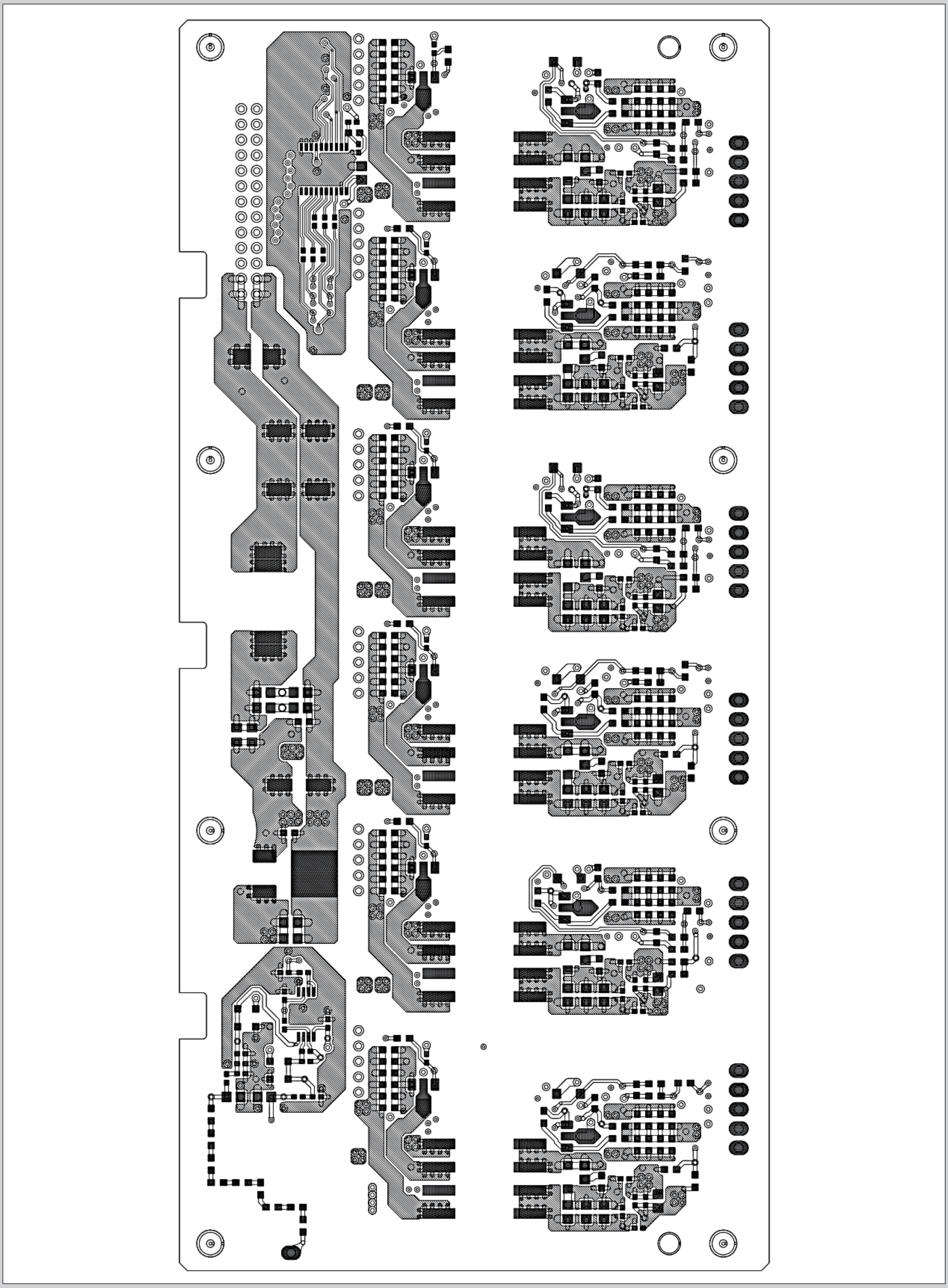


Fig. 7-26 Driver board – Top layer

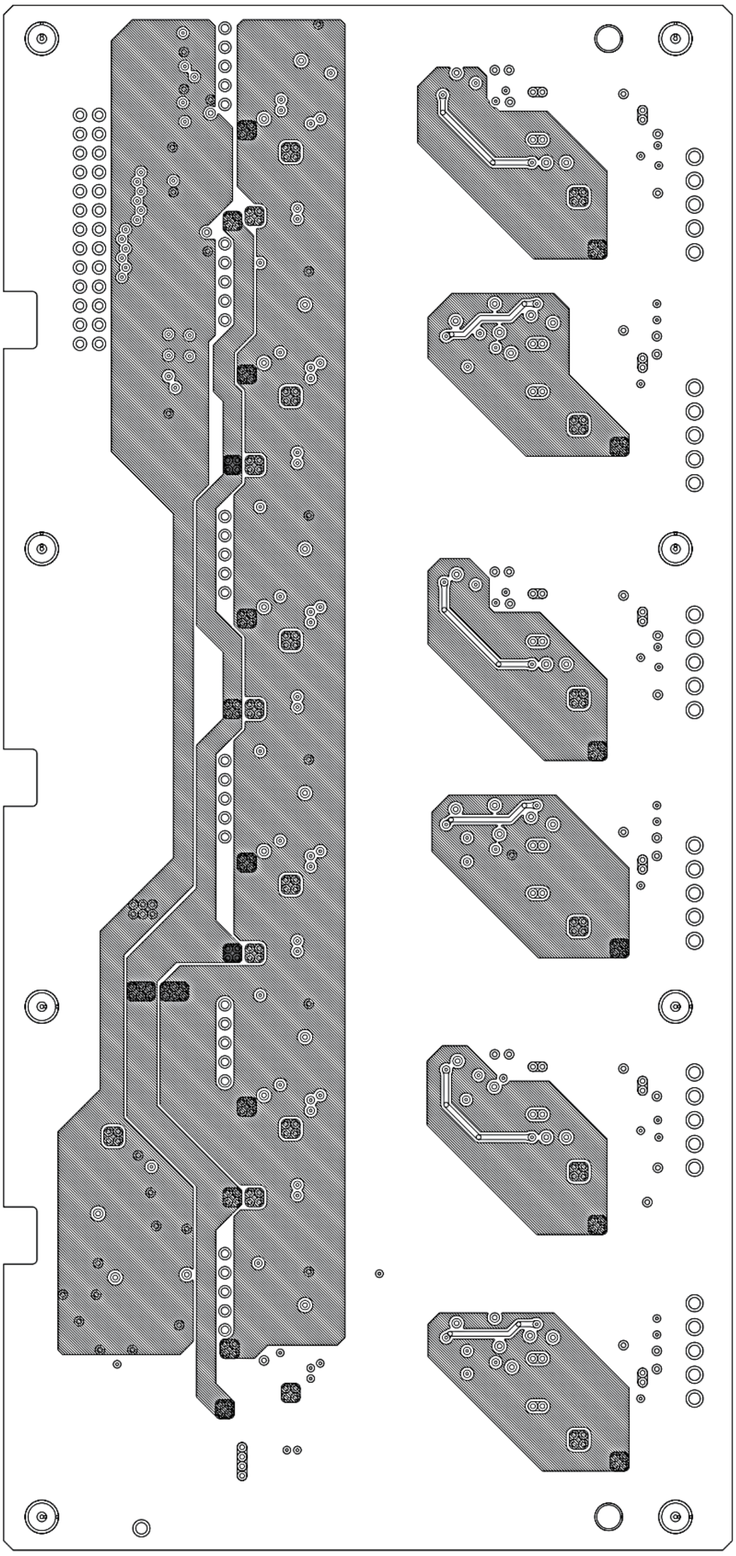


Fig. 7-27 Driver board – Layer 2

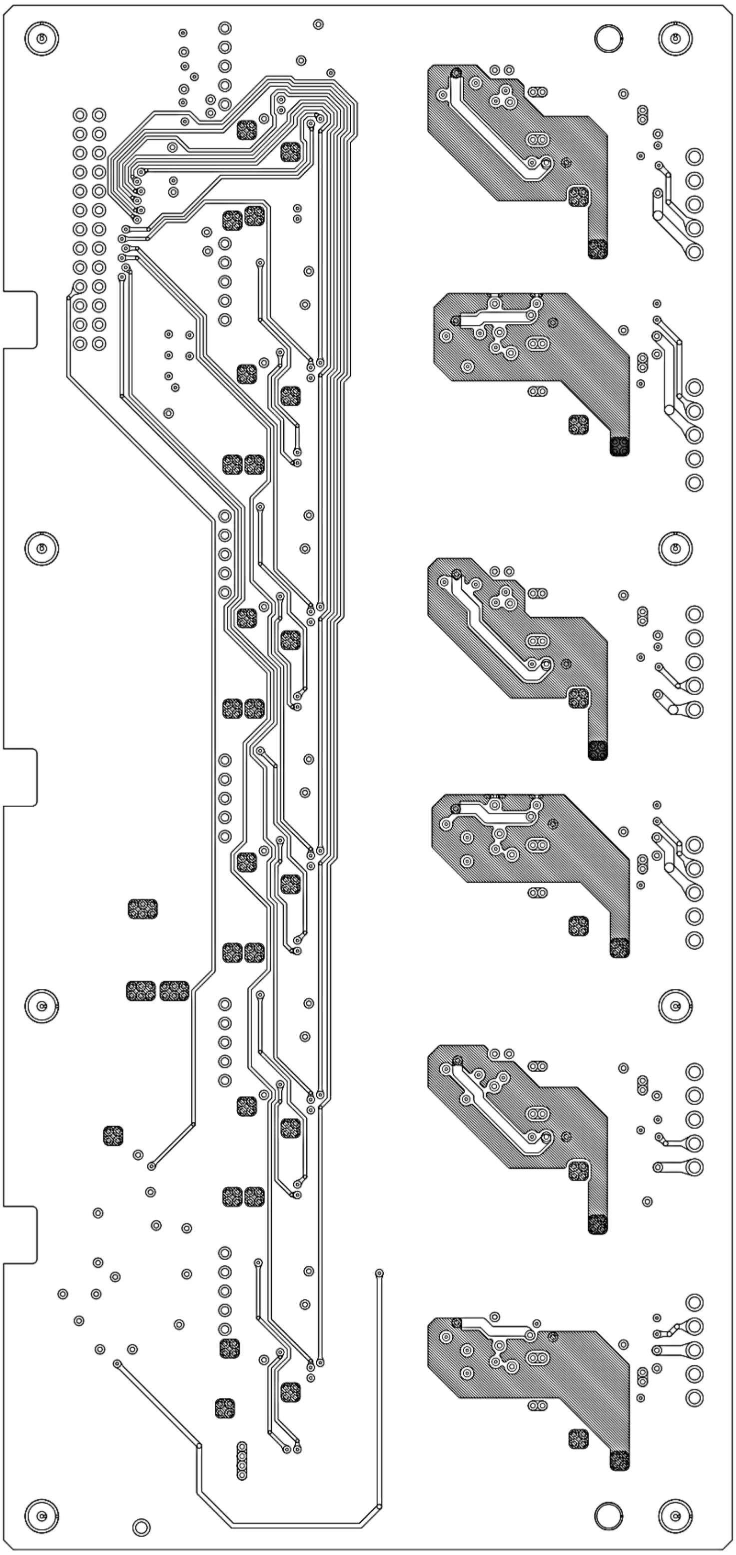


Fig. 7-28 Driver board – Layer 3

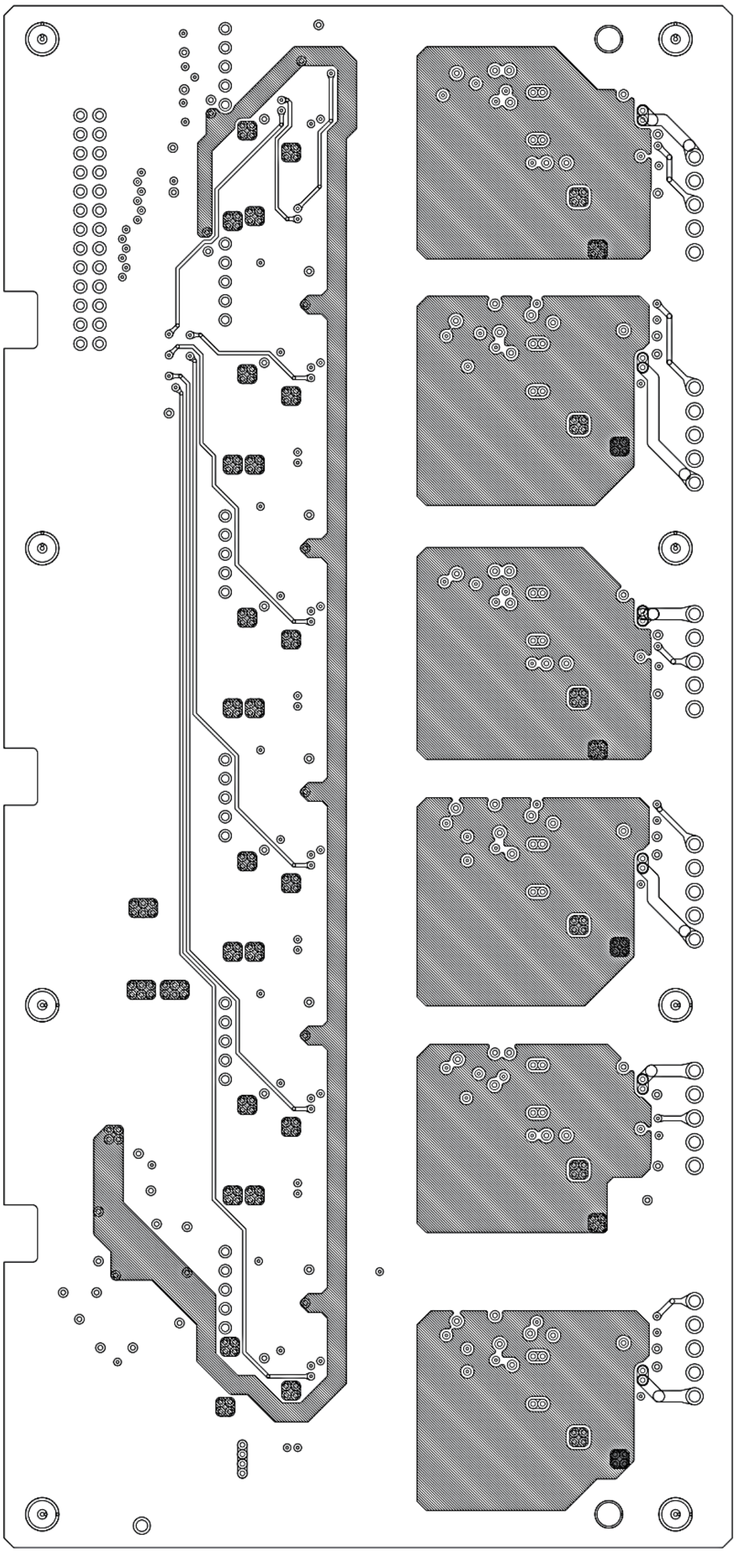


Fig. 7-29 Driver board – Layer 4

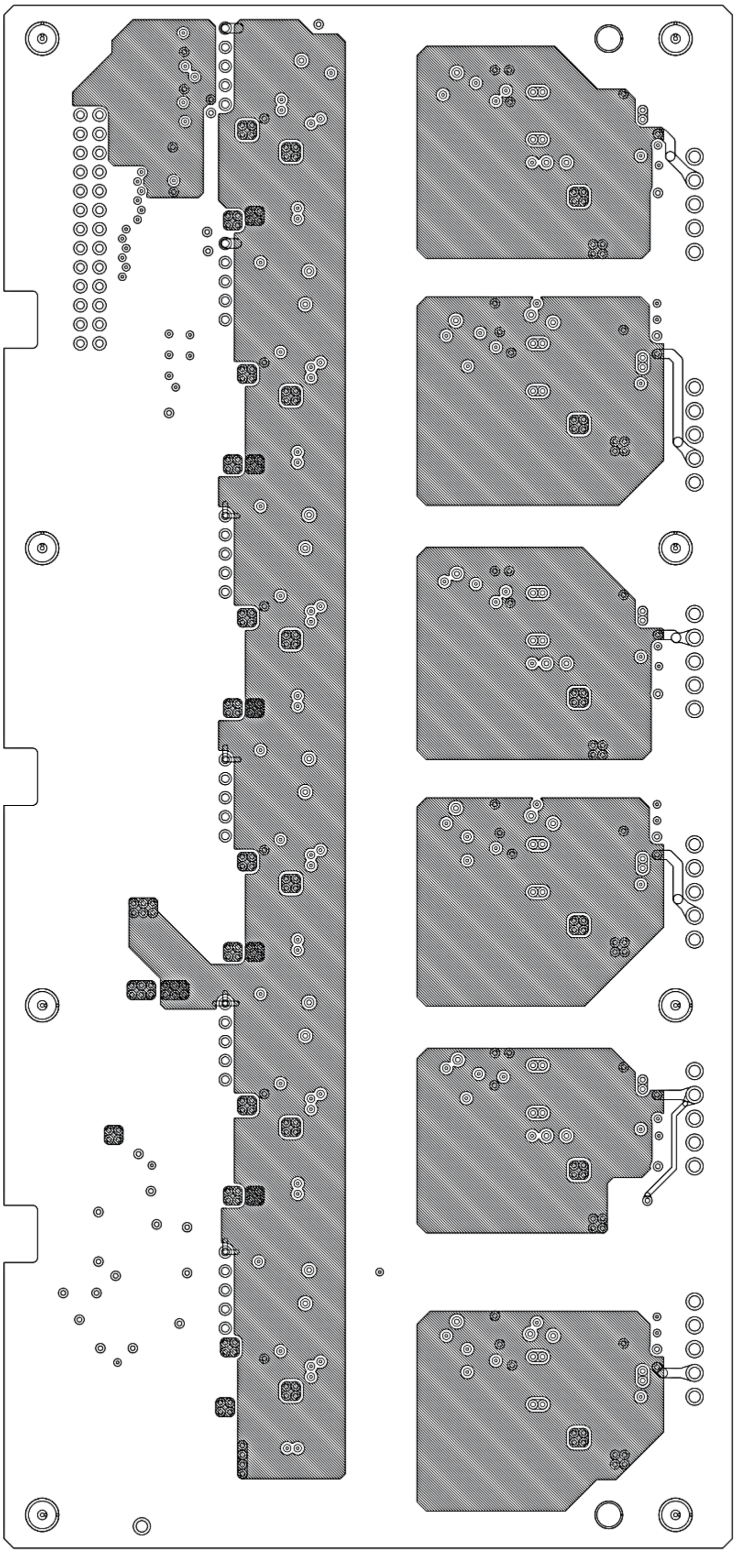


Fig. 7-30 Driver board – Layer 5

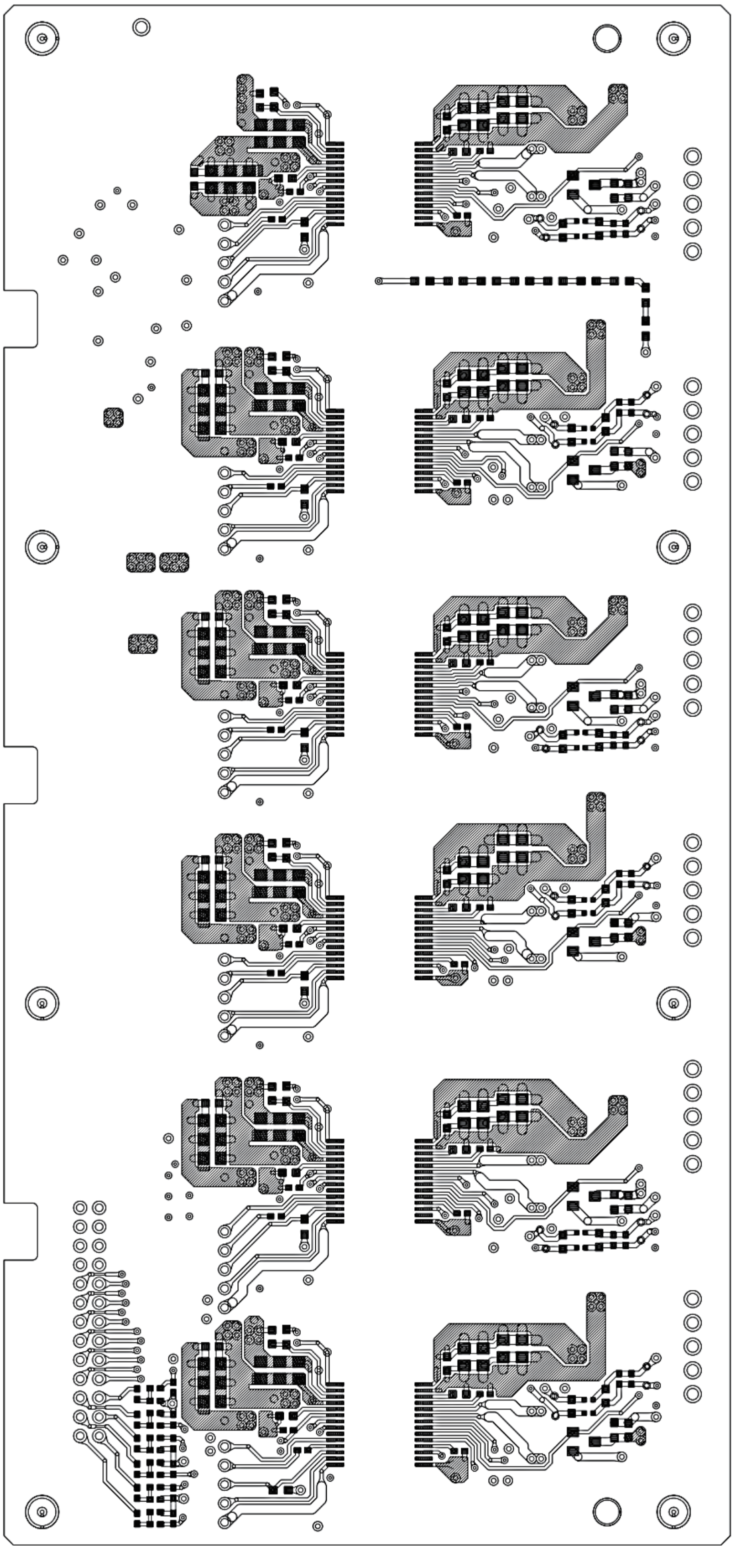


Fig. 7-31 Driver board – Bottom layer

19. Parts List

Table 7-8 Bill of materials for the M653 IGBT module evaluation board

No	Value / Device	Pakage type (JEDEC)	Classification	Reference					
1	SJPZ-N27VR Sanken	No description	Diode	D5101					
2	CRH01 Toshiba	Toshiba:3-2A1A	Diode	D1101	D1201	D1301	D1401	D1501	D1601
3	1SS380TF Rohm	SOD-323	Diode	D1701	D1702	D1721	D1722		
4	2SAR542P Rohm	SOT89	PNP Middle Power Transistor	Q1101	Q1201	Q1301	Q1401	Q1501	Q1601
5	2SK2857C-T1-AZ/AY Renesas	SOT89	Nch MOS-FET	FT4101	FT4201	FT4301	FT4401	FT4501	FT4601
6	SSM3K7002BF Toshiba	TO-236MOD	Nch MOS-FET	FT1102	FT1202	FT1302	FT1402	FT1502	FT1602
7	ADuM413 Analog Devices	ADI:28L SSOP	Driver IC Automotive	IC1101	IC1201	IC1301	IC1401	IC1501	IC1601
8	TA58L05F (T16L1,NQ) Toshiba	HSOP3-P2.30D	Low-dropout regulators	IC2702					
9	TC74VHC9541FT Toshiba	TSSOP14-004-0.65A	Logic IC	IC2701					
10	BA2904Y Rohm	SSOP-B8	OP-Amp Automotive	IC1701					
11	VGT12EEM-200S1A4 TDK	SMD	Transformers Automotive	TR1101	TR1201	TR1301	TR1401	TR1501	TR1601
12	CLF12555T-220M TDK	SMD	Power Inductor	L5101					
13	BLM15AG102SH1 Murata	SMD 1005(mm)	Chip Ferite bead Automotive	L1103	L1203	L1303	L1403	L1503	L1603
				L1104	L1204	L1304	L1404	L1504	L1604
				L2101	L2201	L2301	L2401	L2501	L2601
14	BLM21PG331SH1 Murata	SMD 2012(mm)	Chip Ferite bead Automotive	L5102	L5103				
15	LQG15HHR22J02 Murata	SMD 1005(mm)	Inductor Automotive	L1101	L1201	L1301	L1401	L1501	L1601
				L1102	L1202	L1302	L1402	L1502	L1602

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Table 7-9 Bill of materials for the M653 IGBT module evaluation board (cont'd)

No	Value / Device	Pakage type (JEDEC)	Classification	Reference					
16	25V,100uF	Ø6.3xH7.7	Capacitor	C5106	C5151	C5152			
17	50V,39pF,CH	SMD 1005(mm)	Capacitor	C1702	C1706				
18	50V,100pF,CH	SMD 1005(mm)	Capacitor	C1724					
				C2102	C2202	C2302	C2402	C2502	C2602
19	50V,330pF,CH	SMD 1005(mm)	Capacitor	C2101	C2201	C2301	C2401	C2501	C2601
20	50V,1000pF,CH	SMD 1005(mm)	Capacitor	C1111	C1211	C1311	C1411	C1511	C1611
				C1112	C1212	C1312	C1412	C1512	C1612
				C1114	C1214	C1314	C1414	C1514	C1614
				C1131	C1231	C1331	C1431	C1531	C1631
				C1726					
21	50V, 0.1uF	SMD 1005 (mm)	Capacitor	C1725					
22	50V, 100pF, CH	SMD 1608 (mm)	Capacitor	C1102	C1202	C1302	C1402	C1502	C1602
23	50V, 560pF, CH	SMD 1608 (mm)	Capacitor	C1105		C1305		C1505	
24	50V, 4700pF	SMD 1608 (mm)	Capacitor		C1205		C1405		C1605
25	50V, 0.01uF	SMD 1608 (mm)	Capacitor	C4101	C4201	C4301	C4401	C4501	C4601
26	50V, 0.047uF	SMD 1608 (mm)	Capacitor	C1107		C1307		C1507	
27	50V, 0.068uF	SMD 1608 (mm)	Capacitor		C1207		C1407		C1607
28	50V, 0.1uF	SMD 1608 (mm)	Capacitor	C1115	C1215	C1315	C1415	C1515	C1615
				C2705	C5105				
29	25V, 1uF	SMD 1608 (mm)	Capacitor	C1104	C1204	C1304	C1404	C1504	C1604
				C1106	C1206	C1306	C1406	C1506	C1606
				C1109	C1209	C1309	C1409	C1509	C1609
				C1110	C1210	C1310	C1410	C1510	C1610
				C2701					
30	250V, 100pF	SMD 2012 (mm)	Capacitor	C1701	C1721				
31	25V, 2.2uF	SMD 2012 (mm)	Capacitor	C5101	C5102	C5103	C5104		

Table 7-10 Bill of materials for the M653 IGBT module evaluation board (cont'd)

No	Value / Device	Pakage type (JEDEC)	Classification	Reference					
32	25V, 4.7uF	SMD 2012 (mm)	Capacitor	C1113	C1213	C1313	C1413	C1513	C1613
				C1116	C1216	C1316	C1416	C1516	C1616
				C1117	C1217	C1317	C1417	C1517	C1617
				C1118	C1218	C1318	C1418	C1518	C1618
				C1119	C1219	C1319	C1419	C1519	C1619
				C1120	C1220	C1320	C1420	C1520	C1620
				C1129	C1229	C1329	C1429	C1529	C1629
				C1130	C1230	C1330	C1430	C1530	C1630
				C1135	C1235	C1335	C1435	C1535	C1635
				C1136	C1236	C1336	C1436	C1536	C1636
				C1137	C1237	C1337	C1437	C1537	C1637
				C4132	C4232	C4332	C4432	C4532	C4632
				C4133	C4233	C4333	C4433	C4533	C4633
				C4134	C4234	C4334	C4434	C4534	C4634
				C2702	C2703	C2704			
33	2.7k/D, 0.1W	SMD 1005 (mm)	Resistor	R1710	R1730				
34	62k/D, 0.1W	SMD 1005 (mm)	Resistor	R1712	R1732				
35	680k/D, 0.1W	SMD 1005 (mm)	Resistor	R1711	R1731				
36	1k, 0.1W	SMD 1005 (mm)	Resistor	R1112	R1212	R1312	R1412	R1512	R1612
				R1113	R1213	R1313	R1413	R1513	R1613
37	3k, 0.1W	SMD 1005 (mm)	Resistor	R1110	R1210	R1310	R1410	R1510	R1610
38	4.7k, 0.1W	SMD 1005 (mm)	Resistor	R2102	R2202	R2302	R2402	R2502	R2602
39	10k, 0.1W	SMD 1005 (mm)	Resistor	R1137	R1237	R1337	R1437	R1537	R1637
				R1733	R2710				
40	100k, 0.1W	SMD 1005 (mm)	Resistor	R4102	R4202	R4302	R4402	R4502	R4602
				R1734					
41	0R, 2A	SMD 1608 (mm)	Resistor	R1116	R1216	R1316	R1416	R1516	R1616
				R1701	R1721				
42	330m/F, 0.2W	SMD 1608 (mm)	Resistor	R4104	R4204	R4304	R4404	R4504	R4604
				R4105	R4205	R4305	R4405	R4505	R4605
				R4106	R4206	R4306	R4406	R4506	R4606
				R4107	R4207	R4307	R4407	R4507	R4607
				R4112	R4212	R4312	R4412	R4512	R4612
				R4113	R4213	R4313	R4413	R4513	R4613

Each tolerance of resistor are described on the part table like below image or ±5% unless otherwise specified.
Example: No. 33, 2.7k/D, 0.1W: Character "D" means ±0.5%, "F" means ±1.0%
Maker name of the resistors: TAIYOSHA ELECTRIC CO.,LTD.

Table 7-11 Bill of materials for the M653 IGBT module evaluation board (cont'd)

No	Value / Device	Pakage type (JEDEC)	Classification	Reference					
43	3, 0.25W	SMD 1608 (mm)	Resistor	R1131	R1231	R1331	R1431	R1531	R1631
44	5.6/D, 0.25W	SMD 1608 (mm)	Resistor	R1119	R1219	R1319	R1419	R1519	R1619
				R1120	R1220	R1320	R1420	R1520	R1620
				R1123	R1223	R1323	R1423	R1523	R1623
				R1124	R1224	R1324	R1424	R1524	R1624
45	10, 0.25W	SMD 1608 (mm)	Resistor	R1127	R1227	R1327	R1427	R1527	R1627
46	20, 0.25W	SMD 1608 (mm)	Resistor	R1128	R1228	R1328	R1428	R1528	R1628
47	47/D, 0.25W	SMD 1608 (mm)	Resistor	R1118	R1218	R1318	R1418	R1518	R1618
				R4101	R4201	R4301	R4401	R4501	R4601
48	82/D, 0.25W	SMD 1608 (mm)	Resistor	R1117	R1217	R1317	R1417	R1517	R1617
49	2.7K, 0.25W	SMD 1608 (mm)	Resistor	R1114	R1214	R1314	R1414	R1514	R1614
				R1115	R1215	R1315	R1415	R1515	R1615
				R1138	R1238	R1338	R1438	R1538	R1638
50	20k, 0.25W	SMD 1608 (mm)	Resistor	R1103	R1203	R1303	R1403	R1503	R1603
51	1M/D, 0.25W	SMD 1608 (mm)	Resistor	R1702	R1703	R1704	R1705	R1706	R1707
				R1708	R1709	R1722	R1723	R1724	R1725
				R1726	R1727	R1728	R1729		
52	220, 0.2W	SMD 1005 (mm)	Resistor	R2103	R2203	R2303	R2403	R2503	R2603
53	3.6K, 0.2W	SMD 1005 (mm)	Resistor	R2101	R2201	R2301	R2401	R2501	R2601
54	LY20-26P-DT1-P1E JAE	26pin	Connector for interface	CN1					

Table 7-12 Bill of not populated materials for the M653 IGBT module evaluation board

No	Value / Device	Pakage type (JEDEC)	Classification	Reference					
1		1005R		R2711					
2		1608R		R1101	R1201	R1301	R1401	R1501	R1601
				R1121	R1221	R1321	R1421	R1521	R1621
				R1122	R1222	R1322	R1422	R1522	R1622
				R1125	R1225	R1325	R1425	R1525	R1625
				R1126	R1226	R1326	R1426	R1526	R1626
				R1135	R1235	R1335	R1435	R1535	R1635
3		1608C		C1139	C1239	C1339	C1439	C1539	C1639
4		2012C		C1101	C1201	C1301	C1401	C1501	C1601
5		CRH01		D1102	D1202	D1302	D1402	D1502	D1602

Chapter 8 Sense IGBT Performance

1. Scope

This appendix is explaining about the sense IGBT (Insulated Gate Bipolar Transistor) performance.

Shown typical value and the tendency in this material have been obtained by certain IGBT and test setup.

So the data in this material does not limit the usage of the IGBT and the data are just reference of the outline of the sense IGBT.

2. Function

The function of the sense-IGBT is to detect overcurrent like Short-Circuit (SC) in the IGBT.

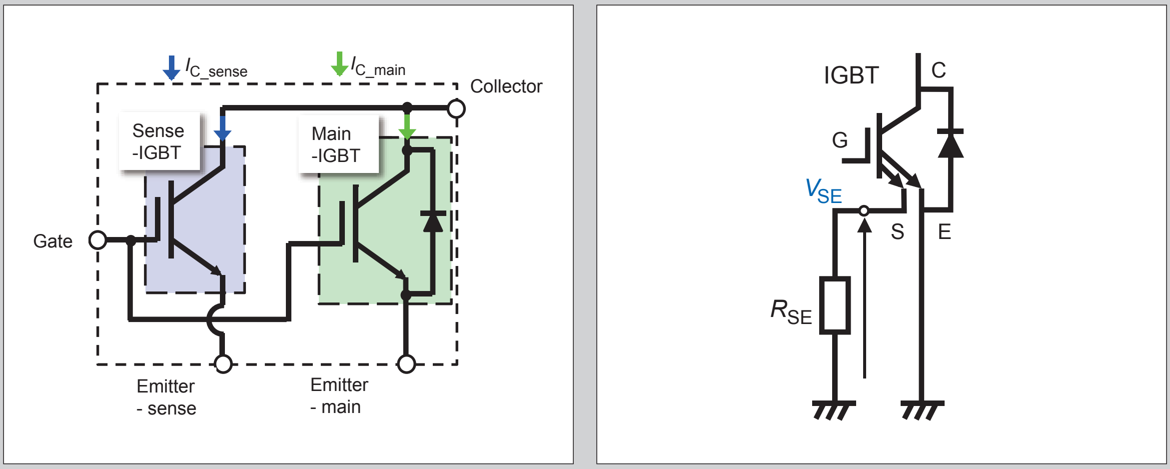
As showing in the Fig. 8-1, the sense IGBT is included in the same IGBT chip.

I_{C_sense} value is following I_{C_main} and flows at a certain split flow ratio.

$$I_{C\_sense} \propto I_{C\_main} \quad \text{--- eq.-1}$$

To detect the overcurrent as a voltage, a sense resistor R_{SE} is recommended.

How to design the R_{SE} is shown in the following pages.



(a) Equivalent circuit of a IGBT with sense-IGBT

(b) Detecting circuit

Fig. 8-1 Function of the sense-IGBT and the usage

3. Recommended R_{SE}: Sense Resistor

Using 2 pair of resistors, R_{SE1} and R_{SE2}, is recommendedas shown in Fig. 8-2, for taking account of easy design for a Short-circuit detecting voltage: V_{SC}.

Total value of R_{SE}, R_{SE1} + R_{SE2}, is designed by following V_{SE} characteristics.

1) Higher R_{SE} is needed for higher SC detection speed.
   As shown in Fig. 8-3(a), steeper dV_{SE} /dt is needed for high speed SC protection, and dV_{SE}/dt tends to increase as R_{SE} value increasing shown in Fig. 8-3(b).
2) On the other hand, when R_{SE} is much higher value, the SC protection circuit and/or IC might be broken down due to turn-off surge voltage of V_{SE}, Fig. 8-3(c).
   The V_{SE} on turn-off depends on R_{SE}, Fig. 8-3(d)
   If SC protection circuit is driven by around 15(V),
   V_{SE} value should be under 15(V), at least.
3) Based on above trade-off and including safety margin, 120Ω of R_{SE} is recommended for Short-circuit current detection resistance.

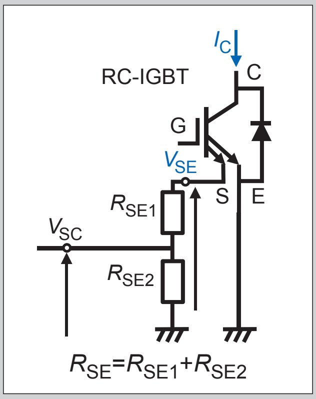
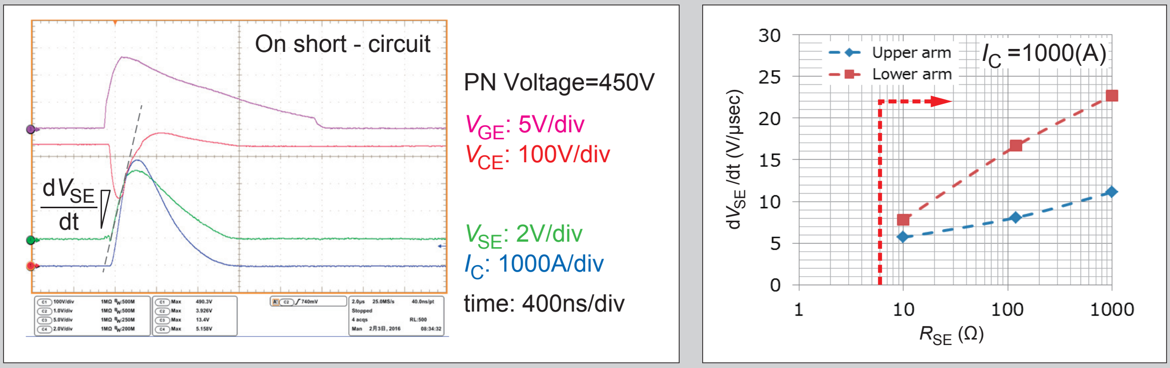


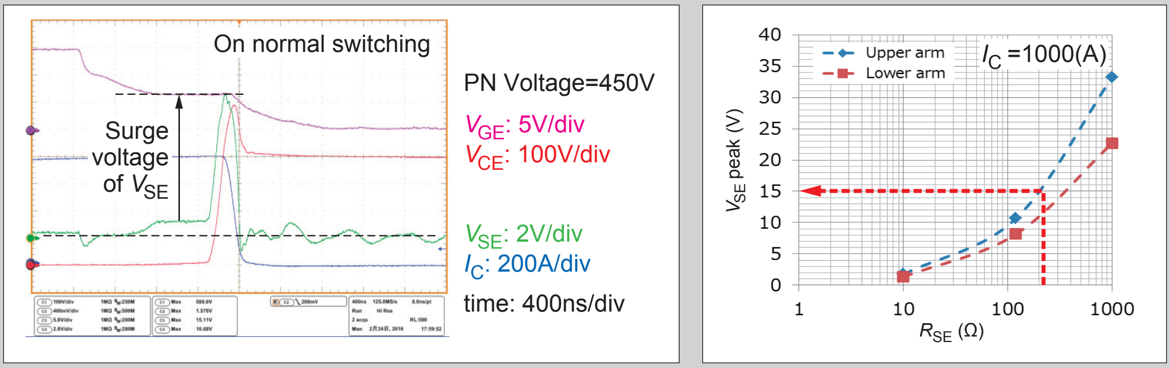
Fig. 8-2 V_{SE} and R_{SE}

*Relating V_{SE} data is taken by typical circuit constant as shown in main manual.
So detail parameter designing should be confirmed under required system setting.



(a) Rise performance of V_{SE}

(b) dV_{SE} /dt vs. R_{SE}



(c) Surge voltage of V_{SE} on turn off

(d) V_{SE} peak on turn-off vs. R_{SE}

Fig. 8-3 V_{SE} performance

4. Typical Characteristics of V_{SE}

V_{SE} is defined as 3 parts on a switching waveform showing in Fig. 8-4.

(i) Short-circuit: transient
(ii) Over-current: transient
(iii) Over-current: steady state

V_{SE} characteristics on each part are illustrated in followings.

Measurement parameters:

- I_C = 200~1000, step 200 (A)
- T_j = -40, 25, 125, 175 (°C)
- R_{SE} = 120 (Ω)

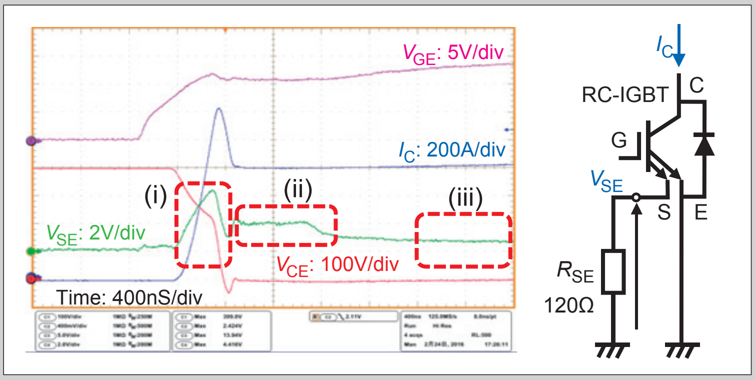
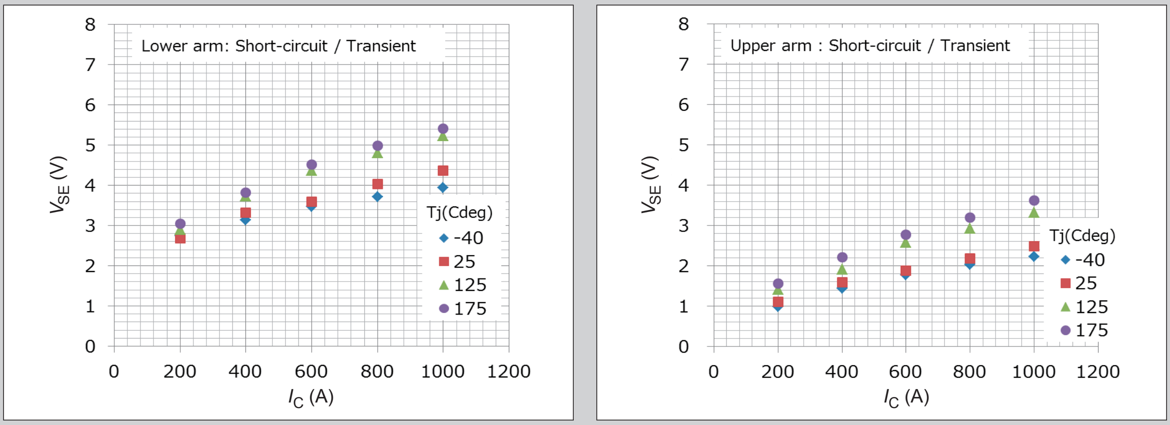


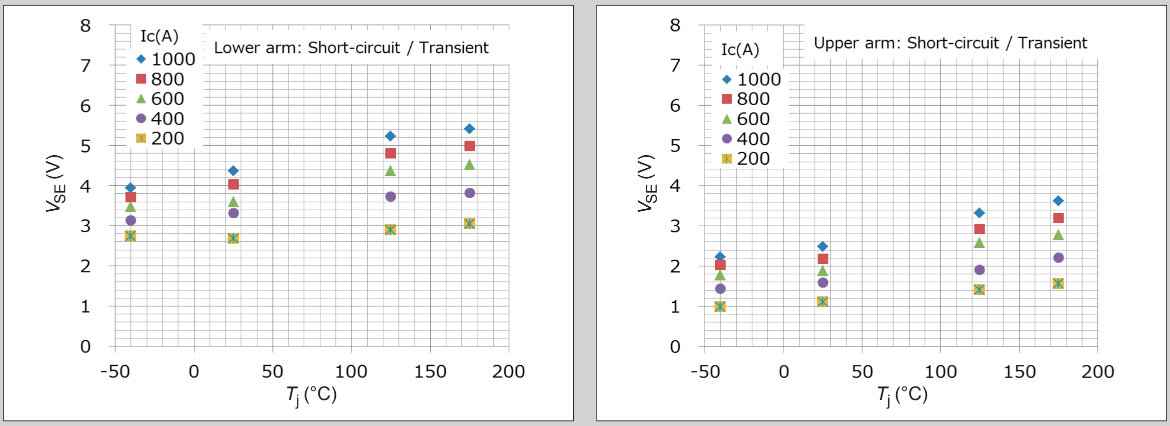
Fig. 8-4 V_{SE} on the switching waveform

5. V_{SE} Dependence of I_C and T_j: (i) Short-circuit / Transient



(a) V_{SE} vs. I_C: Lower arm

(b) V_{SE} vs. I_C: Upper arm



(c) V_{SE} vs. T_j: Lower arm

(d) V_{SE} vs. T_j: Upper arm

Fig. 8-5 Typical data example of V_{SE} characteristics on I_C and T_j at station-(i)

6. V_{SE} Dependence of I_C and T_j: (ii) Over-current / Transient

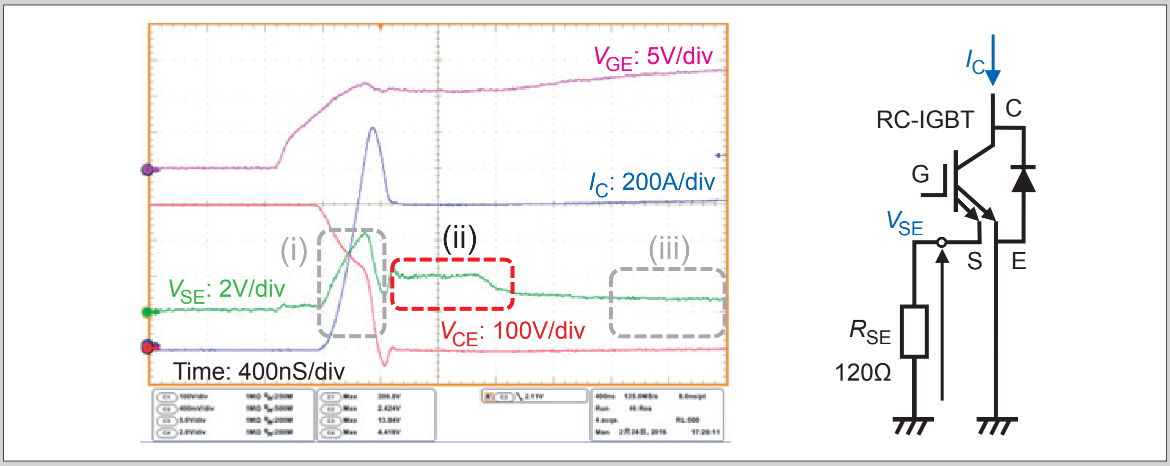
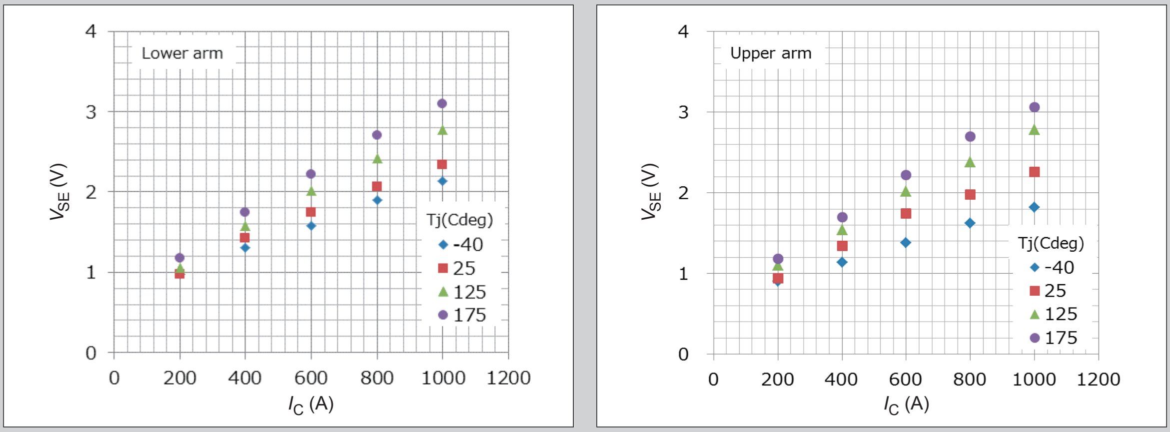
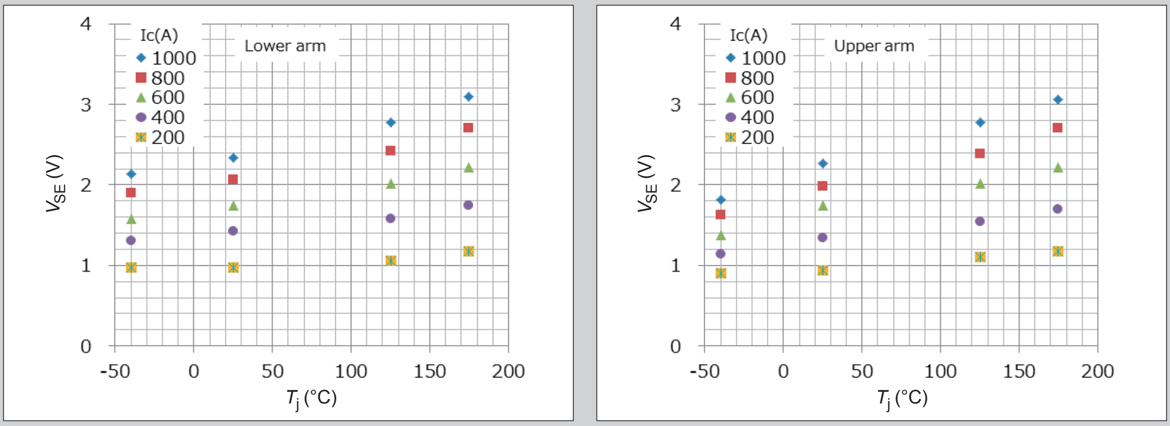


Fig. 8-6 V_{SE} on the switching waveform



(a) V_{SE} vs. I_C: Lower arm

(b) V_{SE} vs. I_C: Upper arm



(c) V_{SE} vs. T_j: Lower arm

(d) V_{SE} vs. T_j: Upper arm

Fig. 8-7 Typical data example of V_{SE} characteristics on I_C and T_j at station-(ii)

7. V_{SE} Dependence of I_C and T_j: (iii) Over-current / Steady state

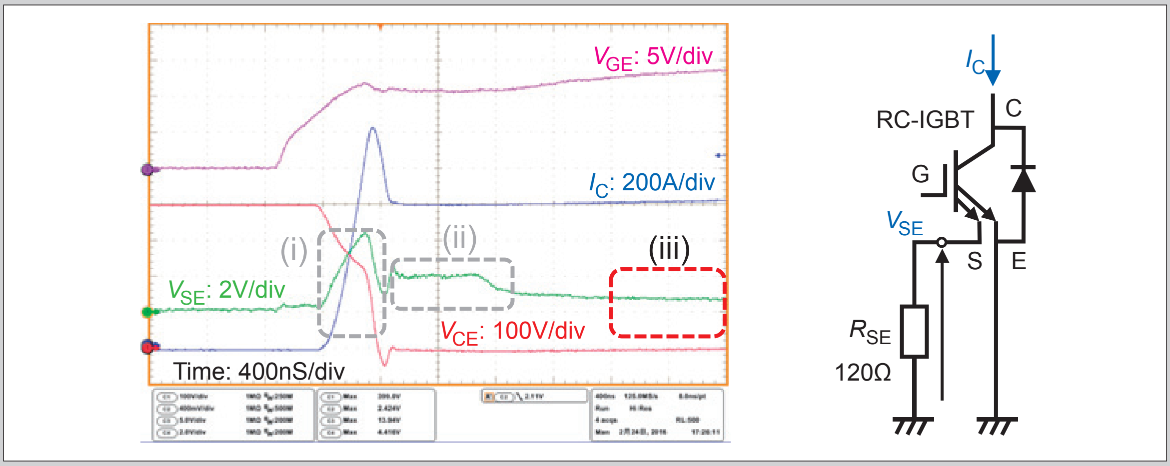
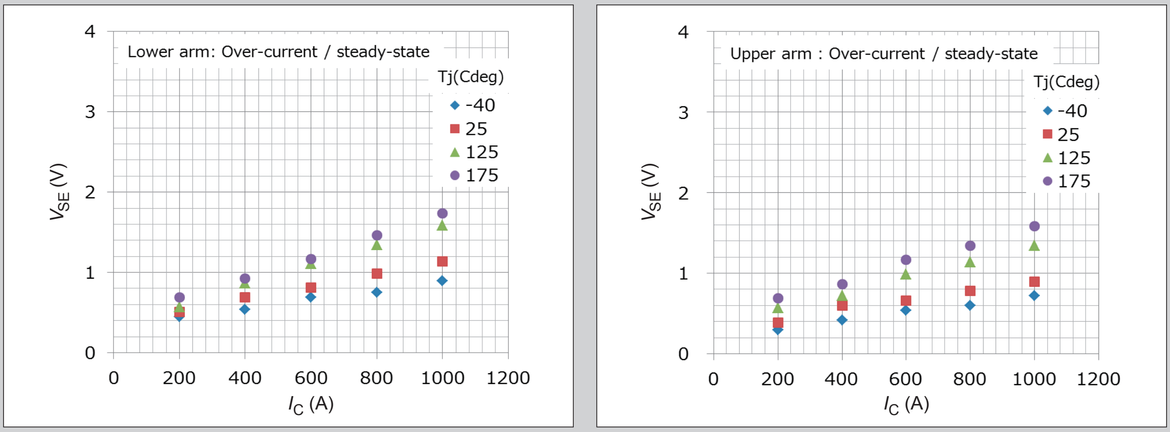
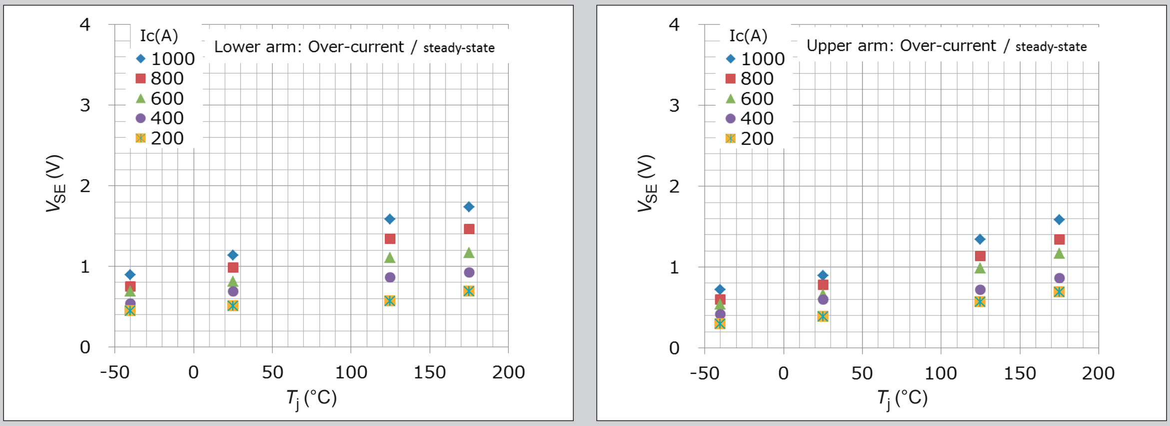


Fig. 8-8 V_{SE} on the switching waveform



(a) V_{SE} vs. I_C: Lower arm

(b) V_{SE} vs. I_C: Upper arm



(c) V_{SE} vs. T_j: Lower arm

(d) V_{SE} vs. T_j: Upper arm

Fig. 8-9 Typical data example of V_{SE} characteristics on I_C and T_j at station-(iii)

8. Application for SC Protection Function by Using ADI- ADuM4138*1.

Procedure of dividing resistor design.

1) Take V_{SE} dependence of T_j operation temperature by certain R_{SE} and I_C conditions.
Where, 120(Ω) of R_{SE} is recommended as explained in front page.
For ADI driver IC, V_{SE} characteristics on the over-current / transient state showing in P8-4 is recommended. Please see (ii) part in Fig. 8-10.
When 120(Ω) of R_{SE} and 800(A) of Ic are used, typical example result: Line-1 is shown in Fig. 8-11.
In this case, 25 to 175(°C) of T_j operation range are assumed.
2) Because V_{SE} value is proportional to T_j , threshold level of V_{SE} is set by maximum operational temperature. → V_{SE} = 2.87@175(°C) --- Line-2
3) On the other hand, V_{SC} level of ADuM4138 is 2(V) type.
$V_{CE} = V_{SE}{}^{*} R_{SE2} /(R_{SE1} + R_{SE2})$ --- eq.-1
$R_{SE1} + R_{SE2} = 120$ --- eq.-2
From eq.-1, eq.-2 and constants, R_{SE1} = 34.3(Ω), R_{SE2} = 85.7(Ω), respectively.
Because E24 series resistor set were used, R_{SE1} =36(Ω) and R_{SE2} = 82(Ω) were selected, respectively.
4) After R_{SE1} and R_{SE2} are replaced by certain resistor's value, the short–circuit protection function on RT of T_j shall be checked.
5) Then, the V_{SE} at SC on T_j operation range are taken. --- Line-3
Where V_{SE} value is peak value of the waveform which is part (ii) in Fig. 8-10.
6) Line-2 never cross Line-3 on T_j operation range is required condition in this setting.

*In the case of short-circuit protection function by using ADI driver IC, even if 12(V) clamp function is activated during mirror term on gate driving, there is no concern on dissipation.
The gate voltage is still increased in this term that is why influence of 12(V) clamp function to the gate voltage fluctuation is negligible.

During normal switching operation which is less than maximum current ratings, even if a V_{SE} value exceeds the threshold level of 2.87(V) on the part-(i), the soft turn-off function is not activated because the peak width is less than 800(nsec) of delay time.

*1) ADI: Analog Devices, Inc.

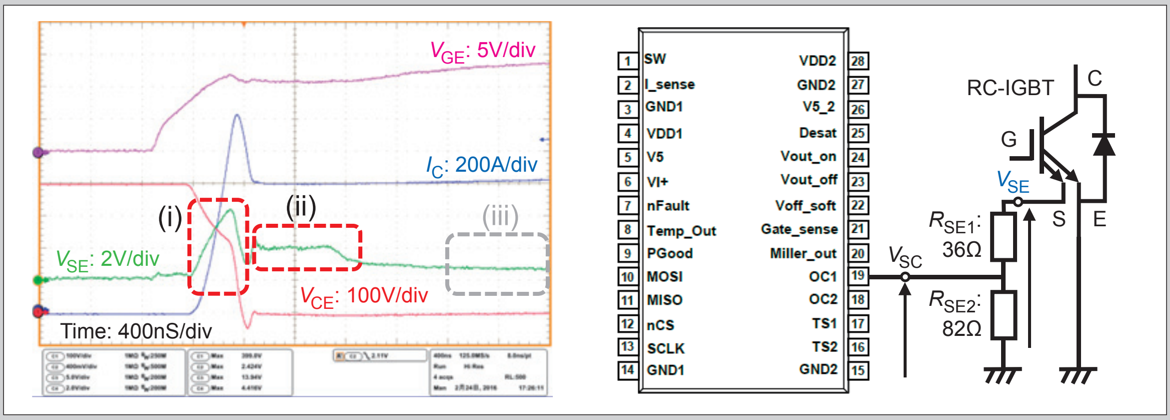


Fig. 8-10 Circuit diagram of SC protection by using ADuM1438

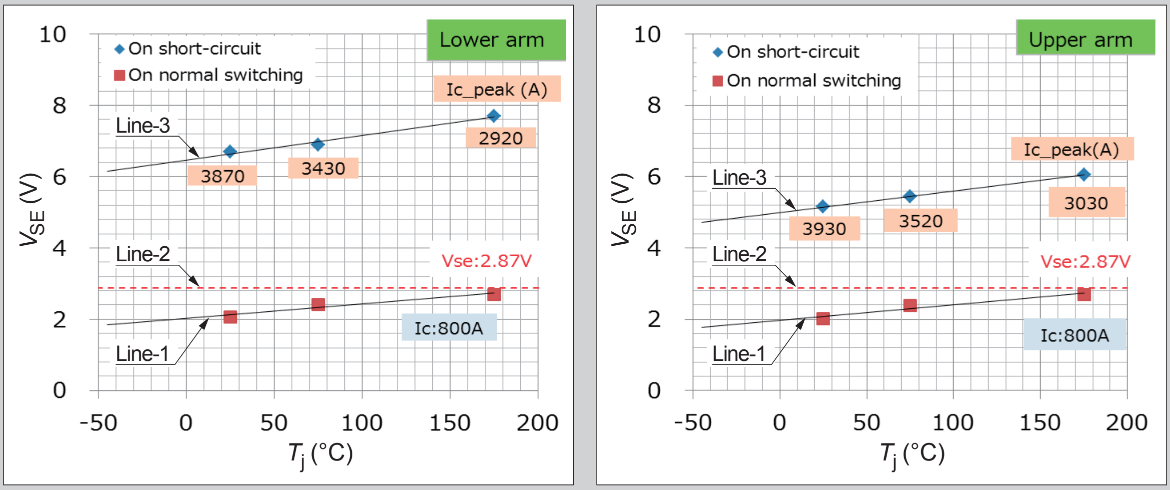


Fig. 8-11 SC protection function characteristics in terms of V_{SE}