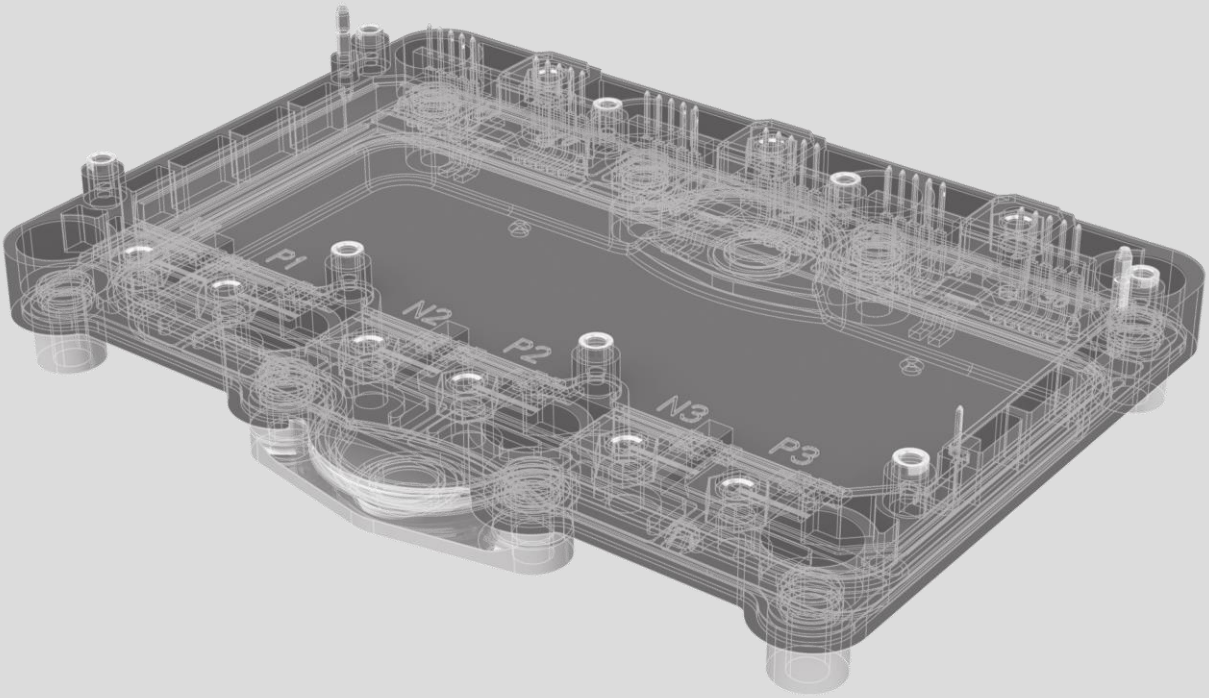

Fuji Automotive IGBT Module

M653 Series

6MBI800XV-075V-01

Application Manual

August 2019 Rev.1.2

Fuji Electric Co., Ltd.

MT5F33743

Warning:

This manual contains the product specifications, characteristics, data, materials, and structures as of August 2019.
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

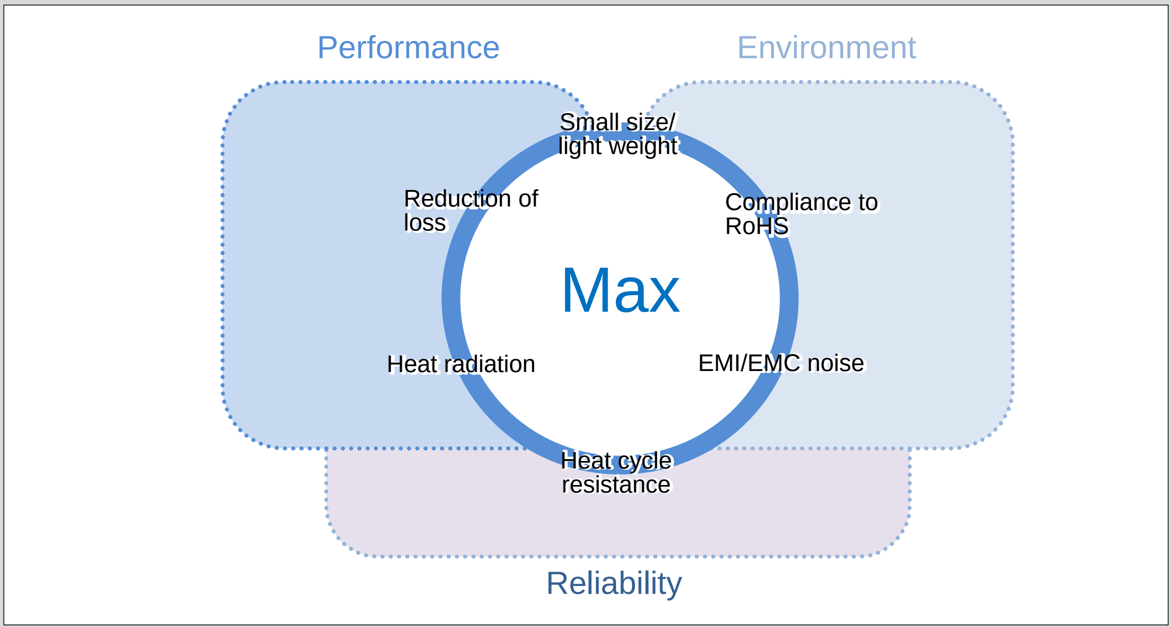


Fig. 1-1 IGBT module development concept targeted by Fuji Electric

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.

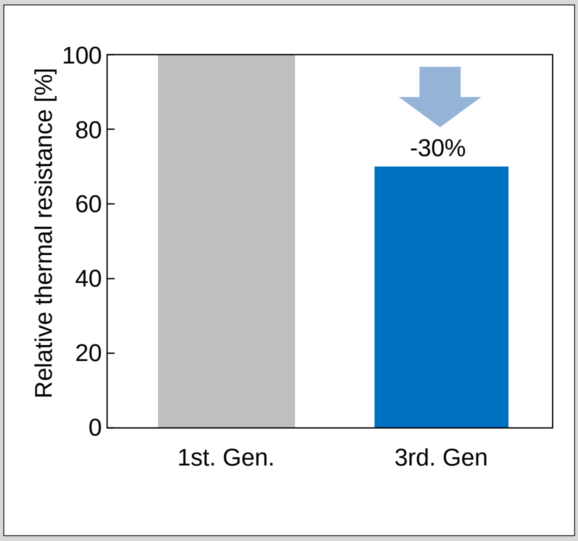
Fig. 1-2 shows the appearance of the newly developed automotive IGBT module developed this time.

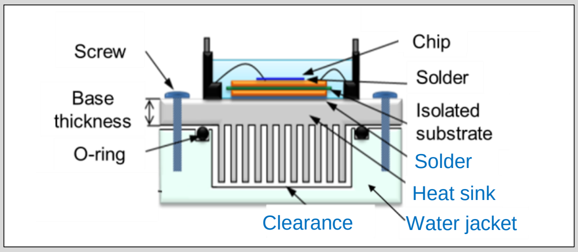
Fig. 1-3 is a comparison of steady-state thermal resistance between the 1st. generation and the 3rd. generation. On 3rd. generation cooling system, a cooling design without clearance increases coolant flow speed between fins, as a result 30% of the thermal resistance is improved.

(a)Top face

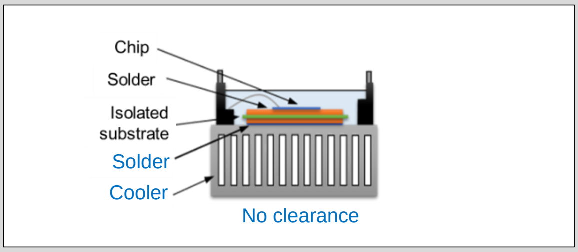
(b)Bottom face

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 X-series 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.

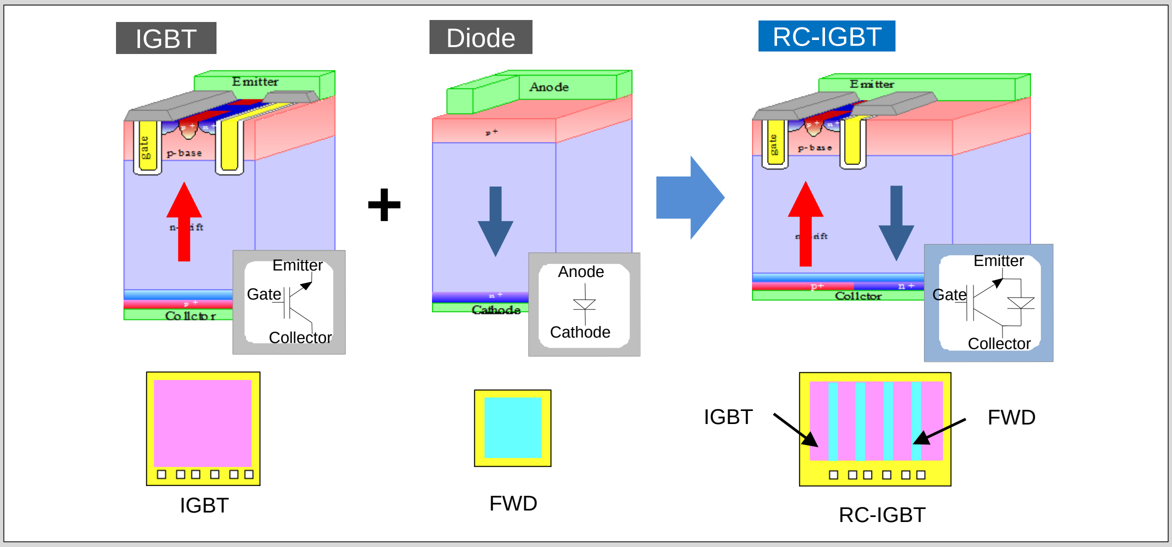


Fig. 1-4 Basic concept of the RC-IGBT

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.

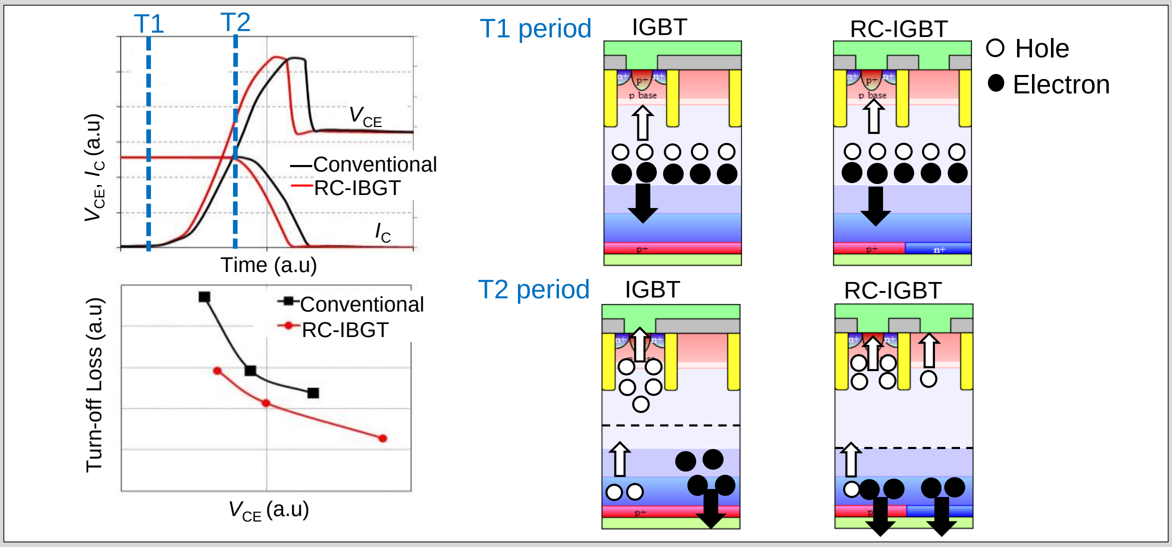


Fig. 1-5 Advantage of the RC-IGBT in loss

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.

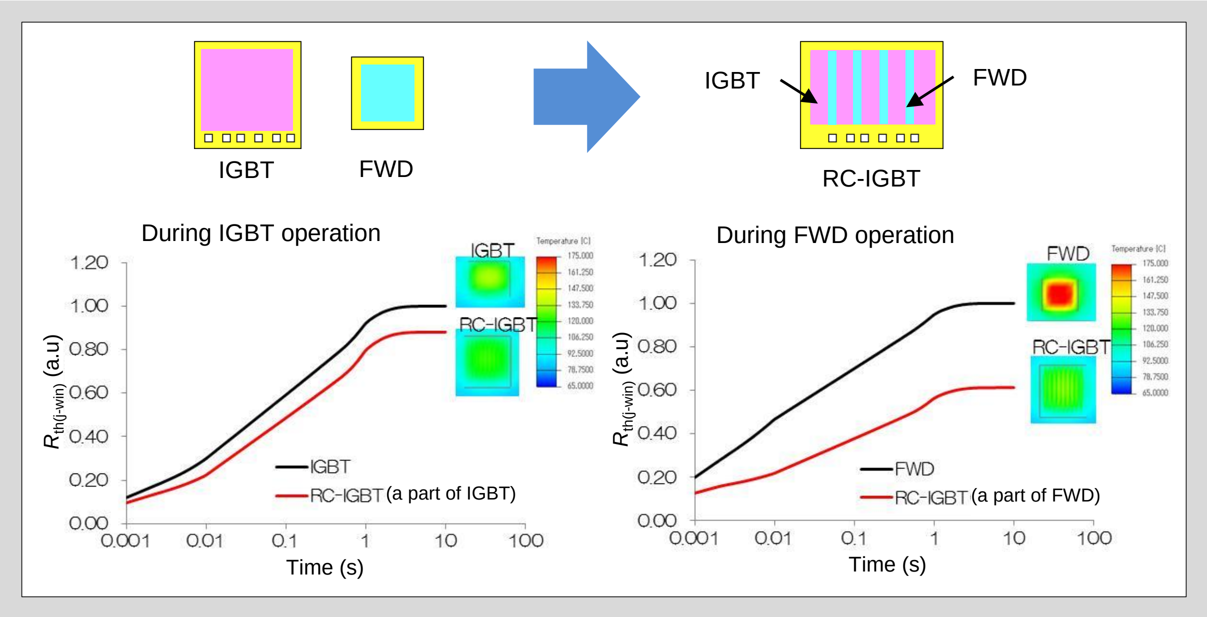


Fig. 1-6 Advantage of the RC-IGBT in thermal resistance

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.

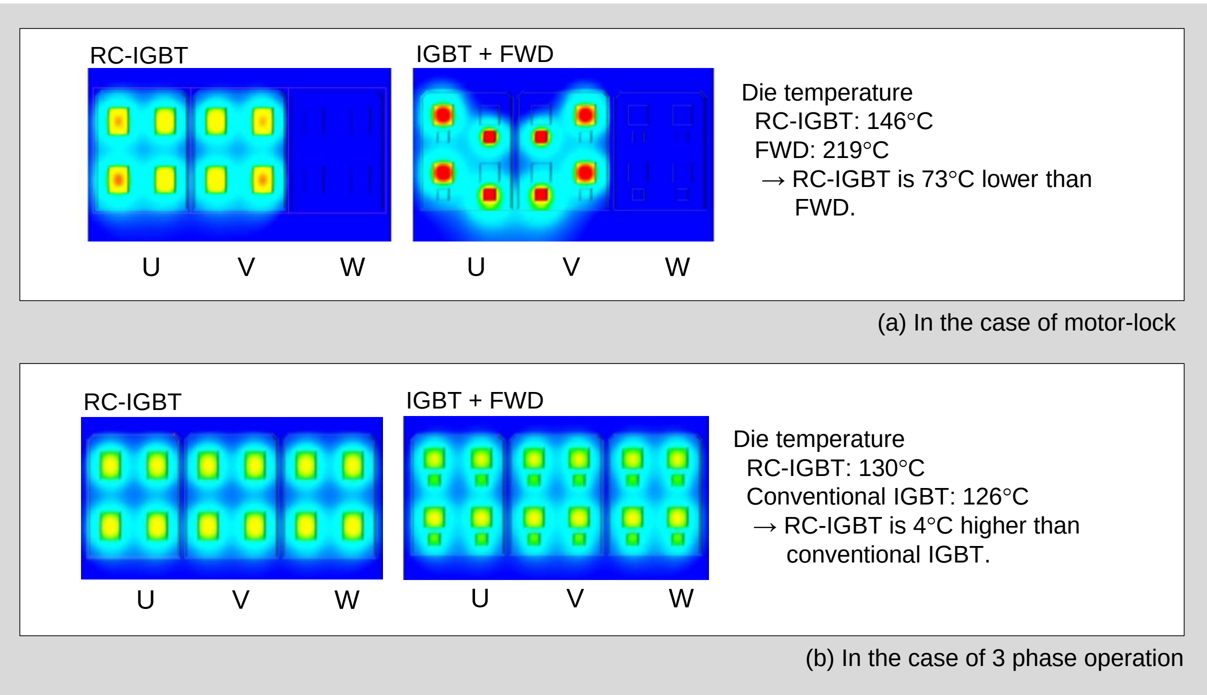


Fig. 1-7 Advantage of the RC-IGBT in rotor lock mode

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_{vj} and a current can be monitored, respectively.

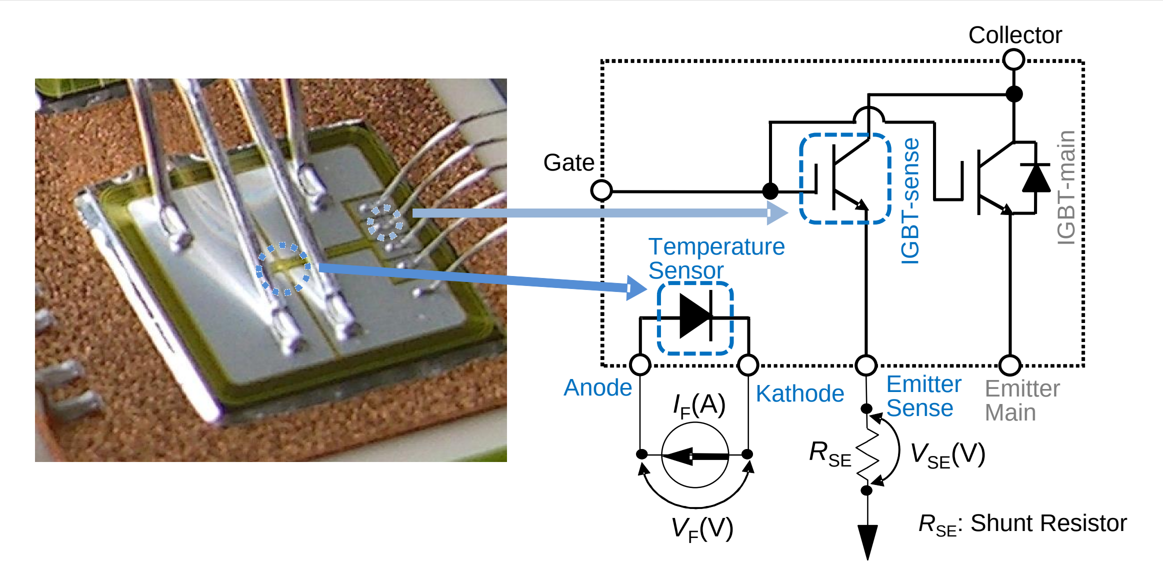
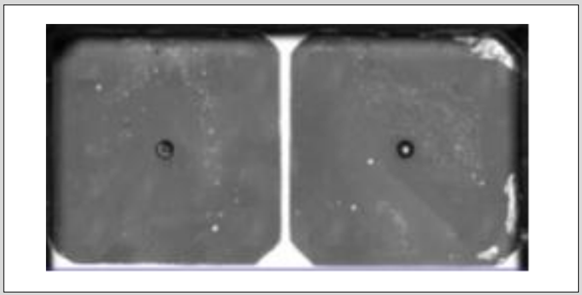


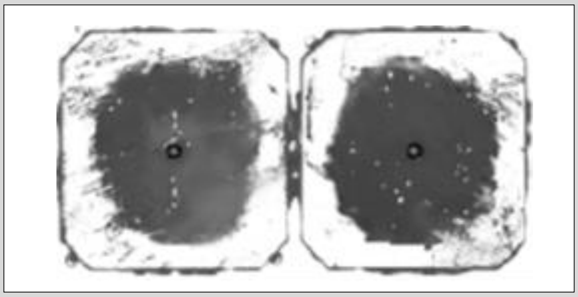
Fig. 1-8 On-chip sensors

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



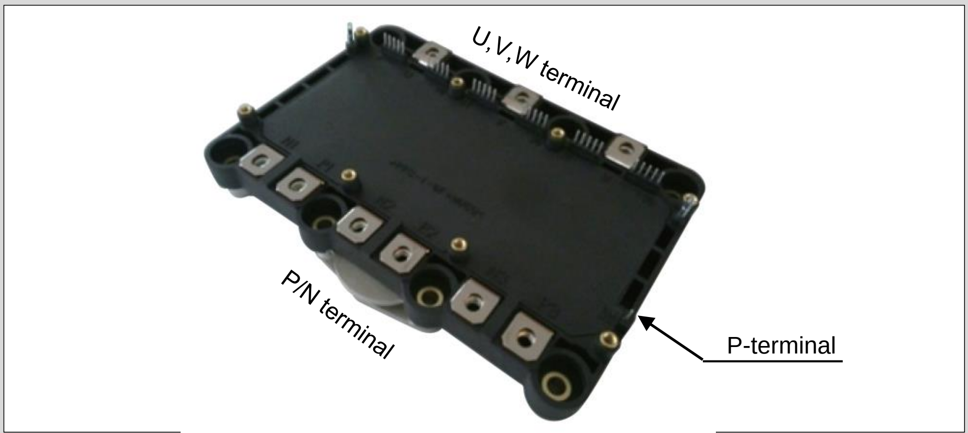
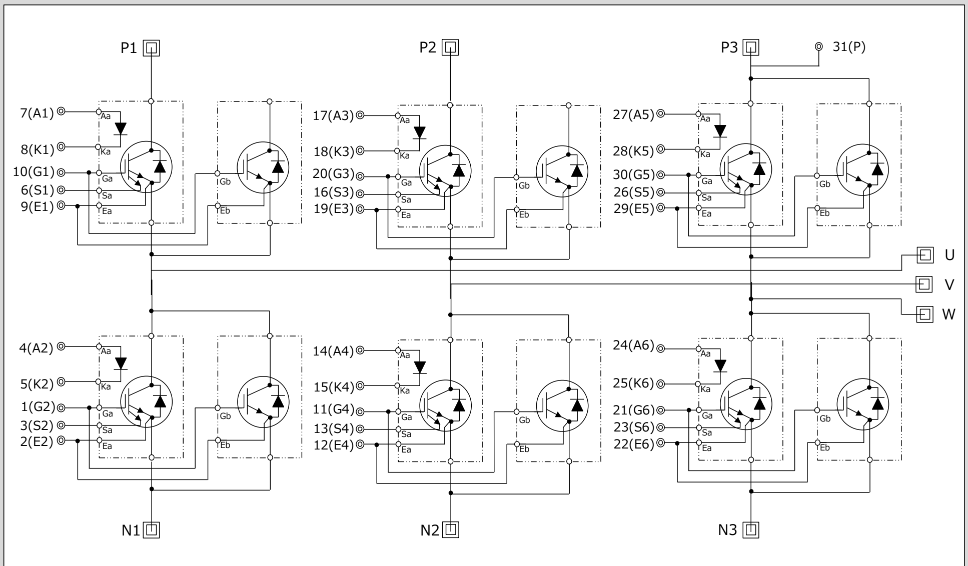
(b) SnAg-series solder

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 one pair 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_{vj} is shown in Fig. 7-3(a) of chapter 7.
Function – 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.
Function – 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
Implemented collector current	I_{CN}	Ratings current
Collector current	I_{Cnom}	Maximum forward DC collector current
	I_C	
	$-I_{Cnom}$	Maximum reverse DC collector current
	$-I_C$	
Collector power dissipation	P_C	Maximum power dissipation per element
Junction temperature	T_{vj}	Maximum chip temperature, at which normal operation is possible. You must not exceed this temperature in the worst condition.
Operating junction temperature	T_{vjop}	Maximum chip temperature during continuous operation
Cooling water temperature	T_{win}	Cooling water temperature on the inlet side of the cooling water channel
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 times	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	$t_{d(on)}$	The time interval between when the gate-emitter voltage rises to 10% of the maximum value and when the collector current rises to 10% of the maximum value during IGBT turn on
	Rise time	t_r	Time required for collector current to rise from 10% to 90% of the maximum value
	Turn-off time	$t_{d(off)}$	The time interval between when the gate-emitter voltage drops to 90% of the maximum value and when the collector current drops to 90% 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_{rrm}	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	HBM	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 collector 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	$R_{th(j-win)}$	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_{vj} of IGBT and FWD in the automotive IGBT module. (See Chapter 3 Heat dissipation design method for details.)

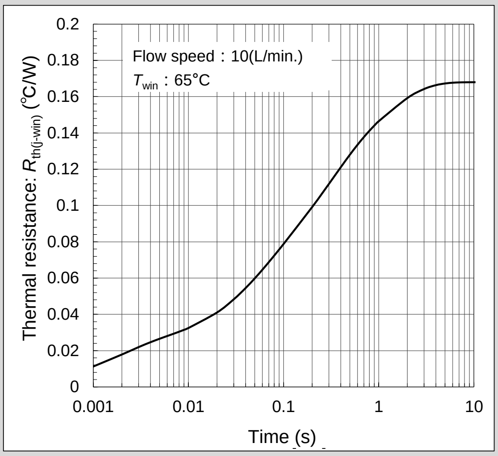


Fig. 2-1 Transient thermal resistance (max.)

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 affect the thermal resistance. Further, 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.

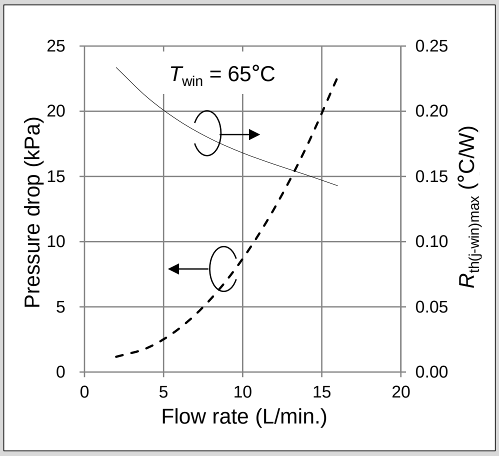


Fig. 2-2 Pressure drop and R_{th} dependence of flow rate

Chapter 3 Heat Dissipation Design Method

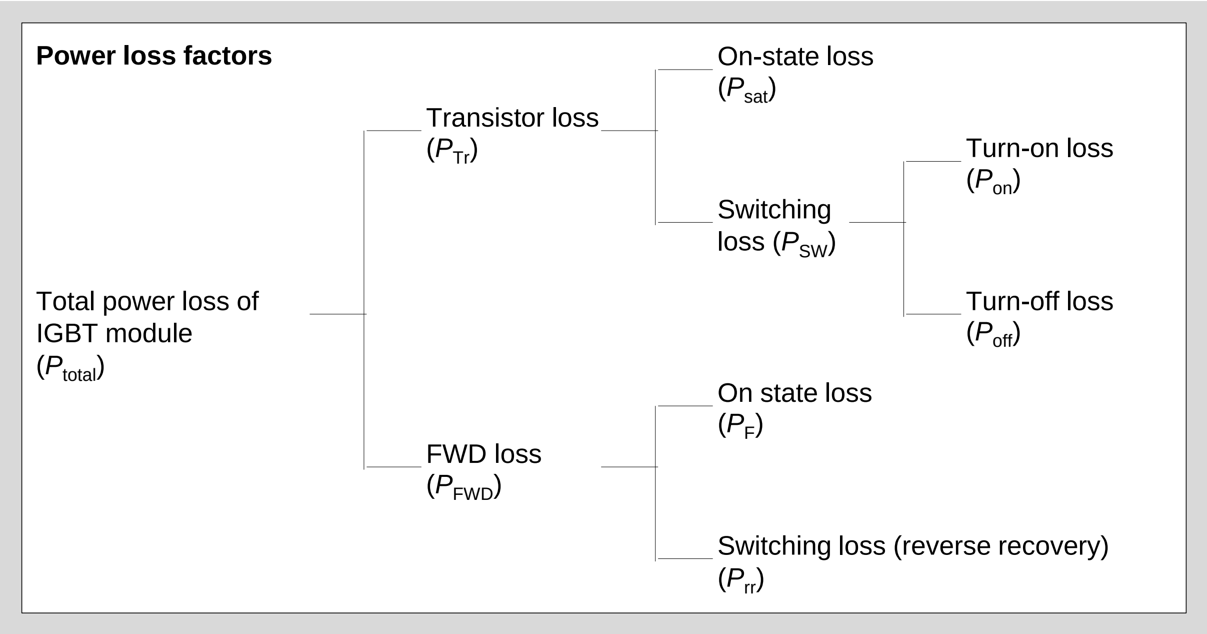
This chapter describes heat dissipation design.
To operate the IGBT safely, it is necessary not to allow the junction temperature (T_{vj}) to exceed T_{vjmax}.
Perform thermal design with sufficient allowance in order not for T_{vjmax} to be exceeded not only in the operation under the rated load but also in abnormal situations such as overload operation.

1. Power Dissipation Loss Calculation

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.



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_{vj} below the maximum rated value.
The on-state voltage and switching loss values at higher junction temperature (T_{vj} = 175℃) 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

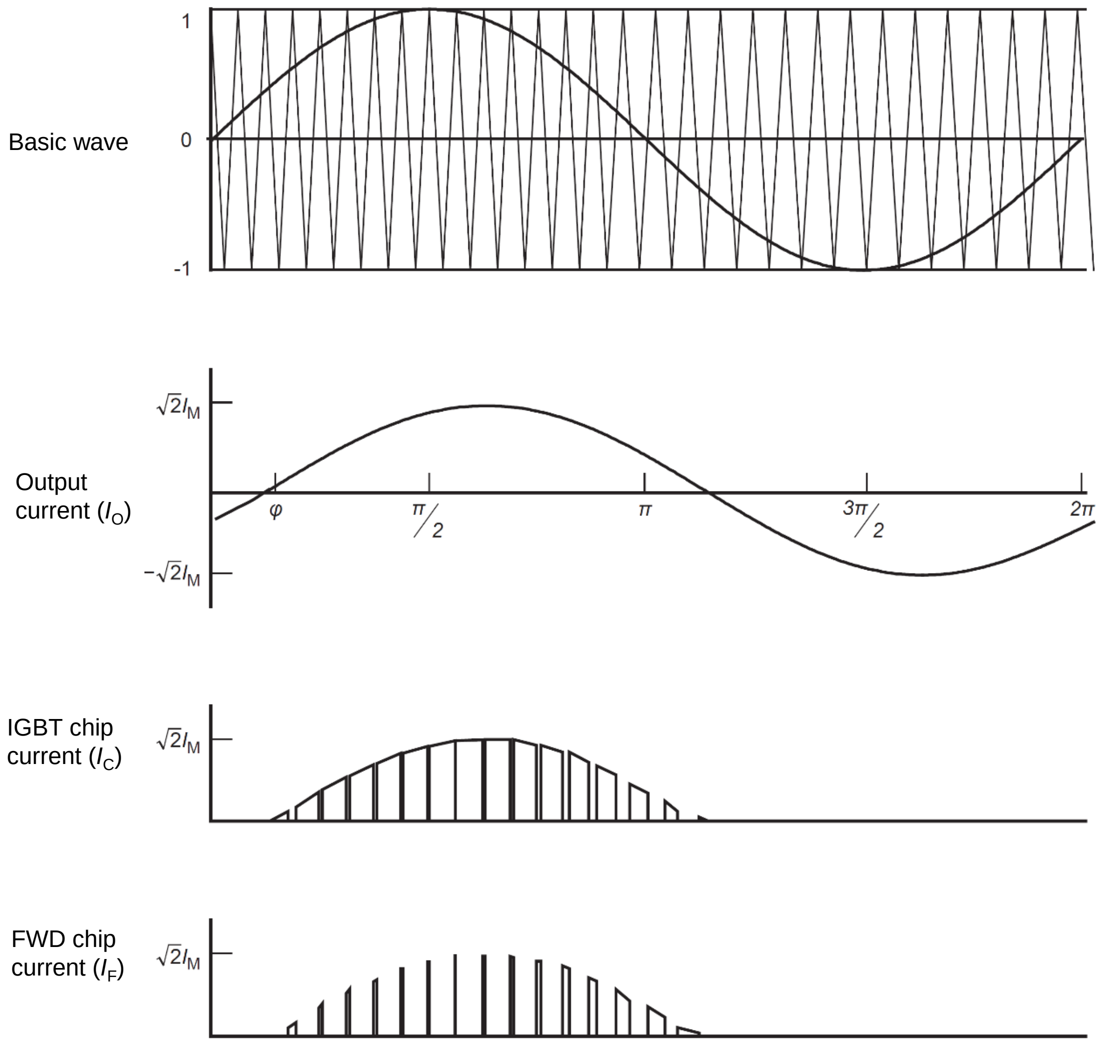


Fig. 3-1 PWM inverter output current

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:

$$\left(P_{sat}\right) = DT\int_0^x I_C V_{CE(sat)} d\theta$$
$$= \frac{1}{2} DT\left[\frac{2\sqrt{2}}{\pi} I_M V_O + I_{M^2} R\right]$$

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

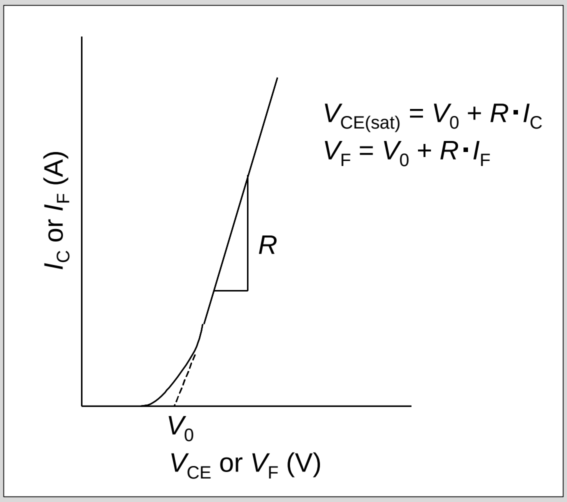


Fig. 3-2 Approximate output characteristic

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

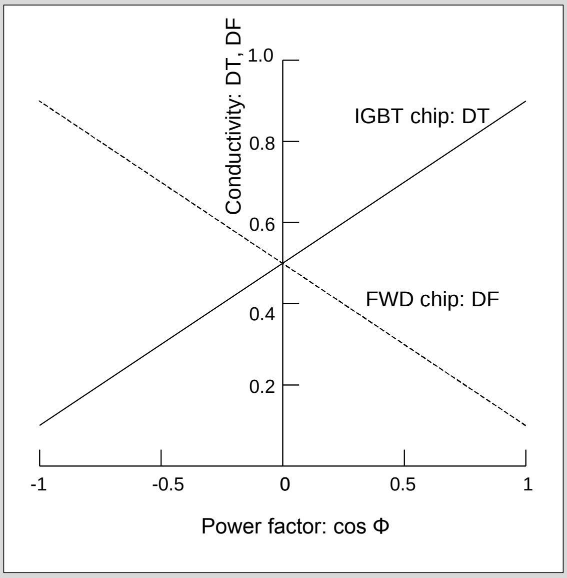


Fig. 3-3 Relationship between power factor sine-wave PWM inverter and conductivity

The switching loss-I_C characteristics are as shown in Fig. 3-4, but are generally approximated by the following equation.

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

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

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

a, b, c: Multiplier
E_{on}', E_{off}', E_{rr}': E_{on}, E_{off} and E_{rr} at rated I_C

The switching losses can be represented as follows:

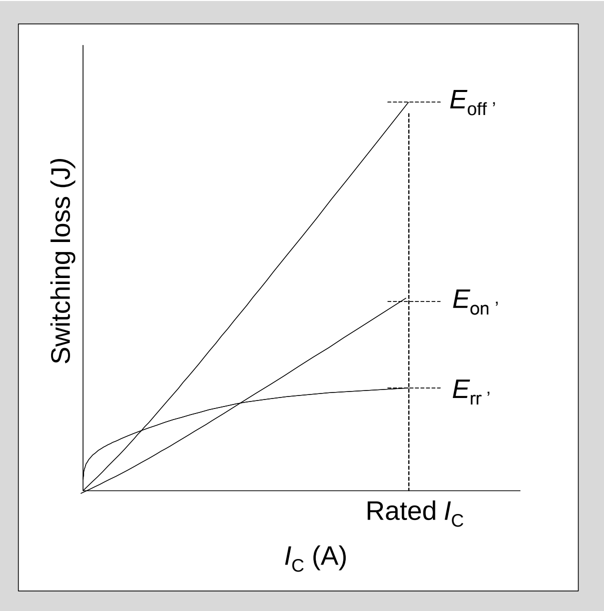


Fig. 3-4 Approximate switching losses

• Turn-on loss (P_{on})

$$P_{on} = fo\sum_{K=1}^{n}(E_{on})k \qquad \left(n: Half-cycle\,switching\;count = \frac{fc}{2fo}\right)$$

$$= foE_{on}'\frac{1}{rated\;I_{C^a}}\sum_{k=1}^{n}\left(I_{C^a}\right)k$$

$$= foE_{on}'\frac{n}{rated\;I_{C^a}\times\pi}\int_0^{\pi}\sqrt{2}I_{M^a}\sin\theta d\theta$$

$$= foE_{on}'\frac{1}{rated\;I_{C^a}}nI_{M^a}$$

$$= \frac{1}{2}fcE_{on}'\left[\frac{I_M}{rated\;I_C}\right]^a$$

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

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

• Turn-off loss (P_{off})

$$P_{off} = \frac{1}{2} fcE_{off}(I_M)$$

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

• FWD reverse recovery loss (P_{rr})

$$P_{rr} \approx \frac{1}{2} fcE_{rr}(I_M)$$

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

Total power loss
Using the results obtained in section 1.2.

IGBT chip power loss: $P_{Tr} = P_{sat} + P_{on} + P_{off}$

FWD chip power loss: $P_{FWD} = P_F + P_{rr}$

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.

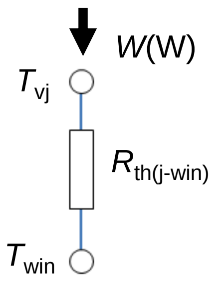
2.1 Thermal equation in steady state

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_{vj}) can be calculated using the following thermal equation:

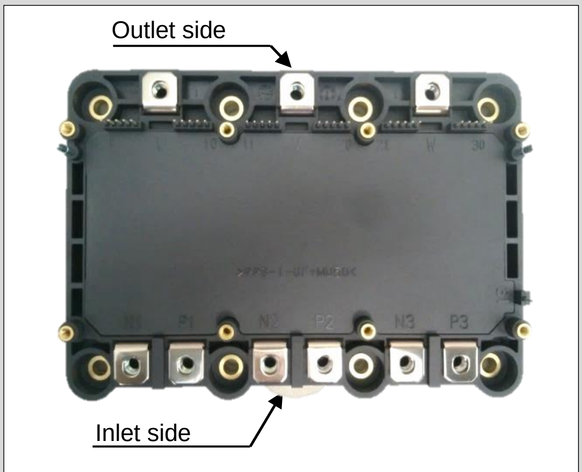
$$T_{vj} = W \times \{R_{th(j-win)}\} + T_{win}$$

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.

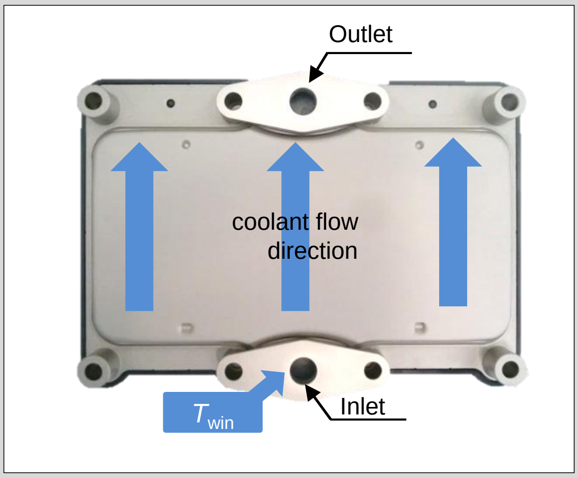


W : Module power loss
T_{vj} : Junction temperature of IGBT chip
T_{win} : Cooling water temperature
$R_{th(j-win)}$: Thermal resistance between junction and cooling water

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 system and the coolant flow direction

2.2 Thermal equations for transient power loss calculations

Generally, it is enough to calculate T_{vj} 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).

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

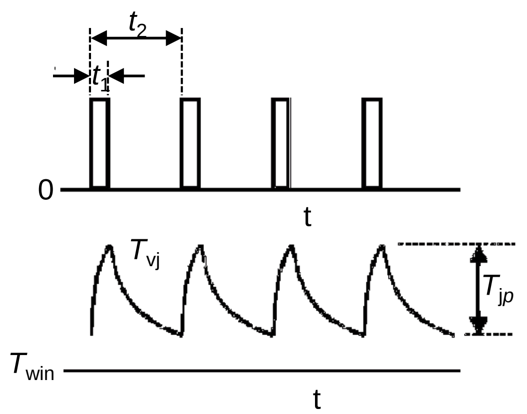


Fig. 3-7 Temperature ripple

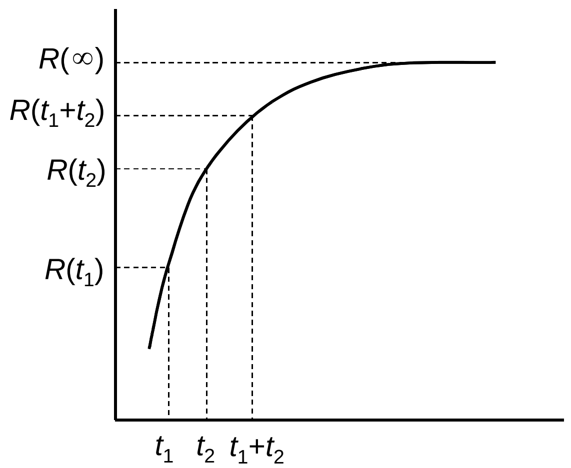


Fig. 3-8 Transit thermal resistance curve

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 inhibitor 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.

Sealing 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_{vj}) of the IGBT module does not exceed the rating or the designed value.

3. Flange Adapter Kit

Flange Adapter Kit is prepared as an optional part.
The kit is including a sealing block with O-rings and nipples to connect the cooler to the water line.
*1) This kit was developed only for evaluation purpose of our IGBT module and it is not a regular product.

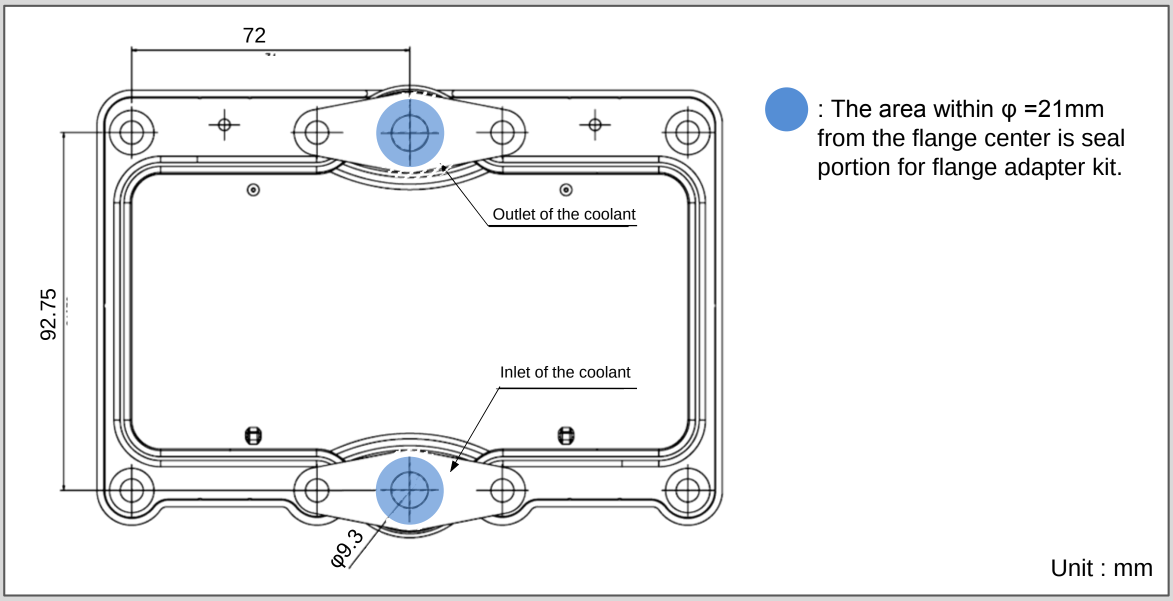
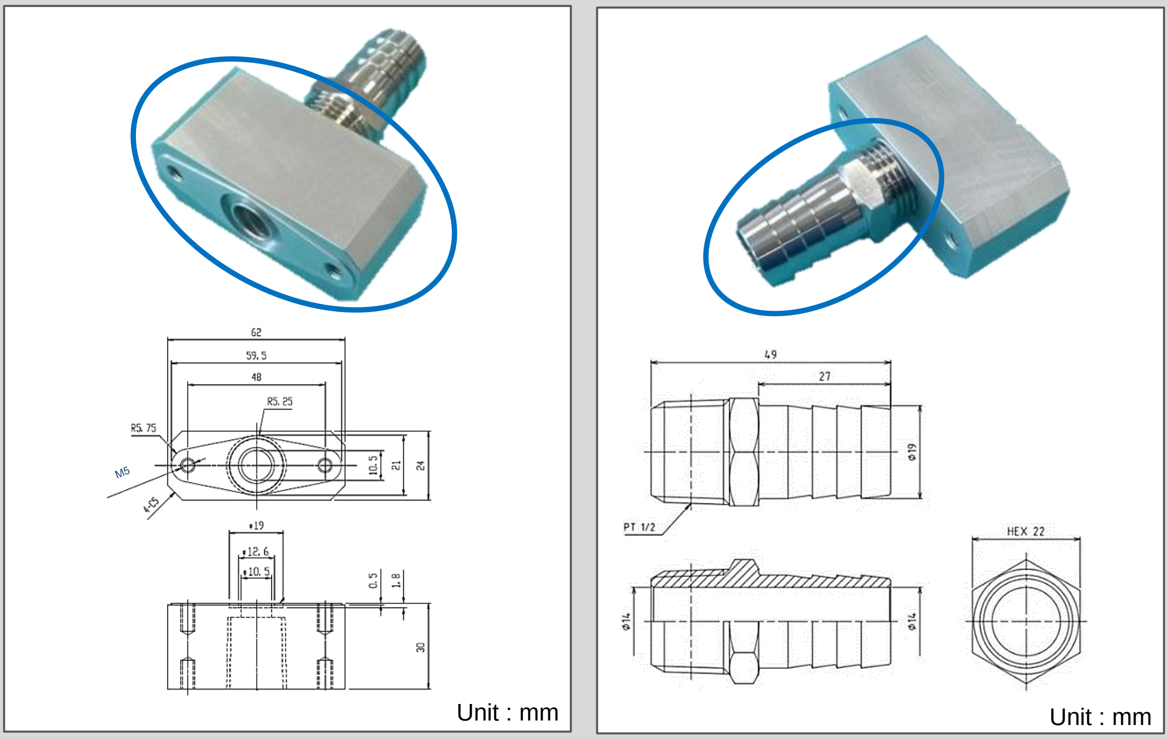


Fig. 3-9 Sealing area of the flange



(a) Flange adapter base

(b) Nipple of flange adapter

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

Reference information of O-ring of the flange adapter kit

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

Table 3-1 Size of O-ring (Unit : mm)

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					

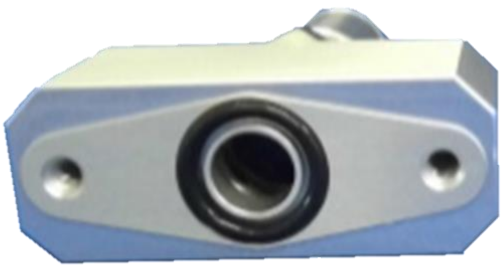


Fig. 3-11 The image of assembled O-ring onto the flange adapter base

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 check point
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	Overheat	Integrity device t_{off} and dead time
			dead time setting mistakes		
		dv/dt malfunction	less reverse gate bias	SCSOA and/or overheat	Faulty turn-on due to dv/dt
			too long gate wiring		
		Noise induced	Gate circuit malfunction		confirm circuit malfunction
			Logic circuit malfunction		
	Output short-circuit	Faulty wiring, abnormal wire contact, load short-circuit			confirm failure phenomenon
	Ground short	Faulty wiring, abnormal wire contact,			Integrity between device ruggedness and protection condition
					Wiring conditions
Overload		Overcurrent	Logic circuit malfunction	Overheat	Logic signal
			protection function setting fault		Redesign of protection condition
Overvoltage	Excessive DC voltage	Overvoltage larger than device breakdown voltage apply between Corrector and Emitter	Excessive input voltage	Excess ratings of V_{CE}	Redesign of protection condition
			Overvoltage protection		
	Excessive spike voltage	Destruction due to excessive surge voltage larger than RBSOA at turn-off		RBSOA	Integrity confirmation RBSOA and operating locus at turn-off
					Redesign of sunbber 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
					sunbber circuit
		Reverse recovery phenomenon at operating with very narrow gate pulse *1)	logic circuit 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 main 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 hundred nano second.

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

<table>
<tr><th colspan="2">External abnormalities</th><th colspan="2">Cause</th><th>Device failure mode</th><th>Further checkpoints</th></tr>
<tr><td colspan="2" rowspan="3">Driver supply voltage drop</td><td rowspan="3">V_{CE} is increased by V_{GE} lower than specified value. As a result, power consumption and Joule head are increased.</td><td>DC/DC converter malfunction</td><td rowspan="3">Overheat</td><td rowspan="3">Check circuit design</td></tr>
<tr><td>Too mach time constant of power supply settling</td></tr>
<tr><td>Gate wiring break</td></tr>
<tr><td colspan="2" rowspan="2">Excessive gate voltage</td><td colspan="2">Electro static discharge on V_{GE}</td><td rowspan="2">Excessive V_{GES}</td><td>Assembly earea environment against ESD</td></tr>
<tr><td colspan="2">Spike voltage larger than V_{GES} is produced by too long gate wiring</td><td>Gate voltage</td></tr>
<tr><td colspan="2">Operation under opened gate circuit</td><td colspan="2">Voltage apply to Corrector and Emitter while gate is opened.</td><td>Overheat</td><td>Gate voltage</td></tr>
<tr><td colspan="2">Overvoltege on temperature diode, sense IGBT</td><td colspan="2">Temperature diode and/or sense IGBT destruction due to ESD</td><td>ESD</td><td>Assembly earea environment against ESD</td></tr>
<tr><td rowspan="3">Overheat</td><td rowspan="2">Lack of heat dissipation capacity</td><td rowspan="2">Anomalous heating due to lack of heat dissipation capacity</td><td>Less flow rate</td><td rowspan="3">Overheat</td><td rowspan="2">Radiation condition or radiation design</td></tr>
<tr><td>Radiator malfunction</td></tr>
<tr><td>Thermal runaway</td><td colspan="2">Total dissipation is increased by carrier frequency increased due to logic circuit malfunction</td><td>Logic circuit on gate</td></tr>
<tr><td rowspan="2">Stress</td><td>Stress</td><td rowspan="2">Soldered portion is broken by stress fatigue</td><td>Stress from external wiring</td><td rowspan="2">Disconnection of circuit</td><td rowspan="2">Mechanical stress due to mounting condition</td></tr>
<tr><td>Vibration</td><td>Stress induced vibration</td></tr>
<tr><td colspan="2">Reliability (Life time)</td><td colspan="2">The application condition exceeds the reliability of the module</td><td>Destruction is different in each case.</td><td>Refer to Fig. 4-1(a-f)</td></tr>
</table>

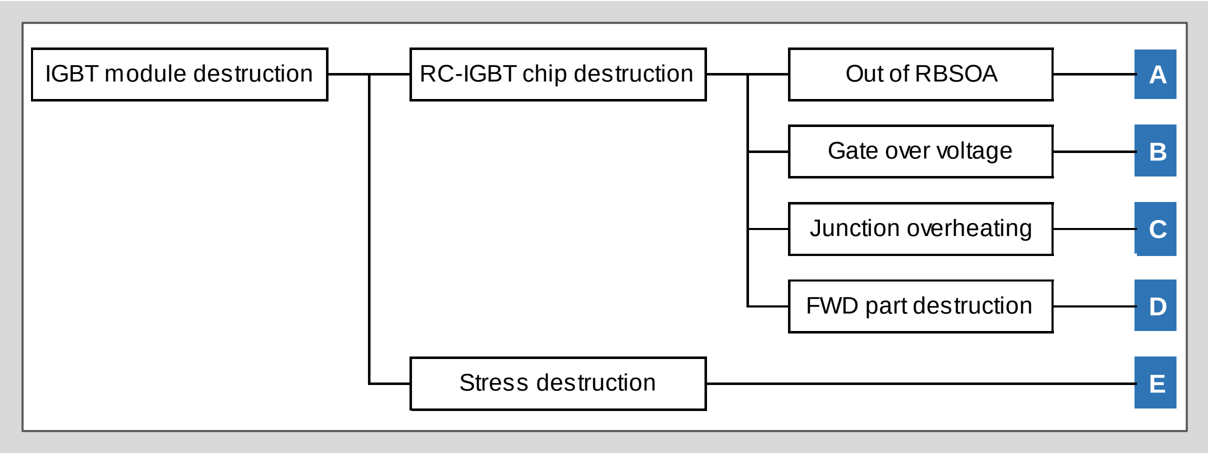


Fig. 4-1(a) IGBT module failure analysis

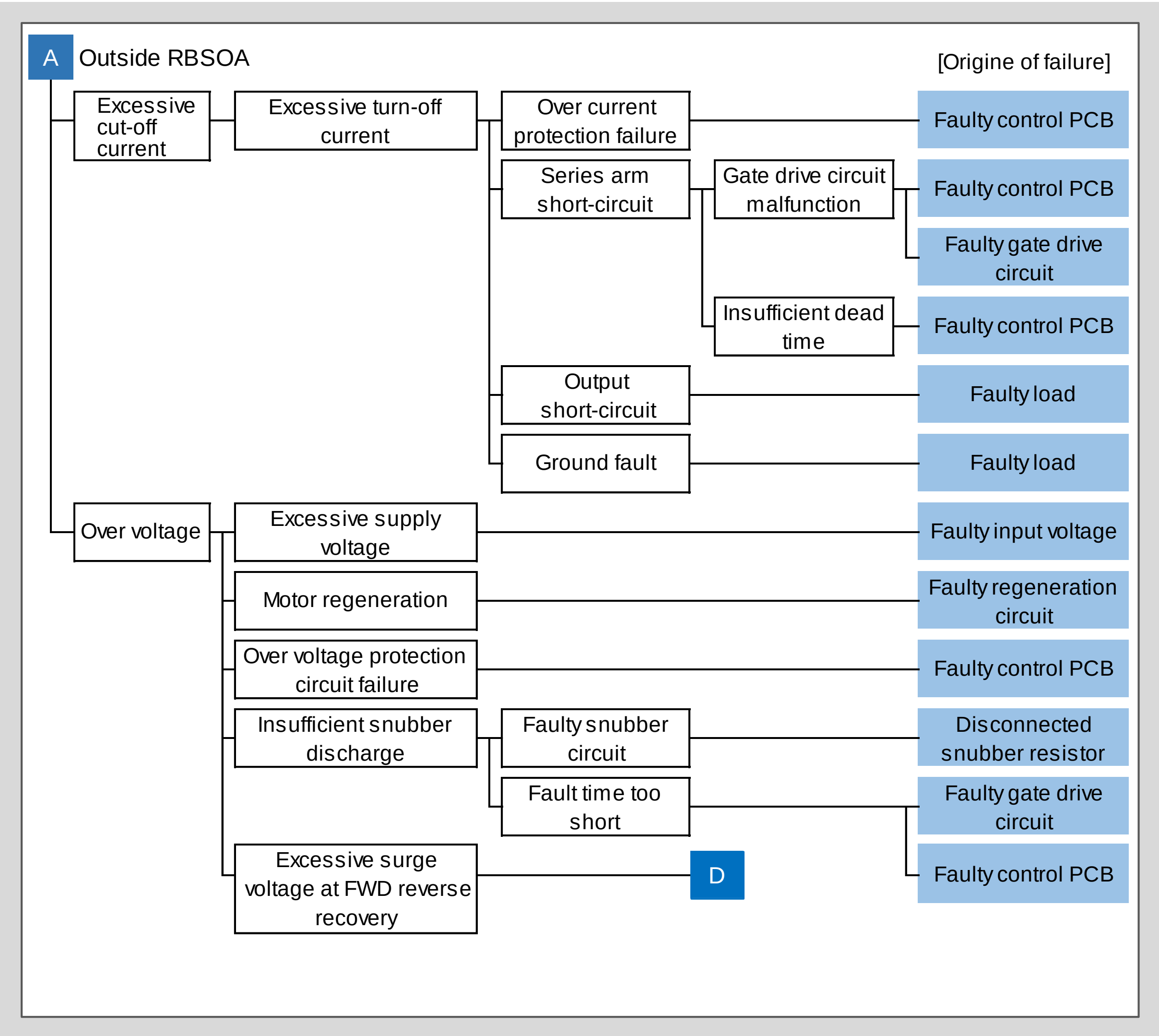


Fig. 4-1(b) Mode A: Outside RBSOA

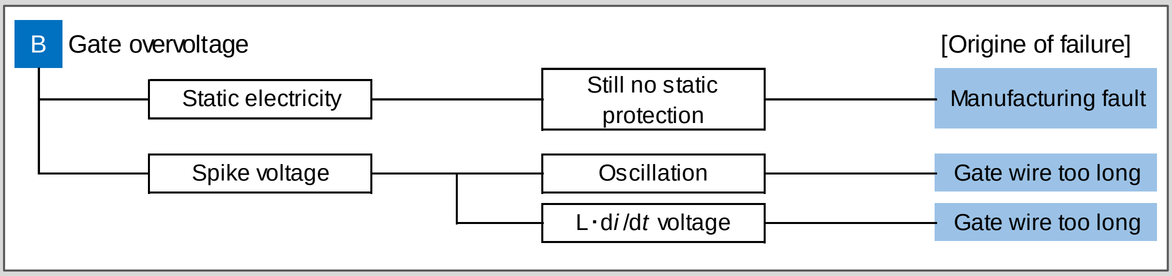


Fig. 4-1(c) Mode B: Gate overvoltage

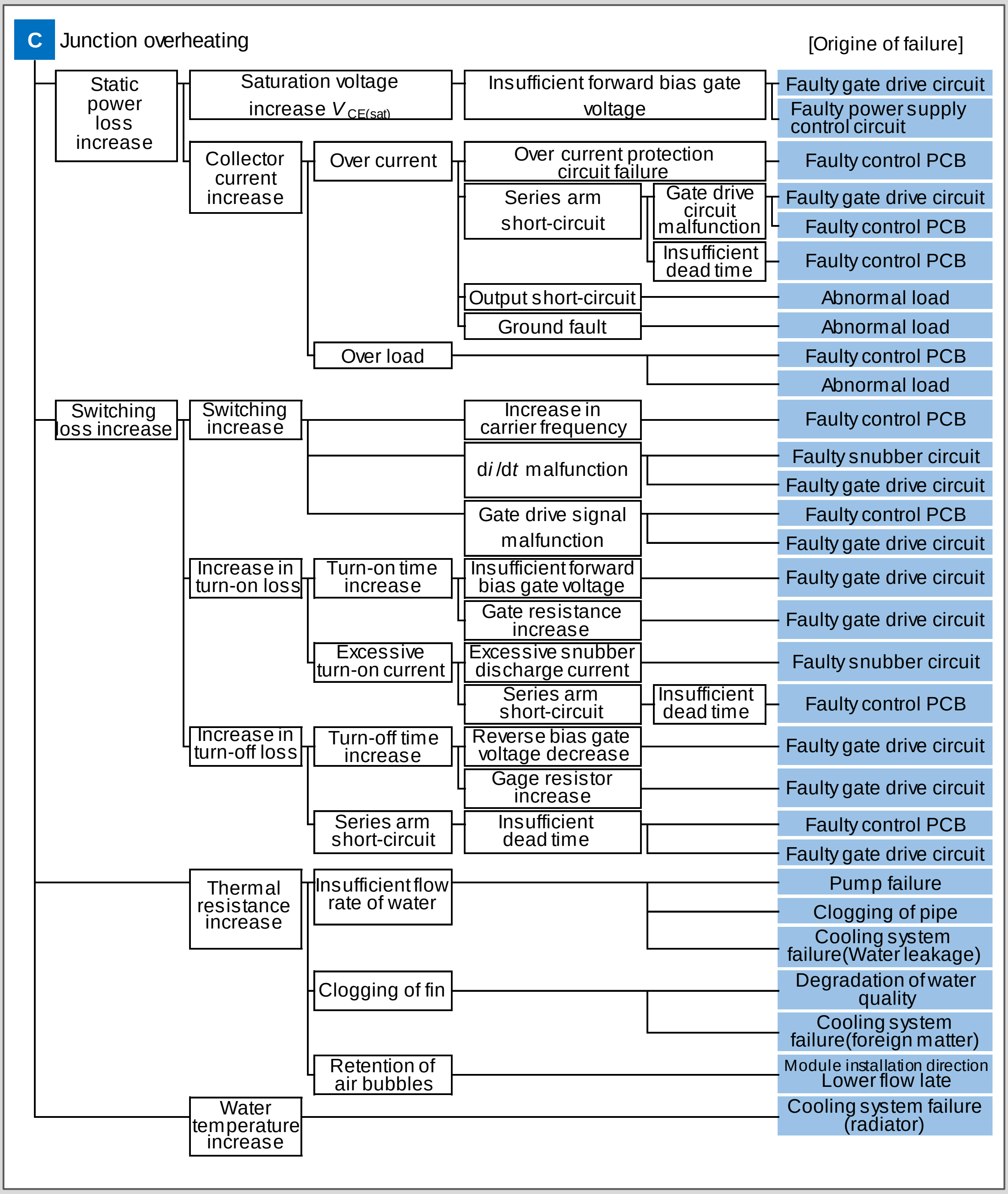


Fig. 4-1(d) Mode C: Junction over heating

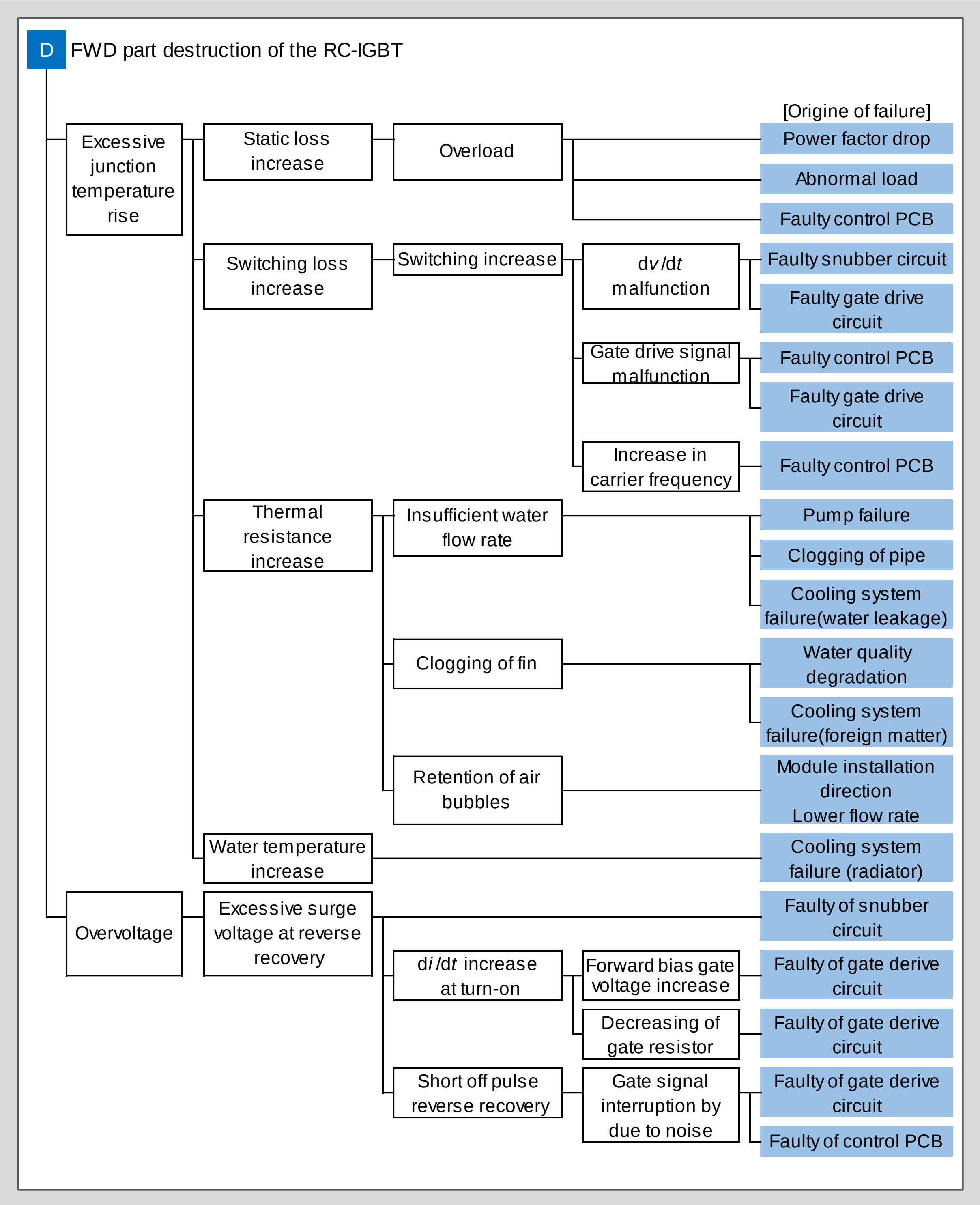


Fig. 4-1(e) Mode D: FWD destruction

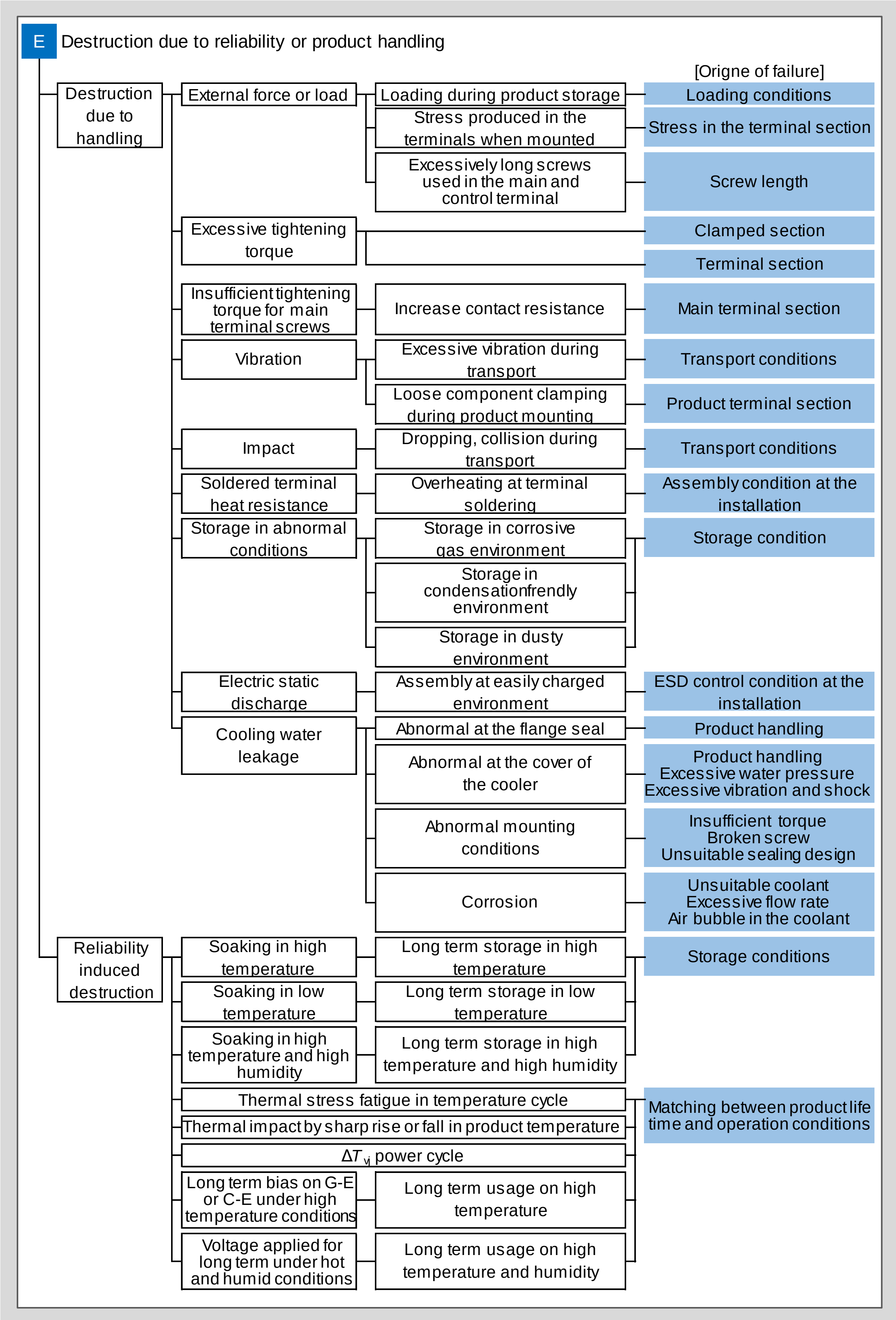


Fig. 4-1(f) Mode E: FWD destruction

Chapter 5 Precautions for Use

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

1. Maximum Junction Temperature T_{vjmax}

As described in specification sheet, this automotive IGBT module can be used under T_{vj} =175℃. 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 d*i*/d*t* is produced in turn-off operation or reverse recovery. So from this large d*i*/d*t* and inductance component contained inside and outside 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.

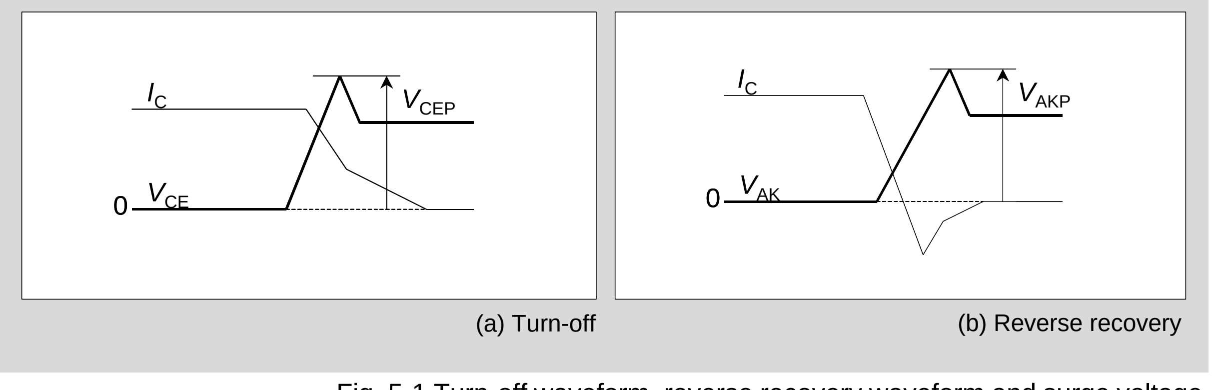


Fig. 5-1 Turn-off waveform, reverse recovery waveform and surge voltage

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.

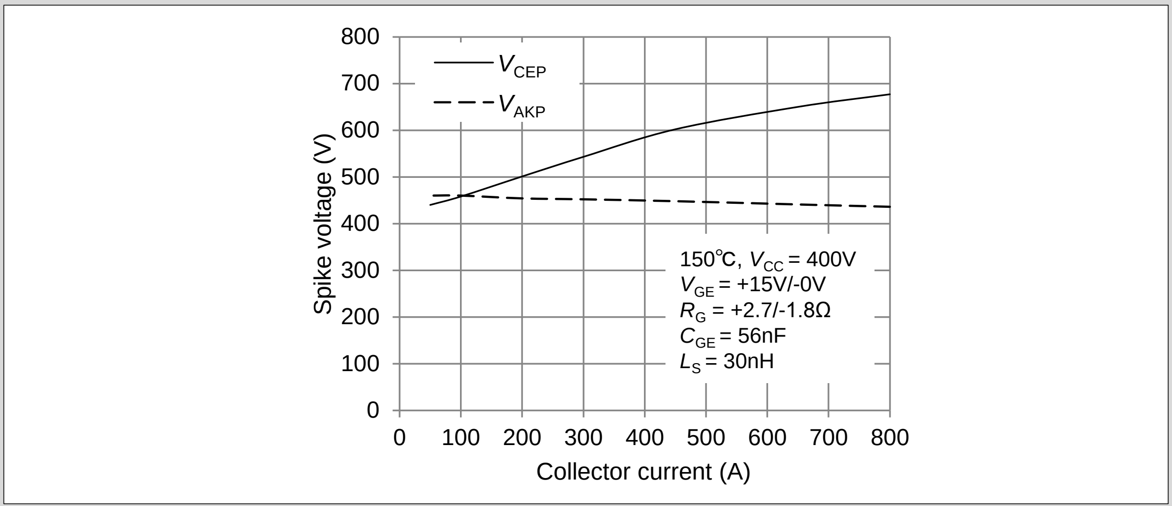


Fig. 5-2 An example of surge voltage dependence of collector current

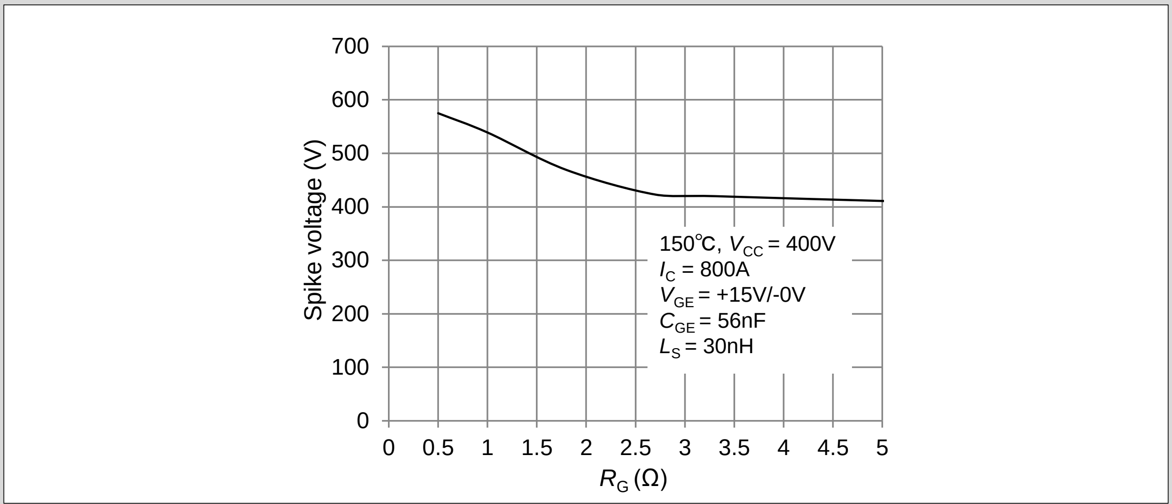


Fig. 5-3 An example of surge voltage of reverse recovery dependence of gate resistor

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.

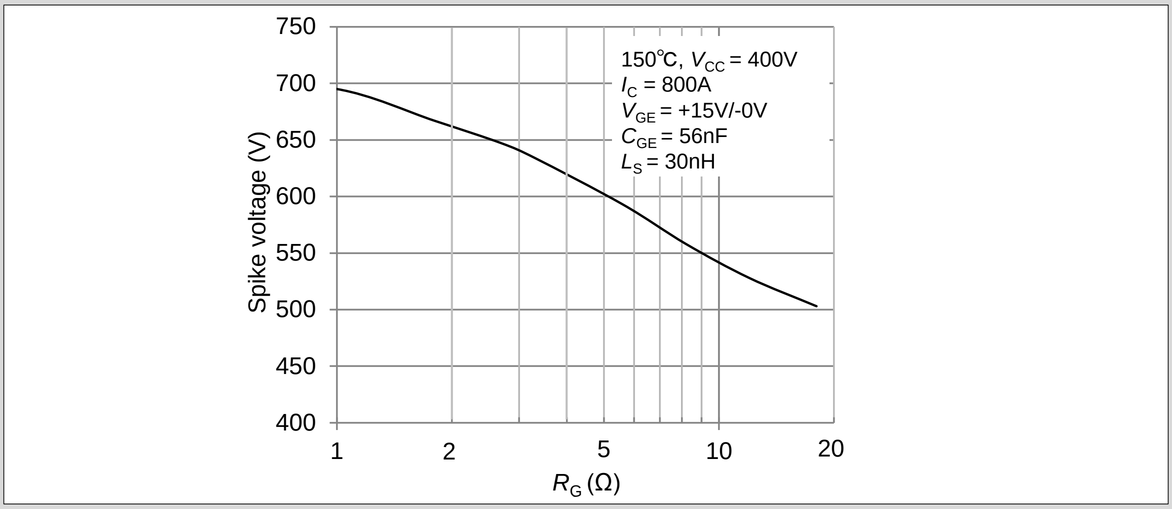


Fig. 5-4 An example of surge voltage of turn-off dependence of gate resistor

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.

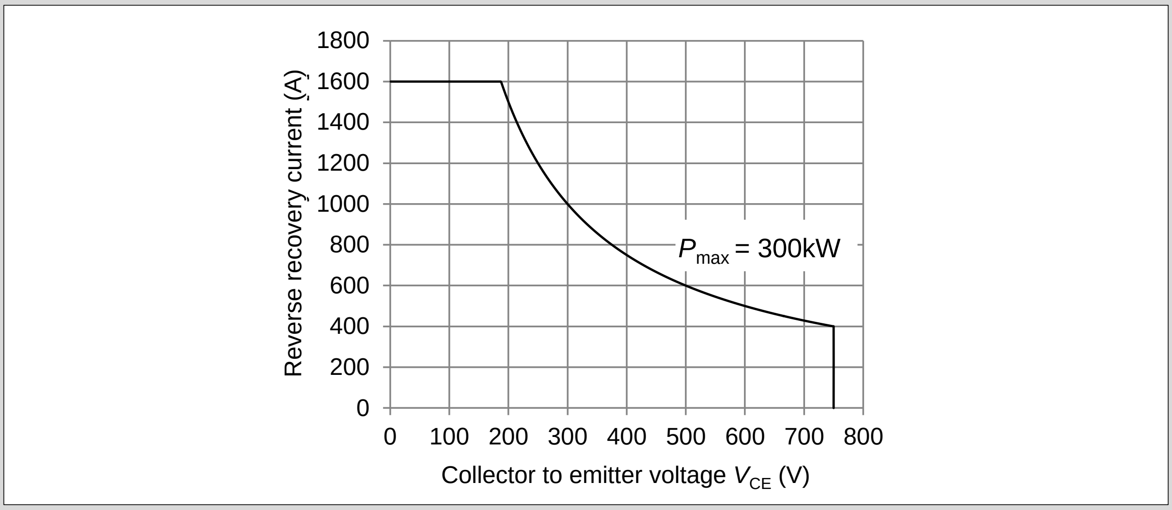


Fig. 5-5 An example of SOA of FWD part

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.

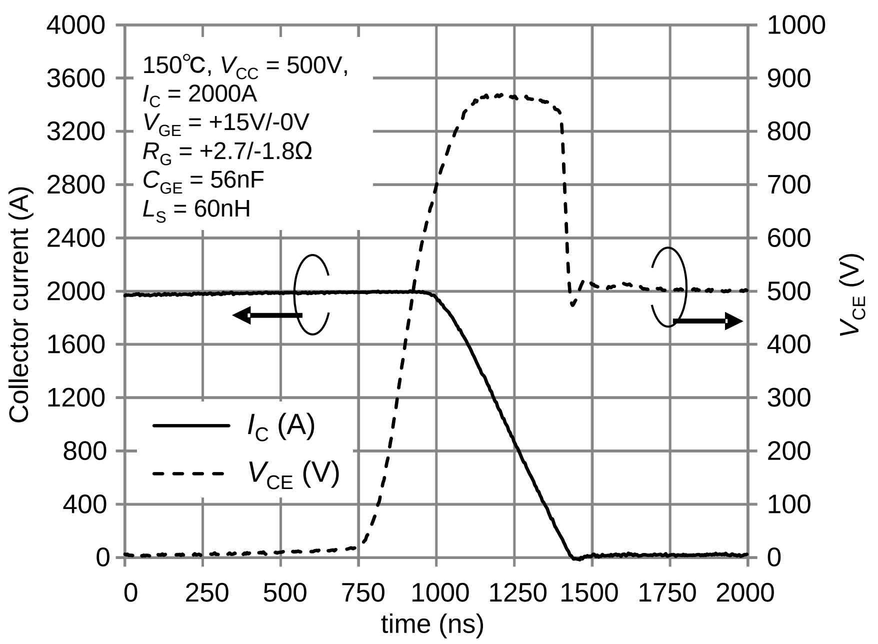


Fig. 5-6 An example of dynamic avalanche waveform

3.5 Spike voltage suppression circuit - clamp circuit -

In general, spike voltage generated between collector to emitter can be suppressed by means of decreasing the stray inductance or installing snubber circuit. However, it may be difficult to decrease the spike voltage under the hard operating conditions. For this case, it is effective to install the active clamp circuits, which is one of the spike voltage suppressing circuits.

Fig. 5-7 shows the example of active clamp circuits.

In the circuits, Zenner diode and a diode connected with the anti-series in the Zenner diode are added. When the Vce over breakdown voltage of Zenner diode is applied, IGBT will be turned-off with the similar voltage as breakdown voltage of Zenner diode.

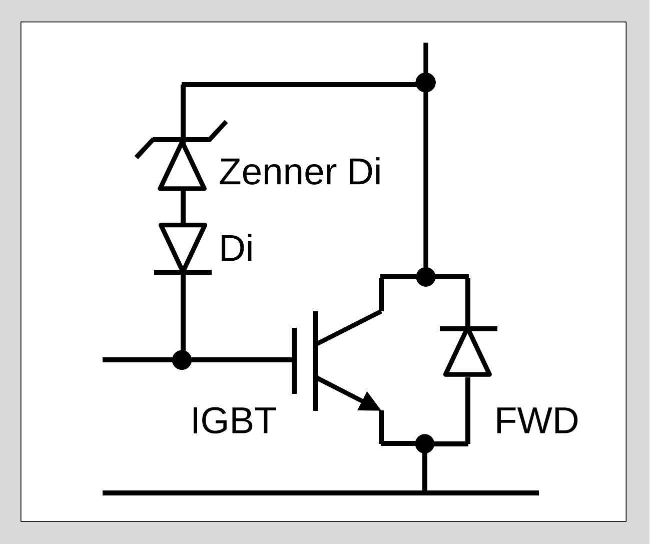


Fig. 5-7 Active clamp circuit

Therefore, installing the active clamp circuits can suppress the spike voltage. Moreover, avalanche current generated by breakdown of Zenner diode, charge the gate capacitance so as to turn-on the IGBT. As the result, d*i*/d*t* at turn-off become lower than that before adding the clamp circuit (Refer to Fig. 5-8). Therefore, because switching loss may be increased, apply the clamp circuit after various confirmations for design of the equipment.

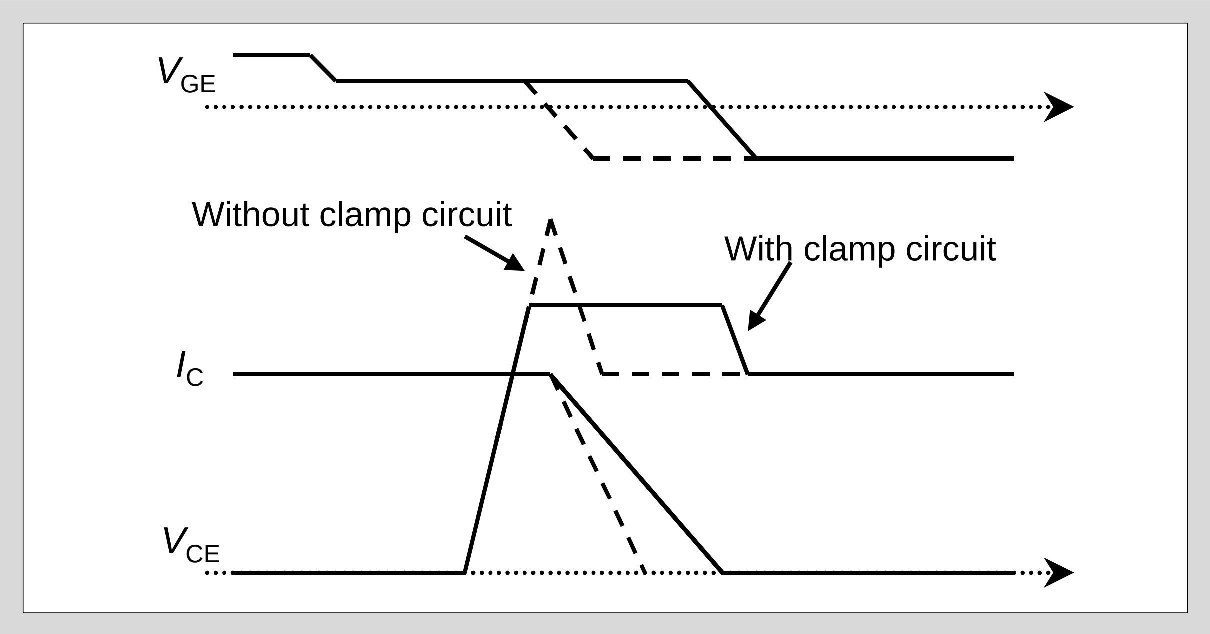


Fig. 5-8 Schematic waveform for active clamp circuit

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 d*v*/d*t* of the FWD's reverse recovery and a pulse collector current may cause unnecessary heat generation. This phenomenon is called a d*v*/d*t* 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, d*v*/d*t* 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 d*v*/d*t*

In this section, the way to avoid the unexpected IGBT turn-on by d*v*/d*t* at the FWD's reverse recovery will be described.

Fig. 5-9 shows the principle of unexpected turn-on caused by d*v*/d*t* 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 d*v*/d*t* according to switching time of $IGBT_1$. Because $IGBT_1$ and $IGBT_2$ have the mirror capacitance C_{GC}, Current is generated by d*v*/d*t* through C_{GC}. This current is expressed by C_{GC} x d*v*/d*t*. This current is flowed through the gate resistance R_G, results in increasing the gate potential.

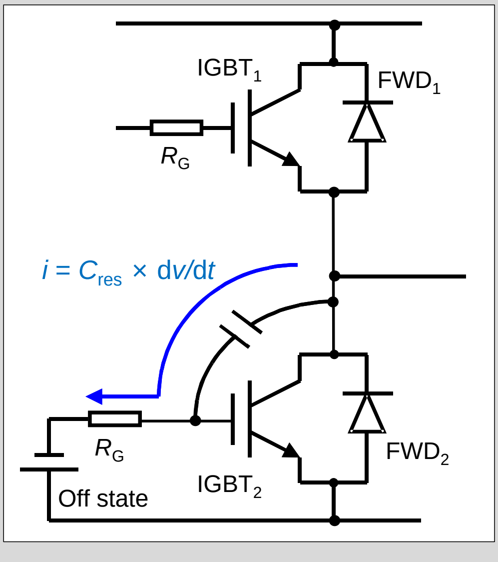


Fig. 5-9 Principle of unexpected turn-on

So, V_{GE} is generated between gate to emitter. If V_{GE} is excess the sum of reverse biased voltage and $V_{GE(th)}$, $IGBT_2$ 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.

Based on this principle, several measures have been devised as methods for avoiding the unexpected turn-on for the IGBT. These include adding a capacitance C_{GE} component between the gate and the emitter, increasing - V_{GE}, and enlarging the gate resistance R_G. The effect of these measures varies depending on the applied gate circuit. Therefore, only apply them after sufficiently confirming your configuration. In addition, also confirm whether there is any impact on switching loss.

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. 5-10) 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.

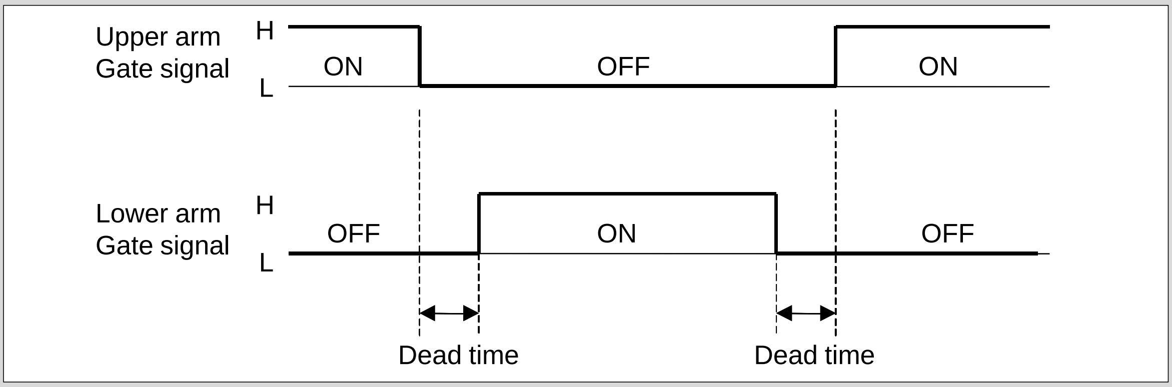


Fig. 5-10 Dead time timing chart

5. Parallel Connections

In high capacity inverters and other equipment that needs to control large currents, it may be necessary to connect IGBT modules in parallel. When connected in parallel, it is important that the circuit design allows for an equal flow of current to each of the modules. If the current is not balanced among the IGBTs, a higher current may build up in just one device and destroy it. The electrical characteristics of the module as well as the wiring design, change the balance of the current between parallel connected IGBTs. In order to help maintain current balance it may be necessary to match the $V_{CE(sat)}$ values of all devices.

Also, when the IGBT module has the cooler with the water jacket, it is necessary to adhere strictly to specifications such as water temperature, water flow and pressure within each water jacket.

For more detailed information on parallel connections, refer to Chapter 10 of this manual.

6. Electrostatic Discharge Countermeasures and Gate Protection

The guaranteed value of V_{GE} for the IGBT module is generally up to ±20 V (Check the specifications for the exact guaranteed value). When a voltage that exceeds the guaranteed value (V_{GES}) is applied between the gate and emitter of the IGBT, the IGBT gate is susceptible to breakage. Therefore, make sure that the voltage applied between the gate and emitter does not exceed the guaranteed value. In particular, the control terminal for the IGBT gate and temperature sensing diode is extremely sensitive to static electricity. Therefore, make sure to observe the following cautions when handling the product.

1) When handling the module after unpacking, first make sure to discharge any static electricity that exists on the human body or clothing with a high-resistance (about 1 MΩ) ground, and then perform the work on a grounded conductive mat.
2) For the IGBT module, since no electrostatic measures have been taken for the terminal after unpacking, do not directly touch terminal components (especially the control terminal), but handle the module using the package body.
3) When performing soldering work on the IGBT terminal, make sure to ground the tip of the soldering iron with an adequately low resistance to ensure that static electricity is not applied to the IGBT through soldering iron or solder bath leakage.

Furthermore, the IGBT is susceptible to breakdown if voltage is applied between the collector and emitter while the gate-emitter are in the open state.

The reason for this is shown in Fig. 5-11 where a change in collector potential causes the gate potential to rise due to the flow of current (i). As a result, the IGBT turns on, and collector current begins to flow, which in turn, could cause IGBT breakdown due to heat generation.

Furthermore, if the product is installed in a piece of equipment, the IGBT is susceptible to breakdown due to the above reasons when a voltage is applied to the main circuit while the gate circuit is broken or not operating normally (gate in the open state). In order to prevent this type of breakdown, it is recommended that a resistor (R_{GE}) of about 10 kΩ be installed between the gate and emitter.

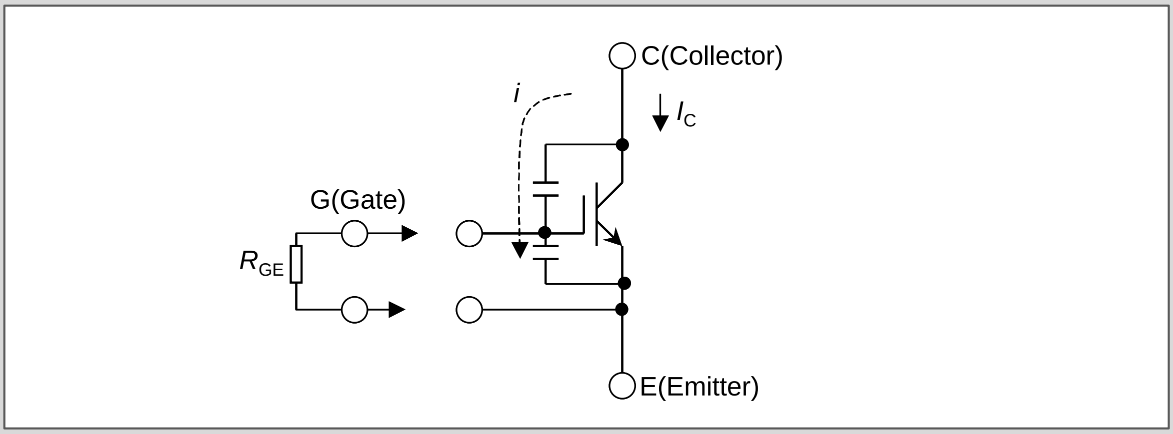


Fig. 5-11 Gate charging from electric potential of collector

7. ESD Conductive Foam

When unpacking the product, it is important that there be no control pin contact when handling the product after removing the conductive foam, as this could cause electrostatic discharge damage. When installing the product in a piece of equipment, it is requested that you only remove the conductive foam just before PCB mounting in order to prevent electrostatic discharge damage. (Refer to the following workflow)

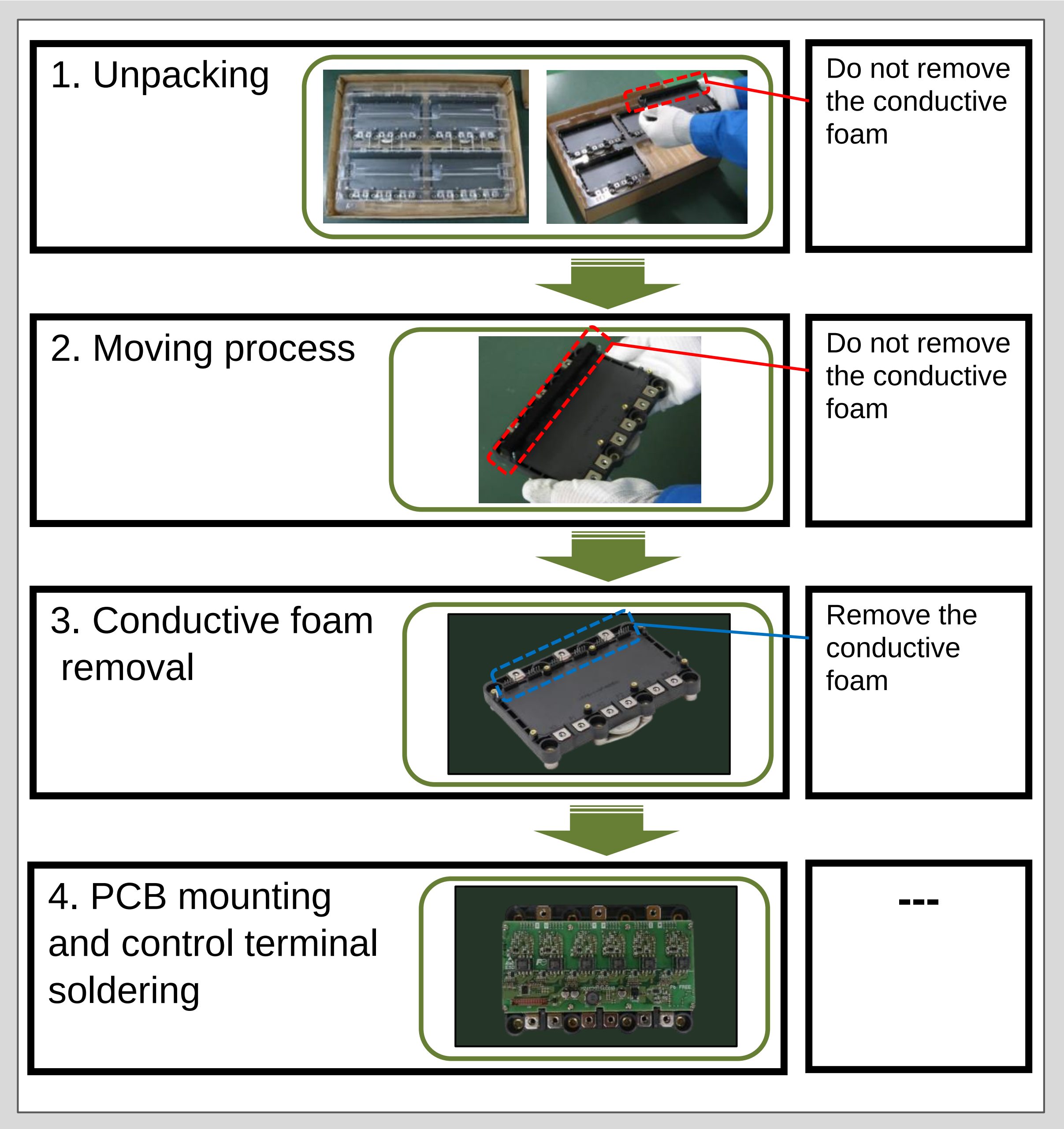


Fig. 5-12 Conductive foam removal procedures

Chapter 6 Recommended Mounting Method

This chapter describes the recommended method of mounting the IGBT module and the PCB. In addition, refer to "Mounting Instruction" separately for detailed mounting method and cautions on M653 package products.

1. Instruction of Mounting the IGBT Module

1.1 Method of fastening the module to customer's system

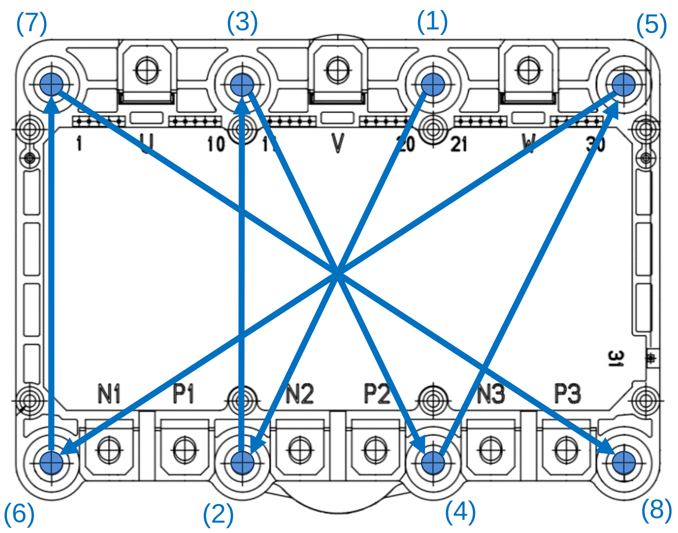
Fig. 6-1 shows the recommended procedure of tightening screws for mounting the IGBT module. The fastening screws should be tightened with the specified torque. See the specification for the specified torque and screws size to be used.

1.2 Prohibited matters:

(1) Excessive tightening torque: IGBT module shall not be used anymore.
Cause of cooling system destruction by deformation of the aluminum cooler and buckling of the stud.

(2) 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.

(3) 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 Flatness of fastening part

The flatness of the fastening portion of the module is specified in the specification. In addition, the following values are recommended for the system flatness at the module area.
System flatness at the module area : ≦50μm
Exceeding the requirement above may lead to damage of the power module.

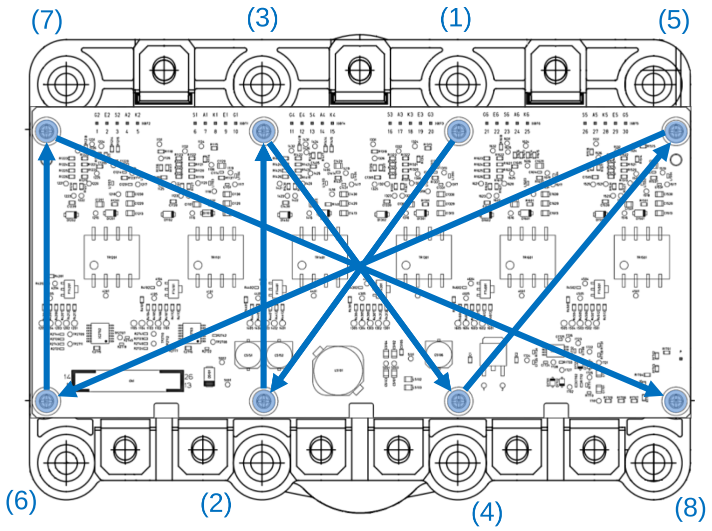
1.4 Installation direction of the IGBT module

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.

1.5 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

1.6 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.

1.7 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

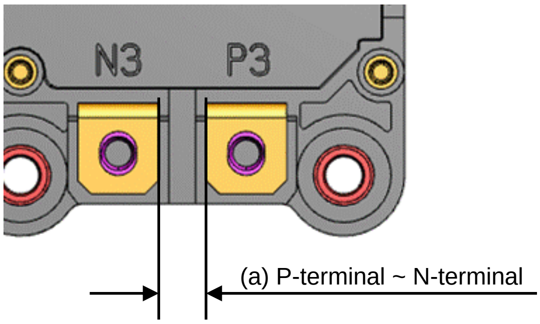
(a) Screw size: M5
(b) Maximum fastening torque: refer to the specification sheet.
(c) Length of the screw: Check the depth of screw holes on the outline drawing.
Adjust the length of the screws depending on the types of screws used if necessary.

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 of Analog Devices,Inc. is used in this evaluation board.

*1) This evaluation board was developed only for evaluation purpose of our IGBT module and it is not a regular product. In addition, the part constants described in this document are intended to assist design, and they do not fully consider variations in parts and conditions of use. In actual design, please consider these parts dispersion and use conditions carefully.

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)

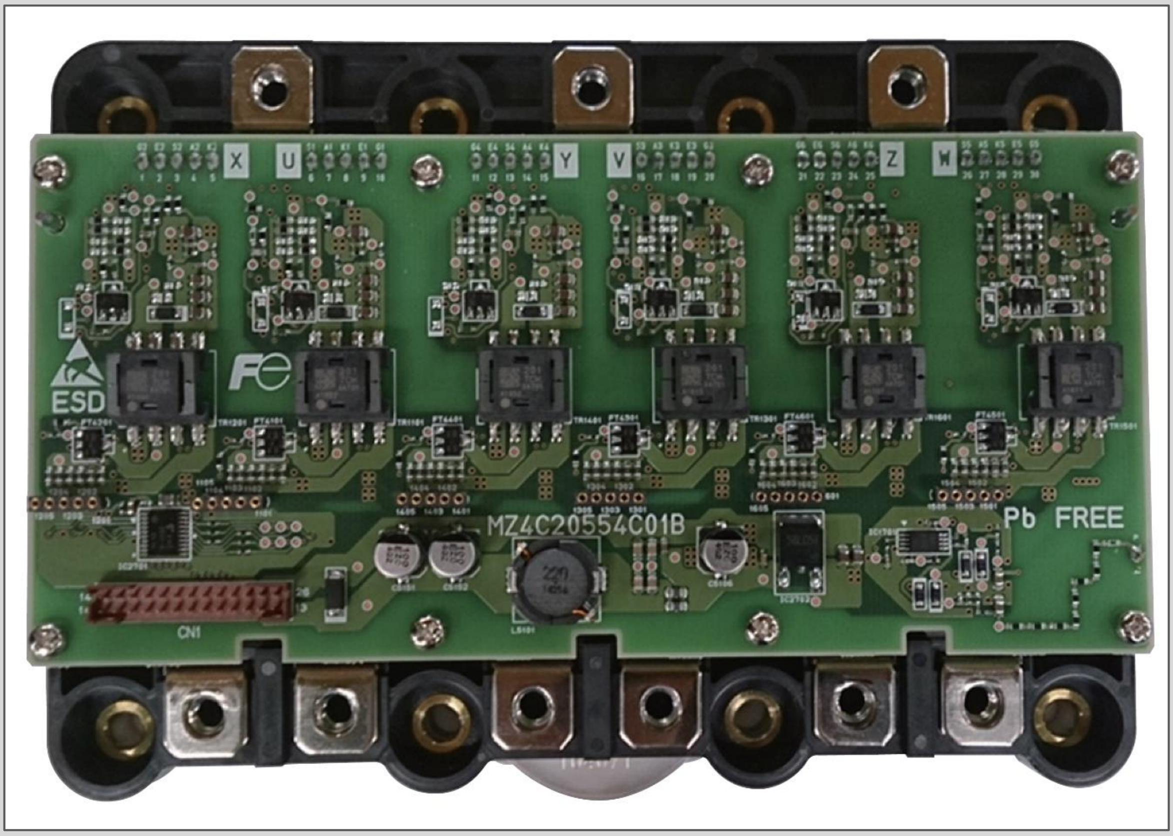


Fig. 7-1 M653 IGBT module evaluation board

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.

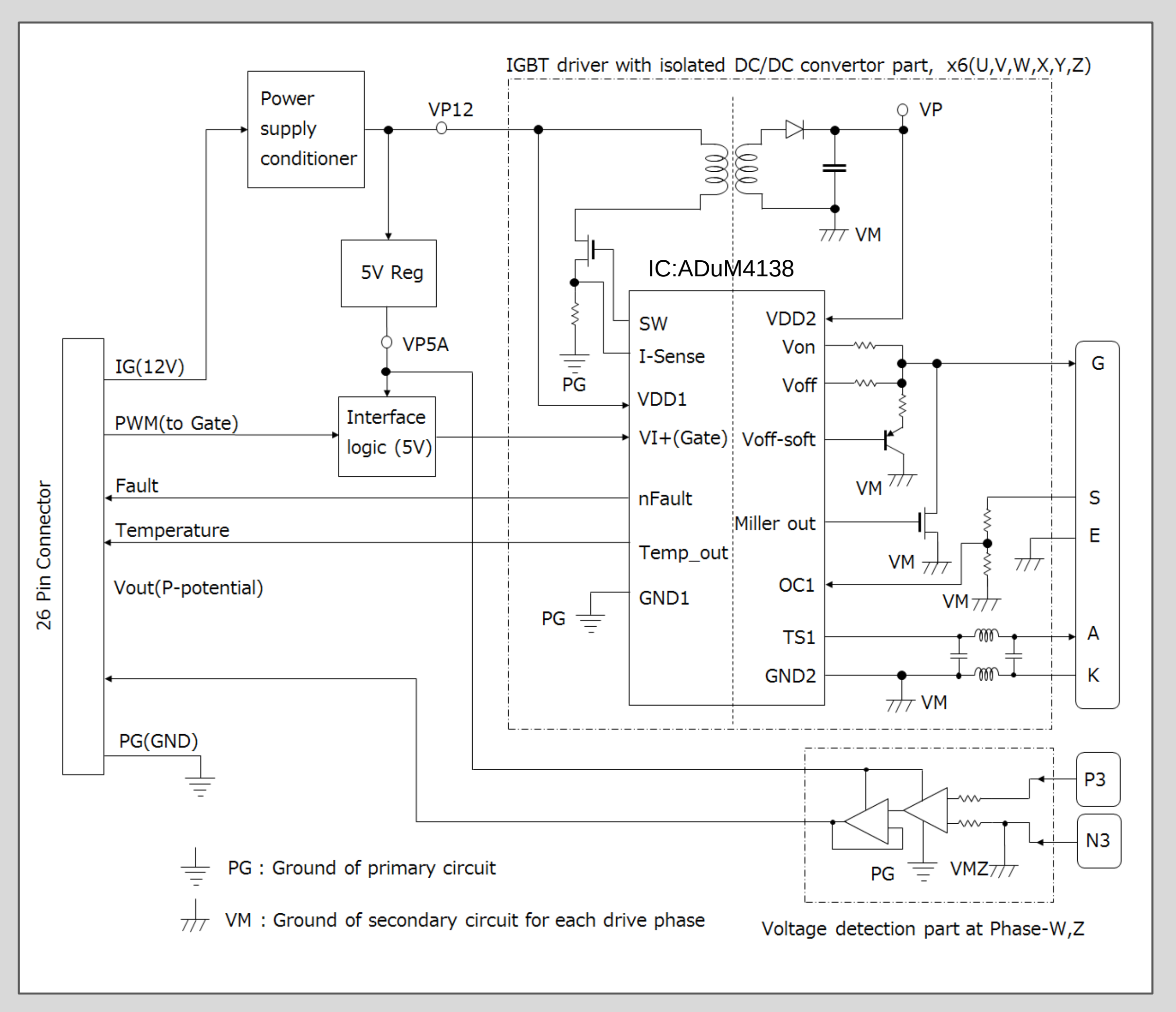


Fig. 7-2 Basic schematic of the M653 IGBT module evaluation board

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		μs
PWM Pulse Off Delay Time	PWM Input to IGBT Gate		0.45		μs
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		ms

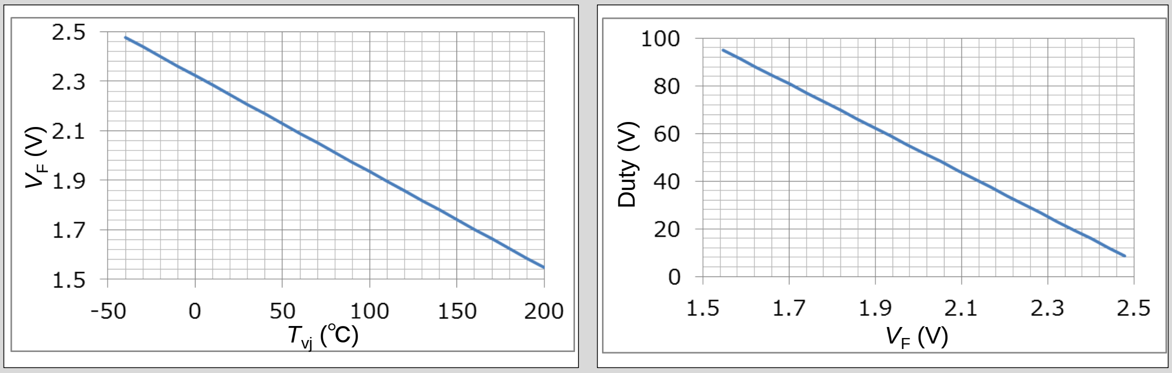
* measured under ambient temperature 25°C. unless otherwise specified.

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 = 2.23V		30		%
PWM duty	Temp V_F = 1.65V		82		%

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



(a) V_F vs. T_{vj} (b) Duty vs. V_F

Fig. 7-3 Relationship among T_{vj}, 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.

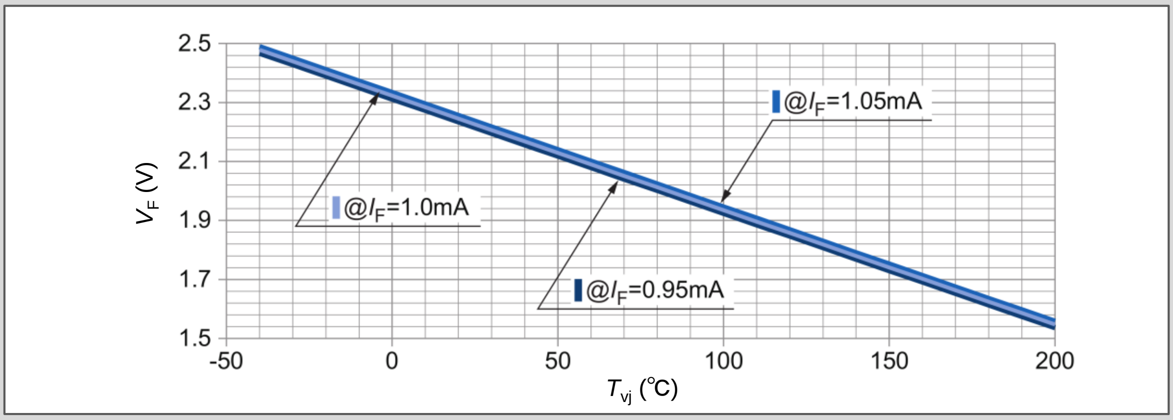


Fig. 7-4 V_F - T_{vj} shift according to I_F@±0.05(mA)

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.

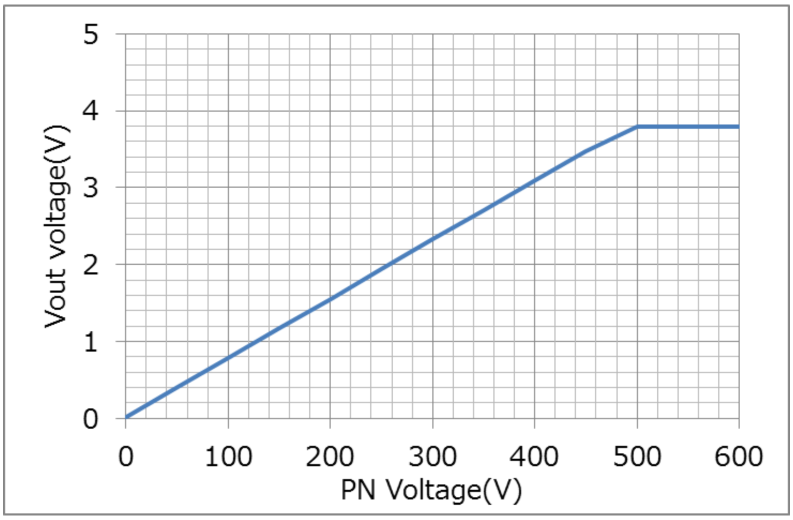


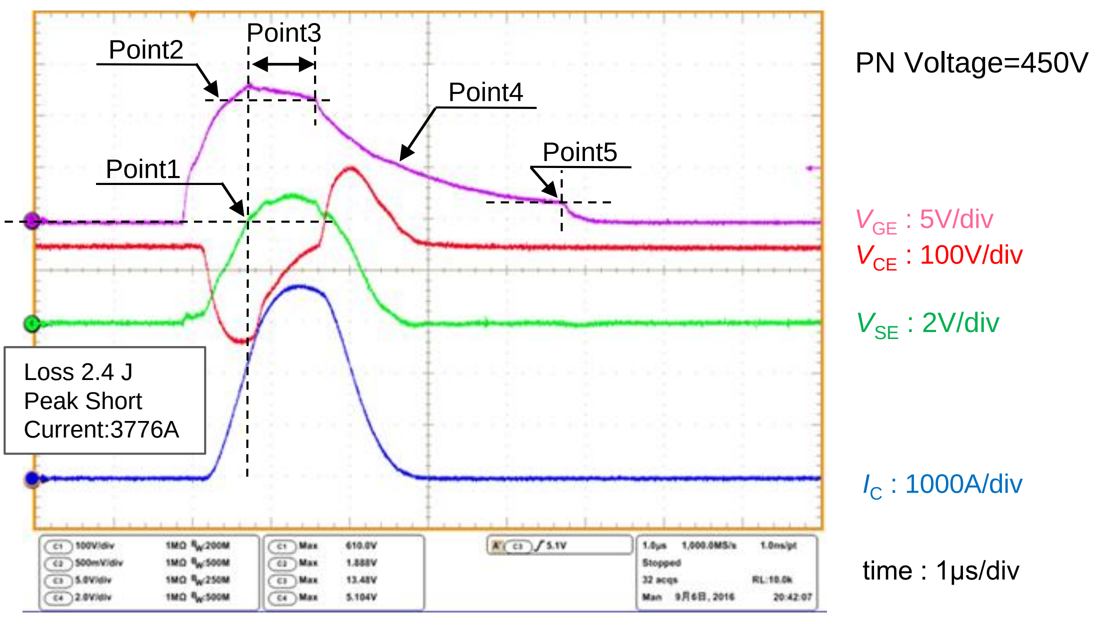
Fig. 7-5 Output voltage vs. PN voltage

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		ns
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} >3.14(V) continues for 800ns
  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)

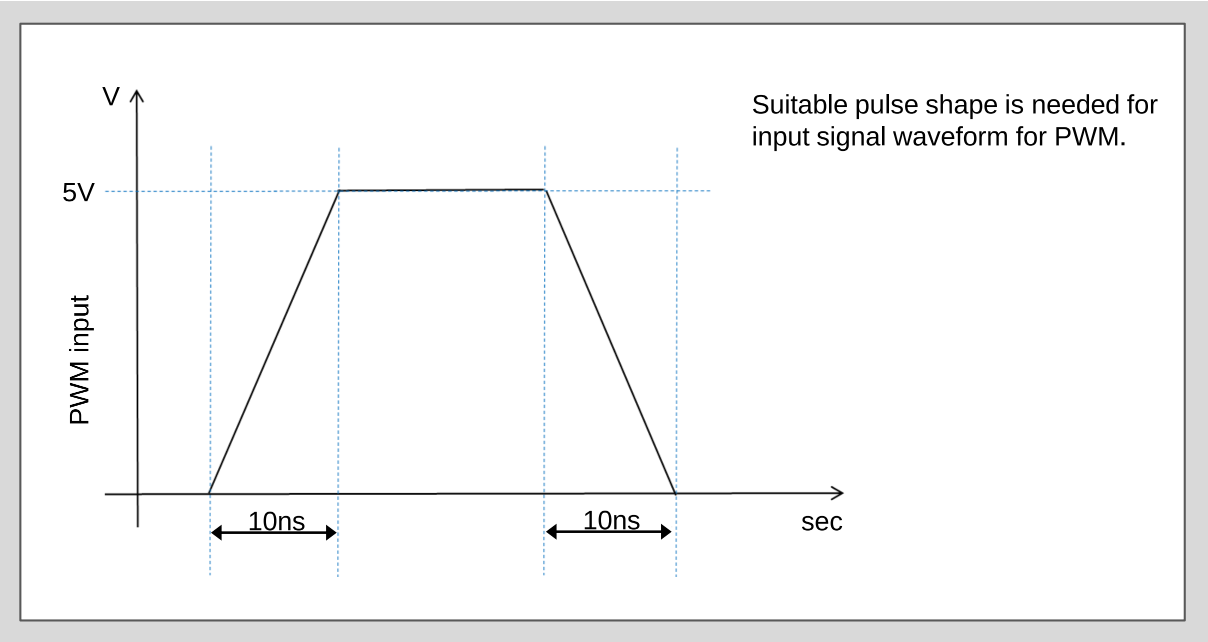


Fig. 7-7 Input signal waveform for PWM input

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℃.

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.

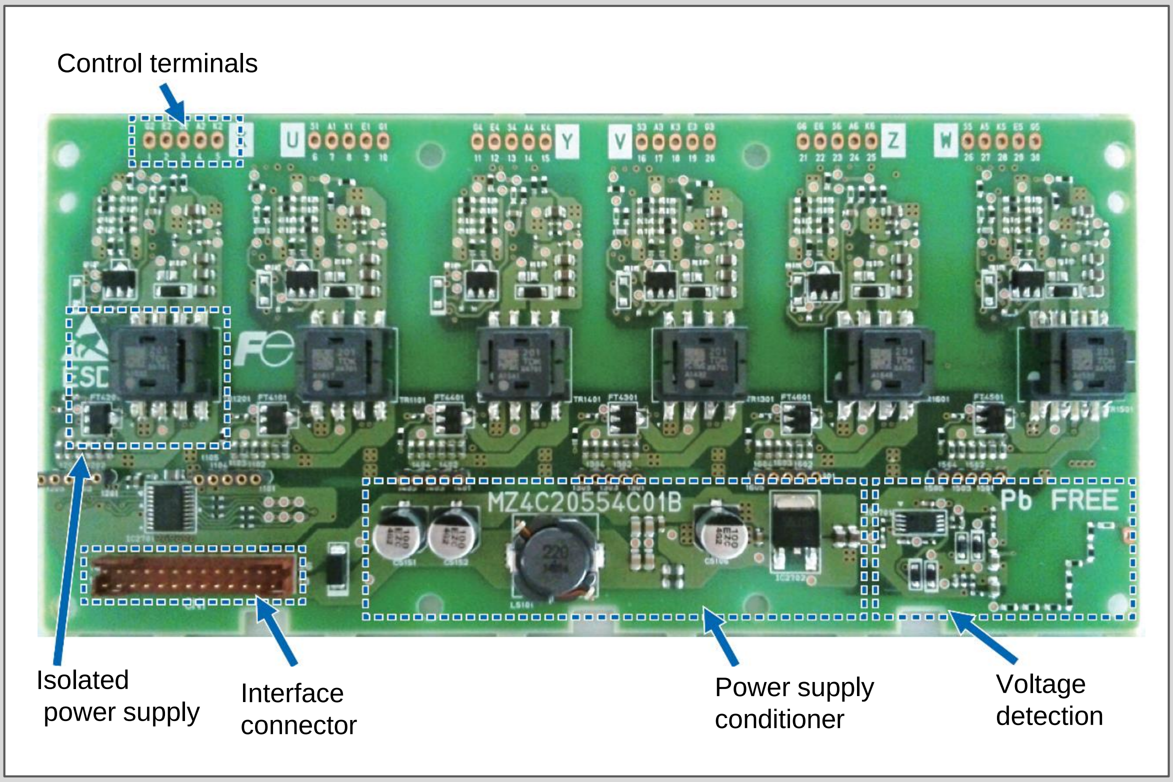
1. Connect the driver through the 26 pin post header to test board and supply +12V through pins 12 and 13.

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

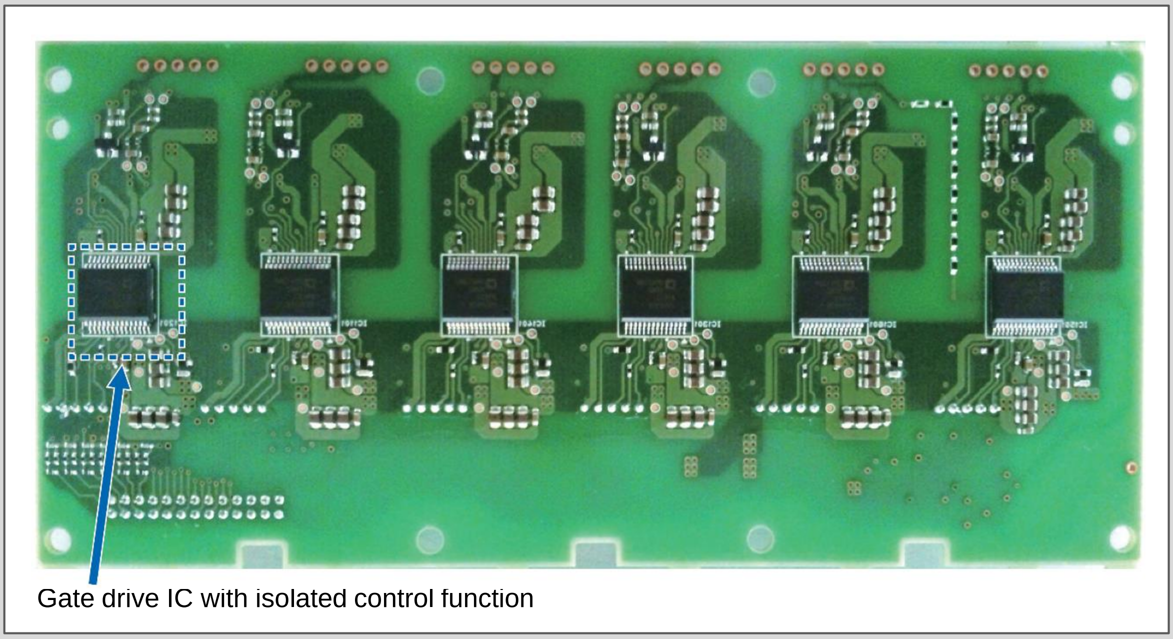
3. Check the gate voltage according to followings:
   a) For the off-state, the nominal gate voltage should be 0V.
   b) For the on-state, it is +14 to +16V
   c) Check the current consumption of the driver without the clock signals and the desired switching frequency driving a capacitive load equivalent 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

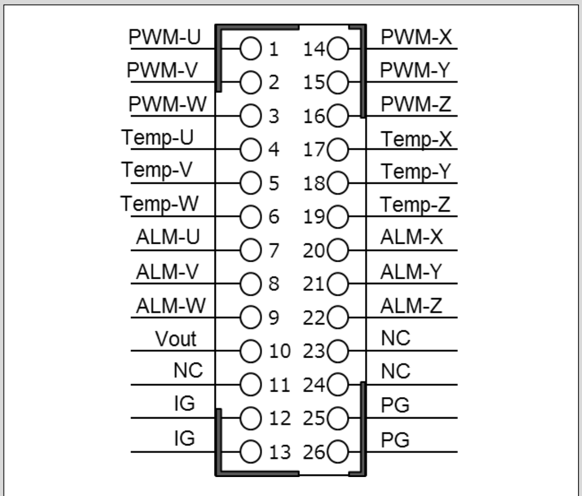


(b) Bottom view (mirror)

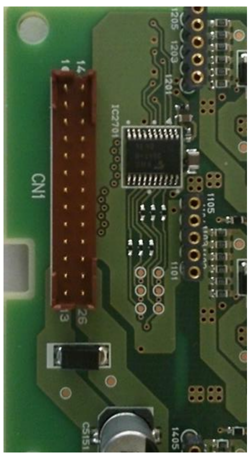
Fig. 7-8 Evaluation board appearance

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	Temperature data output of phase U
5	Temp-V	Output	Temperature data output of phase V
6	Temp-W	Output	Temperature data output of phase W
7	ALM-U	Output	Alarm signal output when any fault is occurred on phase U
8	ALM-V	Output	Alarm signal output when any fault is occurred on phase V
9	ALM-W	Output	Alarm signal output when any fault is occurred 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	Temperature data output of phase X
18	Temp-Y	Output	Temperature data output of phase Y
19	Temp-Z	Output	Temperature data output of phase Z
20	ALM-X	Output	Alarm signal output when any fault is occurred on phase X
21	ALM-Y	Output	Alarm signal output when any fault is occurred on phase Y
22	ALM-Z	Output	Alarm signal output when any fault is occurred 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

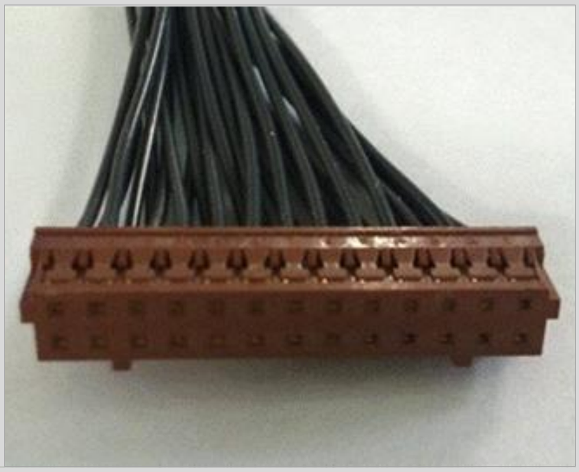
Fig. 7-9 Pin assignment and top view of external connector

13. Interface Connector and Harness

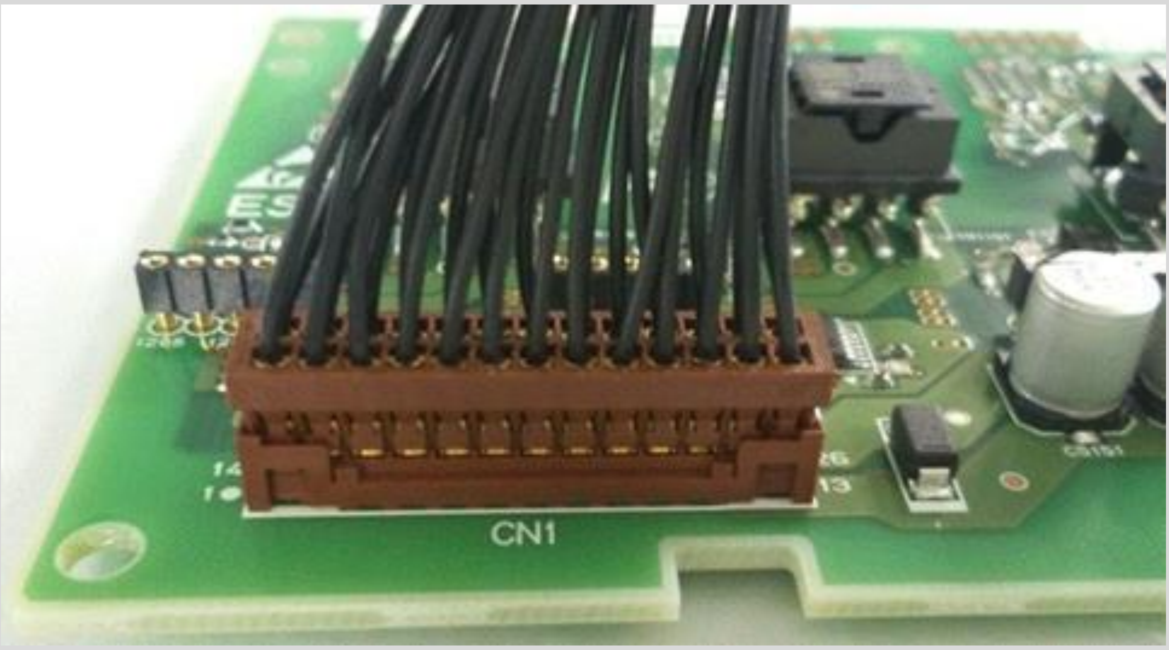
Connection to the evaluation board is performed by an optional interface cable.

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 electro static prior to board installation.

Board installation procedure:

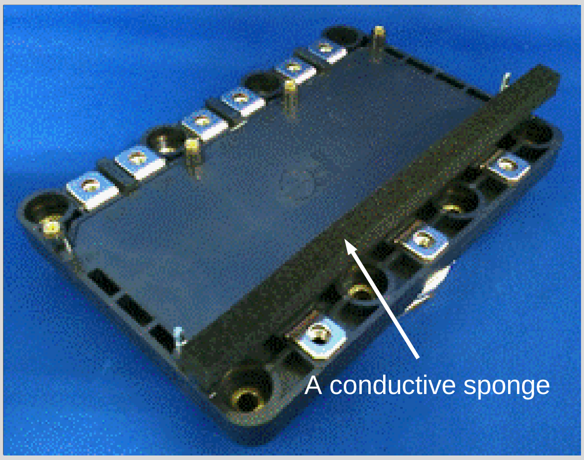
(a) Remove the sponge with take care.
A conductive sponge is attached to protect the module from ESD prior to factory shipment.

(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.

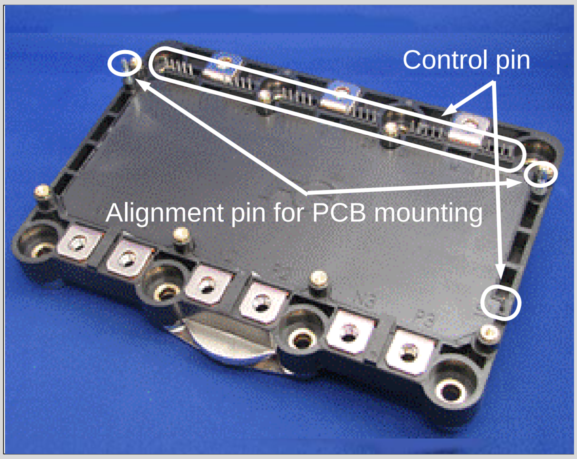
(c) Mount the board along the alignment pin at the both side of the module.

(d) Tighten the screws within specific torque.

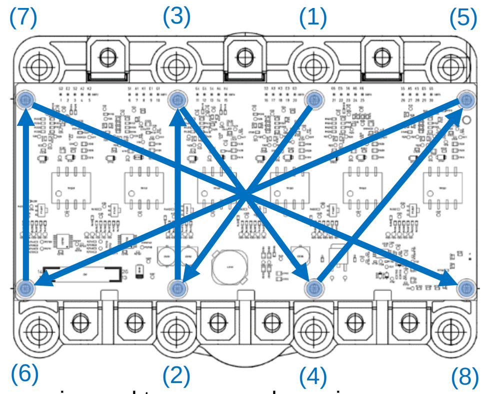
(e) Soldering the control pins. Soldering condition is shown in the specification sheet.



(a) protection the module from ESD

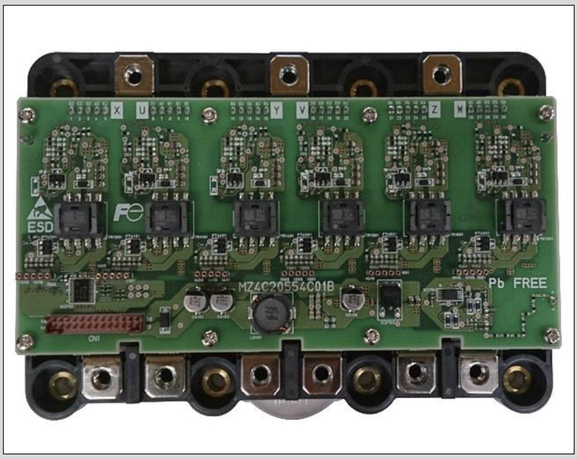


(b) Alignment pin for the board installation



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

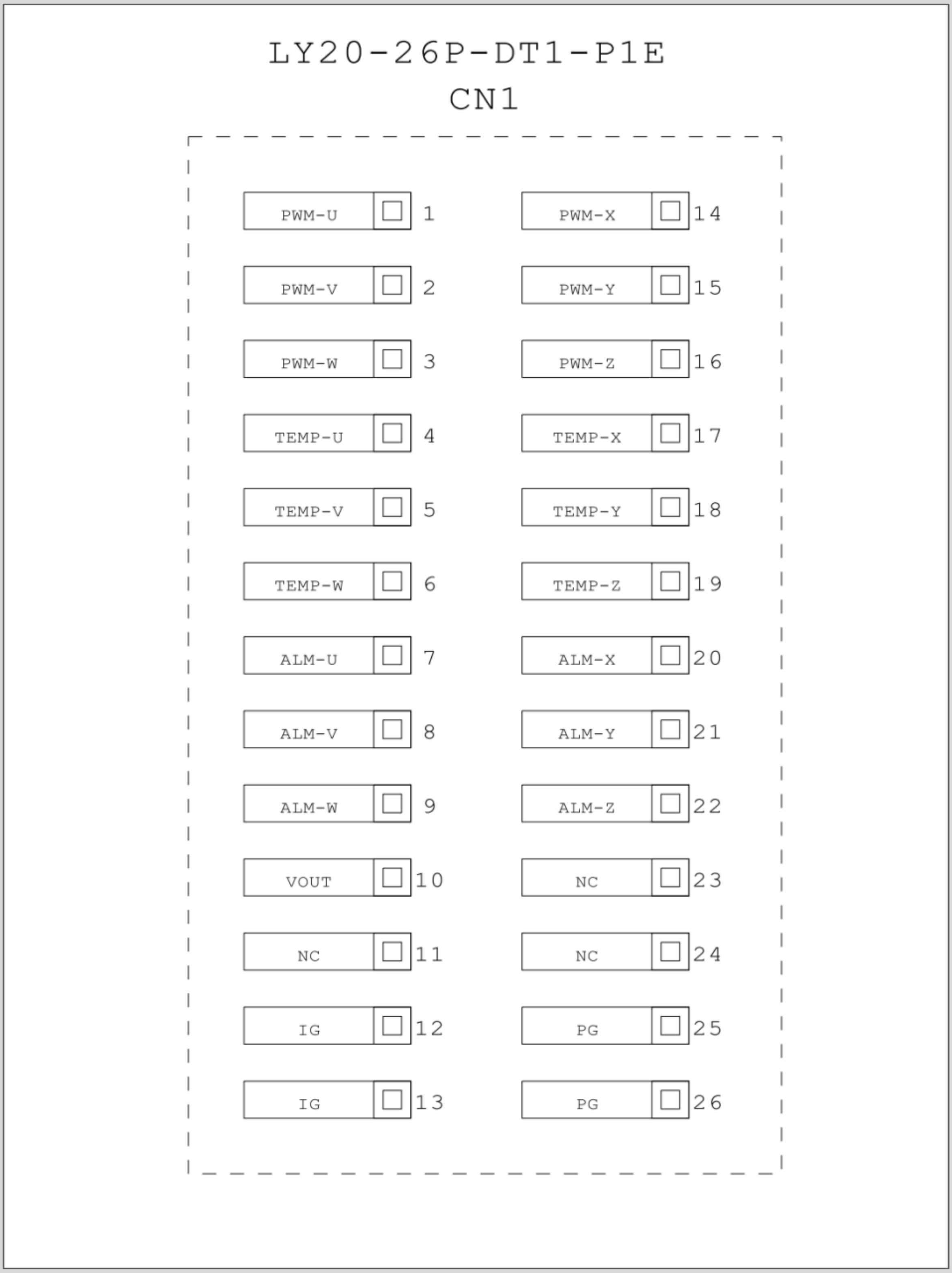


Fig. 7-12 External connector pin assignment

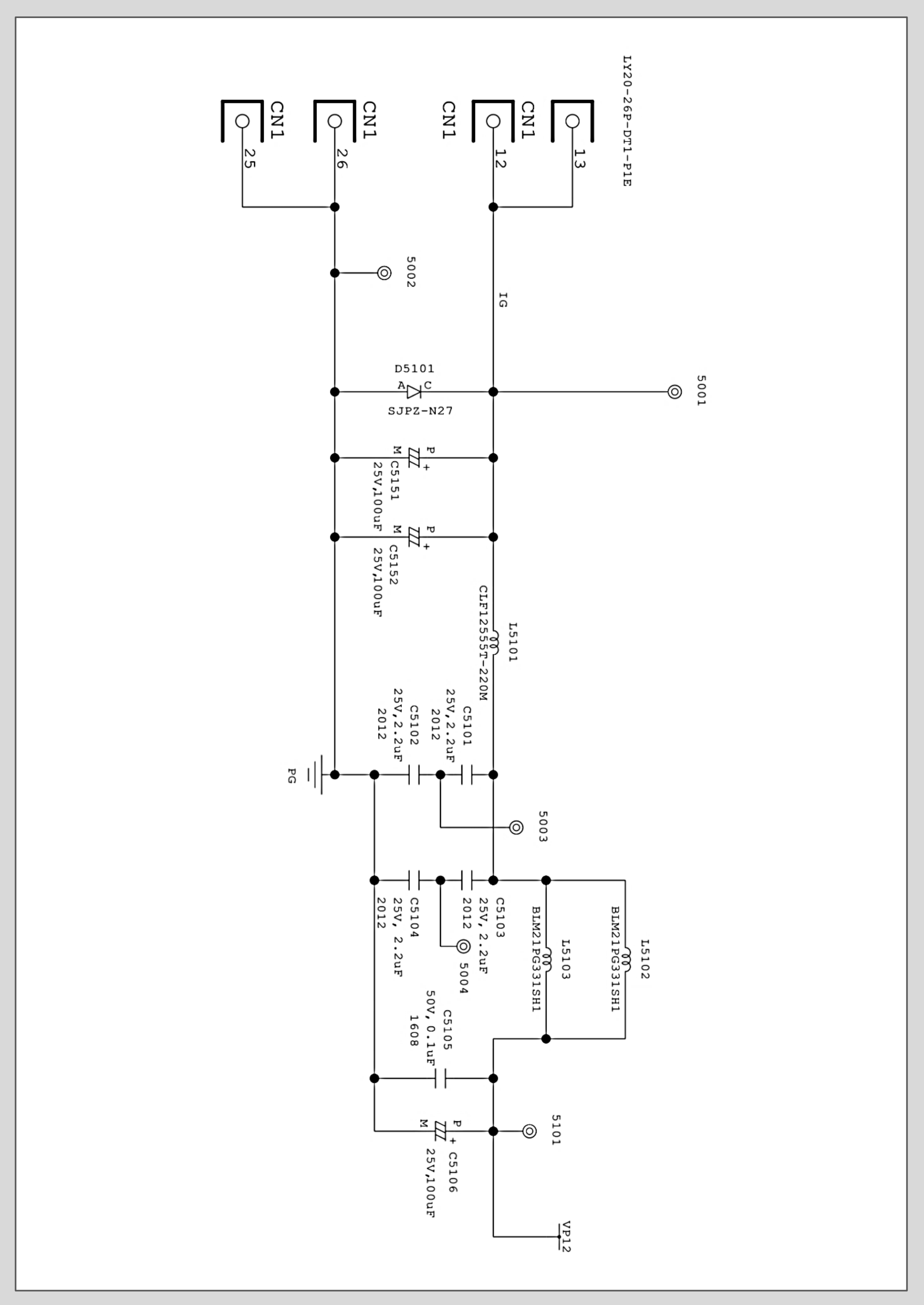


Fig. 7-13 Power supply conditioner

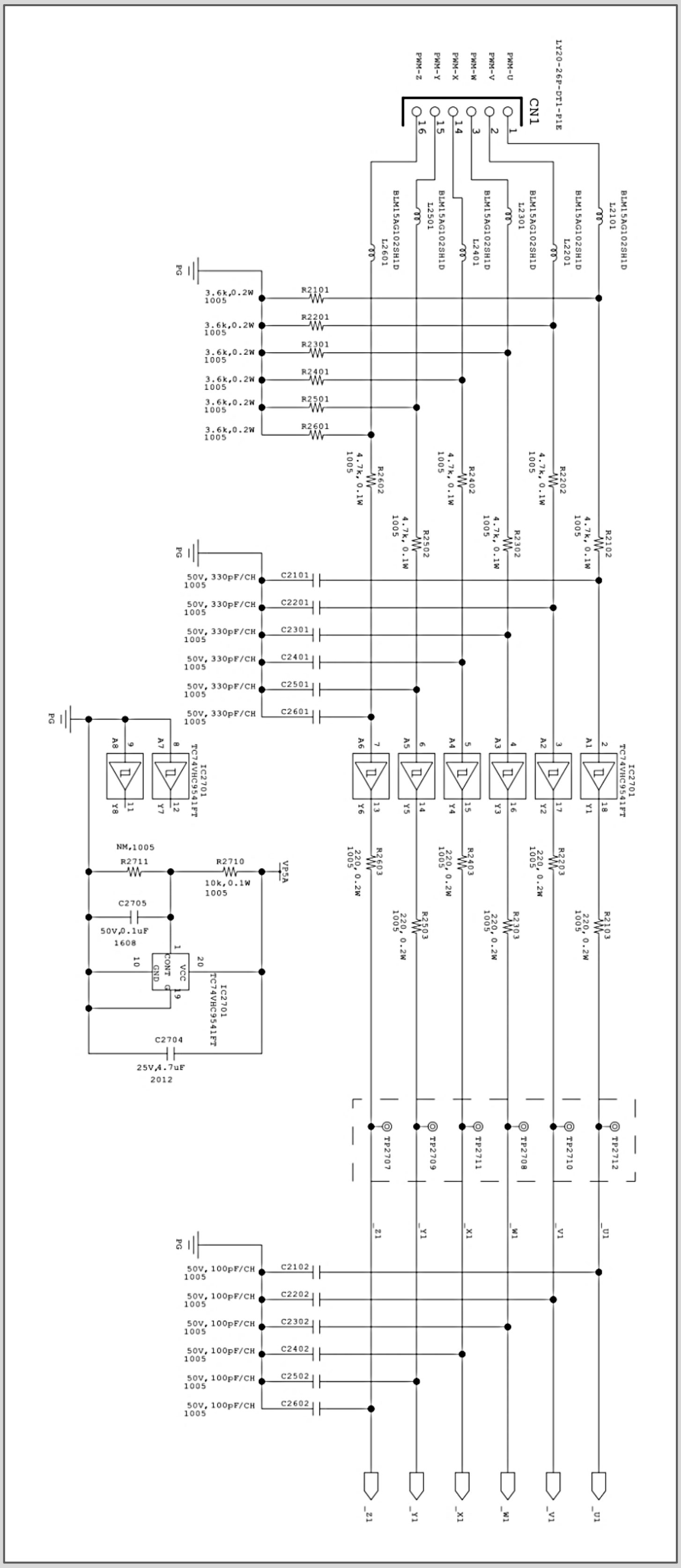


Fig. 7-14 Interface logic

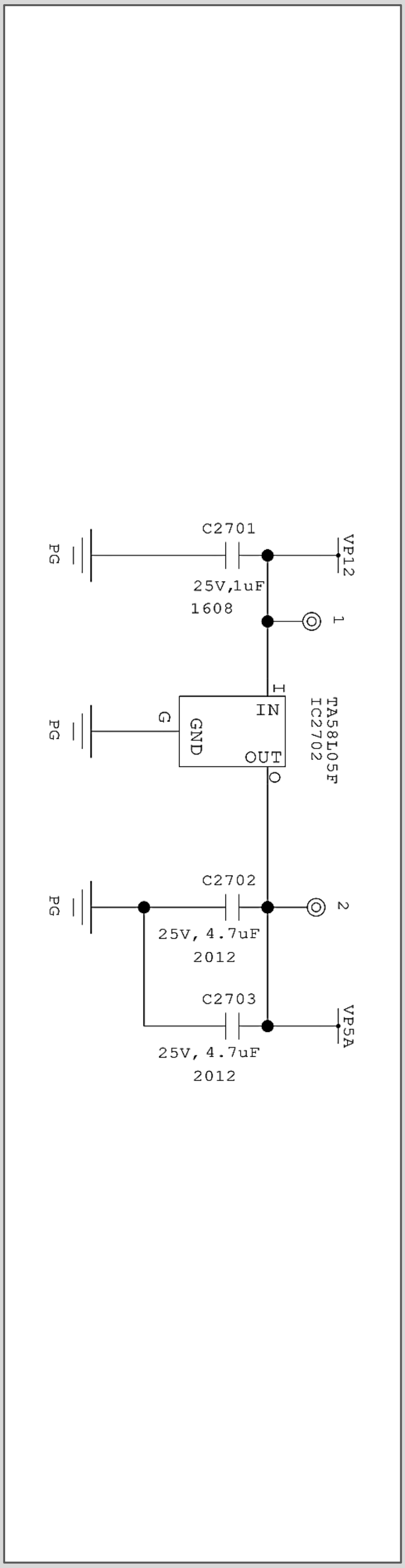


Fig. 7-15 5V power supply

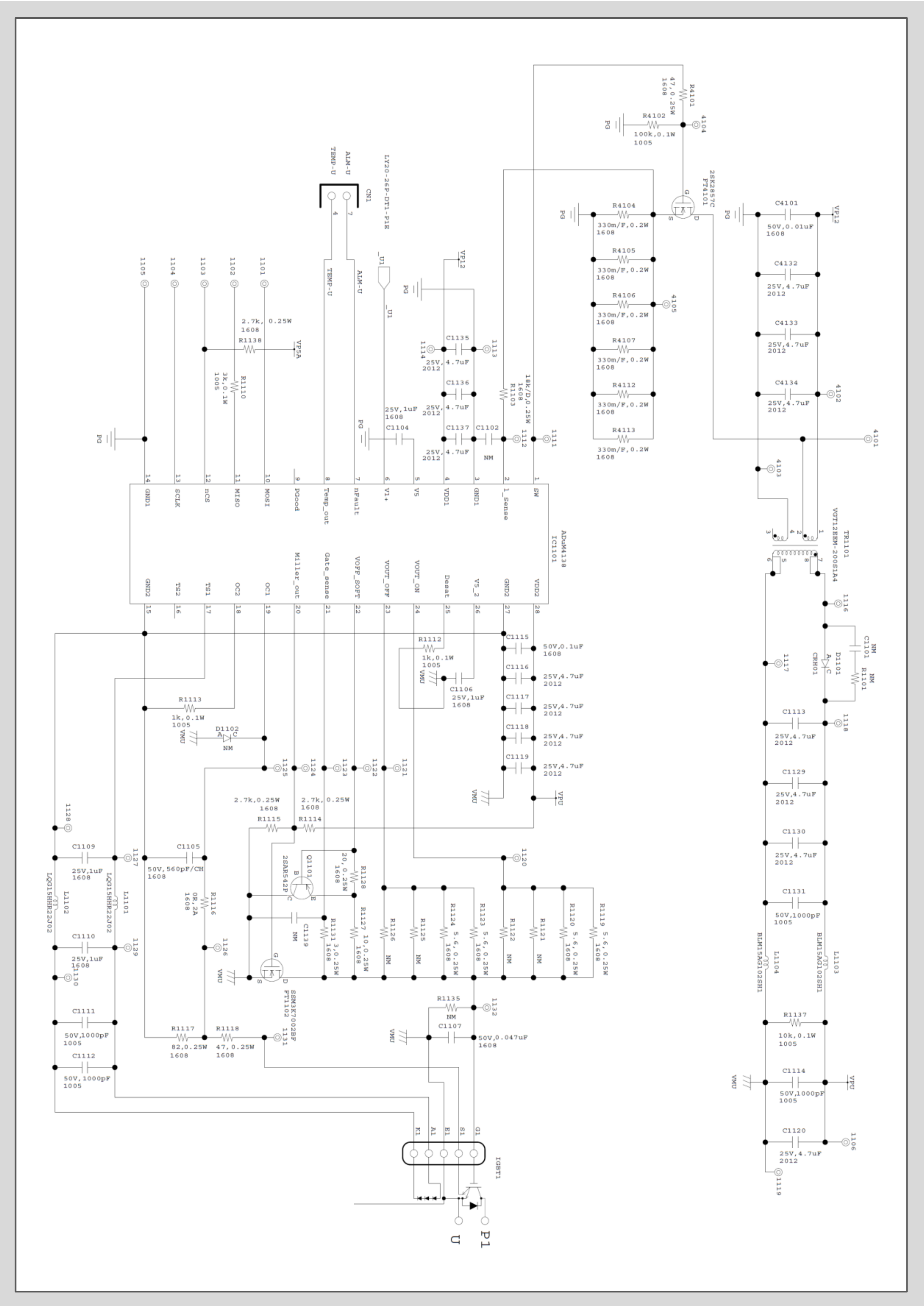


Fig. 7-16 Gate driver for Phase U

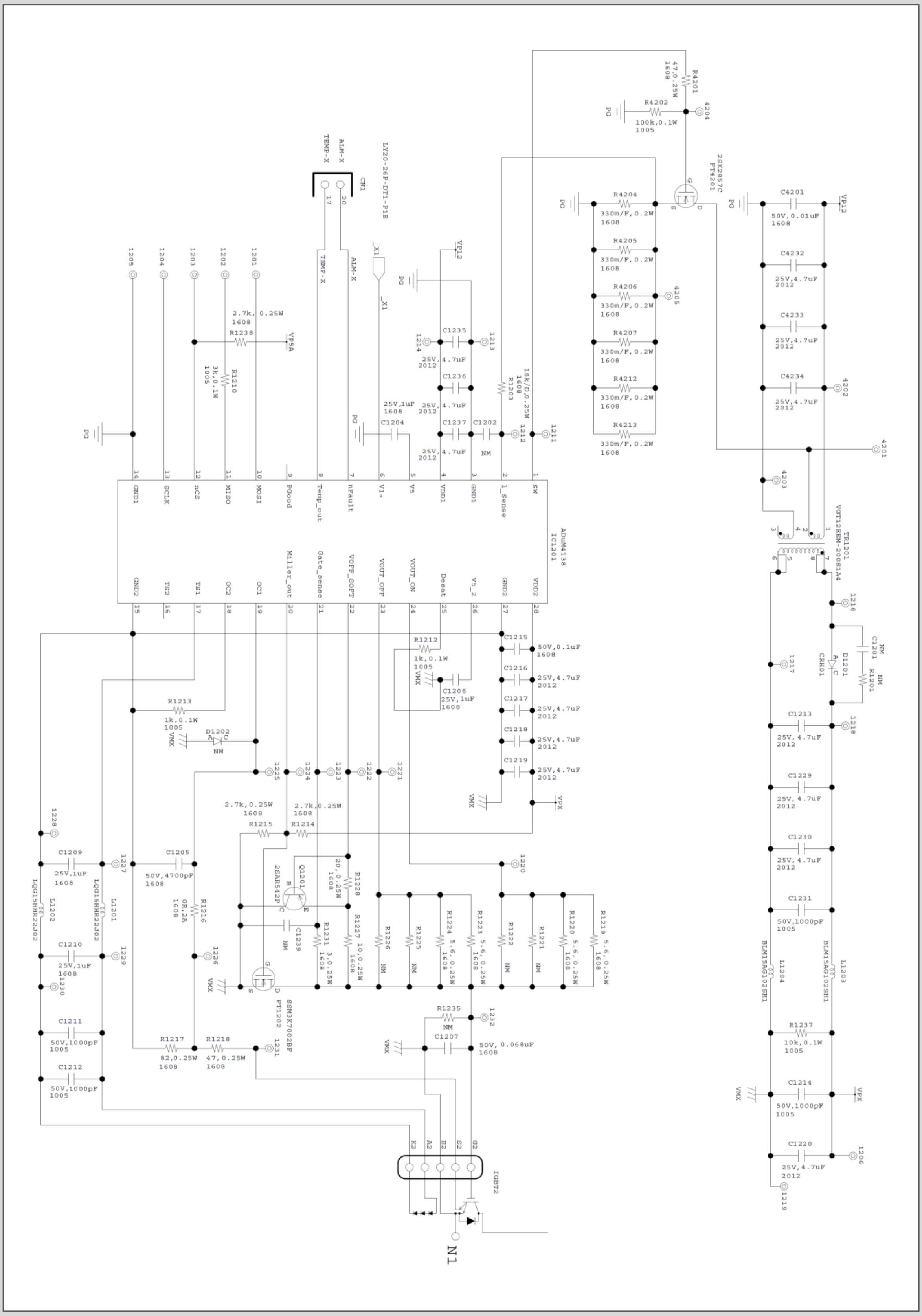


Fig. 7-17 Gate driver for Phase X

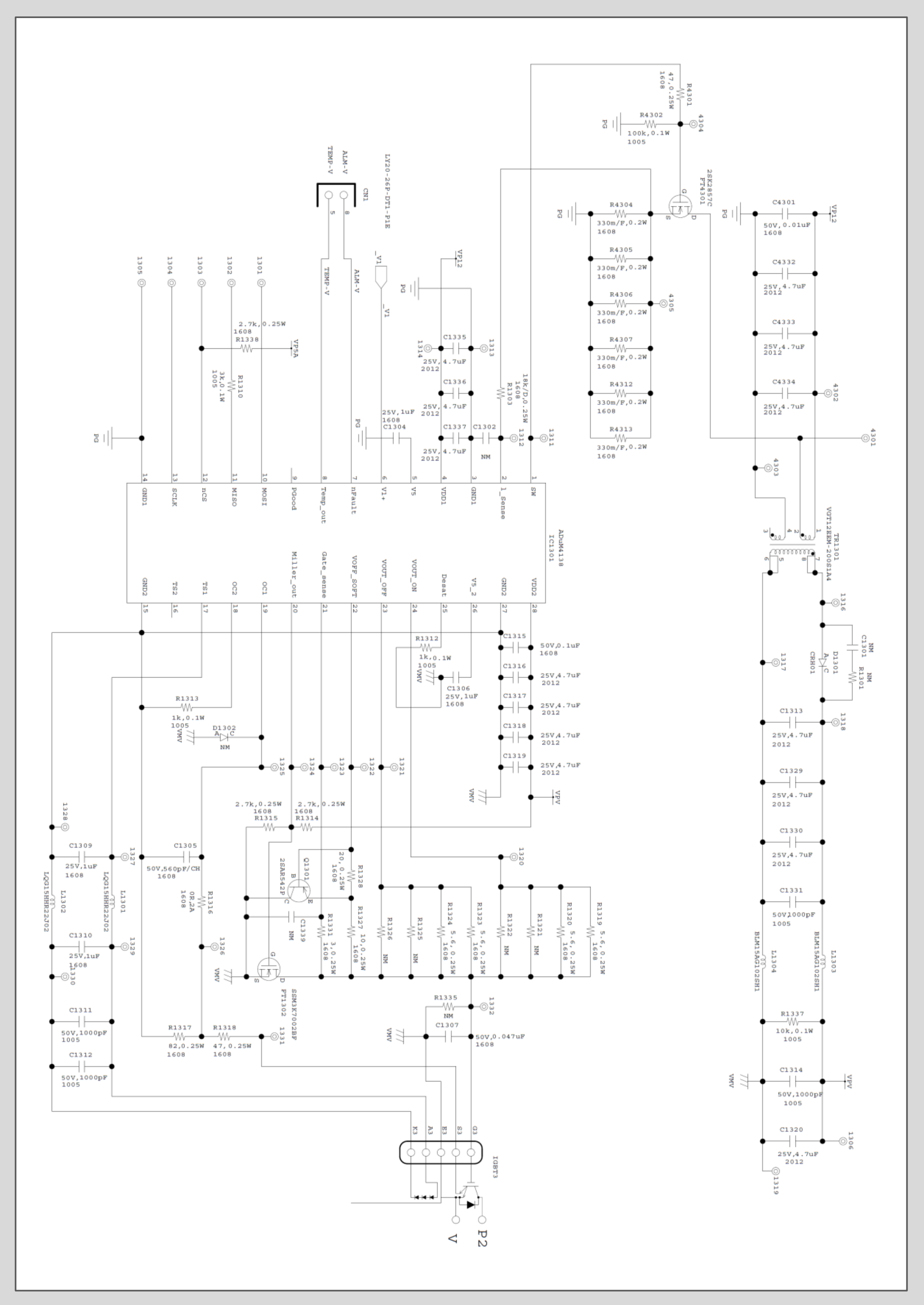


Fig. 7-18 Gate driver for Phase V

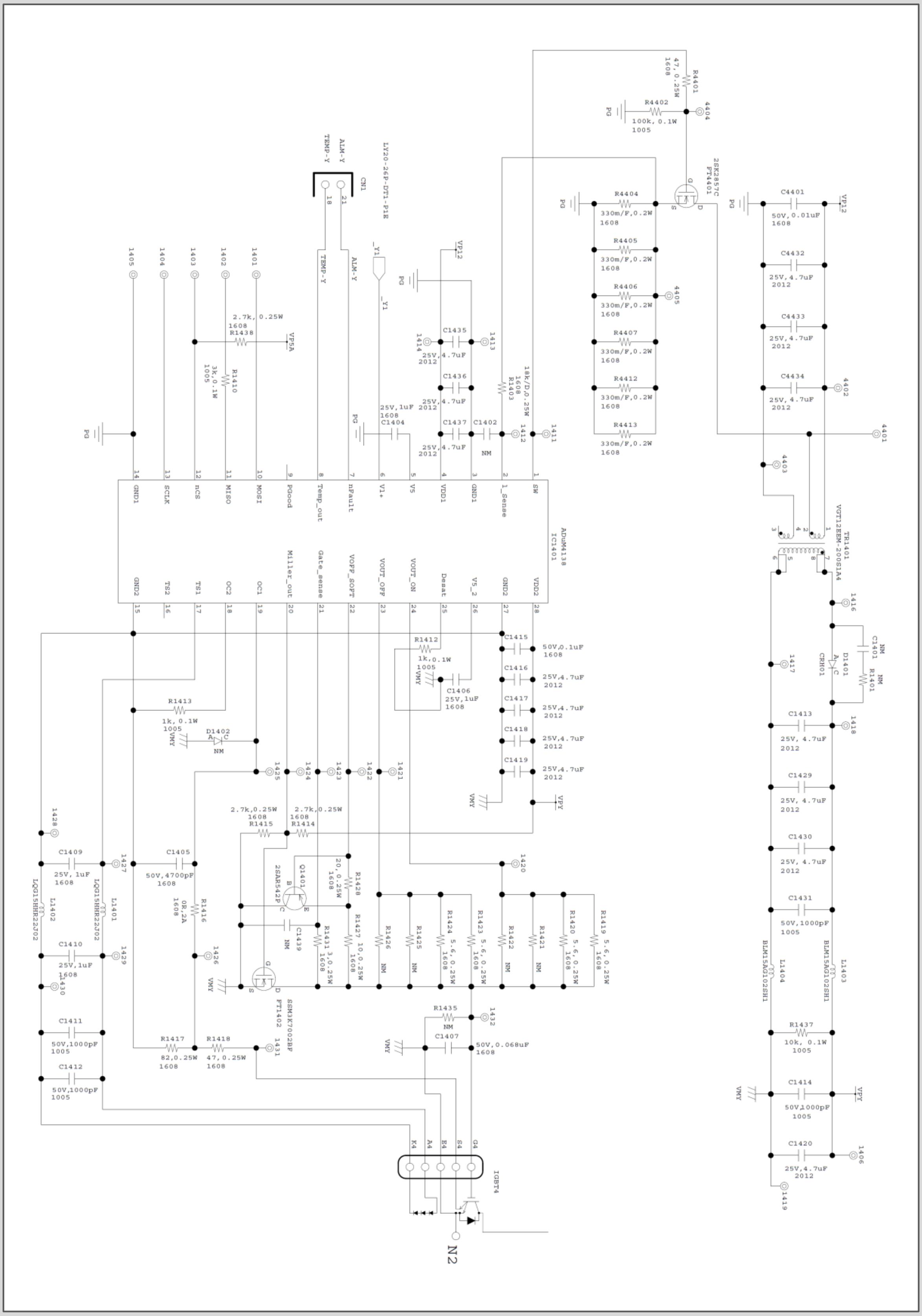


Fig. 7-19 Gate driver for Phase Y

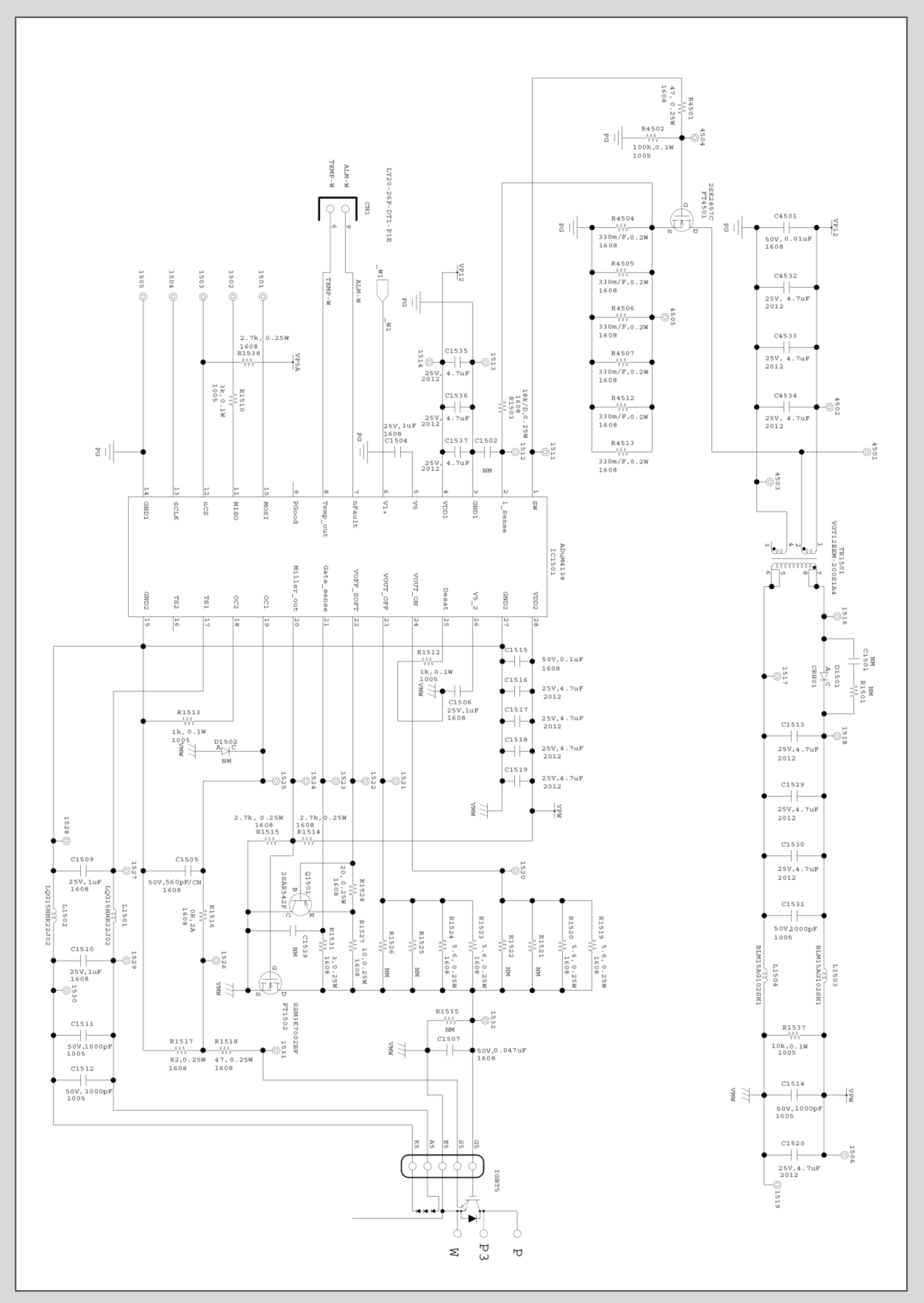


Fig. 7-20 Gate driver for Phase W

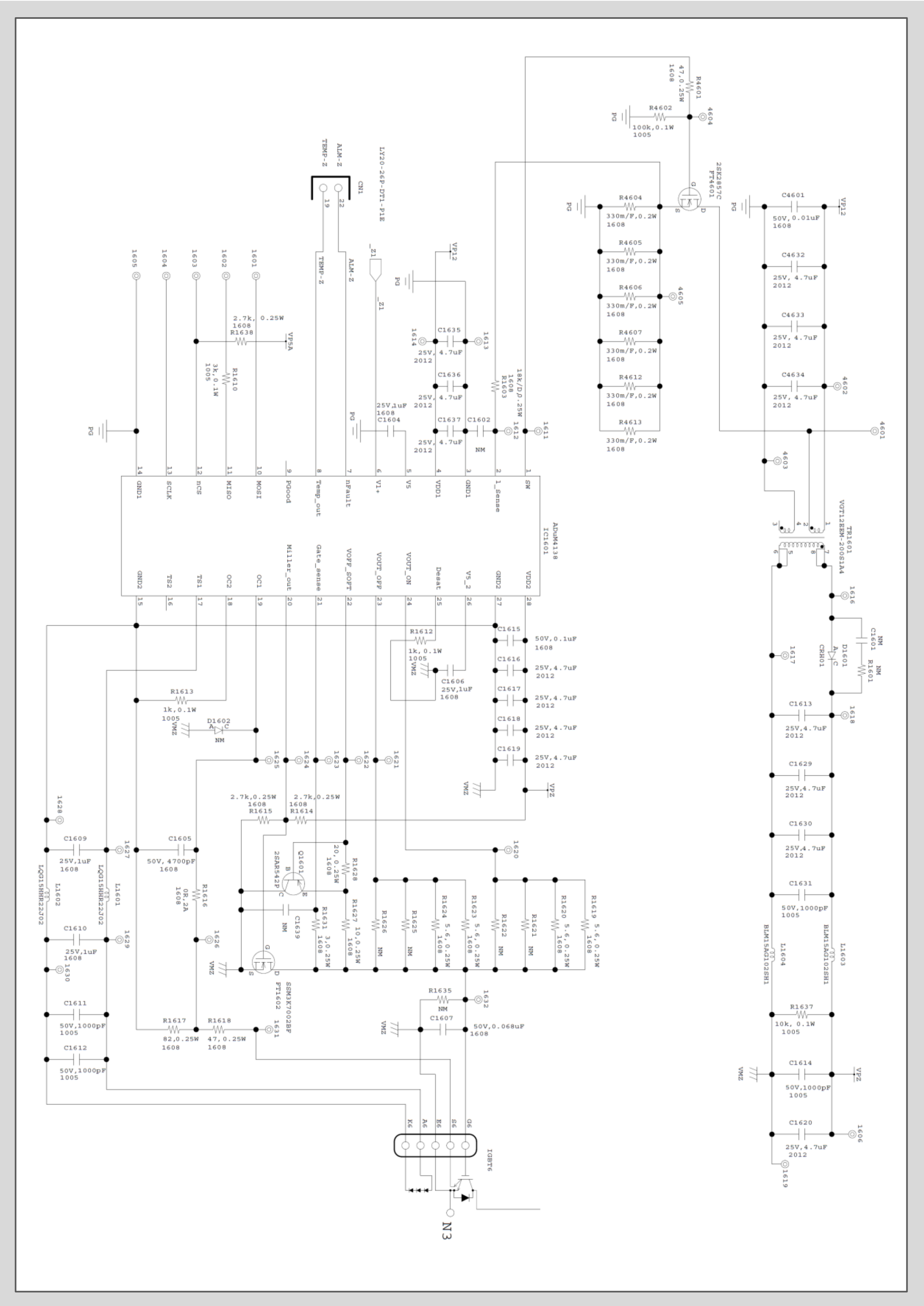


Fig. 7-21 Gate driver for Phase Z

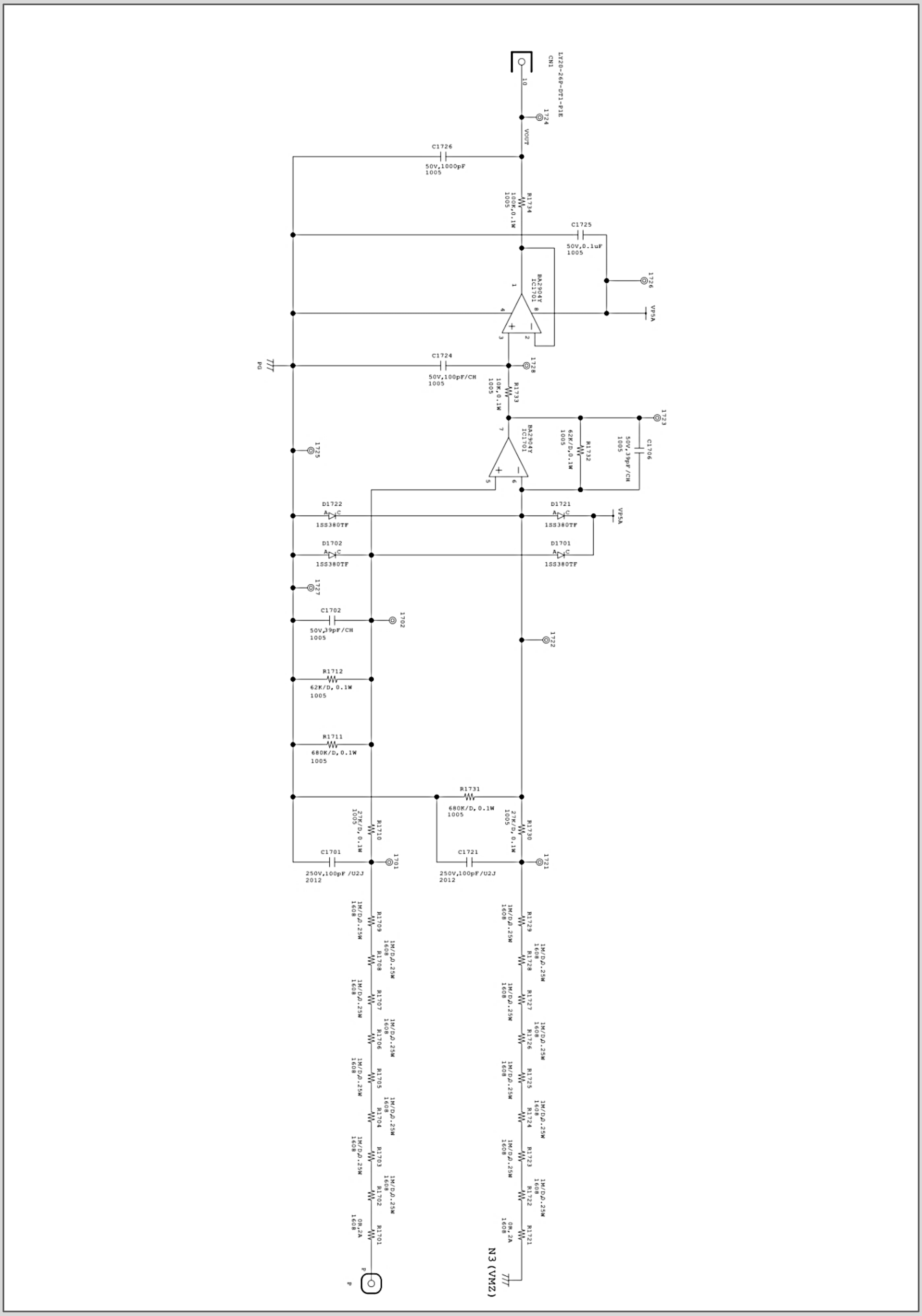
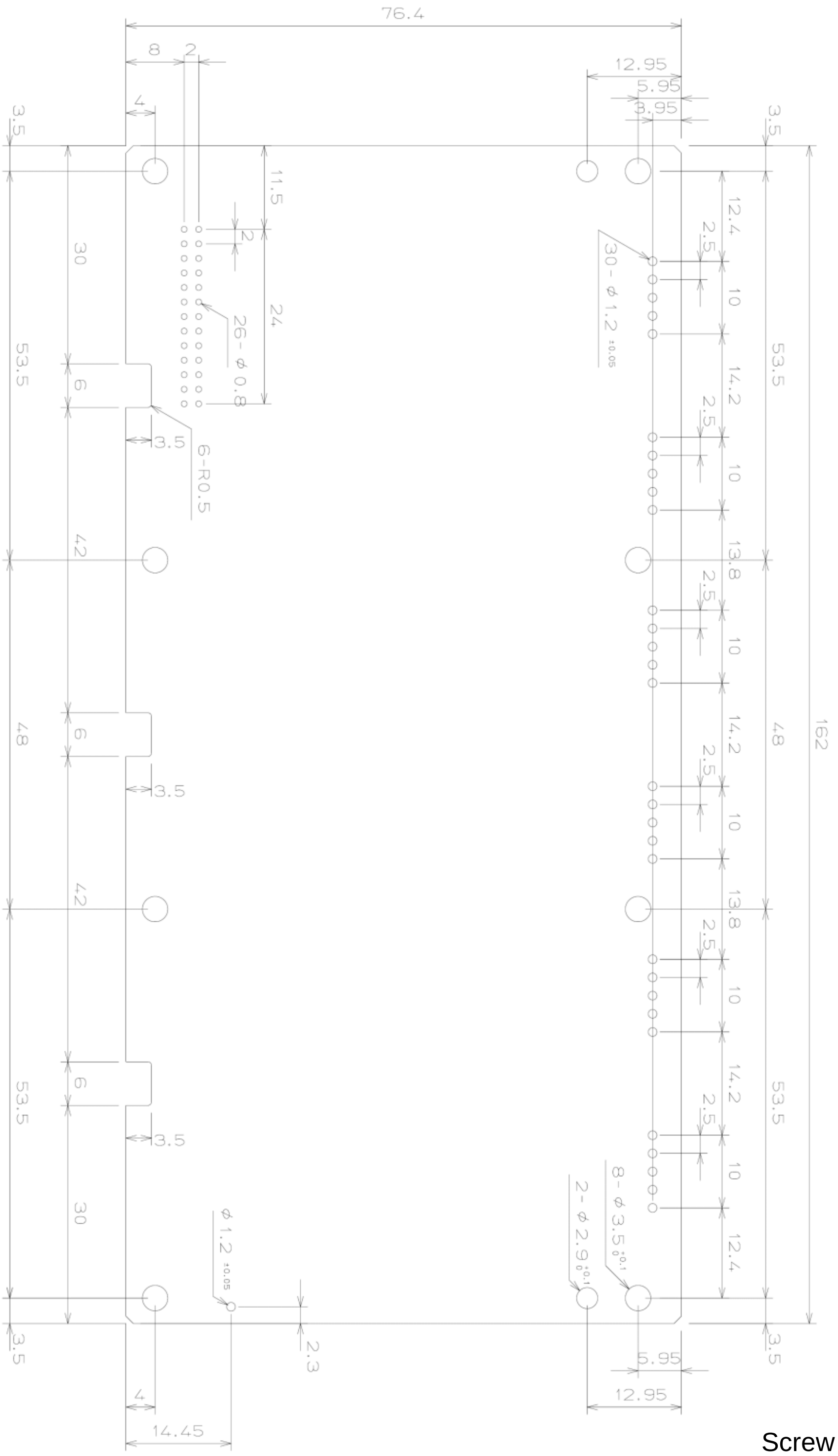


Fig. 7-22 Voltage detection part at Phase W, Z

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

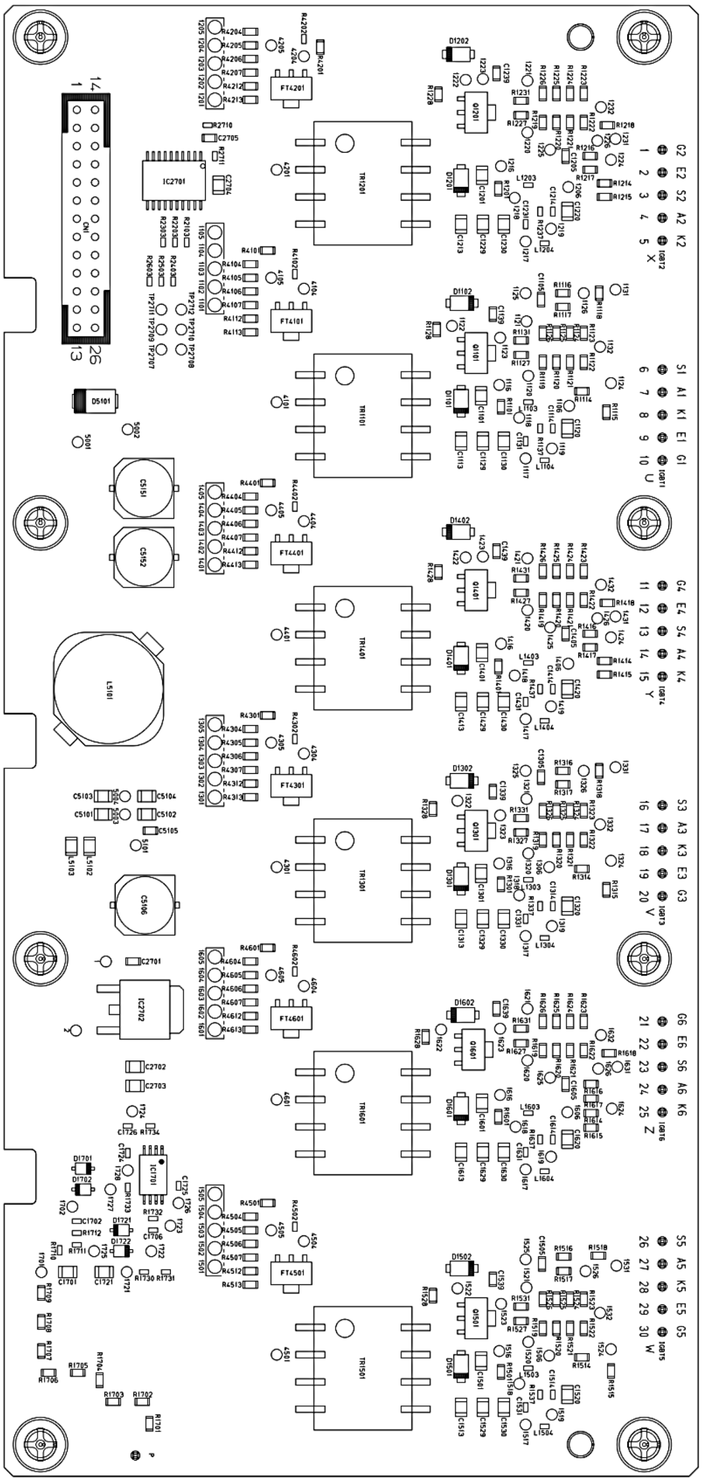


Fig. 7-24 Assembly drawing of the driver board (Top)

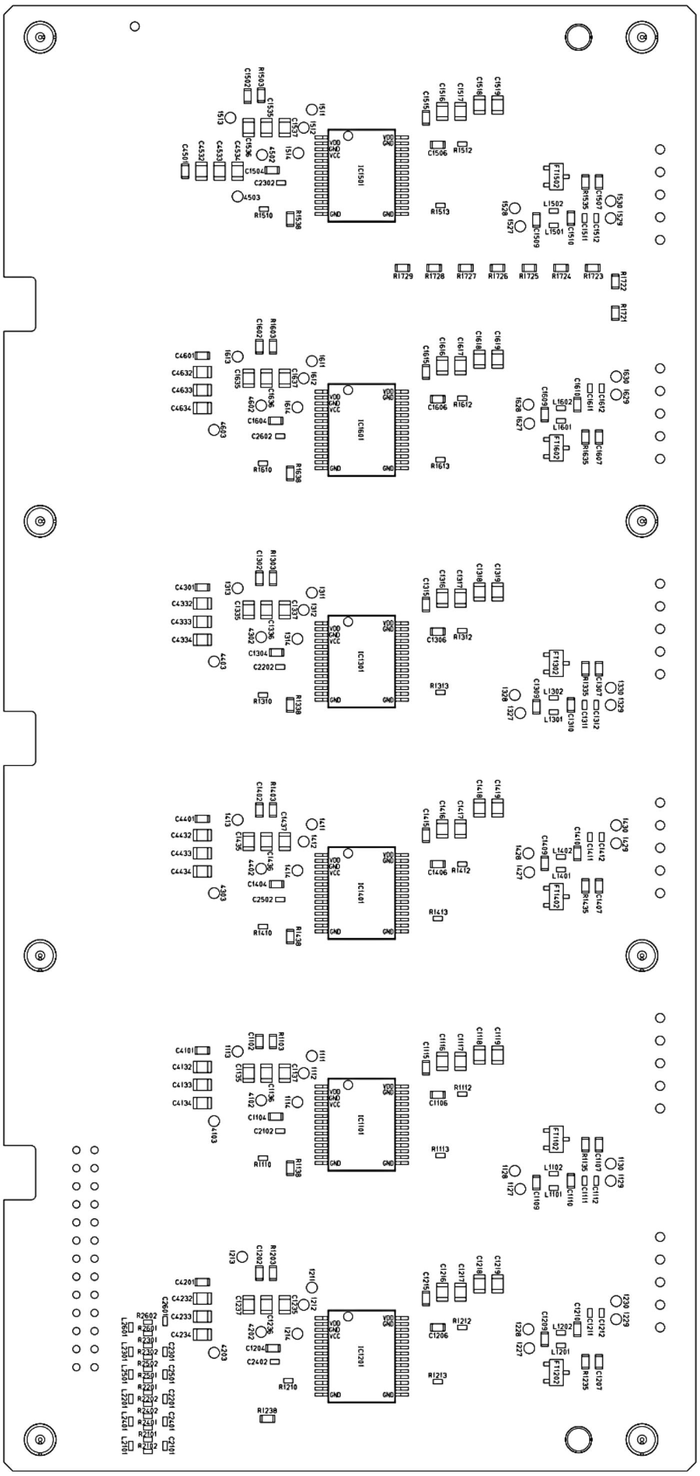


Fig. 7-25 Assembly drawing of the driver board (Bottom)

18. Layout

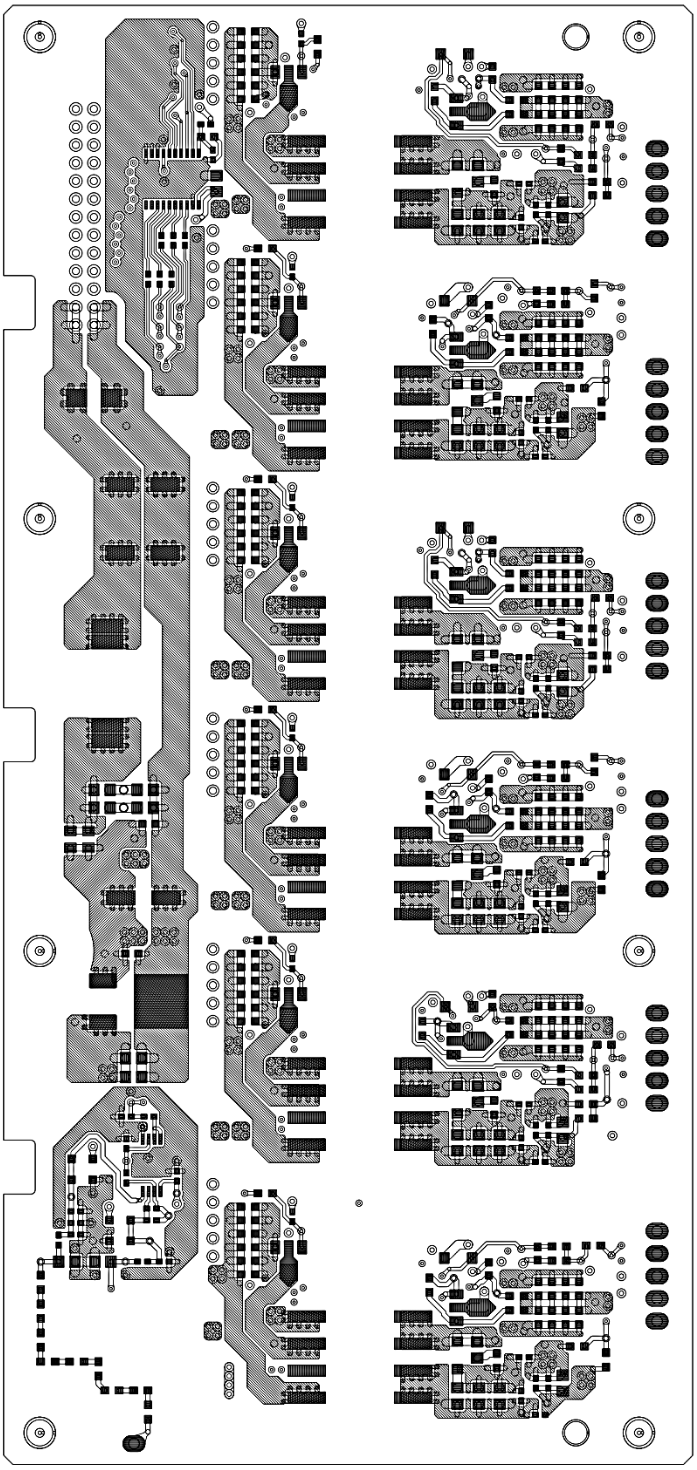


Fig. 7-26 Driver board – Top layer

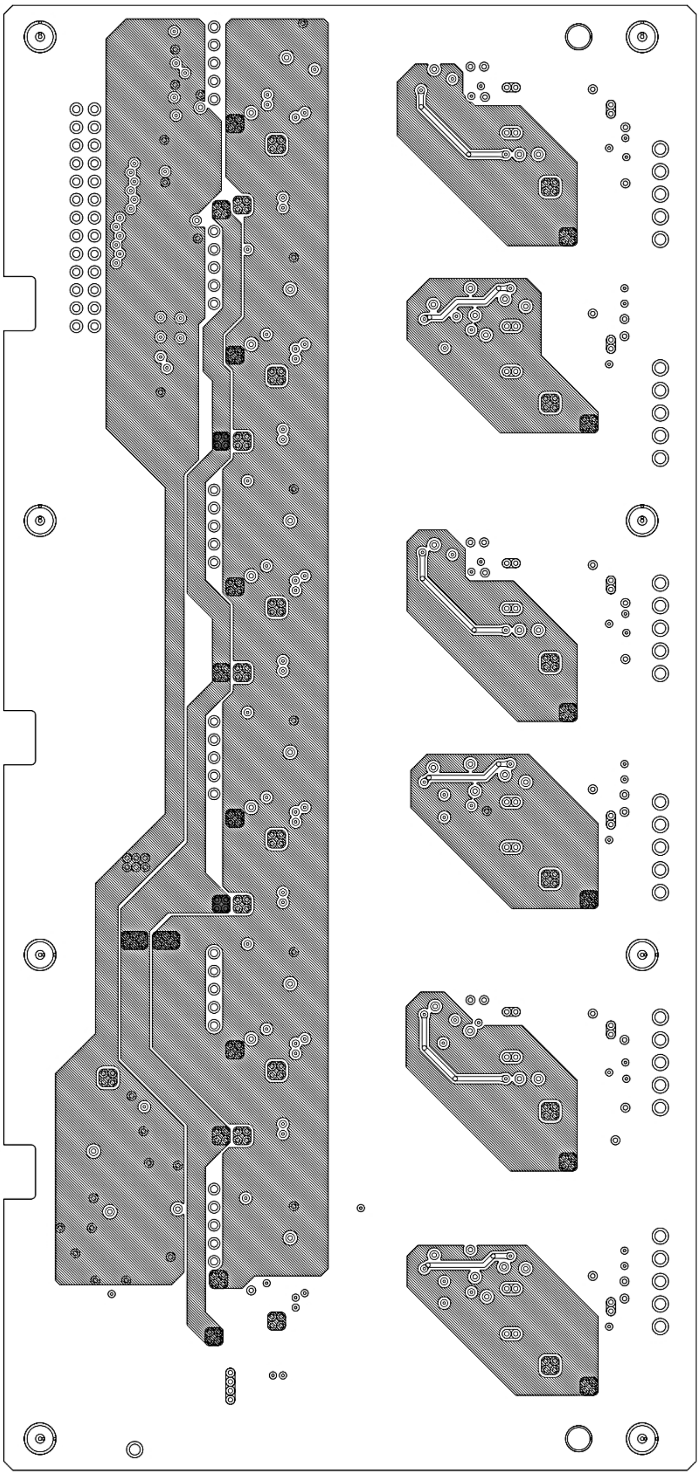


Fig. 7-27 Driver board – Layer 2

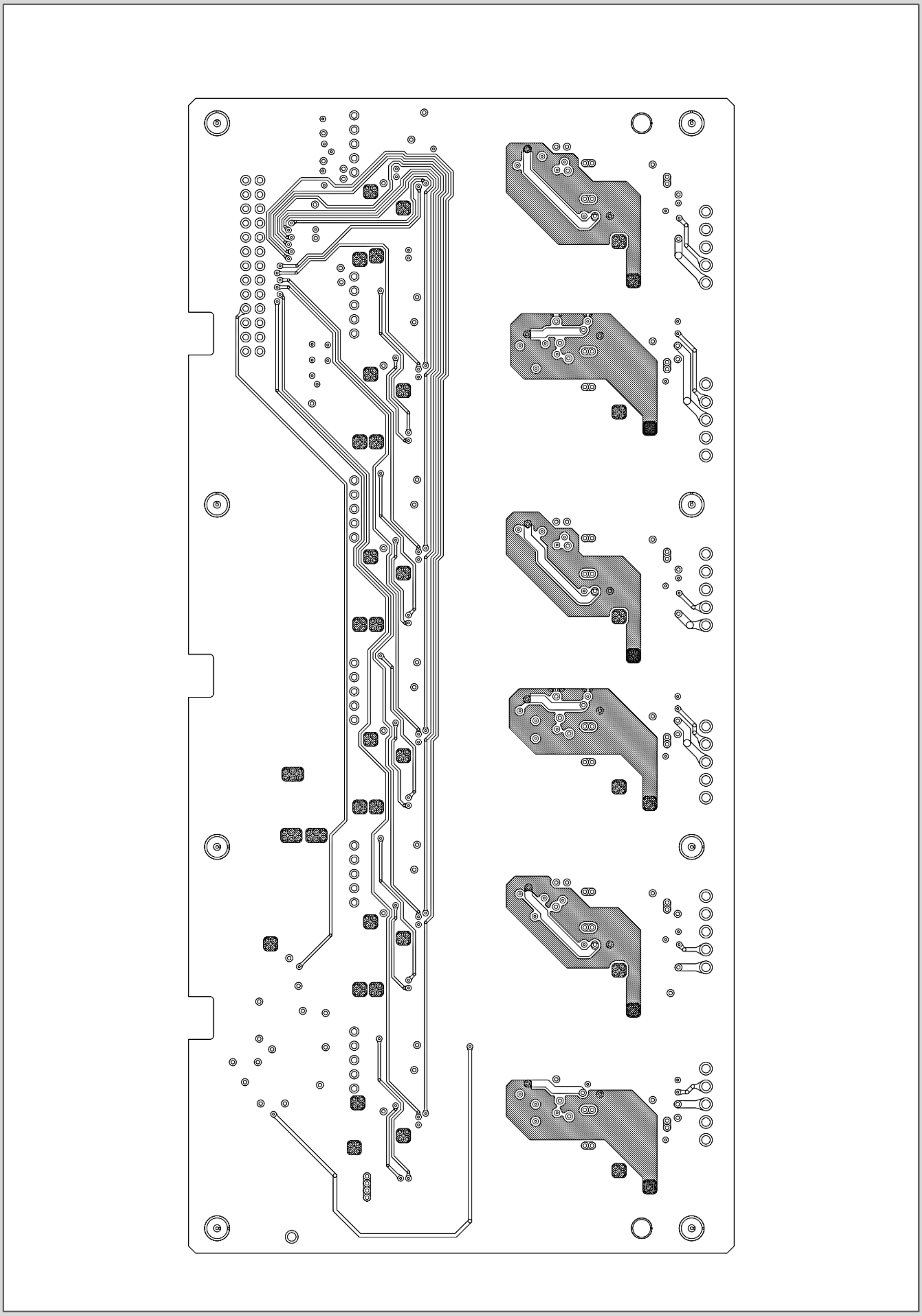


Fig. 7-28 Driver board – Layer 3

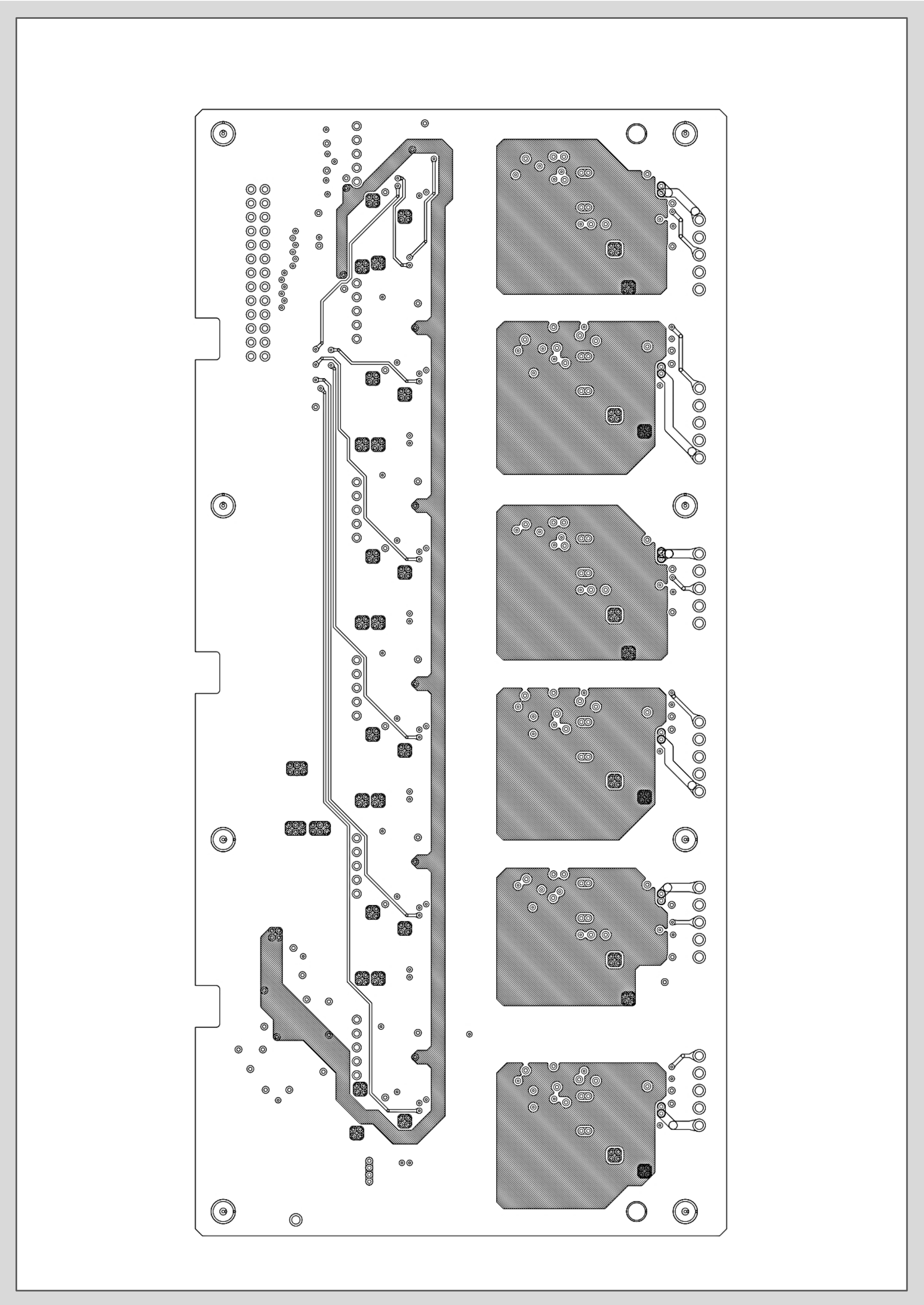


Fig. 7-29 Driver board – Layer 4

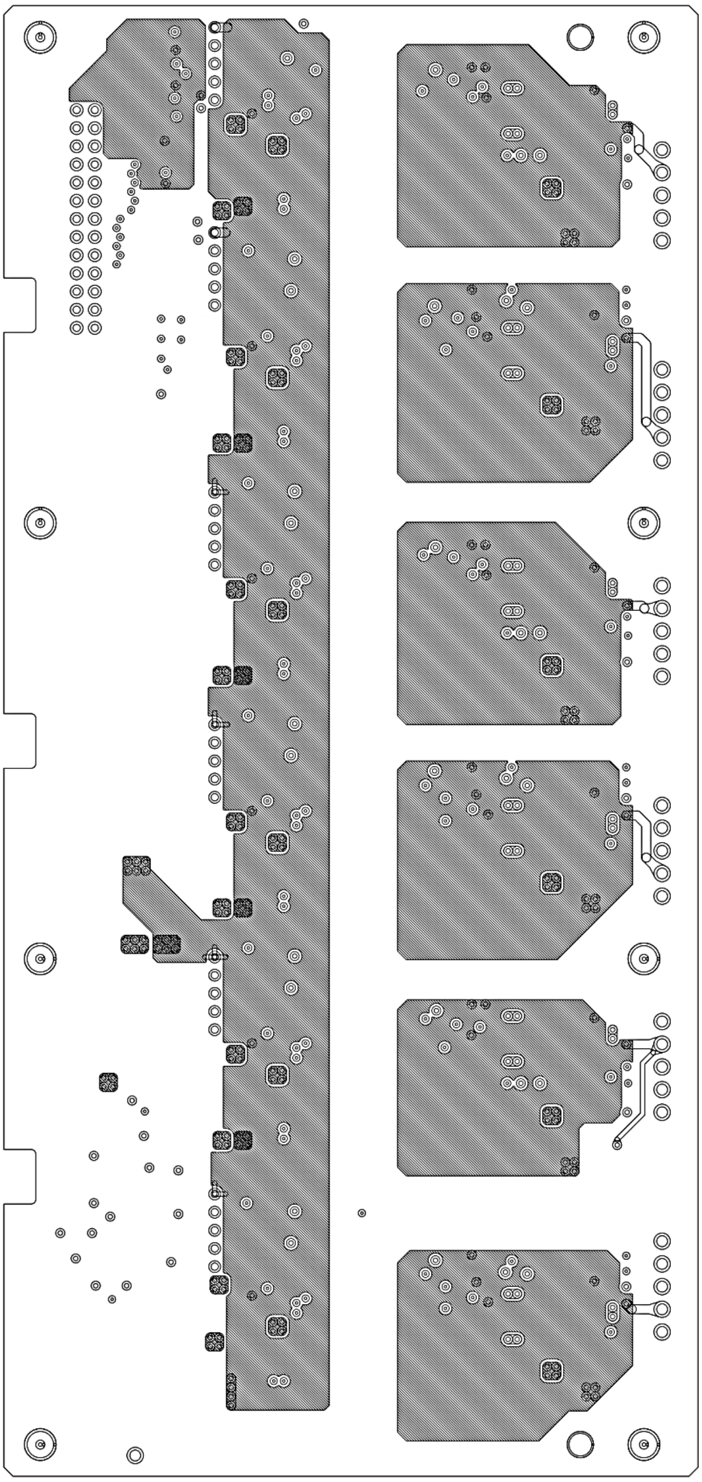


Fig. 7-30 Driver board – Layer 5

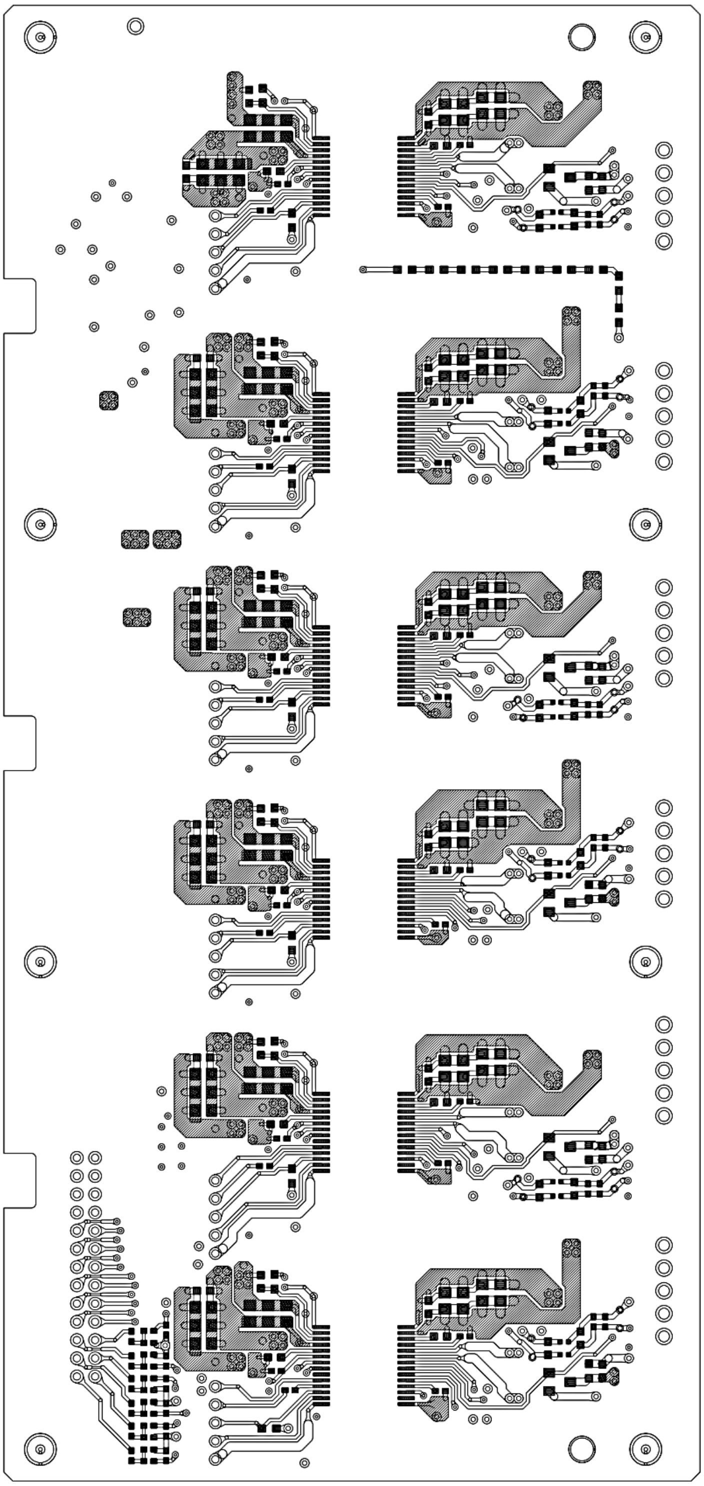


Fig. 7-31 Driver board – Bottom layer

19. Parts List

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

No	Value / Device	Package 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	ADuM4138 Analog Devices	ADI:28L SSOP	Driver IC Automotive	IC1101	IC1201	IC1301	IC1401	IC1501	IC1601
8	TA58L05F 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 ferrite bead Automotive	L1103 L1104 L2101	L1203 L1204 L2201	L1303 L1304 L2301	L1403 L1404 L2401	L1503 L1504 L2501	L1603 L1604 L2601
14	BLM21PG331SH1 Murata	SMD 2012(mm)	Chip ferrite bead Automotive	L5102	L5103				
15	LQG15HHR22J02 Murata	SMD 1005(mm)	Inductor Automotive	L1101 L1102	L1201 L1202	L1301 L1302	L1401 L1402	L1501 L1502	L1601 L1602

Contact to Analog Devices. Inc.

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Taiwan branch:

Person in charge: Jackey Chen, Tel: +886 (2) 2650-2823, Email: Jackey.Chen@analog.com

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

No	Value / Device	Package type (JEDEC)	Classification	Reference					
16	25V,100uF	φ6.3xH7.7	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	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,560pF,CH	SMD 1608(mm)	Capacitor	C1105		C1305		C1505	
23	50V,4700pF	SMD 1608(mm)	Capacitor		C1205		C1405		C1605
24	50V,0.01uF	SMD 1608(mm)	Capacitor	C4101	C4201	C4301	C4401	C4501	C4601
25	50V,0.047uF	SMD 1608(mm)	Capacitor	C1107		C1307		C1507	
26	50V,0.068uF	SMD 1608(mm)	Capacitor		C1207		C1407		C1607
27	50V,0.1uF	SMD 1608(mm)	Capacitor	C1115	C1215	C1315	C1415	C1515	C1615
				C2705	C5105				
28	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					
29	250V,100pF	SMD 2012(mm)	Capacitor	C1701	C1721				
30	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	Package type (JEDEC)	Classification	Reference					
31	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			
32	27k/D,0.1W	SMD 1005(mm)	Resistor	R1710	R1730				
33	62k/D,0.1W	SMD 1005(mm)	Resistor	R1712	R1732				
34	680k/D,0.1W	SMD 1005(mm)	Resistor	R1711	R1731				
35	1k,0.1W	SMD 1005(mm)	Resistor	R1112	R1212	R1312	R1412	R1512	R1612
				R1113	R1213	R1313	R1413	R1513	R1613
36	3k,0.1W	SMD 1005(mm)	Resistor	R1110	R1210	R1310	R1410	R1510	R1610
37	4.7k,0.1W	SMD 1005(mm)	Resistor	R2102	R2202	R2302	R2402	R2502	R2602
38	10k,0.1W	SMD 1005(mm)	Resistor	R1137	R1237	R1337	R1437	R1537	R1637
				R1733	R2710				
39	100k,0.1W	SMD 1005(mm)	Resistor	R4102	R4202	R4302	R4402	R4502	R4602
				R1734					
40	0R,2A	SMD 1608(mm)	Resistor	R1116	R1216	R1316	R1416	R1516	R1616
				R1701	R1721				
41	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. 32, 27k/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	Package type (JEDEC)	Classification	Reference					
42	3,0.25W	SMD 1608(mm)	Resistor	R1131	R1231	R1331	R1431	R1531	R1631
43	5.6/D,0.25W	SMD 1608(mm)	Resistor	R1119 R1120 R1123 R1124	R1219 R1220 R1223 R1224	R1319 R1320 R1323 R1324	R1419 R1420 R1423 R1424	R1519 R1520 R1523 R1524	R1619 R1620 R1623 R1624
44	10,0.25W	SMD 1608(mm)	Resistor	R1127	R1227	R1327	R1427	R1527	R1627
45	20,0.25W	SMD 1608(mm)	Resistor	R1128	R1228	R1328	R1428	R1528	R1628
46	47/D,0.25W	SMD 1608(mm)	Resistor	R1118 R4101	R1218 R4201	R1318 R4301	R1418 R4401	R1518 R4501	R1618 R4601
47	82/D,0.25W	SMD 1608(mm)	Resistor	R1117	R1217	R1317	R1417	R1517	R1617
48	2.7k,0.25W	SMD 1608(mm)	Resistor	R1114 R1115 R1138	R1214 R1215 R1238	R1314 R1315 R1338	R1414 R1415 R1438	R1514 R1515 R1538	R1614 R1615 R1638
49	18k/D,0.25W	SMD 1608(mm)	Resistor	R1103	R1203	R1303	R1403	R1503	R1603
50	1M/D,0.25W	SMD 1608(mm)	Resistor	R1702 R1708 R1726	R1703 R1709 R1727	R1704 R1722 R1728	R1705 R1723 R1729	R1706 R1724	R1707 R1725
51	220,0.2W	SMD 1005(mm)	Resistor	R2103	R2203	R2303	R2403	R2503	R2603
52	3.6k,0.2W	SMD 1005(mm)	Resistor	R2101	R2201	R2301	R2401	R2501	R2601
53	LY20-26P-DT1-P1E JAE	26pin	Connector for interface	CN1					
54	PM-80 Mac8	5pin	Socket pin	TP1101-5	TP1201-5	TP1301-5	TP1401-5	TP1501-5	TP1601-5

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

No	Value / Device	Package type (JEDEC)	Classification	Reference					
1		1005R		R2711					
2		1608R		R1101 R1121 R1122 R1125 R1126 R1135	R1201 R1221 R1222 R1225 R1226 R1235	R1301 R1321 R1322 R1325 R1326 R1335	R1401 R1421 R1422 R1425 R1426 R1435	R1501 R1521 R1522 R1525 R1526 R1535	R1601 R1621 R1622 R1625 R1626 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
6	50V,100pF,CH	SMD 1608(mm)	Capacitor	C1102	C1202	C1302	C1402	C1502	C1602

Chapter 8 Sense IGBT Performance

1. Scope

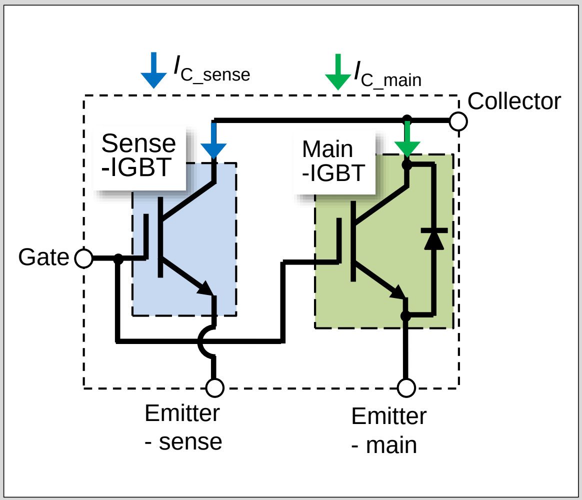
This chapter is explaining about a sense IGBT (Insulated Gate Bipolar Transistor) performance.
Shown typical value and the tendency in this material have been obtained by certain IGBT and test setup.
So the data in this material does not limit usage of the IGBT and the data are just reference of the outline of the sense IGBT.
★Since the driver IC revision differs with respect to the below explanation for the sense IGBT function and the content of the explanation provided for the evaluation board in Chapter 7, there may be differences in certain values such as the threshold voltage, but please understand that these values are only given as references to explain product operation.

2. Function

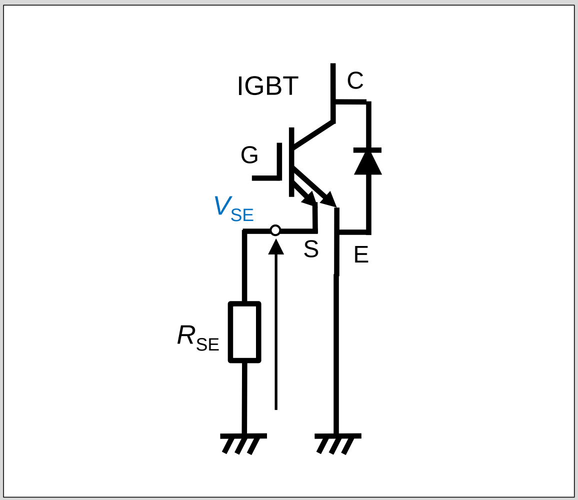
The function of the sense-IGBT is to detect overcurrent like Short-Circuit (SC) in the IGBT.
As showing in the Fig. 8-1, the sense IGBT is included in the same IGBT chip.
I_{C_sense} value is following I_{C_main} and flows at a certain split flow ratio.

$I_{C\_sense} \propto I_{C\_main}$ --- 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 recommended as 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 15V,
   V_{SE} value should be under 15V, at least.
3) Based on above trade-off and including safety margin, 120Ω of R_{SE} is recommended for Short-circuit current detection resistance.

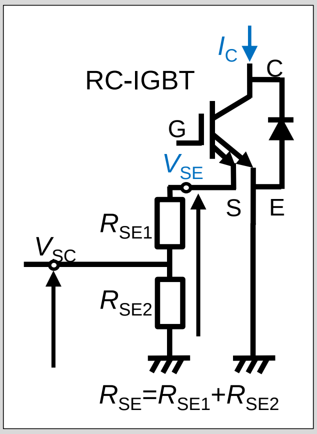
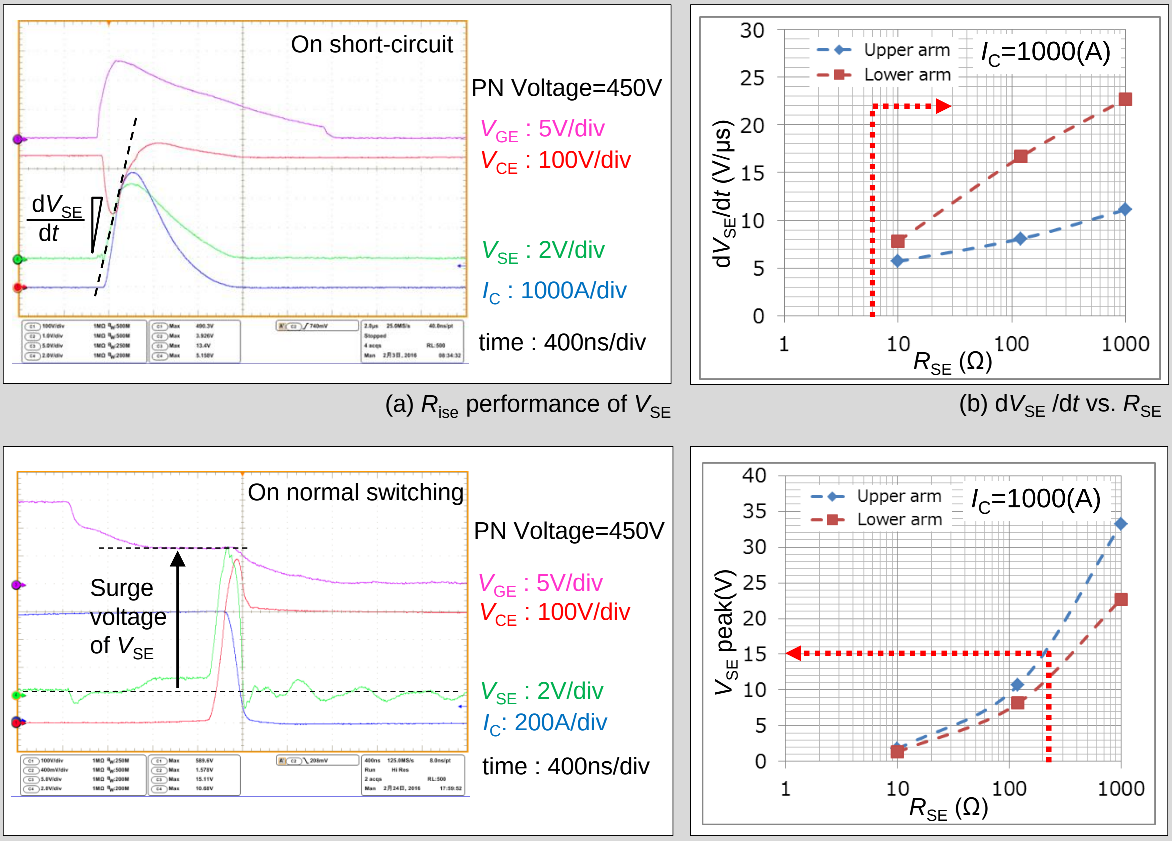


Fig. 8-2 V_{SE} and R_{SE}

*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) R_{ise} 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 200A
- T_{vj} = -40, 25, 125, 175℃
- R_{SE} = 120Ω

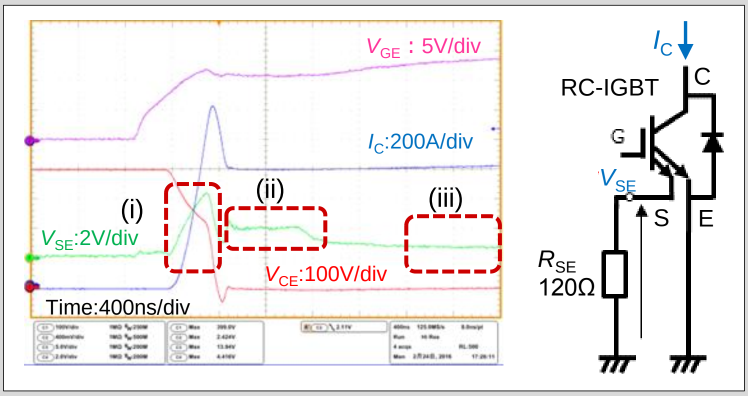
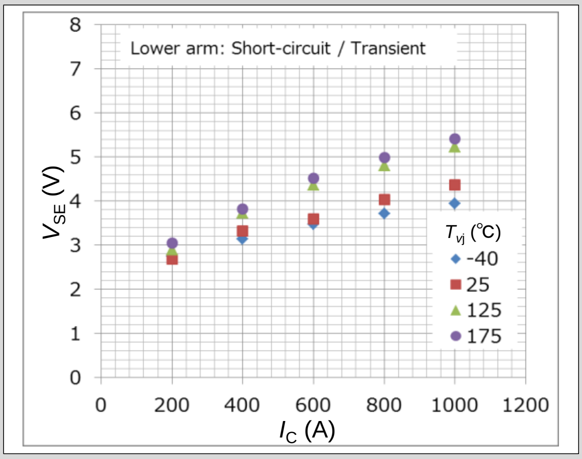
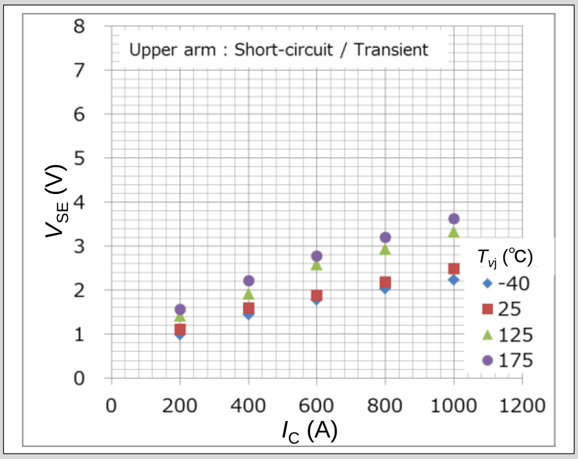


Fig. 8-4 V_{SE} on the switching waveform

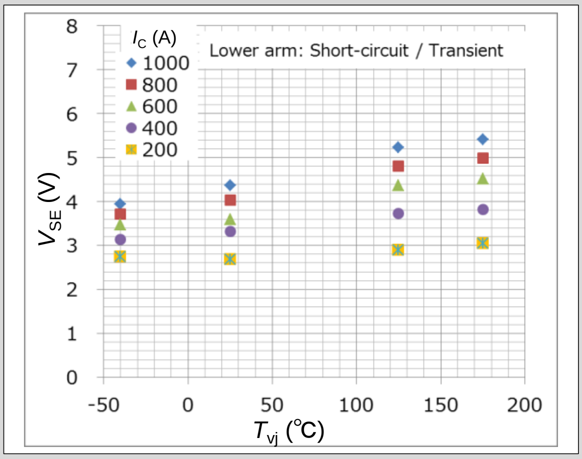
5. V_{SE} Dependence of I_C and T_{vj} : (i) Short-Circuit / Transient



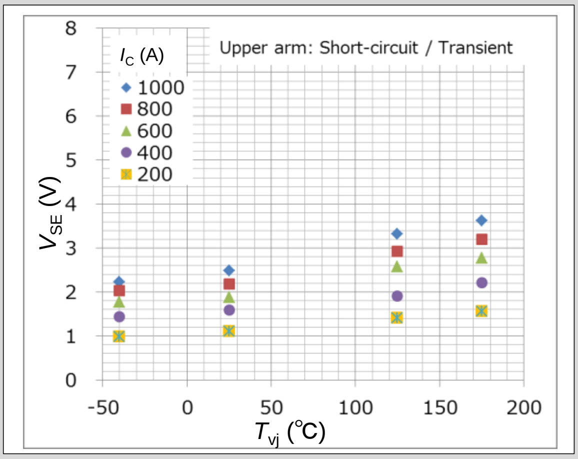
(a) V_{SE} vs. I_C: Lower arm



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



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



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

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

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

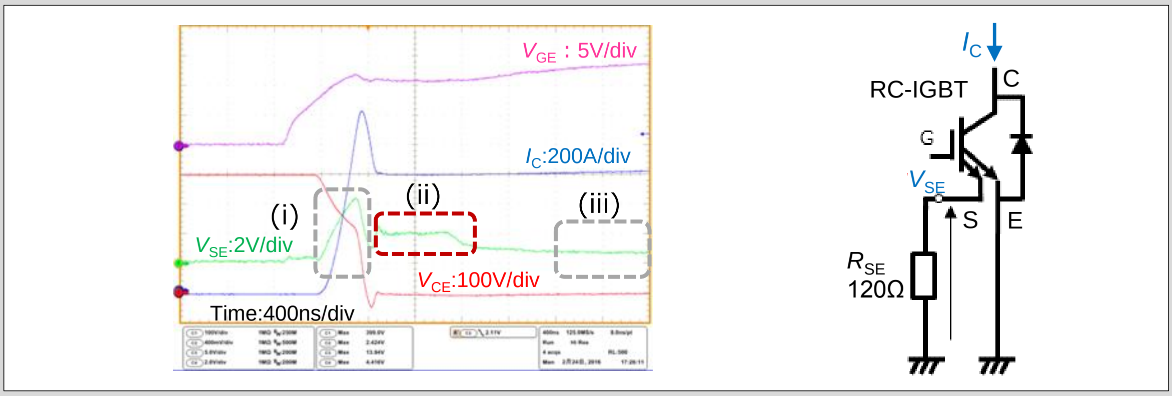
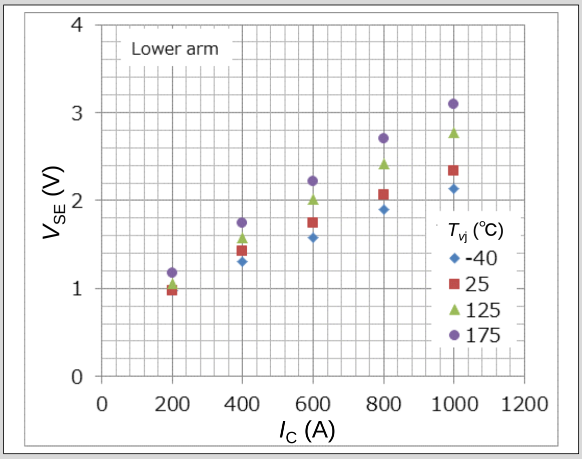
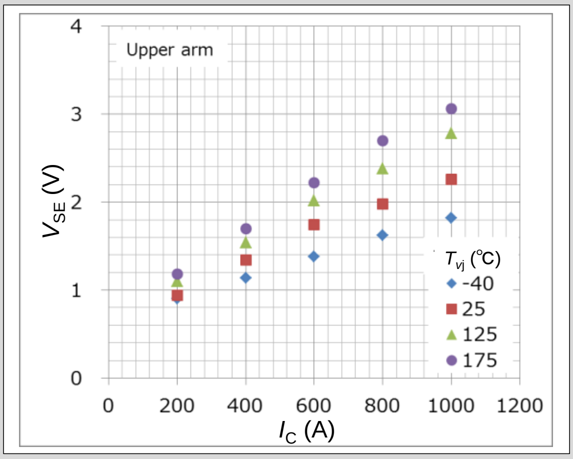


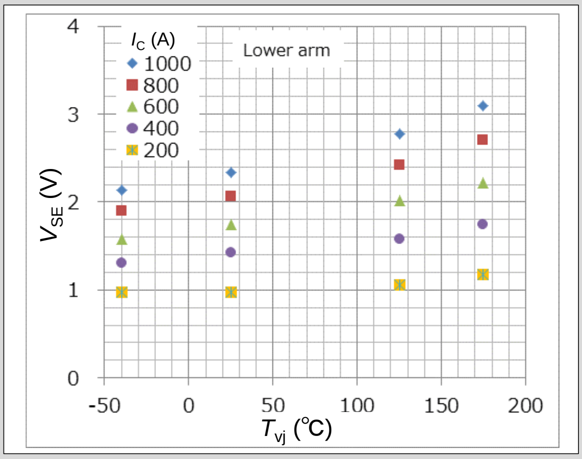
Fig. 8-6 V_{SE} on the switching waveform



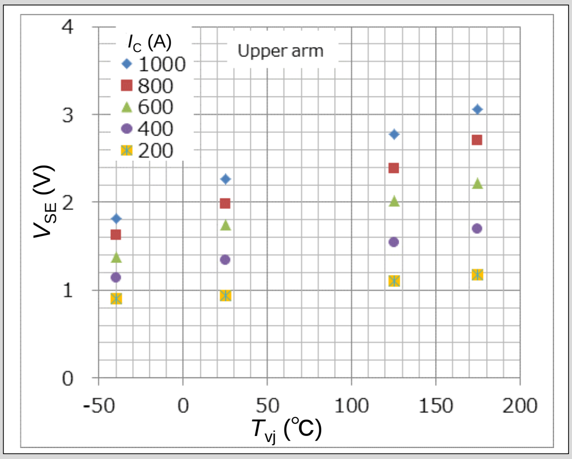
(a) V_{SE} vs. I_C: Lower arm



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



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



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

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

7. V_{SE} Dependence of I_C and T_{vj} : (iii) Over-current / Steady State

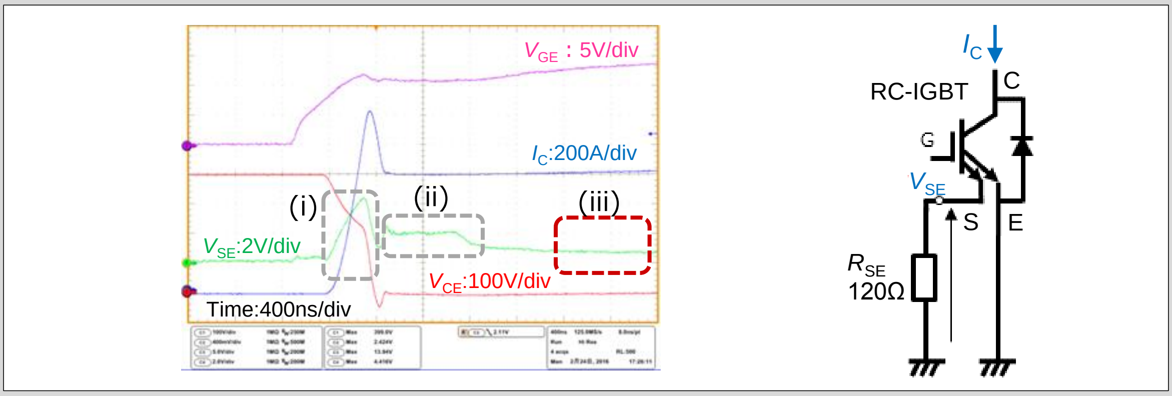
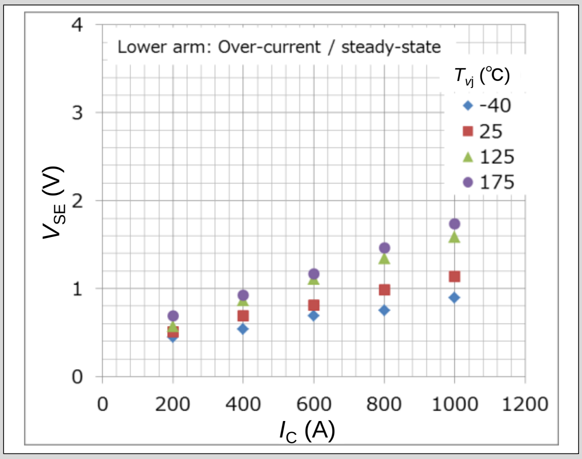
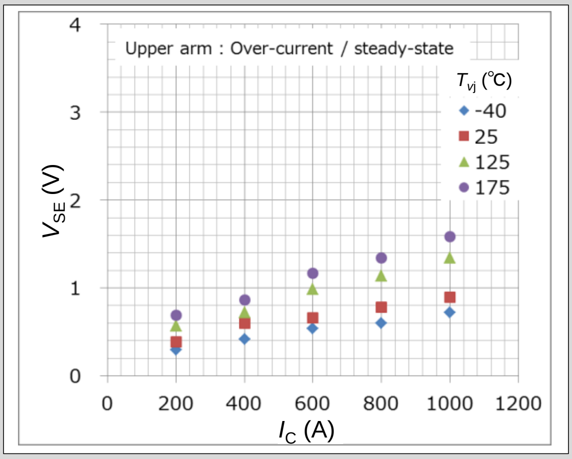


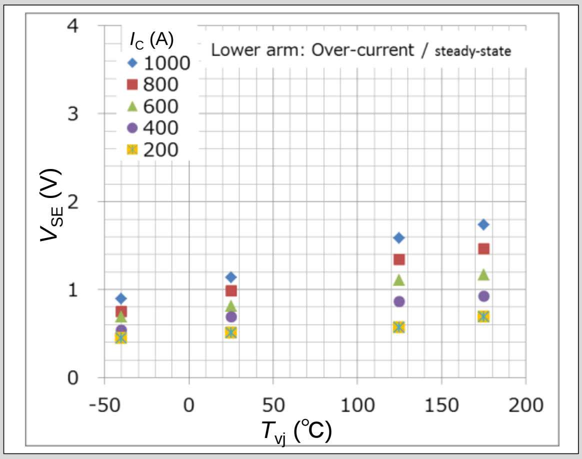
Fig. 8-8 V_{SE} on the switching waveform



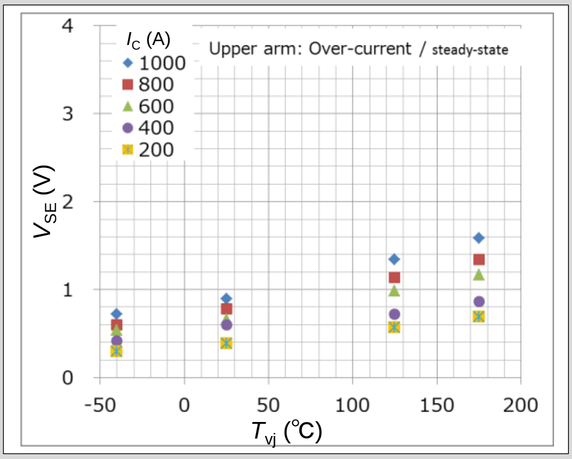
(a) V_{SE} vs. I_C: Lower arm



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



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



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

Fig. 8-9 Typical data example of V_{SE} characteristics on I_C and T_{vj} 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_{vj} operation temperature by certain R_{SE} and I_C conditions.
   Where, 120Ω 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 120Ω of R_{SE} and 800A of IC are used, typical example result: Line-1 is shown in Fig. 8-11.
   In this case, 25 to 175℃ of T_{vj} operation range are assumed.
2) Because V_{SE} value is proportional to T_{vj} , threshold level of V_{SE} is set by maximum operational temperature. → V_{SE} = 2.87@175℃ --- Line-2
3) On the other hand, V_{SC} level of ADuM4138 is 2V type.
   $V_{SC} = V_{SE} * R_{SE2} /(R_{SE1} + R_{SE2})$ --- eq.-1
   $R_{SE1} + R_{SE2} = 120$ --- eq.-2
   From eq.-1, eq.-2 and constants, R_{SE1} = 34.3Ω, R_{SE2} = 85.7Ω, respectively.
   Because E24 series resistor set were used, R_{SE1} =36Ω and R_{SE2} = 82Ω 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_{vj} shall be checked.
5) Then, the V_{SE} at SC on T_{vj} operation range are taken. --- Line-3
   This V_{SE} value is the peak value of the V_{SE} waveform at the short circuit shown in Fig. 8-3(a).
6) Line-2 never cross Line-3 on T_{vj} operation range is required condition in this setting.

*In the case of short-circuit protection function by using ADI driver IC, even if 12V 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 12V 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 2.87V on the part-(i), the soft turn-off function is not activated because the peak width is less than 800ns of delay time.

*1) ADI: Analog Devices, Inc.

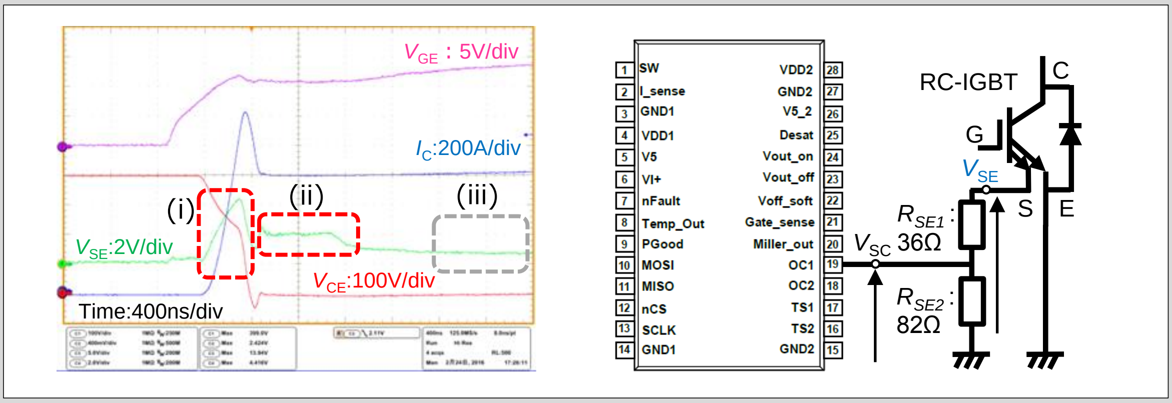


Fig. 8-10 Circuit diagram of SC protection by using ADuM1438

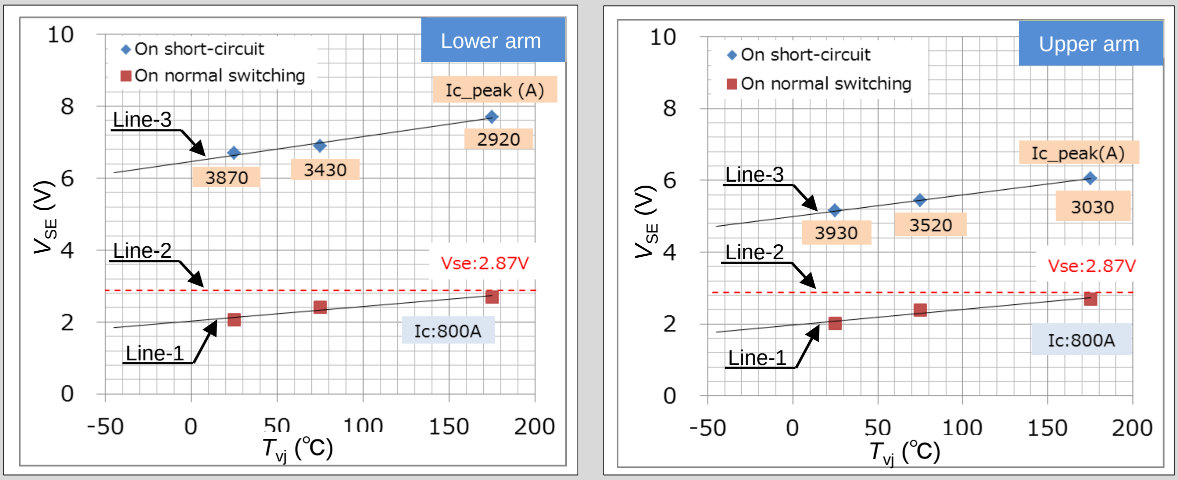


Fig. 8-11 SC protection function characteristics in terms of V_{SE}

Chapter 9 Temperature Sensing Function

1. Scope

This section will describe the temperature sensing function. It will also describe the details of applying the temperature sensing function during actual ADI-ADuM4138 usage, as well as provide details on the correction function and correction method for dealing with temperature sensing voltage fluctuation.

2. Function

The temperature sensing function is a function that detects the IGBT junction temperature T_{vj} . The temperature sensor is integrated on the same chip as the IGBT chip and outputs a temperature sensing voltage that corresponds to T_{vj} based on a constant current flow. The temperature sensing voltage is characterized by its linearity with the temperature, and as such, this characteristic makes it easy to achieve a T_{vj} monitoring function.

3. Temperature Sensing Characteristics

Fig. 9-1 shows the T_{vj} dependence for the temperature sensing voltage V_F when a constant current of 1 mA flows to the temperature sensor. Furthermore, Fig. 9-2 shows the dependence under a state in which the constant current fluctuates at 1 mA ±5%. In such a case, the temperature sensing voltage will fluctuate at ±11 mV.

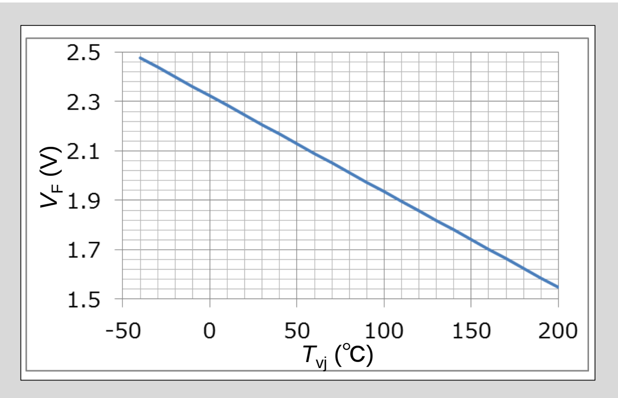


Fig. 9-1 V_F -T_{vj} dependence at I_F = 1 mA

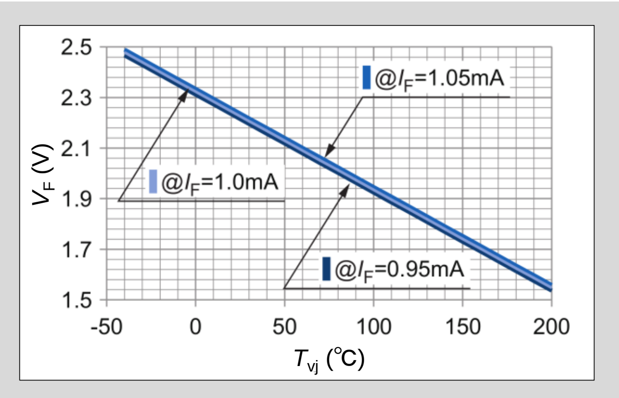


Fig. 9-2 V_F -T_{vj} dependence at I_F = 1±0.05 mA

* Note :

ADuM4138 I_F current specification: ±5% (at I_F = 1 mA)

→ Temperature diode V_F fluctuation at I_F = 1 mA ±5%: ±11 mV

4. Temperature Sensing Function when Using ADI-ADuM4138

The ADuM4138 has a function to supply a constant current to the temperature-voltage conversion sensor built in the IGBT chip and a function to convert the temperature information returned to the voltage into the duty cycle of the PWM signal.

Fig. 9-3 shows an example of the dependence of the duty cycle of the PWM signal on the temperature sense voltage of the ADuM4138.

From the V_F - T_{vj} characteristic shown in Fig. 9-1 and the Duty - V_F characteristic of Fig. 9-3, it is possible to finally obtain the duty cycle of the PWM signal corresponding to the junction temperature: T_{vj} of the IGBT chip.

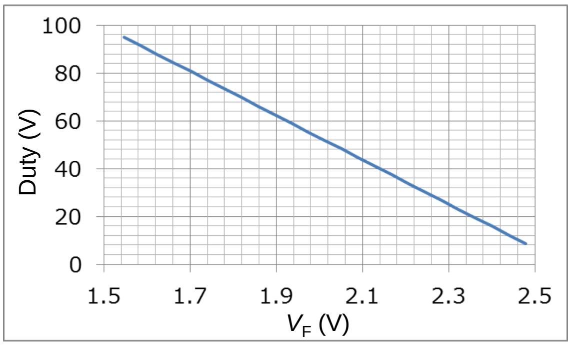


Fig. 9-3 PWM duty - V_F dependence

5. Temperature Sensing Correction Method for ADI-ADuM4138

As shown in Fig. 9-2, the temperature sense voltage output from the IGBT on-chip temperature sensor varies due to variations in the constant current input to the temperature sensor and temperature dependence of the temperature sensor itself. The ADuM4138 has a function to correct the PWM duty cycle output with respect to the temperature sense voltage to realize more accurate temperature sensing. This function corrects the dispersion by adjusting the gain and offset of the operational amplifier for temperature sense voltage detection built into the IC. The correction value can be written to the EEPROM by the SPI communication function.

The correction method will be explained below for your reference. (If you want to correct the PWM duty cycle output in actual product, please contact ADI for detailed correction method.)

5.1 Temperature sensor function correction overview

The correction method is outlined below.

1) Table 9-1 shows the relationship (specification) of junction temperature, temperature sense voltage, and PWM duty cycle.

Table 9-1 Default value of the circuit board parameters

Item	Specification *1)	
Junction temperature T_{vj}	25°C	175°C
Temperature sensing voltage V_F	2.23V	1.65V
PWM duty cycle D_{PWM}	30%	82%

*1) Refer to the specifications of the IGBT module and driver IC for the exact value

2) Get the current uncorrected characteristic data (junction temperature, PWM duty cycle).

3) Calculate the gain and offset value of the operational amplifier for temperature sense voltage detection built into the IC so as to correct the difference of the acquired characteristic data against the specification value. Fig. 9-4 shows the outline of the correction method.

4) Write the calculated gain and offset correction value to the EEPROM using the IC's SPI communication function.

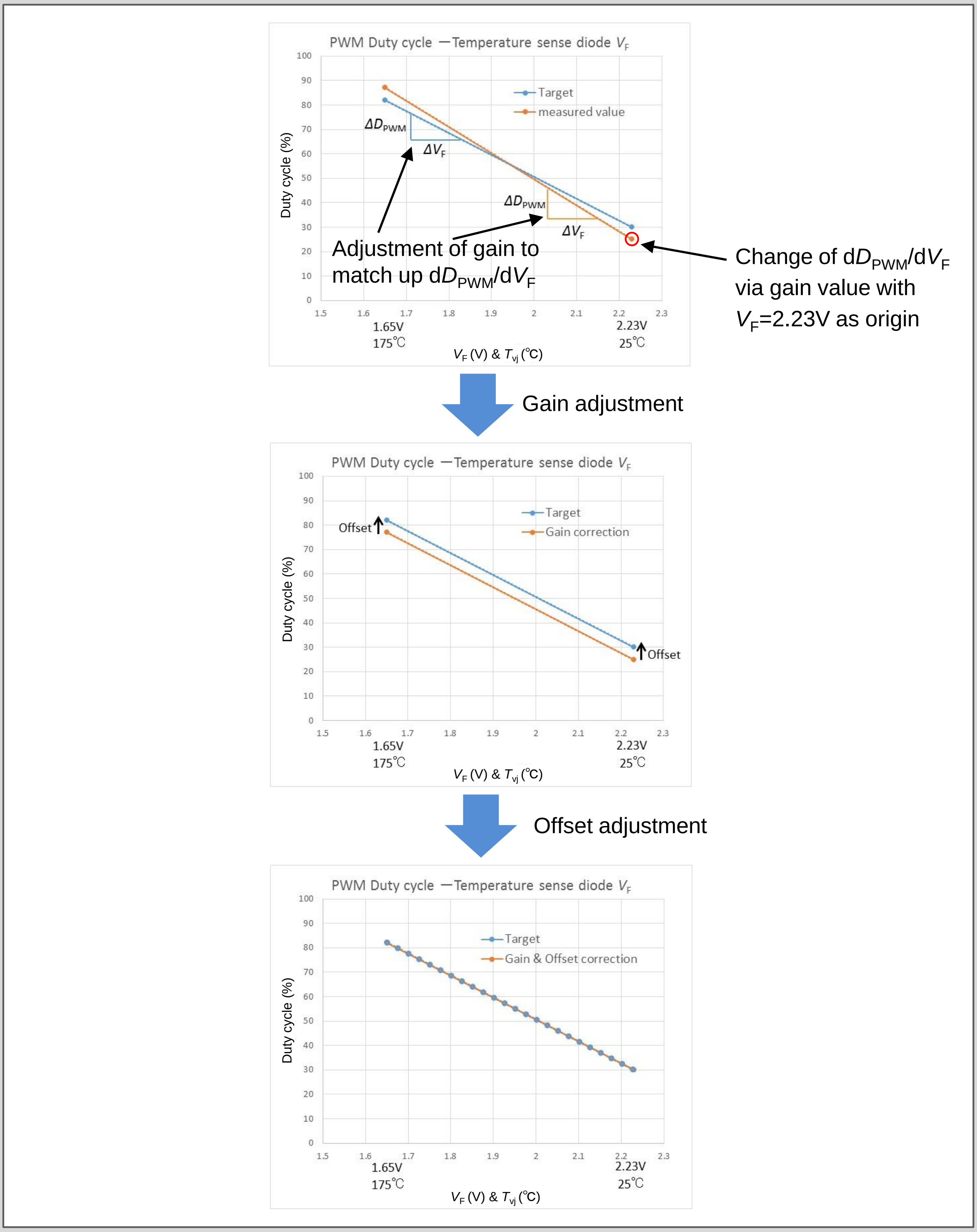


Fig. 9-4 Overview of correction method

5.2 Acquisition of characteristic data

In order to make corrections, it is necessary to acquire current characteristic data.

1) Measurement conditions

Please flow cooling water of a given temperature to the water jacket so that T_{vj} of the IGBT module is at the target temperature. For actual measurement, measurement is recommended after sufficient time has elapsed since the coolant flowed into the water jacket.

2) Measurement items

We recommend data measurement on the low temperature side and measurement at as high a temperature as possible up to 175℃ on the high temperature side. The more accurate the data acquisition in a wide range, the better the accuracy of correction.

Table 9-2 Measurement item

Measurement item	Measurement location	Measurement value	
Junction temperature T_{vj}	Temperature of cooling water and water jacket	Measurement value $T_{vj\ LOW}$	Measurement value $T_{vj\ HIGH}$
PWM duty cycle D_{PWM}	TEMP-U~W TEMP-X~Z	Measurement value D_{LOW}	Measurement value D_{HIGH}

5.3 Calculation of offset correction value

1) From the temperature sense related specification in Table 9-1, find the change amount of V_F with respect to the change of T_{vj} and the change amount of D_{PWM} with respect to the change of V_F.
   - $dV_F/dT_{vj\ spec} = (1.65V - 2.23V) / (175°C - 25°C) = -0.003867$ [V / °C]
   - $dD_{PWM}/dV_{F\ spec} = (82\% - 30\%) / (1.65V - 2.23V) = -89.655$ [% / V]
2) Calculate the change amount of D_{PWM} with respect to the change of T_{vj} before correction the measured values for temperature-PWM duty cycle in Table 9-2.
   - $dD_{PWM}/dT_{vj\ measured} = (D_{HIGH} - D_{LOW}) / (T_{vj\ HIGH} - T_{vj\ LOW})$ = -〇.〇[% / °C]
3) Calculate the estimated value of V_F at 25℃ and 175℃ input to the driver IC from the temperature - PWM duty cycle measurement value.
   - $V_{F\ 25C} = 1 / (dD_{PWM}/dV_{F\ spec}) \times (dD_{PWM}/dT_{vj\ measured} \times (25°C - T_{vj\ HIGH}) + D_{HIGH} - 30\%) + 2.23V$
   - $V_{F\ 175C} = 1 / (dD_{PWM}/dV_{F\ spec}) \times (dD_{PWM}/dT_{vj\ measured} \times (175°C - T_{vj\ HIGH}) + D_{HIGH} - 30\%) + 2.23V$

4) Calculate the offset correction value. Calculate the correction amount so as to correct the difference between the estimated value $V_{F\ 25C}$ of the temperature sensor voltage at 25℃ and the reference value of 2.23V.

- ± offset correction value = **(**$V_{F\ 25C}$ - 2.23V**)** / dV_{OFFSET}/bit
  ★dV_{OFFSET}/bit : Offset correction coefficient = 0.0015

- Process the calculated offset correction value as an integer.
  ★However, since this driver IC has a 6-bit correction bit for offset correction, the range of + offset correction value is 0 to 31, and the range of offset correction value is -1 to -32. Correction is not possible when exceeding this range.

5) Calculate the write value to the EEPROM from the offset correction value.

Table 9-3 Calculation of the offset value to write to the EEPROM

Content	Conversion to binary number
When the integerization offset correction value is positive (+)	Directly convert the positive integerization offset correction value (decimal) to a binary number
When the integerization offset correction value is negative (-)	First calculate 64 + (the negative integerization offset correction value (decimal)), and then convert it to a binary number

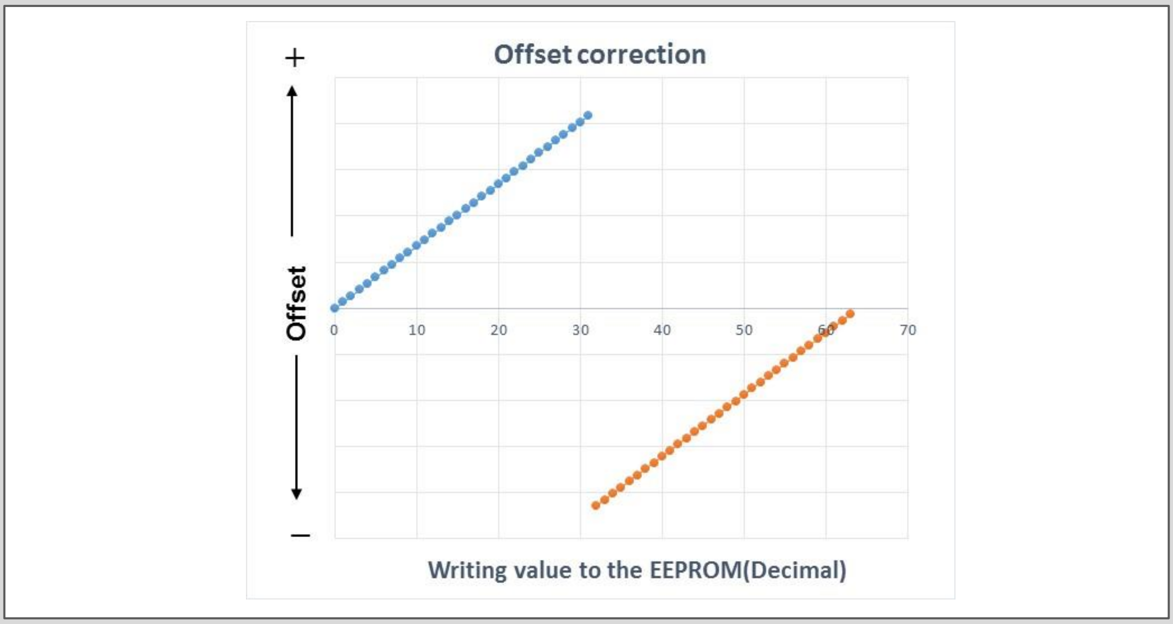


Fig. 9-5 EEPROM write value and offset correction

5.4 Calculation of gain correction value

1) Calculate the gain correction value. Calculate the correction amount so as to correct the difference between the estimated value of the V_F change amount and the specification value with respect to the change of T_{vj} (25℃ to 175℃) calculated from the temperature-PWM duty cycle measurement value.

- ± gain correction value = **(**1 - **(**$V_{F\ 175C}$ - $V_{F\ 25C}$**)** / **(**175°C - 25°C **)** / dV_F/d$T_{vj\ spec}$**)** / dV_{GAIN}/bit
  - ★ dV_{GAIN}/bit : Gain correction coefficient = 0.00618

- Calculate the gain correction value as an integer.
  - ★ However, since this driver IC has a 6-bit correction bit for gain correction, the range of + gain correction value is 0 to 31, and the range of gain correction value is -1 to -32. Correction is not possible when exceeding this range.

2) Calculate the write value to the EEPROM from the gain correction value.

Table 9-4 Calculation of the gain value to write to the EEPROM

Content	Conversion to binary number
When the integerization gain correction value is positive (+)	Directly convert the positive integerization gain correction value (decimal) to a binary number
When the integerization gain correction value is negative (-)	First calculate 64 + (the negative integerization gain correction value (decimal)), and then convert it to a binary number

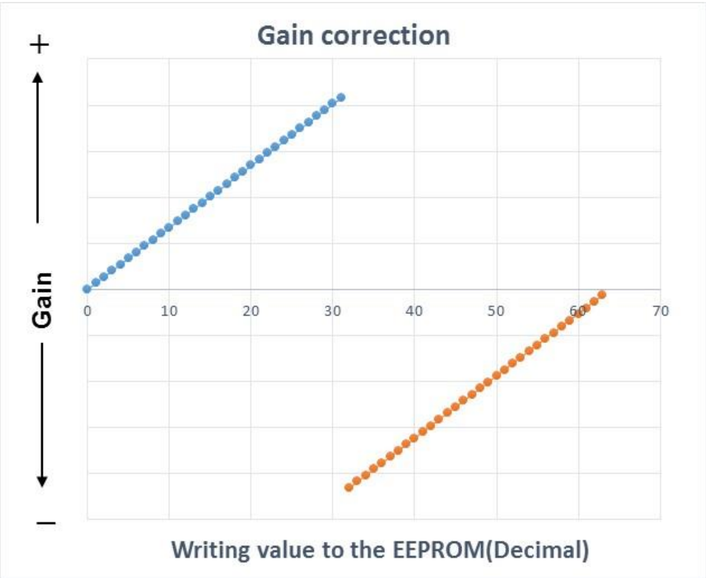


Fig. 9-6 EEPROM write value and gain correction

5.5 Writing data to EEPROM of ADuM4138

In fact, in order to actually write data to the EEPROM in the IC using the SPI communication function of the ADuM4138, it is necessary to have SPI communication module and writing software to connect between PC and IC terminals.

For more information, please contact Analog Devices.

5.6 Example of actual calculation

1) From the temperature sense related specifications in Table 9-1, find the change amount of V_F with respect to the change of T_{vj} and the change amount of D_{PWM} with respect to the change of V_F.
   - $dV_F/dT_{vj\ spec}$ = (1.65V - 2.23V) / (175°C - 25°C) = -0.003867 [V / °C]
   - $dD_{PWM}/dV_{F\ spec}$ = (82% - 30%) / (1.65V - 2.23V) = -89.655 [% / V]

2) Calculate the amount of change in D_{PWM} relative to the change in T_{vj} before correction from the measured temperature-PWM duty cycle in Table 9-5.

Table 9-5 Example measurements

Measurement item	Measurement value	
Junction temperature T_{vj}	28°C ($T_{vj\ LOW}$)	65°C ($T_{vj\ HIGH}$)
PWM duty cycle D_{PWM}	29.37% (D_{LOW})	43.75% (D_{HIGH})

   - $dD_{PWM}/dT_{vj\ measured}$ = (D_{HIGH} - D_{LOW}) / ($T_{vj\ HIGH}$ - $T_{vj\ LOW}$)
     = (43.75% - 29.37%) / (65°C - 28°C)
     = 0.3886 [% / °C]

3) Calculate the estimated value of V_F at 25℃ and 175℃ input to the driver IC from the temperature - PWM duty cycle measurement value.
   - $V_{F\ 25C}$ = 1 / ($dD_{PWM}/dV_{F\ spec}$) × ($dD_{PWM}/dT_{vj\ measured}$ × (25°C - $T_{vj\ HIGH}$) + D_{HIGH} - 30%) + 2.23V
     = 1 / (-89.655 [% / V]) × (0.3886 [% / °C] × (25°C - 65°C) + 43.75% - 30%) + 2.23V
     = 2.250V
   - $V_{F\ 175C}$ = 1 / ($dD_{PWM}/dV_{F\ spec}$) × ($dD_{PWM}/dT_{vj\ measured}$ × (175°C - $T_{vj\ HIGH}$) + D_{HIGH} - 30%) + 2.23V
     = 1 / (-89.655 [% / V]) × (0.3886 [% / °C] × (175°C - 65°C) + 43.75% - 30%) + 2.23V
     = 1.600V

4) Calculate the offset correction value. Calculate the correction amount so as to correct the difference between the estimated value $V_{F\ 25C}$ of the temperature sensor voltage at 25℃ and the reference value of 2.23V.
   - ± offset correction value = ($V_{F\ 25C}$ - 2.23V) / dV_{OFFSET}/bit
     = (2.250V - 2.23V) / 0.0015
     = 13.33

   ★dV_{OFFSET}/bit : Offset correction coefficient = 0.0015

   - Calculate the offset correction value as an integer.
     Integerized offset correction value = 13

5) Calculate the write value to the EEPROM from the offset correction value.
   - + Integerization offset correction value (decimal number) = + 13
     ⇒ EEPROM write value = 13(DEC) = 001101(BIN)

6) Calculate the gain correction value. Calculate the correction amount so as to correct the difference between the estimated value of the V_F change amount and the specification value with respect to the change of T_{vj} (25℃ to 175℃) calculated from the temperature-PWM duty cycle measurement value.

- ± gain correction value = **(**1 - **(**$V_{F\ 175C}$ - $V_{F\ 25C}$**)** / **(**175°C - 25°C**)** / dV_F/d$T_{vj\ spec}$**)** / dV_{GAIN}/bit
  = **(**1 - **(**1.600V - 2.250V**)** / **(**175°C - 25°C**)** / - 0.003867 [V / °C]**)** / 0.00618
  = -19.51

  ★ dV_{GAIN}/bit : Gain correction coefficient = 0.00618

- Calculate the gain correction value as an integer.
  Integerized gain correction value = -20

7) Calculate the write value to the EEPROM from the gain correction value.

- **-** Integerization gain correction value (decimal number) = **-** 20
  ⇒ EEPROM write value = 64 + (-20) = 44(DEC) = 101100(BIN)

Chapter 10 Parallel Connections

This chapter explains the notes when IGBT is connected in parallel.

IGBTs would be connected in parallel in order to enlarge the current capability. In this case, the number of parallel-connected modules has no limitation. However you have to consider some disadvantages of noise or spike voltage increase, which are caused by longer interconnections. You have to pay attention to the following basic notes when connecting IGBT modules in parallel.

(1) Suppression of current imbalance at steady states
(2) Suppression of current imbalance at dynamic state of turn-on or turn-on
(3) Symmetry of gate drive circuit
(4) Strict observance of specifications such as water flow, water temperature and pressure within each water jacket

1. Current Imbalance at Steady State

An on-state current imbalance may be mainly caused by the following two factors:
(1) $V_{CE(sat)}$ distribution
(2) Main circuit wiring resistance distribution

1.1 Current imbalance caused by $V_{CE(sat)}$ distribution

As shown in Fig. 10-1, a difference in the output characteristics of two IGBT modules connected in parallel can cause a current imbalance.

The output characteristics of Q_1 and Q_2 shown in Fig. 10-1, can be approximated as follows:

$$V_{CEQ1} = V_{01} + r_1 \times I_{C1}$$
$$r_1 = V_1/(I_{C1} \_ I_{C2})$$

$$V_{CEQ2} = V_{02} + r_2 \times I_{C2}$$
$$r_2 = V_2/(I_{C1} \_ I_{C2})$$

Based on the above, if the I_{ctotal} ($=I_{C1}+I_{C2}$) collector current is made to flow through the circuit of Q_1 and Q_2 connected in parallel, then the IGBT's collector current becomes the following:

$$I_{C1} = (V_{02} - V_{01} + r_2 \times I_{Ctotal})/(r_1+r_2)$$
$$I_{C2} = (V_{01} - V_{02} + r_1 \times I_{Ctotal})/(r_1+r_2)$$

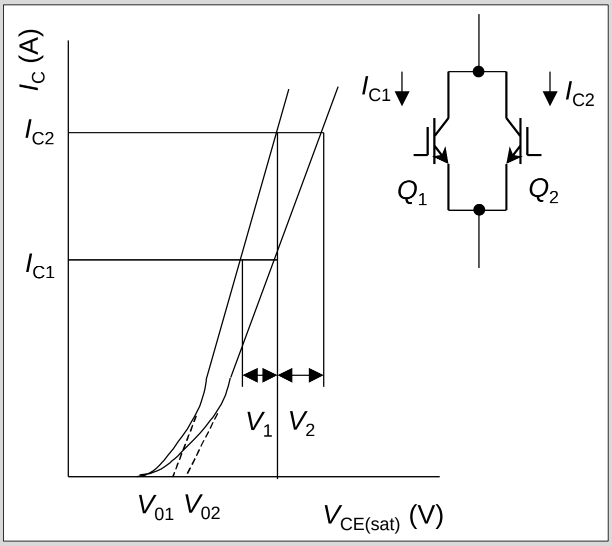


Fig. 10-1 Example of a $V_{CE(sat)}$ pair

For simplicity, assuming $V_{01}=V_{02}$ in the above equations, I_{C1} could be r_2/r_1 times larger than I_{C2}. Also, it can be seen from Fig. 10-1 that r2> r1.This result means that current sharing for Q_1 is larger than Q_2.

In this way, $V_{CE(sat)}$ becomes a major factor in causing current imbalances. Therefore, in order to ensure the desired current sharing it is necessary to pair modules that have a similar $V_{CE(sat)}$ which is small variation. $V_{CE(sat)}$ distribution can be minimized with the use of the same production lot, because influence of fabrication processes is minimized. From this reason, connecting IGBT modules in parallel is recommended with the use of the same production lot.

1.2 Current imbalance by main circuit wiring resistance distribution

The equivalent circuit with the main circuit's wiring resistance is shown in Fig. 10-2. The effect is larger with emitter resistance than with collector resistance, so collector resistance has been omitted here. If there is resistance in the main circuit as shown in Fig. 10-2, then the slope of the IGBT modules' output characteristics will lessen, and the collector current will drop in comparison without emitter resistance. In addition, if $R_{E1}>R_{E2}$, then the slope of the Q_1 output characteristics will lessen and if $I_{C1}<I_{C2}$ then a current sharing imbalance will appear. Moreover, if gate voltage is applied without extra-emitter terminals for parallel-connected IGBTs, the actual gate-emitter voltage drop ($V_{GE}=V_G – V_E$) will be decreased, because an electrical potential difference may appear, depending on how well the collector current can flow through this resistance. So, the IGBTs' output characteristics change and the collector current decline.

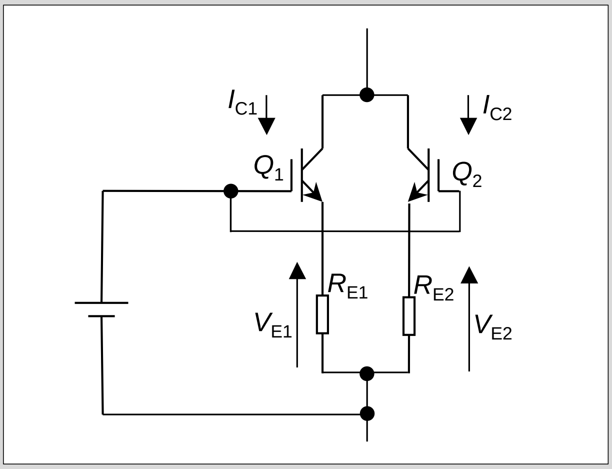


Fig. 10-2 The effect of main circuit wiring resistance

Therefore, in order to reduce this imbalance, it is necessary to make the wiring on the emitter side as short and as uniform as possible as well as to apply the gate voltage between gate terminal and additional emitter terminal.

1.3 T_{vj} dependence of output characteristics and current imbalance

T_{vj} dependency of output characteristics deeply affects current imbalance. Here, output characteristic, whose $V_{CE(sat)}$ is higher and lower with the increase of T_{vj}, is respectively defined as the positive and negative T_{vj} dependency. Fig. 10-3 shows the representative output waveform with negative and positive dependency, which are 100A rating. Collector current at the same V_{CE} is decreased as T_{vj} is increased in case of positive dependency.

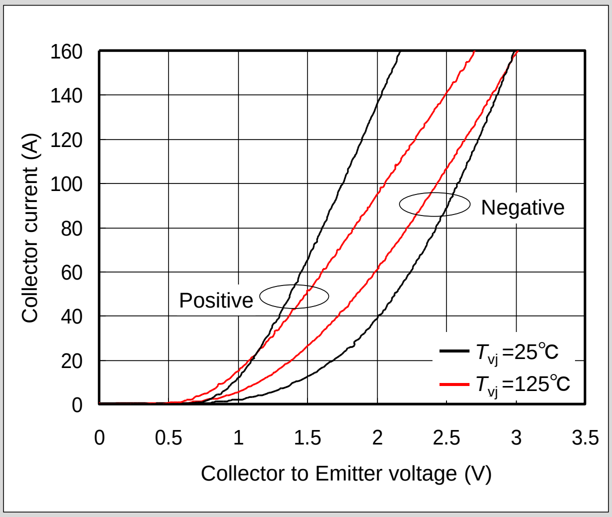


Fig. 10-3 Comparison output characteristics

As described 1.1, shared current of IGBT with lower $V_{CE(sat)}$ is larger at the parallel connecting. Therefore, steady-state loss is larger for IGBT with lower $V_{CE(sat)}$ than another to increase junction temperature. In this way, in case of positive dependency of IGBT, this leads to make shared current between them balanced. On the contrary, in case of negative dependency, current sharing is act as opposite work. Therefore, you need to pay attention to current imbalance in designing the machines or components. Selecting the IGBTs with the positive dependency of output characteristic is recommended when IGBTs are parallel-connected, because IGBTs with positive dependency of output characteristic are relatively easier to use for parallel connection of IGBTs than that with negative one. Please refer to the each series specification for details of T_{vj} dependency of output characteristic.

1.4 Deviation of $V_{CE(sat)}$ and current imbalance rate

Ratio of shared current in parallel connection is called as current imbalance rate, which is determined by deviation of $V_{CE(sat)}$ and T_{vj} dependency of output characteristic.

Fig. 10-4 shows the representative relationship between deviation of $V_{CE(sat)}$ and current imbalance rate. This figure is an example for 2 parallel connections of a series of IGBTs. From this figure, current imbalance rate is found to be larger as deviation of $V_{CE(sat)}$ is increased. Therefore, it is important to use IGBTs for parallel connection, whose deviation of $V_{CE(sat)}$ is small, that is, $\Delta V_{CE(sat)}$ is small.

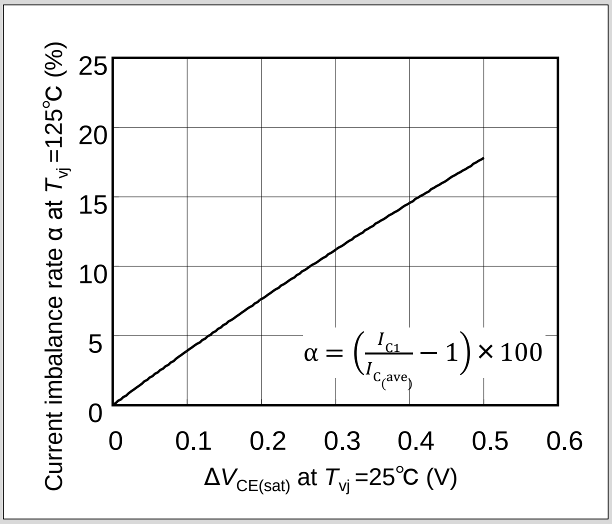


Fig. 10-4 Deviation of $V_{CE(sat)}$ and current imbalance rate

*Fig. 10-4 is an example of an IGBT series. In fact, when calculating the available maximum current (ΣI) for parallel connection, refer to the technical data for each IGBT series.

1.5 Derating in parallel connection using many numbers of IGBTs

Derating (Decrease of total current) is needed in consideration with current imbalance in parallel connection of IGBTs.

When n-number of modules are connected in parallel, the following shows the maximum current that can be applied under the worst case conditions where the entire current is concentrated into one module, whose $V_{CE(sat)}$ is the smallest. Therefore, available maximum current ΣI is expressed by a, which is connected in parallel using 2 modules:

$$\sum I = I_{C(max)}\left[1+(n-1)\frac{\left(1-\frac{\alpha}{100}\right)}{\left(1+\frac{\alpha}{100}\right)}\right] \qquad \alpha = \left(\frac{I_{C1}}{I_{C(ave)}} - 1\right) \times 100$$

Here $I_{C(max)}$ represents the maximum current for a single element, ΣI represents the maximum current in parallel connection. However, to operate in total current ΣI, each module connected in parallel is satisfied with the RBSOA on the specification, T_{vjmax} for dissipation wattage as well. Note especially that T_{vj} rise caused by dissipation wattage is various on the condition such as switching frequency, driving condition, cooling condition and snubber condition and so on.

For example, if α=15%, $I_{C(max)}$ =200A and n=4, then ΣI=643.4A, and the parallel connected total current should be set so as not to exceed this value. In this case, Derating of 19.6% is needed. In this way, the parallel connected total current is need to be derated for simply calculating n × $I_{C(max)}$.

Fig. 10-5 shows the derating rate for α=15%. It is found from this figurer that derating rate is increased as the parallel number n is larger. Therefore, derating the total current for parallel connection, depending on the parallel number n. in addition, note that derating rate is various by current imbalance rate.

Because derating rate for this example is a calculated value. It should be determined after confirmation and verification of imbalance current using designed machines.

If you need to change paralleled modules for troubles and/or maintenances, it is recommended that all the paralleled modules be exchanged. In this case, it is recommended that parallel connection be set up using IGBTs with the same production lots.

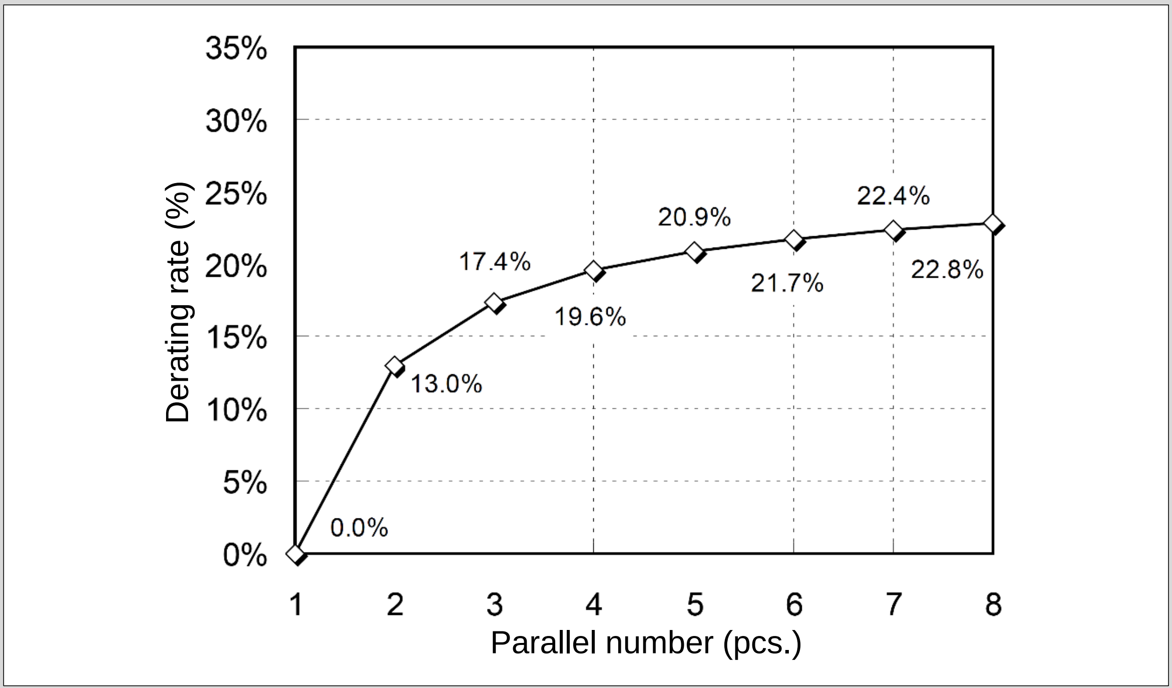


Fig. 10-5 Relationship between derating rate and parallel number

2. Current Imbalance at Switching

Current imbalance at switching may be mainly caused by the following two factors:

(1) Module characteristics distribution

(2) Main circuit wiring resistance distribution

2.1 Module characteristics distribution

An IGBTs' switching current imbalance, especially just before turn-off and after turn-on, is mostly determined by an on-state current imbalance, therefore if the on-state current imbalance is controlled simultaneously as shown previously, so will the switching voltage imbalance.

2.2 Main circuit wiring inductance distribution

Inhomogeneous main circuit wiring inductance caused current sharing. Fig. 10-6 shows the equivalent circuit at parallel connection in consideration with main circuit wiring inductance. When I_{C1} and I_{C2} flow through $IGBT_1$ and $IGBT_2$ respectively, shared currents for them are approximately decided by the ratio of main circuit wiring inductance, $L_{C1}+L_{E1}$ and $L_{C2}+L_{E2}$. So, main circuit wiring is need to be connected as equally as possible in order to relieve current imbalance at switching. However, even if ideal wiring inductance of $L_{C1}+L_{E1}=L_{C2}+L_{E2}$ is realized, the difference between L_{E1} and L_{E2} causes the current imbalance as described bellows.

Inhomogeneous inductance between L_{E1} and L_{E2} causes the different inductive voltage originated di/dt at turn-on. This difference between their inductive voltages affects current imbalance more, because it biases to different way to gate to emitter voltage.

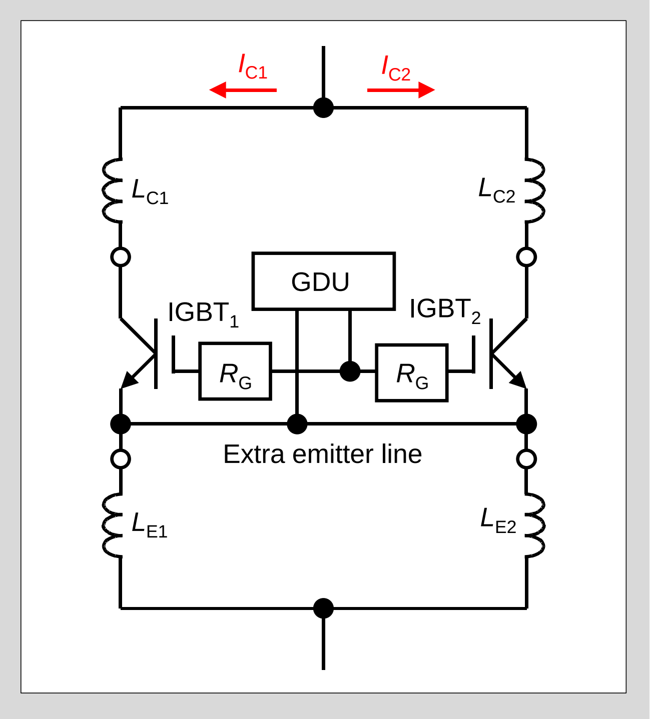


Fig. 10-6 Equivalent circuit at parallel connection in consideration with main circuit wiring inductance

If the inductance of the main circuit is large, then the spike voltage at IGBT turn-off will also be high. Therefore, for the purpose of reducing wiring induction, consider setting the modules that are to be connected in parallel as close together as possible and making the wiring as uniform as possible.

3. Gate Drive Circuit

It would be worried that duration until switching (turn-off or turn-on) is varied by the delay time of gate driving unit (GDU), when each gate of parallel-connected modules is driven by each GDU, separately independent on the number of modules. Therefore, it is recommended that all the gates are driven by just only a GDU, when connecting modules in parallel. This can lead the decrease of deviation for different duration until switching.

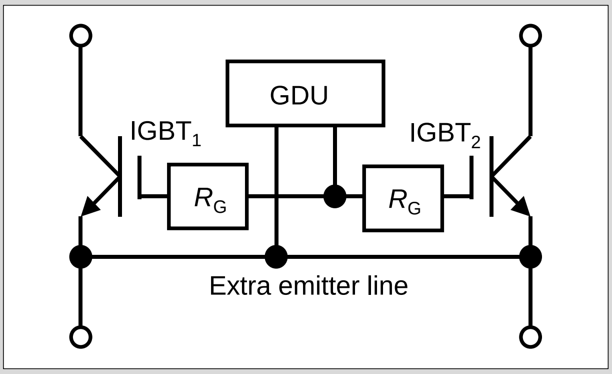


Fig. 10-7 wiring gate drive unit

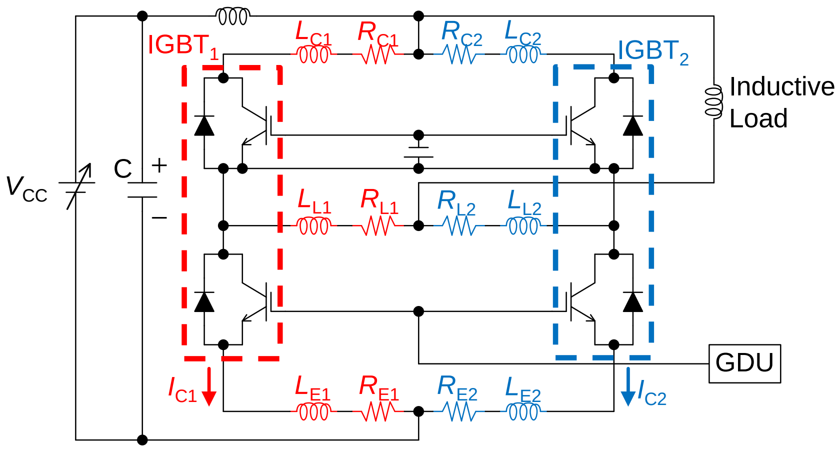
At the same time, connect gate resistances between gate terminal of each module and a GDU so as to avoid the gate voltage oscillation caused by coupling gate wiring inductance with input capacitance of IGBT as shown in Fig. 10-7.

As stated previously, if the drive circuit's emitter wiring is connected in a different position from the main circuit, then the modules' transient current sharing (especially at turn-on) will become imbalanced, because L_{E1} is different from L_{E2} as described in Fig. 10-6.

In general, IGBT modules have an auxiliary emitter terminal for use by drive circuits. By using this terminal, the drive wiring of each module becomes uniform, and transient current imbalances attribute to drive circuit wiring can be controlled. Furthermore, be sure to wind the drive circuit wiring tightly together, and lay it out so that it is as far away from the main circuit as possible in order to avoid mutual induction.

4. Wiring Example for Parallel Connections

As described before, pay attention in order to connect the modules in parallel. Fig. 10-8 shows the equivalent circuit with parallel-connected 2in1 modules. From this figure, it is found that all the wiring to parallel-connected IGBTs ($IGBT_1$ and $IGBT_2$) are connected symmetrically. This can realize the better current sharing.



(Make the wiring $R_{C1}=R_{C2}$, $R_{L1}=R_{L2}$, $R_{E1}=R_{E2}$, $L_{C1}=L_{C2}$, $L_{L1}=L_{L2}$, $L_{E1}=L_{E2}$)

Fig. 10-8 Equivalent circuit with parallel-connected 2in1 modules

5. Cooler

This IGBT module has the cooler with the water jacket. Even when IGBT modules are connected in parallel, please adhere strictly to the specifications of water temperature, water flow and pressure within each water jacket and fully confirm that there are no problems with the junction temperature etc. of each IGBT.