<IGBT module>

7th Generation T/T1 Series NX type / std type Application Note

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1. Features of the 7th Generation Module

In recent years, demand for industrial equipment such as general purpose inverters, elevators, uninterruptible power supply units (UPS), wind power / photovoltaic power generation, servo amplifiers and similar has been increasing more and more as the demand for more efficient energy use and longer life of equipment is increasing. In order to realize power consumption and high reliability, we developed "IGBT module T series (NX type, std type)" with the 7th generation IGBT and diode mounted and improved internal structure of the package. The T series realizes reduction of power loss, compact and lightweight package, rich lineup, simplification of assembly process of applied products.

1) Reduced power loss of the applied products

The 7th Generation chipset features new thinner IGBT chips and RFC diode chips (1200 V products, 1700V product). By adopting the 7th Generation chipset, it is possible to reduce the power loss of the applied products.

2) Compact and lightweight package with new package structure, rich lineup

In the 7th generation IGBT module, a new structure is adopted for NX and std type respectively. In the NX type, a resin-insulated copper baseplate with an insulating part and a base part integrated is adopted, and the solder between the insulating part and the base part which was necessary in the conventional product is not used. DP (Direct Potting) resin is used as an internal filler. In the std type, the internal structure of the main electrode is laminated and a thick copper-ceramic-copper base plate is adopted. Both NX and std types have low inductance that reduces by 30% compared to conventional models by optimizing the internal layout of the module. Both NX and std type offer an extensive line-up of 650V, 1200V and 1700V breakdown voltage.

3) Simplification of the assembly process of the applied products

Optional pre-applied phase change thermal interface material (PC-TIM) makes it possible to eliminate the grease coating process. In addition, the NX type offers optional press-fit pins to eliminate the soldering process to the control board. Thus, it is possible to simplify the assembly process of the applied products.

1.1. Features of the 7th Generation IGBT and Diode Chip

In order to realize the reduction of the on state loss and the switching loss leading to the improvement of the energy saving performance of the product, the 7^{th} generation charge storage type IGBT (CSTBT ™) and MOS (Metal Oxide Semiconductor) chip structure has been optimized using thinner wafers. The 7^{th} generation diode chip has been made with thinner wafer and has applied the RFC (Relaxed Field of Cathode) structure using backside diffusion layer formation technology.

※ CSTBT™: Our proprietary IGBT utilizing carrier accumulation effect
※ RFC diode: P layer is partially added on the cathode side, holes are injected at the time of recovery, and by making the recovery waveform soft the diode can suppress the rise of steep voltage

Reduction of on-voltage (V_{CEsat}) and turn-off loss (E_{off})

Figure 1-1 shows the trade-off characteristic comparison (1200 V withstand voltage) between the 7^{th} generation IGBT and the conventional 6^{th} generation with on-voltage (V_{CEsat}) and turn-off loss (E_{off}). The 7^{th} generation IGBT reduces the ON voltage by about 0.2 V and the turn-off loss by about 7% compared with the 6^{th} generation IGBT.

The IGBT chip improves the trade-off characteristic of this on-voltage and turn-off loss with every generation.
In the 7^{th} generation IGBT chip, this trade-off has been improved by making thinner wafers and optimizing the surface structure.

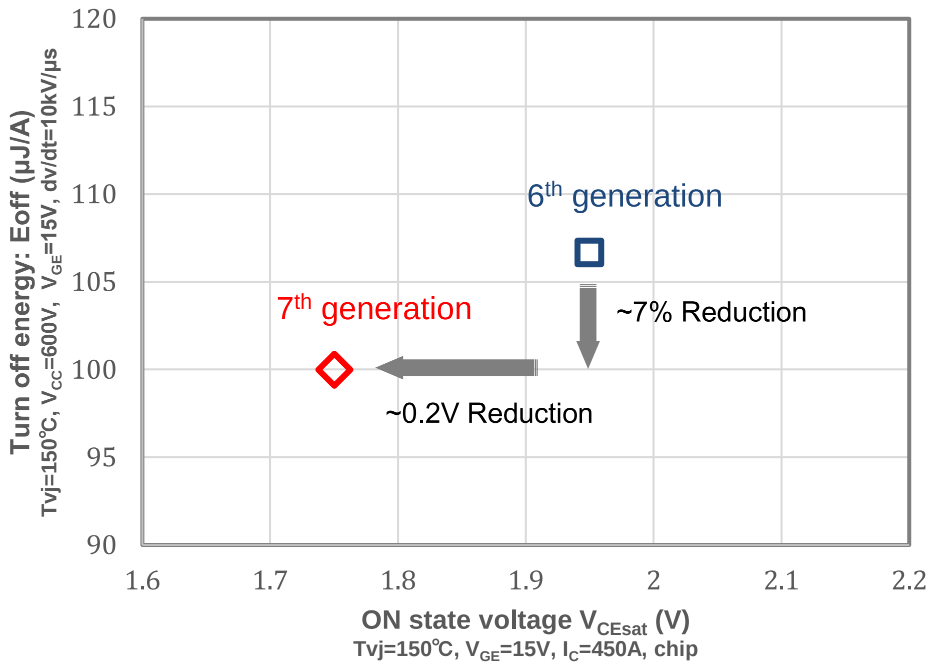


Figure 1-1. Tradeoff Comparison

Improved controllability of turn off loss (Eoff) and dv/dt (off) by R_G

The IGBT module can control the switching speed by changing the external gate resistance RG.
The 7th generation IGBT module improves the controllability of turn off loss (Eoff) and dv/dt (off) by this RG.

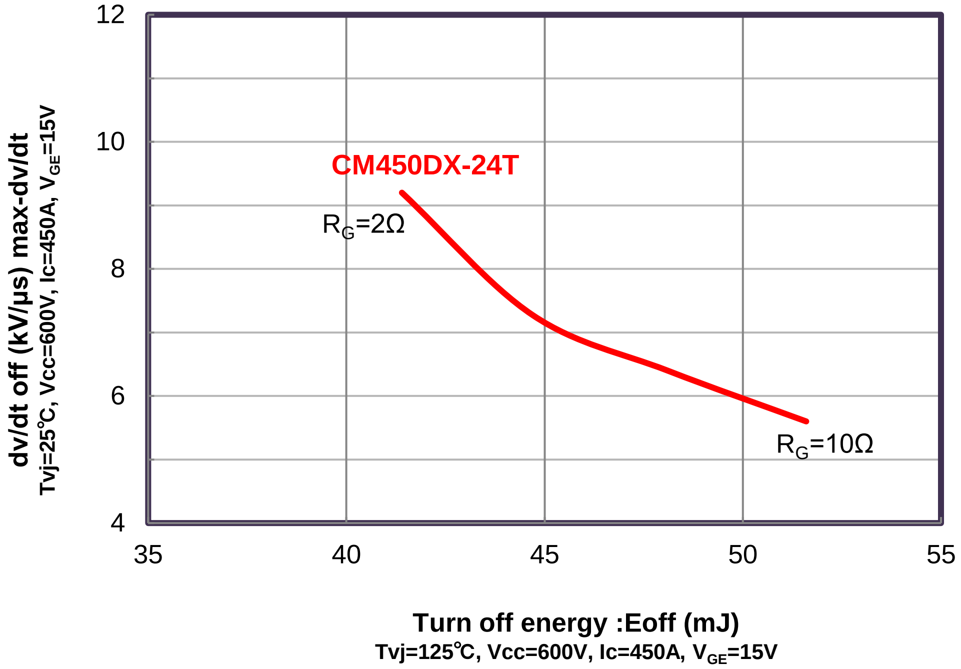


Figure 1-2. dv/dt off - Turn-off loss

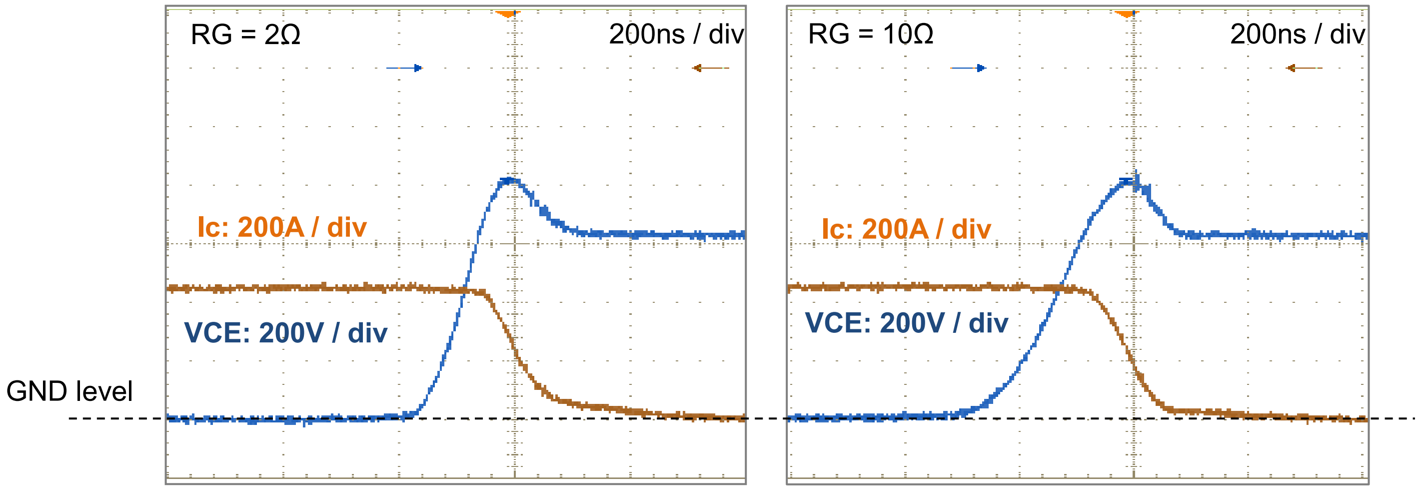
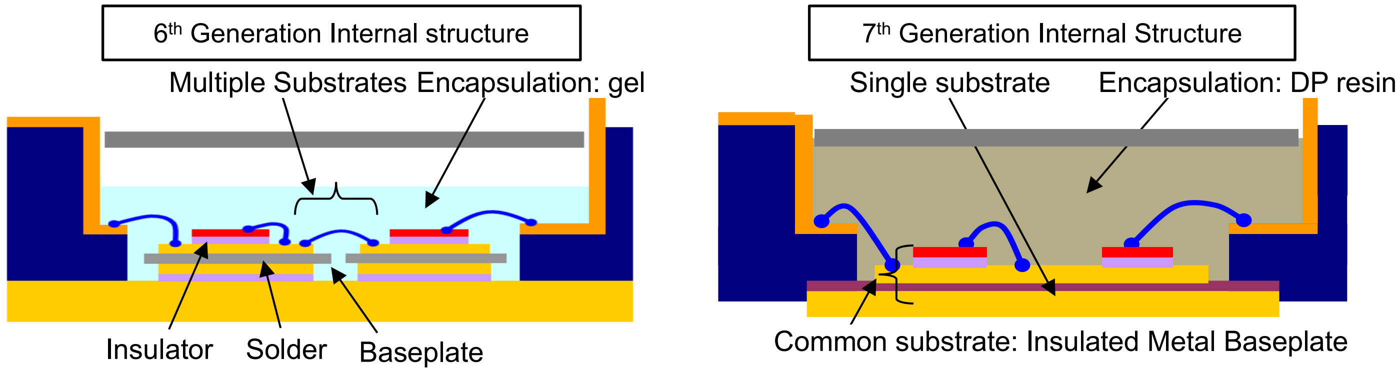


Figure 1-3. Turn-off waveforms (CM450DX-24T)

1.2. Packaging Technology

Package structure and features (NX type)



Item	6th Generation NX	7th Generation NX	Advantage
Internal inductance (ratio)	1	**0.7**	(L_s 30% Reduction)
Package size (W * D * H)	152 × 62 × 17 mm	**152 × 62 × 17 mm**	(Compatible package)
Weight※	350 g	**300 g**	(15% lighter)
Terminal shape	Soldering pins	**Soldering pins Press-fit pins**	(Assembly simplification)

※ Comparison between CM600DX-24T and CM600DX-24S1

- Internal structure of the 7th generation module (NX type)
  A resin insulated copper base board with an insulating part and a base part integrated is adopted, and the solder between the insulation part and the base part which was necessary in the conventional product is not used. In addition, DP resin is used instead of general gel for filler.

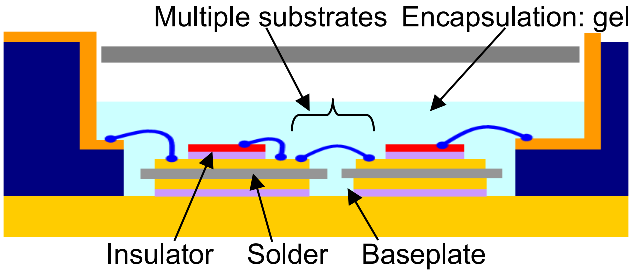
- Compatible and light weight package
  We adopted a conventional NX type compatible package and reduced the weight by 15% by a new internal structure. In addition, by increasing the thickness and width of the copper circuit pattern inside the module and by using an optimized single substrate structure instead of multiple conventional insulating substrates, the chip mounting area is expanded to improve the rated current in the same package.

- Press-fit pin compatible
  By applying press-fit terminals on the top of the module into the through holes of the control board, it is possible to connect all at once. This eliminates the need for soldering the module terminals to the control board through holes, thus simplifying the assembly process. For details, please refer to the application note for press-fit pins.

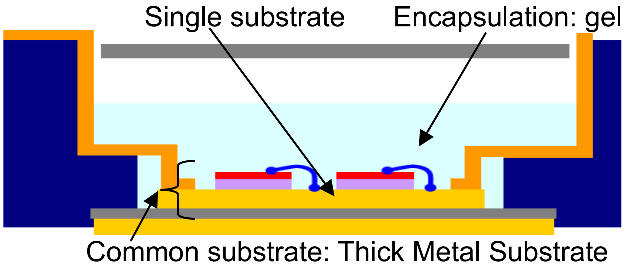
- PC-TIM (option)
  It is possible to eliminate grease application step by pre-application of PC-TIM (Phase Change Thermal Interface Material) to the back side of the product. For details, refer to the application note of PC-TIM.

Package structure and characteristics (std type)

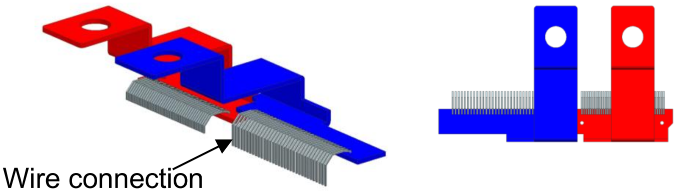
6th Generation Internal Structure



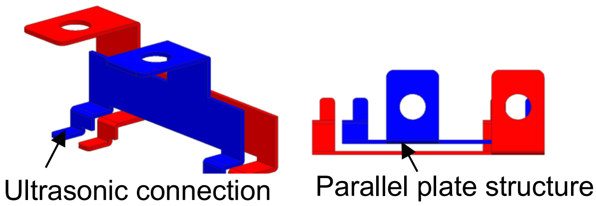
7th Generation Internal Structure



6th Generation Main Terminal Structure



7th Generation Main Terminal Structure



Item	6th Generation std	7th Generation std	Advantage
Internal inductance (ratio)	1	**0.7**	(L_s 30% Reduction)
Package size ※ (W * D * H)	110 × 80 × 29 mm	**108 × 62× 30mm**	(20% Footprint Reduction)
Weight※	580 g	**260 g**	(55% lighter)

※ Comparison with CM600DY-24S and CM600DY-24T

- Internal structure of the 7th generation module (std type)
  The 7th generation module adopted a thick copper-ceramic-copper baseplate without using solder between insulation part and baseplate which was necessary in conventional products. In addition, the ultrasonically (US) bonded terminal electrode is used as the main electrode instead of the conventional aluminum wire connection, and in some packages, the parallel plate structure is adopted.

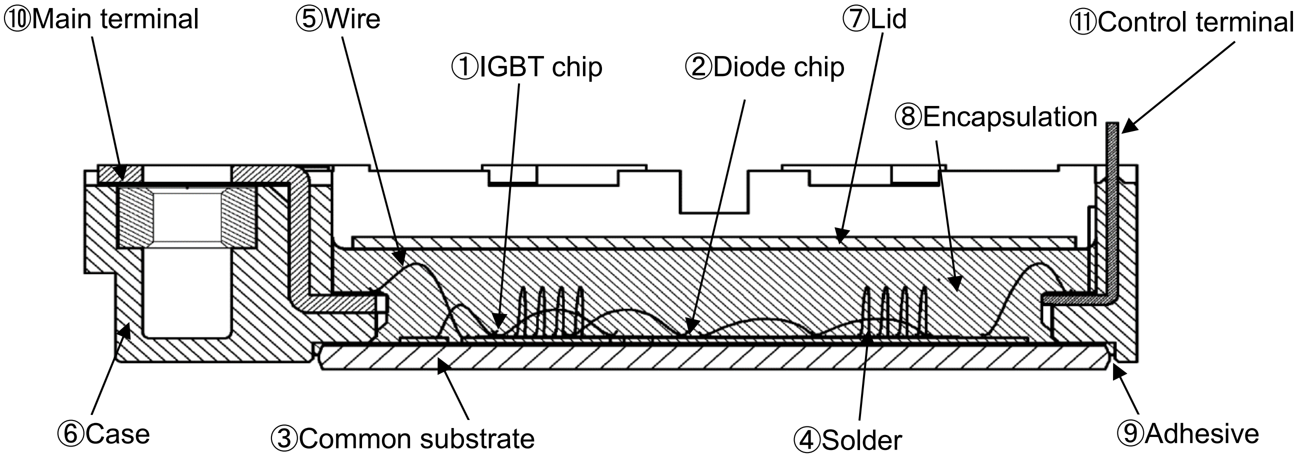
- Compact, lightweight package
  By adopting a single substrate structure and a US bonding technology, we have expanded the chip mounting area and improved the rated current in the same package. The 600A/1200V product, is replaced with a 20% smaller package size and the weight is reduced by 55% compared to the 6th generation.

- PC-TIM applicable (option)
  It is possible to eliminate grease application step by pre-application of PC-TIM (Phase Change Thermal Interface Material) to the back side of the product. For details, refer to the application note of PC-TIM.

1.3. Structure (Parts and Materials)

NX type

The structure diagram of CM150RX-13T is shown as a representative example.

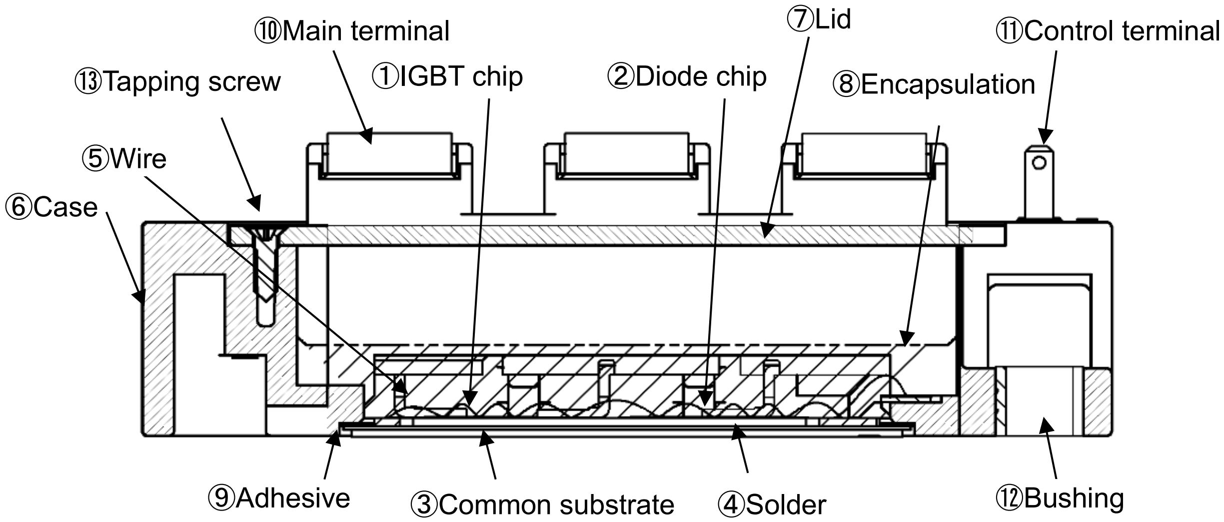


※ This figure shows the structural diagram of a typical example for the material explanation. It does not indicate the exact package size and chip size layout. There are also parts that are not in use in some packages.

	Parts	Material	Flame Retardance
1	IGBT chip	Silicon	
2	Diode chip	Silicon	
3	Common substrate (Insulating Metal Baseplate)	Insulating part: Resin	UL94 V-0
		Baseplate: Copper	
4	Solder	Tin	
5	Wire	Aluminum	
6	Case	PPS	UL94 V-0
7	Lid	PPS	UL94 V-0
8	Encapsulation	Epoxy resin	UL94 HB
9	Adhesive	Epoxy resin	
10	Main terminal	Main material: Copper (Cu) Plating: Nickel (Ni)	
11	Control terminal	Main material: Copper (Cu) Plating: Tin (Sn), Base Plating: Nickel(Ni)	
-	Bushing (Heatsink mounting part)	Steel	

std type

The structure diagram of CM 300DY-13T is shown as a representative example.



※ This figure shows the structure diagram of a representative for the material description. It does not indicate the exact package size and chip size layout. There is also parts that are not in use in some packages.

	Parts	Material	Flame Retardance
1	IGBT chip	Silicon	
2	Diode chip	Silicon	
3	Common substrate (Thick Metal Substrate)	Insulating part: Si_3N_4	
		Base: Copper	
4	Solder	Tin	
5	Wire	Aluminum	
6	Case	PPS	UL94 V-0
7	Lid	PPS	UL94 V-0
8	Encapsulation	Silicone gel	
9	Adhesive	Silicone	
10	Main terminal	Main material: Copper (Cu) Plating: Nickel(Ni)	
11	Control terminal	Main material: Copper (Cu) Plating: Nickel(Ni)	
12	Bushing	Steel	
13	Self-tapping screws	Steel	

2. Glossary

2.1. Common

Item		Description
IGBT	Insulated Gate Bipolar Transistor	Insulated gate bipolar transistor
FWD	Free Wheeling Diode	Free wheel (flywheel) diode
IPM	Intelligent Power Module	Intelligent power module
t_{dead}	Dead time	Pause (no signal) time provided in the ON signal between the upper and lower arm transistors
PC	Optocoupler	Optocoupler
CMR	Common Mode Rejection	The maximum rise of the input-to-output common-mode voltage of the optocoupler
CMH		The maximum rise rate of common-mode voltage between input and output that the preset high level can be maintained
CML		The maximum rise rate of common-mode voltage between input and output that the preset low level can be maintained
CTR	Current Transfer Ratio	The ratio of output current to input LED current of the optocoupler
UL	Underwriters Laboratories	One of the safety standards in the United States. American Insurer Safety Test Laboratory certified. UL certified products of Mitsubishi power module conform to UL 1557.
RoHS Directive	Restriction of Hazardous Substances (Original) DIRECTIVE 2002/95 / EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.	Regulations prohibiting the use of four heavy metals and two types of brominated flame retardants in electrical products. "The basic concept is to make the use of heavy metals of lead, mercury, cadmium, hexavalent chromium and new bromide flame retardants PBB and PBDE to new products of electrical equipment as a rule not to contain by July 1, 2006." WEEE: waste electrical and electronic equipment
PC-TIM	Phase Change - Thermal Interface Material	High thermal conductivity grease. Solid phase at normal temperature and softening with temperature rise
DP resin	Direct Potting Resin	A specially prepared resin material with enhanced coefficient of thermal expansion and adhesion
US	Ultrasonic Bonding	Ultrasonic bonding
PressFit		A system that completes assembly by inserting the press-fit terminal into the through hole of the printed circuit board and eliminates the need for soldering
RFC Diode	Relaxed Field of Cathode Diode	A P layer is partially added on the cathode side, a hole is injected at the time of recovery, and the recovery waveform is made soft so that the transient voltage rise can be suppressed by the diode
CSTBT™		Our proprietary IGBT utilizing carrier accumulation effect

2.2. Maximum ratings

Symbol	Item	Definition or description
V_{CES}	Collector-emitter voltage	Maximum voltage that can be applied for a short time between the collector and the emitter with the gate and emitter short circuited.
V_{GES}	Gate-emitter voltage	Maximum voltage that can be applied for a short time between the gate and emitter with the collector-emitter short circuited.
V_{RRM}	Maximum repetitive reverse voltage (Between anode and cathode)	Maximum voltage that can be applied for a short time between the anode and cathode of the clamping diode.
V_{CC}	Power-supply voltage	DC supply voltage that can be applied between the collector and the emitter.
I_C	Collector current	Maximum current that can flow continuously from the collector to the emitter within the rated junction temperature range.
I_{CRM}	Collector current (Maximum)	Maximum current that can be repeatedly flowed from the collector to the emitter in a short time within the rated junction temperature range. Normally it is twice the I_C.
I_E	Emitter current	Maximum current that can flow continuously from emitter to the collector (freewheel diode) within the rated junction temperature range.
I_{ERM}	Emitter current (Maximum)	Maximum current that can be repeatedly flowed from the emitter to the collector (freewheel diode) in a short time within the rated junction temperature range. Normally it is twice the I_E.
I_F	Forward current	Maximum current that can flow continuously from the anode of the clamp diode to the cathode within the rated junction temperature range.
I_{FRM}	(Maximum) forward current	Maximum current that can be repeatedly flowed from the anode of the clamp diode to the cathode in a short time within the rated junction temperature range. Normally it is twice the I_F.
P_{tot}	Collector loss	The maximum allowable power loss of the IGBT at the specified case temperature.
T_{stg}	Storage temperature	Maximum allowable temperature and minimum allowable temperature in the ambient temperature range when storing without applying power.
V_{isol}	Insulation withstand voltage	The maximum voltage that can be applied between the terminal and the base plate with all main terminals and all auxiliary terminals short-circuited. It is usually expressed as an effective value.
M_t	Tightening torque	Tightening torque range of terminal screws.
M_s	Tightening torque	Tightening torque range of the mounting screws.
T_{vjop}	Continuous operating junction temperature	Allowable temperature range of chip in continuous operation. The ripple caused by the output frequency also must be taken into account within this rating.
T_{vjmax}	Maximum junction temperature	The maximum temperature that the chip can tolerate in instantaneous operation such as overload. The ripple caused by the output frequency also must be taken into account within this rating.

2.3. Temperature ratings

Symbol	Item	Definition or description
T_a	Ambient temperature	When self-cooling or air cooling, the air temperature of a point which is not influenced by the heating element.
T_c	Case temperature	Temperature at a defined point on the enclosure (base plate) of the device.
T_s	Heat sink temperature	Temperature at a defined point on the heat sink.

2.4. Thermal ratings and characteristics

Symbol	Item	Definition or description
R_{th}	Thermal resistance	A value that indicates how many degrees K per unit electric power the junction temperature will rise over the externally specified point when the heat flow due to the power consumption of the junction is in equilibrium.
$R_{th(j-c)}$	Thermal resistance	Thermal resistance from junction (chip) to the surface of the case (baseplate).
$R_{th(c-s)}$	Contact thermal resistance	Thermal resistance from the surface of the case (base plate) to the surface of the heat sink. Normally, it is the value when thermal conductive grease is applied.

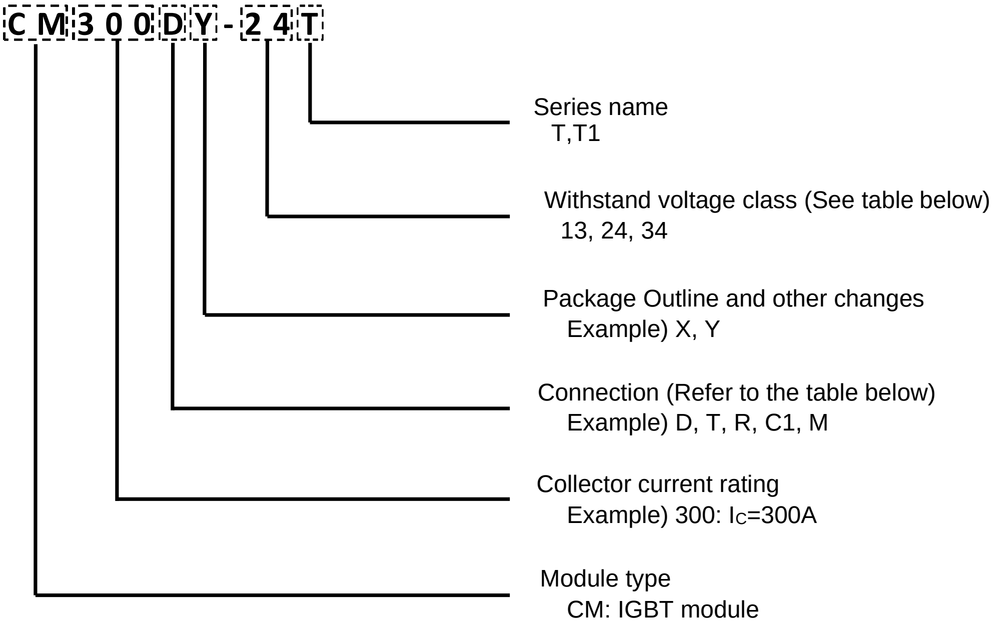
2.5. Electrical characteristics

Symbol	Item	Definition or description
I_{CES}	Collector-emitter cutoff current	The leakage current when applying specified collector-emitter voltage with gate and emitter short-circuited.
I_{GES}	Gate-emitter leakage current	The leakage current when applying specified gate-emitter voltage with collector and emitter short-circuited.
$V_{GE(th)}$	Gate – emitter threshold voltage	The required gate-emitter voltage for the specified collector to flow under the specified collector-emitter voltage.
V_{CEsat}	Collector – emitter saturation voltage	Collector-emitter voltage when the specified collector current flows under the specified conditions.
C_{ies}	Input capacitance	Capacitance between gate and emitter terminal with collector to emitter short-circuited for a.c. under the specified conditions.
C_{oes}	Output capacitance	Capacitance between collector and emitter terminal with gate to emitter short-circuited for a.c. under the specified conditons.
C_{res}	Feedback capacitance	Capacitance between collector and gate terminal with collector to emitter short-circuited for a.c. under the specified conditions.
$t_{d(on)}$	Turn-on delay time	Time interval between 0 % of gate voltage during switching IGBT from off-state to on-state and 10 % of output collector current.
t_r	Rise time	Time interval between 10 % to 90 % of output collector current during switching IGBT from off-state to on-state.
$t_{d(off)}$	Turn-off delay time	Time interval between 90 % of gate voltage during switching IGBT from on-state to off-state and 90 % of output collector current.
t_f	Fall time	Time interval between 90 % to 10 % of output collector current during switching IGBT from on-state to off-state.
t_{rr}	Reverse recovery time	Time interval during flowing reverse recovery current when the current of the built-in freewheeling diode is switched from the forward direction to the reverse direction under the specified conditions.
Q_{rr}	Reverse recovery charge	The charge accumulated in the internal elements when the current of the built-in freewheeling diode is switched from the forward direction to the reverse direction under the specified conditions. Time integral of the reverse recovery current that flows in the reverse direction.
V_{EC}	Emitter to collector voltage	Voltage drop when the specified current flows to the built-in free wheel diode.
R_G	External gate resistance	The recommended range of the gate resistance connected between the element and the drive circuit.
E_{on}	Turn-on energy (Turn-on loss)	Integral of $V_{CE} \times I_C \times dt$ during switching IGBT from off-state to on-state. Integral time is from 10 % rise point of I_C to 10 % drop point of V_{CC}.
E_{off}	Turn-off energy (Turn-off loss)	Integral of $V_{CE} \times I_C \times dt$ during switching IGBT from on-state to off-state. Integral time is from 10 % rise point of V_{CC} to 2 % drop point of I_C.
E_{rr}	Reverse recovery energy (Reverse recovery loss)	Integrall of $V_{EC} \times I_E \times dt$ during switching IGBT from off-state to on-state. Integral time is from forward current of the diode reaches 0 A until reverse recovery current reaches 0 A.

※ The symbols and definitions are subject to change due to revision of the reference standard (IEC, JEC).

3. Product label information

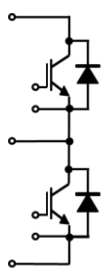
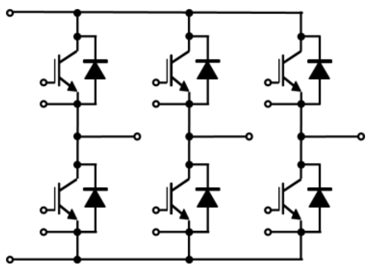
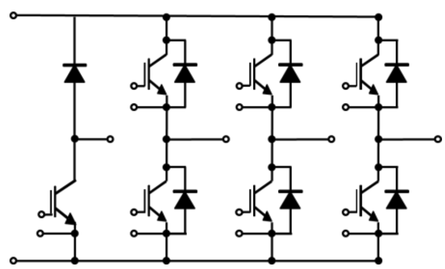
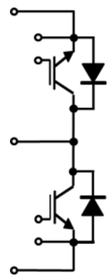
3.1. Configuration of the part number

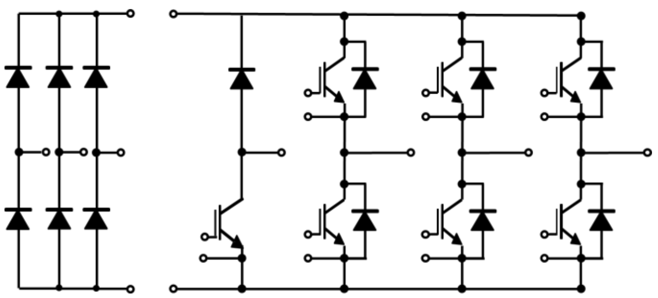


Withstand voltage class (50 times the number rated V_{CES})

Withstand voltage class	V_{CES} (V)
13	650
24	1200
34	1700

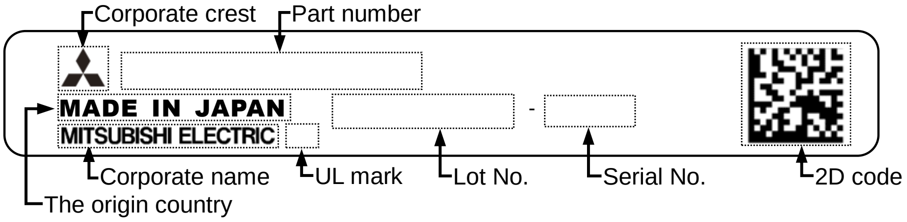
Connection (There is no display on the label)

D: 2 elements	T: 6 elements	R: 7 elements	C1: 2 elements (collector common)
			

M : CIB


3.2. Labeling

1 Label printing example

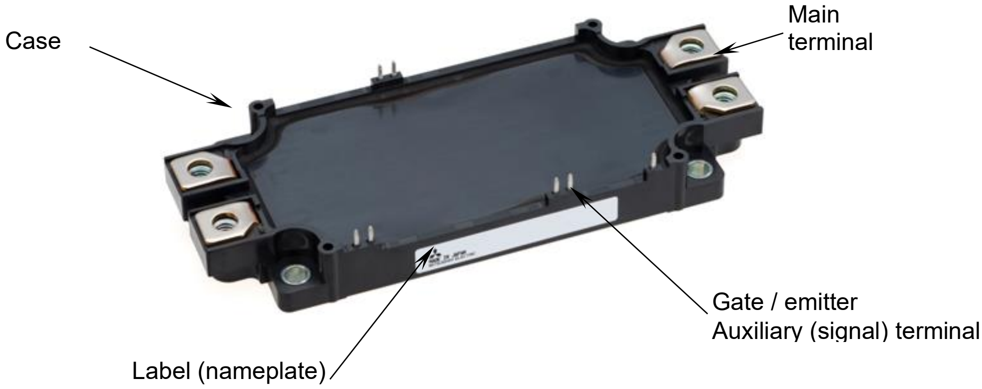


- This product complies with the RoHS Directive (2011/65/EU).
- Restriction of the use of certain hazordous substance in electrical and eltronic equipment.

2 Date code formation

```
S 6 D A A 1 G
| | |   |   └── RoHS directive compliant identification mark
| | |   └────── Manufacturing management number
| | └────────── Manufacturing month:  1 to 9;  January to September
| |                                    O;October, N; 11 months, D; 12 months
| └──────────── Manufacturing year: last-digit of A.D.
└────────────── Factory code (UL factory identification)
```

3 Module Nomenclature (example for 2 elements)



3.3. Two-dimensional barcode configuration

Two-dimensional code specifications

Specification

Item	Specification
Symbology	Data Matrix (ECC200)
Data type	Alphanumeric (ASCII) characters
Error correction ability	20 – 35 %
Symbol size	6.0 mm x 6.0 mm
Code size	24 cell x 24 cell
Cell size	0.25 mm
Data size	39 letters

Data contents

Data item	Letter size
Part number	20
Space (Blank)	2
Data code	8
Space (Blank)	1
Parallel spec. symbol	3
Space (Blank)	1
Serial number	3
Space (Blank)	1
total	39

Data Example

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
C	M	4	5	0	D	X	-	2	4	T	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	N	1	2	H	A	1	G	SP	SP	SP	SP	SP	SP	0	0	1	SP
20																				2		8								1	3			1	3			1

"SP" represents a space (blank = equivalent to ASCII code number 32).

4. Safety standard (UL Standard)

Mitsubishi Power Modules are UL certified (Recognized) for UL Standard 1557 and Category Code QQQX2.
(Except for some special items, File No. E 323585)

Power modules are not certified for other safety standards (TUV, VDE, CSA etc).
(Reinforcement of CE marking is not made considering correspondence to insulation.)
Regarding European CE and China CCC, as of October 2016, the target regulation as a power module has not been confirmed. The authentication by part number can be checked on UL's website. Please refer to the following procedure.

5. Handling Precautions

Elements of a power module may be damaged depending on usage conditions (electrical / mechanical stress, handling, etc.). In order to use our power module safely, observe the following precautions and use correctly.

5.1. Handling Precautions

⚠ Caution	
Transportation method	· During transportation, please keep the shipping box in the correct orientation. If it is inverted or excessive force is applied, the terminals may be deformed or the resin case may be broken. · Throwing or dropping may cause the device to break. · Care should be taken when transporting during rainfall or snowfall to not expose the device to water. Do not use the device if it is exposed to water as it may malfunction at the time of use.
Storage method	· The temperature and humidity of the storage location is desirably within the normal temperature and humidity range of 5 - 35°C and 45 - 75%. If stored in a more extreme environment than this temperature and humidity, the performance and reliability of the device may decrease.
Long-term storage	· When storing the product for a long term (over 1 year), please take measures for dehumidification. In addition, please confirm that there is no scratch, dirt, rust etc. on the device when using after long term storage.
Usage environment	· Use in environments where high humidity (including condensation), organic solvents directly adhere, where corrosive gas is generated, or in places where explosive gas, dust, salt, etc. are present may cause serious accidents. Please avoid usages in these environments.
Flame retardance	· Although the case and lid materials are in conformity with UL94 V-0 standards, it should be noted that those are not non-flammable.
Countermeasure against static electricity	· Please observe the following items in order to prevent damage due to static electricity. (1) Precautions to prevent static electricity destruction If static electricity charged on the human body and packing materials becomes an excessive voltage (±20V or more) and is applied between the gate and the emitter, the device may be damaged. The basic principle of static electricity countermeasure is to minimize the generation of static electricity and to avoid application of the voltage to the device. * Do not use containers that are susceptible to static electricity for transportation and storage. * It is recommended to short-circuit the gate and emitter with carbon cloth/foam etc. until just before using the module. Also, please wear gloves so as not to touch the terminals with bare hands. Avoid gloves and work clothes that are easy to charge, such as nylon. * During assembly, ground the equipment to be used and the person performing work. It is also recommended to ground a conductive mat on the surface of the work table and the floor around the work table. Assembly refers to the point in time when the product is removed from the packing box. * Please note that when the gate-emitter is open on the printed circuit board on which the element is mounted, it may be destroyed by the static electricity charged on the printed circuit board. * When using a soldering iron, use a low voltage (12 V to 24 V) soldering iron for semiconductors, Ground the tip. (2) Open Gate-emitter Guidelines * Do not apply voltage between the collector and the emitter while the gate and emitter are open. * When removing the element, short the gate and emitter and remove it.

Caution	
Countermeasure against static electricity	(3) Interior shipping container Conductive plastic is used for the interior box, so the conductive foam used for short circuiting between gate and emitter is not necessary. As with the conventional conductive foam, this conductive plastic tray is not an electrostatic component that completely shorts the gate and emitter or clamps the overvoltage. Please take adequate measures against static electricity during the process of taking out the module out of the packing box to mounting in the equipment, by using a conductive mat grounded to earth with a band to the operator. If you take out the module out of the interior box and store it in another container etc, please implement electrostatic measures such as using a conductive container for the storage container. Also, since the module main body is not fixed to the interior tray, please be careful about handling so as not to drop the module while taking out or unpacking the interior tray.  Built-in tray packing example
Antistatic measures	· When performing an acceptance test (saturation voltage test etc.) such as applying a voltage between the gate and the emitter, Discharge between the gate and the emitter before returning to the packing tray or storage (conductive) container after the test is completed. Please discharge the electric charge with a high resistance (about 10 kΩ).
Connection Method	· When mounting the module in the product, do not apply excessive stress to the screw terminal (structure). The terminal structure itself and the joint of the terminal structure case may be damaged. · When connecting to the module pins by using printed circuit board etc, please be careful not to deform with excessive stress. · When fixing the printed circuit board to the module case with tapping screws, please pay attention to the size of the screws and mounting method. If you mistake the screw size and installation method, the case of the module may be damaged.

5.2. Flame Retardance

NX type

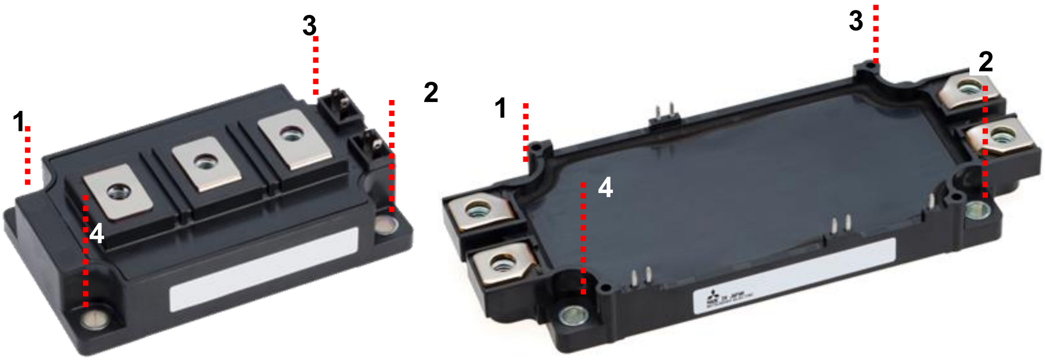
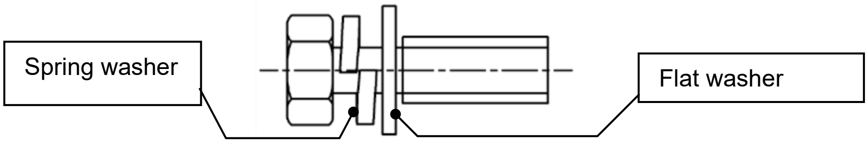
The case and lid used in the IGBT module have a flame retardance complying with UL94 V-0 and have self-extinguishing properties. If the module is cut off from the combustion source, there is no danger of spreading fire.
The encapsulating resin has only UL94 HB-compliant flame resistance and is not self-extinguishing. In case of fire, it is necessary to extinguish the fire using powder fire extinguisher, carbon dioxide extinguisher, foam extinguisher, etc.
Other components such as the silicon chip, copper baseplate, etc. do not have applicable UL flame retardance standards.

std type

Since the PPS used for the case and lid of the IGBT module has flame retardance conforming to UL 94 V-0 and has self-extinguishing properties, there is no danger of spreading fire if the combustion source is cut off. Silicone gel is flammable and does not comply with UL 94 V-0. Products with characteristics with a flash point of 340°C, an ignition point of 450°C, and dielectric breakdown strength after curing of 10 kV/mm or more are used. Also, there is no self-extinguishing property, so in case of fire, it is necessary to extinguish by using powder fire extinguisher, carbon dioxide extinguishing agent, foam extinguishing agent etc.
Other components such a silicon chip, copper baseplate, etc. do not have applicable UL flame retardance standard.

6. Precautions on Actual use

6.1. Method of attaching the module to the heat sink

	⚠Caution
Mounting method	When attaching the module to a heat sink or similar, if extreme tightening is performed, stress will be applied to the insulating ceramic substrate or silicon chip inside the module, causing destruction or deterioration of the element. An example of tightening sequence is shown in Figure 6-1.  2-point tightening module Temporary tightening ① → ②, final tightening ② → ①  4-point tightening module Temporary tightening ① → ② → ③ → ④, final tightening ④ → ③ → ② → ① Figure 6-1. Mounting screw tightening order * Temporary tightening torque should be set to 10 to 30% of maximum rating as a guideline * Please use spring washer and flat washer. We recommend installing screws with the spring washer + flat washer built-in.  Figure 6-2. Example of Washer embedded screw (spring and flat washers)
	・ In order to maximize heat dissipation, it is necessary to minimize the contact thermal resistance by maximizing the contact area as much as possible. ・ The flatness of the heat sink should be -50 μm ~ +50 μm (※The flatness p-p<50μm for std type) (for a length of 100 mm) on the module mounting surface (see Fig. 8-3). Also, the surface roughness should be within 10 μm for a length of 100 mm. Sufficient flatness must be provided on the surface of the heat sink. Excessive minus (concave) warp will increase the contact thermal resistance $R_{th(c-s)}$ and affect the heat dissipation of the module. Excessive plus (convex) warpage may cause stress to be applied to the inside of the module during installation, which may cause

damage to the module.

Note: Please judge the decision from user's side by deeply investigating possibility of any failure and decrease of thermal resistance performance in case recommended condition is not kept by actual usage.

- 7th generation IGBT modules are offered to optionally be pre-coated with PC-TIM (Phase Change - Thermal Interface Material) on the baseplate. For details on handling, please refer to the "PC-TIM Application Note".
- It is also possible to apply heat conductive grease (herein referred to as grease) to the contact surface between the module and the heat sink. In this case, please apply so that it becomes uniform with thickness of 50μm to 100μm.
- Long term performance related to thermal conductive grease and PC-TIM (including but not limited to aspects such as the increase of thermal resistance due to pumping out, etc.) should be verified under your specific application conditions. Each temperature condition ($T_{vj\,max}$, $T_{vj\,op}$, $T_{C\,max}$) must be maintained below the maximum rated temperature throughout consideration of the temperature rise even for long term usage.
- Use a torque wrench for tightening and tighten to the required torque. If the tightening torque is too large, there is a danger of breakage or deterioration of the element as well as the tightening components.

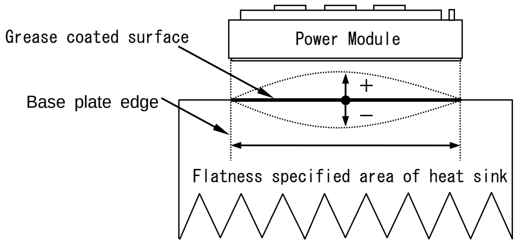


Figure 6-3. Flatness of the heat sink

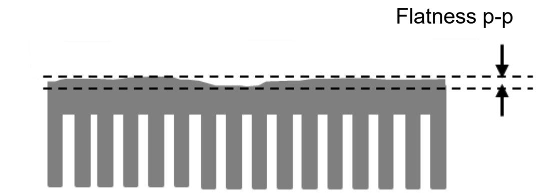


Figure 6-3-a. Flatness of the heat sink for std type

Required shape of the module mounting heatsink hole

The outermost diameter dimension of the threaded hole in Figure 6-4 (ΦA) as shown in Table 6-1 is recommended for securing the axial force of the mounting screw (to prevent screw looseness) and preventing stress concentration on the case resin material.

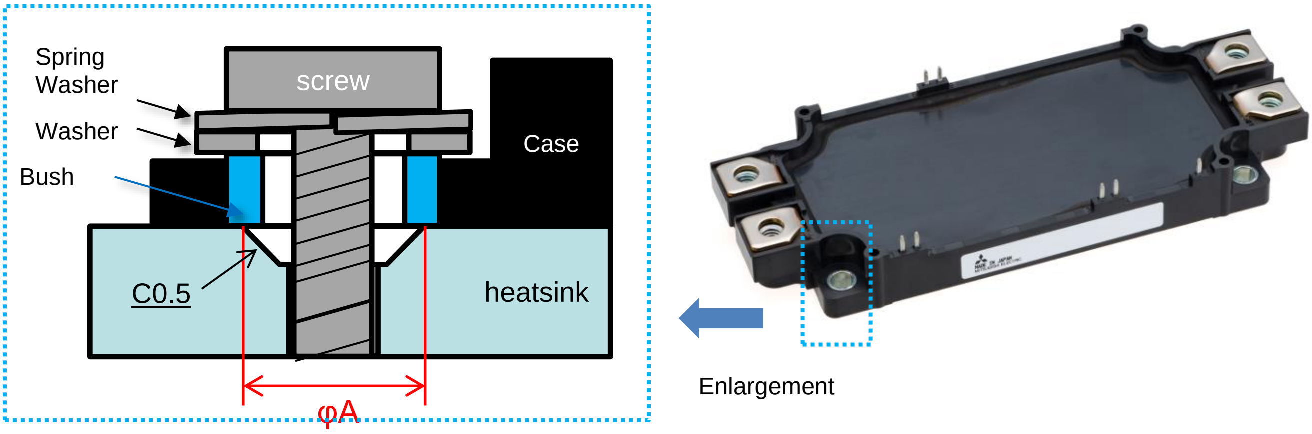


Figure 6-4.Schimatic of module mounting heatsink hole

Table 6-1. Recommended maximum outer diameter dimension of heat sink side threaded hole φA

PKG type	Mounting screw	The recommended maximum φA [mm]
NX type	M5	6
std type	M6	7

6.2. Power module implementation

Capacitor Connection

During switching, high voltage is induced in power circuit stray inductance by the high di/dt of the main current when the stray inductance is large. This voltage can appear on the IGBT module and cause IGBT or diode destruction. In order to avoid this problem, guidelines that should be followed in designing the circuit layout are:

① Reduce the L1 inductance by bringing the connection of the smoothing capacitor close to that of the module and arranging the return connection in a laminated plate structure to cancel the magnetic field.
② Connect the snubber capacitor close to the module terminal in order to bypass the high frequency current and absorb the surge voltage.
③ The smoothing capacitor itself should be of low impedance type.
④ Decrease the di/dt by slowing the switching speed of the element (increase the gate resistance, etc.).

It is a general measure to suppress the wiring inductance (L1) of the main circuit as much as possible by ① or ③, and still suppress surge voltage using ② or ④ when the surge voltage is large. Regarding ②, if the wiring inductance (L1) is large, the voltage oscillation may increase due to the resonance between C and L1. At that time, oscillation can be suppressed by changing the value of C.

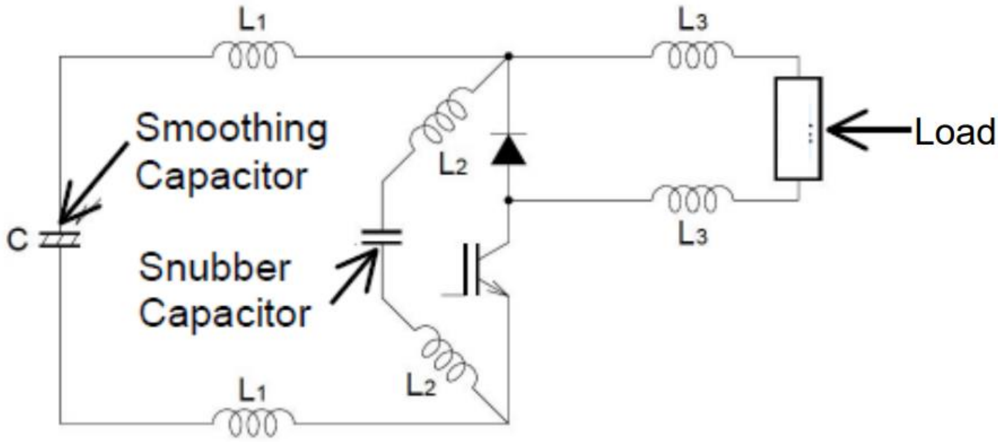


Figure 6-5. Power Module application circuit

L1: Inductance of the wiring connecting the smoothing capacitor and the IGBT module. Since it is a round-trip line, it is necessary to use laminated conductors made of parallel flat metal plates sandwiching an insulator so that mutual magnetic fields are canceled.
L2: Inductance of the snubber capacitor lead wire. If this inductance is large, it will not be an effective bypass.
L3: Inductance of the wiring connecting the load.

Precautions for mounting/installation

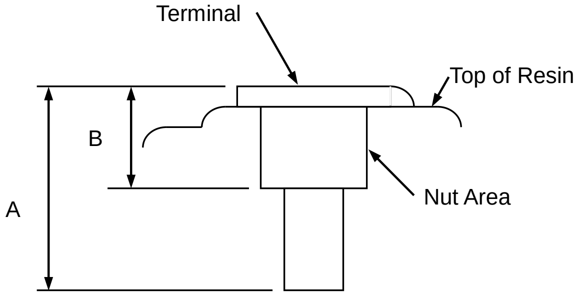
Please install using hand tightening method when possible. When tightening with an electric screwdriver or similar, the excess thermally conductive grease should be squeezed out by pushing the module against the heat sink, etc. before tightening. Also, it is necessary to sufficiently lower the tightening speed or to apply a low viscosity grease. If tightening at high speed with a high viscosity thermally conductive grease, the module may deform and be damaged.

Note)
In case of PC-TIM, softening starts at 45°C or higher after mounting on heat sink.

Please use mounting screws and washers that match the module mounting hole size. If screws with a size smaller than the recommended screw size (with flat washer) are used, there is a possibility that a misalignment of the center line of the screw occurs, a shearing force is applied to the flat washer, and the clamping force is not evenly applied to the module mounting hole. This will cause loosening of the mounting screws. An attaching method that makes axial force uniform and that the head end face of the screw can be held within the center line deviation so as to cover the whole mounting hole is ideal.

When using iron screws for module installation and screw terminal connection, the tightening torque is limited by the strength of the resin case etc. of the module body. Please note that tightening with the standard tightening torque of the iron screw specified in JIS etc. may cause damage to the case.

Note)
Please note the screw length. If screws longer than necessary are used, it may cause resin breakage at the terminal.
Please refer to the following dimensions and use the screw of the optimum length.



Terminal screw hole depth

Screw and size		Model	A	B	Terminal thickness
Main terminal	M5		13.0	5.2	0.8
					1.0
Main terminal	M6		14.3	6.3	1.0
		  	13.9	7	1.5

※Dimensions A and B do not include floating of the terminal.

There are products with 2 terminals and 3 terminals as power terminals. Each external terminal is internally connected, but be sure to use all terminals for external connection. With only 1 of the terminals connected, the current capacity will be insufficient as the main terminal, and the temperature rise of the terminal may exceed the acceptable level of the product.

6.3. Stand-off recommended use (NX type)

Recommended use conditions

Recommended conditions for tightening the standoff screws to attach the printed circuit board are described below.

7th generation recommended screws

Thread type	Screw size	Tightening torque	Tightening Method
B1 tapping screw	φ2.6x10	0.75N· m±10%	1. Manual method by hand (equivalent to electric driver 30 rpm) 2. Electric screwdriver 600 rpm or less
B1 tapping screw	φ2.6x12		
PT® Screw	K25x8	0.55N· m±10%	
PT® Screw	K25x10	0.75N· m±10%	
DELTA PT® Screw	K25x8	0.55N· m±10%	
DELTA PT® Screw	K25x10	0.75N· m±10%	

※ PT® · DELTA PT® is a registered trademark of EJOT.

* 1 The above conditions are tightening conditions when printed circuit board thickness t=1.6mm.
* 2 When considering other screws or when changing tightening conditions, please separately evaluate and check the acceptability.
* 3 When using a high-speed tightening tool such as electric screwdriver, ensure it has performance that meets the recommended conditions and is regularly calibrated for both rotation speed and torque.
* 4 The standoff may only be used 1 time and is not recommended to be reused.
* 5 The above conditions may differ depending on usage environment etc. Please be sure to determine the conditions after actual evaluation.

Pin terminal

・7th generation terminal specification

Item	Specifications	
Terminal Material	Copper(Cu)	
Plating type	Tin(Sn)	
	Base: Nickel(Ni)	
Plating thickness	Sn	4~10μm
	Ni	1~6μm

・ Recommended soldering conditions

Soldering by solder immersion (flow soldering)

Solder temperature	Immersion time
260°C±5°C	10 seconds±1 second

Soldering with a soldering iron (manual soldering)

Tip temperature	Heating time
360°C±10°C	5 seconds±1 second

Press-fit

In addition to the conventional solder pin type, the NX type has a lineup of press-fit pin type that eliminates the need for soldering to the printed circuit board. (Model name: CM ** XP - ** T)

By inserting into the through hole at the prescribed pressure and speed, a metallic bond with the plating of the through hole part is made, and soldering becomes unnecessary. Care must be taken of suitable printed circuit boards, installation equipment / jigs, installation methods, etc.. For handling details please refer to the separate "Press Fit Application Note".

6.4. Thermally conductive (heat dissipating) grease application example

Method of applying the thermally conductive grease to the power module:

① Materials Required: Power module, thermally conductive grease, screen, electronic mass meter, gloves
What is called a thermal compound basically performs the same function as the thermally conductive grease. When using a highly viscous compound, thoroughly stir before spreading so that it spreads over the entire baseplate.

② The relationship between the amount and the thickness of the thermally conductive grease to be applied is as follows:

$$\text{Thickness of thermally conductive grease} = \frac{\text{amount of grease [g]}}{\text{baseplate area of module }[\mathrm{cm}^2] \times \text{density of grease }[{}^{g}/_{cm^3}]}$$

Our recommended thermal conductivity grease thickness is 50μm to 100μm.
Note, this thickness is the initial value at the time of coating, it changes depending on the flatness of the base plate and heat sink after installation.

Calculate the amount of thermal conductive grease required for the power module. Calculation example:
Mounting area 97 mm × 58 mm, for case of G-747 made by Shin-Etsu Chemical Co., Ltd. for heat conductive grease

$$50\mu m = \frac{\text{amount of grease [g]}}{56.26\ [\mathrm{cm}^2] \times 2.65\ [{}^{g}/_{cm^3}]}$$

∴ Thermally conductive grease amount ≒ 0.75 [g].

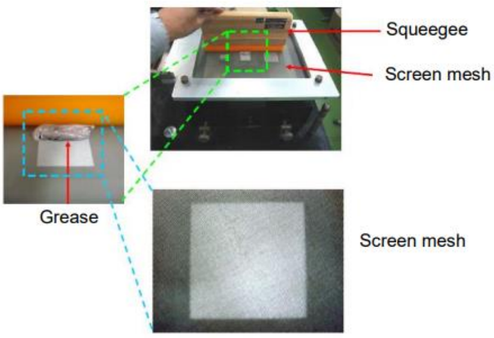
③ Measure the mass of the power module without grease applied.

④ Add the amount of thermally conductive grease calculated in ① to the base plate of the power module using an electronic mass meter. There is no specific/required method for applying the grease.

⑤ Apply the added thermal conductive grease to the entire surface of the base plate so as to be uniform. There is no particular limitation on the application method as long as the target thickness is nearly uniform over the entire surface of the baseplate of the power module.

Please be careful not to contaminate with foreign matter and bubbles when applying the grease. When coating with a roller etc., please be careful that bubbles do not get mixed in the grease. When using metal spatula, please be careful not to scratch the baseplate surface. It is possible to reduce the aging effect of the thermally conductive grease on the baseplate by not wiping off the excess grease after installing to the heatsink.

Example of using a squeegee and mesh screen (mask)
(Application example: Shin-Etsu Chemical Co., Ltd.)



Grease for aluminum conductor connections is mainly aimed at improving the contact properties of the aluminum surface and lowering electrical contact resistance by preventing corrosion. Although there seems to be a long-term use record, it is not intended to improve the heat conduction of the contact part, so it cannot be expected to make much reduction in contact thermal resistance. If this grease is adopted, sufficient heat dissipation design/study is required.
The optimum thermal conductivity grease varies depending on the application and usage, so please contact directly to the grease maker at the time of selection / specification.

6.5. Concept of thermal resistance

The module datasheet defines the thermal resistance $R_{th(j\text{-}c)}$ between the chip junction and case (baseplate) and the contact thermal resistance $R_{th(c\text{-}s)}$ between case (baseplate) and heat sink. The reference point of thermal resistance (case temperature) is just under the chip. Chip placement of each product is described in the data sheet. An example of that is described below.

Tr** indicates the center position of the IGBT chip, Di** indicates the center position of the FWD chip. For 2 elements, Tr1/Di1 indicates the upper arm and Tr2/Di2 indicates the lower arm.

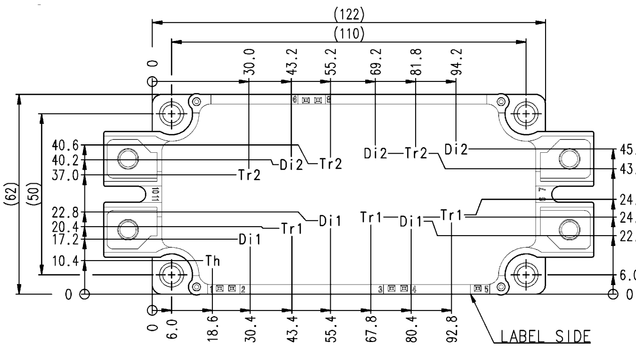


Figure 6-6 Chip location (CM225DX-24T dual module)

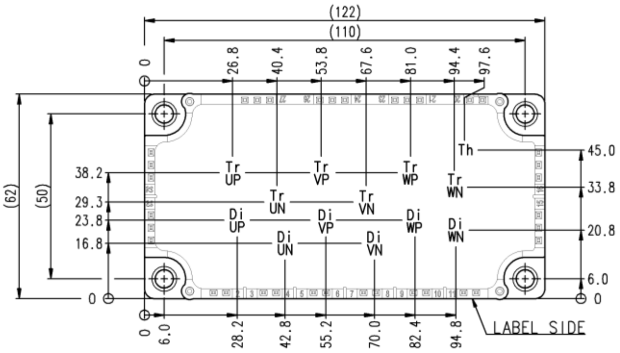


Figure 6-7 Chip location (CM200TX-24T 6-pack module)

Measure the base plate and heat sink temperature by attaching a thermocouple to the position (directly under the chip) shown in the figure.

Notes

- The thermal resistance of the heat sink will change depending on the material, area, and thickness used. Generally, with heat sinks of the same material, the smaller the area and the thinner the heatsink, the higher the thermal resistance.

- The contact thermal resistance $R_{th(c\text{-}s)}$ shown in the data sheet is the typical value under noted application conditions of thermal conductive grease. The thermal conductivity conditions of the grease for the Rth(c-s) values are 0.9W/(m・K) for NX type and 3.0W/(m・K) for std type respectively. Actual contact thermal resistance varies depending on the type of grease, the applied amount and the heat generation conditions, so confirm (measure) with the grease and heat sink actually used and in actual operation conditions.

- Water-cooled heat sink:
  The general industrial power module is assumed to be used in a cooling system using a natural convection heatsink or air cooling heat sink. If you using a water-cooled heat sink, thermal resistance $R_{th(j\text{-}c)}$ and contact thermal resistance $R_{th(c\text{-}s)}$ may change significantly due to the nature of heat spreading. Further, if condensation occurs, discharge may occur between the main electrodes. Destruction due to dew condensation is possible due to overvoltage breakdown due to the surge voltage generated by the discharge. Since there is no dew condensation countermeasure as part of the module, it is necessary to take dew condensation measures in the unit using the module when it is used with water cooling. The sealing material (DP resin) filled in the module has moisture permeability.

- Package for general industrial power module is not airtight structure, so liquid can be absorbed by module. Both the package materials and semiconductor chips are not designed assuming long-term contact with anything other than the DP resin. Therefore, characteristics and reliability cannot be guaranteed when the module is immersed in silicone oil or similar.

6.6. Example of thermocouple attachment

Example of thermocouple attachment for case temperature measurement just under the chip are shown below.

●Case temperature measurement
Case temperature just under chip is used for estimation of junction temperature.
(Please see “8. Power loss and heat dissipation design” for the detail estimation procedure.)
Thermocouple attachment examples for NX type and std type are shown below.

NX type
<Step 1>
Drill into the IGBT module as shown in Figure 6-8.
(The depth of the groove is 0.8mm, the width is 1mm as a guideline when a thermocouple with a wire diameter of 0.3mm (recommended value) is used.)
Please be careful that the base of the thermocouple tip (blue line) comes to the point you want to measure (just under the chip).

<Step 2>
Insert a thermocouple into the groove drilled in Step 1, place it on the module baseplate, and seal with a high thermal conductivity filler from the top so that the thermocouple does not move

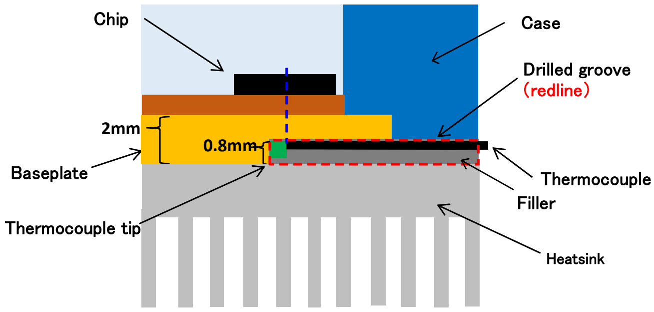


Figure6-8. Thermocouple attachment on NX type baseplate

Figure 6-9 shows an example of groove drilling on the back of the module. Please be careful not to impact the flatness of the module by burrs and filling materials after the groove processing.

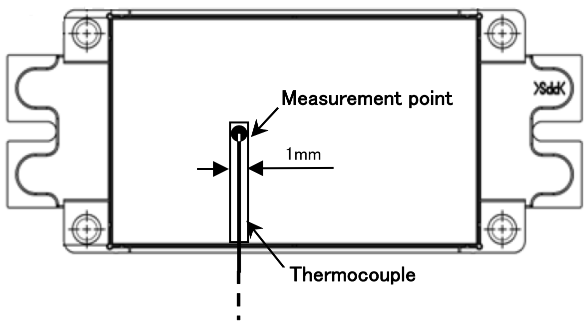


Figure 6-9: Drilling Example (NX type module back)

std type
<Step 1>
Drill into the module as shown in Figure 6-10 (the depth of the groove is 0.4mm, the width is 0.3mm as a guideline when a thermocouple with a wire diameter of 0.1mm (recommended value) is used. At this time, please be careful that the base of the thermocouple tip comes to the point you want to measure (just under the chip).

<Step 2>
Insert a thermocouple into the groove drilled in Step 1, place it on the module baseplate, and seal with a high thermal conductivity filler from the top so that the thermocouple does not move

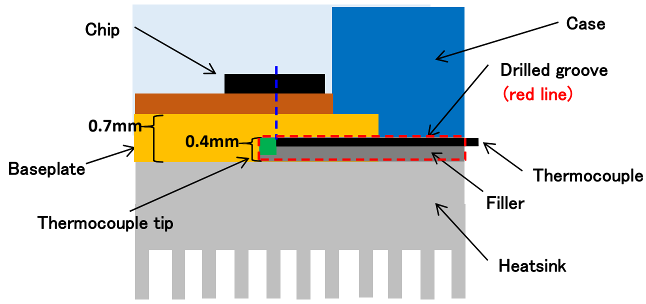


Figure6-10. Thermocouple attachment on std type baseplate

Figure 6-11 shows an example of groove drilling on the back of the module. Please be careful not to impact the flatness of the module by burrs and filling materials after the groove processing.

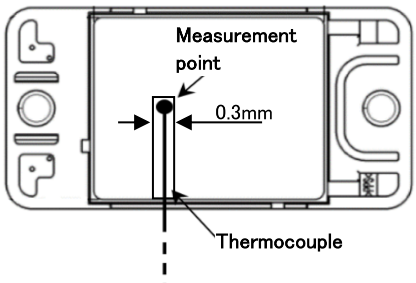


Figure 6-11: Drilling Example (std type module back)

Note) For the junction temperature estimation, it is recommended to measure the case temperature with a cooling system actually employed to your application. If heatsink temperature needed to be obtained, please refer the following example.

●Heatsink temperature measurement (NX type and std type common)

<Step 1>
Drill into the heat sink as shown in Figure 6-12.
(The depth of the groove is 0.8mm, the width is 1mm as a guideline when a thermocouple with a wire diameter of 0.3mm (recommended value) is used.
Please be careful that the base of the thermocouple tip (blue line) comes to the point you want to measure (just under the chip).

<Step 2>
Insert a thermocouple into the groove drilled in Step 1, place it on the heat sink, and seal it with a high thermal conductivity filler from the top so that the thermocouple does not move. It is no problem even if the thermocouple is caulked to the heat sink.

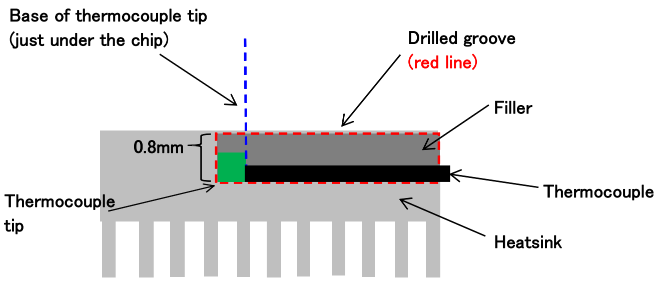


Figure6-12 Example of heatsink thermocouple mounting

Figure 6-13 shows an example of groove processing on a heat sink.
Be careful not to impact the flatness of the heat sink by burrs and filling materials after the groove processing.

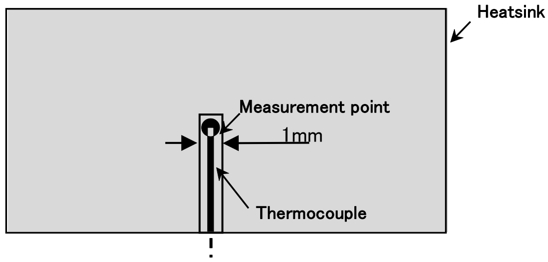


Figure 6-13: Drilling Example (heatsink)

6.7. Snubber circuit

Snubber circuit application example

A snubber circuit application example is shown in Figure 6-15. The following is reference design values of the snubber inductance (L_2) and the snubber capacitor (C_s) in the application circuit. A waveform example of collector-emitter voltage V_{CE} in turn-off is shown in Figure 6-16. Here the total inductance L is defined as $2 \times L_1 + 2 \times L_2$.

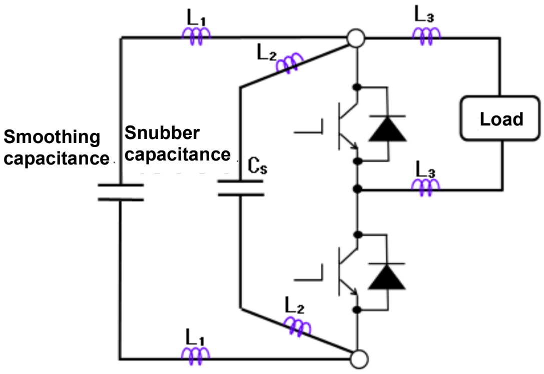


Figure 6-15. Snubber circuit application example

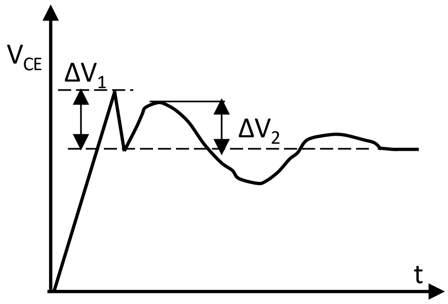


Figure 6-16. Waveform example of V_{CE} in turn-off

In the circuit of Figure 6-15, at first, a surge voltage ($\Delta V_1 = 2 \cdot L_2 \cdot di/dt$) is generated by di/dt due to turning off the IGBT and wiring inductance (L_2) of the snubber capacitor (C_s). In order to suppress ΔV_1, it is necessary to reduce the snubber wiring inductance L_2. Reference design values for snubber inductance are shown in Figure 6-17. As for di/dt, a tangent line is drawn on the current waveform of actual measured turn-off as a typical value. Since it may vary somewhat depending on the characteristics, snubber circuit wiring inductance ($2 \cdot L_2$) should be considered as a guideline and checked thoroughly by actual evaluation.

Next, when L_1 is sufficiently large, resonance occurs between $L_1 + L_2$ and the snubber capacitor (C_s), and its peak voltage ΔV_2 appears. In order to suppress ΔV_2, it is necessary to increase the value of snubber capacitor C_s. Reference design values for snubber capacitance are shown in Figure 6-18. C_s is calculated by using the formula in the figure. I_{OFF} assumes the current flowing during short-circuit, and it is calculated as 5 times rated current.

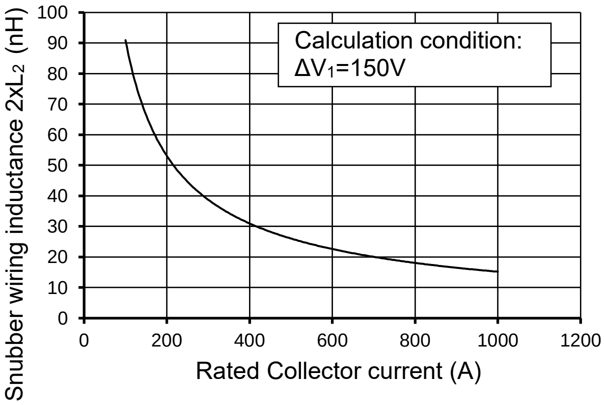


Figure 6-17. Snubber capacitance - Collector current dependence

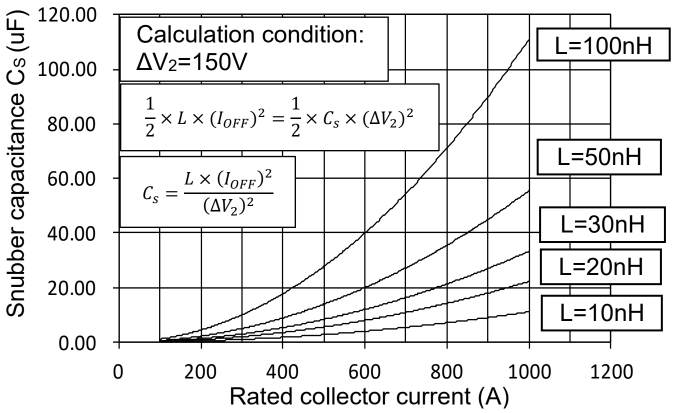


Figure 6-18. Snubber inductance - Collector current dependence

Calculation example of the snubber inductance (L_2)

Rated collector current	Snubber inductance $2 \times L_2$ (nH)
100A	＜ 89 nH
200 A	＜ 54 nH
300 A	＜ 39 nH
450 A	＜ 28 nH
600A	＜ 22 nH
1000A	＜ 15 nH

Conditions: ΔV_1=150V
Assumed di/dt in turn-off at rated collector current
(Ic=rated, typ; @T_{vj}=25℃)

Calculation example of Snubber Capacitance (C_s)

Rated collector current	Total inductance L (nH)	Snubber capacitance Cs (μF)
100A	＜ 100 nH	＞1.1
200 A	＜ 50 nH	＞2.2
300 A	＜ 30 nH	＞3.0
450 A	＜ 20 nH	＞4.5
600A	＜ 15 nH	＞6.0
1000A	＜ 10 nH	＞11.1

Conditions: ΔV_2=150V
Assumed 5 times rated collector current

In the case of module parallel connection, it is recommended to attach a snubber circuit to each module individually. In the case of increasing snubber capacitance by paralleling snubbers, it is recommended to divide snubber circuit and attach those circuits to multiple modules. It is considered better for the snubber wiring inductance (L_2) reduction and the current capacity of the snubber.

Measures to reduce surge voltage

① Reduction of circuit inductance (L1, L2)

●Reduction A (6 and 7 packs): printed circuit board with lamination

● 100 A to 1000A (dual modules): Parallel flat (laminated) bus plates

② Snubber circuits

● 50 to 200A (6 and 7 packs): snubber circuit (a) or (b)

●(a)0 to 600A (dual module): snubber circuit (a) for each phase or (b) for each phase

● f00A or more: snubber circuit (a) and (c) for each phase

Table 6-2. Applicable snubber circuits

Module	Applicable Snubber Circuit
NX type	a, b, or a + b,
std type	a, b, or c

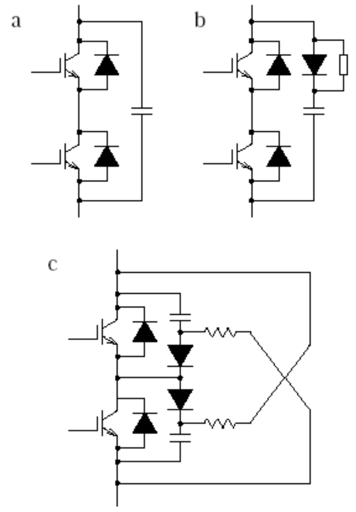


Figure 6-19. Various snubber circuit examples

Wiring example of the power module

It is suggested to layout by using two DC bus conductor plates (P layer, N layer) which are sandwiching an insulating layer. The stacking order has no effect on wiring inductance. An example of how to connect this multilayer bus to the module is shown below.

Layout example when a three-phase full-bridge is used as one unit

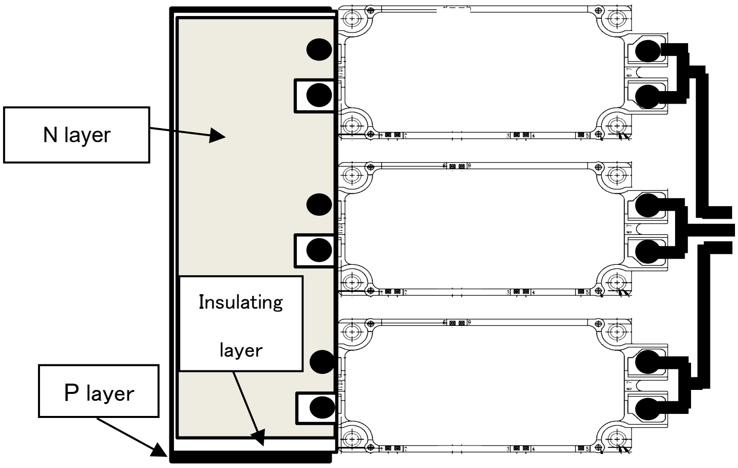


Figure 6-20. Example of NX type (dual module)

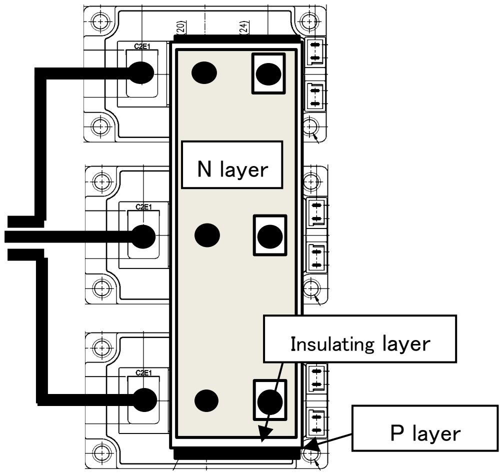


Figure 6-21. Example of std type (dual module)

Low inductance laminated bus bar Manufacturer example: Ryoden Kasei Co., Ltd.: "Laminated bus bar"
http://www.ryoka.co.jp/
For details, please contact directly to the manufacturer.

6.8. Use of Thermistor

(1) Basic characteristics of NTC thermistor

A thermistor is a resistor whose resistance depends on temperature, and thus has a function as a temperature sensor. The thermistor installed in NX modules is NTC (Negative Temperature Coefficient) thermistor and then is resistance decreases with increase in temperature. The resistance R is defined as the following equation.

R25 is the resistance at T25(25 °C) = 298.15 [K]. B is called B-constant which means the slope of temperature dependence. Each thermistor has its own B-constant and is defined in the datasheet of IGBT modules as the following table. Two temperature points must be defined for B-constant. We define B(25/50) as the B-constant with 25 °C and 50 °C.

Symbol	Item	Conditions	Limits			Unit
			Min	Typ	Max	
R_{25}	Zero-power resistance	T=25 °C	-	5.00	-	kΩ
$B_{(25/50)}$	B-constant	Approximate by equation	-	3375	-	K

To be precise, B-constant has a temperature dependence. Thus, more precise resistance value is given in the thermistor characteristics curve in the datasheet as Fig. 6-22.

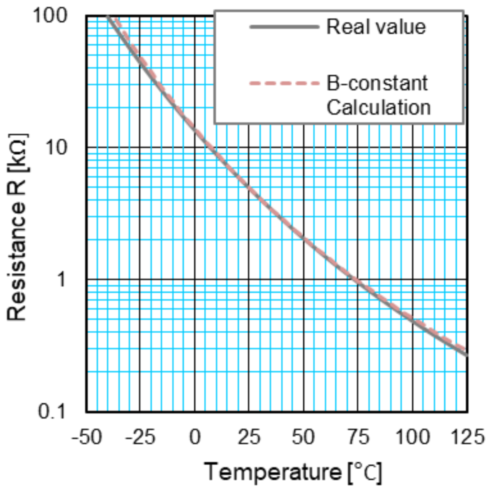


Fig. 6-22: Thermistor characteristics curve

In Fig. 6-22, the calculation result with B(25/50) is shown with red dashed line in addition to the thermistor characteristics curve. The calculation result matches the actual thermistor resistance very well. Then it is confirmed that the equation with B(25/50) is enough accurate in the range of operation temperature of power semiconductors. Also, calculation result with B-constant is even higher than real temperature and then it is safer side estimation.

$$R_{\square} = R_{25} exp\left\{B\left(\frac{1}{T} - \frac{1}{T_{25}}\right)\right\}$$

(2) NTC thermistor position

NTC thermistor is located on the substrate. Heat from power semiconductor chips is transferred to the thermistor via the substrate. Therefore, the thermistor temperature is lower than the chip temperature and rather closer to the case temperature

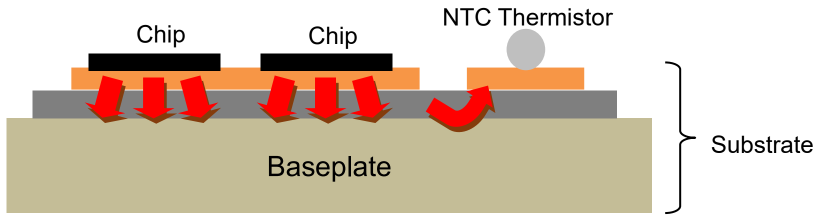


Fig. 6-23: NTC thermistor position and heat dissipation path

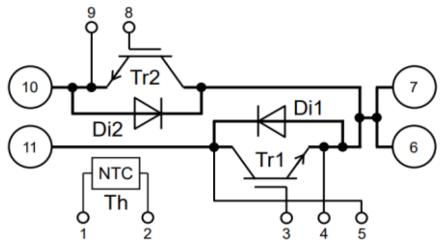


Fig. 6-24: Circuit diagram of NX module

NTC thermistor is connected with No. 1 and No. 2 terminals in Fig. 6-24. and the thermistor temperature can be calculated by measuring resistance between the two terminals.

(3) Measurement method of NTC thermistor resistance

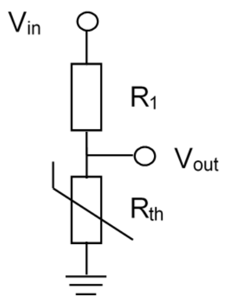
For thermistor temperature measurement, its resistance needs to be measured. A voltage divider is applicable for the resistance measurement. The resistance for series connection with the thermistor needs to be chosen to have precise measurement at the target temperature

The thermistor resistance is calculated with the divided voltage of the thermistor by the following equation.

$$R_{\square} = \frac{V_{out}}{V_{in} - V_{out}} \cdot R_1$$

The thermistor temperature is estimated with the calculated thermistor resistance by the following equation.

$$T = \frac{1}{\frac{1}{B}\, ln\left(\frac{R_{\square}}{R_{25}}\right) + \frac{1}{T_{25}}}$$



$$V_{out} = \frac{R_{\square}}{R_{\square} + R_1} \cdot V_{in}$$

Fig. 6-25: Temperature measurement circuit

6.9. Others

In the IGBT module, the insulation distance is designed to UL 840 as a reference standard, but there is a risk that the clearance might become insufficient at high altitude. Due to decreased air pressure, the withstand voltage for the same spatial distance decreases and the insulation capability decreases in general.

Also, as the altitude increases, the cosmic radiation will increase rapidly. It is known that as more cosmic radiation hits a semiconductor, the possibility of random failure increases. Please refer to application notes "About Isolation Voltage and LTDS".

7. How to use the IGBT module

7.1. IGBT Module Selection

(1) Voltage rating

The voltage rating of the IGBT module is determined by the input supply voltage of the applicable device or the bus voltage applied between P and N of the module. Generally, Table 7-1 shows the input power supply voltage, bus voltage, and rating of module.

Table 7-1. Application example of input power supply voltage and device rating

	Voltage rating of the IGBT module		
	650V	1200V	1700V
Input supply voltage (AC)	~ 240Vrms	~ 480Vrms	~ 690Vrms
P-N bus voltage (DC)	~ 450V	~ 850V	~ 1200V

(2) Current rating

It is a current value that can flow as a DC current. For switching operation (pulse), up to twice the rated current can be tolerated. However, in actual use, it is necessary to consider junction temperature, case temperature, life (lifetime of power cycle, thermal cycle etc) etc.

7.2. Recommended driving conditions and driving circuit

(1) Recommended driving conditions

The positive recommended gate voltage is $+V_{GE}$ = 15V±10%. If it is used under conditions above this recommended range, short circuit energy will increase by increasing the short circuit current, so it is necessary to shorten the time to shut off. Also, if it is lower than the recommended range, it is assumed that the operation will be in the active area, as shown in the output characteristics of the 7th generation IGBT (CM600DX-24T example) in Figure 7-1. When used in this active area, caution is necessary as there is a possibility of thermal destruction in a short time due to rapid temperature rise.

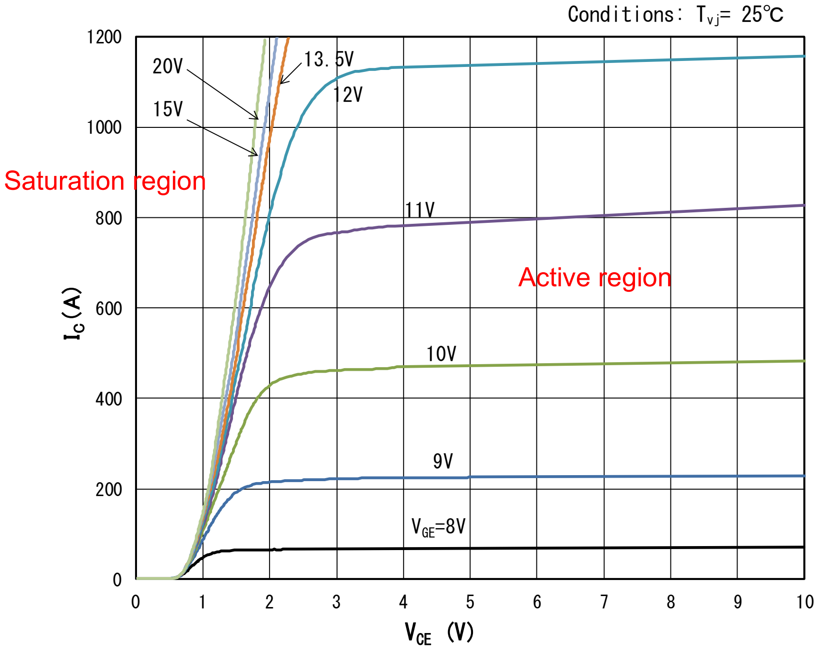


Figure 7-1. Output characteristics of the CM600DX-24T

Negative gate voltage is recommended $-V_{GE}$=-15V due to dependence of reverse bias voltage and switching loss. Apply a reverse bias voltage that does not allow false turn-on by external noise or dv/dt.

(2) Drive circuit

Key points of gate drive circuit design of IGBT module are gate voltage, gate resistance and wiring.
The basic form of the gate circuit is shown in Figure 7-2.

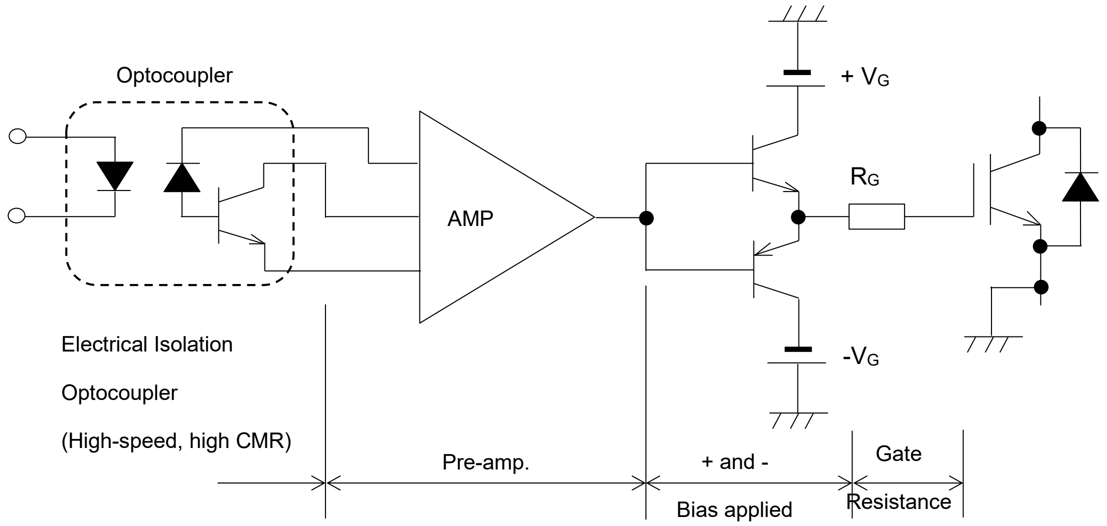


Figure 7-2. Basic form of the gate circuit

- Electrically isolate the IGBT module and the input signal by using an optocoupler. The optocoupler must be high speed with high noise immunity (high CMR).
- Be sure to design the buffer circuit to apply the positive and negative bias so that the gate current can flow sufficiently.
- Reduce the wiring between the gate drive circuit and the IGBT module as much as possible. Avoid noise induced from main circuit etc. by e.g. twisting a pair of the gate wiring and the emitter wiring. Do not bind up the gate wiring with the one for the other phases.
- When the load is short-circuited, the gate-emitter voltage V_{GE} rises and may break down due to the larger current flowing. Therefore, it is recommended to suppress surges of the gate-emitter voltage. An example is shown below in Figure 7-3.
- If a voltage is applied to the main circuit before the control voltage supply becomes stable, the IGBT module may be destroyed.
- In case a voltage is applied to the main circuit before the control voltage supply becomes stable, it is recommended to insert a resistor between the gate and the emitter. (Resistance value example: several kΩ to several tens of kΩ)
- Some optocoupler is available in market which can drive IGBT directly. Please contact the optocoupler or drive circuit manufacturer for the information.

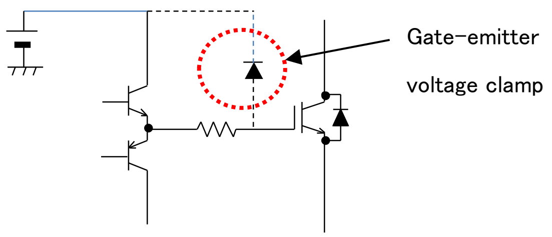


Figure 7-3. Gate-emitter voltage surge clamp example

(3) Selection of gate resistance

As for the gate resistance RG, upper and lower are listed as recommended values in the data sheet. The lower recommended value is the gate resistance condition that regulates the electrical characteristic switching time of the IGBT module, and is the minimum resistance value assuming actual use conditions. The gate resistance RG greatly affects switching time and switching loss. Below is a graph of switching time vs. RG and switching loss vs. RG of CM600DX-24T.

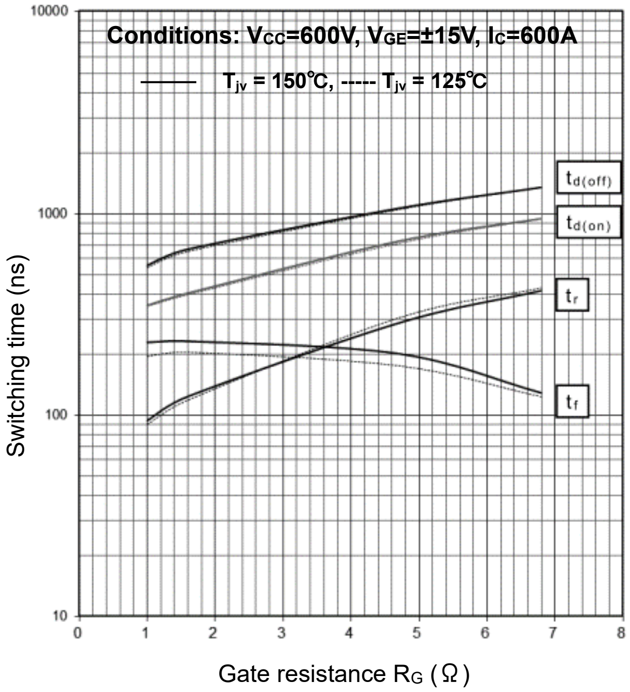


Figure 7-4. Switching time -RG

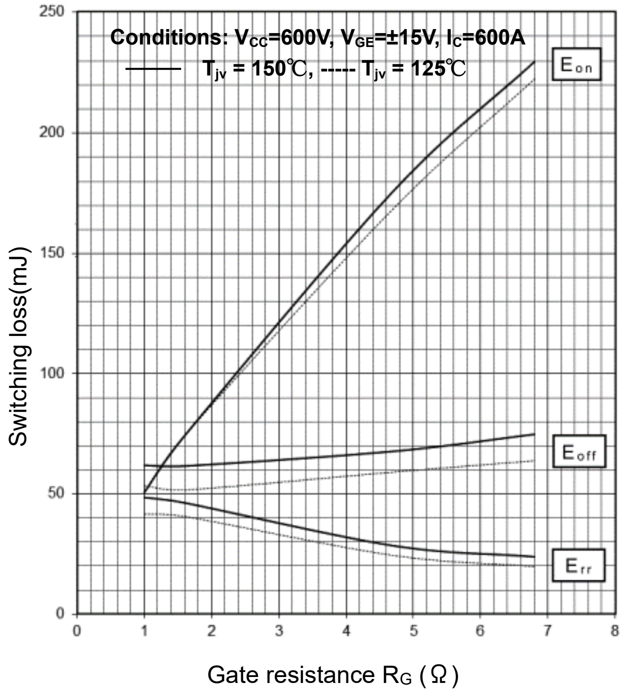


Figure 7-5. Switching losses -RG

It is necessary to select the optimum RG value from characteristics such as switching time, switching loss, surge voltage and so on. Optimum RG should be selected with careful confirmation for no occurrence of any maximum rating violation (Tvj, Vces, etc.) or any unexpected malfunction (arm-shoot-through, oscillation, etc.) at the actual application conditions. Too small RG may cause failure of IGBTs or FWDs. RG selection higher than its lower recommended value is strongly recommended. RG selection higher than its upper recommended value is not restricted, unless switching loss increase or any unexpected malfunction (arm-shoot-through, oscillation, etc.) are carefully checked.

Since the surge voltage will change depending on the wiring inductance of the equipment and the snubber circuit etc., the optimum value varies depending on the user. In order to maximize the device performance, it is recommended to individually set the gate resistance on turn-on side and turn-off side.

7.3. Gate drive power supply

A gate drive power supply that can supply sufficient gate current and drive power is necessary. Once the gate voltage and gate resistance R_G are determined, the gate current of the drive circuit and the required drive power are calculated as follows.

(1) Average current (When driven with V_{GE} = ±15V, excluding consumption by drive circuit)

Average drive current (Typ) = Q_G (-15V→+15) ×fc

Q_G: gate charge amount (-15V→+15V)

f_c: Switching carrier frequency

Figure 7-6 shows the characteristics of the gate charge of the CM600DX-24T.

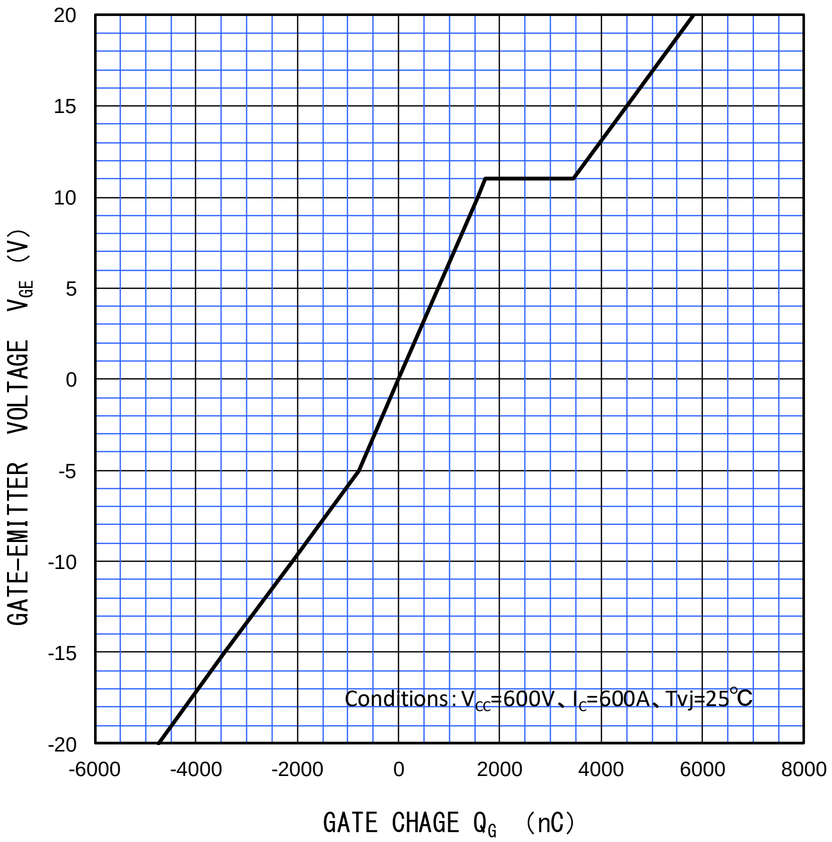


Figure 7-6. Gate voltage and Gate Charge

(2) Peak output current

$$I_{Gpeak} = \frac{(+V_{GE}) - (-V_{GE})}{R_G(external) + r_g(module\ internal)}$$

Note) In actual practice, the peak current value may be smaller than the calculated value due to the delay of the drive circuit, the inductance of the drive wiring, etc.

(3) Average drive power

$$= \frac{1}{T}\int V \bullet i dt$$

$$= (+V_{GE})\frac{1}{T_1}\int i dt + (-V_{GE})\frac{1}{T_2}\int i dt$$

$$= (+V_{GE}) \bullet Q_G \bullet fc + (-V_{GE}) \bullet Q_G \bullet fc$$

$$= ((+V_{GE}) + (-V_{GE})) \bullet Q_G \bullet fc$$

7.4. Dead time setting

In the inverter circuit etc., it is necessary to set the upper and lower arm dead time in the sequence of the drive signals in order to prevent upper and lower arm short circuit.

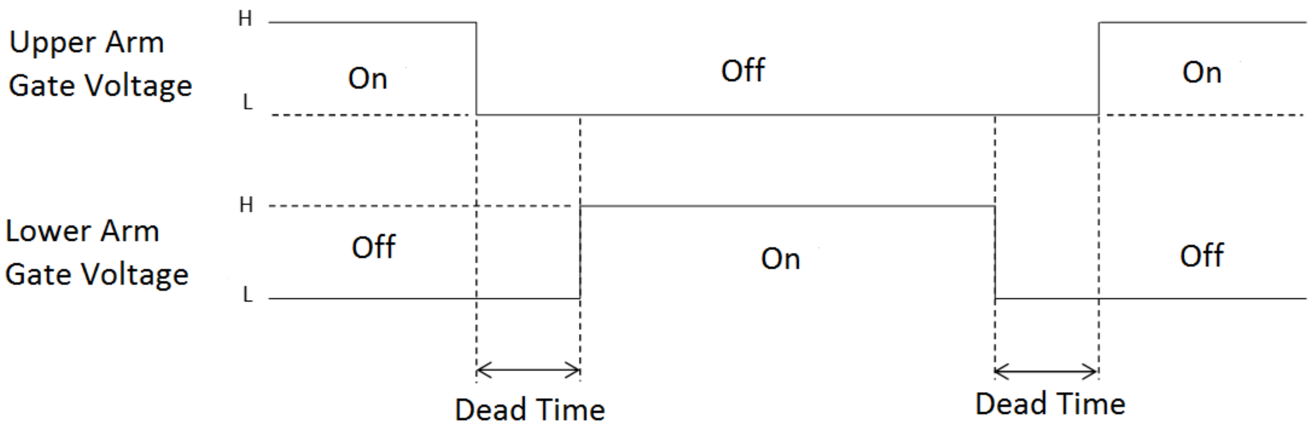


Figure 7-7. Upper and lower arm dead time

The required dead time depends on the switching time when the upper and lower arms turn on and turn off. Therefore, the required dead time will change depending on the gate resistance value. If the dead time is too short, upper and lower arms are short-circuited in the same phase and short-circuit current flows, so there is a possibility of thermal destruction. After testing with the actual unit, please set the dead time appropriately.

7.5. Short Circuit Protection

The short-circuit SOA (safe operation area) is defined in the data sheet.

(1) Conditions for short-circuit SOA (Please refer to data sheet for safe operation area)

·650V withstand voltage devices

V_{CC}≦400V, V_{GE}=±15V, T_{vj} = 25 - 150℃, R_G=recommended gate resistance value, short time t_w≦8μs, non-repetitive

·1200V withstand voltage devices

V_{CC}≦800V, V_{GE}=E0V, VT_{vj} = 25 - 150℃, R_G=recommended gate resistance value, short time t_w≦8μs, non-repetitive

The definition of short-circuit time t_w is shown in Figures 7-8 and 7-9.

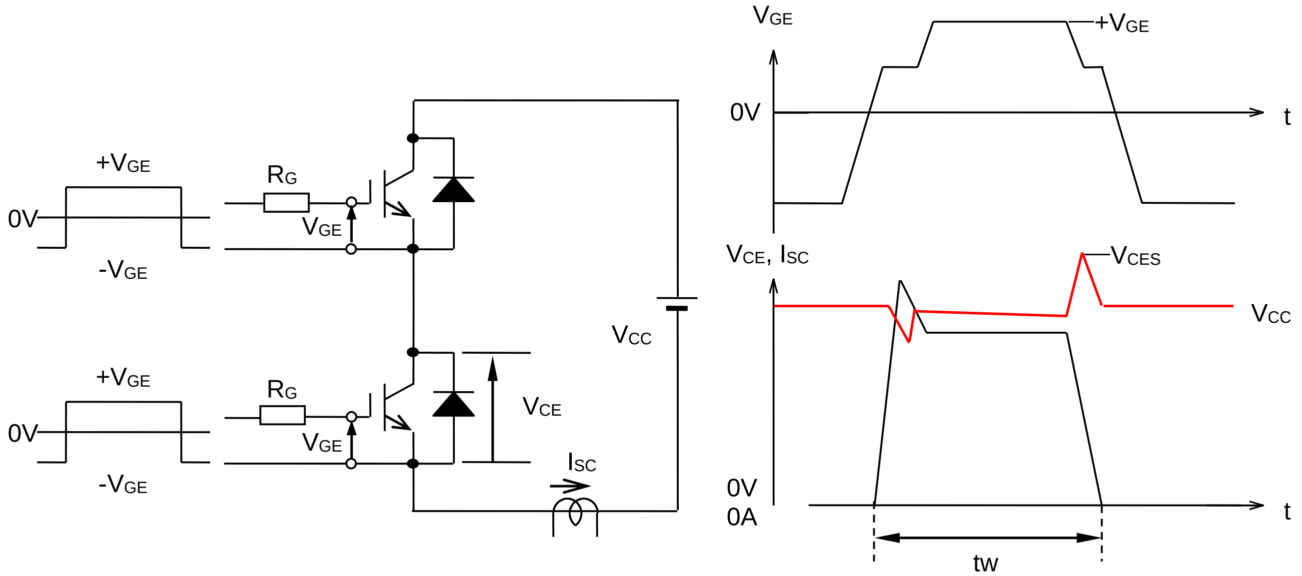


Figure 7-8. Definition of the short-circuit time t_w in the case of arm short circuit

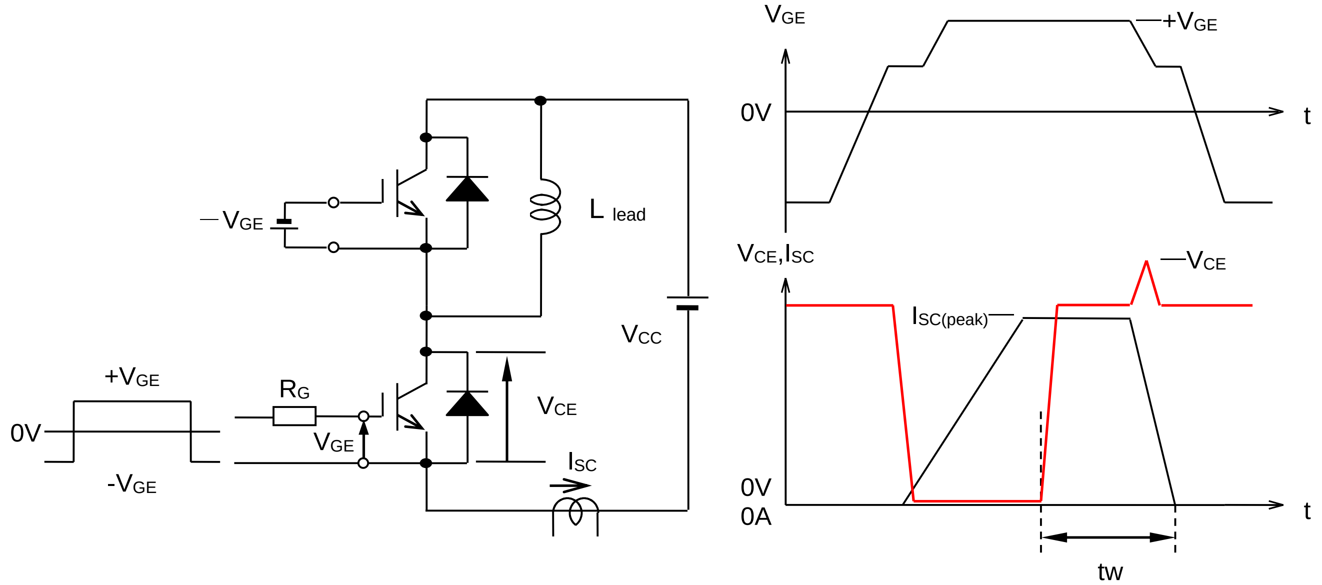


Figure 7-9. Definition of the short-circuit time in the case of load short-circuit t_w

(2) Short-circuit protection method

As a method of simply detecting the occurrence of a short circuit without detecting the collector current, a method of detecting the on-voltage (V) when the IGBT is on is often used. IGBT drivers etc. with built-in short circuit protection function are also on the market. The short-circuit protection circuit built in the IGBT driver judges the short circuit condition when the gate output is on and the collector potential of the IGBT is high, then shuts off the gate voltage. Since surge voltage (C-E) becomes high when cutting off a large current quickly, we recommend a method to suppress the gate voltage softly to suppress the surge voltage (C-E).

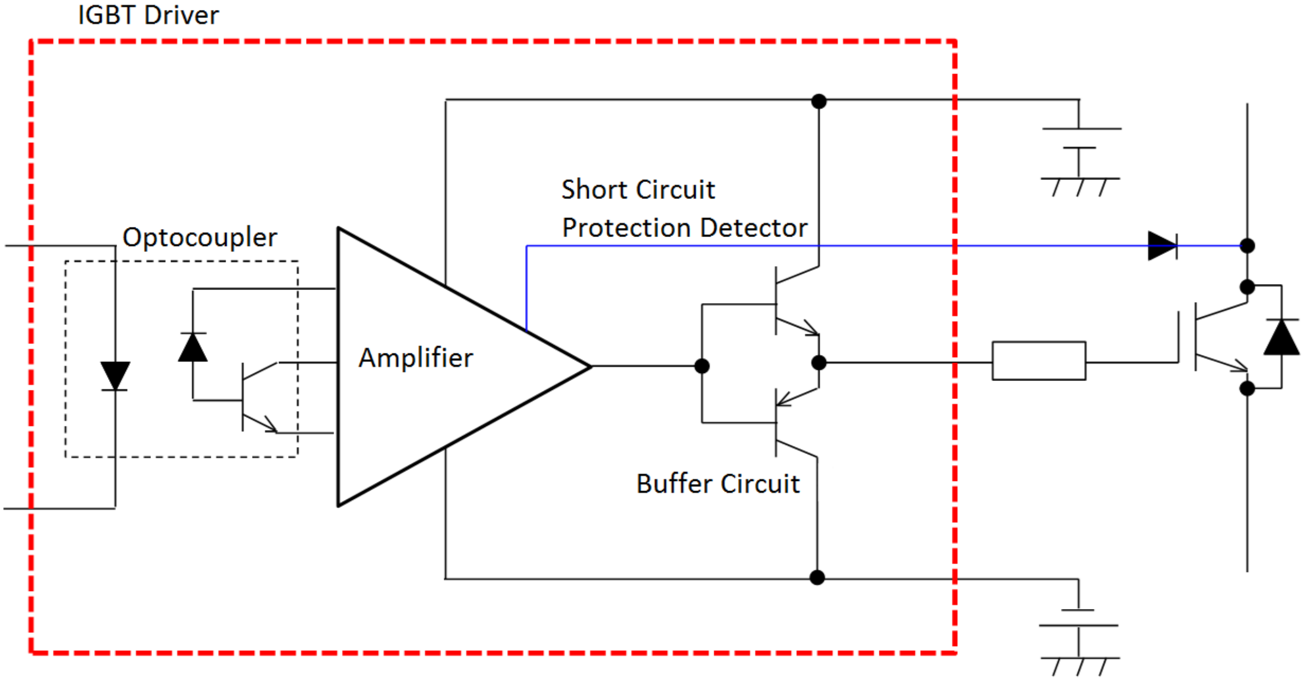
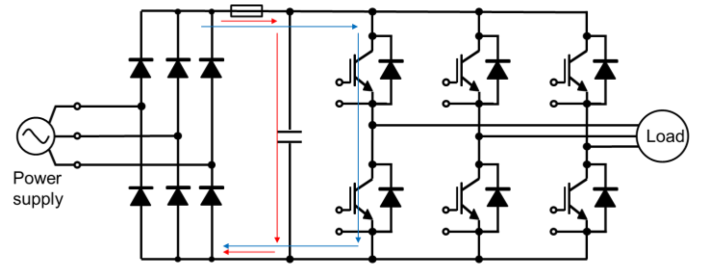
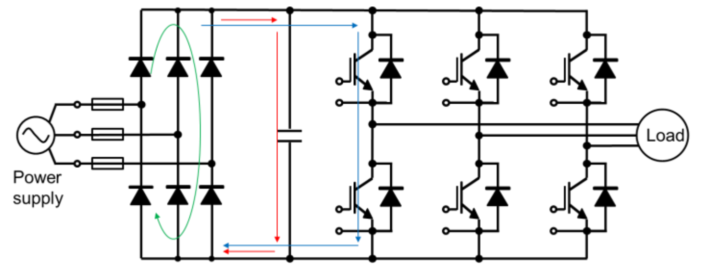
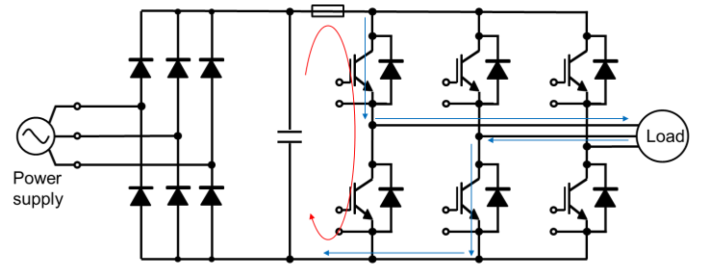


Figure 7-10. Example of short-circuit protection of IGBT driver

(3)Protection by fuse

Switching element/diode/capacitor destruction may cause secondary electrical damage to the commercial power supply or the system unit. In order to prevent the secondary damage, attach fuses or a breaker to the appropriate location. The references of the fuse location are shown below. Select properly rated fuse considering using voltage and blocking current.

Examples

	Protection detail
	Prevent power supply damage caused by arm short circuit or capacitor destruction.
	Prevent power supply damage and ground fault caused by capacitor destruction, arm short circuit or converter diode destruction
	Prevent system unit destruction and ground fault caused by arm short circuit or load short circuit.

7.6. Parallel connection of IGBT modules

(1) Parallel Operation

The following sub-sections outline the basic requirements and considerations for parallel operation of 7th generation IGBT module of dual switch configuration with ratings of 200A or more. 7th generation IGBT module lineups paralleling-specification type which is specially designated for parallel use.

V_{CEsat}-I_C characteristics of the 7th generation IGBT modules signify a positive with temperature coefficient. This feature (positive temperature coefficient) facilitates the reduction in the imbalance of the collector current between paralleled devices. When the junction temperature of IGBT rises, the V_{CEsat} increases and the collector current reduces accordingly.

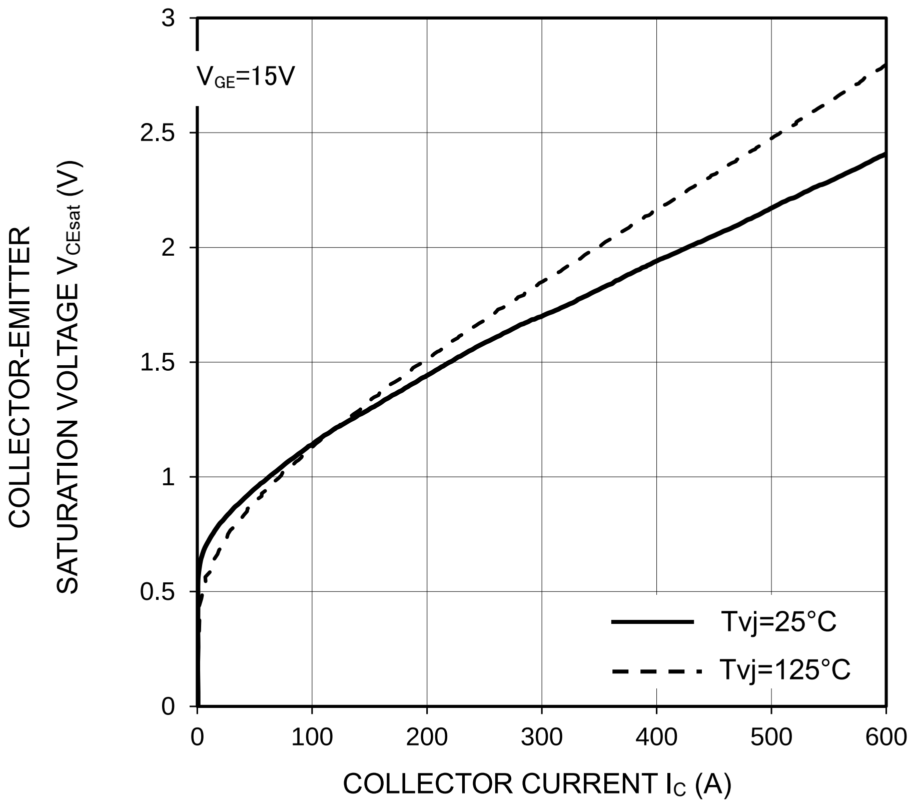


Figure 7-11. V_{CEsat} characteristics of CM300DX-24T

When two 7th generation IGBT modules with parallel specification are paralleled, the ratio of the maximum static current imbalance will be restricted to ±15% . Using modules from the same lot number in parallel is recommended since a smaller deviation in the V_{CEsat} results in a smaller ratio of the static current imbalance between two modules. (Please inquire of your sales contact the detail of the parallel specification)

As the number of modules connected in parallel increases, there is a possibility for any one single module to experience a high collector current. When modules are paralleled, calculate the derating current with formula shown below:

$$\left\{1-\frac{(n-1)\times\frac{1-x}{1+x}+1}{n}\right\}\times 100\%$$

Where n: number of paralleled modules

x: ratio of static current imbalance

Matching V_{CEsat} is effective for maintaining good static steady state current balance. Gate drive conditions and power circuit layout have the greatest impact on dynamic current balance between paralleled devices. The IGBT modules should be connected with a short and symmetric connection with low impedance to the application circuit in order to minimize the current imbalance.

Layout of main circuit

- Circuit connections should be low inductance and laid out symmetrically for balanced inductance.
  Difference in the circuit inductance between each device may result in current imbalance.
  Asymmetrically high power loss may occur on one particular device and cause thermal destruction. (Figure 7-12)

- Use snubber circuit for each module individually and reduce circuit inductance in order to minimize surge voltage.

<Example of Imbalanced current>
Collector current through each device has a large deviation due to an imbalance in the circuit inductance between devices.

<Example of balanced current>
Collector current flows symmetrically due to balanced circuit inductance between devices

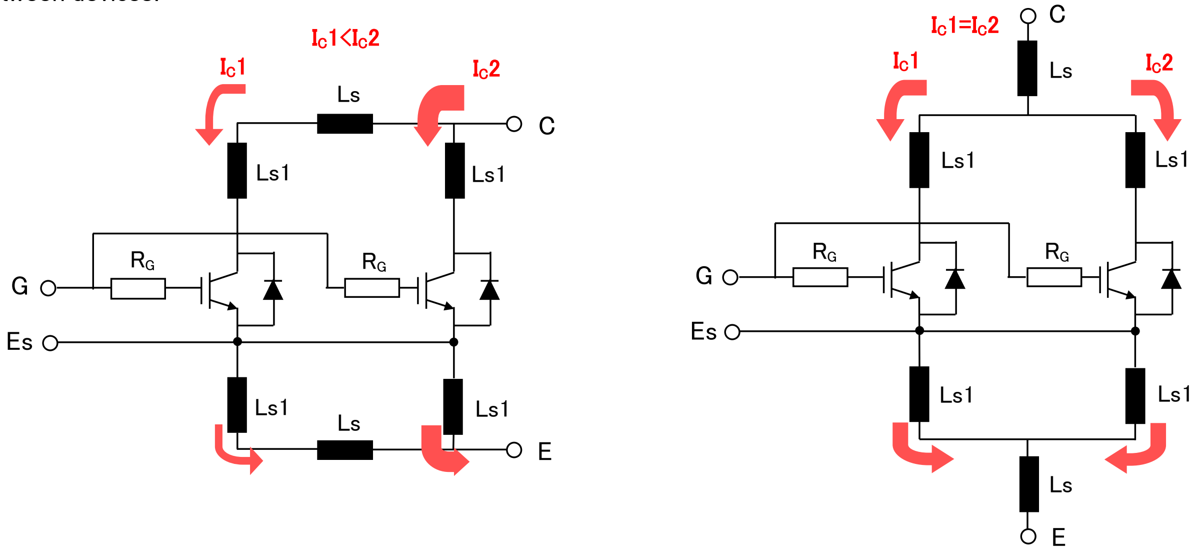


Figure 7-12. Current imbalance caused by an asymmetric main circuit inductance

Gate Drive Circuit

- Uniform impedance of each gate drive circuit. In case the difference in the impedance consisting of gate resistance and stray inductance is high, current imbalance may occur.

- Use short and tightly-twisted wires of equal length.

- Gate resistance should not be too high.

- Avoid running the wiring of drive circuit in parallel to main circuit.

- Use gate resistor for each device individually to prevent gate oscillation. (Figure 7-13)

- Insert a low value resistance (e.g. 0.1 Ω) or ferrite core in the emitter wiring of the gate drivers in case an inductive current flows in the loop of the main emitter wiring and the gate driver wiring. This loop current may cause a difference in the switching speeds between paralleled devices by influencing the instantaneous gate voltage. (Figure 7-14)

<Example of Imbalanced current>
Only a single gate resistor is employed to connect the gates of the paralleled devices.

<Example of Current balance>
Use gate resistors for each device individually to prevent gate oscillations

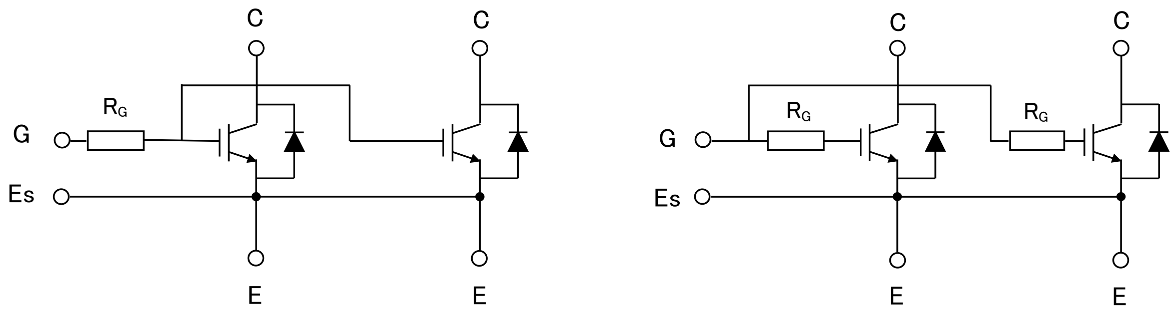


Figure 7-13. Measures to limit gate oscillation

<Example of Imbalanced current>
Inductive current flows through the drive circuit via emitter connection due to a difference in the value of the inductances Ls1 and Ls2.

<Example of Current balance>
Insert resistors (Rs =0.1ohm) or ferrite core in emitter wiring of the gate drive circuit to limit the inductive current flow.

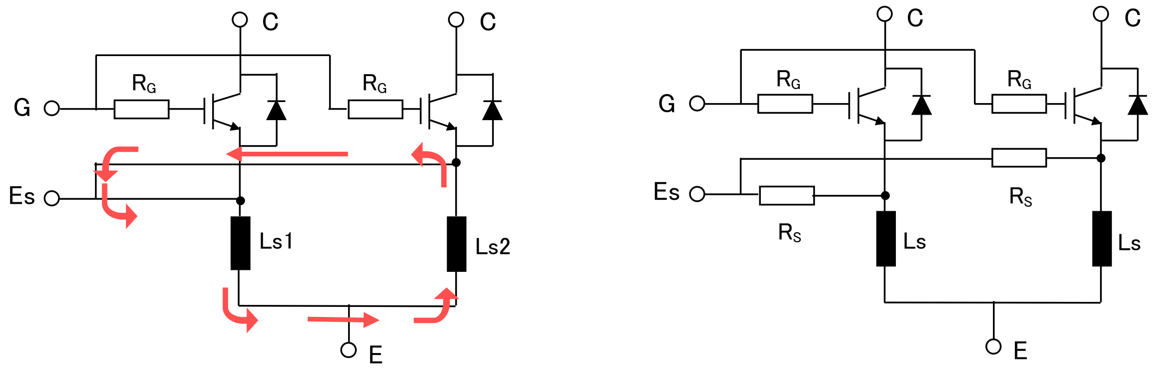


Figure 7-14. Measures to limit inductive current in emitter wiring

8. Power loss and heat dissipation design

8.1. How to calculate the power loss

Loss calculation of the power module

In order to use the power module safely, it is necessary to calculate the power loss and the junction temperature under the conditions to be used, and to use the module within the absolute ratings. When selecting a power module, you can download and use simulation software from our website.

Download site: **http://www.mitsubishielectric.com/semiconductors/simulator/index.html**

Please click "Register" on the page, and after entering the necessary information, the download page will be displayed.

*: Supported OS is Windows® 98SE or later only.

For the usage of the software, please download the manual “POWER LOSS SIMULATION Ver. * User’s Manual”

Power loss and junction temperature

It is very important to understand the junction temperature when using the IGBT module. How to obtain the junction temperature is explained by taking the waveform of Figure 8-1 as an example. The calculation of the IGBT part is shown below as an example, but the calculation method of the diode part is basically the same. Regarding the temperature rise, please be careful not only to the maximum rating, but also to the power cycle lifetime due to temperature swing.

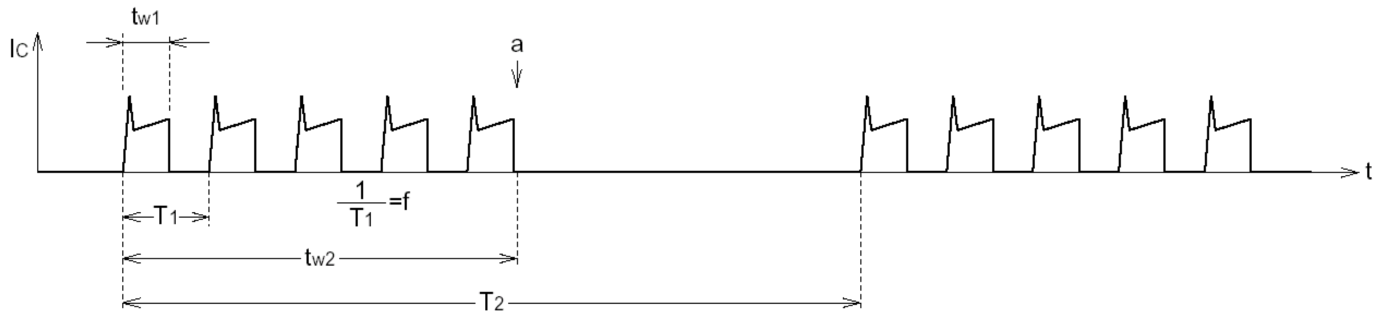


Figure 8-1. Determination of the junction temperature

Power loss

To determine the junction temperature, the user will need to know the losses of the IGBT module. The loss per pulse should be first determined. The loss of one pulse is considered divided into steady-state and switching losses.

(1) Steady-state loss

Using a graph of V_{CEsat} vs. I_C characteristics, calculate the energy (J).

$$E_{(sat)} = \frac{I_{C1} \times V_{CEsat1} + I_{C2} \times V_{CEsat2}}{2} \times t_{w1}$$

Note) The above expression is simplified. Originally described as:

$$E_{(sat)} = \int_0^{tw'} I_C(t) \bullet V_{CE}(t) dt$$

In this case, data of T_{vj} = 150℃ is used for the graph of V_{CEsat} vs. I_C.

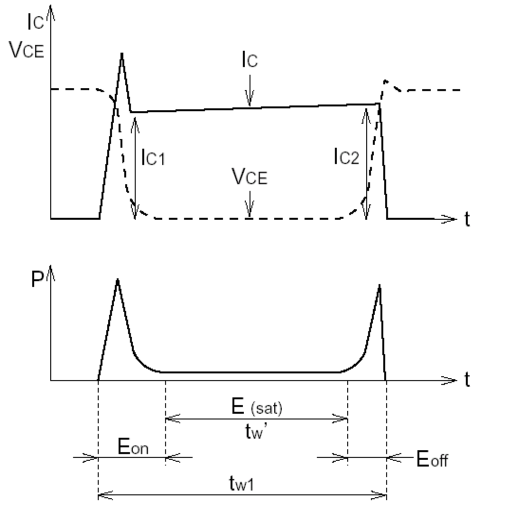


Figure 8-2. Steady-state Loss and Switching Loss

(2) Switching losses

The switching loss is obtained from the actual waveform by the piecewise quadrature.

$$E_{on} / E_{off} = \int_{ta}^{tb} I_C(t) \bullet V_{CE}(t) dt = \frac{1}{n} \sum_{n-1}^{n} P_n \times (t_b - t_a)$$

n: number of divisions (Equally divide the section of ta - tb, averaging the power loss for each point)

by summing (1) and (2), the loss of the IGBT E_1 per pulse is:

$$E_1 = E_{sat} + E_{on} + E_{off}$$

Also, the loss of the FWD section is calculated similarly to the IGBT section.

$$E_{rr} = \int_{ta}^{tb} I_E(t) \bullet V_{EC}(t) dt = \frac{1}{n} \sum_{n-1}^{n} P_n \times (t_b - t_a)$$

Refer to the integration range of switching loss as follows

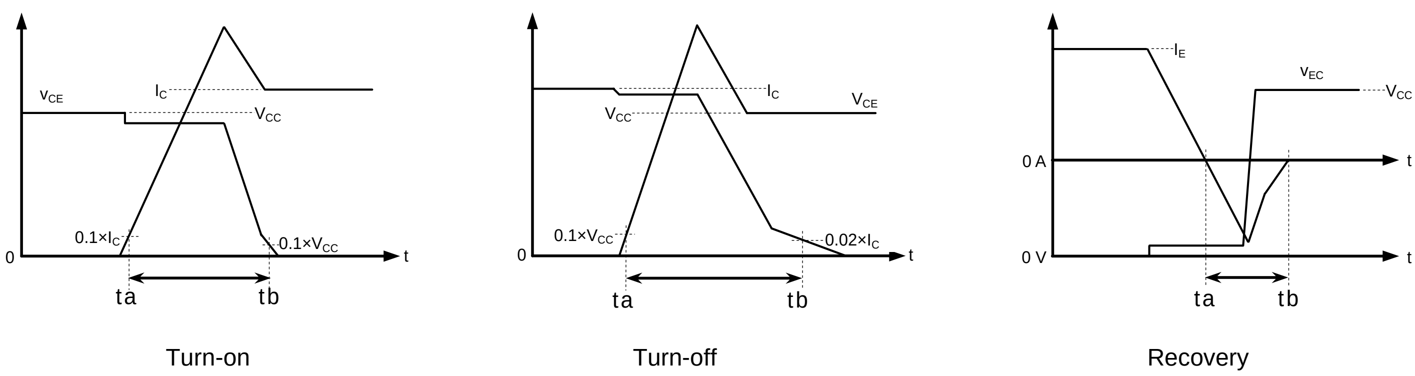


Figure 8-3. Integration range of switching loss

(3) Calculate the average power loss.

The average power loss in one pulse is

$$P_1 = \frac{E_1}{t_{w1}} \quad (W)$$

If the waveform in Figure 8-1 is approximated as a rectangular wave with respect to power, it is represented as shown in Figure 8-4.

Figure 8-4. Concept of Average Power Loss 1

Calculate the average power loss in the period t_{w2}. (See Figure 8-5)

$$P_{av} = \frac{E_1}{t_{w2}} \times N \quad (W)$$ N: number of pulses within the t_{w2} period

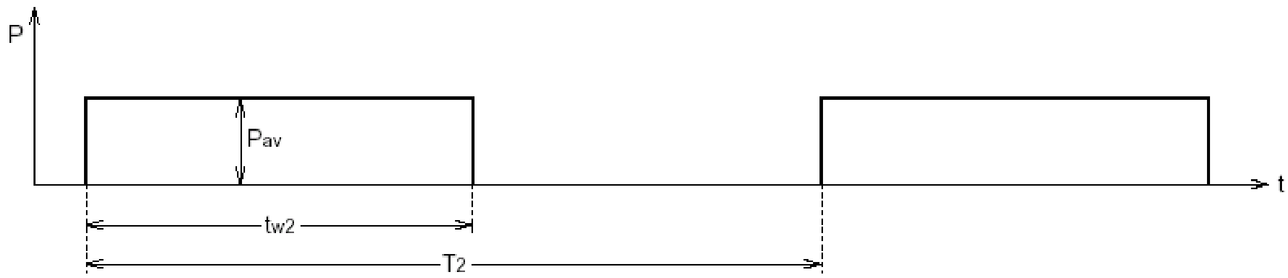


Figure 10-5. Concept of Average Power Loss 2

Calculate the overall average power loss. (See Figure 8-6)

$$P_{AV} = P_{av} \times \frac{t_{w2}}{T_2} \quad (W)$$

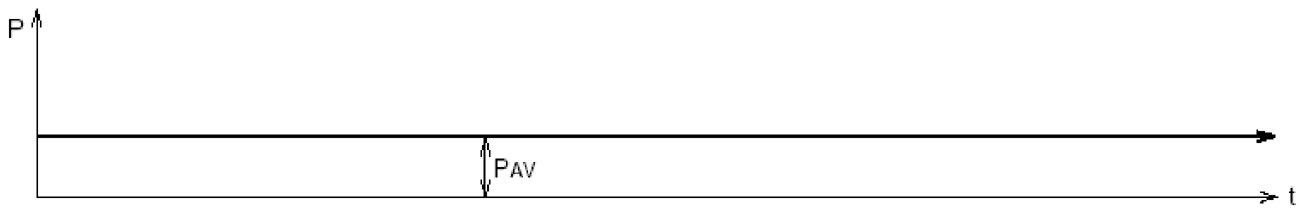


Figure 8-6. Concept of Average Power Loss 3

8.2. Calculation of temperature rise

Calculate the junction temperature using P_1, P_{av}, P_{AV} obtained above.

(1) $t_{w1} << 1ms$

In the approximation in Figure 8-5, the junction temperature is highest when the case temperature (or heat sink temperature) reaches steady state and the time when t_{w2} expires. (See Figure. 8-7)

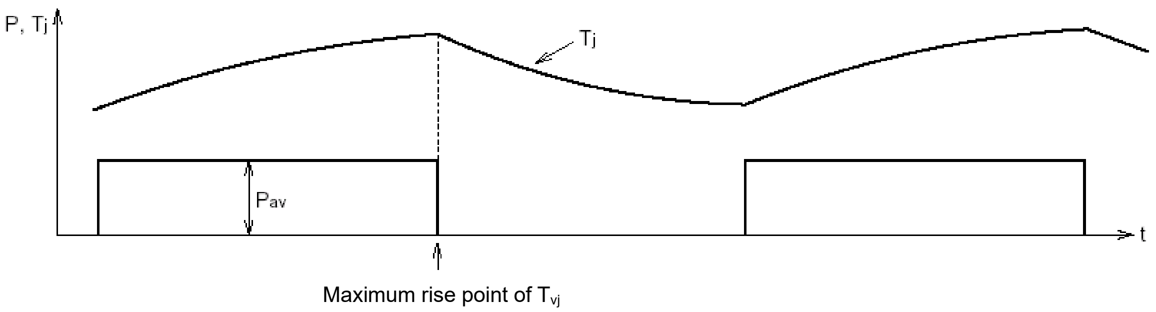


Figure 8-7. Concept of the junction temperature 1

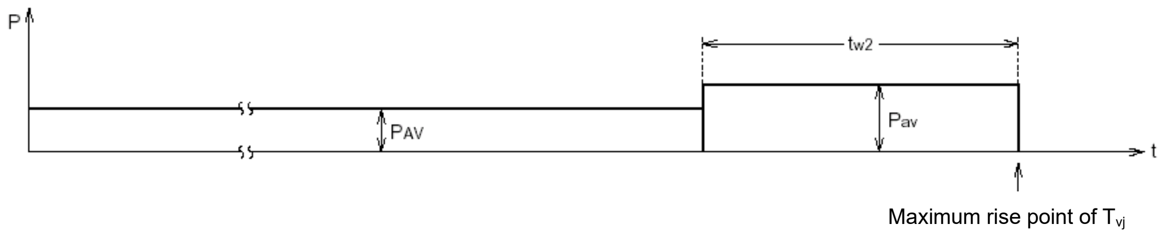


Figure 8-8. Concept of junction temperature 2

Assuming that the temperature difference between the junction and case is $\Delta T_{(j-c)}$

$$\Delta T_{(j-c)} = R_{th(j-c)} \times j_{AV} - Z_{th(j-c)}@t_{w2} \times 2_{AV} + Z_{th(j-c)}@t_{w2} \times P_{av} = R_{th(j-c)} \times j_{AV} + (P_{av} - P_{AV}) \times Z_{th(j-c)}@t_{w2}$$

$R_{th(j-c)}$ ······chermal resistance between junction and case

$Z_{th(j-c)}@t_{w2}$······Transient thermal impedance at the time of t_{w2} between junction and case

Using the above calculated $\Delta T(j\text{-}c)$, the junction temperature can be calculated as

$T_{vj} = T_c + \Delta T_{(j-c)}$ (Here Tc is measurement value at the position of just under chip by e.g. thermocouple)

Also, in order to keep the T_{vj} lower than the maximum rating T_{vjmax}= 175°C, the allowable case temperature rise can be calculated as:

$T_{C(max)} = 175 - \Delta T_{(j-c)}$.

Please also note that the case temperature T_C should not exceed its maximum rating T_{Cmax}.

(2) Overload from steady-state operation

In this case, ripple due to P_{OL} must also be taken into consideration. As in the case of (1), perform a square wave approximation as shown in Fig. 8-9.

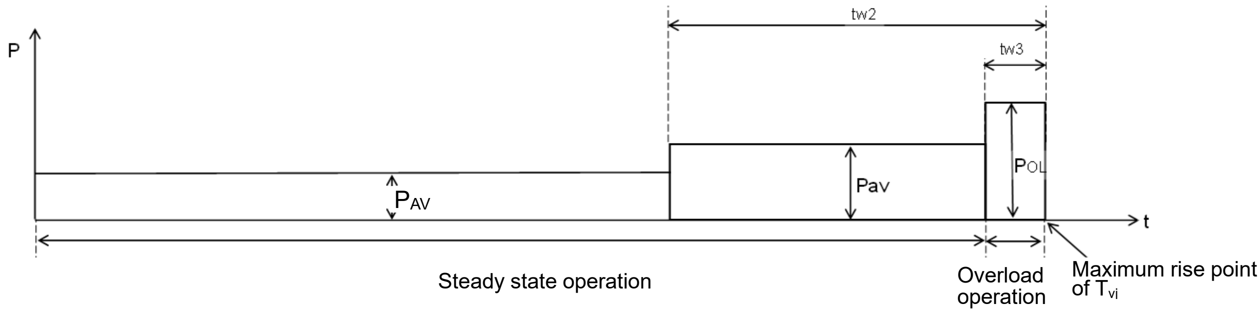


Figure 8-9. Concept of the junction temperature 3

$$\Delta T_{(j\text{-}c)} = R_{th(j\text{-}c)} \times j_{AV} - Z_{th(j\text{-}c)}@t_{w2} \times 2_{AV} + Z_{th(j\text{-}c)}@t_{w2} \times P_{av} - Z_{th(j\text{-}c)}@t_{w3} \times P_{av} + Z_{th(j\text{-}c)}@t_{w3} \times 3_{OL}$$

$$= R_{th(j\text{-}c)} \times j_{AV} + (P_{av} - P_{AV}) \times Z_{th(j\text{-}c)}@t_{w2} + (P_{OL} - P_{av}) \times Z_{th(j\text{-}c)}@t_{w3}$$

$R_{th(j\text{-}c)}$ j-chermal resistance between junction and case

$Z_{th(j\text{-}c)}@t_{w2}$ 2-Transient thermal impedance at the time of t_{w2} between junction and case

$Z_{th(j\text{-}c)}@t_{w3}$ -cTransient thermal impedance at the time of t_{w3} between junction and case

Using the above calculated $\Delta T_{(j\text{-}c)}$, the junction temperature can be calculated as

$T_{vj} = T_c + \Delta T_{(j\text{-}c)}$ （Here Tc is measurement value at the position of just under chip by e.g. thermocouple）

Please also note that the case temperature T_C should not exceed its maximum rating T_{Cmax}.

(3) Transient thermal impedance

Transient thermal impedance is calculated by the following equation.

The details of $R_{th(j\text{-}c)}$, R_i and τ_i are written in the each product data sheet.

$$Z_{th(j-c)} = R_{th(j-c)} \times \sum_{i=1}^{4} \left\{ R_i \times \left(1 - e^{-\frac{t}{\tau_i}} \right) \right\}$$

Heat sink selection

Figure 8-10 shows the thermal equivalent circuit when multiple modules are mounted on one heat sink.

In this equivalent circuit, the temperature of the heat sink is $T_s = T_a + (P_{Q(AV)} + P_{D(AV)}) \times N \times R_{th(s-a)}$

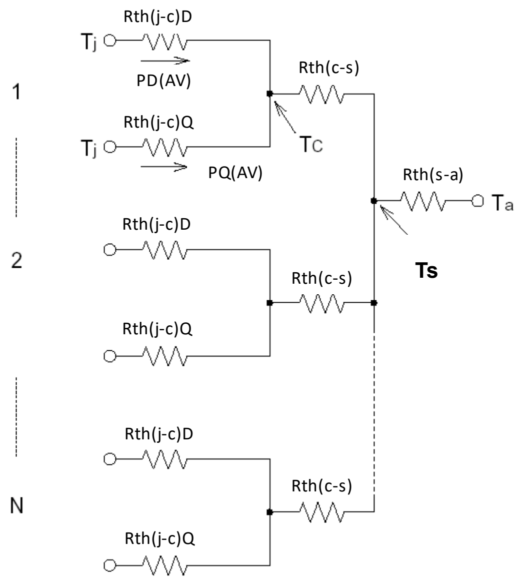


Figure 8-10. Thermal equivalent circuit

T_a: Ambient temperature

$P_{Q(AV)}$: average power loss of transistor part (W)

$P_{D(AV)}$: average power loss of diode part (W)

N: number of modules

$R_{th(s-a)}$: thermal resistance from heatsink to ambient (K/W)

In this equivalent circuit, case temperature T_C is calculated as:

$T_C = T_s + (P_{Q(AV)} + P_{D(AV)}) \times R_{th(c-s)}$

$\quad = T_a + (P_{Q(AV)} + P_{D(AV)}) \times N \times R_{th(s-a)} + (P_{Q(AV)} + P_{D(AV)}) \times R_{th(c-s)}$

$R_{th(c-s)}$: Contact thermal resistance between case and heat sink

Heat sink should be selected so that the calculated Tc above not exceed the value $T_{C(max)}$ which is obtained in 8.2.(1).

Therefore, the required thermal resistance of heat sink is calculated as:

$$T_C = T_a + (P_{Q(AV)} + P_{D(AV)}) \times N \times R_{th(s-a)} + (P_{Q(AV)} + P_{D(AV)}) \times R_{th(c-s)} < T_{C(max)}$$

$$\therefore R_{th(s-a)} < \frac{T_{C(max)} - T_a - (P_{Q(AV)} + P_{D(AV)}) \times R_{th(c-s)})}{(P_{Q(AV)} + P_{D(AV)}) \times N}$$

The $T_{C(max)}$ value obtained from the power loss of the IGBT part should be compared with the value obtained from the power loss of the diode part, and the lower $T_{C(max)}$ value should be applied.

(However, please also note that the case temperature T_C should not exceed its maximum rating T_{Cmax})

General precautions when applying to inverters

The above calculation method is a simplified calculation method. Please pay attention to the following when conducting detailed calculations.

① One period of output current should be divided into multiple pulses and it is necessary to calculate the the power loss and the temperature based on actual "PWM duty", "Output current" and "V_{CEsat}, V_{EC}, E_{on}, E_{off}, E_{rr} at the output current" ,and to accumulate the results.

② PWM duty depends on the signal generation method (modulation method).

③ The relationship between the output current waveform (or output current) and the PWM duty depends on various factors such as signal generation method (modulation method), load, etc. Therefore the output current should be based on actual measured waveforms.

④ For V_{CEsat} and V_{EC}, use the value of T_{vj} = 150℃.

⑤ For E_{on}, E_{off}, and E_{rr}, the value at T_{vj} = 150℃ under half bridge operation is used.

General precautions for thermal design

① It is necessary to consider the operating conditions that make the worst case losses.

② Temperature change due to output current frequency/period should be taken into account.
(Approximately +30% at 60 Hz. When the output current fundamental frequency is low (several Hz) and lasts several seconds, it will be similar as the temperature when DC continuous switching operation at its peak current.

③ In addition to T_{vjmax}, the influence of power cycles and thermal cycles must also be taken into consideration.

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