(Ref.No. : NO.IGBT-HI-00002 R2)

(HIGH VOLTAGE IGBT MODULE)

Application Manual

Hitachi Power Semiconductor Device, Ltd.

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- The handler of the Hitachi high-voltage IGBT module (hereinafter, this product) is advised to keep this manual within reach.
  Refer to the "Contract" separately for details on the agreement and warranty for this product.
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  - Problem details (with as much detail as possible, describe the state before and after the problem occurred)

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Safety Precautions

Before using the Hitachi IGBT modules, please thoroughly read this manual and refer to its diagrams and materials for proper use. Be sure to familiarize yourself with knowledge of the device, safety information, and all precautions before use.
In this manual, safety precautions are ranked as "WARNING" or "CAUTION."

Definition of Symbols

: A potentially hazardous situation which, if the product is mishandled, could result in death or serious injury.

: A potentially hazardous situation which, if the product is mishandled, could result in minor or moderate injury and / or damage to property.

Furthermore, even some items described in ⚠CAUTION , may lead to serious results depending on the situation.
Please observe both symbols as they provide important information.

* The degree of damage is classified based as follows.

Serious Injury	: requires hospitalization, long-term outpatient treatment, and / or results in aftereffects such as blindness, injury, burns (high temperature or low temperature), electric shock, fractures, poisoning.
Minor Injury	: does not require hospitalization or long-term outpatient treatment. (Other than the above)
Property Damage	: refers to extensive damage related to equipment and / or property.

Concerning the safety of the Hitachi IGBT module, these safety precautions are based on the principles to ensure necessary safety and are important as they complement the various measures in the product itself. Please establish safety measures observing various standards for the safe operation and maintenance of equipment and facilities.

> Apart from the warning mentioned above, matters necessary to prevent damage to the product and for its proper operation are also mentioned as **Important Notice** . Please observe these as well.

Safety Precautions (Continued)

<General Precautions>

- Semiconductor devices may experience failures due to accidents or unexpected surge voltages. Accordingly, you should always adopt fail-safe design techniques, redundancy, etc. to avoid extensive damage in the event of failure.

- Semiconductor devices were not specifically designed as a device to be used in life-threatening situations.
  For those applications where extremely high reliability is required (such as nuclear power control, aerospace and aviation, transportation equipment, life-support-related medical equipment, fuel control equipment, and various kinds of safety equipment), use a semiconductor device with extremely high reliability and incorporate fail-safe precautions and other safety measures. In addition, please consult Hitachi's sales department staff in such cases.
  (If the semiconductor devices fail, its wiring, wiring patterns, etc. may emit smoke or catch on fire or the semiconductor device itself may burst as a result.)

- High Current Load Test
  Please perform an actual loading test that covers current, voltage, frequency, pulse width conditions, etc. that may occur when actually using the equipment.

The following warnings are for the Hitachi IGBT module. Failure to observe these warnings may cause hazardous conditions that may result in death or serious injury. In addition, this list is not arranged in any order of importance. All warning items are important.

⚠ WARNING	Page Listed
(Chapter 7 Failure Precautions) **(7-1. Warnings)** **(7-1-1. Precautions for Package Bursting)** ● When either a load- or arm- short circuit occurs in an IGBT module, it must be turned OFF immediately (in a few microseconds). Otherwise, the module case may burst.	35
(7-1-2. Warnings Against Burns and Electric Shock) ● Do not go near or touch the product when it is powered on. Such actions may cause burns or electric shock.	35

The following precautions are for the semiconductor device. Failure to observe these precautions may cause hazardous conditions that may result in minor injuries and / or damage to property. In addition, this list is not arranged in any order of importance. All warning items are important.

⚠ CAUTION	Page Listed
(Chapter 2 Contents of Specifications) ●Regardless of any changes in external conditions during use, "absolute maximum ratings" should never be exceeded when designing electronic circuits using semiconductor devices. Furthermore, in pulsed-mode situations, the rated value of "safe operating area (SOA)" should always be observed.	3
(Chapter 7 Failure Precautions) **(7-2. Cautions)** ● After the IGBT breaks down, ensure that a short-circuit current does not continue flow for a long time (several hundred microseconds). This may cause smoke or fire.	35

History List

Revision No.	History (revisions and reasons)	Date	Created by	Reviewed by	Approved by	Remarks
Revision 0	New Issue	2000/10/12	Koga	Kurosu	Uehara	
Revision 1	3-1 Derating item correction (P7) 3-7 Thermal Impedance and Heat Dissipation Design item correction (P20)	2002/10/23	Kato	Saito	Koga	
Revision 2	Content correction ・ Front Cover ・ Important Notice ・ Safety Precautions ・ Table of Contents ・ Body 1-1 Type Numbering System 1-3 The Basic Structure of Module 2-1 Contents of Specification 3-4 Dynamic Avalanche 3-7 Thermal Impedance and Heat Dissipation Design 3-8 Dead Time 4-1 Mounting IGBT Modules to Heat Sinks 4-2 Mounting to the Terminal 5-3 Reliability Test	2009/12/15	Nakamura	Koike	QA/Abe	

Introduction

This manual is a written explanation of the specifications of the IGBT module, a type of semiconductor device, its tables of characteristics, external dimensional drawings, and precautions for use. It is intended for people who are familiar with the testing of the IGBT module itself, or the design, manufacture, or testing of inverters or other electrical equipment that use the IGBT module. In addition, in order to use and clearly understand the contents of this manual, it requires a level of knowledge or education equivalent to a graduate of a technical high school who enrolled in an electrical engineering course.

The IGBT module is the voltage control type semiconductor switch for controlling the on-off of the main circuit current by controlling the voltage applied to the gate.

This manual describes methods of handling required in order for the IGBT module to function smoothly and safely.

This manual is subject to change without prior notice to accommodate technology changes which affect product characteristics.

For latest information (details about the individual specifications and application of each product), please refer to the following website.

(http://www.hitachi-power-semiconductor-device.co.jp/en/)

If there is anything unclear, please contact our sales office.

Explanation of Terms and Abbreviations

Please refer to the table below for the meanings of terms and abbreviations used in this manual.

Terminology and Abbreviations	Original Term	Definition
IGBT	Insulated Gate Bipolar Transistor	Insulated Gate Bipolar Transistor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor	Metal Oxide Semiconductor Field Effect Transistor
FWD	Fly Wheel Diode	Fly Wheel Diode *Here, refers to the diode connected in reverse order with the IGBT
RBSOA	Reverse Biased Safe Operating Area	Reverse Biased Safe Operating Area

Organization of this Manual

This manual is a written explanation of the specifications of the IGBT module, a type of semiconductor device, its tables of characteristics, external dimensional drawings, and precautions for use. *These instructions should be read and clearly understood before use, and the IGBT module should be used accordingly by people who are familiar with the testing of the IGBT module itself, or the design, manufacture, or testing of inverters or other electrical equipment that use the IGBT module.

The contents of this manual are organized as follows.

Chapter 1 IGBT module: Explanation of the IGBT module numbering system, structure, and operating principles

Chapter 2 Specification items: Explanation of specification items mentioned

Chapter 3 Precautions for use: Explanation of precautions to be observed when using the IGBT module

Chapter 4 Precautions on mounting: Explanation of precautions to be observed when mounting the IGBT module

Chapter 5 Reliability: Explanation of the reliability of and quality assurance for the IGBT module

Chapter 6 Troubleshooting: Explanation of the IGBT module's failure mode and methods of checking for electrical characteristics during breakdown

Chapter 7 Failure Precautions: Explanation of safety precautions when failures related to the IGBT module occur

Table of Contents

Chapter 1 General Description of IGBT Modules

1-1. Numbering ……P1

1-2. Production Lot Numbering ……P1

1-3. Structure of Module ……P1

1-4. Structure of the IGBT Die ……P2

1-5. Equivalent Circuit and Operational Principle of the IGBT ……P2

Chapter 2 Contents of Specification

2-1. Contents of Specification ……P3

2-2. Characteristic Curves ……P4

2-3. IGBT Terms, Symbols and Definitions ……P5

2-4. Defintive Figures of IGBT characteristics ……P6

Chapter 3 Precautions for Safe Use

3-1. Derating ……P7

3-2. Snubber Circuits ……P8

3-3. Gate Driving ……P11

3-4. Dynamic Avalanche ……P13

3-5. Parallel Connections ……P14

3-6. Calculation of Power Dissipation ……P18

3-7. Thermal Impedance and Heat Dissipation Design ……P20

3-8. Dead Time ……P22

3-9. Short Circuit Protection ……P24

Chapter 4 Mounting Precautions

4-1. Mounting IGBT Modules to Heat Sinks ……P25

4-2. Mounting to the Terminal ……P27

4-3. Mounting Environment ……P27

4-4. Storage And Shipping Precautions ……P27

4-5. Precautions against Electrostatic Failure ……P28

4-6. IGBT Module Circuit Arrangement and Wiring Method ……P28

4-7. Measurement Precautions ……P28

Chapter 5 Reliability

5-1. Failure Rate ……P29

5-2. Failure Factors ……P29

5-3. Reliability Test ……P30
5-4. Quality Assurance System Diagram ……P32

Chapter 6 Troubleshooting
6-1. IGBT Failure Modes (Electrical Failure Mode) ……P33
6-2. Device Check Method ……P34

Chapter 7 Failure Precautions
7-1. Warnings ……P35
7-2. Cautions ……P35

List of Figures

Figure No.	Name	Page No.
Figure 1.1	Basic Structures of an IGBT Module	-1-
Figure 1.2	Structure of an IGBT Die	-2-
Figure 1.3	Equivalent Circuit	-2-
Figure 1.4	Operational Description	-2-
Figure 2.1	Definition of IGBT Switching Characteristics (ton, toff)	-6-
Figure 2.2	Definition of FWD Reverse-Recovery Characteristics (trr)	-6-
Figure 3.1	Features of Various Snubber Circuits	-8-
Figure 3.2	Turn-OFF Mode of Bottom Arm IGBT	-8-
Figure 3.3	Equivalent Circuit in a Transient State	-8-
Figure 3.4	IGBT Module Current (Ic) and Voltage (VCE) Waveforms with Snubber Circuit	-9-
Figure 3.5	Waveforms of Each Snubber Circuit Part	-9-
Figure 3.6	Example of IGBT Switching Waveform (Current and Voltage)	-11-
Figure 3.7	Gate Charge (QG) Characteristics	-11-
Figure 3.8	Driving Voltage and Gate Charge Characteristics	-12-
Figure 3.9	Example of IGBT Turn-OFF Waveform	-13-
Figure 3.10	Example of Dynamic Avalanches Area	-13-
Figure 3.11	Example of Parallel Connection between IGBT Modules and Driver Circuit	-15-
Figure 3.12	Wiring to Equalize Main Wiring Inductance Values	-16-
Figure 3.13	Equalization of Unbalanced Current	-16-
Figure 3.14	Parallel Connection Operations (without Snubber)	-17-
Figure 3.15	Parallel Connection Operations (with Snubber)	-17-
Figure 3.16	Ic vs. VCE Characteristic	-18-
Figure 3.17	Switching Loss vs. Collector Current	-18-
Figure 3.18	Forward Current vs. Forward Voltage	-19-
Figure 3.19	Temperature Measuring Points	-20-
Figure 3.20	Thermal Equivalent Circuit	-20-
Figure 3.21	Temperature Ripple	-21-
Figure 3.22	Transient Thermal Impedance	-21-
Figure 3.23	Inverter Operating Temperature Ripple	-21-
Figure 3.24	Typical Configuration of a Major Circuit (Single-Phase Top and Bottom Arms)	-22-
Figure 3.25	Control Signal, Driver Voltage, and IGBT Collector Voltage Waveforms	-22-

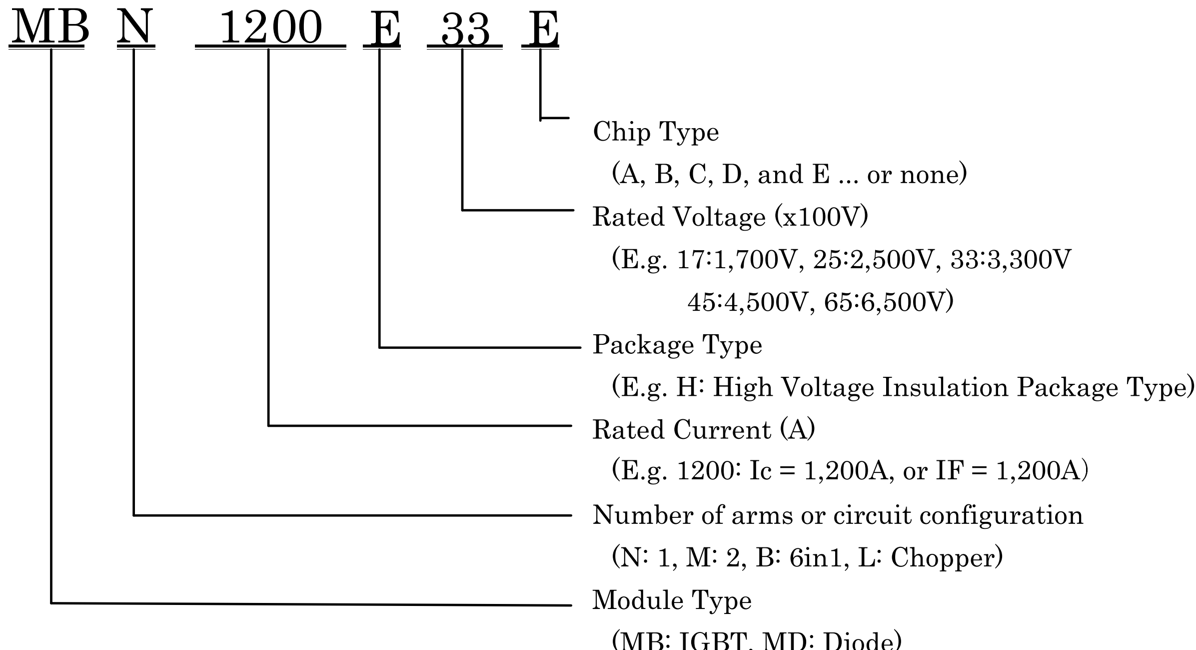
Figure 3.26 Verification Circuit Configuration (Half-Bridge Circuit) ······························-23-
Figure 3.27 Control Signal and Gate Waveforms ······························-23-
Figure 3.28 Top and Bottom Arm Short-Circuited Waveform ······························-23-
Figure 3.29 Short-Circuit Protection Waveforms ······························-24-
Figure 4.1 Grease Application Method with Screen ······························-25-
Figure 4.2 Clamping Order for IGBT Module ······························-26-
Figure 4.3 Example of Improper Heat Sink Mounting ······························-26-
Figure 4.4 Cross-Sectional View of Screw Hole ······························-27-
Figure 5.1 Module Failure Regions (Bathtub-Shaped Curve) ······························-29-
Figure 6.1 Electrical Failure Analysis ······························-33-

List of Tables

Table No.	Name	Page No.
Table 2.1	Specifications Sheet (Example)	-3-
Table 2.2	Characteristic Curve Items	-4-
Table 2.3	IGBT Terms, Symbols and Definitions	-5-
Table 3.1	Example of Short-Circuit Protection	-24-
Table 4.1	Recommended Clamping Torque Values for IGBT Mounting	-25-
Table 4.2	Recommended Grease and Specific Gravity	-26-
Table 4.3	Recommended Mounting Hole Diameter and Chamfering Value (mm)	-26 -
Table 4.4	Recommended Clamping Torque for Terminals	-27-
Table 4.5	Size for Screw Hole	-27-
Table 5.1	Failure Mechanisms	-29-
Table 5.2	Reliability Test Types and Descriptions	-30-
Table 5.3	Reliability Test Types and Testing Conditions	-31-
Table 5.4	Chart of Hitachi's Quality Assurance System	-32-
Table 6.1	IGBT Electrical Characteristics Check Method (Reference)	-34-

1. General Description of IGBT Modules

1-1. Numbering



1-2. Production Lot Numbering

The nameplate on the module has a production lot number (in a format different from the above) such as the following.

Lot number example: 9 06404

- 06404 — Internal control number (assembly lot - serial number)
- 9 — Production year (Last digit of the Western calendar year)

1-3. Structure of Module（Example ; single pack module）

Figure 1.1 shows a cross-sectional representation of the internal structure of a Hitachi IGBT module, specially a single pack module.

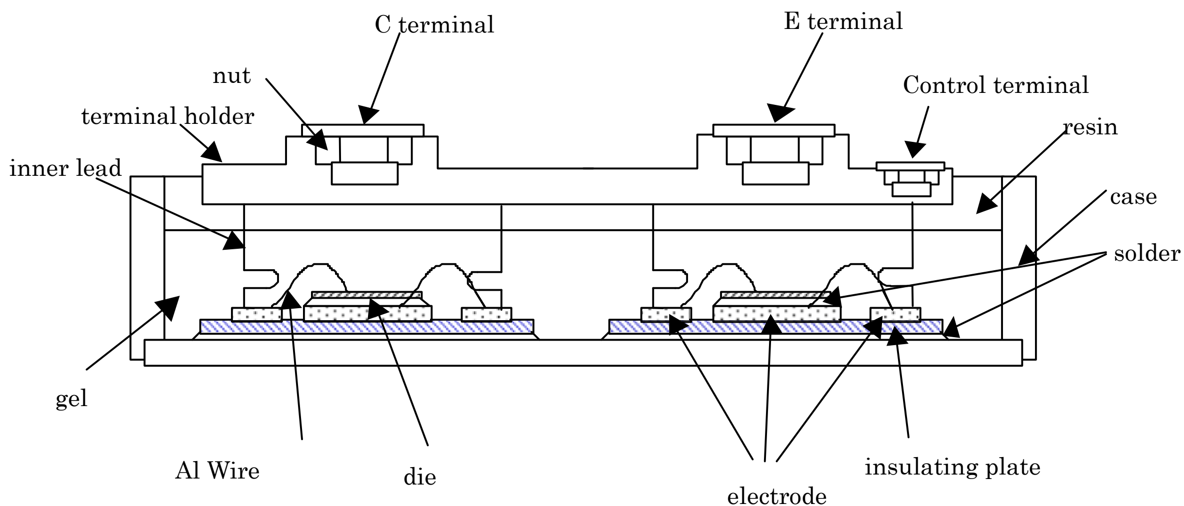


Figure 1.1 Basic Structures of an IGBT Module

1-4. Structure of the IGBT Die

Figure 1.2 shows the structure of IGBT Die.
An IGBT die is similar to an n-channel MOSFET in its structure. Although the MOSFET is constituted of N-N base, the IGBT is P-N base, so the parasitic pnp transistor is formed an additional Player.

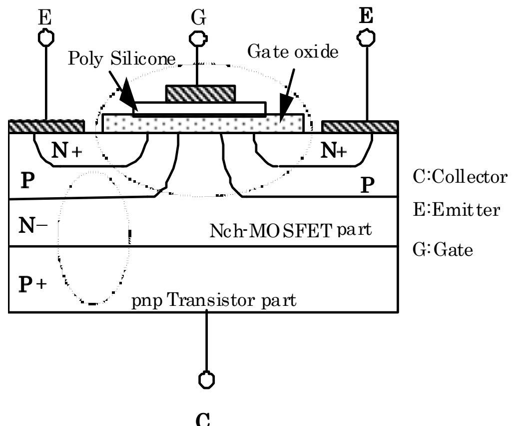


Figure 1.2 Structure of an IGBT Die

1-5. Equivalent Circuit and Operating Principle of the IGBT

1-5-1. Equivalent Circuit of the IGBT

Figure 1.3 shows the equivalent circuit symbol of the IGBT. The symbol and equivalent circuit are as shown in figure 1.3.
The equivalent circuit is designed with very little resistance at the npn transistor base-emitter junction to prevent latchup linked with the pnp transistor.
For the IGBT module, FWD is normally connected in parallel, and in this case, the diode symbol connects in parallel with the IGBT.

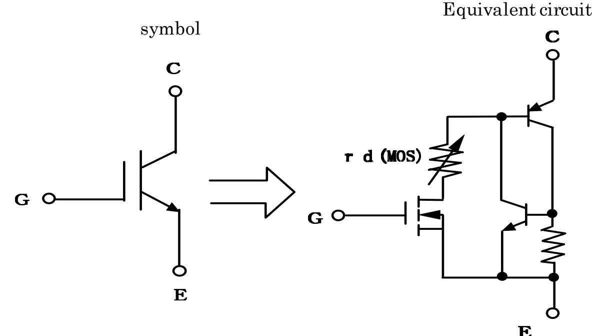
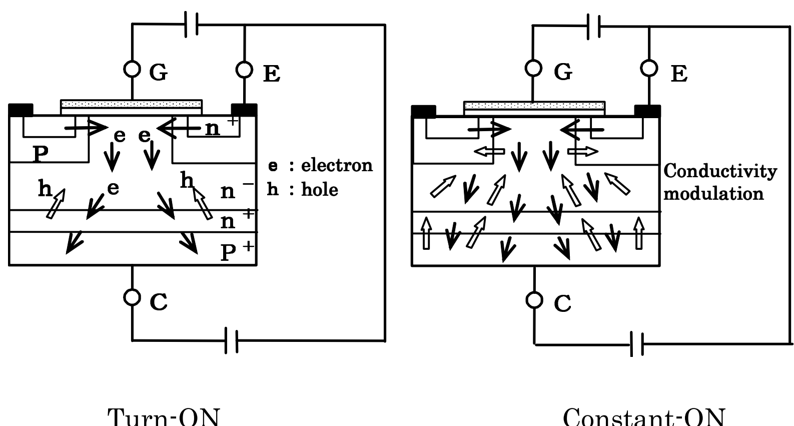


Figure 1.3 Equivalent Circuit

1-5-2. Operating Principle of the IGBT

Figure 1.4 shows the operating Description of the IGBT. MOSFET is turned ON by first applying a voltage to gate-emitter electrode. As a consequence, the MOSFET's drain current flows as the base current of the pnp transistor. This base current turns ON the pnp transistor, and the IGBT reaches its ON state. When the gate-emitter voltage becomes below the Gate-Emitter Threshold (a zero or minus bias), the MOSFET's current and the base current of the pnp transistor will be cut off, thus causing the IGBT to reach an OFF state. Therefore, the IGBT module is a composite device with the MOSFET and the pnp transistor, but by constructing them into a single chip, a phenomenon referred to as conductivity modulation occurs during conduction which greatly reduces resistance during current conduction.



Turn-ON

Constant-ON

Figure 1.4 Operating Description

2. Contents of Specification

⚠ CAUTION
● Regardless of any changes in external conditions during use, "absolute maximum ratings" should never be exceeded when designing electronic circuits using semiconductor devices. Furthermore, in pulsed-mode situations, the rated value of "safe operating area (SOA)" should always be observed.

2-1. Contents of specification

Table 2.1 shows an example of specification.

(a) Absolute Maximum Ratings(1) of Table 2.1)

Absolute maximum ratings apply to electrical, mechanical and thermal conditions that must be adhered to in order to prevent IGBT module destruction. Such conditions are generally expressed in terms of the maximum or minimum parameter values or to regions of Safe Operation Area (SOA). (If the module operates outside the listed scopes, it may break down.)

(b) Electric Characteristic(2) of Table 2.1)

The electrical characteristics for IGBT module are set under the same condition and its outcome is expressed in maximum, typical, and minimum values. These values are divided into three main characteristics; which are static characteristic, dynamic (switching) characteristic, and thermal characteristic.

(c) Other precautions (3) and 4) of Table 2.1)

Precautions on the maximum rating and other matters are listed.

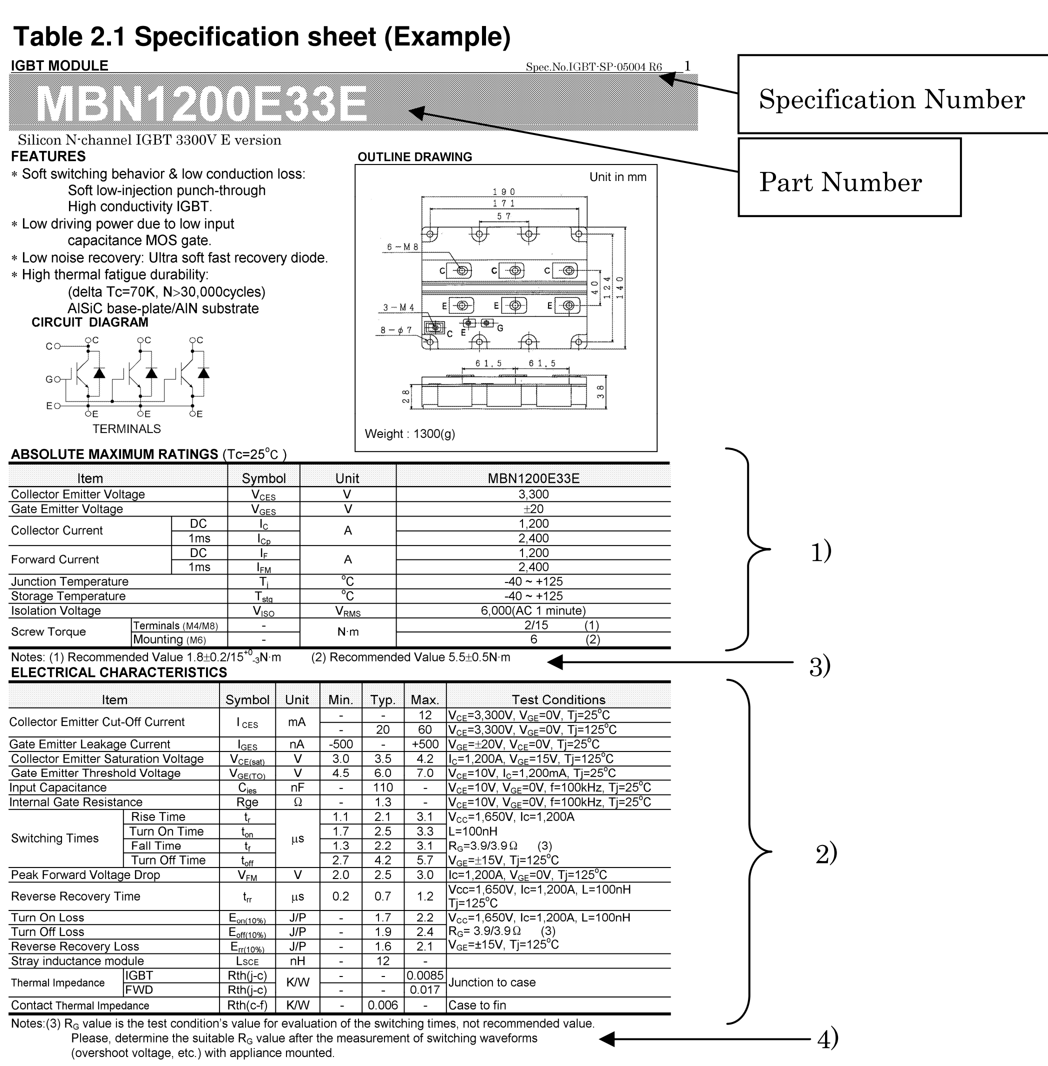


Table 2.1 Specification sheet (Example)

IGBT MODULE Spec.No.IGBT-SP-05004 R6 1

Specification Number

MBN1200E33E

Part Number

Silicon N-channel IGBT 3300V E version

FEATURES

* Soft switching behavior & low conduction loss:
  Soft low-injection punch-through
  High conductivity IGBT.
* Low driving power due to low input
  capacitance MOS gate.
* Low noise recovery: Ultra soft fast recovery diode.
* High thermal fatigue durability:
  (delta Tc=70K, N>30,000cycles)
  AlSiC base-plate/AlN substrate

CIRCUIT DIAGRAM

OUTLINE DRAWING

ABSOLUTE MAXIMUM RATINGS (Tc=25°C)

Item		Symbol	Unit	MBN1200E33E
Collector Emitter Voltage		V_{CES}	V	3,300
Gate Emitter Voltage		V_{GES}	V	±20
Collector Current	DC	I_C	A	1,200
	1ms	I_{Cp}		2,400
Forward Current	DC	I_F	A	1,200
	1ms	I_{FM}		2,400
Junction Temperature		T_j	°C	-40 ~ +125
Storage Temperature		T_{stg}	°C	-40 ~ +125
Isolation Voltage		V_{ISO}	V_{RMS}	6,000(AC 1 minute)
Screw Torque	Terminals (M4/M8)	-	N·m	2/15 (1)
	Mounting (M6)	-		6 (2)

1)

Notes: (1) Recommended Value 1.8±0.2/15$^{+0}_{-3}$N·m (2) Recommended Value 5.5±0.5N·m

3)

ELECTRICAL CHARACTERISTICS

Item		Symbol	Unit	Min.	Typ.	Max.	Test Conditions
Collector Emitter Cut-Off Current		I_{CES}	mA	-	-	12	V_{CE}=3,300V, V_{GE}=0V, Tj=25°C
				-	20	60	V_{CE}=3,300V, V_{GE}=0V, Tj=125°C
Gate Emitter Leakage Current		I_{GES}	nA	-500	-	+500	V_{GE}=±20V, V_{CE}=0V, Tj=25°C
Collector Emitter Saturation Voltage		$V_{CE(sat)}$	V	3.0	3.5	4.2	I_C=1,200A, V_{GE}=15V, Tj=125°C
Gate Emitter Threshold Voltage		$V_{GE(TO)}$	V	4.5	6.0	7.0	V_{CE}=10V, I_C=1,200mA, Tj=25°C
Input Capacitance		C_{ies}	nF	-	110	-	V_{CE}=10V, V_{GE}=0V, f=100kHz, Tj=25°C
Internal Gate Resistance		Rge	Ω	-	1.3	-	V_{CE}=10V, V_{GE}=0V, f=100kHz, Tj=25°C
Switching Times	Rise Time	t_r	µs	1.1	2.1	3.1	V_{CC}=1,650V, Ic=1,200A
	Turn On Time	t_{on}		1.7	2.5	3.3	L=100nH
	Fall Time	t_f		1.3	2.2	3.1	R_G=3.9/3.9Ω (3)
	Turn Off Time	t_{off}		2.7	4.2	5.7	V_{GE}=±15V, Tj=125°C
Peak Forward Voltage Drop		V_{FM}	V	2.0	2.5	3.0	Ic=1,200A, V_{GE}=0V, Tj=125°C
Reverse Recovery Time		t_{rr}	µs	0.2	0.7	1.2	Vcc=1,650V, Ic=1,200A, L=100nH Tj=125°C
Turn On Loss		$E_{on(10\%)}$	J/P	-	1.7	2.2	V_{CC}=1,650V, Ic=1,200A, L=100nH
Turn Off Loss		$E_{off(10\%)}$	J/P	-	1.9	2.4	R_G= 3.9/3.9Ω (3)
Reverse Recovery Loss		$E_{rr(10\%)}$	J/P	-	1.6	2.1	V_{GE}=±15V, Tj=125°C
Stray inductance module		L_{SCE}	nH	-	12	-	
Thermal Impedance	IGBT	Rth(j-c)	K/W	-	-	0.0085	Junction to case
	FWD	Rth(j-c)		-	-	0.017	
Contact Thermal Impedance		Rth(c-f)	K/W	-	0.006	-	Case to fin

2)

Notes:(3) R_G value is the test condition's value for evaluation of the switching times, not recommended value.
Please, determine the suitable R_G value after the measurement of switching waveforms (overshoot voltage, etc.) with appliance mounted.

4)

2-2. Characteristic Curves

Table 2.2 shows the items, descriptions, and intended use of the typical IGBT module characteristic curve.

Table 2.2 Characteristic Curve Items

No.	Characteristic Curve Item	Description of Characteristics	Intended Use
1	Collector Current vs. Collector-Emitter Voltage Characteristics <Ic-VCE>	Shows the relation between Collector-Emitter Voltage and Collector Current. The parameter is the Gate - Emitter voltage.	Used for calculating the power loss of an IGBT's ON state. Use data of 125°C.
2	Collector-Emitter Voltage vs. Gate-Emitter Voltage Characteristics <VCE-VGE>	Shows the relation between Collector-Emitter Voltage and Gate-Emitter Voltage. The parameter is the collector current.	Shows the gate-emitter voltage area suitable for operating an IGBT. Generally used as VGE = 15V.
3	Gate Charge Characteristics <VGE-QG>	Shows the relation between gate charge (QG) and gate-emitter voltage (VGE).	Shows the amount of electric charge required to operate an IGBT, used to determine the power supply capacitance at the output of a gate driver circuit.
4	Forward Voltage Characteristics of a diode <IF-VF>	Shows the forward voltage characteristics of a diode integrated in the module.	Used for calculating power loss associated with the integrated diode's ON state. Use data of 125°C.
5	Switching Time vs. Collector Current Characteristics <Ic-t>	Shows IGBT module turn-ON and turn-OFF switching times dependency upon collector current.	Used to verify the influence parameter to switching time. It is used especially to set up the device's non-lapped period (dead time) with the drive of the top and bottom arms.
6	Switching Time vs. Gate Resistance Characteristics <t-RG>	Shows IGBT module turn-ON and turn-OFF switching times dependency upon gate resistance.	Same as above
7	Switching Loss vs. Collector Current Characteristics <SW. Loss-Ic>	Shows the power loss dependency upon collector current during IGBT module turn-ON and turn-OFF.	Used for calculation of switching loss. It is the producing energy of per single pulse at the inductive load switching circuit and is used for calculating loss in terms of switching frequency (carrier frequency).
8	Switching Loss vs. Gate Resistance Characteristics <SW. Loss-RG>	Shows the power loss dependency upon RG during IGBT turn-ON and turn-OFF.	Same as above

2-3. IGBT Terms, Symbols, and Definitions

Table 2.3 IGBT Terms, Symbols Definitions

TERMS	SYMBOLS	DEFINITIONS
Collector-Emitter Voltage	VCES	Maximum allowable collector-emitter voltage at shorted gate.
Gate-Emitter Voltage	VGES	Maximum allowable gate-emitter voltage at shorted collector.
Collector Current	IC	Within allowable collector power dissipation, maximum allowable value of DC current to collector terminal.
Collector Power Dissipation	PC	Under specified heat conditions, maximum allowable value of constant collector power dissipation.
Junction Temperature	Tj	Range of allowable temperature at junction as basis of ratings.
Storage Temperature	Tstg	Range of allowable temperature for storage of IGBT module.
Screw Torque	-	Maximum allowable value of clamping torque when IGBT module is mounted onto heat sink or support, using specified grease on screw and contact portions.
		Maximum allowable clamping torque when wiring or bus is mounted to IGBT module terminals.
Collector-Emitter Cut off Current	ICES	Under specified conditions, collector current for applying collector-emitter voltage in cut-off state. Note: Gate Emitter terminals are shorted.
Gate-Emitter Leakage Current	IGES	Under specified conditions, gate current for applying gate-emitter voltage in cut-off state. Note: Collector Emitter terminals are shorted.
Collector-Emitter Saturation Voltage	VCE(sat)	Under specified conditions, value of saturation voltage when collector current is conducting. Depending on the difference in the terminal set-up, the value shows Collector-Emitter voltage between main terminals or auxiliary terminals.
Gate-Emitter Threshold Voltage	VGE(TO)	Under specified conditions, value of gate-emitter voltage when collector current starts to flow (in threshold region). The collector current in the beginning is set as 1/1000 of rated value.
Input Capacitance	Cies	Under specified conditions, value of capacitance between gate and emitter terminals.
Reverse Transfer Capacitance	Cres	Under specified conditions, value of capacitance between gate and collector terminals.
Output Capacitance	Coes	Under specified conditions, value of capacitance between collector and emitter terminals.
Turn-ON Time	ton	Under specified conditions, time required for collector-emitter voltage to reach 10% of its initial value after the moment when ON-gate voltage has reached 10% of its final value and through the subsequent switching of IGBT module from OFF state to ON state(td(on)+tf)
Turn-ON Delay Time	td(on)	Time required for collector current to reach 90% of its initial value after the moment when ON gate voltage has reached 10% of its final value.
Fall Time	tf	Time required for collector current to reach 90% from 10% of its initial value.
Turn-OFF Time	toff	Under specified conditions, time required for collector-current to reach 10% of its initial value after the moment when OFF-gate voltage has reached 90% of its initial value and through the subsequent switching of IGBT module from OFF state to ON state(td(off)+tf)
Turn-OFF Delay Time	td(off)	Time required for collector current to reach 90% of its initial value after the moment when OFF-gate voltage has reach 90% of its initial value.
Rise Time	tr	Time required for collector-emitter voltage to reach 90% to 10% of its initial value.
Thermal Impedance	Rth(j-c)	Under thermal steady-state while IGBT module is continuously energized, value of temperature difference between junction and case per unit power dissipation at junction. Unit is ℃/W
Reverse Recovery Time (Diode)	trr	Time required for reverse recovery current of the diode to vanish, under specified circuit and temperature conditions.
Forward Current (Diode)	IF	Maximum allowable continuous peak current in forward direction of free-wheeling diode under specified conditions.
Peak Forward Voltage Drop (Diode)	VFM	Maximum instantaneous value of voltage drop between anode and cathode Of free-wheeling diode under specified conditions of forward current (IF) and temperature.

2-4. Definitive Figures of IGBT Characteristics

1) Figure 2.1 shows the defined switching characteristic waveforms of an IGBT.

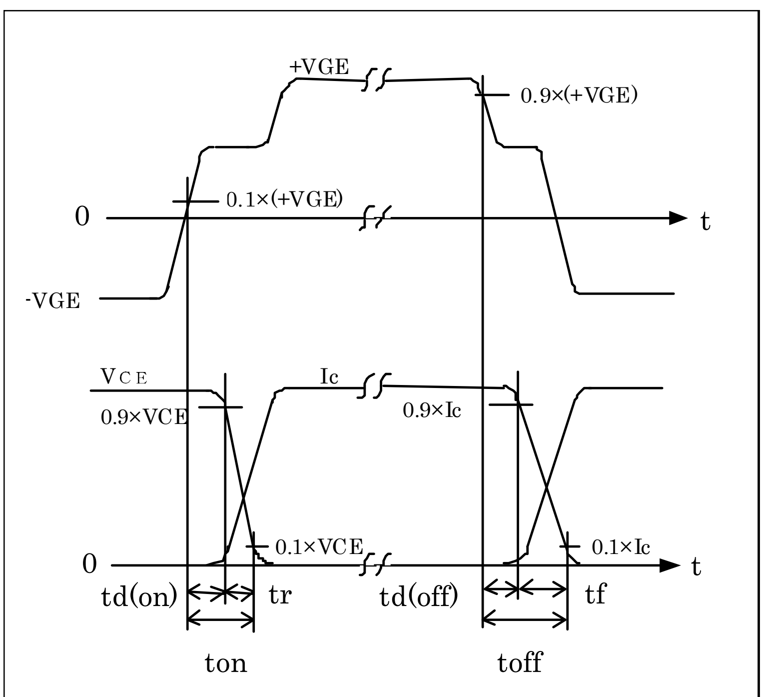
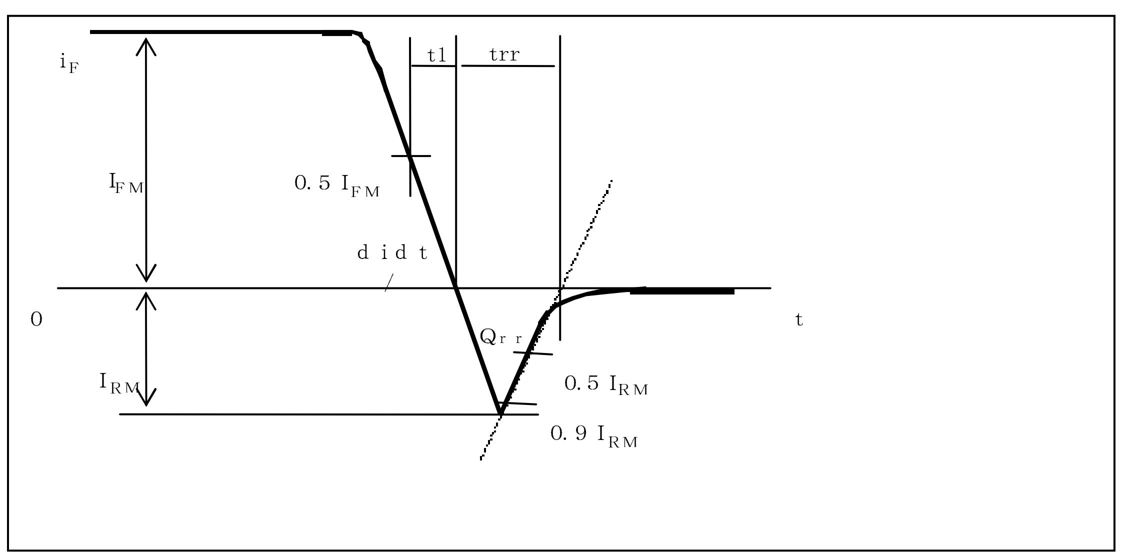


Figure 2.1 Definition of IGBT Switching Characteristics (ton, toff)

2) Figure 2.2 shows the definitive figure of reverse-recovery characteristic waveform for diode.



$$Q_{rr} \equiv \frac{1}{2}\, trr\, I_{RM} \qquad di/dt \equiv \frac{0.5\ I_{FM}}{t1}$$

Figure 2.2 Definition of FWD Reverse-Recovery Characteristics (trr)

3. Precautions for Safe Use

3-1. Derating

To ensure IGBT module reliability, please follow each of derating listed below.

Although a three-phase inverter will be used as an example here, the idea of derating can also be used in other applications.

(1) Voltage : Maximum peak voltage should not exceed 80% of rated voltage VCES, and the DC voltage should not exceed 50 to 60% of VCES.

At maximum peak (non-steady-state), VCES is under 90% (peak voltage value).

Note: Use Equation 1 to calculate the rated voltage of an IGBT module for a given AC line input voltage at the inverter.

$$VCES = Vin \times \sqrt{2} + Vs + Vreg + \alpha \qquad \text{------ (1)}$$

VCES	; Raged voltage of IGBT module
Vin	; Input voltage of AC line
Vs	; Overshoot voltage
Vreg	; Increased voltage dependence on regeneration.
α	; Margin

(2) Current: During the steady-state condition, IGBT module DC current should not exceed 50 to 60% of the rated DC current (repetitive current peak value)

Maximum value (non-steady-state) should not exceed 90% of the rated DC current (repetitive current peak value). However, if derating at the junction temperature, current is derated accordingly.

In addition, 1ms rated current (Icp) in the specifications is the peak current value including recovery current (a few µs or less) during reverse recovery of the free-wheeling diode, and are intended to serve as protection against accidents such as load short-circuits. In particular, this value cannot be used repeatedly during faults such as load short circuit protection that leaves thermal history.

Selection of the rated DC current (rated collector current) of IGBT module that takes into account derating can be considered by using the following equation.

$$Ip = Pinv \times \kappa \div Vac \div \sqrt{3} \times \sqrt{2} \times \lambda \qquad \text{------ (2)}$$

$$Ic > Ip \div \beta \qquad \text{------ (3)}$$

Ip	; Peak current
Pinv	; Inverter capacitance
κ	; Overload factor
Vac	; AC voltage
λ	; Current ripple factor
Ic	; Rated DC current of IGBT module (rated collector current)
β	; Derating factor

(3) Junction temperature: During the steady-state condition, below 80% of the rated junction temperature (maximum value)

Maximum (non-steady state) condition, the junction temperature should be no more than 90% of the rated maximum.

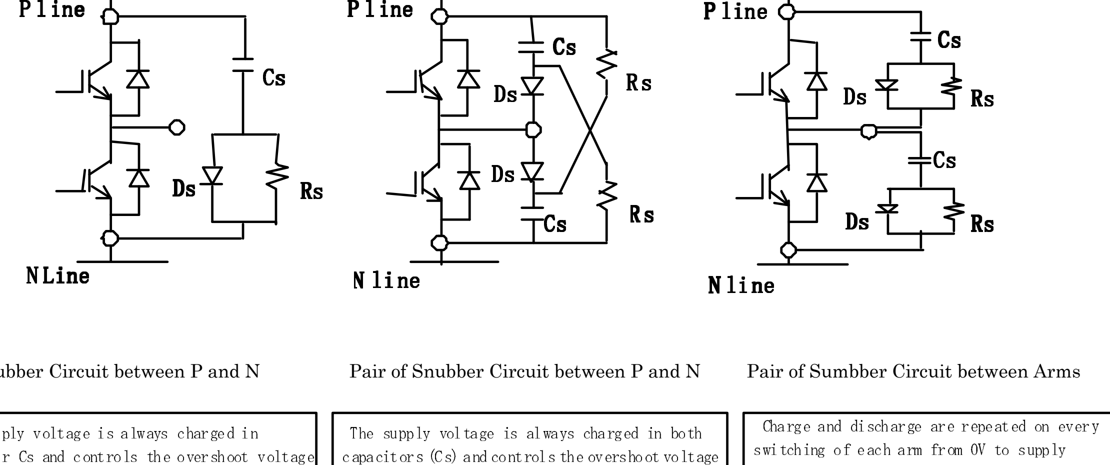
Case temperature should not exceed 100℃.In addition, repetitive change in junction temperature Tj and case temperature Tc causes stress to internal parts of the module, and depending on how frequently they are changed, it may reduce the life of the device, so please be careful.

Please refer to Section 3-7 "Thermal Impedance and Heat Dissipation Design" for details.

3-2. Snubber Circuit

The snubber circuit is a circuit inserted to protect the switching device (when the switching device is turned OFF) from the overshoot voltage generated by the charged energy in the line inductance. There are generally two types: a non-polar type consisting of C and R and a polar type with an added diode. With the IGBT, the polar type with high voltage surge suppression is used. In addition, the IGBT may be used without the snubber circuit if the main circuit line inductance is greatly reduced and the peak surge voltage can be controlled to about 80% or less of the IGBT module's maximum rating.

3-2-1. Features of Various Snubber Circuit



Snubber Circuit between P and N	Pair of Snubber Circuit between P and N	Pair of Sumbber Circuit between Arms
The supply voltage is always charged in capacitor Cs and controls the overshoot voltage Upper and lower-side relations between Ds, Rs, Cs are free, so this type of circuit is utilized for small capacity situations.	The supply voltage is always charged in both capacitors (Cs) and controls the overshoot voltage at each arms. This type of circuit is utilized for large capacity situations.	Charge and discharge are repeated on every switching of each arm from 0V to supply voltage. Because the snubber los is large, this circuit is best suited to narrow Reverse Biased Safe Operation Area (RBSOA) device and would, general, not be used with IGBT modules.

Figure 3.1 Features of Various Snubber Circuits.

3-2-2. Snubber Circuit Operation

Figure 3.2 represents a circuit in the overvoltage occurrence mode of a bottom-arm IGBT at the time of turning OFF. Figure 3.3 represents an equivalent circuit in a transient state at the same time.

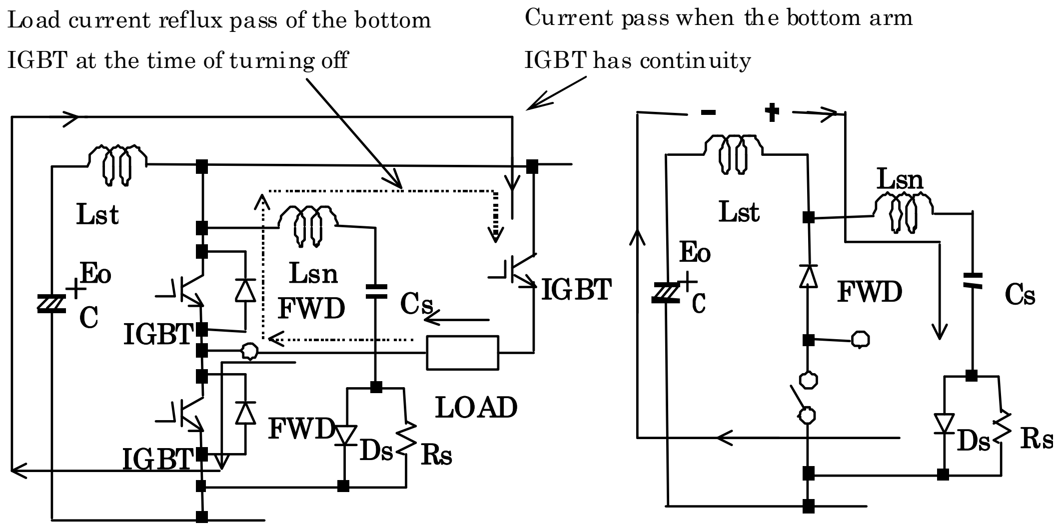


Figure 3.2 Turn-OFF Mode of Bottom Arm IGBT **Figure 3.3 Equivalent Circuit in a Transient State in Fig.3.2**

Figure 3.3 represents changes in the current pass when the bottom IGBT, which was ON, is turned OFF. When the bottom arm IGBT is turned off, the load current passes through the FWD at the top arm and is refluxed. Discharge of energy accumulated in Lst is applied to the bottom arm IGBT as an overvoltage in case of the absence of a snubber circuit which results in the loss of a discharge destination.

Figure 3.3 shows that installing a snubber circuit results in Lst energy passing through the snubber circuit and being refluxed. This allows overvoltage suppression. However, in reality, the snubber circuit also has wiring inductance Lsn which may cause overvoltage. How can Lst and Lsn be reduced? The answer is to choose the right components and to lay them out appropriately.

3-2-3. Snubber Circuit Current and Voltage Waveforms

Referring to Figure 3.2 above, consider the current and voltage waveforms in the circuit when the IGBT is turned OFF. Figure 3.4 represents the IGBT module's turn-OFF current and voltage waveforms and clearly shows that use of a snubber circuit inhabits surge voltage stemming from wiring inductance Lst to Eo+ΔV.

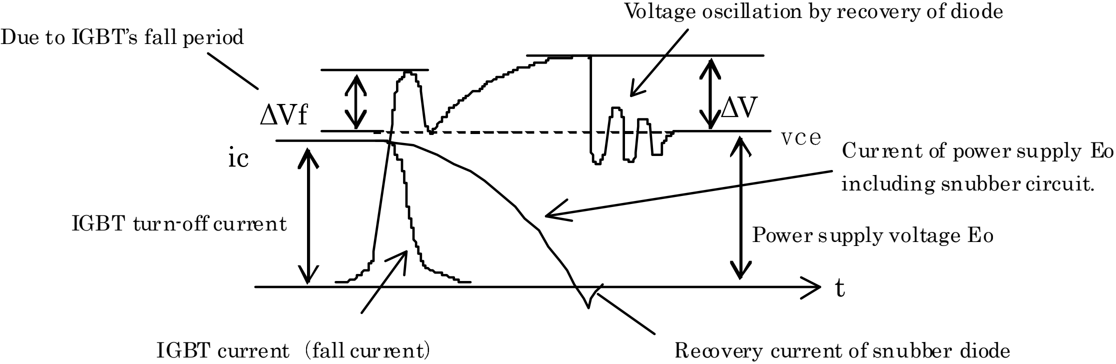


Figure 3.4 IGBT Module Current (Ic) and Voltage (VCE) Waveforms with Snubber Circuit

Figure 3.5 shows current and voltage waveform of the snubber diode Ds when the snubber circuit functions.

$$Ts = \frac{2\pi\sqrt{Lst \times Cs}}{4} \quad \ldots\ldots(1)$$

$$\Delta V = Ic \times \sqrt{\frac{Lst}{Cs}} \quad \ldots\ldots(2)$$

$$\Delta Vf = Lsn \times dic/dt + Vfr \quad \ldots\ldots(3)$$

Definitions:

Ic IGBT turn-OFF current

Lsn Snubber circuit inductance as viewed from IGBT's collector and emitter terminals

Vfr Forward recovery voltage (typically about 50V)

dic/dt Current change ratio in IGBT's fall period.

$Tn \fallingdotseq 3 \times Cs \times Rs \quad \ldots\ldots(4)$

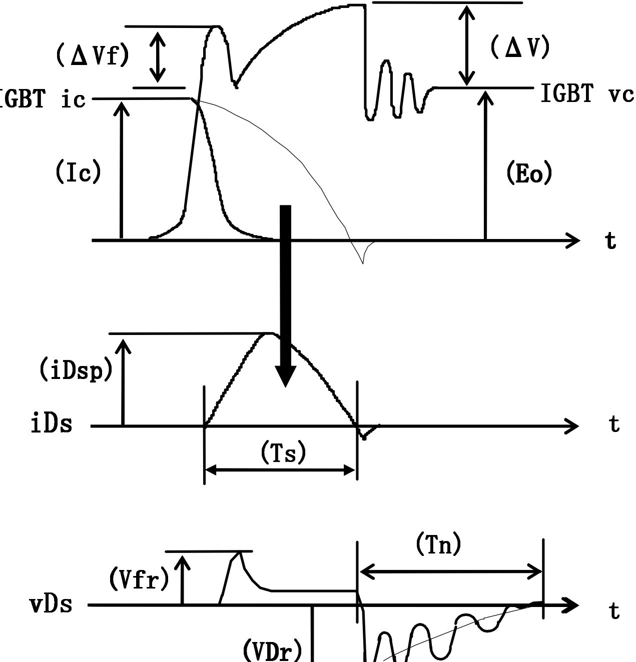


Figure 3.5 Waveforms of Each Snubber Circuit Part

In addition, the value Tn which is defined as the time required to discharge 95% of the overcharge voltage of Cs is approximated using equation (4). Here, Rs must be set to a value such that Ts+Tn<1/fc.

Note：In the above equations for the case of a three-phase circuit, the value for Ts in Equation (1) must be multiplied by $\sqrt{3}$, and the ΔV in for Equation (2) must be multiplied by $1/\sqrt{3}$.

3-2-4. Collector Current Class and Snubber Capacitor Values

The snubber circuit capacitor Cs value can be calculated using the following equation assuming I is switching current maximum value and voltage gain is ΔV.

$$Cs \fallingdotseq Lst \cdot \left(\frac{I}{\Delta V} \right)^2 \quad \cdots\cdots\cdots(5)$$

- For a snubber capacitor, use a polyester film capacitor or an oil capacitor with good frequency characteristics.
- Note that if the capacitor's lead wire is thin, high temperatures may arise due to charge/discharge current.

3-2-5. Snubber Resistance Selection

The resistor value varies according to capacitor value and the IGBT's driving frequency.

When Voltage ΔV overcharged to the snubber is used, εSN generated when the current I is turned OFF becomes, according to the equation (6):

$$\varepsilon SN = 0.5 \times Cs \times \Delta V^2 \quad \cdots\cdots\cdots(6)$$

Equation (7) indicates what resistance value mast be selected to prevent oscillation of the collector current at IGBT turn-ON.

$$Rs \geqq 2\sqrt{\frac{Lsn}{Cs}} \quad \cdots\cdots\cdots(7)$$

where Lsn is the inductance of the snubber wiring.

Also, be aware of maximum values since Rs becomes a resistance to discharge the ΔV overcharge to Cs, （Depends on carrier frequency, the Cs voltage ΔV should be promptly discharged).

3-2-6. Snubber Diode Selection

Select a snubber diode having the same class as the IGBT's rated collector emitter voltage value. Use an IGBT module with a current rating of 1/10 to 1/5 that of the IGBT used.

Use diodes with high speed specifications. Note that if the reverse-recovery characteristics tend to be a hard-recovery diode, high frequency oscillation may occur with collector voltage at IGBT turn-OFF.

3-3. Gate Driving

3-3-1. IGBT Gate Current and Gate Electric Charge

Figure 3.6 shows the waveform of current and voltage during IGBT module operation. During turn-ON and turn-OFF, the gate current necessary to charge and discharge input capacitance (Cies) and reverse transfer capacitance (Cres) flows between gate- and emitter-controlling electrodes. The gate-emitter voltage becomes a fixed positive or negative bias based on the time product of these gate currents, or in other words, the transfer of gate electric charge.

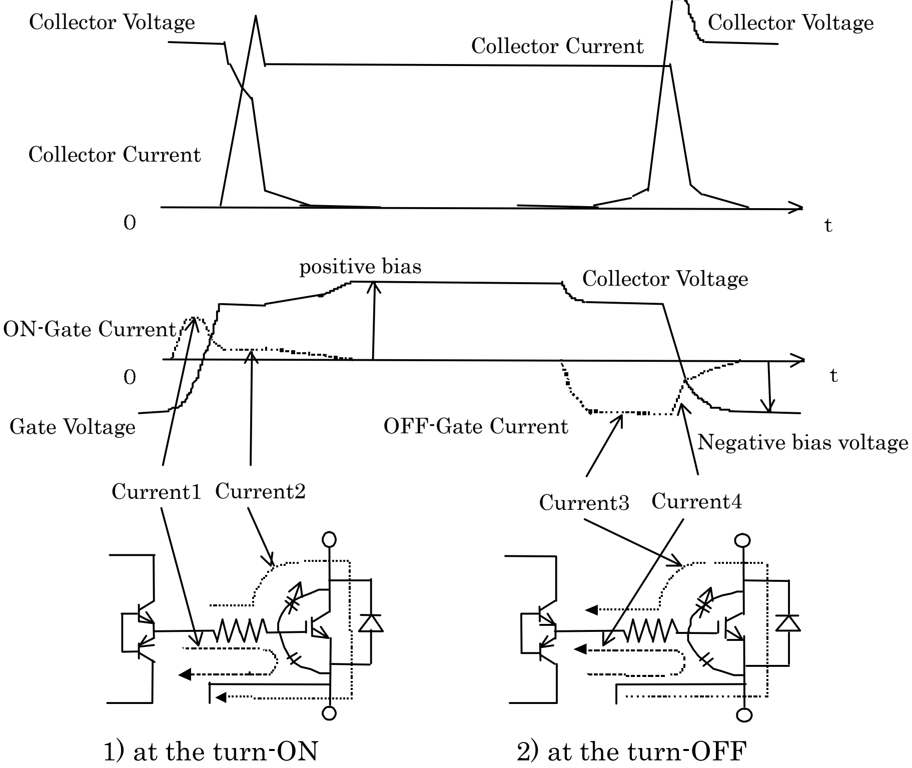


Figure 3.6 Example of IGBT Switching Waveform (Current and Voltage)

3-3-2. Gate Electric Charge Characteristics (QG Characteristics)

Figure 3.7 shows the relation between gate electric charge(QG) and gate-emitter voltage and segments the gate electric charge characteristics into three regions (labeled A, B and C).

A; Region A clearly shows that the electric charges (QG) determined by gate voltage and input capacitance(Cies) of IGBT module.
Period when the collector current is not flowing yet.

B; Region B shows the negative reverse transfer ("mirror effect") of reverse transfer capacitance (Cres). Here, gate-emitter voltage cannot vary, but collector-emitter voltage does and, as a consequence, gate current remains constant with value determined by the output voltage of the gate driver and gate resistance.

C; Region C shows the situation where the collector-emitter voltage approaches the saturation voltage and reverse transfer capacitance(Cres) approaches maximum value.
The input capacitance and reverse transfer capacitance are connected in parallel, and the collector-emitter capacitance reaches the maximum value (appx. 2 times of the input capacitance Cies value).

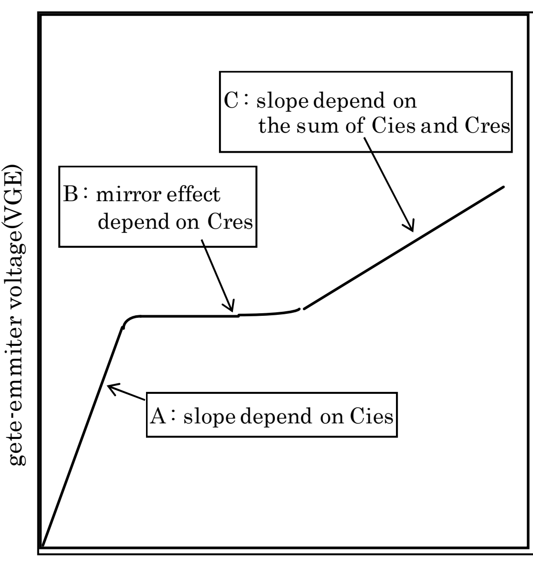


Figure 3.7 Gate Charge (QG) Characteristics

3-3-3. Gate Driving Loss

Gate driver circuit power loss can be calculated from an examination of the gate electric charge characteristics. Figure 3.8 shows the gate electric charge characteristics (including the negative bias voltage area) where
VGP and VGN are the positive and negative bias voltage values.

Gate electric charge varies as the value of QG0 depend on VGN to VGP transfer (that is, turn–ON) and VGP to VGN transfer (that is, turn-OFF). In this case, Equation (1) can be used to calculate the driver circuit (PG) power(where fc represents switching frequency).

$$PG=(VGP+|VGN|)\times QG0\times fc \quad \text{-----}(1)$$

Power for switching must be supplied by the driver circuit power supply, so remember to take this fact into account when designing the power supply circuit. Note that if voltage does not stabilize and decreases with regulation, it may lead to the destruction of the IGBT module.

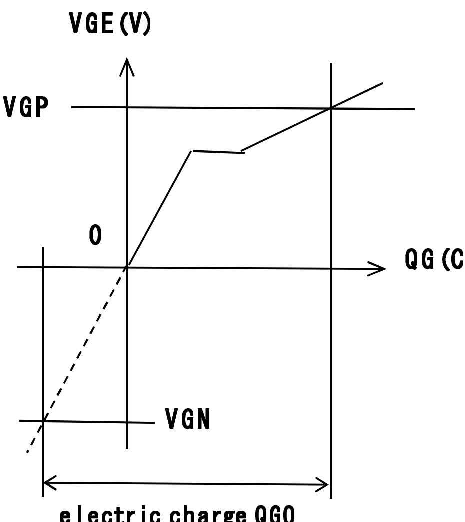


Figure 3.8 Driving Voltage and Gate Charge Characteristics

3-3-4. IGBT Driving Voltage

The IGBT driving voltage needs to set up both positive and negative bias voltages. Lower positive bias caused increased ON-state loss, and higher positive bias promotes increased short-circuit current. For these reasons, it is particularly important to always select an appropriate driving voltage.

Note: A positive bias of 15V±10% and negative bias from -5 to -15V are recommended to prevent misoperation when the other arm (device) switching occurs.

3-3-5. Precaution for Drive Circuit Power Supply of Lower Arm

Be sure the driver circuit power supply of the lower arm is independent for single-phase or multiple-phase circuit applications.
This is because during the steady-state, the emitter of the lower arm has the same electrical potential, but for IGBT switching, high induced voltages occur at the main circuit wiring portion of the lower arm, and this voltage has adverse effects such as increased delay time in other phases of IGBT switching.

The time change rate (di/dt) of the IGBT collector current can be several thousands of A/µs, and several tens of nH of inductance of the line that makes up the lower arm main circuit is induced by several tens of V.

In the case of a common driver circuit power supply for the lower arm, voltage is induced in the main wiring through a common driver circuit power supply or common wiring and creates noise in other phases of the IGBT lower arm gate-emitter which may cause malfunctions or instability in switching.

3-3-6. Gate-Emitter Resistance (RGE)

IGBT is a voltage-driven device similar to MOSFET, and its gate-emitter impedance is extremely high.

With such a device, if the driver is not connected or the state of the gate voltage bias is unstable due to the driver side output impedance, etc., an "ON" state will result due to the application of the collector voltage.

In particular, note that if the control circuit power supply has not been established when the main circuit's power supply has been interrupted, it will cause problems.

In such a case, the IGBT module's control terminal (gate-emitter) is forced to confirm the IGBT "off" by connecting a resistor RGE of several thousand Ohmes to tens of thousands of Ohmes (confirm on the actual machine).

When connecting to RGE, watch out for decrease of power supply voltage of the drive circuit due to continuous conduction of current. In addition, watch out for decrease of Gate-Emitter Voltage due to voltage divide of gate resistance RG.

3-4. Dynamic Avalanche

After the IGBT turn-OFF, VCE will rise, but after a certain level, voltage does not increase and is controlled. (See Figure 3.9)

This phenomenon is called dynamic avalanche. To explain simply, the channel of the MOSFET section is closed at turn-OFF, and current begins to decrease, but when the carriers remaining in the device disappear, they ionize by collision with silicon atoms because they pass through the high electric field inside the device and thus create electrons-holes pairs.

The electron and holes created then collide with other silicon atoms creating one electron-hole after another. This is the dynamic avalanche.

When a dynamic avalanche occurs, current attenuation becomes slow, and VCE voltage spikes are suppressed. Voltage when dynamic avalanche occurs varies depending on current. An example is shown in Figure 3.10.

When a dynamic avalanche occurs, it does not necessarily destroy the IGBT immediately, but rather the turn-OFF loss will be increased, and eventually the IGBT will be destroyed by latchup.

Accordingly, during turn-OFF, please keep it in the region listed in Figure 3.10.

In addition, please note that this region changes depending on temperature; the area becomes small especially at low temperatures.

Moreover, if there are special conditions concerning dynamic avalanche, please follow them.

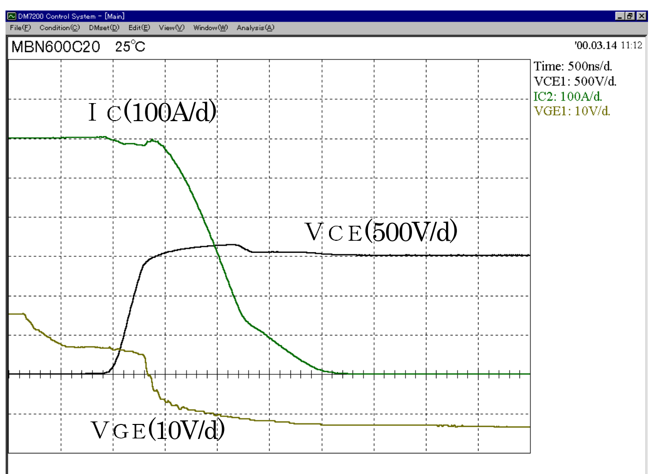


Figure 3.9 Example of IGBT Turn-OFF Waveform

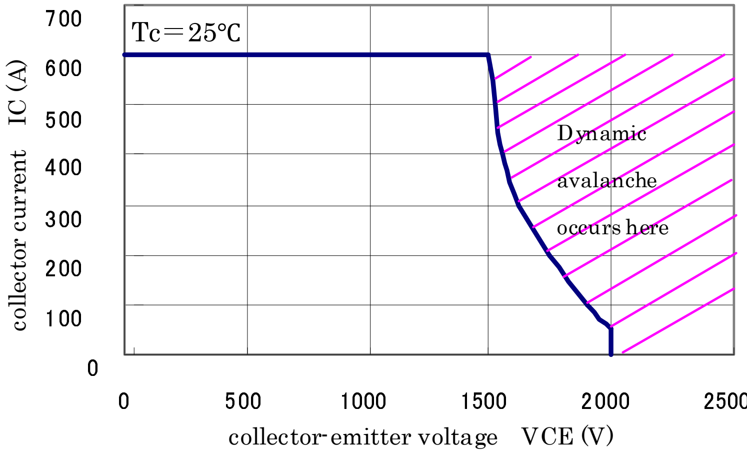


Figure 3.10 Example of Dynamic Avalanche Area

3-5. Parallel Connections

3-5-1. Saturation Voltage Range [ΔVCE(sat)] Classify and Current Unbalanced Rate

When using high-voltage IGBT connected in parallel, we as a rule pair those with similar VCE(sat), however this pairing condition does not guarantee the parallel connections. Imbalances occur because of unbalanced wiring inductance due to the physical structure of the device as well as the gate drive circuit and drive conditions, please use the product only after evaluating in advance. Further details will be discussed with the user and Hitachi.

Definition of the current unbalanced rate α of parallel connections is as follows.

$$\alpha = \left(\frac{Ic'}{(Itotal \div 2)} - 1 \right) \times 100\ (\%) \quad \text{.........(1)}$$

Ic: Current value per individual IGBT module
Itotal: Total current per parallel connection pair

Note that this definition is generally used for the rated current value, but in the case of the same module, unbalanced rate α varies greatly depending on the total current value (α is larger with low current).

In addition, when IGBTs are connected in series, it becomes harder for the voltages to be distributed evenly, and there is a possibility of overshoot voltage exceeding the module's breakdown voltage. Therefore, along with matching static characteristics of VCE (sat) and the dynamic characteristics of td (on) and td (off), circuits to balance voltage between modules connected in series, voltage dividing resistors and snubber circuits, etc. are required.

3-5-2. Parallel Connections and Current Derating

Although there is no limitation to the number of IGBT modules that can be connected n parallel, the negative effect reflected in an increase in the line inductance for power supply connections, e.g., surge voltage, etc. must always be taken account.

For High Voltage IGBT, up to 4 parallel connections are realistic.

Under worst-case conditions, that current is concentrated in on IGBT module, with the current derating(R) as expressed by equation (2).

$$R = \frac{1 + (n-1) \times \left(1 - \frac{\alpha}{100}\right) / \left(1 + \frac{\alpha}{100}\right)}{n} \times 100\ (\%) \quad \text{......(2)}$$

Definitions:

N Number of parallel connection

α Current unbalanced rate (15%)

Example : For the case involving four (4) IGBT modules connected in parallel and having rated current of 600A, the current derating value R equals 80.4%, resulting current of 600A×4 parallel ×0.804＝1,929 Amps.

3-5-3. Parallel Connection Unbalancing Notes

(1) Basic points to consider for Parallel Connection

When connecting IGBTs in parallel, always take into consideration the following two key points:

(a) Minimize the difference in VCE(sat) of the elements in order to prevent current unbalance during stable operation, and

(b) Minimize line unbalancing when arranging the elements in parallel in order to minimize transient current unbalancing when the main circuit is either turned ON or OFF.

(2) Number of Drivers per Arm

To avoid adverse effects in parallel motion caused by deviations in delayed outputs from multiple drivers, use a one-driver arrangement that contains some signal processing circuit (photo-coupler, over-current protector, etc.) and connect all the drive elements in parallel.

(3) Connecting Gate Resistors in Parallel Circuits

Figure 11 shows a recommended arrangement to connect the gate resistor to the parallel circuit to minimize gate voltage variation due to mutual interference among the respective modules. In addition, attention needs to be paid to the following points when using this particular configuration:

(a) Make use of twisted pair cable for the driver output line to minimize line impedance.

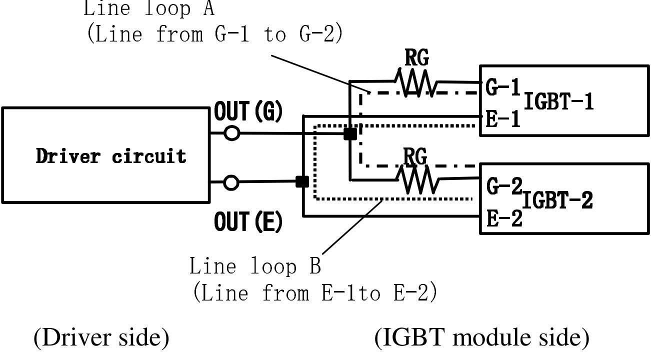
(b) Have the same impedance (Lgst) in each loop (A and B) and minimize its value as much as possible.

Note: The objective of the recommendation described under items (a) and (b) is to avoid giving adverse effect due to inductance created when the main circuit is switched ON or OFF.

(c) Recognize the fact that the gate voltage variation stated above occurs when the main circuit is either turned ON or OFF. To avoid the variation, maintain the relationship between the gate resistor (RG) and loop inductance (Lgst) which can satisfy Equation (1).

$$2 \times RG > 2\sqrt{\frac{Lgst \times 2}{Cies/2}} \quad \text{......(1)}$$

Where Cies represents the gate input capacitance of the IGBT.



(Driver side) (IGBT module side)

Figure 3.11 Example of Parallel Connection between IGBT Modules and Driver Circuit

3-5-4. Necessity for Symmetry of Main Circuit Wiring

(1) Wiring Equalization

For IGBT modules to be connected in parallel, it is essential to equalize the wiring on the collector and the wiring on the emitter with each other to keep inductance values in balance.

Figure 3.12 represents an example of double parallel wiring and shows a schematic diagram of a parallel circuit including main circuit wiring inductance circuits.

For the collector, wiring inductance circuit LCA and LCB are shown, and for the emitter, wiring inductance circuits LEA and LEB.

When the IGBT (A) and (B) are turning ON, the current generated on each individual collator depends on the variations of the inductance circuits rather than on each element's characteristics.

Because the current balance depends principally on the inductance ratio, it is important keep symmetry in wiring by matching the inductance values.

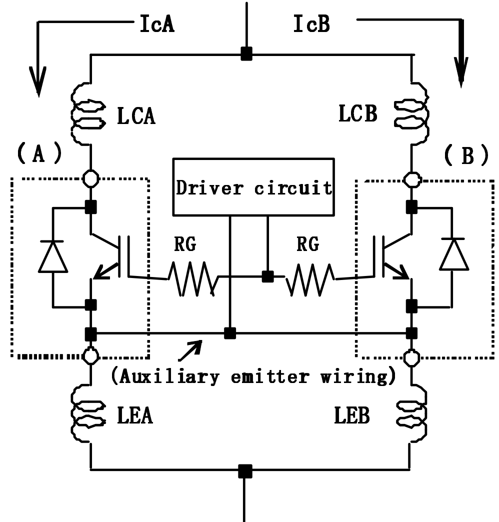


Figure 3.12 Wiring to Equalize Main Wiring Inductance Values

Wiring method to equalize LCA and LCB, LEA and LEB is required.

For example, referring Figure 3.12, if wiring inductance of A and B sides are unbalanced (that is, LCA+LEA < LCB+LEB) and the VCE(sat) value of IGBT(A) is smaller, then the current sharing is depicted in Figure 3.13 will result.

In particular, if emitter lines LEA and LEB are unbalanced, the IGBT gate voltage will be adversely influenced, causing an unbalanced current.

(2) Unbalanced Current Period caused by Wiring

Figure 3.13 shows that once a current imbalance occurs when turning ON an IGBT, it will be equalized during the steady-state condition after activating the IGBT, finally settling down to values IcA and IcB as determined by VCE(sat). The time required for the unbalanced current to be equalized can be calculated as the attenuation over the L-R circuit caused by the inductance within the closed-loop forming a parallel circuit and the operating resistance of the IGBT element. The operating resistance "ron" can be easily calculated from the output characteristics curve.

For example, for an MBN1200E33E module having a single arm, an "ron" of approximately 3.4 milliohms (when Tj＝25℃、1/2 rated current) will be present. IF the loop inductance is 100nH for a parallel configuration, (LCA+LCB+LEA+LEB), the equalization in unbalanced current occurs based on the time constant τ is approximated by equation (1).

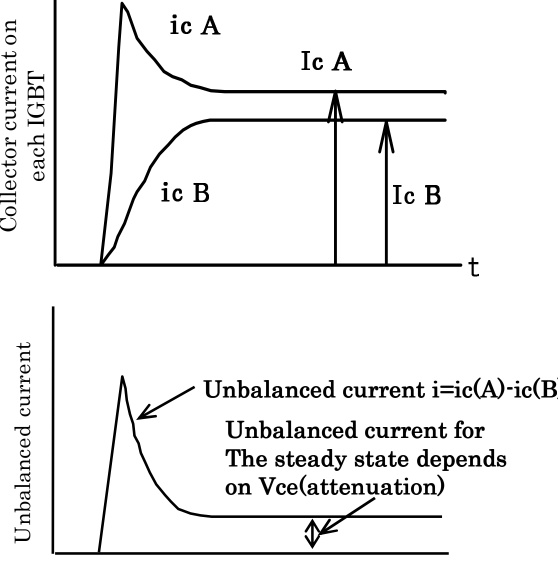


Figure 3.13 Equalization of Unbalanced Current

$$\tau = \frac{100\text{nH}}{3.4\text{m}\Omega \times 2} = 15 \quad \mu\text{s} \qquad \text{......(1)}$$

If the stability in the current variation is assumed to be 3 times τ (that is, valuation is approximate, up to 95%), the current balance cannot be determined by VCE(sat) within 45μs after turning ON. This means if the carrier frequency is high or the active time is shorter, the current balance may be determined by the wiring (including the shape) for almost the whole period.

(3) Notes on Gate Wiring

When using gate wiring in parallel, note the following:

(a) To avoid noise generation in gate wiring or main circuit wiring due to mutual induction or excessive potential difference, use orthogonal wiring or keep adequate distance between cables. If you must use balanced wiring, maintain low inductance over the gate wiring.

(b) Since there is a high potential difference between the upper and lower arm gate wires, keep them sufficiently apart from each other.

(c) For the upper and lower arm gate wires, make equal the lengths and inductance values of the wires connecting to the drivers. (Use twisted pairs of the same length for the gate wires)

3-5-5. Dynamic Avalanche and Parallel Connections

The dynamic avalanche voltage is lower than the rated voltage as shown in Figure 3.10, so when used in parallel and used beyond the area shown in Figure 3.10, more current flows toward the lower dynamic avalanche voltage. An example is shown in Figure 3.14.

Figure 3.14 is a waveform for when there are no snubbers, but if there are snubber circuits, because the turn-off current is transferred to the snubber circuit, a decrease in collector current is faster than when there are no snubbers, so unbalanced current tends to occur in areas with high collector voltage. (See Figure 3.15)

In any case, when connected in parallel, be especially aware of unbalanced current and be sure to not use beyond the area shown in Figure 3.10.

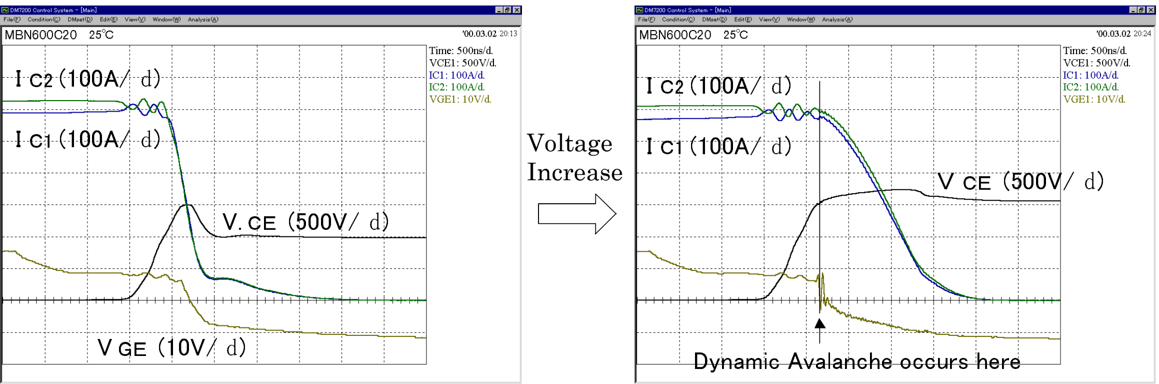


Figure 3.14 Parallel Connection Operations (without Snubber)

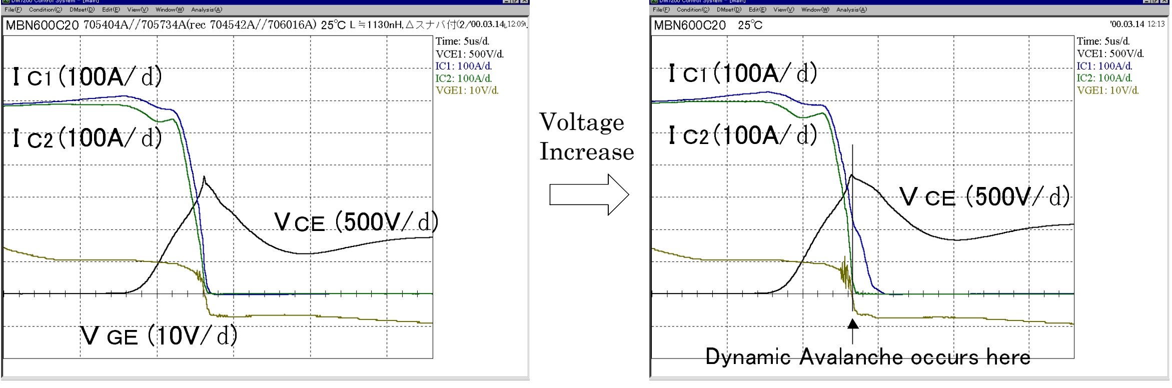


Figure 3.15 Parallel Connection Operations (with Snubber)

3-6. Calculation of Power Dissipation

This section introduces a general calculation of power dissipation when using IGBTs in the PWM inverter circuit.

Note: All calculations are based on a premise that the inverter output is a sine wave.

In addition, the power dissipation in the IGBT module with a 1-in-1 configuration is as follows.

Total power dissipation = Power dissipation in IGBT＋Power dissipation in FWD
IGBT power dissipation = Steady-state power dissipation (Pon)
+Turn-ON power dissipation (Pton)
+Turn-OFF power dissipation(Ptoff)
FWD power dissipation = Forward power dissipation (Pf)＋Recovery power dissipation (Prr)

3-6-1. IGBT Power Dissipation

(1) Steady-state Power Dissipation (Pon)

$$Pon = \frac{1}{2\pi}\int_0^{\pi} i \times v \times D \times d\theta \quad \text{------ (1)}$$

D stands for On duty mode during sinewave output

$$D = \frac{1 + \sin\theta}{2} \quad \text{------ (2)}$$

If modulation factor K during PWM control is considerd

$$D = \frac{1 + K \cdot \sin\theta}{2}$$ is what it controls in reality

In this case, K＝1 is supposed.

The steady-state power dissipation Pon can be obtained using Equation (3)

$$Pon = \frac{\sqrt{2} \cdot Io}{2\pi} \cdot \left(a + \frac{\pi}{4} b \cdot \sqrt{2} Io + \frac{\pi}{4} \cos\phi \cdot \left(a + \frac{8}{3\pi} b \cdot \sqrt{2} Io \right) \right) \quad \text{------ (3)}$$

i ：Collector current flowing to IGBT(instantaneous value)

v ：Salutation voltage(instantaneous value)

Io：Inverter phase output current rms value (equal to the IGBT current)

a, b：Linier approximate curve value represented by VCE(sat)＝a＋b･I (Obtain it from Ic-VCE characteristics shown in Figure 3.16.)

cosφ：Load power factor

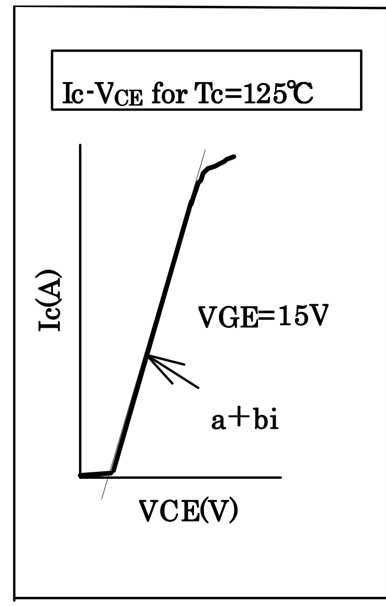


Figure 3.16 Ic vs. VCE Characteristic

(2) Turn-ON Power Dissipation and Turn OFF Power Dissipation

Supposing that the inverter phase current rms value is Io, the output current peak value becomes $\sqrt{2} \cdot Io$.

The average value of IGBT module turn-ON current and turn-OFF current is, according to Equation (4),

$$Iave = \frac{2}{\pi} \cdot \sqrt{2} \cdot Io \quad \text{------(4)}$$

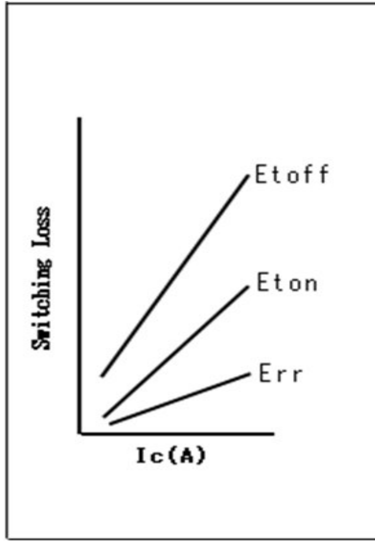


Figure 3.17 Switching Loss vs. Collector Current

Obtain the turn-OFF power dissipation and turn-ON power dissipation for the above Iave(per pulse) and specify them as Eton, and Etoff(Figure 3.17), respectively.

Equation (5) and (6) can be used to calculate turn-ON power dissipation Pton and turn-OFF power dissipation Ptoff as a function of carrier frequency fc.

$$Pton = Eton \cdot \frac{fc}{2} \quad \text{------(5)}$$

$$Ptoff = Etoff \cdot \frac{fc}{2} \quad \text{------(6)}$$

3-6-2. Power Dissipation in a Free-Wheeling Diode

(1) Forward Power Dissipation (Pf)

Equation (7) provides a mean for calculating forward power dissipation in a free-wheeling diode.

$$Pf = \frac{1}{2\pi} \int_0^{\pi} \sqrt{2} Io \cdot \sin\theta \, (a + b \sqrt{2} Io \cdot \sin\theta) \cdot \frac{1 - \sin(\theta + \phi)}{2} \, d\theta$$

$$= \frac{\sqrt{2} \cdot Io}{2\pi} \cdot a + \frac{\pi}{4} b \cdot \sqrt{2} Io - \frac{\pi}{4} \cos\phi \cdot \left(a + \frac{8}{3\pi} b \cdot \sqrt{2} Io\right) \quad \text{------ (7)}$$

Io	: Inverter phase output current rms value
a, b	: Linear approximate curve value represented by Vf=a+bi.(refer to Figure 3.18)
cosφ	: Load power factor

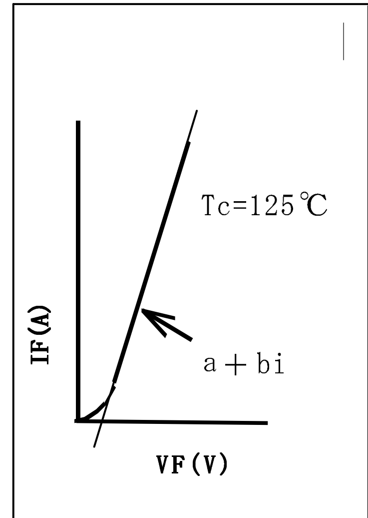


Figure 3.18 Forward Current vs. Forward Voltage

(2) Recovery Power Dissipation (Prr)

Supposing that the current peak value is $\sqrt{2} \cdot Io$, the forward average current (as calculated using equation (8)) becomes:

$$Iave = \frac{2}{\pi} \times \sqrt{2} \times Io \qquad (8)$$

For the above Iave (per pulse), obtain the recovery power dissipation, specify it as Err (Figure 3.17), and then use equation (9) to obtain the value for Prr.

$$Prr = Err \times \frac{fc}{2} \qquad (9)$$

3-7. Thermal Impedance and Heat Dissipation Design

3-7-1. Thermal Impedance

Thermal impedance between junction and case (Rth(j-c)) of IGBT and diode is restricted in the device specification.

3-7-2. Definition of Temperature Measurement Point

Case temperature and heat sink temperature measurement point is defined in Figure 3.19.

Thermal impedance of junction to case [Rth (j-c)] and thermal impedance of case to fin [Rth(c-f)] are defined by this definition.

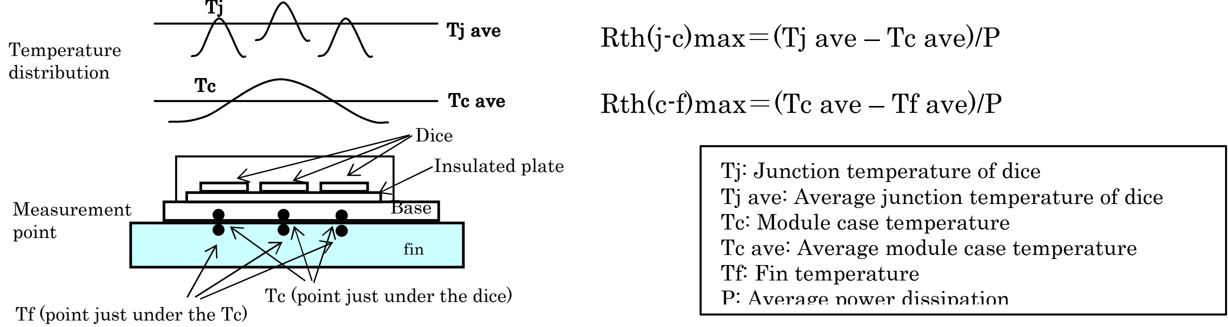


Figure 3.19 Temperature Measurement Points

3-7-3. Heat Dissipation Design

This section presents a basic procedure for selecting a heat sink based on steady state and transient state considerations.

(1) Steady State

Figure 3.20 represents the thermal equivalent circuit and includes the parameter notations used in the equations which follow.

This junction temperature (Tj(IGBT)) can be estimated using equation (1).

$$T_j(IGBT) = P(IGBT) \times R_{th}(j\text{-}c)(IGBT) + \{P(IGBT)+P(diode)\} \times R_{th}(c\text{-}f) + \{P(IGBT)+P(diode)\} \times R_{th}(f\text{-}a) + T_a \quad \text{------}(1)$$

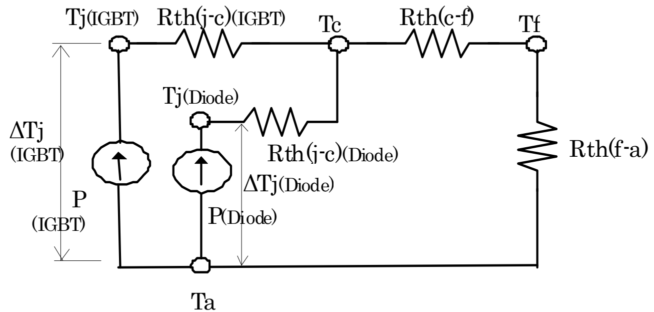
Also, the change in junction temperature (ΔTj(IGBT)) can be calculated using equation (2).

$$\Delta T_j = P(IGBT) \times R_{th}(j\text{-}c)(IGBT) + \{P(IGBT)+P(diode)\} \times R_{th}(c\text{-}f) + \{P(IGBT)+P(diode)\} \times R_{th}(f\text{-}a) \quad \text{------}(2)$$

Here, the measurement points for Tc and Tf is shown in Figure. 3.19.

Also, to determine the junction temperature of the diode, it can be determined similar to assuming the temperature rise between junction and case as P (diode) × Rth(j-c)(diode).

Note that if the case temperature measurement point is different, heat resistance is different from the value listed in the catalog.



P ; Average power dissipation
Tj ; Junction temperature of dice
Tc ; Case temperature
Tf ; Fin temperature
Ta ; Air Temperature
Rth(j-c) ; Thermal impedance of junction to case
Rth(c-f) ; Thermal impedance of case to fin
Rth(f-a) ; Thermal impedance of fin to air

Figure 3.20 Thermal Equivalent Circuit

(2) Transient State

Generally, it is sufficient to consider the steady-state junction temperature Tj for radiation design. However, because the power dissipation is actually swinging with pulse state, so that Tj relates to the temperature ripple based on Tc as shown in Figure 3.21.

In this case, the ripple peak value of the junction temperature (Tjp) can be estimated approximately using Equation (3).

$$Tjp=P1\times\{Rth(st)\times t1/t2+(1-t1/t2)\times Rth(t1+t2)-Rth(t2)+Rth(t1)\}+Tc \quad \text{----(3)}$$

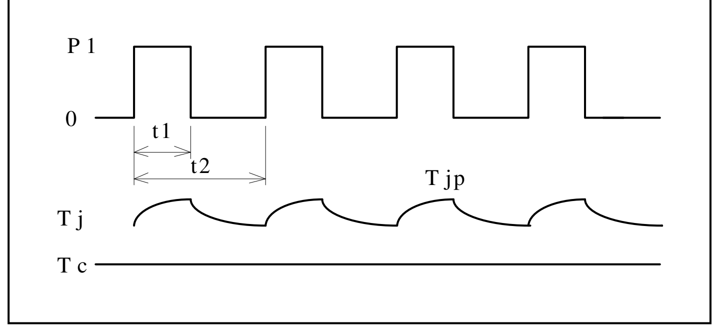


Figure 3.21 Temperature Ripple

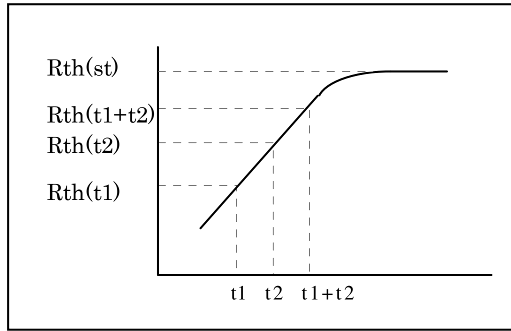


Figure 3.22 Transient Thermal Impedance

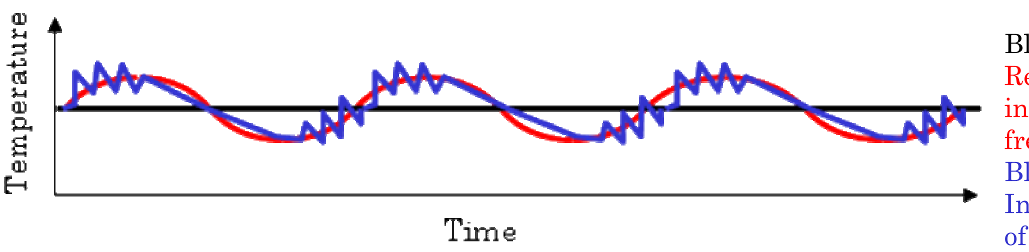


Figure 3.23 Inverter Operating Temperature Ripple

Figure 3.23 shows the temperature ripple for inverter operation. The junction temperature is oscillating in the same cycle as the output frequency. In addition, it is also oscillating in the same cycle as the carrier frequency. Considering this fact, Tjmax is the value that should never be exceeded.

3-7-4. Notes on Temperature Ripple and Temperature Change

(1) Note for when there is a temperature ripple

(a) Consider factors such as those in the previous section and make sure that the temperature ripple peak value (Tjmax) of the junction temperature does not exceed the rated value when selecting the fin.

(b) Stress applied to structural parts inside the module increases with the size of the temperature ripple, and the risk of reducing the life time of the module increases with the number of cycles. In particular, carefully consider applications where high temperature ripples occur, and moreover, where there are a large number of cycles.

(c) In addition, note that if the generated loss changes and occurs with respect to time, due to the presence of case to fin contact thermal resistance, case temperature (Tc) may also change according to the incurred loss.

(2) Module Lifetime Curve of the Power Cycle Mode

Changes in the cooling system and module case temperature (Tc) rarely occur, and there is a power cycle tolerance in the life category of the mode where junction temperature (Tj) of the device changes.

This shows the relationship between the change value (ΔTj) of the module temperature change and the repeat cycle number (N), and the depletion-mode where mainly the bonding portion of the wire is stressed and VCE(sat) may change.

With our testing method, we apply the module's rated current for several seconds, and then induce a change in the junction temperature by turning it off for a few seconds. We define this as one cycle.

However, you cannot ignore the existence of the module's case to fin contact thermal resistance in actual use, and the case temperature may change, so please evaluate the ΔTj by junction to fin.

3-8. Dead Time

This section describes the basic concepts of the operation of the IGBT device.
If the upper and lower arms turn on at the same time, it causes a short circuit in the arm and overcurrent flows through the device.
Please set the dead time and overcurrent protector.

3-8-1. The Relationship Between Dead Time of Logic and Dead Time with IGBT Devices

(1) Main Circuit Configuration Example

Consider an example involving a voltage inverter. Figure 3.24 shows a single-phase configuration for the top and bottom arms which represents a typical configuration of a major circuit (one phase worth). Top and bottom arms are provided between the P and N of a DC voltage Eo, based on the assumption of a mode where the IGBTs of the top and the bottom arms alternately keep turning ON and OFF. To prevent power supply short circuiting due to simultaneous ignition(communication), a top and a bottom IGBT OFF period (dead time) are set using a control signal. This dead time period is also known as the non-lapped period.

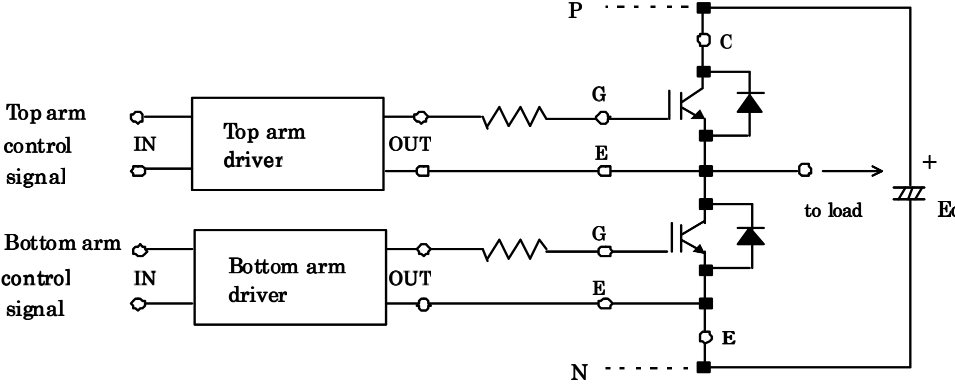


Figure 3.24 Typical Configuration of a Major Circuit (Single-Phase Top and Bottom Arms)

(2) Comparing Dead Time and Real Dead time

Figure 3.25 illustrates the various phase relationships among control signal, driver output voltage, and IGBT collector-emitter voltage.

Because the dead time (TD) of the logic circuit changes with the magnitude of the delay times t1 through t4 and results in a real dead time.(TD)

The next examines and verifies delays (t1 and t3) on the driver line and delays (t2 and t4) in the IGBT modules, this situation results in a real dead time referred to as TD'.(see below);

t1 : Output delay time between ON control and ON drive voltage
t2 : Output delay time between ON drive voltage and IGBT turn-OFF
t3 : Output delay time between ON control signal and OFF drive voltage
t4 : Output delay time between OFF drive voltage and IGBT turn-OFF
(provided that, in each of the above cases, there is no difference between the top and bottom arms).

The relationship between the dead time (TD) set on the logic and that of real dead time time(TD') between IGBT and CE are expressed by equation (1).

$$TD' = TD - (t3+t4) + (t1+t2) \qquad \text{-----(1)}$$

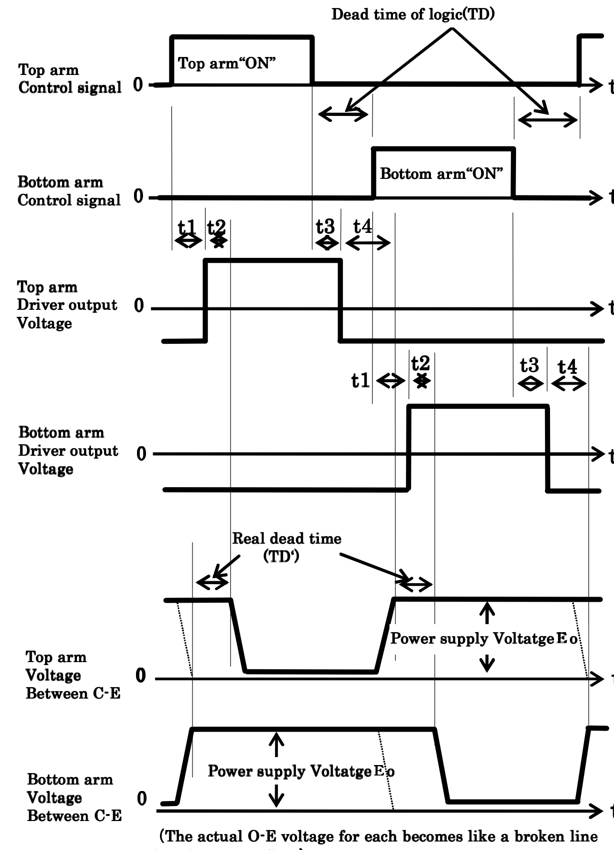


Figure 3.25 Control Signal, Driver Voltage, and IGBT Collector Voltage Waveforms

Thus the dead time (TD) of the logic circuit changes with the magnitude of the delay times t1 through t4 and results in a real dead time(TD'). Therefore, please examine and verify delays on the driver line (t1, t3) and delays in the IGBT modules (t2, t4).

(3) Example of Dead Time Verification

(a) Verification Circuit Configuration

Figure 3.26 shows a half-bridge circuit that will be used to illustrate verification based on an assumption that the top arm turns ON when the collector current of the bottom arm is shut down and a signal is given to the top and the bottom driver circuit.

(b) How to Observe Switching Waveforms

The non-overlap at the top and the bottom arm can be checked in various ways. Special care must be taken when observing voltage waveforms with different potential levels. Any floating-state voltage can be observed with an optical insulation cable or with a differential probe, but these methods require elaborate care delays and other factors.

(c) How to Check Vertical Motion

Figure 3.27 represents waveforms observed at the time of the verification. The turn-OFF of the bottom arm is regarded as the point (Point B) where the gate voltage starts shifting to a reverse bias, and the phase relationship between it and the peak point(Point A) of the gate current of the top arm is used to determine whether overlap or non-overlap is present.

If the point A occurs earlier than does Point B, the top and bottom arm can be considered to be short-circuited, collector current becomes something like what is indicated by broken lines in figure 3.27, with a rise in switching loss. In the gate voltage waveform at this time, a rise in Point B voltage observed. (If significant short-circuiting arises, the system shifts from gate source voltage to reverse bias voltage.)

(d) Typical Verification

Figure 3.28 represents how a typical verification can be conducted in a circuit configuration as shown in Figure 3.26 and in waveform observations in Figure 3.27. This example has been observed with the control signal phase of the top arm changed. Figure 3.28 (1) shows the no short-circuiting situation, while Figure 3.28 (2) reflects the short-circuited top and bottom arms condition.

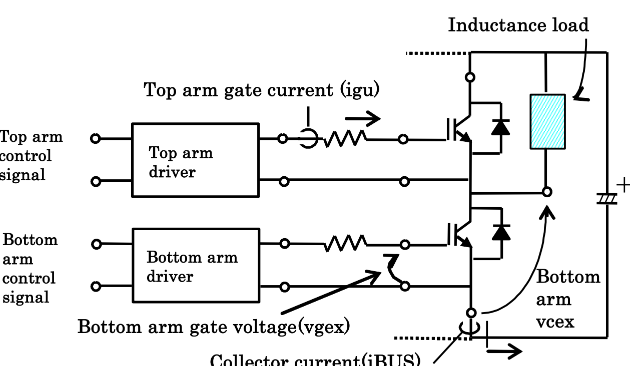


Figure 3.26 Verification Circuit Configuration (Half-Bridge Circuit)

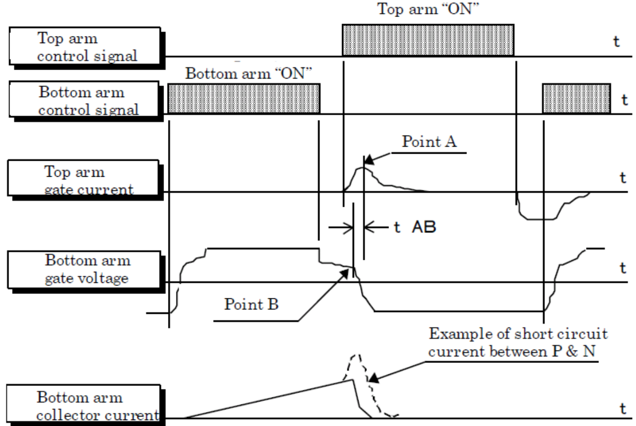


Figure 3.27 Control Signal and Gate Waveforms

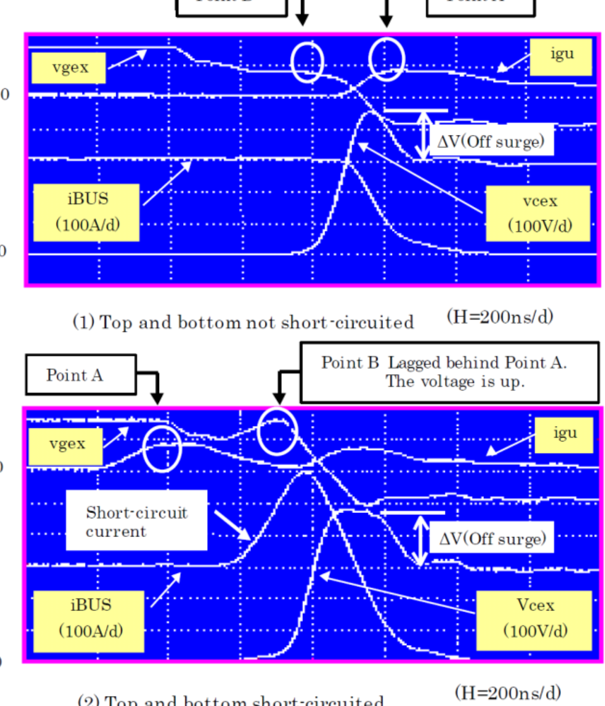


Figure 3.28 Top and Bottom Arm Short-Circuited Waveform

1) Both top and bottom arms are not short-circuited (dead time is almost 0us)

2) Both top and bottom arms are short-circuited (300ns of short-circuit current flows through)

3-9. Short Circuit Protection

3-9-1. Short Circuit Pattern

The short circuit pattern in the inverter can occur in two ways:

(1) In the inverter side (due to IGBT module destruction, control circuit trouble, equipment ground fault, etc.)

(2) In the load side (due to connection error, load trouble, ground fault, etc.)

3-9-2. IGBT Operation during Short Circuit

When the short circuit occurred, in the case where an IGBT is maintained in either the ON steady state or turn-ON state, the short-circuit current increases up to the IGBT's saturation current.(This current increases up to approximately six (6) times the rated current.) Also, almost the entire circuit voltage is applied to the IGBT. If such a status occurs continuously, the IGBT will be destroyed. To prevent this phenomenon, the short-circuit current must be cut off before the onset of IGBT destruction is approached.

3-9-3. Short-circuit Current Cut-off

To prevent IGBT destruction, whatever protection method is chosen must cut off the current within 10 microseconds after short-circuit current has begun to flow.

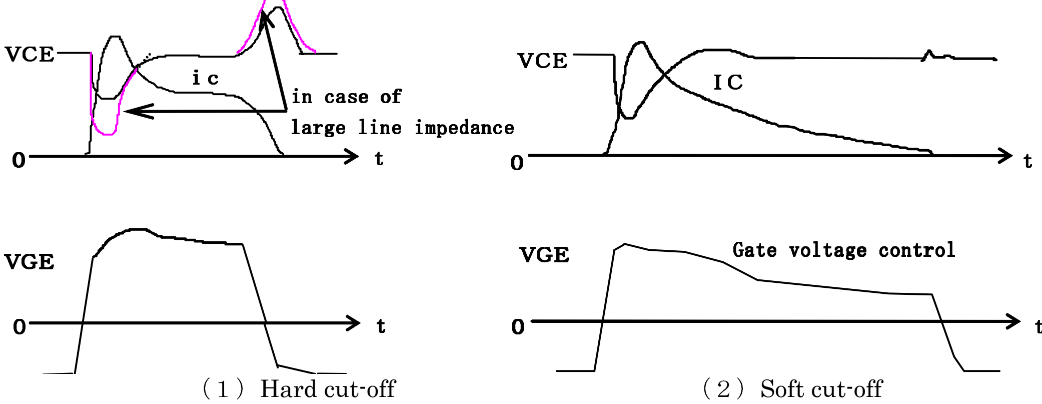
Furthermore, there are high-voltage IGBT devices that do not guarantee short-circuit cut-off, so please check for such guarantee.

The two main short-circuit protection methods are described in the following table.

In addition, the general current and voltage waveforms for each method are as shown in Figure 3.29.

Table 3.1 Example of Short-circuit Protection

№	Short Circuit Protection Method	Method in Detail	Features	Notes
1	Short-circuit current Hard Cut-off	1) IGBT normally turns OFF after detecting an over - current. 2) Monitoring of over-current is performed using a Current Transformer (CT), etc. (Other than for output line, CT is also needed for DC circuit current.)	1) Only current detecting. 2) Large turn-OFF surge voltage. 3) Large snubber circuit surge voltage. (Effect of large cut-off current)	1) Protection against surge voltage is necessary. 2) Because over-current is large, precautions should be taken to prevent the snubber circuit voltage from increasing. (Surge voltage is determined by the overcurrent value and snubber C.) <At the very least, do not exceed the rated VCE. In addition, if there are individual limitations on peak voltage, follow them.>
2	Short-circuit current Soft Cut-off	1) The gate output voltage is controlled after detecting the overcurrent. 2) The driver circuit monitors abnormal VCE (sat) (i.e. increase in voltage due to over-current) and performs a soft cut-off of the current.	1) Small surge voltage 2) The driver needs a circuit to detect its own arm's VCE (abnormality detection). 3) Identifying the abnormal arm is possible by diverting the detection function. (Requires a different circuit.)	1) Avoid false detection during turn-on in various operation modes (prevents false detection by setting detection delay). 2) Care must be taken especially for malfunctions in areas with large current. <At the very least, do not exceed the rated VCE. In addition, if there are individual limitations on peak voltage, follow them.>



（1） Hard cut-off　　（2） Soft cut-off

Figure 3.29 Short-Circuit Protection Waveforms

4. Mounting Precautions

4-1. Mounting IGBT modules to Heat Sinks

4-1-1. Recommended Clamping Torque

Table 4.1 lists the recommended pre-clamping and clamping torque values.

Table 4.1 Recommended Clamping Torque Values for IGBT Mounting

№	Screw	Rated Torque (N・m)	Recommended Torque (N・m)	Pre-clamping Torque (N・m)	Clamping Torque (N・m)
1	M5	2.8	2.6	1.0 - 1.5	2.6
2	M6	6.0	5.5	1.5 - 2.0	4.9 - 5.9

4-1-2. Method for Applying Grease (Thermal Compound) and Module Mounting

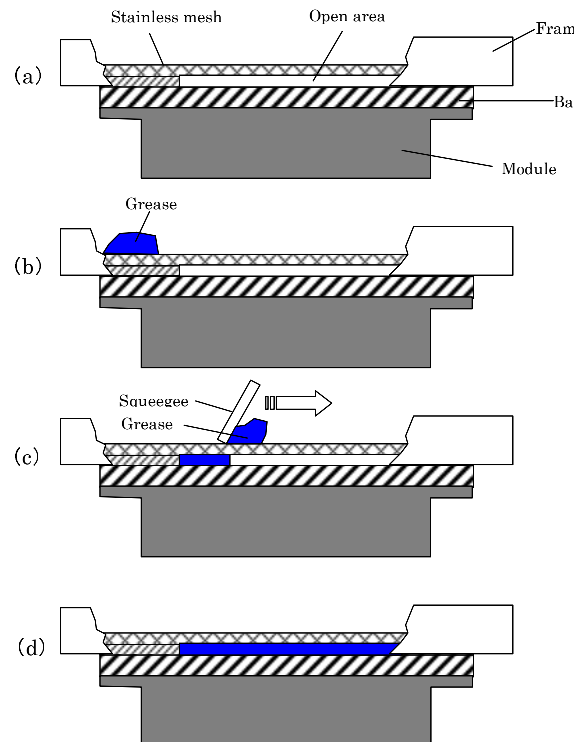
Grease is required for cooling the device, but if it is incorrectly applied, it may cause damage to the module's internal structures (insulated substrate). Here we show that the screen printing method was confirmed by Hitachi for mounting. In addition, we believe the optimal mounting method differs due to the shape of the heat sink side. Please understand that this method shows a mounting example and is not intended to guarantee the state after mounting.

(1) Please remove all foreign matter from the surface of the module base and heat sink. Apply the grease to the base surface of the module using the screen.
Apply with a roller, brush, or using the screen printing method as shown in Figure 4.1.

(2) The recommended thickness of grease is in the range of 100μm to 150μm. After mounting, coat with grease so that it protrudes out from the entire periphery of the module base (wipe off the grease protruding out).
Table 4.2 shows the grease recommended and its specific gravity.

(3) Place the module in its mounting location, and press down on the heat sink so that the grease spreads and covers the base entirely. Set the bolt placing a spring washer in between.

(4) Clamp the screws in the order shown in Figure 4.2 and with the torque shown in Table 4.1.
Clamp manually or with an electric screw driver (when using an electric screw driver, beware of torque overshoot).
If you deviate from the sequence and torque values shown in Figure 4.2, the base may warp due to the viscosity of the grease, and isolation breakdown of the insulated substrate inside the device may occur.
In addition, if the rest time (interval) between pre-clamping and final clamping is short, the base may warp due to the viscosity of the grease, and isolation breakdown may occur, so be sure to check the rest time (interval). Moreover, please confirm with an isolation voltage test after the module is mounted.



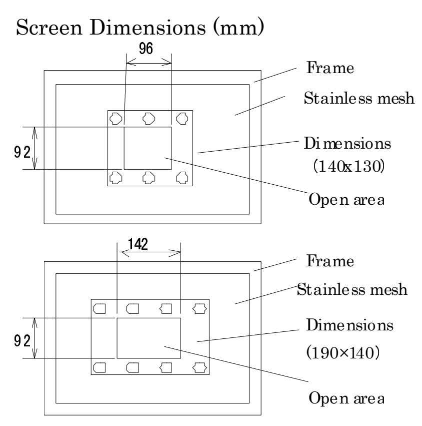


Figure 4.1 Grease Application Method with Screen

(5) After final clamping, let it stand for six or more hours and then clamp again (this is called "retightening").

Use the same torque and the method of clamping screws used for final clamping

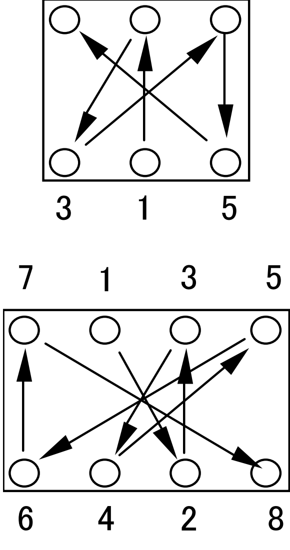


Figure 4.2 Clamping Order for IGBT Module

4-1-3. Recommended Clamping Order of Screws

When pre-clamping and final clamping 6 mounting holes module or 8 mounting holes module, follow the order indicated in Figure 4.2

Pre-clamping Order : 1⇒2⇒3⇒4…

Final Clamping Order : …4⇒3⇒2⇒1

The order of clamping should be done in diagonal. There are no rules where to start. (Same condition applies for tightening.)

Table 4.2 Recommended Grease and Specific Gravity

№	Manufacturer	Type	Specific Gravity
1	Shin-Etsu Chemical Co.,Ltd.	G747	2.81g/cm^3
2	Momentive Perfomance Materials lnc.	YG6260	2.50g/cm^3

4-1-4. Surface Roughness and Warp of Heat Sink

Important Notices

- The surface roughness of the heat sink, should be "25S" or higher.
- The convex or concave warp of the heat sink should not be more than 50μm (between the mounting screw holes).
- Confirm that the surface of the heat sink is free of burrs and be sure to chamfer the screw holes.
- Always be certain to look for and remove all foreign substances, such as cutchips, which may get caught between the IGBT module and heat sink.

4-1-5. Heat Sink Mounting Hole

Select the mounting hole diameter suited to the screw to be used.

Note: If the heat sink mounting hole diameter is too large, the module's base may be deformed and the dice in the module damaged as shown in Figure 4.3.

Table 4.3 shows the mounting hole diameter for the screw size to be used and the recommended chamfering value.

Table 4.3 Recommended Mounting Hole Diameter and Chamfering Value (mm)

№	Screw	Mounting Hole Diameter Unit (in. mm)	Recommended Chamfering value Unit (in mm.)
1	M4	ϕ5	C0.5
2	M5	ϕ6	C0.5
3	M6	ϕ7.5	C0.5
4	M7	ϕ9.5	C0.5

If the hole diameter is too large, the module's base may be deformed.

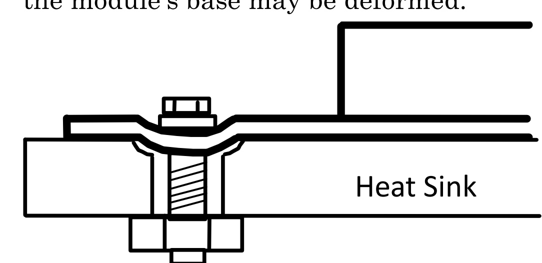


Figure 4.3 Example of Improper Heat Sink Mounting

4-2. Mounting to the Terminal

4-2-1. Handling of the Terminal

Do not apply 15kgf / terminal or more compression or tensile stress to the main terminal. The internal wiring of the device may short-circuit if the main terminal's packaging is deformed.

Do not lift, bend, or stretch the main / auxiliary terminal. Otherwise, the terminal may defected.

In addition, if the terminal area is structured such that it holds a heavy load, it may damage the terminal due to excessive weight being applied to it. Be sure to evaluate in advance based on a vibration test performed on the actual device.

4-2-2. Recommended Clamping Order of Mounting Screws

The clamping order of mounting screws for the IGBT's main terminal is not critical.

4-2-3. Clamping Method for Mounting Screws

Table 4.4 lists values for the mounting screw clamping torque. Use of either a hand- or electromotive-driver tool is recommended for such operations.

Table 4.4 Recommended Clamping Torque for Terminals

№	Screw	Rated Torque (N-m)	Recommended Torque (N-m)	Minimum Torque (N-m)	Remarks
1	M4	2.0	1.8	1.6	Auxiliary Terminal
2	M8	15.0	15.0	12.0	

4-2-4. Recommended Screw Length

Figure 4.4 shows cross sectional view of the screw hole in the module side. The recommended screw length is such that "d" dimension extends one to two millimeters below the nut.

Table 4.5 shows the hole size for each screw, but these dimensions do not include the thickness of bus-bar and other items.

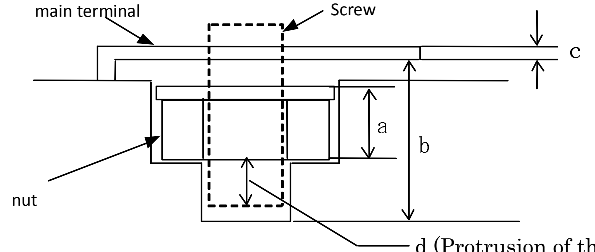


Figure 4.4 Cross-Sectional View of Screw Hole

Table 4.5 Size for Screw Hole

№	Screw	A(mm)	B(mm)	C(mm)	Remarks
1	M4	3.2	10.0	0.6	Auxiliary Terminal
2	M8	8.0	17.0	1.5	

4-3. Mounting Environment

Important Notices

Concerning the mounting environment for the module please be aware of the following.

- ●Harmful Substances : When an IGBT module is exposed to corrosive gases, such as sulfur dioxide or chlorine gas, conductivity or heat radiation may decrease because of terminal or base corrosion and parts may discolour. Make sure to always keep IGBT modules away from such substances.
- ●Exposure to Elements : Protect the IGBT module from both rain and water.

4-4. Storage and Shipping Precautions

Important Notices

(1) IGBT modules should always be stored under the following conditions.

- ●Temperature : 40 degrees Celsius, maximum.
- ●Humidity : 60% Relative Humidity, maximum.
- ●Dust : Avoid storing the module in locations subject to dust.

- Harmful substances : The installation location should be free of corrosive gases such as sulfur dioxide and chlorine gas.
- Other : Do not remove the conductive sponges or tapes attached to the signal gate and emitter gate.

(2) Shipping Method

- To prevent the case cracking and/or the electrode bending, appropriate consideration should be given to properly insulate the shipping container from mechanical shock or sever vibration situation.
- Do not throw or drop the case while shipping. Treat them with care. The devices may break if they are not handled with care. Please do not use the IGBT modules that were dropped or damaged.
- Appropriate labeling on the outside of the shipping container should always be present.
- The shipping container itself should always be properly protected from both rain and water.

4-5. Precautions against Electrostatic Failure

Important Notices

Because the IGBT has a MOS gate structure, you should always take the following precautions as measures to avoid generating static electricity.

- Before starting operation, do not remove the conductive sponge or tape mounted between gate and emitter.
- When handling the IGBT module, ground our body via a high-value resistor (between 100kΩ and 1MΩ), hold the package body, and do not touch the gate terminal.
- Be sure to ground any parts which the IGBT module may touch, such as the work table or soldering iron.
- Before testing or inspection, be sure to check that any residual electric charge in measuring instruments has been removed. Apply voltage to each terminal starting at 0V and return to 0V when finishing.

4-6. IGBT Module Circuit Arrangement and Wiring Method

(1) Place the IGBT module so as to minimize the wiring inductance from the power supply. If this wiring inductance becomes large, it may generate an overshoot voltage during switching and destroy the IGBT module. In order to reduce inductance of the main circuit wiring, please use laminated bus bars.

(2) And keep the cable between the gate circuit and IGBT module as short as possible. If the cable is long, gate voltage will rise or fall more slowly and the switching time will become longer. In addition, the likelihood of noise generation will be increased. In order to reduce wiring inductance and prevent noise, either a two-wire stranded cable or shielded cable should be used.

4-7. Measurement Precautions

(1) Before beginning V_{CES} measurements, be sure to shout-circuit the signal gate and emitter terminals.

If the signal gate and emitter terminals are kept open or their contact is defective during measurement, the IGBT module may be damaged.

In addition, if there is a risk of condensation on the module due to a heat cycle test or other factors, after drying for more than 2 hours at approx. 100℃, measure within the specified temperature conditions.

(2) Within the IGBT module, a cable is laid between the chip in the module and the external connection terminal. The voltage applied to the chip and the voltage of the external terminal is not identical, especially during switching.

For expressing the time rate of change in current as di/dt and the cable inductance as L, an inductive voltage equal to L×di/dt will be generated within the cable. Typically, cable inductance L is about 20 to 40 nH. So when the IGBT module is turned ON, the external terminal voltage observed is higher than the voltage applied to chip.

Conversely, when the IGBT module is turned OFF, the observed external terminal voltage is lower than the voltage applied to the chip.

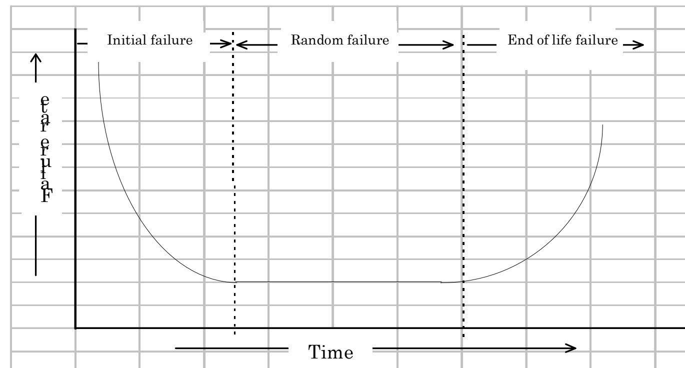
The voltage applied to the chip should not be permitted to exceed the rated voltage of the device.

5. Reliability

General matters and terminology are explained in this chapter.
In addition, reliability test items and content specific to the module structure are explained.

5-1. Failure Rate

In general, the failure rate of semiconductor devices changes with time as shown in Figure 5.1.



Initial failure: a failure that occurs at a relatively early stage due to design and production reasons, or incompatibility with the usage environment.

Random failure: Failure that occurs incidentally after the initial failure period but before the end-of-life failure period.

End-of-life failure: Failure that occurs during the period when the failure rate increases with time due to fatigue, wear, and degradation.

Figure 5.1 Module Failure Regions (Bathtub-Shaped Curve)

5-2. Failure Factor

Factors that determine the likelihood of the failure of semiconductor parts can be divided into external factors of use and internal factors of construction as shown in Table 5.1.

If failures such as those shown in the following table occur, analyze the factors that caused them and take appropriate countermeasures.

Table 5.1 Failure Mechanisms

Failure Factor		Examples
Internal Factors	Materials and Structures of parts	(1) Chemical interactions among metals or with die
		(2) Mismatching of thermal expansion rate
	Deviation in Product Process	(1) Failure of Al wire bonding (depends on position, pressure, crack etc.)
		(2) Scar of die surface pattern
		(3) Failure of air-tight packaging
		(4) Failure of solder
External Factors	Thermal Stress	(1) Destruction, wear, and degradation due to thermal expansion
		(2) Facilitation of chemical change (compound generation, etc.)
	Electrical Stress	(1) Package destruction due to exceeding isolation voltage
		(2) Die destruction due to exceeding isolation voltage (For a die with a MOS structure)
	Mechanical Stress	(1) Connection bending
		(2) Package cracking
		(3) Isolation breakdown (package)
	Chemical Stress	Corrosion of outer electrode Rusting of terminals
	Radiation	Change in device electrical characteristics due to accumulation of surface electric charge

5-3. Reliability Test

5-3-1. Reliability Test Types and Descriptions

Examples of the types and content of the reliability tests performed by Hitachi on the module product are shown in Table 5.2.

Table 5.2 Reliability Test Types and Descriptions

№	Type of Test	Test Method and Descriptions
1	Temperature Cycling	Determine the tolerance when exposed to both high and low temperature conditions. Temperature: (low-temperature, normal temperature, and high temperature), Time: 60 minutes each, Number of cycles: 200
2	Mechanical shock	Determine the tolerance to shock. Acceleration: 100G, Direction: (X, Y, Z), Time: 6μs. Performed three times in each direction.
3	Mechanical Vibration	Determine the tolerance to vibration. Acceleration: 10G, Frequency: 100Hz-2kHz, Direction: (X, Y, Z), 2 hours in each direction
4	Screw torque (Main terminal / Mounting)	Determine the tolerance to screw torque when mounting the main terminal, etc. Screw torque: the rated torque, Storage time: 336 hours
5	Intermitting operation life	Determine the electrical and mechanical tolerance of the device with respect to temperature rise and drop due to intermittent application of current. ΔTc = 70°C, 50 Hz half sine wave, Ip = rated current (IGBT 180° FWD 90°flow), Number of cycles: 30,000
6	Applied DC Voltage	Determine the electrical and thermal tolerance by applying electrical and thermal stress over a long period of time. Ta: 125 °C, Applied voltage: 80% of the rated voltage, Application time: 1,000hours
7	Applied AC Voltage	Determine the electrical and thermal tolerance by applying electrical and thermal stress over a long period of time. Ta: 125 °C, Applied voltage (peak value): rated value, Application time: 1,000hours
8	High temperature Storage	Determine the tolerance when stored at high temperatures. Ta: 125 °C (rated maximum storage temperature), Applied time: 1,000hours
9	Low temperature storage	Determine the tolerance when stored at low temperatures. Ta: -40 °C (rated minimum storage temperature), Applied time: 1,000hours
10	High humidity	Determine the tolerance to use and storage over a long period of time in high temperature and high humidity. RH = 90%, Ta: 60 °C, Storage time: 1,000 hours

5-3-2. Reliability Test Reference Values

The criteria for device degradation for the above reliability tests are determined by the following items and values.

(1) Ices, Iges < 2.0 times rated value.

(2) Vce(sat), Vf < 1.2 times rated value.

(3) Rth(j-c) < 1.5 times rated value.

5-3-3. Sample Testing Criteria

The number of samples and pass / fail criteria for the reliability test are as follows

(1) Number of Samples : 6 pieces for each test

(2) Number of Rejects : 0 Rejects allowed

5-3-4. Reliability Test Period

The periods when the reliability tests are conducted are as follows.

(1) Reliability tests are conducted when the initial prototype is completed (development stage).

(2) Reliability tests are conducted when the final prototype is completed (mass production stage).

(There are times when the testing data of modules with similar designs are substituted for one another.)

5-3-5. Test results (example)

The table below shows the reliability test items and conditions for our main products.

(1) IGBT module overview

Type No.: MBN1200E33E

Rating : 3,300V/1,200A

Tj : -40～125℃

(2) Test items and conditions

Test data: Test type and conditions

Table 5.3 Reliability Test Types and Testing Conditions

	Type of Test	Test Condition	Sample Size	No. of Passes
Environmental Function	High-temperature Storage	Temperature : 125℃, Storage time : 1,000h	6	6
	Low-temperature Storage	Temperature : -40℃, Storage time : 1,000h	6	6
	Temperature cycling	-40℃ to RT to 125℃ Hold Time: 60 minutes each temperature Number of repetition cycles : 200	6	6
	High humidity	Temperature : 60℃ Humidity : 90%R.H. Time : 1,000h	6	6
	Temp. Humidity Storage	Temperature : 85℃ Humidity : 85%R.H. Voltage : 2.6kV_{DC}, Time : 1,000h	6	6
Mechanical Function	Vibration(1) Variable Freq.	Acceleration; 10G, Frequency Range; 100Hz～2kHz Direction : 2 hours of each X, Y, Z	6	6
	Vibration(2) Variable Freq.	Total amplitude 1.5mm, Frequency Range; 10Hz～55Hz Direction : 2hours of each X, Y, Z	6	6
	Vibration(3) Variable Freq.	Acceleration; 10G, Frequency Range; 60±20Hz, Test time, Direction; 32 hours of each X, Y, Z	6	6
	Mechanical shock	Acceleration; 100G, Pulse width; 6ms Test time, Direction : 3 cycles of each X, Y, Z	6	6
	Mounting strength	the rated torque storage : 336h, temperature : RT, 100μm Al fin	6	6
	Thermal strength	the rated torque storage : 336h, temperature:RT, FAfin (20μm≤) 5t Cu plate	6	6
Electrical Function	Temp. Bias(AC)	Temp.; 125deg.C, gate-emitter short Apply Voltage; 3,300Vp(C-E) Test duration; 1,000h	6	6
	Temp. Bias(DC)	Temp.; 125deg.C, gate-emitter short Apply Voltage; 2,600Vp(C-E) Test duration; 1,000h	6	6
	Temp. Bias(AC)	Temp.; 125deg.C, collector-emitter short Apply Voltage; 20Vp(G-E) Test duration; 1,000h	6	6
	Thermal Fatigue Test	I_F=1,200A ⊿Tc=70℃ V_{GE}=15V 30,000 Cycle (Note)IGBT : 180°, Diode:90°	6	6
	Power Cycle	I_C=1,200A(IGBT side) ⊿Tj=60℃、 100,000 cycle	6	6
	Electrostatic Discharge	Capacitor C; 200pF, Resistance R; 0Ω Test Voltage; 200V, collector-emitter short	6	6
	Isolation	Applied Voltage; 5,700Vrms×8min. + 4,500Vrms×22min. Judgment: no destruction after test (≤10mA)	6	6

5-4. Quality Assurance System Diagram

The table below shows Hitachi's quality assurance system.

Table 5.4 Chart of Hitachi's Quality Assurance System

Business \ Section in charge	Sales Sec.	Design Sec.	Manufacturing Sec.	QA Sec.	Purchasing Dept.	Vender	Transportation Sec.	QA control Sec.
Marketing	Marketing Order							
Design Development	(new product)	·Development planning ·Design, Traial production ·Design review ·Characteristics qualification ·Failure analysis,	(developed product) Trial production Preproduction for mass					
Purchasing plan Purchasing of parts				·Audit of vender ·Audit of subcontractor				
Confirmation Test for quality level				Trial production & Preproduction for mass qualification test Approval test of quality level (Complition of thedevelopment)				
Production Planning			·Production planning ·Process control		(parts) Order of parts & materials	parts production		
Control of Purchasing parts		Producing indication		(new parts) Approval test for purchasing parts	Incoming inspection			
Production control Process control			Device production ·Production control (fabrication→assenbly) ·Process quality contorol ·PQC activity					
Characteristics Inspection			Characteristics inspection	Data check				
Reliability Test				Reliability test (process change) (regular confirmation)				
Warehouse			Warehouse					
Ship-out			Preparation for shipping	Shipping test			·packing & ·shipping	
Installation Planning	(Production facilities)		Installation planning & design		Order	Installation production facilities		
Measurement Equipment Control			Instrument equipment & installation control					Instrumens calibration
Service	(Catalogue)	·Catalogue ·Operating manual ·Application note		Confirmation				
Trouble shooting			Analysis of Failure Parts Decision of Counter Measure	Power Semiconductor Device QA & Inspection Sec. Analysis report (claims)			Customer (report)	

＜Remarks＞
- → : Device production route
- - - → : Device development route
- → : Sub route
- ·······> : Claim route
- (white box) : Business, Meeting
- (grey box) : Development business
- (grey rounded box) : Report

6. Troubleshooting

6-1. IGBT Module Failure Modes (Electrical Failure Mode)

When the IGBT breaks down, please investigate the cause of the breakdown in accordance with the following tree. However, although this tree will help in investigating the cause of the IGBT breakdown, it does not necessarily mean that you will be able to determine the cause.

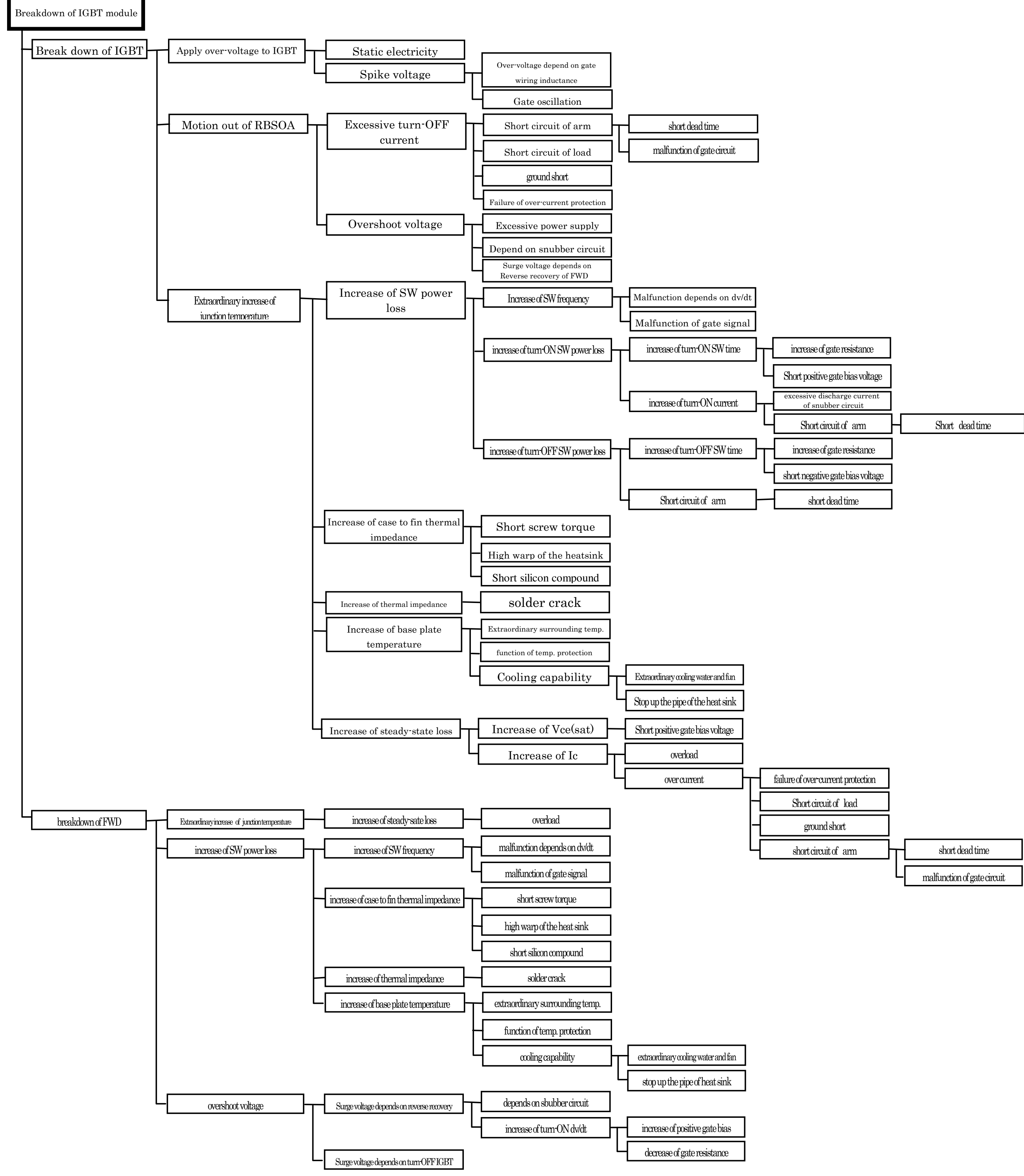


Figure 6.1 Electric Failure Analysis

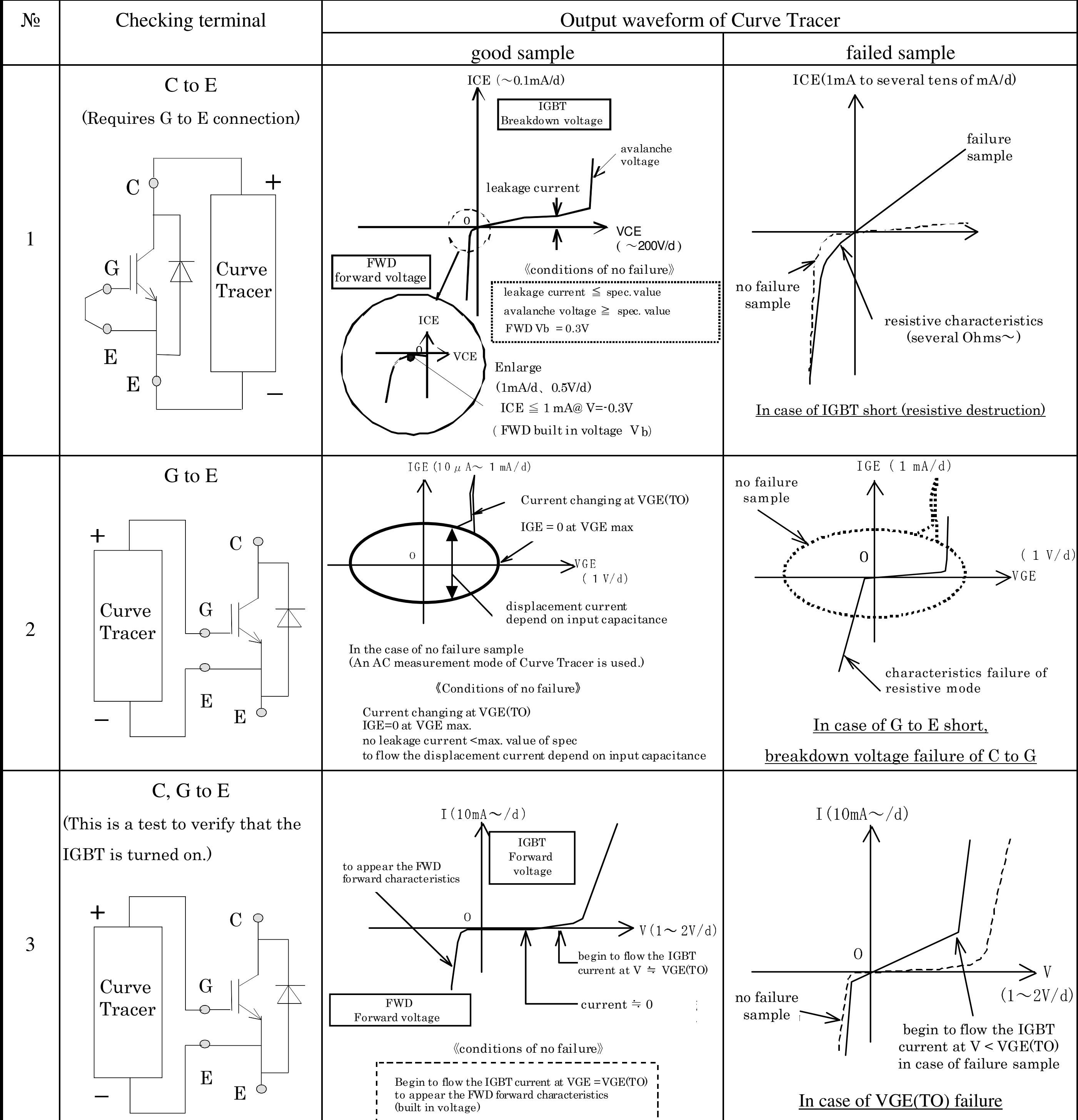
6-2. Device Check Method

To check IGBT electrical characteristic, a "Curve Tracer" is generally used to measure voltage and current.

Figure 6.1 shows both good and bad sample examples for checking IGBT module characteristics.

In addition, please note that if the device has degraded or has been damaged, using this method may lead to secondary damage.

Table 6.1 IGBT Electrical Characteristic Check Method (Reference)



№	Checking terminal	Output waveform of Curve Tracer	
		good sample	failed sample
1	C to E (Requires G to E connection) C, G, E, E, +, −, Curve Tracer	ICE (～0.1mA/d) IGBT Breakdown voltage avalanche voltage leakage current 0 VCE (～200V/d) FWD forward voltage 《conditions of no failure》 leakage current ≦ spec. value avalanche voltage ≧ spec. value FWD Vb = 0.3V ICE 0 VCE Enlarge (1mA/d、0.5V/d) ICE ≦ 1 mA@ V=-0.3V (FWD built in voltage Vb)	ICE(1mA to several tens of mA/d) failure sample no failure sample resistive characteristics (several Ohms～) In case of IGBT short (resistive destruction)
2	G to E +, −, Curve Tracer, C, G, E, E	IGE (10 μA～ 1 mA/d) Current changing at VGE(TO) IGE = 0 at VGE max 0 VGE (1 V/d) displacement current depend on input capacitance In the case of no failure sample (An AC measurement mode of Curve Tracer is used.) 《Conditions of no failure》 Current changing at VGE(TO) IGE=0 at VGE max. no leakage current <max. value of spec to flow the displacement current depend on input capacitance	IGE (1 mA/d) no failure sample 0 (1 V/d) VGE characteristics failure of resistive mode In case of G to E short, breakdown voltage failure of C to G
3	C, G to E (This is a test to verify that the IGBT is turned on.) +, −, Curve Tracer, C, G, E, E	I (10mA～/d) IGBT Forward voltage to appear the FWD forward characteristics 0 V (1～ 2V/d) begin to flow the IGBT current at V ≒ VGE(TO) current ≒ 0 FWD Forward voltage 《conditions of no failure》 Begin to flow the IGBT current at VGE =VGE(TO) to appear the FWD forward characteristics (built in voltage)	I (10mA～/d) 0 V (1～2V/d) no failure sample begin to flow the IGBT current at V < VGE(TO) in case of failure sample In case of VGE(TO) failure

*1. In this case, we described the measurement mode of the curve tracer as AC (alternating current power output), but if necessary, observe as DC mode (positive or negative voltage output).
You may wish to use DC mode to make it easier to observe leakage failure due to the low displacement current.

*2. Verifying characteristic failure of the module due to isolation voltage or temperature change is difficult using this method.

*3. Module characteristics checks with testers with low power supply voltage (simple testers with a few Vs) is also possible, but in such cases, it is difficult to "fully understand" the condition of the module.

7. Failure Precautions

7-1. Warnings

7-1-1. Precautions for Package Bursting

⚠ WARNING

- When either a load- or arm- short circuit occurs in an IGBT module, it must be turned OFF immediately (within a few microseconds).
  Otherwise, the module case may burst.

This is because energy at the time of short circuit accumulates in the module and will be released instantaneously.

Always be certain that you take the following precautions:

1) Keep the IGBT module in a closed case to prevent operator harm should it ever burst.
2) Never open the IGBT module's closed case while an electric current is being supplied to the module.

7-1-2. Warnings against Burns and Electric Shock

⚠ WARNING

- Do not go near or touch the product when it is powered on.
  Such actions may cause burns or electric shock.

7-2. Cautions

⚠ CAUTION

- After the IGBT breaks down, ensure that a short-circuit current does not continue flow for a long time (several hundred microseconds).
  This may cause smoke or fire.

Although IGBT modules use fire-retardant material, such as UL94VO, you should always make use of fuse-based circuitry to protect the module.