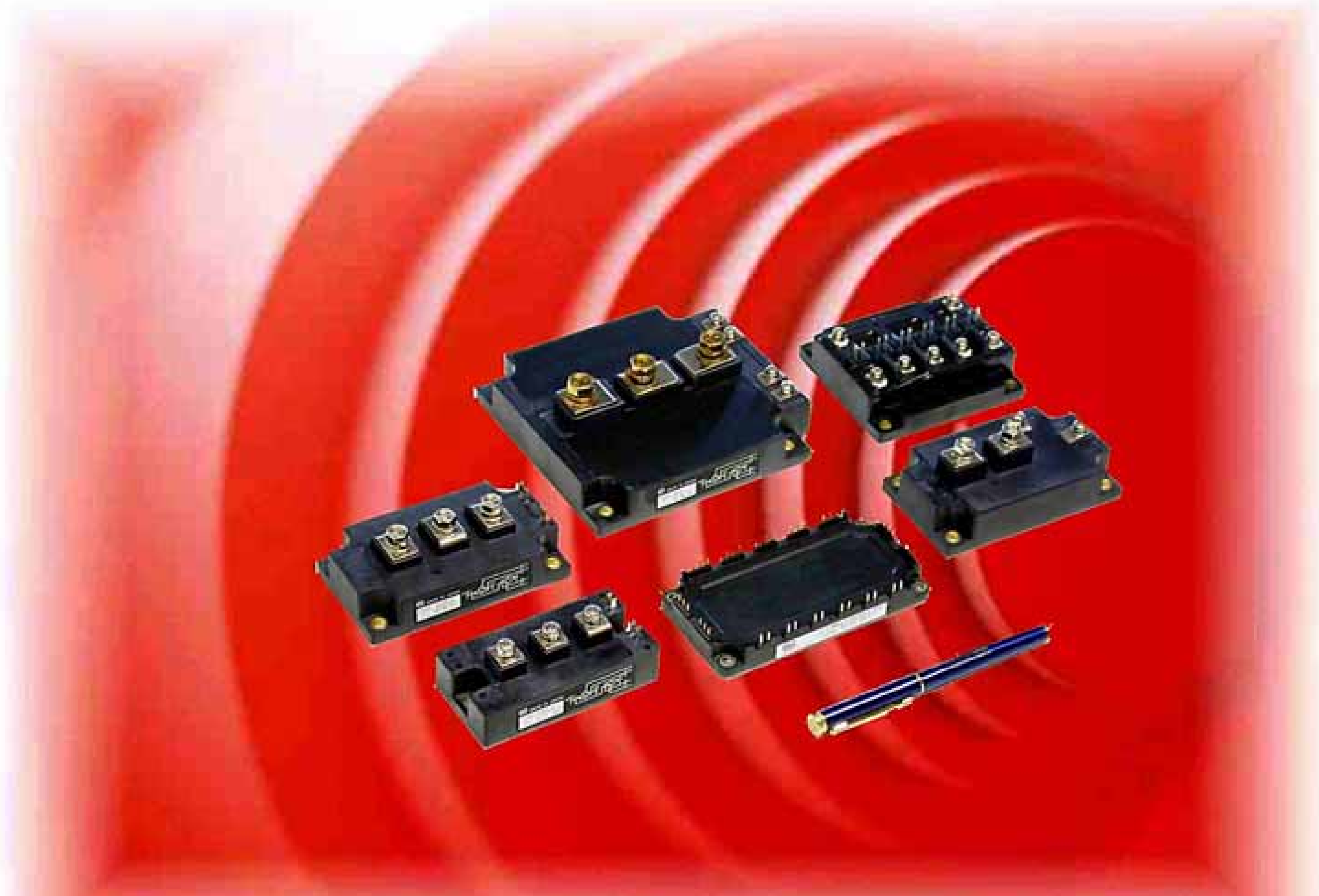
IGBT
APPLICATION NOTE



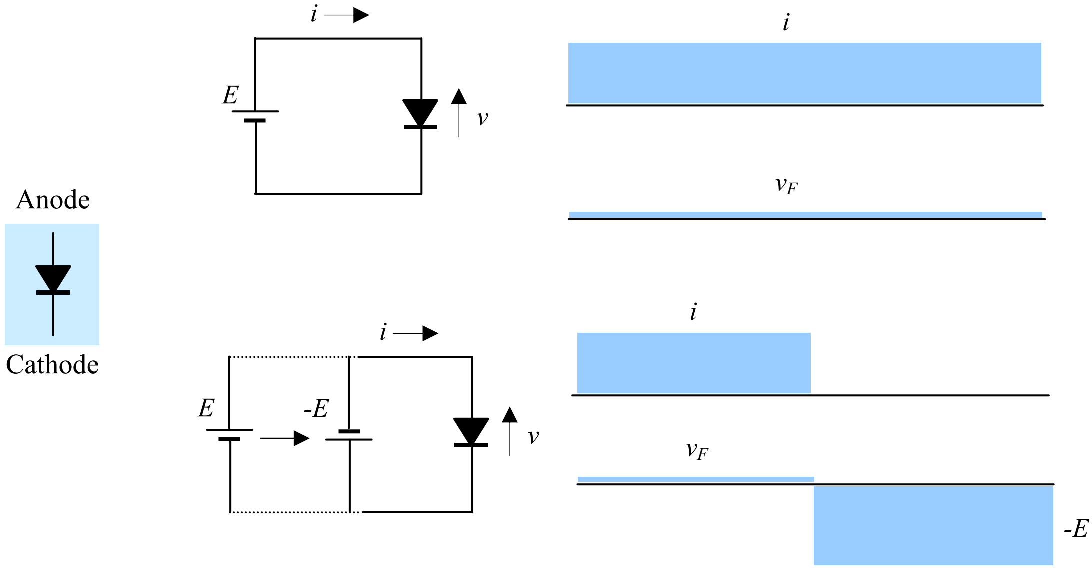
Nihon Inter Electronics Corporation
http://www.niec.co.jp/

CONTENTS

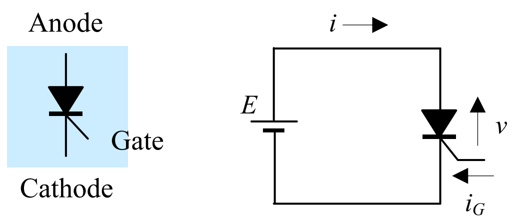
POWER DEVICES and IGBT

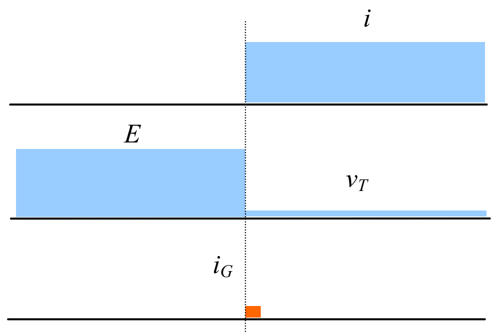
Diode is a fundamental semiconductor. Based on diode, switching characteristics of Thyristor, Bipolar Transistor, MOSFET, and IGBT are illustrated.

DIODE



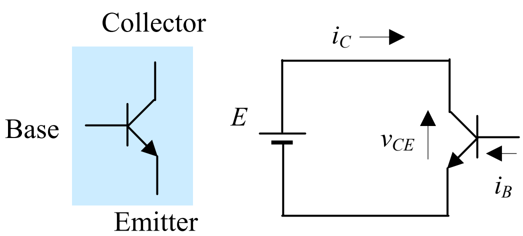
THYRISTOR (SCR)

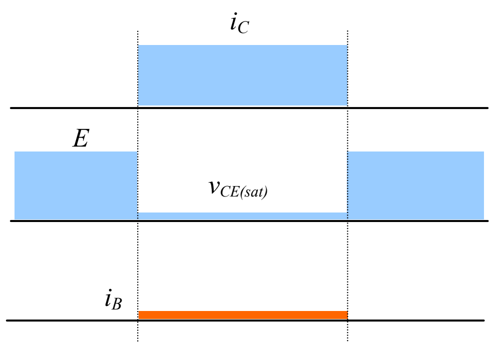




Thyristor can be switched on by DC or pulse gate current. But, it cannot be turned off by gate signal.

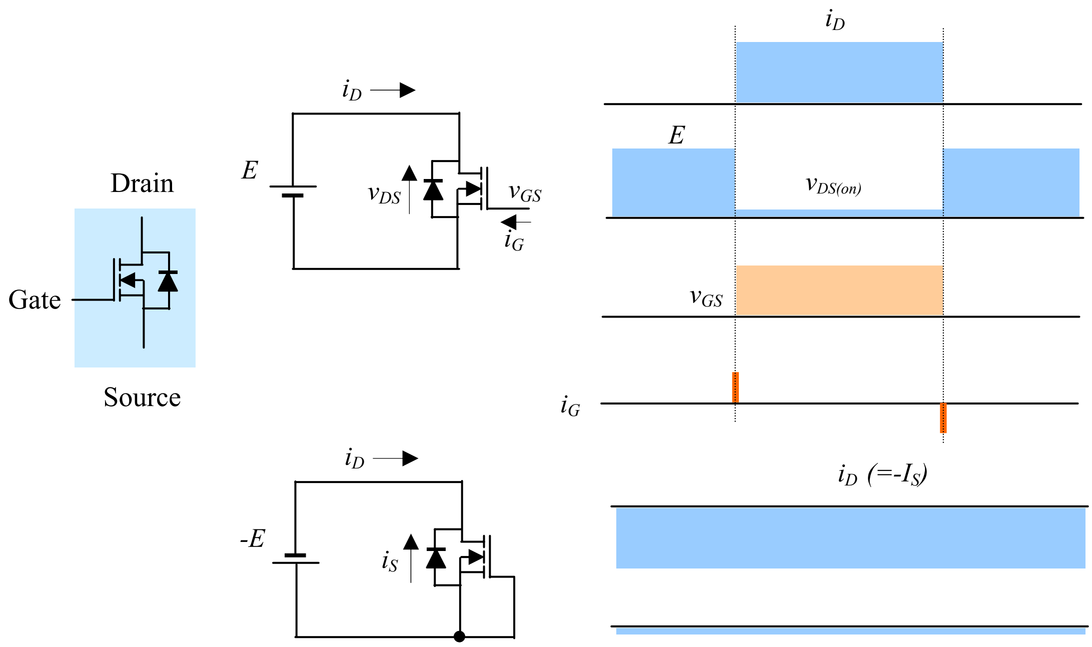
TRANSISTOR (NPN)





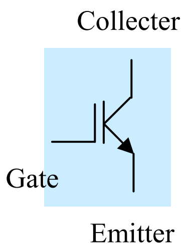
Transistor can be turned on during the period when base *current* is supplied.

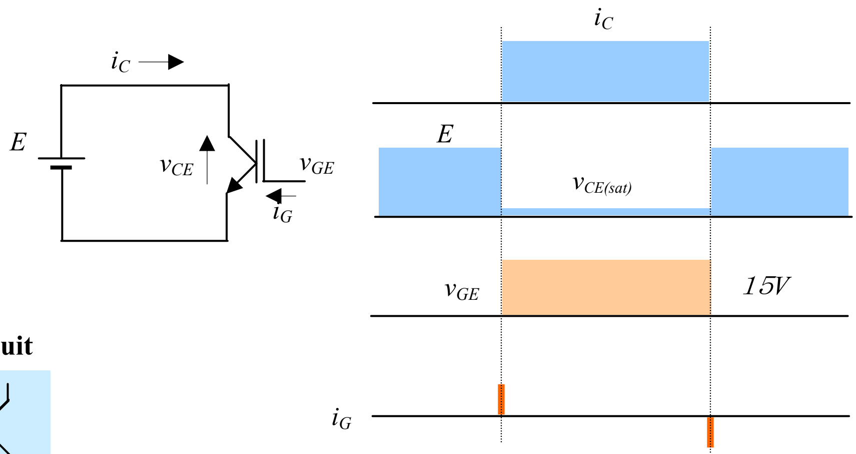
MOSFET (Nch)



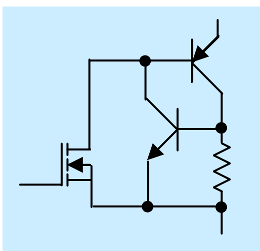
MOSFET can be turned on during the period when gate *voltage* is applied. Gate current flows only for a short period at turn-on and at turn-off. Between Drain and Source, diode is built-in on chip, and its current runs opposite to drain current.

IGBT





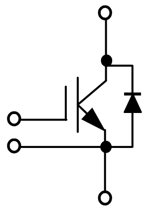
Equivalent circuit



IGBT, same as MOSFET, can be turned on during the period when gate voltage is applied, and gate current flows also only for a short period at turn-on and at turn-off. However, diode is not integrated on chip. In some IGBT Modules, discrete diode are assembled in the package.

VARIATION of NIEC’s IGBT Modules

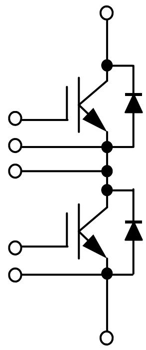
PHMB



Single

Example : PHMB400B12

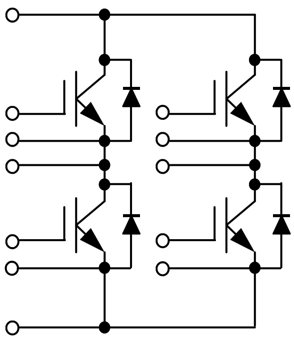
PDMB



Doubler, 2 in 1

Example : PDMB100B12C

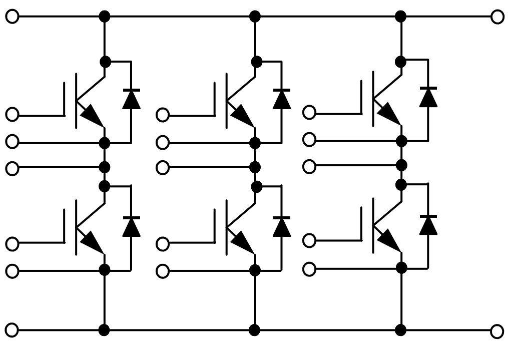
PBMB



Single-phase bridge, 4 in 1

Example : PBMB100B12C

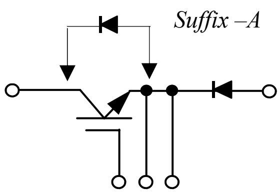
PTMB



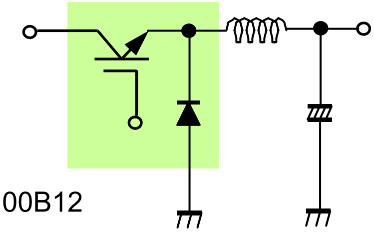
3-phase bridge, 6 in 1

Example : PTMB100B12C

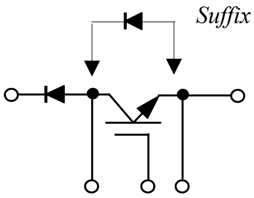
PCHMB



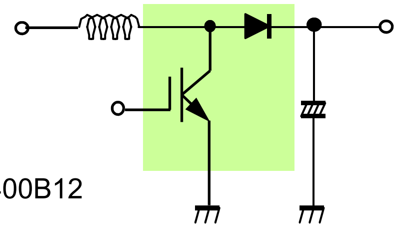
Example : PCHMB100B12



PRHMB(-A), PRFMB

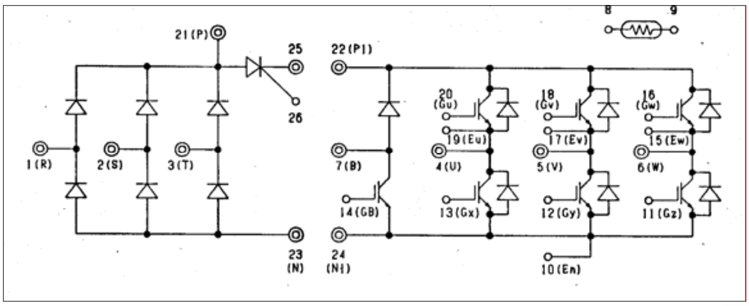


Example : PRHMB400B12

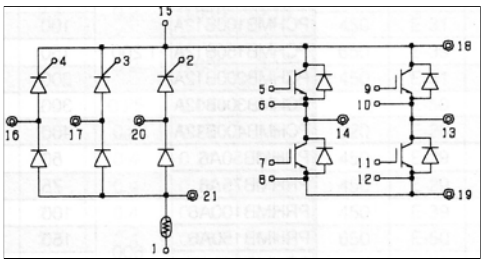


1 : PRFMB for 600V E-series

PVD



Example : PVD150-12



Example : PVD30-8

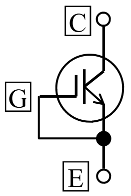
Ratings and Characteristics

For example, ratings and characteristics of PDMB100B12 are discussed here.

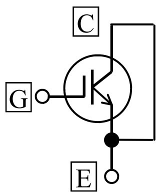
MAXIMUN RATINGS Tc=25℃

Item	Symbol	Rated Value	Unit
Collector-Emitter Voltage	V_{CES}	1200	V
Gate-Emitter Voltage	V_{GES}	±20	V

An excessive stress over these ratings may immediately damage device, or degrade reliability. Designers should always follow these ratings.



Maximum collector-emitter voltage with gate-emitter shorted



Maximum gate-emitter voltage with collector-emitter shorted

Collector Current	DC	I_C	100	A
	1ms	I_{CP}	200	A
Collector Power Dissipation		P_C	500	W

Maximum DC or pulse collector current

Maximum power dissipation per IGBT element. This module (PDMB100B12) has two IGBT elements, so this value is effective for each of two elements.

Junction Temperature	T_j	−40～ +150	℃
Storage Temperature	T_{stg}	−40～ +125	℃

Chip temperature range during continuous operation

Storage or transportation temperature range with no electrical load

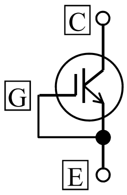
Isolation Voltage (Terminal to Base, AC, 1minute)		V_{ISO}	2,500	V
Mounting Torque	Module Base to Heatsink	F_{tor}	3 (30.6)	N･m (kgf･cm)
	Busbar to Main Terminal		2 (20.4)	

Maximum voltage between any terminal and base, with all terminals shorted

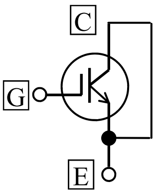
Maximum mounting torque, using specified screws

ELECTRICAL CHARACTERISTICS Tc=25℃ (Per one IGBT)

Characteristics	Symbol	Test Condition	Min.	Typ.	Max.	Unit
Collector-Emitter Cut-off Current	I_{CES}	V_{CE}=1200V, V_{GS}=0V			2.0	mA
Gate-Emitter Leakage Current	I_{GES}	V_{GS}=±20V, V_{CE}=0V			1.0	μA

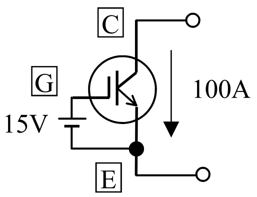


Collector leakage current, with gate-emitter shorted

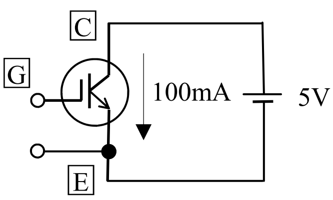


Gate leakage current, with collector-emitter shorted

Collector-Emitter Saturation Voltage	$V_{CE(sat)}$	I_C=100A, V_{GS}=15V		1.9	2.4	V
Gate-Emitter Threshold Voltage	$V_{GE(th)}$	V_{CE}=5V, I_C=100mA	4.0		8.0	V



A measure of IGBT steady-state power dissipation, which refers to forward voltage of diode, on-state voltage of SCR, or on-resistance of MOS-FET.



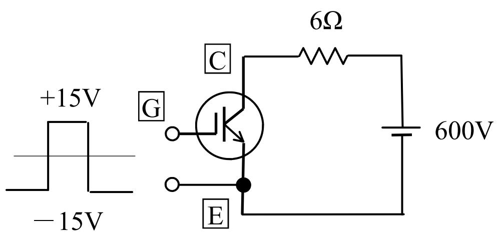
Gate-emitter voltage when IGBT starts to conduct

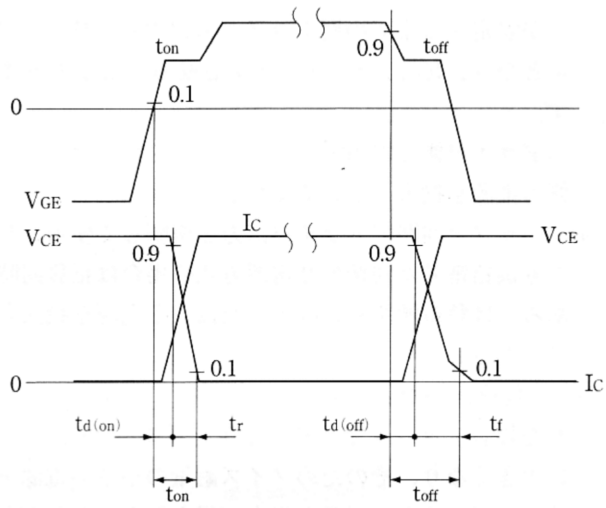
Input Capacitance	C_{ies}	V_{CE}=10V, V_{GE}=0V, f=1MHz		8,300		pF

Gate-emitter capacitance, with collector-emitter shorted in AC

Switching Time	Rise Time	t_r	V_{CE}=600V, R_L=6Ω, R_G=10Ω V_{GE}=±15V		0.25	0.45	μs
	Turn-on Time	t_{on}			0.40	0.70	
	Fall Time	t_f			0.25	0.35	
	Turn-off Time	t_{off}			0.80	1.10	

Definition of switching times



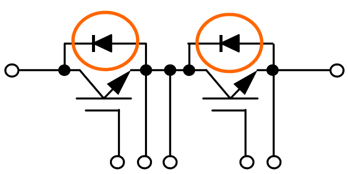


PDMB100B12 Maximum

$t_{d(on)}$	t_r	t_{on}	$t_{d(off)}$	t_f	t_{off}
(0.25μs)	0.45μs	0.70μs	(0.75μs)	0.35μs	1.1μs

MAXIMUN RATINGS AND ELECTRICAL CHARACTERISTICS OF FWD Tc=25℃

Forward Current	DC	I_F	100	A
	1ms	I_{FM}	200	A

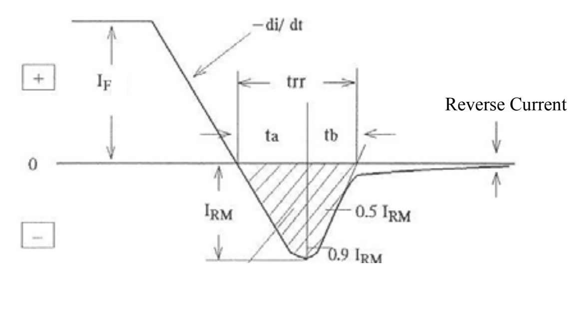


Maximum DC or pulse forward current of built-in diode

Characteristics	Symbol	Test Condition	Min.	Typ.	Max.	Unit
Forward Voltage	V_F	I_F=100A, V_{GE}=0V		1.9	2.4	V
Reverse Recovery Time	t_{rr}	I_F=100A, V_{GE}=−10V −di/dt = 200A/μs		0.2	0.3	μs

Forward voltage of built-in diode at specified current

Required time for built-in diode to recover reverse blocking state



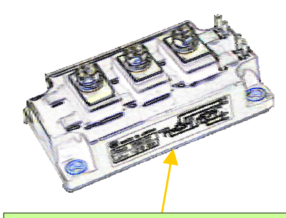
Definition of reverse recovery time

THERMAL CHARACTERISTICS

Characteristics		Symbol	Condition	Min.	Typ.	Max.	Unit
Thermal Resistance	IGBT	Rth(j-c)	Junction to Case			0.24	℃/W
	Diode					0.42	

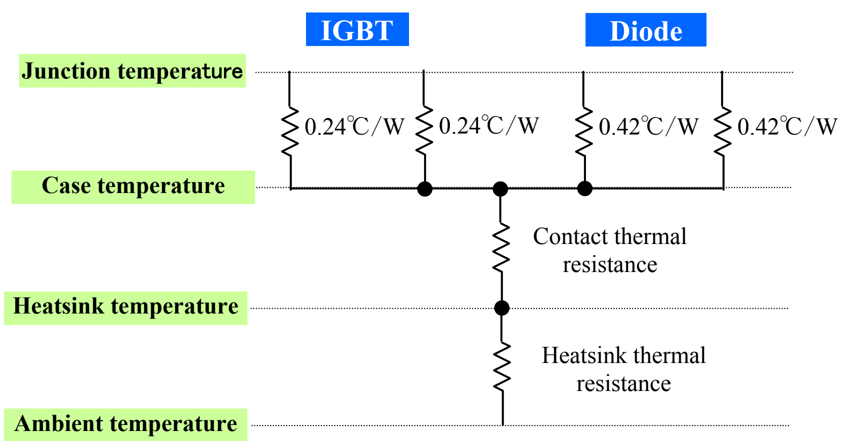
Thermal resistance of each of IGBT or built-in diode

Measuring point of Case temperature



* Measuring point is at the center of metal base plate.
* Thermo-couple is inserted into a hole of 1mm in diameter and 5mm in depth.

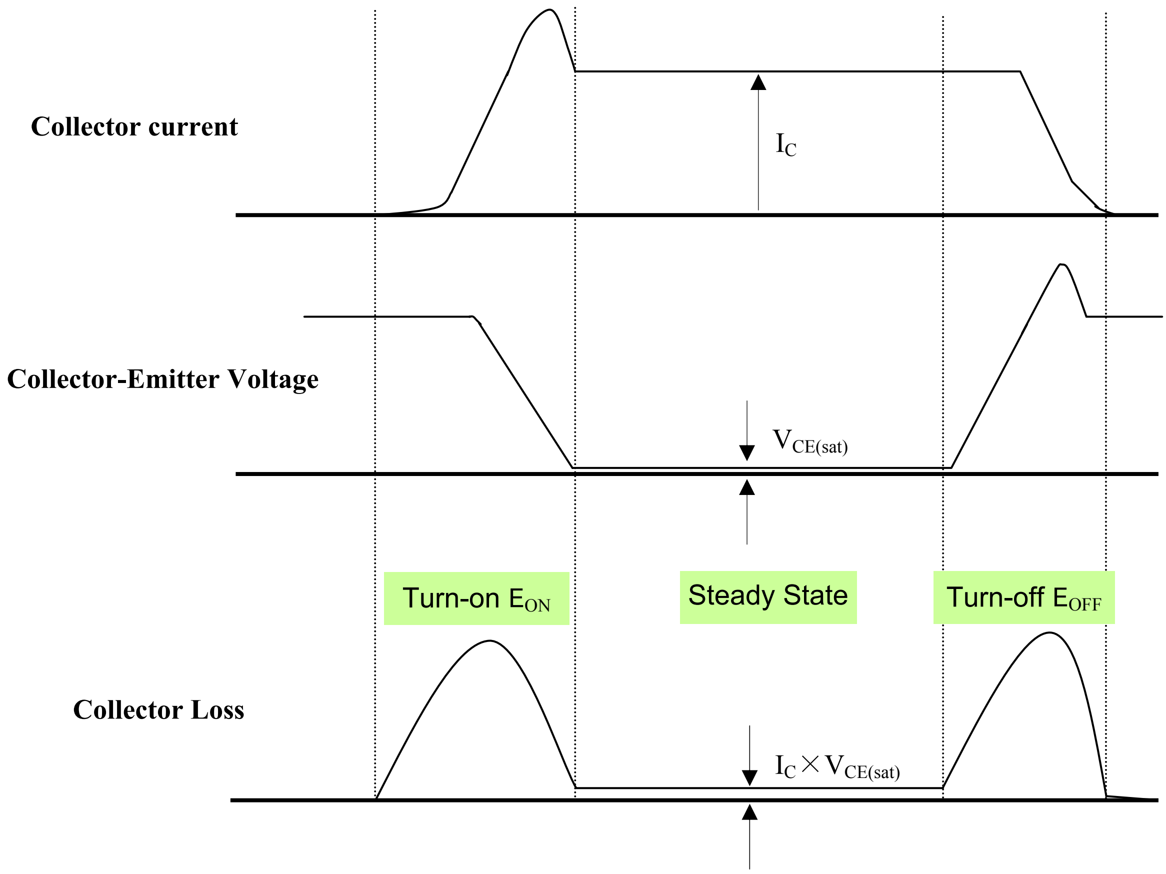
To define Rth(j-c), Tc is measured at metal base plate just below IGBT or diode chip.



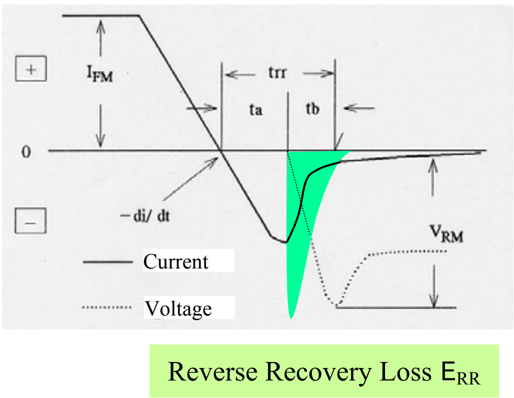
Power Loss and Thermal design

Power loss in IGBT consists of steady-state (conduction) loss and switching loss. And, switching loss is sum of turn-on loss (Eon) and turn-off loss (Eoff) Also, that's of built-in diode is sum of steady state and switching (E_{RR} - reverse recovery). You can calculate average loss by multiplying E_{ON}, E_{OFF}, E_{RR} times switching frequency.

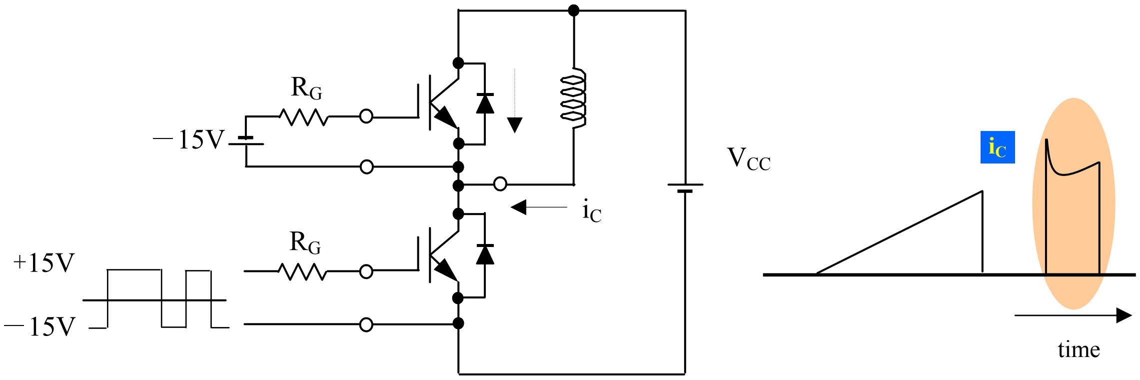
IGBT Losses



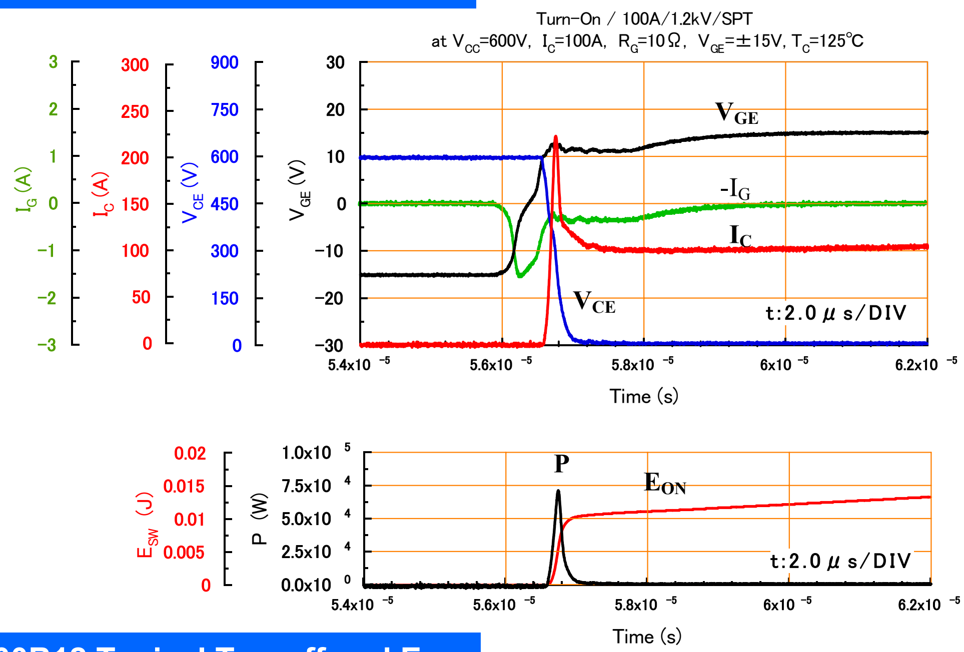
Reverse Recovery Loss



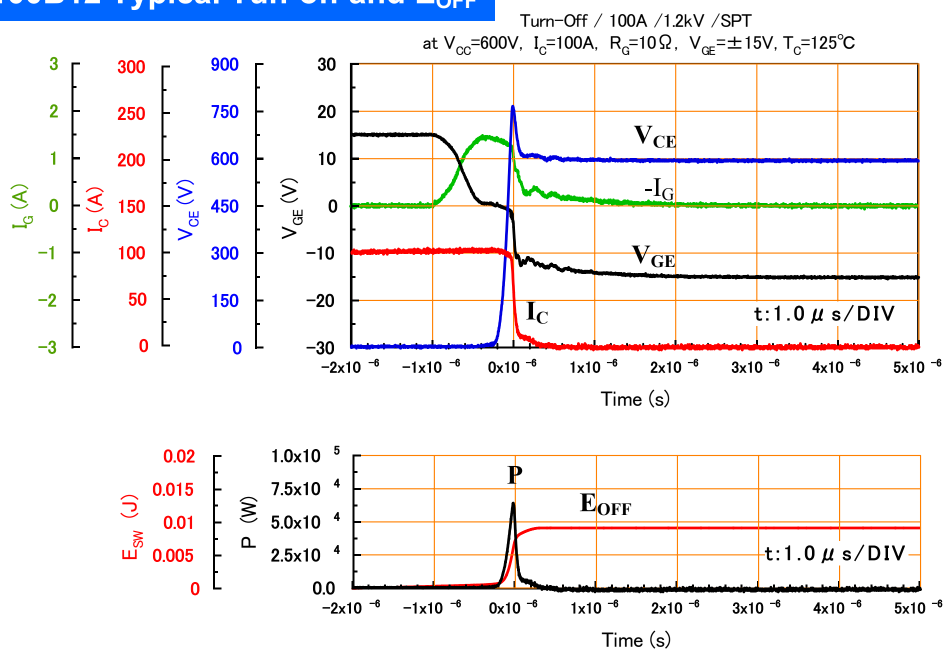
Measuring switching characteristics



PDMB100B12 Typical Tun-on and E_{ON}

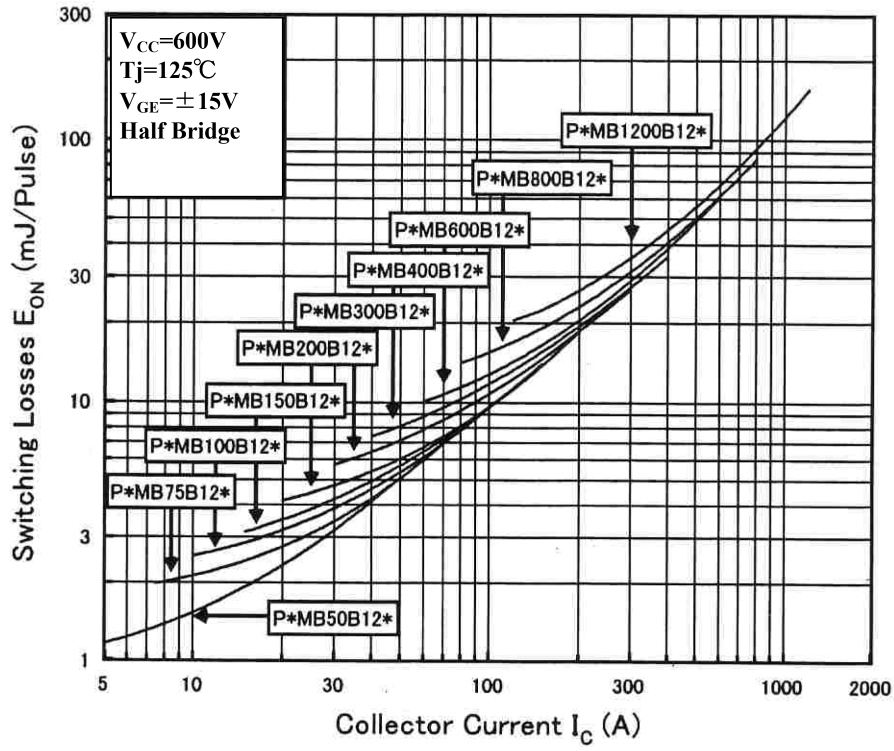


PDMB100B12 Typical Tun-off and E_{OFF}



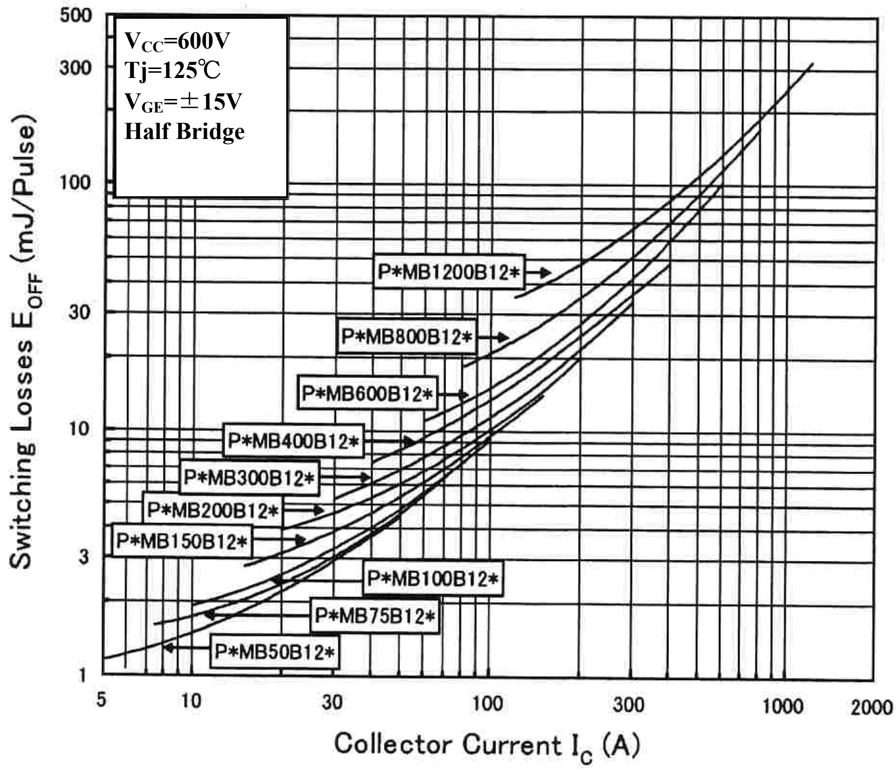
1200V B-series Turn-on Loss E_{ON} (Tj= 125℃)

Find R_G (gate series resistance) on Datasheet.

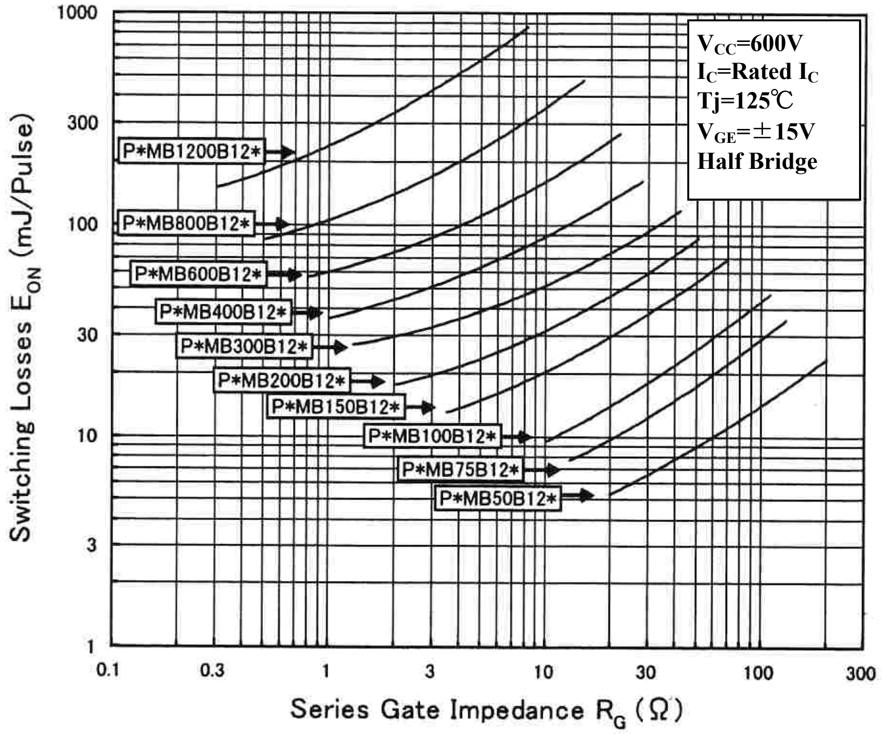


1200V B-series Turn-off Loss E_{OFF} (Tj= 125℃)

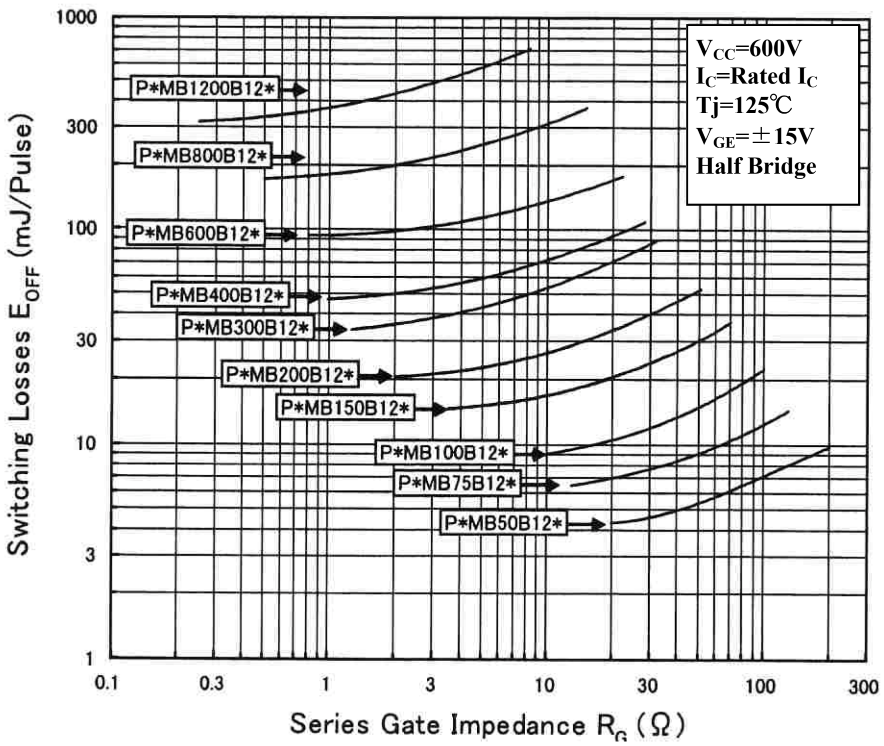
Find R_G (gate series resistance) on Datasheet.



1200V B-series Dependence of R_G on E_{ON} (Tj= 125℃)

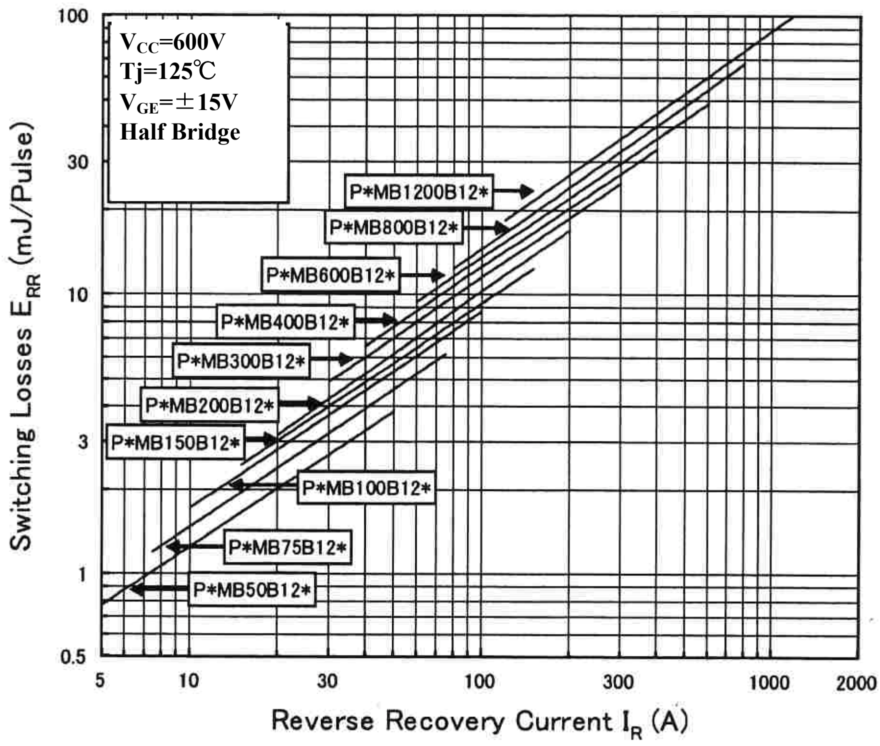


1200V B-series Dependence of R_G on E_{OFF} (Tj= 125℃)

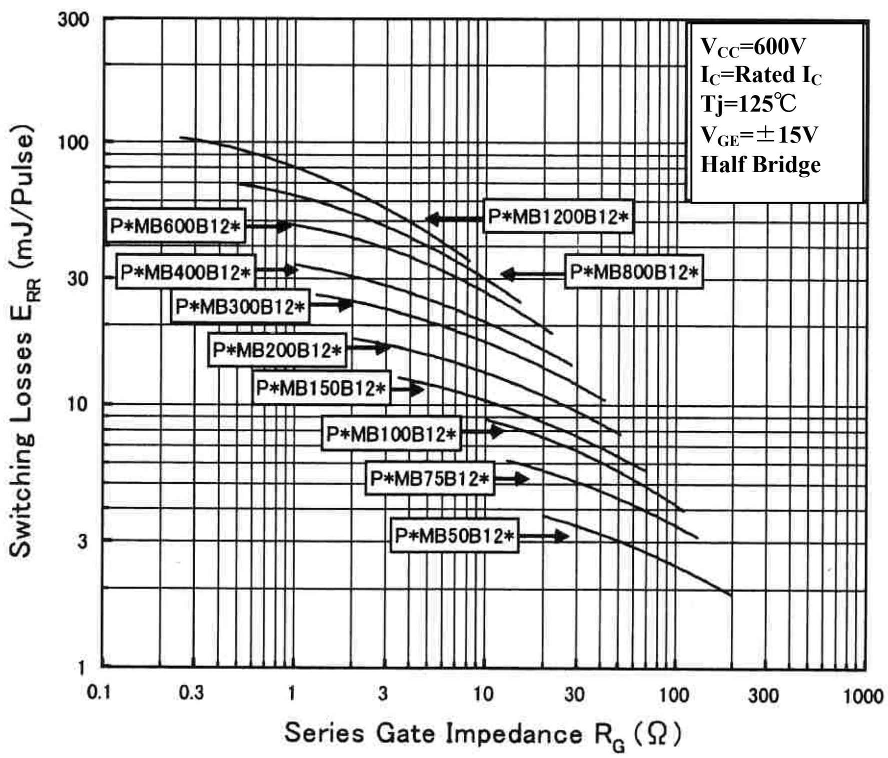


1200V B-series Diode Reverse Recovery Loss E_{RR} (Tj= 125℃)

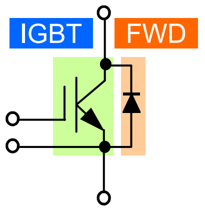
Find R_G (gate series resistance) on Datasheet.



1200V B-series Dependence of R_G on E_{RR} (Tj= 125℃)



Losses in IGBT Module



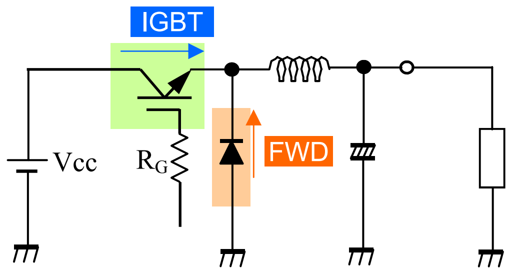
IGBT

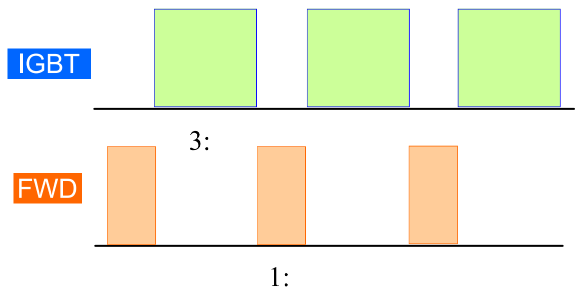
Steady-State Loss
Switching Losses (Turn-on Loss E_{ON}, Turn-off Loss (E_{OFF})

FWD

Steady-State Loss
Switching (Reverse Recovery) Loss E_{RR}

Calculation of Average Loss in a Chopper circuit





An example of average loss calculation

PRHMB100B12、Vcc=600V、Ic=100A、R_G=10Ω、V_{GE}=±15V、f=10kHz、Duty:3:1

IGBT Steady-state Loss : 100(A)×2.2[*1](V)×3/4=160(W)
Turn-on Loss : 9.5(mJ)×10(kHz)=95(W)
Turn-off Loss : 9.5(mJ)×10(kHz)=95(W)
IGBT Loss in total : 350(W)

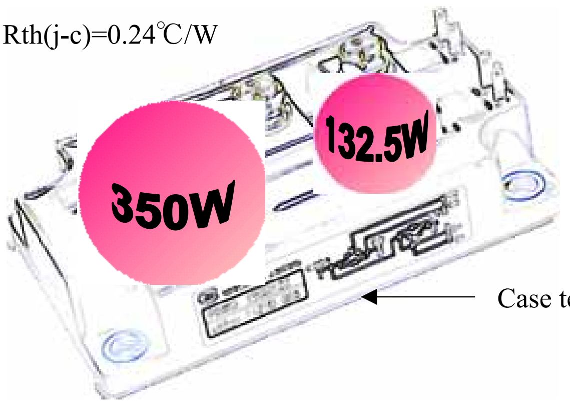
FWD Steady-state Loss : 100(A)×1.9[*2](V)×1/4=47.5(W)
Switching (Reverse Recovery) Loss : 8.5(mJ)×10(kHz)=85(W)
FWD Loss in total : 132.5(W)

Module Loss 482.5(W)

*1 Collector-Emitter saturation voltage @ Ic=100A, T_J=125℃
*2 Forward voltage @ I_F=100A, T_J=125℃

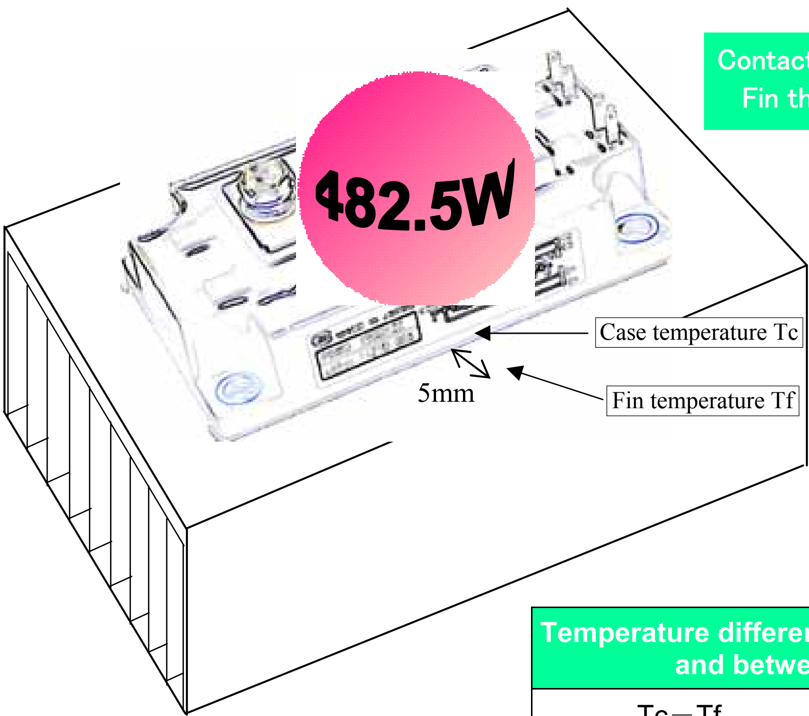
Calculations follow the condition on previous page.

Junction to Case Temperature Rise



Temperature Difference between Tc and Tj	
IGBT	FWD
84℃ (350×0.24)	*55.65℃ (132.5×0.42)*

Case to Fin, and Case to Ambient Temperature Rise



Contact thermal resistance Rth(c-f)
Fin thermal resistance Rth(f-a)

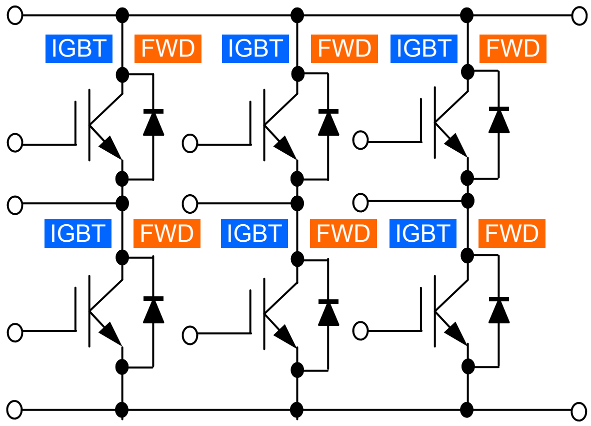
Temperature difference between Tc and Tf, and between Tf and Ta	
Tc－Tf	Rth(c-f)×482.5
Tf－Ta	Rth(f-a)×482.5

Loss and Temperature Rise in 3-phase Inverter

We cannot easily estimate losses for applications which have sophisticated operating wave-form, such as PWM inverter. In these cases, we recommend directly measure losses, using DSO. (Digital Storage Oscilloscope) which features computerized operation. (For example, Tektronix introduces TDSPWR3 software to analyze complicated losses.)
For choice of heatsink, an example how to evaluate losses is shown below.

EXAMPLE

PTMB75B12C, Inverter output current (I_{OP}) 75A, Control Factor (m) 1, Switching frequency (f) 15kHz, Power factor cosϕ 0.85



Let's review losses in IGBT module. Losses in IGBT are sum of steady-state (conduction) loss Psat, turn-on loss P_{ON}, and turn-off loss P_{OFF}. And, losses in FWD are sum of steady-state loss P_F and reverse recovery loss P_{RR}.

$$\mathrm{Psat} = \frac{1}{2\pi}\int_0^{\pi} \{I_{OP}\sin\theta \times V_{CE(sat)}\sin\theta \times (1 - m\sin(\theta + \phi)/2\}\, d\theta$$

$$= I_{OP}\, V_{CE(sat)} \left(\frac{1}{8} + \frac{m}{3\pi}\cos\varphi\right)$$

Given I_{OP}=75A, $V_{CE(sat)}$ =2.2V (125℃), m=1, cosφ=0.85,
Psat=35.5(W)

$$P_F = \frac{1}{2\pi}\int_0^{2\pi} \{(-I_{OP}\sin\theta) \times (V_F\sin\theta) \times (1 - m\sin(\theta + \phi)/2\}\, d\theta$$

$$= I_{OP}\, V_F \left(\frac{1}{8} - \frac{m}{3\pi}\cos\varphi\right)$$

V_F of FWD is 1.8V @75A、125℃;
P_F=4.7W

Referring datasheet, we know turn-on loss, turn-off loss, and reverse recovery loss per pulse are 7.5mJ、7mJ、and 6mJ, respectively. Multiplying frequency (15kHz) and 1/π, we after all have average losses.

E_{ON}=35.8(W)、E_{OFF}=33.4(W)、E_{RR}=28.6(W)

*1 $\frac{1}{2\pi}\int_0^{\pi}\sin\theta\, d\theta$

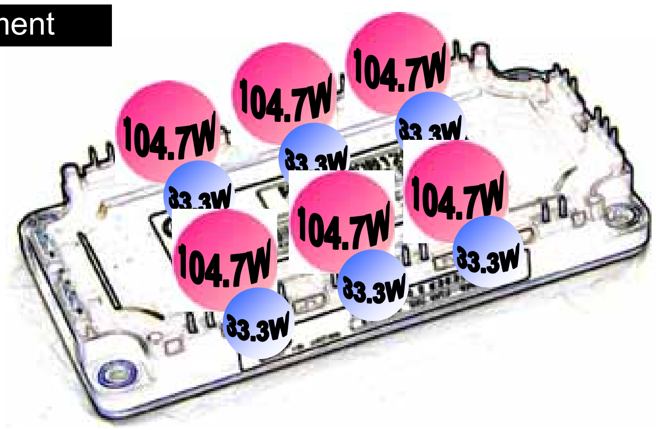
Loss and Temperature Rise in 3-phase Inverter (Continued)

Loss per IGBT and FWD

Average Loss per IGBT	Average Loss per FWD
104.7W ($Psat+P_{ON}+P_{OFF}$)	*33.3W* (P_F+P_{RR})

Loss in each element

Total Loss 828W



Temperature Rise of each element

IGBT

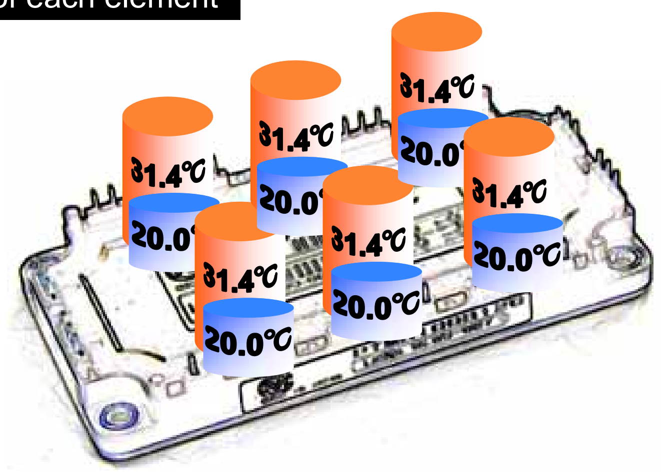
Rth(j-c)=0.3℃/W

ΔT(j-c)＝31.4℃

FWD

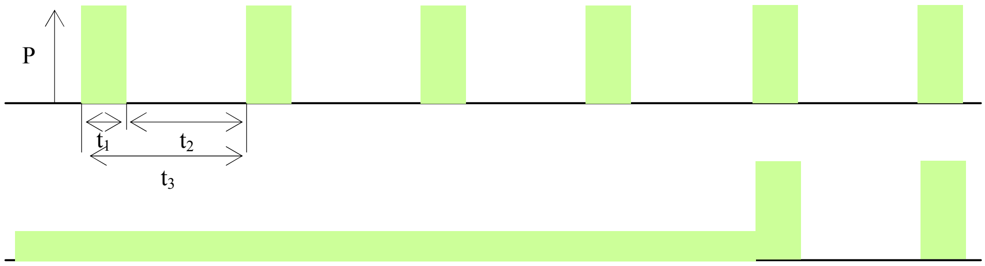
Rth(j-c)=0.6℃/W

ΔT(j-c)＝20.0℃



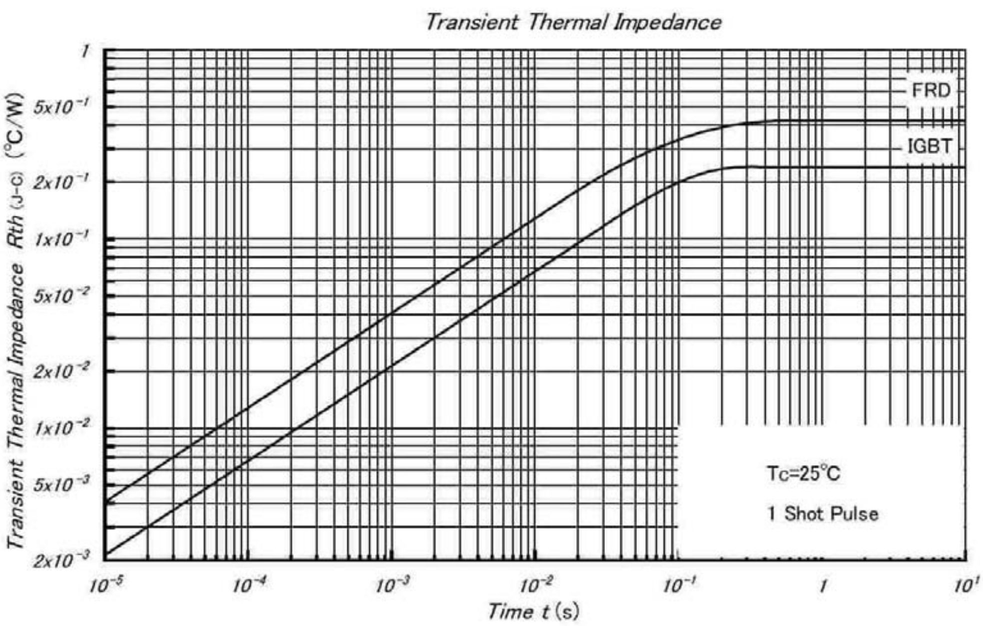
Junction to Case Transient Temperature Rise

On previous page, the temperature rise is average (steady-state) value. Using transient thermal resistance, you can calculate peak temperature, when necessary.



$$\Delta T(j\text{-}c) = P \times (t_1/t_3) \times \{Rth(j\text{-}c) - r_{th}(t_3+t_1)\} + P \times (r_{th}(t_3+t_1) - r_{th}(t_3) + r_{th}(t_1))\}$$

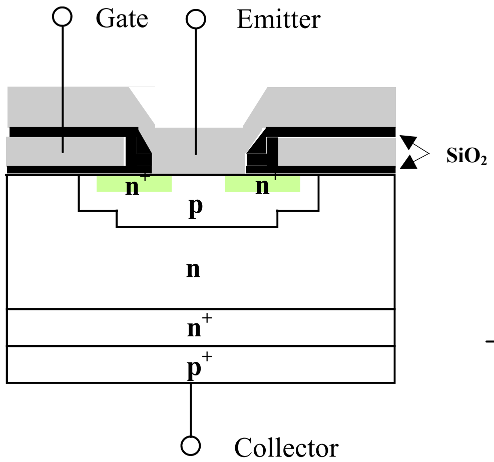
$r_{th}(t)$ is transient thermal resistance at time t



Check which is the highest temperature among IGBT elements, and consider transient temperature variation over average temperature.

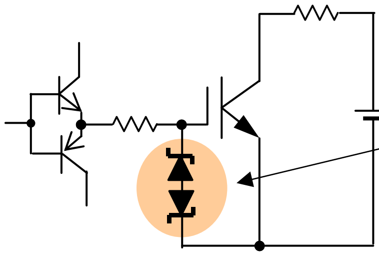
Gate Drive

Rated (Maximum) Gate Drive Voltage



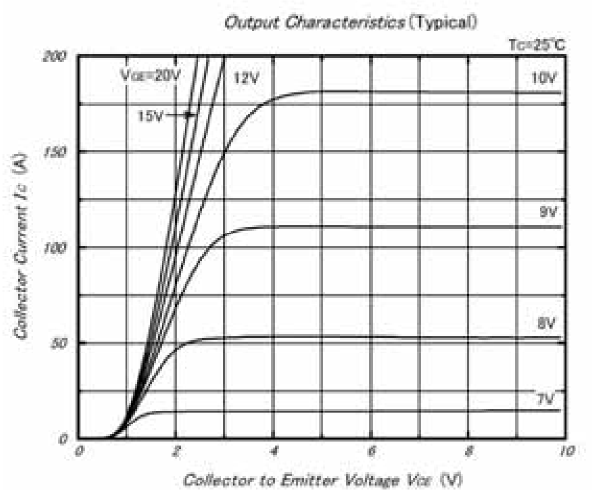
Gate voltage range should be within ±20V

Exceeding this rating may destroy gate-emitter oxide (SiO_2), or degrade reliability of IGBT.



Zener Diode (18V or so) to absorb surge voltage

On-Gate Drive Voltage



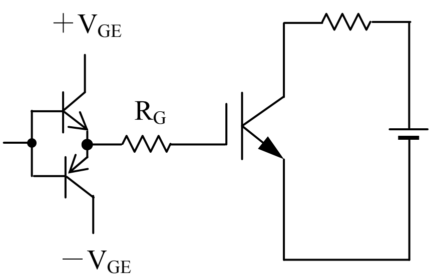
I_C=100A (V_{CE}=600V)

V_{GE}	8V	10V	12V	15V
$V_{CE(on)}$	(600V)	2.25V	2.05V	1.95V
P_C	(60,000W)	225W	205W	195W

Lower gate voltages, such as 12V or 10V, cause an increase in collector loss. Lower voltage as low as 6V cannot lead IGBT to be on-state, and collector-emitter voltage maintains near supply voltage. Once such a low voltage is applied to gate, IGBT may possibly be destroyed due to excessive loss.

Standard On Gate Drive Voltage is +15V.

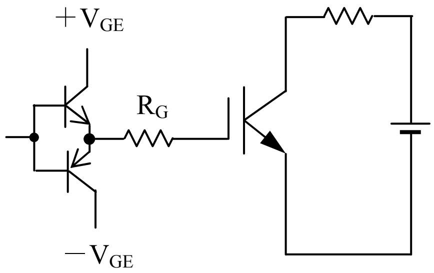
Reverse Gate Bias Voltage during Off-period (- V_{GE})



To avoid miss-firing, apply reverse gate bias of (-5V) to -15V during off-period.

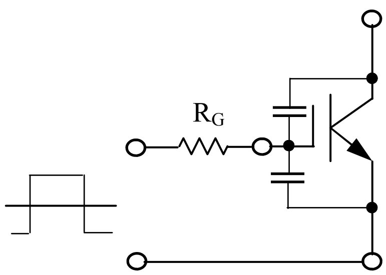
(-5V) ~ -15V
Standard : -15V

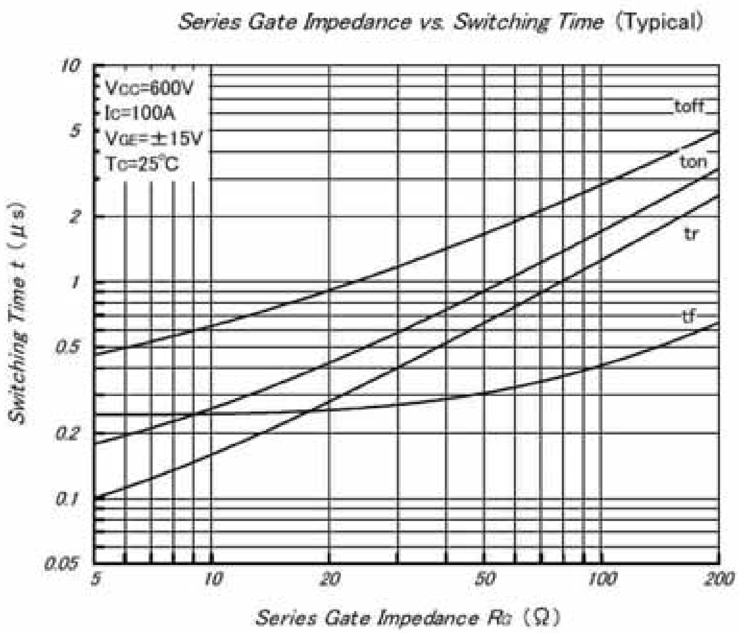
Dependence of on-gate voltage and off-gate bias on switching speed and noise



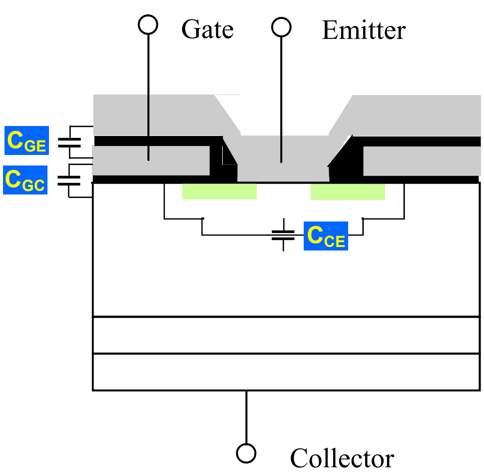
Increase in on-gate voltage (+V_{GE}) results in faster turn-on, and turn-on loss becomes lower. It follows additional switching noise.
As a matter of course, higher off-gate voltage (-V_{GE}) causes higher turn-off speed and lower turn-off loss. As expected, it follows higher turn-off surge voltage and switching noise.
R_G, +V_{GE}, and -V_{GE} are major factors which significantly affect switching speed of IGBT.

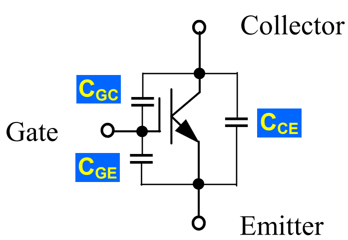
Effect of gate resistance R_G on switching





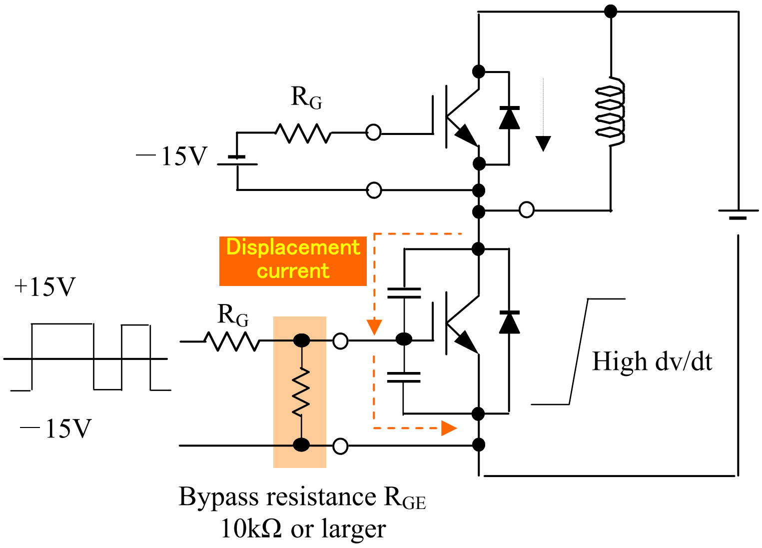
Gate Capacitance



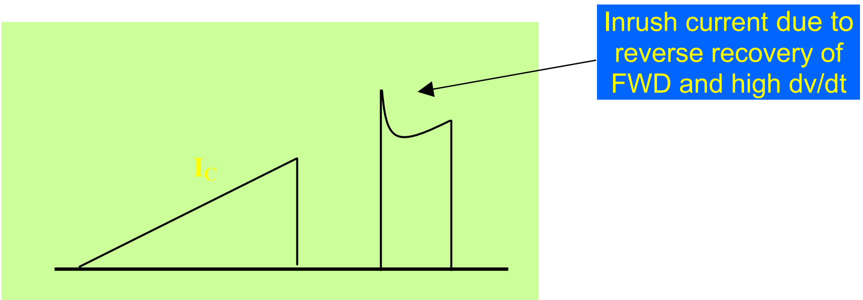


Input Capacitance	Cies = Cge + Cgc
Reverse Transfer Capacitance	Cres = Cgc
Output Capacitance	Coes = Cce + Cgc

Gate Reverse Bias Voltage and Gate-Emitter Resistance R_{GE}



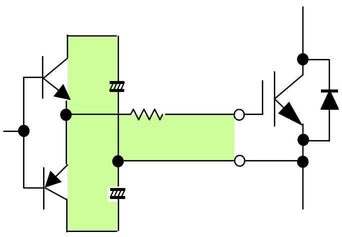
Displacement current flows due to high dv/dt, and gate voltage rises.



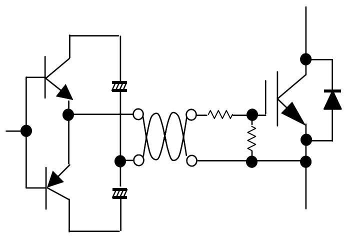
Reverse gate bias and bypass resistance surpress inrush current and accompanied loss.

Gate Wiring

To be free from harmful oscillation, be sure to confirm following points.



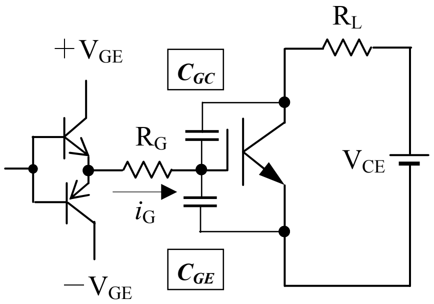
Minimize loop area



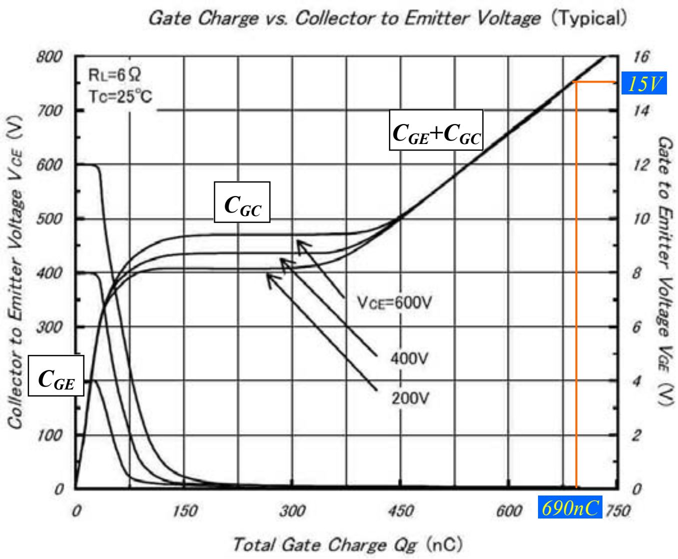
Twist

*Set gate wiring as far as possible from power wiring, and do not set parallel to it.
*If crossing is inevitable, cross in right angles.
*Do not bundle gate wiring pairs.
*Additional common mode inductor or ferrite bead to gate wiring is sometimes effective.

Using Gate Charge to estimete Drive Current and Power



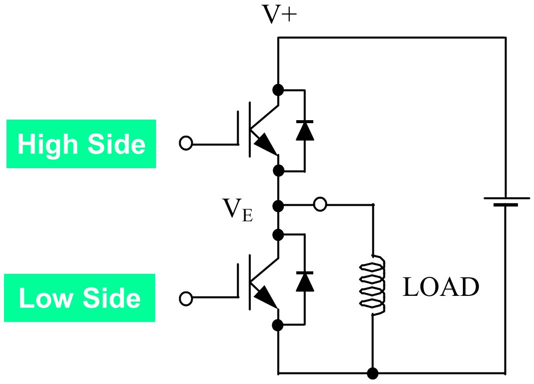
Gate Drive Dissipation P_G, Peak Gate Drive Current i_{GP}
(+V_{GE}=15V、-V_{GE}=-15V、f=10kHz)



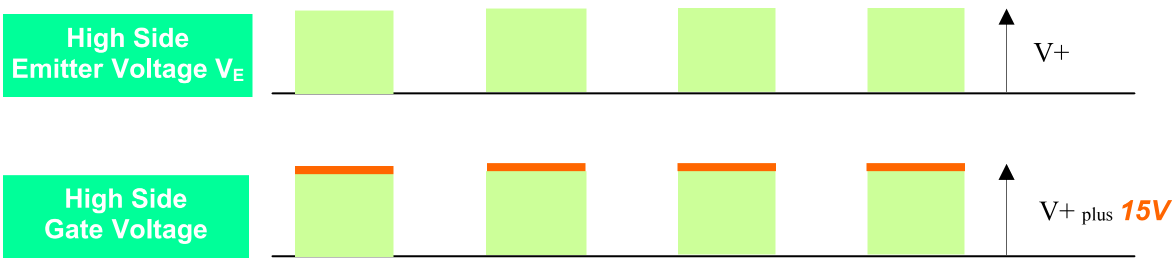
P_G={(+V_{GE})-(-V_{GE})}×Qg×f
=30×690×10^{-9}×10^4
=0.207 (W)

Assuming turn-on time is 500ns ;
i_{GP} = Qg / ton
=690×10^{-9} / 500×10^{-9}
=1.4 (A)

High Side and Low Side

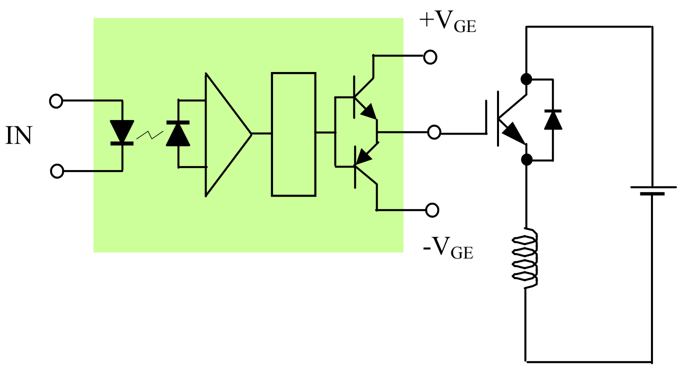


IGBT is driven referred to emitter voltage. During switching operation, emitter voltage of high side IGBT V_E swings from 0V to bus voltage V+. So, required gate drive voltage for high side IGBT in AC200V circuit is as high as 300V (bus voltage) plus 15V, 315V. Consequently, we need high side drive circuit not influenced by switching operation.



Optocoupler or high voltage driver IC is usable solution these days.

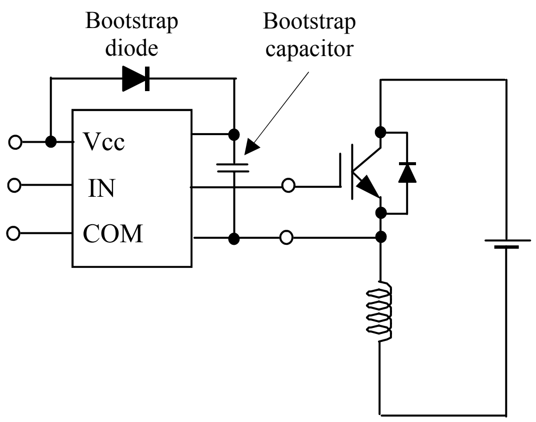
High Side Drive Using Optocoupler



For high power applications, optocoupler is utilized for isolation, and, discrete buffer is added as output stage.
For medium or less power applications, hybrid IC integrated in a package illustrated on the left is a popular choice.

* Use high common mode rejection (CMR) type.
* To minimize dead time so as to decrease IGBT loss, use one with shortest transfer delay times, t_{PLH} and t_{PHL}. t_{PLH} and t_{PHL} are differences in delay time for output changes from L to H, or L to H, referred to input, respectively.
* Major suppliers are Toshiba, Agilent Technologies, Sharp, NEC, and etc.
* Application note of Agilent Technologies indicates that optocoupler ICs are recommended to $200V_{AC}$ motor driver of 30kW or less (600V IGBT), and to $400V_{AC}$ driver of 15kW or less (1,200V IGBT). (For higher power applications, discrete optocoupler plus buffer is used as gate driver.)

High Side Drive using Driver IC



Available line-ups are;
- High side
- Half bridge
- High and Low
- 3-phase bridge

Many have rating of 600V, while some have of 1200V.

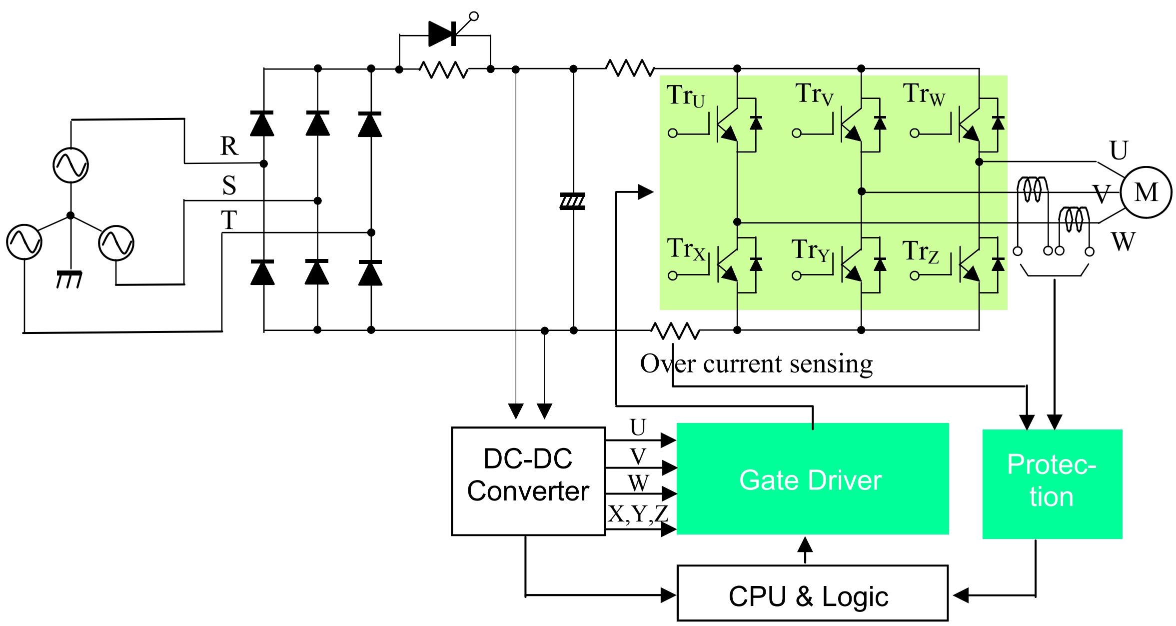
＊ Bootstrap diode should be fast recovery type, and its V_{RRM} should be same as V_{CES} of IGBT.
＊ For bootstrap capacitor, use high frequency capacitor, such as film or ceramic, or add it in parallel.
＊ Reduce line impedance of Vcc as small as possible.

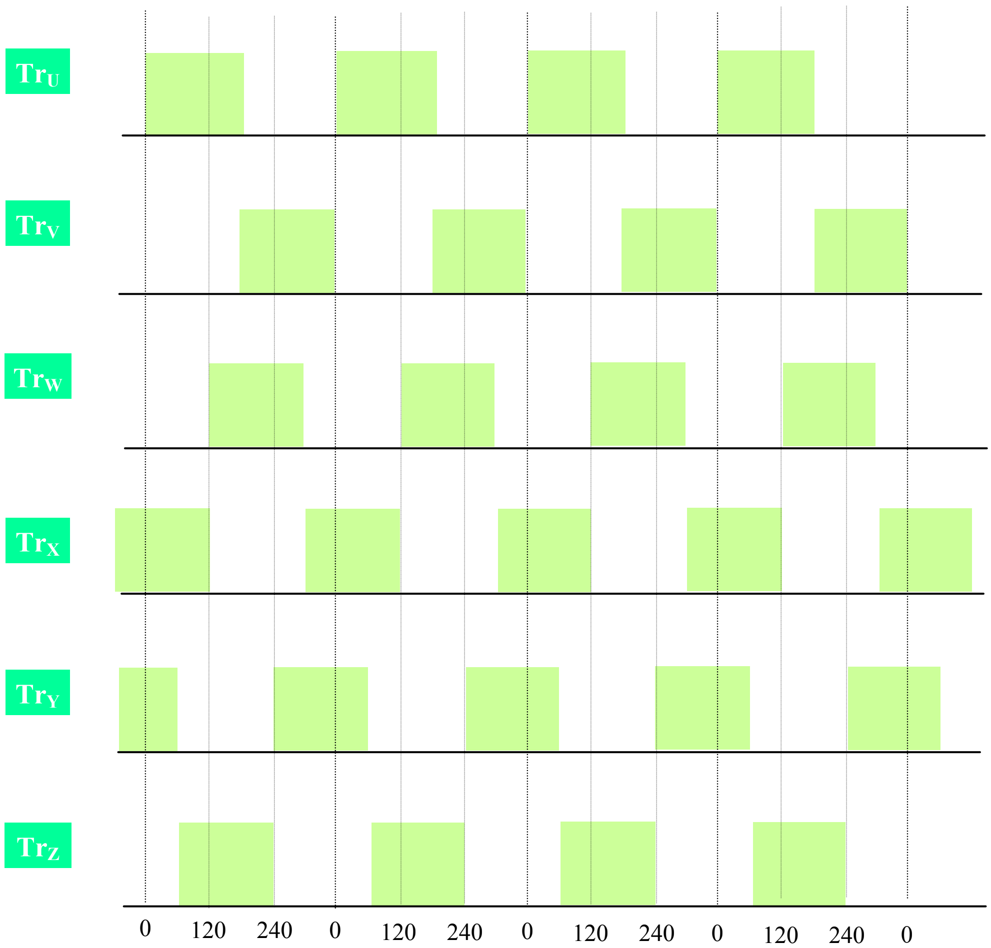
Optocoupler vs. Driver IC

Comparison between the two are as follows.

	Optocoupler	Driver IC
Application Technique	Relatively easy	Relatively not easy
Structure	Hybrid	Monolithic
AC400V line		Tough on use
Typical Vcc current	10mA	Less than 2mA
Dead time	More than 2μs	Less than 1μs is available
Assembly area	Large	Small
Protection	Built-in some	Plus current sensing
Inverter output		Especially useful for 3-phase 2.2～3.7kW
Improvements	Drive capability, Protection, Noise margin, Less difference in characteristics, Integrated current-sensing, etc	

3-phase Induction Motor Driver and Output Timing Chart





AC line Voltage and Corresponding IGBT Rated V_{CES}

AC Line Voltage	200～240V	400～480V	575, 690V
IGBT V_{CES}	600V	1200V	1700V

Motor Output and IGBT Rated I_C (3-phase bridge)

$I_{AC}=P / (\sqrt{3}\times V_{AC}\times\cos\theta\times\eta)$

I_{AC} : Motor Drive Current (A_{RMS})
P : 3-phase Motor Output (W)
V_{AC} : Rated Voltage (V_{RMS})
$\cos\theta$: Power Factor
η : Efficiency

Assuming power factor is 0.8, and efficiency is 70%,
$I_{AC}=P / (0.970V_{AC})$

$$I_C = \sqrt{2}\times I_{AC}\times\underbrace{1.1}_{\text{Derating for line voltage fluctuation}}\times\underbrace{1.1}_{\text{Derating for distortion in output current}}\times\underbrace{Kg}_{\text{Derating for short period overload : 1.2}}\times\underbrace{1.3}_{\text{Temperature Derating}}$$

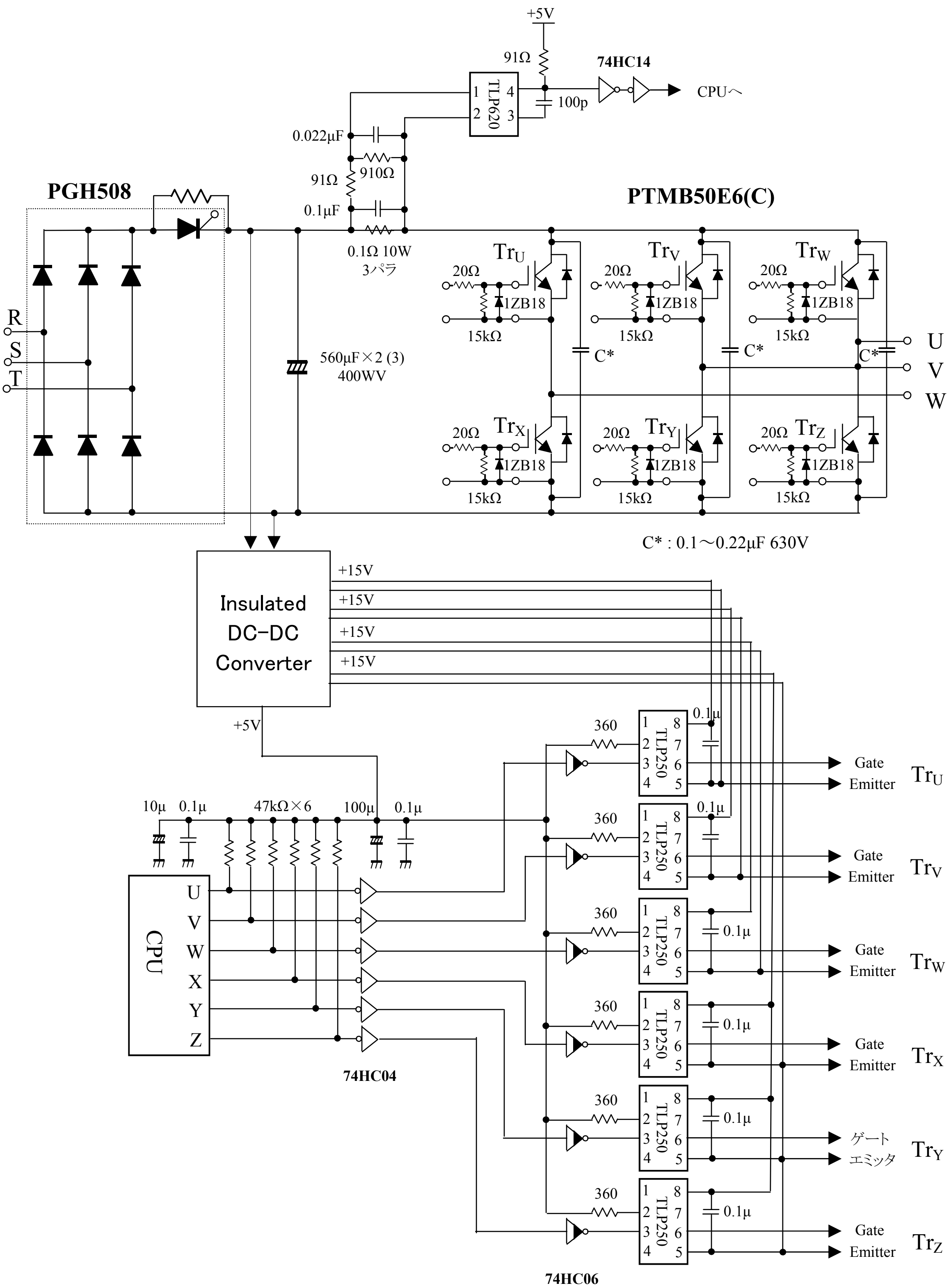
AC200V applications $I_C = 0.0138P$
AC400V applications $I_C = 0.00688P$

3-phase Motor Output	AC200V I_C of 600V IGBT	AC400V I_C of 1,200V IGBT
3.7kW	50A (51.0A)	25A (25.5A)
5.5kW	75A (75.9A)	
7.5kW	100A (103.5A)	50A (51.0A)
15kW	200A (207A)	100A (103.5A)
30kW	400A (414A)	200A (207A)
45kW	600A (621A)	300A (309.6A)
55kW		400A (379.5A)

( ) : Calculated Value

An example of AC200V 3-phase 2.2kW Inverter Circuit

Shown below is an example for study, and not for practical use. It is referred to March, 1999 issue of Transistor Gijutsu under approval of the author, Mr. Hajime Choshidani.
Original is designed for 0.75kW output, and is partially modified for 2.2kW output.

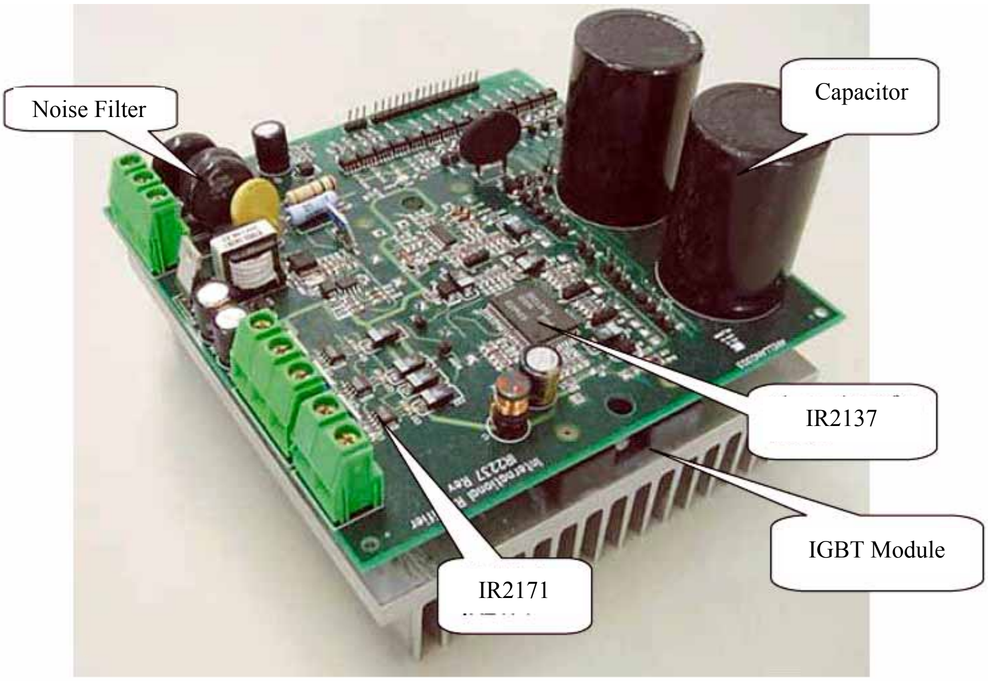


Designing 3-phase Inverter using Driver IC

Design note how to apply 600V 3-phase driver IC IR2137 and current sensing IC IR2171 to 2.2kW inverter is available from International Rectifier (IR).
http://www.irf-japan.com/technical-info/designtp/jpmotorinv.pdf

Also, you can buy the design kit IRMDAC4 from IR.
http://www.irf.com/technical-info/designtp/irmdac4.pdf

These are very helpful to know driver IC.



Design kit
using driver IC IR2137 and current sensing IC IR2171
(International Rectifier)

Short-circuit and Over-voltage Protection

Flow to protect short-circuit and over-voltage

Abnormal happens.

Why happened?

Over-current flows.

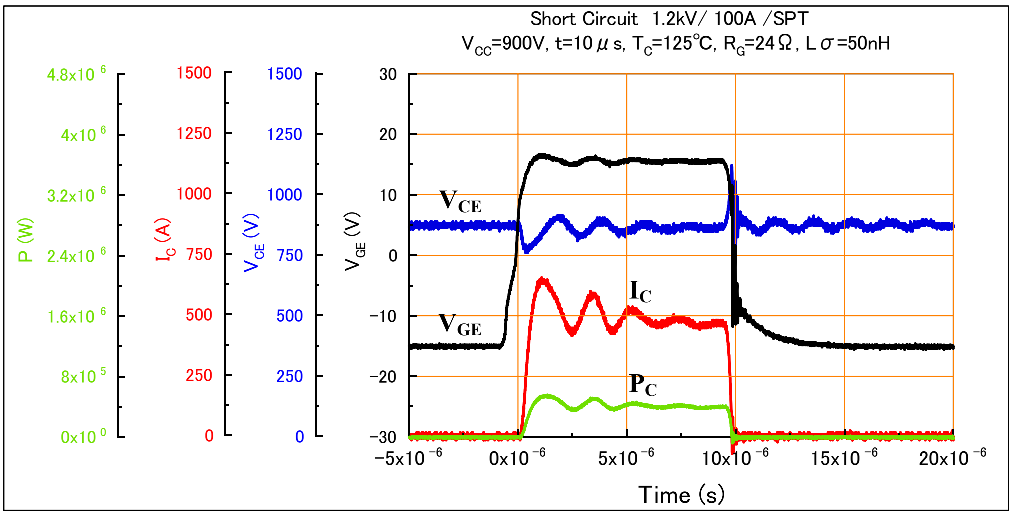
Monitor the current
(Where? By what?)
Or monitor C-E voltage.

Over the design criteria?

Shut down IGBT within 10µs
(Unless the IGBT will be failed.)

C-E voltage and turn-off loss increases due to over–current

Soft turn–off and proper snubber are required.

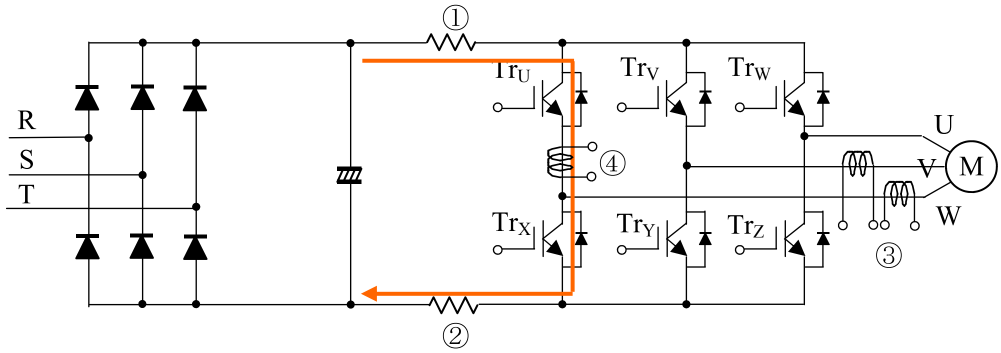


10µs short circuit SOA operation without additional protectiive devices.

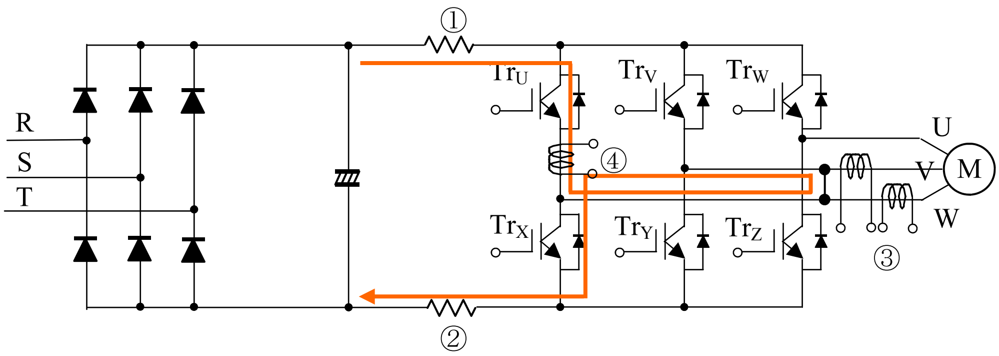
Causes and Sensing of short-citcuit current

Causes	Current Sensors
INVERTER Device or Controller failure, Case isolation **LOAD** Load failure, Arm short-circuit, Ground fault	Current Transformer CT （AC, DC, or HF type） Shunt Resistor Current Sensing IC

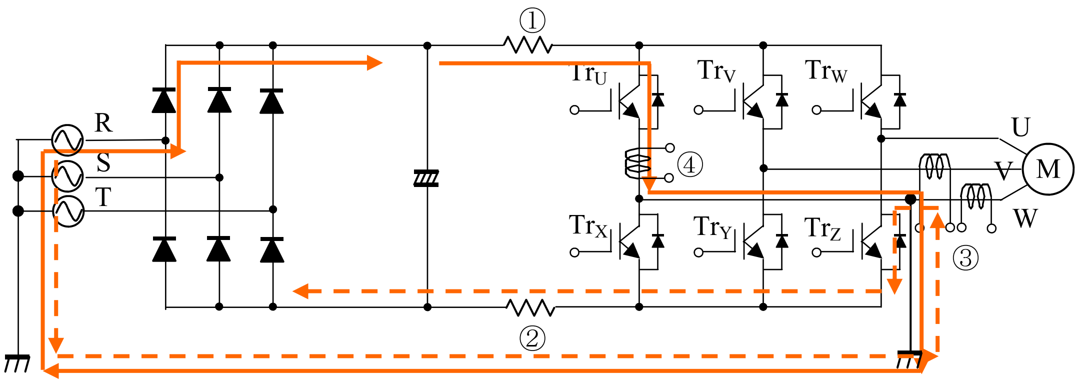
Arm short-circuit due to device failure or to controller failure (Insufficient dead-time)



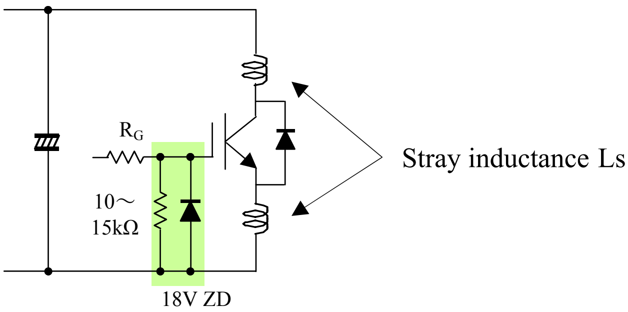
Short-circuit current due to series arm



Short-circuit current due to ground fault（Through ① or ② path）

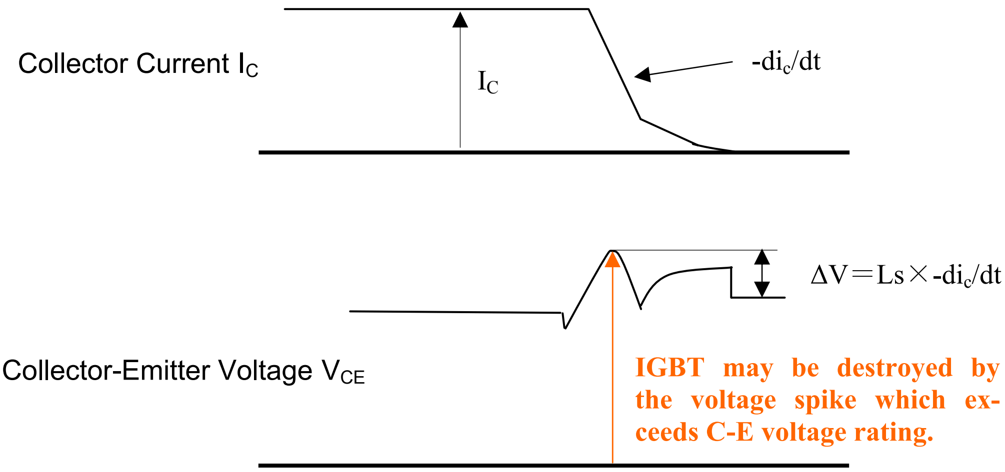


Collector-Emitter Surge Voltage during turn-off of short-circuit current



In the event of arm (load) short-circuit, current is so large because it is only limited by ESR of electrolyte capacitor and gain of IGBT. Corresponding loss is also large, and IGBT will fail unless it is not turned-off within 10µs. Simultaneously, it followed by surge voltage (inductive voltage kick), and which is the product of collector-emitter stray inductance Ls and -di/dt. Assuming Ls is so small as 0.1µH, the voltage reaches as high as 200V if -di/dt is 2,000A/µs. To reduce -di/dt, IGBT should be turned-off slowly. In addition to soft turn-off, stray inductance should be minimized as small as possible

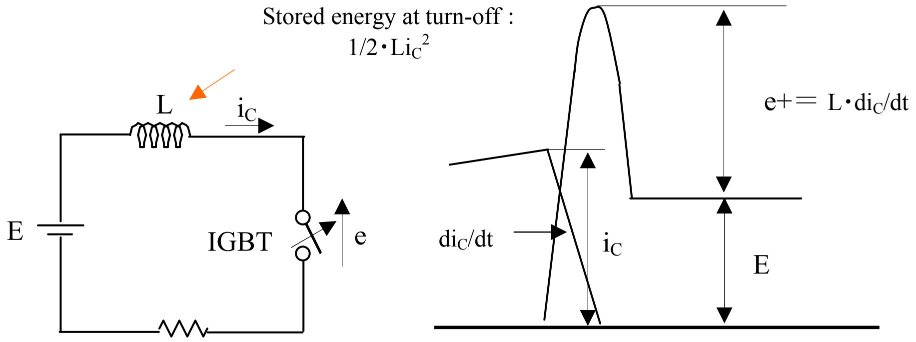
During transition from on-state to off-state, collector voltage rises. As a result, gate is charged up through reverse transfer capacitance Cgc. Given this situation, collector current is increased more and more, and gate is possibly destroyed. We recommend addition of both by-pass resistor and zener diode between gate and emitter terminals.

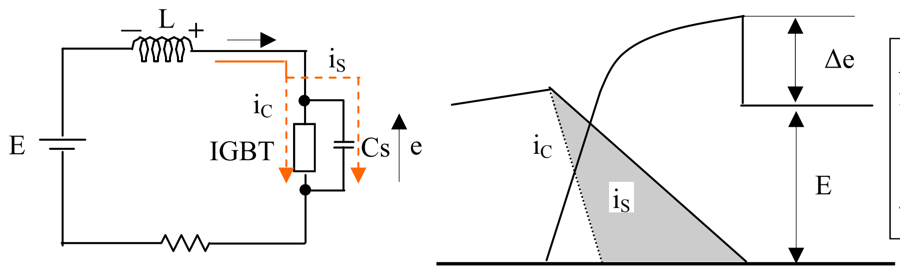


Snubber

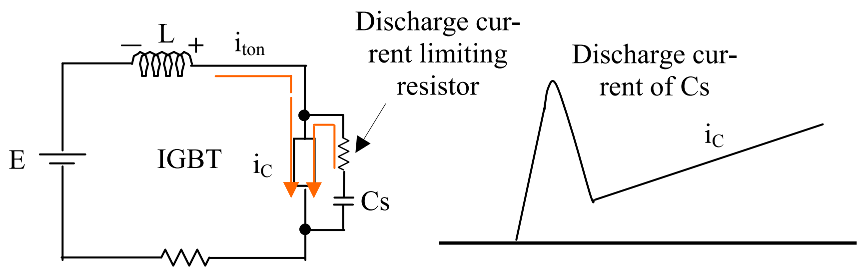
At turn-off, stored energy in inductance generates surge voltage, which is applied to collector-emitter of IGBT. As snubber capacitor is responsible for a part of turn-off energy, snubber circuit can suppress over-voltage and incidental turn-off loss. As a matter of course, stacked up energy in capacitor should be dissipated properly.

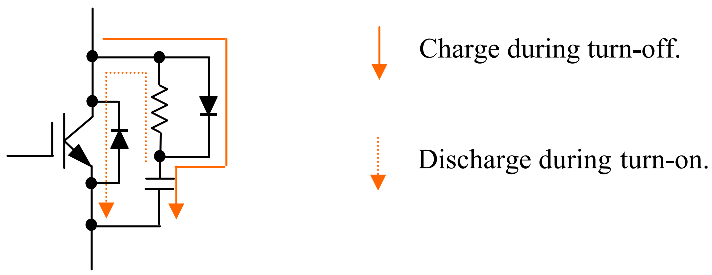
RCD Snubber



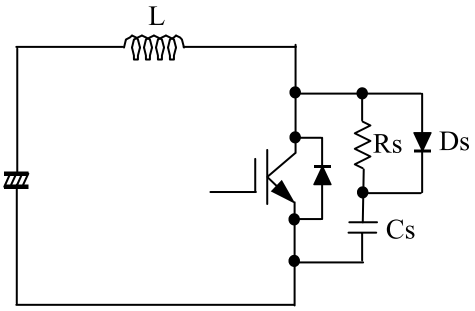


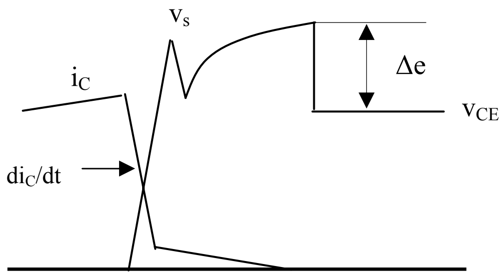
Assuming all the energy in L is transferred to Cs,
$1/2 \cdot L \cdot i_C^2 = 1/2 \cdot Cs \cdot \Delta e^2$
So,
$\Delta e = i_0 \times \sqrt{L/Cs}$





Loss in RCD Snubber



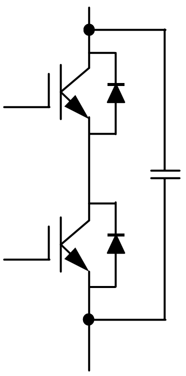


Snubbers individually connected to each IGBT are more effective than ones between DC bus and ground. But, we have a difficulty that loss in Rs is large. Loss in Rs is Li_c^2 times switching frequency, for example, the loss is 20W, assumed L=0.2μH, i_c=100A, and f=10kHz. In this case, total snubber loss reaches as high as 120W in 3-phase circuit. So, our choice is to set frequency lower, or, to regenerate the energy.
To reduce Δe, minimize stray inductance in main circuit loop at first, so we will have a smaller Cs in accordance to the reduced inductance.
The v_s is the sum of (dic/dt)×(stray inductance of wiring), forward recovery voltage of Ds, and dic/dt × (stray inductance of Cs).

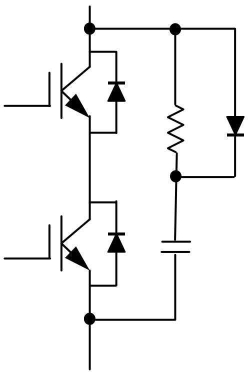
Considerations on snubber are;
*Drive IGBT in lower -dic/dt.（Turn-off IGBT slowly.）
*Place electrolytic capacitors as close to IGBT module as possible, apply copper bars to wiring, and laminate them where possible, so as to minimize wiring inductance of main circuit
*Also, set snubber as close to IGBT module as possible, use high frequency oriented capacitors, such as film capacitors.
*Use low forward recovery, fast and soft reverse recovery diode as Ds.

Popular Snubbers

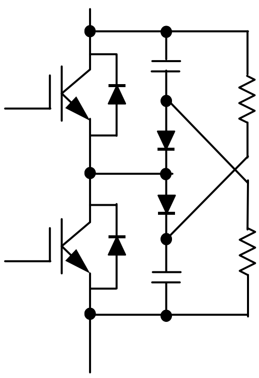
Shown are lump snubbers (between power buss and ground).



Snubber1



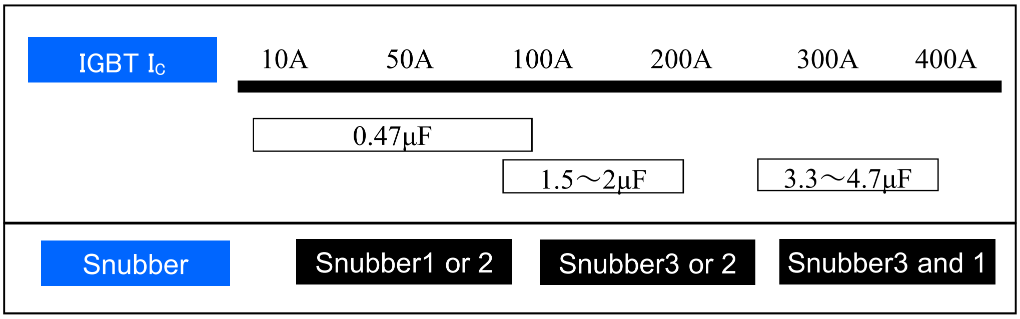
Snubber2



Snubber3

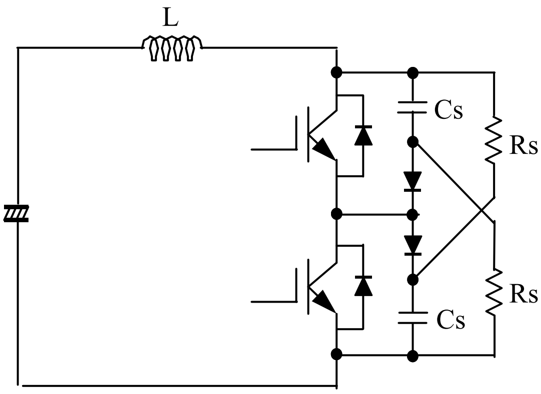
Guideline of Snubber Capacitance

Snubber1 on previous page cuts damping resistor, and sometimes oscillations occur on power buss. So, it is fit for lower power applications. Among 3 types of snubbers, you will find which is the generic choice, and capacitance for lump snubber below. Half of the capacitance is right value when snubber is attached to each IGBT.



In highest power applications, snubbers would be not enough to be free from device failure or malfunction due to noise otherwise wiring inductance could be minimized using copper bars or laminated them.

Discharge Surpressing Snubber (Snubber3)



Assuming all of the stored energy in L is absorbed by Cs,

$$1/2 \cdot L \cdot i_C^2 = 1/2 \cdot Cs \cdot \Delta e^2$$

Thus,

$$Cs = L \times (i_C/\Delta e)^2$$

Charge in Cs must be fully discharged before the next turn-on, and we focus on time constant (Cs×Rs). To discharge below 90%;

$$Rs \leqq 1/(2.3 \cdot Cs \cdot f) \qquad f: \text{switching frequency}$$

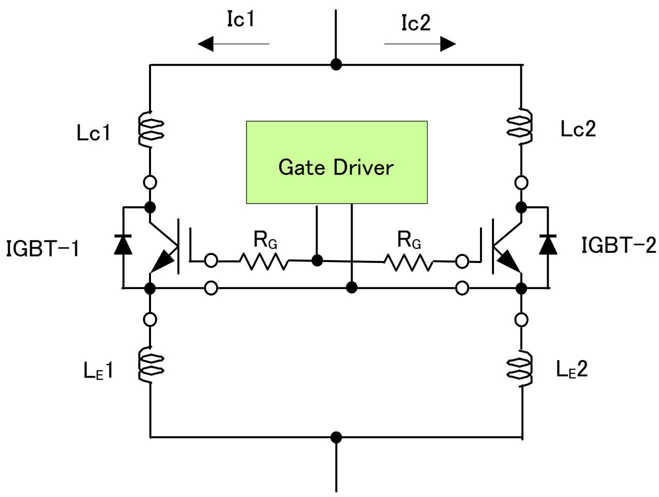
This relationship indicates minimum value of Rs. In addition, an excessively small Rs may result in harmful oscillation at turn-on, so, somewhat larger resistance would be preferable.

Dissipation in Rs, P(Rs), is independent of Rs.

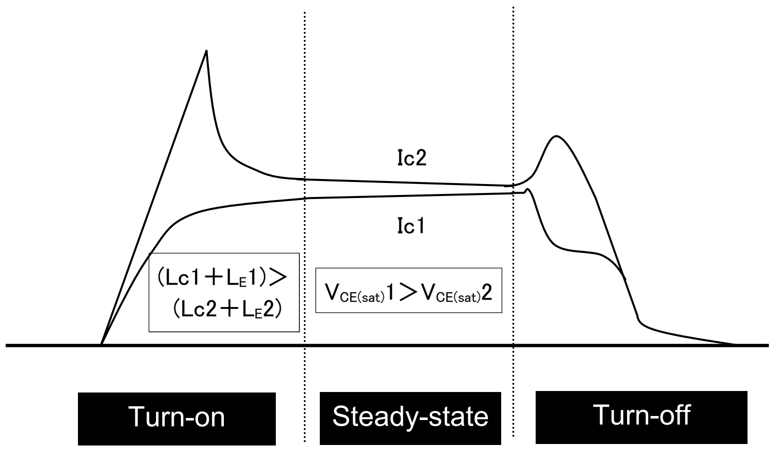
$$P(Rs) = 1/2 \cdot L \cdot i_C^2$$

Parallel Operation and Current Imbalance

We introduce high current IGBT modules, which extend to 1,200A for 600V series, and 800A for 1,200V series. So, we cover up to 100kW 3-phase inverters. Consequently, parallel operation of IGBT modules is not so important, but, when designing 3-phase inverters, information on rules for parallel operation may possibly be useful.
Let us show you the points in brief.



Current sharing during parallel operation depends on both circuit design and device characteristics.
Oscillations caused by gate-emitter wiring inductance L_G、resistance R_G、and Cies, will possibly be the origin of device failures as a result of malfunction or non-saturation of IGBT. Minimal R_G required is in proportion to $\sqrt{L_G}$. Accordingly, minimize the inductance, and R_G should also be larger than or equal to recommended.



*Differences in wiring inductance lead to poor current sharing at turn-on or at turn-off. Collector and emitter wiring to each IGBT should be equal and minimal.
*Each IGBT needs gate resistor, and gate wirings should also be equal and minimal. Connect emitter wiring to auxiliary emitter terminal, not to main emitter terminal.
*Saturation voltage $V_{CE(sat)}$ and some other characteristics are depend on temperature. Obtain smallest possible deference in temperature rises among modules.

$V_{CE(sat)}$ Rank for Parallel Operation

Some current imbalance in parallel operation is inescapable, and handling current per module is roughly decreased to 80%. For example, expected total current of 4 300A modules in parallel is 300×0.8×4=960A.
On your request, we can ship $V_{CE(sat)}$ ranked modules for larger than 1,200A/600V or 800A/1200V applications. Contact us for further information.

For your repeat order when repair is needed, we ship group of modules in a $V_{CE(sat)}$ rank, but the rank may not be same as the original.