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# NGTG12N60TF1G

## Application Note

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How to Use IGBT (Application in part switching PFC circuit)

1. Beginning

IGBT is the abbreviation for Insulated Gate Bipolar Transistor, which operates like MOSFET, applying voltage between gate and emitter and controlling collector-emitter current. The table below summarized the similarities and differences in structure and operation compared with Power MOSFET.

The point is, in comparatively high voltage (V>400V) and large current application, IGBT has a less conduction loss because of its low RDS(on). By contrast, in small current area, its conduction loss may be higher than MOSFET because it has PN junction on collector structurally, which results in a forward voltage(VF) of the diode. Furthermore, in high-frequency application, switching loss of IGBT will be higher than that of MOSFET because when switching off, the accumulated carries injected from collector's P layer into N layer do not cease to exist immediately and subsequently tf tailing occurs. Therefore, IGBT is recommended to be used in comparatively low frequency (30kHz).

| | | IGBT | MOSFET |
|---|---|---|---|
| | *Voltage Assume ≥400V<br>e: electronic current<br>h: hole current | E G N⁺ P e N⁻ h P⁺ C<br>P layer is formed on collector, because of the holes injected from this P layer (conductivity modulation), ON resistance is reduced. | S G N⁺ P e N⁻ N⁺ D<br>For all the paths current flows, if you want to increase N-type voltage, you will have to increase N-layer resistance. High-volt. MOSFET has a disadvantage in ON resistance compared with IGBT. |
| | Current controlling method | Gate-emitter voltage, which is applied to switch on C-E current. 8~15V is common. | Gate-source voltage, which is applied to switch on D-S current. 10~15V is common. |
| | Conduction loss | For high current, lower than MOSFET | RDS(on) will also increase as you increase the voltage |
| | Switching loss | Will be higher than MOSFET due to tf tailing | |
| | Recommended frequency | 30kHz or below | 20~100kHz |

2. How to see the specifications (especially the major items) and the design point

2-1) Absolute maximum rating

Take NGTG12N60TF1G as an example as shown in Table 1. The important items are explained as follows.

VCES: in this instance, the maximum voltage applicable to VCE is 600V. When using in L load switching, you should pay attention to VCE voltage as to whether or not exceed the absolute maximum rating because of a steep VCE increase that may occur due to the circuit floating inductance when input signal is OFF and the occurrence of ringing voltage.

Ic: because Ic is subject to Tc, when Tc changes, Ic also changes (refer to *1). The higher the temperature rises, the smaller the current that can be flowed. It is roughly considered that when the temperature rises by Δ75deg the current will become half.

PD(Power Dissipation): because NGTG12N60TF1G is a full-molded TO-3P package, PD is calculated low compared with TO-3PB. In case of NGTG12N60TF1G, PD is 54W. Compared with full-molded package, Ic rating description of the backside metal package is large. But in actual use, because the backside is insulated with heat sink or PCB, the actual PD of TO-3PB will be rarely different from that of TO3-PF, sometimes even smaller.

Table 1 The Absolute Maximum Ratings (Example: NGTG12N60TF1G)

**Absolute Maximum Ratings** at Ta = 25°C, Unless otherwise specified

| Parameter | Symbol | Conditions | | Ratings | Unit |
|---|---|---|---|---|---|
| Collector to Emitter Voltage | VCES | | | 600 | V |
| Gate to Emitter Voltage | VGES | | | ±20 | V |
| Collector Current (DC) | IC*1 | Limited by Tjmax | @ Tc=25°C *2 | 24 | A |
| | | | @ Tc=100°C *2 | 12 | A |
| Collector Current (Pulse) | ICP | Tjmax(Ref :ASO graph) | | 88 | A |
| Allowable Power Dissipation | PD | dissipation condition) *2 | | 54 | W |
| Junction Temperature | Tj | | | 150 | °C |
| Storage Temperature | Tstg | | | - 55 to +150 | °C |

2-2) Electrical characteristics (Table 2)

Gate to Emitter cutoff voltage-VGE(off): in order to prevent malfunctions due to noises, VGE(off) should be lower than minimum value at the time of OFF. Because the temperature-dependency is negative, special attention should be paid to the OFF voltage at high temperature. On the other hand, when flowing Ic, VGE=15V±1V is recommended in order to obtain low enough VCE(sat). Sometimes, the Gate is put in minus potential in order to speed turn-off, but the absolute maximum rating of VGE is ±20V. So, this range should be used for design.

Collector to Emitter voltage- VCE(sat): very important when comparing devices. Ic rating varies according to package, but VCE(sat) depends on the chip's characteristic. So, VCE(sat) does not change even if the package is different (When temperature is the same). Therefore, **VCE(sat) is especially useful to evaluate IGBT's conduction loss.** Temperature-dependency of VCE(sat) is positive when Ic flows sufficiently, it is necessary to pay attention to heat dissipation design.

**Table 2 Electrical Characteristics (major items)**

**Electrical Characteristics** at Ta = 25°C, Unless otherwise specified

| Parameter | Symbol | Conditions | | Ratings min | Ratings typ | Ratings max | Unit |
|---|---|---|---|---|---|---|---|
| Collector to Emitter Breakdown Voltage | V(BR)CES | IC=500μA, VGE=0V | | 600 | | | V |
| Collector to Emitter Cut off Current | ICES | VCE=600V, VGE=0V | Tc=25°C | | | 10 | μA |
| | | | Tc=125°C | | | 1 | mA |
| Gate to Emitter Leakage Current | IGES | VGE=±20V, VCE =0V | | | | ±100 | nA |
| Gate to Emitter Threshold Voltage | VGE(th) | VCE =20V, IC=250μA | | 4.5 | | 6.5 | V |
| Collector to Emitter Saturation Voltage | VCE (sat) | VGE=15V, IC=12A | Tc=25°C | | 1.4 | 1.6 | V |
| | | | Tc=125°C | | 1.6 | | V |
| Input Capacitance | Cies | VCE =20V,f=1MHz | | | 2000 | | pF |
| Output Capacitance | Coes | | | | 60 | | pF |
| Reverse Transfer Capacitance | Cres | | | | 50 | | pF |

Input capacitance Cies: when turning on/off gate-emitter, this capacitance will influence in case switching time and/or Eon/Eoff is made smaller. The smaller they are, the faster the switching speed tends to be. Depending on the value of Cies, in order to make Eon/Eoff smaller, the output of drive IC is not added directly to the gate of IGBT, instead a Buffer Tr is used sometimes. In this way, an interface circuit of the gate becomes important in order to drive IGBT efficiently.

Next, we will introduce the optimal driving method in consideration of making IGBT's Eon/Eoff smaller.

3. IGBT's gate drive characteristic

As shown in below fig.2, taking NGTG12N60TF1G's Rg (Gate Resistance) as X-axis, switching loss (measured at IGBT's L load: fig.1) is positively correlated with Rg (fig.2). If you put weight on reducing switching loss, you should select a small Rg preferably in consideration of the impact of operation noise (47Ω or below is recommended).

Additionally, when control IC output is insufficient, Buffer Tr needs to be added between control IC and the IGBT. In that case, resistance in OFF direction can be made smaller than in ON direction for improving toff performance.

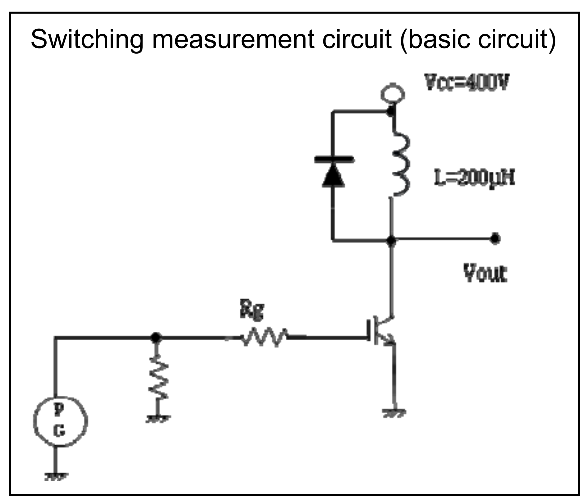



fig.1 Measuring circuit

SW loss(Eon,Eoff) VS Rg(Gate resistor)

Vcc=400V
L=200μH
Ic=20A

Eon、Eoff [μJ]: 400, 600, 800, 1000, 1200, 1400

Rg [Ω]: 0, 10, 20, 30, 40, 50, 60

Eoff
Eon

fig.2 Switching loss (characteristic)

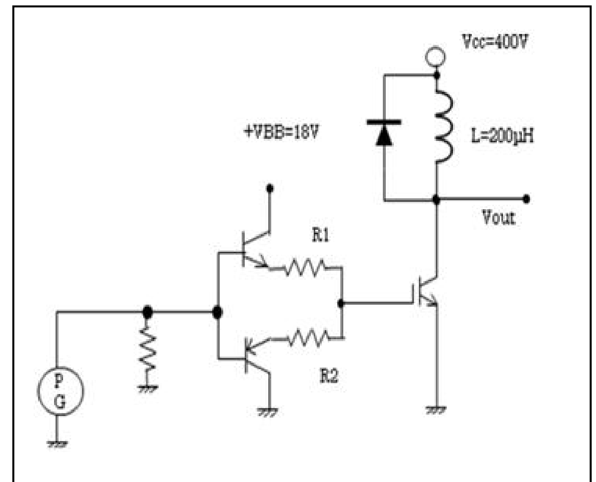



fig.3 Circuit with an added Buffer

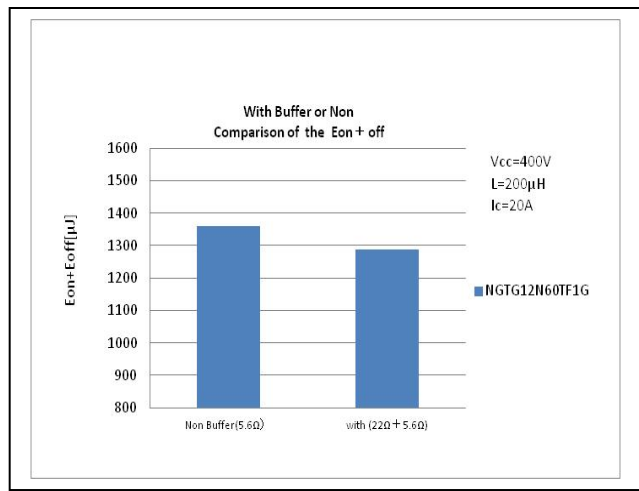



fig.4 Comparison of Switching loss

Drive circuit design example:

Spec. of Buffer Tr and drive current:

IG=(VBB+|VEE|)/Rg(total)

For emitter-common, usually separate paths are set for IGON and IGOFF (refer to fig.5),

so Rg is considered as R1 and R2 in parallel:

IGp'= (15+5)/(22×4.7÷(22+4.7))=5.17A.

**In this case, a buffer tr that meets Icp>5.2A is needed.**

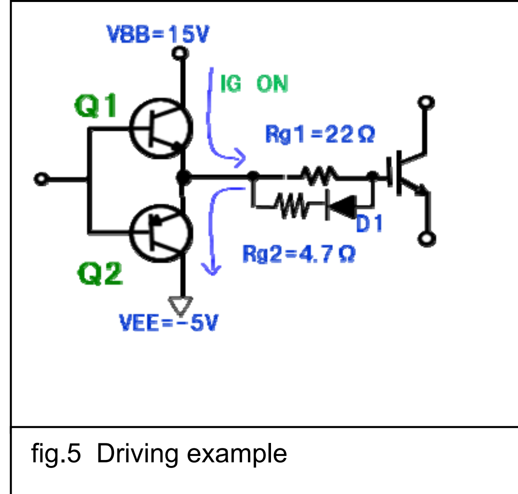



fig.5 Driving example

4. Losses calculation

Losses occur to IGBT when used in inverter circuit, switching circuit and etc. The losses are roughly divided into ON loss and switching (turn-on/turn-off) loss. The sum of the two types is almost the total loss. Additionally, a radiator is installed in order to achieve enough heat radiation in use.

4-1) Calculation of switching loss

Assume a basic switching waveform of continuous operation like in fig.6.

[IGBT]

ON loss: VCE(sat) is assumed constant during ON period.

PVCE(sat)=(Ic1 + Ic2) ÷ 2 × VCE(sat) × Ton/T

Regarding turn-on/turn-off, calculate by using the measured Eon & Eoff of each device at the value of Ic2.

Pon=Eon×f f: operating frequency

Poff=Eoff×f

So, P(IGBT total) = PVCE(sat) + Pon + Poff

However, because Eon, Eoff varies according Rg and Ic, use the data in the near distance for calculation.

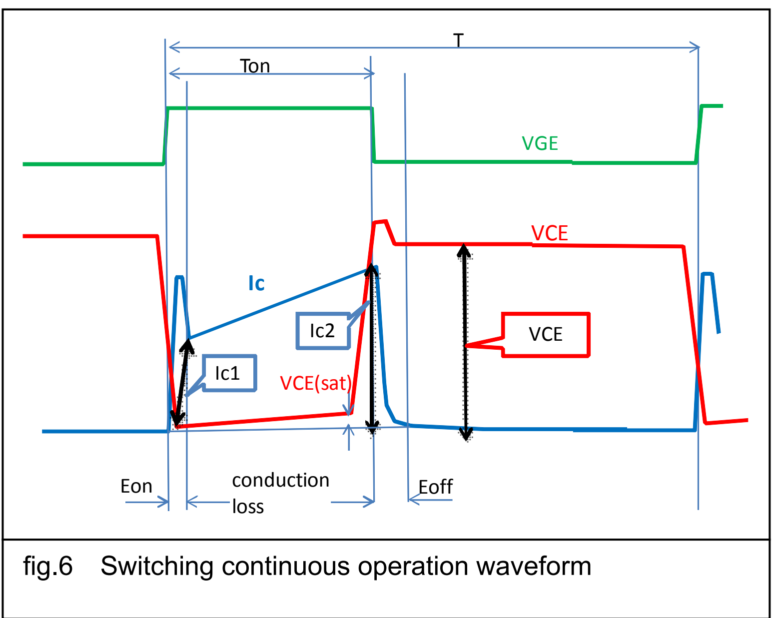



fig.6 Switching continuous operation waveform

5. Application circuit centering with part SWPFC

NGTG12N60TF1G and NGTG20N60L2TF1G are the types without freewheel diode built in. As typical application circuit, there are part SW PFC circuits, inverter's brake circuits.

5-1) part SW PFC circuit

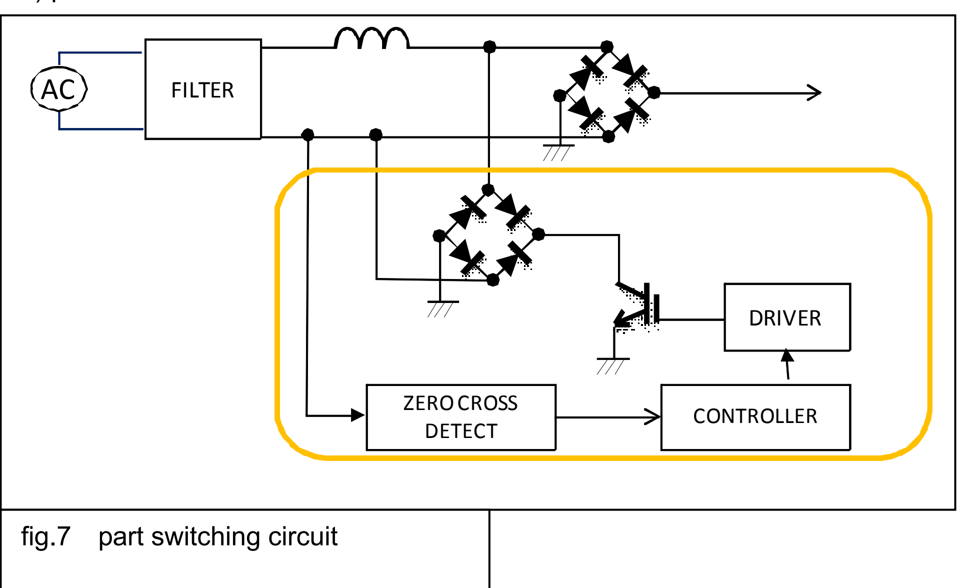



fig.7 part switching circuit

In order to improve Power Factor, current is flowed into the inductance forcibly, and used as a switch that expands the angle of input current flow.

*However, in such cases for PFC where multiple times of switching are performed in 1 cycle or full switching method, VCE ringing occurs at the time of Ic cutoff, which may result in minus-direction voltage(emitter side is plus), so you need to add a freewheel diode between C-E in parallel or use some device with built-in FRD like NGTB20N60L2TF1G.

Image of input voltage and current:

Take AC input voltage as "V", current as "i".

Waveform seen from AC input when operating part SW circuit is shown as fig.8 (a). Power Factor can be improved by having input current waveform approach input voltage waveform by operating on the PFC IGBT within certain period and flowing input current i.

Power factor is estimated to be 0.9~0.97.

Twice the commercial frequency is used. (That is, operate at 100Hz when commercial freq. is 50Hz)

Waveform of Ic is triangle wave starting at zero cross.

See WP.1 (operate with IGBT) for your reference.

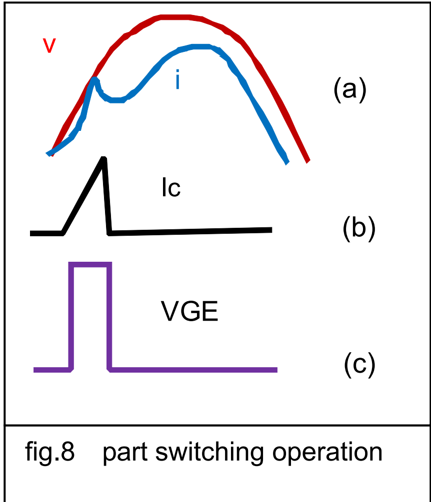
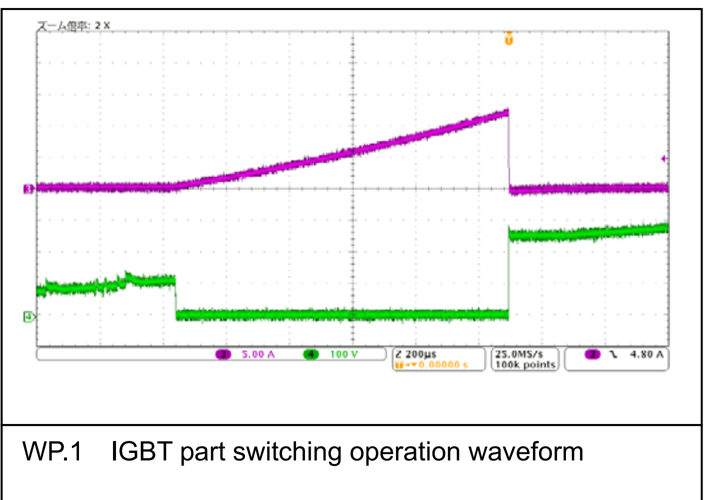



fig.8 part switching operation



WP.1 IGBT part switching operation waveform

5-2) Other IGBT application circuit example…Inverter brake circuit

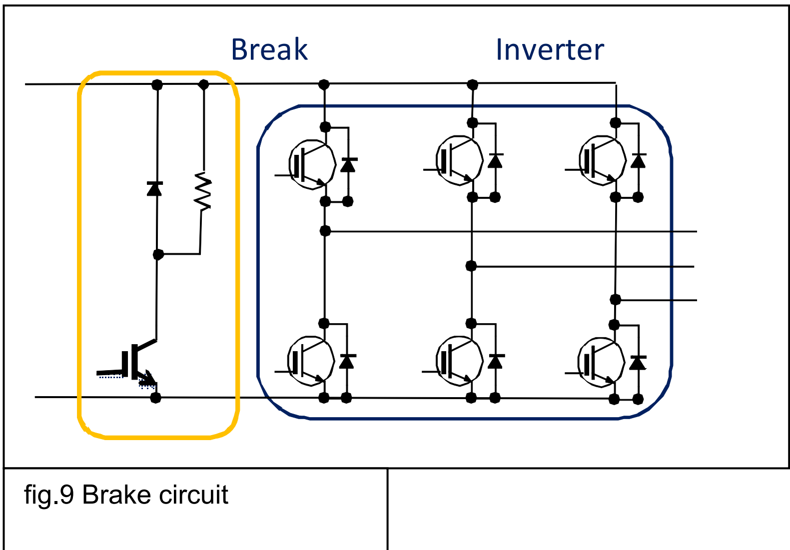



fig.9 Brake circuit

Used as switch of resistance circuit in order to suppress Vcc line voltage rise in regenerative operation in applications such as AC servo.

6. Calculation of Losses in PFC circuit (part switching method)

IGBT is used for improving the Power Factor of the applications such as air-conditioner. We explained part switching PFC circuit in 5-1) as an example of low-frequency switching circuit.

The loss when IGBT is used in the part switching PFC circuit is calculated based on the waveform.

Part switching Ic waveform is a triangle waveform. Therefore, the losses may be considered as the sum of conduction loss [VCE(sat) loss] and Poff loss. Calculation is done by assuming f=100~120Hz.

Because the frequency is low, Poff loss is small compared with VCE(sat) loss. VCE(sat) loss is calculated as the main loss.

Ic starts from 0A and reaches Icp, so assume VCE(sat) linear from 0[A] to Icp[A], calculate by approximating VCE(sat) and Ic as straight line. For Poff, use Eoff at Icp, and calculate by Poff=Eoff×f.

For conduction loss P(VCE(sat)), assume 0.6V as start (because the current begins to rise at approx. 0.6V). Take the current as Ax and the voltage as Bx+0.6, then integrate Ax×(Bx+0.6) of TON segment.

However, because the segment is 0~Ton, A=Icp/TON & B=(VCEsat(@Icp)-0.6))/TON. The formula becomes:

$$\int_0^{TON} f(x)dx=\int_0^{TON}(Icp/Ton\times Icp\times(VCEsat@Icp-0.6)\times x^2+0.6\times Icp/Ton\times x)dX$$

$$= \left[1/(3\times Ton)\times Icp(VCEsat@Icp\times Icp-0.6)\times x^3+1/(2\times Ton)\times 0.6\times Icp\times x^2\right]_0^{Ton}$$

$$=1/6\times(2\times Icp\times VCEsat@Icp+0.6\times Icp)\times Ton \quad \ldots(1)$$

Regard the period as T, then conduction loss PVCE(sat) is

PVCE(sat) = formula (1)/T …(2)

Furthermore, Ptotal becomes:

Ptotal= PVCE(sat)+Poff …(3)

Take NGTG12N60TF1G as example, in case of 20A (Tc=100deg), VCE(sat)=1.8V based on Ic-VCE(sat) dependency(fig.10-2).

Given TON=1.33mS, T=8.33mS(120Hz).

Assign the above TON and T in formula (2):

PVCE(sat) = Ton/T ×1/6×Icp(2×VCEsat+0.6)=2.24[W]

And because Poff is: Eoff=825μJ at Icp=20A (see fig.7-2),

$Poff=120\times825\times10^{-6}=0.099[W]$.

Therefore, Ptotal= PVCE(sat)+Poff=2.34[W]



fig.10-1 Loss equivalent waveform

Above is an example when regarding Icp=20A. Pay attention that Ton changes when Icp changes(assume inclination as constant), and the loss will also change. fig.10-3 shows how Pc changes when Icp changes.

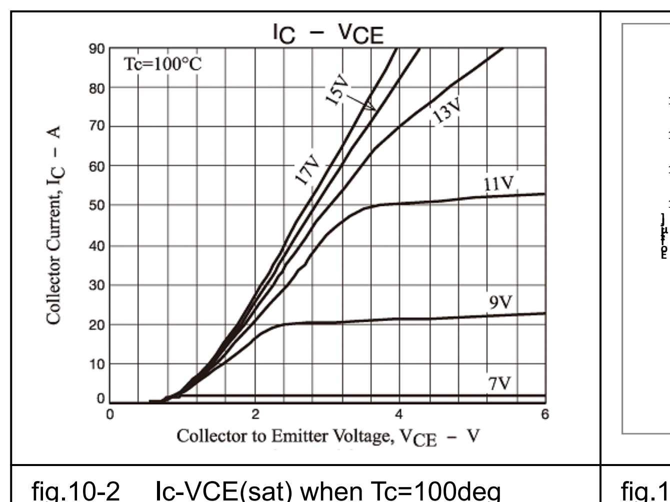



fig.10-2 Ic-VCE(sat) when Tc=100deg

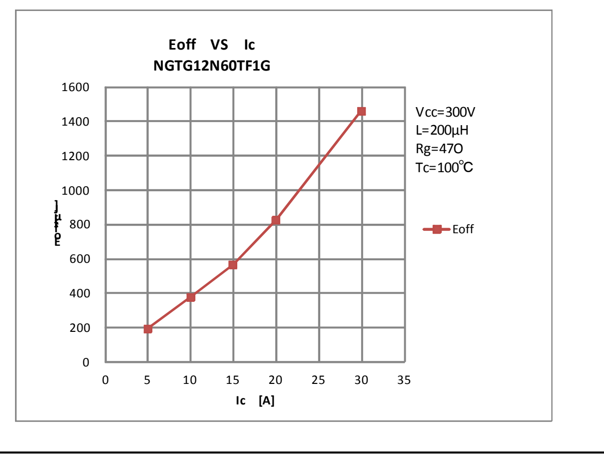



fig.10-3 Eoff when Icp changes

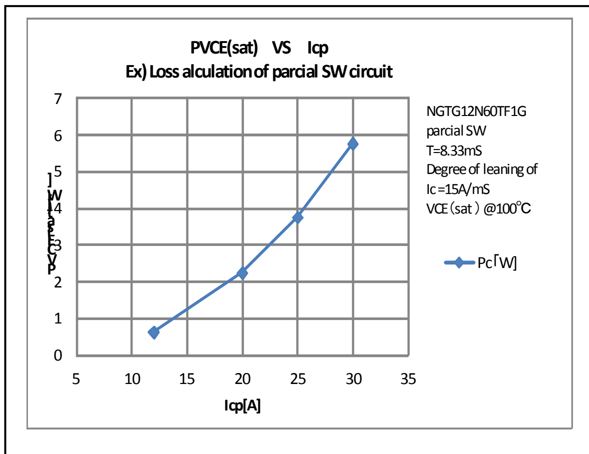



fig.10-4 Calculation of VCE(sat) loss when Icp changes

## 7. Heat sink design (centering with NGTG12N60TF1G)

NGTG12N60TF1G's Tjmax is 150 degrees Celsius, heat sink should be designed so as not exceed 150deg even in the worst case. Furthermore, when taking high reliability of switching operation into account, Tc(Case Temperature) is recommended to be 100~110 degrees Celsius.

In part SW operation Icp=30A, PVCE(sat)=5.8W(fig.7-4), Eoff=1460μJ when Icp=30A(fig.7-3),

Based on formula (3), Ptotal=5.8+120×1460×$10^{-6}$=5.98W

In order to hold Tc=100deg,

suppose Tamax=60deg, the heat sink becomes:

Θh=(100-60)÷5.98=6.6 deg/W.

For the above device, Tj becomes Rth(j-c)=2.33deg/W rather than the specification sheet,

So, Tj = 5.8×2.33+100=113.5 degrees Celsius (against Tjmax=150deg)

## 8. ASO (or SOA) (Area of Safe Operation)

ASO(SOA*) is critical parameter that assure the device to be used in circuits safely, especially for high-voltage high-current power device used in switching circuit. ASO is divided into two areas: FB(Forward Bias) and RB(Reverse Bias). Which ASO is used for evaluation depends on gate input condition. *Generally SOA is called, but in accordance with NGTG12N60TF1G's specification sheet, ASO is used hereinafter.

8-1) FB/ASO (Forward-biased Area of Safe Operation)

FB/ASO is a parameter used to evaluate 2-dimentional locus of the voltage/current between collector and emitter when gate voltage exceeds Vth and forward collector current flows.

This ASO depends on the powered time (PT).

The area is composed of the following:

□ Icp-restricted area

○ Tjmax-restricted area

△ secondary breakdown restricted area

◇ VCESmax-restricted area

For NGTG12N60TF1G, it is shown as in fig.11

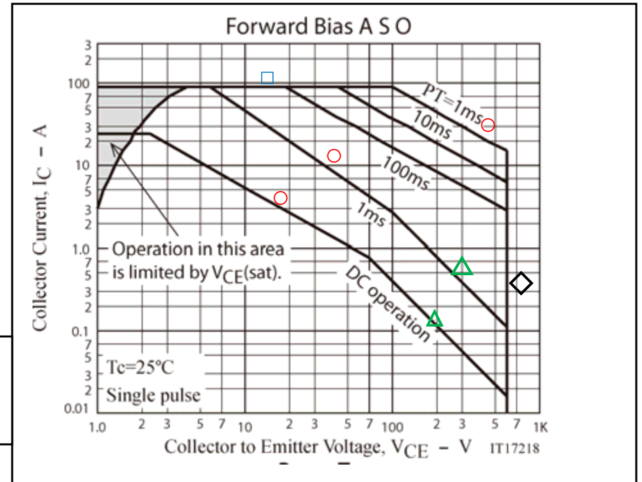



fig.11 Example of FB・ASO for NGTG12N60TF1G

FB/ASO is also dependent on temperature. The higher the temperature is, the narrower the ASO becomes. So attention should be paid when temperature rises. Please consult FB/ASO when temperature rises separately.

8-2) RB/ASO　(Reverse Bias Area of Safe Operation)

RB/ASO is a parameter used to evaluate the locus between collector and emitter in the area where gate voltage is less than Vth. In switching operation at L load, although gate voltage is usually made to be 0V or negative in order to OFF the operation, the current decreases behind time as the collector voltage rises, this makes a unique locus.

Especially in case of L-load SW, RB/ASO becomes critical. Graph of RB/ASO is shown in fig.12.
RB/ASO is usually described by two areas: one restricted by peak collector current and the other restricted by collector-emitter voltage(VCES).

For example, if you plot ASO locus of the operation as WP.1 around the RB/ASO graph, (fig.12)
You can see this operation is within the area.
We recommend you conduct verification actually in the worst case (both current and voltage are max.) to check whether RB/ASO is exceeded or not.

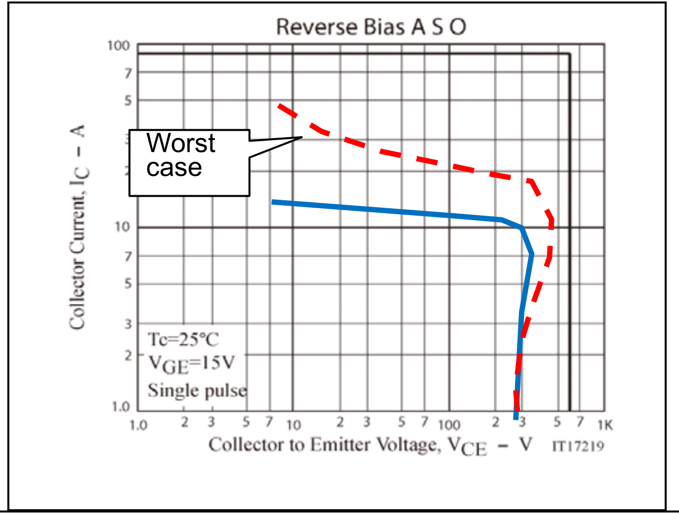
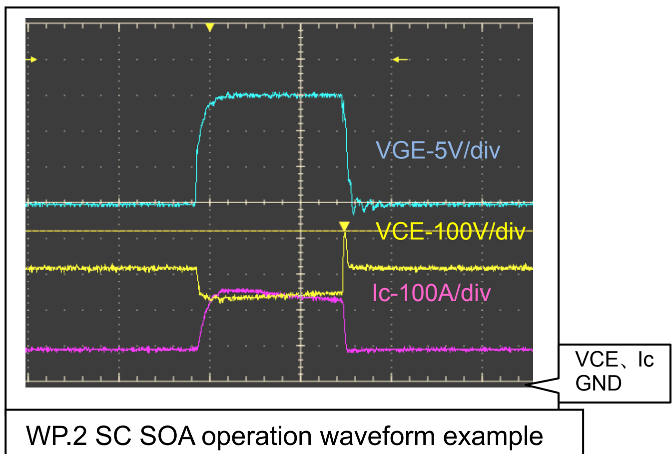



fig. 12 RB・ASO and operation locus (NGTG12N60TF1G)

9. Short-circuit capacity Safe Operating Area (SC SOA)

It is a parameter to show how long the device can operate without being destructed when C-E is shorted. In protection circuit, it is necessary to have the protection circuit operate earlier than the time SC SOA is reached and completely turn-off the gate voltage.
Please pay attention that SC SOA will become smaller(shorter) when the device temperature or VGE becomes higher, plus when the voltage of the collector side power line becomes higher.
In case of NGTG12N60TF1G,
under Tc=100 degrees Celsius,
VGE=15V and Vcc=300V,
5μS is the design guarantee.




WP.2 SC SOA operation waveform example

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