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MBT (IGBT) MODULES

Shôichi Furuhata
Tadashi Miyasaka
Shinji Yamaguchi

1. FOREWORD

Bipolar power transistors and power MOSFET are widely used in the motor control inverter of machine tools, robots, air conditioners, etc. and in the uninterruptible power supplies of OA equipments, medical equipments, etc.

The bipolar power transistor are commercialized up to 1,200V/800A and its range of application is wide, but since its switching time is long (turn-off time: about 10μs) and switching loss is large, its applicable frequency is limited to several kHz. The power MOSFET can operate at several tens kHz or greater, but because it is difficult to make its breakdown class large, its range of applications is limited to the low capacity field.

Recently, making the equipment smaller and lighter and lowering the noise in the audible frequency band have become a large topic with equipment used in offices and near hospitals and other places where people live. The trend is toward raising the switching frequency to 10kHz or greater as a method of solving this problem.

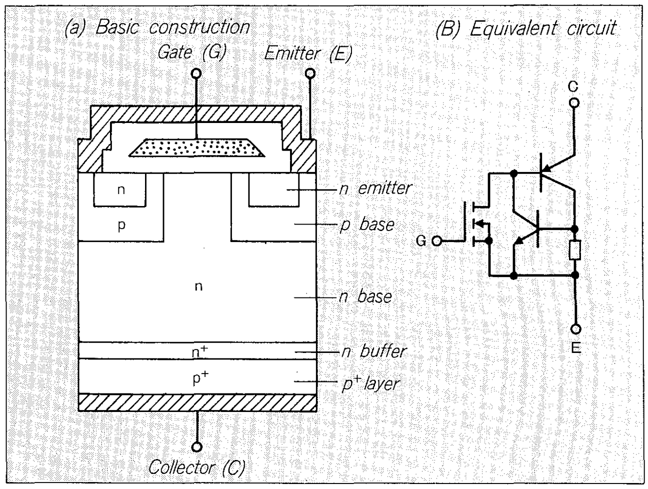
The MBT (MOS-gate Bipolar Transistor: Fuji Electric name) is a device with the voltage drive and high speed switching characteristics of the MOSFET and low saturation voltage characteristic of the bipolar transistor for the demand for a capacity and frequency above this.

An outline of the MBT developed and serialized up to about the same capacity as the bipolar transistor this time is introduced.

2. CONSTRUCTION OF THE MBT

The basic construction of the MBT is shown in *Fig. 1(a)*. Basically, the MBT consists of a construction with one p^+ layer provided at the drain side of an MOSFET. The conductivity modulation state is induced by injecting positive hole from this p^+ layer to the n base layer. The equivalent circuit is shown in *Fig. 1(b)*. It is a composite transistor with an n channel MOSFET connected to the base of a pnp transistor.

Fig. 1 MBT basic construction and equivalent circuit



3. MBT MODULE SERIES AND CONSTRUCTION

3.1 Series

The MBT modules serialized this time are shown in *Table 1*.

MBT modules with a withstand voltage of 600V and 1,200V which can be used with AC240V and 480V input and current ratings up to the 8~400A range of the bipolar power transistor have been serialized (part under development).

Generally, the voltage impressed on the power device at an inverter is considered as follows.

When the AC input is made V_{in}, the regulation is made 10%, the inverter starts the regenerating operation and an overvoltage is detected at 10% or more of the DC after rectification and the protection circuit was operated at 5% or more because of the delay of the overvoltage protection circuit, the maximum DC power supply voltage $V_{DC\,max}$ is shown by Eq. (1).

$$V_{DC\,max} = V_{in} \times \sqrt{2} \times 1.1 \times 1.1 \times 1.05 \quad \ldots\ldots\ (1)$$

When the spike voltage cuased by the storage inductance of the snubber wiring is made V_{SP} and margin

Table 1 MBT module series table

$I_{C(DC)}$ Collector current	BV_{CES} Collector-emitter voltage					
	600V			1,200V		
(A)	1-pack	2-pack	3-pack	1-pack	2-pack	6-pack
8						6MBI8-120
10			6MBI10-060 •			
15			6MBI15-060			6MBI15-120 •
20			6MBI20-060 •			
25					2MBI25-120	6MBI25-120
30			6MBI30-060			
50		2MBI50-060			2MBI50-120	6MBI50-120 •
75		2MBI75-060			2MBI75-120 •	
100		2MBI100-060			2MBI100-120 •	
150		2MBI150-060			2MBI150-120	
200		2MBI200-060		1MBI200-120 •		
300		2MBI300-060 •		1MBI300-120 •		
400	1MBI400-060					

Fig. 2 MBT module exterior views

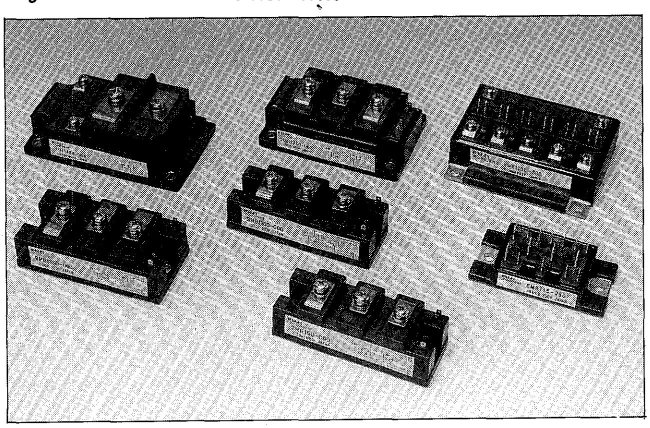
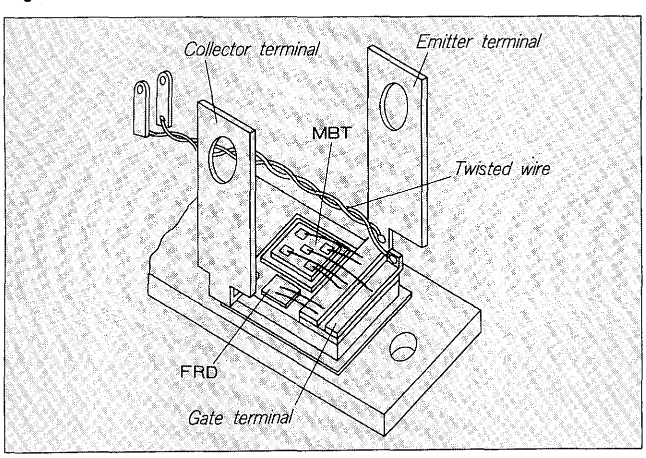


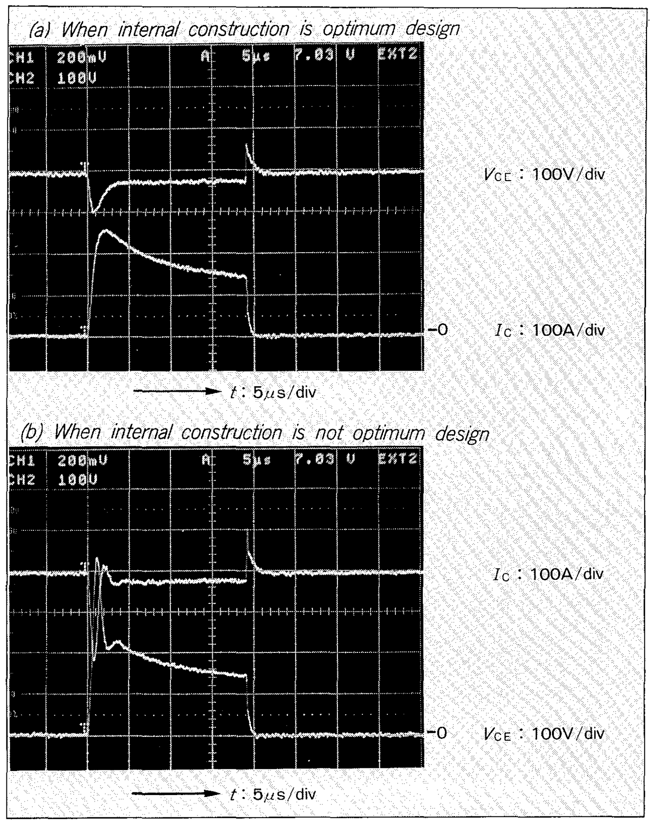
Fig. 3 MBT module internal construction



(2) is considered, the spike voltage peak value (V_{surge}) becomes Eq. (2).

$$V_{surge} = V_{DC\,max} + V_{SP} + \alpha \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Fig. 4 Load short circuit waveform comparison



From Eq. (2), a 500V and 1,200V device withstand voltage is necessary for AC 240V and 480V inputs, respectively.

3.2 Construction

Exterior views and the internal construction of the MBT module are shown in *Fig. 2* and *Fig. 3*. The MBT is a device for processing high voltage and large current at a high frequency. It is constructured so to the gate signal is not affected by the main current. Concretely, as shown in *Fig. 3*, the inductance component of the gate wiring is minimized by

(1) making the gate and emitter A1 wiring the same direction
(2) optimizing the gate-emitter terminal distance
(3) using twisted wire at the auxiliary or drive terminal wiring.

Fig. 4 shows the waveforms at a load short when the gate wiring is optimum and not suitable.

4. ELECTRICAL CHARACTERISTICS

The electrical characteristics of the 600V/50A, 2-pack: 2 MBI50-060 are introduced here as a typical example of the serialized MBT modules.

4.1 Output characteristics

The output characteristics with the collector-emitter voltage ($V_{CE(sat)}$ and collector current (I_c) relationship as a parameter are shown in *Fig. 5*. At rating I_c = 50A, V_{GE} = 15V, $V_{CE(sat)}$ is 3V strong at T_C = 25°C and 4V strong at T_C = 150°C and a lower saturation voltage characteristic than the MOSFET is shown. The temperature dependency is also smaller.

4.2 Switching characteristics

The relationship between switching time and collector current is shown in *Fig. 6*.

The switching time becomes longer as the collector current increases. However, at I_c, the turn-on time is a short 0.88μs and is approximately 1/10 that of a bipolar transistor of the same rating. The relationship between switching loss and collector current is compared to the bipolar transistor and shown in *Fig. 7*. At I_c, the MBT loss is approximately 10mJ/time (turn-on loss + turn-off loss) and is about 1/3 smaller than that of the bipolar transistor (approximately 30mJ/time) and high frequency operation is said to be possible.

Fig. 5 Output characteristics (typical values)

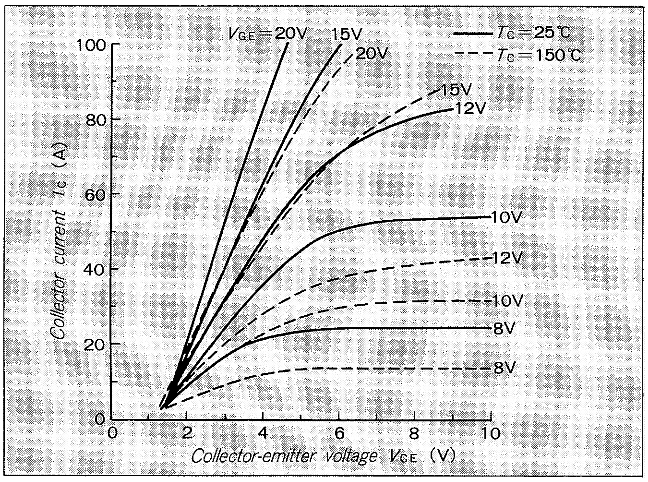


Fig. 6 Collector current-switching time characteristics (typical valu (typical values)

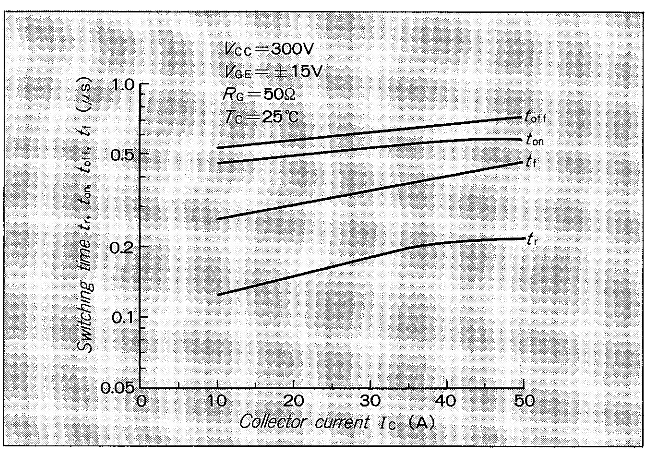


Fig. 7 Collector current-switching loss characteristics (typical values)

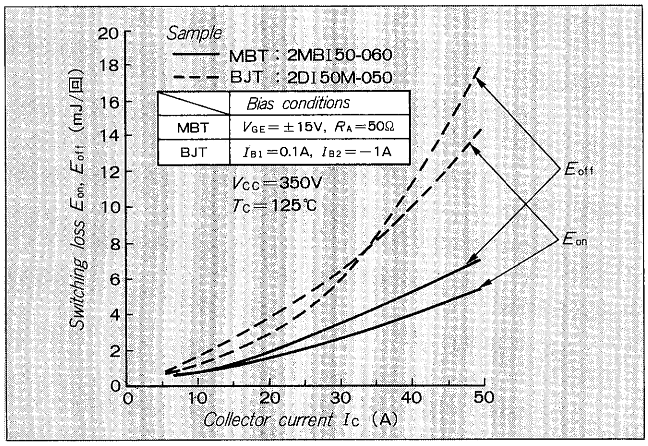
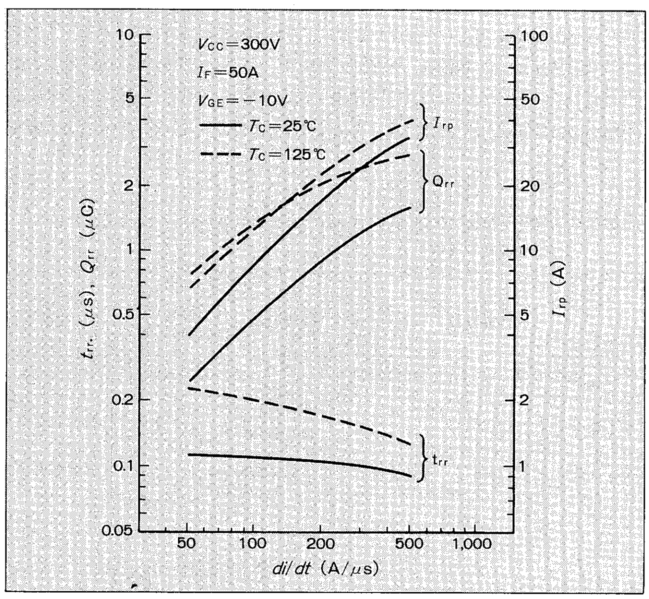


Fig. 8 Internal FWD reverse recovery characteristics (typical values)



4.3 Freewheeling diode (FWD) characteristics

The MBT turn-on current at an inverter circuit is the sum of the load current and the FWD reverse recovery current. The MBT turn-on loss is affected considerably by the FWD recovery current characteristic. Since the FWD reverse recovery loss also increases at high frequency operation, not only the MBT, but also the FWD must have a high speed characteristic. The serialized MBT modules contain the dedicated high speed FWD having reverse recovery characteristics shown in *Fig. 8*.

5. MBT APPLICATIONS

5.1 Gate circuit design points

The device characteristics of the MBT change with the gate drive conditions, the same as the change of the switching characteristics and safe operating region of the bipolar transistor change with the base drive conditions. The relationship between the MBT gate drive conditions and device characteristics is shown in *Table 2*. This does not mean that when the gate drive conditions are changed, all the characteristics changed toward the optimum value at the same time.

The turn-off characteristic of the bipolar transistor is changed by the base conditions (I_{B1}, I_{B2}). However, as shown in *Fig. 12* and *Fig. 14*, the change of the turn-off characteristic of the MBT by the gate conditions (V_{GE}, R_G) is small. Therefore, careful attention to the turn-on characteristic, normal on characteristics, load short circuit resistance, and erroneous operation are points.

The gate circuit design approach using the 2MB150-060 data is described here.

(1) $+V_{GE}$ selection

As shown in *Fig. 9*, *Fig. 10*, and *Fig. 11*, when $+V_{GE}$ is make large, $V_{CE(sat)}$ become small and the turn-on loss also becomes small. However, the collector current at a load short circuit increases and the time up to destruction becomes short. Therefore, when using the MBT at equipment which generates load short circuits, $+V_{GE}$ should be made the minimum value required. From *Fig. 9*, the recommended value when used up to the rated current (50A) is 15V which almost saturates the $V_{CE(sat)}$-$+V_{GE}$ characteristic. From *Fig. 14*, at load short circuit generation, the gate voltage must be suppressed within 5 μS which does not destroy the device.

(2) $-V_{GE}$ selection

When two MBT connected in series at an inverter circuit are turned on and off alternately, a very high dv/dt voltage is impressed between the collector and emitter of the off side device at FWD recovery. At this time, gate-emitter voltage rises above the gate threshold voltage and the collector current flows in the form of a pulse. This phenomena can be prevented by applying a reverse bias

Table 2 Relationship between gate drive condition and device characteristics

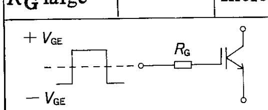
Character-istic / Condition	$V_{CE(sat)}$	$t_{on}E_{on}$	$t_{off}E_{off}$	Load short circuit resistance	dv/at current
$+V_{GE}$ large	Decrease	Decrease	–	Decrease	Increase
$-V_{GE}$ large	–	–	Small decrease	–	Decrease
R_G large	–	Increase	* Increase	–	Decrease
			*: When an certain range is exceeded.		

Fig. 9 Gate voltage-collector-emitter voltage characteristics (typical values)

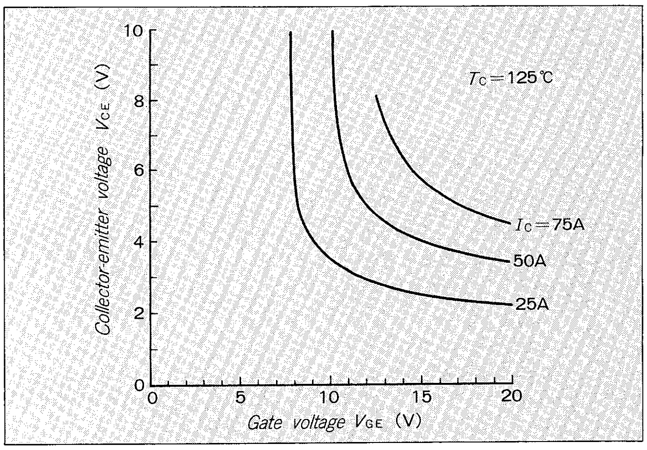


Fig. 10 Gate voltage-turn-on loss characteristics (typical values)

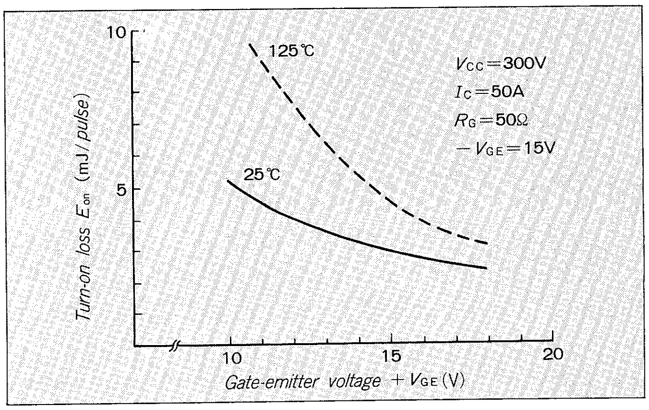


Fig. 11 Reverse bias voltage-turn-off loss characteristics (typical values)

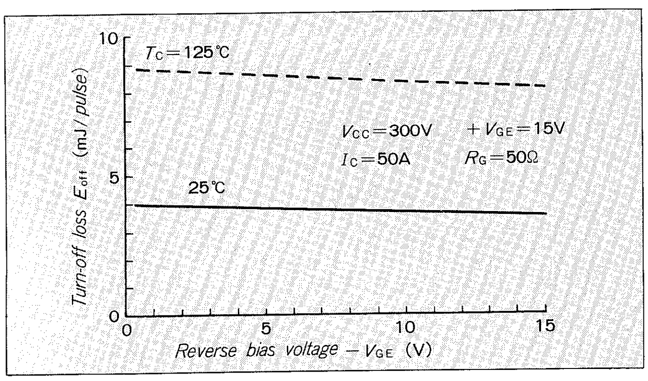


Fig. 12 Reverse bias voltage-erroneous operation collector current characteristic (typical values)

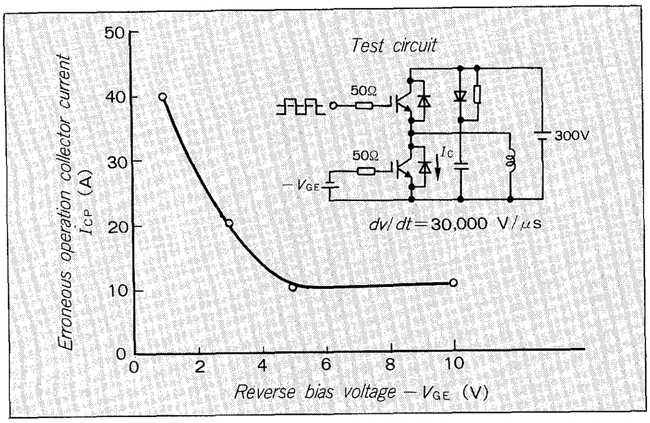


Fig. 13 Gate resistance-switching loss characteristics (typical values)

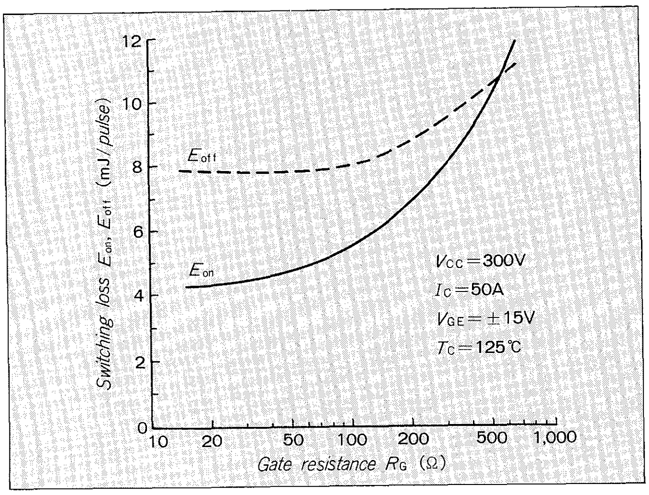


Fig. 14 Forward gate voltage-pulse width for destruction characteristics

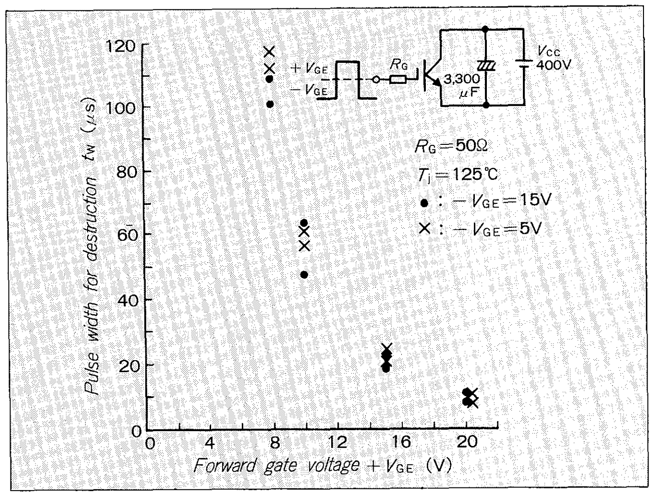
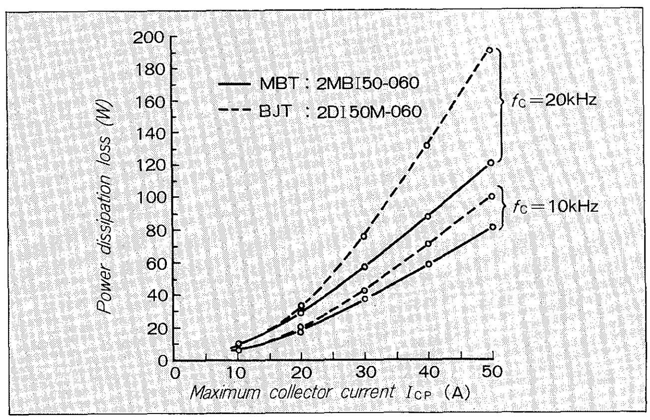


Fig. 15 Comparison of power dissipation loss in PWM inverter use (calculated values)



between the gate and emitter. *Fig. 12* shows the relationship between the erroneous on collector current and reverse bias voltage when a dv/dt of 30,000V was applied to an off state MBT. Fro this, a reverse bias of –5V or greater is necessary to prevent the MBT from operating erroneously.

(3) R_G selection

The relationship between the gate resistance connected in serise and switching loss is shown in *Fig. 13*. When the gate resistance (R_G) is make small, the switching loss becomes small. When R_G is made small, the di/dt at turn-on becomes high and easily causes the erroneously operation previously described and R_G loss also increases. Therefore, R_G should be made large within the range at which switching loss is not lost. The turn-on and turn-off losses of the 2MI50-060 increases sharply at R_G:100Ω or greater. R_G should be 100Ω or less.

5.2 Power dissipation loss in PWM inverter use

The power dissipation loss when the MBT is used with a PWM inverter is compared to a bipolar transistor and shown in *Fig. 15*.

Fig. 15 is the result of sine wave approximation of the inverter output current waveform by using the output characteristics and switching loss-I_c characteristics of the device and finding the average value of the sum of the switching loss and normal on loss at each carrier frequency and averaging this over the output current-cycle. This calculated value coincides well with the measured value.

6. CONCLUSION

The characteristics and application technology of the MBT module serialized this time were introduced above. We are confident that this MBT will meet the expectations of the inverter equipment field which is demanding smaller size, higher performance, and less noise. We plan to upgrade our technology farther and make efforts to develop new products which meet the diverse market demands in the future.