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POWER MOSFETS AND MOS MODULES FOR INVERTER APPLICATIONS

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1. FOREWORD

Recently, the field of application of power MOSFET has expanded not only to switching mode power supplies, but also to the inverter for motor control and uninterrupted power supply (UPS) fields. This is because the carrier frequency is increased and low acoustic noise can be realized because of the good RF response of the power MOSFET. In these applications, a free wheeling diode which circulates the energy stored in the load is necessary. Since, because of its construction, the power MOSFET has a built-in diode, it is often considered to be perfect for this application. However, when the built-in diode in the conventional power MOSFET is used as a free wheeling diode, it has the following disadvantages:

(1) Long reverse recovery time increases the turn-on loss
(2) Sudden destruction by dv/dt and di/dt in reverse recovery period

To overcome these disadvantages, the power MOSFET was used by using the following method:

(1) A Schottky barrier diode (SBD) is connected in series, then a discrete free wheeling diode (FWD) is connected in parallel so that commutation current does not flow in the parasitic diode. (*Fig. 1*)
(2) An inductor was inserted into the power line and a fast recovery diode is inserted in parallel with the inductor and the $-di/dt$ applied to the element is reduced. (*Fig. 2*)
(3) The turn-on time is lengthened by increasing the gate series resistance of the power MOSFET.

However, these methods have the following problems:

(1) Higher cost due to the additional diodes
(2) Higher loss

We have developed power MOSFETs for inverter that solve these problems and MOS modules suited for their application. These power MOSFETs and MOS modules are reported below.

2. DEVELOPMENT OF POWER MOSFET FOR INVERTER

The internal construction and internal equivalent circuit of the power MOSFET are shown in *Fig. 3*. As can be seen from *Fig. 3*, internally, the power MOSFET is constructured by connecting a parasitic bipolar transistor connected in parallel with a power MOSFET. When such a power MOSFET is used in the bridge circuit of an inverter, etc., the diode between the collector and base of the parasitic bipolar transistor can be used as a free wheeling diode. When the resistance connected by between base and

Fig. 1 Inverter circuit without parasitic diode

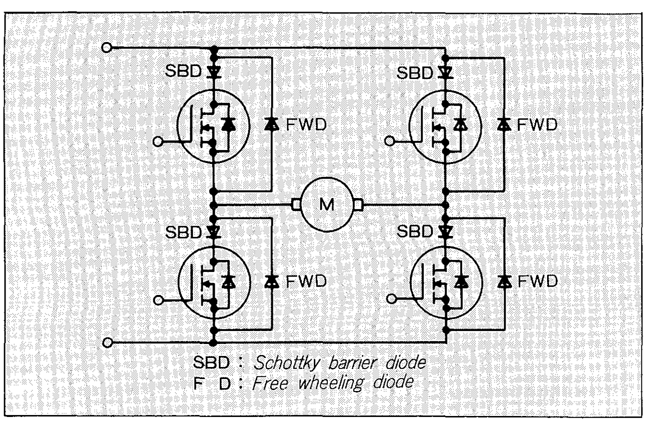


Fig. 2 Inverter circuit with smooth $-di/dt$

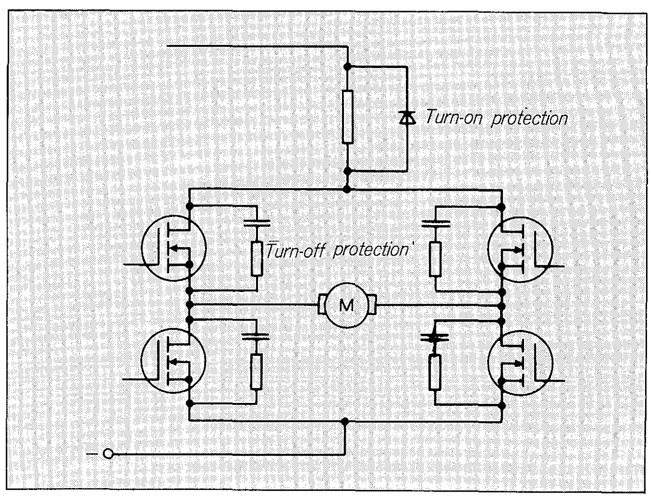


Fig. 3 Power MOSFET internal construction and equivalent circuit

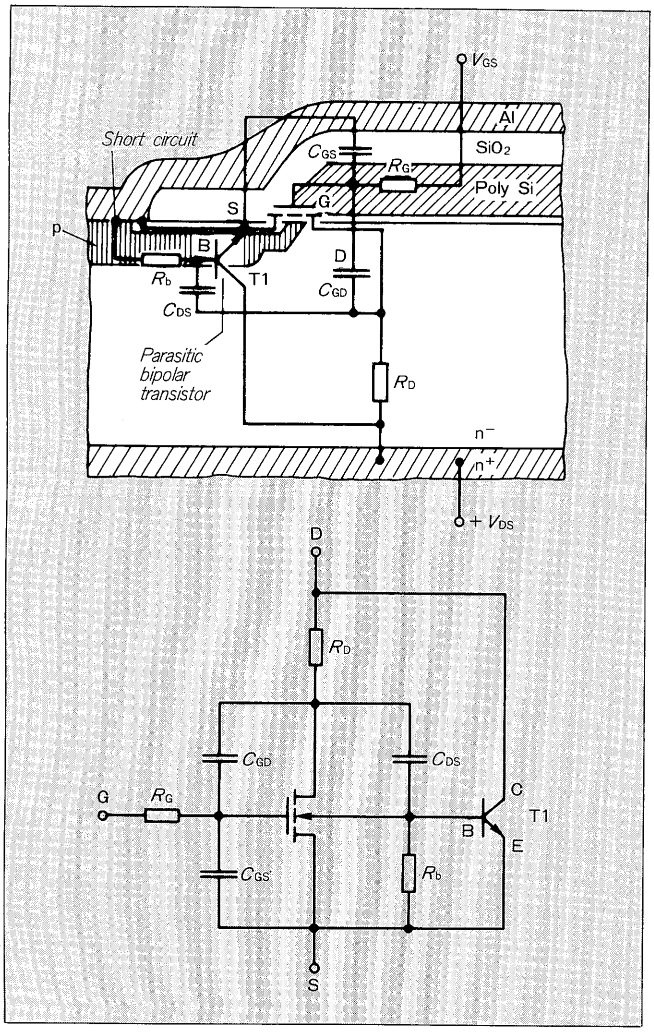


Fig. 4 Carrier frequency and total loss

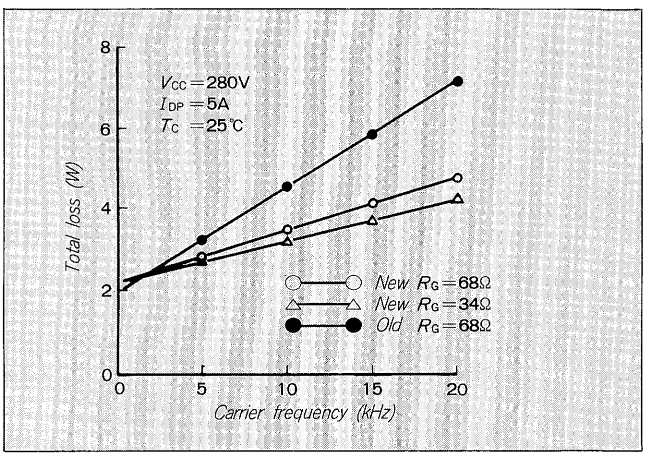


Table 1 Power MOSFETs for inverter applications

Item / Type	V_{DS}	I_D	$R_{DS(on)}$	g_{fs}	t_{rr}	Package
2SK1276	250V	20A	0.20Ω	12S	100ns	TO-3P
2SK1277		30A	0.12Ω	20S	100ns	
2SK1278	500V	10A	1.10Ω	8S	150ns	
2SK1279		15A	0.58Ω	13S	150ns	
2SK1280		18A	0.50Ω	14S	150ns	

emitter of the parasitic bipolar transistor is large, the reverse recovery current and dv/dt current flow between the base and emitter and the parasitic bipolar transistor is triggered erroneously and destroyed. The contents of the improvements in the ruggedness based on this destruction mechanism are shown below.

(1) Use of base-emitter resistance reduction process
(2) Use of reverse current reduction process
(3) Chip pattern design which does not concentrate the reverse recovery current

As a result, development of rugged power MOSFET perfect for inverter and UPS applications was achieved. Realization of high ruggedness enables to leave out additional SBD's and FWD's in inverter circuits and realizes lowering of the gate series resistance and reduction of the turn-on loss. To verify this effect, the relationship between loss and carrier frequency when this element was used in an inverter was simulated. The results are shown in *Fig. 4.* As shown in *Fig. 4*, the loss is lower and the carrier frequency is higher than the conventional element.

2.1 Series and ratings

The line-up and ratings of the power MOSFET for inverter applications are shown in *Table 1.*

2.2 Features

The features of the power MOSFET for inverter are:

(1) Turn-on loss: 30% or less than conventional products products
(2) Parasitic diode reverse recovery ruggedness (allowable $-di/dt$ value): About 3 times that of conventional products
(3) Avalanche ruggedness ($L = 100\,\mu$H): More than 10 times that of conventional products
(4) Parasitic diode reverse recovery ruggedness guarantee: -200A/μs (rated current value) guaranteed

3. DEVELOPMENT OF POWER MOS MODULE

A single-phase H-bridge or 3-phase bridge are used for inverters and UPS. (*Fig. 5*) Configuration with these circuit configurations as a unit is often prompted from the standpoint of the number of installation processes and modularization is difficult. A single in-line module (SIL) and large capacity MOS module were developed for inverters and

Fig. 5 Single-phase H-bridge and 3-phase full bridge circuit

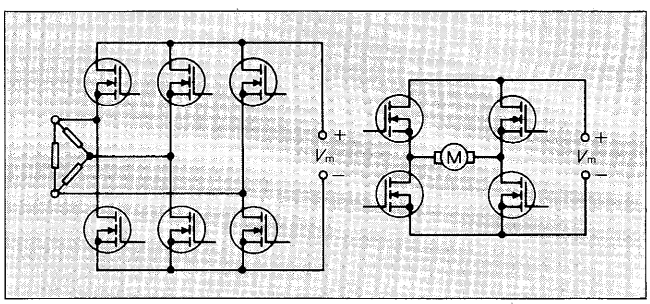


Fig. 6 SIL modules

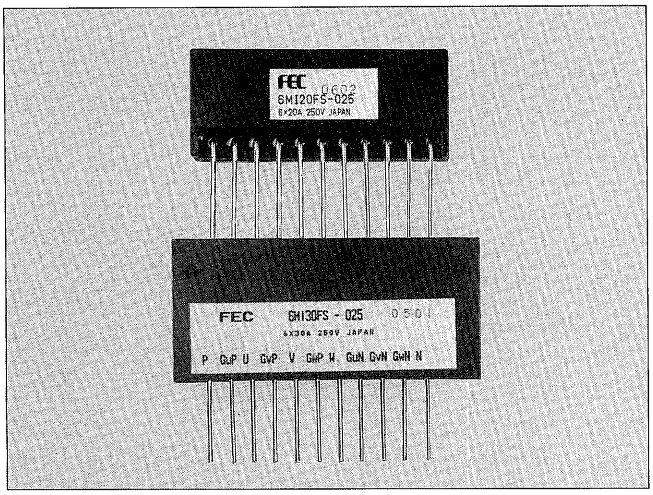


Table 2 SIL module series and ratings

Type	Withstand voltage	Current	On resistance (max.)
6MI15FS-050	500V	15A	0.58Ω
6MI20FS-025	250V	20A	0.20Ω
6MI30FS-025	250V	30A	0.12Ω

Fig. 7 Large capacity MOS modules

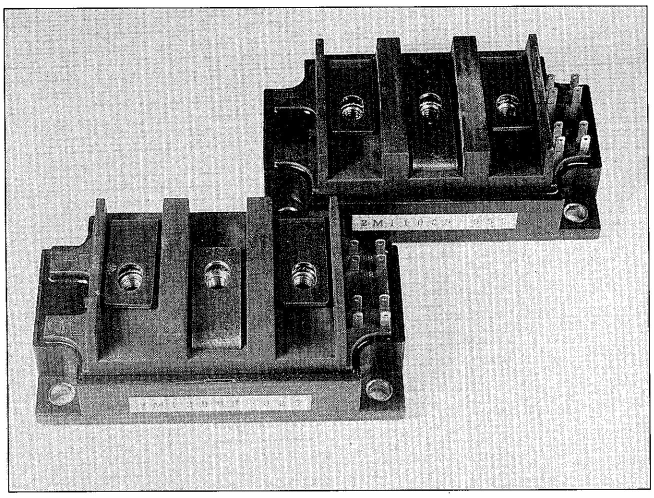


Table 3 Large capacity MOS modules

Type	Withstand voltage	Rating current	Allowable loss	$V_{GS(th)}$	$R_{DS(on)}$	t_{rr}
2MI200F-025	250V	200A	800W	2.1V~ 4.0V	0.015Ω	150ns
2MI100F-050	500V	100A			0.062Ω	200ns

<Note> $R_{DS(on)}$ and t_{rr} are the maximum values.

UPS by using the newly developed power MOSFET for inverter application.

3.1 SIL module

Because the power MOSFET is a unipolar device, its high frequency response is excellent but there is no conductivity modulation like a bipolar transistor and IGBT. Therefore, the high voltage pwoer MOSFET has a higher on-state voltage than a bipolar transistor and IGBT. However, in the low current (up to several amps) region, the on-state voltage difference from the bipolar transistor and IGBT is small and the power MOSFET has priority. Small inverters and UPS that use this low current region demand a compact package from the standpoint of set miniaturization. The SIL module is perfect for this.

3.1.1 Series and ratings

The photographs and ratings of SIL modules are shown in *Fig. 6* and *Table 2*, respectively.

3.1.2 Features

The SIL module has the following features:

(1) Small size, light weight, and thin package realized by using aluminum insulated substrate.
(2) Forming applicable to various mounting methods is possible by lead wire system.
(3) Use of round terminals simplifies PCB mounting and increases mounting efficiency.

3.2 Large capacity MOS module

In inverter application, the carrier frequency is up to about 20kHz. In UPS application, a carrier frequency of about 50kHz is used. When a bipolar transistor and IGBT is used at these carrier frequencies, the loss becomes large. Therefore, the power MOSFET is used, but conventionally, a 500V/50A class MOSFET was the largest. To raise UPS capacity, this MOS module was connected in parallel to increase the current capacity, but this increased the mounting area and number of mounting processes and made a large capacity MOS module desirable. However, to realize a large capacity MOS module, it is necessary to lower the internal wiring inductance. We developed a large capacity

Fig. 8 Module internal equivalent circuit

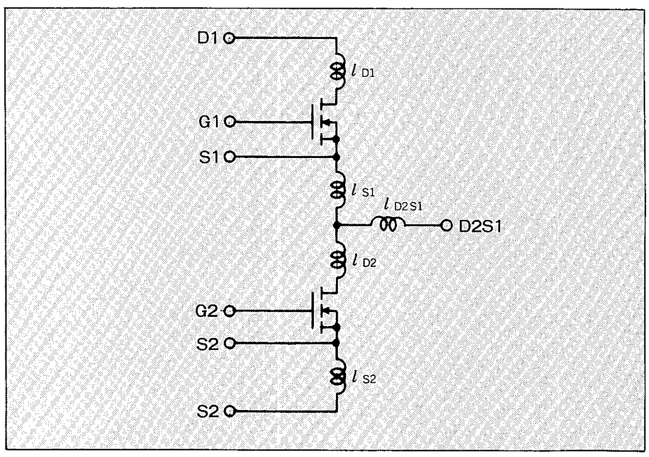


Table 4 Internal wiring inductance (calculated value)

l_{D1}	l_{S1}	l_{D2S1}	l_{D2}	l_{S2}
24.4nH	7.6nH	23.8nH	4.1nH	25.4nH

Fig. 9 Current and voltage waveforms when diode not added

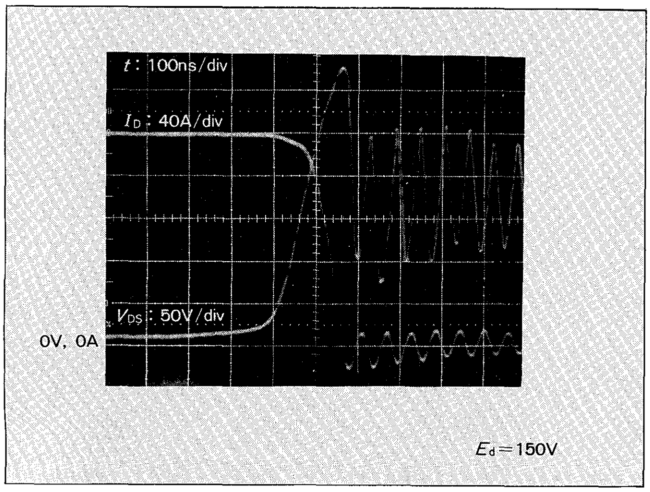


Fig. 10 Turn-off *–di/dt* reduction method

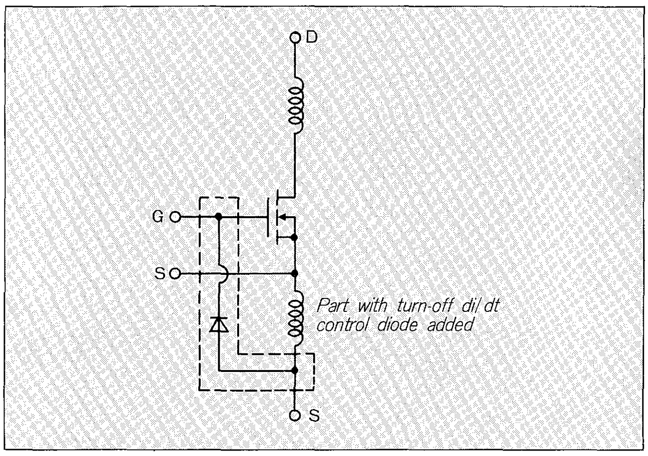
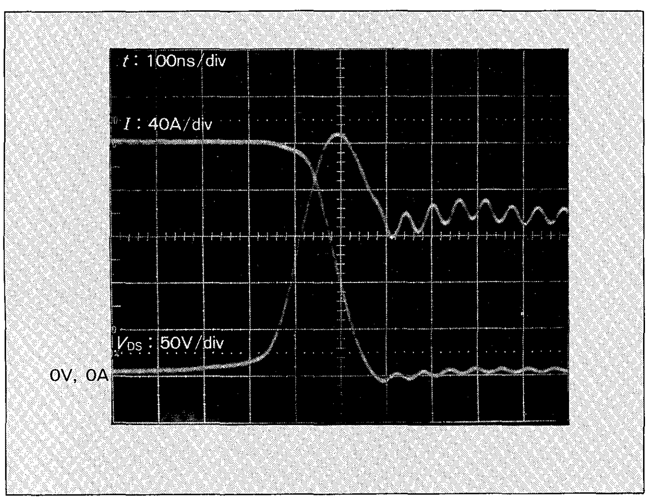


Fig. 11 Current and voltage waveforms when diode added



MOS module with low turn-on loss by effectively using the internal wiring inductance of a module package with lower internal wiring inductance.

3.2.1 Series and ratings

The photographs and ratings of the large capacity MOS modules are shown in *Fig. 7* and *Table 3*, respectively.

3.2.2 Features

The large capacity MOS modules have the following features:

(1) Low internal wiring inductance package used.

(2) Twice the capacity of conventional MOS modules (250V/100A, 500V/50A) realized resusting in reducing the number of parallel connections.

3.2.3 Study on module internal construction

In order to suppress the spike voltage between the drain and source in a power MOSFET due to the internal wiring inductance, a package with a low internal wiring inductance was developed. The calculated internal wiring inductance of this package is shown in *Table 4.*

3.2.4 Reduction of turn-off loss

The turn-off spike voltage was lowered by using a package with a low internal wiring inductance. However, since the turn-off spike voltage was larger than the conventional MOS module (2MI50F-050), the turn-off loss was a big problem. The current and voltage waveforms at turn-off are shown in *Fig. 9*. The turn-off loss large because of the high *–di/dt* at turn-off. In order to overcome this problem, a diode is inserted between the gate and source as shown in *Fig. 10*, and the *–di/dt* at turn-off is lowered and the spike voltage between the drain and source is suppressed. The gate voltage drop at turn-off becomes soft by applying the counter-electromotive force of the source side internal wiring inductance generated at turn-off to the gate. The current and voltage waveforms when this countermeasure was taken are shown in *Fig. 11*. The gate series resistance could be made small and the loss could be reduced. Thus, a large capacity MOS module with double the capacity of the conventional MOS modules were developed and commercialized.

4. CONCLUSION

The power MOSFETs for inverter and MOS modules were introduced above. We are confident that these power MOSFETs and MOS modules can contribute to meeting the need for smaller and higher performance equipment. We plan to upgrade this technology and develop new products in the future.