Fuji Electric's Power Semiconductor Devices

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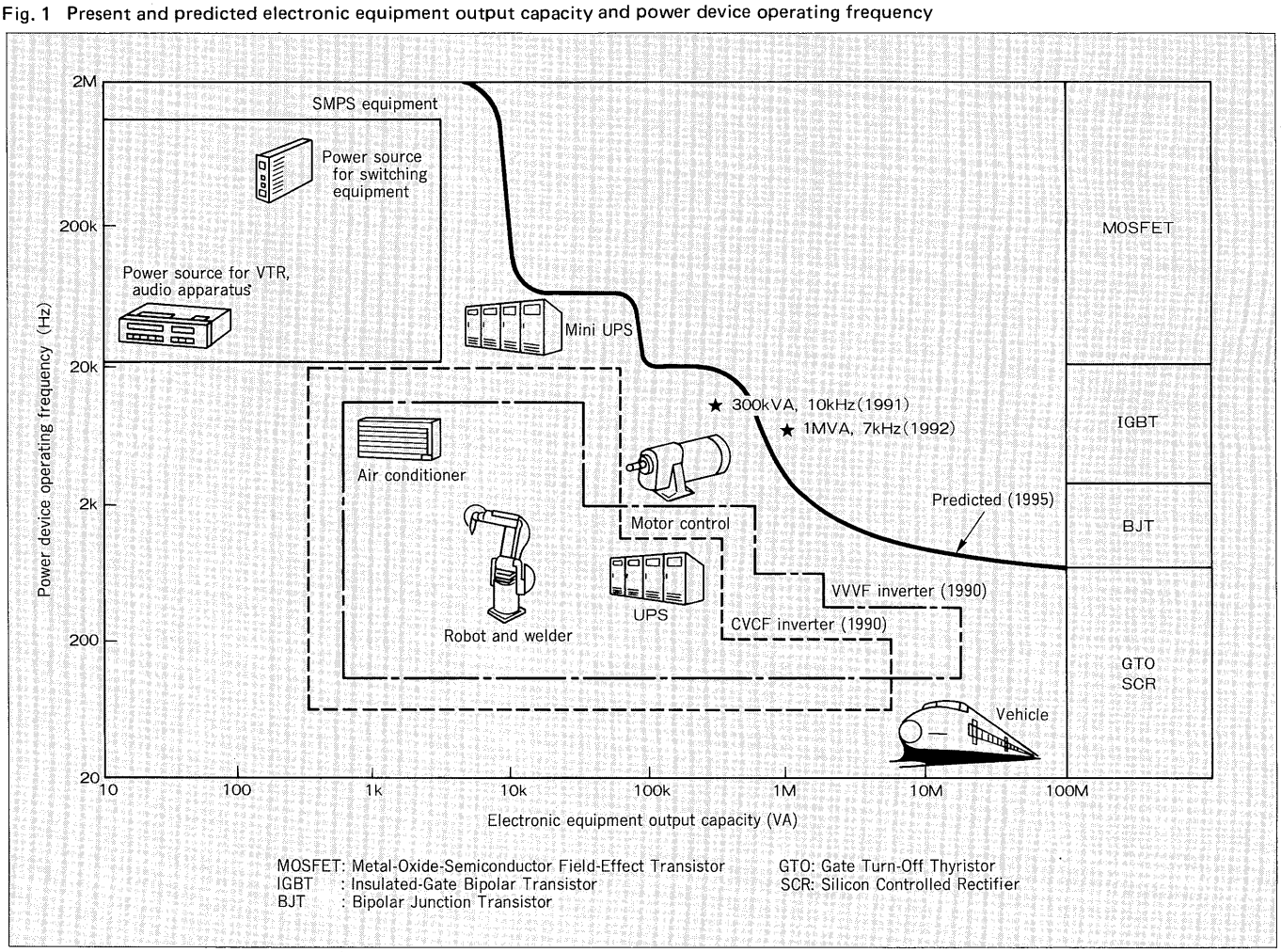
1. Introduction

Power semiconductors along with power electronics play an important role in the technology revolution occuring within industrial, household and automotive electronics, and also information systems. There are many different devices and applications of power semiconductors. New information provided by power semiconductor related fields is promoting progress in the development of new power devices and their performance.

Power switching devices constructed from MOS (Metal Oxide Semiconductor) gated power devices allow high speed switching and simplification of the gate driving circuit (voltage driving). This has led to major breakthroughs in the power electronics field.

In **Fig. 1** we see the VVVF (Variable Voltage Variable Frequency) inverter, the CVCF (Constant Voltage Constant Frequency) inverter and the SMPS (Switching Mode Power Supply), all of which are commonly used power electronic equipment. The voltage output (VA) and the

Fig. 1 Present and predicted electronic equipment output capacity and power device operating frequency



operating frequency of this equipment as of 1990 and predicted values for 1995 are listed in **Fig 1**. The 300 kVA 10 kHz VVVF inverter which uses parallel 1,200V, 300A IGBTs (Insulated Gate Bipolar Transistors) and the 1 MVA 7 kHz CVCF inverter with parallel 600V, 600A IGBTs were introduced as products in 1991 and 1992 respectively. The capacity of high frequency IGBT inverters has increased much faster than was anticipated[(1)].

It is expected that demand for the following types of power semiconductor devices will increase in the future.

(1) Low power loss devices
(2) Easy to operate intelligent devices
(3) High voltage and large capacity decices
(4) Resonant inverter devices
(5) Devices suitable for outerspace

The following is a summary of Fuji Electric's general power semiconductor technology based on the above topics.

2. Low Power Loss Devices

2.1 MOSFET (Metal Oxide Semiconductor Field Effect Transistor)

As can be seen in **Fig. 2**, the on-state resistance of MOSFETs is dramatically improving each year mainly through improvements in fine process technology. Fuji Electric is currently producing a 60V, 500V, and 1,000V MOSFET product series. Improvements are continually being made in the avalanche capability of the MOSFET series. Avalanche capability is the amount a component resists *di/dt* power surges created by circuit inductance during component switching.

2.2 IGBT

An IGBT is a bipolar device in which conductivity modulation occurs in order to decrease the impedance to current flow in high voltage MOSFETs.

Following the introduction of the first generation IGBTs in 1988, Fuji Electric has made technological advances in power loss characteristics as its primary goal and has developed second and third generation IGBT devices. The results of technological advancements made by Fuji Electric can be seen in the third generation IGBT characteristics shown in **Fig. 3**. The third generation IGBT can operate in the 15 kHz carrier range with less power loss than a bipolar transistor in the 3 kHz range.

Listed below are the main concepts of the third generation IGBT series.

(1) An internal self protection function which controls excess current inflow to the modules (**Fig. 4**)
  (a) Improvement of Vce(sat) and t_f trade off within IGBT devices which has led to faster switching
  (b) Improved range of safe operation for the modules
(2) Improvement of the surge characteristics during switching through the utilization of an optimized IGBT chip design and silicon crystal profiles
(3) Decreased reverse recovery time and improvement of the soft recovery feature for the Free Wheeling Diode

Fig. 2 Improvement of power MOSFET's on-resistance

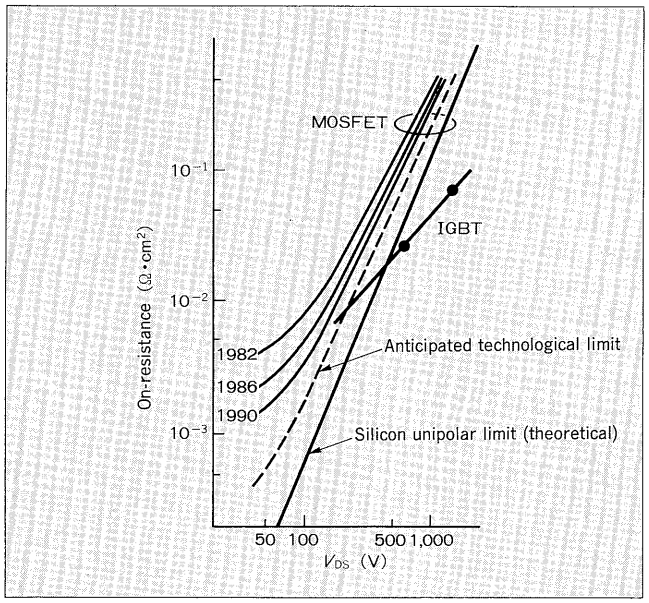


Fig. 3 Energy loss of BJT and IGBT modules in PWM inverter

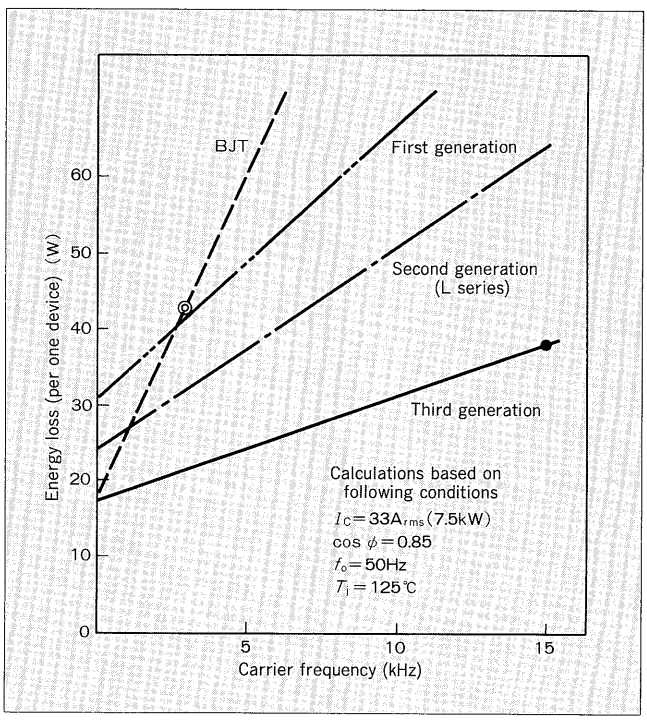
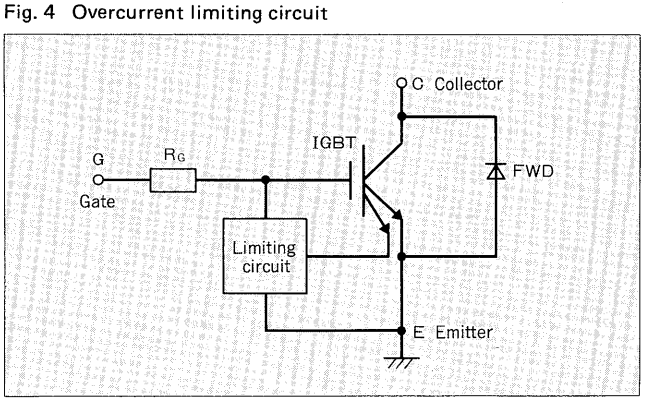


Fig. 4 Overcurrent limiting circuit



(FWD) within the IGBT module

(4) Drastically reduced operation power loss as compared with the second generation IGBT devices

The 600V, 1,200V and 1,400V series IGBT devices are currently being produced and marketed by Fuji Electric.

2.3 The MOS gated thyristor

In order to further reduce power loss within MOS gated devices it will be necessary to improve trade off characteristics to reduce Vce(sat). However, third generation IGBT device characteristics appear to have reached the theoretical limit for present concept IGBTs. There have been recent proposals for new MOS gated thyristor structures that will lead to decreased Vce(sat). Fuji Electric has proposed a Double Gate MOS (DGMOS) device[2] and, is developing next generation devices while evaluating and comparing other new devices.

3. Intelligent Devices

In **Fig. 5** we see the circuit diagram of the motor controlled inverter system. The development of intelligent devices has become a hot topic in the effort to meet needs of high functionality, small size, and operating ease while at the same time simplifying system construction.

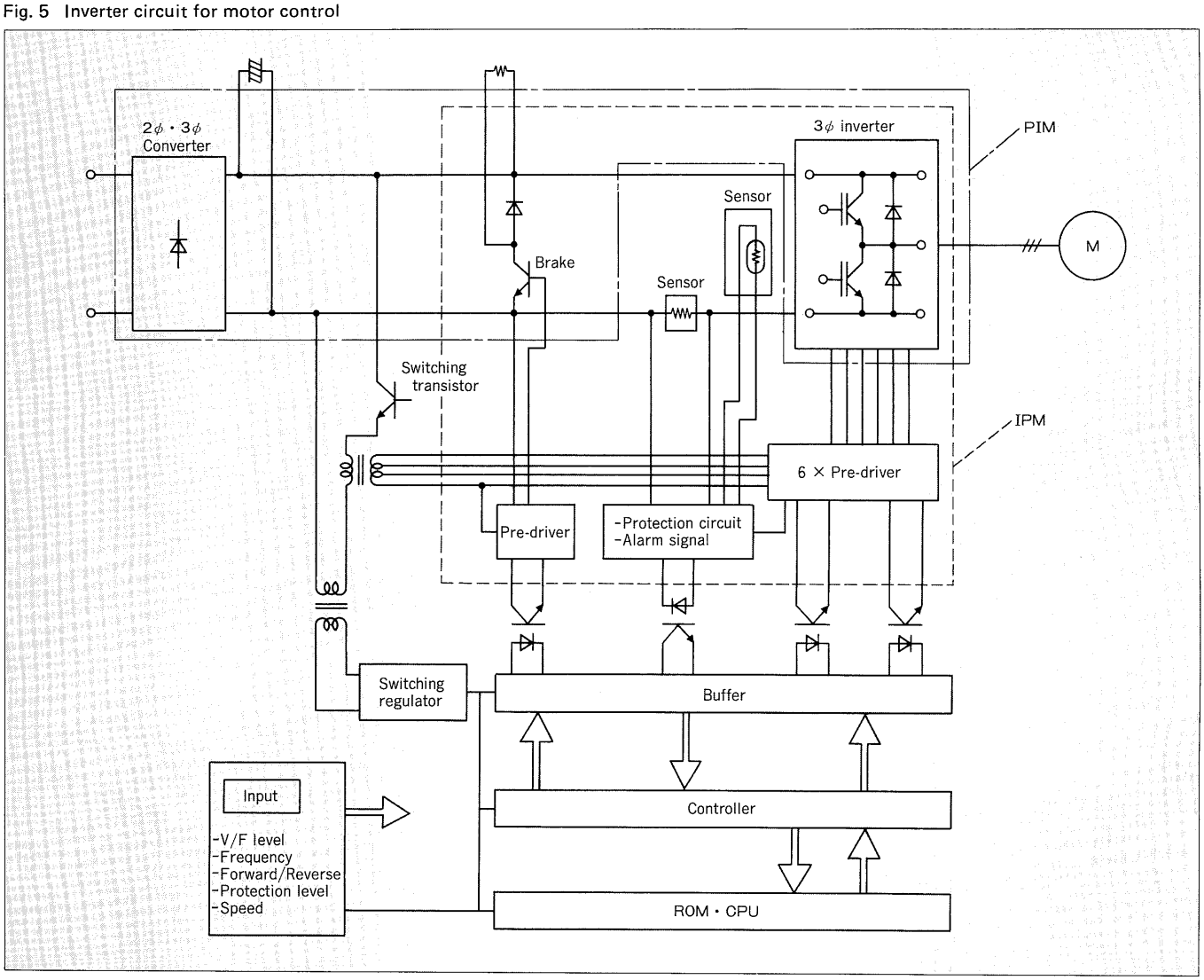
Required intelligent functions should include functions such as detection with sensors, judgement and control (or protection).

Fuji Electric is currently producing the Intelligent Power Module (IPM), and the Intelligent Power Switch (IPS). Fuji Electric is also developing a module with dual converter/inverter functions known as the Power Integrated Module (PIM).

3.1 IPM

Fuji Electric is currently developing 600V and 1,200V series IGBT IPM that employ third generation IGBT chips with current flow sensors to monitor current flow within the devices. The IPM contains a protection function which outputs an alarm signal and shuts off the power output if there is an excess current flow, short circuit, lowering of the electric power source, or overheating. Compact IGBT IPM is possible through improved drive conditions, custom IC development, and advances in wiring and circuit

Fig. 5 Inverter circuit for motor control



design.

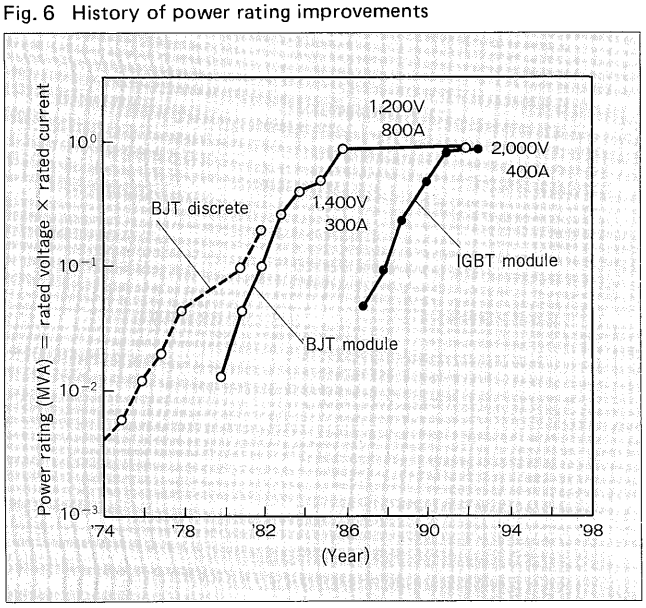
3.2 IPS

In **Table 1** we see the prominent features of Fuji Electric's IPS product line. IPS chips are constructed from both power MOSFETs and Complimentary MOS (CMOS) IC, for use in sensing, judgement and control. Through the development of high voltage CMOS structures and the adoption of self-isolation technology, Fuji Electric aims to create devices with high performance and low cost.

Table 1 IPS product series

Classification / Item	High-side	Low-side
Product series	F5001H F5012H F5017H (under development)	F5002L F5015L
Construction	DMOS CMOS	DMOS NMOS
Isolation technology	Self isolation	Self isolation
Features	Heatsinkless Self protection functions built-in (Overvoltage protection Overcurrent protection Over temporature protection) Withstands high electrostatic voltages	Low on-state resistance (Typically 50mΩ) Self protection functions built-in (Overvoltage protection Overcurrent protection Over temperature protection) Minimized temperature dependence of over-current limitation (Typically ±1A (−55 to 150°C))

Fig. 6 History of power rating improvements



3.3 PIM

A small, thin package module is achieved by molding the metal terminals of module into the plastic case block. Through use of a soldered terminal structure, PIM helps to reduce equipment size and weight.

4. High Voltage, Large Capacity Devices

Improvements made in the power ratings (given as the product of rated voltage and rated current) of IGBT modules are shown in **Fig. 6**. The rated capacity of IGBT devices has grown in accordance with improvements made in the characteristics of IGBT devices. High voltage, large capacity devices have been replacing Gate Turn Off Thrystors (GTO) in electrical train systems.

Fuji Electric has developed the standard 2,000V/400A IGBT module and is continuing development on a large capacity series. The flat package structure of IGBT modules is also being studied to further reduce the inductance and thermal resistance in large capacity IGBT devices.

5. Resonant Inverter Devices

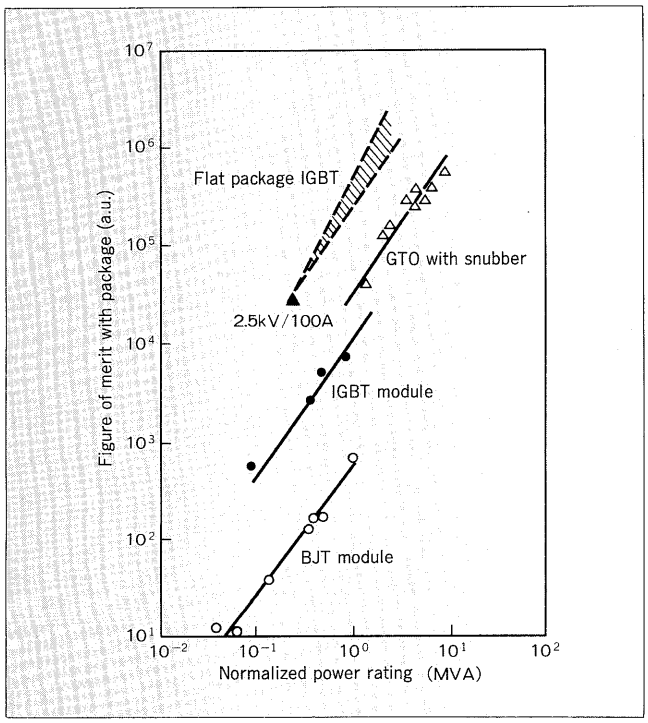
Application of the new IGBT devices developed for voltage resonant inverters are listed in **Table 2**. Fuji Electric has developed a one package mold type IGBT that contains both IGBT and FWD chips. The new IGBT devices were developed for use in microwave ovens, rice cookers and other inductive heating (IH) equipment. These new IGBT devices are small in size, light weight, highly reliable and help reduce the number of components. Switching loss has been decreased and breakdown resistance voltage enhanced.

A variety of different applications are made possible through the optimization of related IGBT devices. Fuji Electric has developed IGBT devices that are optimized for CRT horizontal deflection circuits and for switching mode power supplies.

Table 2 Mold type IGBT for voltage resonant inverter

Item / Application		Inverter type power supply (Microwave oven, induction heating rice cooker, electromagnetic cooker)	CRT horizontal deflection drive	Switching mode power supply
Product line	Type	1 MBH60D-090A 1 MBH65D-090A 1 MBH70D-090A	1MB12-140 1MBA06-140	1MBA10-090
	Rating	60 to 70A/900V	6A, 12A/1,400V	10A/900V
	Package	TO-3PL	TO-3PF (Full molded)	TO-3PF (Full molded)
Features		FWD included in one package High speed switching Low saturation voltage High breakdown withstand capability	High breakdown withstand voltage Large current driving High speed switching	High speed switching Low saturation voltage

Fig. 7 FOM for BJT, IGBT and GTO



6. Devices Suitable for Use in Outerspace

Fuji Electric has developed bipolar transistors, namely the 2SC4136, 2SC4534 and 2SC4832 for use in satellites and space stations. After developing these bipolar transistors, Fuji Electric then developed the MOSFET 2SK2271 which is suitable for use in outerspace. These types of devices must have a wide temperature range for storage and operation, be able to withstand radiation in space, and be highly reliable. Bipolar transistors produced by Fuji Electric were installed in the H-II rocket which was launched in February of 1994.

7. Future Trends

As improvements are made to IGBT device characteristics, it is possible that in the future IGBT devices will be used in place of bipolar transistors and GTOs (which are used in high power applications). For development to continue it is necessary to have active discussions concerning what form of high capacity devices would be best. Fuji Electric has suggested one possibility, the flat package IGBT which has a greater FOM (Figure Of Merit) than the GTO (see **Fig. 7**)[1].

It is believed that developments in key technologies will lead to devices that are easier to use. Perhaps intelligent technology (technology related to intelligent devices) will become a key technology in the future. Currently sensor and protection technologies are being applied in intelligent devices. There is an increasing need for the creation of devices to meet individual customer demands in areas such as improved sensor accuracy and new control technology. These devices are known as Application Specified Intelligent Power (ASIP) devices. Fuji Electric is considering the development of ASIP devices through a combination of IC control and power device technologies.

8. Conclusion

It is believed that the development of devices that consume less energy, are highly efficient and are electromagnetically compatible (low noise) will become important topics for the new generation of control systems. Fuji Electric will continue to develop technology in advance to meet this increased need. Fuji Electric also believes that continual effort must be made to improve performance and reduce costs for all power semiconductor devices.

References

(1) Shigekane, H. et al.: Development in Modern High Power Semiconductor Devices. ISPSD '93, p. 16-21 (1993)
(2) Momota, S. et al.: Double Gate MOS Devices having IGBT and MCT Performances, ISPSD '92, p. 28-33 (1992)