2nd-Generation Small IPM

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ABSTRACT

Fuji Electric has been developing small intelligent power modules (IPMs) that integrate into a single package the power devices and control IC needed in the system construction of motor drives. We have now developed a 2nd-generation small IPM based on 7th-generation IGBT technology to achieve even more energy savings. The module reduces the loss by 10% or more in the intermediate load region, such as in the case of a 5.6-kW air conditioner, and by 20% or more in the rated and maximum load region compared with the 1st-generation module. In addition, temperature rise in the soldering on the circuit board has also been reduced by approximately 20 °C compared with the 1st-generation module. Overall, the module achieves enhanced energy savings, expands output current, and increase reliability during circuit board mounting and a greater degree of freedom during system design.

1. Introduction

As there is a growing interest in global environmental issues, there is increasing demand to save on the energy consumed by consumer electronics such as air conditioners and washing machines and industrial motor drive systems.

For consumer electronics, energy-saving regulations based on the annual performance factor (APF), which indicates energy consumption efficiency close to the actual use, have been tightened globally. The focus is, thus, given not only to improving efficiency under the rated and maximum load conditions but also to reducing loss in the intermediate load condition, which is closer to the actual use. In the Japanese and Chinese markets, in particular, significant improvement of energy saving performance is required for popular models, which form the main range, in addition to high-end models.

In addition, with inverters and servos for industrial use, there is increasing demand for chassis downsized by improving power density.

In order to meet these demands, Fuji Electric has commercialized small intelligent power modules (IPMs) that integrate into a single package the power devices and control IC needed in the system construction of motor drives[(1)]. Small IPMs, which integrate a 3-phase inverter bridge circuit with control and protection circuits, have been making contributions to size reduction and energy saving of inverters.

To achieve further energy saving in each application, we have developed the 2nd-generation small IPM by inheriting the 1st-generation small IPM and using the basis of a 7th-generation insulated-gate bipolar transistor (IGBT) technology[(2)], which combines wafer thinning and miniaturization.

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2. Product Overview

Figure 1 shows the external appearance of the 2nd-generation small IPM and Table 1 the product lineup and major characteristics. The 2nd-generation small IPM has a compatible package structure with the same external size and pin assignment as those of the 1st-generation products. The product line includes the 600-V/10- to 30-A ratings. New addition of the 10-A rating has been made for air conditioner compressors with an input power of 1.5 kVA and for small-capacity industrial inverters and servos with 0.1- to 0.2-kW outputs. The module provides 2 types of temperature protection function: with analog temperature output only and with overheat protection added.

Figure 2 shows the configuration of internal equivalent circuit of the small IPM. The small IPM integrates a 3-phase inverter bridge circuit composed of low-loss IGBTs and high-speed free wheeling diodes (FWDs) on an insulating metal substrate. It has a low voltage integrated circuit (LVIC) chip for driving

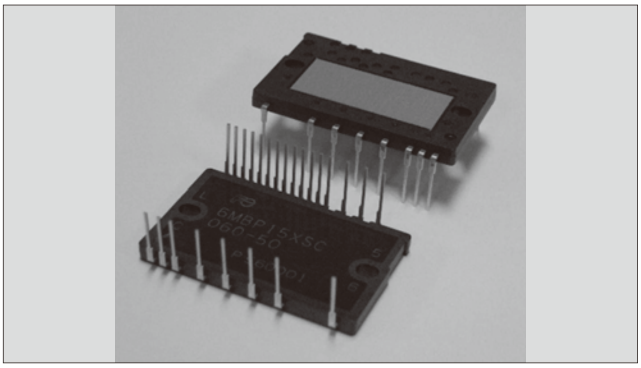

Fig. 1 2nd-generation small IPM

Table 1 Product lineup and major characteristics

Voltage	Type	I_C	I_{CP}	$V_{CE(sat)}$ (typ.)	V_F (typ.)	Temperature protection function
600 V	6MBP10XSA060-50	10 A	30 A	1.40 V	1.40 V	Temperature sensor output
	6MBP10XSC060-50					Temperature sensor output and overheat protection
	6MBP15XSA060-50	15 A	45 A	1.40 V	1.40 V	Temperature sensor output
	6MBP15XSC060-50					Temperature sensor output and overheat protection
	6MBP20XSA060-50	20 A	60 A	1.40 V	1.55 V	Temperature sensor output
	6MBP20XSC060-50					Temperature sensor output and overheat protection
	6MBP30XSA060-50	30 A	90 A	1.40 V	1.45 V	Temperature sensor output
	6MBP30XSC060-50					Temperature sensor output and overheat protection

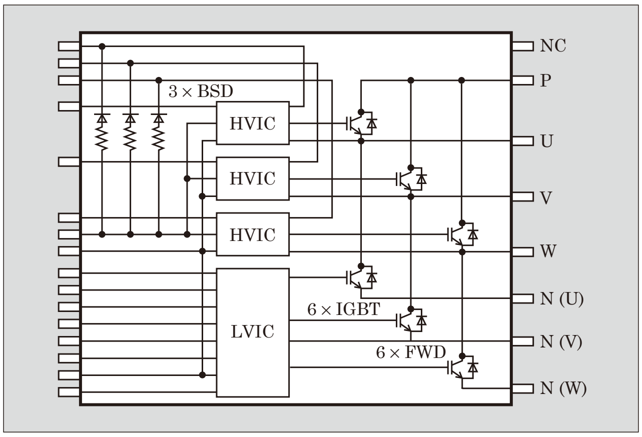

Fig. 2 Configuration of internal equivalent circuit

the IGBTs on the low side and high voltage integrated circuit (HVIC) chips for driving the IGBTs on the high side of this 3-phase inverter bridge circuit. By providing boot strap diodes (BSDs) with built-in a current limiting resistor for the drive circuit on the high side, insulated power supply can be constructed with a small number of external parts.

The 2nd-generation small IPM has not only achieved a significant reduction of loss from the 1st-generation but also the guaranteed operating temperature range has expanded from 125 °C to 150 °C. In addition, it has realized a greater degree of design freedom and expanded the operating range of inverters by optimizing the overheat detection level and improving the overcurrent detection accuracy.

3. Features

Table 2 shows the characteristics of the 2nd-generation small IPM. The following describes the features.

(1) Improvement of APF by loss reduction

Using the low-loss device based on the 7th-generation IGBT technology and optimizing the drive performance allow for a significant reduction of loss and improvement of the APF.

(2) Improvement of degree of design freedom and expansion of operating range of inverters

Increasing the guaranteed operating temperature $T_{j(ope)}$ increases the allowable current, which allows the operating range to be expanded. In addition, expanding the peak collector current rating and improving the accuracy of short circuit detection allow the overload operating range, where a large current flows instantaneously at startup, to be expanded. This makes it possible for the same rating to accommodate a motor capacity of one level higher.

Table 2 Characteristics of 2nd-generation small IPM

Item	2nd generation	1st generation
Type	6MBP15XSC060-50	6MBP15VSC060-50
V_{CE}	600 V	600 V
I_C	15 A	15 A
I_C(pulse)	45 A	30 A
$T_{j(ope)}$	– 40 °C to +150 °C	– 40 °C to +125 °C
$V_{CE(sat)}$ (typ.)	1.40 V	1.80 V
E_{off} (typ.)	0.26 mJ	0.56 mJ
V_F (typ.)	1.40 V	1.65 V
Short-circuit protection detection accuracy	480 ± 25 mV	480 ± 50 mV
Temperature protection	Temperature sensor output and overheat protection (143 °C ± 7 °C)	Temperature sensor output and overheat protection (125 °C ± 10 °C)

(3) Reduction of thermal resistance

A high-heat-dissipation aluminum insulating substrate with the thermal conductivity improved by approximately 1.5 times from the 1st-generation small IPM has been employed to reduce the thermal resistance. This has successfully suppressed the increase in junction temperature, which, together with the loss reduction, has increased the allowable current.

3.1 Features in device design

(1) Low-loss power device design

Figure 3 shows a comparison of the IGBT cross-section structure. The 7th-generation IGBT device is based on the field stop (FS) structure that we have developed up to now and combines further wafer thinning and miniaturization technology.

For the 2nd-generation small IPM, the specific resistance and thickness of the drift layer have been optimized based on the 7th-generation IGBT technology. In addition, the FS layer profile and the surface channel density and layout have been optimized, thereby improving the trade-off between the $V_{CE(sat)}$ and E_{off}

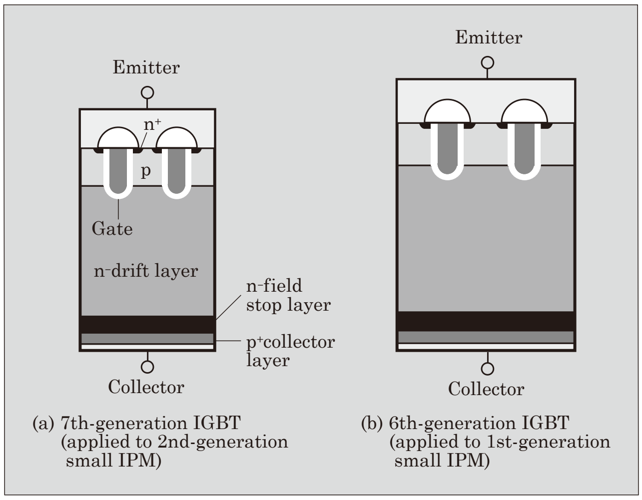

Fig. 3 IGBT cross-section structure

characteristics.

Figure 4 compares the trade-off between the $V_{CE(sat)}$ and E_{off} characteristics with that of the 1st-generation small IPM and Fig. 5 compares the turn-off waveforms. The trade-off between the $V_{CE(sat)}$ and E_{off} characteristics shows an improvement from the 1st generation by approximately 25% in terms of $V_{CE(sat)}$ and approximately 50% in terms of E_{off} due to the tail current reduction through wafer thinning. In this way, we have improved the APF, which is an index of energy saving, by reducing loss under the intermediate load conditions and increased the allowable current by significantly reducing the loss under the maximum load conditions.

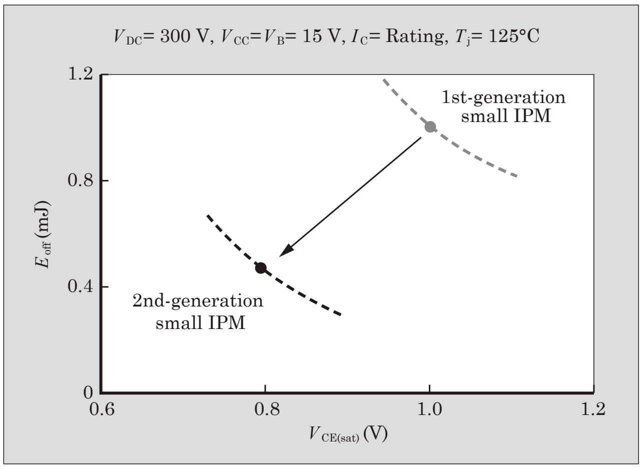

Fig. 4 Trade-off between $V_{CE(sat)}$ and E_{off} characteristics

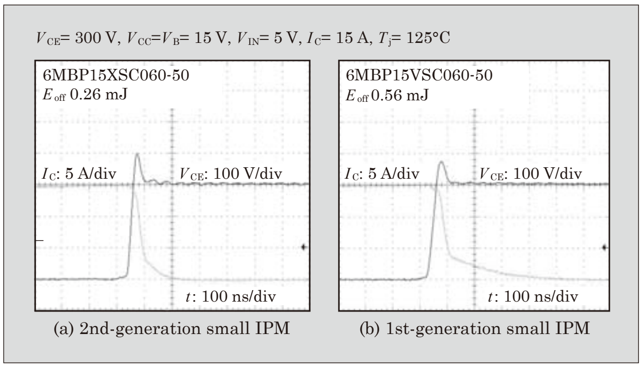

Fig. 5 Turn-off waveforms

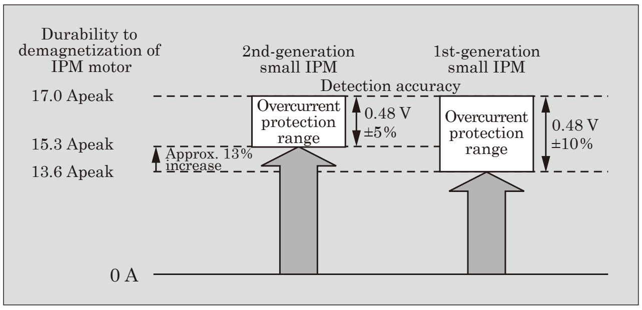

Fig. 6 Comparison of overcurrent protection level

(2) Improvement of overcurrent detection accuracy

Figure 6 shows a comparison of the overcurrent protection level of interior permanent magnet (IPM) motors in two generations. For IPM motors used for compressors of air conditioners, the motor's demagnetization capability in high output conditions must be ensured. Therefore, overcurrent protection in the overload region is important. To expand the operating range, the detection accuracy for overcurrent protection makes a major contribution.

With the 2nd-generation small IPM, the range of detection accuracy for overcurrent protection can be reduced by half from 10% of the 1st generation to 5%. This brings out the motor characteristics close to the limits, thereby increasing the current under the maximum load conditions by approximately 13%.

3.2 Features in package design

(1) High-temperature operation guarantee

To increase the guaranteed operating temperature $T_{j(ope)}$ described above, it is necessary to improve reliability including the power cycle capability in view of actual use.

For that purpose, the 2nd-generation small IPM has the thermal fatigue of the wire bonds reduced so as to improve the power cycle capability. In this way, the thermal stress of the package components in high-temperature operation can be reduced. This has enabled the device to satisfy the level of 15 kcycles or more in the power cycle test assuming $T_{j(ope)}$ = 150 °C (ΔT_j = 100 °C).

(2) Reduction of temperature rise

In order to increase the allowable current along with the expansion of the operating range, it is necessary to reduce the thermal resistance of the package to restrain the temperature rise of the power device.

Figure 7 shows the cross-section structure of the package. The structure of the small IPM employs a high-heat-dissipation aluminum insulating substrate for the terminal case, and the efficiency has been improved. The issue is to both reduce the thermal resis-

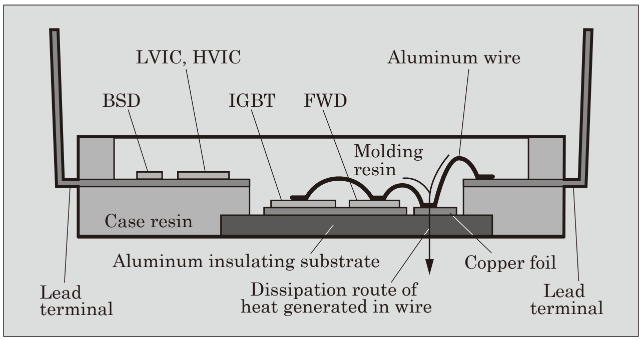

Fig. 7 Package cross-section structure

tance and ensure a sufficient withstand voltage of the aluminum insulating substrate. To do this, we have focused on and optimized the trade-off between the thickness of the insulating layer in the aluminum insulating substrate, which is a major factor that determines the package thermal resistance characteristics, and the withstand voltage.

To increase the allowable current, it is necessary to reduce the temperature rise in the soldering part on the circuit board. Accordingly, the 2nd-generation small IPM is built with a structure that dissipates the heat generated in the wire to the aluminum insulating substrate side in order to reduce the temperature rise in the soldering part. Temperature rise is reduced by dissipating the Joule heat, which is generated in the wire when a current is flowed, to the aluminum insulating substrate side.

4. Effect of Application

Figure 8 shows the results of a trial calculation of the loss under the 150% overload conditions assuming a 0.75-kW industrial inverter. Comparing with the 1st generation, the 2nd-generation small IPM has achieved a loss reduction of approximately 20%. This means the device can also be applied to inverters of 1.0 kW, one level higher capacity.

Figure 9 shows the results of trial calculation of loss in the individual operation mode assuming an air conditioner of 5.6-kW output that uses a 600-V/15-A IPM. The 2nd-generation small IPM shows lower loss than the 1st-generation in all load ranges. In the intermediate load region, which has an impact on the APF performance in particular, the loss is lower by more than 10%.

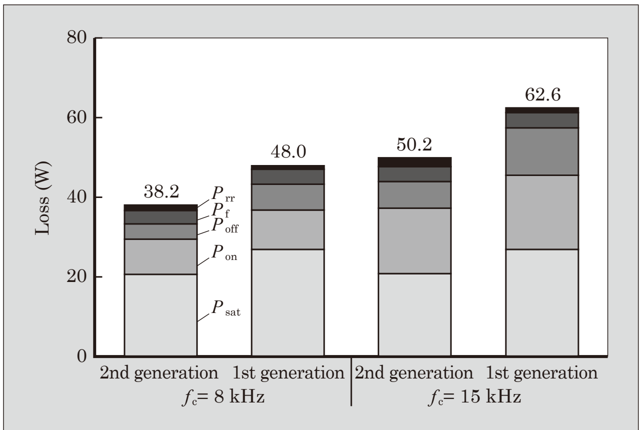

Fig. 8 Trial calculation results of loss for 0.75-kW industrial inverter

The loss is also lower in the rated and maximum load ranges by more than 20%, which allows the device to be applied to an air conditioner of 7.2 kW, a one level higher capacity, with the 15-A rating.

Figure 10 shows the results of evaluating the temperature rise during PWM operation, which corresponds to steady-state operation of an air conditioner. The 2nd-generation small IPM has achieved an approximately 25% increase of the allowable output current from the 1st generation by increasing the guaranteed operating temperature ($T_{j(ope)}$ = 150 °C) along with loss reduction and reduction of temperature rise.

In addition, temperature rise in the soldering part on the circuit board has also been reduced by about 20 °C compared with the 1st-generation module. With the 2nd-generation module, the output current has

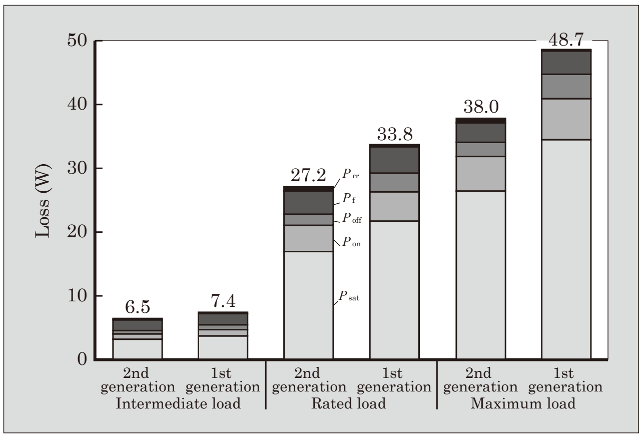

Fig. 9 Trial calculation results of loss for 5.6-kW air conditioner

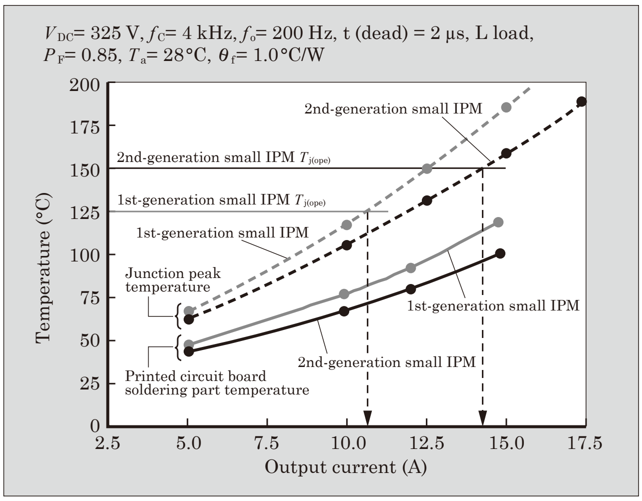

Fig. 10 Evaluation results of temperature rise during PWM operation

been increased and reliability when it is mounted on the circuit board is improved, which provides improved degree of design freedom as well.

Figure 11 shows the result of evaluating the conduction noise with the module mounted on a 5.6-kW output air conditioner. In the frequency region from 500 kHz to 30 MHz, the tolerance of the quasi peak (QP) value of the CISPR14-1 standard is satisfied and, together with the loss reduction described above, low noise has also been confirmed.

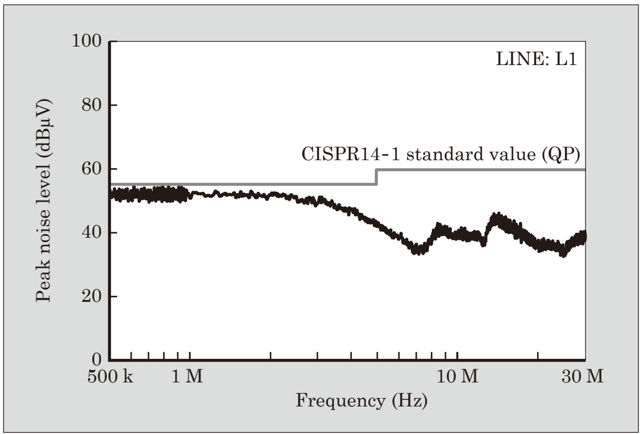

Fig. 11 Evaluation results of conduction noise for 5.6-kW air conditioner

5. Postscript

This paper has described the features of the 2nd-generation small IPM. By applying the optimized IGBT device based on the 7th-generation IGBT technology, the 2nd-generation small IPM achieves a significant loss reduction and contributes towards energy saving of various systems. In addition, the allowable current has been increased by raising the guaranteed operating temperature and reducing the thermal resistance. In this way, the product helps to expand the applicable motor capacity and improves the degree of design freedom of systems.

We intend to continue developing products capable of realizing energy saving in overall systems with an even wider product lineup.

References

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(2) T. Heinzel. et al. “The New High Power Density 7th Generation IGBT module for Compact Power Conversion Systems”. Proceeding of PCIM Europe 2015, p.359-367.

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