IPM for Automotive Air Conditioning Systems

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ABSTRACT

Fuji Electric has developed an IPM that integrates a 3-phase inverter circuit, a control circuit and a protection circuit for the electric compressor in automotive air conditioning systems. This IPM is based on “X Series” IGBT chip and FWD chip technologies and utilizes low-loss and low-noise devices especially suited for automotive use. By applying this 600-V/30-A product to control the electric compressor in automotive air conditioning systems, it suppressed surge voltage during turn-off and reduced total loss by about 2% during operation at a carrier frequency of 20 kHz.

1. Introduction

In recent years, CO_2 emission regulations have been strengthened mainly in Europe, China, North America and Japan in order to mitigate global climate change due to increased greenhouse gas emissions. As a result, the market size for electric vehicles, such as hybrid vehicles, plug-in hybrid vehicles, and electric vehicles, has been rapidly expanding.

Unlike conventional internal combustion engine vehicles, the air-conditioning systems mounted in electric vehicles use the electric motor to drive the compressor. Although the air-conditioning volume is smaller than that of residential air conditioners, the heat insulation performance of vehicles is not high. Therefore, it is necessary to utilize a compressor that operates at several kilowatts. In order to secure the power needed, the system needs to be connected directly to the same high-voltage battery as the driving power supply for the drive motor, while also making sure to achieve the required amount of energy savings and safety.

From such a background, we have recently developed an intelligent power module (IPM) for automotive air conditioning systems based on 2nd-generation small-IPM technology[(1),(2)]. The IPM integrates a 3-phase inverter bridge circuit, control circuit and protection circuit into a single package to achieve the energy savings, safety, high output frequency, high carrier frequency drive and low noise required of the electric compressors for the air conditioners of electric vehicles. In this paper, we will introduce the features of this IPM.

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2. Product Overview

The electric compressor system is responsible for driving a brushless DC motor using the same 3-phase inverter circuit as residential air conditioners. However, since the compressor and inverter circuits are mounted at a location closer to the passengers in the vehicle, they need to achieve low noise and vibration. Therefore, power devices are being required to support a high output frequency and carrier frequency drive.

At the same time, suppression of noise interference to automotive devices such as the vehicle control computer and radio also needs to be achieved.

In 2015, Fuji Electric commercialized a 2nd-generation small-IPM for residential air conditioners and industrial inverters. The IPM utilizes “X Series” insulated gate bipolar transistor (IGBT) chip technology[(3)] to achieve low loss and energy savings.

Figure 1 shows the external appearance of the IPM for automotive air conditioning systems developed on the basis of these technologies, and Table 1 provides the main characteristics. The product dimensions are W43.0 × D26.0 × H4.0 mm. It utilizes a compact package to contribute to electric compressor miniaturiza-

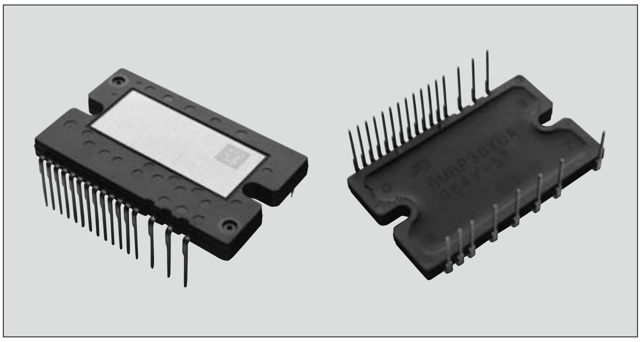

Fig.1 IPM for automotive air conditioning systems

Table 1 Main characteristics

Item	Characteristic values
V_{CE}	600 V
I_C	30 A
$V_{CE(sat)}$	1.27 V (typ)
V_F	2.00 V (typ)
T_{vj}	150°C
V_{iso}	2.5 $kV_{(rms)}$ AC*
Protection function	Over current protection, Under voltage protection, Temperature sensor output function, Fault signal output function

* When the creeping distance and clearance between the lead pin and heat sink is 2.5 mm or more

tion. The product is rated 600 V/30 A and has various built-in protection functions.

Figure 2 shows the internal equivalent circuit for the recently developed IPM for automotive air conditioning systems, and Fig. 3 shows the cross-sectional structure of the package. The IPM for automotive air conditioning systems utilizes an optimized low-loss IGBT and low-noise free wheeling diode (FWD) based on X Series IGBT chip technology and FWD chip technology. A 3-phase inverter bridge circuit consisting of these devices has been mounted on an insulated aluminum substrate. A single low-voltage integrated circuit (LVIC) is utilized as the control circuit for driving the low-side IGBT of the 3-phase inverter bridge circuit, and three high-voltage integrated circuits (HVIC) chips are utilized as the control circuit for driving the high-side IGBT. Each of these chips is mounted on the lead frame.

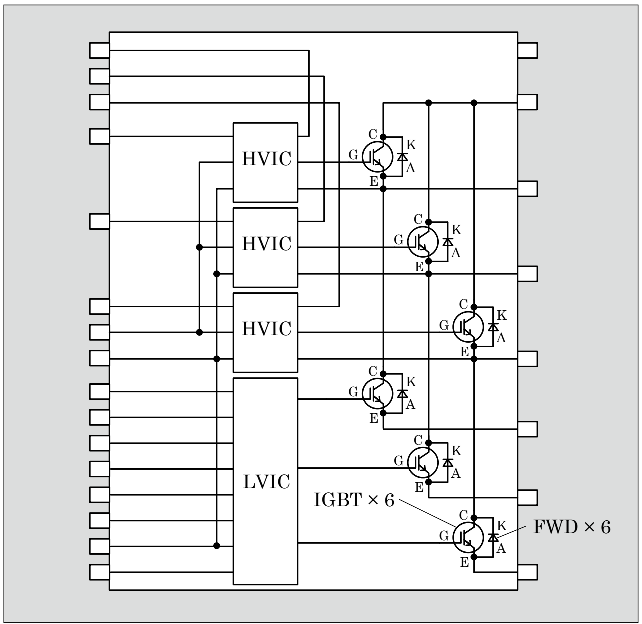

Fig.2 Internal equivalent circuit

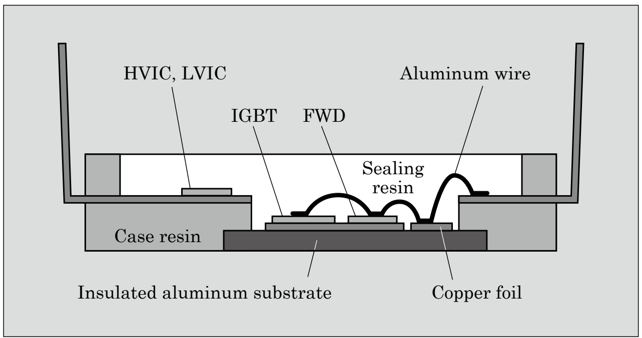

Fig.3 Package cross-sectional structure

3. Product Design

3.1 Device design

In order to improve energy savings, this product has been designed to dissipate less power and reduce the switching noise that causes interference noise.

(1) IGBT loss and noise reduction

Figure 4 shows the cross-sectional structure of the X Series IGBT chip installed on the IPM for automotive air conditioning systems.

X Series IGBT chip technology combines wafer thinning and smaller design rules based on the field-stop structure.

The chip was designed to reduce conduction loss by optimizing the specific resistance and thickness of the n^- drift layer, as well as the placement of the surface n^+ cell pitch and concentration of the channel p layer in order to ensure that it was a device suitable for IPM for automotive air conditioning systems.

In addition, it also minimizes increases in turn-off loss and reduces $-dI_c/dt$ by optimizing the back surface structure of the IGBT to support high carrier frequency driving and suppress surge voltage at turn-off.

(2) Reduction of forward voltage V_F at FWD turn-on

The surge voltage at turn-off consists of the superimposing of not only the voltage generated by the IGBT $-dI_c/dt$, but also the forward voltage V_F of the diode transiently generated at FWD turn-on.

V_F of the FWDs of this IPM at turn-on is reduced by approximately 67% by optimizing the diode structure compared with that of the standard X Series FWDs, while maintaining the blocking voltage of 600V, as shown in Fig. 5.

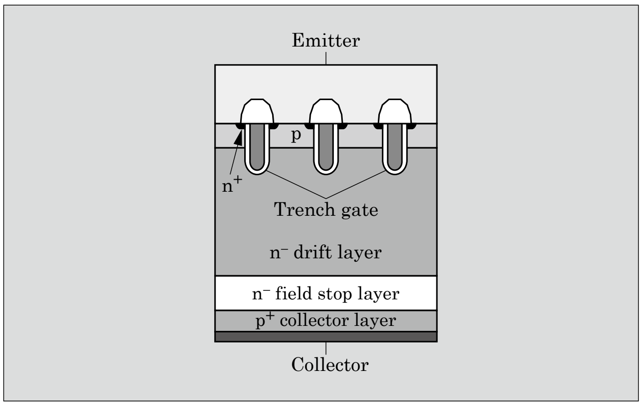

Fig.4 "X-Series" IGBT chip cross-sectional structure

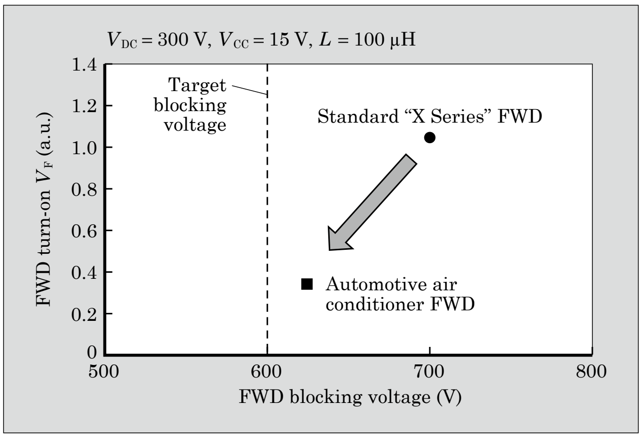

Fig.5 V_F and blocking voltage characteristic at FWD turn-on

(3) Effect of lower loss and noise

Figure 6 shows the switching waveform at turn-off when $-dI_c/dt$ at IGBT turn-off and V_F at FWD turn-on are reduced. As shown in Fig. 7, the turn-off loss is suppressed to an almost similar level and surge voltage is reduced by approximately 53%. As shown in Fig. 8, total loss is the same or lower than previous levels.

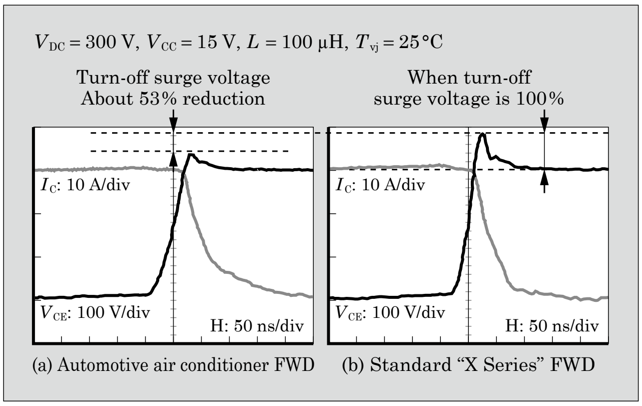

Fig.6 Switching waveform at turn-off

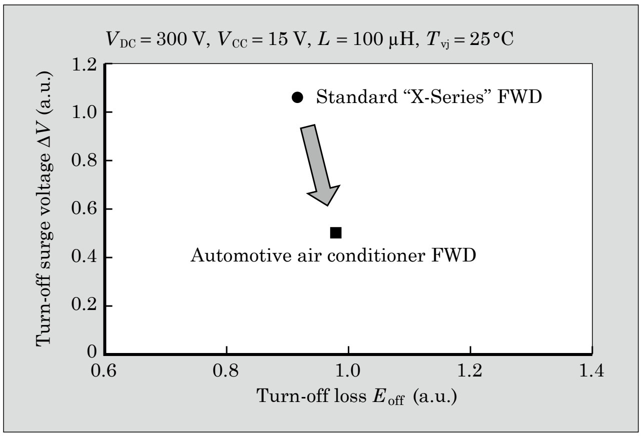

Fig.7 Turn-off surge voltage and turn-off loss trade-off characteristic

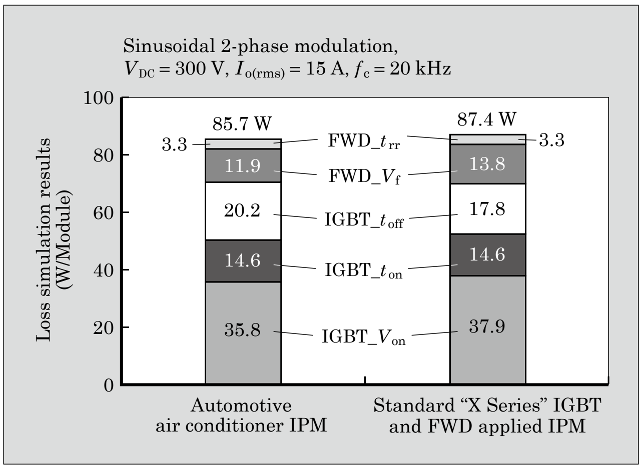

Fig.8 Loss simulation results

3.2 Control circuit design

The input pins of the IPM for automotive air conditioning systems can receive 3.3-V and 5-V input signals, because they receive signals from a microcomputer called an electronic control unit (ECU) that controls the inverter circuit of the electric compressor for the automotive air conditioning system.

The high-side drive circuit consists of HVICs. Since this eliminates the need for an external power supply for the drive circuit, the 3-phase inverter circuit can be configured with only a small number of external components.

Protection functions built into the IPM for automotive air conditioning systems include overcurrent protection, under voltage protection, temperature sensor output function and fault signal output function.

With regard to temperature sensor output function, the LVIC's built-in temperature sensor can measure temperatures ranging from approximately 0°C to 150°C with high accuracy. Information on the case temperature of the IPM is output for control, it can be used for safety design.

3.3 Package design

(1) Reliability design for automotive applications

Since automotive electric air conditioning systems use the same high voltage batteries as a power supply that drive motors use, they are required to have the same high reliability as the drive inverter.

The package of the IPM for automotive air conditioning systems uses the same insulated aluminum substrate as our previously developed DC-DC converter module for automotive applications, thereby ensuring the isolation voltage and a low thermal resistance.

Table 2 shows the reliability test results of the main items. By optimizing the package design, it has achieved compliance with AEC-Q101 or its equivalent, the reliability standard for automotive electronic components.

(2) Support for automatic mounting

Table 2 Reliability test results (main items)

Test item	Test conditions	Guaranteed value	Result
Temperature cycle	Low temperature side = −40 °C High temperature side = +125 °C 30 minutes at each temperature (Reference standard: JESD 22 A-104)	1,000 cycles	77/77 OK

In order to support the automatic mounting of the IPM for automotive air conditioning systems, we changed the screw fastened component in the resin part of the case from an oblong hole shape to a notched structure (see Fig. 1). When making this change, the case and notched structure needed to be designed so as to ensure sufficient strength.

4. Application Effects of the Product

Figure 8 shows the results of testing the effect of using a 600-V/30-A product for controlling the electric compressor of an automotive air conditioning system. Surge voltage at turn-off was suppressed and total loss was reduced by approximately 2% compared with the standard X Series IGBT and FWD when driving at a carrier frequency of 20 kHz.

5. Postscript

In this paper, we introduced our IPM for automotive air conditioning systems.

This product is capable of improving energy savings in the inverter circuits of electric compressors by utilizing optimized design principles for automotive applications based on “X Series” IGBT and FWD chip technology. Furthermore, the quality demanded of automotive applications is ensured through the use of an optimally designed package.

In the future, we plan to continue developing products that help improve the energy saving performance of electrical equipment systems and reduce noise and ensure quality for automotive components as products suitable for not only automotive air conditioning systems, but also for the electrical equipment drive modules of electric vehicles (xEV).

References

(1) Araki, R. et al. 2nd-Generation Small IPM. FUJI ELECTRIC REVIEW. 2015, vol.61, no.4, p.242-246.

(2) Ohashi, H. et al. “The 2nd Generation Small Intelligent Power Module for General-purpose Inverter”. proc. 2016 PCIM Asia.

(3) Kawabata, J. et al. 7th-Generation “X Series” IGBT Module. FUJI ELECTRIC REVIEW. 2015, vol.61, no.4, p.237-241.

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