

2nd-Generation Small IPM Series

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ABSTRACT

Fuji Electric has recently added products with current ratings of 20 and 30 A to our 2nd-generation small IPM series to meet the needs of motor drive devices. Applying the 7th-generation IGBT chip technology as a base and optimizing the lifetime control and drift layer thickness of the FWD, we have significantly reduced the temperature rise while lowering noise and loss. We ran a temperature rise simulation of a package air conditioner that has a standard cooling capacity of 14 kW at the maximum load, which are expected to be actual conditions. It showed 11°C lower temperatures than the 1st-generation small IPM. It can therefore expand the allowable output current of the devices.

1. Introduction

In recent years, there has been increasing demand for energy-saving in motor drive devices to prevent global warming caused by the increase in greenhouse gases. Among these devices, packaged air conditioners (for commercial use), which consume a relatively large amount of energy, were designated as being subject to the “Top Runner Program” in FY2015, thus requiring a significant improvement in their annual performance factor (APF, indicates year-round efficiency in energy consumption) and higher efficiency in the intermediate load region. Furthermore, compactness and space savings are also being required, as well as improvement of loss under high loads in order to expand the range of operating temperatures in outdoor units.

In addition, there has also been increased demand for high efficiency in industrial-use general-purpose inverters and servo systems, whose housings and frames have been increasingly downsized, in order to correspond to the expansion in output capacity.

Fuji Electric has met these demands with the development of its compact, low-loss and low-noise small-intelligent power module (IPM⁽¹⁾), which integrates a 3-phase inverter bridge circuit, control circuit and protective circuit, for application in inverter type small-motor drives.

Recently, in order to further improve the energy-saving performance of motor drive devices in packaged air conditioners, general-purpose inverters and servo systems, we have introduced a 20 and 30 A rated current 2nd-generation small IPM⁽²⁾ equipped with 7th-generation insulated gate bipolar transistor (IGBT) chip technology⁽³⁾ into our product line-up.

2. Product Overview

Figure 1 shows the external appearance of the recently developed 2nd-generation small IPM, and Table 1 shows the product line-up and the main characteristics.

The products employ the same compact package as the currently mass produced 10- and 15-A products, the external dimensions of which is 43 × 26 × 3.7 (mm), and the modules contribute to the miniaturization of inverter circuit.

Similar to the 10- and 15-A products, 2 different types of temperature protection functions are available: one type with only analog temperature output, and the other type with analog temperature output and overheat protection.

The recently developed 20- and 30-A products can be used for a variety of devices such as compressor driving units of packaged air conditioners with capacity of 8 to 14 kW, general-purpose inverters with an output of 1.0 to 2.2 kW, and servo amplifiers with 0.4

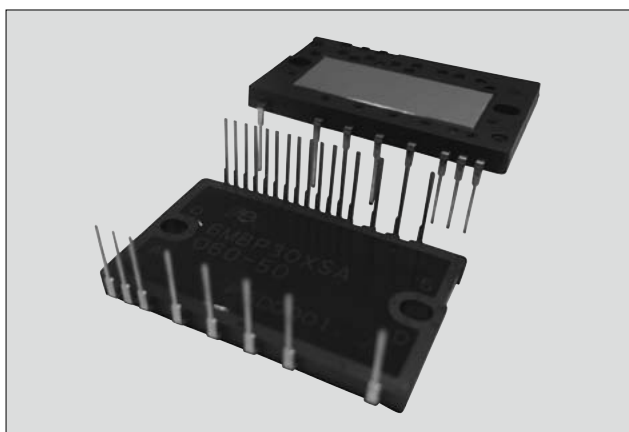


Fig.1 2nd-generation small IPM

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Table 1 Product lineup and main characteristics

Type name	V_{CE}	I_C	$V_{CE}^{(sat)}$ (typ.)	V_F (typ.)	Temperature protection function
6MBP20XSA060-50	600 V	20 A	1.45 V	1.50 V	Analog temperature output
6MBP20XSC060-50					Analog temperature output + overheat protection
6MBP30XSA060-50		30 A	1.45 V	1.55 V	Analog temperature output
6MBP30XSC060-50					Analog temperature output + overheat protection

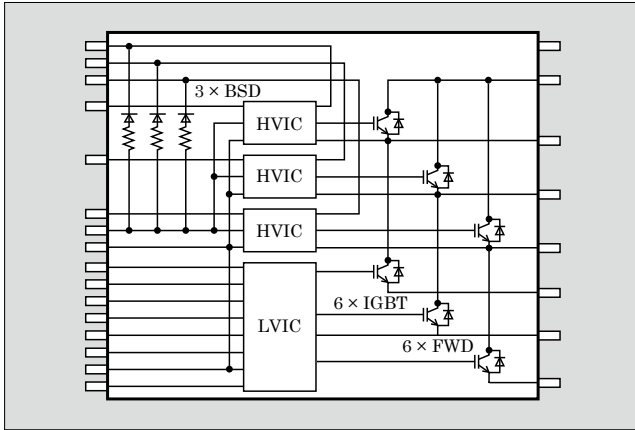


Fig.2 Internal equivalent circuit

to 1.0-kW output.

Figure 2 shows the internal equivalent circuit. Similar to the 10- and 15-A products, the modules mount a 3-phase inverter bridge circuit composed of low-loss IGBTs utilizing 7th-generation IGBT chip technology and high-speed freewheeling diodes (FWD) mounted on an aluminum insulating substrate. A single low voltage integrated circuit (LVIC) for operating the low-side IGBTs of the 3-phase inverter bridge circuit and 3 high voltage integrated circuits (HVIC) for operating the high-side IGBTs are directly mounted on the lead frame.

In addition, by including the boot-strap-diodes (BSD) with built-in current limiting resistor, the power supply of the high-side drive circuit can be configured with only a small number of components.

Compared with the 1st-generation small IPM, the 2nd-generation small IPM has expanded the permissible output current of the inverter circuit and improved design flexibility by utilizing low-loss devices and expanding the operation-guaranteed temperature T_j (ope) from 125 °C to 150 °C.

3. Design

3.1 Device design

The expansion of the current capacity brought concern about an increase in the noise generated during switching operation. Thus, as a countermeasure, a low-noise design for improving the trade-off between switching loss and noise has been adopted.

(1) Reduction of conduction loss

We have optimized the gate threshold voltage and

the cell pitch layout of the trench gate of the IGBT based on the 7th-generation IGBT chip technology to reduce conduction loss.

Figure 3 shows the IGBT on-state voltage and collector current characteristics. Compared with the 1st-generation small IPM, the on-state voltage of the 30-A rated products is reduced by approximately 8% at the rated current, and approximately 7% at the low-current region, which greatly influences APF, that is, an important factor for air conditioning applications.

(2) Reduction of turn-off loss

Though increasing the switching speed is one of the measures to reduce turn-off loss, it may increase generated noise due to the sharp rise in dv/dt .

For the 2nd-generation small IPM, we have suppressed dv/dt to the same level as that of the 1st-generation small IPM while successfully suppressing the tail current generated during IGBT turn-off, and improved the trade-off between noise and turn-off loss. In order to suppress the tail current, we have optimized the thickness of the IGBT drift layer and the amount of carriers injected from the rear-surface pn junction and field stop layer.

Figure 4 shows the trade-off characteristics between turn-off loss and the voltage noise level based on the frequency analysis of the turn-off waveforms of the IGBT. The module has the same voltage noise level as the 1st-generation small IPM at the rated current of 30 A while also significantly reducing the turn-off loss by approximately 50%.

(3) Reduction of turn-on loss

Figure 5 shows the switching waveforms during re-

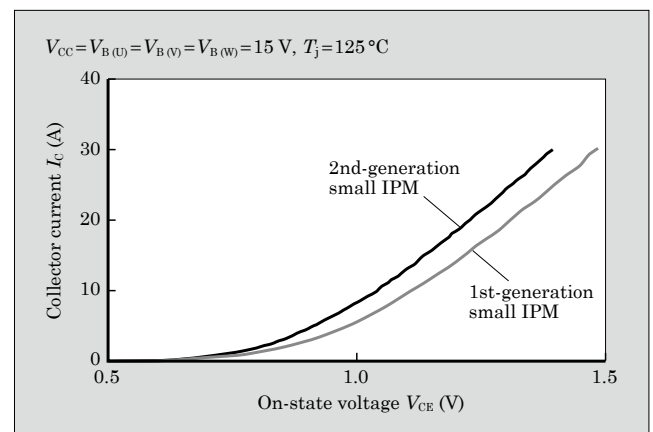


Fig.3 IGBT on-state voltage and collector current characteristics

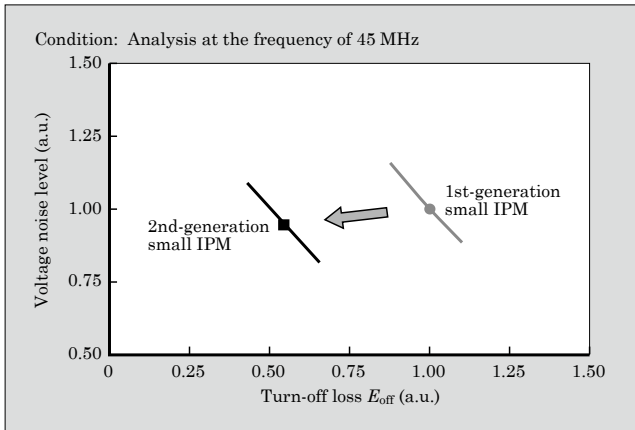


Fig.4 Trade-off characteristics between IGBT voltage noise level and turn-off loss

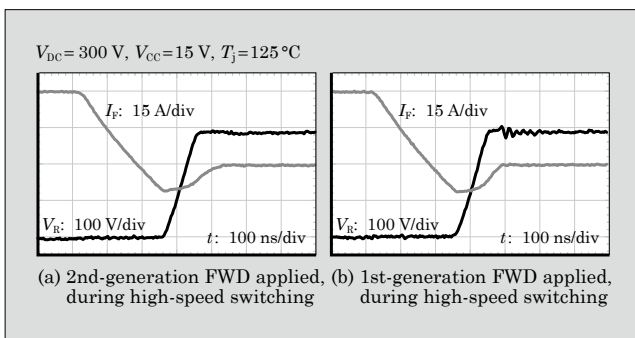


Fig.5 Switching waveforms during recovery

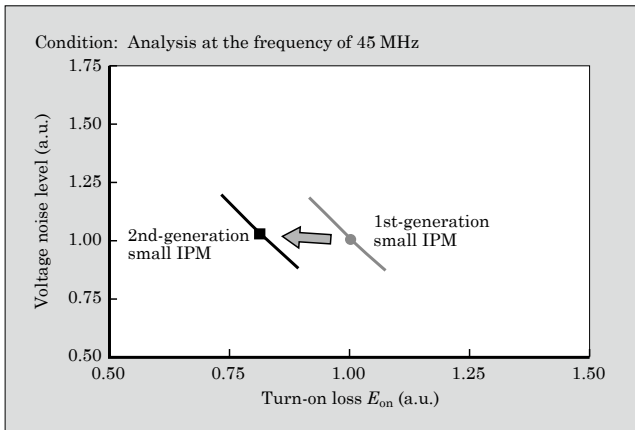


Fig.6 Trade-off characteristics between FWD voltage noise level and turn-on loss

covery. If we use the FWD of the 1st-generation small IPM and increase the switching speed to reduce the switching loss, there would be a large increase in generated noise due to the increase in surge voltage. In order to simultaneously suppress generated noise and reduce turn-on loss, it is necessary to reduce the recovery current and suppress the surge voltage.

Figure 6 shows the trade-off characteristic between the turn-on loss and voltage noise level during FWD recovery. We have optimized the recently developed product in terms of the lifetime control and thickness

of the FWD drift layer and reduced the turn-on loss by approximately 20% compared with the 1st-generation small IPM at a rated current of 30 A while maintaining the same voltage noise level.

3.2 Control circuit design

The LVIC overheat protection function needs to ensure that the LVIC junction temperature $T_{j(LVIC)}$ does not exceed the operation-guaranteed value while also making sure that the protection function is not engaged due to temperature rise during continuous operation of the IGBT.

The upper limit of the operating temperature range of the LVIC junction temperature $T_{j(LVIC)}$ in the 2nd-generation small IPM is 150°C as shown in Fig. 7. Furthermore, when the temperature of IGBT reaches the upper limit of the IGBT operation-guaranteed temperature $T_{j(ope)}$ of 150°C, the temperature of the adjacent LVIC will rise to 136°C, and as a result, it is necessary to ensure that overheat protection is not engaged at this temperature or below. Therefore, we have suppressed the variation in detection of LVIC junction temperature and established an overheat protection range of 143°C ±7°C. On the other hand, 135°C is specified for the upper limit of the LVIC junction operating temperature range $T_{j(LVIC)}$ in the 1st-generation small IPM. Furthermore, when the junction operating temperature reaches the upper limit of the IGBT operation-guaranteed temperature $T_{j(ope)}$ of 125°C, the temperature of the adjacent LVIC will rise to 115°C. As a result, the overheat protection range was set at 125°C ±10°C. Therefore, the 2nd-generation small IPM not only expands the operating temperature range of the LVIC, but by increasing the precision of the reference power circuit inside the IC to ensure that the detection range is ±7°C or lower. Consequently, we have expanded the IGBT operation-guaranteed temperature $T_{j(ope)}$ to 25°C above that of the 1st-generation small IPM, or 150°C, which allows the expansion of permissible output current. In addition, by maintaining compatibility with the 1st-generation

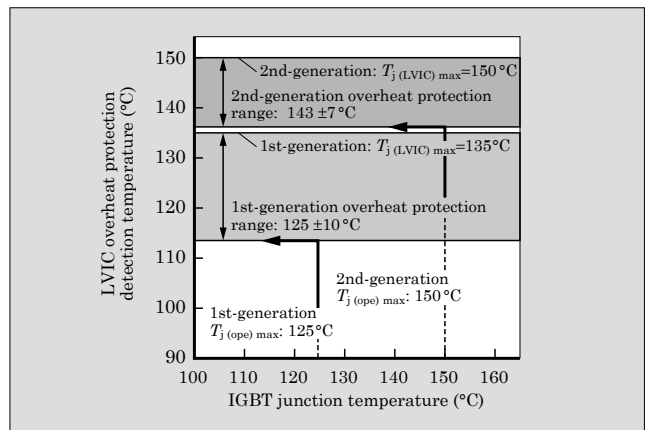


Fig.7 LVIC overheat protection detection temperature and IGBT junction temperature

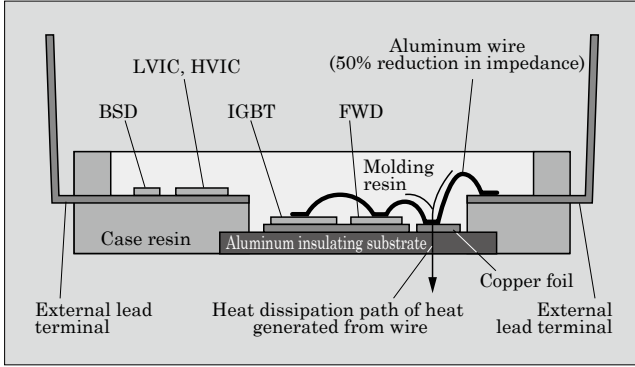


Fig.8 Package's cross section structure

ation small IPM in regard to the characteristic value of the analog temperature output function built into the LVIC, we can support our customers to standardize protection circuit designs.

3.3 Package design

The 2nd-generation small IPM has the package structure that the package is directly soldered to the printed circuit board of equipment, such as packaged air conditioners and general-purpose inverters. As the output current of the printed circuit board increases, the temperature of the external lead terminal rises, and as a result, the temperature at the soldered parts also rises. On the other hand, in order to ensure the reliability of the soldered parts, the temperature at the soldered parts during operation must be kept within 90°C to 100°C or below. To achieve this, the output current had to be restricted.

Figure 8 shows the cross section structure of the package. Similar to previous 10- and 15-A products, the recently developed modules have the structure that conducts Joule heat generated by the wire to the aluminum insulating substrate. In addition, according to the expansion of the current capacity, they use 50% lower impedance wires than that of the conventional products to suppress temperature rise at the external lead terminal, thus reducing the Joule heat.

4. Application Effect

This section provides the application effect of the 600-V/30-A products used for packaged air conditioners and servo amplifiers.

Figure 9 shows the simulation results of temperature rise at maximum load for a standard 14 kW packaged air conditioner.

A temperature rise at maximum load is lower for the 2nd-generation small IPM than the 1st-generation small IPM by 11°C because of the loss-reduction effect previously mentioned. In addition, compared with the 1st-generation small IPM, the 2nd-generation small IPM has expanded the operation-guaranteed temperature $T_{j(ope)}$ from 125°C to 150°C, thus enabling operation at the operation-guaranteed temperature $T_{j(ope)}$ or

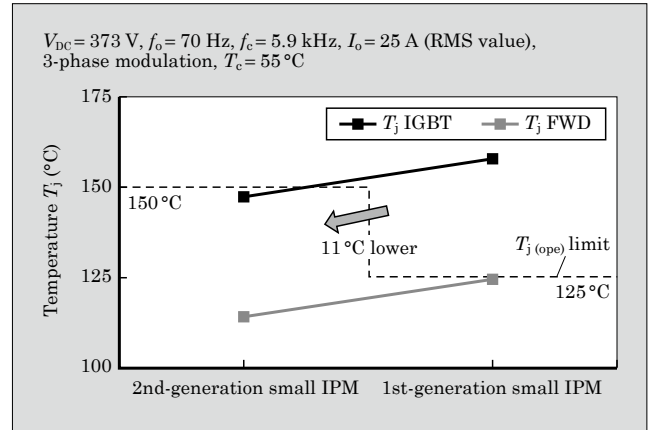


Fig.9 Results of temperature rise simulation during maximum load in package air conditioner

below. As a result, it can be used for the air conditioners, the output current capacity of which require larger rating IPM than the 1st-generation small IPM.

Figure 10 shows the results of the temperature rise simulation during acceleration/deceleration in a servo amplifier with an output of 1.0 kW, and Figure 11 shows the results of the temperature rise simulation during the motor lock operation.

The temperature rise during acceleration and deceleration and the motor lock operation for the 2nd-generation small IPM is nearly identical to that of the 1st-generation small IPM. On the other hand, the 2nd-generation small IPM has an extended operation-guaranteed temperature $T_{j(ope)}$ of 150°C, which is higher than that of the 1st-generation small IPM, 125°C, thus enabling operation at the operation-guaranteed temperature $T_{j(ope)}$ or below. As a result, it can be used for the servo amplifiers, the output current capacity of which require larger rating IPM than the 1st-generation small IPM.

Figure 12 shows the measured results of the temperature at the soldered parts of the printed circuit board for a package air conditioner mounted with the 600-V/30-A product operating in an ordinary state

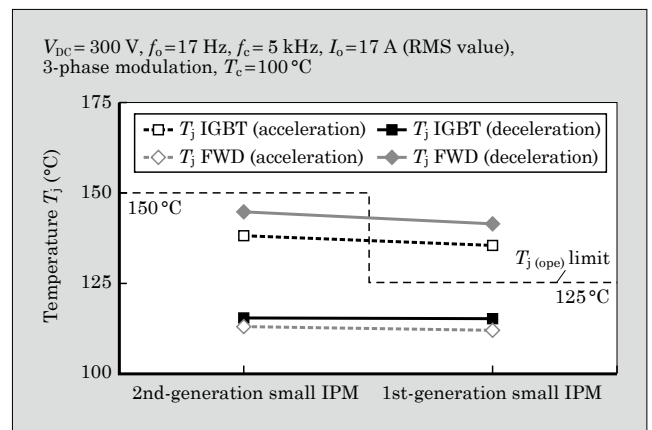


Fig.10 Results of temperature rise simulation during acceleration/deceleration in servo amplifier

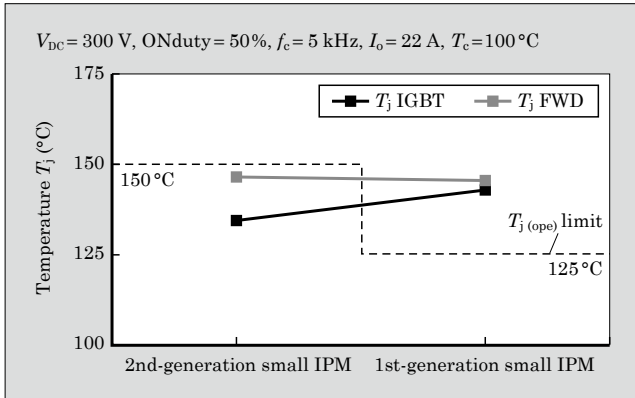


Fig.11 Results of temperature rise simulation during motor lock operation in servo amplifier

under pulse width modulation (PWM). The soldered parts of the 2nd-generation small IPM is lower than that of the 1st-generation small IPM by approximately 14°C because of the lower loss of the device and the suppression effect in the temperature rise of the exter-

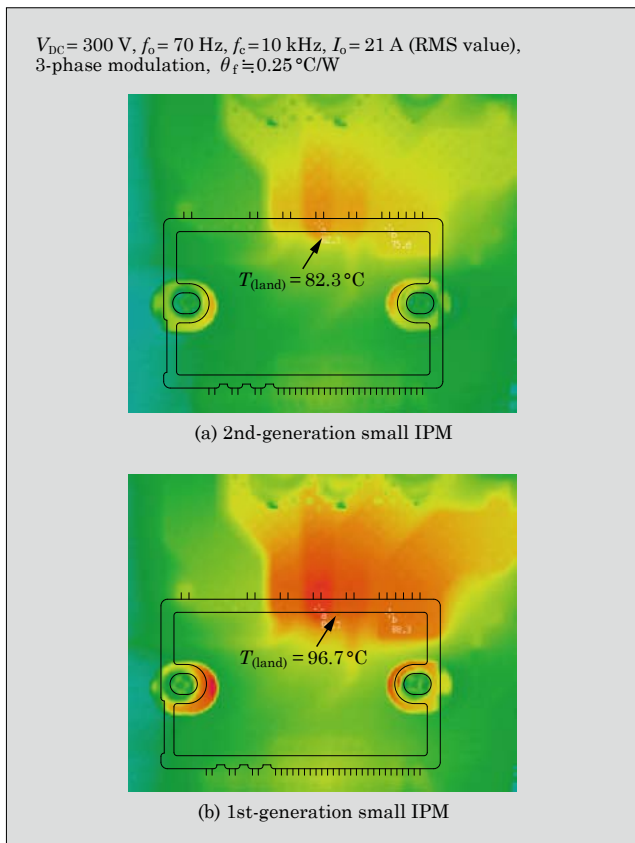


Fig.12 Results of measuring temperature of soldered components during PWM operation in package air conditioner

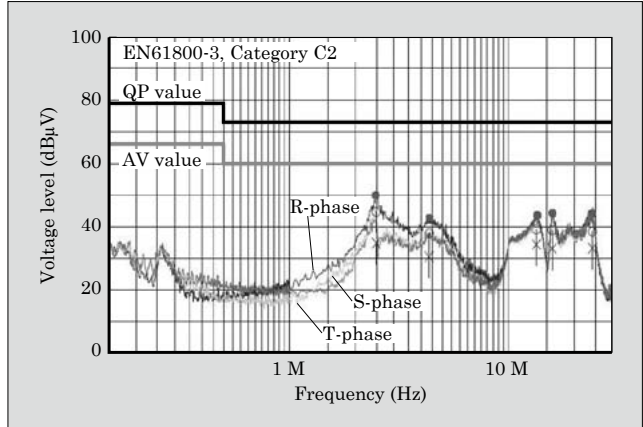


Fig.13 Results of conduction noise evaluation in servo amplifier

nal lead terminals of the package. Consequently, the ability to suppress the temperature rise in the soldered parts has enabled the expansion of permissible output current by approximately 19%.

Figure 13 shows the evaluation results regarding conduction noise when applying in a servo amplifier with an output of 0.75 kW. The module is compliant with the limit value (QP) prescribed in Category C2 of EN61800-3 and achieved the desired low-noise characteristic in combination with the previously described temperature-rise suppression effect.

5. Postscript

In this paper, we described the 20- and 30-A products which expanded the current capacity of the 2nd-generation small IPM series. Similar to the currently being mass produced 10- and 15-A products, these products employ optimized low-noise, low-loss devices based on the 7th-generation IGBT chip technology, and they can achieve energy savings in inverter controlled motor drive devices.

In the future, we plan to continue developing products that contribute to improving the energy-saving performance of motor drive devices.

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