1. Introduction
There is a growing demand for power semiconductors applied to motor drive inverters for electric vehicles (EVs) and hybrid electric vehicles (HEVs). Based on the results of the development and mass production of automotive power semiconductors, which require very high reliability and functionality, Mitsubishi Electric has developed the J-Series Intelligent Power Modules (IPMs) and J-Series Transfer-Molded Power Modules (T-PMs) for multipurpose automotive applications.

2. J-Series IPM
The J-Series IPMs are designed for automotive applications, providing both high functionality and reliability required for automotive power modules. The J-Series line-up offers six models: Type-A (600 V/300 A, 1,200 V/150 A), Type-B (600 V/600 A, 1,200 V/300 A), and Type+B (600 V/800 A, 1,200 V/500 A) (Fig. 1). Each module is configured in an all-in-one package consisting of six sets of IGBTs and diodes, IGBT drive circuit, protection circuit, isolation circuit, and input-output processing circuit. The 600 V/800 A and 1,200 V/500 A models are equipped with a built-in power supply circuit, as well. These IPMs enable customers to enhance the functionality and reliability of their automotive inverter system and to improve the development efficiency.

![Fig. 1 J-Series IPM](image1)

Figure 2 shows the internal structure of the J-Series IPM Type-A. Lead-free solder is used to comply with the End of Life Vehicles (ELV) Directive. For ease of attachment by the user, the base plate is designed flat and made of a copper-based material with good thermal conductivity. In addition, a shielding plate is inserted to shield against radiation noise from the IGBT to the IPM control board and the inverter. For connection to the customer’s upper system, an automotive connector has been employed considering ease of assembly and vibration resistance. Furthermore, the analytical result of the structure under vibration has been considered in the design to improve the vibration resistance of the control board and entire IPM structure.

![Fig. 2 Type-A structure](image2)

In addition to the drive circuit and protection circuit, the J-Series IPM has also integrated the functions of IPM RDY, chip temperature monitoring, and DC-Link voltage monitoring (option at order). Protection functions are provided for over-current, over-temperature, and control-power-supply under-voltage. The over-current protection, in particular, employs a quick-response on-chip current sensor to ensure that the IGBT safely operates below its saturation current (Fig. 3).

![Fig. 3 Short circuit protection curve (example)](image3)
The IPM RDY function allows input and output of the IPM ready signal. When an error occurs, the customer's system can directly shut down the IPM by sending an "inoperable" signal. The chip temperature monitoring function provides an analog output (Tout) to indicate the surface temperature at the chip center. Compared to the temperature monitoring with a thermistor on the base plate, it gives a higher accuracy and linear output in the normal to high temperature range, which is advantageous for IPM protection, adjustment of inverter load and other controls. The DC-Link voltage monitoring function provides an analog output (VDCout) to indicate the voltage across the IPM's main P and N terminals, which helps to provide high functionality such as the battery management function. The primary and secondary circuits are isolated using mass production proven photo-couplers. The Tout and VDCout signals are also isolated by the photo-couplers so that they can be safely utilized in the customer's system. Regarding electromagnetic compatibility (EMC), high noise immunity has been achieved by employing the current drive method for the input signals and optimizing the circuit board pattern.

Excellent reliability has been achieved, demonstrating thermal and power cycle resistance, respectively, 5–10 times and 1.5–2 times that of general industrial products. In addition, reliability of the control board has been verified specifically for automotive applications such as through high-temperature and high-humidity bias tests.

The J-Series offers all-in-one IPMs that allow high functionality and safety design of the inverters for automotive applications.

3. J-Series T-PM

The J-Series T-PMs are high capacity power modules fabricated in a transfer-molded package developed for automotive applications. The line-up offers three models, 300 A/600 V, 600 A/600 V and 300 A/1,200 V, in the same package size (Fig. 4). For user's T-PM evaluation purposes, evaluation kits are also available. The J-Series T-PMs are completely lead-free products with a low environmental burden.

Figure 5 shows a schematic structure of the J-Series T-PM. The rear surfaces of the power chips (IGBT and diode) are soldered to the heat spreader. The front surfaces are directly soldered to the inner lead, which is extended from the main terminal, to form the main circuit wiring structure referred to as a direct lead bonding (DLB) structure. Compared to the conventional main circuit structure using aluminum wire bonding, the DLB structure has achieved: (1) lower wiring resistance, (2) lower self inductance, and (3) longer power cycle life (to be described later). Thermally Conductive electrically Isolated Layer (TCIL) has been inserted beneath the bottom surface of the heat spreader, and the sheet material was selected so that it has heat conductivity higher than that of the mold resin. The thermal resistance has been reduced with this configuration, where the heat generated by the chips is spread by the heat spreader, and then passes through the TCIL. In addition, the transient thermal resistance has also been reduced by directly connecting the chips to the heat spreader having a large heat capacity. These internal structures are encapsulated by the mold resin to ensure the mechanical structure, strength, insulation, and environmental durability for the module.

The thermal and power cycle performance of the J-Series T-PMs is more than 30 times that of Mitsubishi Electric's industrial case-type modules. The lifetime in thermal cycling test is determined by the thermal strain in the solder beneath the chips. The J-Series T-PM module has reduced the strain and hence achieved long lifetime by employing the resin encapsulation structure and making the coefficient of thermal expansion of the mold resin close to that of the heat spreader (Fig. 6). The lifetime in power cycling test has also been improved by employing the DLB structure for the internal main circuit wiring, which has eliminated the peeling problem of aluminum wires experienced with the conventional case-type modules.
4. Conclusion

We have developed the “J-Series” IPMs and T-PMs, automotive power devices for HEV and EV applications. The “J-Series” is expected to meet the various needs of customers and contribute to an environmentally conscious society. We will continue to enhance the product line-up, striving for higher functionality, higher reliability and lighter weight.