# High Current IPS for Vehicle

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**ABSTRACT**

Fuji Electric has developed a high current intelligent power switch (IPS) for controlling high output motors of vehicles. The power MOSFET using a trench structure and the control IC are built into a chip-on-chip structure, thereby realizing low on-state resistance (maximum of 5 mΩ) with a compact package. To achieve high reliability, protective functions such as overcurrent/overheat detection and low voltage detection have been provided. In addition, a package with good heat dissipation properties has been adopted, and a configuration that offers well-balanced energy distribution in parallel connections is provided. This package can thereby cope with temperature rises caused by an increased current due to a low on-state resistance.



## 1. Introduction

In the field of automotive electrical components, reduction of exhaust gas, safe vehicle control and advanced combustion technology are used as means to improve fuel efficiency under the keywords of “environment,” “safety” and “energy saving.” This has accompanied increasing complexity of electronic systems, which is causing electronic control units (ECUs) to grow in size. An ECU is installed near the engine or other location in order to create space for mounting and the temperature of the installation environment is becoming higher every year. For that reason, a size reduction of ECUs and an improvement of their reliability in a high-temperature environment have been strongly desired and hence there are increasing applications of smart power devices, which integrate power semiconductors and their peripheral protective circuits, state detection and output circuits, drive circuits, etc.

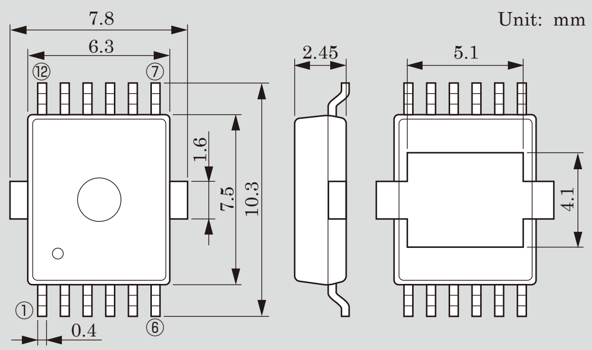
To meet these demands, Fuji Electric has developed a high-current intelligent power switch (IPS) for vehicles.

## 2. Features and Functions

### 2.1 Features

Figure 1 shows a full view of the high-current IPS for vehicles. This product is designed especially for use in applications including control of inductive loads such as motors and replacement of mechanical relays with semiconductors. The main features are as follows.

(1) Low on-resistance
(2) Compact package with high-heat-dissipation
(3) Various protective functions




| Terminal no. | Terminal name | Terminal no. | Terminal name |
|---|---|---|---|
| ① to ④ | OUT | ⑨ | NC |
| ⑤ | NC | ⑩ | IN |
| ⑥ | VCC | ⑪, ⑫ | VCC |
| ⑦, ⑧ | GND | | |

Fig.1 Full view of high-current IPS for vehicles

The functions are provided to suppress temperature rise in battery reverse connection.

(4) High inductive load energy withstand capability

This prevents any breakage caused by motor stalling and allows energy to be distributed in parallel connections.

### 2.2 Basic performances

In order to achieve the low on-resistance of 5 mΩ ($T_c$=25 °C, $I_{out}$=40 A) and the small package (see Fig. 1) as development target, we used the 3rd-generation trench gate metal oxide semiconductor field-effect transistor (MOSFET) technology, which has a proven track record in devices for automotive electrical components, to develop a low-$R_{on}$·A power MOSFET chip. The 4th-

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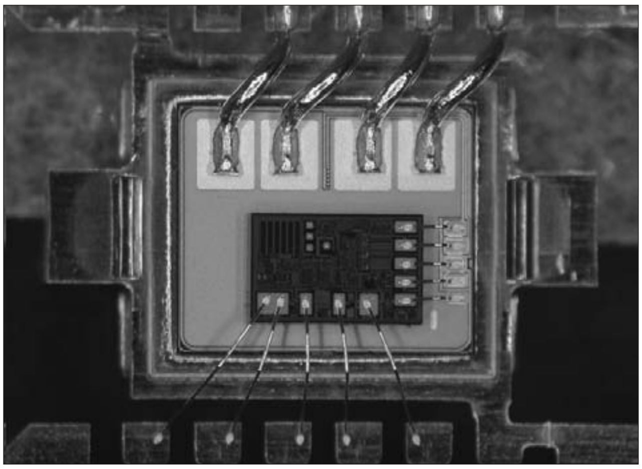

Fig.2 Chip of high-current IPS for vehicles

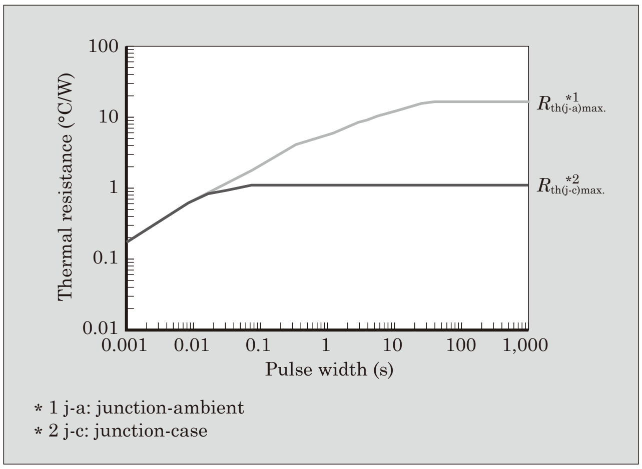


Fig.3 Example of thermal resistance characteristics in board-mounted condition

Table 1 Specifications of high-current IPS for vehicles

| Item | | | Rating | |
|---|---|---|---|---|
| Rating | Operating power voltage | | 6.0 to 16.0 V | |
| | Output current | | 80 A | |
| | Allowable power loss | | 114 W (at 25 °C) | |
| | Junction temperature | | 150 °C | |
| **Item** | | | **Condition** | **Standard** |
| Characteristic | Static power supply current | $I_{cc(off)}$ | $V_{cc}$=16 V, OUT-GND short circuit, 110 °C | 50 μA (max.) |
| | On-resistance | $R_{on}$ | 25 °C, 40 A, 16 V | 5.0 mΩ (max.) |
| | | | 150 °C, 40 A, 16 V | 9.0 mΩ (max.) |
| | | | 25 °C, 40 A, 6 V | 7.5 mΩ (max.) |
| | | | 150 °C, 40 A, 6 V | 14.5 mΩ (max.) |
| | Switching time | $t_{d(on)}$ | $V_{cc}$=16 V, $R$=0.25 Ω | 0.2 ms (max.) |
| | | $t_r$ | | 0.8 ms (max.) |
| | | $t_{d(off)}$ | | 0.8 ms (max.) |
| | | $t_f$ | | 0.7 ms (max.) |
| | Steady-state thermal resistance | $R_{th(j-c)}$ | – | 1.1 °C/W |
| Protective function | Inductive load clamping capacity | | $I_{out}$ ≤ 80 A, $V_{cc}$=16 V, $T_c$=150 °C | 800 mJ (min.) |
| | Overcurrent detection function (load short-circuit protection) | | $V_{cc}$=16 V, load short circuit | 100 A (min.) |
| | Overheat detection function | | Detection 155 °C (min.), Recovery 150 °C (min.) | |
| | Low voltage detection function | | Detection 4.0 V (min.), Recovery 6.0 V (max.) | |
| **Item** | | | **Condition** | **Result** |
| Reliability | Temperature cycle test | | −55 °C to +150 °C | > 1,000 cycles |
| | Pressure cooker test | | 130 °C, 85% | > 300 hours |
| | High temperature high humidity bias test | | 85 °C, 85%, 16 V | > 1,000 hours |
| | Power cycle test | | $\Delta T_j$=100 °C | > 20,000 cycles |

generation IPS device and process technology has been applied to the circuit portion to realize a circuit chip size reduction with the protective functions described in Section 2.3 added. The chip-on-chip (COC) assembly technology (see Fig. 2) has been used to arrange the circuit chips on top of the power MOSFET chip, allowing to energize a high current with a compact package[1]. The specifications of this product are shown in Table 1, and the thermal resistance $R_{th}$ characteristics observed as it is mounted on board are shown in Fig. 3.

### 2.3 Protective functions

This product has been made to be suitable for applications including control of inductive loads such as motors and replacement of mechanical relays with semiconductors. In order to realize high reliability and minimize redundant design in the ECU, the following protective functions are provided.

(1) Load short-circuit protection function (overcurrent and overheat detection functions)

This product has been designed to realize a high response to power MOSFET temperature rises and prevent power MOSFET breakage even in a load short-circuit condition. This is achieved by mounting the current and temperature sensors on the power MOSFET chip to detect load short-circuit conditions. The load short-circuit protection provides dual protection against overcurrent and overheat; and for overcurrent protection, 2 types, namely limiting and latch types, have been made available to allow the user to select according to the application.

(2) Low voltage detection function

This product takes into account direct connection of VCC terminals to the battery. Sufficient energizing capability is ensured even if the battery voltage drops to a certain level in midwinter. In addition, a low voltage detection function has been provided, which turns off the output completely when the voltage has dropped below that level.

(3) Battery reverse polarity protection function

Reverse connection of the battery with low load impedance causes a high current to flow in the body diode of the power MOSFET. The heat generated in this condition raises the temperature of the chip, which

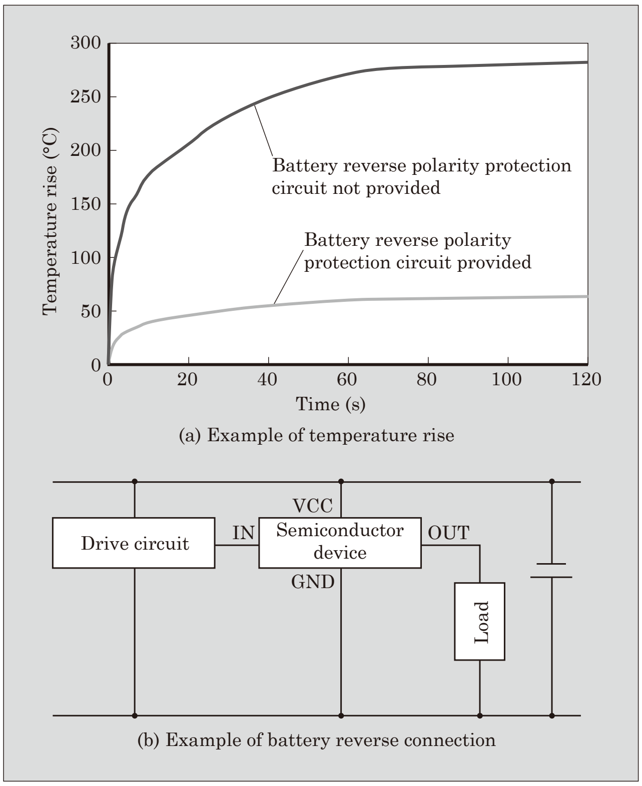


Fig.4 Example of circuit and temperature variation in battery reverse connection

may create a risk of melting the solder on the terminals (see Fig. 4).

This product has adopted a battery reverse polarity protection circuit, which actively turns on the power MOSFET when the battery has been connected in reverse. Energization of the power MOSFET leads to a significantly lower loss than running current in the body diode, thus preventing breakage of the power MOSFET due to the loss generated by battery reverse connection.

(4) Inductive load clamping capacity

One issue with power MOSFETs that drive inductive loads such as motors is to process the excessive inductive load energy generated when a high current is cut off due to motor stalling. To that end, a design is required that does not cause element breakage even if high inductive load energy is applied when the motor is stalled.

With this product, the inductive load clamping capacity per element has been increased. In addition, as a redundant design for driving inductive loads in parallel connections, the inductive load energy is distributed among all elements connected in parallel for improving avalanche capability.

### 2.4 Power package

This product has adopted a power package with good heat dissipation properties (PSOP-12) to deal with the current increase caused by the lowered on-resistance. In addition, the COC assembly technology has been used to place the power MOSFET that runs a high current at the center of the chip mounting area to achieve a good heat dissipation balance. Furthermore, in order to confirm the spread of solder in the cooling part on the back side from the front side at the time of mounting, the package has a structure with the frame projecting from both sides (see Fig. 5).

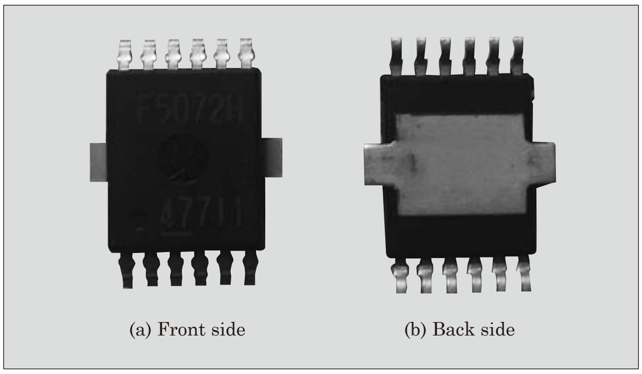


Fig.5 Structure of power package (PSOP-12)

## 3. Applied Technology

### 3.1 3rd-generation trench gate MOSFET technology

To realize the on-resistance of 5 mΩ ($T_c$=25 °C, $I_{out}$=40 A) as development target, the 3rd-generation trench gate MOSFET technology has been applied to the power MOSFET. Of this technology, the microfabrication technology has been incorporated to improve the cell density by 40% or more, and the process and wafer specifications have also been optimized to achieve a significant reduction of the on-resistance and a higher current (see Fig. 6). In addition, to ensure reliability of the thinned trench gate, the shape, process and screening conditions have been optimized.

### 3.2 IC circuit miniaturization and function enhancement technology

In order to realize miniaturization and function enhancement of IC circuits, this product applies the 4th-generation IPS device and process technology[(2)]. This

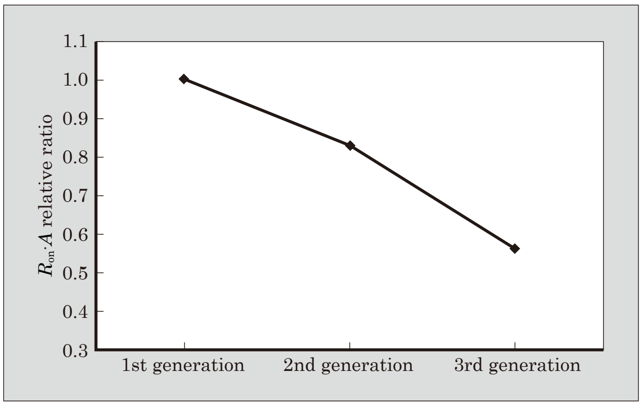


Fig.6 $R_{on}$·$A$ of trench MOSFETs of respective generations technology has not only achieved smaller design rules of the element devices themselves but also successfully reduced the area of wiring for connection between element devices by applying multi-metal layer technology.

As devices for IC circuits, 60 V CMOS devices are provided in addition to 5 V CMOS devices for circuits. The 60 V devices are of the high side type and have the back side of the chip directly connected to power supply terminals, which satisfies the requirements for resistance to various surges such as a load dump surge that may be generated in 12 V batteries for vehicles.

As the gate oxide film, 2 types are available, namely thin film and thick film. A MOSFET with a thin gate oxide film has a low threshold voltage and can be used for a circuit that requires driving when the battery voltage has dropped. Meanwhile, a MOSFET with a thick gate oxide film has a high threshold voltage, and the breakdown voltage of the gate can be made high. This, for example, makes it suitable for a circuit that requires gate driving at a high voltage such as the one directly driven by the external power supply voltage VCC.

Polysilicon-applied devices, which eliminate the possibility of parasitic operation, and trimming devices have also been made available.

By combining these element devices, higher integration and accuracy than those of the conventional products can be achieved to meet market demands.

## 4. Postscript

This paper has described the features and functions of the high-current IPS for vehicles and technologies applied to the product. Fuji Electric will start supplying the high-current IPS to vehicles by the end of FY2014. Concerning semiconductors for high-current applications, we intend to continue working on miniaturization and function enhancement by further reducing the on-resistance using power MOSFETs and evolving smaller design rules of ICs to serve the market needs in the future.

### References


(1) Imai, M. el al. “Development of Power Chip-On-Chip (COC) Package Technology”. Mate 2008. p.323-326.

(2) Toyoda, Y. et al. “60 V-Class Power IC Technology for an Intelligent Power Switch with an Integrated Trench MOSFET” ISPSD 2013. p.147-150.

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