# Intelligent Power MOSFETs

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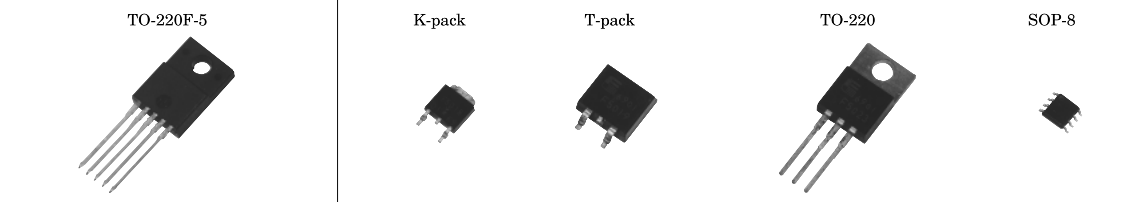
## 1. Introduction

The development of automotive electronics is accelerating year after year. Currently, the percentage of cars equipped with anti-skid brake systems (ABS) and air bags, which were very highly priced several years ago, is rising at an increasing rate. Manufacturers' and users' concern for safe and environment-friendly automobiles has grown so high that the inclusion and superiority of these electronics systems is regarded as adding value to automobiles, and has become a sales point.

At present, technical developments in advanced vehicle control technology to ensure safety and advanced combustion technology to reduce exhaust gas and improve fuel consumption are progressing year by year. It is expected that in the future, as promoted by the Ministry of Transportation, the technical trends represented by advanced safety vehicles (ASV: advanced safety vehicles integrally controlled by electronics technologies for safety prevention and accident avoidance during normal driving and safety in case of collision) and "automated travel" to minimize manual operation will create a greater incentive to develop and increase the scale of car control electronics, and automobile manufacturers will desire to reduce the size and cost of these increasing systems.

Intelligent power MOSFETs (metal-oxide-semicon-

Table 1 List of intelligent power MOSFET series

| Type | High-side | | | | Low-side | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IPS | | | | | Intelligent power MOSFET | | | | | | | | | | | |
| Model | F5001H | F5016H | F5017H | F5021H | F5015L | F5020 | F5022 | F5018 | F5019 | F5023 | F5027 | F5029 | F5030 | F5031 | F5032 | F5028 | F5033 |
| Package | TO-220F-5 | | | | | K-pack | | | T-pack | TO-220 | T-pack | TO-220 | T-pack | K-pack | | T-pack | SOP-8 |
| |  | | | | | | | | | | | | | | | | |
| Rated voltage ∗1 | 60V | 60V | 60V | 50V | 45V | 40V | 60V | 40V | 40V | | 40V | 40V | | 40V | 40V | 40V | 40V |
| Rated current ∗2 | 3A | 3A | 6A | 3A | 10A | 3A | 3A | 8A | 12A | | 52A | 18A | | 14A | 6A | 28A | 1A |
| ON-state resistance (max.) | 0.16Ω | 0.16Ω | 0.16Ω | 0.16Ω | 0.07Ω | 0.4Ω | 0.5Ω | 0.14Ω | 0.14Ω | | 0.02Ω | 0.07Ω | | 0.07Ω | 0.2Ω | 0.04Ω | 0.6Ω |
| Functions: Overcurrent protection | ○ | | | | | ○ | | | | | | | | | | | |
| Functions: Overtemperature protection | ○ | | | | | ○ | | | | | | | | | | | |
| Functions: Overvoltage protection | ○ | | | | | × | | | | | | | | | | | |
| Functions: Open load detection | ○ | | | | | × | | | | | | | | | | | |
| Functions: Status output | ○ | | | | × | | | | | | | | | | | | |
| Functions: Induced voltage clamping | ○ (Reference – 11V) | | | | ○ (Reference – 42V) | Drain-gate zener diode | | | | | | | | | | | |

∗1: Limited by drain-gate zener diode, ∗2: Limited by overcurrent and short-circuit protection ductor field-effect transistors), which integrate control, protection, self-diagnosis circuits and a power device on a chip, can be used to integrate electronic parts at a lower price than that of conventional automobile manufacturers. MOSFETs are becoming regarded as devices capable of constructing highly reliable systems.

To meet the above requirements for automotive electronics, Fuji Electric has developed two lines of intelligent power MOSFETs, an IPS (intelligent power switch) series and an intelligent power MOSFET series that is described below.

## 2. Overview of the Products

### 2.1 Overview of the product series

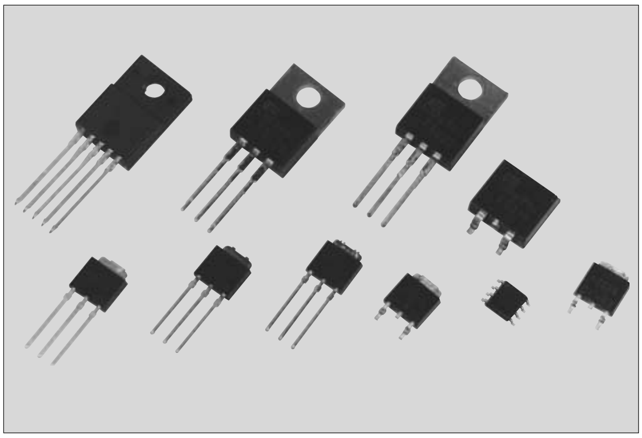
Table 1 shows a list of Fuji Electric's intelligent power MOSFET series.

The IPS series incorporates a power device, drive and protection circuits, and a function to communicate with the CPU on a single chip and is enclosed in a TO-220F-5 (5 terminals) package.

A new device among this series, the F5021H, retains the basic performance of the former series that performed well in solenoid valve, lamp, and motor drive applications, while expanding the range of use and reducing the chip size by lowering the on-state resistance of the output stage MOSFET. The F5021H has the following special features.

(1) Low on-state resistance achieved by shrinking the power MOSFET to half the former size.
(2) Improved induced voltage clamping capacity for high-speed switching of inductive loads (lowering clamping voltage from ref. – 11V to ref. – 42V achieves times higher speed than the former devices)
(3) Reduced EMI (electro-magnetic interference) noise by reducing control circuit standby current (to half the former value, when IPS is on)
(4) Improved current conducting capacity at high temperatures by making the over current detection value dependent on lower temperature (half the former value)

Fig.1 Appearance of intelligent power MOSFETs



Although the intelligent power MOSFET series incorporates a power device and an overvoltage protective function similar to the IPS series, it has a discrete 3-terminal package construction similar to unit MOSFETs and bipolar transistors. The intelligent power MOSFET series is easy to handle and enables the configuration of reliable systems. This series is well suited for automated mounting as surface-mount type packages are widely available. Figure 1 shows the external appearance of packages in this series.

This intelligent power MOSFET series is described below.

### 2.2 Main characteristics

The F5020 device is selected as a typical device from among the low-side intelligent power MOSFET series. Tables 2 and 3 list its main characteristics, and Figs. 2 and 3 show the block diagram and chip appearance, respectively. Main features are listed below.

(1) Short-circuit protection with built-in short-circuit and overtemperature detection functions
(2) Over voltage protection and high-speed switching for inductive loads with a built-in dynamic clamping circuit
(3) Can withstand a high ESD (electro-static discharge) voltage (withstands 25kV between drain and source, and 10kV between gate and source at

Table 2 F5020 absolute maximum ratings (at $T_c = 25°C$)

| Item | Symbol | Rating | Unit |
|---|---|---|---|
| Drain-source voltage | $V_{DSS}$ | 40 | V |
| Gate-source voltage | $V_{GSS}$ | – 0.3 to +7.0 DC | V |
| Drain current | $I_D$ | 3 | A |
| Max. power dissipation | $P_D$ | 10 | W |
| Operating junction temperature | $T_j$ | 150 | °C |
| Storage temperature | $T_{stg}$ | – 55 to +150 | °C |

Table 3 F5020 electrical characteristics (at $T_c = 25°C$)

| Item | Symbol | Condition | Standard Min. | Standard Max. | Unit |
|---|---|---|---|---|---|
| Drain-source voltage | $V_{DSS}$ | $I_D$=1mA $V_{GS}$=0V | 40 | 60 | V |
| Gate-source threshold voltage | $V_{GS(th)}$ | $I_D$=1mA $V_{DS}$=13V | 1.0 | 2.8 | V |
| Gate-source leakage current | $I_{GSS(n)}^{*1}$ | $V_{GS}$=5V | | 500 | μA |
| | $I_{GSS(un)}^{*2}$ | | | 800 | |
| Drain-source ON-state resistance | $R_{DS(on)}$ | $I_D$=1A $V_{GS}$=5V | | 0.4 | Ω |
| Overtemperature protection | $T_{trip}$ | $V_{GS}$=5V | 150 | | °C |
| Overcurrent detection | $I_{OC}$ | $V_{GS}$=5V | 5 | | A |
| Dynamic clamping energy dissipation | $E_{CL}$ | $T_j$=150°C | 50 | | mj |
| Thermal resistance | $R_{th(j-c)}$ | | | 12.5 | °C/W |

*1: during normal operation, *2: when protection is activated

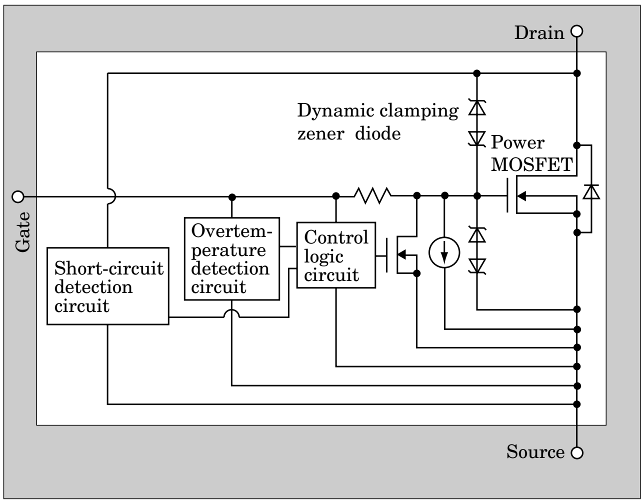


Fig.2 F5020 block diagram

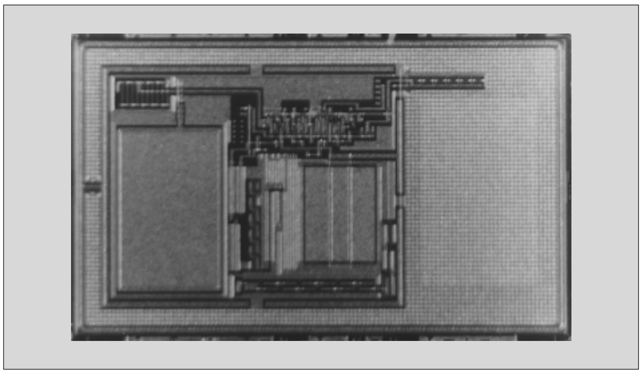


Fig.3 F5020 chip

150pF, 150Ω)

(4) Can directly drive a microcomputer possible with 5V gate drive
(5) Built-in function turns off output when the gate terminal is open to fail-safe the system as a whole
(6) Control unit and power MOSFET unit integrated on a single chip
(7) Low price achieved by utilizing self-isolation ND (N-channel diffusion)-MOS process
(8) Smaller size and automated mounting by utilizing SMD (surface mounted device) packages

## 3. Intelligent Power MOSFET Series Product Line

As shown in Table 1, this intelligent power MOSFET series is for current ratings of 1 to 50A.

The 1A device is being developed for the control of the many types of 1.4W class warning lamps mounted in instrument panels, or for the lower-than-1A class of solenoid valves used for fuel injection control. Utilizing an SOP-8 package for this sort of intelligent device, the chips are packaged together in two channels to make the system small and flat.

The 50A device is used for solid-state relays in automotive electronic systems or for the control of body

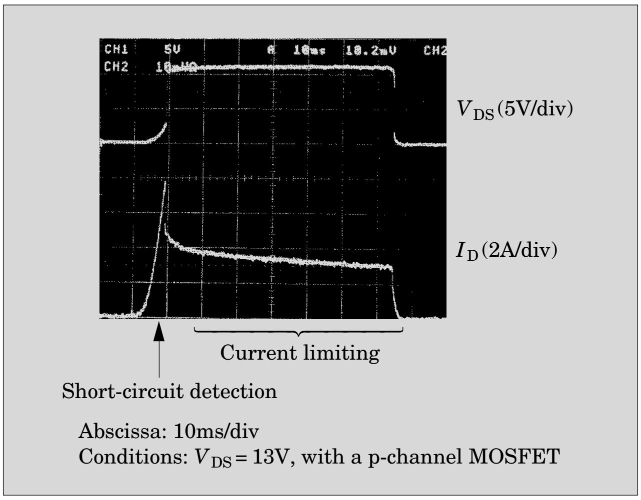


Fig.4 F5020 waveforms from short-circuiting to current limiting

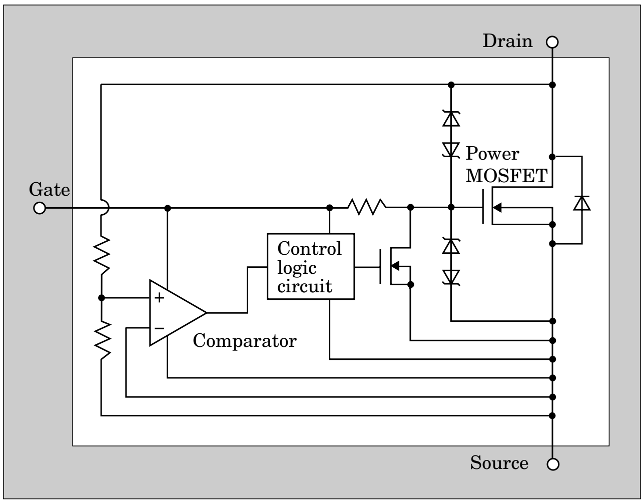


Fig.5 F5020 short circuit detection circuit

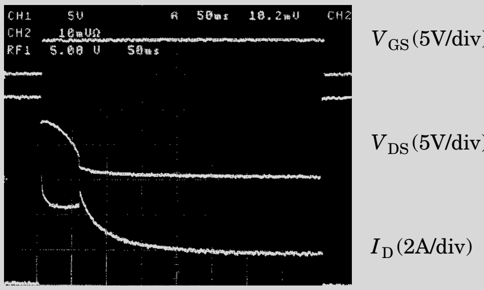
systems, large capacity motors and lamps.

## 4. Characteristics

### 4.1 Short-circuit protection

The intelligent power MOSFET incorporates a short-circuit detection circuit to protect the system, load, and device itself even when a drop in load impedance causes an excessive current. As an example, Fig. 4 shows the waveforms of F5020 operation from short-circuiting to current limiting. To obtain the waveforms, using a test circuit with a p-channel MOSFET as the load, the drain current was gradually increased from 0A, and F5020 operation from short-circuit detection to current limiting was observed. Figure 5 shows the short-circuit detection circuit. The circuit monitors the ON-state voltage of the MOSFET output stage, and the comparator for monitoring drain-source voltage detects drain currents exceeding the short-circuit detection value and lowers the gate voltage of the MOSFET output stage to a fixed value to limit output current and prevent the device from short-

Fig.6 Waveforms of F5020 driving a lamp load




Abscissa: 50ms/div
Conditions: $V_{DS}$ = 13V, with a 21W lamp load

Fig.7 Different time required for protection due to different temperature sensor positions

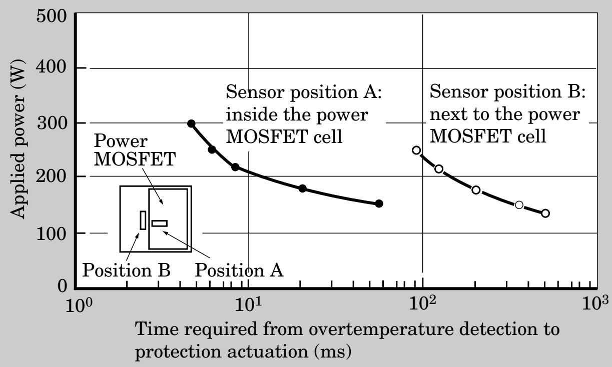
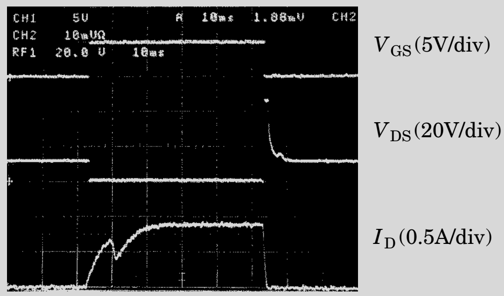



Fig.8 Waveforms of F5020 operating a solenoid valve




Abscissa: 10ms/div
Conditions: $V_{DS}$ = 13V, with a solenoid valve of 10mH, 10Ω

circuit breakdown. This detection circuit does not use a conventional current detection system that requires a large-scale circuit configuration such as a current sensing device and an operational amplifier, but instead uses an ON-state voltage monitoring system to reduce the size of the current detection circuit.

The intelligent power MOSFET uses this current-limiting system for short-circuit protection for the following reasons.

Figure 6 shows the F5020 waveform (40V/3A/0.4Ω) driving a lamp load (21W/12V). Since the load is 21W, a rush current of approximately 20A flows when started in cold temperature. When selecting a device to drive a lamp with such a rating, a device rated at 10A or more is generally selected in consideration of the above-mentioned rush current. The F5020 rated at 3A is judged to have insufficient current capacity. However, in the region where the applied lamp load causes a rush current to flow, even when the current is more than the rated current, the F5020 does not completely shut down output current, but actively maintains the ON state by limiting the output current at a given value. With this short-circuit protection system that limits output current, the F5020 is able to perform basic switching of the 21W lamp without concern over the rush current. Therefore, if this intelligent power MOSFET is selected for a system design that requires lamp load drive, devices can be selected based not on rush current but on steady current, thereby enabling systems to be designed with devices rated at about half the conventional current.

Further, the current-limiting system is a short-circuit protection system suitable not only for lamp loads but also for systems such as ABS that requires a constant current supply even when an excessive current flows due to a drop in load impedance.

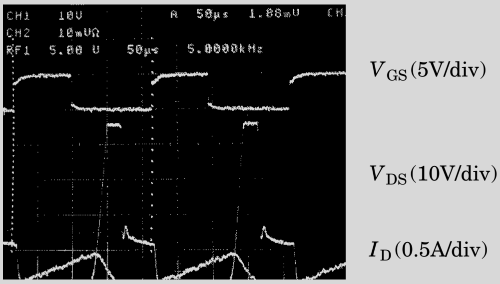
The problem with applying latch type systems, completely shutting down the output current upon detecting a short circuit to the short-circuit protection system, is that self-reset by the device itself is impossible. This means that the output current will be completely shut down even by an instantaneous short circuit such as loose short-circuiting. A means for reset is necessary in order to restart the device. This complication is disadvantageous to the system design.

The intelligent power MOSFET, which incorporates a built-in short-circuit protection circuit based on the above design concept, does not require short-circuit protection circuit components formerly added by the system side to protect the power device from external DC short-circuiting. This enables smaller size and lower cost systems.

### 4.2 Overtemperature protection

If the above-mentioned current-limiting operation continues after a short circuit is detected due to an external DC short circuit, excessive heat will be generated in the intelligent power MOSFET. The response time of a circuit is critical to avoid damage due to overheating of a protection circuit. To reduce the response time when overheating is detected, the intelligent power MOSFET has a temperature sensor on the power MOSFET cell as shown in Figs. 7 and 3. The response time is approximately ten times quicker than that of the case of where a temperature sensor is

Fig.9 Waveforms of F5020 performing PWM on an inductive load




Abscissa: 50µs/div
Conditions: $V_{DS}$ = 13V, $L$ = 3mH, $R$ = 5Ω

located next to the power MOSFET cell. The result is highly coordinated protection.

### 4.3 Dynamic clamping function

In devices used in automobile systems where there are many inductive loads such as solenoid valves, there is a problem of dealing with the $LI^2/2$ energy accumulated in the inductive load.

The intelligent power MOSFET incorporates a dynamic clamping circuit which clamps at approximately 50V the surge voltage generated by turning off the inductive load and absorbs energy accumulated in the inductive load by the power MOSFET itself. Additional external components, such as a snubber circuit, are not necessary. Figure 8 shows actual waveforms of the F5020 operating a solenoid valve. It can be clearly seen that the F5020 rapidly processes energy accumulated in the inductive load when the dynamic clamping voltage is set to a value near the power MOSFET withstand voltage of 60V. Figure 9 shows waveforms of the F5020 performing PWM (pulse width modulation) on an inductive load. It can be seen that at a frequency of approximately 5kHz, the F5020 is able to perform adequate PWM control without adding components to the system.

### 4.4 Electrostatic breakdown withstand voltage

The intelligent power MOSFET has been designed with careful consideration to withstand surge voltages in the severe surge environment of automobiles. In the intelligent power MOSFET, low-voltage devices for control circuits and a vertical power MOSFET for output are integrated into a single chip using a self-isolation process that requires less steps than junction or dielectric isolation. It is said the self-isolation process is superior in cost performance, but inferior in surge withstand voltage to the dielectric isolation process because of the greater number of parasitic devices. However, in the intelligent power MOSFET, the construction of the zener diode for surge suppression and the layout of the control circuit's internal resistance have been optimized such that the electrostatic breakdown voltage of the F5020 (for example) (at 150pF, 150Ω) is greater than 25kV between the drain and source, and more than 10kV between the gate and source. Moreover, its AC latch-up voltage (at 150pF, 150Ω, $V_{DS}$ = 13V, $V_{DS}$ = 0V and 5V) is greater than 25kV between both the drain and source and between the gate and source.

## 5. Conclusion

This paper has presented an overview and described characteristics of the line of intelligent power MOSFETs, focusing on the low-side intelligent power MOSFET series. Products have been introduced on the assumption that they will be used in the automotive electronics field, however the intelligent power MOSFET series can be used in various applications because of its high versatility.

In the future, Fuji Electric will expand the line of intelligent power MOSFETs to meet the needs of diversified applications and establish technologies to further improve performance.