“F5202H” 5th-Generation Intelligent Power Switch for Automotive Applications

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ABSTRACT

As automobiles have been electrified, their electronic control system is becoming large scale. This has increased the demand for miniaturization and high heat dissipation in system components. It is against this backdrop that Fuji Electric developed the “F5202H” 5th-generation intelligent power switch (IPS) for automotive applications. The F5202H comes with an operational amplifier that detects load currents with high accuracy, and utilizes a device with a triple-diffused structure. As a result, it has reduced a chip size by 45%, while maintaining the same basic functions. Furthermore, it uses a small outline non-leaded (SON) package to contribute to miniaturization and high heat dissipation, reducing the package size by 45% and thermal resistance by 80%. The F5202H is designed to be used in the harsh environments of engine compartments and complies with the AEC-Q100 reliability standard for automotive electronic components.

1. Introduction

Today, as automobiles become more electrified, automated, and IT-oriented, electronic control systems are becoming increasingly large-scale. As a result, there is a constant demand to achieve size reduction and higher heat dissipation for individual components in the system. In addition, amid the increase in the number of electrically powered vehicles, the sales of vehicles with internal combustion engines, such as hybrid electric vehicles (HEV) and plug-in hybrid vehicles (PHV), are also on the rise.

Fuji Electric has developed and mass-produced intelligent power switch (IPS) products that control the ON and OFF of the current that drives loads, such as solenoid valves in hydraulic control systems and motors in exhaust gas recirculation (EGR) systems in the powertrain consisting of an engine and a transmission. An IPS integrates vertical power metal-oxide-semiconductor field-effect transistors (MOSFETs) for the output stage and a horizontal power MOSFETs for the control and protection circuits on a single chip. In addition to these circuits, Fuji Electric has developed and mass-produced the IPS with built-in operational amplifiers that detect load current with high accuracy to improve fuel efficiency and reduce emissions[(1)].

Fuji Electric has recently developed the “F5202H” 5th-generation automotive IPS that contributes to further size reduction and higher heat dissipation in electronic control systems. This document describes details of the development.

2. Product Features

Figure 1 shows the external appearance of the

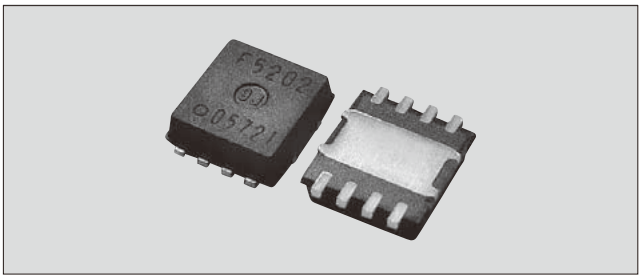

Fig.1 Appearance of “F5202H”

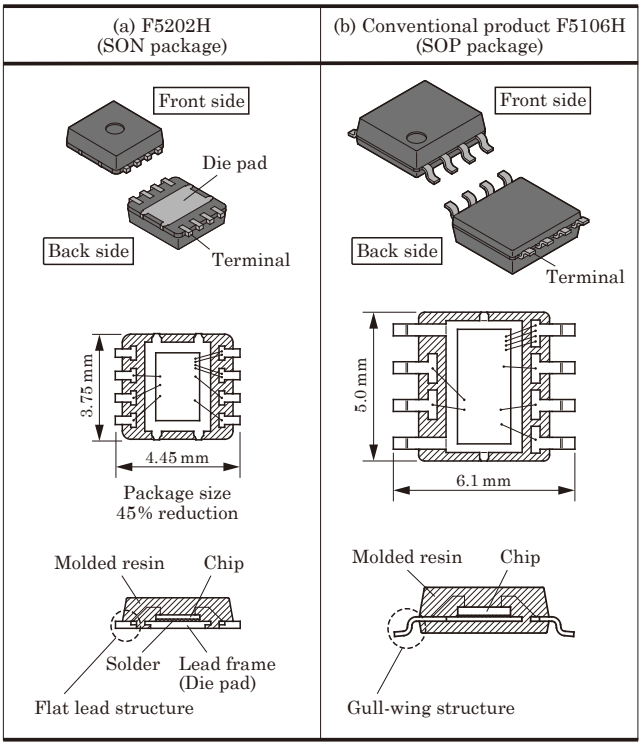

Fig.2 Comparison of package appearance and internal structure

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F5202H, and Fig. 2 compares the internal structure of the package with previous devices. In the conventional "F5106H[1]," which uses a small outline package (SOP), the lead portion protrudes to the left and right due to its gull wing structure as shown in Fig. 2(b). On the other hand, the new F5202H, which uses a small outline non-leaded (SON) package, combines the features of a flat lead structure arranged parallel to the backside of the package and a non-leaded structure with minimized protruding terminal length as shown in Fig. 2(a). The die pad with the chip is also exposed on the backside. Therefore, the F5202H is smaller than previous packages, reducing the mounting area. Furthermore, since the die pad where the chip is mounted is exposed on the backside, heat dissipation is significantly improved when connected to the substrate.

Figure 3 shows the circuit block diagram, and Fig. 4 illustrates a usage example. The F5202H uses the following features and innovations to reduce the size of the chip while maintaining the high current detection accuracy and other electrical characteristics of previous products.

(a) By applying the 5th-generation IPS device and processing technology, the control and protection circuits, especially in the operational amplifier part, have been reduced in size while maintaining the basic performance of the electrical characteristics, resulting in a 45% reduction in chip size compared with previous devices.
(b) Mounted in a small SON package with excellent heat dissipation, the new product successfully reduced thermal resistance by 80% while reducing the package size by 45% compared to previous products.
(c) The maximum rating of the junction temperature T_{vj} is 175 °C, assuming that it is installed in the engine compartment where the temperature environment is severe. In addition, this model complies with AEC-Q100*, a reliability standard for integrated circuits (ICs) used in automobiles.
(d) It has a built-in high-precision operational amplifier that detects the load current flowing in controlled equipment, such as hydraulic valves, with an accuracy of ±3.1% when the load current is 1 A (see Fig. 3). As shown in Fig. 4, an electronic control system that monitors the load current can be constructed by connecting both end potentials of an external shunt resistor to the input of an operational amplifier and outputting the voltage amplified by the operational amplifier to a microcomputer.
(e) Low voltage operation at a supply voltage of 4 V is possible.
(f) Built-in protection functions against system abnormalities (undervoltage detection, overcurrent detection, output current oscillation under overcurrent mode, and overheating detection) to prevent destruction of elements.
(g) It has a built-in Zener diode for absorbing low-impedance surges to ensure high electrostatic discharge (ESD) immunity.

With these ideas and innovations, the F5202H has a smaller package and better heat dissipation, which will contribute to further miniaturization and higher heat dissipation of electronic control systems.

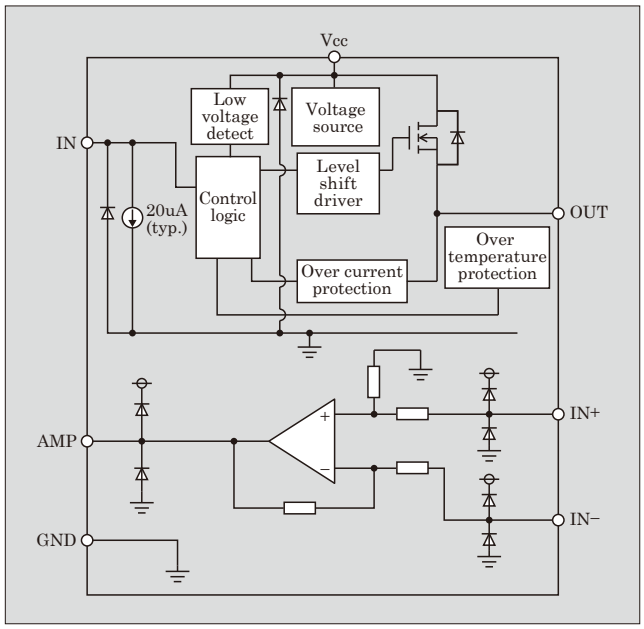


Fig.3 Circuit block diagram of "F5202H"

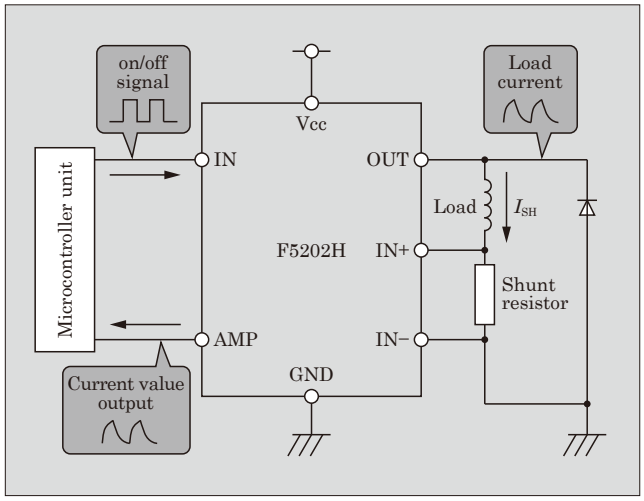


Fig.4 Example of the use of "F5202H"

* AEC-Q100: AEC stands for "Automotive Electronics Council," a standardization organization for electronic components used in automobiles. Q100 is a standard for the component category of integrated circuits (ICs).

3. Electrical Characteristics

3.1 Electrical characteristics of the IPS section and operational amplifier section

Table 1 indicates the electrical characteristics of the IPS section, and Table 2 indicates the electrical characteristics of the operational amplifier section. Despite the reduced size, the F5202H has the same electrical characteristics as its predecessor, the F5106H.

3.2 Operational amplifier section

The current flowing in the load is detected as the voltage drop when the load current I_{SH} flows through the shunt resistor R_{SH}. In the operational amplifier, this voltage drop is input as the operational amplifier input voltage V_{IN+}, which is amplified eight times and output as the output voltage. As an example of current detection accuracy, the load current can be monitored

Table 1 Electrical characteristics of the IPS section

Item	Symbol	Condition	Characteristics			Unit
			min.	typ.	max.	
Operating voltage	V_{cc}	V_{cc} = when decreased	3.6	–	16	V
		V_{cc} = when increased	3.8	–	16	V
Under voltage detection	UV_1	V_{IN} = 5 V, V_{cc} = when decreased	–	3.0	3.6	V
Under voltage recovery	UV_2	V_{IN} = 5 V, V_{cc} = when increased	–	3.2	3.8	V
Standby current	$I_{cc(L)\,1}$	V_{IN} = 0 V, R_L = 10 Ω	–	0.26	0.8	mA
Input threshold voltage (with hysteresis)	V_{IN}	V_{cc} = 4.5 – 16 V, R_L = 10 Ω	1.5	–	2.8	V
Input current	$I_{IN(H)}$	V_{IN} = 5 V	–	20	–	μA
On-state resistance	$R_{DS(on)}$	T_{vj} = 25 °C, I_{OUT} = 1.5 A	–	0.08	–	Ω
		T_{vj} = 175 °C, I_{OUT} = 1.5 A	–	0.17	–	Ω
Over-current detection	I_{OC}	V_{cc} = 13 V, V_{IN} = 5 V	2	–	7	A
Over-temperature detection	T_{trip}	V_{IN} = 5 V	175	–	207	°C
Turn-on delay Time	T_{ACCON}	V_{cc} = 13 V, V_{IN} = 5 V – 0 V R_L = 10 Ω	–	10	–	μs
Turn-off delay Time	T_{ACCOFF}		–	20	–	μs
Rise Time	T_{on}		–	20	–	μs
Fall Time	T_{off}		–	10	–	μs

*Unless otherwise noted, T_{vj} = −40 °C to +175 °C, and V_{CC} = 8 to 16 V.

Table 2 Electrical characteristics of the operational amplifier section

Item	Symbol	Condition	Characteristics			Unit
			min.	typ.	max.	
Power supply rejection ratio	PSRR	DC	80	–	–	dB
AMP output voltage range	V_{OH}	R_{AMP} = 50 kΩ	0	–	5	V
AMP output clamp voltage	V_{ACL}	R_{AMP} = 50 kΩ	5	–	7	V
AMP output current	I_{AMP} (SOURCE)	When V_{IN+} = 375 mV, V_{AMP} = V_{OAMP} V_{AMP} = 0.977*V_{OAMP}	−10	–	−0.1	mA
	I_{AMP} (SINK)	When V_{IN+} = 375 mV, V_{AMP} = V_{OAMP} V_{AMP} = 1.023*V_{OAMP}	0.1	–	10	mA
AMP slew rat	SR	R_{AMP} = 50 kΩ V_{IN+} = 0.625 V	–	0.9	2	V/μs
AMP gain	G	–	–	8	–	times
Current detection accuracy 1	I_{sns5}	V_{IN+} = 250 mV R_{AMP} = 50 kΩ	−3.1	–	3.1	%
Current detection accuracy 2	I_{sns11}	V_{IN+} = 250 mV V_{cc} = 14±1 V R_{AMP} = 50 kΩ T_{vj} = 25 °C	−2.1	–	2.1	%
AMP output voltage range during normal operation	V_{OAMP}	V_{IN+} = 12.5 to 375 mV V_{CC} = 4 to 16 V	0.053	–	3.947	V
	V_{OAMP0}	V_{IN+} = 0 mV V_{CC} = 4 to 16 V	−0.053	–	0.053	V

*Unless otherwise noted, T_{vj} = −40 °C to +175 °C, and V_{CC} = 8 to 16 V.

at ±3.1% at a current value of I_{SH} = 1 A (R_{SH} = 0.25 Ω). In general, the accuracy decreases when the operational amplifier becomes smaller. Despite the reduced size of this model, however, the implementation of the following three aspects secured a high current detection accuracy equivalent to that of previous products over a wide temperature range of −40 °C to +175 °C.

(a) For the differential amplifier part of the operational amplifier, a low voltage horizontal p-channel MOSFET (PMOS) with a triple-diffused structure, which is a 5th-generation device and processing technology, was used instead of the 4th-generation technology middle voltage horizontal p-channel MOSFET, as described in Chapter 4. This 5th-generation technology allows the MOSFET groups that make up the differential amplifier to be placed in close proximity to each other, allowing the chip to be reduced in size while maintaining high current detection accuracy.

(b) A common-centroid layout is used in the differential amplifier section to narrow distribution in current detection accuracy.

(c) The number of test pads and decoder circuits were reduced by revising the trimming circuit to compensate for deviations in current detection accuracy. The chip was thereby reduced in size.

4. The 5th-Generation IPS Device and Processing Technology

4.1 Technology overview

In previous products, the 4th-generation IPS device and processing technologies[2] were applied to reduce the size of the chip, mainly by changing the output stage power MOSFET from planar gate type to trench gate type. By applying the 5th-generation IPS device and processing technology, the F5202H employs a low voltage horizontal p-channel MOSFET with a triple-diffused structure and a polysilicon-insulator-polysilicon (PIP) capacitor to reduce the size of the control circuit.

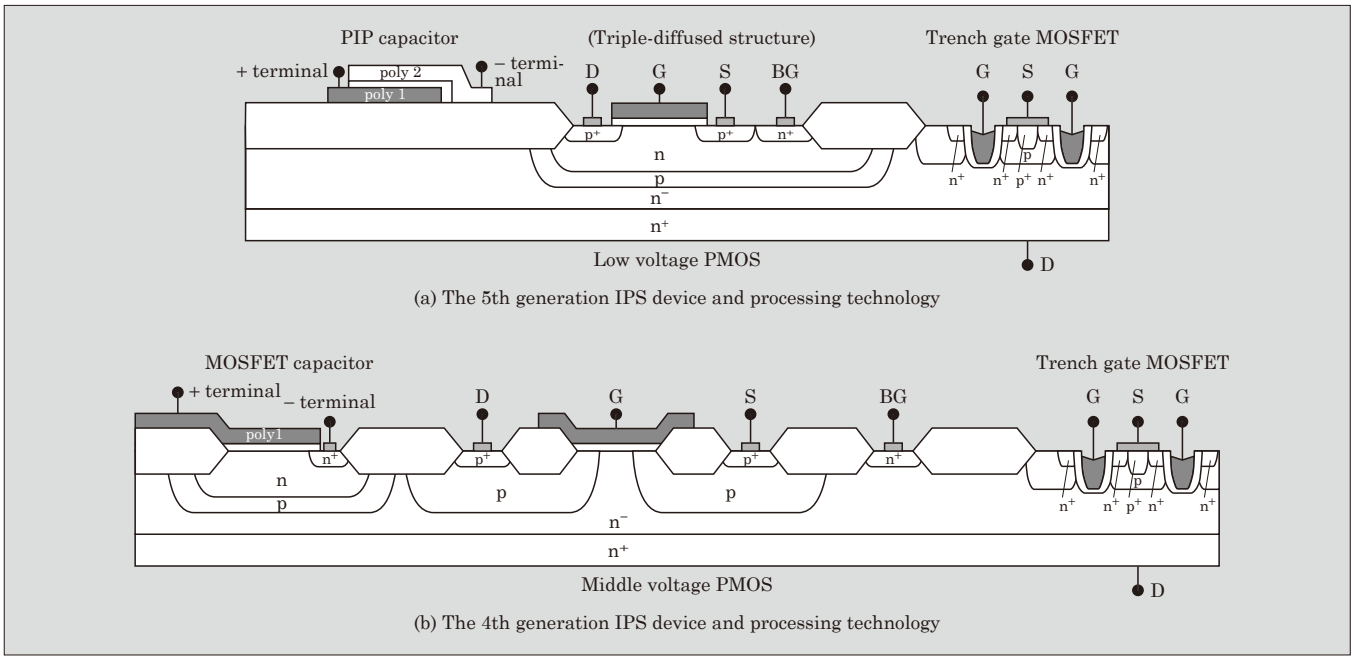
4.2 Low voltage horizontal p-channel MOSFET (PMOS)

In the 4th-generation IPS device and processing technology, as shown in Fig. 5(b), the PMOS used an n^- substrate as the back gate layer. Thus, the back gate potential was inevitably fixed to the drain potential of the vertical trench MOSFET (battery potential of the electronic control system), and a high voltage was applied between the back gate and each node. Therefore, circuits such as the 4th-generation IPS operational amplifiers need to use middle voltage PMOS with a high blocking voltage structure for each node to withstand this high voltage, leading to an increase in circuit area.

Therefore, using the 5th-generation IPS device and processing technology, we have developed a low voltage PMOS with a triple-diffused structure. The triple-diffused structure of the p-layer prevents high voltage from being applied between the back gate and each node, enabling the use of small low voltage PMOS instead of the conventional middle voltage PMOS and reducing the circuit area.

4.3 Triple-diffused structure

In the triple-diffused structure, it is necessary to form a deeper diffusion layer than before to ensure the blocking voltage between diffusion layers. In the 5th-generation IPS device and processing technology, the



(a) The 5th generation IPS device and processing technology

(b) The 4th generation IPS device and processing technology

Fig.5 Comparison of key device and processing technologies for operational amplifiers and output stages

accelerating voltage conditions for ion implantation have been optimized so that deep diffusion layers can be formed without changing the heat treatment conditions of the conventional 4th-generation IPS device and processing technology. Therefore, devices that do not need to be changed from the conventional 4th-generation IPS can be used in the 5th-generation IPS while maintaining their characteristics. As a result, changes from the previous product specification are minimized and replacement is made easy.

4.4 PIP capacitors

Previous products used MOSFET capacitors that were necessary to achieve desired operational amplifier characteristics. However, since this capacitors requires a guard ring structure and the capacitance fluctuates with the applied voltage, the device area needs to be large.

The 5th-generation IPS device and processing technology enables the use of PIP capacitors that do not require a guard ring structure, have less capacitance fluctuation, and can be used in a smaller area by optimizing and improving control of the insulating film thickness. This enabled to reduce the size of the IPS as a result.

5. SON Package

5.1 Smaller size and higher heat dissipation with SON package

The F5202H uses the SON package. As shown in Fig. 6, the package size has been reduced by 45% compared with the previous F5106H (SOP package). In addition, since the die pad (drain electrode of vertical trench MOSFETs) on which the chip is mounted is exposed on the backside, heat dissipation is greatly improved when connected to the substrate, reducing thermal resistance by 80%.

5.2 Conformity with AEC-Q100

The F5202H is designed to be used in the harsh environment of the engine compartment and complies with the AEC-Q100 reliability standard for automotive integrated circuits (ICs). The chip thickness and the composition and thickness of the solder that connects the chip to the lead frame were optimized in order to satisfy standards such as the temperature cycling test and the power and temperature cycling test while ensuring thermal stress resistance.

In addition, T_{vj} is guaranteed to be 175 °C in anticipation of long-term operation in a high-temperature environment. For this purpose, high-reliability wire is used[3] to improve the reliability of the bonding interface between the wire and electrode pad.

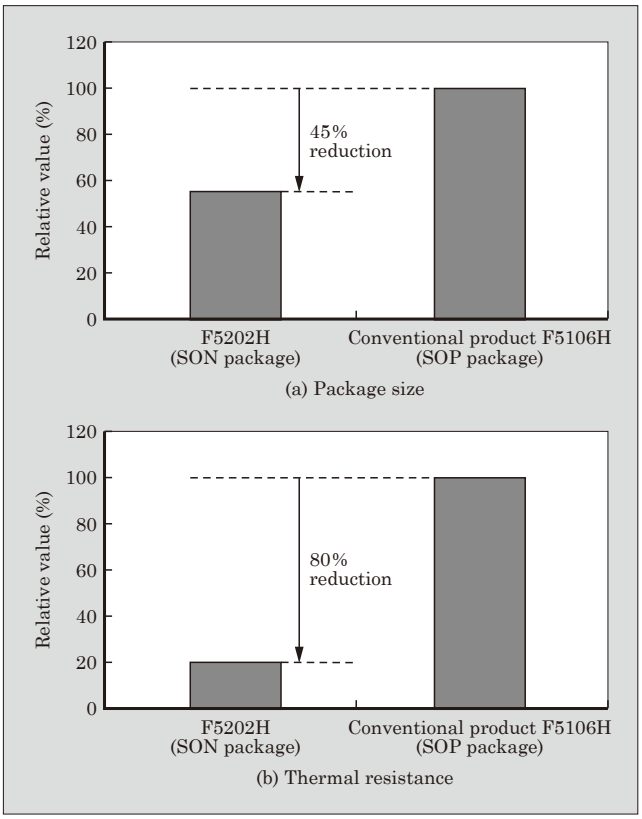


Fig.6 Comparison of SON package and conventional SOP package

6. Postscript

This article described the F5202H, 5th-generation automotive IPS that contributes to the size reduction and high heat dissipation of automotive electronic control systems. Fuji Electric is committed to make continuous contributions to the automotive industry by making further efforts to reduce the number of parts through the incorporation of peripheral parts and other efforts to make them smaller and more functional.

References

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