# A Self-isolated Single-chip Igniter (F6008L) for Automobiles

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## 1. Introduction

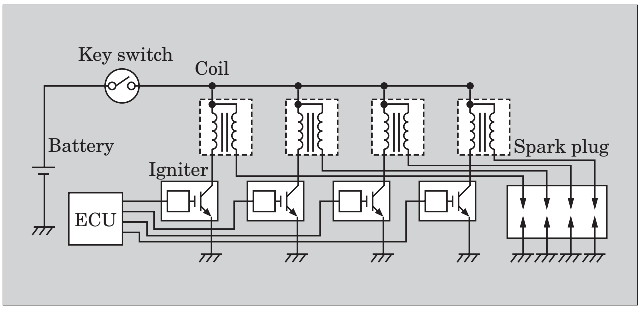
Driving by concerns for preventing atmospheric pollution and global warming caused by gas emissions, the automobile industry has, in recent years, aggressively promoted the development of vehicles capable of achieving dramatically lower fuel consumption and reducing the amount of hazardous substances in gas emissions. These capabilities are also in demand for automotive parts.

Regarding the ignition control sub-assembly of a gasoline engine control system, there are also strong demands for more stable ignition coil voltage and more precise control in order to achieve higher fuel efficiency and lower gas emissions. Consequently, instead of the conventional distributor method in which a mechanical mechanism is used to distribute a high voltage to an ignition spark plug for each cylinder, the use of an individual ignition method has increased in popularity in recent years. In the individual ignition method, a coil and switch are provided for each ignition spark plug and the ignition interval is adjusted according to the operational timing of each cylinder. Figure 1 shows an example block diagram of an individual ignition system for each cylinder.

In response to requests for higher performance, Fuji Electric commercialized the world's first single-chip igniter (F5025) that incorporated an IGBT having a self-isolation structure, and has been mass-producing this device since 1998.

This paper introduces the newly developed F6008L, which adds an overtemperature protection function to Fuji Electric's popular F5025 product line of single-chip igniters.

Fig.1 Example configuration of the individual ignition system




## 2. Overview

An igniter device is used in the central part of the engine drive system and because device failure would likely cause the engine to stop operating, extremely high

Fig.2 F6008L schematic diagram

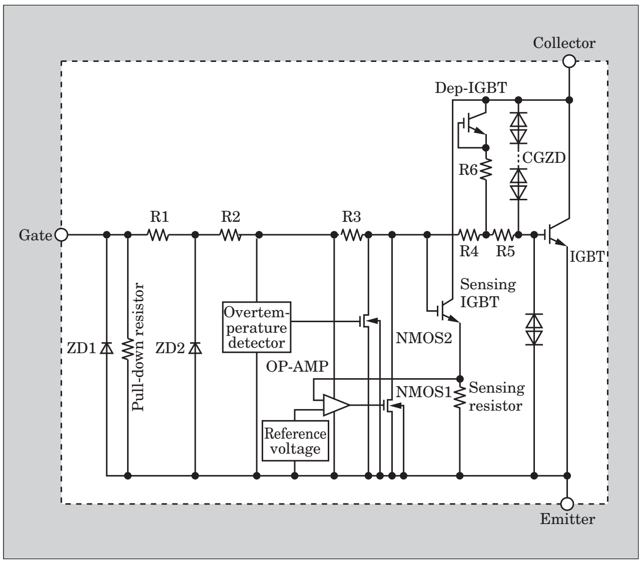
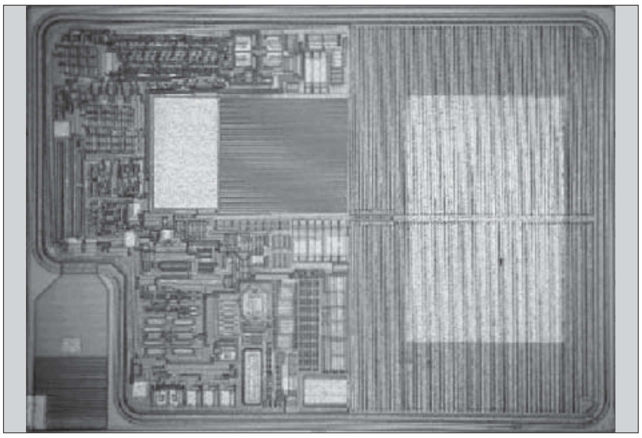



Fig.3 F6008L chip die photo



reliability is required. The F6008L has the following features and capabilities to satisfy such requirements.

(1) The F6008L achieves high system reliability by incorporating current-limiting and overtemperature protection functions.

(2) The F6008L realizes the same high surge withstand capability, high inductive load protection, high electromagnetic noise immunity and high resistance to adverse environmental conditions as the F5025, and additionally is provided with an overtemperature protection function.

(3) The F6008L integrates an igniter device and overtemperature protection function into the same TO-220 compact package as used to house the F5025.

A block diagram of the internal circuitry of the F6008L is shown in Fig. 2 and a chip die photograph is shown in Fig. 3.

## 3. Characteristics and Functions

Main electrical specifications and specific features of the F6008L are described below.

### 3.1 Electrical characteristics

Table 1 lists main electrical characteristics of the F5025 and F6008L. Electrical characteristics of the newly developed F6008L basically inherit those of the F5025, allowing easy device substitution without requiring additional circuit modification.

The collector-emitter voltage is determined by the Zener diode connected between the collector and gate, and the gate-emitter voltage is determined by the value of the surge protection Zener diode (ZD1). Because a current detection resistor is not used in the emitter line, the collector-emitter saturation voltage is low as same as the usual IGBT saturation voltage.

### 3.2 Overtemperature protection function

If a gate signal is input to the igniter device for a longer than usual duration, because the igniter load is a coil, the load current will reach an overcurrent state and device temperature will rise. In this case, the igniter device will activate its current-limiting function that is able to self-protect the device for a certain period of time. During normal operation, the duration of the gate signal input does not extend for a longer period of time than a certain presumed duration. But, for whatever reason, in the case where the duration of the ON signal exceeds this duration interval or the ambient temperature rises to an abnormal level or the like, the chip will generate an abnormal amount of heat that exceeds the design temperature, and this generated heat may cause damage to the chip.

For cases such as the above when an abnormally high temperature is reached, the F6008L is provided with an overtemperature protection function that operates to protect the chip from heat damage by forcibly turning off the IGBT collector current when the chip temperature reaches a certain value.

Figure 2 shows a schematic diagram of the overtemperature protection circuitry that is built into the chip. The F6008L integrates an IGBT power circuit and a control circuit into a single chip. An overtemperature detection unit built into the IGBT power circuit and a decision unit provided in the control circuit operate to detect and determine the temperature of the chip, and when a specific temperature is reached, the IGBT's gate is pulled-down to cutoff the collector current.

Features of the F6008L's overtemperature protection function are described below.

(1) High precision temperature detection using trimming technology

The F6008L uses Zener-zap trimming technology to suppress fluctuation in the overtemperature detection threshold temperature. Because the F6008L has overtemperature sensor and detection functions built into a single chip, temperature trimming can be

Table 1 Electrical characteristics of the F5025 and F6008L

| Item | Symbol | Measurement condition | F5025 | | F6008L | |
|---|---|---|---|---|---|---|
| | | | Min. | Max. | Min. | Max. |
| Collector breakdown voltage | $V_{CE}$ | $I_C$ = 10 mA * | 370 V | 460 V | Same as at left | |
| Gate breakdown voltage | $V_{GE}$ | $I_{GE}$ = 10 mA | 6 V | 10 V | Same as at left | |
| Limiting current | $I_{CL}$ | $V_{GE}$ = 3.5 V * <br> $V_{CE}$ = 5 V | 8.5 V | — | Same as at left | |
| Collector-emitter saturation voltage | $V_{CE\ (sat)}$ | $V_{GE}$ = 3.5 V * <br> $I_C$ = 6 A | — | 1.7 V | Same as at left | |
| Gate-emitter threshold voltage | $V_{CE\ (th)}$ | $V_{CE}$ = 16 V * <br> $I_C$ = 3 mA | 0.7 V | — | Same as at left | |
| Gate leakage current | $I_{CES}$ | $V_{CE}$ = 300 V | — | 500 µA | Same as at left | |
| Gate pull-down current | $I_{GES}$ | $V_{GE}$ = 3.5 V * | 2 mA | 3.5 mA | 2 mA | 4 mA |
| Turnoff time | $T_d$ <br> $T_f$ | $V_{GE}$ = 3.5 V * <br> $I_C$ = 6 A | — <br> — | 35 µs <br> 15 µs | Same as at left | |
| Overtemperature detection | $T_{trip}$ | — | — | | 175°C | 205°C |

* $T_j$ = −40 to +150°C (otherwise $T_j$ = 25°C)

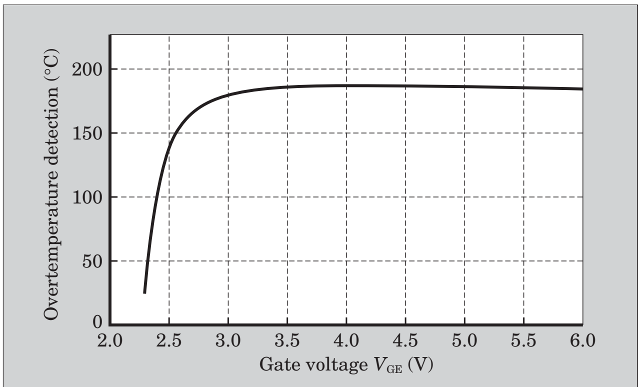
implemented by directly comparing fluctuations of both these characteristics. In the wafer probing process, both characteristics are compared and a selector is used to select the optimal detection value and correct the detection temperature. This technology has enabled the realization of high precision temperature trimming with an NMOS circuit.

(2) Realization of an overtemperature protection function using a 3-pin configuration

The F6008L is constructed such that the control circuit is provided with power via the gate input pin, and this enables overtemperature protection to be realized with the same 3-pin configuration as a stand-alone IGBT or F5025, without requiring the provision of an additional power supply pin, thereby achieving package interchangeability with the F5035. However, fluctuation in the characteristics of the overtemperature detection circuit (detection temperature fluctuation) due to fluctuation of the gate voltage (fluctuation of the power supply voltage for the control circuit) is a problem. The voltage of the gate signal from an electronic control unit (ECU) is typically in the range of 4.0 to 5.0 V, but an igniter device must be designed with the assumption that gate voltage will be lowered to 3.0 V or less. For an overvoltage detection circuit constructed from NMOS circuitry, the constituent circuitry will have a large fluctuation in detection temperature characteristics in this range of power supply voltage, and accordingly, the detection temperature will have a large dependency on gate voltage. To address this problem, the F6008L adds a circuit to correct for the fluctuation in characteristics caused by gate voltage, thereby making the detection temperature less dependent on gate voltage. Furthermore, so that the overtemperature detection threshold temperature does not rise above the maximum value of 205°C while the gate voltage is low, the F6008L has been designed such that its overtemperature detection threshold temperature will decrease together with the decrease in gate voltage.

These measures have dramatically decreased the fluctuation of detection temperature due to gate voltage fluctuation and have realized a mechanism that safely halts igniter operation when the gate voltage decreases. Figure 4 shows the gate voltage (circuit voltage) dependency of the overtemperature detection threshold temperature.

Fig.4 Overtemperature characteristics



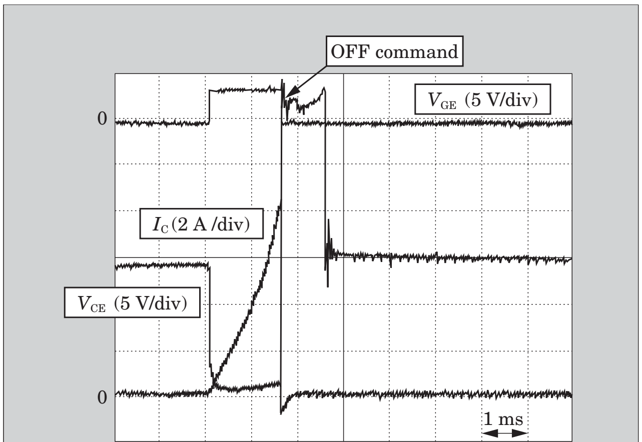

### 3.3 Current-limiting function

Because the igniter has a coil as its load, if the ON signal from the ECU continues for a long time, the collector current will increase up to the value determined by the battery voltage and the circuit inductance and resistance, and in the worst case scenario, the igniter will be damaged by an overcurrent. To prevent this from happening, it is critically important to add a current-limiting function.

Fuji Electric's single-chip igniter utilizes a current detection and limiting method based on sensing IGBT technology. Because this method does not require a current-detecting shunt resistor to be connected directly in series with the main IGBT, there is no voltage drop due to the flow of collector current through a shunt resistor, and therefore $V_{CE(sat)}$ can be reduced.

Also, to prevent the surge in collector-emitter voltage generated at the start of the current-limiting operation (which would generate an unnecessary voltage at the secondary coil and could potentially cause

Fig.5 F6008L operating waveforms




(a) Normal operation waveform (pulse width: 1.5 ms)

(b) Overtemperature operation waveform (pulse width: 6 ms)

Fig.6 Dynamic clamping characteristics

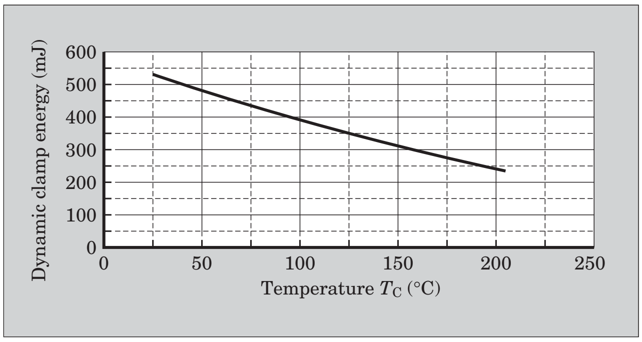
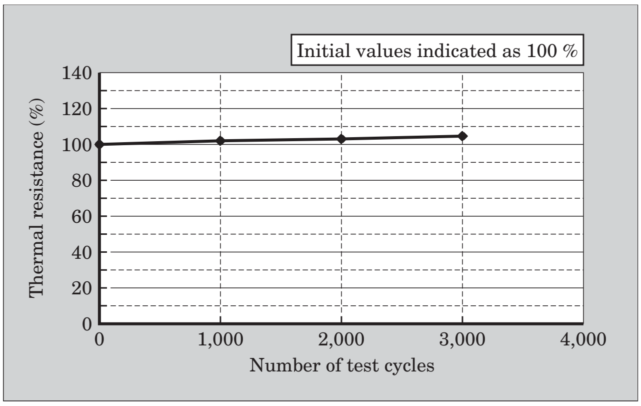



Fig.7 Thermal shock test results




unintentional ignition sparking), our single-chip igniters also utilize Fuji Electric's proprietary technology for preventing oscillation during current limiting, thereby resolving a problem which had been difficult to handle with only IGBT-based technology.

Waveforms during normal operation and in the case where current-limiting and overtemperature detection functions are active are shown in Fig. 5(a) and 5(b), respectively. Waveforms are shown assuming operation in the two cases where an ON signal is input for the usual ON duration (approximately 2 ms) and for a longer-than-usual ON duration (approximately 6 ms, where the ambient temperature was 170°C so that overtemperature detection would be easy to activate). It can be seen that the current-limiting function is not activated for the usual ON duration, but in the case of an extended ON duration, after current-limiting is activated, the overtemperature protection function acts to turn off the current even before an OFF signal is input.

### 3.4 Dynamic clamping

If the igniter device misfires, the device must be able to process the inductive load energy stored in the ignition coil. The amount of such energy is usually in the range of several tens of mJ to 100 mJ. Since the F6008L is specified for overtemperature detection in the range from 175°C to 205°C, a dynamic clamping capability of 100 mJ is guaranteed at the overtemperature detection threshold temperature.

Figure 6 shows typical dynamic clamping characteristics of the F6008L. It can be seen that the F6008L has sufficient capability even at the maximum overtemperature detection threshold temperature of 205°C.

### 3.5 Electromagnetic noise immunity

Electromagnetic noise immunity of the F6008L was verified using the TEM-cell method. We verified that in an electric field of 200 V/m and frequency range of 10 MHz to 1 GHz, there were no operational anomalies during current-limiting, overtemperature detection or ON-OFF switching operation.

Also, based on the assumption that noise will be input from the ignition coil or elsewhere to the gate pin, we performed a test in which an ESD (electrostatic discharge) surge (150 pF, 150 Ω, 5 to 25 kV) was applied between the gate and emitter pins as noise, and then verified that there was no anomaly in the operation of the overtemperature detection circuit under these conditions.

### 3.6 Resistance to environmental conditions

There is demand for igniter systems to be made smaller in size or packaged together with a coil in order to eliminate the high-tension lead between a coil and igniter device, and Fuji Electric is considering an integrated package as it continues to develop single-chip igniter technology. In the case of integration with a coil, because the resultant device will be mounted directly on an engine, it must be highly resistant to adverse environmental conditions in order to withstand the extreme temperature fluctuations in an engine compartment. Fuji Electric's single-chip igniter uses low-stress high-density resin and stress-resistant solder. As a result, after 3,000 cycles of a thermal shock test (– 55 to +150°C, $\Delta T_C$ = 205 K) the change in thermal resistance, which is an indicator of deterioration, was suppressed to 5 % or less, thereby verifying the strong resistance to environmental conditions. Figure 7 shows a graph of the thermal shock test cycle and change in thermal resistance.

## 4. Conclusion

Similar to the requirements automotive systems, ignition systems are also expected to require smaller size, greater functionality, higher performance and higher reliability in the future. In response to those requirements, Fuji Electric intends to promote the development of new small-size, multi-function, single-chip igniter products as successors to the F5025 and F6008L.

### Reference


(1) Yoshida, K. et al. A Self-Isolated Intelligent IGBT for Driving Ignition Coils. Proceedings of the 10th ISPSD 1998, p.105-108.