Technologies for Motor Driver ICs with Controller to Downsize In-Vehicle Motor Systems

In recent years, among the many moving parts of various sizes used in automobiles, almost all mechanically driven parts have been replaced by electrically driven parts using motors. In the field of motor driver integrated circuits (ICs), technologies for integrating various circuit parts and countermeasures against heat dissipation are essential to achieve a balance between high-density mounting of power semiconductor chips on packages and reduction of the size of packages, in order to realize compact in-vehicle motor systems.
Toshiba Electronic Devices & Storage Corporation is engaged in the development of motor driver IC products for automotive use. These products include monolithic ICs equipped with power elements and a controller in one chip, and system in packages (SiPs) equipped with field-effect transistors (FETs) and a controller in one package for high-current applications. The new motor driver IC products were successfully fabricated by optimizing the package design utilizing thermal simulations at the initial stage of development and applying a technology to detect current and temperature while reducing the number of parts.

1. Introduction

The automotive electric motor market is currently expanding steadily. **Figure 1** shows the world market forecast[1] according to the application segments of the motor systems, and the demand in 2025 is expected to be about 1.5 times that in 2016. Among major cause of this market expansion are environmental regulations and fuel efficiency regulations for different countries as well as the need to provide more convenience and comfort for drivers.

As for CO_2 (carbon dioxide) emissions, regulations will mandate a reduction to 159g/km in 2020 for China and 95g/km in 2021 for Europe. In order to achieve these targets, the proportion of electric vehicles such as pure EVs (electric vehicles) and HEVs (hybrid electric vehicles) will increase, as well as component trends such as the switching of valves and pumps from mechanical to electric types.

For the engines, adoption of electronic controls for the throttle and electrically operated valves for optimizing fuel economy is increasing. Even in the standard vehicle category, four to five H-bridge driver ICs are used within an engine control unit. In order to place an ever-increasing number of driver ICs inside the ECU (Electronic Control Unit), downsizing the package and improving heat dissipation are critical measures.

On the other hand, with regard to providing more convenience and comfort, relatively large motors with currents of several tens of amperes used for the slide doors, rear doors, seat adjusters, etc., are on the rise. In these applications, electronic circuits are often configured using discrete FETs. However, when a circuit for driving

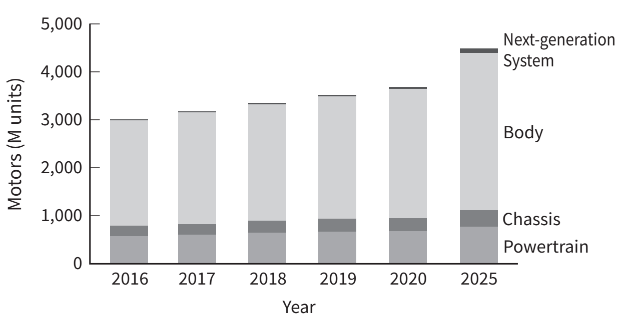


Figure 1: Forecast of scale of global market for in-vehicle motor systems by application areas

Demand in 2025 is expected to be about 1.5 times that in 2016.

a motor and for detecting an abnormal state (such as over-current and overheating) is installed in order to ensure safety, there is a problem that the number of parts will increase.

Drivers with currents less than 10A must be consolidated into monolithic ICs in order to reduce product costs. Meanwhile, since drivers of 10A or more are technically difficult to mix in one chip, SiP technology for enclosing the controller and the FET in the same package is required. With a SiP, the parts constituting the circuit can be drastically reduced.

Although methods for achieving miniaturization of packages may differ, the problem common to monolithic IC and SiP is optimization of heat dissipation. Techniques for heat dissipating countermeasures are different for applications where the vehicle operates continuously when the vehicle is stopped versus when it is operated only when people are getting into and out of the car or for loading and unloading of luggage. Especially for the latter applications, it is important to design the motor driver IC such that the heat dissipation countermeasures applied will not be excessive for transient temperature rises.

Here we describe a technology developed by using an H-bridge driver with a rated current of 5A with a monolithic IC in a small package, and the technology for incorporating an FET in a SiP.

2. Thermal design of monolithic ICs

The TB9051FTG, a monolithic IC designed for valve control of engines, consists of a motor control logic composed of CMOS (Complementary Metal-Oxide-Semiconductor) transistors and DMOS (Double-diffused Metal-Oxide-Semiconductor) transistors with a 5A H-bridge driver circuit all on one chip. The development focused on how much the package can be miniaturized by maximizing the heat dissipation while satisfying user requirements such as current capacity, ON resistance, and switching speed.

2.1 Reduction of thermal resistance by using Cu plates

The TB9051FTG was developed with a compact package having a high heat dissipation capability. Utilizing thermal analysis for the upstream design during the early stages of development, we verified the effectiveness of various heat dissipation methods in order to ensure that we achieve the target thermal resistance.

The main structure for the heat dissipation involves a Cu (copper) plate positioned on the die pad. The chip is then placed on this Cu plate (**Fig. 2**). This helps suppress the increase in the junction temperature Tj of the chip, particularly for transient currents.

For transient heat dissipation, the volume and material selection and the die pad on which the chip is placed are key points. In general, the die pad is integrated with the lead frame, such that neither thickening the die pad only nor increasing the thickness of the entire lead frame are desirable methods from the viewpoint of manufacturability and cost. Therefore, in order to ensure sufficient heat dissipation, it is common to increase the size of the package and to widen the area of the die pad.

The newly developed package adopts a structure in which a Cu plate is mounted on the die pad in a single step. As a result, the thickness of the Cu plate can be selected according to the necessary thermal resistance, and sufficient heat dissipation can be achieved even when using a small package.

Fig. 3 shows the results of verifying transient heat dissipation characteristics of the TB9051FTG. We were able to reduce the increase in T_j by 1.5°C after 0.1s for the same existing 6mm square product.

2.2 Heat dissipation to PCB by E-PAD structure

Another feature is the adoption of an “Exposed Pad” (E-PAD) structure that exposes the die pad from the bottom of the package. The interfaces between the chip and the Cu plate and between the Cu plate and the die pad are mounted with a paste having a high

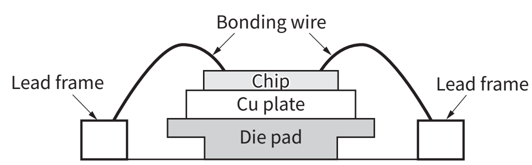


Figure 2: Structure of monolithic package of the TB9051FTG motor driver IC

Improved heat dissipation and manufacturability were attained by placing a Cu plate over the die pad where the chip is positioned.

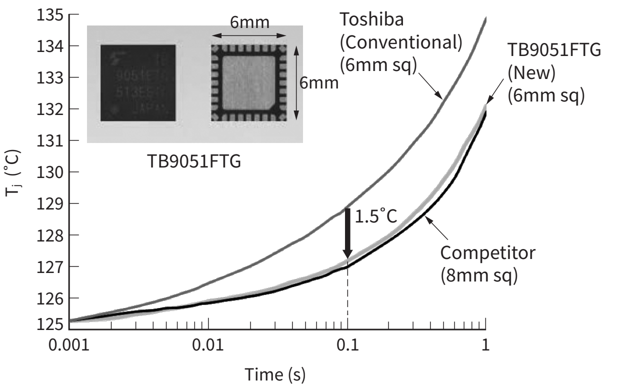


Figure 3: Results of measurements of transient thermal resistance of motor driver IC packages

Using the new TB9051FTG, the rise in Tj was reduced by 1.5˚C after 0.1s, compared with an earlier product having the same dimensions. Also, the mouting area was reduced by 44% compared to similar products by competitors.

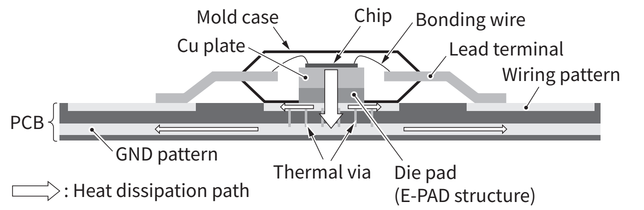


Figure 4: Cross-sectional view of package mounted on printed circuit board (PCB) and heat dissipation paths

By adopting an E-PAD structure that separates the die pad from the mold case, heat generated by the chip is released via the PCB's patterns.

thermal conductivity. The die pad is exposed from the bottom of the package, to realize a thermal design to release the heat from the chip to the printed circuit board (PCB) (**Fig. 4**). The exposed surface of the die pad uses standard reflow soldering to bond to the printed wiring board (PWB). By adopting the E-PAD structure, heat dissipation mechanisms provided on the PCB such as the GND (ground) pattern and the thermal via holes that penetrate the board can also be employed to cool the chip.

2.3 Reduction of mounting area

By means of the Cu plate and the adoption of the E-PAD structure, the package size of the TB9051FTG has shrunk to 6mm square. Compared with similar competing products (8mm square), the mounting area is reduced by 44%, contributing to miniaturization of the ECU board.

3. Thermal design technology of SiP

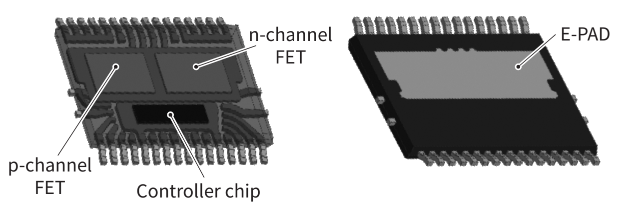
Traditionally, mechanical relays have been used for the motor drive circuitry of power sliding doors and power-assisted seats. In recent years, to improve reliability as well as reduce noise, there is a trend toward use of discrete semiconductor components. Furthermore, integration of electromechanical parts (mechanical and electronic functions) and reduction in size of ECU are accelerating, resulting in the need for highly integrated and miniaturized semiconductors.

In response to these needs, we developed the TB9111FNG as a SiP product containing FETs and a controller chip that can drive large currents in one package.

3.1 3-in-1 Packaging Technology

The TB9111FNG is a 3-in-1 package SiP product in which a total of 3 chips, namely, a high-side driver FET (p-channel), a low-side driver FET (n-channel), and a controller for controlling the gates, are enclosed inside one package. The appearance and internal structure are shown in **Fig. 5**.

The top surface of the FET consists of the source electrode through which large currents flow, and it is connected to the lead terminal of the IC with a bonding wire or clip. With this structure, since other chips cannot be stacked onto this source electrode, the three chips



(a) Internal structure (Top view) (b) External structure (Bottom view)

Figure 5: Outline and internal structure of SiP of the TB9111FNG motor driver IC

Two FETs are mounted on the heat-dissipation E-PAD, inside the same package as the controller chip.

described above are arranged in a plane. On the other hand, the lower surface of the FET consists of the drain electrode through which large currents flow, such that it is not connected to the lead terminal of the IC, but rather to the E-PAD itself and integrated with the output terminal.

The heat sources are two FETs, and the radiation paths to the outside of the package housing (main body) are primarily the upper and lower surfaces. When comparing the upper and lower sides, one can achieve higher thermal conductivity using the path from the lower surface, which can radiate heat directly from the E-PAD to the PCB. In order to increase the current drive capability and the thermal conductivity of the FET, it is important to design the area of the E-PAD on which the FET is mounted to be made as large as possible.

On the other hand, in order to ensure reliable mounting to the PWB, it is required that the lead terminal have a gull-wing shape for large packages. In this product, an SOP (Small Outline Package) with lead terminals aligned in two directions was adopted, and the package width (short side) was set to a maximum of 8mm. To accommodate this width, in order to widen the area of the E-PAD, the shape of the FET was made rectangular and placed horizontally inside the package's longitudinal direction. Furthermore, by making the shape of the controller chip as narrow as possible, it was possible to reduce total package size and maximize the E-PAD area.

3.2 Thermal analysis technology

When integrating FETs with control circuitry, heat countermeasures pose a problem. The FET chip itself generates heat due to the current to drive the motor, and if the T_j of the chip rises too much, it can cause deterioration and breakdown. Therefore, it is necessary to optimize the usage conditions and the PCB design.

Depending on the application and usage conditions, the built-in FET generates about 30 to 50A of current and associated heat. To prevent deterioration and destruction of the chip due to heating, the thermal design of the IC becomes important. The TB9111FNG utilizes thermal analysis technology to optimize the ON-resistance of each FET, the area of E-PAD, chip shape, material of the package, etc., at the initial stage of product development, taking into account the package size constraints.

Fig. 6 shows the thermal analysis results of the developed TB9111FNG. In the mounted FET, the absolute maximum rating of the T_j was 175°C, and it was possible to keep it within 175°C even after the target period of 1s.

3.3 Current and temperature detection technology

With discrete FETs by themselves, the current and temperature cannot be detected. In the case of current, it is common to perform voltage conversion with a shunt resistor and measure using a combination of an operational amplifier and an MCU (Micro Control Unit). However, this configuration leads to an increase in cost and PCB size due to the complexity. In the case of temperature, arranging thermistors on the PCB is widely adopted, but temperature measurements using thermistors are not very accurate.

Therefore, the TB9111FNG includes devices for current and temperature measurements in each of the p-channel and n-channel FETs. The controller chip measures the current and temperature of the FET (**Fig. 7**). In addition, since the function to

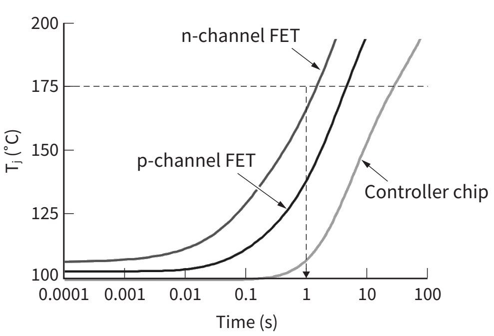


Figure 6: Results of thermal simulation of temperature of chips in the TB9111FNG package

Thermal analysis confirmed that it is possible to keep Tj under 175˚C (FET's absolute maximum rating) even after the target period of 1s.

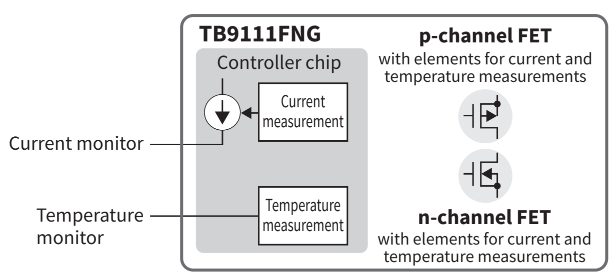


Figure 7: Functional confi guration of the TB9111FNG

Components used in conventional configurations were eliminated by using the controller chip to monitor the elements for current and temperature measurement integrated into the FETs.

convert the current to voltage is built in, the shunt resistor and the operational amplifier needed for conventional configurations can be eliminated. As for temperature, by measuring the voltage of the temperature detection device built in the FET with the controller chip, it is possible to achieve high measurement accuracy and thereby eliminate the need for separate thermistors.

4. Conclusion

The number of motors installed in automobiles will continue to increase, and it is expected that heat dissipation issues related to the ICs driving the motors will become increasingly important.
For many years, Toshiba Electronic Devices & Storage Corporation has been developing the process technology, circuit technology, and thermal analysis technology of analog ICs and discrete semiconductors. We will continue to improve the motor driver ICs to meet the expanding market needs and contribute to the electrification and high performance of automobiles.

References

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