TOSHIBA

Technical Review

Technologies for Semiconductor Relay Power Devices Allowing Reductions in Size and Weight of In-Vehicle Equipment

Demand has been increasing in the automotive field for improvement of fuel consumption in order to reduce carbon dioxide emissions as a global warming countermeasure. On the other hand, the amount of in-vehicle equipment has also recently been increasing in order to enhance safety and usability, leading to increased vehicle weight and a consequent deterioration in fuel consumption. The need has therefore arisen for compact and lightweight components for in-vehicle equipment. In particular, there is a trend toward the use of semiconductor relays as a replacement for the large number of conventionally installed mechanical relays that both constrain the placement and hinder the realization of compact and lightweight vehicles.

In line with this trend in the development of semiconductor relays, Toshiba Electronic Devices & Storage Corporation has developed and released products including power metal-oxide-semiconductor field-effect transistors (MOSFETs) and controller integrated circuits (ICs) to control the gate on/off state of power MOSFETs for automotive semiconductor relays. We are also developing next-generation products with a reduced mounting area.

1. Introduction

In recent years, automotive requirements have been changing dramatically. As demand increases for enhanced safety and user-friendliness, automobiles have come to be equipped with plenty of versatile in-vehicle equipment. However, an increase in the amount of in-vehicle equipment causes space constraints and a decrease in fuel efficiency because of increased vehicle weight. On the other hand, accompanying a worldwide increase in the number of automobiles, particularly in emerging markets, the issue of carbon dioxide (CO_2) emissions and other environmental considerations are becoming increasingly important. In response, the authorities are tightening vehicle emissions regulations in many jurisdictions. Under these circumstances, it is necessary to reduce the size and weight of components for in-vehicle applications. In particular, mechanical relays impose constraints on reducing the size and weight of an automobile because the positions where they can be installed are limited owing to their large size and because an automobile uses lots of mechanical relays.

Mechanical relays are primarily used to provide electrical connections between batteries and electronic control units (ECUs) and to control electricity flow to various loads, including exterior lamp bulbs and window heaters. The mechanical relays used for such applications are housed in a single unit called a junction box

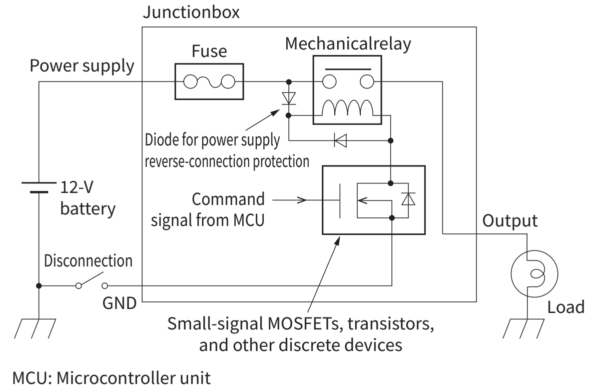


Figure 1: Block diagram of junction box equipped with mechanical relay

A junction box is composed of mechanical relays, fuses, small-signal MOSFETs, transistors, and other types of components. Therefore, there is a limit to reducing the size and weight of a junction box.

because they require periodic maintenance. **Figure 1** shows the block diagram of a relay junction box. Components such as mechanical relays and fuses are tall, and the requirement for fuse holders adds extra height to fuses. For efforts to reduce the size and weight of a junction box, these components constitute a bottleneck.

In line with the safety and user-friendliness requirements, automated driving will spur demand for in-vehicle equipment, requiring further reductions in its size and weight. In this context, mechanical relays are being replaced by semiconductor relays. Semiconductor relays incorporating protection and diagnostic functions such as current limiting (including overcurrent protection) in the event of a shorted load are expected to eliminate the need for fuses and facilitate considerable reduction in the size and thickness of in-vehicle equipment.

Toshiba Electronic Devices & Storage Corporation is developing key technologies for power MOSFETs for semiconductor relays as well as those for controller integrated circuits (ICs) for the gate drive of power MOSFETs. Below, we offer an overview of these technologies and discuss their prospects.

2. Technologies necessary for semiconductor relays

The following technologies are necessary to replace mechanical relays in in-vehicle equipment with semiconductor relays:

(1) Reduction in conduction loss and standby supply current
Simplifies thermal design and reduces the size of in-vehicle equipment. It also helps reduce voltage drops and thereby stabilize the voltage supplied to equipment.

(2) Reduction in size and weight
Increases fuel efficiency

(3) Switching off power MOSFETs in the event of disconnection of GND (ground line) Prevents a malfunction

(4) Integration of a power supply reverse-connection protection
Protects ECUs

(5) High-precision current sensing (including overcurrent protection)
Reduces the maximum current in the event of a shorted load, protects power MOSFETs, improves reliability, and reduces the diameter and therefore the weight of wire harnesses.

2.1 Development of low-voltage power MOSFETs for automotive applications

Low-voltage power MOSFETs for automotive applications are designed for in-vehicle electronics and electroactuation. They are available in p-channel and n-channel versions. Our development efforts are focused on MOSFETs with a drain-source voltage of 40 to 100 V. The performance requirements for power MOSFETs include low on-resistance, high-current capability, and thermally enhanced small packages.

Figure 2 shows trends in the per-area on-resistance ($R_{on}A$) of our n-channel power MOSFETs. We have reduced $R_{on}A$ by 60% over the period from the fourth generation to the ninth generation using our proprietary trench-gate U-MOS processes.

In addition, we provide the packaging options shown in **Figure 3 (a)** with different current ratings, incorporating technologies to reduce internal resistance and improve heat dissipation (**Figure 3 (b)**). By leveraging these technologies, we have realized a power MOSFET with an on-resistance of less than 1 mΩ in an SOP Advance package measuring 5 mm × 6 mm, as shown in **Figure 3**.

2.2 Development of controller ICs for the gate drive of power MOSFETs

For semiconductor relays composed of a power MOSFET and a controller IC, it is necessary to consider various factors, including the process structure, in order to provide the protection from power supply reverse connection and disconnection of GND.

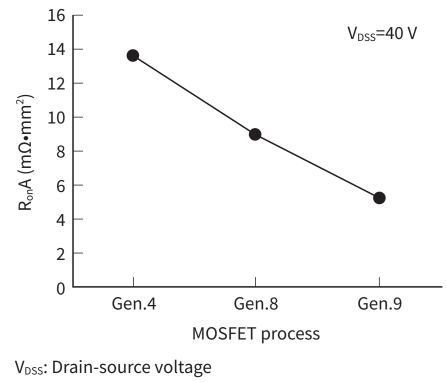
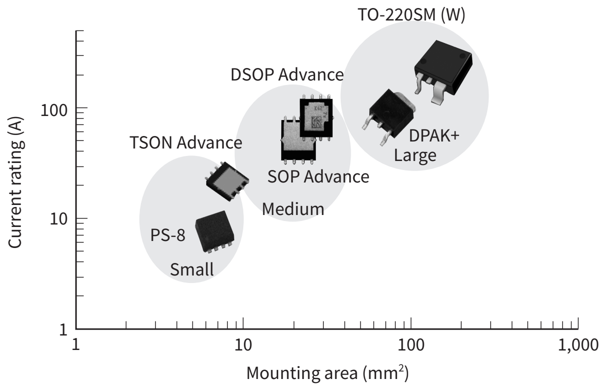
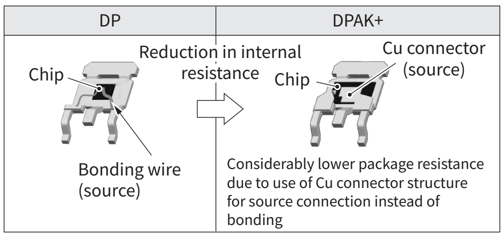


Figure 2: Trends in on-resistance of Toshiba n-channel power MOSFETs

Per-area on-resistance ($R_{on}A$) has been reduced by shrinking trenchgate MOSFET process geometries.



(a) Lineup of surfacemount packages



(b) Internal structure of DP, DPAK + packages

TSON: Thin Small Outline Non-Leaded
SOP: Small Outline Package
DSOP: Double-Side-Cooling SOP
DPAK: Discrete Packaging
TO: Transistor Outline

Figure 3: Lineup of surface-mount packages

Various surface-mount packages are available for different applications. DPAK+ exhibits considerably lower package resistance than DP because DPAK+ uses a copper (Cu) connector structure for the source connection.

2.2.1 Power supply reverse-connection protection

Since the contact of a mechanical relay is fully open when no current is flowing through the coil, a small-power diode can be used to block current flow to the coil in the event of a power supply reverse connection.

In contrast, since current flows through the drain-source body diode of a power MOSFET in a semiconductor relay, it is necessary to add an external current-blocking circuit or reduce power loss by keeping the power MOSFET in the "on" state.

2.2.2 Protection from disconnection of GND

Semiconductor relays in a junction box are used as high-side switches. It is therefore necessary to provide protection in case of disconnection of GND in a controller IC or disconnection of a GND connector of an ECU while a load is connected. In a typical IC, the potential of a p-type substrate is fixed to the lowest potential (e.g., GND) in the IC so as to provide electrical isolation among its internal elements. However, if GND of a power MOSFET is

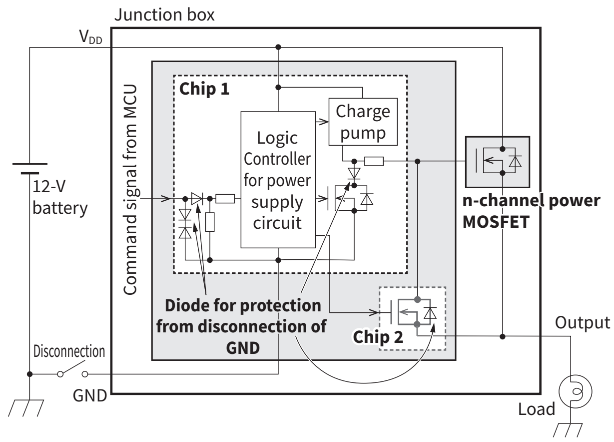


Figure 4: Circuit for disconnection of GND protection

The controller IC consists of two chips and a diode for disconnected GND protection

disconnected, the potential of the p-type substrate becomes unstable, possibly causing internal supply current to flow to the gate through a ground loop and thereby charging it to a "half-on" state. To avoid such a condition, a power MOSFET must either maintain the "off" state or transition from the "on" state to the "off" state in the event of disconnection of GND.

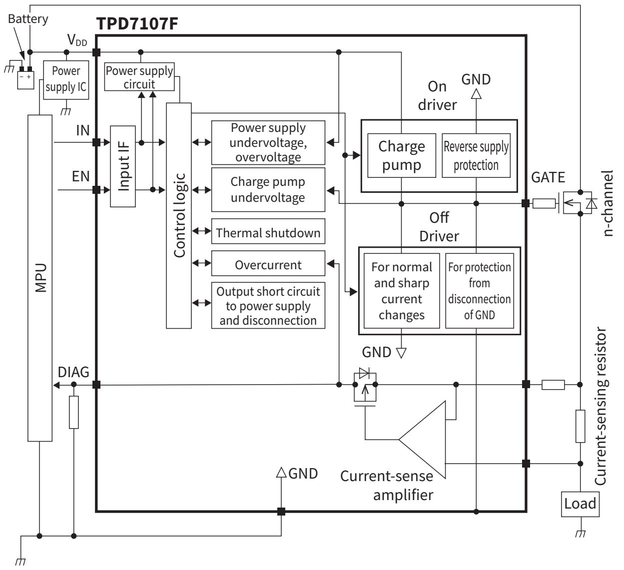
The TPD7107F controller IC, which is under development, is designed as follows to achieve this functionality (**Figure 4**).

(1) The TPD7107F consists of two chips so as to be able to return the power MOSFET gate charge to the source in the event of disconnection of GND.

(2) The TPD7107F detects disconnection of GND via the voltage between power supply (V_{DD}) and GND pins. It uses a diode to prevent supply current from flowing through an external ground loop so that the GND potential is independent of external conditions in the event of disconnection of GND. In the case of an under voltage (UV) condition, the TPD7107F is disabled and removes gate charge with reference to the source.

Figure 5 shows the block diagram of the TPD7107F, and **Table 1** gives its target specifications. In addition to the protection from power supply reverse connection and disconnection of GND, the TPD7107F incorporates a current-sensing function (including overcurrent protection for a power MOSFET). Chip-to-chip wire bonding technology is leveraged to house the TPD7107F in the 10-pin very-very-thin small-outline no-lead (WSON 10) package measuring only 3 × 3 mm.

The TPD7107F also provides a protection function that shuts down a power MOSFET to prevent self-damage in the event of a fault and



MCU: Microprocessor
EN: Enable pin
IF: Interface
DIAG: Diagnosticoutputpin
IN: Input pin
GATE: Gate pin

Figure 5: Block diagram of TPD7107F controller IC

In addition to the circuit for disconnected GND protection shown in Figure 4, the TPD7107F incorporates protection for disconnection of GND, current sensing, fault detection, and other functions.

Table 1: Target specifi cations of TPD7107F

Characteristics		Spec 1		Spec 2		Spec 3	
		Self-protection	Diagnostic output	Self-protection	Diagnostic output	Self-protection	Diagnostic output
Protection/ diagnostic output function	Power supply undervoltage	○	○	—	○	—	—
	Power supply overvoltage	○	○	—	○	—	—
	Charge pump undervoltage	○	○	—	○	—	—
	Current sense output	—	○	—	○	—	○
	Overcurrent	○	○	—	○	—	—
	Thermal shutdown	○	○	—	○	—	—
	Power supply reverse connection	—	—	○	—	○	—
	Disconnected GND	○	—	○	—	○	—
Chipprocess		BiCD 0.13 µm (1st generation)					
Package		WSON10 (3×3 mm, 0.5 mm pitch)					

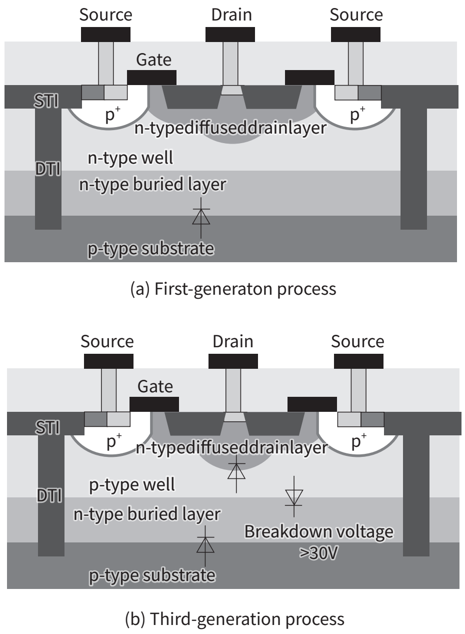
BiCD: Bipolar +complementary MOSFET+double-diffused MOSFET
○: Available —: Not available

a diagnostic output function that notifies a microcontroller unit (MCU) of the fault. However, some users may want to shut down a power MOSFET via an input from an MCU. To address such a need, we are planning to release variants of the TPD7107F that provide a diagnostic output but not current-sensing and self-protection functions.

3. Future prospects

Figure 6 shows the cross-sectional structures of the MOSFETs fabricated with the first- and third-generation BiCD processes. Protection from disconnection of GND cannot be integrated on a single chip with the first-generation process. Therefore, disconnection of the GND protection chip must be implemented separately from the TPD7107F that is also fabricated with the first-generation process. However, the third-generation process (that can tolerate negative voltage) replaces the n-type well between the n-type diffused drain and n-type buried layers with a p-type well so that parasitic current does not flow through a ground loop even when the p-type substrate potential becomes unstable. Consequently, the third-generation process provides electric isolation between the drain and the p-type substrate and thereby a breakdown voltage of more than 30 V.

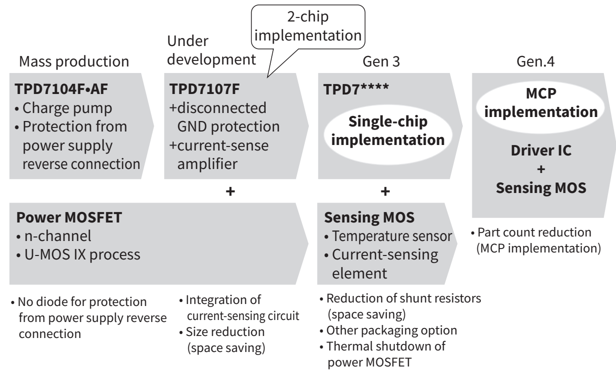
Figure 7 shows our product development plan. We will consider integrating the protection element for disconnected GND and double-diffused MOS (DMOS) on a single chip using the third-generation process. The newly developed TPD7107F has been designed to use an external current-sensing resistor in order to eliminate the need for a fuse and reduce the diameter of a wire harness. However, we will also consider eliminating the need for an external current-sensing resistor by using a sensing MOS device because a current-sensing resistor for high-current applications is physically large. In the future, we will develop MCP products incorporating power MOSFET and gate drive controller IC chips.



STI: Shallow Trench Isolation
DTI: Deep Trench Isolation

Figure 6: Comparison of cross-sectional structures of nchannel power MOSFETs fabricated with BiCD 0.13 µm processes

The first-generation process cannot electrically isolate the elements in a chip because parasitic current flows through a ground loop when the p-type substrate potential becomes higher than the source potential. With the third-generation process, the p-type well provides electric isolation between the drain and the p-type substrate.



MCP: Multi Chip Package

Figure 7: Actual and planned deliveries of Toshiba semiconductor relay products

Our next step is single-chip and MCP implementation to enable further replacement of mechanical relays with semiconductor relays.

4. Conclusion

To date, mechanical relays have been replaced by semiconductor relays so as to reduce the size and weight of in-vehicle equipment. Demand for semiconductor relays is expected to further increase in the years ahead since it is necessary to enhance the vehicle quality and the reliability of in-vehicle equipment through protection and fault diagnosis functions in order to realize automated driving.

We have developed various semiconductor devices, including automotive intelligent power devices (IPDs), power MOSFETs, and controller ICs for driving these devices. As in-vehicle electronics and electroactuation continue to advance, the market needs are becoming increasingly diverse. To contribute to the development of the automotive industry, we will continue to develop semiconductor devices that satisfy these needs.