Development of the Motor Driver IC SIM1 Series

Kawashima Ryota* **Yamakawa Yuhei***

Abstract The SIM689xM Series offers a wide range of current ratings and is used in inverter-driven white goods. It is assumed that white goods in general will shift to inverters worldwide to promote energy conservation. The market demands a more stable supply and improved quality from this versatile series.

The new SIM1 Series meets these market requirements by adopting the next-generation MIC process to shorten lead time, adding H side OCP (overcurrent protection) to prevent secondary breakdowns, and adding an ESD protection element between LS (low-side power IGBT emitter) and COM (common) to avoid electrostatic breakdown risks during set assembly. In addition, the loss characteristics of some ratings of IGBT products have been optimized and reduced to meet the driving conditions of market applications, thereby broadening the range of applications in which they can be used.

1. Introduction

In recent years, inverter technology, which achieves energy savings, has been advancing in the white goods market, and the need for motor driver ICs has expanded accordingly.

Among our existing motor driver IC products, the SIM689xM series is available in a wide range of ratings from 2A to 10A, and is used in a wide variety of applications. Therefore, as the demand for motor driver ICs increases worldwide in the future, a more stable supply will be required.

Some of the regions where inverter-based products will be newly popularized in the future have poor power supply conditions, and overvoltage due to power supply voltage fluctuations may occur in some of those regions. When overvoltage breakdown occurs, there is a risk of secondary breakdowns spreading, leading to fatal breakdowns such as acoustic or package rupture. To prevent secondary destruction, both the H side and L side of the inverter arm should be able to shut down in case one of them breaks down, so that the other arm can shut down.

As inverter products become more widespread worldwide, set manufacturers are establishing factories in various regions, including emerging countries, to assemble such products in order to ensure mass production. Therefore, there is a risk of destruction by static electricity due to inadequate quality control. Sufficient ESD tolerance is required, including pins to which static electricity may be applied directly to the gates of power elements.

In addition, the existing SIM689xM series has adopted FS-IGBT, a shrink process, in the development process to date, which has expanded the ratings of the power chips that can be mounted from the previous 5A to 10A. However, this series lacks heat dissipation performance because it does not have a down-set structure, which is common for 10A products. Washing machines, which are the main application of this series, require high frequency. Therefore, the adoption of this 10A product has been limited to some small-capacity models with low drive motor current due to the limitation of allowable power dissipation. In terms of current rating, we believe that optimization of the loss characteristics will allow this 10A product to be expanded to a larger capacity model.

To solve these problems, we developed the successor SIM1 Series (Figure 1) in the same package.

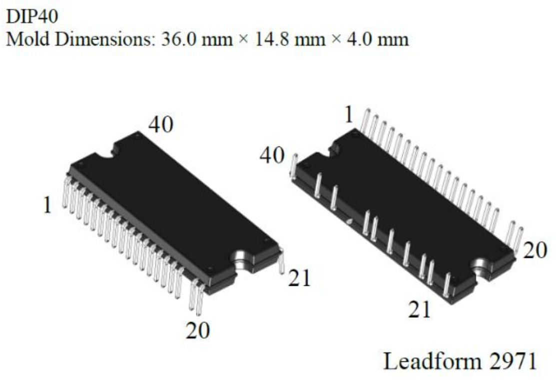

Figure 1: SIM1 Package (Full Mold)

*Development Section 1, Intelligent Power Module Development Department
Power Module Development Division, Engineering Development Headquarters

2. SIM1 Series Configuration

The structure of the product is the same as the conventional product, with four types of chips (power chip, H-side MIC and L-side MIC that control the power chip, and bootstrap diode for current rectification) mounted on a lead frame and molded with high thermal conductivity resin. The package size is the same as the conventional product, 14.8 mm (H) × 36.0 mm (W) × 4.0 mm (D). We have multiple production bases: two in the U.S. and two in Japan for MIC chips, five in Japan and overseas for power chips, and three in Japan, China, and Korea for assembly, to ensure a stable supply even in the event of a disaster. Figure 2 shows the internal block diagram of the SIM1 Series. As for protection functions, the same UVLO (undervoltage lockout), L-side OCP (overcurrent protection), and TSD (thermal shutdown) are provided as in the conventional products. In addition, a new H-side OCP was added. This allows the H side to be shut down even if the Low side breaks down due to overvoltage, preventing secondary destruction.

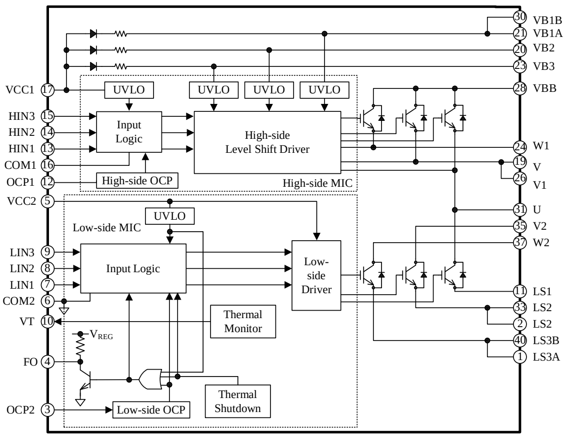

Figure 2: Internal Block Diagram of SIM1 Series

Table 1 shows the main specifications of the SIM1 Series.

In the SIM1 Series, the L-side OCP specification was not changed from the conventional SIM689xM Series, but the H side OCP specification was optimized.

The L-side MIC of the SIM1 Series is equipped with a high-precision temperature monitoring function. The MIC's excellent linearity makes temperature control easy for set manufacturers and provides a temperature monitoring function with a temperature detection accuracy of ±3°C, equivalent to that of a chip thermistor. The temperature monitor output vs temperature characteristics of the SIM1 Series are shown in Figure 3.

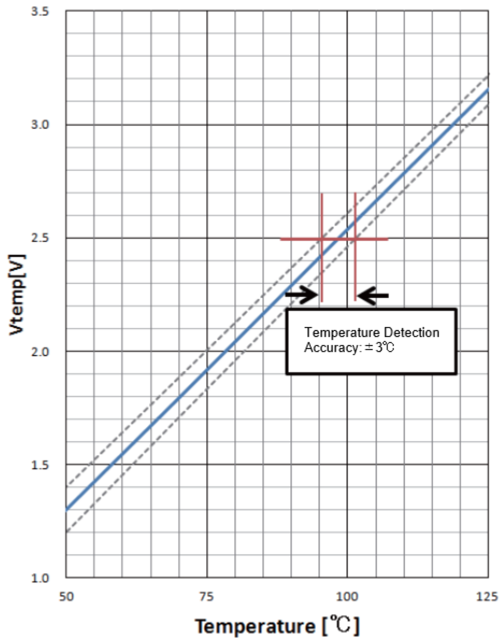

Figure 3: SIM1 Series Temperature Monitor Output vs Temperature Characteristics

Item	Symbol	Specification Value					Unit	Conditions
		SIM1-02D2M	SIM1-03A1M	SIM1-05A1M	SIM1-10F1M	SIM1-10F1A		
Output Power Element	-	SJ-MOS	IGBT				-	
Rated Breakdown Voltage	V_{CES}	600					V	
Rated Output Current	I_O	2.0	3.0	5.0	10.0	10.0	A	
IGBT Output Saturation Voltage TYP/MAX	$V_{CE(SAT)}$	-	1.8/2.3	1.75/2.2	1.65/2.1	2.05/2.5	V	I_C=I_O (Rated Output Current)
MOSFET On-resistance TYP/MAX	$R_{ds(on)}$	3.2/3.6	-	-	-	-	Ω	I_d=I_O (Rated Output Current)/2
Insulation Voltage (MIN)	V_{ISO}	1,500					Vms	Between back surface and lead terminal for AC 1minute
Terminal Spacing	P	1.778					mm	
Thermal Resistance (Junction-to-case)	$R_{(J-C)}$	3.6					°C/W	All elements operate
Thermal Resistance (Joint to Ambient)	$R_{(J-A)}$	25.0					°C/W	
Bootstrap Power Supply Undervoltage Protection	V_{UVHL}	10.0±1.0					V	
	V_{UVHH}	10.5±1.0					V	
Control Power Supply Undervoltage Protection	V_{UVLL}	11.0±1.0					V	
	V_{UVLH}	11.5±1.0					V	
Overheat Protection Operating and Releasing Temperature	T_{DH}	150°C±15°C					°C	
	T_{DL}	120°C±15°C					°C	
H-side Overcurrent Protection Trip Voltage	V_{tripH}	0.7V±10%					V	
L-side Overcurrent Protection Trip Voltage	V_{tripL}	0.5V±8%					V	
H-side Overcurrent Protection Hold Time MIN/TYP	T_{ocpH}	20/25					us	
L-side Overcurrent Protection Hold Time MIN/TYP	T_{ocpL}	5/10					ms	

Table 1: Main Specifications of the SIM1 Series

3. Development of the SIM1 Series

In developing new products, there are four main development concepts to solve the aforementioned issues.

The first is the use of a next-generation process optimized for high-voltage driver ICs to shorten lead times and ensure stable supply. At the same time, we will continue to commonalize MICs by changing the functions of wire options, as well as BCP support for chip and assembly factories.

Second, in addition to the OCP function of the L-side MIC of the existing SIM689xM series, we have added an OCP function to the H-side MIC, to enable upper and lower OCP operation. In regions where power supply conditions are unstable, even if one of the upper and lower arms is damaged by overvoltage, the other arm will always turn off instantly with OCP operation, preventing secondary destruction such as fatal acoustic or package rupture breakdowns.

The third concept is to protect the LS pin, which is connected to the application of static electricity to the gate of the power element with relatively low ESD tolerance, by connecting an ESD protection element installed in the MIC with internal wiring. This avoids the risk of electrostatic breakdown during set assembly.

The fourth concept is to reduce practical losses in 10A-rated IGBTs by optimizing the IGBT process conditions, focusing on washing machine applications where the carrier frequency is set relatively high. This will enable the adoption and deployment of large-capacity models in washing machines, which are the main application of this product.

3.1. Adoption of a next generation MIC process (1)

In the development of our high voltage tolerance BCD process, we have made a selling point of the fact that the process can be used for power supply IC applications, such as high voltage tolerance switching regulators, as well as high-voltage drivers, in a single process. In order to reduce element size and improve performance, development has been mainly directed toward reducing design rules, assuming an all-purpose process.

However, in the high-voltage integrated circuits (HVICs) used in IPM, there are few CMOS logic circuits that can benefit from this technology, so it does not offer much advantage. Therefore, we developed a next-generation process targeting IPMs (Intelligent Power Modules), for which supply stability is desired, by reducing epitaxial growth, the number of masks, and the number of processes, and by applying a revised (expanded) design rule. This shortened lead time and satisfied the demand for stable supply.

Table 2 shows an overview of the process and the main devices to be mounted, comparing the current process with the next-generation process. The maximum operating voltage tolerance of CMOS is set to 20V, in accordance with IPM product specifications. Considering the circuit scale of low-voltage CMOS Logic, the gate oxide film was changed from the dual configuration of the current process to a single configuration of 600Å. The CMOS sidewall formation process and silicide process, which are necessary for miniaturization, were eliminated. The guaranteed voltage for high voltage tolerance devices has also been lowered to 700V to meet specifications.

Figure 4 shows a cross-sectional schematic of the diffusion structure for each process. In the next-generation process, N-Well (NW) regions are formed by high-temperature and long-time diffusion in the P-sub. The NW diffusion layer is set at an appropriate depth to prevent P-Well (PW)-Psub punch-through. The absence of an embedded N+-type diffusion layer shortens lead time by reducing epitaxial growth and embedding processes.

The next-generation process reduces the number of wafer fabrication steps by 25% compared to the current process, thereby reducing fabrication lead time and wafer fabrication cost. Significant improvements have been achieved in both production and cost.

Table 2: Outline of Current and Next-generation Processes

Element Item		Current	Next-generation
Process	Design rule	0.25um	0.50um
	Gate oxide thickness	180Å/800Å	600Å
	Embedded Epi	Applied	Not applied
	Sidewall	Applied	Not applied
	Salicide	Applied	Not applied
	Wiring Structure	2Poly/2Metal	
Device	CMOS	5V/7V	7V
		20V/30V	20V
	NPN	7V/20V/30V	20V/30V
	PNP	7V/20V/40V	なし
	Diode	Various	
	Resistance	Various	
	Capacitor	Various	
	高圧Nch MOS	150V/600V/900V	700V
	高圧Pch MOS	150V/600V	なし
	JFET	900V	700V

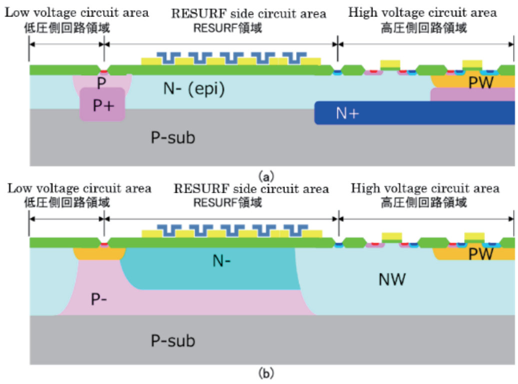

Figure 4: Cross-sectional View of Diffusion Structure
(a) Current process (b) Next-generation process

3.2. H-side OCP function to prevent secondary destruction

Figure 5 shows a circuit diagram around the control pins of SIM1. In the SIM1 Series, the OCP function and OCP pin are also added to the H-side IC. As with the L side, a shunt resistor Rs is connected to the OCP pin to enable the OCP function on the H side. This allows the gate of the H-side power element to be shut down immediately in the event that a short-circuit failure of the L-side power element due to an anomaly turns on the H side and causes an excessive through-current to flow, thereby preventing secondary breakdown of the H-side power element.

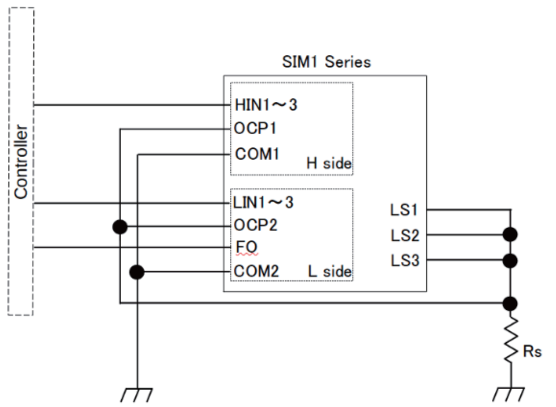

Figure 5: Circuit Diagram Around the Control Pins of SIM1

Here, due to the limitation of the number of SIM1 terminals, the FO (error signal output) pin could not be provided on the H side as shown in Figure 5. However, when the H-side OCP operates, the L-side OCP also always operates to transmit alarm signals from the FO pin to the host controller.

3.3. Optimization of 10A-rated IGBT Process Conditions

Compared to the conventional 10A product SIM6897M, the new 10A product SIM1-10F1M has reduced switching losses through revision of the FS-IGBT process conditions, resulting in reduced losses in washing machine applications driven at a relatively high carrier frequency.

As shown in Figure 6, the *V*ce (sat) – *E*off(switching OFF loss) trade-off characteristic is improved by increasing the size of the FS-IGBT, and reducing the collector dose significantly reduces *E*off while keeping the *V*ce (sat) rise to a minimum. Note that a smaller collector dose results in a smaller tail current at switching OFF (see Figure 7), and thus a smaller *E*off.

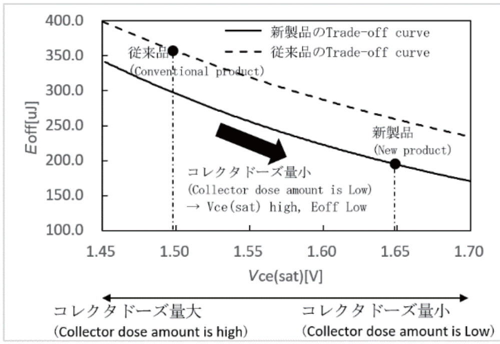

Figure 6: How to Optimize IGBT Process Conditions

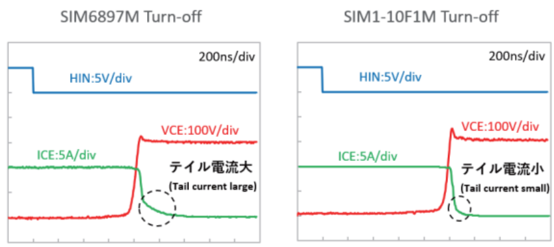

Figure 7: Comparison of SW Waveforms at Turn-off

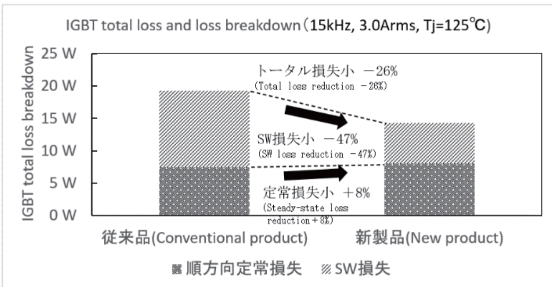

Figure 8: IGBT Total Loss and Loss Content

As shown in Figure 8, when the carrier frequency is high, the switching loss associated with the *E*off reduction decreases. As a result, the IGBT total loss was reduced by 26% compared to the conventional product. This compensates for the lack of heat dissipation performance of the SIM package and enables deployment to high-capacity models.

4. Conclusion

The adoption of the next-generation MIC process to shorten lead times and other measures has made it possible to provide the stable supply required by the growing demand for motor driver ICs in the future.

In addition, the addition of the H-side OCP function prevents the expansion of secondary breakdown after the breakdown of the one-arm power element, and the addition of an ESD protection element between LS and COM avoids the risk of electrostatic breakdown during set assembly. These changes result in a significant improvement in quality over the previous SIM689xM Series, and enable safe use in various regions.

Furthermore, by reducing switching losses, the SIM1 Series has been able to expand its application area beyond that of conventional products by reducing losses through optimization of IGBT process conditions, even in the case of washing machine applications where the carrier frequency is relatively high.

In the future, we will consider improving heat dissipation by adopting a down-set structure, etc., to further expand the area of use.

References

(1) Aoki; Sanken Technical Report, Vol. 55, p.22-25, (2023.11)