Features and precautions for DTMOS VI(HSD)

Description

DTMOS VI(HSD) (High Speed Diode) is a super junction MOSFET with a high-speed body diode type. This document shows the technical features of DTMOS VI(HSD), compares its characteristics with our conventional products and competitors' products, and explains its performance when mounted on actual power supplies.

Toshiba Electronic Devices & Storage Corporation

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1. Product Overview

DTMOS VI(HSD) (High Speed Diode) is a super junction MOSFET with a lifetime control process applied to the DTMOS VI standard product. It is a successor product group to the previous generation DTMOS IV(HSD). It has the characteristic of low reverse recovery charge, which is a feature of the HSD type, and has reduced the performance index "on-resistance between drain and source × reverse recovery charge" ($R_{DS(ON)}$ × Qrr). In addition, the performance index "on-resistance between drain and source × gate-drain charge" ($R_{DS(ON)}$ × Qgd) has been greatly improved compared to DTMOS IV(HSD). It is an optimal product for LLC resonant DC-DC converters (LLC) and phase-shift full-bridge circuits (PSFB) on the primary side of industrial power supplies, communication and server power supplies, and contributes to improving power conversion efficiency of power supplies.

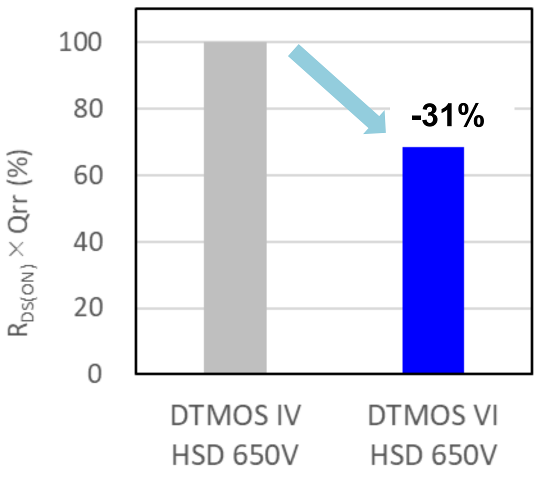


Figure 1.1 $R_{DS(ON)}$ × Qrr

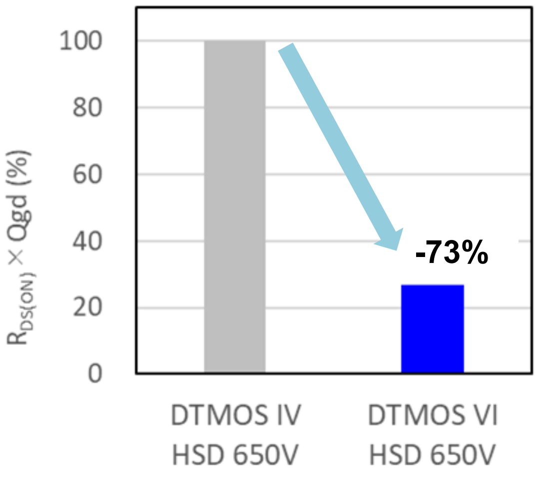


Figure 1.2 $R_{DS(ON)}$ × Qgd

2. Product Positioning and Features in Application

2.1. Product positioning in Application

In the industrial power supply market, the power dissipation for power supplies for servers, data centers, and base stations, which are the core of digitalization such as 5G, big data, AI, IoT, robotics and DX is rapidly increasing with the expansion of demand, and the necessity of high efficiency and low loss is increasing. To achieve high efficiency and to reduce the switching losses, the soft switching topology is progressing. LLC and PSFB are being adopted as major soft switching circuits. In these circuits, the reverse recovery characteristics of the body diode of the MOSFET is important. For example, in the LLC circuit, when the switching frequency of the MOSFET decreases and deviates from the resonant frequency during overload, etc. (Figure 2.3), one MOSFET turns on while the body diode of the other MOSFET is conducting current, entering reverse recovery mode, and causing large losses or destruction due to through current. Similarly, during power startup or similar situations, before the conduction current of the MOSFET changes from reverse direction (source to drain) to forward direction (drain to source), if the other MOSFET turns on (as shown in Figure 2.4), it also enters reverse recovery mode. In this case, the through current may lead to significant losses or damage. By shortening this reverse recovery operation, it is possible to reduce losses or destruction. The HSD type MOSFET products improved reverse recovery characteristics.

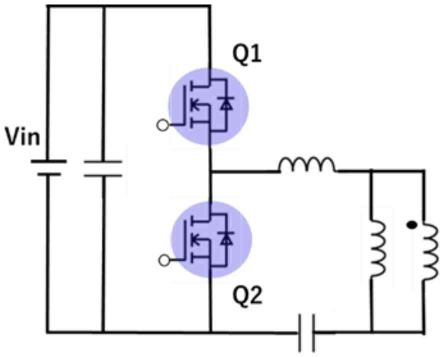


Figure 2.1 Primary side circuit diagram of LLC converter

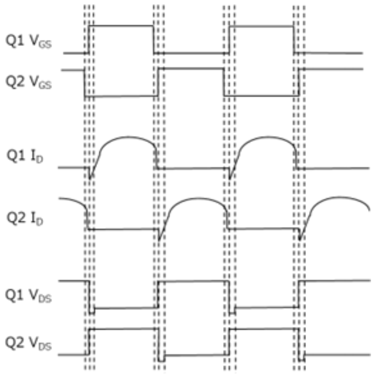
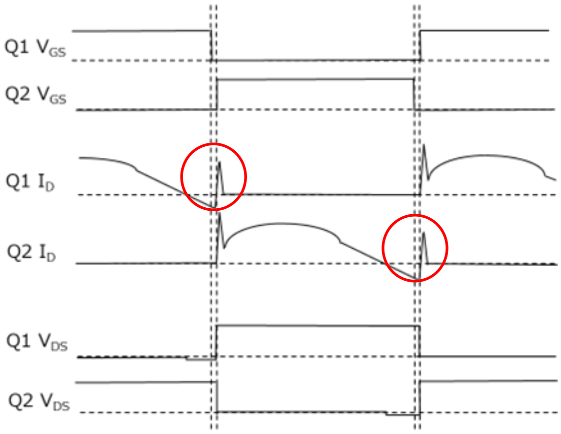
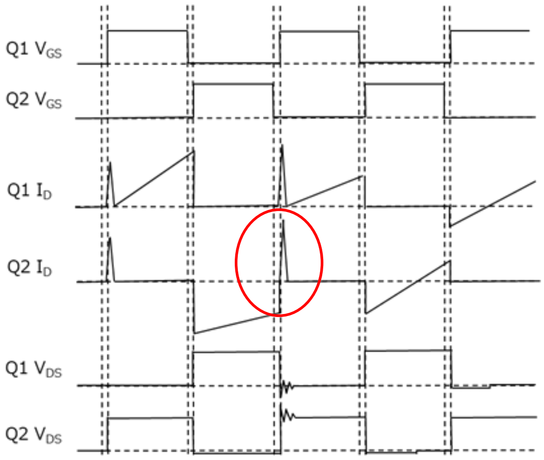


Figure 2.2 MOSFET operation on the primary side of LLC converter



○ : Area with high reverse recovery loss

Figure 2.3 MOSFET operation when deviating from resonance in LLC



○ : Area with high reverse recovery loss

Figure 2.4 MOSFET operation during power supply startup in LLC

2.2. Reverse Recovery Operation

A large number of carriers are injected by applying a forward bias voltage between the source to the drain of body diode of the MOSFET. And then, if the bias is applied between the drain and the source while current flows the source to the drain, the injected holes move to the source and the electrons move to the drain. The time until completed these carriers move is called the reverse recovery time (trr). During this trr operation, a shoot-through current flows into the MOSFET and causing losses.

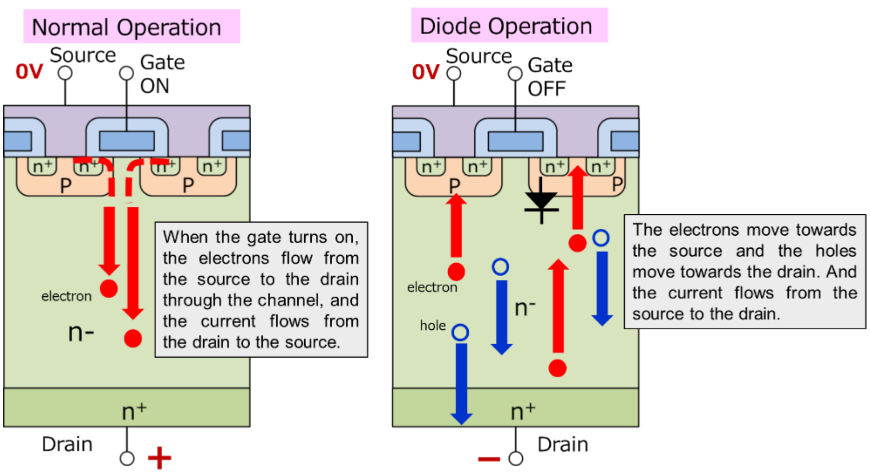


Figure 2.5 Carrier movement in the body diode

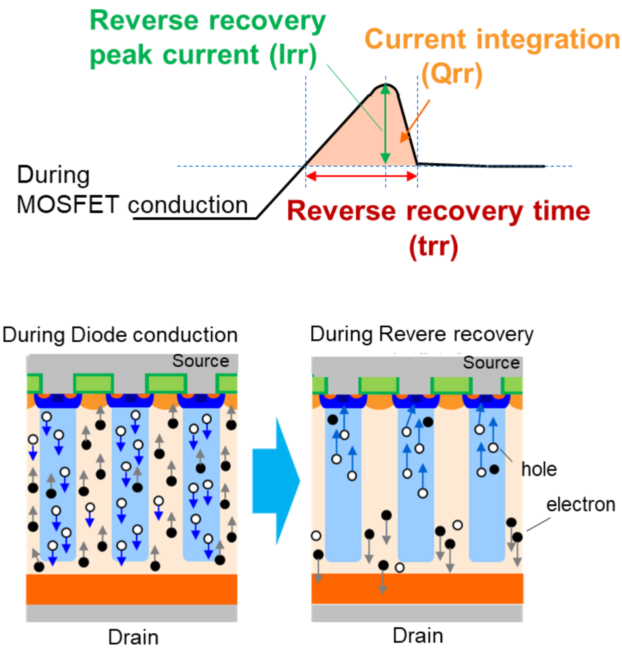


Figure 2.6 Reverse recovery operation

2.3. Improvement of Reverse Recovery Characteristics

To reduce losses in reverse recovery operation, it is necessary to shorten the reverse recovery time of the diode. In DTMOS VI(HSD), a method of injecting impurities into the drift layer to create trap levels (lifetime control process) was applied to promote the disappearance of carriers by recombining electrons and holes. As a result, the carriers injected during diode conduction are trapped and reduced, and trr is shortened.

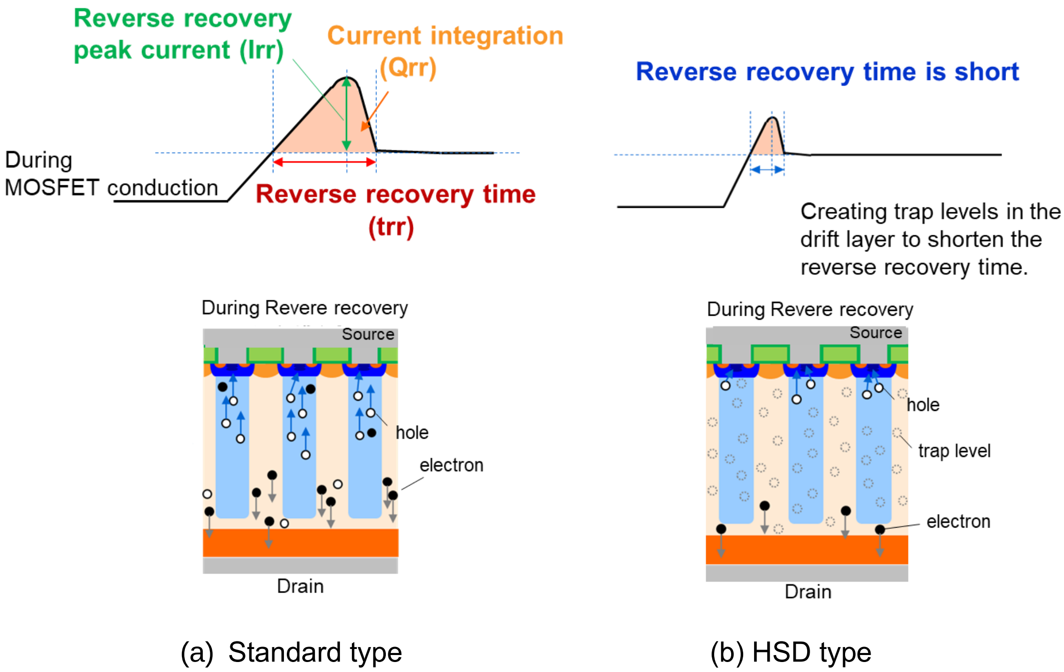


Figure 2.7 Improvement of reverse recovery operation

2.4. Product Features

DTMOS VI(HSD) is a product group of the latest generation of DTMOS VI with a lifetime control process introduced. It improves various characteristics compared to the standard type of DTMOS VI and the previous generation DTMOS IV(HSD). Compared to the standard type of DTMOS VI, it achieves a 65% reduction in reverse recovery time (trr) and an 88% reduction in reverse recovery charge (Qrr) (test conditions: $-dI_{DR}/dt$=100A/μs). Compared to DTMOS IV(HSD), the high-temperature I_{DSS} characteristics have been improved. In addition, $R_{DS(ON)}$ × Qgd maintains the same characteristics as the standard type of DTMOS VI and is reduced by 70% compared to DTMOS IV(HSD).

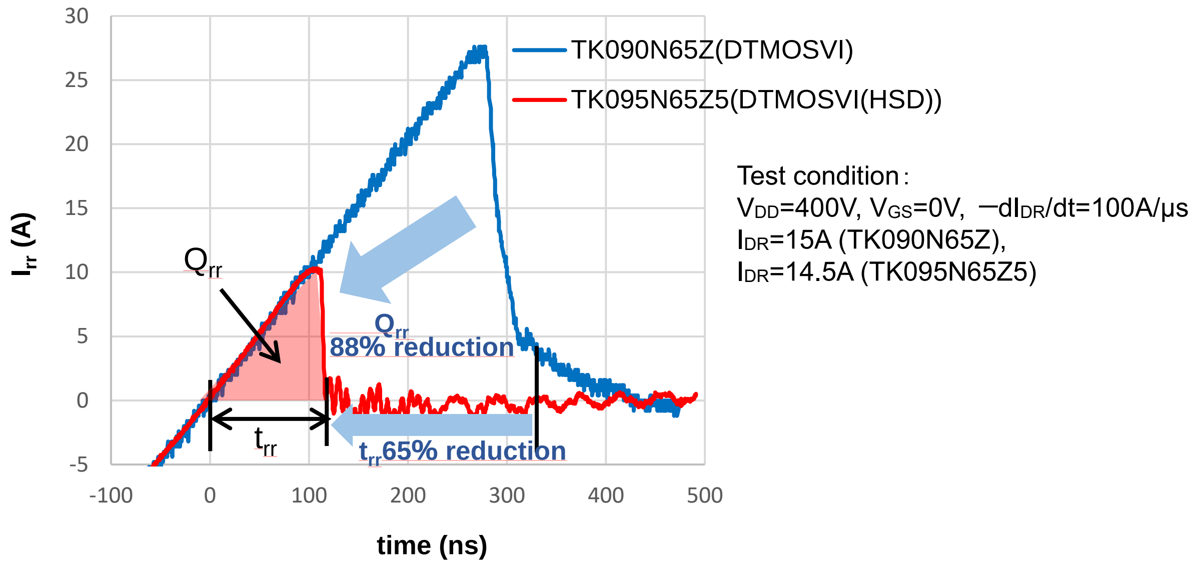


Figure 2.8 Comparison of trr and Qrr between DTMOS VI HSD type and STD type

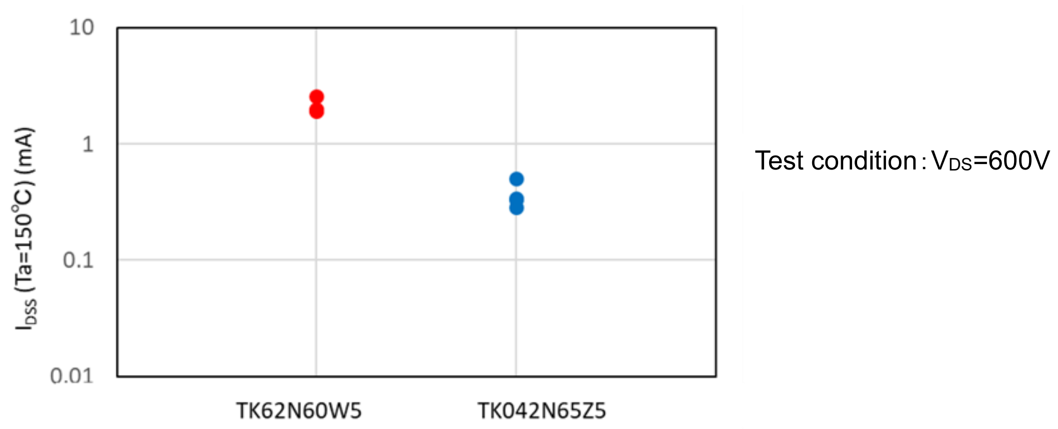


Figure 2.9 Comparison of I_{DSS} (Ta=150℃) between DTMOS IV(HSD) and DTMOS VI(HSD)

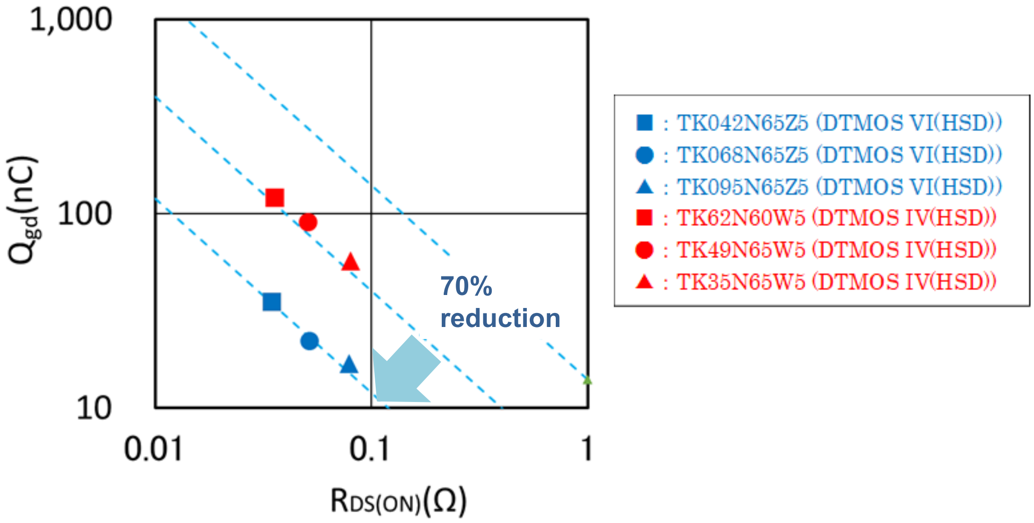


Figure 2.10 Comparison of $R_{DS(ON)}$ × Qgd

3. Characteristic Comparison

To confirm the positioning of DTMOS VI(HSD), the main items of product characteristics were compared with previous generation products and competitors' products. The comparison was made with previous generation products (TK62N60W5, TK49N65W5) and competitors' products (Competitor A, B, C, D) that have equivalent $R_{DS(ON)}$ characteristics to TK042N65Z5 of DTMOS VI(HSD).

Table 3.1 List of competitors' product characteristics

Competitor	V_{DSS}	$R_{DS(ON)}$ max
Competitor A	600V	40mΩ
Competitor B	650V	41mΩ
Competitor C	600V	40mΩ
Competitor D	600V	43mΩ

3.1. Reverse Recovery (trr) Characteristics

As a characteristic of the MOSFET's body diode, the trr waveform comparison is shown in the figure 3.1. TK042N65Z5, which is DTMOS VI(HSD), has the same level of trr characteristics as Competitor B with the same 650V withstand voltage. When TK042N65Z5 is mounted on an actual power supply, it is expected that the loss in reverse recovery operation will be the same as Competitor B.

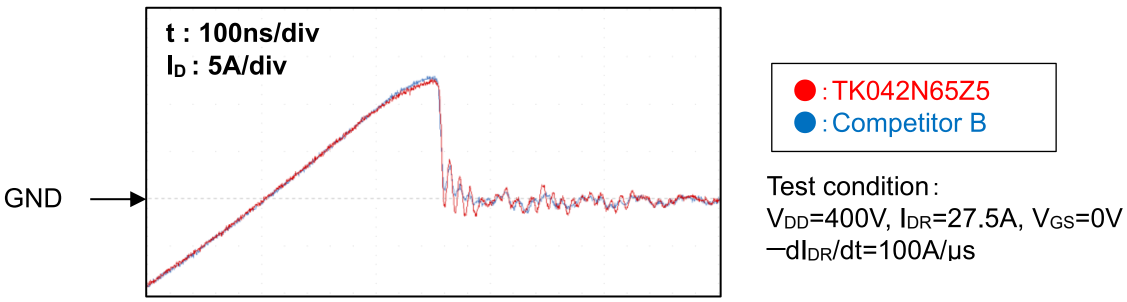


Figure 3.1 trr waveform comparison

In addition, destruction tolerance under high $-dI_{DR}/dt$ conditions during trr operation was compared. The results are shown in Figure 3.2. DTMOS VI(HSD) tends to have higher tolerance compared to competitor products. This characteristic makes DTMOS VI(HSD) a product that is easy to use in various circuit boards due to its high tolerance under high $-dI_{DR}/dt$ conditions.

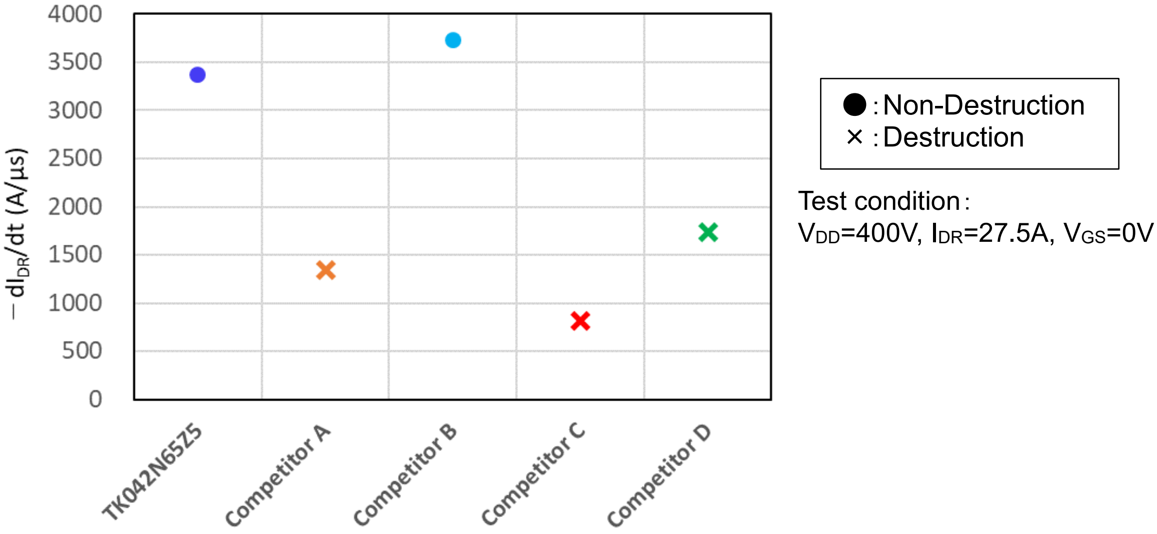


Figure 3.2 trr Tolerance Comparison

3.2. V_{DSF} Characteristics

As a characteristic of the body diode, the I_{DR}-V_{DSF} characteristic comparison is shown in Figure 3.3. The comparison is made under the condition of V_{GS}=5V. Since the channel opens and the FET conducts at V_{GS}=5V or higher, the low on-resistance characteristic of TK042N65Z5 results in a low V_{DSF} value. This characteristic is effective when the body diode conducts in an LLC circuit and when the gate voltage is applied in that state, contributing to the reduction of overall power loss when using DTMOS VI(HSD) products in LLC circuits.

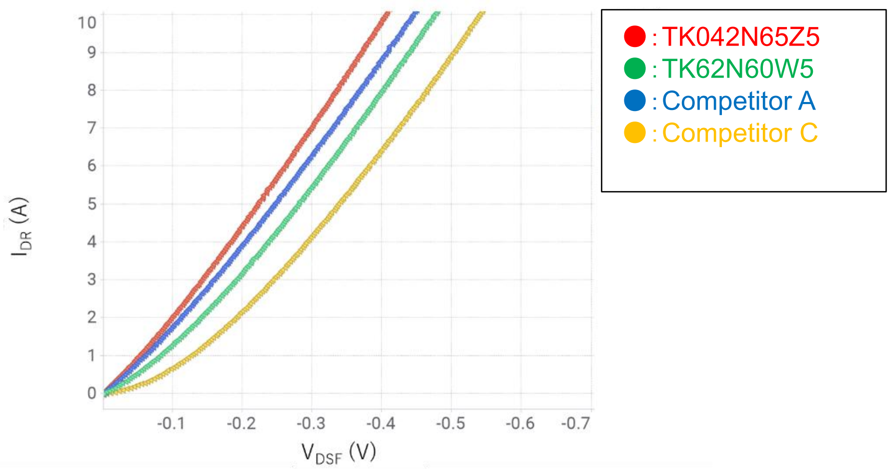


Figure 3.3 I_{DR}-V_{DSF} (V_{GS}=5V) Comparison

3.3. I_{DSS} Characteristics

The I_{DSS} of the HSD type is a large value compared to the standard type and is an item to be noted. The high-temperature characteristic comparison of I_{DSS} (Ta=100 - 150℃) is shown in Figure 3.4. DTMOS VI (HSD) has the same limit as DTMOS IV(HSD) at room temperature with an upper limit of 100μA, but its performance is significantly improved at high temperatures. In the high-temperature comparison of I_{DSS} at Ta=150℃ with competitors, TK042N65Z5 shows an I_{DSS} value of less than half that of Competitor C, making DTMOS VI(HSD) superior.

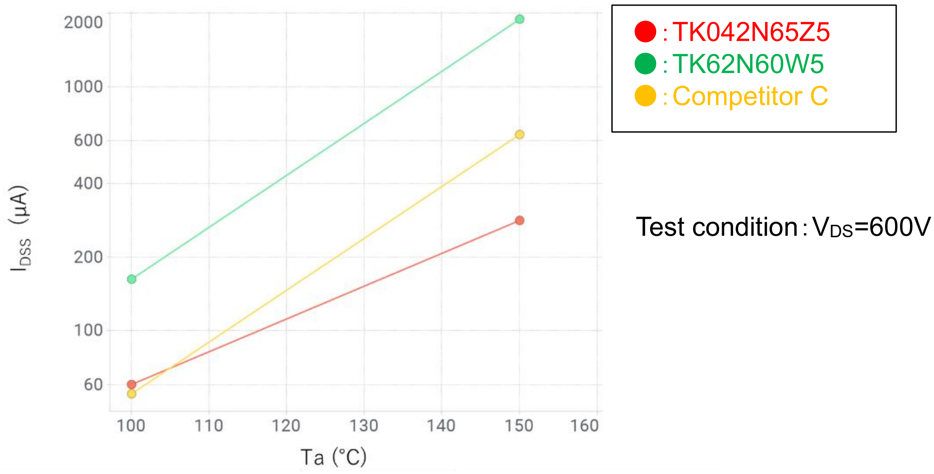
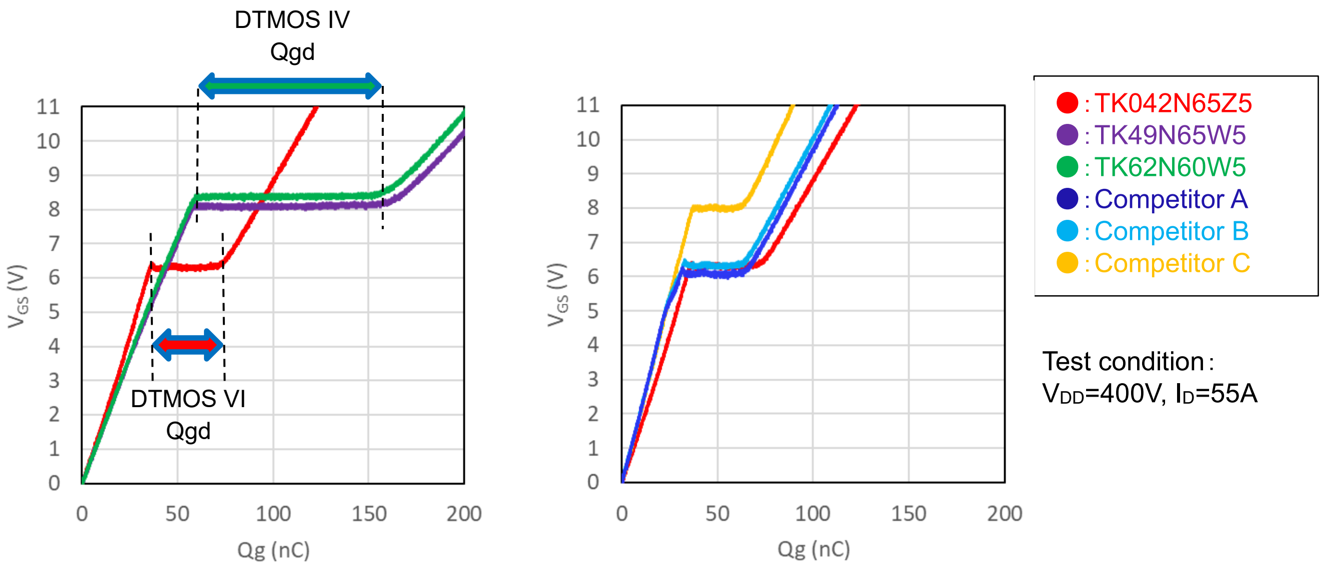


Figure 3.4 High-Temperature I_{DSS} -Ta Comparison

3.4. Qg Characteristics

The Qg waveform comparison is shown in Figure 3.5. DTMOS VI(HSD) has significantly improved Qg and Qgd by optimizing the MOSFET structure, reducing the capacitance between the gate-source and gate-drain (Qg: 40% reduction, Qgd: 65% reduction) compared to DTMOS IV(HSD). This improves the switching speed of the MOSFET and reduces switching losses. It also reduces gate drive losses and the load current of the driver. In comparison with competitor products, Qgd of DTMOS Ⅵ(HSD) is second lowest after Competitor C and equivalent to Competitor A and B.



(a) Qg Self-Comparison (b) Qg Competitor Comparison

Figure 3.5 Qg Waveform Comparison

3.5. L-Load Switching Characteristics

We compared the waveforms and losses when the MOSFET was operated with inductive(L) Load switching. The measurement circuit diagram is shown in Figure 3.6, and the switching waveforms and measurement points are shown in Figures 3.7 and 3.8. The measurement point is the dV/dt of the V_{DS} rise waveform at turn-off, and the comparison is made by varying the external Rg. The Eon and Eoff during switching were also measured and compared by varying the Rg. The dV/dt comparison results are shown in Figure 3.9. DTMOS VI(HSD) TK042N65Z5 tends to have a lower dV/dt value compared to other products. It was also confirmed that increasing the value of the external Rg further reduces the dV/dt value. Depending on the actual board used, the dV/dt value may increase, but it can be adjusted by changing the external Rg.

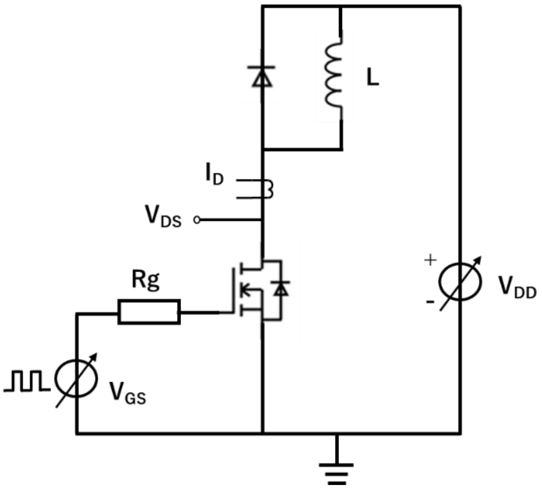
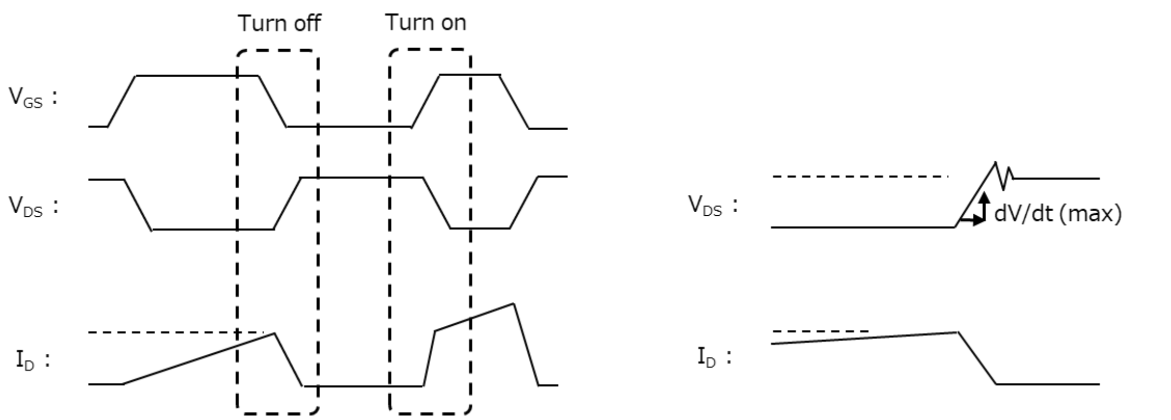


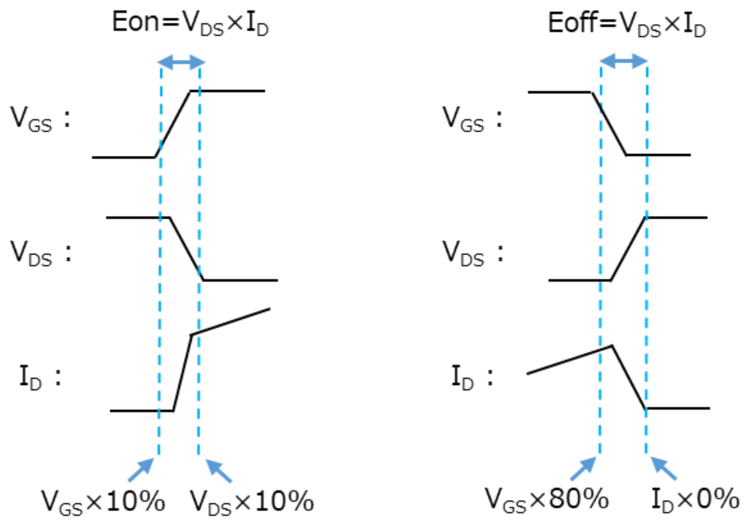
Figure 3.6 L-Load Switch Measurement Circuit



(a) Overall Waveform Image

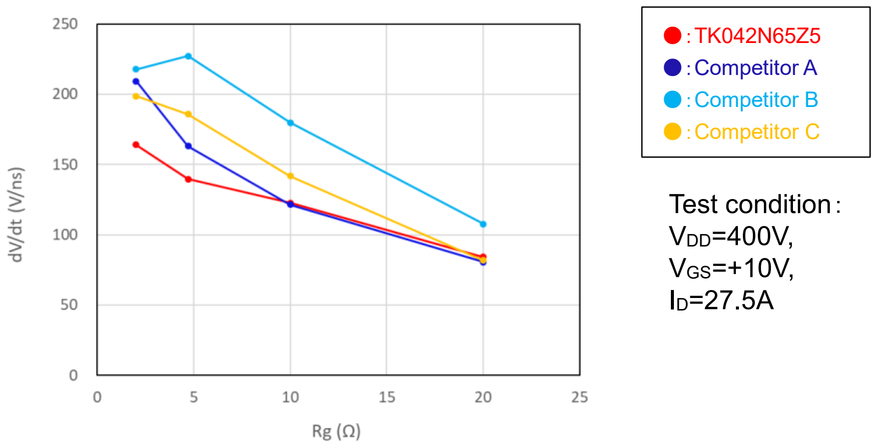
(b) Enlarged Waveform Image (Turn off)

Figure 3.7 L-Load Switch Waveform and dV/dt Measurement Points



(a) Eon Waveform Image (b) Eoff Waveform Image

Figure 3.8 L-Load Switch Waveform and Eon, Eoff Measurement Points



Test condition:
V_{DD}=400V,
V_{GS}=+10V,
I_D=27.5A

Figure 3.9 L-Load Switch dV/dt Comparison by Rg Condition

The total loss Eon+off in L-load switching in the circuit of Figure 3.6 was compared. The Eon+off comparison by I_D current condition is shown in Figure 3.10. DTMOS VI(HSD) TK042N65Z5 has the lowest value in all current ranges. Especially at higher current condition, the difference with Competitor C widens significantly, making it superior to competitor products. It is understood that DTMOS VI(HSD) has low loss, and it is considered that it can contribute to improving efficiency under heavy load conditions when mounted on an actual power supply. Figure 3.11 shows the comparison of Eon+off when the I_D current condition is fixed at 27.5A and the external Rg condition is varied. In all Rg ranges, the Eon+off value of TK042N65Z5 is smaller and stable with low loss compared to competitor products. It is possible to control the waveform with the external Rg to adjust the dV/dt, while also suppressing a significant increase in loss even when increasing the Rg.

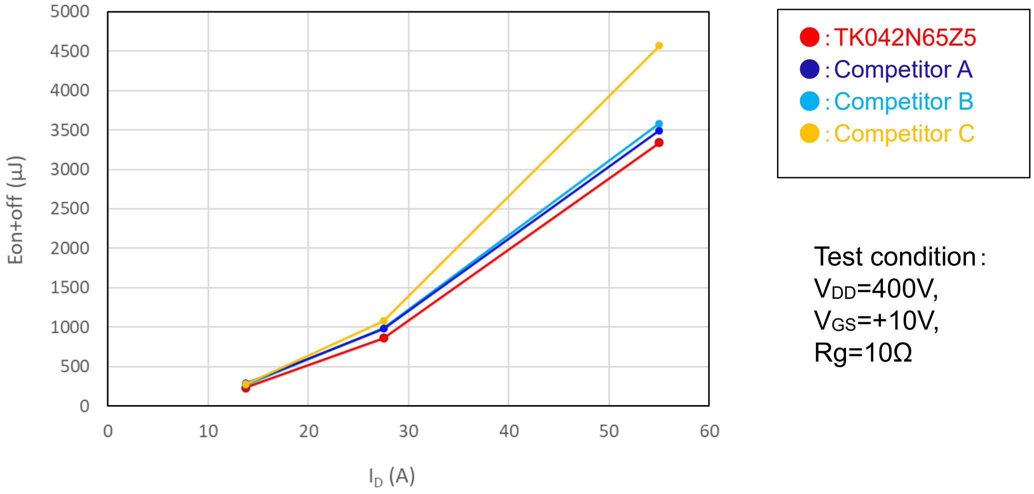


Figure 3.10 Eon+Eoff Comparison by I_D Condition

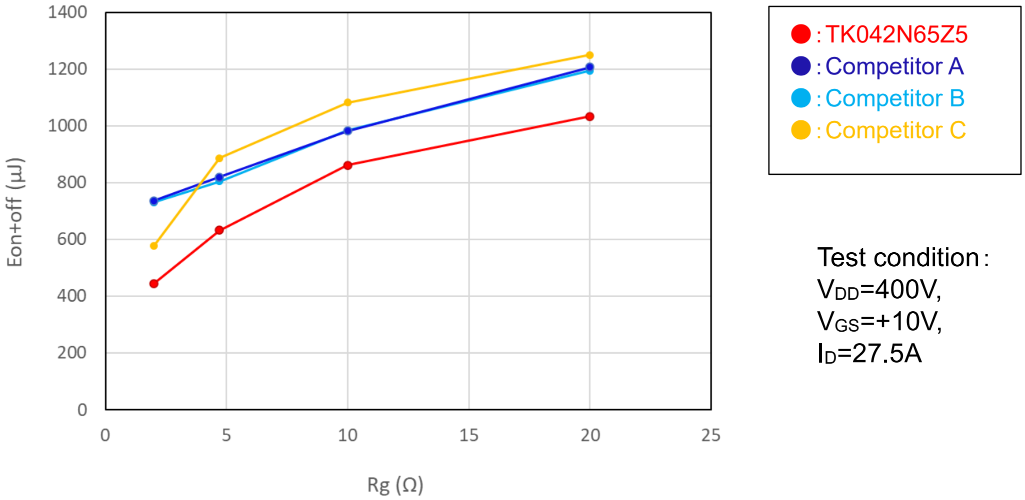
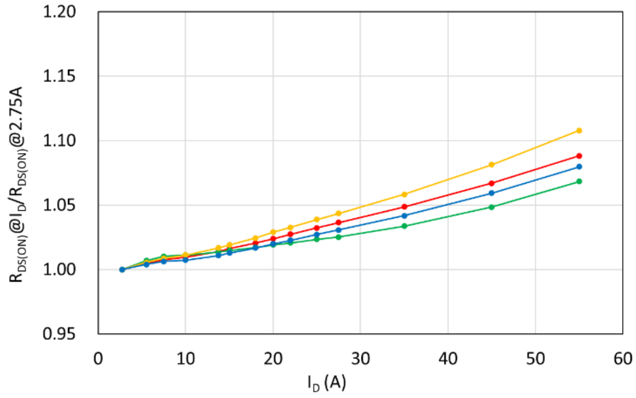


Figure 3.11 Eon+Eoff Comparison by Rg Condition

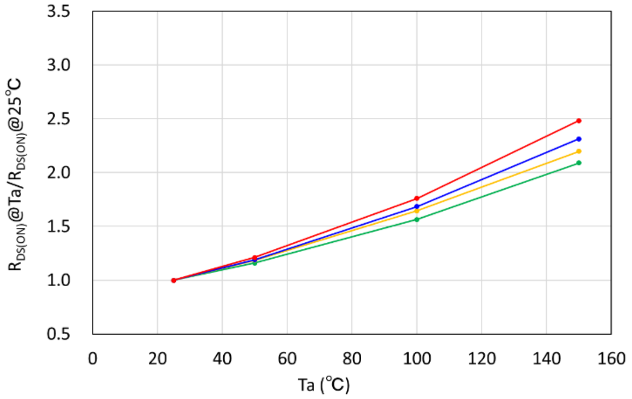
3.6. $R_{DS(ON)}$ Characteristics

The comparison of $R_{DS(on)}$ characteristics with competitor products is shown below. As I_D increases, $R_{DS(on)}$ also increases, but DTMOS VI(HSD) shows a similar rate of increase to competitor products. Regarding $R_{DS(on)}$-Ta characteristics, there is a tendency for $R_{DS(on)}$ to increase at high temperatures. Although the rate of increase for DTMOS VI(HSD) is slightly higher than that of competitor products, it is generally considered to be not significantly different. Please pay attention to the temperature environment and operating temperature during actual use, and it is recommended to use temperature derating.



Test condition: V_{GS}=10V, Ta=25℃

Figure 3.12 Normalized $R_{DS(on)}$-I_D Comparison



Test condition: V_{GS}=10V, I_D=27.5A

Figure 3.13 Normalized $R_{DS(on)}$-Ta Comparison

4. Efficiency of Actual Board (Competitor Comparison)

4.1. Comparison When mounted on LLC Converter

We conducted a comparative evaluation of power conversion efficiency when replacing MOSFETs in an actual power supply. The evaluation used a 1.5kW output LLC resonant DC-DC converter board, and the results of measuring the power conversion efficiency when replacing the primary side MOSFETs Q1 and Q2, as shown in Figure 4.1, are presented in Figure 4.2.
The efficiency when using DTMOS VI(HSD) TK042N65Z5 is improved across all load ranges compared to when using DTMOS IV(HSD) TK62N60W5. As confirmed in the MOSFET characteristics comparison (Table 4.1), the $R_{DS(on)}$ is reduced, improving conduction losses, and the improvement in switching losses Eon+Eoff (Figure 4.3) is also reflected in the actual efficiency. Additionally, in comparison with competitor products, the efficiency when using DTMOS VI(HSD) is at the same level as when using Competitor A. Since the $R_{DS(on)}$ values of the main MOSFET characteristics are similar, there is no significant difference in actual efficiency. The Eon+Eoff is superior in DTMOS VI(HSD), contributing to higher efficiency under heavy load conditions.

Table 4.1 Comparison of Measured Characteristics of Products Used in Actual Evaluation

Product	$R_{DS(ON)}$ (I_D=27.5A,V_{GS}=10V)	V_{DSF} (I_D=-55A,V_{GS}=0V)	Qrr (V_{DD}=400V,I_{DR}=27.5A, -dI_{DR}/dt=100A/μs)
TK042N65Z5 (DTMOSVI)	32.2 mΩ	1.04 V	1009 nC
TK62N60W5 (DTMOSIV)	36.6 mΩ	1.12 V	660 nC
Competitor A	33.8 mΩ	1.16 V	825 nC

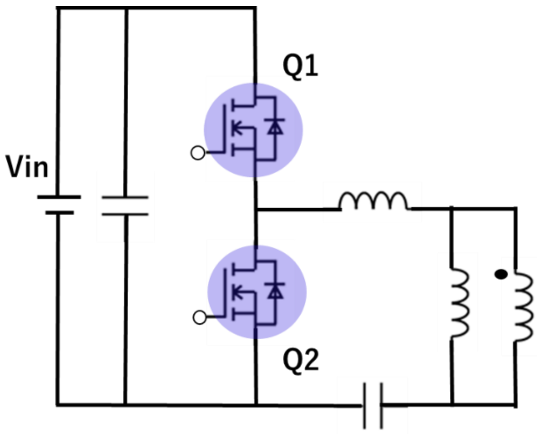
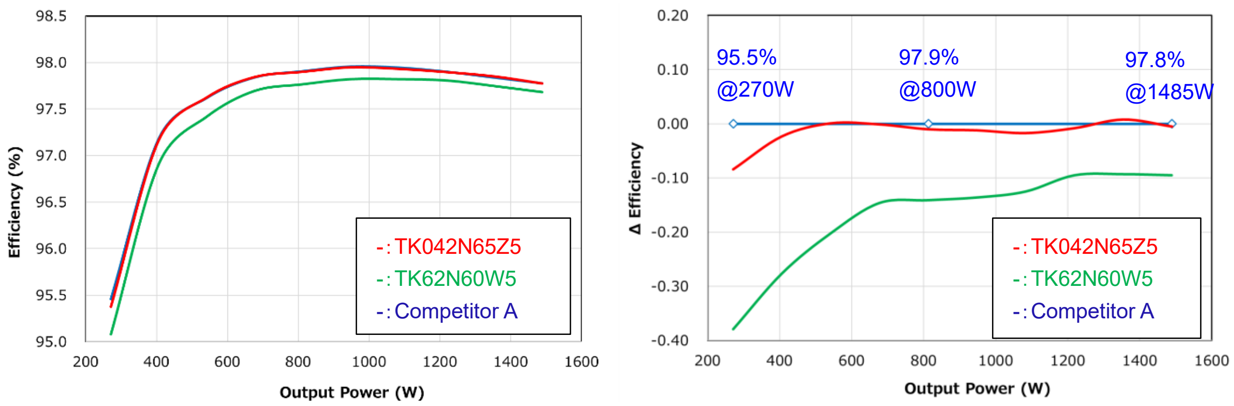


Figure 4.1 1.5kW LLC Converter Primary Side Circuit Diagram

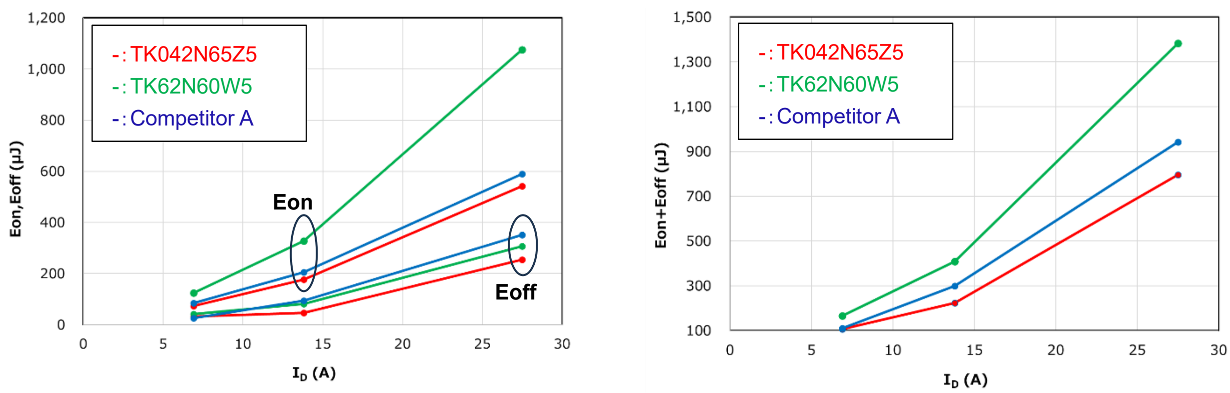
Table 4.2 Evaluation Conditions in LLC Converter

Input Voltage	380V
Output Voltage	54V
Output Power	～1485W
Gate Driving Conditions	V_{GS}=14V External Rg (on)=47Ω External Rg (off)=1.0Ω



(a) Absolute Efficiency Curve Comparison (b) Baseline Efficiency Curve Comparison

Figure 4.2 Efficiency Comparison



Test condition : V_{DD}=400V, V_{GS}=+10V, Rg=10Ω

Test condition : V_{DD}=400V, V_{GS}=+10V, Rg=10Ω

(a) Eon, Eoff Comparison (b) Eon+Eoff Comparison

Figure 4.3 Switching Loss Eon, Eoff, Eon+Eoff Comparison

4.2. Comparison When mounted on PSFB

We conducted a comparative evaluation of power conversion efficiency when replacing MOSFETs in the primary side (phase-shift full-bridge (PSFB) circuit) of a 1.6kW AC-DC power supply board. The results are shown in Figure 4.5.
Comparing the efficiency of DTMOS IV(HSD) TK095N65Z5 (650V, 95mΩ Max, TO-247 package) with a similarly spec'd Competitor E (600V, 90mΩ Max, TO-247 package), the efficiency of TK095N65Z5 is higher across all load ranges. As for product characteristics, although the $R_{DS(on)}$ of TK095N65Z5 is higher than that of Competitor E (see Figure 4.7), its lower V_{DSF} characteristic (see Figure 4.6) and lower switching loss (Eon+Eoff) characteristic (see Figure 4.8) contribute to be higher efficiency.

Table 4.3 Comparison of Measured Characteristics of Products Used in Actual Evaluation

Product	$R_{DS(ON)}$ (I_D=14.5A, V_{GS}=10V)	V_{DSF} (I_D=-25A, V_{GS}=0V)	Qrr (V_{DD}=400V, I_{DR}=14.5A, -dI_{DR}/dt=100A/μs)
TK095N65Z5 (DTMOSVI)	74.7 mΩ	0.98 V	630 nC
Competitor E	71.9 mΩ	1.09 V	449 nC

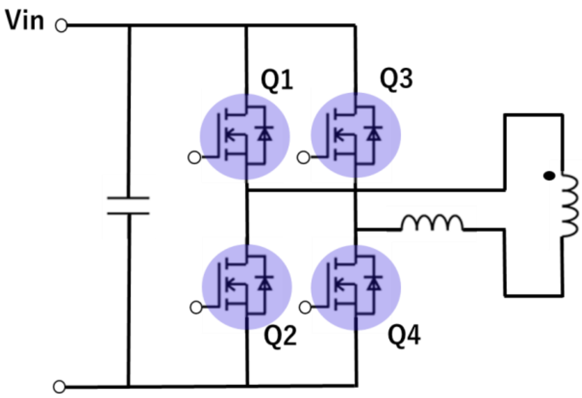


Figure 4.4 1.6kW AC-DC Power Supply PSFB Primary Side Circuit Diagram

Table 4.4 Evaluation Conditions in 1.6kW AC-DC Power Supply

Input Voltage	230V AC
PSFB Input Voltage	400V DC
PSFB Output Voltage	48V DC
Switching Frequency	100kHz
Output Power	~1600W
Gate Driving Conditions	V_{GS}=±12V External Rg (on)=3.3Ω External Rg (off)=3.3Ω

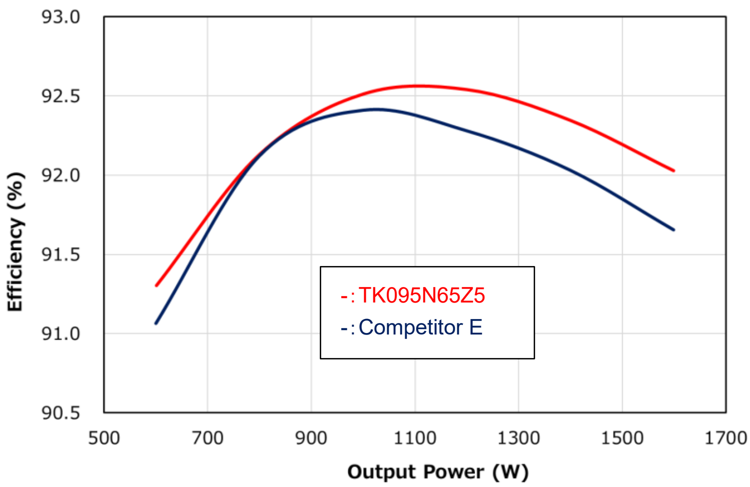
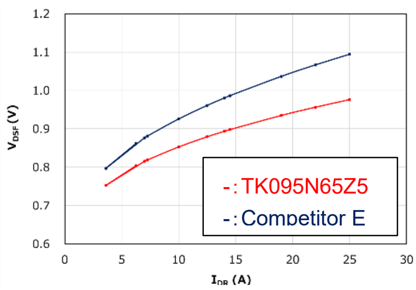
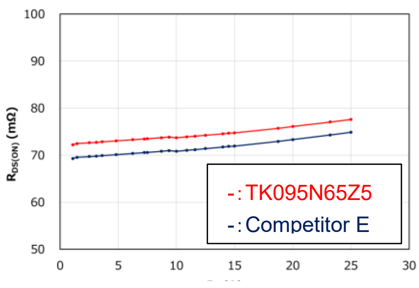


Figure 4.5 Efficiency Comparison



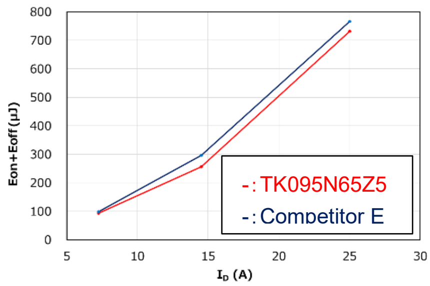
Test condition: V_{GS}=0V

Figure 4.6 V_{DSF}-I_{DR} Comparison



Test condition: V_{GS}=10V

Figure 4.7 $R_{DS(on)}$–I_D Comparison



Test condition: V_{DD}=400V, V_{GS}=+10V, Rg=10Ω

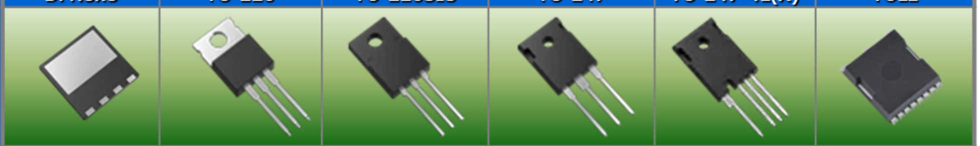
Figure 4.8 Eon+Eoff Comparison

5. DTMOS VI(HSD) Lineup

The DTMOS VI(HSD) series lineup of 650V and 600V rated products is being expanded as shown in the table below.

Table 5.1 DTMOS VI(HSD) Lineup

As of September 2025

V_{DSS} (V)	$R_{DS(ON)}$ Max (Ω)	DFN8x8	TO-220	TO-220SIS	TO-247	TO-247-4L(X)	TOLL
							
650	0.200	TK200V65Z5	TK200E65Z5	TK200A65Z5			TK200U65Z5
	0.165	TK165V65Z5	TK165E65Z5	TK165A65Z5			TK165U65Z5
	0.115	TK115V65Z5	TK115E65Z5	TK115A65Z5	TK115N65Z5	TK115Z65Z5	TK115U65Z5
	0.095	TK095V65Z5	TK095E65Z5	TK095A65Z5	TK095N65Z5	TK095Z65Z5	TK095U65Z5
	0.068				TK068N65Z5	TK068Z65Z5	TK068U65Z5
	0.042				TK042N65Z5	TK042Z65Z5	
600	(0.155)/(0.165)	TK(165)V60Z5	TK(155)E60Z5	TK(155)A60Z5			TK(155)U60Z5
	(0.125)/(0.13)	TK(130)V60Z5	TK(125)E60Z5	TK(125)A60Z5			TK(125)U60Z5
	(0.090)/(0.095)	TK(095)V60Z5	TK(090)E60Z5	TK(090)A60Z5	TK(090)N60Z5	TK(090)Z60Z5	TK(090)U60Z5
	(0.073)/(0.077)	TK(077)V60Z5	TK(073)E60Z5	TK(073)A60Z5	TK(073)N60Z5	TK(073)Z60Z5	TK(073)U60Z5
	(0.055)/(0.058)	TK(058)V60Z5			TK(055)N60Z5	TK(055)Z60Z5	TK(055)U60Z5
	(0.040)				TK(040)N60Z5	TK(040)Z60Z5	
	(0.034)				TK(034)N60Z5	TK(034)Z60Z5	

In mass production
Under development

6. Summary

We have developed the DTMOS VI(HSD) as a high-speed body diode type super junction MOSFET using in high-power, high-efficiency power supplies for data centers, base stations, and AI servers. Compared to the DTMOS VI standard products, this product series improves the trr characteristics of the body diode and reduces the high-temperature I_{DSS} characteristics. Additionally, it improves the performance index $R_{DS(on)}$×Qgd by 73% compared to the previous DTMOS IV(HSD) products. This contributes to improved power supply efficiency by reducing losses. In our actual measurement using power supplies, we confirmed the efficiency improvements by using DTMOS Ⅵ(HSD) compared to our existing products.
We are expanding the lineup of this series and provide products that contribute to reducing losses and energy saving in power supplies and other industrial equipment.

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