

Efficiency Evaluation and Loss Analysis of 300W isolated DC-DC converter

Toshiba U-MOSX-H Series Power MOSFET
Ideal for 48Vin, 12Vout DC-DC converters

Description

This application note first describes the basic operation of the 300W isolated DC-DC converter adopted for the reference design ^(Note1). After that, the efficiency evaluation results are explained. Furthermore, the loss of the switching devices is analyzed using a high accuracy electric circuit model that simulates this reference design. The device model (SPICE model) of the switching devices for the loss simulation uses a sub-circuit model originally developed by Toshiba (hereinafter referred to as the G2 model). The G2 model is a SPICE model that expresses the nonlinearity of the capacitance of a power device and is suitable for transient simulations of power devices.

(Note1) Reference design refers to the data information about application design listed at the Reference Design Center on the Toshiba Device & Storage website. The reference design includes schematics, board data, BOM information, reference guides and design guides.

Table of Contents

Description	1
Table of Contents.....	2
1. 300W Isolated DC-DC Converter	4
1.1. Schematic diagram of 300W isolated DC-DC converter	5
1.2. Operating waveforms of the 300W isolated DC-DC converter	6
2. Power MOSFETs lineup for efficiency evaluation device	9
2.1. List of Switching devices to be compared.....	9
3. Efficiency evaluation results of actual device	10
3.1. Effect of secondary-side switching device on power conversion efficiency	11
4. Spike voltage	12
5. Loss Analysis using the high accuracy simulator circuit ^(Note2)	13
5.1. Loss definition of secondary MOSFET	14
5.2. Comparative analysis of efficiency between actual evaluation board and simulation	14
5.3. Loss analysis.....	15
6. Conclusion	16
7. Application support.....	16
8. Device Model (SPICE Model) Support.....	16
Notes on Contents	16
RESTRICTIONS ON PRODUCT USE	17

List of Figures

Fig. 1.1 300W DC-DC converter evaluation board.....	4
Fig. 1.2 Simplified schematic diagram of 300W DC-DC converter.....	5
Fig. 1.3 Actual schematic diagram around the output side synchronous rectifying MOSFETs	5
Fig. 1.4 300W DC-DC converter operation mode 1~4	6
Fig. 1.5 300W DC-DC converter operation mode 5~8	7
Fig. 1.6 Simplified operating waveforms of 300W DC-DC converter	8
Fig. 2.1 Product lineup of the U-MOSⅧ-H, U-MOSⅨ-H, and U-MOSⅩ-H MOSFET series.....	9
Fig. 3.1 Connection between evaluation board and each equipment for efficiency measurement	10
Fig. 3.2 Output load dependency of secondary MOSFET efficiencies and temperatures	11
Fig. 4.1 Parasitic snubber circuit.....	12
Fig. 4.2 Synchronous rectifier circuit of DC-DC converter secondary side	12
Fig. 4.3 R-load switching circuit diagram and turn off waveform comparison of V_{DS}	12
Fig. 5.1 Simulation circuit.....	13
Fig. 5.2 Comparison of actual measurement and simulation characteristics of device model.....	13
Fig. 5.3 Timing chart of loss calculation for secondary MOSFET	14
Fig. 5.4 Load dependent characteristics comparison (Reference model and Simulation circuit)	14
Fig. 5.5 Results of loss analysis for each mounted component.....	15
Fig. 5.6 Secondary MOSFET loss analysis results.....	15

List of Tables

Table 1.1 Input and output characteristics of 300W DC-DC converter	4
Table 2.1 Main specifications of evaluation MOSFETs.....	9

1. 300W Isolated DC-DC Converter

This converter operates over an input voltage range of 36 to 75VDC and provides 300W power at 12VDC output. This converter is suitable for various applications, including telecommunication equipment with 48VDC lines and industrial systems powered by 48V batteries. This reference design provides various design information, which can help reduce the time and effort in designing a DC-DC converter according to actual required specifications. This converter uses Toshiba's latest small surface-mount power MOSFETs (TPN1200APL, TPH2R408QM) as switching devices on both the primary and secondary sides and small surface-mount components for other types of devices. Consequently, despite the use of a general-purpose winding transformer, small PCB size (82mm x 82mm x 24mm) and high efficiency (94%) are achieved.



Fig. 1.1 300W DC-DC converter evaluation board

Table 1.1 Input and output characteristics of 300W DC-DC converter

Parameter	Condition	Min.	Typ.	Max.	Unit
Input characteristics					
Input voltage		36		75	V
Input current	$V_{in} = 48\text{ V}$, $I_{out} = 25\text{ A}$			12	A
Output characteristics					
Output voltage		11.4	12.0	12.6	V
Output current				25	A
Output power				300	W
Ripple				200	mV
Switching frequency			185		kHz

1.1. Schematic diagram of 300W isolated DC-DC converter

Fig.1.2 is a schematic diagram of DC-DC converter used in this evaluation. With the transformer T_1 as the boundary, the primary side (input side) is composed of four switching devices TR_1 to TR_4 consisting of two arms, the secondary side (output side) is composed of two devices TR_5 , TR_6 that is intended for synchronous rectification and output smoothing filter circuits consisting of inductance L_2 and capacitor C_2 . Fig. 1.3 shows a detailed schematic diagram of the secondary side MOSFET. TR_5 and TR_6 have two MOSFETs connected in parallel. This converter generates 12V output voltage by phase-shifted full-bridge (PSFB) topology. The output voltage is regulated by phase-shifted operation between an arm of TR_1 , TR_2 and the other arm of TR_3 , TR_4 with a 50% duty cycle. In the dead time between the high side MOSFET and low side MOSFET to prevent shoot-through, zero voltage switching(ZVS) is achieved and reduces the switching loss of the power converter.

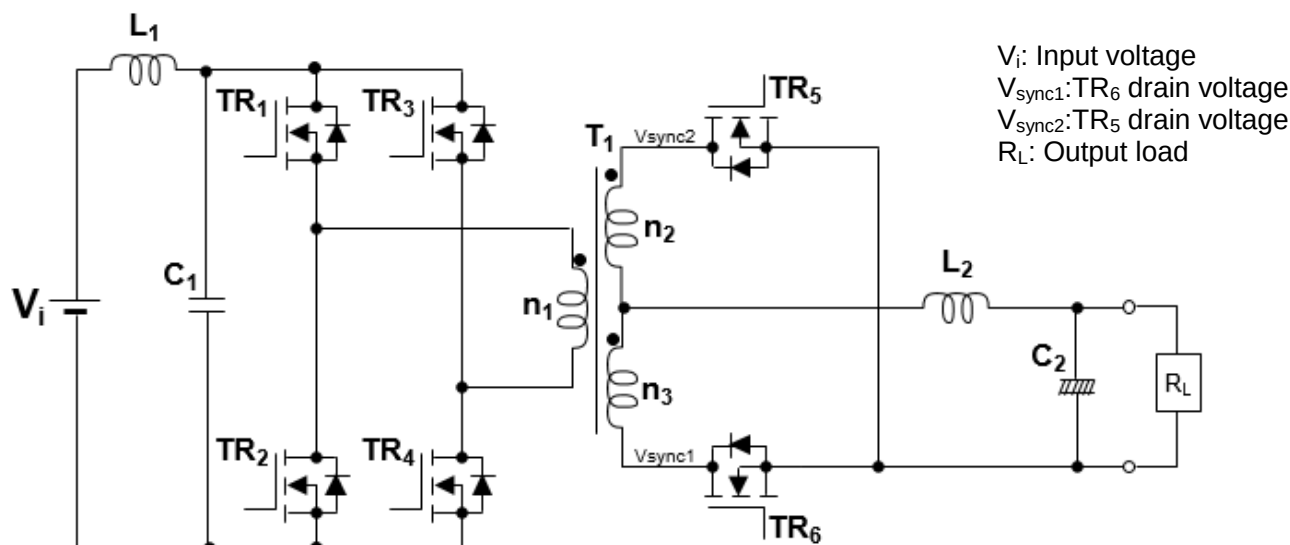


Fig. 1.2 Simplified schematic diagram of 300W DC-DC converter

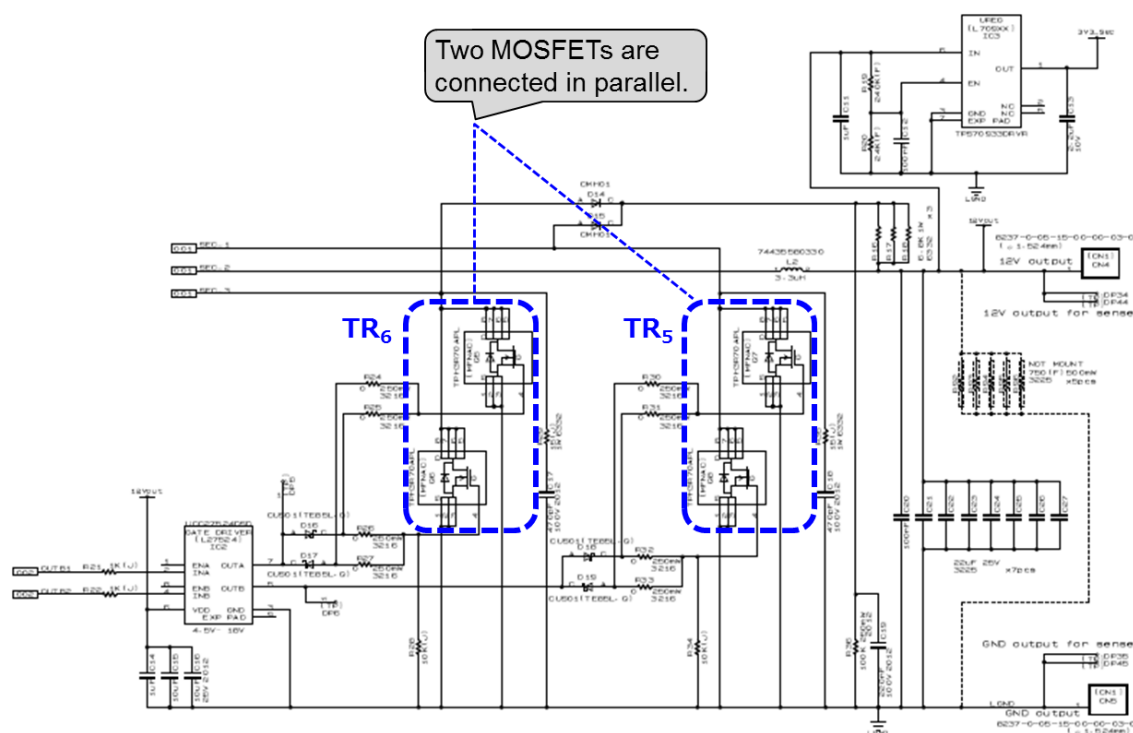


Fig. 1.3 Actual schematic diagram around the output side synchronous rectifying MOSFETs

1.2. Operating waveforms of the 300W isolated DC-DC converter

This chapter introduces the principle of switching operation by describing the eight different modes. Fig.1.4 and Fig.1.5 show the current path in each operation mode, and Fig.1.6 shows the waveforms of each switching device and L_2 .

- Operation mode-1: TR₁ and TR₄ are ON state, TR₂, TR₃ and TR₅ are OFF state

As shown by the dotted arrows in Fig.1.4(a), while TR₁ and TR₄ are ON state, current flows through TR₁ and then flows through the primary end of T₁, and then flows through TR₄. Here, the energy is transferred from the primary side (n_1) to the secondary side (n_3) through the transformer T₁, and C₂ is charged through TR₆ and L₂.

- Operation mode-2: TR₁ and TR₆ are ON state, TR₂, TR₃ and TR₅ are OFF state, TR₄ is turn-off

When TR₄ turns off, the current that flows on the primary side causes a freewheeling operation through the body-diode of TR₃ after charging the output capacitance C_{oss} of TR₂ and TR₄ as shown by the dotted arrows in Fig. 1.4(b). Because of the freewheeling operation, energy is not transferred from the primary side (n_1) to the secondary side (n_3) through the transformer T₁, but on the secondary side, the current that flows along the path of the blue dotted arrow comes from L₂ due to energy stored. In addition, the current also flows along the red dashed arrow through body diode of TR₅.

- Operation mode-3: TR₁ and TR₆ are ON state, TR₂ and TR₄ are OFF state, TR₃ and TR₅ is turn-on

When TR₃ turns on, the freewheeling current in TR₃ flows through the transistors rather than through the body diodes. In addition, when TR₅ turns on, current in TR₅ flows through the transistors rather than through the body diode along the red dashed arrows.

- Operation mode-4: TR₃ and TR₅ are ON state, TR₂ and TR₄ are OFF state, TR₁ and TR₆ are turn-off
- When TR₁ turns off, the freewheeling operation stops and no current flows at the primary. However, on the secondary, the current flows along the red dashed arrow through the on-state TR₅ from L₂ due to energy stored.

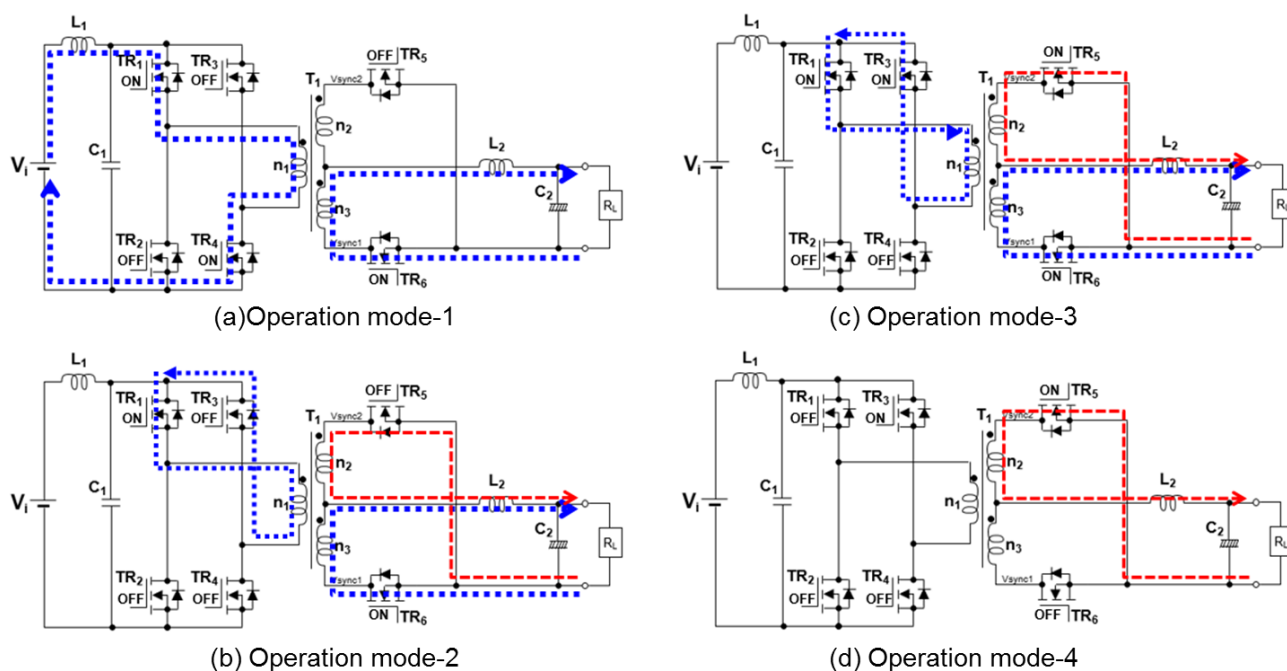


Fig. 1.4 300W DC-DC converter operation mode 1~4

- Operation mode-5: TR₂, TR₃ and TR₅ are ON state, TR₁, TR₄ and TR₆ are OFF state

As shown by the dotted arrows in Fig.1.5(a), while TR₂ and TR₃ are ON state, the current flows through TR₃ and then flows through the primary(n_1) of T₁, and then flows through TR₂. Here, the energy is transferred from the primary side(n_1) to the secondary side(n_2) through the transformer T₁, and C₂ is charged through TR₅ and L₂.

- Operation mode-6: TR₂ and TR₅ are ON state, TR₁, TR₄ and TR₆ are OFF state, TR₃ turn off

When TR₃ turns off, the current flows on the primary side causes a freewheeling operation through body-diode of TR₄ after charging the output capacitance C_{oss} of TR₁ and TR₃ as shown by the dotted arrows in Fig. 1.5(b). Because of the freewheeling operation, energy is not transferred from the primary side (n_1) to the secondary side (n_2) through the transformer T₁, but on the secondary side, the current that flows along the path of the blue dotted arrow comes from L₂ due to energy stored. In addition, the current also flows along the red dashed arrow through body diode of TR₆.

- Operation mode-7: TR₂ and TR₅ are ON state, TR₁ and TR₃ are OFF state, TR₄ and TR₆ are turn-off

When TR₄ turns on, the freewheeling current in TR₄ flows through the transistors rather than through the body diodes. In addition, when TR₆ turns on, current flows in TR₆ through the transistors rather than through the body diode along the red dashed arrows.

- Operation mode-8: TR₄ and TR₆ are ON state, TR₁ and TR₃ are Off state, TR₂ and TR₅ are turn-off
- When TR₂ turns off, the freewheeling operation stops and no current flows at the primary. However, on the secondary, the current flows along the red dashed arrow through the on-state TR₆ from L₂ due to energy stored.

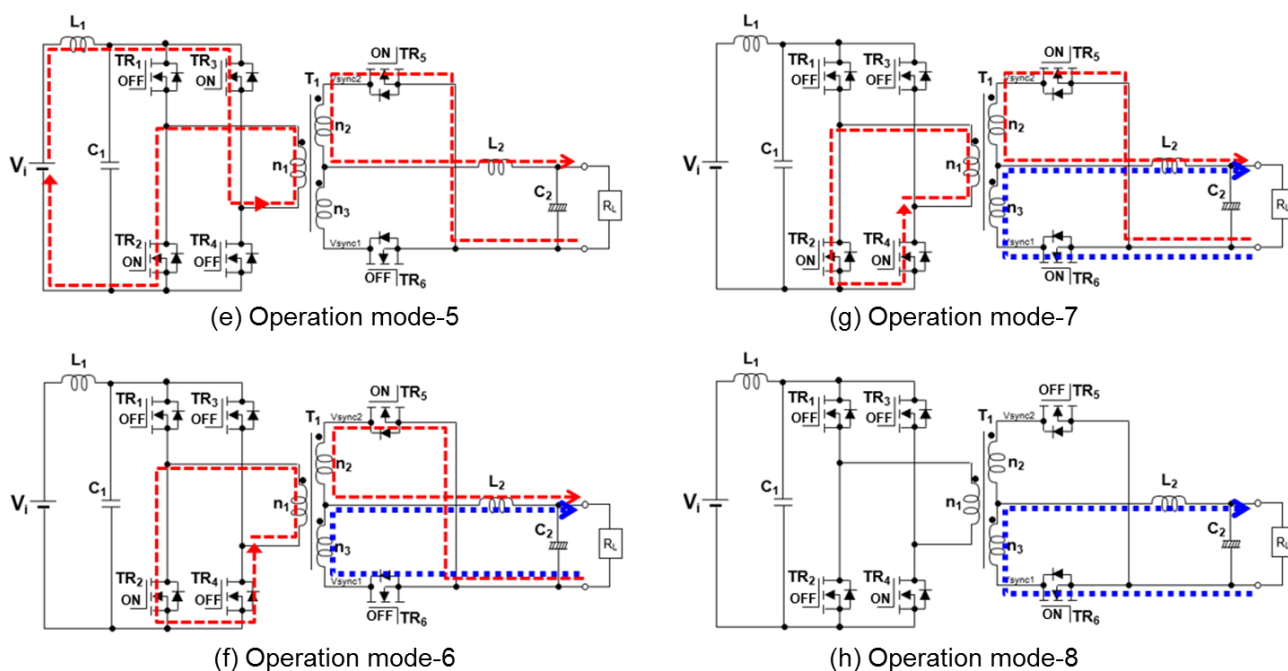


Fig. 1.5 300W DC-DC converter operation mode 5~8

Fig.1.6 shows the simplified operating waveforms of 300W isolated DC-DC converter. For the operation modes-1 to 8 shown in Fig.1.4 and Fig.1.5, the gate voltage (V_G) and drain current (I_D) of the switching devices TR_1 to TR_6 , drain-source voltage (V_{sync1} , V_{sync2}) of TR_5 and TR_6 , and the inductance voltage (V_{L2}) and current (I_{L2}) of L_2 are described. The current through TR_5 and TR_6 are denoted by a negative value because the current flows from the source to the drain.

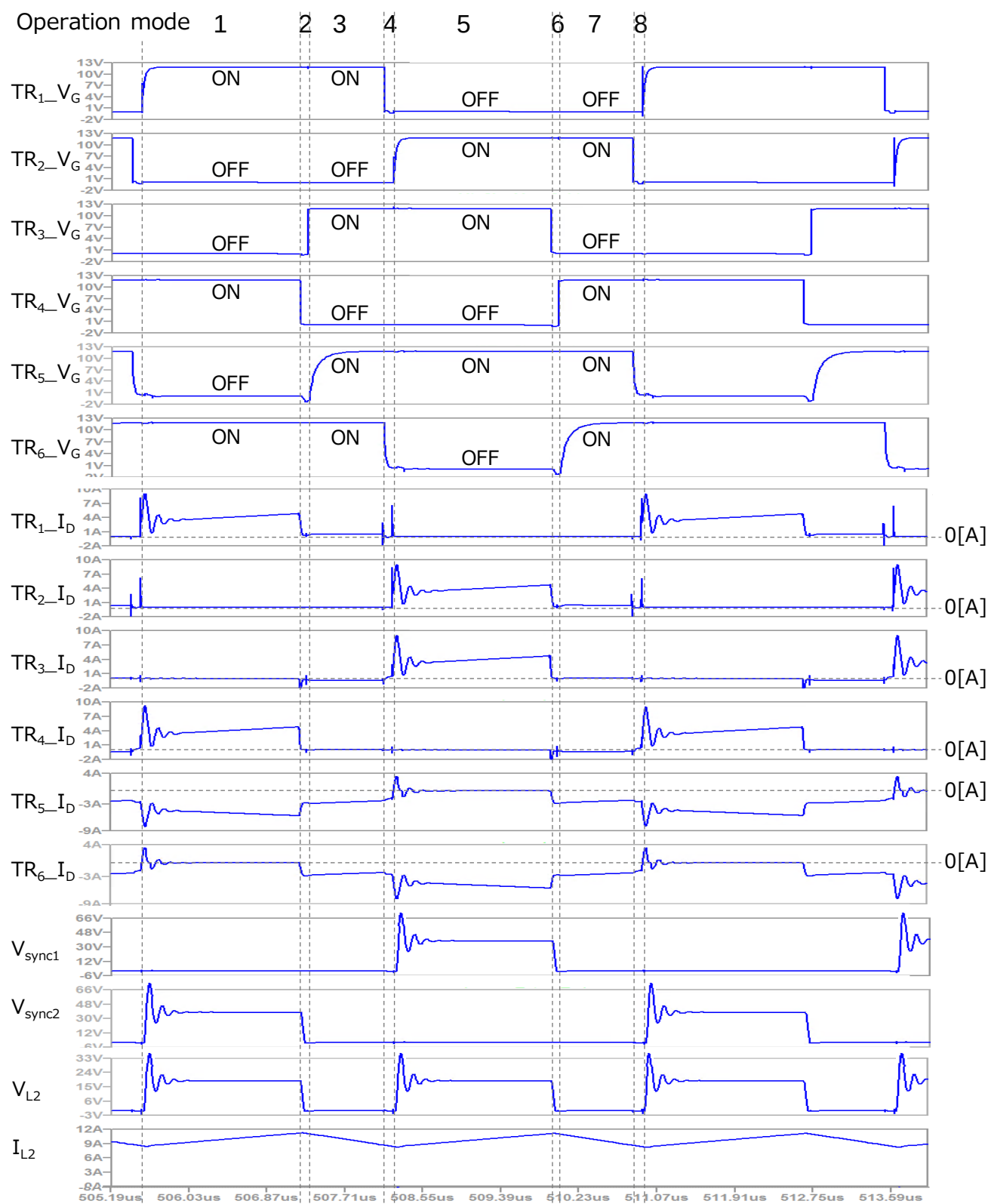


Fig. 1.6 Simplified operating waveforms of 300W DC-DC converter

2. Power MOSFETs lineup for efficiency evaluation device

Toshiba offers the U-MOS $\text{\text{VIII}}$ -H, U-MOS $\text{\text{IX}}$ -H and U-MOS $\text{\text{X}}$ -H low-voltage MOSFET series which suits the primary (main switch) and secondary (synchronous rectification) sides of DC-DC converters. Toshiba provides MOSFETs with a wide range of V_{DS} from 30V to 250V and various on-resistance types in each V_{DS} class so it is easy to find proper MOSFETs when designing a DC-DC converter, according to the desired circuit topology, input and output voltages, output current, and the locations of MOSFETs on the circuit (primary or secondary side). Fig. 2.1 shows the lineup of the U-MOS $\text{\text{VIII}}$ -H, U-MOS $\text{\text{IX}}$ -H and U-MOS $\text{\text{X}}$ -H MOSFET series.

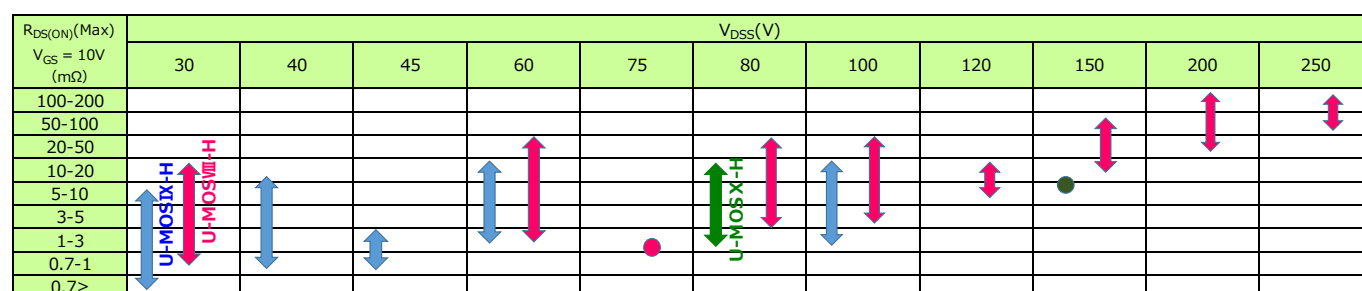


Fig. 2.1 Product lineup of the U-MOS $\text{\text{VIII}}$ -H, U-MOS $\text{\text{IX}}$ -H, and U-MOS $\text{\text{X}}$ -H MOSFET series

2.1. List of Switching devices to be compared

Table 2.1 shows the main specifications of MOSFETs used in this evaluation. The dominant losses on secondary MOSFET are conduction loss and reverse recovery loss in general, therefore the better efficiency especially on mid-load to heavy load is expected on the latest generation U-MOS $\text{\text{X}}$ -H 80V product TPH2R408QM which has a lower on-resistance($R_{DS(ON)}$) and a smaller reverse recovery charge(Q_{rr}) compared with other products.

Table 2.1 Main specifications of evaluation MOSFETs

Characteristics	Symbol	Unit	Primary Side	Secondary Side	
			TPN1200APL	TPH2R408QM	Company A
Drain-source breakdown voltage (Min)	$V_{(BR)DSS}$	V	100	80	80
Gate threshold voltage (Max)	V_{th}	V	2.5	3.5	3.0
Drain-source on-resistance (Typ)	$R_{DS(ON)}$	mΩ	9.8	1.9	2.2
Input capacitance (Typ)	C_{iss}	pF	1425	5870	5200
Reverse transfer capacitance (Typ)	C_{rss}	pF	15	60	38
Output capacitance (Typ)	C_{oss}	pF	205	1340	840
Gate resistance (Typ)	r_g	Ω	2.1	1.9	1.9
Switching time (rise time) (Typ)	t_r	ns	6	10.8	14
Switching time (turn-on time) (Typ)	t_{on}	ns	19	29	18
Switching time (fall time) (Typ)	t_f	ns	6	26	16
Switching time (turn-off time) (Typ)	t_{off}	ns	34	123	47
Total gate charge (Typ)	Q_g	nC	24	87	74
Gate-drain charge(Typ)	Q_{gd}	nC	4.9	19	16
Gate switch charge(Typ)	Q_{SW}	nC	7.5	28	25
Output charge(Typ)	Q_{oss}	nC	24	90	88
Reverse recovery charge(Typ)	Q_{rr}	nC	47	74	92

3. Efficiency evaluation results of actual device

In this evaluation, we verified the efficiencies of our 300W isolated DC-DC converter using the products listed in Table 2.1. The switching frequency of PSFB circuit is set by an external resistor connected to the RT terminal of the PWM controller. In this evaluation, the external resistor is set to 27kΩ and PSFB switching frequency is set to 370kHz. The PWM controller switches MOSFET (TR₁, TR₂ and TR₃, TR₄) of the left and right arms of the primary bridge at 1/2 of PSFB switching frequency (185kHz).

Efficiency is one of the most important characteristics of DC-DC converters. Efficiency is the ratio of the output power to the input power to DC-DC converter and it is calculated by the following formula.

$$\text{Efficiency} = (V_{\text{out}} \times I_{\text{out}}) / (V_{\text{in}} \times I_{\text{in}}) \times 100 [\%]$$

In this evaluation, we measured V_{in} , I_{in} , V_{out} and I_{out} for 2 patterns of switching device combinations under the following conditions, then calculated and compared the efficiency. Fig.3.1 shows the connection diagram for efficiency measurement. DC-DC converter circuit board is forcibly air-cooled by cooling –fan located nearby.

Input voltage (V_{in}) = 48V
 Output voltage (V_{out}) = 12V
 Ambient temperature (T_{a}) = 25°C
 Output-load current (I_{out}) = 1A, 3A, 5A, 7A, 10A, 14A, 16A, 18A, 20A, 25A

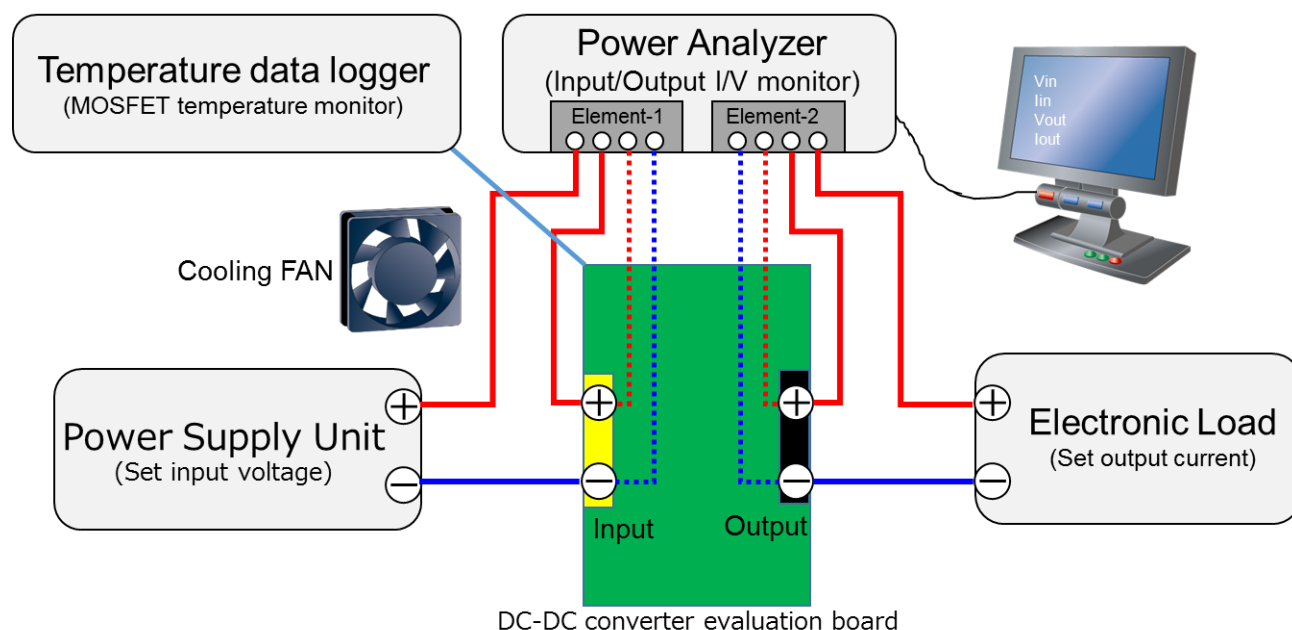
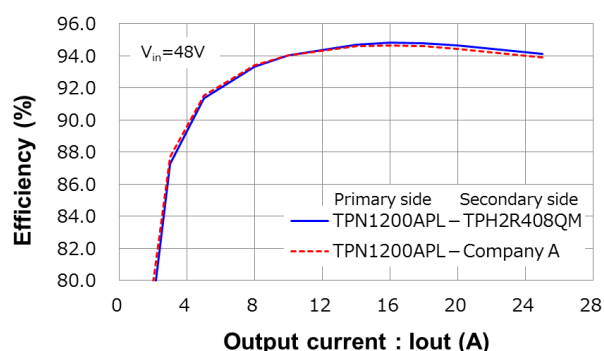


Fig. 3.1 Connection between evaluation board and each equipment for efficiency measurement

3.1. Effect of secondary-side switching device on power conversion efficiency

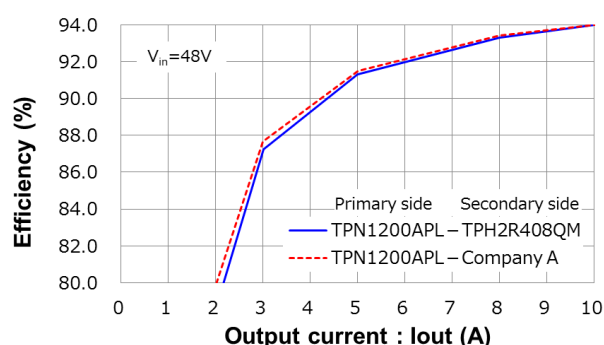
Figures 3.2 (a) to (c) show the efficiency curves when TPN1200APL is chosen as the primary MOSFET and TPH2R408QM or Company A's MOSFET is chosen as the secondary side MOSFET. Since conduction loss is dominant in medium to heavy loads, TPH2R408QM with the smallest drain-source on-resistance is superior. The maximum efficiency is 94.83% at 16A of output load and 94.12% at 25A of full load. On the other hand, the on-resistance of Company A is about 16% larger than that of TPH2R408QM, resulting in 94.65% at 16A of output load and 93.89% at 25A of full load. Fig.3.2 (d) shows the results of measuring MOSFET device temperatures of the secondary side. Even under heavy loads, TPH2R408QM has a temperature lower than 45°C, which indicates that it generates less heat than MOSFET produced by Company A.

(a) Efficiency comparison of secondary side MOSFETs (TR₅ and TR₆)

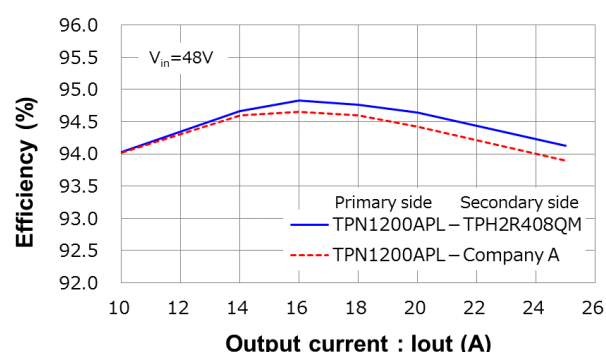


Secondary Side	Efficiency[%]		
	light load (I _{out} =3[A])	peak efficiency (I _{out} =16[A])	heavy load (I _{out} =25[A])
TPH2R408QM	87.24	94.83	94.12
Company A	87.67	94.67	93.89

(b) Light load (I_{out}=1 to 10A)



(c) Medium load to heavy load (I_{out}=10 to 25A)



(d) Device temperature of the secondary side MOSFETs (TR₅ and TR₆)

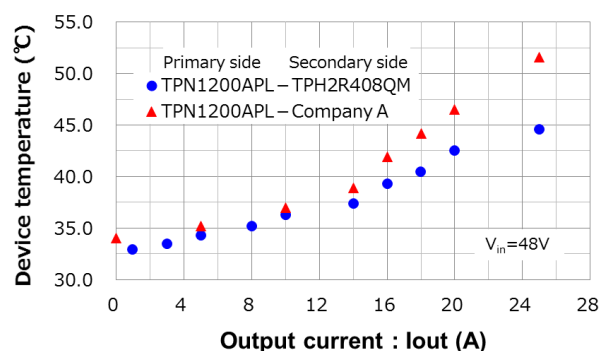
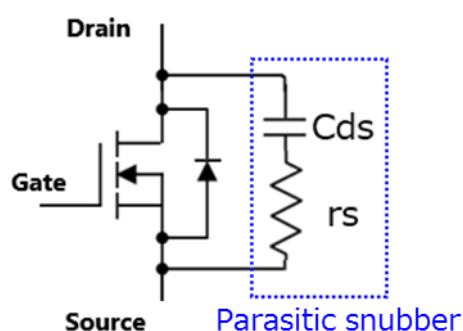


Fig. 3.2 Output load dependency of secondary MOSFET efficiencies and temperatures

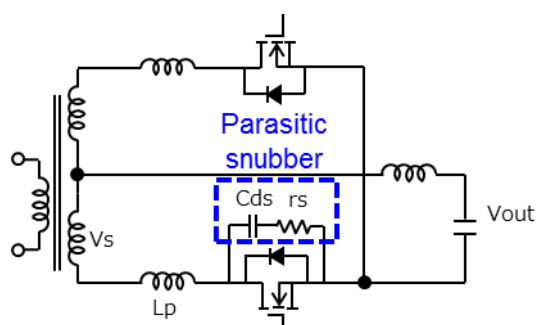
4. Spike voltage

Low-spike performance is one of the advantages of TPH2R408QM used on the secondary side. TPH2R408QM adopts a new structure in the gate trench. As shown in Fig. 4.1, parasitic capacitance and parasitic resistance exist between the drain and source, and a CR-snubber circuit is constructed, thereby suppressing the spike voltage. This effect is explained in this chapter using the secondary synchronous rectifier of DC-DC converter with the parasitic inductances L_p of the circuit boards shown in Fig.4.2. The damping coefficient (ζ) of this circuit is expressed by Equation (1). Since the numerator has r_s and C_{ds} , the larger each value, the larger the damping coefficient, the faster the damping speed, and the faster the ringing converges. Also, since the spike voltage (V_{Cds}) expressed by Equation (2) has r_s and C_{ds} in the denominator, it can be understood that the larger the value, the smaller the value of the spike voltage. The spike voltage reduction reduces noise and ringing concern and enables easier to design power supply circuit such as voltage safety margins. Fig.4.3 shows the R-load switching evaluation board circuit and TPH2R408QM and Company A's turn-off waveform (V_{DS}). TPH2R408QM has a V_{DS} spike voltage of 50.91V and a ringing time of 48ns. On the other hand, V_{DS} spike voltage of Company A is 56.61V and the ringing time is 71ns, indicating that TPH2R408QM is superior in both V_{DS} spike voltage and the ringing time.



C_{ds} : Drain-source capacitance of MOSFET
 r_s : Embedded source-wire resistor for MOSFET

Fig. 4.1 Parasitic snubber circuit



$$\text{Damping coefficient } \zeta = \frac{r_s}{2} \times \sqrt{\frac{C_{ds}}{L_p}} \quad \dots \text{equation(1)}$$

$$\text{Spike voltage } V_{Cds} = \frac{1}{r_s} \times \frac{V_s}{\omega_0 \times C_{ds}} \quad \dots \text{equation(2)}$$

L_p : Substrate parasitic inductance
 ω_0 : Angular frequency of the LCR series resonant circuit
 V_s : Secondary voltage

Fig. 4.2 Synchronous rectifier circuit of DC-DC converter secondary side

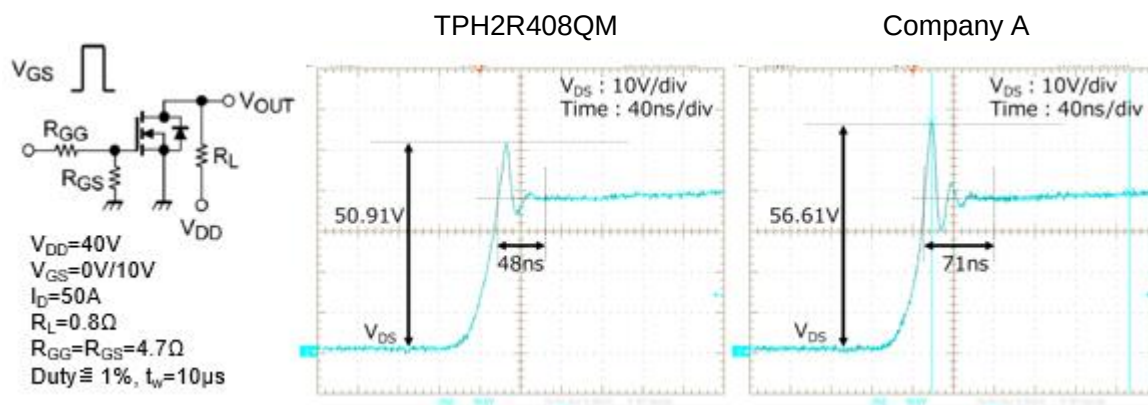


Fig. 4.3 R-load switching circuit diagram and turn off waveform comparison of V_{DS}

5. Loss Analysis using the high accuracy simulator circuit (Note2)

Fig.5.1 is a schematic diagram of the simulation circuit. The reference model uses a phase-shifted full-bridge PWM controller IC, but this simulation circuit uses the alternative control model making feedback according to the voltage and current sensing. All sensing points are connected to the control model, and primary or secondary side's MOSFET are controlled by this control model to regulate the output voltage. The transformer and reactors which greatly affect the simulation accuracy use equivalent circuit models created based on actual measurement results. (Note2) The high accuracy simulation circuit is originally developed for loss analysis.

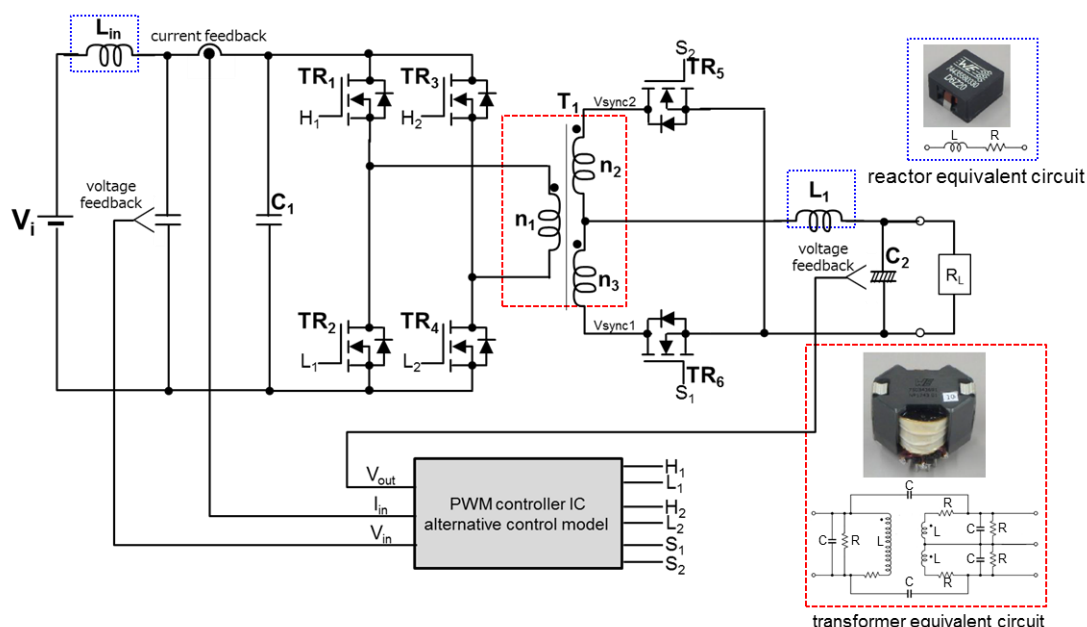


Fig. 5.1 Simulation circuit

In addition, this simulator uses a high-accuracy device model (G2 model) that enhances the reproducibility of the high-current-domain characteristics of I_D - V_{DS} curve and the voltage-dependent characteristics of the parasitic capacitance, and allows closer switching simulations to actual measurements. Fig.5.2 (a) to (d) show the comparison results between actual measurements and simulations of the main characteristics (I-V and C-V). Fig. (e) and (f) show turn off characteristics of R-load switching using this device model. The simulated waveform (Fig.(e)) is accurately reproduced the actual measured waveform(Fig.(f)).

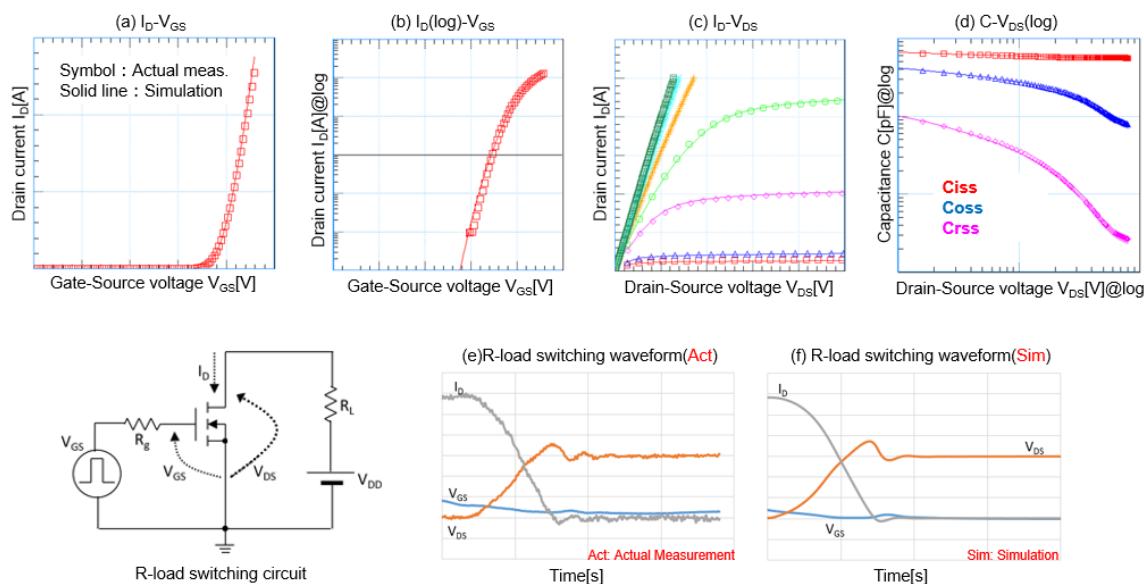


Fig. 5.2 Comparison of actual measurement and simulation characteristics of device model

5.1. Loss definition of secondary MOSFET

Figure 5.3 shows the timing chart of the secondary MOSFET that operate as synchronous rectification and each loss calculation section defined as E_{diode1} , E_{sync} , E_{diode2} , E_{recovery} , E_{block} , and E_{gate} . Each loss is defined with the conduction state in mind, and E_{diode1} , E_{sync} , E_{diode2} , E_{recovery} and E_{block} are calculated by the time integration of the product of the drain-to-source voltage V_{DS} and the drain current I_{D} . On the other hand, E_{gate} is calculated by time integration of the product of gate-to-source voltage V_{GS} and gate current I_{G} .

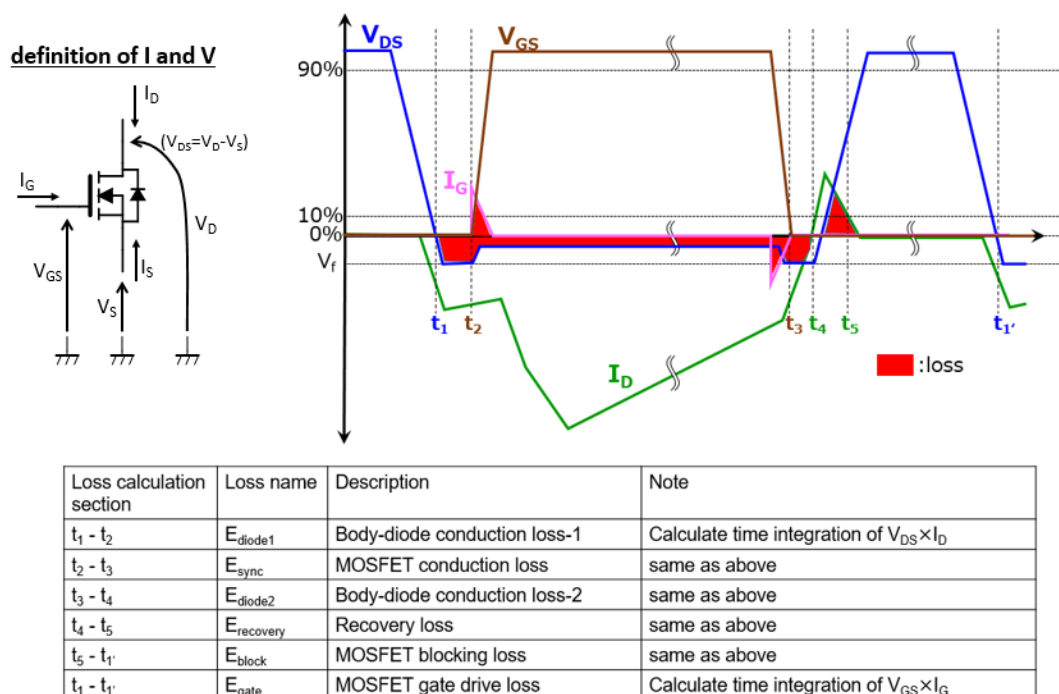


Fig. 5.3 Timing chart of loss calculation for secondary MOSFET

5.2. Comparative analysis of efficiency between actual evaluation board and simulation

Fig. 5.4 shows the Efficiency-Output current(load) dependency of the evaluation board and the simulated circuit when TPN1200APL is chosen as the primary MOSFET and TPH2R408QM or Company A's MOSFET is chosen as the secondary side MOSFET. The efficiency difference between the evaluation board and the simulation result from medium load to heavy load region is 1 % or less. The main reason for this difference is the loss not considered in this simulation circuit such as the loss of the controller and the change in characteristics caused by the heat generated by each component constituting the circuit. However, since there is no discrepancy on relative merits between TPH2R408QM and Company A's MOSFET in the evaluation with evaluation board and simulation, it can be said that the operation of this simulation circuit can almost simulate the actual evaluation board. In the next section, we use this simulator to analyze the loss of components mounted on the evaluation board including the secondary MOSFET for one cycle.

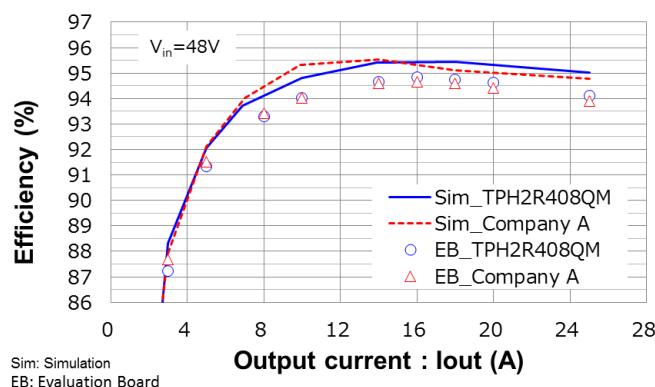


Fig. 5.4 Load dependent characteristics comparison (Reference model and Simulation circuit)

5.3. Loss analysis

Fig. 5.5 shows the results of loss-simulation for a 300W isolated DC-DC converter using TPN1200APL for the primary MOSFET and TPH2R408QM for the secondary MOSFET on the high-accuracy simulation circuits. The loss ratios of the components at the output current of 25 [A] are 24.9% for the primary MOSFET (Pri_Side), 17.7% for the secondary MOSFET (Sec_Side), 20.2% for the transformer (Transformer), 15.2% for the reactor (Reactor), 6.1% for the snubber (Snubber), and 15.9% for the rest (others), indicating that approximately 43% of the loss is generated by MOSFET on the primary and secondary sides. The rate of MOSFET loss increases as the output current decreases. This shows that it is crucial to reduce MOSFET losses to improve the efficiency of DC-DC converter. Fig. 5.6 shows the power loss amount for one cycle of TPH2R408QM used on the secondary side. Recovery loss (E_{recovery}) of the body diodes is dominant, but the increment is not sensitive to the output current. On the other hand, looking at the conduction loss (E_{sync}), it increases greatly as the output current increases. Therefore, for secondary MOSFET, it is desirable to select products with low recovery charge (Q_{rr}) associated with recovery loss and low drain-to-source on-resistance ($R_{\text{DS(ON)}}$).

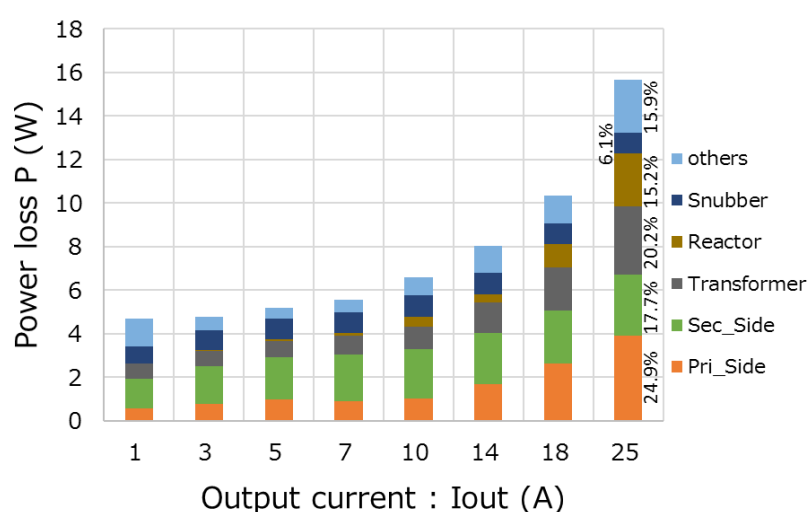


Fig. 5.5 Results of loss analysis for each mounted component

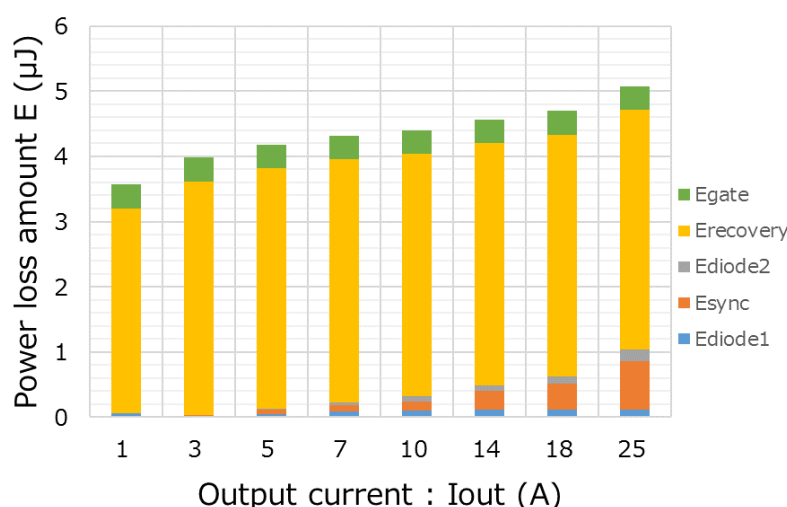


Fig. 5.6 Secondary MOSFET loss analysis results

6. Conclusion

The loss of the secondary MOSFET of the 300W isolated DC-DC converter is dominated by conduction and recovery losses as shown in Fig. 5.6. Therefore, it is recommended to select a MOSFET with low drain-source on-resistance and low reverse-recovery charge. Finally, it was confirmed in this evaluation that using TPH2R408QM on the secondary side resulted in the highest efficiency this time.

7. Application support

Detailed information on the reference designs adopted for this application note can be found at the following URL:

https://toshiba.semicon-storage.com/ap-en/semiconductor/design-development/referencedesign/articles/300w-isolated-dc-dc_powermanagement_rd024.html

8. Device Model (SPICE Model) Support

The SPICE models used in this application note are available at the following URLs.

Primary switching MOSFET : TPN1200APL

<https://toshiba.semicon-storage.com/ap-en/semiconductor/product/mosfets/12v-300v-mosfets/detail.TPN1200APL.html>

Secondary switching MOSFET : TPH2R408QM

<https://toshiba.semicon-storage.com/ap-en/semiconductor/product/mosfets/12v-300v-mosfets/detail.TPH2R408QM.html>

Description of grade notation for device models (SPICE models).

<https://toshiba.semicon-storage.com/info/docget.jsp?did=139481>

Notes on Contents

1. Block Diagrams

Some of the functional blocks, circuits, or constants in the block diagram may be omitted or simplified for explanatory purposes.

2. Equivalent Circuits

The equivalent circuit diagrams may be simplified or some parts of them may be omitted for explanatory purposes.

RESTRICTIONS ON PRODUCT USE

Toshiba Corporation and its subsidiaries and affiliates are collectively referred to as "TOSHIBA".

Hardware, software and systems described in this document are collectively referred to as "Product".

- TOSHIBA reserves the right to make changes to the information in this document and related Product without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA's written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product's quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. **TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.**
- **PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE").** Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, lifesaving and/or life supporting medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, and devices related to power plant. **IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT.** For details, please contact your TOSHIBA sales representative or contact us via our website.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- **ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.**
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. **TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.**