U-MOSIX-H 60V
Low V_{DS} spike products

Description

TPH1R306P1 is an advanced U-MOSIX-H process product, and its main target applications are the secondary synchronous rectifier of DC-DC converters and AC-DC converters, and motor drives. We have been mass-producing TPH1R306PL since December 2015. For low $R_{DS(ON)}$ products of the SOP Advance, which are often used in secondary synchronous rectifiers and motors, we are preparing a lineup of products that can reduce spike voltage , as well as high-efficiency standard products. TPH1R306P1 with low V_{DS} spike characteristics can reduce spike voltage and shorten ringing periods by making the internal gate resistance (r_g) value larger than the standard gate resistance one.

This application note compares and verifies the V_{DS} spike levels and ringing periods of TPH1R306PL and TPH1R306P1 on a power supply to confirm their effectiveness and also explains the mechanism of low V_{DS} spikes.

<Major Product Characteristics>

Part number	Generation	V_{DSS} (V)	$R_{DS(ON)}$ (mΩ) @V_{GS}=10 V	Package	Feature
TPH1R306P1	U-MOSIX-H	60	1.28	SOP Advance	Low V_{DS} spike product
TPH1R306PL	U-MOSIX-H	60	1.34	SOP Advance	Standard product

Table of Contents

List of Figures

List of Tables

1. On-resistance Improvement for Each Generation

Our low voltage MOSFETs have continuously improved their performance by optimizing device structures using superior fine process.
The features are as follows.

- Low on-resistance characteristics using superior fine process
- Low-loss performance with improved trade-off between on-resistance and gate charge
- Lineup of a wide range of breakdown-voltage and packages for many kinds of applications
- High durability, represented by avalanche withstandability
- Device structure with suppressed switching noise to make the design easy

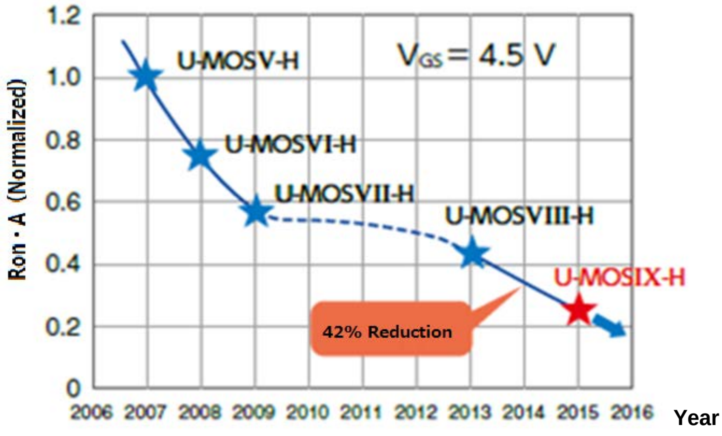


Figure 1.1　Continuous improvements of chip on-resistance (SOP Advance 30V products)

※ Ron•A: Drain-source on-resistance per unit area

2. Loss Improvements and Structures of U-MOSVIII-H and IX-H Generations

The U-MOSVIII-H and U-MOSIX-H generations have excellent MOSFET performance in "conduction loss and drive loss", "conduction loss and switching loss" and "conduction loss and output charge loss". The U-MOSIX-H generation, in particular, has been miniaturized and cell structure has been optimized to greatly reduce output charge losses, which are critical for power supply and motor-drive applications, from the U-MOSVIII-H generation.

Conduction loss and drive loss

Conduction loss and switching loss

Conduction loss and output charge loss

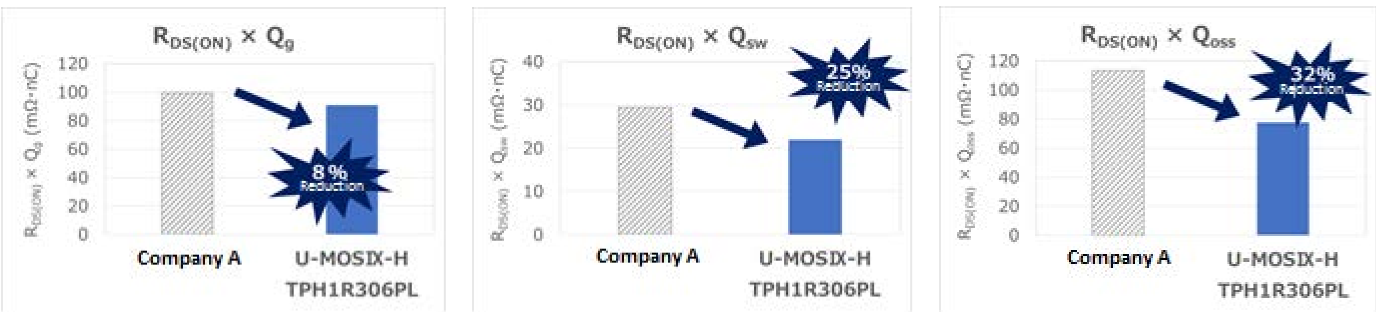


Figure 2.1　Reduction of conduction loss

※ For each parameter

- $R_{DS(ON)}$: Drain-source on-resistance [mΩ] (an indicator of conduction loss)
- Q_g : Total gate charge [nC] (an indicator of driving loss)
- Q_{sw} : Gate switch charge [nC] (an indicator of switching loss)
- Q_{oss} : Output charge [nC] (an indicator of output charge loss)

2.1. Structures of U-MOSVIII-H and IX-H Generations

The U-MOSVIII-H and U-MOSIX-H generations adopt new structures in the gate trench to achieve the above-mentioned performance. Since the new structure has parasitic capacitance and parasitic resistance between the drain and source and the snubber (CR) circuit is constructed, the U-MOSVIII-H and IX-H generations can suppress spike voltage compared to conventional U-MOSVII-H generation.

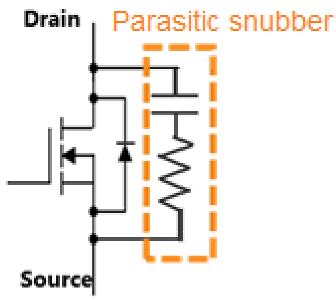


Figure 2.2 Parasitic snubber circuit

2.2. Structure of TPH1R306P1

As described in 2.1, the U-MOSIX-H generation TPH1R306PL adopts new trench structures and can achieve snubber effects. TPH1R306P1 optimizes the resistances of the gate and source by optimizing the patterns on the MOSFET surfaces in order to suppress spike voltage.

2.3. Features of TPH1R306P1

TPH1R306P1 (low V_{DS} spike product) optimizes r_g and r_s by optimizing surface patterns from TPH1R306PL (standard product). TPH1R306P1 has a lower $R_{DS(ON)}$ than TPH1R306PL does.

The product characteristics are shown in Table 2.1 and 2.2.

Table 2.1 Electrical characteristics of low V_{DS} spike product “TPH1R306P1”

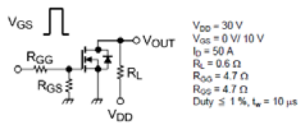
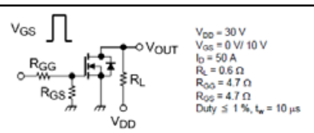
Item	Symbol	Measurement conditions	Minimum	Typical	Maximum	Unit
Gate leakage current	I_{GSS}	V_{GS} = ±20 V, V_{DS} = 0 V	-	-	±0.1	nA
Drain cut-off current	I_{DSS}	V_{DS} = 60 V, V_{GS} = 0 V	-	-	10	nA
Drain-source breakdown voltage	$V_{(BR)DSS}$	I_D = 10 mA, V_{GS} = 0 V	60	-	-	V
Drain-source breakdown voltage	$V_{(BR)DSX}$	I_D = 10 mA, V_{GS} = -20 V	45	-	-	V
Gate threshold voltage	V_{th}	V_{DS} = 10 V, I_D = 1.0 mA	1.5	-	2.5	V
Drain-source on-resistance	$R_{DS(ON)}$	V_{GS} = 4.5 V, I_D = 42 A	-	1.5	2.3	mΩ
		V_{GS} = 10 V, I_D = 50 A	-	0.96	1.28	mΩ
Input capacitance	C_{iss}	V_{DS} = 30 V,	-	6250	8100	pF
Reverse transfer capacitance	C_{rss}	V_{GS} = 0 V,	-	80	-	pF
Output capacitance	C_{oss}	f = 1 MHz	-	1160	-	pF
Gate resistance	r_g	-	-	2.2	3.3	Ω
Switching time (rise time)	t_r		-	8	-	ns
Switching time (turn-on time)	t_{on}		-	20	-	ns
Switching time (fall time)	t_f		-	22	-	ns
Switching time (turn-off time)	t_{off}		-	92	-	ns
Reverse recovery time	t_{rr}	V_R = 30 V, I_{DR} = 25 A, V_{GS} = 0V, - dI_{DR}/dt = 100 A/μs	-	44	-	ns

Table 2.2 Electrical characteristics of standard product “TPH1R306PL”

Item	Symbol	Measurement conditions	Minimum	Typical	Maximum	Unit
Gate leakage current	I_{GSS}	V_{GS} = ±20 V, V_{DS} = 0 V	-	-	±0.1	nA
Drain cut-off current	I_{DSS}	V_{DS} = 60 V, V_{GS} = 0 V	-	-	10	nA
Drain-source breakdown voltage	$V_{(BR)DSS}$	I_D = 10 mA, V_{GS} = 0 V	60	-	-	V
Drain-source breakdown voltage	$V_{(BR)DSX}$	I_D = 10 mA, V_{GS} = -20 V	45	-	-	V
Gate threshold voltage	V_{th}	V_{DS} = 10 V, I_D = 1.0 mA	1.5	-	2.5	V
Drain-source on-resistance	$R_{DS(ON)}$	V_{GS} = 4.5 V, I_D = 42 A	-	1.5	2.3	mΩ
		V_{GS} = 10 V, I_D = 50 A	-	1.0	1.34	mΩ
Input capacitance	C_{iss}	V_{DS} = 30 V,	-	6250	8100	pF
Reverse transfer capacitance	C_{rss}	V_{GS} = 0 V,	-	80	-	pF
Output capacitance	C_{oss}	f = 1 MHz	-	1160	-	pF
Gate resistance	r_g	-	-	0.5	1.0	Ω
Switching time (rise time)	t_r		-	8.3	-	ns
Switching time (turn-on time)	t_{on}		-	20	-	ns
Switching time (fall time)	t_f		-	14.7	-	ns
Switching time (turn-off time)	t_{off}		-	70	-	ns
Reverse recovery time	t_{rr}	V_R = 30 V, I_{DR} = 25 A, V_{GS} = 0V, - dI_{DR}/dt = 100 A/μs	-	47	-	ns

3. Effects on the Secondary Side of DC-DC Converter

3.1. Effects of optimized r_s

The secondary-side synchronous rectifier is often in the t_{rr} mode (reverse recovery mode of diode) and ringing occurs between the drain and the source. TPH1R306P1 suppresses ringing in t_{rr} mode by optimizing the parasitic resistor r_s with slight effect on power supply efficiency.

3.2. Theoretical Calculation of Voltage Spike

This section explains the mechanism for reducing V_{DS} spike by referring to the DC-DC buck converter shown in Figure 3.1 as LCR series resonant circuit. L is the stray inductance of the wire Lp, Cds is capacitance between Drain and Source of the low-side MOSFET, and R is the r_s of the low-side MOSFET.

※ For each parameter
- L(Lp): wiring parasitic inductance
- C (Cds): Drain-source capacitance of low-side MOSFET
- R (r_s): r_s of the low-side MOSFET

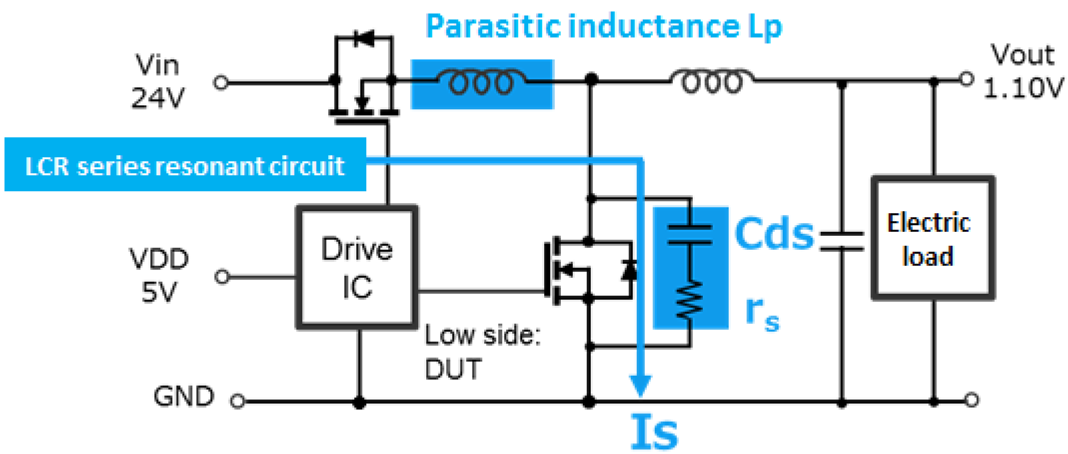


Figure 3.1 LCR series resonant circuit

When treated as an LCR series resonant circuit, it can be expressed as follows.

Angular frequency of the LCR series resonant circuit $\omega 0 = \frac{1}{\sqrt{Lp \times Cds}}$ -- equation (a)

Damping of the LCR series resonant circuit $\alpha s = \frac{rs}{2Lp}$ -- equation (b)

Attenuation coefficient of the LCR series resonant circuit $\zeta_s = \frac{\alpha s}{\omega 0}$ -- equation (c)

When equations (a) and (b) are substituted into equation (c), the attenuation coefficient of the LCR series resonance circuit ζ_s is,

$\zeta_s = \frac{rs}{2Lp} \times \sqrt{Lp \times Cds} = \frac{rs}{2} \times \sqrt{\frac{Cds}{Lp}}$ -- equation (d)

On the other hand, the voltage V_{Cds} across Cds, which becomes spike voltage, is

$V_{Cds} = \frac{1}{\omega 0 \times Cds} \times Is$

Here, $Is = \frac{Vin}{rs}$ is substituted for $I = \frac{V}{R}$ in the equation of the LCR series resonance circuit,

$$V_{Cds} = \frac{1}{\omega 0 \times Cds} \times \frac{Vin}{rs} = \frac{Vin}{\omega 0 \times Cds \times rs} = \frac{1}{rs} \times Q \quad \text{-- equation (e)}$$

From equations (d) and (e), the attenuation coefficient and spike voltage can be expressed by the following equations.

$$\text{Attenuation coefficient } \zeta_s = \frac{rs}{2} \times \sqrt{\frac{Cds}{Lp}} \quad \text{-- equation (f)}$$

$$\text{Spike voltage } V_{Cds} = \frac{1}{rs} \times Q \quad \text{-- equation (g)}$$

Where $Q = \frac{Vin}{\omega 0 \times Cds}$.

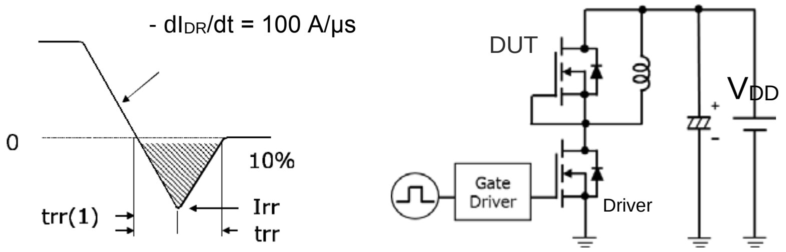
Since there is an r_s in the numerator in equation (f), the larger the r_s, the larger the attenuation factor ζ_s, and the faster the rate of attenuation. Therefore, the larger the r_s, the faster the ringing converges. Equation (g) also shows that the larger the r_s, the smaller the spike voltage V_{Cds}, since the denominator has the r_s.

Considering TPH1R306P1 and TPH1R306PL, the Cds, Lp, and Q are the same. TPH1R306P1 (low V_{DS} spike product) is designed to have a larger r_s than the TPH1R306PL (standard product), so the following effects can be obtained.

[1] Spike voltage decreases.
[2] Ringing converges become faster

3.3. Measurement of t_{rr} Value of MOSFET

The operation waveforms and effects of our products were checked under the t_{rr} mode, which is the most problematic of the secondary synchronous rectifiers of switching power supplies. The V_{DS} spike at the beginning of t_{rr} mode was reproduced by the evaluation circuit shown in Figure 3.2, and the t_{rr} was measured.



Test condition
V_{DD}: 30 V、
I_D: 25 A
Gate Drive Voltage: 10 V
T_a: 25°C

Figure 3.2 t_{rr} test circuit

Figure 3.3 shows the measured operating waveforms.

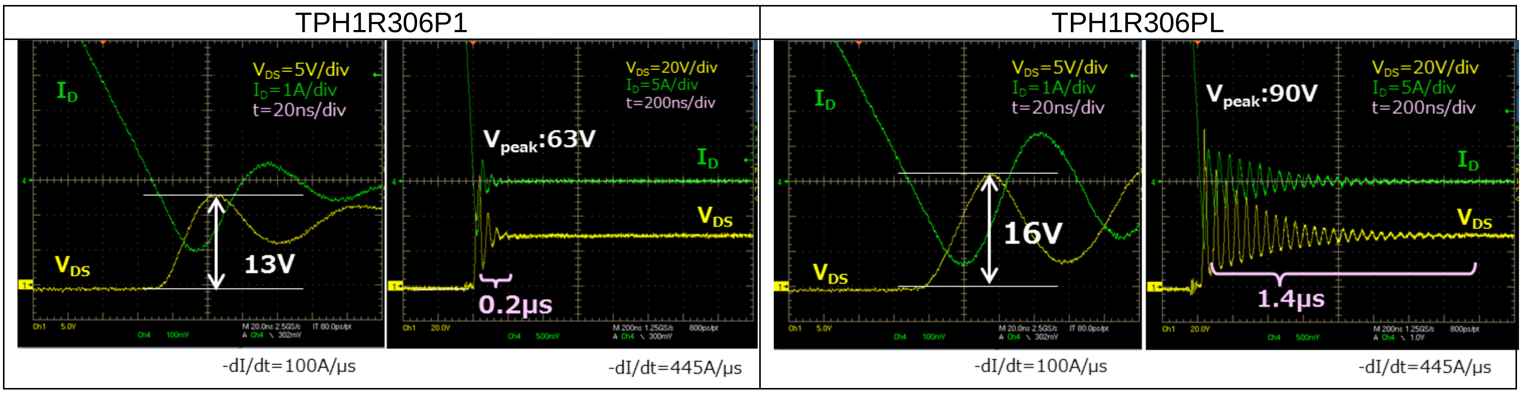
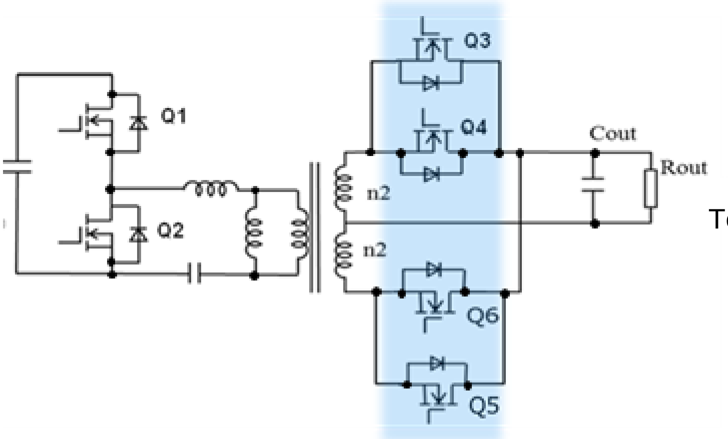


Figure 3.3 t_{rr} operation waveforms

Figure 3.3 shows that TPH1R306P1 has smaller V_{DS} spike and shorter ringing periods than TPH1R306PL. The results show that the TPH1R306P1 is suitable for secondary synchronous rectification because of low-noise performance.

3.4. Actual Measurement by Isolated DC-DC Converter Evaluation Board

The effect of low V_{DS} spike product is confirmed by MOSFET device test. Thus, we evaluate MOSFET in the power supply. We compare the V_{DS} spike, ringing periods and efficiency on the 500 W AC-DC converter evaluation board of the circuit shown in Figure. 3.4.



Test condition
Input Voltage: 120 V
Output Voltage: 12 V
Load Current: 18.7 A
LLC Frequency: 80-115 kHz

Figure 3.4 500W AC-DC converter evaluation board

The operating waveforms of MOSFET are shown in Figure 3.5.

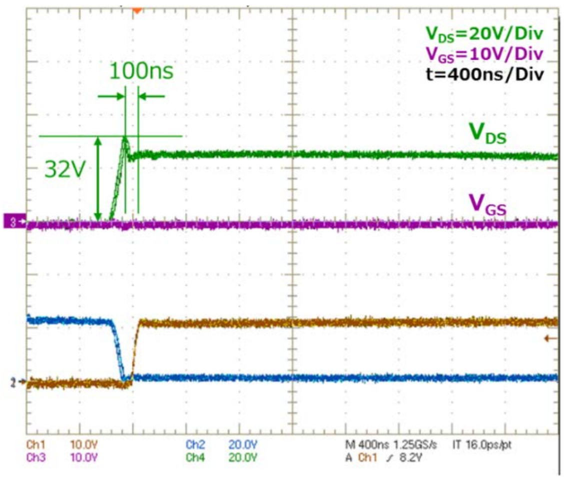
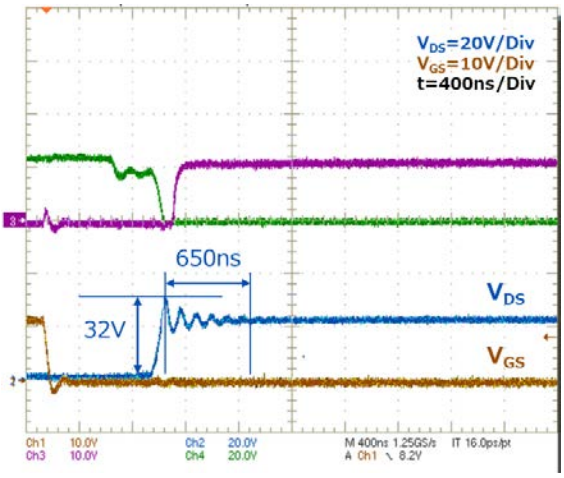
TPH1R306P1	TPH1R306PL
	

Figure 3.5 Measured waveforms on 500W AC-DC converter evaluation board

The waveforms show that TPH1R306P1 reduced ringing from 650 ns to 100 ns compared to TPH1R306PL. On the other hand, the levels of V_{DS} spike remained same on this board. However, V_{DS} spike is expected to be reduced in some power supplies.

We also compared the efficiencies of TPH1R306P1 and TPH1R306PL. The results are shown in Figure 3.6.

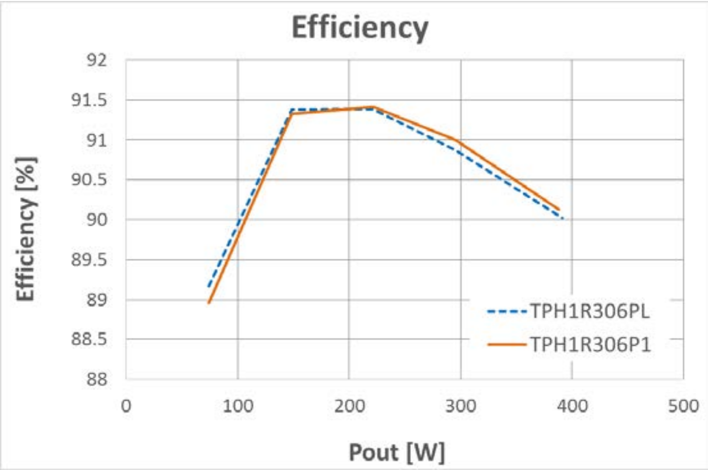


Figure 3.6 Efficiency comparison by AC-DC converter evaluation board

As shown in Figure 3.6, there are no significant differences in efficiency, but the results show that the standard product is slightly more efficient in the low current range, and that the low V_{DS} spike product is slightly more efficient in the high current range.

The switching loss of the low V_{DS} spike product is large in the low current range due to the effect of r_g, and the conduction loss is small in the high current range due to the effect of $R_{DS(ON)}$.

3.5. Conclusion of the Evaluation on the Secondary Side of Isolated DC-DC Converter

It has been confirmed that the low-V_{DS} spike product, TPH1R306P1, with TPH1R306PL cell layout modified, can significantly reduce ringing periods in the secondary synchronous rectifier.

4. Effects on the Primary Side of DC-DC Converter

4.1. r_g Effects

The low V_{DS} spike product has a larger r_g than the standard product, so when used on the primary side of the power supply, it switches slowly and is less efficient, but the V_{DS} spike is suppressed.

4.2. MOSFET Switching Times and Gate Current

This section briefly explains the effect of the gate resistance r_g on the switching time (t_{off}).

Than Q=It

$Q_g = I_G\ t_{off}$

$\leftrightarrow t_{off} = \frac{Q_g}{I_G}$ --- equation (h)

From V = IR,

$V_{GS} = I_G\ (r_g + R_G)$

$\leftrightarrow I_G = \frac{V_{GS}}{(r_g + R_G)}$ --- equation (i)

It can be seen from equation (h) that the larger the r_g, the smaller the I_G. It can be seen from equation (f) that the smaller the I_G, the larger the t_{off}, since Q_g remains unchanged. That is, the larger the r_g, the smaller the I_G and the slower the t_{off} (turn-off time).

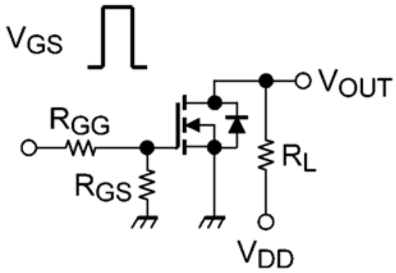
※ The symbols shown here represent the following:

- Q_g: Total gate charge (nC),
- I_G: Gate current (A),
- t_{off}: Turn-off time (ns),
- V_{GS}: G-S voltage (V),
- r_g: Internal gate resistance (Ω),
- R_G: External gate resistance (Ω)

Detailed description of gate drive is omitted. Please refer to our application note "MOSFET gate drive circuits" for more information.

4.3. Measurement of Switching Time of MOSFET

As described above, theoretically, a large r_g can reduce V_{DS} spike. We compared the switching characteristics of low-V_{DS} spike products with those of standard products using the test circuit shown in Figure 4.1. Test condition is V_{DS} = 30 V, I_D = 50 A, R_{GG} = R_{GS} = 4.7 Ω.



Test condition
V_{DS}: 30 V
I_D: 50 A
R_{GG}=R_{GS}: 4.7 Ω
Gate Drive Voltage: 10 V

Figure 4.1 Switching test circuit

Figure 4.2 shows the results of comparison of switching characteristics. The spike voltage was 73.7 V for TPH1R306P1, while the spike voltage was 84.8 V for TPH1R306PL. TPH1R306P1 shows ability to suppress V_{DS} spike.

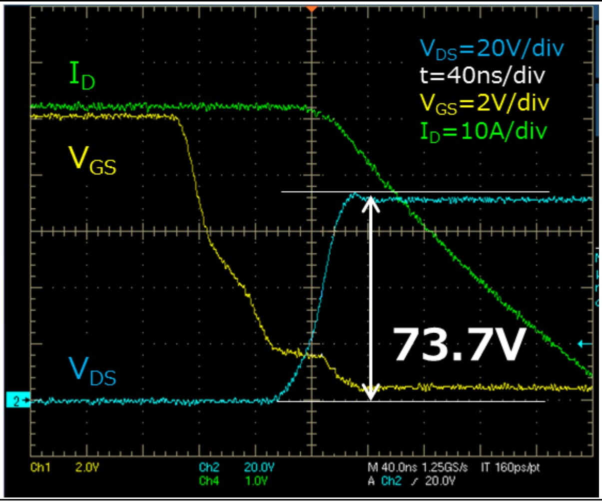
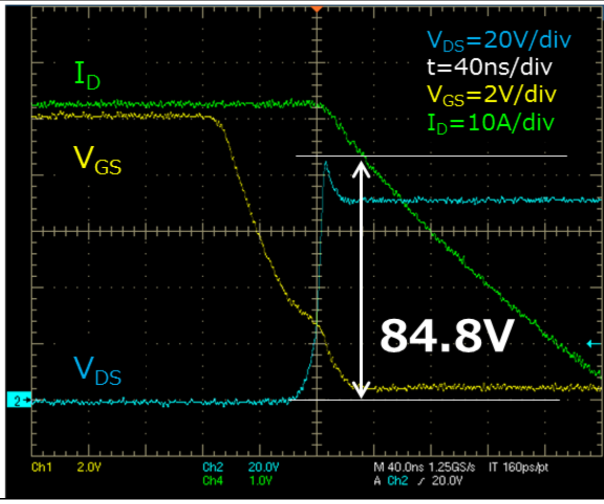
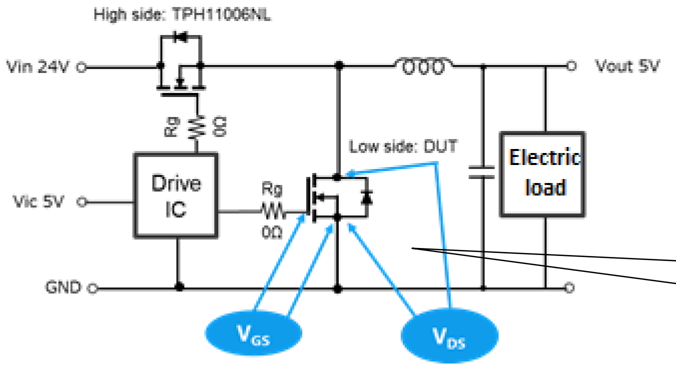
TPH1R306P1	TPH1R306PL
	

Figure 4.2 Comparison of switching characteristics

4.4. Actual Measurement by Non-isolated DC-DC Converter Evaluation Board

Similar evaluation is performed on power supply to verify the effects of increasing the r_g. The following shows comparison of V_{DS} spike and ringing on a non-isolated DC-DC converter evaluation board as shown in Figure 4.3.



Test condition
Input Voltage: 24 V
Output Voltage: 5 V
Frequency: 160 kHz
Gate Drive Voltage: 5 V

Probe is set near MOSFET to avoid the influence of wiring inductance.

Figure 4.3 Non-isolated DC-DC converter evaluation board (circui diagram)

The results are shown in Figure 4.4. V_{DS} spike decreased from 44.0 V to 32.0 V, and ringing periods decreased from 88 ns to 40 ns. From this result, the TPH1R306P1 of low V_{DS} spike product can be expected to reduce V_{DS} spike and ringing periods even on the primary side.

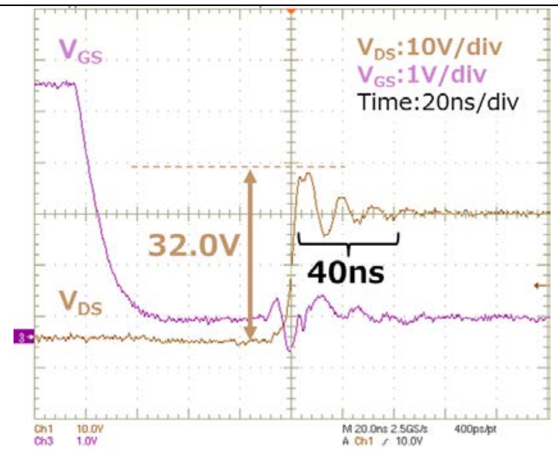
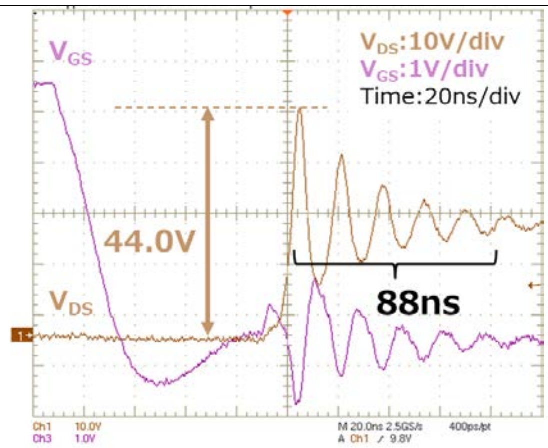
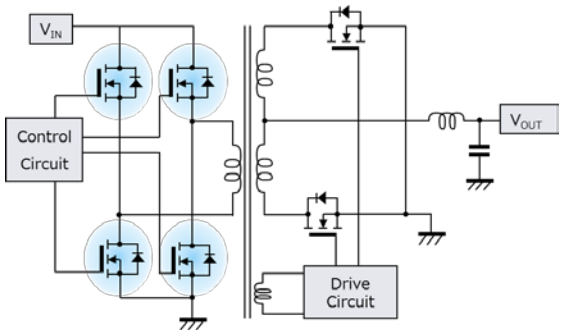
TPH1R306P1	TPH1R306PL
	

Figure 4.4 Comparison of switching waveforms on non-isolated DC-DC converter

4.5. Actual Measurement by Isolated DC-DC Converter Evaluation Board

In addition, the same evaluation was performed on the isolated DC-DC converter evaluation board as shown in Figure 4.5.



Test condition
Input Voltage: 24 V
Output Voltage: 5 V
Frequency: 160 kHz
Gate Drive Voltage: 5 V

Figure 4.5 Isolated DC-DC converter evaluation board (Full-bridge circuit)

The switching waveform is shown in Figure 4.6.

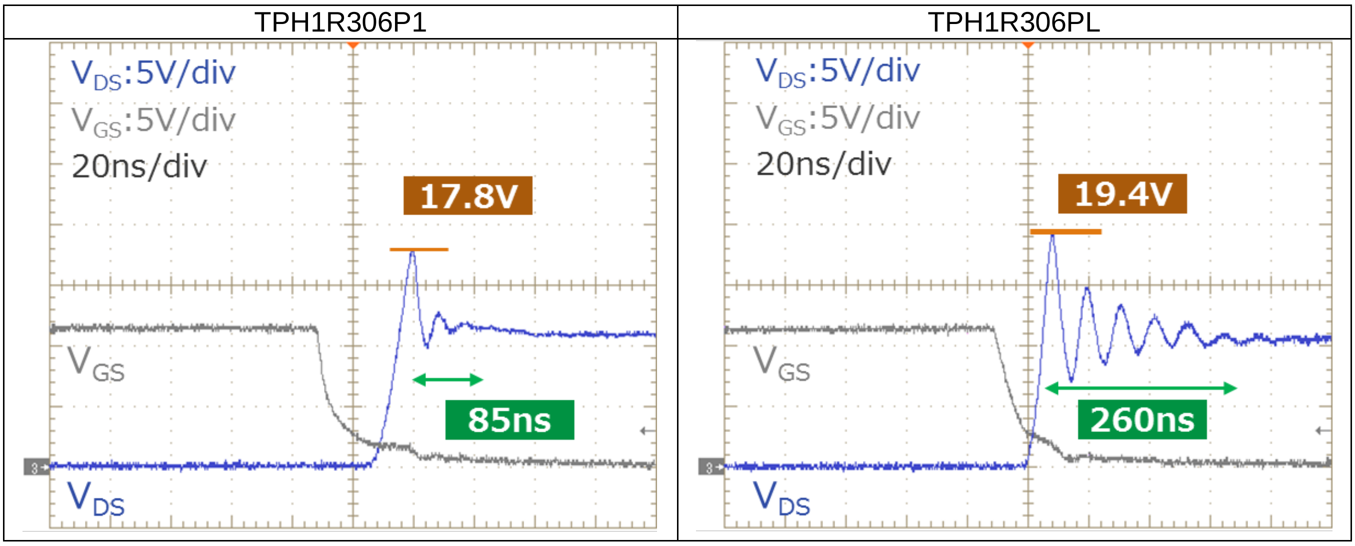


Figure 4.6 Comparison of switching waveforms

TPH1R306P1 (low V_{DS} spike product) is effective in reducing V_{DS} spike and ringing period on primary side compared to TPH1R306PL.

The results show that V_{DS} spike and ringing are reduced by using TPH1R306P1 for the primary side of isolated DC-DC converter.

The efficiency results are shown in Figure 4.7.

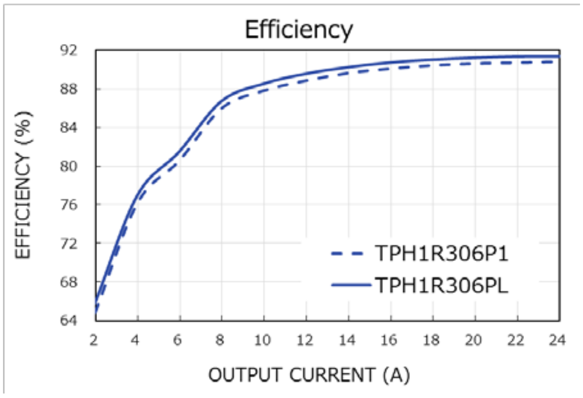


Figure 4.7 Efficiency comparison

TPH1R306P1 is slightly less efficient when used on the primary side.

4.6. Conclusion of the evaluation on the primary side of isolated DC-DC converter

TPH1R306P1 (low V_{DS} spike product) is effective in reducing V_{DS} spike and ringing period not only in synchronous rectification operation on the secondary side but also in switching operation on the primary side.

5. Product Selection According to the Purpose of Use

Low V_{DS} spike product TPH1R306P1 is a product with r_g larger than TPH1R306PL. This is useful for reducing V_{DS} spike and ringing period on both the primary and secondary sides. In particular, the secondary side can be expected to reduce V_{DS} spike and ringing period by optimizing r_s.

On the other hand, we reaffirmed that the standard product TPH1R306PL is more efficient on the primary side than the low V_{DS} spike product TPH1R306P1.

Our U-MOSIX-H 60 V lineup includes both TPH1R306P1 of low V_{DS} spike product and a TPH1R306PL of standard product. We recommend to select the most appropriate product for the equipment.

Points of Attention Regarding the Content

1. **Block diagram**
   Some of the functional blocks, circuits, constants, etc. in the block diagram may be omitted or simplified in order to explain the functions.

2. **Equivalent circuit**
   Some of the equivalent circuits may be omitted or simplified to explain the circuits.

Precautions and Requests for Use

Notes on Handling

(1) Absolute Maximum Rating is a specification that must not exceed any one value of multiple ratings at any instant in time.
It cannot be exceeded for any of several ratings. Exceeding the absolute maximum rating may cause damage, damage, and deterioration, which may result in damage due to rupture or combustion.

(2) Use an appropriate power supply fuse to prevent a large current from continuing to flow in the event of an overcurrent or IC failure. The IC may be damaged due to usage exceeding the absolute maximum rating, incorrect wiring, abnormal pulse noise induced by wiring or load, etc. As a result, a large current may continue to flow through the IC, resulting in smoke and fire. It is necessary to set the capacity of the fuse, the blowing time, the position of the inserted circuit, etc. in order to minimize the influence by assuming the inflow and outflow of a large current in the case of breakage.

Points to Remember on Handling

(1) Overcurrent detection circuit
The overcurrent detection circuit does not protect the IC in any case. After operation, promptly cancel the overcurrent condition.
Otherwise, the over-current limiting circuit may not operate properly or the IC may be damaged before operating. If an overcurrent continues to flow for a long time after operation, the IC may be damaged due to heat generation, depending on the operation method and conditions.

(2) Heat-blocking circuit
A thermal shutdown circuit (usually a thermal shutdown circuit) does not protect the IC in any case. Release the heating condition immediately after operation.
If the product is used in excess of the absolute maximum rating, the heat interruption circuit may not operate properly or the IC may be damaged before it operates.

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