Power switching device

Precautions during gate-source voltage measurement

Power devices such as MOSFET and IGBT are used as switching devices in various power supply applications and power line. As SiC MOSFET has relatively huge current and voltage change during switching operation which usage has been increasing in recent years would need precise measurement for surge in between Gate and Source terminal described in "Gate-source voltage behaviour in a bridge configuration" application note. Hereupon this application note will explain the precautions during the gate – source voltage measurement.

General measurement Method

In many cases, power switching devices used for power supply units typically have heatsink for the cooling and due to this, voltage probe etc. cannot be directly attached to the target device terminals while measuring terminal voltages. For that reasons it is necessary to solder extended cable to the device lead wire then connect the voltage probe outside the test box for the measurement.

Figure 1. demonstrates the example of connecting voltage probe to the extended cable with heatsink mounted onto our evaluation board (P02S). The extended cable (length 12cm) for voltage probe is soldered to the DUT (Device Under TEST) terminal and twisted in order to minimize the radiation noise.

![Figure 1. Gate- source voltage measurement using extended cable](image)

We conducted double pulse test with bridge configuration shown in Figure 2. using this measurement methodology. Implemented Rohm SCT3040KR for high-side (HS) and Low-side (LS) switch. Kept LS always OFF (0V) and switched HS power device. Extended cable described in Figure 1. is soldered to the gate terminal and the source terminal.

![Figure 2. Double pulse test circuit](image)

Measured gate-source voltage waveform is as shown in Figure 3. When external gate resistor RG is 10 ohms, there are minor effect from using extended cable but changing RG to 3.3 ohms and increasing the switching speed then measured waveform now fluctuates significantly due to the noise from changing voltage and/or current or by induced high frequency operation.
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One should notice that extended cable in the system will cause changes in the frequency band due to the extra impedance resulting observing totally different waveform from what original should be.

Figure 3. Gate-source voltage waveform
(a) Turn-On, (b) Turn-Off

Figure 4. Equivalent circuit of differential probe

Connecting Probes

In this manner, measured waveform will be significantly affected by how the voltage probe was connected. To verify the differences of the measurement result depending how it was connected, we took general procedure of following approaches.

(a) Directly connect probe head to the device terminal
(b) Use twisted extension wire to connect probe head
(c) Use long twisted extension wire with 100 ohms damping resistor to connect probe head
(d) Use short twisted extension wire with 100 ohms damping resistor to connect probe head

(a) connect voltage probe head directly to the DUT. (b) twisted extension cable (approximately 12cm) soldered to DUT terminal and connect voltage probe to the other end of the cable. (c) connect 100 ohms resistor in the middle of the twisted extension cable used in (b). (d) use short twisted extension cable (approximately 4cm).
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Figure 5. Shows actual extension cables used in the measurement and Figure 6. Shows how the probe head was connected.

(b) Twisted cable

c) Twisted cable with 100 ohm damping

d) Twisted shorter cable with 100 ohm damping

Figure 5. Extension Cables

Figure 6. Voltage probe connection
(a) Directly
(b) Long extension cable,
(c) Long extension cable +100 ohm,
(d) Short extension cable +100 ohm

Figure 6. Voltage probe connection

Figure 7. shows gate-source voltage waveform of double pulse test using different connections from Figure 6. (a) to (d).
Figure 7. (a) is gate-source voltage at signal turning On and (b) is at signal turning Off.
Looking at LS side switching, result showing huge waveform
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differences depending the measurement conditions. With the measurement condition (a), voltage probe head forms loop and this causes the flux change going through this probe head loop during HS MOSFET turn ON period when start switching the current. The negative voltage surge can be observed due to clockwise electrification from the flux change on LS side probe head as shown in Figure 8. This basically should be positive surge like observed with condition (c) or (d) *3.

![Figure 7. Waveform comparison by different voltage probe connection](image)

With condition (b) on the other hand, large surge can be observed due to the ringing induced from extended cable impedance increase.

![Figure 8. Electromotive force by commutation](image)

Therefore, it is necessary to minimize the closed loop formed by the jig and gate-source terminal connections to avoid inducing influence of the flux change delivered from the current flow to get accurate measurement result.

On another note, with Figure 6. (b) to (d), formed loops are minimized as extension cables are soldered to terminals directly under the MOSFET package.

Selecting the measurement point

Next thing to be cautioned is selecting DUT measurement point.

Upon measuring the waveform with actual product, it is often the case that to pick measurement point where probes can easily access to. This is because most of the case heatsink etc. is attached to the DUT and probing directly to the lead terminal is problematic and or DUT is populated with long lead terminal due to the lead forming. As a result, the measurement point can be very much affected by the product structure and may not necessarily measuring at optimal point.

Hereupon, selected three different measurement points to verify the differences.

(a) Adjacent to the DUT molding package
(b) At PCB soldering point of populated DUT
(c) At check pin soldered to the PCB
(d) At check pin soldered to the PCB + Twisted wire + 100 ohm
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Figure 9. Measurement point
(a) Direct to lead, (b) Tip of the lead, (c) On PCB, (d) On PCB + Twisted cable + 100 ohm
Precautions during gate-source voltage measurement

Figure 9 describes the differences of the measurement points. Measurement point (a) is minimum lead access to the DUT. Measurement point (b) will use board soldering side lead terminal suppose lead terminal have been stretched due to the lead forming etc. Measurement point (c) suppose there is check pin prepared beforehand and using it as a probing point. In here used check pin pad nearby the MOSFET. (d) use same measurement point but soldered twisted wire and separated probe head from the board.

Figure 10 shows the result of the measurement. Result shows there are huge surge waveform differences between different measurement points.

(a) shows stable waveform where measurement point was nearby the DUT. (b) catches the electromotive from the package lead wire which exist within the measurement network. (c) and (d) see the noise from closed loop pattern formed in the DUT to check pin.

From these results, it is desirable to select measurement point as near to the DUT as possible.

Probe head installation location

One other thing to be precautious about is the voltage probe head installation location.

Generally speaking, environment where power switching device being used draws high current (up to hundreds of current of amperes) at high switching frequency and thus the flux change $\frac{d\Phi}{dt}$ caused by change of current $\frac{di}{dt}$ is also large. Also change of voltage $\frac{dv}{dt}$ also will get extremely large and with under extremely high voltage condition, current change is not by any means small.

Therefore, placing the voltage probes carelessly in such high flux change space, probe head receives the influence of magnetic flux change. Resulting superimposed fluctuations on to the measurement waveform.

Here conducted four different installation location to verify the influence.

(a) Inside of main circuit loop
(b) Outside of main circuit loop
(c) Use 12cm twisted wire and set apart from main circuit loop
(d) Use 12cm twisted wire + 100 ohms and set apart from the main circuit loop

Figure 11 shows the difference in between the locations of the probe head and showing current path of the main circuit loop with arrows. (a) locate probe inside of the main loop where $\frac{d\Phi}{dt}$ is largest. (b) locate probe outside of the main loop where $\frac{d\Phi}{dt}$ is relatively large if not largest. (c) use extension cable to locate probe head apart from the main circuit loop to minimize the influence of $\frac{d\Phi}{dt}$.
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Figure 11. Installation location of probe
(a) Inside main circuit loop, (b) Outside main circuit loop,
(c) Apart using extension cable, (d) Apart using Extension cable +100 ohm
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Figure 12 shows the gate-source voltage waveform measurement results for four different probe installation location. Looking at LS side, surge can be observed at the timing of switching strongly influenced by the radiation noise with (a) which flux change is the largest. (c) showing larger fluctuation than (b) due to the inductance of extension cable. (d) shows the minimum fluctuation by adding 100 ohms damping resistor to the extension cable. The test conducted while HS switching and keeping LS at always off state (0V). Because of this since there are no driving current flowing into the gate terminal thus LS device was susceptible to the flux change. On the other hand, HS MOSFET gate have DC current flowing through thus less susceptible to the flux change resulting stable waveform compared to the LS measurement.

Precaution with Bridge configuration

Lastly, high voltage differential probe or differential probe is commonly used for waveform observation when measuring

Figure 13. $V_{GS}$ waveform when HS/LS switching
(a)Turn-On, (b)Turn-Off
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High-side MOSFET in bridge configuration. However due to the degradation of CMRR performance at high frequency band of the probes used for the measurement, the measured waveform may get fluctuated. Especially for gate-source voltage $V_{GS}$ would require measuring surge that is in several volts level, and it is necessary to distinguish the original waveform from the fluctuated waveform caused by performance degradation of CMRR.

Figure 13. shows the waveform comparison when HS is switching versus LS is switching in bridge configuration. The probe used here is differential probe YOKOGAWA 701297 (150MHz, 1400V). By looking at commutation side surge, it is obvious that HS $V_{GS}$ is largely fluctuated when switching LS switch. This is caused by the CMRR performance degradation when HS is switched at high dV/dt such as 20 – 50 V/ns.

Figure 14. shows CMRR performance of the differential probe measurement result. Measured voltage probe plus and minus side by connecting to HS and LS of source terminal respectively. Please refer to Tektronix application note [ABCs of Probes]*2 for measurement method detail.

It shows the waveform when turn-on (a) and Turn-Off (b) respectively. It shows HS source voltage switches at about 200KHz (Duty 50%) on 800V DC and is synchronized to is $V_{DS}$ change unlike the LS MOSFET source voltage remains stable. The fluctuation here shows to positive with fall-down of $V_{DS}$ and to negative with rise-up of $V_{DS}$ but note that depending on the differential probe characteristics it may behave opposite.

These days, fiber optically-isolated differential probes are offered from measurement equipment manufacturers which are immune to CMRR characteristics and gathering attention for effective solution to get accurate waveform measurement result.

Figure 16. shows the gate-source voltage measurement results using optically-isolated differential probe from Tektronix using IsoVu® technology and traditional high voltage differential
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As the PCB board (P02SCT3040KR-EVK-001) used for the measurement was missing MMCX connector land pattern to connect optically-isolated probe, we have connected optically-isolated probe and voltage probe simultaneously as shown in Figure 15.

To neutralize adverse effect to the waveform from probe installation location or measurement point as previously described, we have connected voltage probe with short extension cable with 100 ohms damping resistor which soldered directly under the MOSFET.

Measurement result with using voltage probe shows exceeding operation voltage 18V after turning on the HS switch (a) and falling below 0V when turning off the HS (b) due to the CMRR performance degradation. On the other hand, optically-isolated probe measurement result shows stable output for both 18V and 0V which can be said that it is catching the accurate waveform.

These results are obvious from the CMRR frequency response shown in Figure 17. *4 Optically-isolated probe has extremely wide frequency band response compared to the voltage probe which is capable of sufficiently eliminating the common mode noise at several dozens of MHz frequency.

**Summary**

Below are three important points to assure the accurate measurement of MOSFET gate-source voltage.

- Minimize the loop created by probe head when placing the probe upon testing.
- Minimize the circuit loop created with the device measurement terminal/pin when selecting the measurement point of the device.
- Minimize the influence of the flux change from the main circuit when selecting the probe head installation point.
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Verification through this paper resulted that in order to get most accurate waveform in the testing was to use “extension cable + damping resistor” and take measurement at directly under device terminal. However, the best policy of the measurement method would differ depending on the circuit configuration, PCB layout etc. thus it is necessary to have countermeasure for each individual case based on the tendency described in this paper.

Form now on, it is essential to consider not only to pay close attention on measuring method but also to integrate the functions for the measurement from the beginning of product design to get an accurate testing result for high speed power switching devices.

Lastly, we hope by taking an account what is described in this application note will provide true judgement for the measurement waveform as each individual product have different measurement conditions.

Reference:
*1 「Gate-source voltage behaviour in a bridge configuration.」
   Application Note (No. 60AN135ERev.001)
   RHOM Co., Ltd., May, 2018

*2 「ABCs of Probes.」
   Application Note (No. EA 60W-6053-14)
   Tektronix, January, 2016

*3 「Improvement of switching loss by driver Source.」
   Application Note (No. 62AN040ERev.001)
   ROHM Co., Ltd., October, 2019

*4 「Complete ISOLATION Extreme COMMON MODE REJECTION.」
   White Paper (0/16 51W-60485-1)
   Tektronix, 2016

*5 「User’s Manual Model 701927 PBDH0150 Differential Probe.」
   Yokogawa Test & Measurement Corporation, March, 2018

*6 「WaveLink Medium Bandwidth(8-13GHz) Differential Probe.」
   Operator’s Manual (924243-00)
   TELEDYNE LECROY, May 2014

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