

Power switching device

Precautions during gate-source voltage measurement

Power devices such as MOSFETs and IGBTs are used as switching devices in various power supply applications. Due to the steep voltage and current slopes present during the switching transients of a SiC MOSFET device, the measurement of the gate-source voltage should be performed carefully. As described in “Gate-source voltage behaviour in a bridge configuration” [1] application note, it is necessary to determine with accuracy the voltage peaks between gate and source, so that the limits specified in the data sheet are not violated. This application note will explain the precautions that need to be taken during the gate - source voltage measurement.

General measurement method

In many cases, the device terminals are not accessible to the probes due to layout and space constraints of the circuit itself. Because of that, it might be necessary to solder additional cables to the terminals to connect the probes.

Figure 1 shows an example of a voltage probe connected to a cable extension in our evaluation board (P02SCT3040KR -EVK-001). The extension cable (12cm long) for the voltage probe is soldered to the terminals of the device under test (DUT), and the cables are twisted, in order to minimize picking up radiated noise.

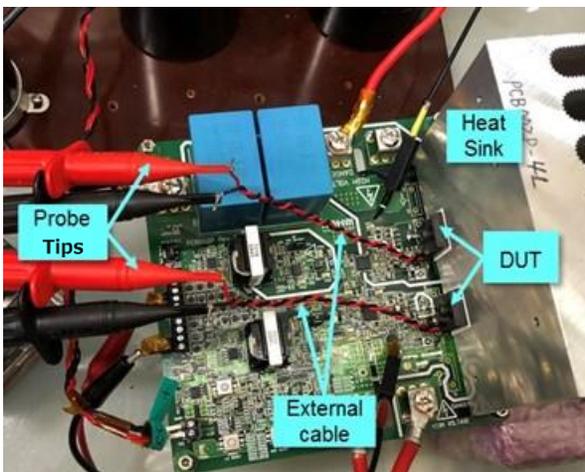


Figure 1. Gate- source voltage measurement using cable extension

We conducted a double pulse test with the half bridge configuration shown in Figure 2 using this measurement method. ROHM SCT3040KR SiC MOSFETs were selected for the high-side (HS) and low-side (LS) switches. The LS switch was kept permanently OFF (0V) and the HS side was switched. The cable extension shown in Figure 1 is soldered to the gate and source terminals.

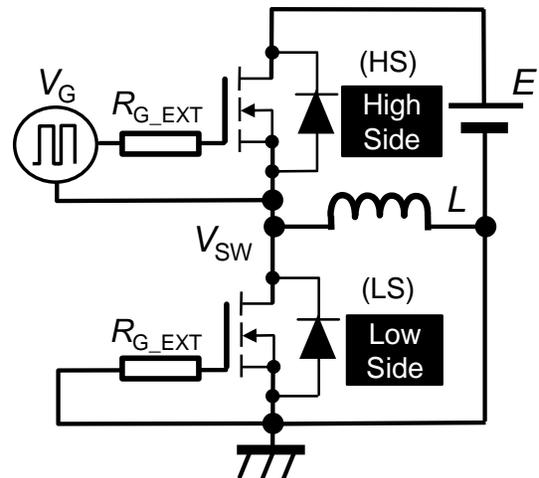


Figure 2. Double pulse test circuit

Measured gate-source voltage waveforms are shown in Figure 3. The effect of using extension cables with $R_{G_EXT} = 10$ Ohm is negligible. However, if R_{G_EXT} is reduced to 3.3 Ohm, the measured waveforms clearly show some ringing due to the noise from the steeper voltage and current slopes and/or

induced by high-frequency operation.

The extension cable in the system will cause changes in the frequency band due to its additional impedance. This will result in a distortion of the original waveform if a probe is connected to them.

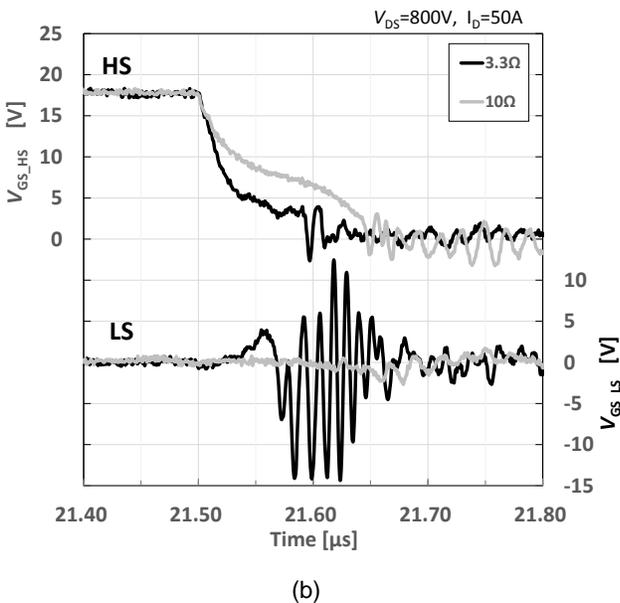
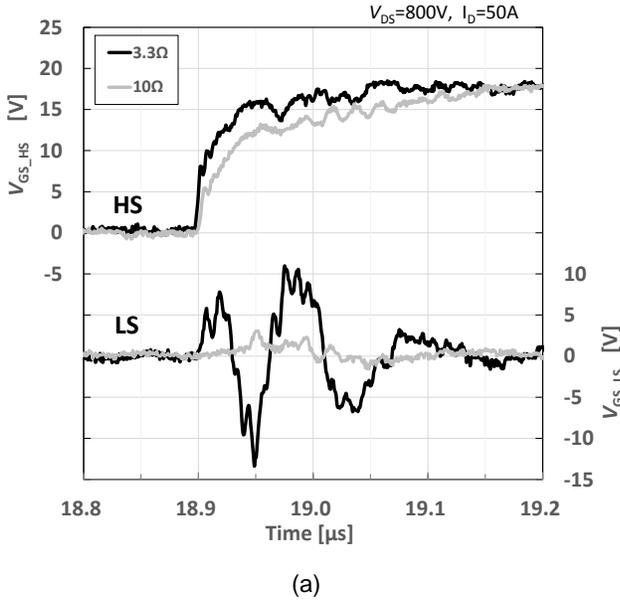


Figure 3. Gate-source voltage waveform
(a) Turn-on, (b) Turn-off

Figure 4 describes the equivalent circuit of a differential voltage probe connected to the DUT through an extension cable [2, 6]. The added impedance of the extension cable

connected between the probe and the DUT will cause a resonance between the stray inductance L_{EXT} and the input capacitance C of the voltage probe. This resonance will superimpose high frequency voltage ringing to the original voltage waveform. Thus, the measured surge voltage will be higher than the one at the device terminals.

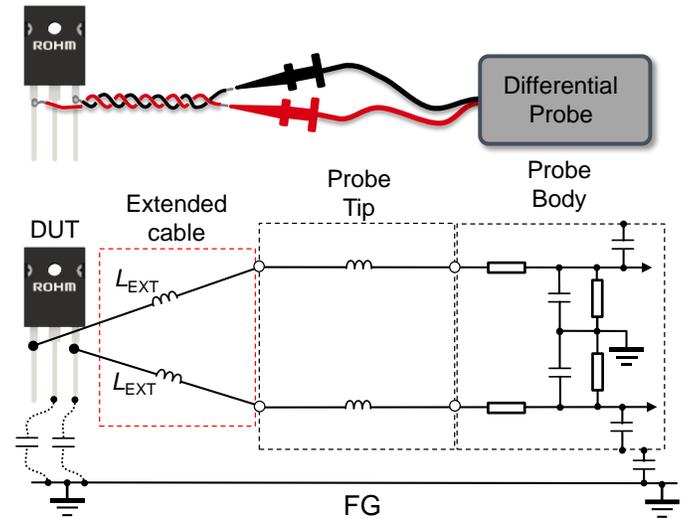


Figure 4. Equivalent circuit of differential probe

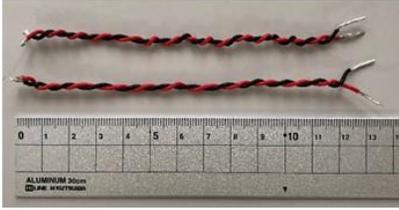
Connecting probes

As previously explained, the measured waveform will be significantly affected by the way the voltage probe is connected to the device. To verify the differences of the measurement results depending on how it was connected, following cases were studied:

- (a) Directly connect probe tip to the device terminal
- (b) Use twisted extension wire to connect probe tip:
A 12-cm long twisted extension cable was soldered to the DUT terminals. The voltage probe was connected to the other end.
- (c) Use long twisted extension wire with 100 Ω:
The 100 Ω resistor was placed in the middle of the twisted cable used in (b).
- (d) Use short twisted extension wire with 100 Ω:
The cable used in (c) was shortened to 4 cm and connected between DUT and voltage probe.

Figure 5 shows actual extension cables used in the measurement and Figure 6 shows how the probe tips were connected.

(b) Twisted cable



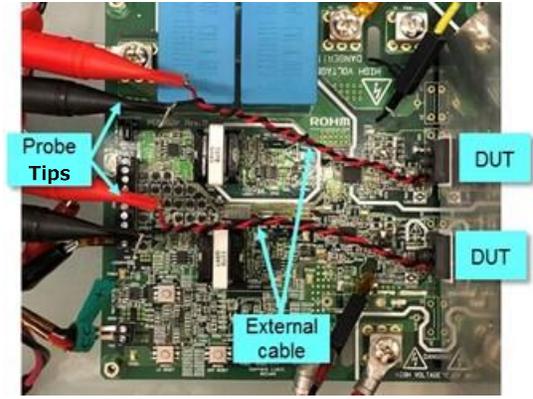
(c) Twisted cable with 100 ohm damping



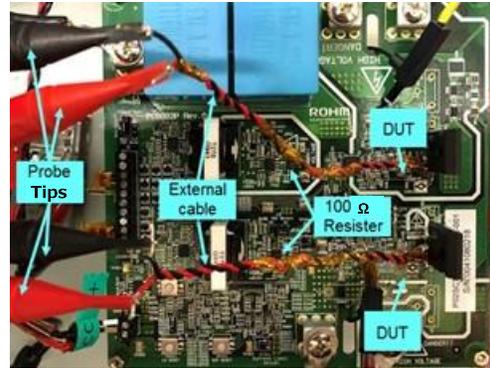
(d) Twisted shorter cable with 100 ohm damping



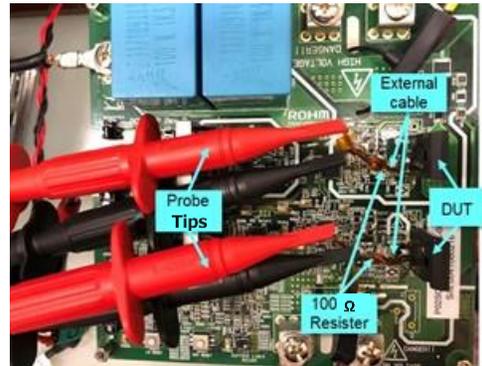
Figure 5. Extension Cables



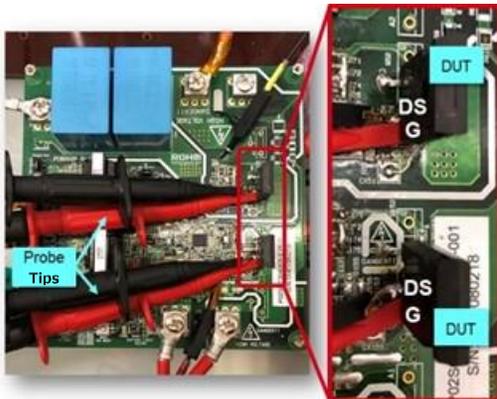
(b)



(c)



(d)



(a)

Figure 6. Voltage probe connection
(a) Directly

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

Figure 7 shows the gate-source voltage waveforms for turn-on and turn-off using the connections from Figure 6 (a) to (d).

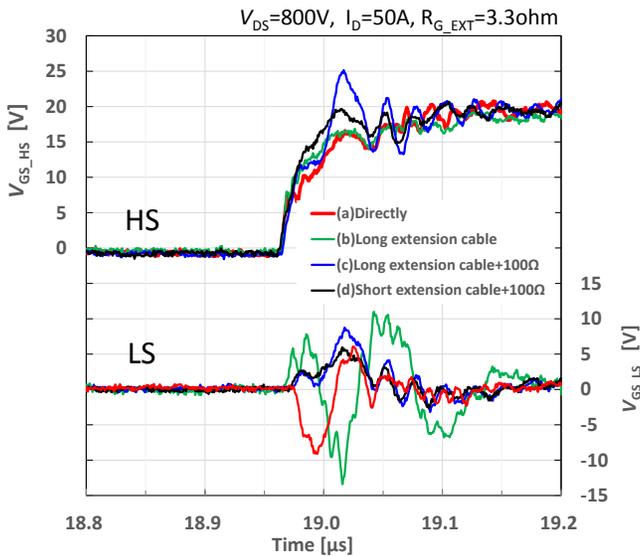
The LS waveforms show major differences depending on the measurement conditions. With the measurement condition

(a) there is a loop formed by the probe tips, probe cables and the device, see Figure 8. There will be a magnetic flux change in this loop during the switching transient when HS MOSFET turns on.

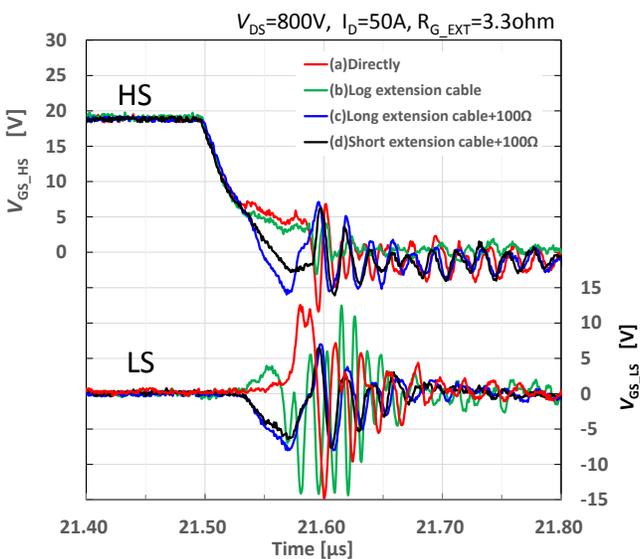
The waveforms show that for method (a) there is a negative voltage peak first. This peak is the result of the current induced by the magnetic flux change, which charges the capacitance of the LS probe body, see Figure 4(c). Measurement methods

(c) and (d) do not show a negative peak, which is closer to the actual behaviour of the device [3].

With condition (b), on the other hand, a significant ringing can be observed. This comes from the ringing induced by the added impedance of the extension cable.



(a)



(b)

Figure 7. Comparison of waveforms with different voltage probe connection methods
(a) Turn-on, (b) Turn-off

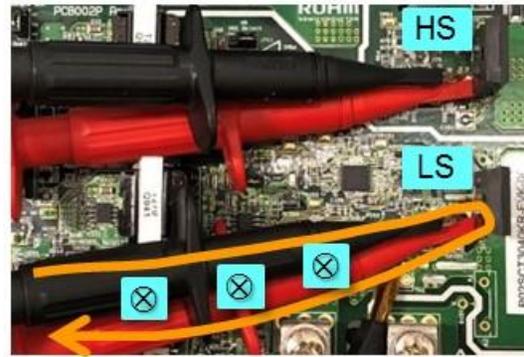


Figure 8. Electromotive force induced during commutation of the power device

Therefore, it is necessary to minimize the loop formed by the probe tips and gate-source terminal connections to reduce the influence of the magnetic flux variation due to the commutation of the device current in the measurement. One way of achieving this can be seen in Figure 6 (b) to (d), where the loops are minimized by soldering the tightly twisted extension cables directly to the device terminals.

Selecting the measurement point

When measuring power devices usually the probes are connected to an easily accessible point of the circuit. A direct connection to the device terminals is not always possible due to layout or space restrictions. As a result, the selected measurement point might not be the optimal one. To verify this, four different measurement methods have been selected:

- (a) Probe tip adjacent to the DUT mold package
- (b) Connection to the PCB soldering pad of the DUT
- (c) Connection to a test pin soldered to the PCB
- (d) Like (c) + twisted wire + 100 Ω

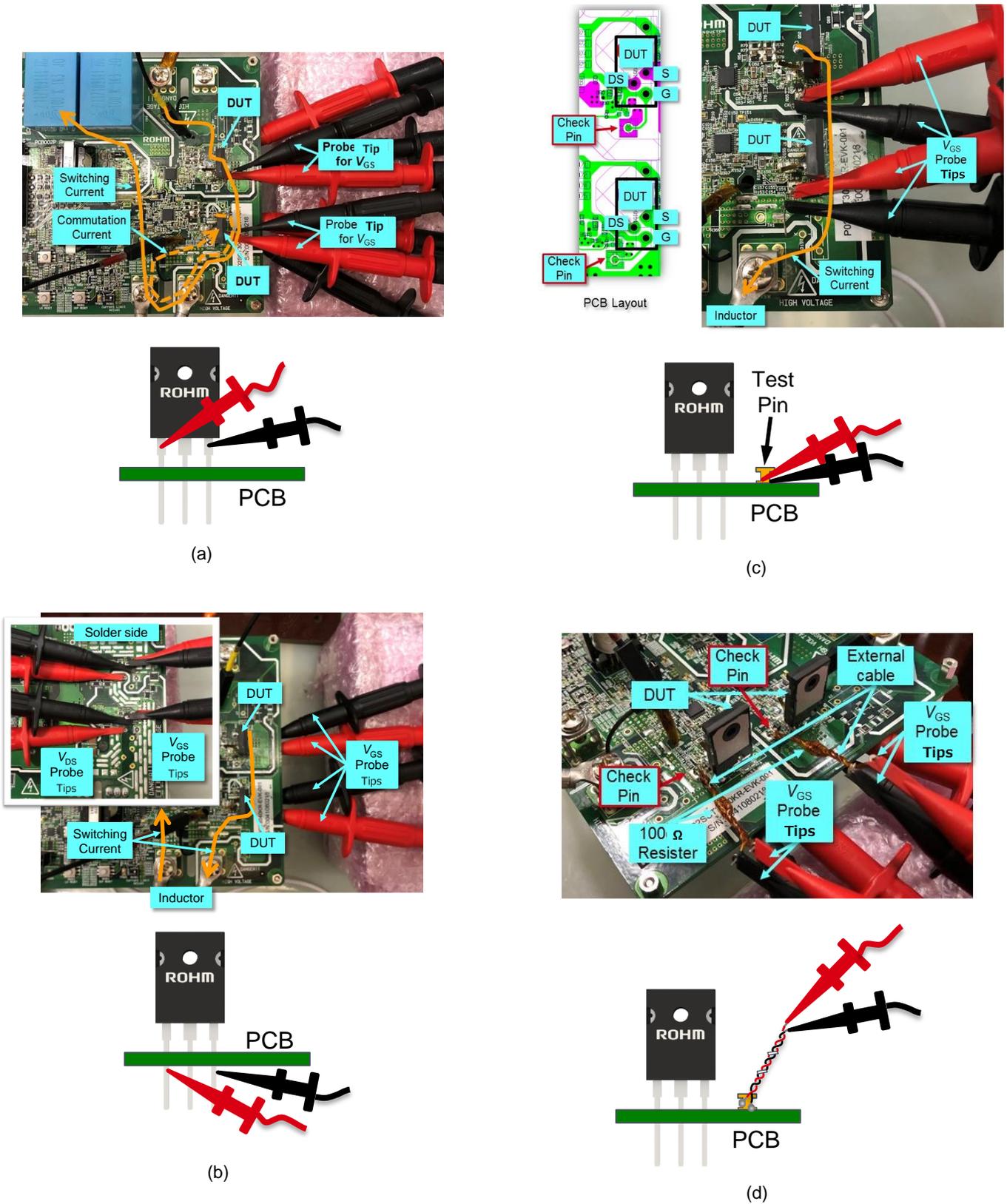


Figure 9. Measurement point

(a)Direct to lead, (b)Tip of the lead, (c)On PCB, (d)On PCB + twisted cable + 100 Ω

Figure 9 describes the different measurement methods. Measurement method (a) has the shortest distance from the probe tip to the DUT chip. In method (b), the probes are connected to the bottom side of the PCB, where the DUT pins are soldered. For measurement method (c) a test pin located close to the DUT was used. Method (d) uses the same point as (c) but the probe is connected through a twisted wire with a damping resistor to the DUT.

Figure 10 shows the measurement results. The difference between the different methods is clear.

Method (a), with the probe tip close to the DUT, shows a stable waveform. Method (b) catches the EMF from the measurement network through the package leads. Methods (c) and (d) collect the noise through the closed loop formed by the DUT and the test pin.

It is clear that, according to these results, it is desirable to select the measurement point as near to the DUT as possible.

Probe tip placement

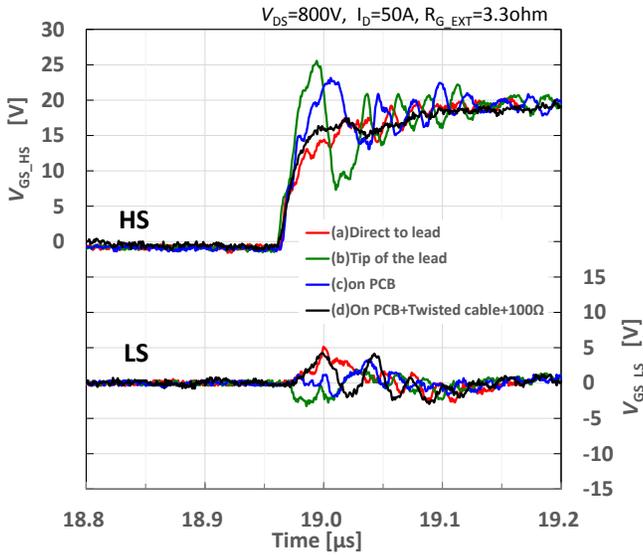
Besides the measurement point itself, also the placement of the probe tip can be critical.

Due to the noisy environment generated by high-speed power switching devices, attention is needed when placing the probe. The influence of the magnetic flux change will be superimposed to the measured waveforms if the tip is not carefully placed.

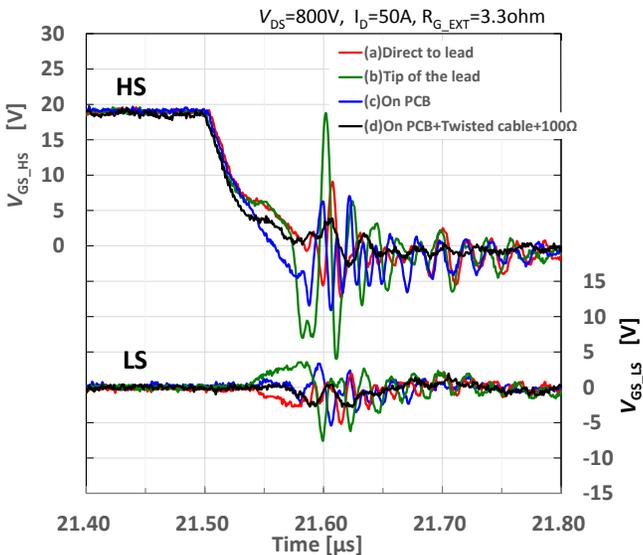
To understand this better, four different placement locations and connection methods have been tested:

- (a) Probe placed inside of the main circuit loop
- (b) Probe placed outside of the main circuit loop
- (c) Probe out of the main circuit loop connected through 12 cm twisted wire to the PCB
- (d) Same as (c), but with an additional 100 Ω damping resistor

Figure 11 shows each of these placement methods and the corresponding current path of the main circuit loop. Placement (a) exposes the probe to the maximum $d\phi/dt$. In (b) the probe is placed at the edge of the main loop, where $d\phi/dt$ is still relatively large. In the case of (c), the probe is placed away from the main loop to minimize $d\phi/dt$ influence. Method (d) adds 100 Ω damping resistance to the cable connection.



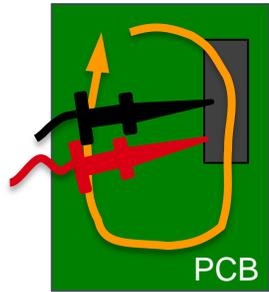
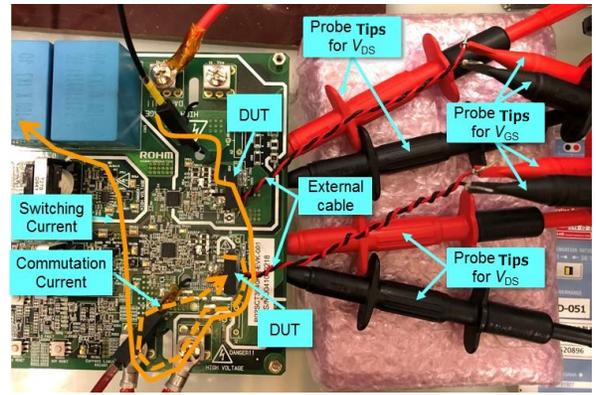
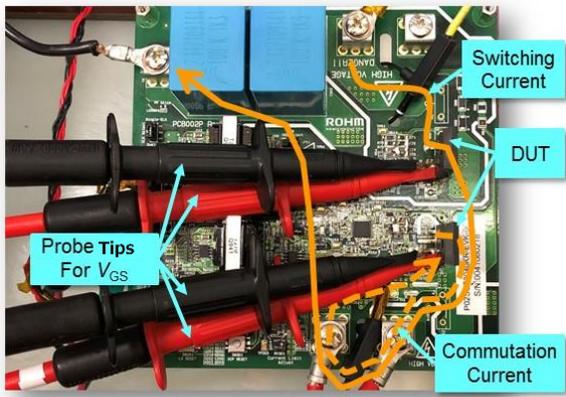
(a)



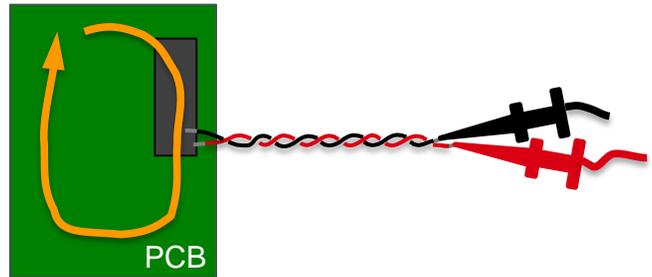
(b)

Figure 10. Waveform comparison for different measurement points

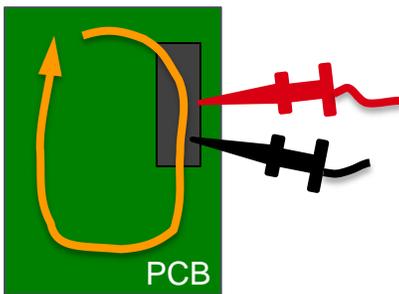
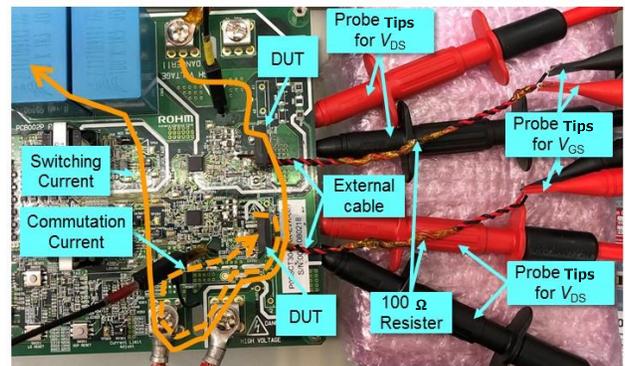
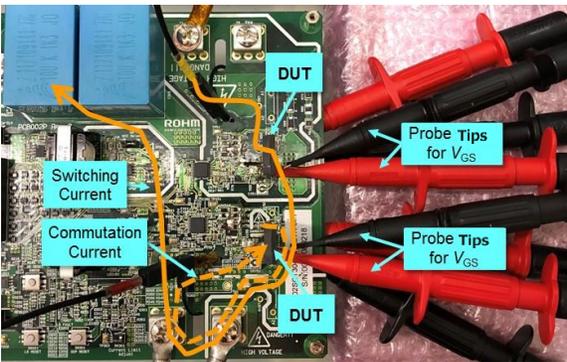
(a) Turn-on, (b) Turn-off



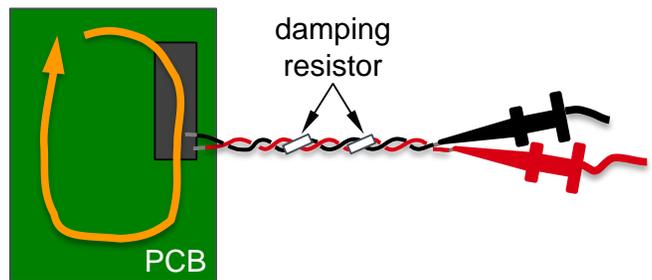
(a)



(c)



(b)



(d)

Figure 11. Probe placement

- (a) Inside main circuit loop, (b) outside main circuit loop,
- (c) outside using extension cable, (d) apart using extension cable +100 Ω

Figure 12 shows the different gate-source voltage waveforms for the aforementioned placement methods. It can be appreciated that the voltage surge at the LS device is the largest for method (a), where the flux change rate is at its maximum. In the case of (c), this shows a larger fluctuation than (b) due to the added inductance of the extension cable. The 100 Ω damping resistance helps in diminishing the amplitude of the oscillations, as it can be seen in (d).

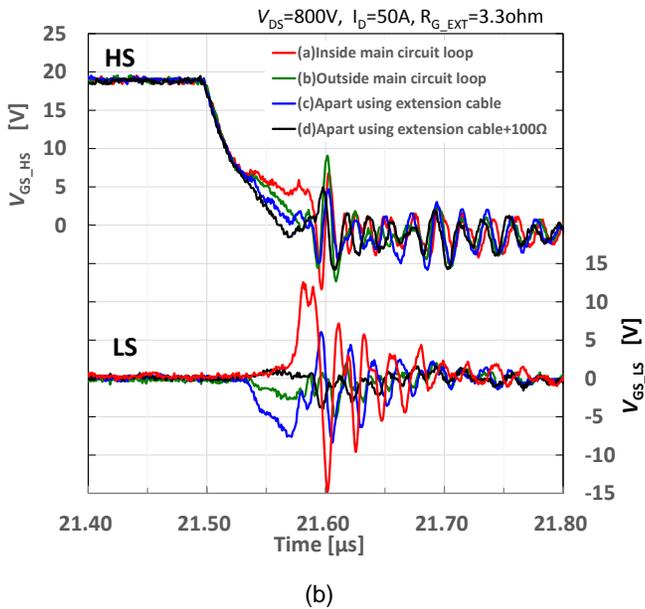
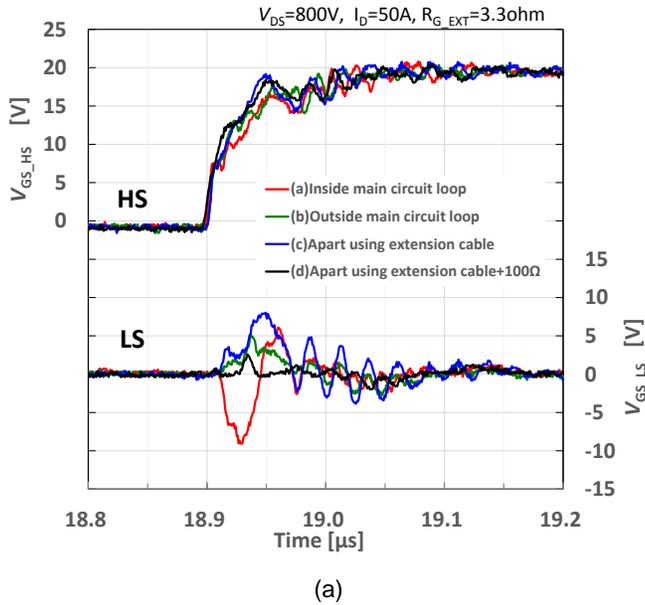


Figure 12. Waveform comparison for different probe placement locations
(a) Turn-on, (b) Turn-off

The test was conducted by switching the HS device and keeping the LV device off (0 V). Since the LS switch has no driving current flowing into the gate it is more susceptible to the flux change than the HS device, which is currently being turned on. This results in more stable waveforms for the HS device.

Precaution with bridge configuration

High voltage differential probes are commonly used for voltage measurements of power devices in half-bridge configuration.

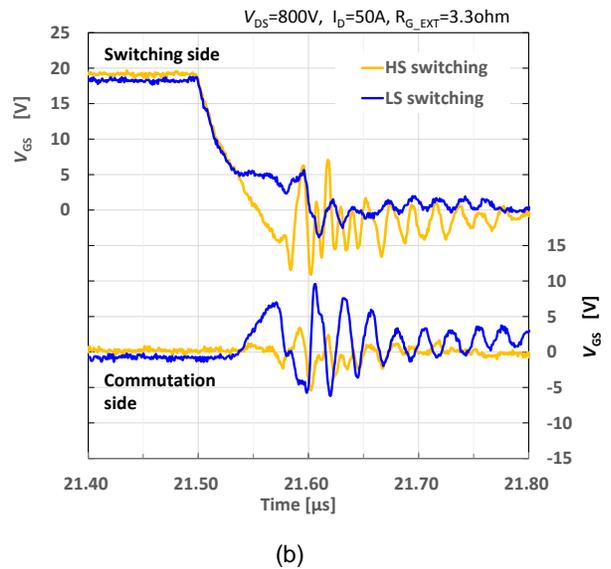
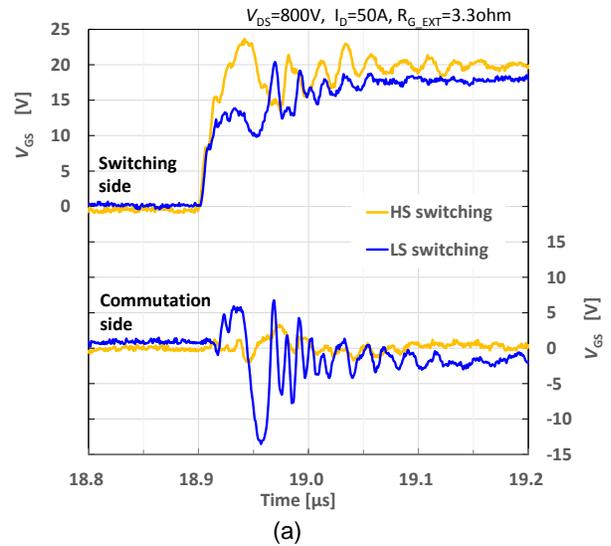


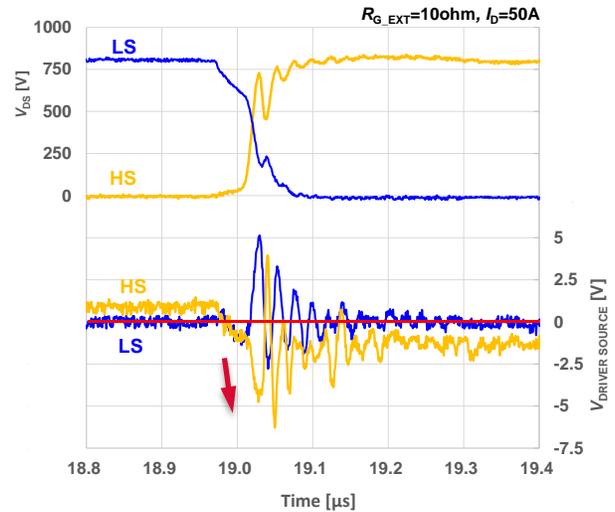
Figure 13. V_{GS} waveform when HS/LS switching
(a) Turn-on, (b) Turn-off

However, it is necessary to be aware of the distortion introduced to the voltage waveforms due to the limited common mode rejection ratio (CMRR) in the high frequency band. The V_{GS} measurement is particularly critical, as the distortion through CM voltages can be of the same order of magnitude of the measured signal.

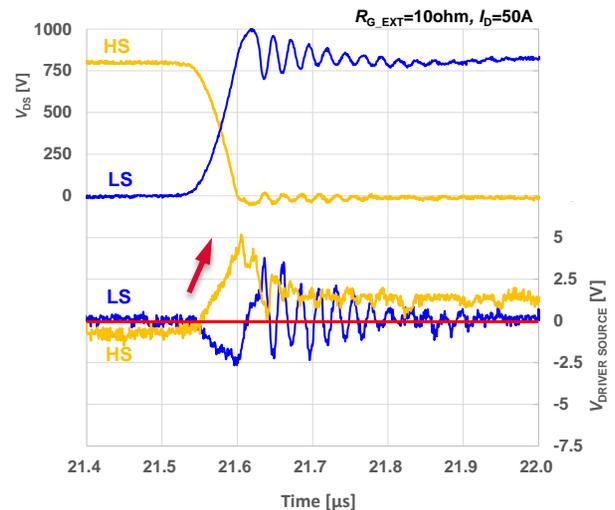
Figure 13 shows the waveforms for a half-bridge configuration with either the HS or the LS device switching. The instrument corresponds to a YOKOGAWA 701297 active differential probe (150MHz, 1400V). It can be appreciated that the ringing of the commutation side device is higher when the LS device is switched. This is caused by the limited CMRR when the device is switching at a dV/dt in the range of 20 to 50 V/ns.

Figure 14 shows CMRR performance of the differential probe by $V_{DRIVER SOURCE}$ measurement result during turn-on (a) and turn-off (b). It is measured voltage of source terminal of HS and LS of respectively. The plus and minus tips of that probe are connected together to the source terminal. Please refer to Tektronix application note "ABCs of Probes" [2] for measurement method detail.

Drain-source voltage V_{DS} switches at about 200 kHz (Duty 50%) on 800V DC and HS and LS $V_{DRIVER SOURCE}$ is synchronized to V_{DS} change. The LS one can keep zero (0) voltage level after switching, see Figure 14(a). On the other hand, the HS switch shows an offset of a few volts on $V_{DRIVER SOURCE}$, which is positive before the LS turn-off and negative after it. This is just a CMRR error. The LS $V_{DRIVER SOURCE}$ voltage shows a positive surge when LS V_{DS} falls and a negative surge when it rises. However, that may change depending on the differential probe characteristics.



(a)



(b)

Figure 14. Isolated voltage probe CMRR characteristics
(a)Turn-on, (b)Turn-off

Optically isolated differential probes offer an improved CMRR rating, which can lead to distortion-free high-side V_{GS} measurements. Figure 16 shows a comparison of gate-source voltage measurements performed with an optical probe (Tektronix IsoVu®) and a traditional differential probe.

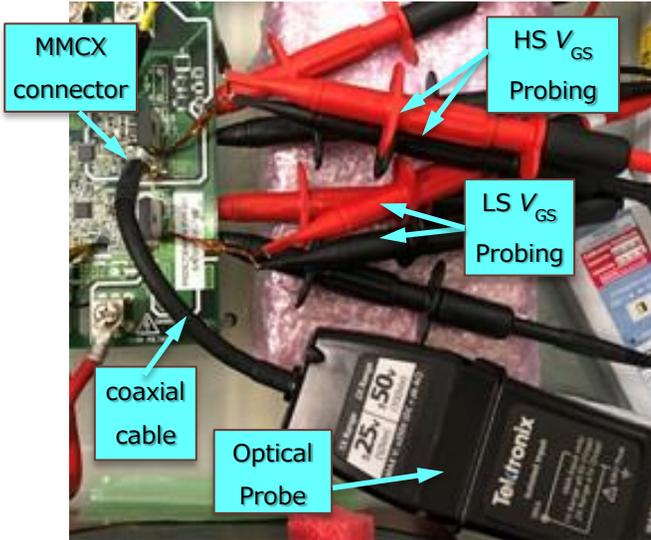
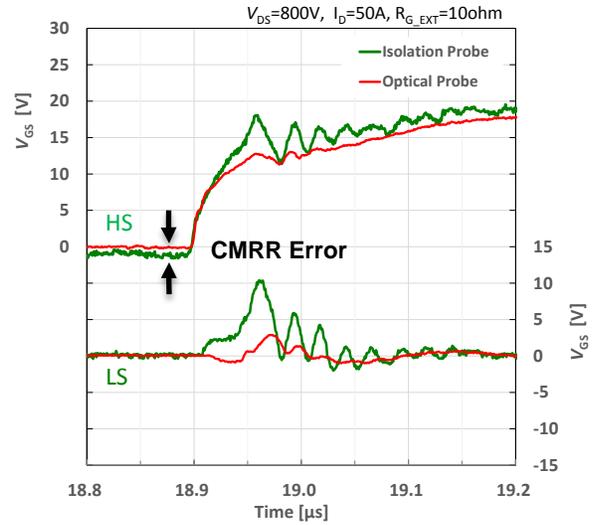


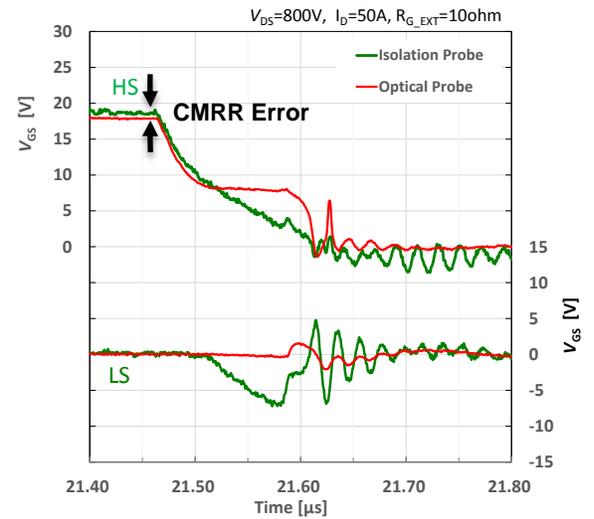
Figure 15. Optically-isolated probe (bottom) and traditional isolated differential probes (top) connection

Since the PCB board (P02SCT3040KR-EVK-001) used for the measurement lacked of proper MMCX connection interface, the optical probe was connected to the same measurement points as the traditional probe, see Figure 15.

The traditional differential probe was connected with a short extension cable and 100 Ω damping resistor to the PCB, as this minimizes the flux change influence on the measurement.



(a)



(b)

Figure 16. V_{GS} waveform when HS switching (a)Turn-on, (b)Turn-off

The results show that the measurement with the non-optically isolated probe has some distortion, exceeding 18 V when turning on, and falling below 0 V when turning off. The optical probe, on the other hand, shows accurate 0 V and 18 V levels without ringing, which match the gate driver setup.

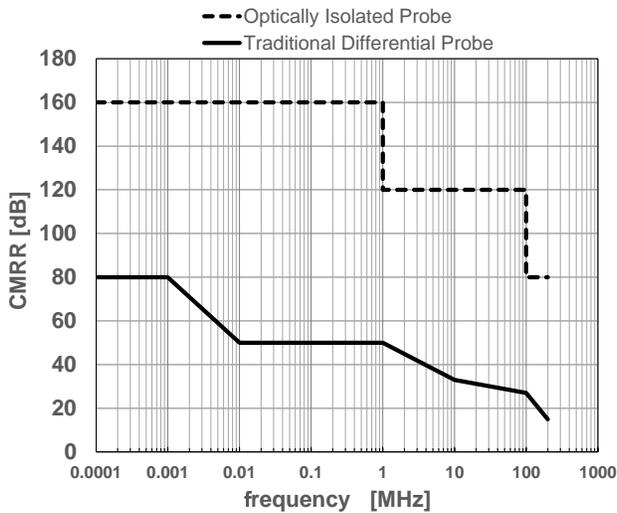


Figure 17. CMRR frequency response characteristics

Tektronix ; MMCX50 (IsoVu®)

YOKOGAWA ; 701927

The improved results obtained with the optical probe can be easily explained by the higher value of the CMRR at high frequencies, as shown in Figure 17 [4, 5].

Summary

In order to improve the measurement accuracy with differential probes, following measures can be taken:

- Minimize the loop created by the probe tip and cables.
- Minimize the loop created between the device terminals and the measurement point.
- Minimize the influence of the flux change from the main circuit when placing the probe.

The results shown in this paper indicate that the solution with the most accurate output is the use of an extension cable plus damping resistor to connect the probe leads. The cable should be connected directly at the device terminals. This should be adapted for each individual measurement configuration.

It is expected that with the help of this document, the user of high-speed power devices is able to judge in a more critical way the measured voltage waveforms and avoid possible error sources.

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」
User's Manual (IM701927-01EN, 6th Edition)
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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