A New Comparator-Less Miller Clamp Circuit for SiC MOSFET to Prevent Self-Turn-On

Shinya Tajima
Mitch Van Ochten
Seiya Kitagawa

Biography:

Shinya Tajima, system solution engineer at ROHM Co., Ltd.

Shinya Tajima received the B.S. degree in electronic system engineering from The University of Shiga Prefecture. Since 2015, he has been working at ROHM as a power device application engineer, focusing on SiC power electronics and circuit simulations. He is currently responsible to support a global field application engineering team and develop system solutions to optimize customers' power converter design using the latest SiC power device technology.

Mitch Van Ochten is currently an Applications Engineer for ROHM Semiconductor. His power electronics experience includes design of Gate Drivers for High Frequency Welders and for a 2.2 MW Wind Turbine Converter. Mitch is a Senior Member of the IEEE and holds five US Patents. You can reach him at mvanochten@rohmsemiconductor.com.

Agenda

ROHM SEMICONDUCTOR

◆ Background

- Fast Switching of SiC-MOSFETs and issue
- V_{GS} overshoot and parasitic turn-on

◆ Conventional circuits

- Conventional countermeasures and their issue

◆ A New Miller Clamp Circuit

- Turn-on operation
- Non-switching side operation
- Turn-off operation

◆ Simulation

◆ Evaluation results

◆ Summary

Background

SiC-MOSFETs have been widely used in high-voltage and fast switching applications. Superior switching characteristics and power conversion efficiency have been repeatedly demonstrated.

Target Applications for SiC-MOSFETs

PV Inverter

xEV Application

Charging Station

Power Supply

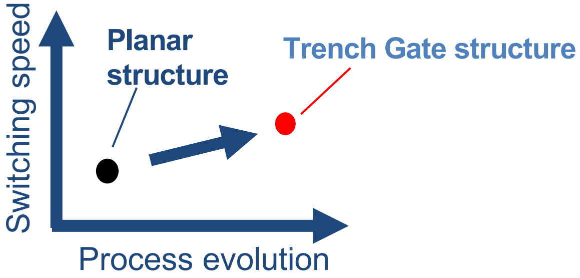
Example requirements

- SiC-MOSFET
- 1200V withstand
- I_D : 50A or more

The trend toward fast switching

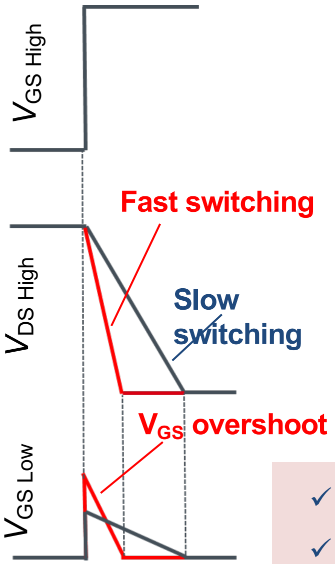
The Applications become higher power

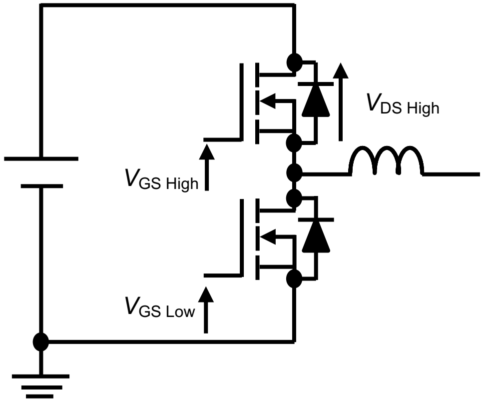
Trench gate structure is the mainstream for fast switching



Issue due to fast switching

Switching waveforms

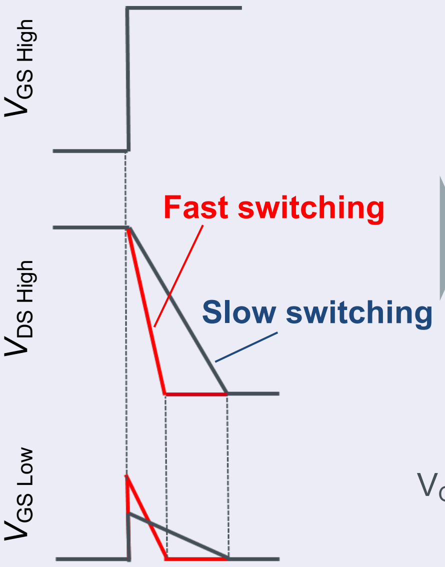


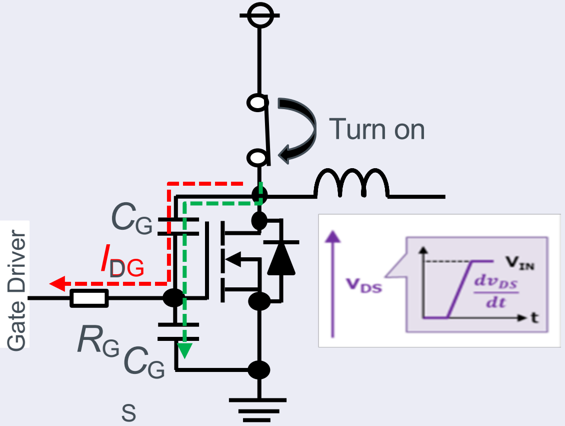


- ✓ dV/dt : **Fast switching** > **Slow switching**
- ✓ V_{GS} overshoot : **Fast switching** > **Slow switching**

V_{GS} overshoot causes parasitic turn-on, and the efficiency deteriorates from shoot-through current!

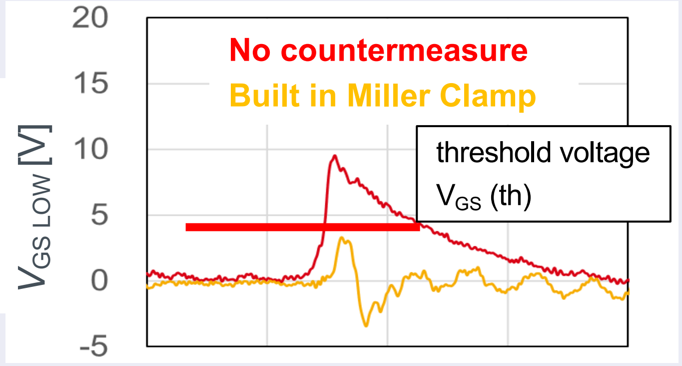
< Parasitic turn-on phenomenon >





V_{GS} overshoot occurs between gate and source

$$V_{GS\ overshoot} = I_{DG} * R_G = C_{GD} * R_G * \frac{dv_{DS}}{dt}$$



V_{GS} (th) < V_{GS} overshoot

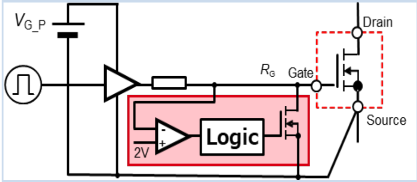
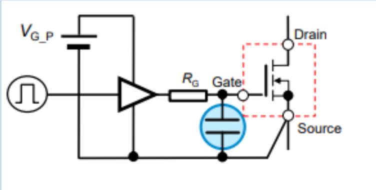
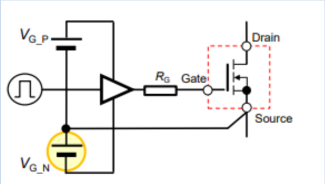
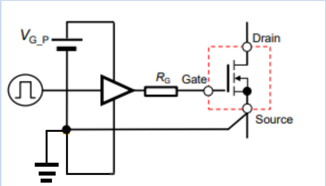
The threshold voltage is exceeded (parasitic turn-on).

Shoot through current → less efficiency

With SiC MOSFETs it is important to prevent parasitic turn-on!

Conventional circuit

Conventional techniques against parasitic turn-on involve the addition of external components and a negative bias voltage. However, these measures have been difficult to solve the issues.

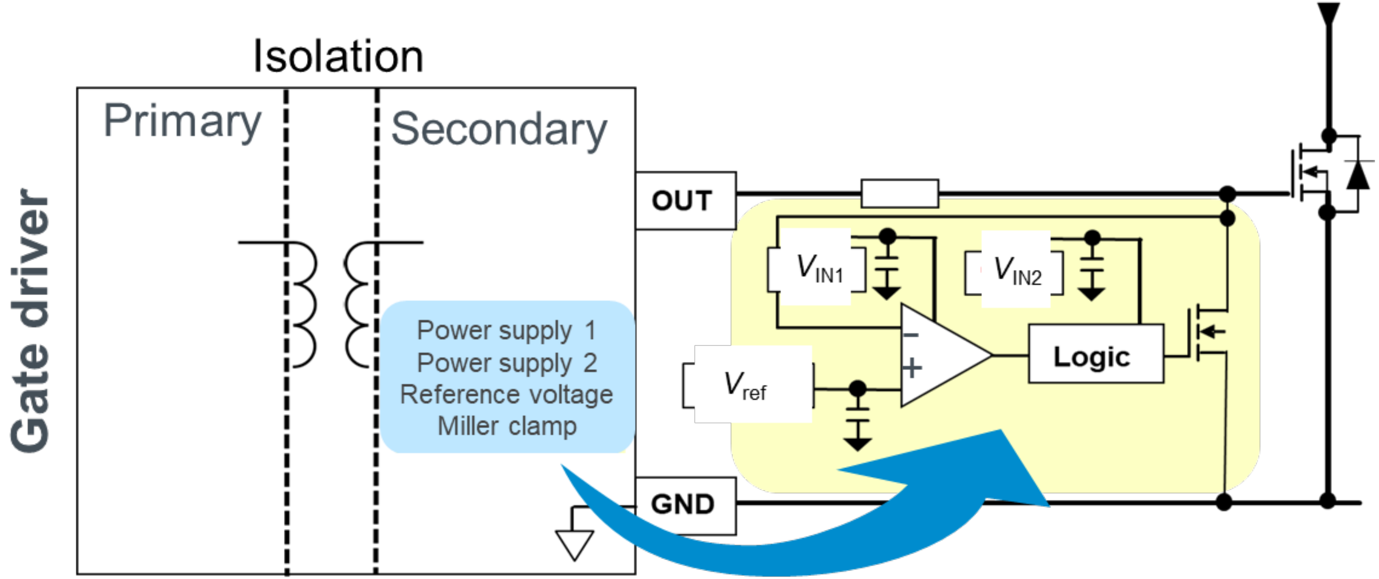
	(1) Built in Miller Clamp	(2) Add a capacitor between gate and source	(3) negative bias voltage	(4) No countermeasure
Circuits				
Issues	1. Complex logic circuit. 2. Not always available	Higher switching loss	Difficult to use with trench gate structure	Need to replace the gate driver

(2) and (3) are difficult to solve.

A Miller clamp circuit is needed that could be operated externally without changing the gate driver.

Analysis / Approach

Traditional external Miller clamp circuits are not always practical due to the issues

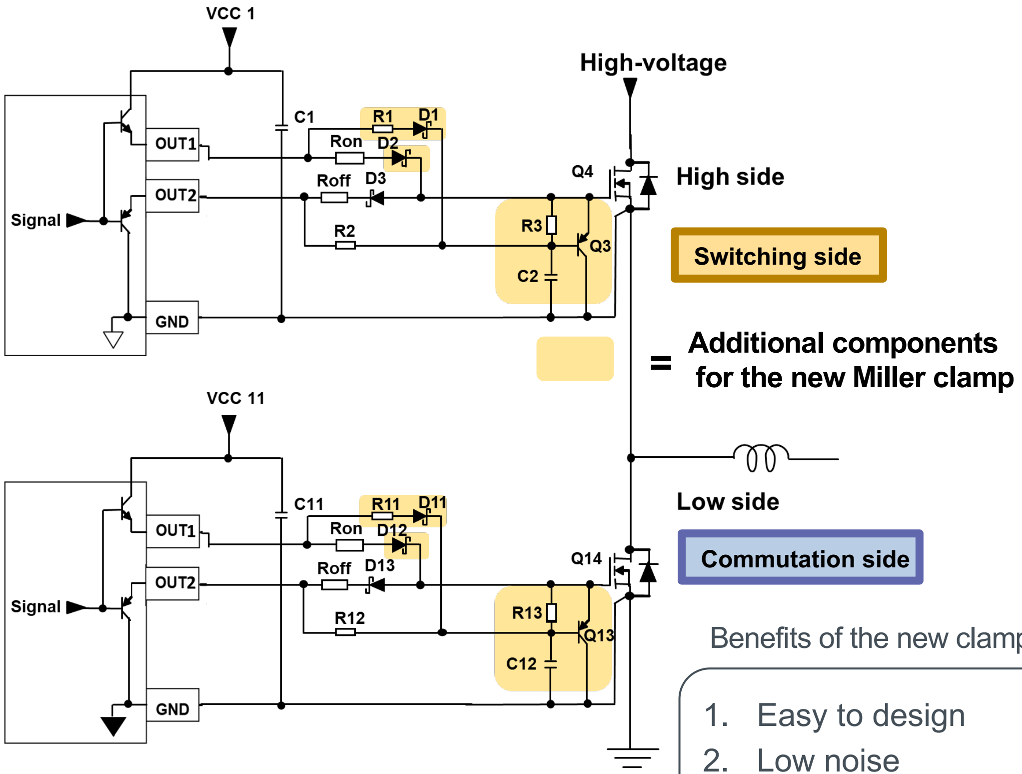


Issues of the circuit

1. Multiple additional power supplies are required for the comparator and Logic.
2. The comparator may malfunction due to ringing of the Gate signal.

Solution

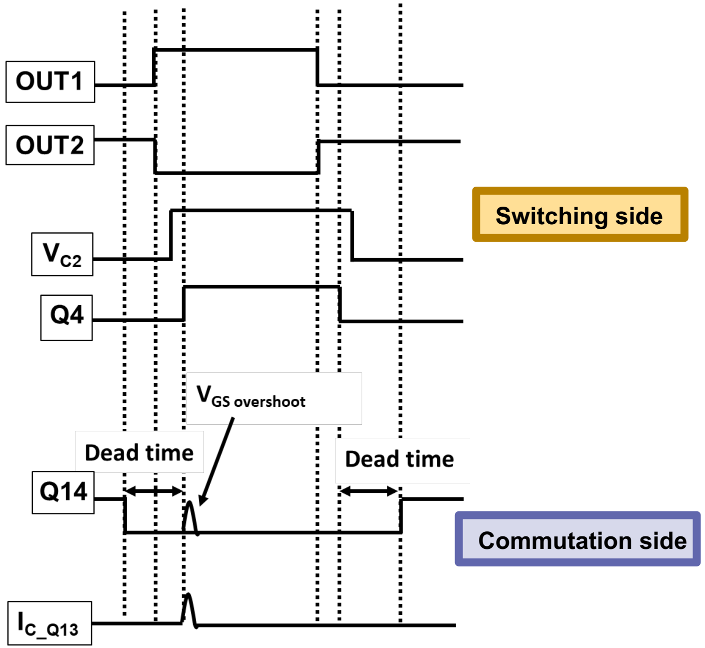
A new external Miller clamp was devised which overcomes the problems of conventional circuits



Gate Driver Circuit

Benefits of the new clamp

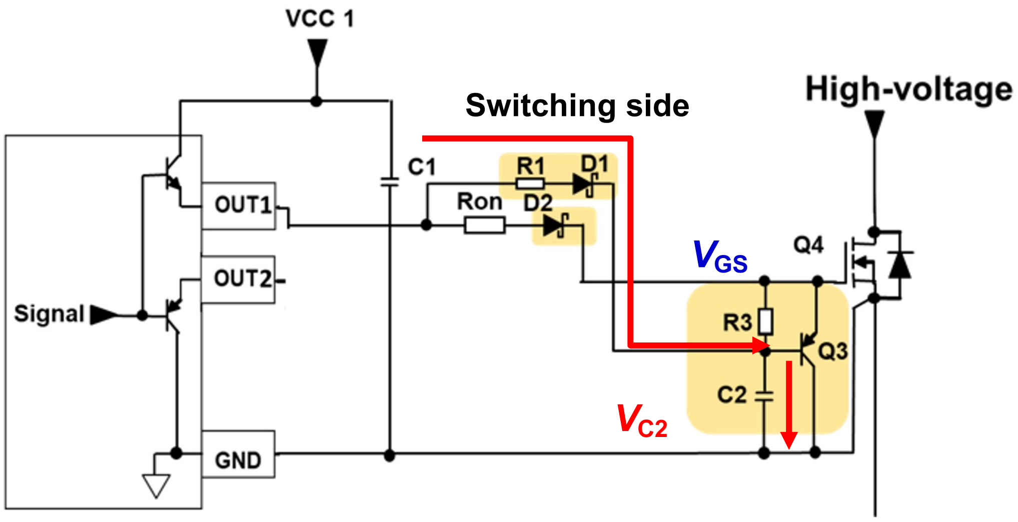
1. Easy to design
2. Low noise
3. Low cost



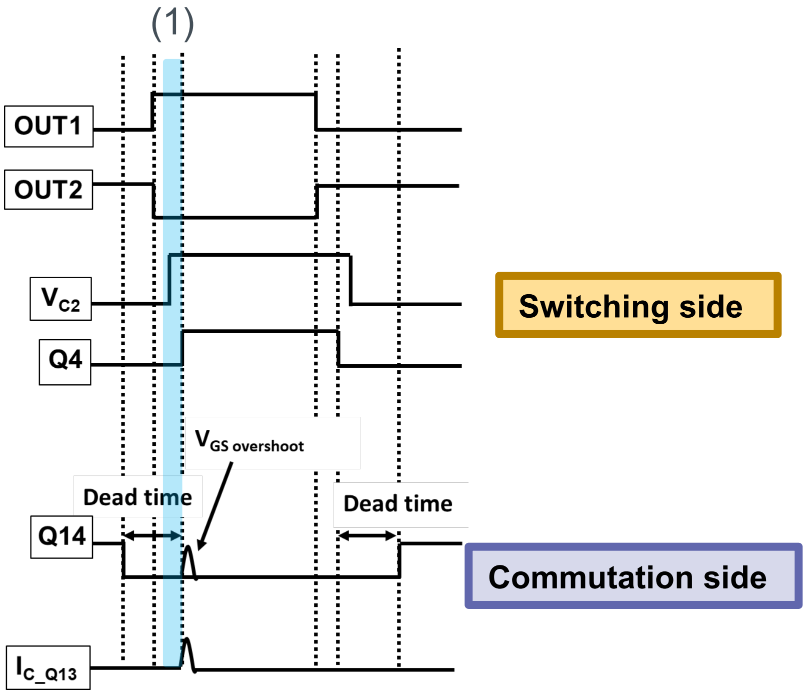
Time chart

Turn-on operation

(1) Switching side, Q4 turns-on



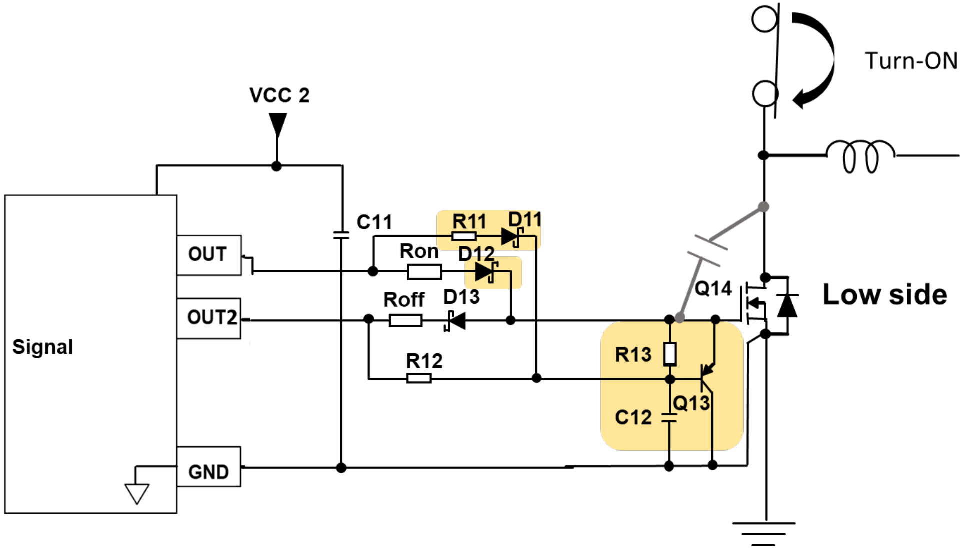
Equivalent circuit when SiC-MOSFET turns-on

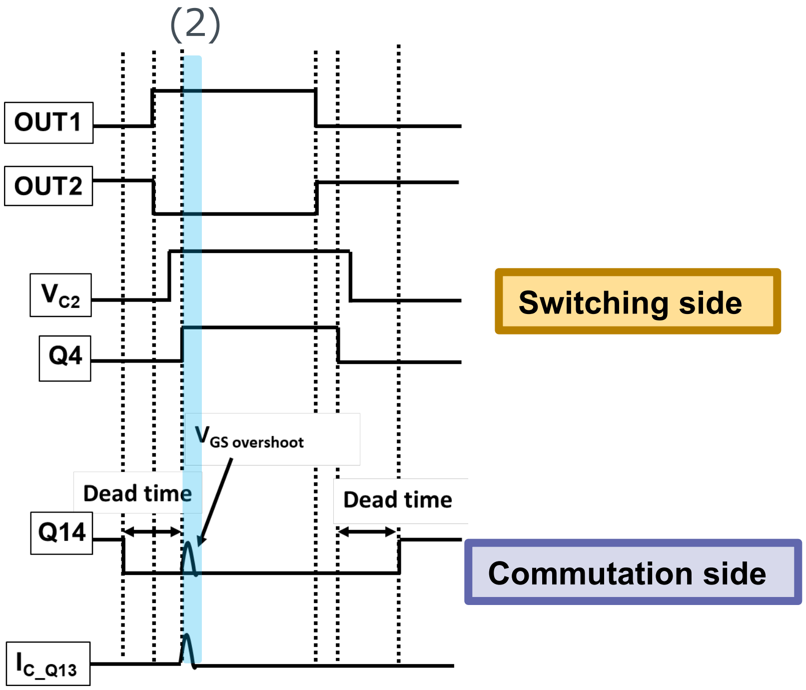


- Switching side
  When the Gate Driver goes HIGH, R1 and D1 are used to charge C2 and prevent Q3 from turning ON

Turn-on operation

(2) Commutation side, Miller clamp operation



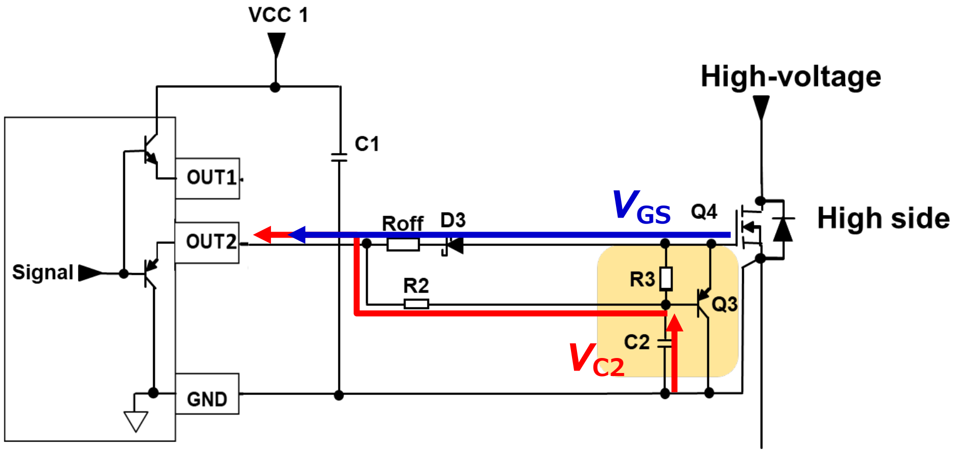


- Commutation side

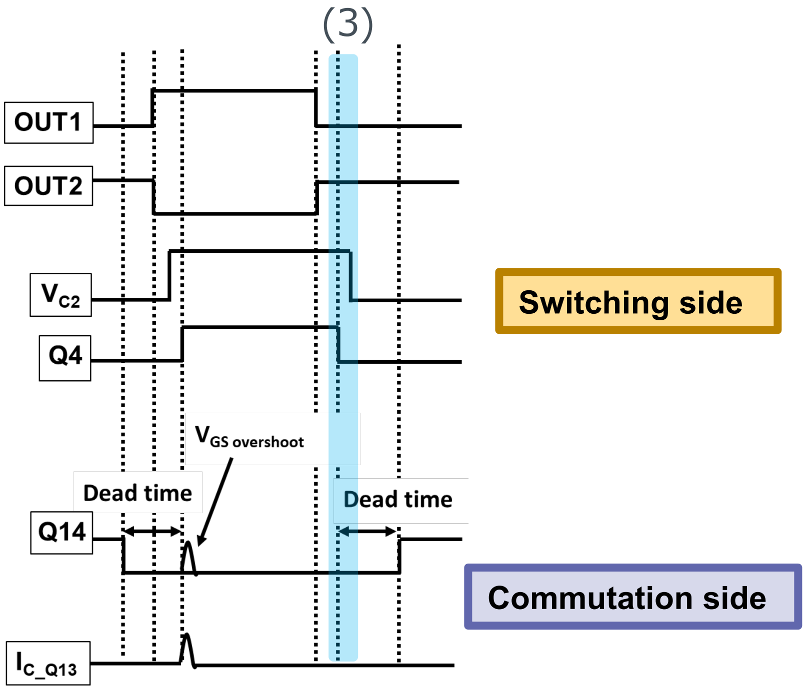
When the switching side SiC-MOSFET turns ON, a positive gate surge is observed in Q14 on the commutation side. Since C12 is not charged at this time, a charging current flows through R13 to charge C12, and a negative voltage V_{BE} rises between the base and emitter of Q13, enabling Q13 to turn on and clamp the positive surge at the gate of Q14.

Turn-off operation

(3) Switching side, Q4 turns-off



Equivalent circuit when the SiC-MOSFET Turns-off

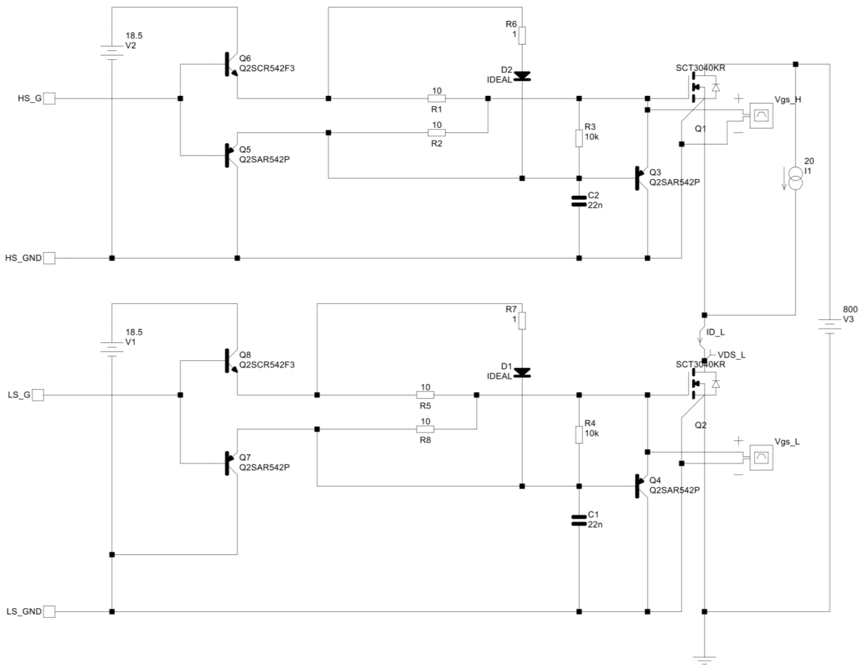


- Switching side

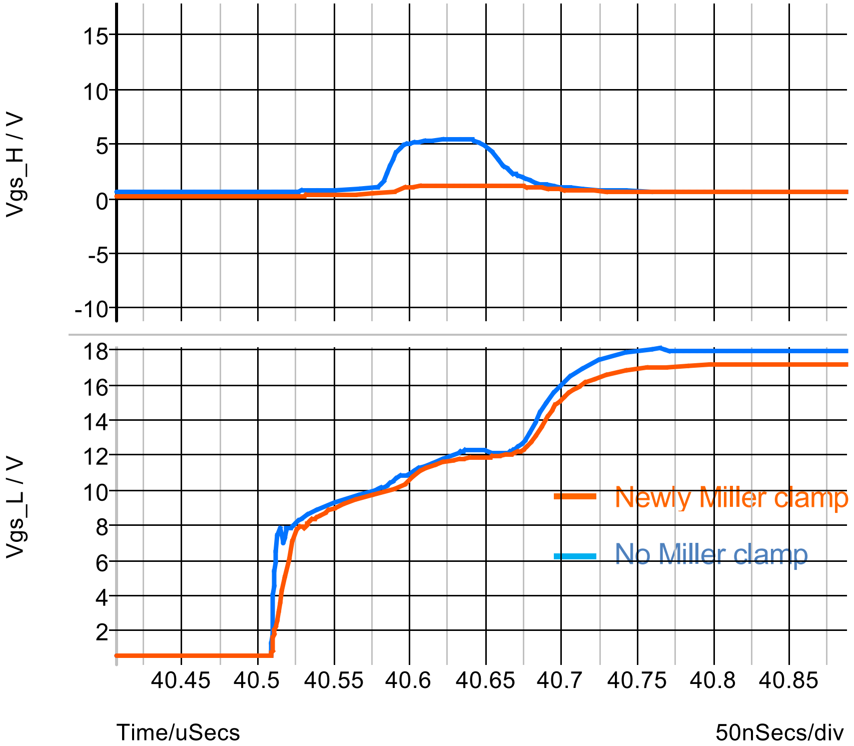
When the SiC-MOSFET turns OFF, R2 and the Gate Driver provide a path to discharge C2 later than the gate of the SiC-MOSFET, to keep Q3 in its OFF state.

Simulation

The operation of the new Miller clamp circuit was verified by simulation



Simulation circuit

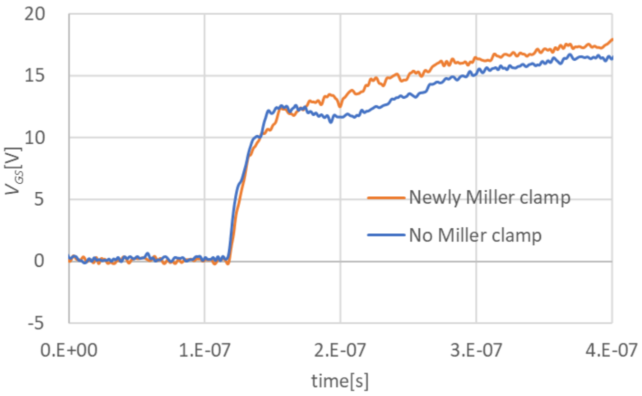


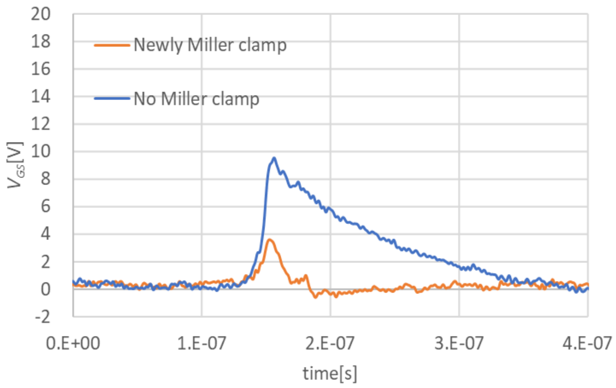
Simulation result

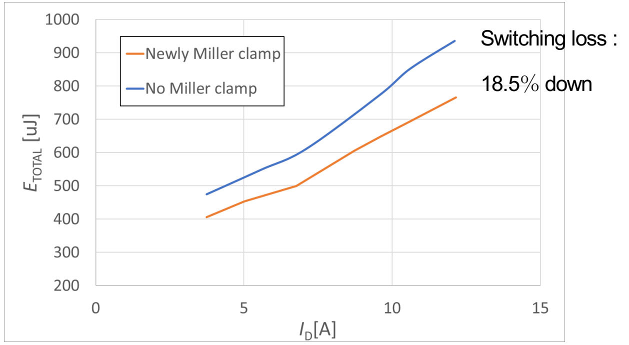
Evaluation results

Measured the switching waveforms with new Miller clamp circuit and without Miller clamp

V_{GS} overshoot was improved and switching loss was also reduced







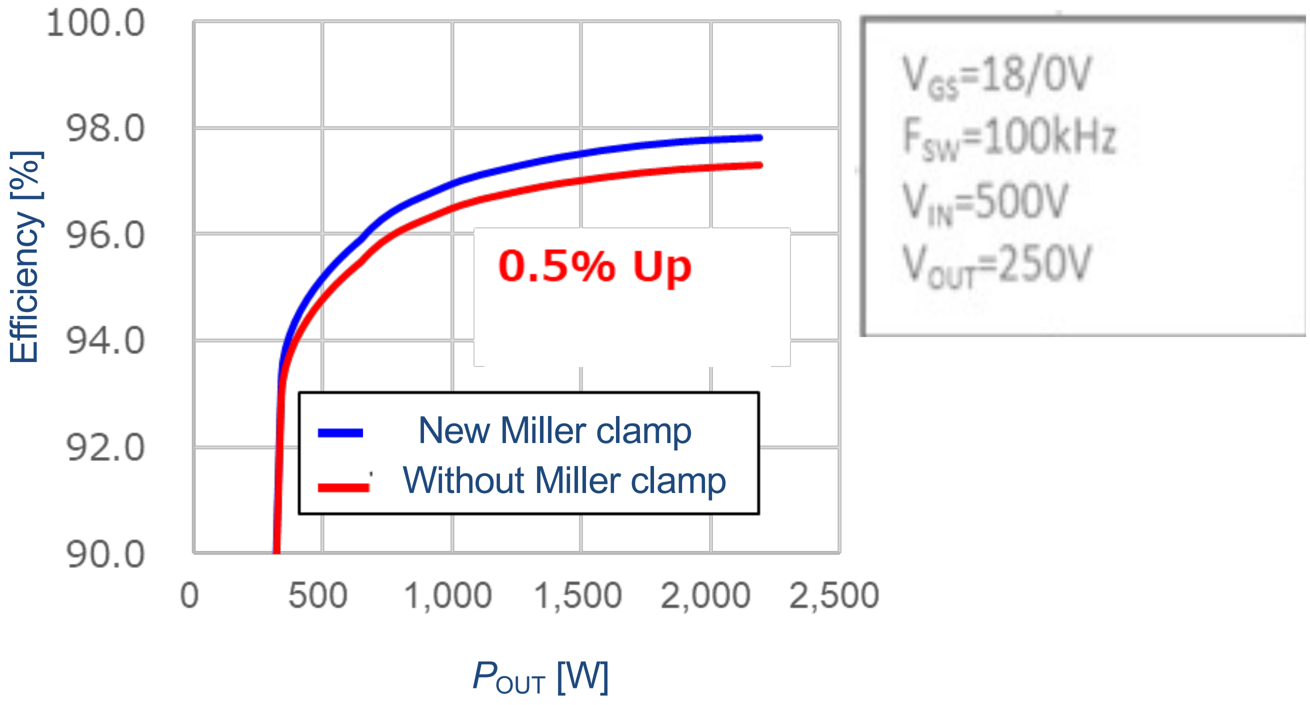
Commutation side gate voltage

Switching side gate voltage

Switching loss comparison

Evaluation results

Efficiency measurements with the new Miller clamp showed a significant improvement in efficiency compared to without the Miller clamp. Now we can fully exploit the performance of SiC-MOSFETs!



Summary

- SiC-MOSFETs have been widely considered for use in high-voltage and fast switching applications.

- As the applications become higher power, it is important to take measures to prevent increased losses due to parasitic turn-on.

- In the new Miller clamp circuit, it was possible to reduce the switching loss by 18.5%.

Thank you for your interest!

By Shinya Tajima, Mitch Van Ochten
Email: shinya.tajima@mnf.rohm.co.jp
mvanochten@rohmsemiconductor.com

Phone: +81 80 2486 2668

Power Devices: Performance, Achievements & Road Ahead
IS11.1