pcim ASIA Hybrid Platform

Visualization of noise current distribution in power module

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Self-introduction

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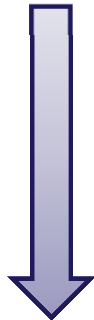
- Affiliation: Osaka university, graduate school of engineering, Division of Electrical, Electronic, and Infocommunications Engineering
- Position: Professor

Outline

- Introduction
- Switching noise
  - Difference among device type in frequency spectrum
  - Time and frequency analysis of EMI noise
  - Noise generation and propagation in power module
- Conclusion

Introduction

Requirement for power electroncis

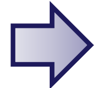


- High power density
- High reliability

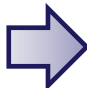
Wide-bandgap power semiconductor devices (Si→SiC, GaN,…)

- High voltage, Large current
- Fast & High frequency switching

Large di/dt, dv/dt × parasitic components



- Voltage spike
- High-frequency ringing oscillation



EMI noise problem

- Minimize parasitic inductance of wiring pattern
- Optimize electro thermal packaging design

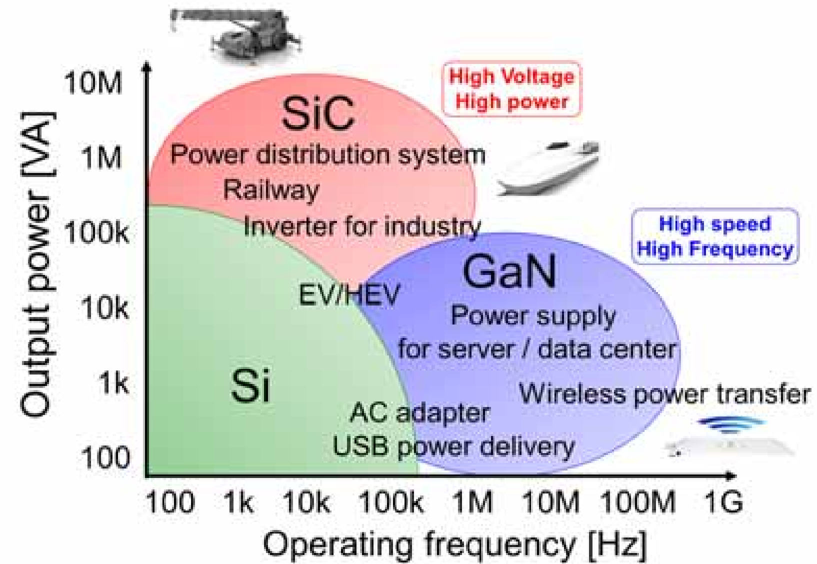
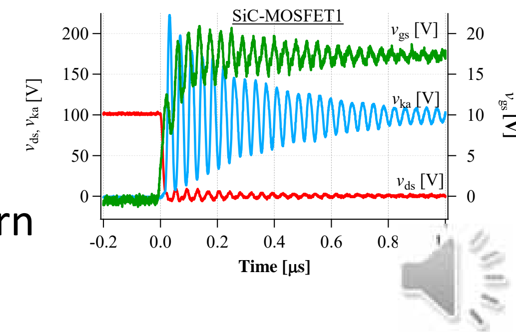
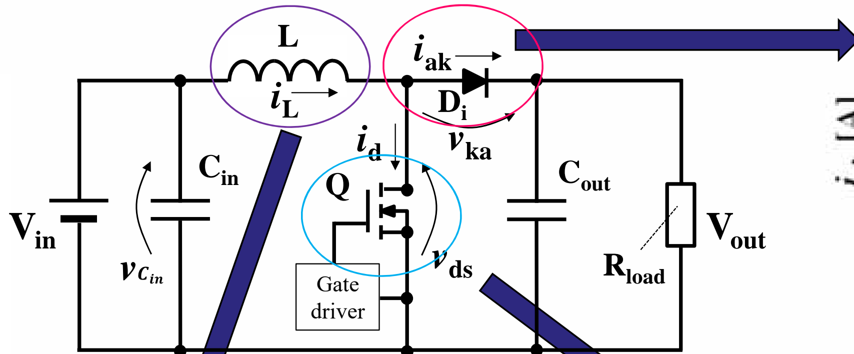
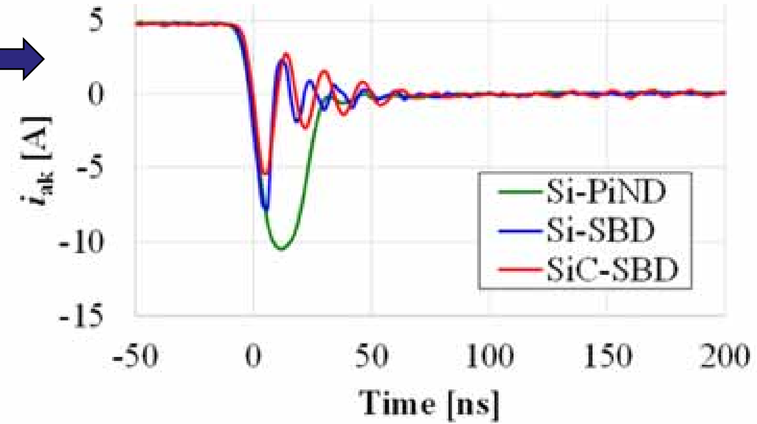


Fig. Expected application map for SiC/GaN power device

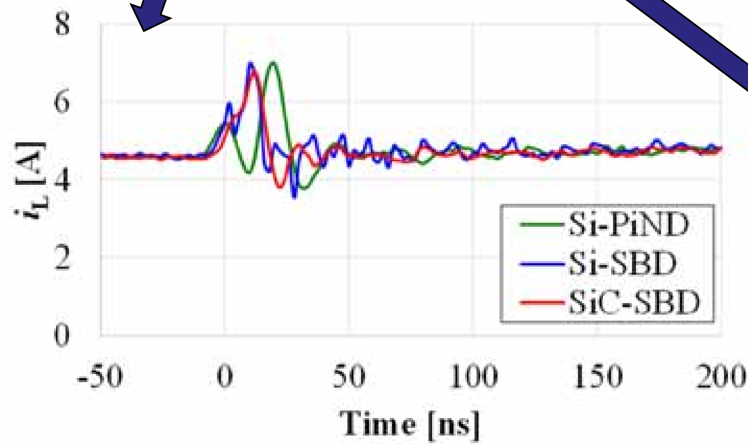


Current behavior at diode turn-off

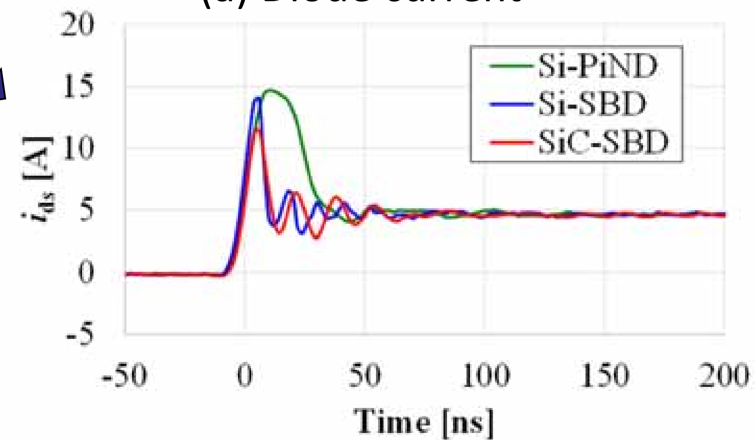




(a) Diode current



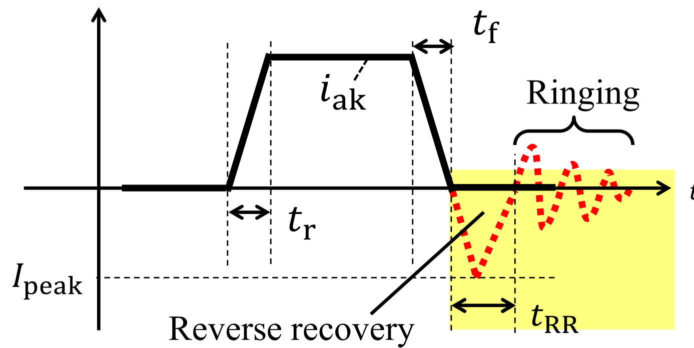
(b) Inductor current

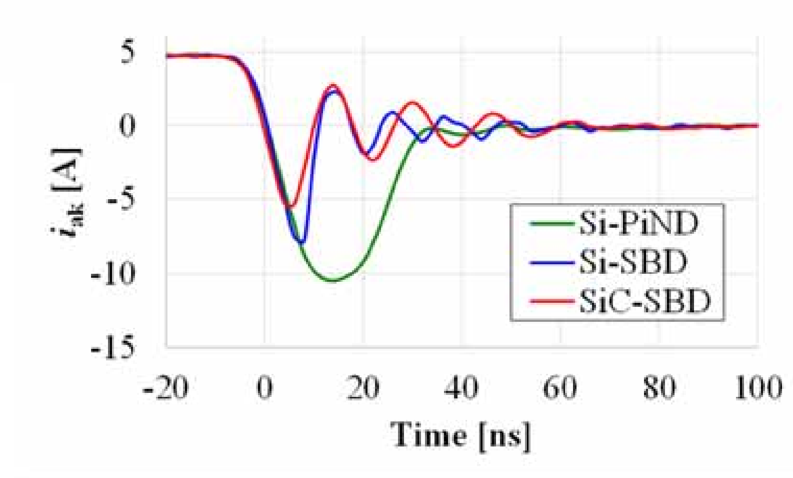


(c) MOSFET drain-source current

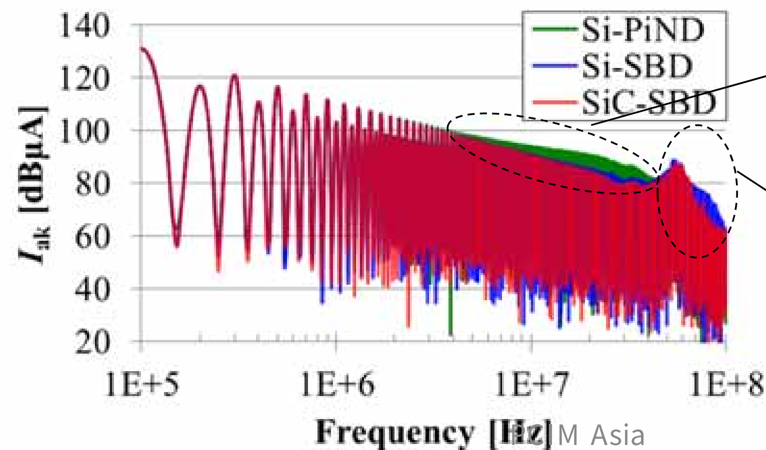
Noise current spectrum diode type dependency

Time-domain waveform





Fourier spectrum of diode current



Large reverse recovery current peak (Si-PiND)

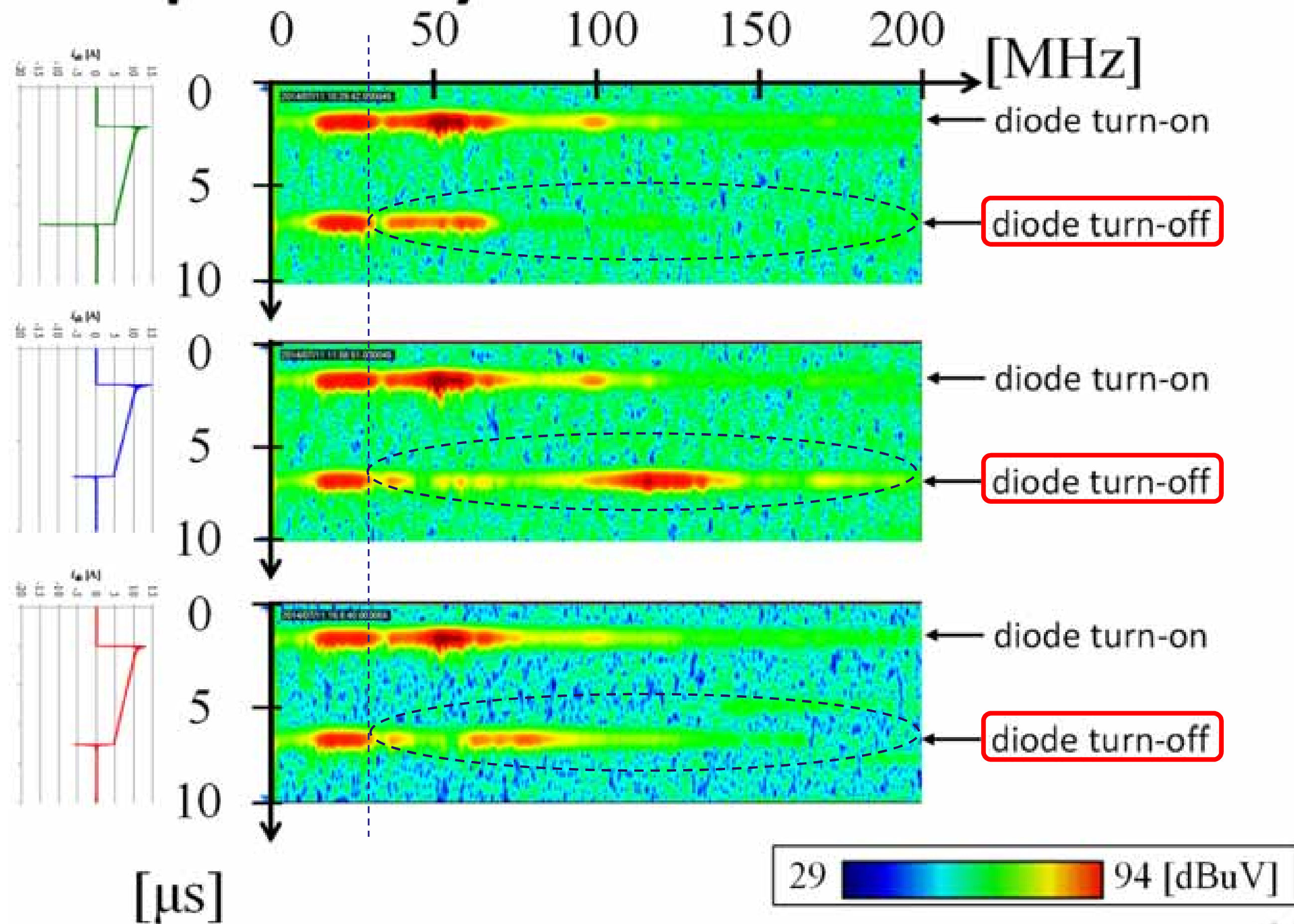
Ringing oscillation at diode turn-off & turn-on

Spectrogram of conducted emission Diode type dependency

Si-PiND

Si-SBD

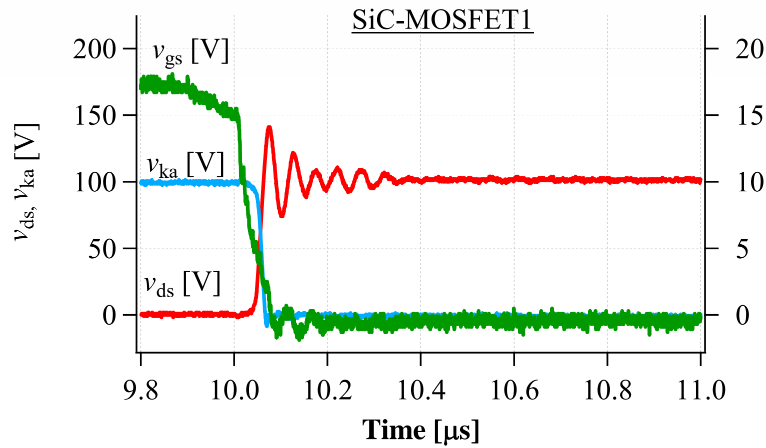
SiC-SBD



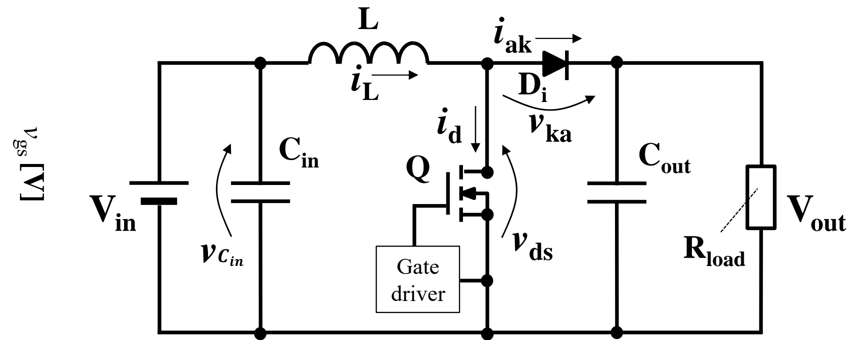
The conducted emission difference of diode type

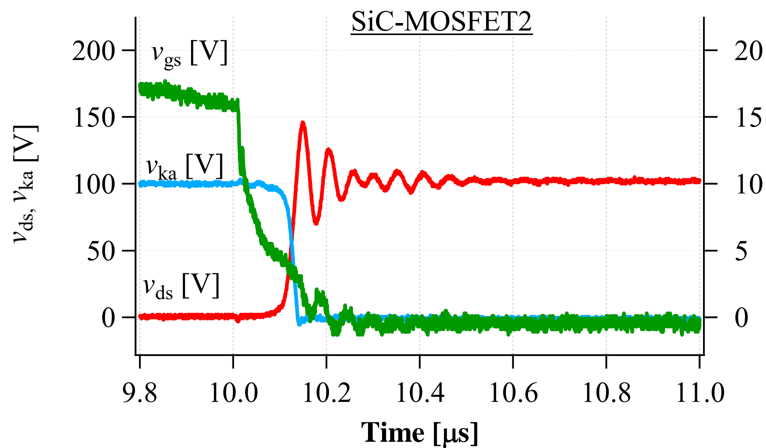
→ in higher than 30 MHz (at diode turn-off)

Voltage behavior at MOSFET turn-off

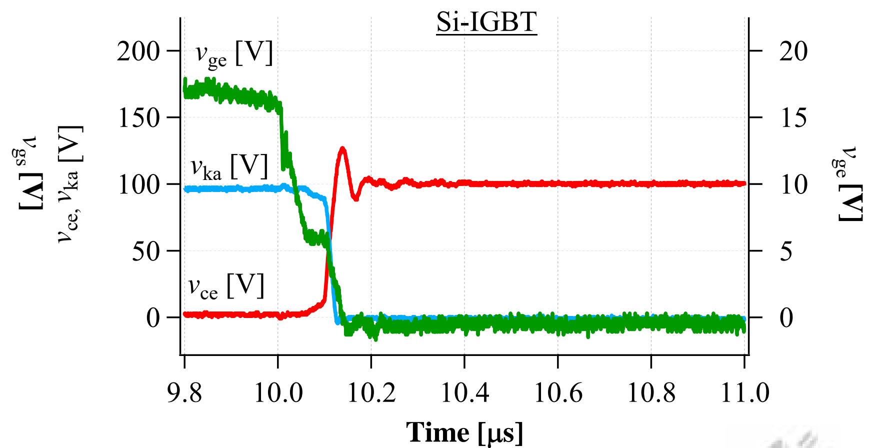


(a) C2M0080120D (SiC-MOSFET)



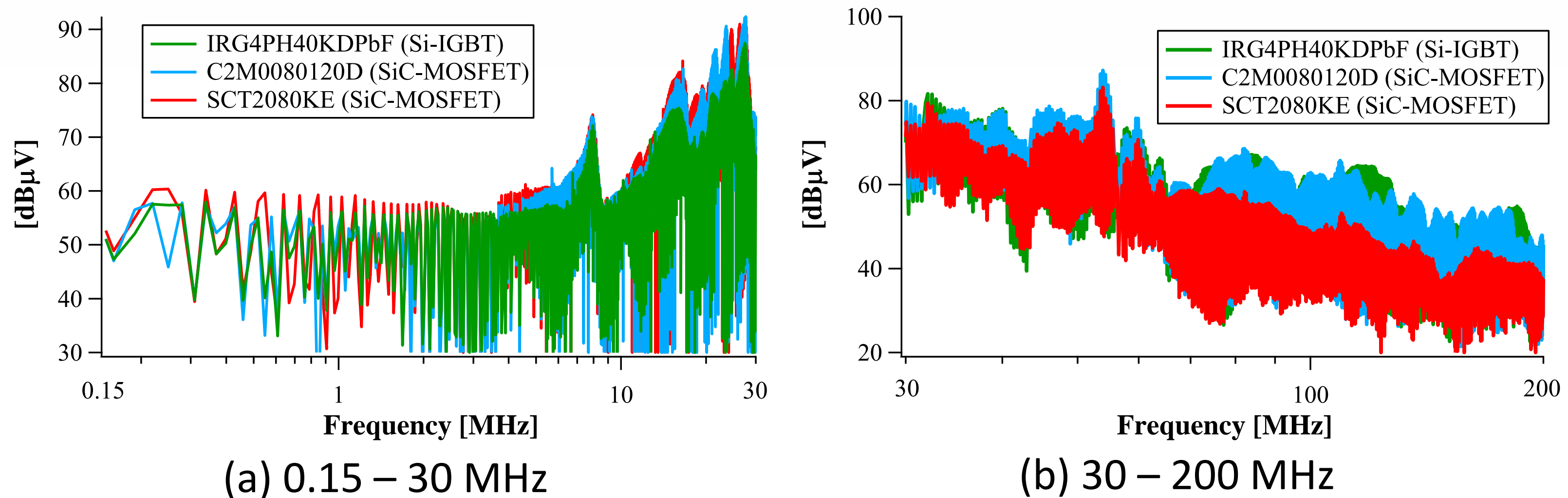


(b) SCT2080KE (SiC-MOSFET)



(c) IRG4PH40KD (Si-IGBT)

Noise spectrum of conducted emission
Transistor type dependency



(a) 0.15 – 30 MHz (b) 30 – 200 MHz

Fig. Conducted noise spectrum (Rg=10Ω)

- Almost same for < few MHz
- Peak at several MHz
  → ringing oscillation at turn off
- Peak at 20 〜 30 MHz
  → ringing oscillation at turn on → Depend on turn off of diode

- Spectrum level difference
  → difference in switching speed (turn on)
  → Depend on internal Rg, Ciss, gm

Spectrogram of conducted emission
Transistor type dependency

Frequency [MHz]

10 20 30 40 50 60 70

(a) IRG4PH40KDPbF (Si-IGBT)

(b) C2M0080120D (SiC-MOSFET)

(c) SCT2080KE (SiC-MOSFET)

v_{ds} [V]

0 40 80 120

-14 -10 -6 -2 2 6

Time [4µs/div.]

Transistor turn off

Transistor turn on

48 3 [dBµV]

Magnetic near-field scanning system to observe noise current distribution in power module

Magnetic field
field probe
Current
Magnetic field
Metal
strip
Electric field
Ground plane

Magnetic field probe DUT

Spectrum analyzer
(Agilent E4402B)

EM Scanner system
(NEC Engineering 4EM500)

y
x
Mapping

PC

Control
box

DUT

Frequency range：
150kHz – 1GHz
(comply with IEC 61967-6)

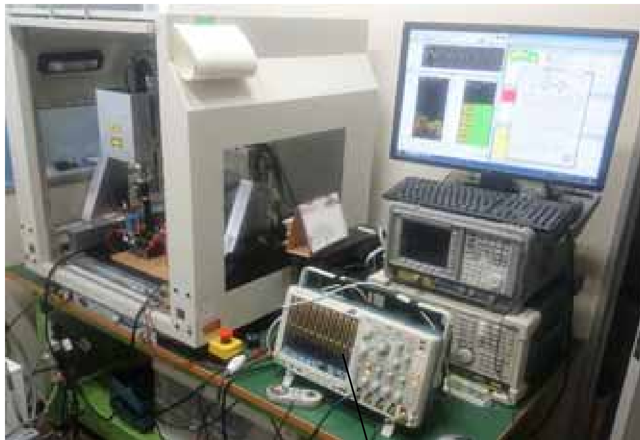
Magnetic Field
Marker

Magnetic field probe
(NEC Engineering MP-10L)

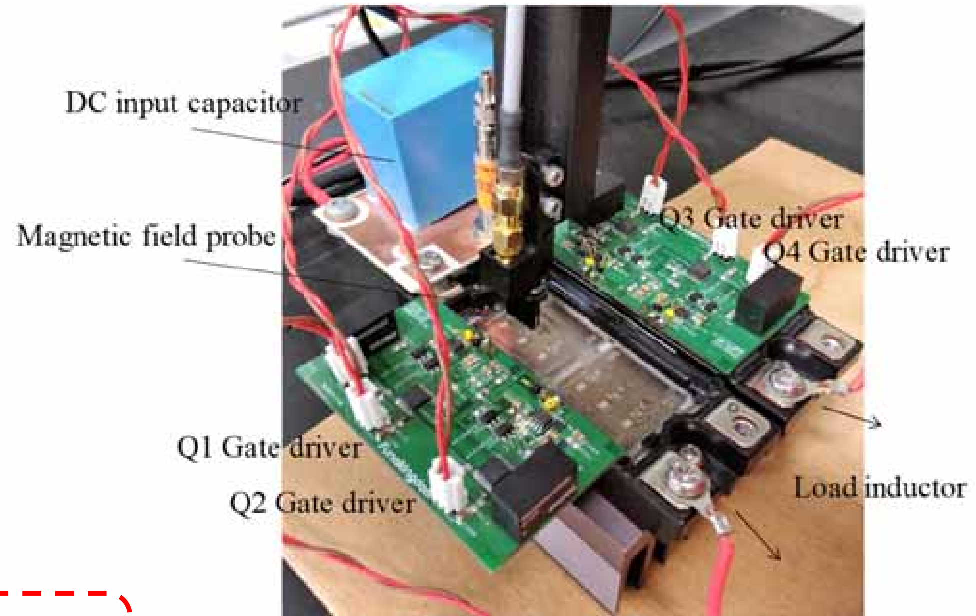
Fig. Measurement system

Time and frequency spectrum distribution observation by magnetic near-field scanning system

EM Scanner system
(NEC Engineering 4EM500)



Mixed domain oscilloscope
(Tektronix, MDO4104C-6)

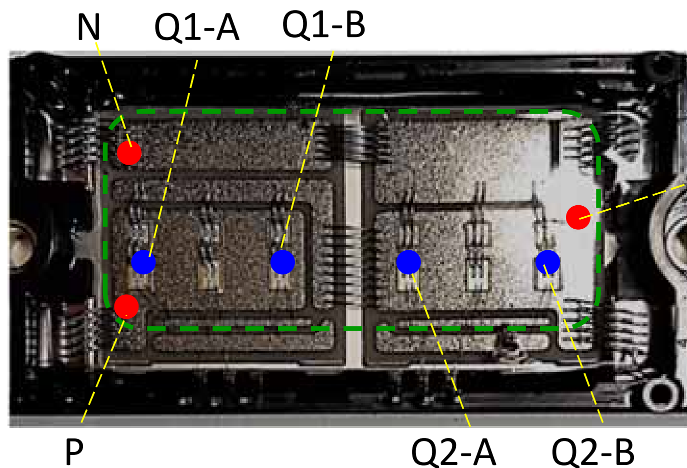


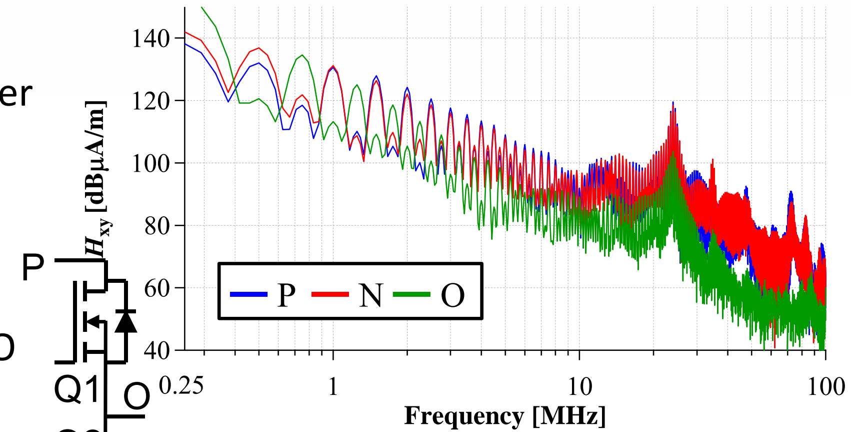
- SW Freq. = 250 kHz
- Duty = 0.45, R_g = 2 Ω

DUT：SiC power module
Trigger for synchronization：gate voltage of Q1(Q4)
Magnetic near-field measurement: use RF port of oscilloscope as a spectrum analyzer

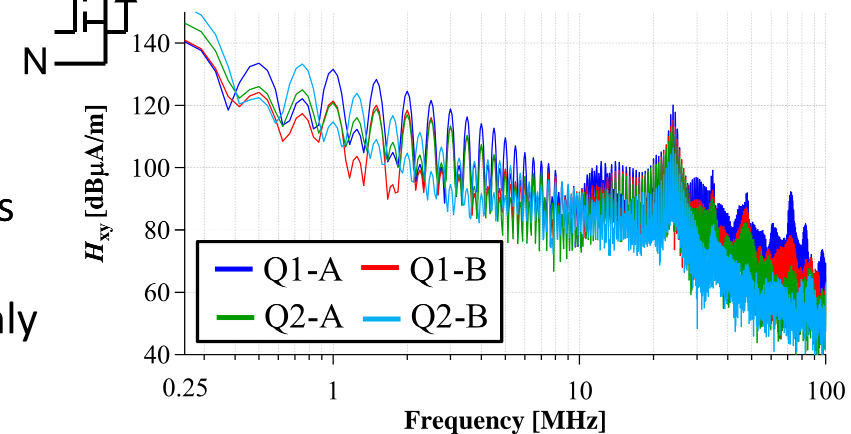
Frequency spectrum of magnetic near-field

Magnetic near-filed measurement in power module for continuous switching operation





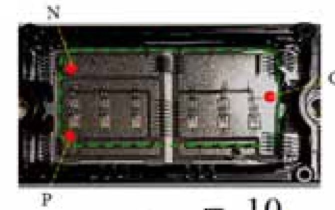
(a) Output terminal (P, N,O)

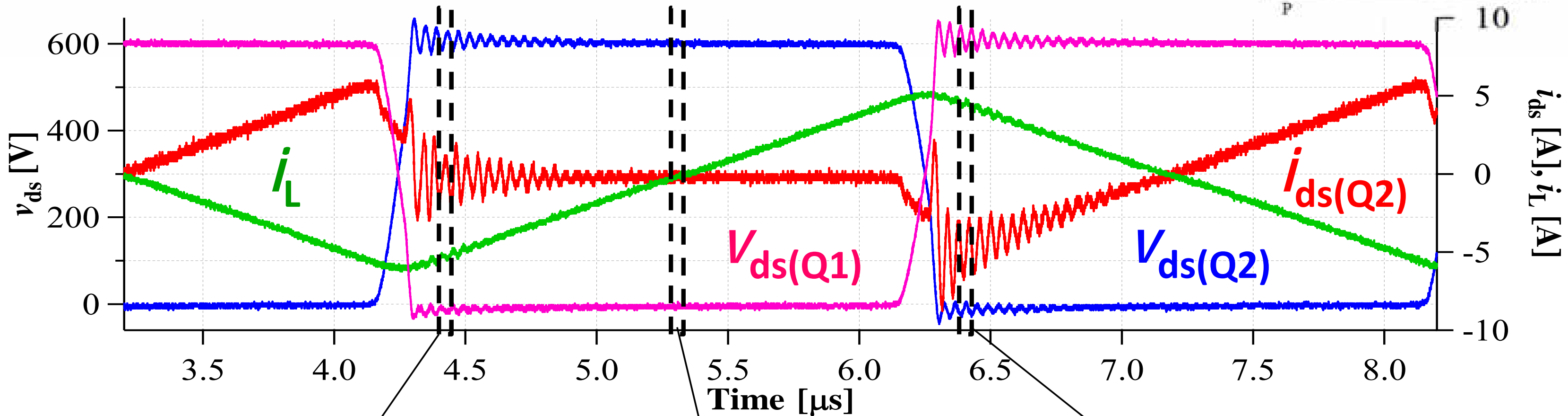


(b) MOSFET

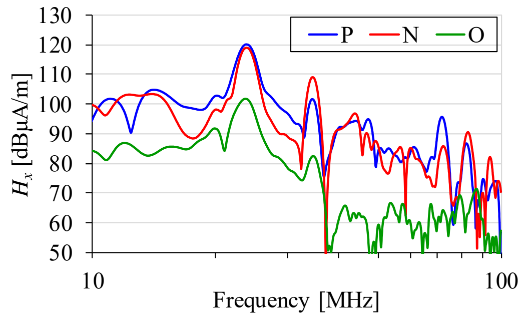
- Frequency character at P, N coincides
- PN intensity is higher 10dB than O
- Noise current does not uniformly distributed among MOSFETs

Voltage, current behavior and corresponding frequency spectrum of magnetic near field

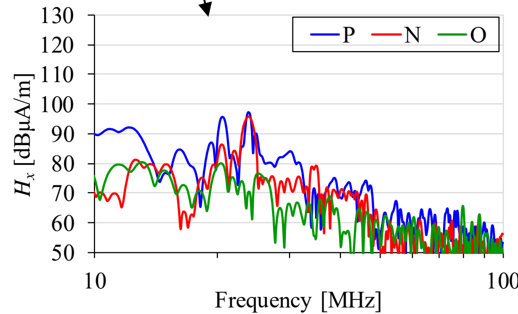




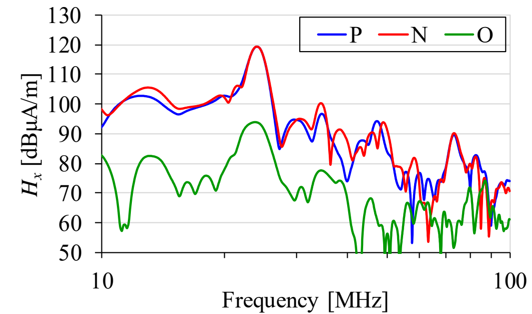
(a) Time response of circuit voltage and current



(b) Q1 turn on



(c) Q1 conducting

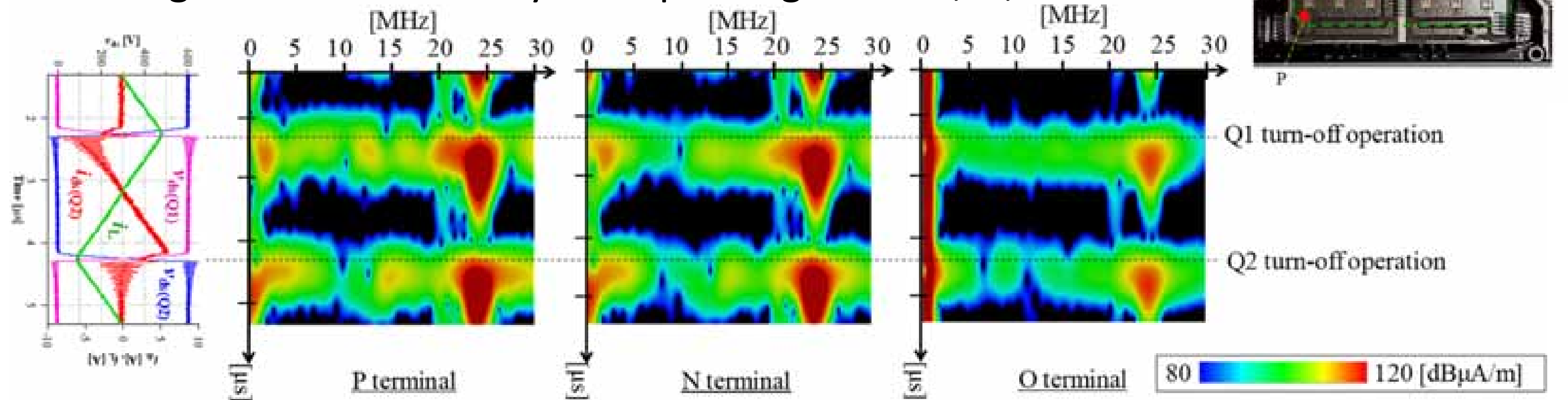


(d) Q1 turn off

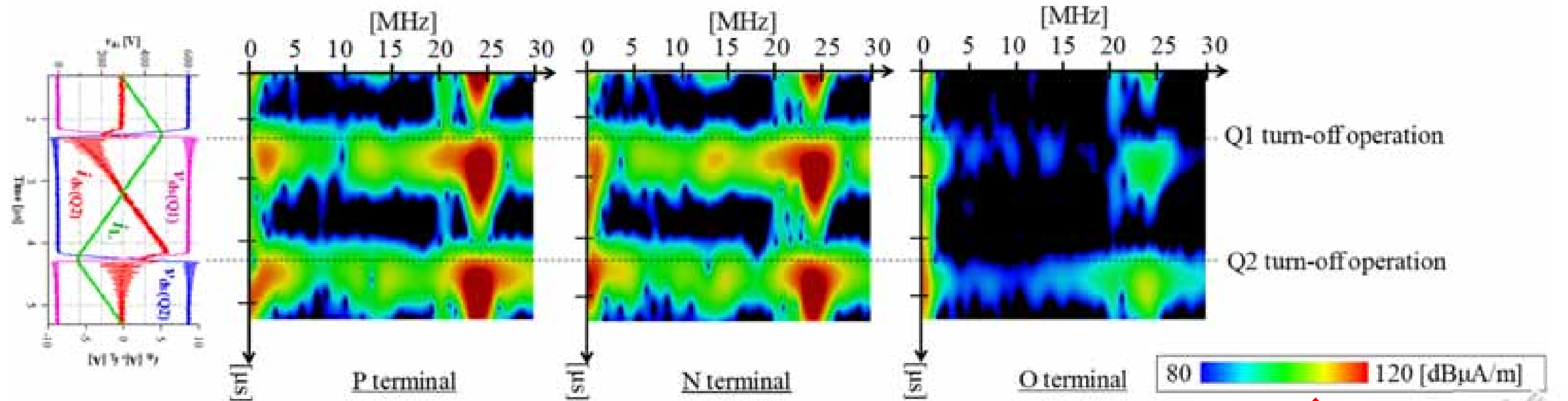
Frequency spectrum of magnetic near field at module terminal P, N, O

Time and frequency domain analysis of magnetic near-field

Magnetic field intensity and spectrogram at P, N, O terminal



(a) Magnetic field for X axis direction Hx



(b) Magnetic field for Y axis direction Hy

Magnetic field distribution in switching transient of MOSFET (1.25MHz)

Q1 turn-off turn-on

Q1 Q2

Gate Q1,Q4

Gate Q2,Q3

$+V_{in}$, $v_L(t)$, $-V_{in}$

$i_L(t)$

$i_{Q1}(t), i_{Q4}(t)$

$i_{Q2}(t), i_{Q3}(t)$

N, P, O, y, x

115 140 [dBµA/m]

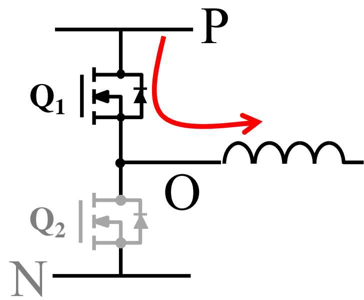
(a) Turn off of Q1, 1.25 MHz, H_{xy}

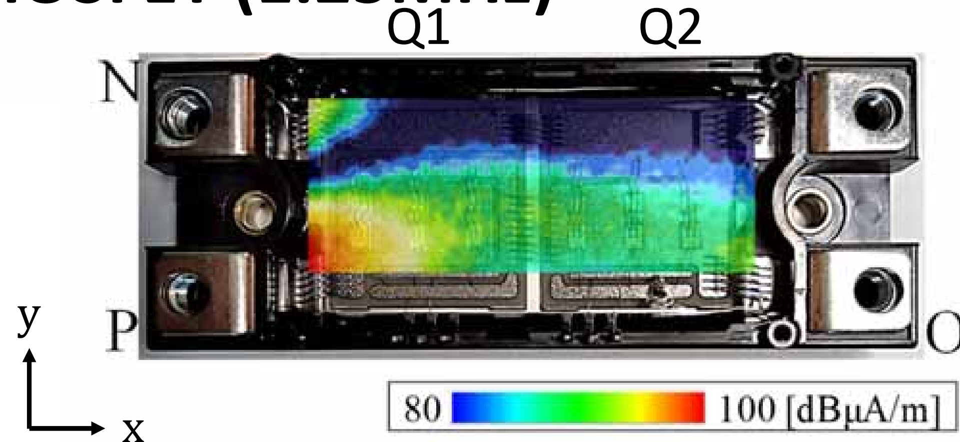
115 140 [dBµA/m]

(b) Turn on of Q1, 1.25 MHz, H_{xy}

Magnetic field distribution in conducting condition of MOSFET (1.25MHz)

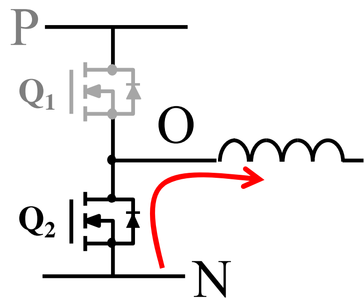
Current path: P→Q1→O

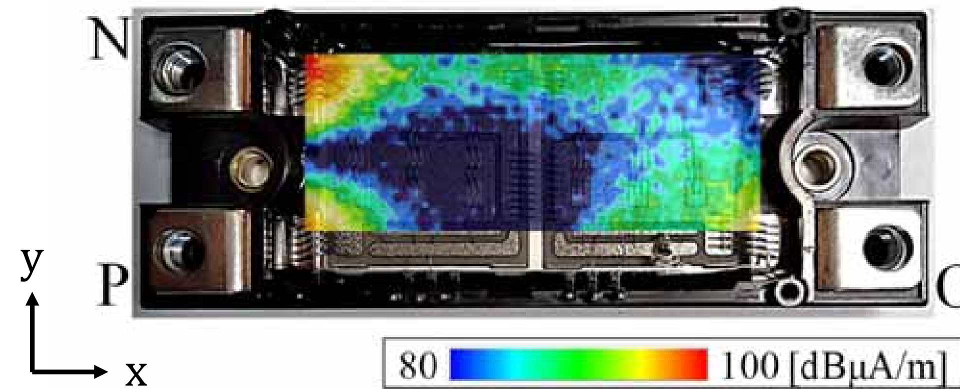




(a) Q1:on, Q2:off, 1.25 MHz, Hy

Current path: N→Q2→O





(b) Q1:off, Q2:on, 1.25 MHz, Hy

Noise current distribution in switching operation (24MHz)

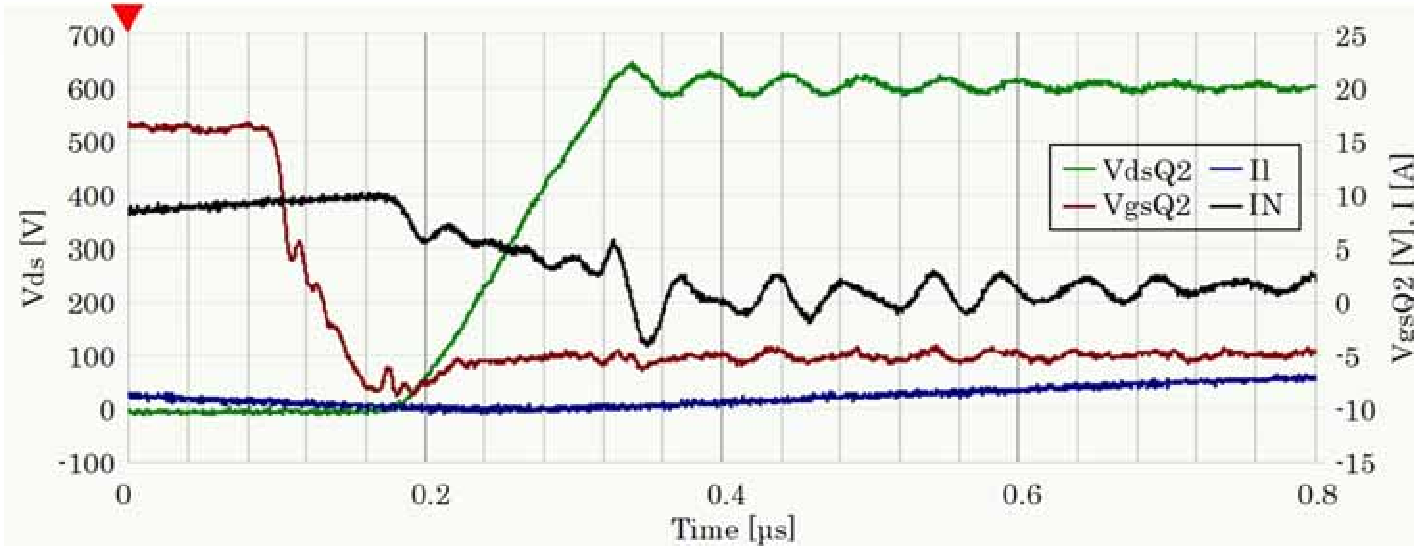
(a) Q1 turn off, 24 MHz, H_{xy}

(b) Q1 turn on, 24 MHz, H_{xy}

High intensity around P-N terminal ⇔ Low intensity around O terminal (small effect on load current)

Correspond with current response and spectrogram

Noise current propagation (24MHz)



y

x

24 MHz

Conclusion

- Fast switching of Wideband gap device
  - Bipolar (IGBT, PiND) -> unipolar (MOSFET,SBD)
    - No reverse recovery, no tail current
    - Fast switching operation
      - Wide band noise spectrum
  - Visualization of noise component
    - Emergence and extinction of noise current location can be detected