



A Study of Conducted Noise Overlap and Modeling in Multiple Inverters Considering Positions

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- **Research Background and Purpose**
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 - Comparison of Current Amplitudes
- **Simulation Method and Results**
 - Simulation Method
 - Simulation Circuit Configuration
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 - Comparison of Resistance Values
- **Conclusion**

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Research Background

Research Background

With the spread of power semiconductors, there has been an increase in cases where multiple power converters operate in closeness

Issues

The superposition and interference of conducted noise during multi-unit drive, which vary depending on the positional relationship, necessitate the development of a new simulation methodology

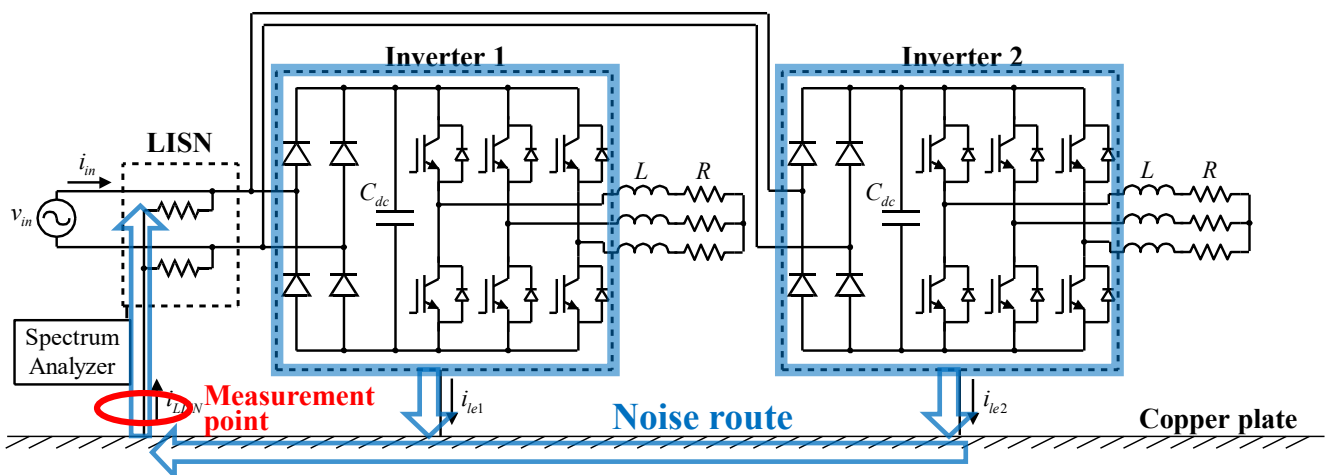
Purpose

Proposal of a conducted noise superposition modeling method
Evaluating noise overlap from power converter positioning

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Experimental Environment and Conditions



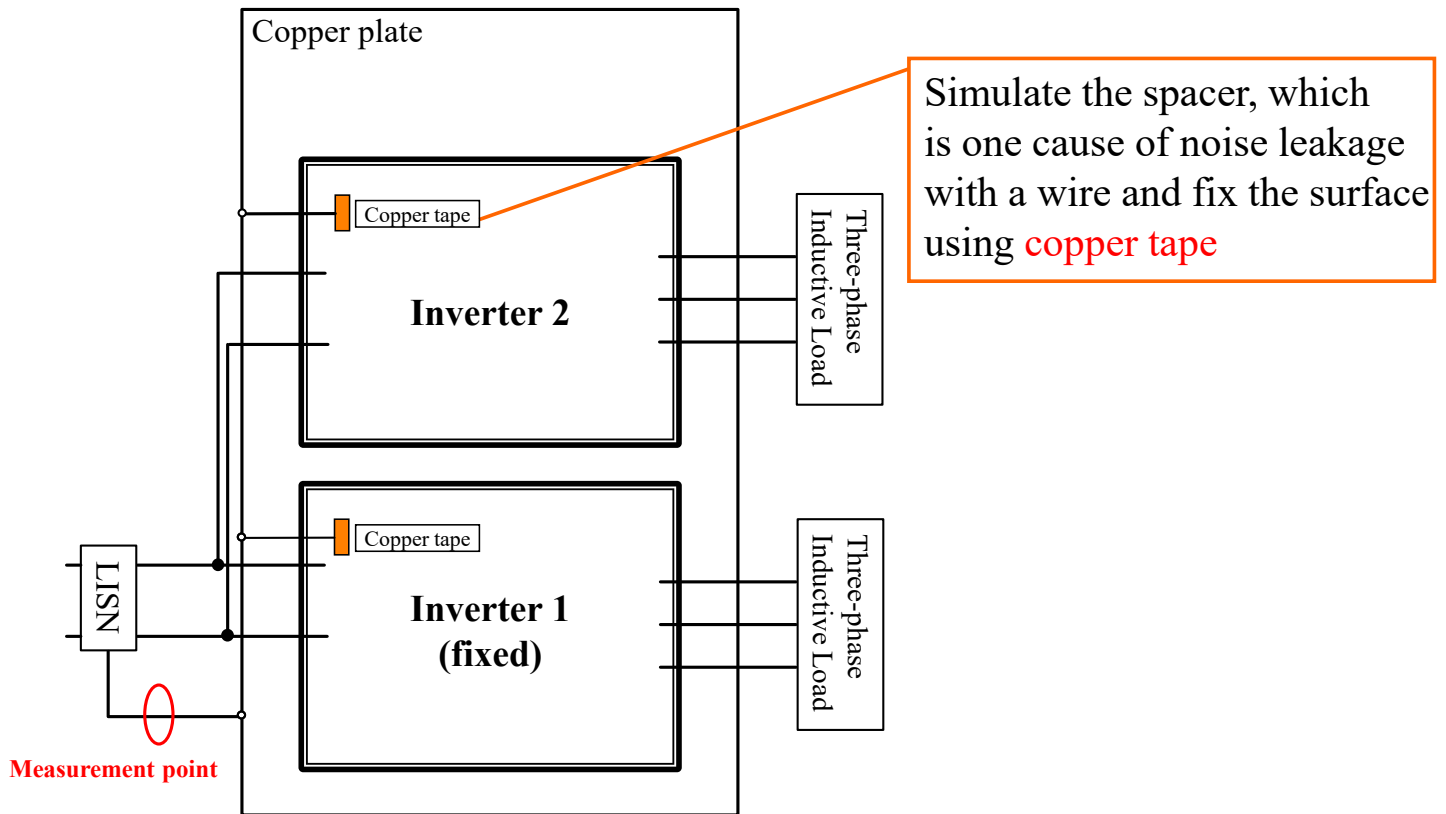
Input voltage v_{in}	100 V
Input current i_{in}	5.18 A
DC bus capacitor C_{dc}	1360 μ F
Switching frequency f_s	12.5 kHz
AC frequency f	100 Hz
Load R, L	8 Ω , 2 mH
Output power P_{out}	326 W

Measurement and analysis flow

- Connect Inverters surface and copper plate with a wire
- Measure leakage current into LISN
- Apply FFT analysis to leakage current
 - Leakage current is analyzed at specific events to ensure consistent conditions

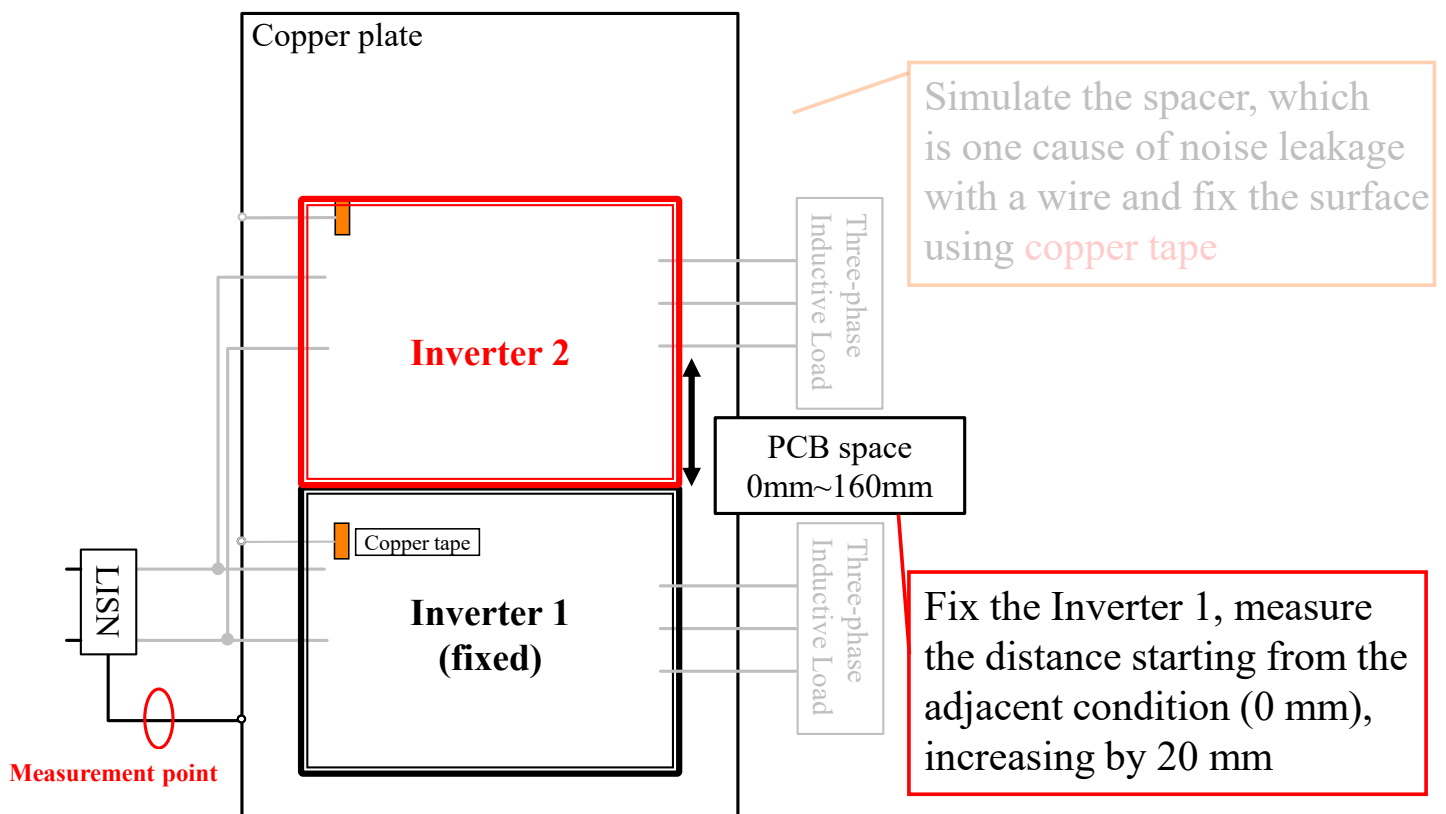
Experimental Environment and Conditions

Experimental Outline



Experimental Environment and Conditions

Experimental Outline

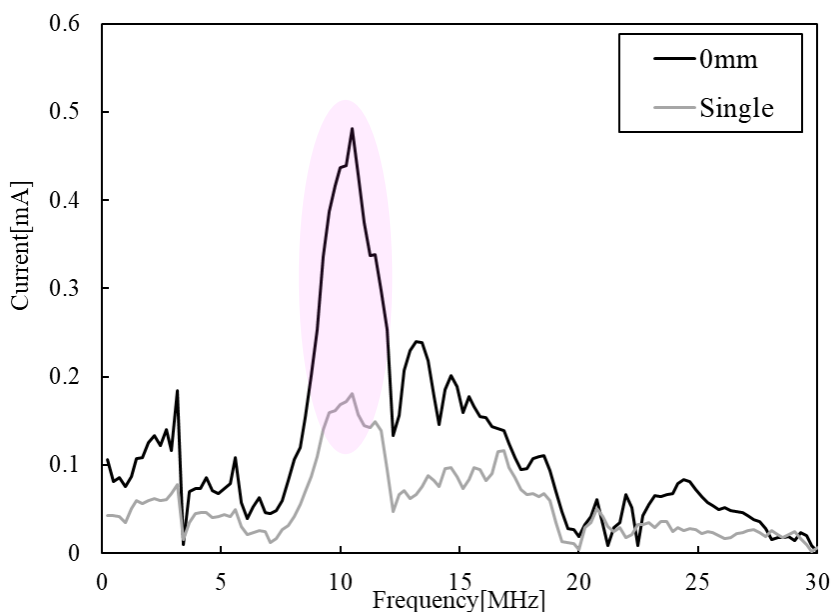


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Comparison of Experimental Results

■ FFT analysis of leakage current



■ FFT amplitude of current

Condition	Max amplitude
0 mm	0.48 mA
Single Drive	0.18 mA

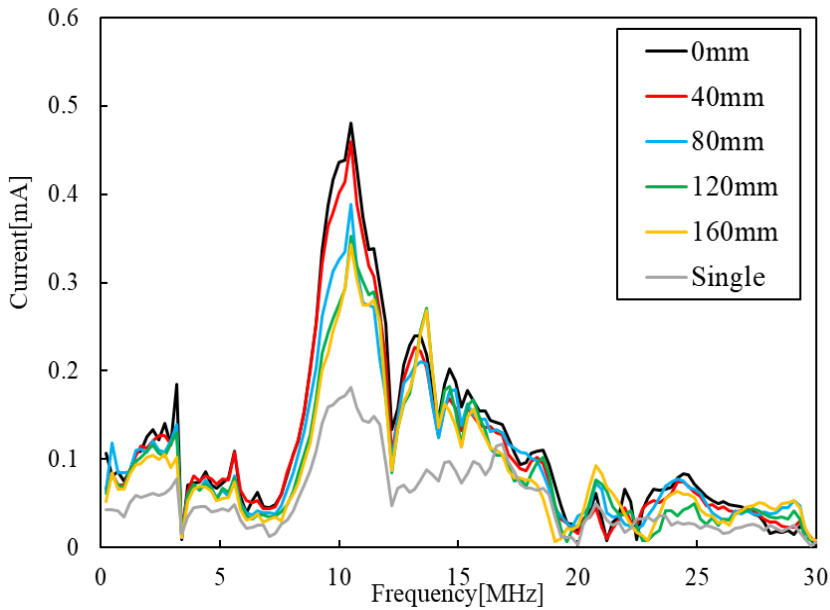
■ Current waveform amplitude

Condition	Max amplitude
0 mm	13.3 mA
Single Drive	6.36 mA

Noise superposition increases the overall current amplitude

Comparison of Experimental Results

FFT analysis of leakage current

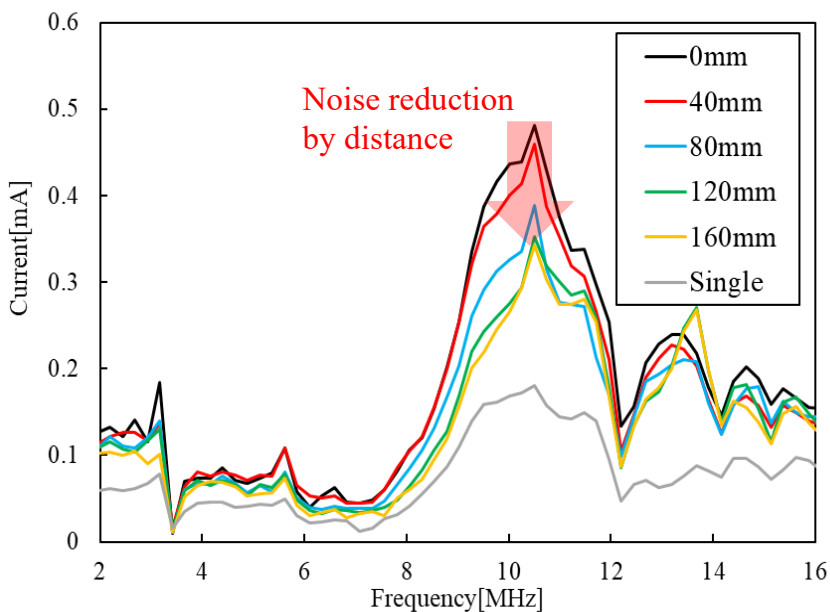


FFT amplitude of current

Condition	Max amplitude
0 mm	0.48 mA
40 mm	0.46 mA
80 mm	0.39 mA
120 mm	0.35 mA
160 mm	0.34 mA
Single Drive	0.18 mA

Comparison of Experimental Results

FFT analysis of leakage current(2 ~ 16 MHz)



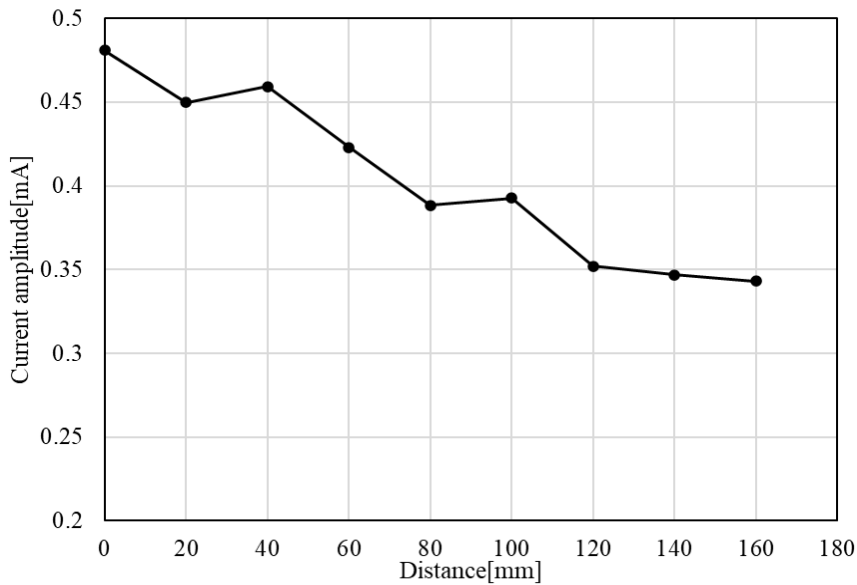
FFT amplitude of current

Condition	Max amplitude
0 mm	0.48 mA
40 mm	0.46 mA
80 mm	0.39 mA
120 mm	0.35 mA
160 mm	0.34 mA
Single Drive	0.18 mA

At the distance increase, the noise tends to decrease

Comparison of Experimental Results

Variation of current amplitude with distance



FFT amplitude of current

Condition	Max amplitude
0 mm	0.48 mA
40 mm	0.46 mA
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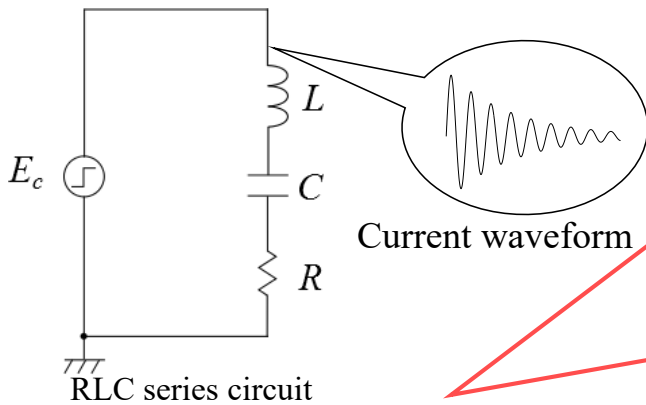
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Modeling Circuit

RLC series circuit



$$i(t) = \frac{E_c}{Z_0} e^{-\zeta \omega_n t} \sin \omega_n t$$

$$\omega_n = 2\pi f, Z_0 = \frac{E_c}{i_{peak}}, \zeta = \frac{R}{2Z_0}$$

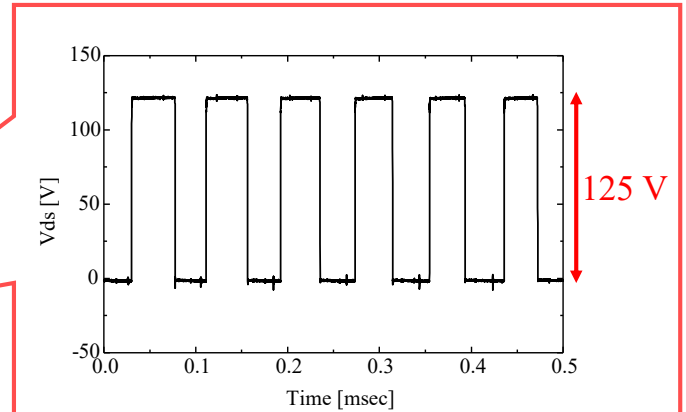
ω_n : Natural Vibration Frequency

Z_0 : Characteristic Impedance

i_{peak} : Maximum Value of Current

ζ : Attenuation Coefficient

Determination of step voltage source E_c

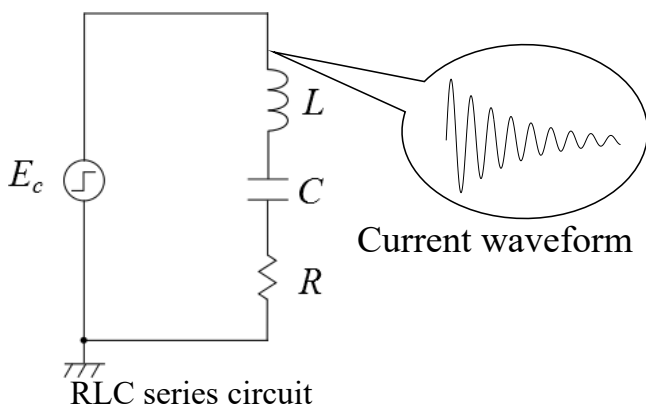


Measurement result of drain-source voltage

$$E_c = 125 \text{ V}$$

Modeling Circuit

RLC series circuit



$$i(t) = \frac{E_c}{Z_0} e^{-\zeta \omega_n t} \sin \omega_n t$$

$$\omega_n = 2\pi f, Z_0 = \frac{E_c}{i_{peak}}, \zeta = \frac{R}{2Z_0}$$

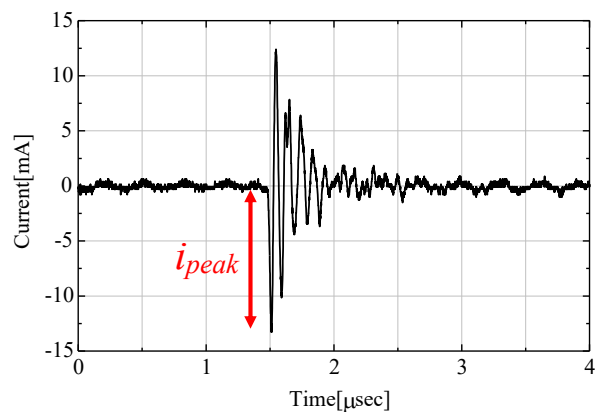
ω_n : Natural Vibration Frequency

Z_0 : Characteristic Impedance

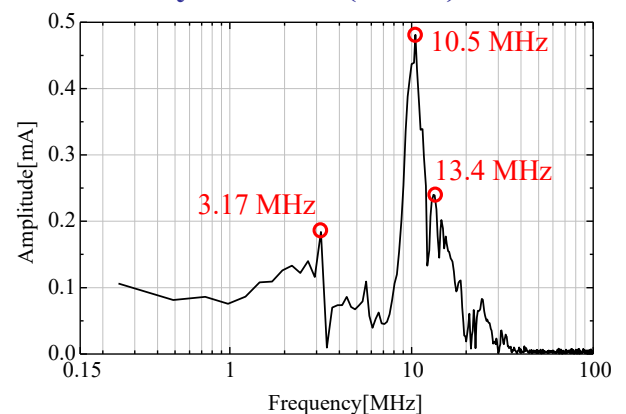
i_{peak} : Maximum Value of Current

ζ : Attenuation Coefficient

Analysis target (0 mm)



FFT analysis result (0 mm)

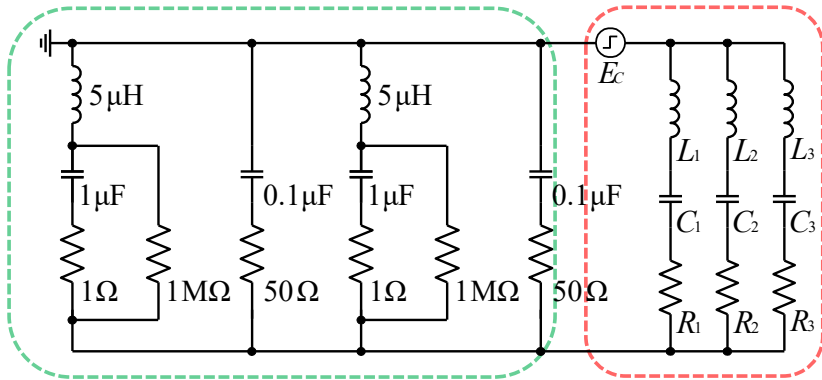


Simulation Result (PCB space 0 mm)

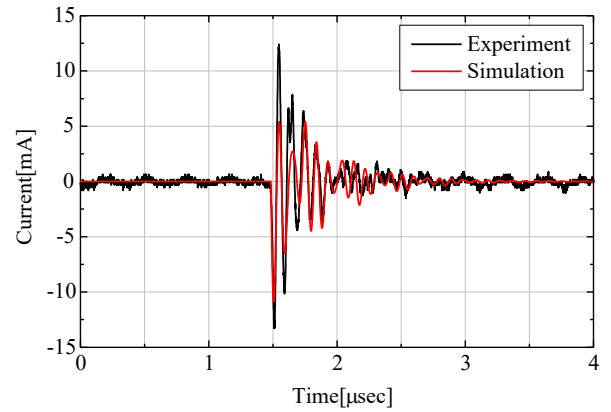
Simulation circuit

Equivalent circuit of LISN

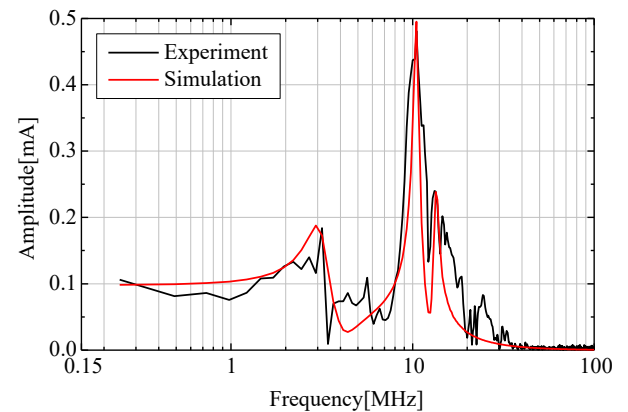
Modeling circuit



Leakage current simulation



FFT analysis simulation



Circuit parameters (0 mm)

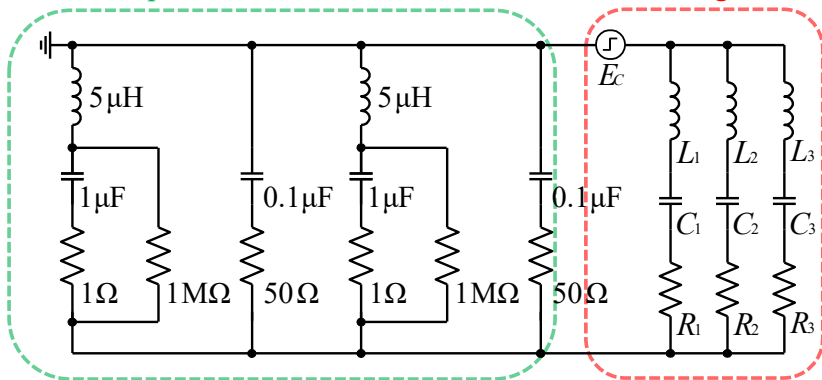
f	3.17 MHz	10.5 MHz	13.4 MHz
E_C	125 V	125 V	125 V
i_{peak}	2.71 mA	7.06 mA	3.51 mA
ω_n	19.9 Mrad/s	66.0 Mrad/s	84.4 Mrad/s
Z_0	46.1 k Ω	17.7 k Ω	35.6 k Ω
L_1, L_2, L_3	2.32 mH	0.268 mH	0.422 mH
C_1, C_2, C_3	1.09 pF	0.857 pF	0.333 pF
R_1, R_2, R_3	13.3 k Ω	1.31 k Ω	2.28 k Ω

Simulation Result (PCB space 160 mm)

Simulation circuit

Equivalent circuit of LISN

Modeling circuit



Circuit parameters (160 mm)

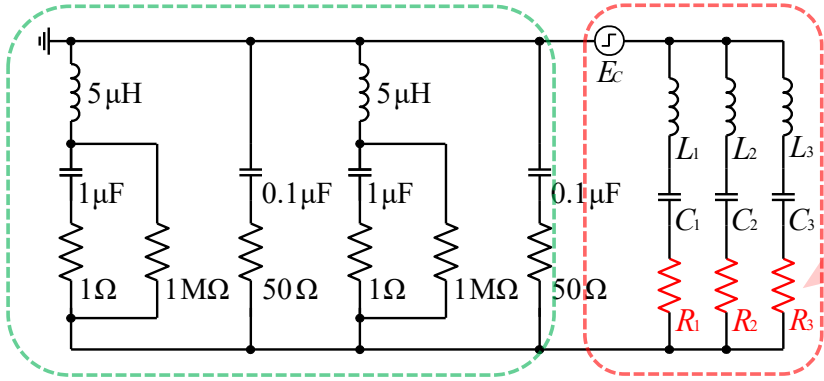
f	3.17 MHz	10.5 MHz	13.4 MHz
E_C	125 V	125 V	125 V
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ω_n	19.9 Mrad/s	66.0 Mrad/s	84.4 Mrad/s
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L_1, L_2, L_3	2.32 mH	0.268 mH	0.422 mH
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Simulation Result (PCB space 160 mm)

Simulation circuit

Equivalent circuit of LISN

Modeling circuit



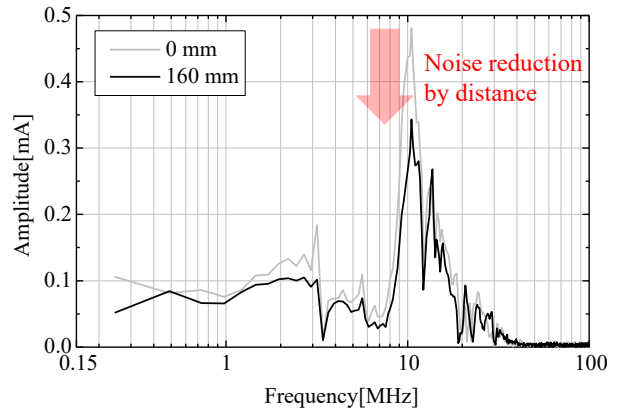
Simulation Approach

Simulations were performed by varying only the R , based on the 0 mm parameters and FFT results

Circuit parameters (160 mm)

f	3.17 MHz	10.5 MHz	13.4 MHz
E_C	125 V	125 V	125 V
i_{peak}	2.71 mA	7.06 mA	3.51 mA
ω_n	19.9 Mrad/s	66.0 Mrad/s	84.4 Mrad/s
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L_1, L_2, L_3	2.32 mH	0.268 mH	0.422 mH
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R_1, R_2, R_3			

FFT analysis result

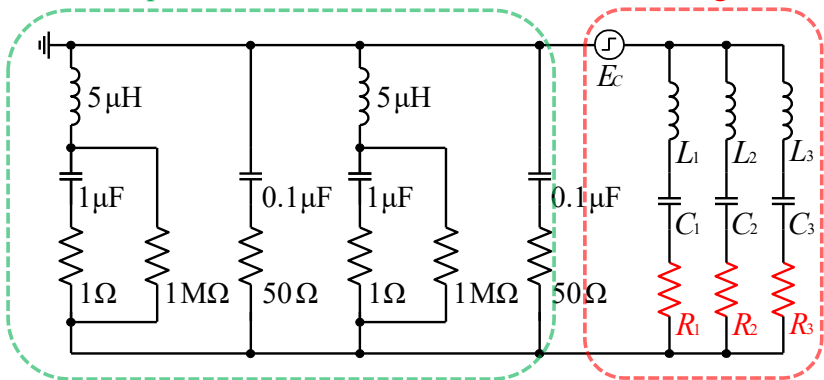


Simulation Result (PCB space 160 mm)

Simulation circuit

Equivalent circuit of LISN

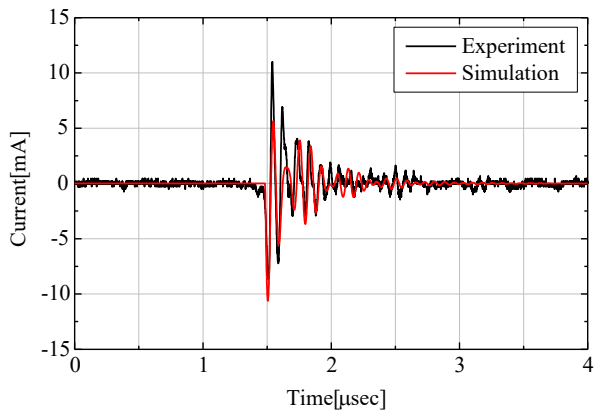
Modeling circuit



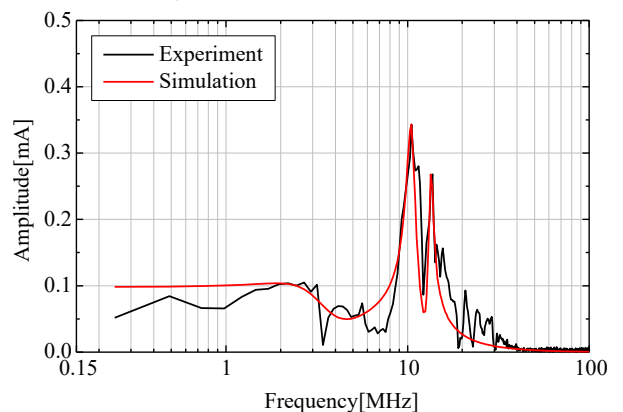
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L_1, L_2, L_3	2.32 mH	0.268 mH	0.422 mH
C_1, C_2, C_3	1.09 pF	0.857 pF	0.333 pF
R_1, R_2, R_3	40.0 kΩ	1.92 kΩ	2.03 kΩ

Leakage current simulation

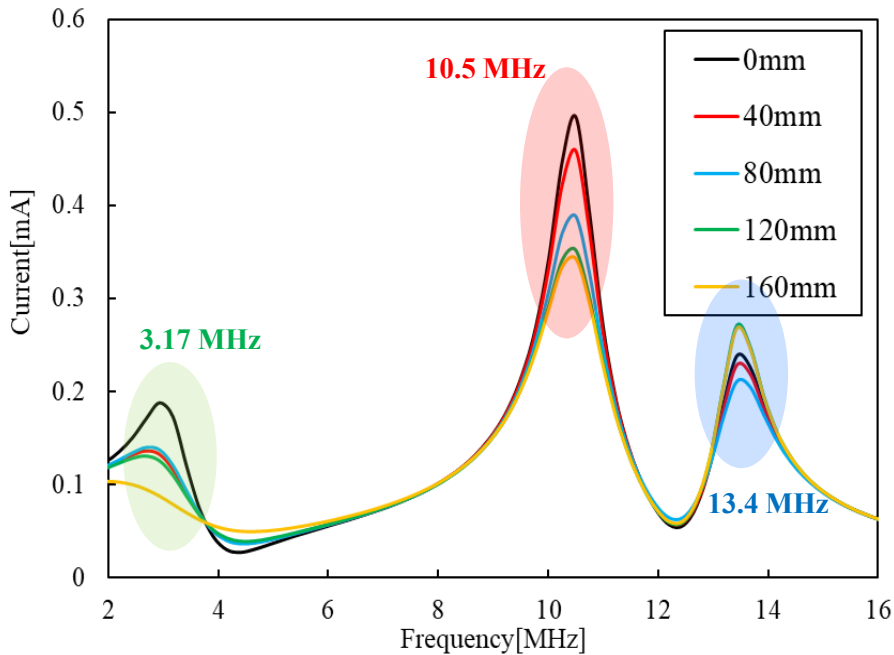


FFT analysis simulation



Simulation Results Comparison

■ FFT analysis of leakage current(2 ~ 16 MHz)



Primary resonance (10.5 MHz)

The amplitude gradually decreases as the distance increases

Minor resonance (13.4 MHz)

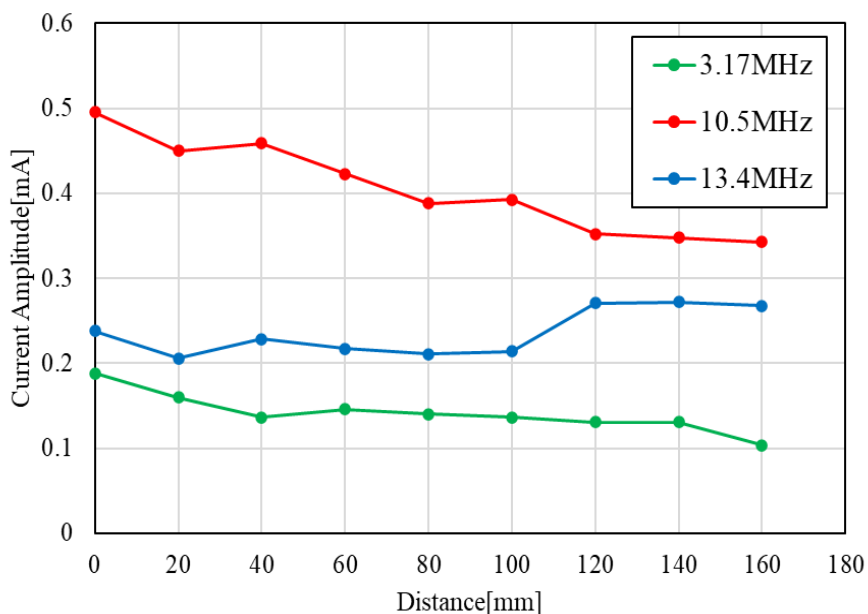
The amplitude remains relatively stable until 100mm, after which it surges rapidly

Minor resonance (3.17 MHz)

The amplitude gradually decreases as the distance increases

Simulation Results Comparison

■ Variation of current amplitude with distance



Primary resonance (10.5 MHz)

The amplitude gradually decreases as the distance increases

Minor resonance (13.4 MHz)

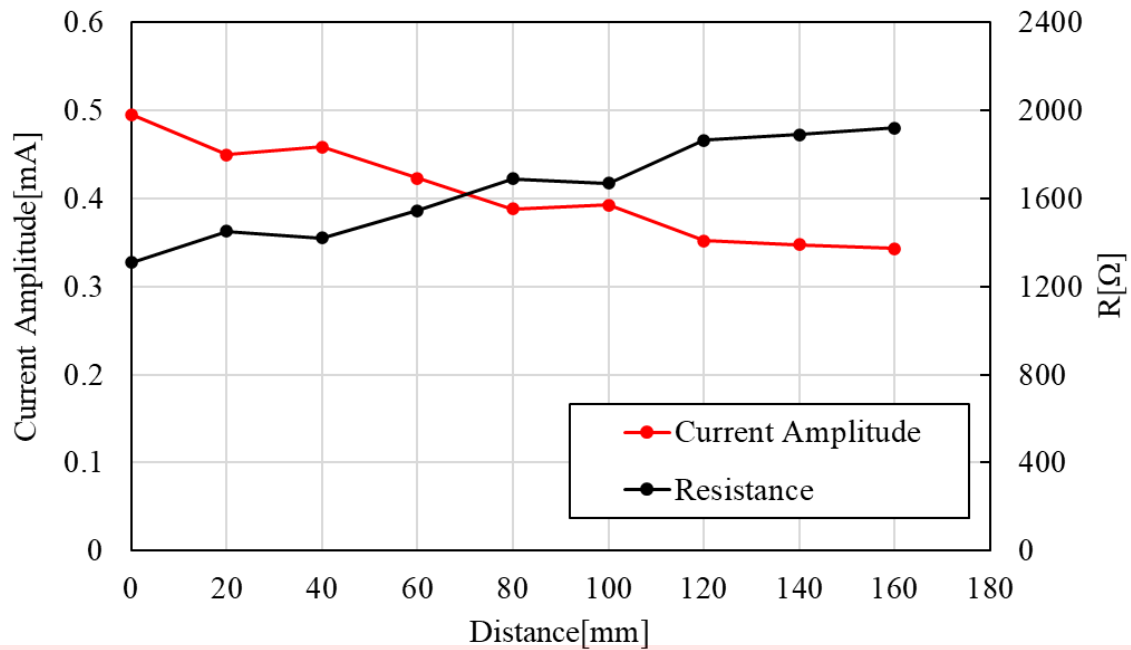
The amplitude remains relatively stable until 100mm, after which it surges rapidly

Minor resonance (3.17 MHz)

The amplitude gradually decreases as the distance increases

Correlation of Distance and R

■ Relationship between resistance and current amplitude at Primary resonance



At the distance increase, the resistance R increases linearly

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Conclusion

Research

- Proposal of a conducted noise superposition modeling method
- Evaluating noise overlap from power converter positioning

Results

- Derived the high-frequency equivalent circuit from leakage current, and confirmed the usefulness of this method based on simulation results
- Confirmed noise variation depending on positional conditions
- Confirmed correlation between resistance and distance

Future Work

- Improving the accuracy of equivalent circuit
- Filter-insertion experiments and analysis
- Applying Genetic Algorithm to the modeling circuit