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EMI Noise Reduction for PFC Converter with Improved Efficiency and High Frequency Clock

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Outline

- Background
- Conventional PFC Power Supply
- Proposed PFC Power Supply
  1. EMI Reduction
  2. High Efficiency
- Conclusion

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- Background
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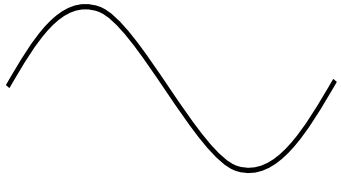
- Proposed PFC Power Supply
  - —Using frequency modulation
- Diode recovery current reduction
- Conclusion

Power Supply Circuit is Everywhere

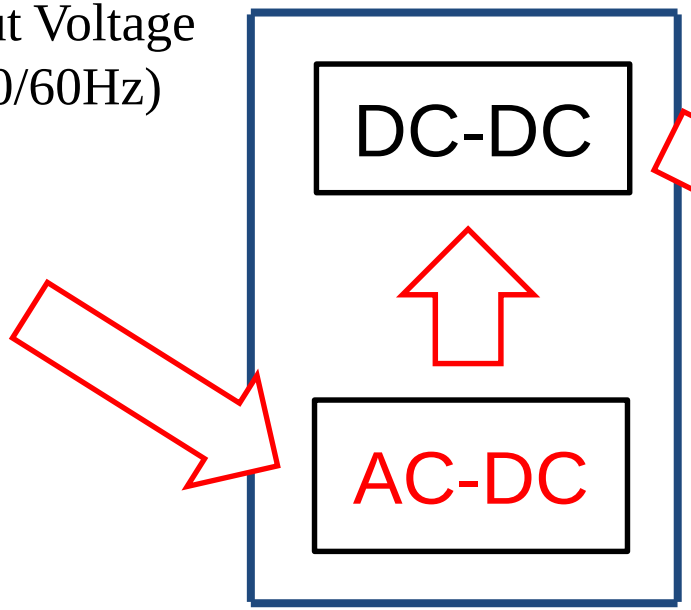
- Voltage change

  AC (100 / 200V) → DC (ex. 300V)



Input Voltage
(50/60Hz)

Output Voltage



Power Supply

Research Objective

AC-DC converter improvement

1. EMI noise reduction ⇛ Frequency modulation

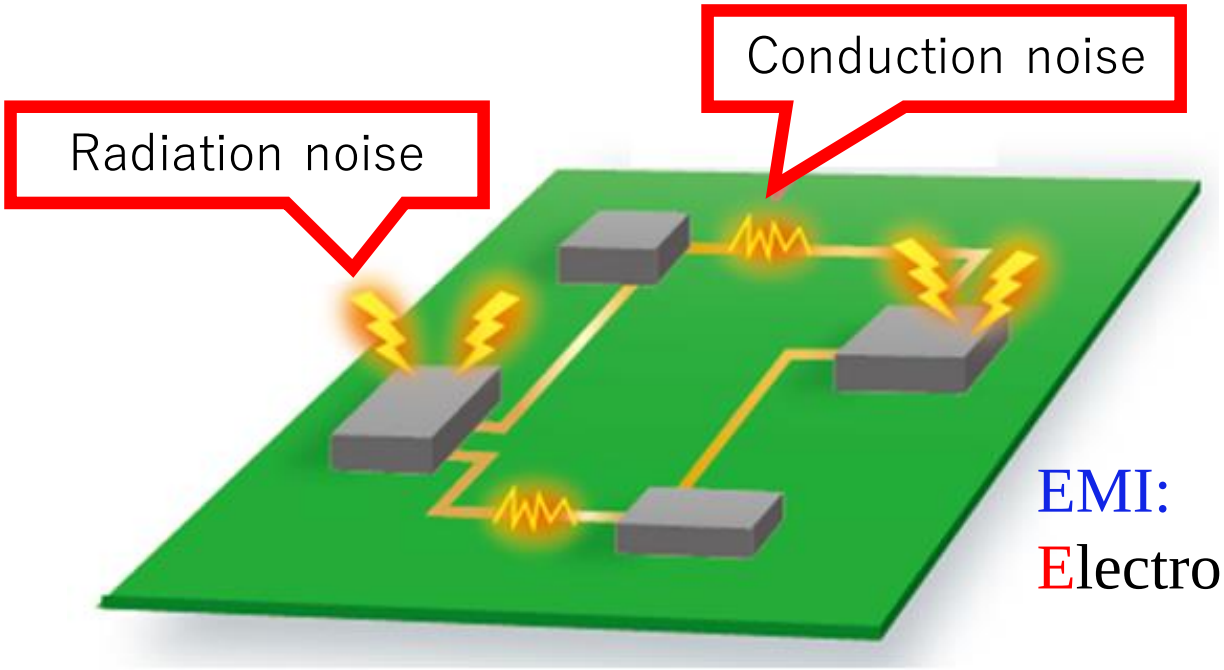
2. Efficiency improvement ⇛ SiC-SBD

3. Input LPF size reduction ⇛ SiC-SBD
   (high clock frequency)

SBD: Schottky Barrier Diode

EMI Noise

- Current flow → EMI noise generation



EMI:
Electro-Magnetic Interference

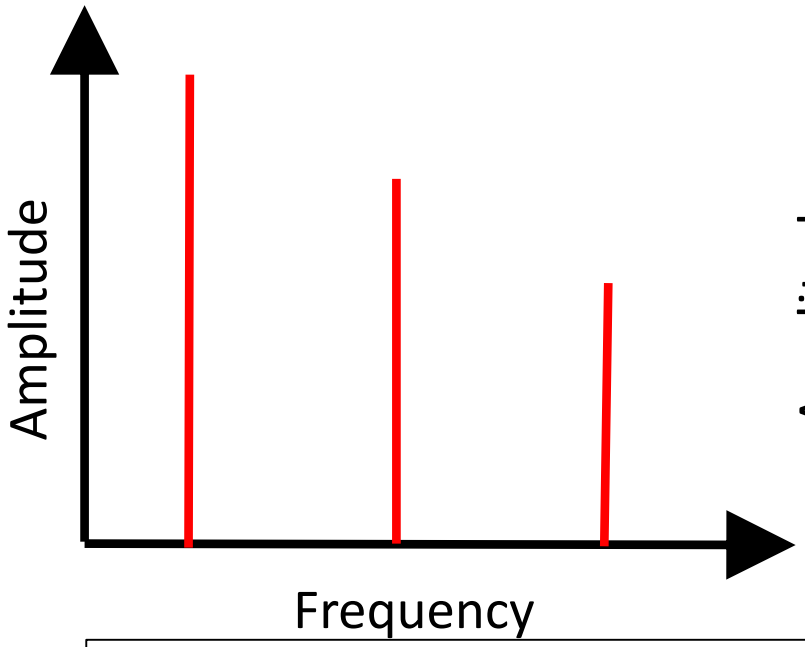
- EMI noise reduction → Input LC LPF

Regulation for products

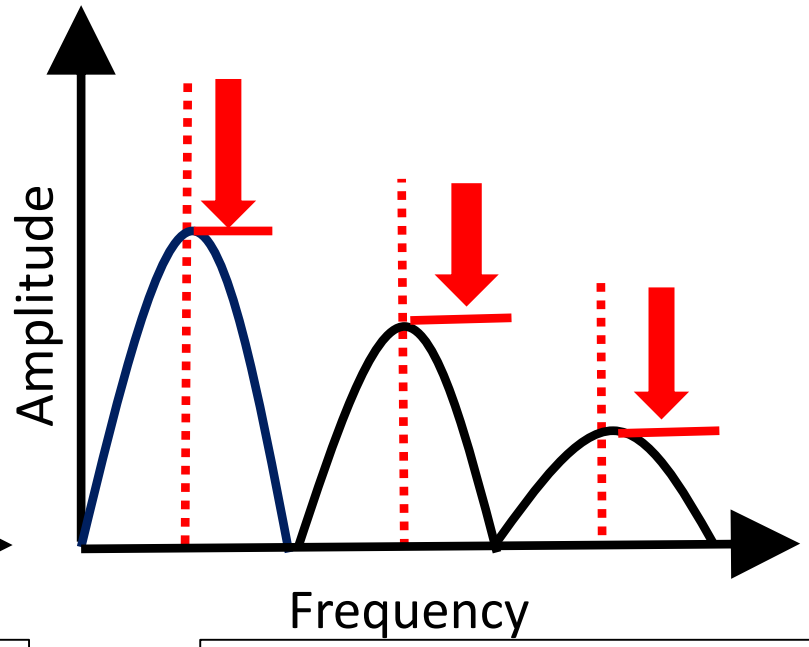
Larger circuit!

Noise Spectrum Spread

- Clock frequency modulation
  - → Noise spectrum ⇨ Spread
  - → Harmonics peak reduction



Without clock modulation



With clock modulation

High Frequency Operation Problem

Clock frequency increase

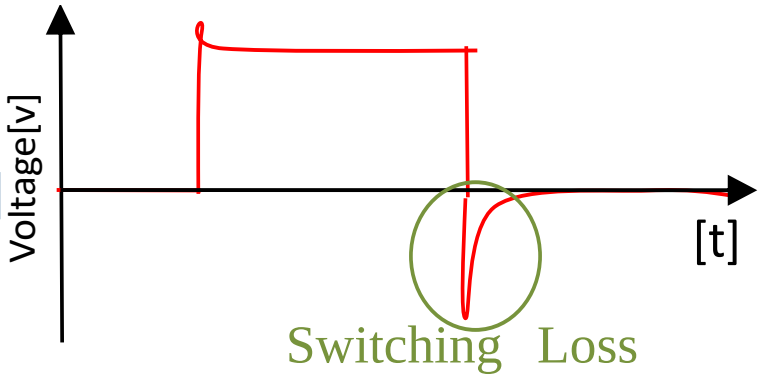
- Faster response
- Smaller LC

⇔

- Efficiency down
- Recovery current increase

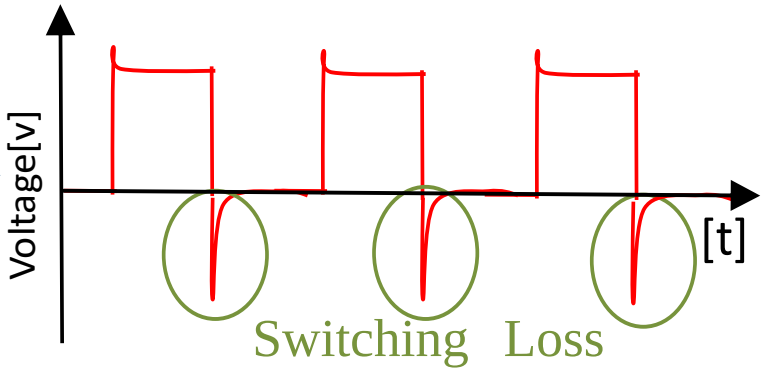
Low clock freq.

Smal loss



High clock freq.

Large loss



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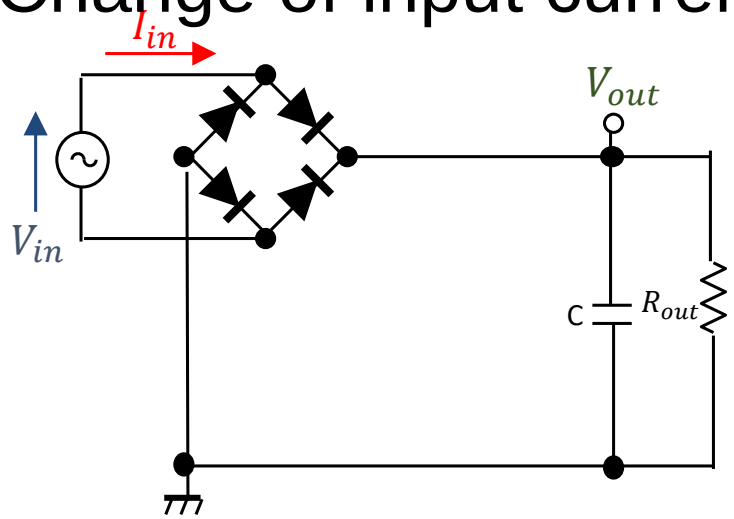
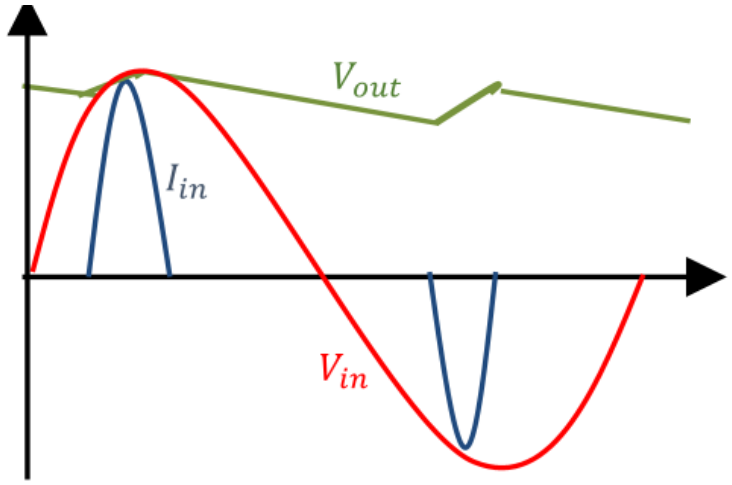
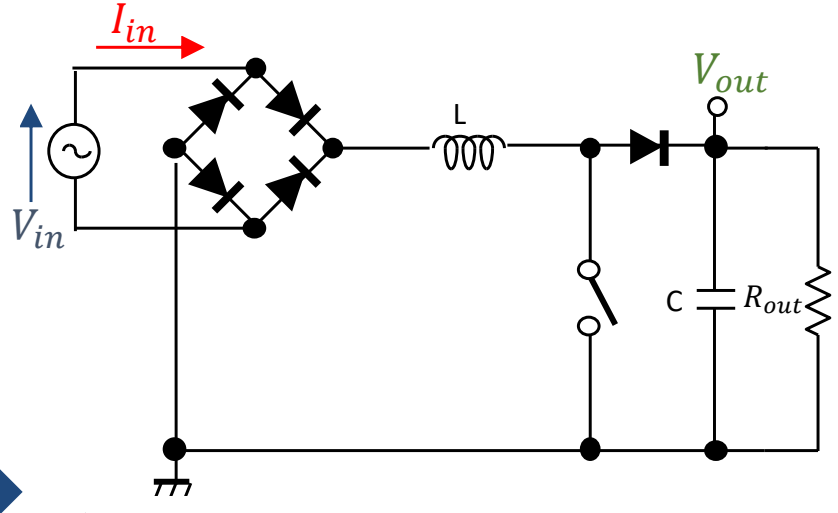
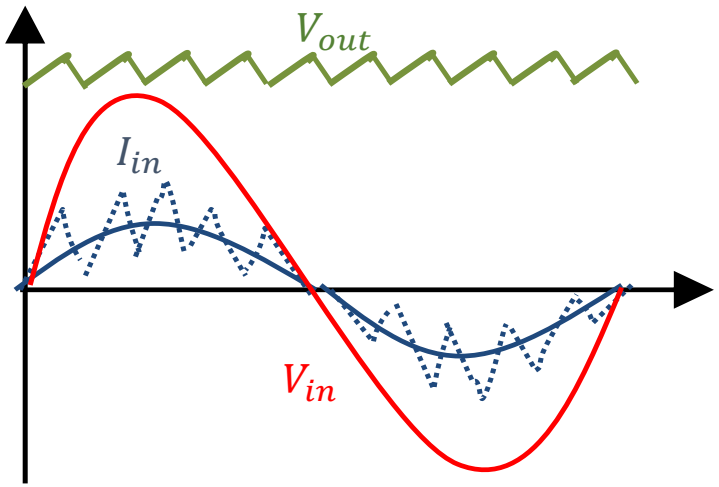
PFC Operation

Change of input current waveform









Without PFC ($\eta < 0.6$)

With PFC ($\eta > 0.9$)

PFC: Power Factor Correction η: efficiency

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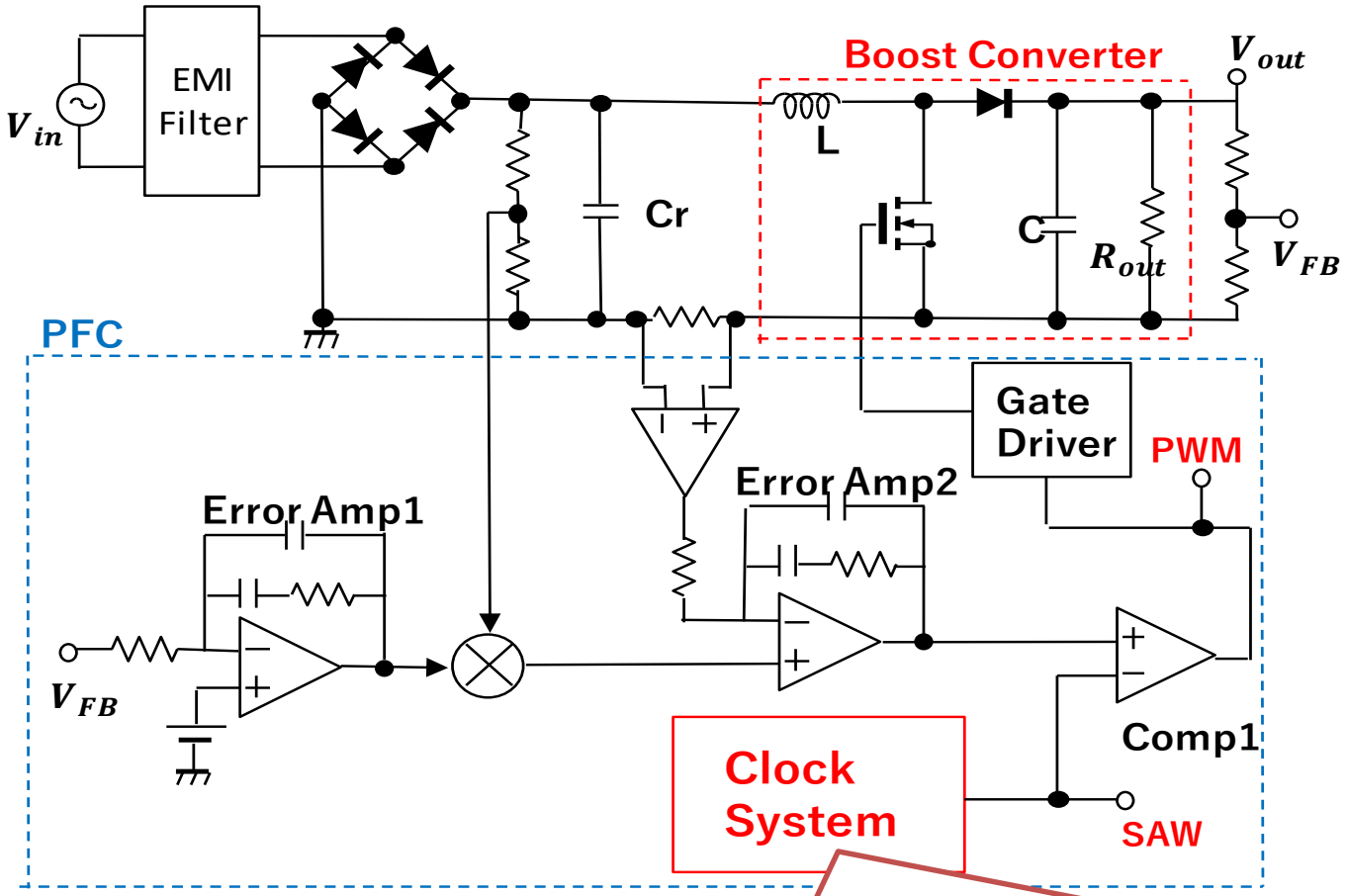
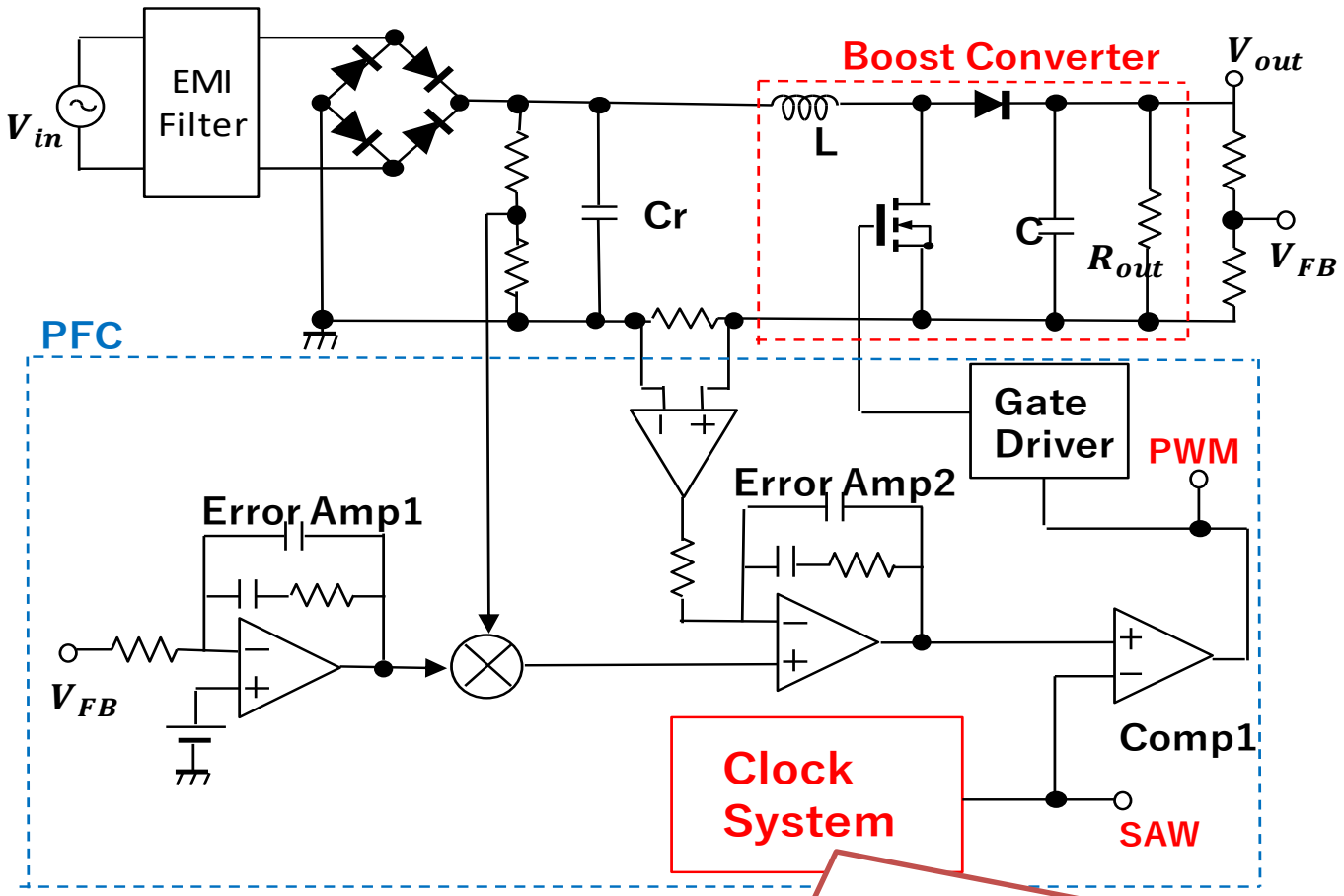
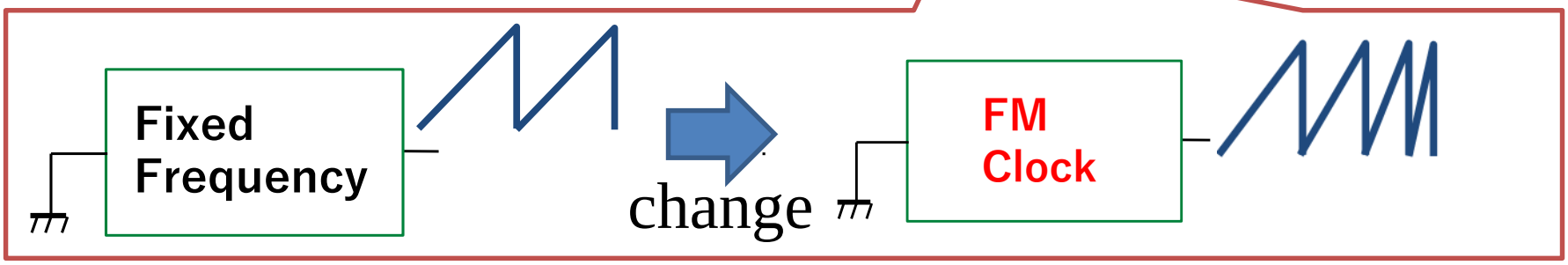
Conventional PFC Circuit



Proposal PFC Circuit

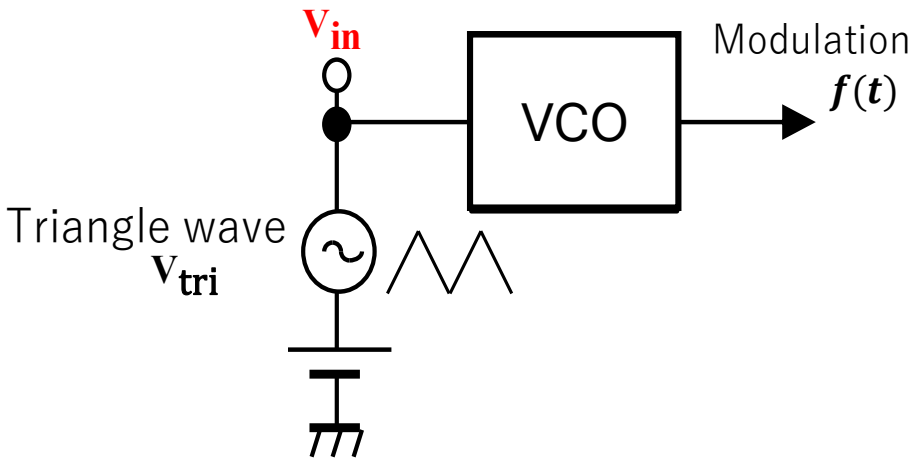


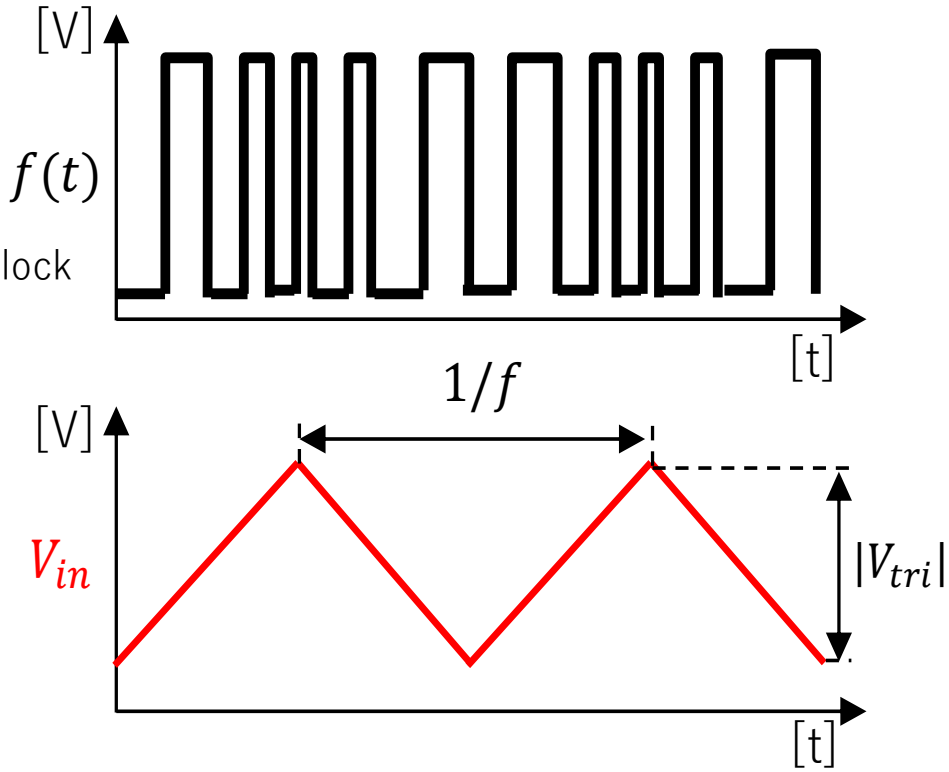


Frequency Modulation

- Modulate clock frequency

  → Clock noise spectrum is spread

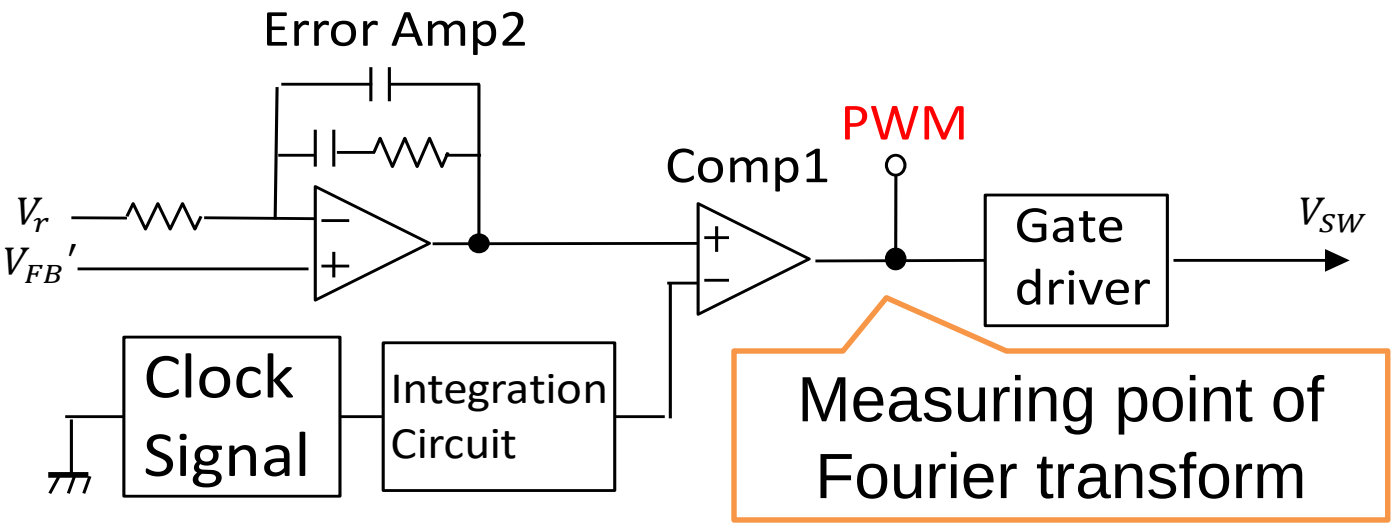




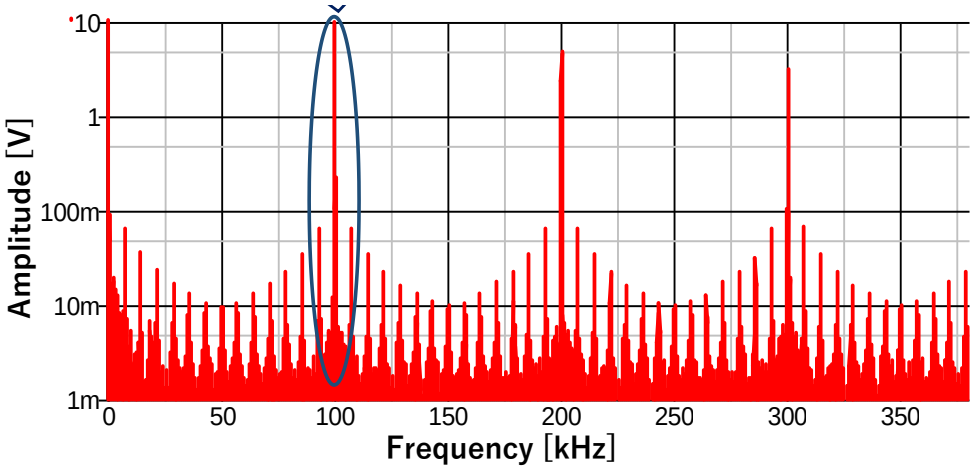
VCO: Voltage Controlled Oscillator

PFC Circuit for Simulation

Parameter	Simulation Value
Vin	AC 100V/50Hz
L	2.2 mH
Cout	330 μF
Vout	400V
Fck	100 kHz



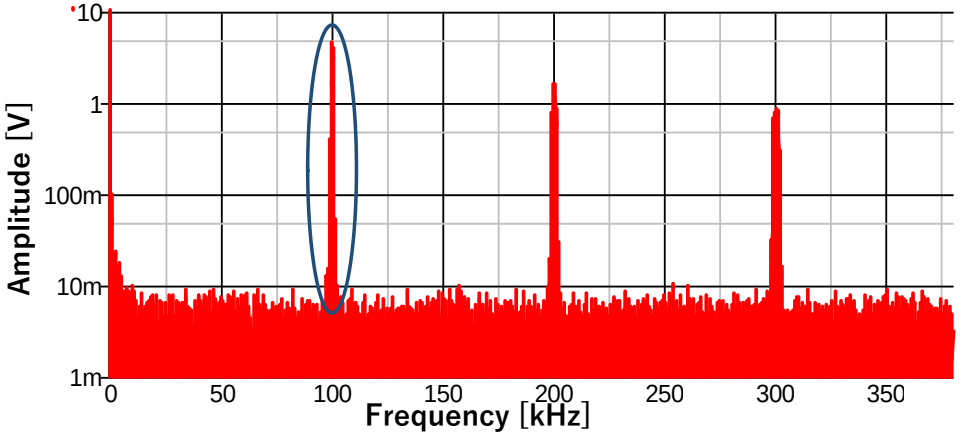
Comparison of PWM Spectrum



Large voltage!

9.5V
(fixed frequency)

- 9.7dB

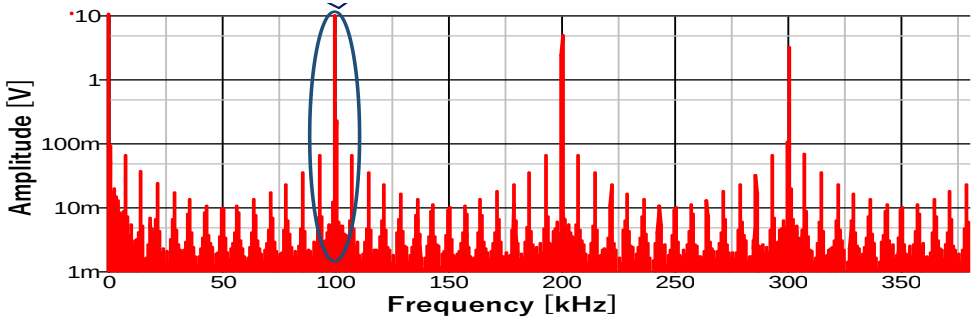


3.1V

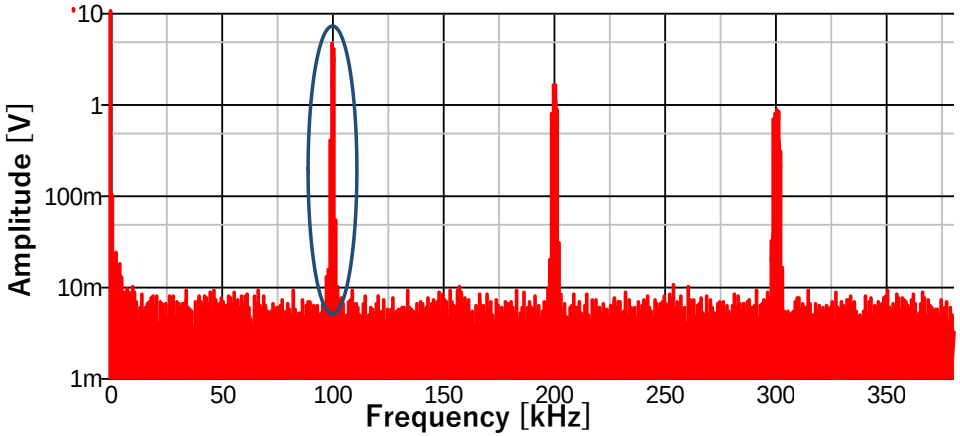
Good!

(modulated frequency
Δf=±1kHz)

Improvement of PWM Spectrum

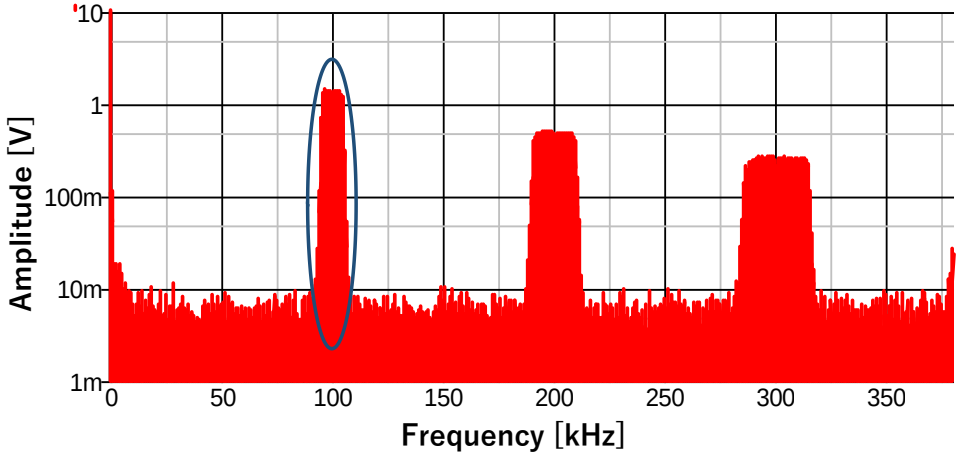


9.5V
(fixed frequency)



3.1V
(△f=±1kHz)

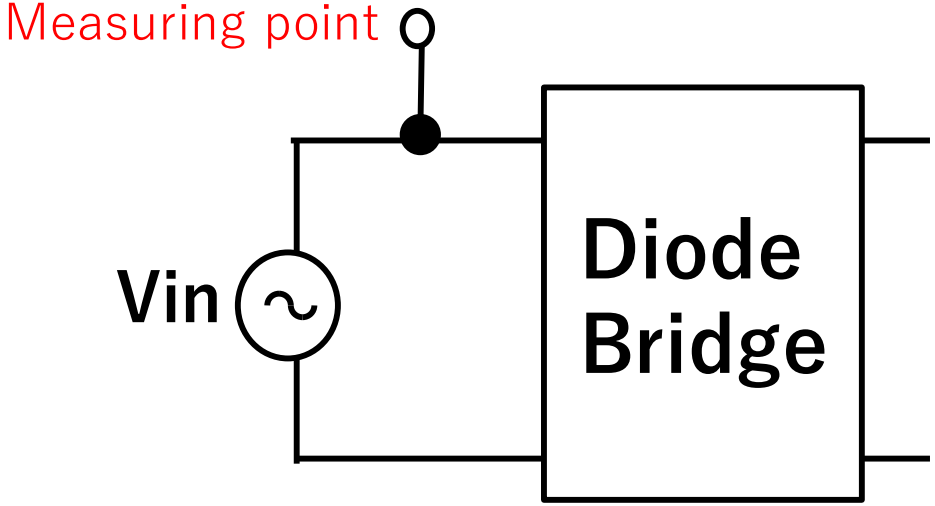
- 17.3dB

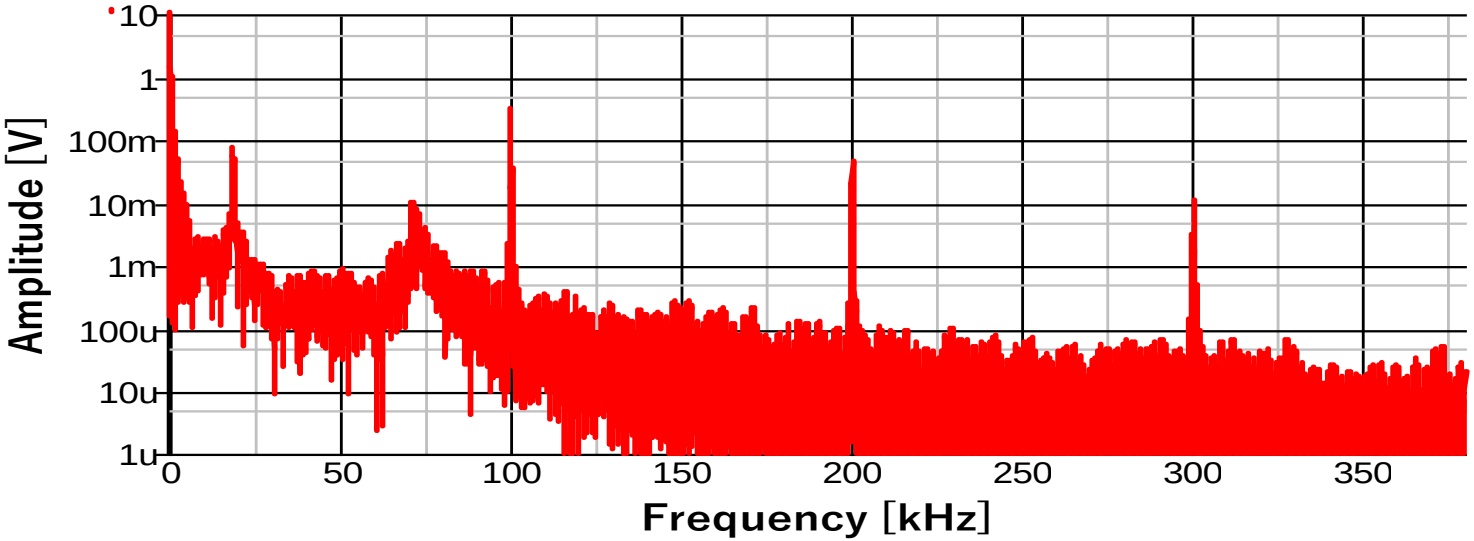


1.3V
(△f=±10kHz)

Very good!

Conduction Noise of Conventional PFC





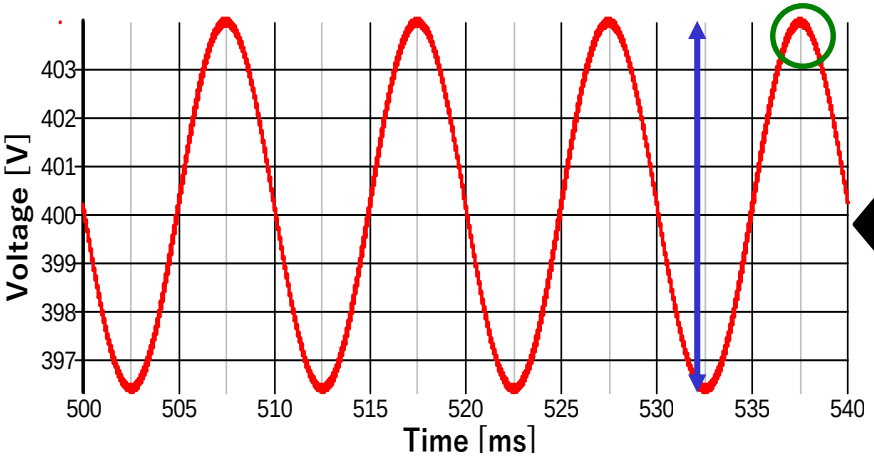
Peak spectrum is low → PFC operation

Output Voltage Ripple

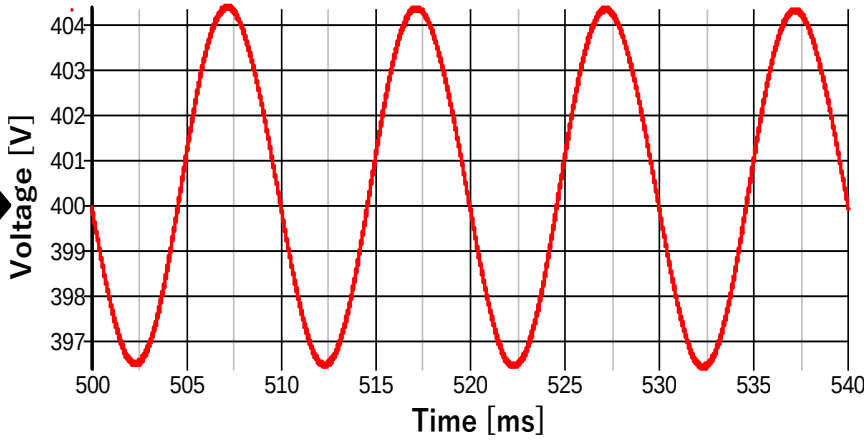
- Change of Fck

1)Input AC ripple ⇨ Large ripple: < 8Vpp

2)Modulation ripple ⇨ Small ripple: < 10mV



100kHz ±10kHz



200kHz ±10kHz

Almost the same output waveform

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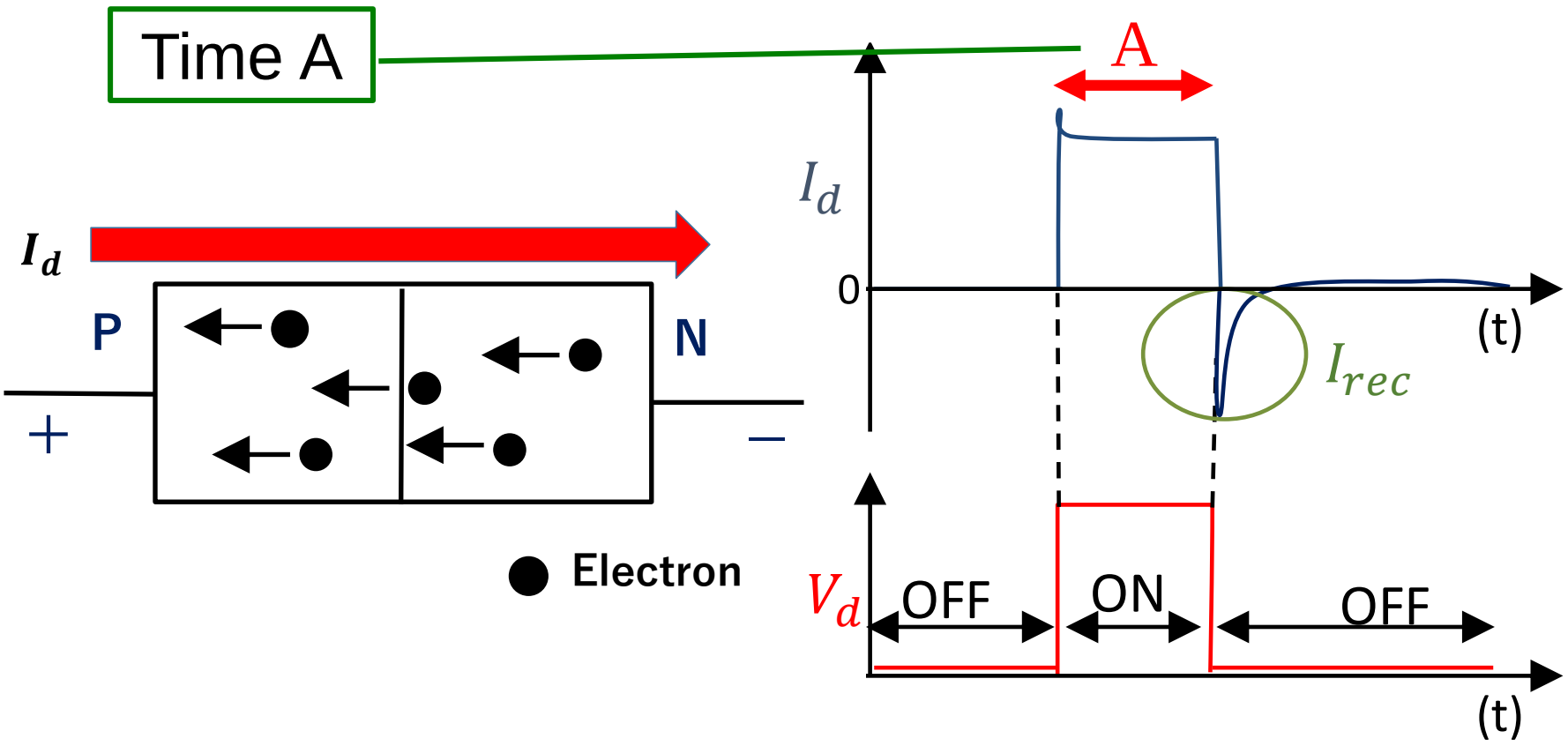
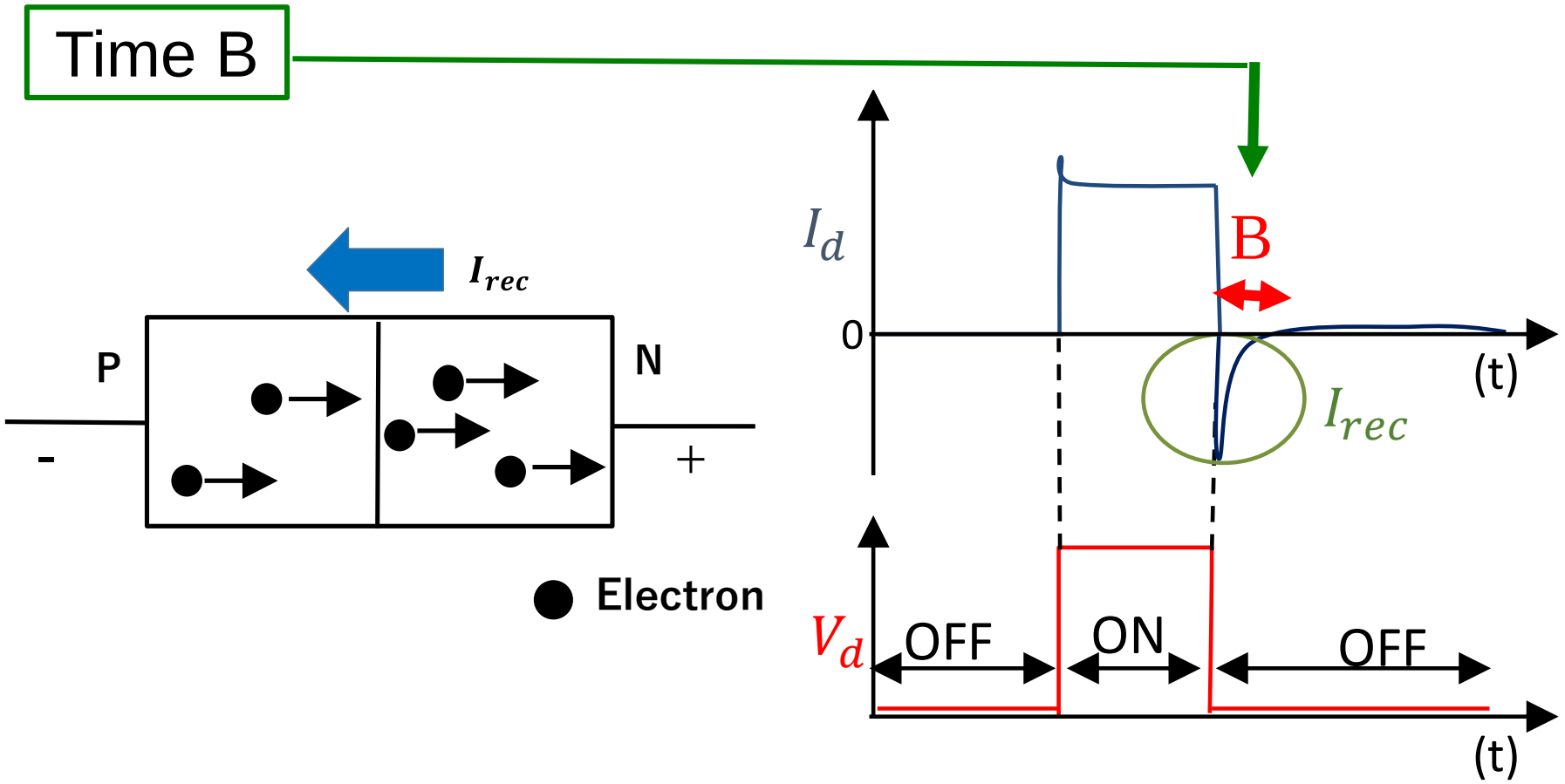
Diode Recovery Current (1/3)



- On-timing : Forward voltage to diode

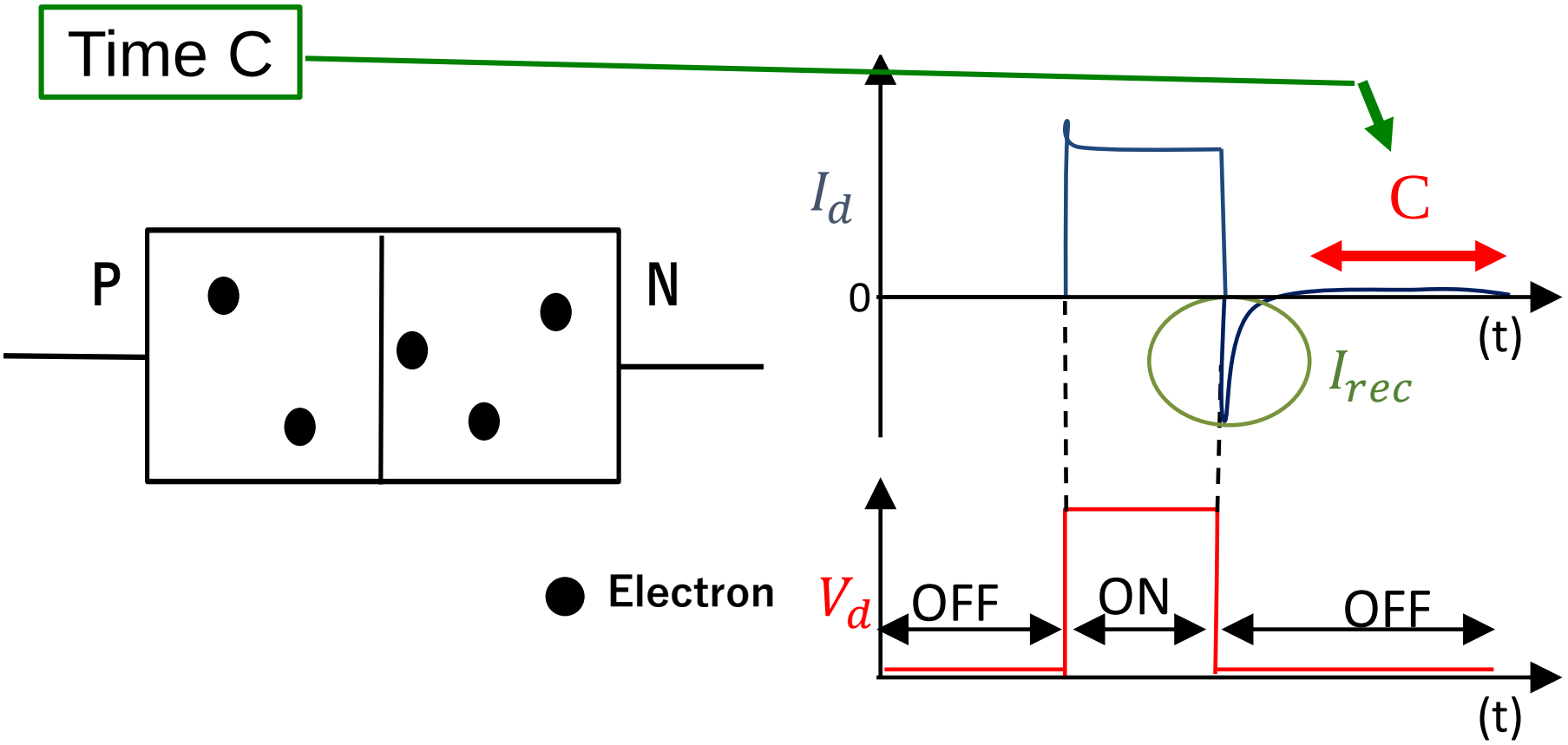
Diode Recovery Current (2/3)



- At turn off : Recovery current generation

  → No conducted carriers move reversely

Diode Recovery Current (3/3)



- Off time : No current flow

Recovery Current Reduction Approach

Fck increase → Switching Loss increase

How to reduce recovery current?

→ Schottky Barrier Diode(SBD) usage

Breakdown voltage

Si-SBD (200V) → SiC-SBD (600V)

Power supply circuit usage

However, SiC-SBD has a problem.

SiC Features

Comparison of SiC with Si

- Pro - High breakdown voltage
  - High speed operation
- Con - High cost

Cost of SiC is high. (now)

↕

L, C, LPF are smaller.

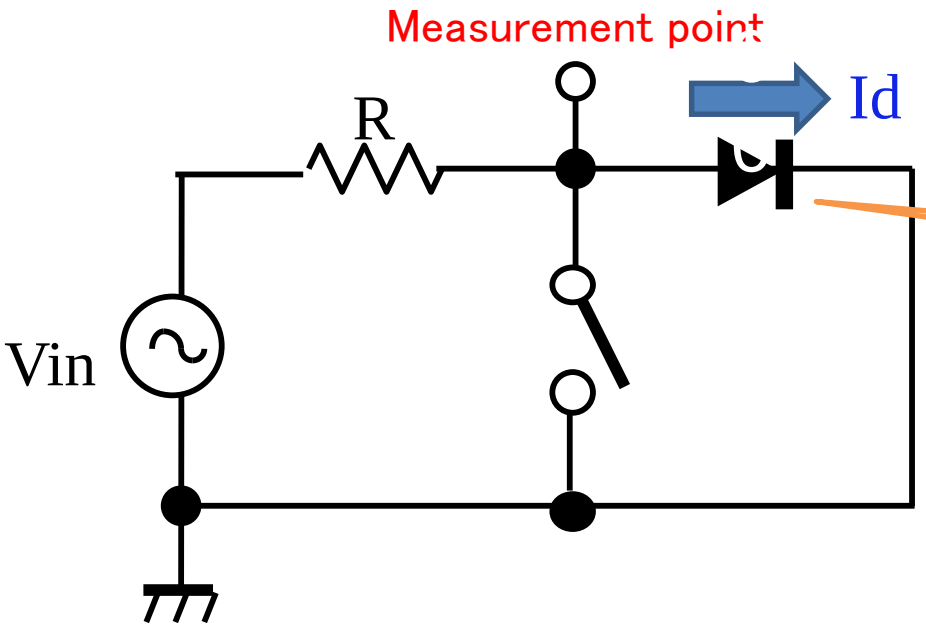
↓

Total cost down at circuit level !

Comparison of Diodes

- Check diode current
- Calculate loss
  by SIMetrix

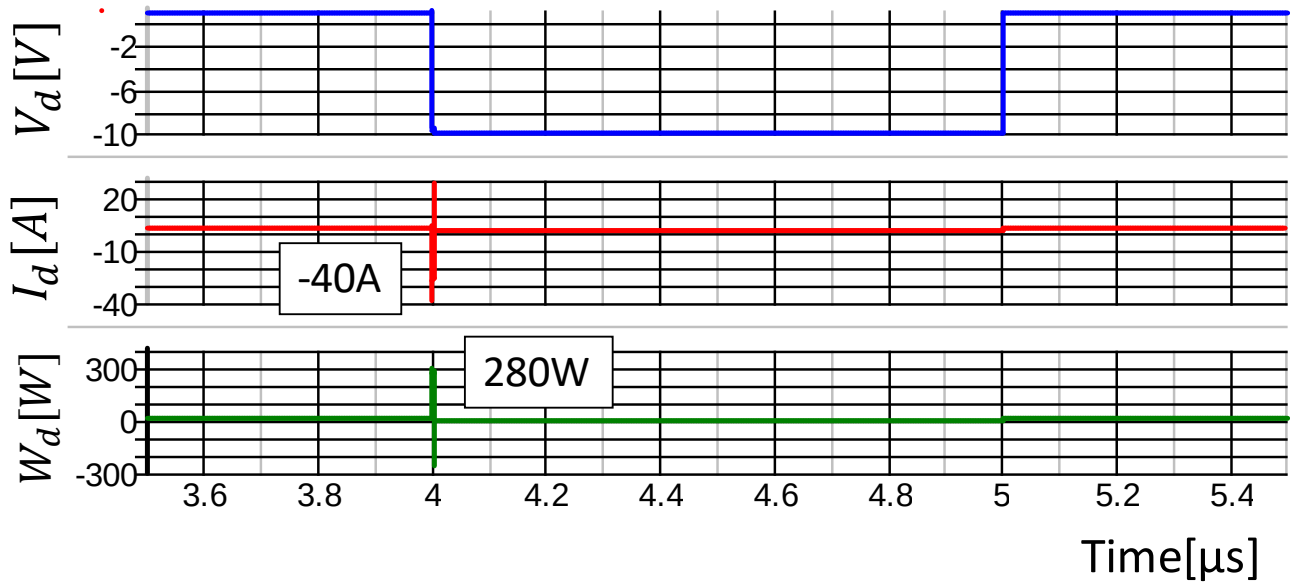
Parameter	Simulation Value
Vin	DC 20V
R	10 Ω
Fck	500 kHz
Iout	2.0 A



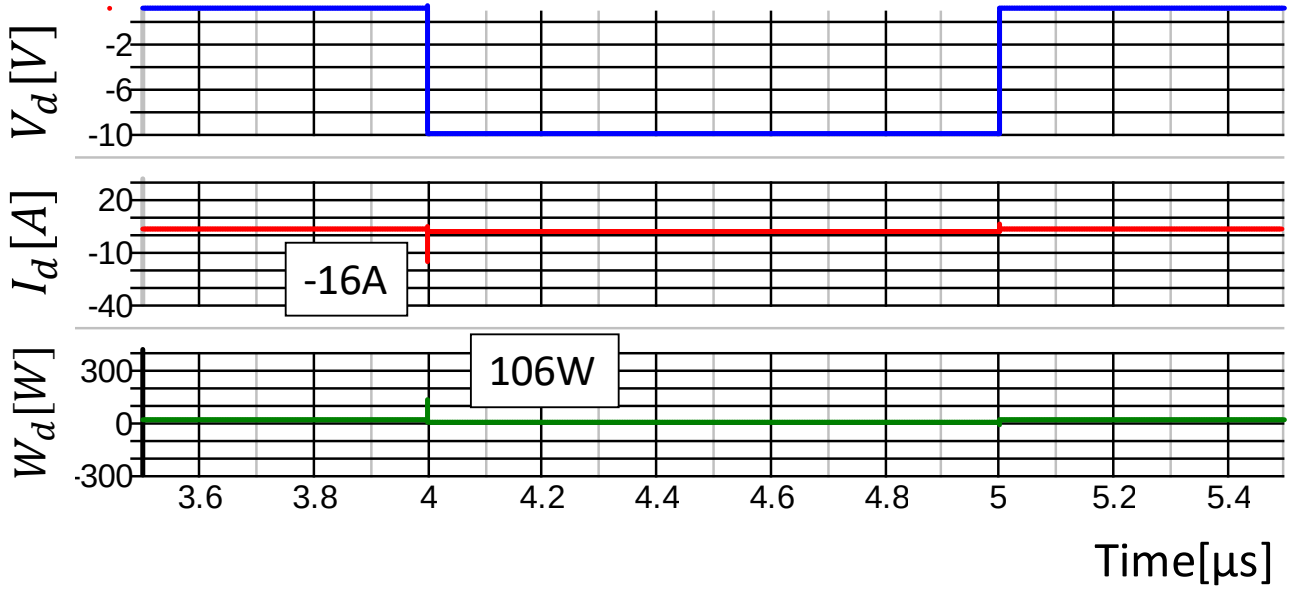
- PN-Di(20ETS12)
- SiC-SBD(SCS206AJHR)

Simulation Results

PN-Di



SiC-SBD



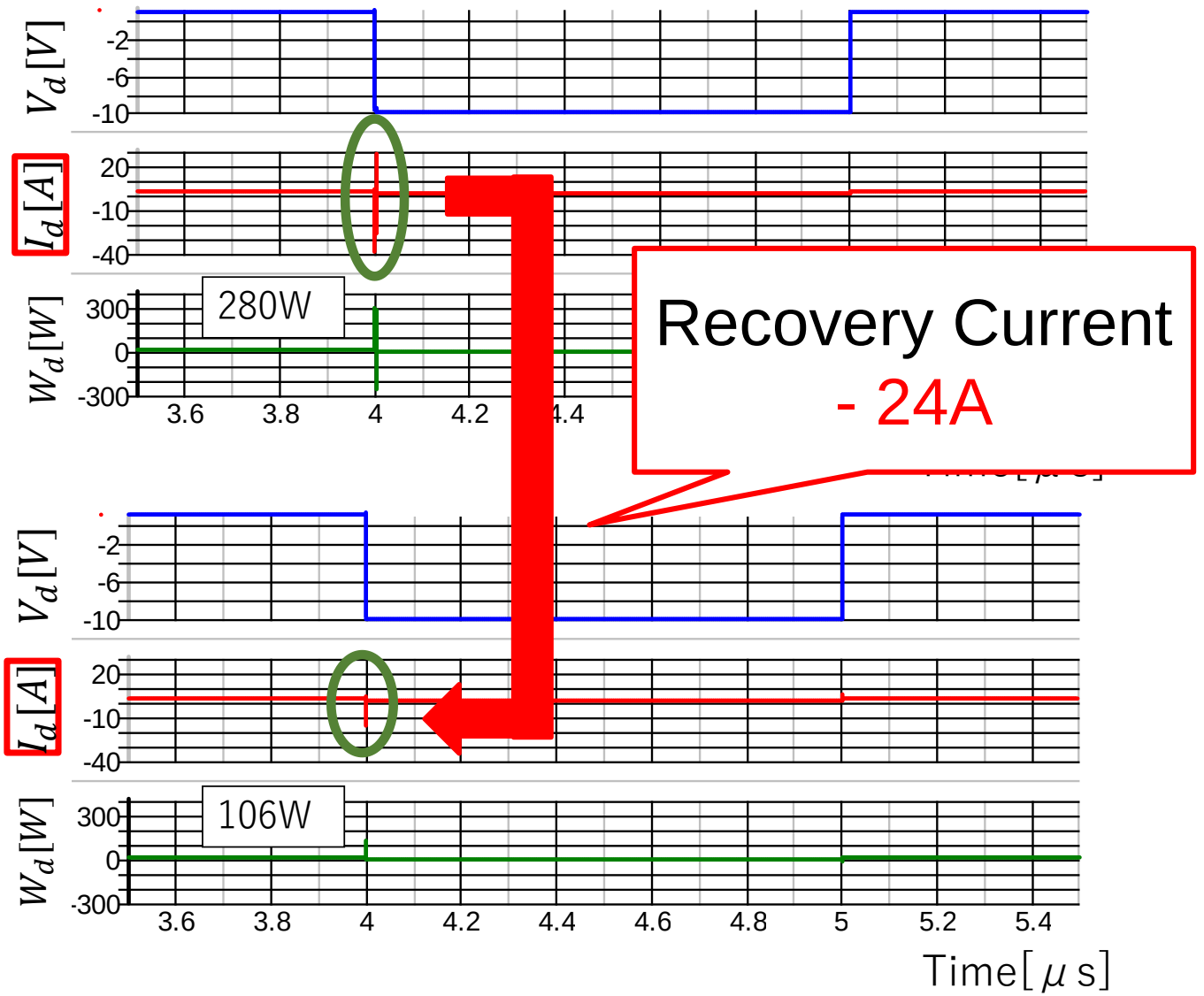
Recovery Current Comparison

PN-Di

$I_{pd} = 40A$

SiC-SBD

$I_{pd} = 16A$



I_{pd} : Peak Diode Current

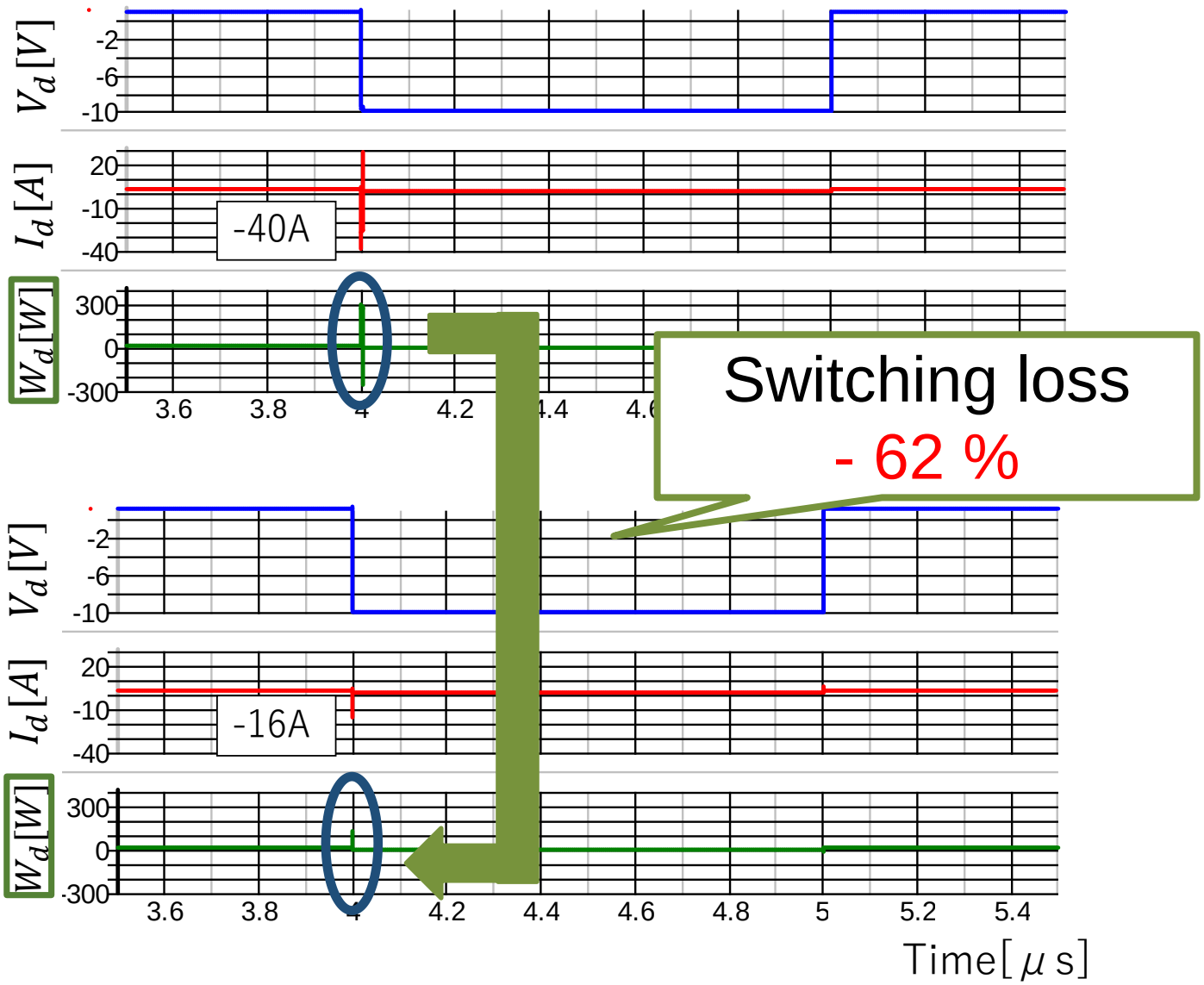
Switching Loss Comparison

PN-Di

$P_{pd} = 280W$

SiC-SBD

$P_{pd} = 106W$



P_{pd} : Peak Diode Power

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Conclusion

Proposal for PFC power supply in high speed

- PFC with frequency modulation

  Fixed frequency → Frequency modulation

  ➡ EMI noise reduces more than 17 dB

- Diode recovery current reduction

  PN-Di → SiC-SBD employment

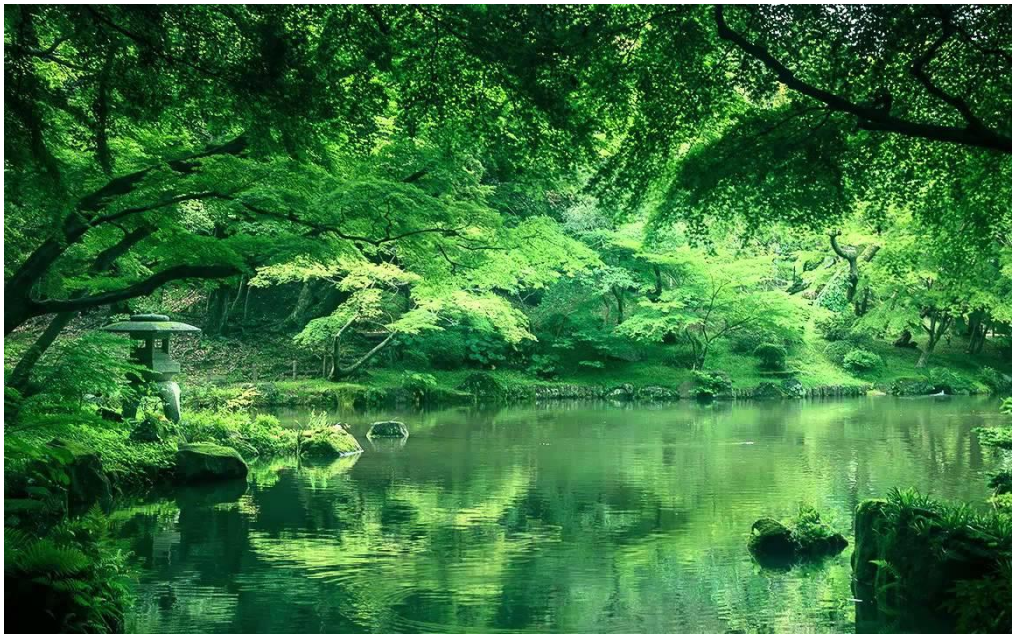
  Comparison with switching loss

  ➡ Efficiency improvement

Thank you for listening

謝 謝

Calm environment and energy saving are very important !



Appendix

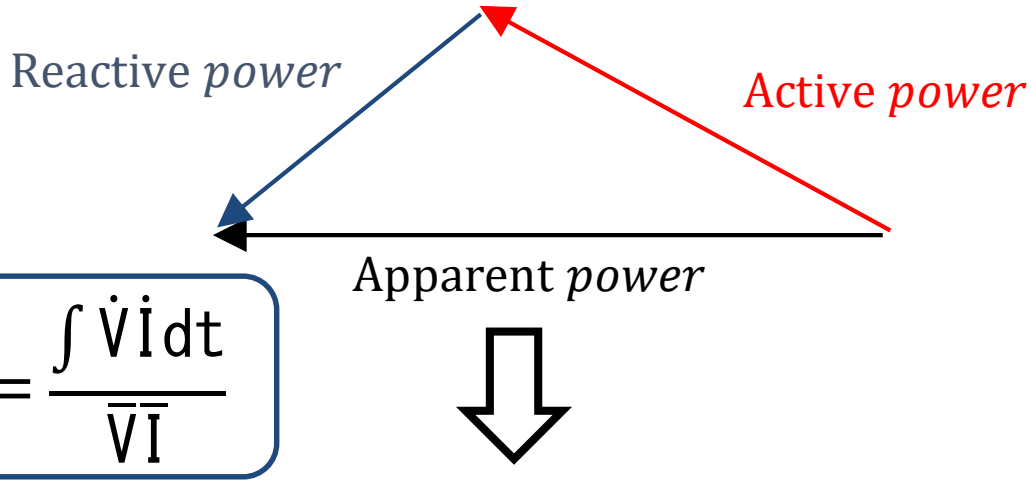
PFC Operation

PFC Circuit

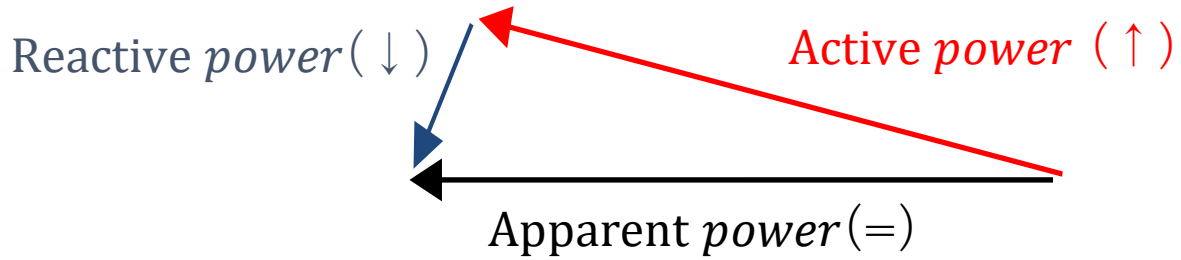
Input current, input voltage: same waveforms

→ Harmonics reduction

→ Loss reduction

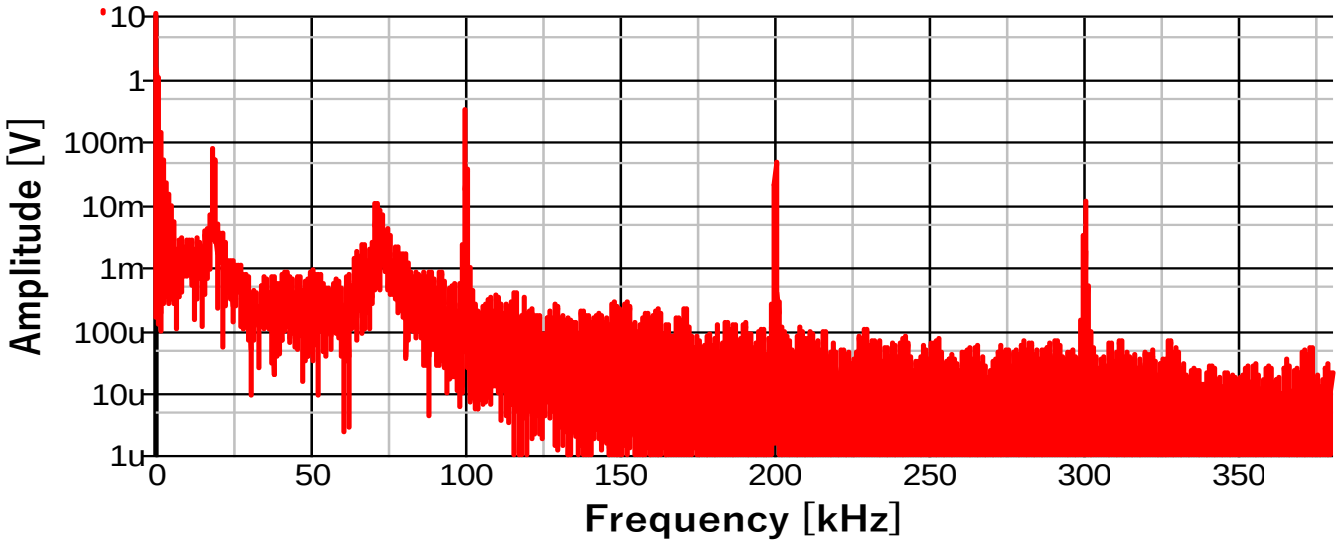


$$\mathrm{PFC} = \frac{\text{Effective power}}{\text{Apparent power}} = \frac{\int \dot{V}\dot{I}\,dt}{\bar{V}\bar{I}}$$

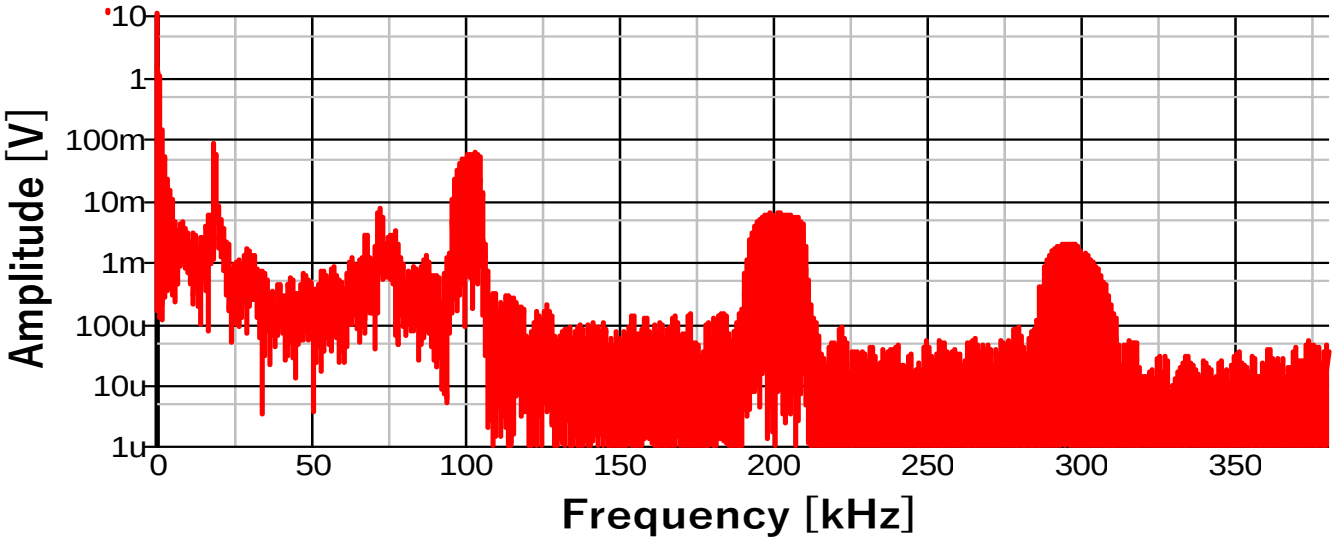


PFC: Power Factor Correction

Compared of Conduction noise

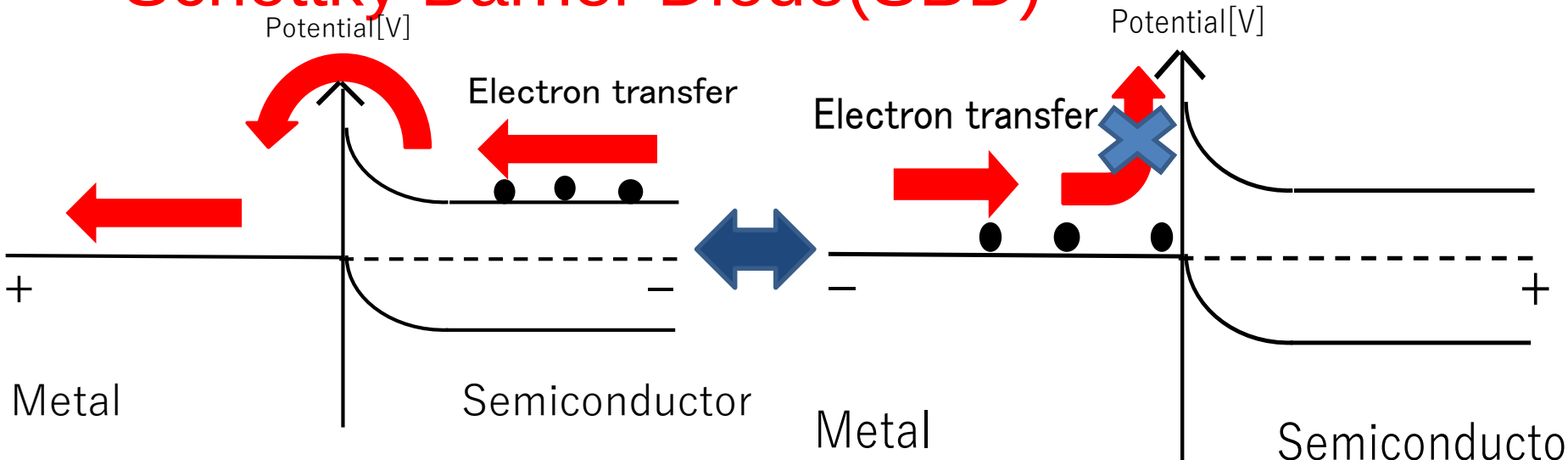


303 mV



55 mV

- Schottky Barrier Diode(SBD)



No recovery current

質問

Q.ノイズ低減を今回周波数拡散で行ったが、
　他に手法はあるのか？

A.（実際上手は答えられなかった）
　他にもリニアな変化でないランダム拡散といった
　手法でEMIノイズを低減することができる