2019 13th IEEE International
Conference on ASIC
Oct. 29 – Nov. 1, 2019, Chongqing, China

Session C6: Power Management
Friday, November 1, 11:45~12:00
C6-3

EMI Noise Reduction and Output Ripple Cancellation for Full-Wave Type Soft-Switching Converter

Yifei Sun, Tran Minh Tri, Yasunori Kobori,
Anna Kuwana, Haruo Kobayashi

Gunma University

Kobayashi
Laboratory

OUTLINE

- Introduction & Objective
- Full-wave type voltage-mode soft-switching converter
- EMI reduction and output ripple cancellation
- Improvement of ZVS (Zero Voltage Switch) operation with ripple cancellation circuit
- Conclusion

OUTLINE

- Introduction & Objective
- Full-wave type voltage-mode soft-switching converter
- EMI reduction and output ripple cancellation
- Improvement of ZVS (Zero Voltage Switch) operation with ripple cancellation circuit
- Conclusion

Research Background

100V AC

4.2V DC

Switching converter

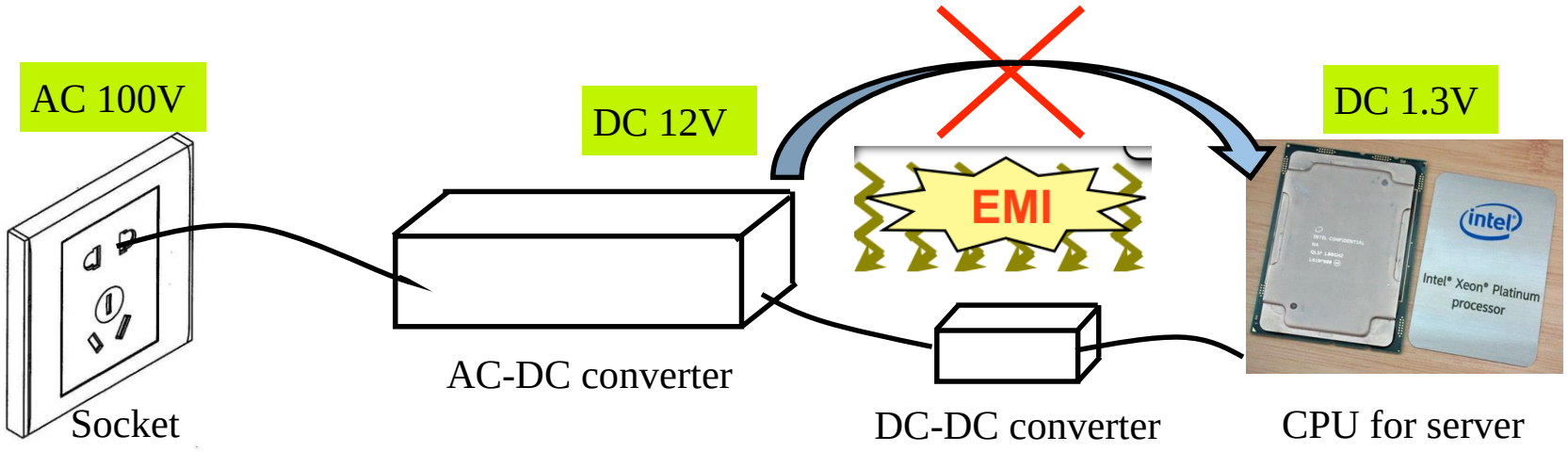
Power supply

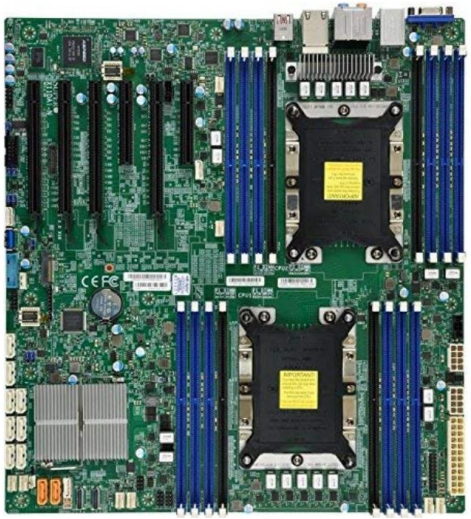
Desktop

Interface

Power supply is a functional part that supplies the voltage required to operate these electronic components

Research Background





CPU for server

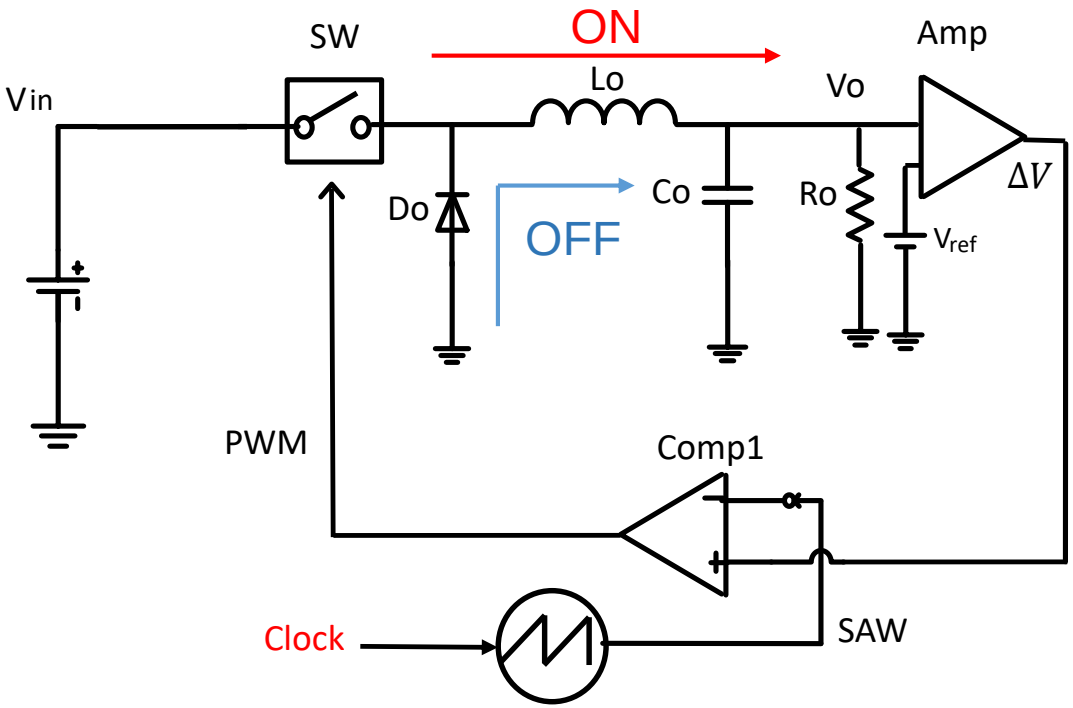
Need

High density

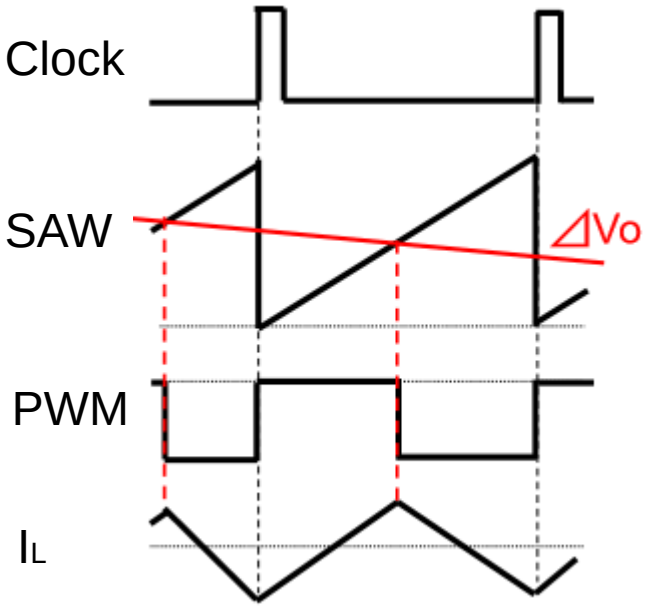
Large current

High frequency

Basic Buck Converter



6-1 Basic buck converter basic configuration



6-2 Operation waveforms

- Saw-tooth signal is generated by external clock
- PWM is generated by comparing ΔV and SAW signal
- SW is controlled by PWM signal

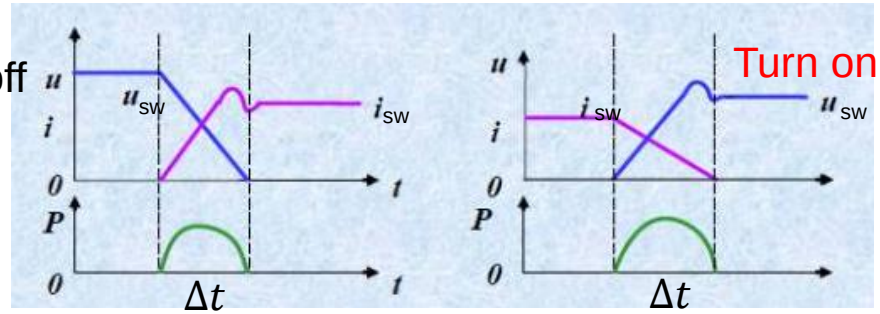
PWM: Pulse Width Modulation
SAW: Saw-Tooth

Basic Buck Converter

Switching loss

$$P_{sw} = \int_0^{\Delta t} I(t) \cdot V(t) dt$$

Turn off



a Turn-off process b Turn-on process

7-1 Hard Switching

During switching

- The voltage and current are not zero, and overlap was appeared ⇒ switching loss
- The voltage and current change rapidly, and the waveform is overshoot ⇒ switching noise

Merits

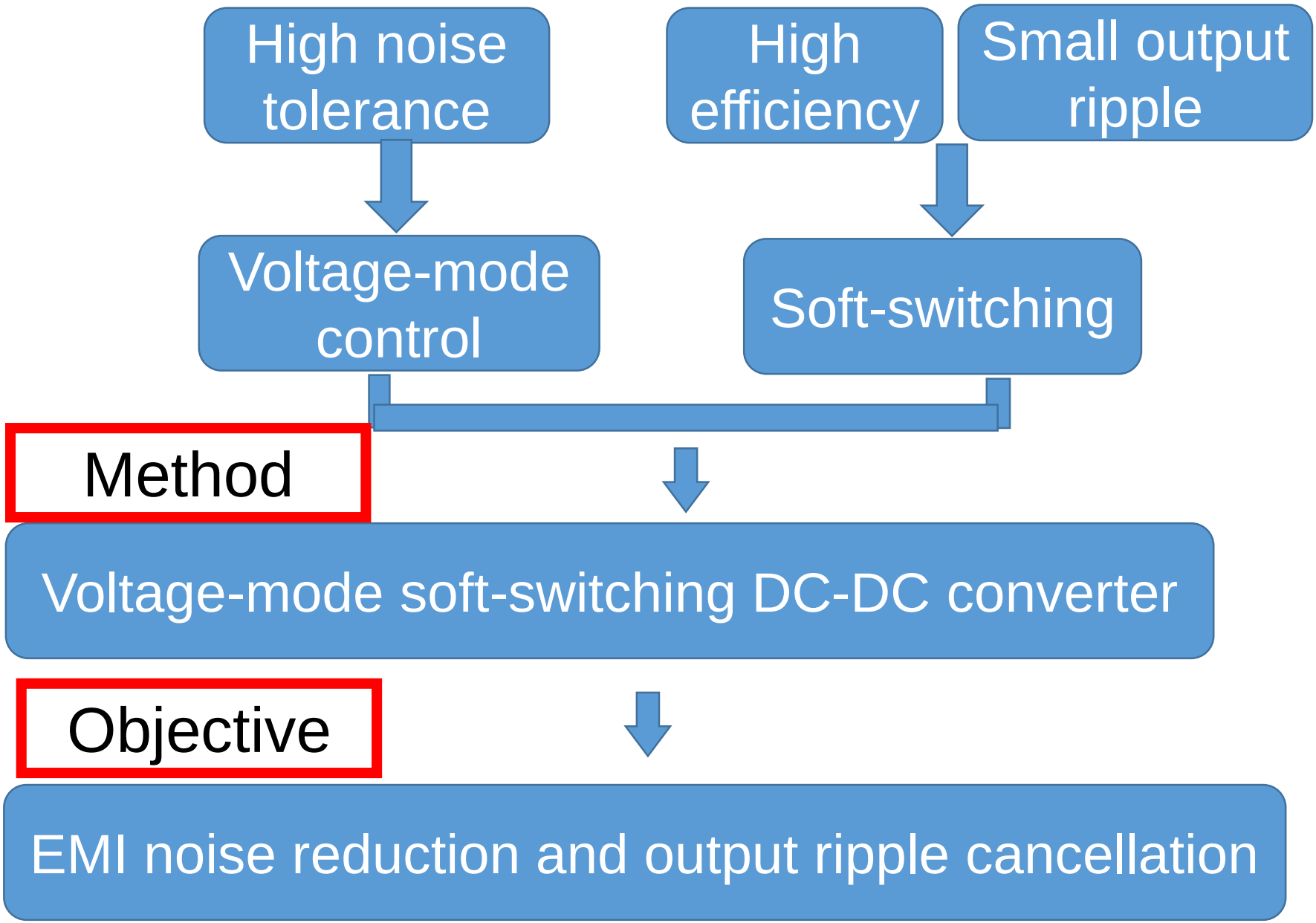
- High efficiency
- Downsizing
- Gives off little heat

Demerits

No good

- Large switching noise
- Large output ripple
- EMI due to high di/dt and dv/dt

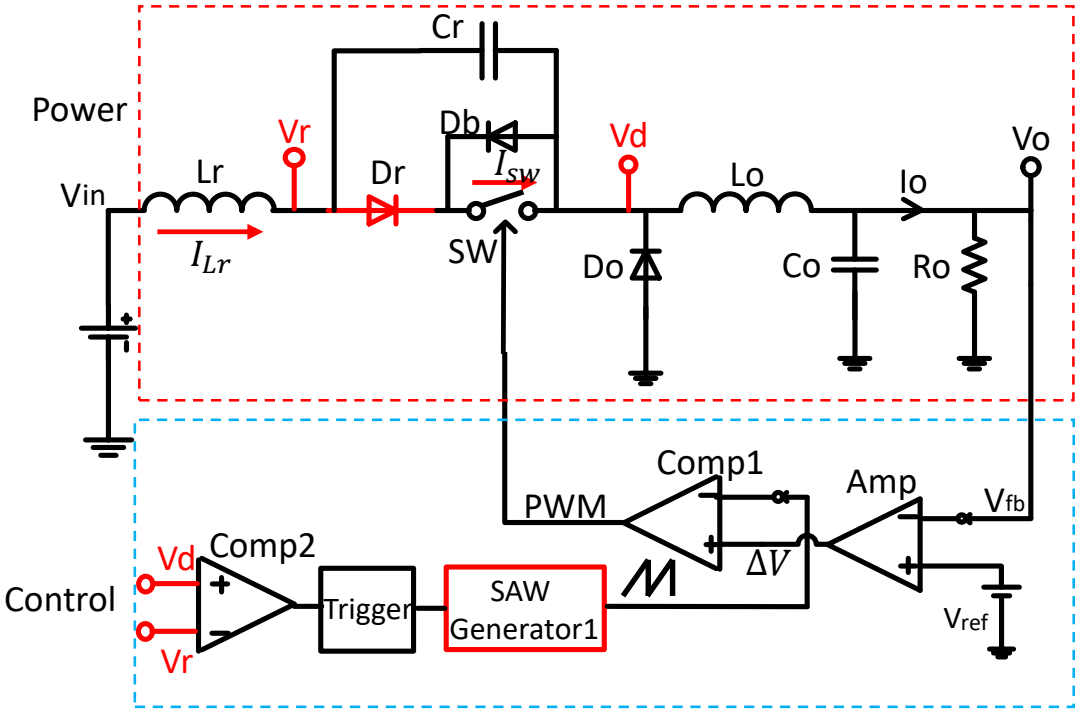
Research Objective



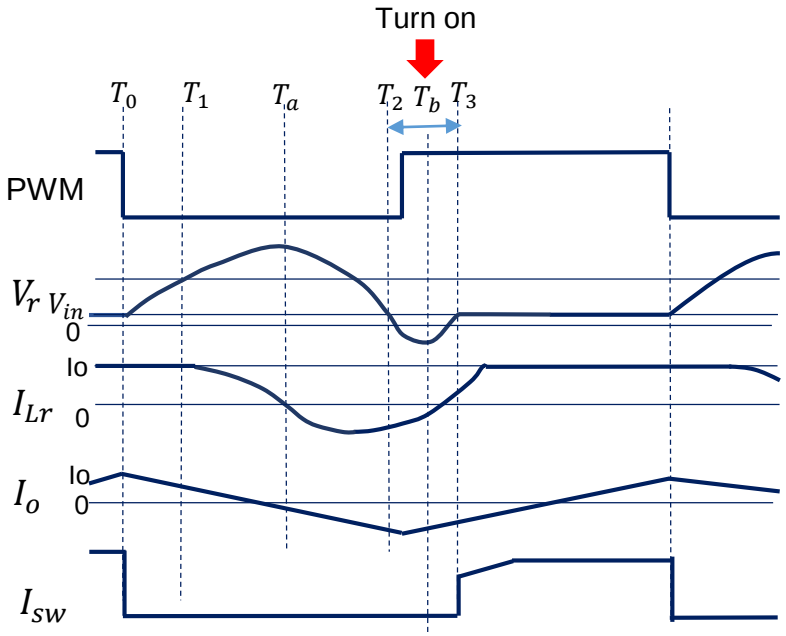
OUTLINE

- Introduction & Objective
- Full-wave type voltage-mode soft-switching converter
- EMI reduction and output ripple cancellation
- Improvement of ZVS (Zero Voltage Switch) operation with ripple cancellation circuit
- Conclusion

Full-wave Type Voltage-mode Soft-Switching Converter



10-1 Full-wave type soft-switching Converter



10-2 Key Waveform

Added

- Resonant inductor Lr & Resonant Capacitor Cr
- Diode Dr (Full-wave type)

SAW is generated without clock ⇒ SAW is triggered & PWM turns on, when Vr=Vd

Full-wave Type Voltage-mode Soft-Switching Converter

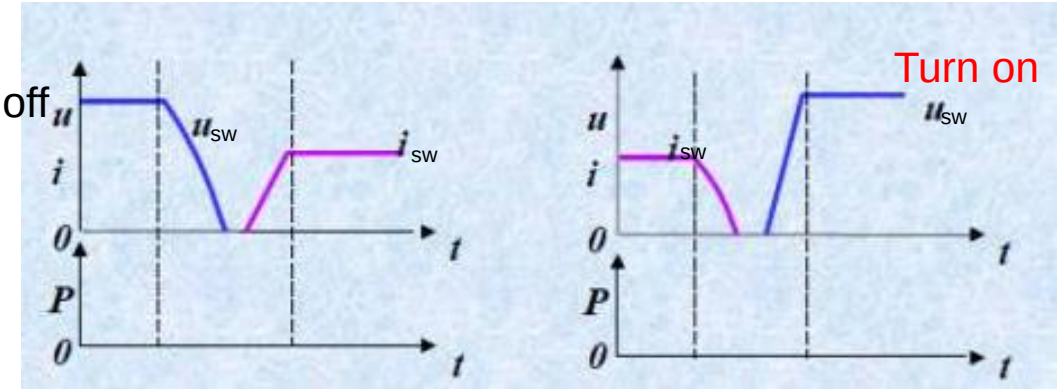
T1 The switch turns off when Vr is nearly 0
T2 The switch turns on when Isw is nearly 0

Switching loss

$$P_{sw} = \int_0^{\Delta t} I(t) \cdot V(t) dt = 0$$

Soft-switching is achieved

Reduce switching loss

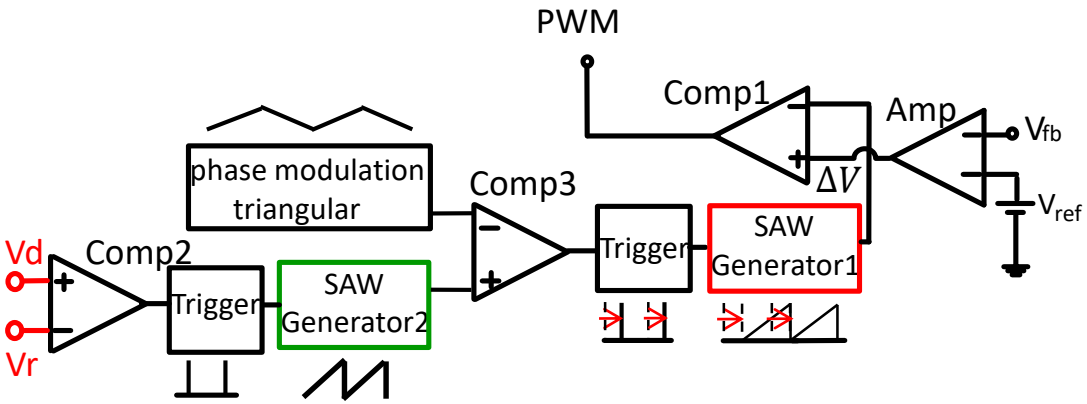


a Turn-off process b Turn-on process

11-1 Soft Switching

Merits
- Low EMI
- Lower losses
- Allows high frequency operation

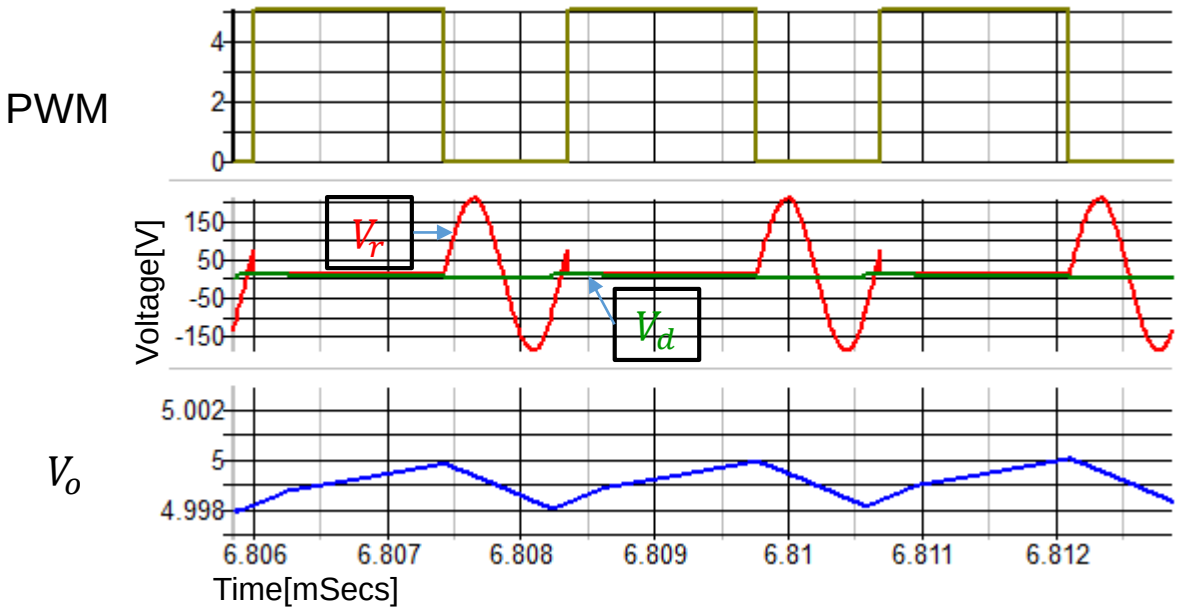
EMI Reduction with Spread Spectrum



12-1 EMI reduction modulation circuit

V_{in}	10.0V
V_o	5.0V
I_o	0.25A
L_o	200μH
C_o	470μF
F_{ck}	500kHz

12-2 Parameter values in simulation

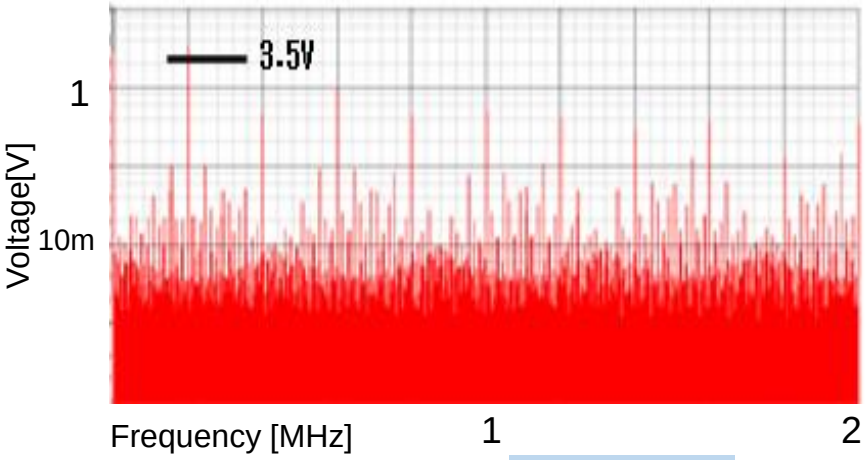


12-3 Simulation waveforms in EMI reduction modulation circuit

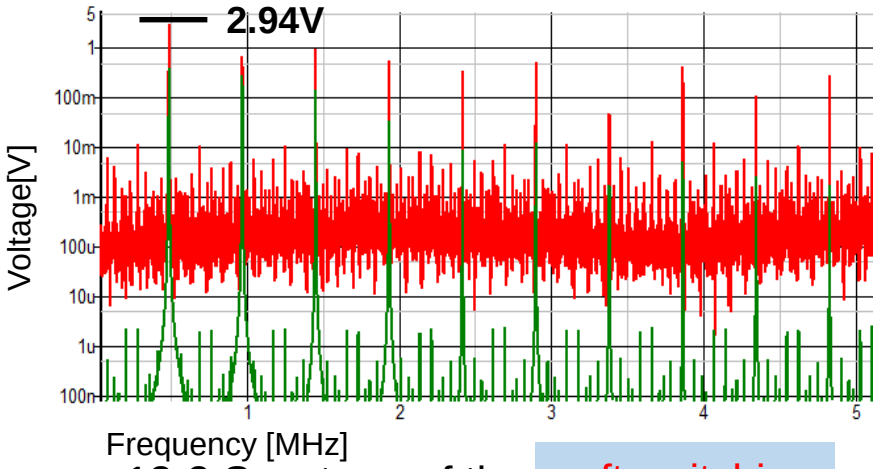
Evaluation index

- Spectrum
- Output ripple
- ZVS operation

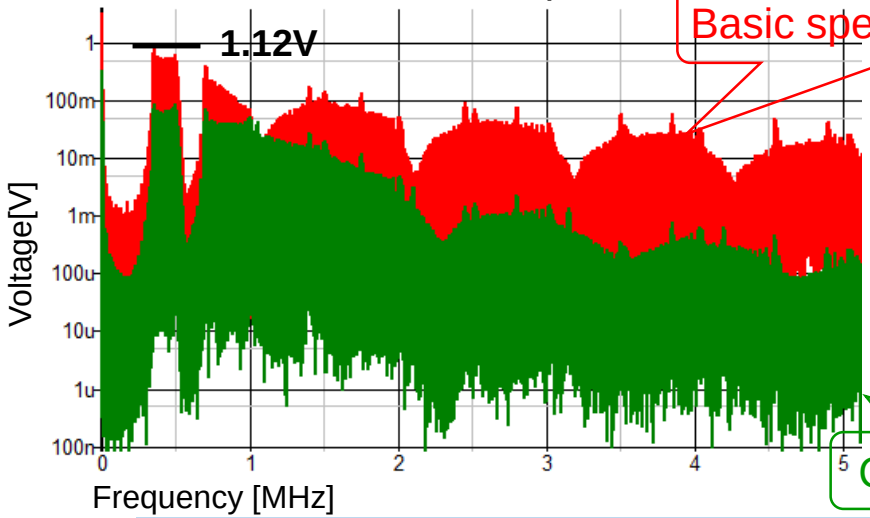
Spread Spectrum Comparison



13-1 Spectrum of the buck-type PWM converter output



13-2 Spectrum of the soft-switching converter output

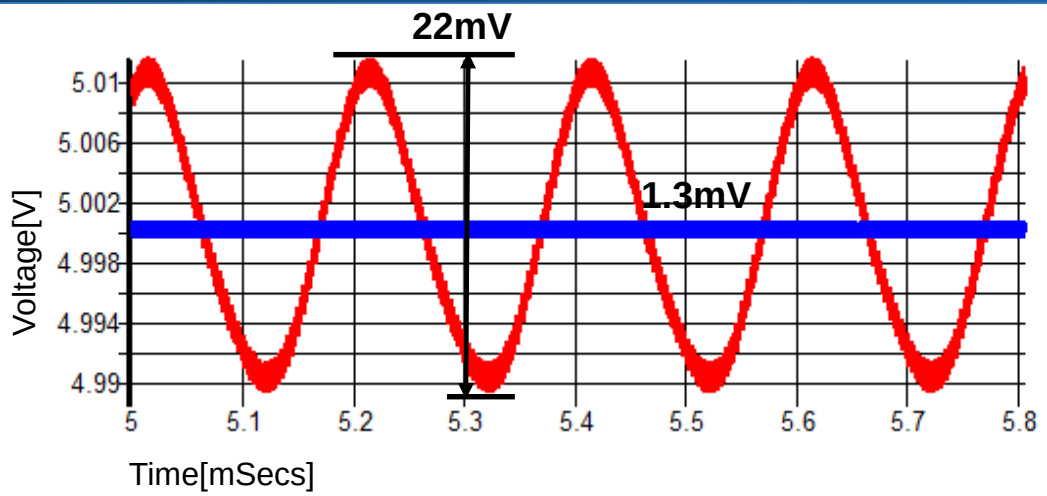


13-3 Spread spectrum of the soft-switching converter output

- Peak level ⇒ reduced from 3.5V ⇒ 2.94V ⇒ 1.12V
- Conduction noise⇒ reduced from 359mV ⇒ 132mV

good

Output Ripple in Soft-switching Converter



14-1 Soft-switching converter output ripple

Output ripple ΔV_o without EMI reduction

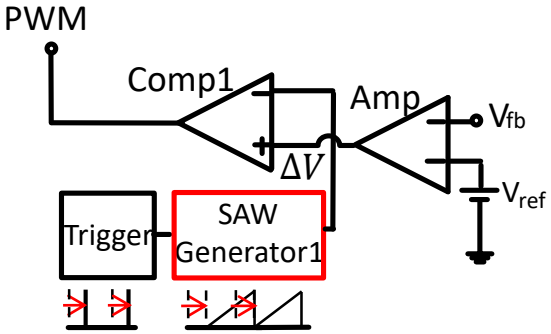
Output ripple ΔV_o with EMI reduction

Output ripple

Increment Not good

Need improvement

The reason for ripple increase



14-2 Phase modulation of SAW

Phase modulation the start timing of the SAW

Duty ratio of the PWM signal was also modulated

OUTLINE

- Introduction & Objective
- Full-wave type voltage-mode soft-switching converter
- EMI reduction and output ripple cancellation
- Improvement of ZVS (Zero Voltage Switch) operation with ripple cancellation circuit
- Conclusion

Output Ripple Cancelation with EMI Reduction

Full-wave type soft-switching converter

PWM duty ratio *D* :

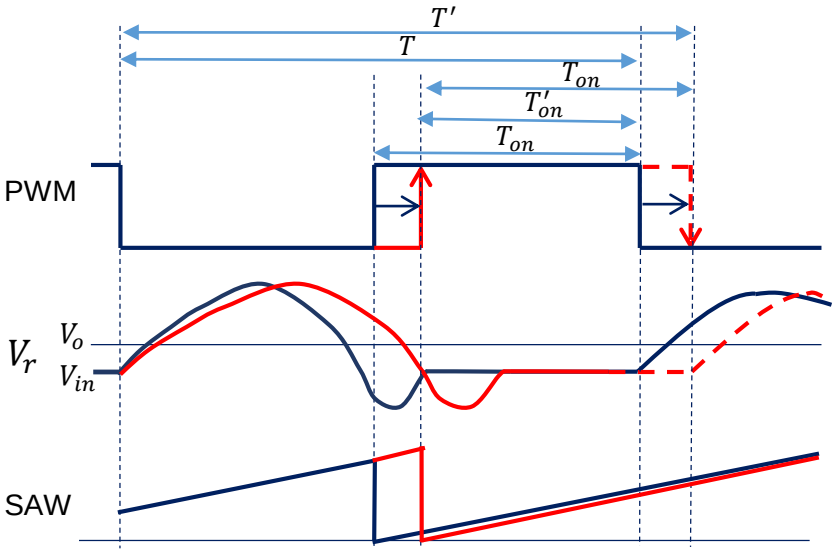
$$D = \frac{T_r}{T_o} \ (T_r: Resonance\ time, T_o: Operating\ cycle)$$

In the EMI reduction method: modulated

$$D' = \frac{T_r'}{T} = \frac{T_r + \Delta T_r}{T} \qquad D \neq D' \Rightarrow \ D > D'$$

The ripple cancelation method (let duty constant):

$$D'' = \frac{T_r'}{T'} = \frac{T_r + \Delta T_r}{T + \Delta T} = D'$$



T_{off} delay ⇒ Duty changed

⇓

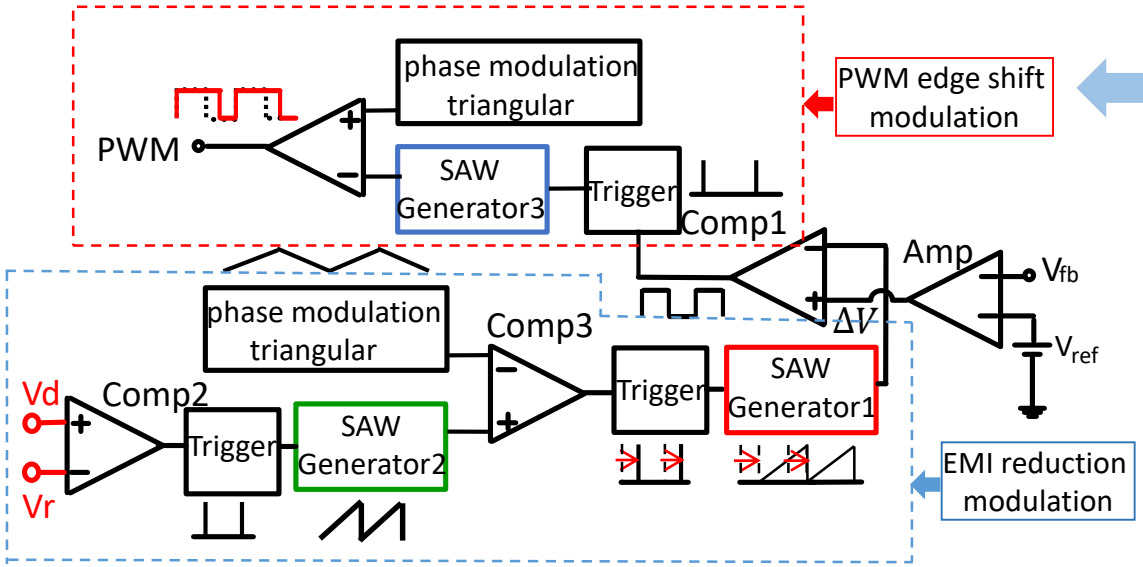
Let duty constant ⇒ T_{on} extension

⇓

Operation cycle changed
in the opposite direction

16-1 Waveforms in the ripple cancellation circuit

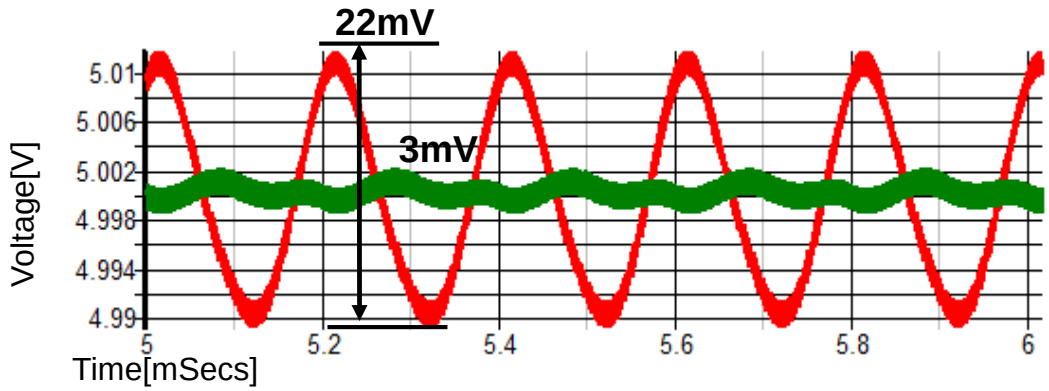
Output Ripple Cancelation with EMI Reduction



Cancel the modulated duty ratio with other signals

The change in the duty ratio changed in the cancel direction

17-1 Circuit of the output ripple cancellation method



EMI reduction ripple cancellation

22mV ⇒ 3mV

Very small

17-2 Output ripple with EMI reduction (red) and ripple cancellation (green)

OUTLINE

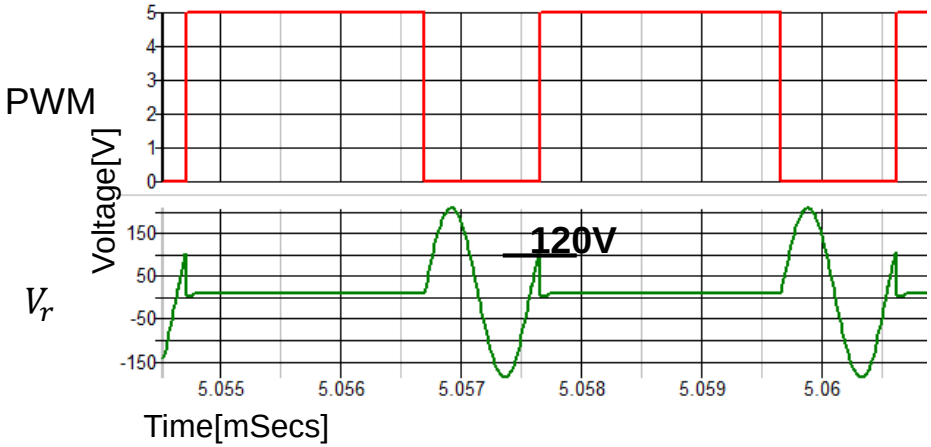
- Introduction & Objective
- Full-wave type voltage-mode soft-switching converter
- EMI reduction and output ripple cancellation
- Improvement of ZVS (Zero Voltage Switch) operation with ripple cancellation circuit
- Conclusion

Improvement of ZVS Operation

Evaluation index

full-wave type voltage-mode resonant switch control

- Spectrum ⇒ Good
- Output ripple ⇒ improved
- ZVS operation ⇒ waiting for solution



19-1 Circuit of the output ripple cancellation method

PWM : phase modulated by shifting ($V_d = V_r$)

⇓

On-timing of the SW for realizing ZVS is delayed

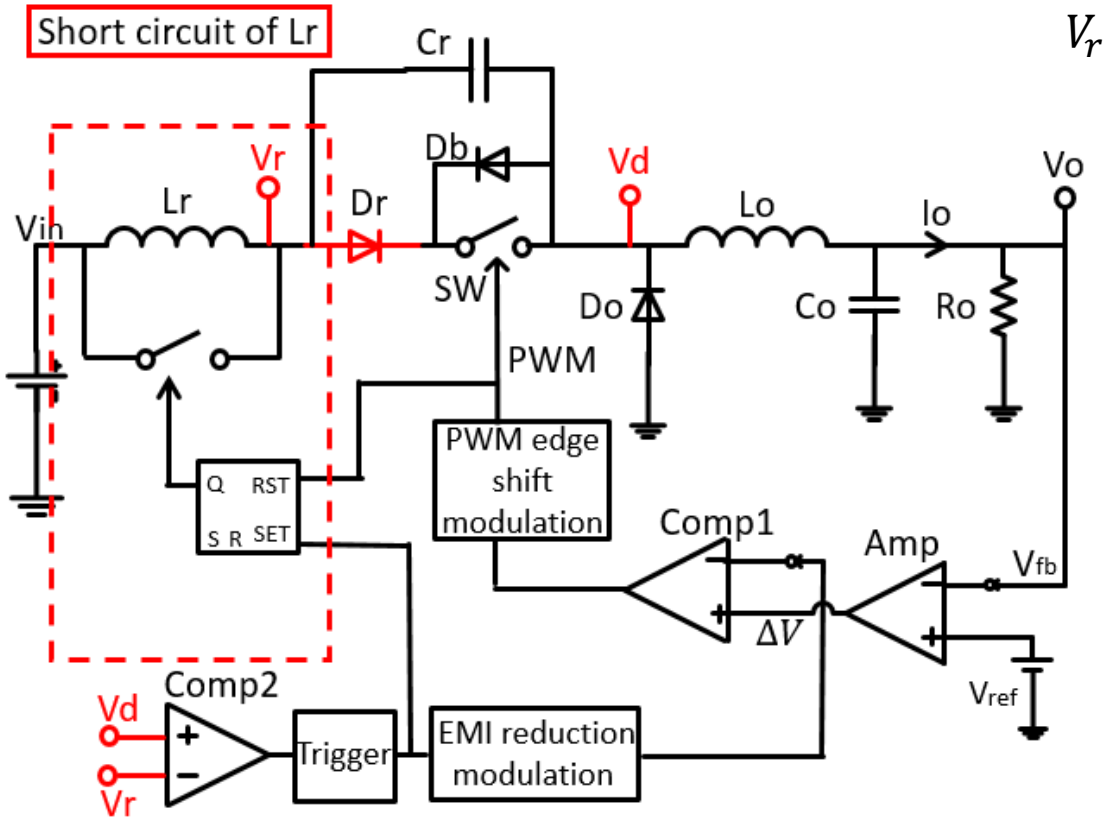
⇓

Resonant voltage V_r causes over-resonant ⇒ 120V

⇓ Need to

Cancel this over-resonant while keeping EMI reduction and ripple cancellation enabled

Improvement of ZVS Operation with Ripple Cancellation Circuit



20-1 ZVS operation improvement circuit

ZVS operation: need to maintain the $V_r = V_d$ even during the over-resonant period

⬇ Method

Timing from $V_r = V_d$ to SW ON

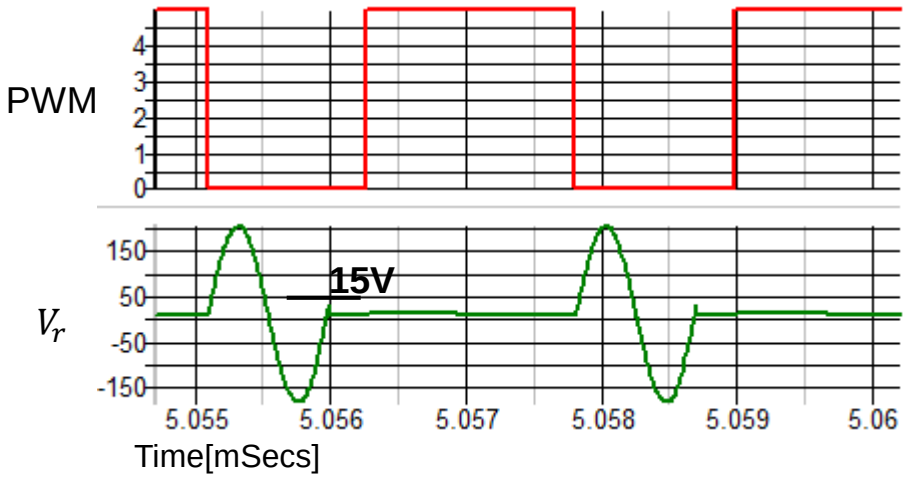
⬇

Short both ends of the L_r to maintain the current value of I_{Lr}

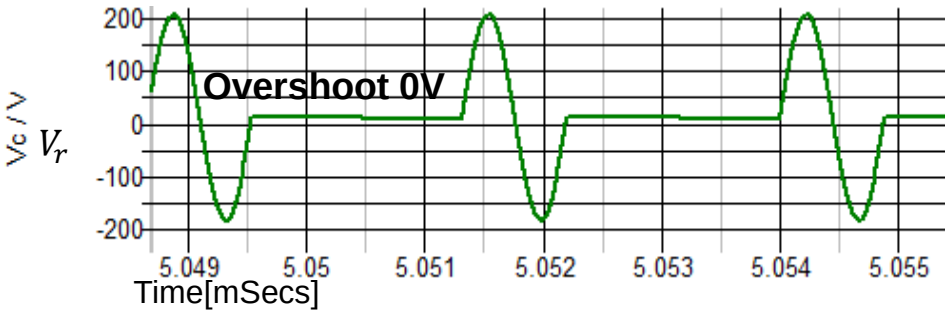
⬇

C_r is stopped and resonance voltage is maintained at 0V

Waveforms of ZVS Operation Improvement



21-1 Waveforms of ZVS operation improvement



21-2 Simulation of the resonant voltage improvement

The control pulse of SW is turned off simultaneously with the on-timing of the PWM signal

Resonance voltage ⇒ small overshoot =15V

Still big

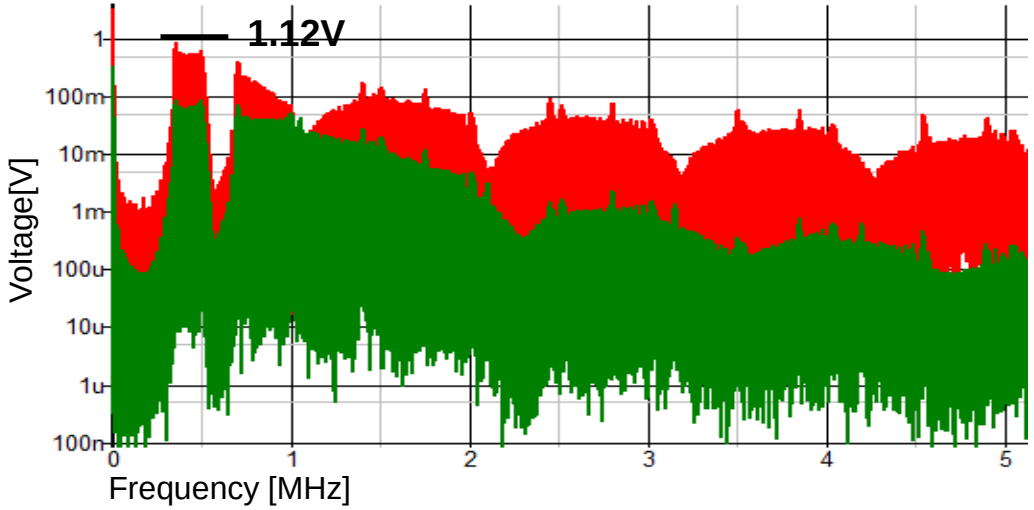
Reason

Delay time until L_r is shorted after detection of $V_r = V_d$

Method

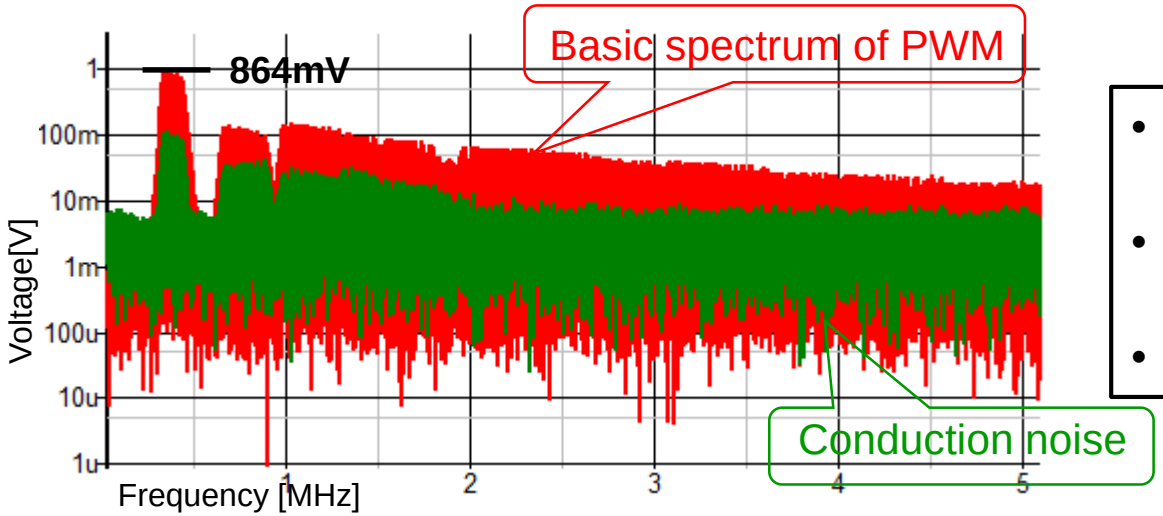
Set the V_d to be low about -5V than compared with V_r

Simulation Result with ZVS Improvement



11-3 Spread spectrum of the soft-switching converter output

- Peak level ⇒ reduced from 1.12V ⇒ 864mV
  About 2.3dB reduction
- Conduction noise⇒
  Almost the same in Low frequency



22-2 Spectrum of ZVS improvement circuit

Evaluation index

- Spectrum ⇒ Better
- Output ripple ⇒ improved
- ZVS operation ⇒ achieved

OUTLINE

- Introduction & Objective
- Full-wave type voltage-mode soft-switching converter
- EMI reduction and output ripple cancellation
- Improvement of ZVS (Zero Voltage Switch) operation with ripple cancellation circuit
- Conclusion

Conclusion

- We have proposed the output ripple cancelation method for the EMI reduction full-wave type soft-switching converter

➢EMI reduction (spectrum peak level)

Buck type		Normal soft switching		Spread spectrum		ZVS improvement
3.5V	⇒	2.94V	⇒	1.12V	⇒	864mV

➢Conducted noise

Normal soft switching		Spread spectrum of soft switching
359mV	⇒	132mV

➢Output ripple

Very small : 3mV

Thank you for listening