ICTSS2018
April 18-20,2018
Kiryu, Japan

Wed, April 18, 2018
13:00 – 14:30
Room A I03-09

Multi-Phase Clock-less Switching Converter with EMI Noise Reduction

Yi Xiong*, Koyo Asaishi, Natsuko Miki, Yifei Sun
Nobukazu Tsukiji, Yasunori Kobori, Haruo Kobayashi

Gunma University

Research Objective

Objective

Development of power supply with
- Fast response
- Large current

Approach

- Constant on-time control
- Multi-phase

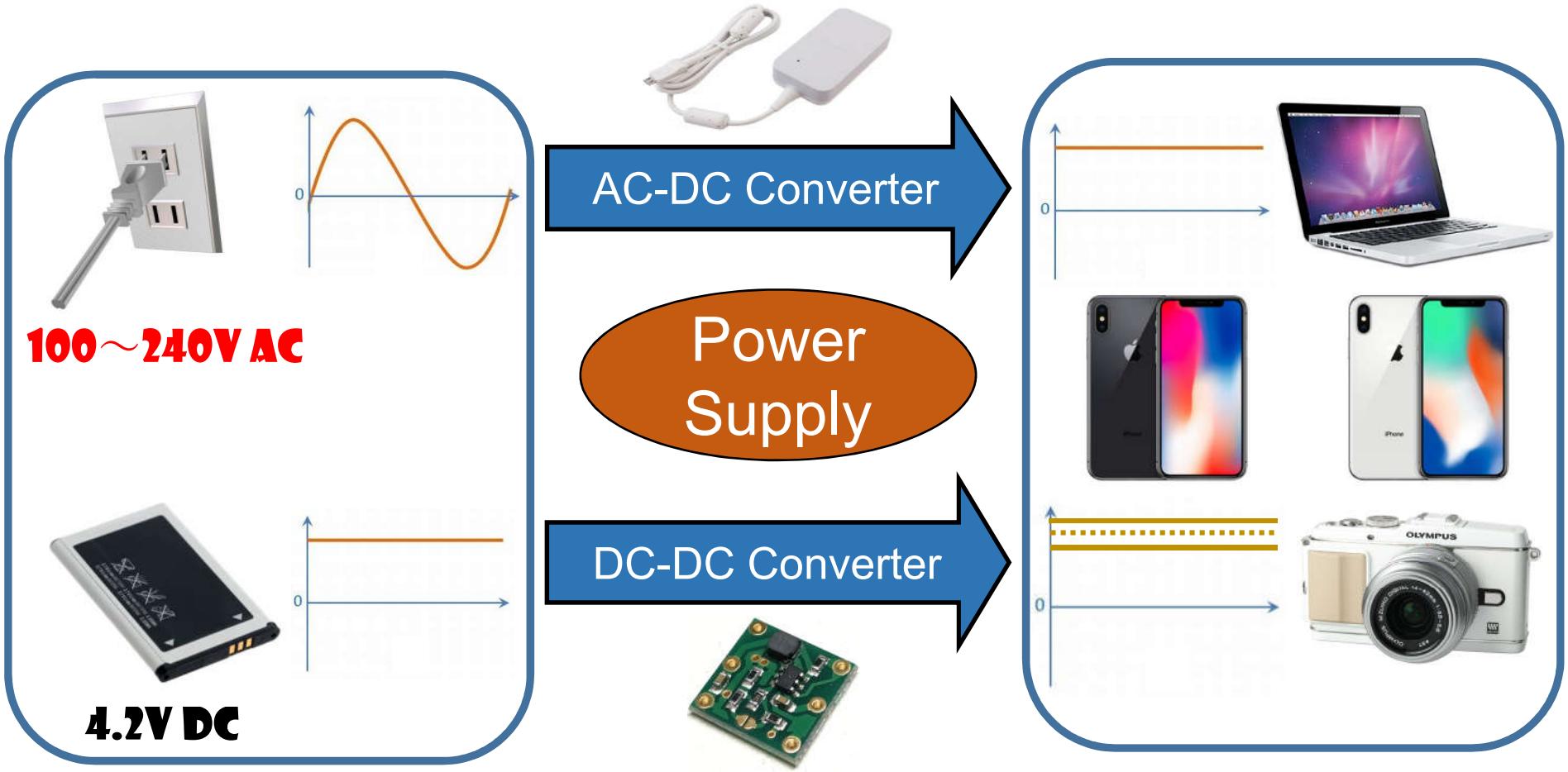
Contents

- Research background
- Constant on-time control
- Four-phase converter solution
  via saw-tooth wave circuit
- Simulation result
- Transfer function characteristics
- EMI reduction via pulse phase modulation
- Conclusion

Contents

- Research background
- Constant on-time control
- Four-phase converter solution via saw-tooth wave circuit
- Simulation result
- Transfer function characteristics
- EMI reduction via pulse phase modulation
- Conclusion

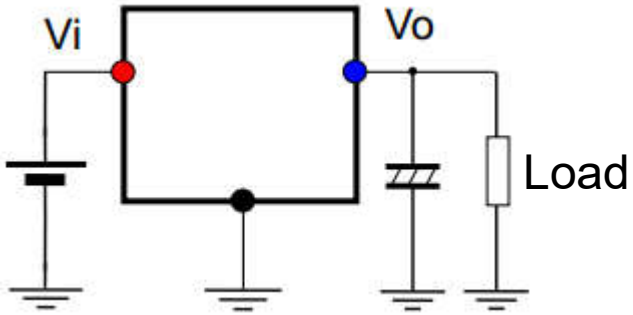
What is Power Supply



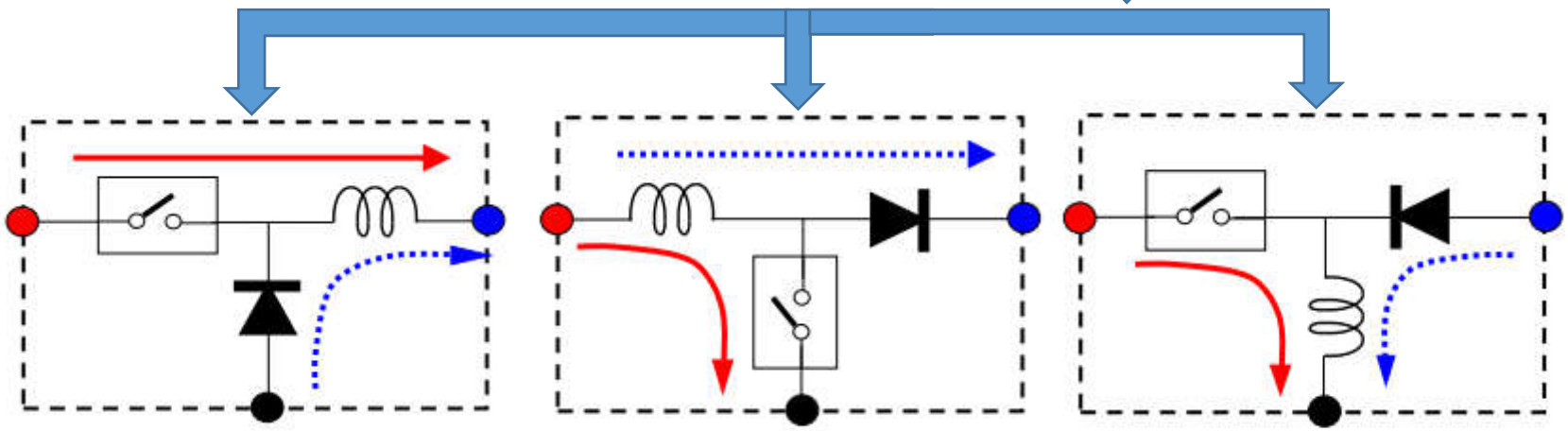
Power supply is demanded everywhere to provide appropriate voltage for electronic device

Classifications of DC-DC Converter

DC-DC converter



Basic configuration



Buck

Vin > Vo

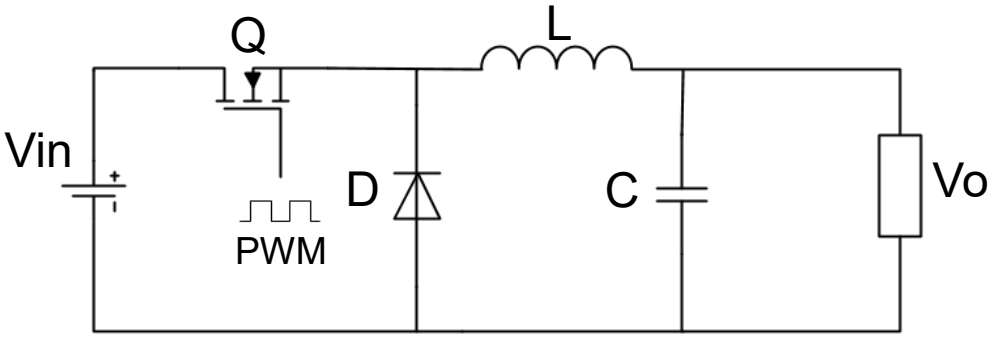
Boost

Vin < Vo

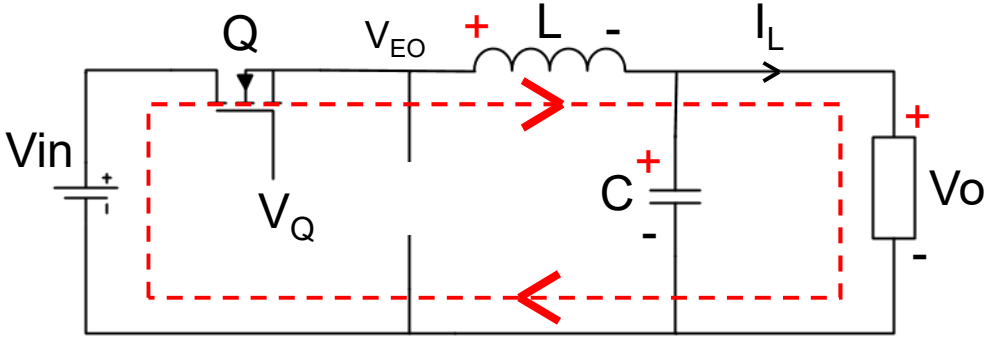
Buck-Boost

Vin ≷ Vo

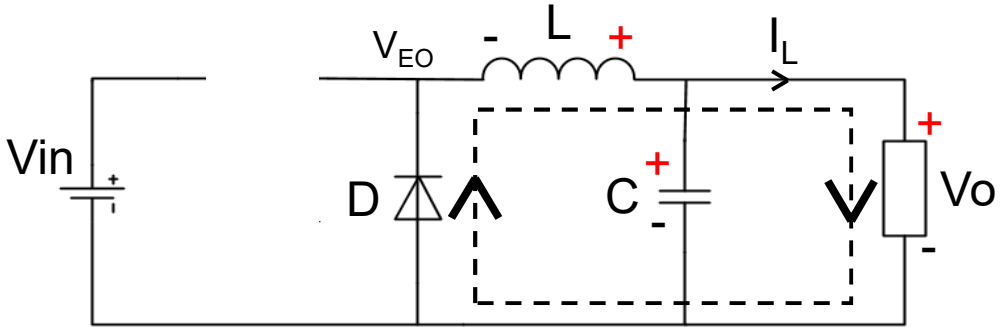
Operation of Buck Converter



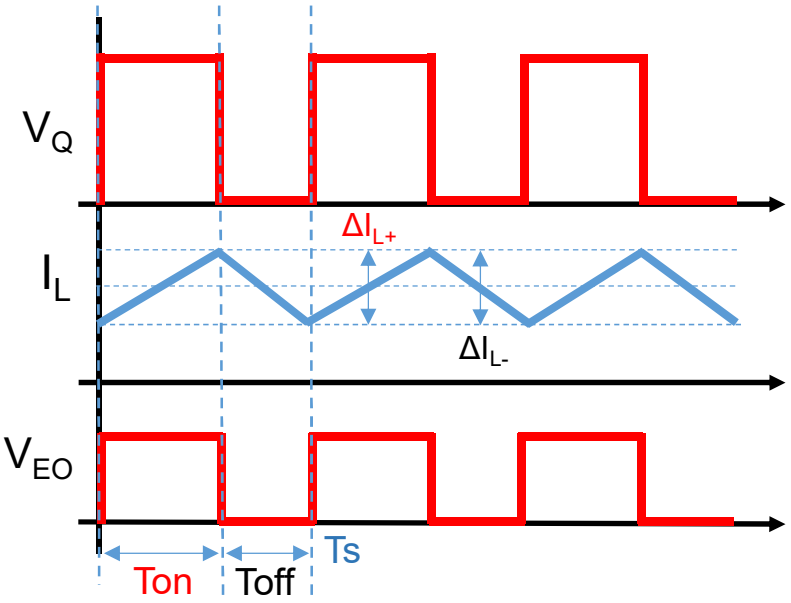
Buck Converter



On State: Q on D off



Off State: Q off D on



On State

$V_{Lon} = Vin - Vo = L \cdot (\Delta i_{L+} / \Delta t_{on})$

Off State

$V_{Loff} = -Vo = L \cdot (\Delta i_{L-} / \Delta t_{off})$

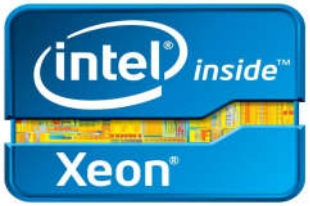
Volt-second Balance

$\Delta i_{L+} = \Delta i_{L-}$

$$Vo = Vin \frac{T_{on}}{T_s}$$

Demand for Power Supply of Process

DC input	DC output	Max. output current	Max. output current step	Max. output current slew rate
12V	1.5V	120A	100A/us	930A/us



Large current

Ripple control

High speed response

Multi-phase

Four-phase Ripple Control Converter

Contents

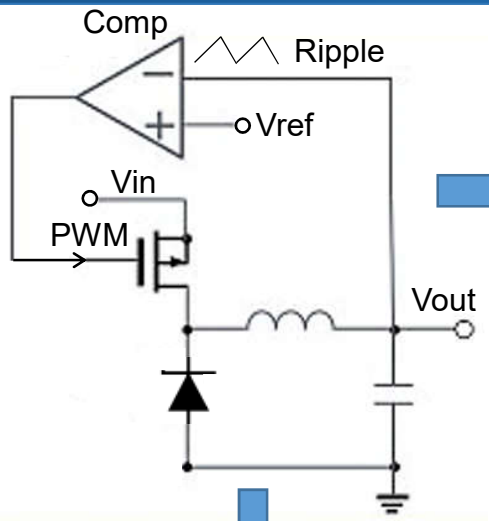
Merit of Constant on-time control

Ripple Control

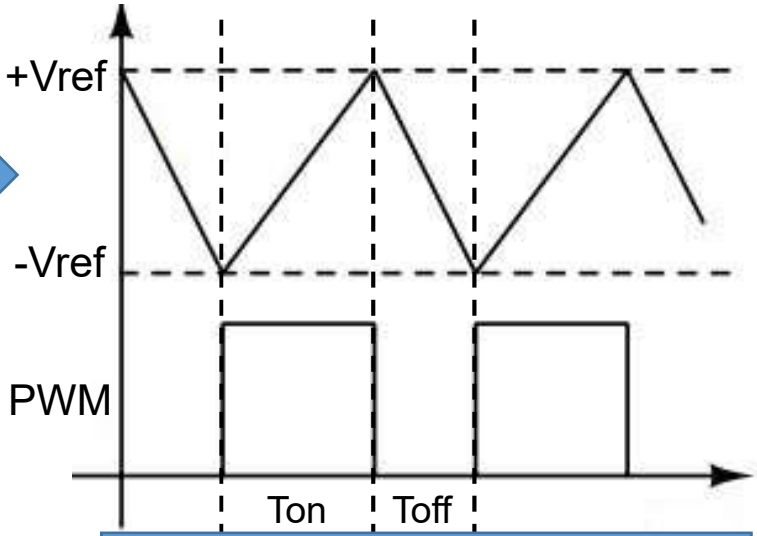
Hysteresis window control

Extreme fast response

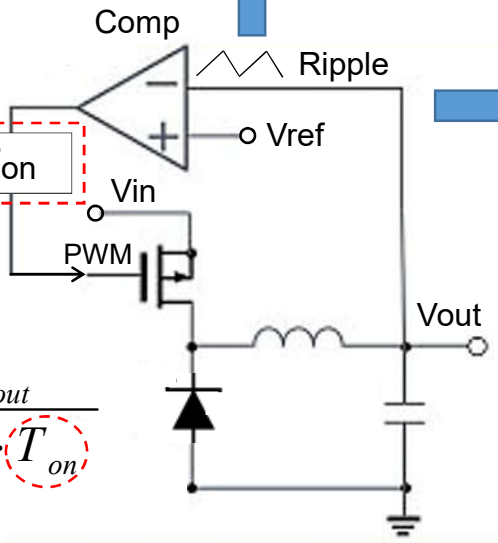
Constant on-time control

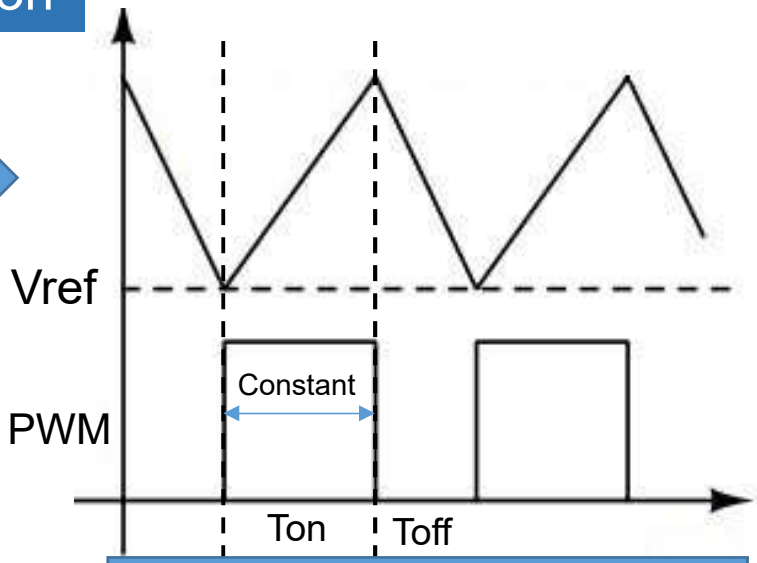


No phase compensation



Frequency swings usually





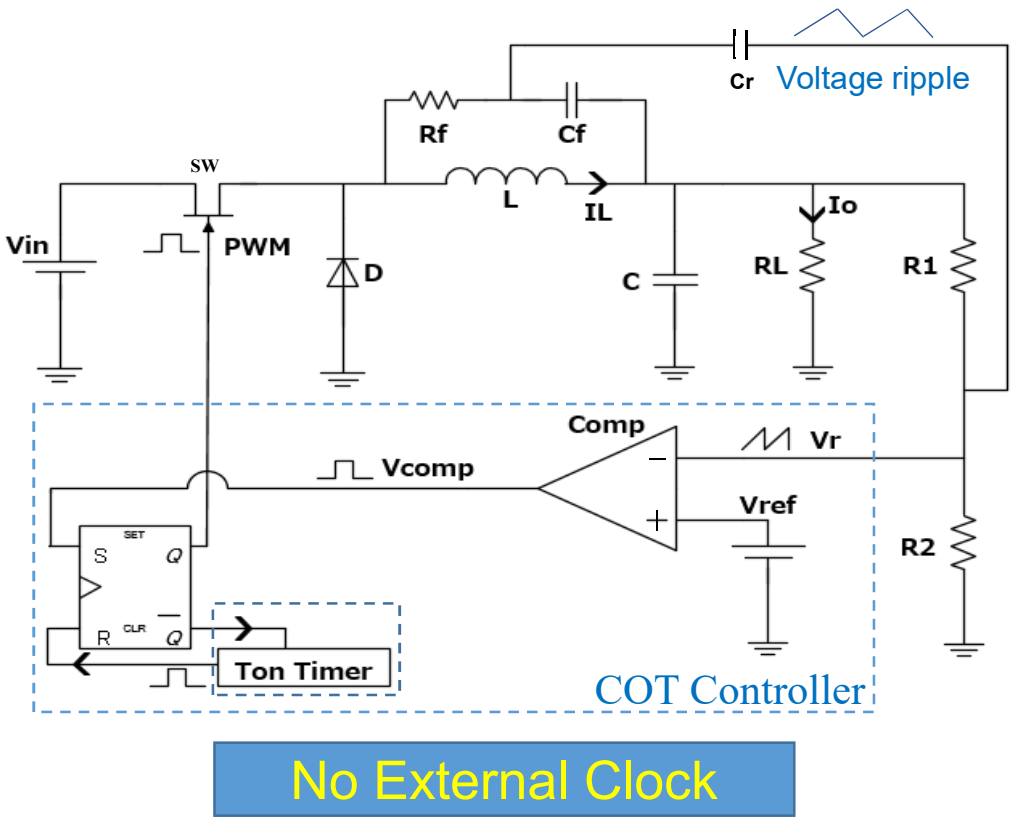
Frequency keeps stable

$$V_{out} = V_{in}\frac{T_{on}}{T_s} \Rightarrow f_s = \frac{V_{out}}{V_{in}\cdot T_{on}}$$

$$f_s = \frac{1}{T_s}$$

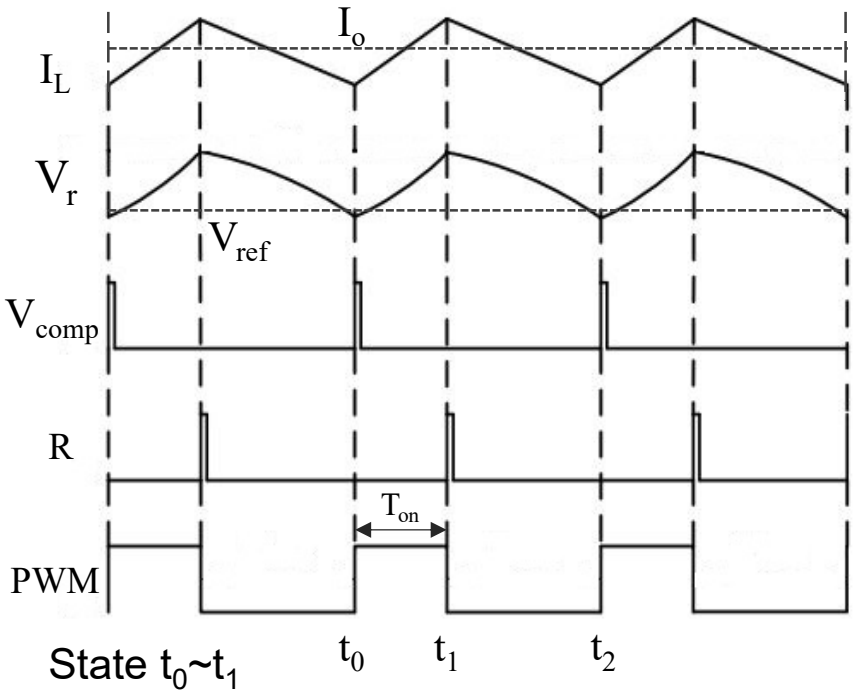
Operation of Constant on-time control

Proposed COT Converter



No External Clock

Operation waveform



State t_0~t_1

① V_r reaches to V_{ref}, V_{comp} comes out

② RS flip-flop is started by V_{comp},

③ PWM goes to HIGH, meanwhile Ton timer is started.

④ Ton timer is over

⑤ RS flip-flop is reset automatically

⑥ PWM goes to LOW.

State t_1~t_2

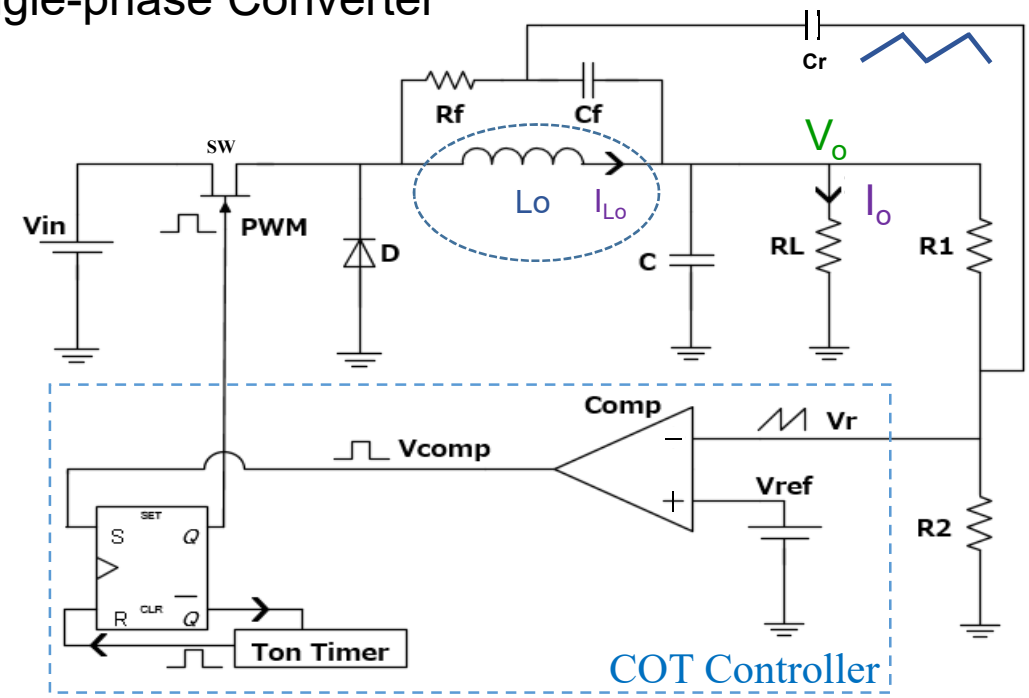
⑦ PWM keeps LOW until next cycle

Contents

- Research background
- Constant on-time control
- Four-phase converter solution via saw-tooth wave circuit
- Simulation result
- Transfer function characteristics
- EMI reduction via pulse phase modulation
- Conclusion

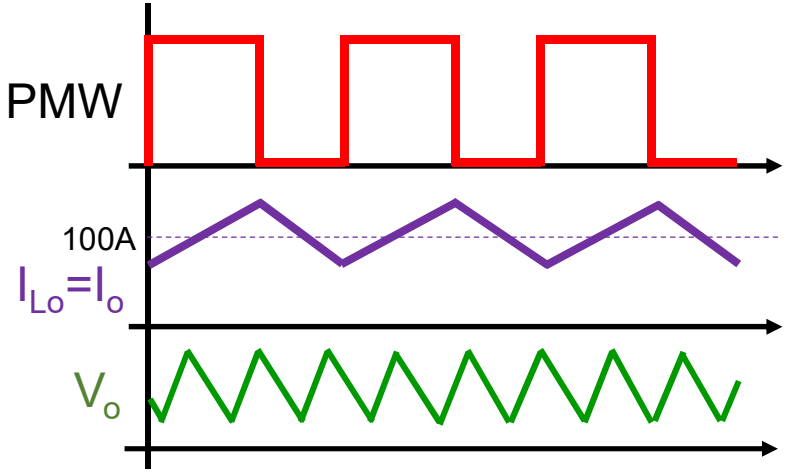
Demerit of Single-Phase Converter

Single-phase Converter

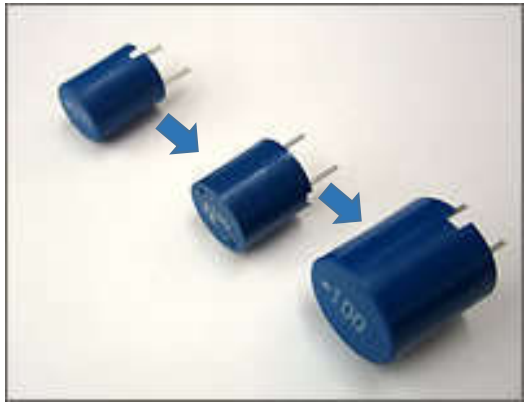


Io flows only through inductor Lo

Lo will be large in size

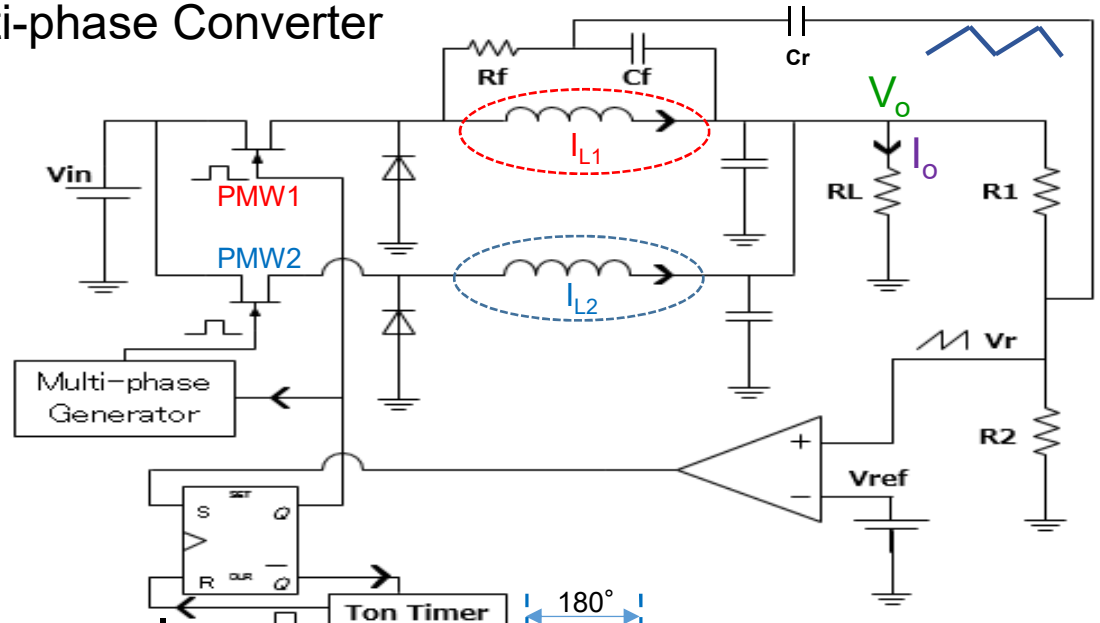


Large load on Inductor Lo



Merit of Multi-Phase Converter

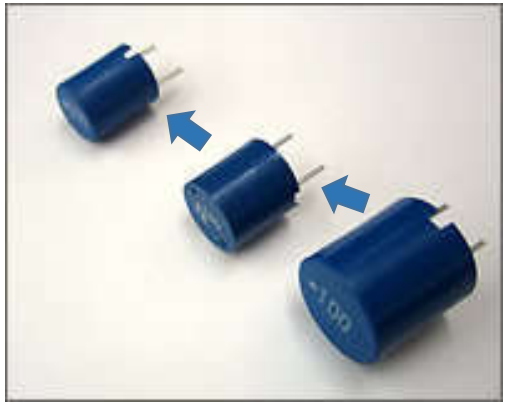
Multi-phase Converter

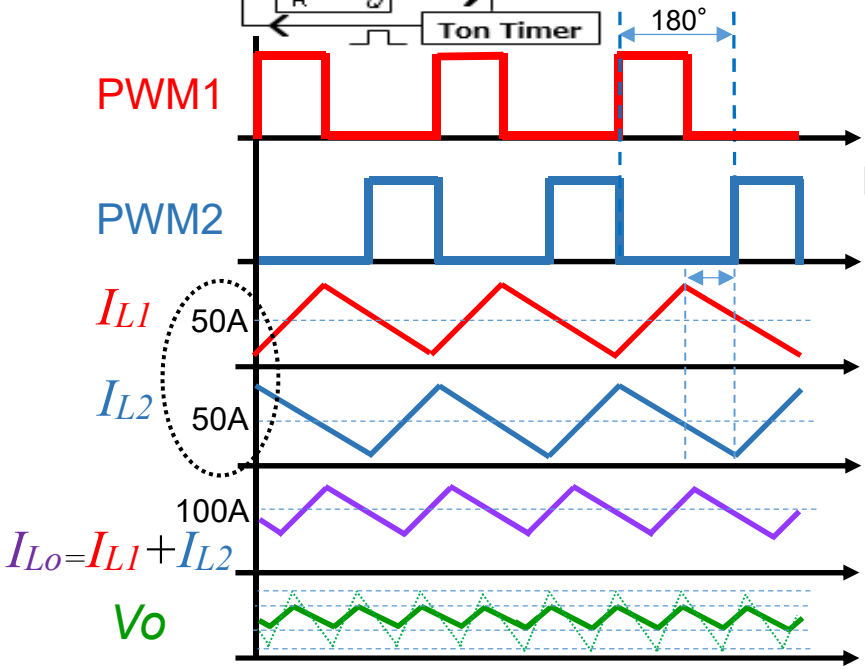


Tracking PWM2 with PWM1 is demanded without clock

Inductor L1 and L2 will go shares with the Io

L1 and L2 will be small in size





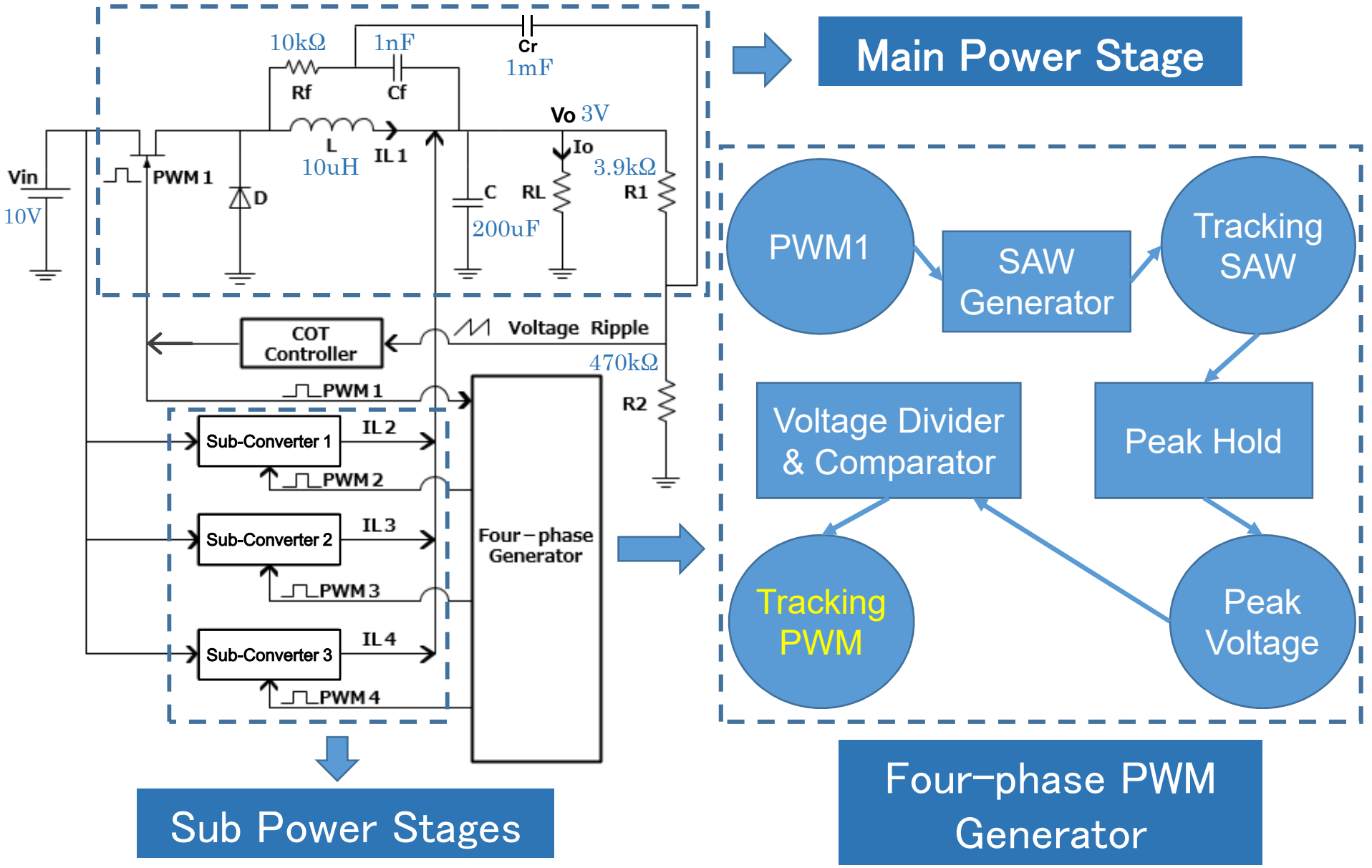
180° phase difference

Load of each phase's inductor halved

Simulative frequency multiplication

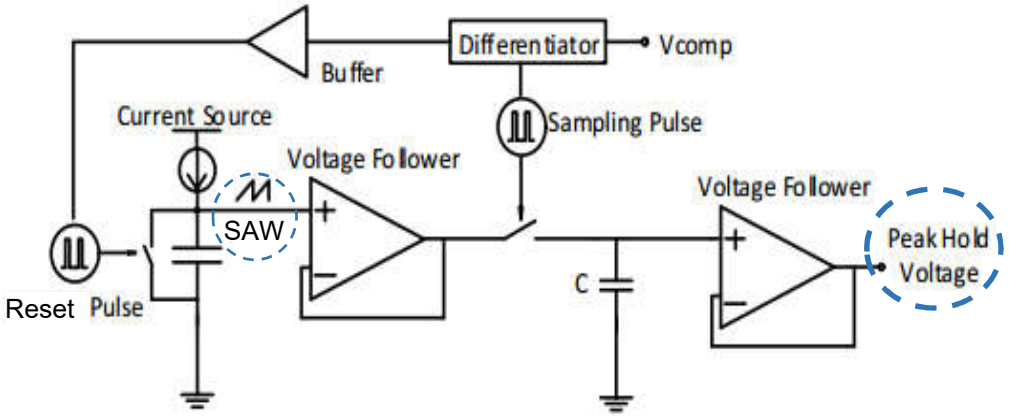
Low ripple by shifted two-phase peak current

Proposed Four-Phase Converter Solution

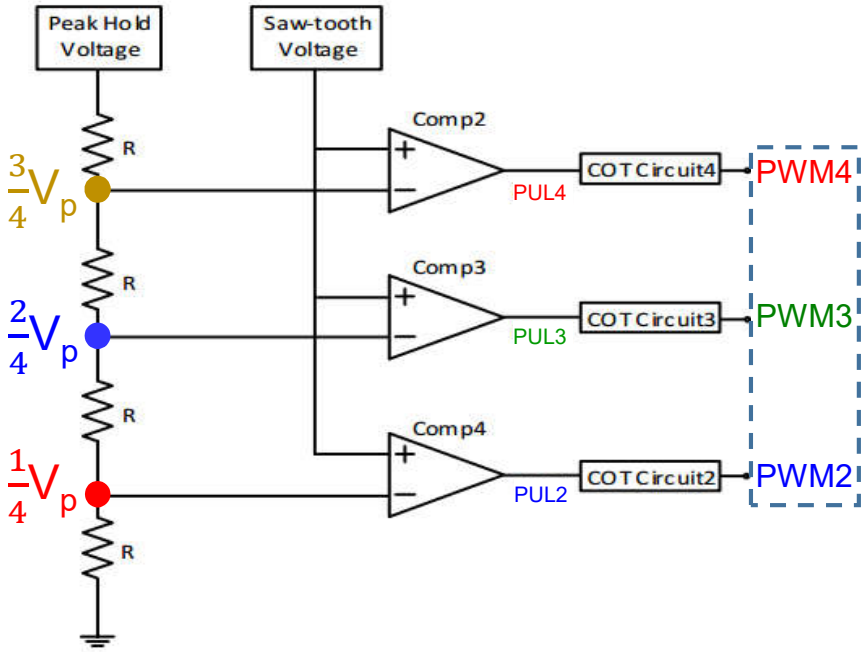


Generation of Four-Phase PWM

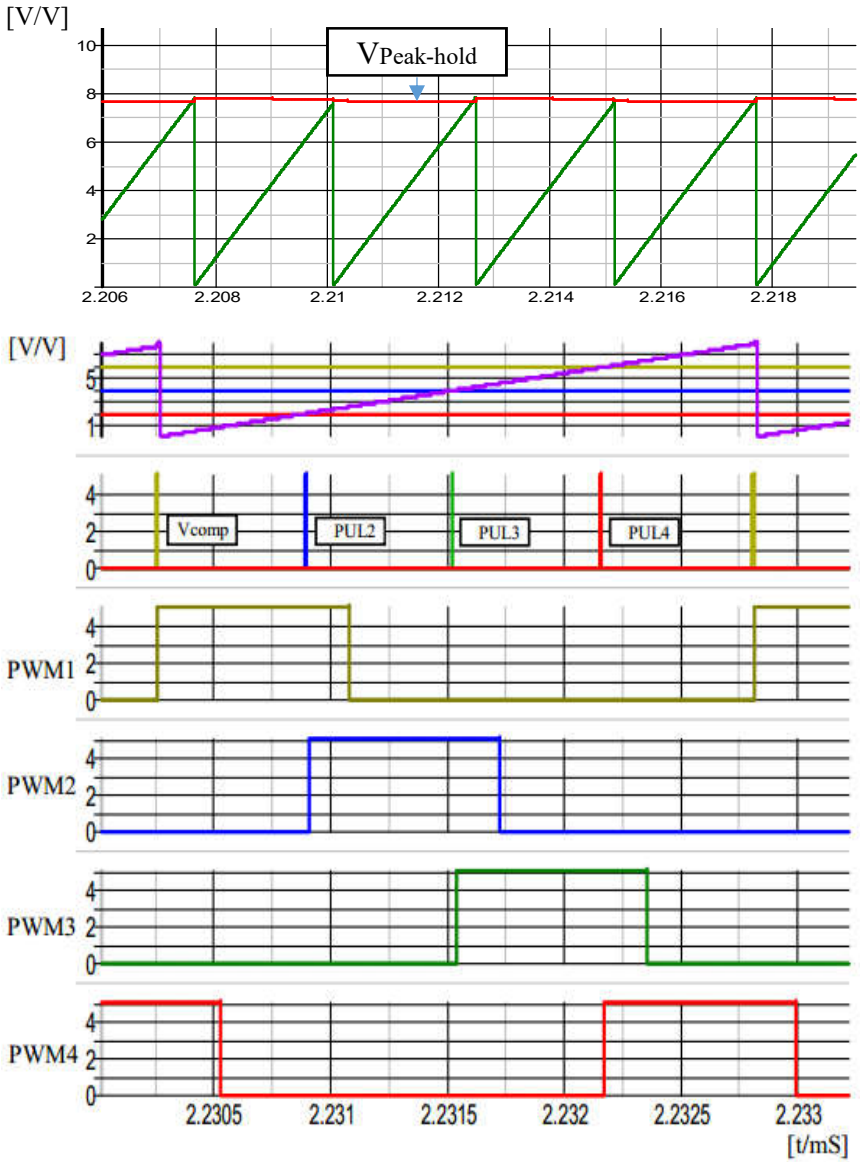
SAW Generator & Peak Hold



Voltage Divider & Comparator



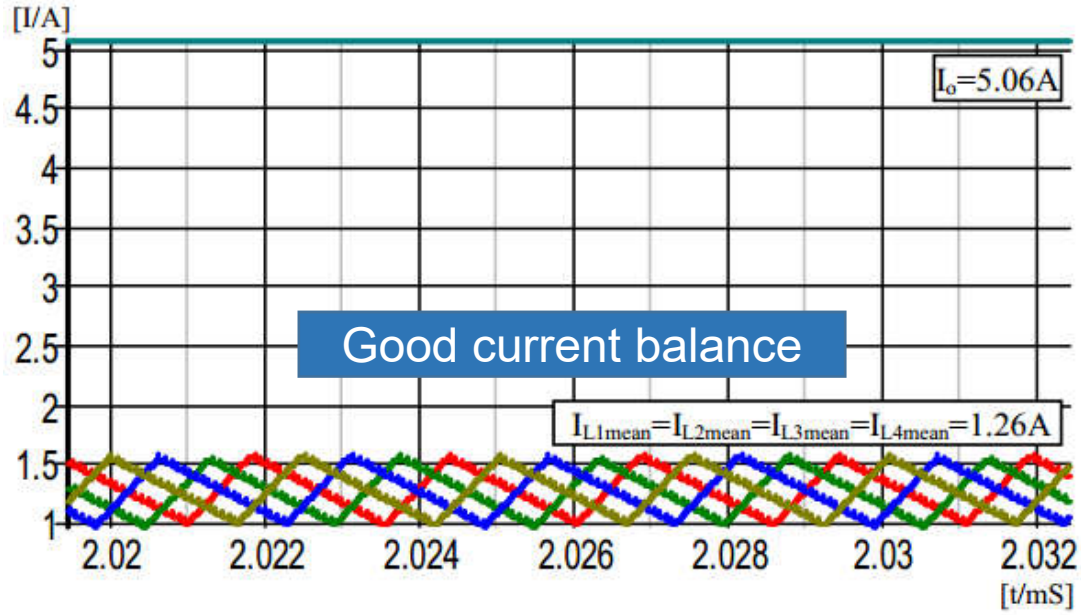
Operation waveform

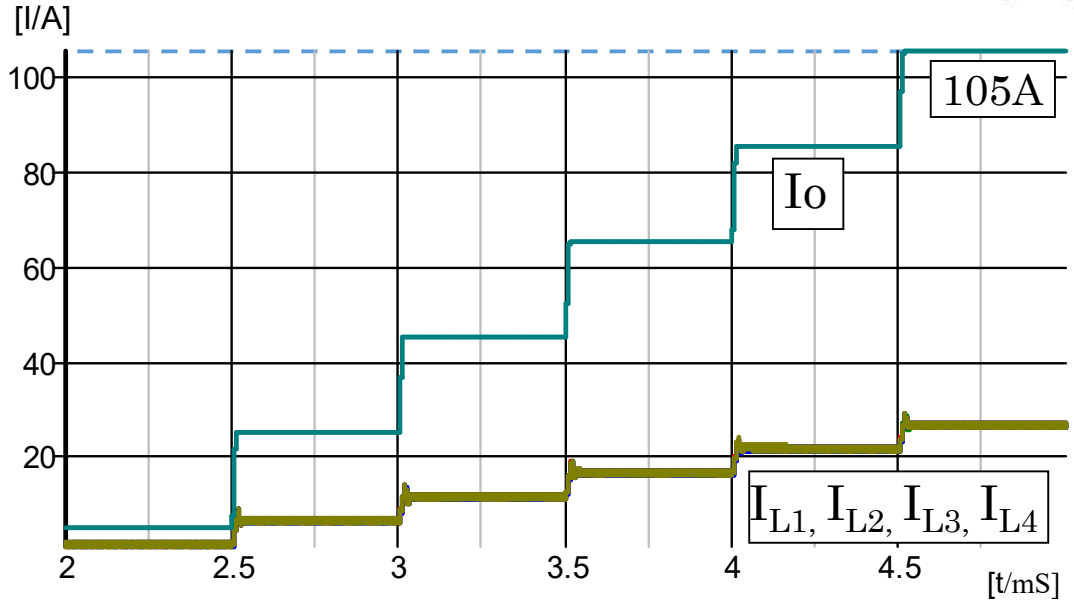


Contents

- Research background
- Constant on-time control
- Four-phase converter solution
  via saw-tooth wave circuit
- Simulation result
- Transfer function characteristics
- EMI reduction via pulse phase modulation
- Conclusion

Current Balance





Current balance offset ΔI_L
($\Delta I_L = |I_L - I_o/n|$)

I_o = 5.06A

$I_{L1} = I_{L2} = I_{L3} = I_{L4}$ =1.26A

$\Delta I_{L1} = I_{L1} - I_o/4$

$= |1.26-5.06/4| = 0.005A$

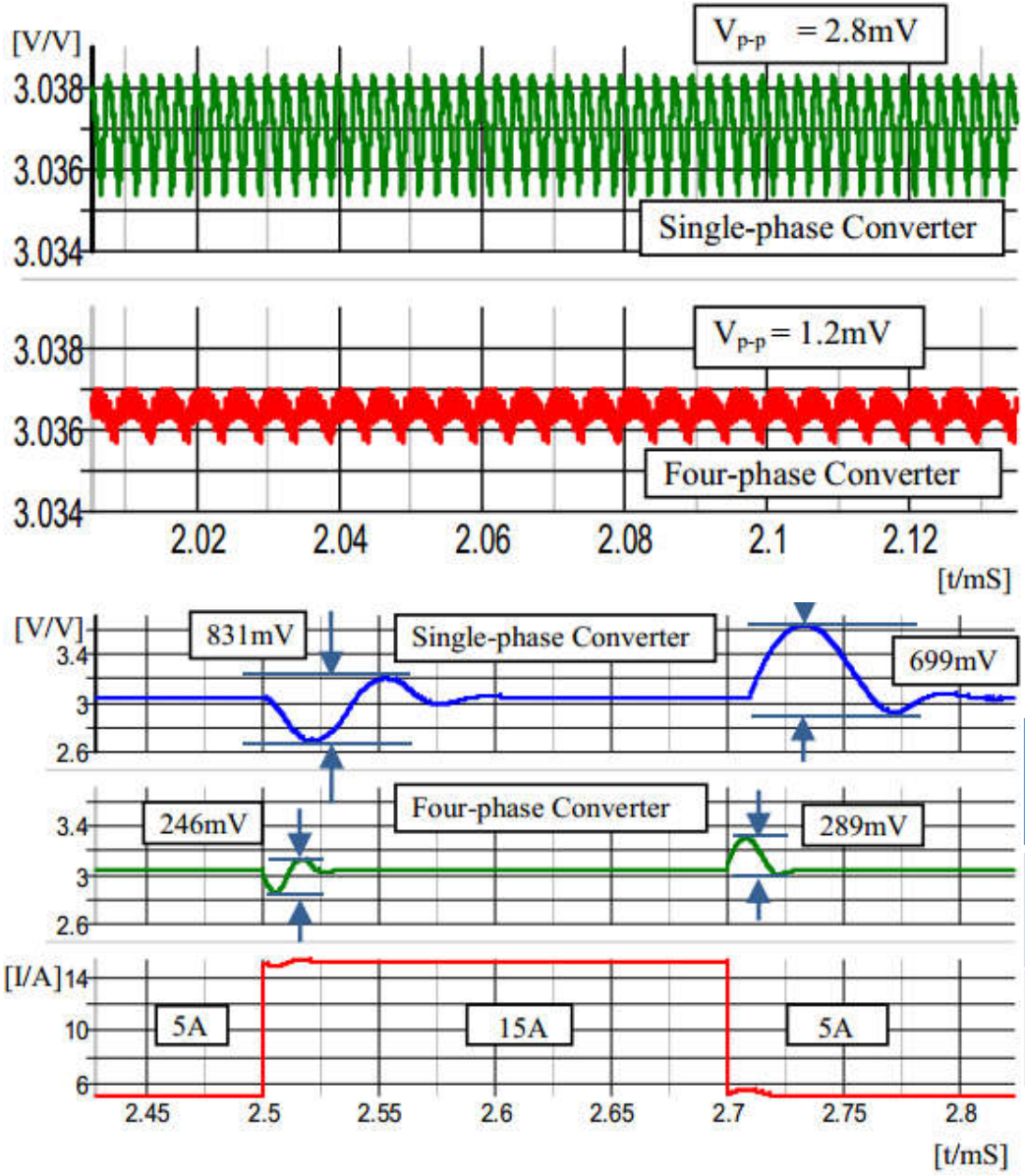
$\delta = 0.005/(5.06/4) \times 100\%$

$= 0.39\%$

Large load current achieved

Good current balance during transient response

Comparison



V_{out} : 3V

Static state characteristic

	Ripple peak to peak	Ripple range
Vout	57%off 2.8mV⇒1.2mV	under1%

I_{load} : 5A ⇨ 10A ⇨ 5A

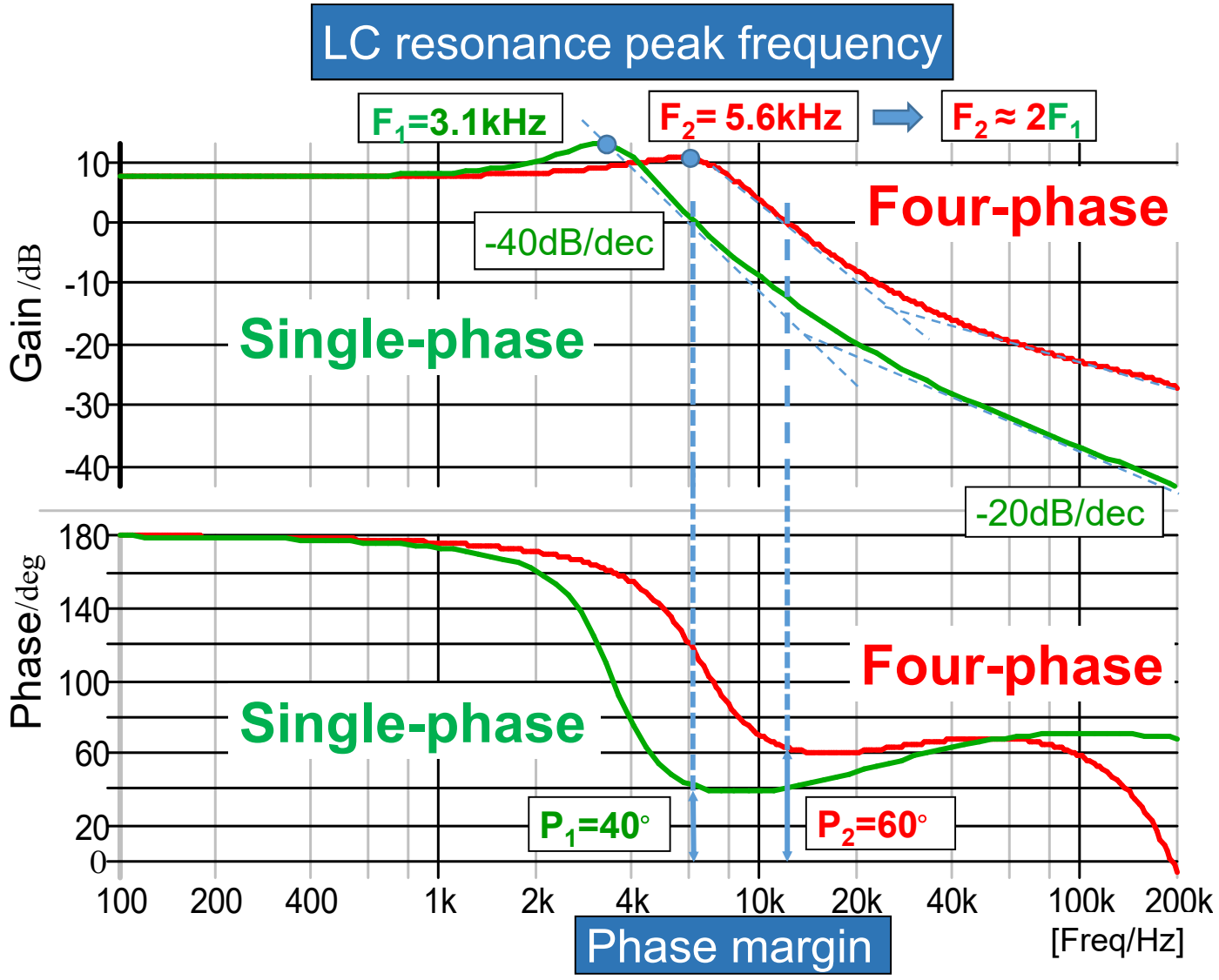
Dynamic load regulation

Transient response	Undershoot	Overshoot
Peak to Peak voltage	70%off 831mV ⇒ 246mV	59%off 699mV ⇒ 289mV
Recovery time	75%off 104us ⇒ 30us	80%off 123us ⇒ 27us

Contents

- Research background
- Constant on-time control
- Four-phase converter solution
  via saw-tooth wave circuit
- Simulation result
- Transfer function characteristics
- EMI reduction via pulse phase modulation
- Conclusion

Transfer function characteristics



Single-phase

Power Stage: One

LC Resonance Peak Frequency:

$$F_1 = \frac{1}{2\pi\sqrt{LC}}$$

Four-phase

Power Stage: Four
(Parallel Connection)

LC Resonance Peak Frequency :

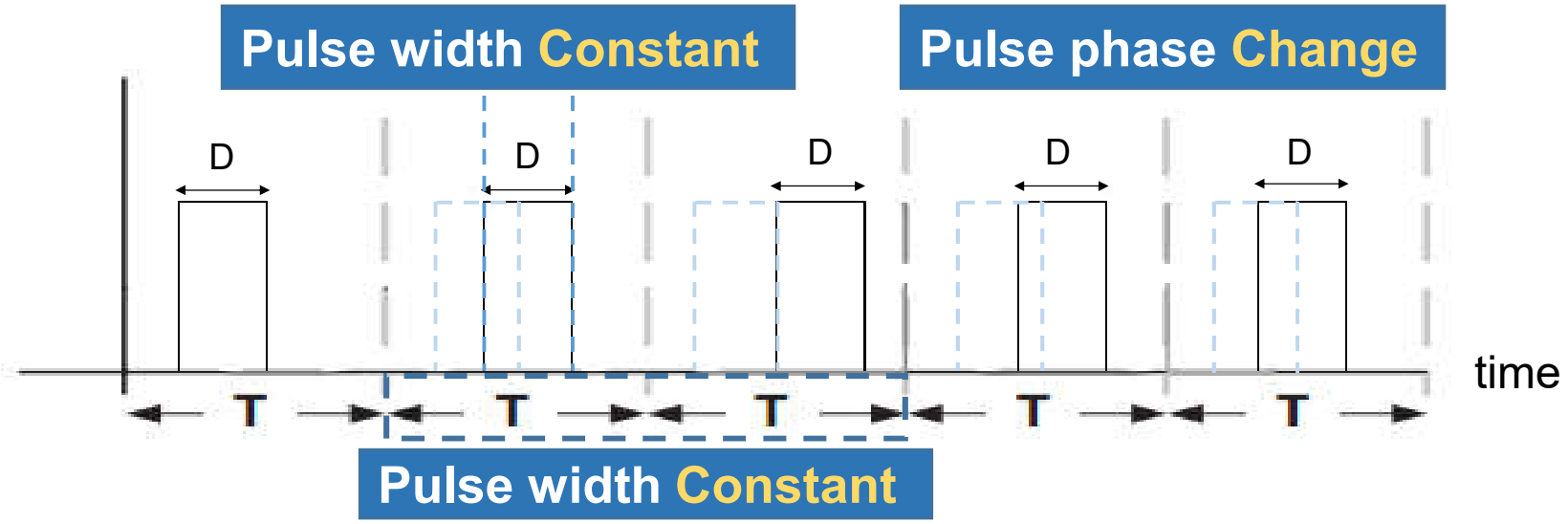
$$F_2 = \frac{1}{2\pi\sqrt{\frac{1}{4}LC}}$$

$$= \frac{1}{\pi\sqrt{LC}} = 2F_1$$

Contents

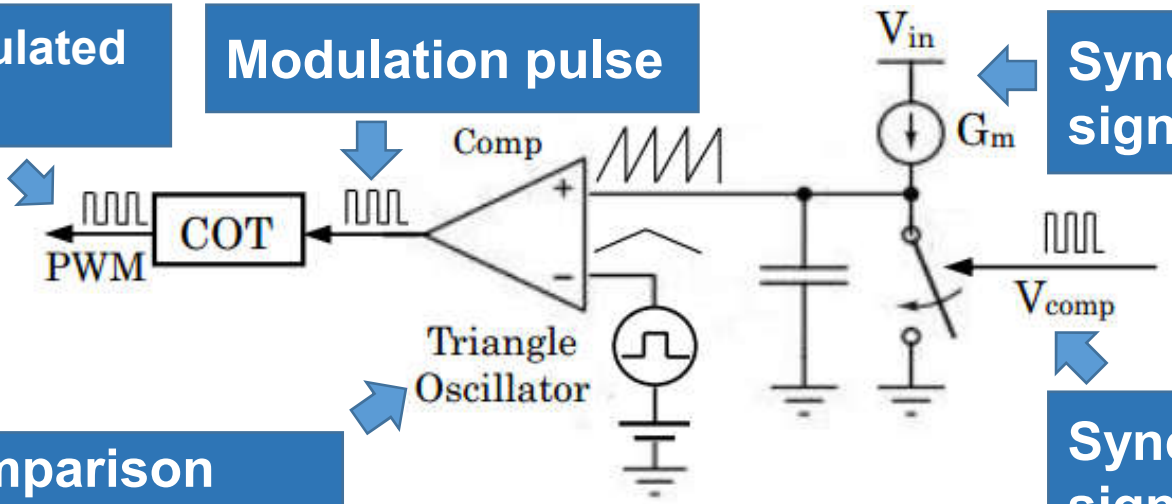
- Research background
- Constant on-time control
- Four-phase converter solution
  via saw-tooth wave circuit
- Simulation result
- Transfer function characteristics
- EMI reduction via pulse phase modulation
- Conclusion

Pulse Phase Modulation



Phase Modulated Pulse

Modulation pulse



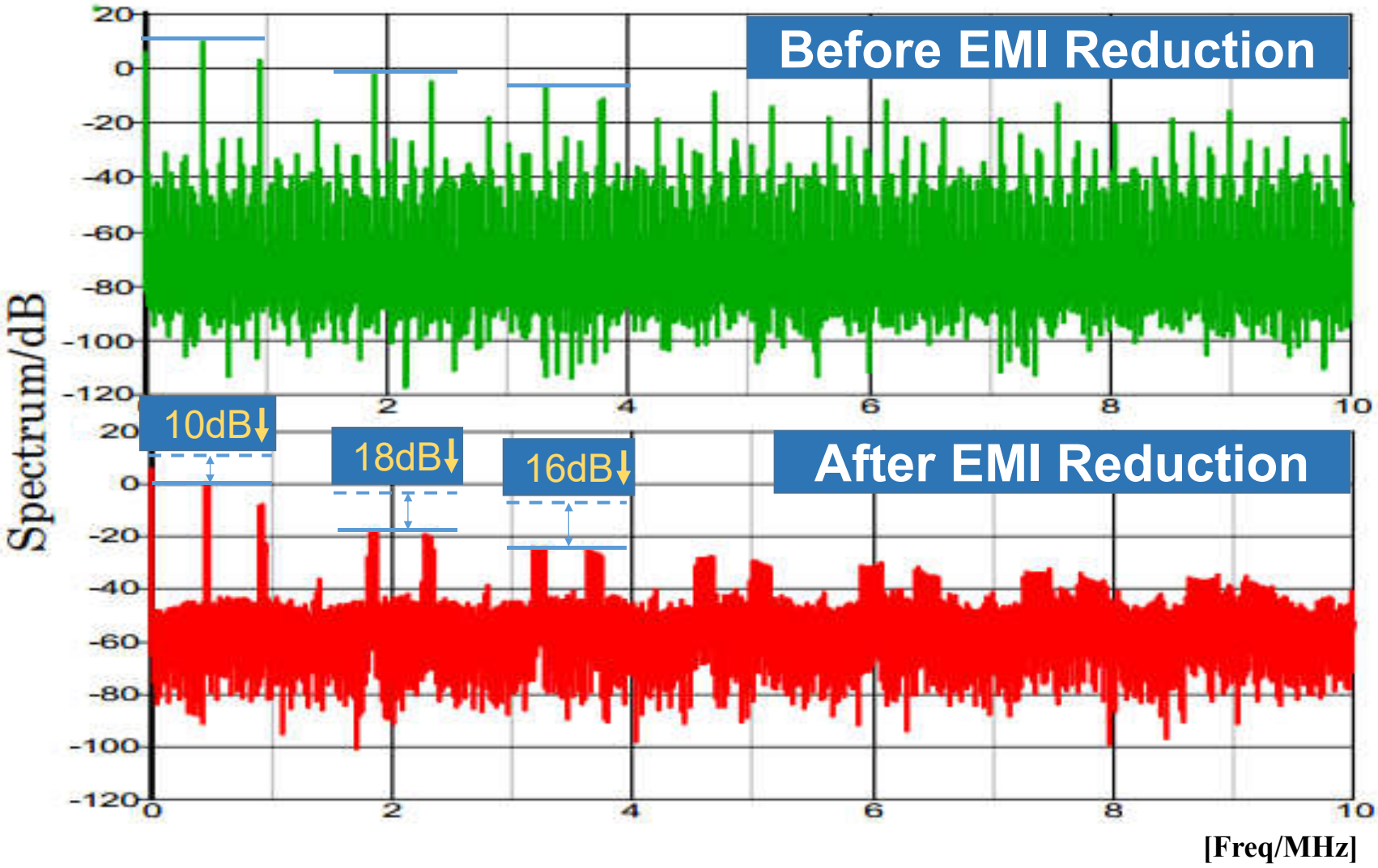
Synchronized SAW signal to V_{comp}

Comparison between SAW & Triangle wave

EMI Reduction Circuit

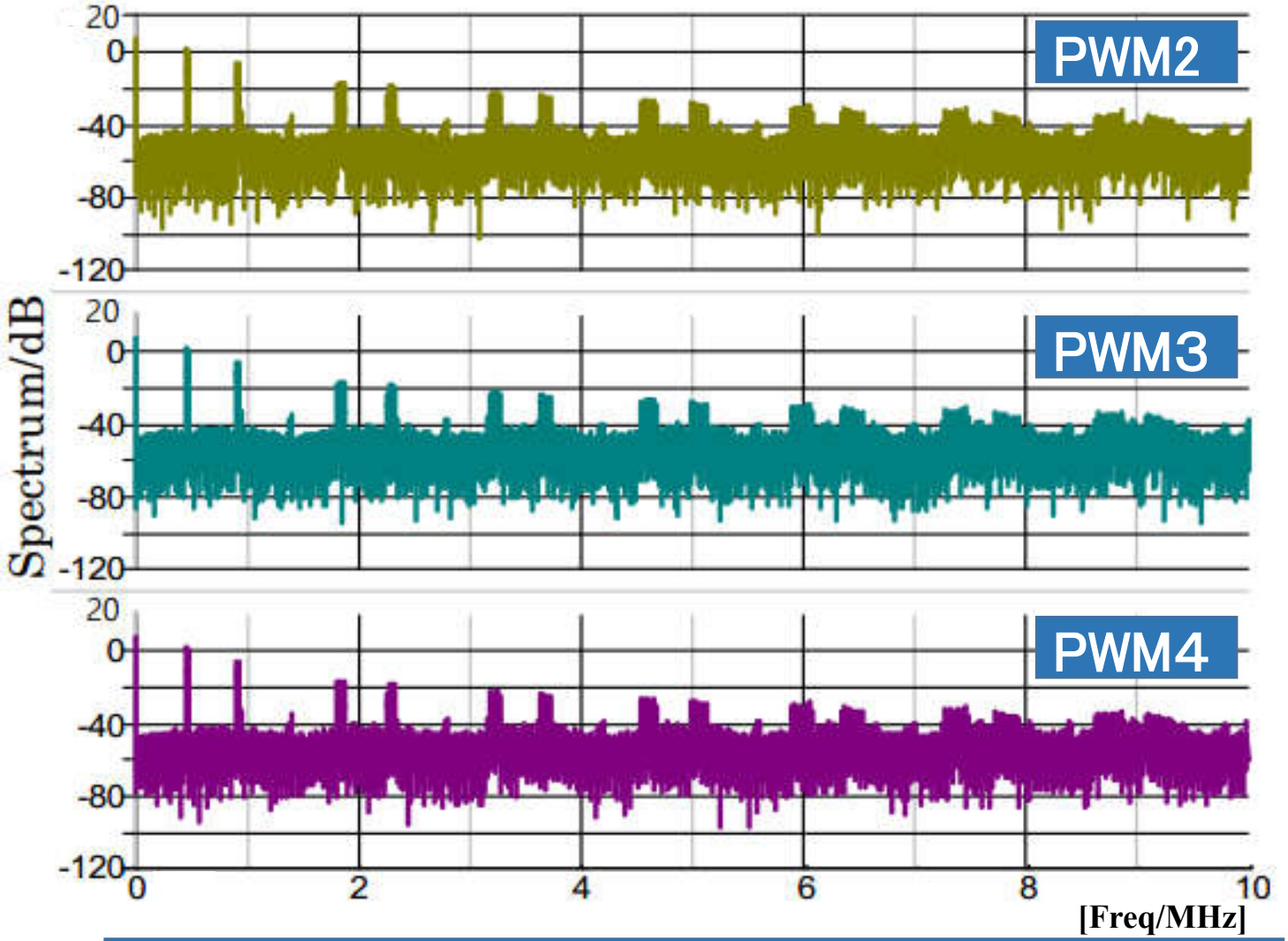
Synchronized pulse signal to PWM

Spectrum Diffusion Effect of PWM1



The EMI reduction circuit only used in PWM1

Spectrum Diffusion Effect of other PWMs



Other three phase PWMs has the same spectrum diffusion effect

Conclusion

- Proposal of four-phase DC-DC converter with constant-on-time control
- Good current balance, Large load current
- Low output voltage ripple, Fast response
- Four-phase converter shew better phase margin, higher operating frequency
- EMI reduction is achieved by pulse phase modulation, the four-phase PWMs

Thank you for your attention

思而不学則殆

学而不思則罔

Q&A

Q:Have you considered about the efficiency?

A: As for a power supply the efficiency is an important performance, but the first purpose of this research is fast response and large load current. On the basis of these achievement ,I will consider about the efficiency in the next step.