International Conference on
Mechanical, Electrical and Medical Intelligent System 2017 (ICMEMIS2017)
Nov 29, 30 & Dec 1, 2017 (Kiryu, Japan)

IPS01-11
Wednesday, November 29, 2017
14:00 – 14:20

Constant On-Time Controlled Four-Phase Buck Converter via Saw-Tooth-Wave Circuit and its Element Sensitivity

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

Gunma University

Kobayashi Laboratory

群馬大学
GUNMA UNIVERSITY

Research Objective

Objective

Development of power supply with
- Fast response
- Large current

Approach

- Constant on-time control
- Multi-phase

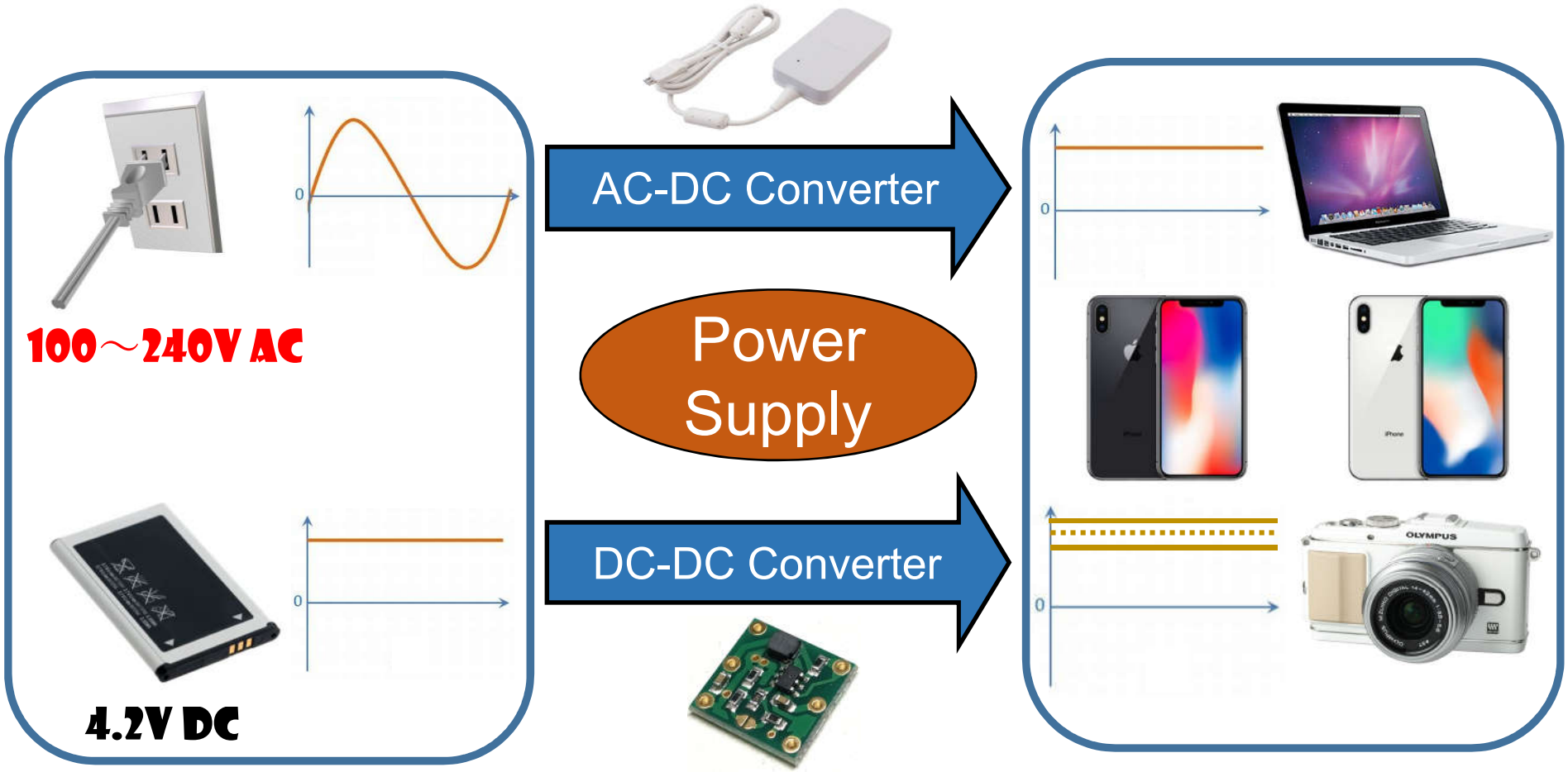
Contents

- Research background
- Constant on-time control
- Four-phase converter solution
  via saw-tooth wave circuit
- Simulation result
- Element sensitivity
- Conclusion

Contents

- Research background
- Constant on-time control
- Four-phase converter solution via saw-tooth-wave circuit way
- Simulation result
- Element sensitivity
- Conclusion

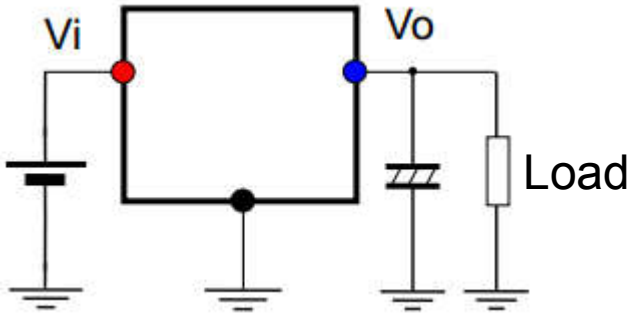
What is Power Supply ?



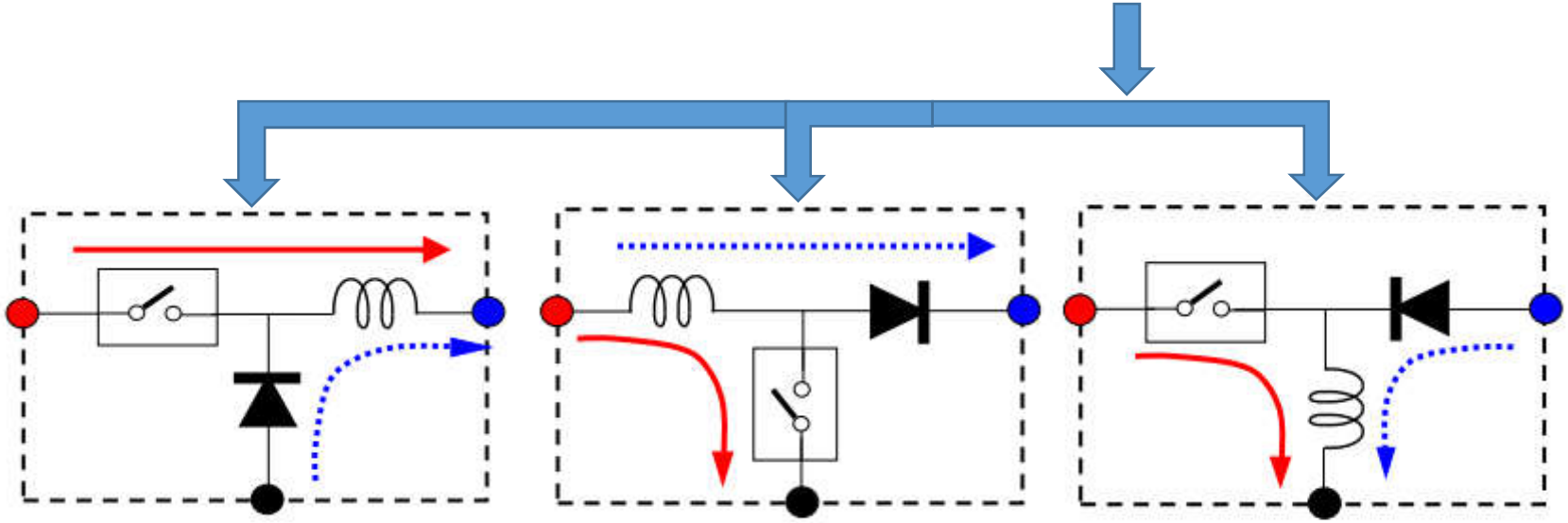
Power supply is demanded everywhere to provide appropriate voltage for electronic device

Classifications of DC-DC Converter

DC-DC converter



Basic configuration



Buck

Vin > Vo

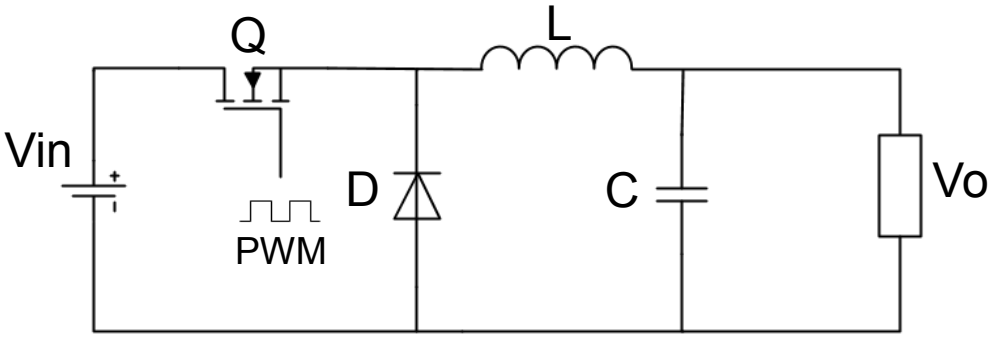
Boost

Vin < Vo

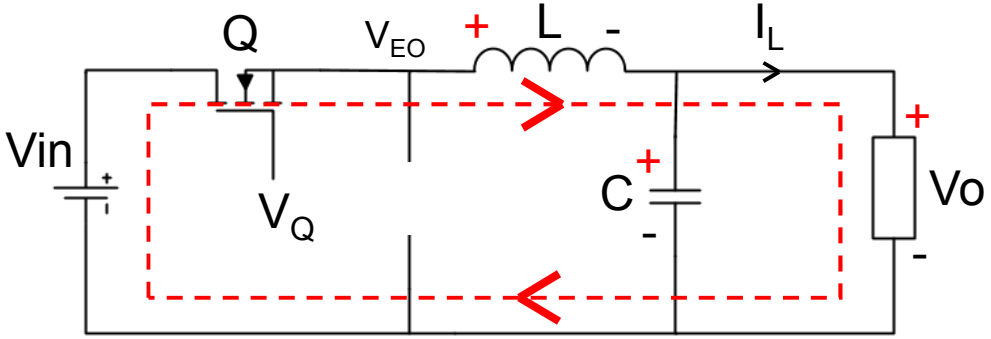
Buck-Boost

Vin ≷ Vo

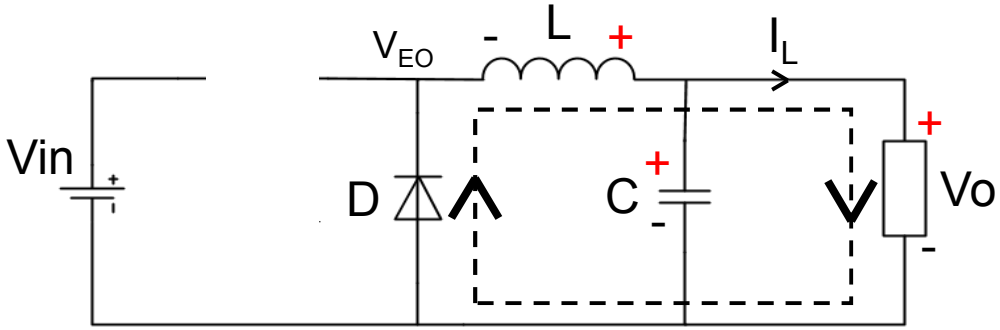
Operation of Buck Converter



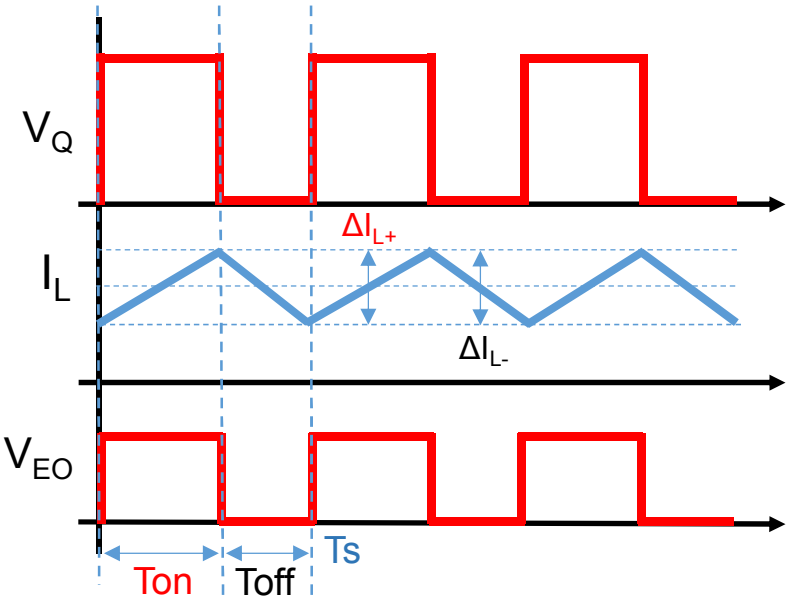
Buck Converter



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

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

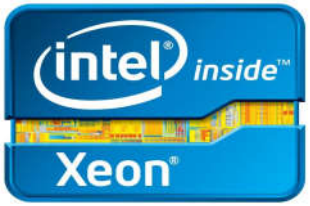
Volt-second Balance

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

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

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

- Research background
- Constant on-time control
- Four-phase converter solution via saw-tooth-wave circuit
- Simulation result
- Element sensitivity
- Conclusion

Merit of Constant on-time control

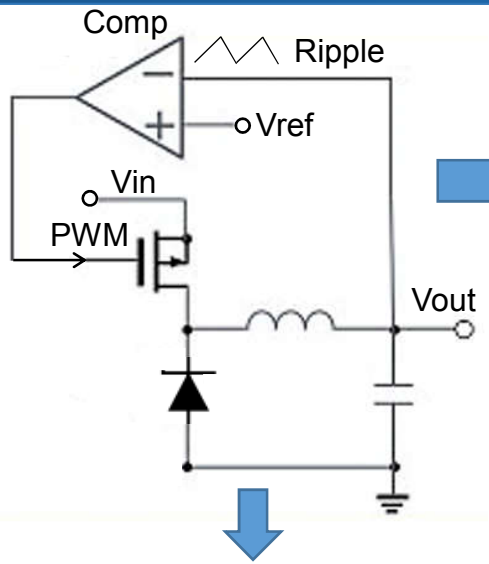
Ripple Control

Hysteresis window control

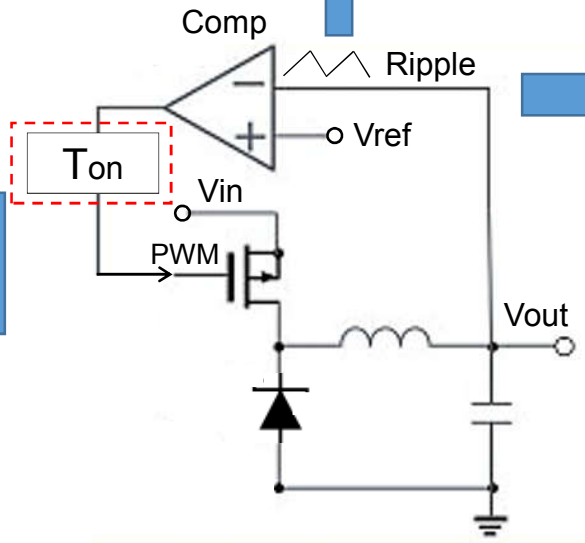
Extreme fast response

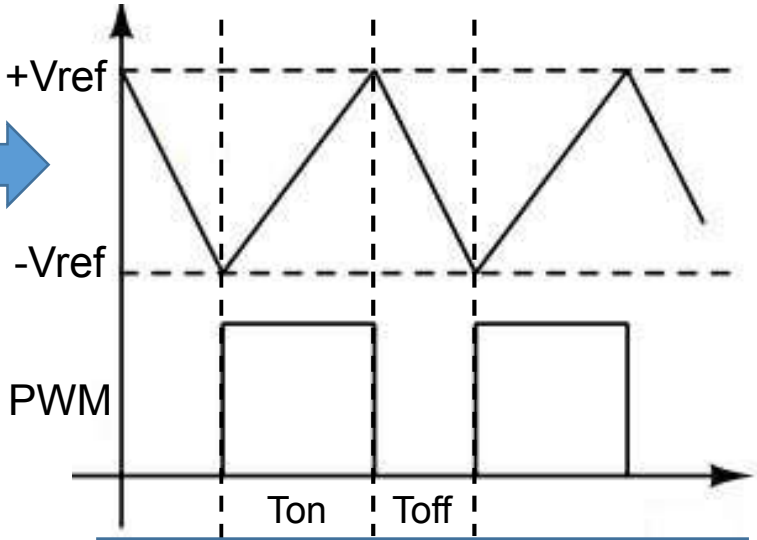
Constant on-time control

$$f_{sw} = \frac{Vo}{Vin \cdot T_{on}}$$

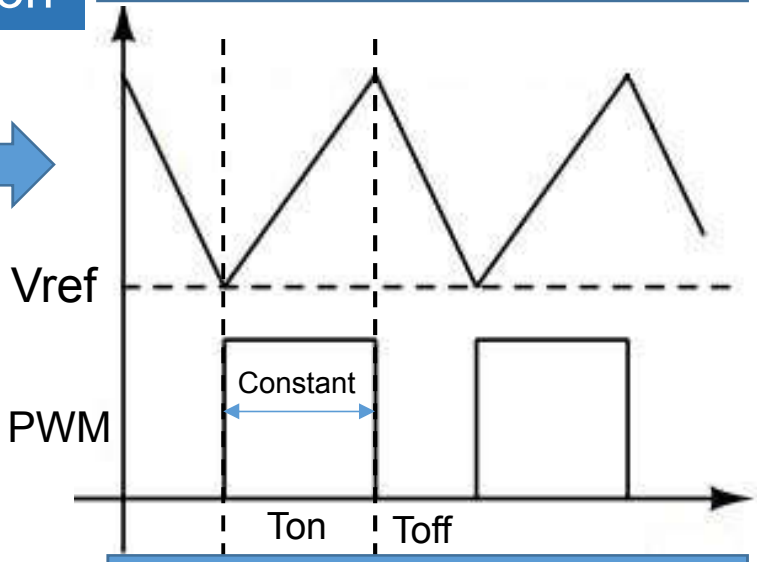


No phase compensation





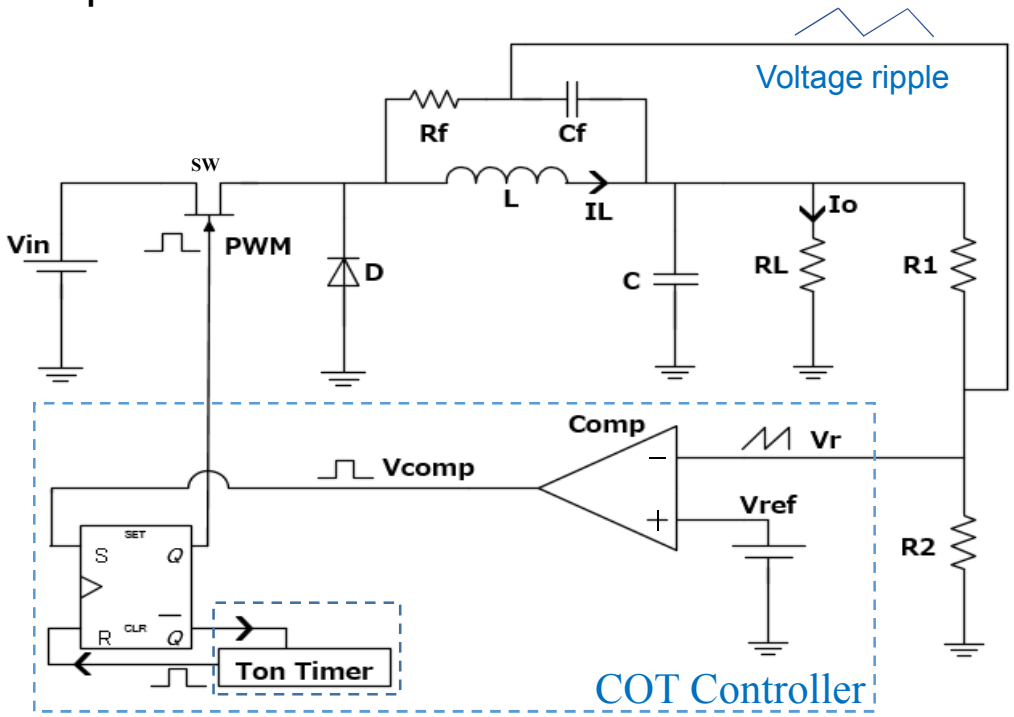
Frequency swings usually



Frequency keeps stable

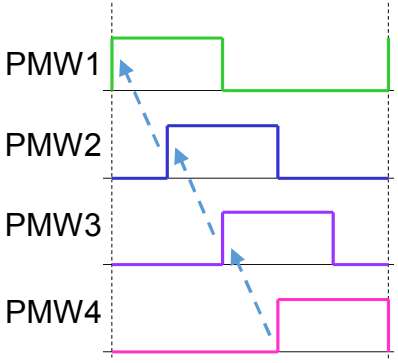
Operation of Constant on-time control

Proposed COT Converter

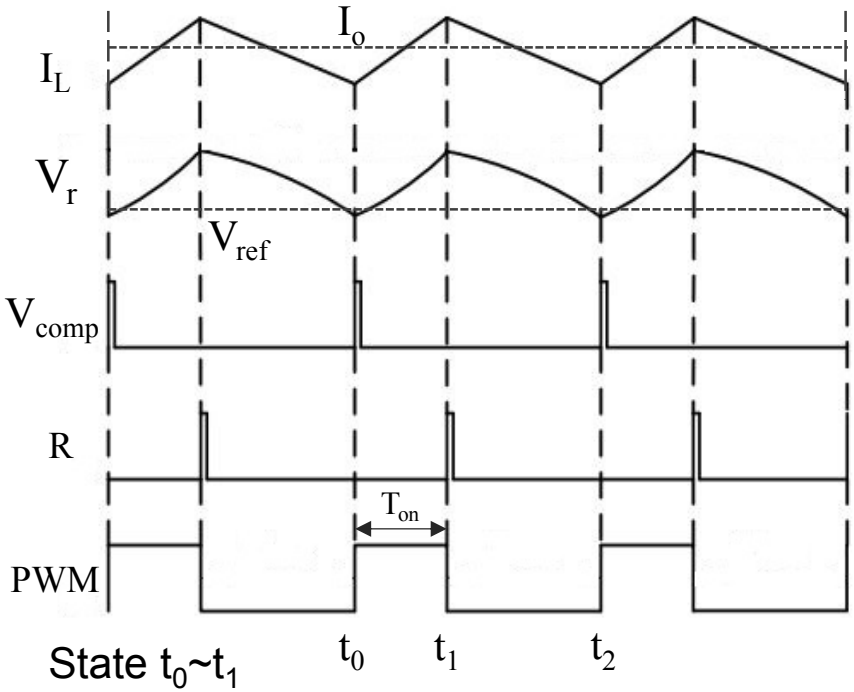


No External Clock

Tracking PWM with PWM1 is demanded without 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

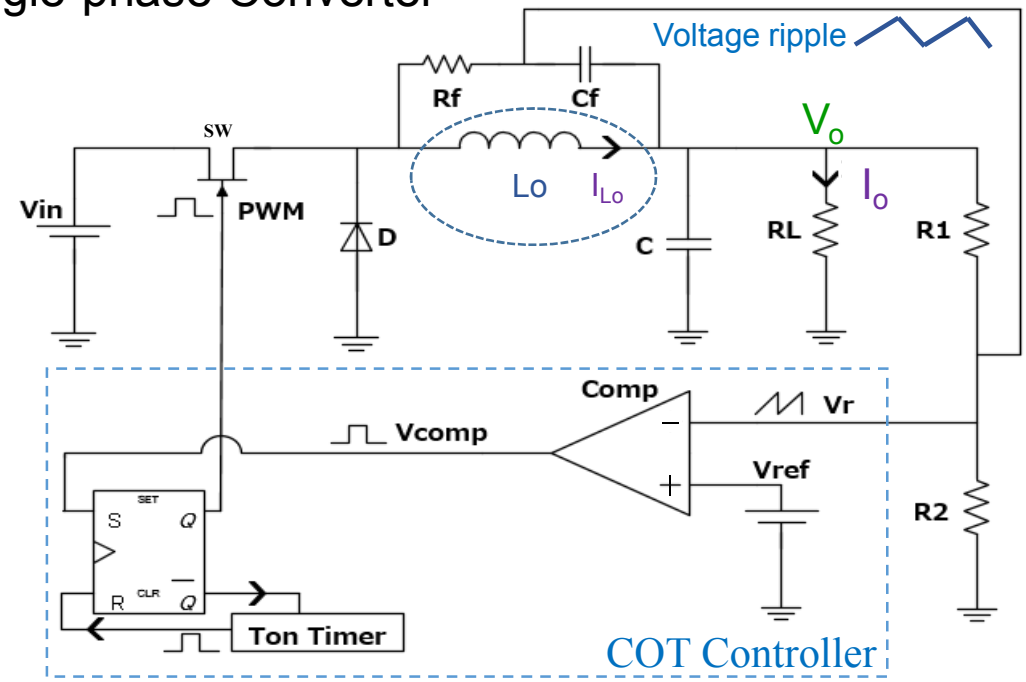
⑦ PWM keeps LOW until next cycle

Contents

- Research background
- Constant on-time control
- Four-phase converter solution via saw -tooth-wave circuit
- Simulation result
- Element sensitivity
- Conclusion

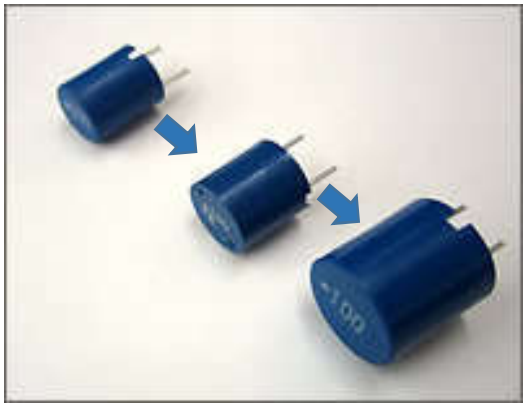
Demerit of Single-Phase Converter

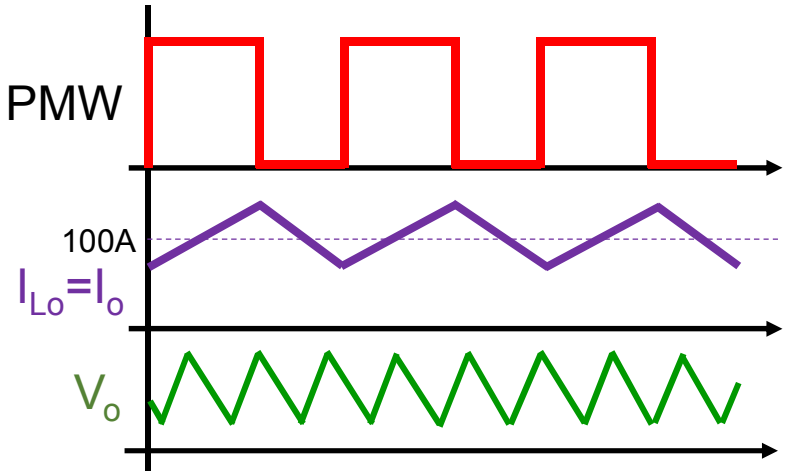
Single-phase Converter



The whole output current Io will flows only through inductor Lo

Lo will be large in size

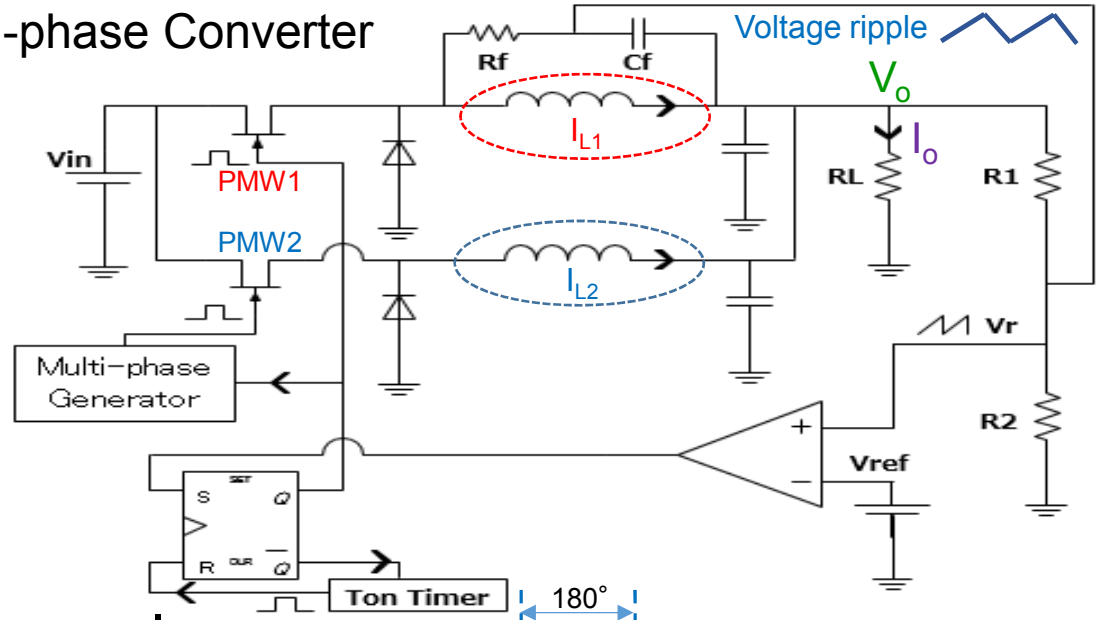


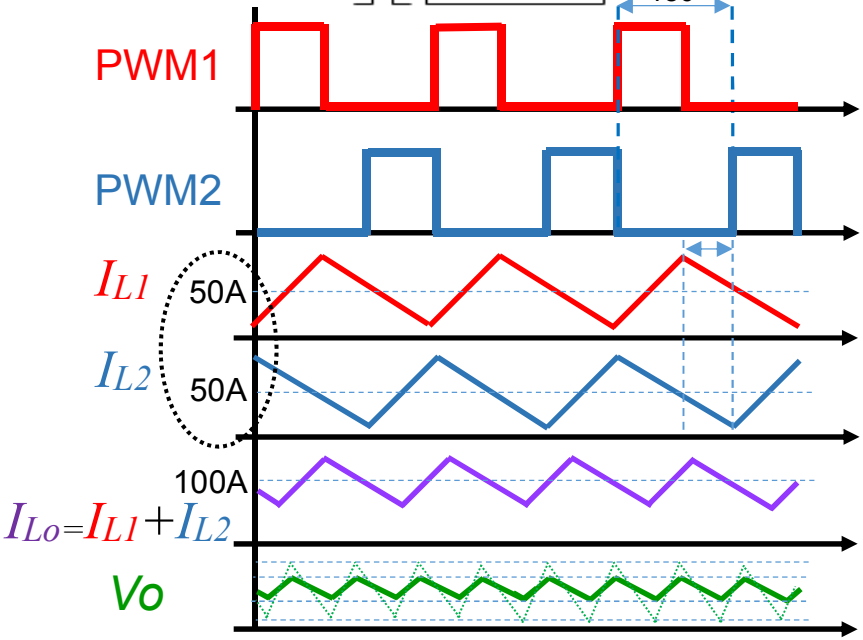


Large load on Inductor Lo

Merit of Multi-Phase Converter

Multi-phase Converter





180° phase difference

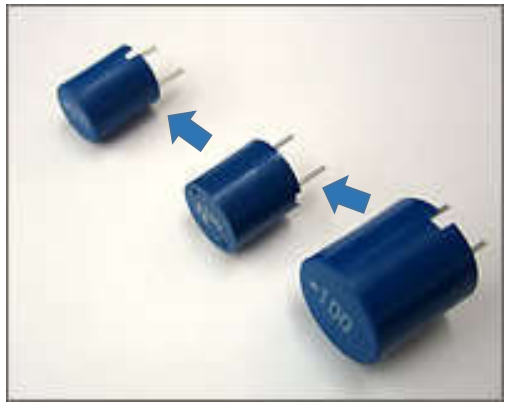
Load of each phase's inductor halved

Simulative frequency multiplication

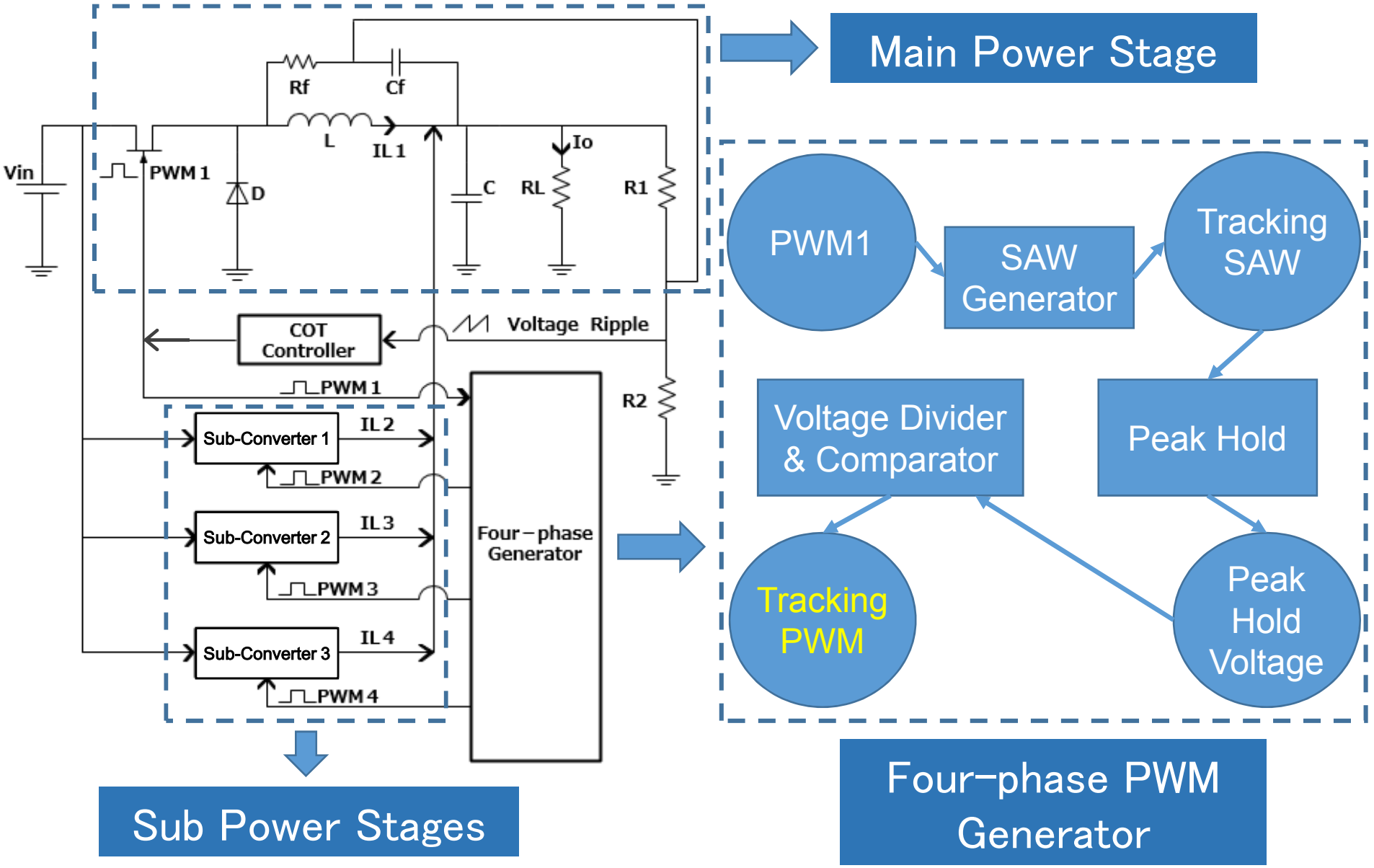
Low ripple by shifted two-phase peak current

Inductor L1 and L2 will go shares with the Io

L1 and L2 will be small in size

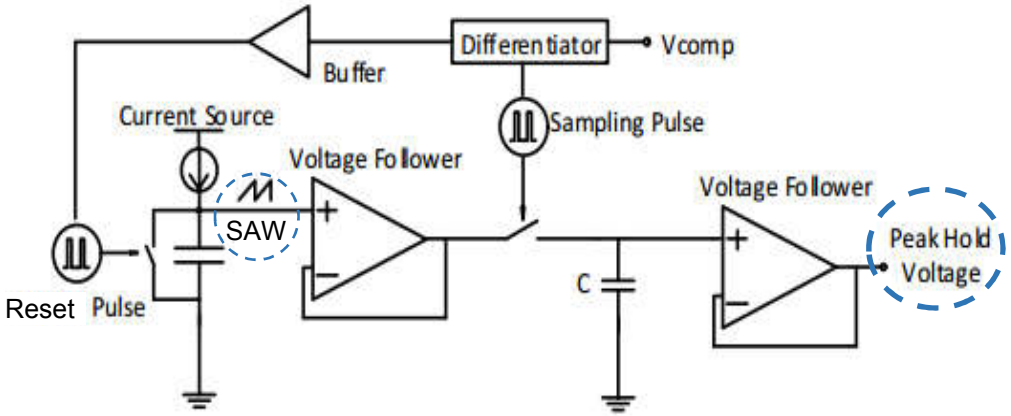


Proposed Four-Phase Converter Solution

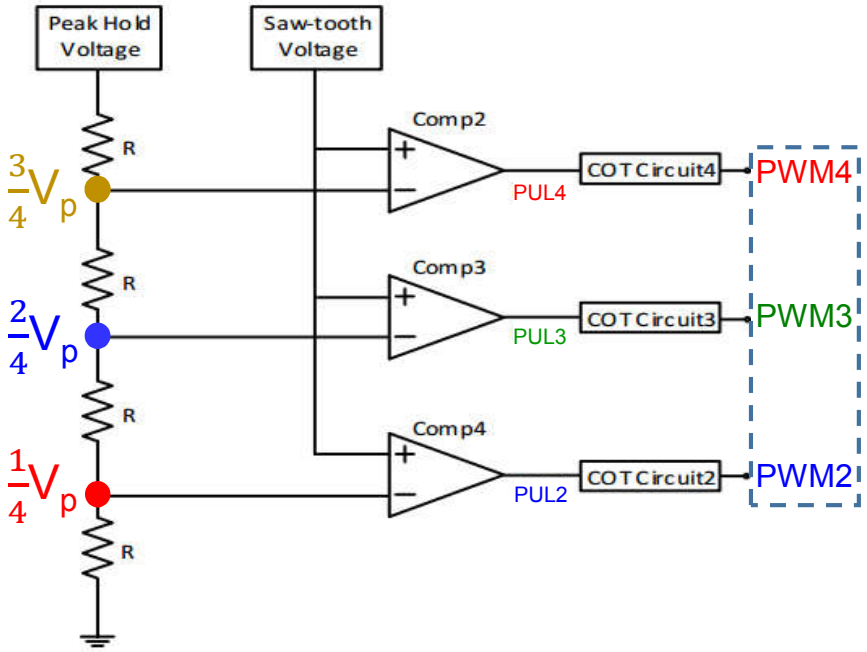


Generation of Four-Phase PWM

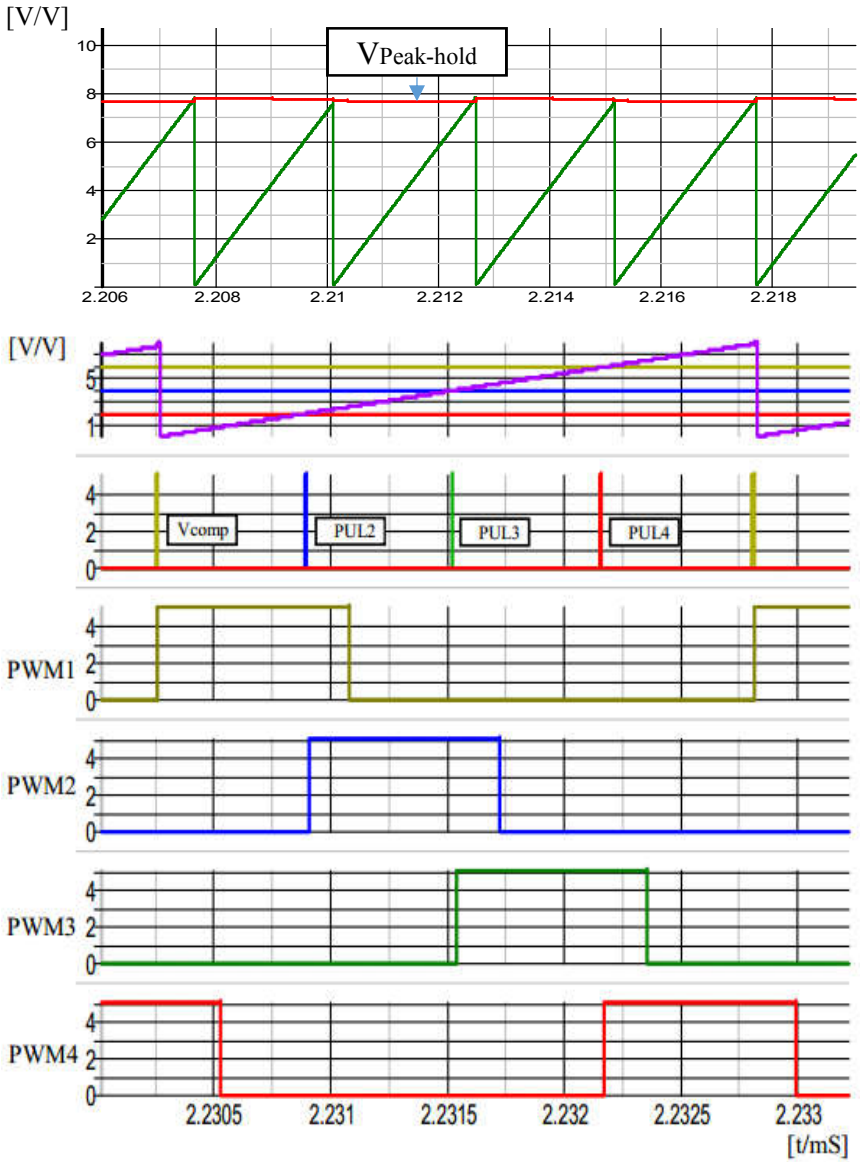
SAW Generator & Peak Hold



Voltage Divider & Comparator



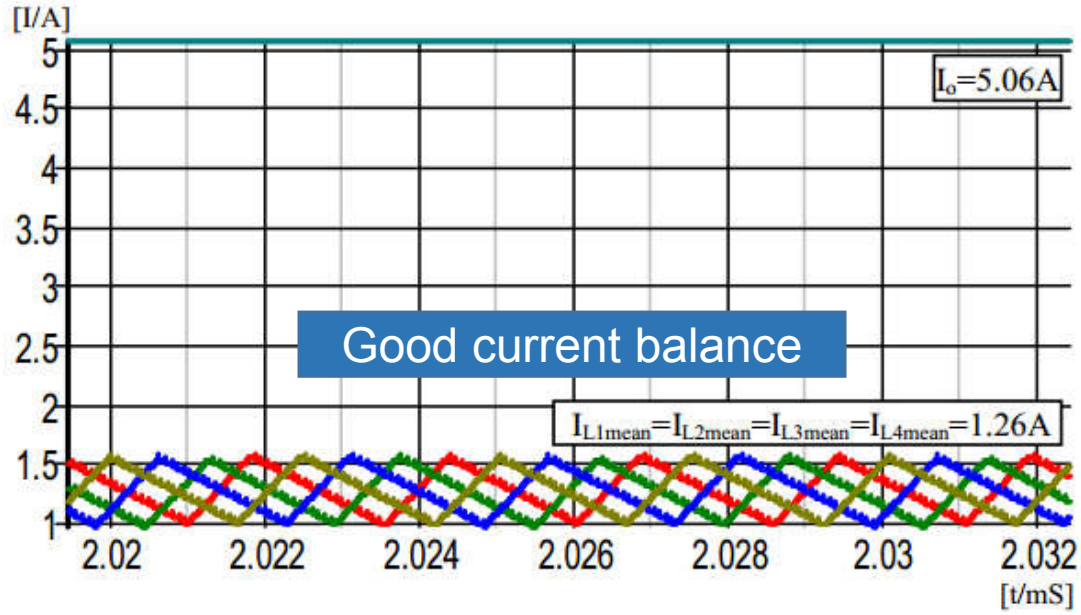
Operation waveform

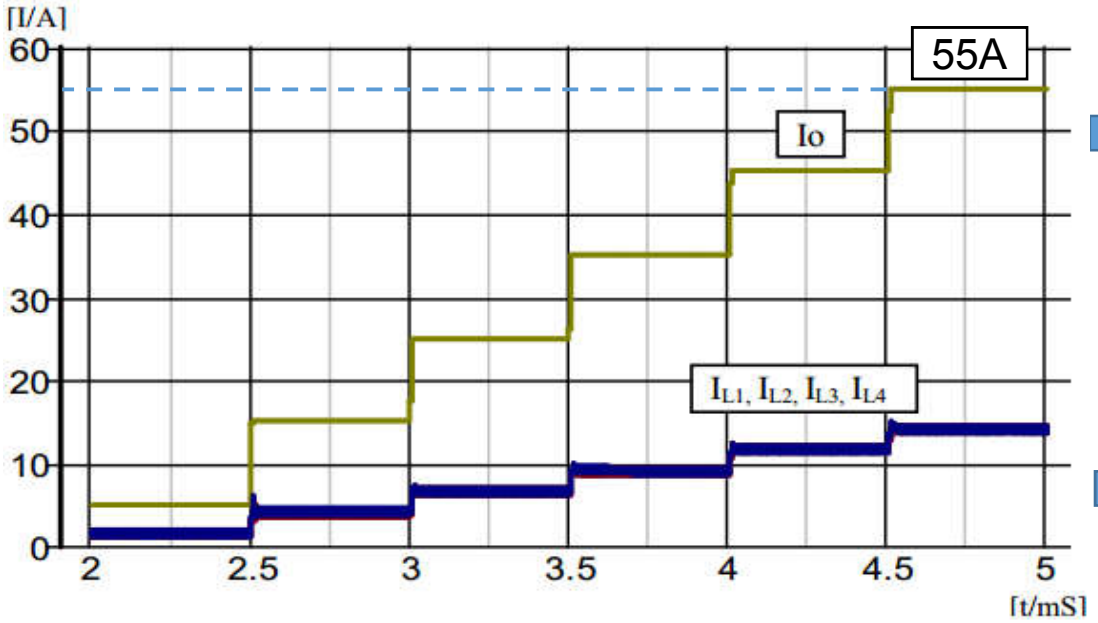


Contents

- Research background
- Constant on-time control
- Four-phase converter solution via Saw-tooth-wave circuit
- Simulation result
- Element sensitivity
- Conclusion

Current Balance





Current balance offset ΔI_L
($\Delta I_L = |I_L - I_o/2|$)

I_o = 5.06A

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

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

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

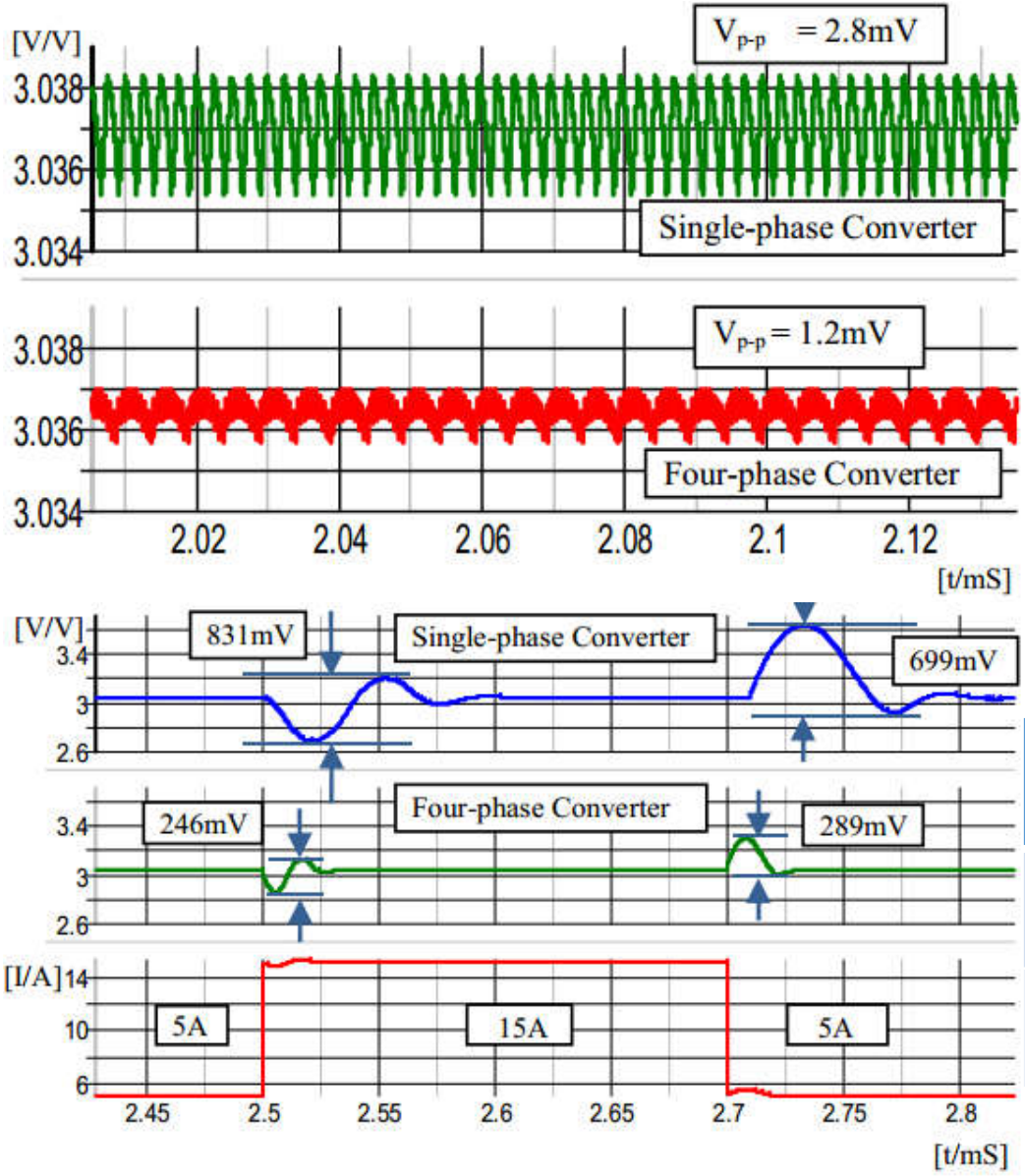
$\delta = 0.005/(5.06/4) \times 100\%$

$= 0.39\%$

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	under1%

I_{load} : 5A ⇨ 10A ⇨ 5A

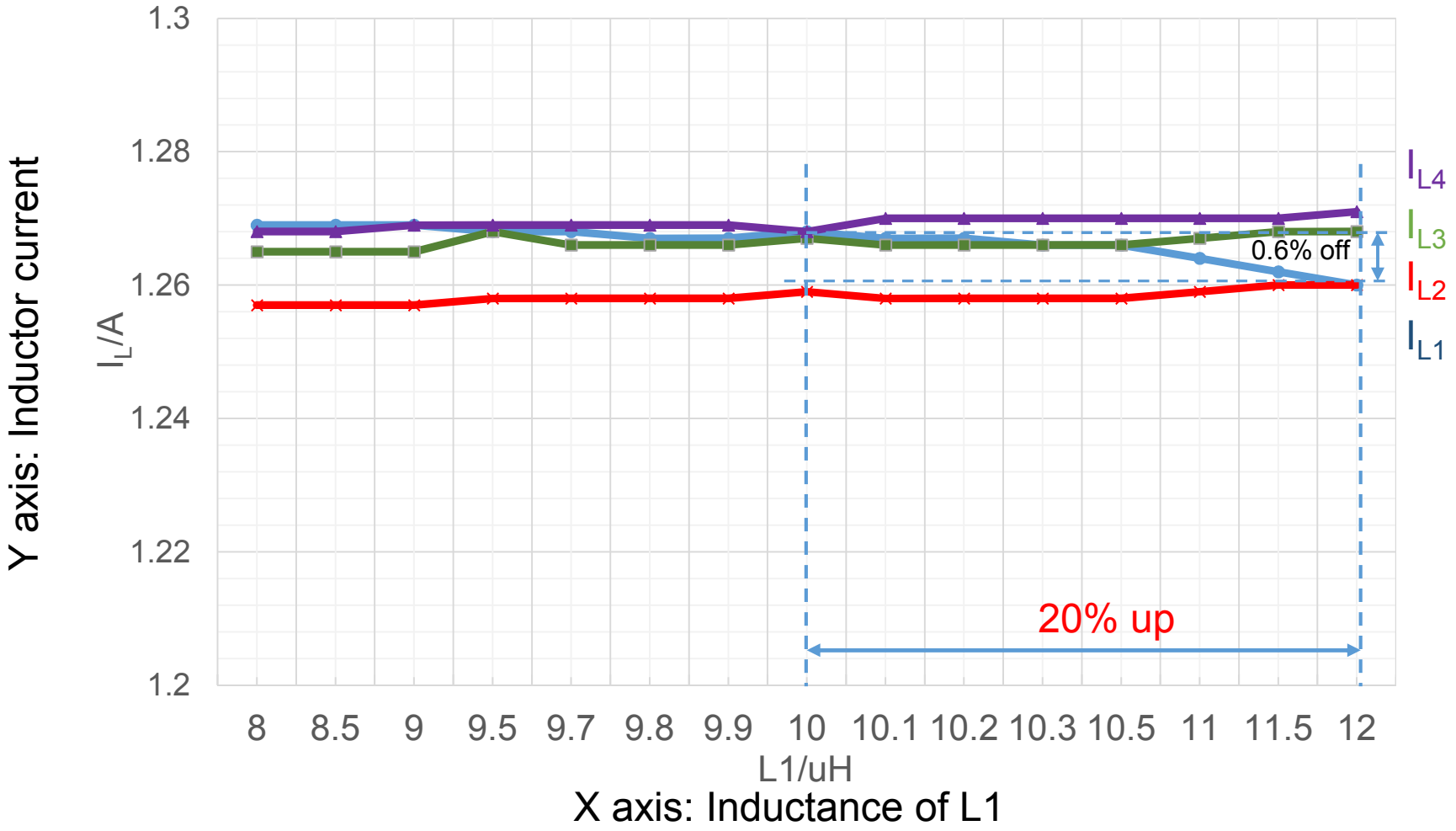
Dynamic load regulation

Transient response	Undershoot	Overshoot
Peak to Peak voltage	70%off	59%off
Recovery time	75%off	80%off

Contents

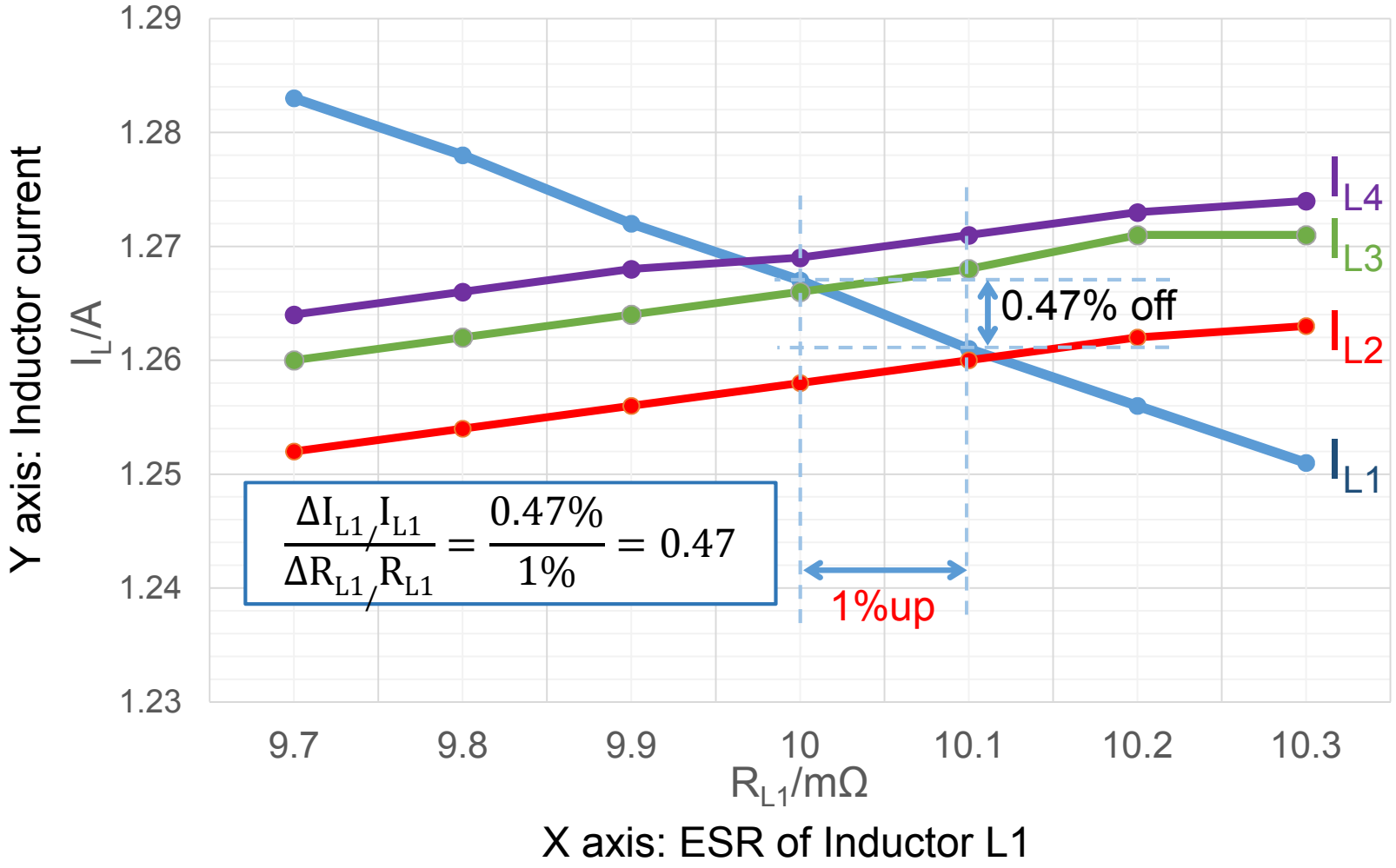
- Research background
- Constant on-time control
- Four-phase converter solution via Saw-tooth-wave circuit
- Simulation result
- Element sensitivity
- Conclusion

Current balance via ΔL1



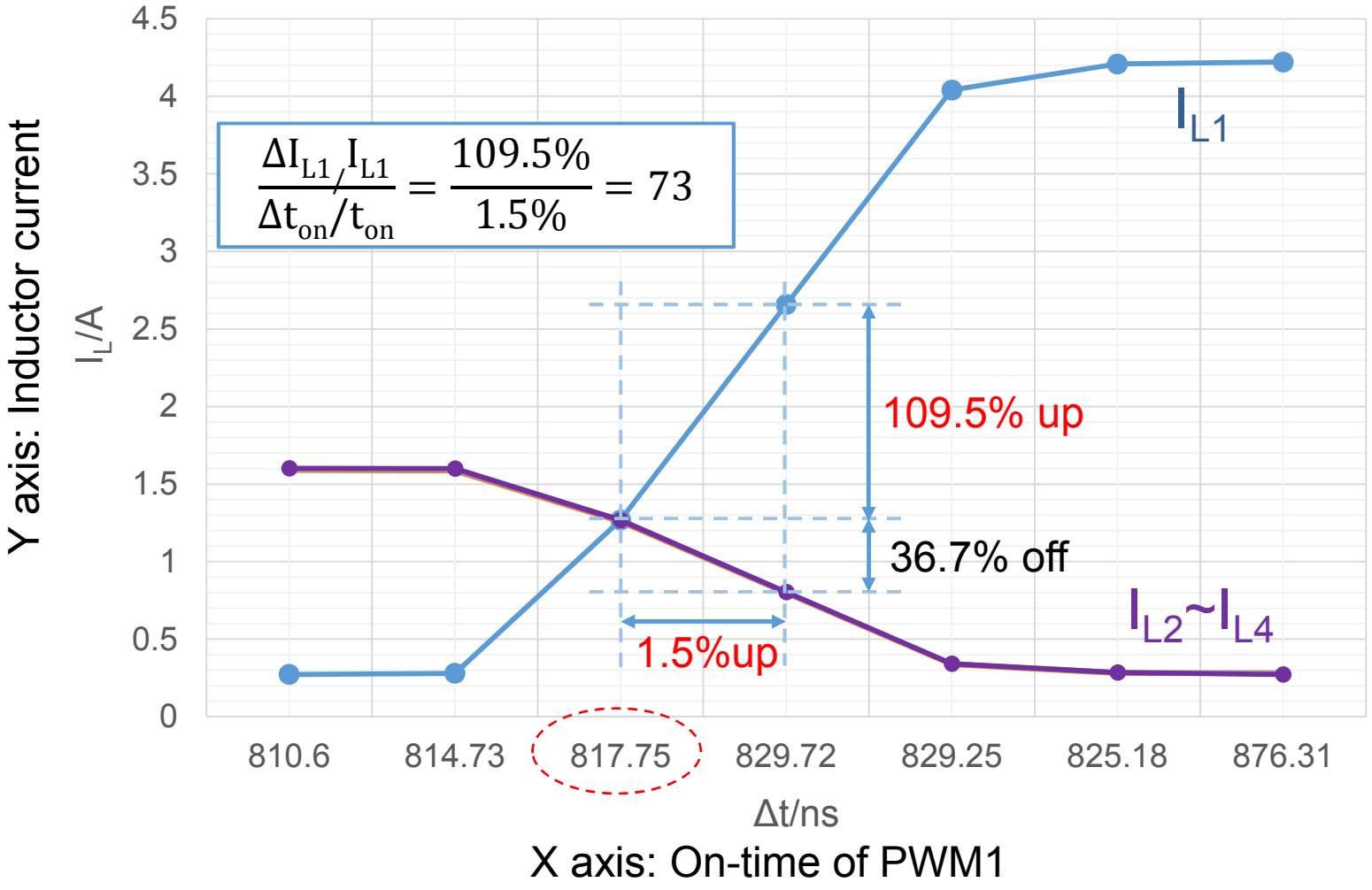
Current balance shows extreme low sensitivity to Inductance of L1

Current balance via ESR of L1



Current balance shows
low sensitivity to ESR of L1

Current balance via on-time of PWM1

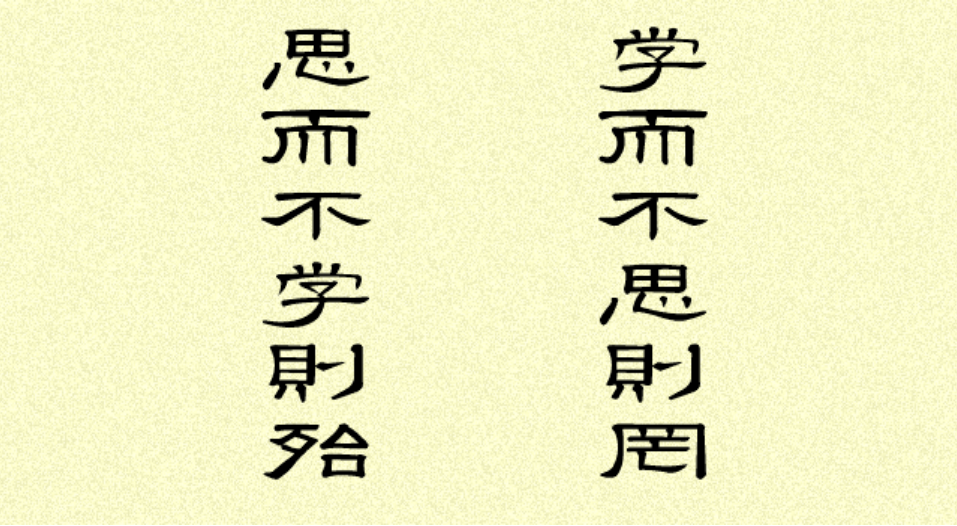


Current balance shows extreme high sensitivity to on-time of PWM1

Conclusion

- Proposal of four-phase DC-DC converter with constant-on-time control
- Four-phase PWM generators designed with analog circuits
- Good current balance, Large load current
- Low output voltage ripple, Fast response
- Current balance offset via ΔL1 shows low sensitivity
- Current balance offset via on-time of PWM1 Δt shows high sensitivity and the Δt must be set at a certain time with few deviation

Thank you for your attention



Q&A

- Q:Will your make the converter into six-phase or more
- A:Of course. But the first thing I have to do is to make the circuit into practical application. As you see, it is not enough to test the characteristic just by simulation.