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

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Research Objective

Objective

Development of power supply with

- EMI noise Reduction
- Fast response
- Low output voltage ripple control

Approach

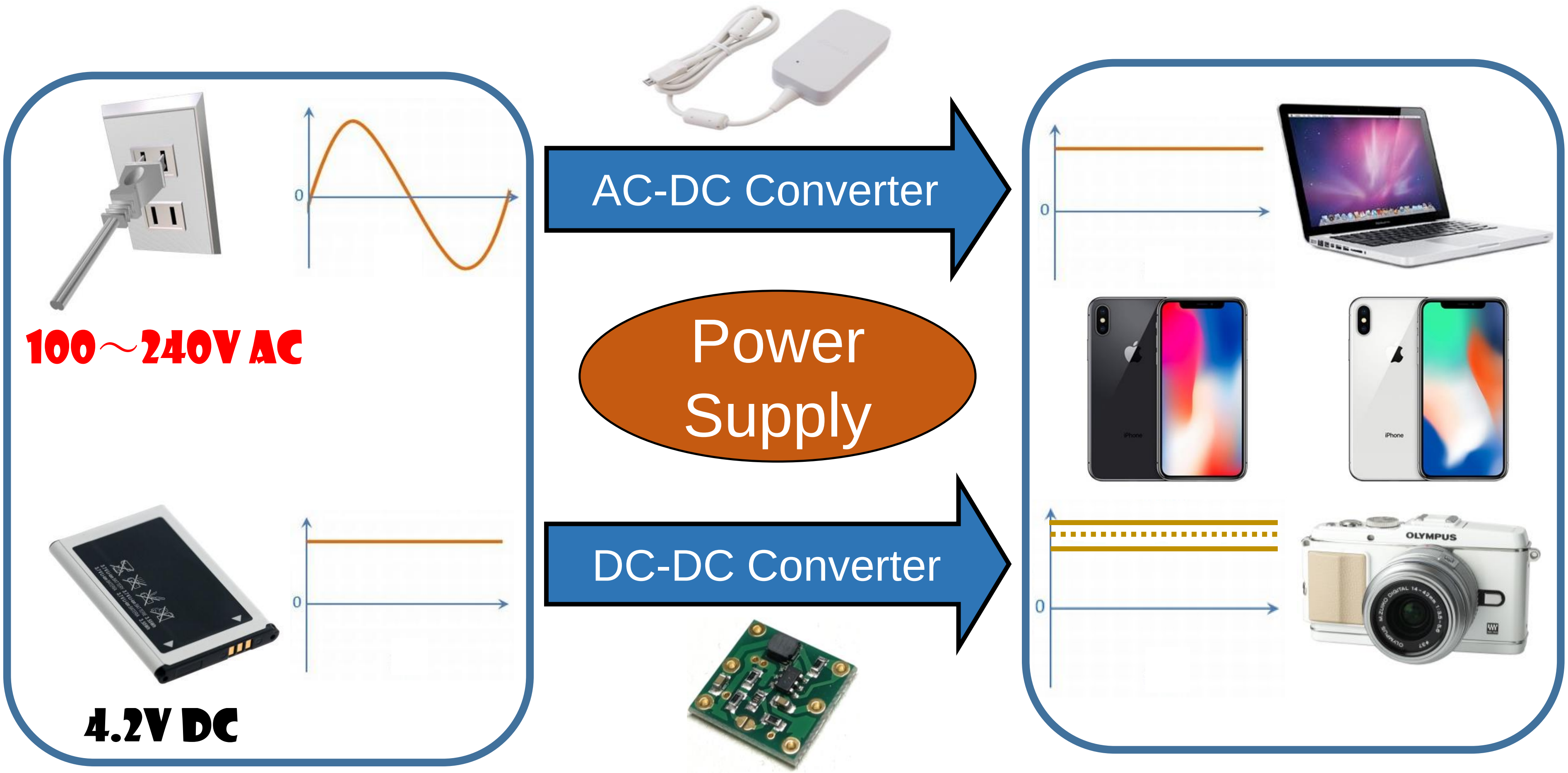
- Constant on-time control
- Multi-phase

Contents

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

Contents

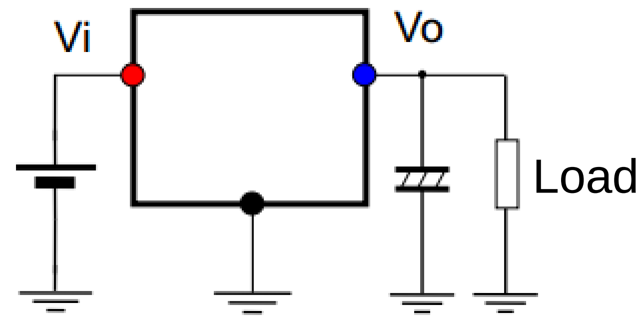
What is Power Supply



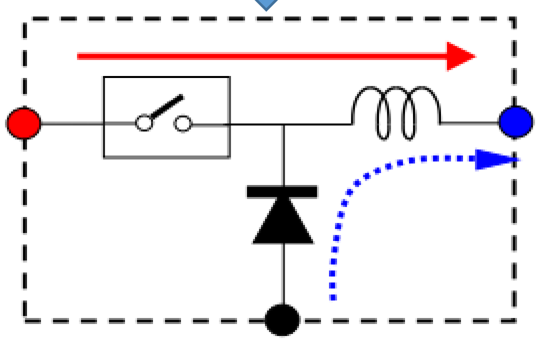
Power supply ➡ demanded everywhere
to provide appropriate voltage for electronic device

Classifications of DC-DC Converter

DC-DC converter

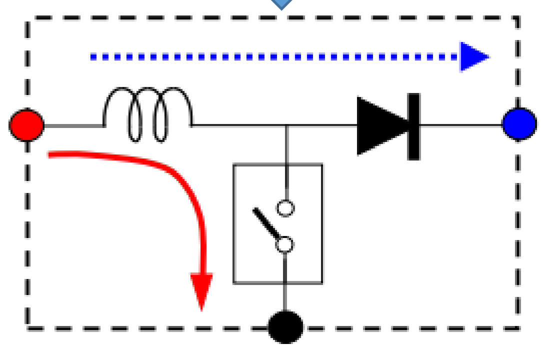


Basic configuration



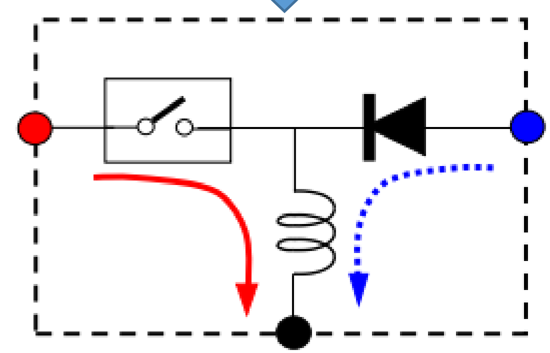
Buck

Vin＞Vo



Boost

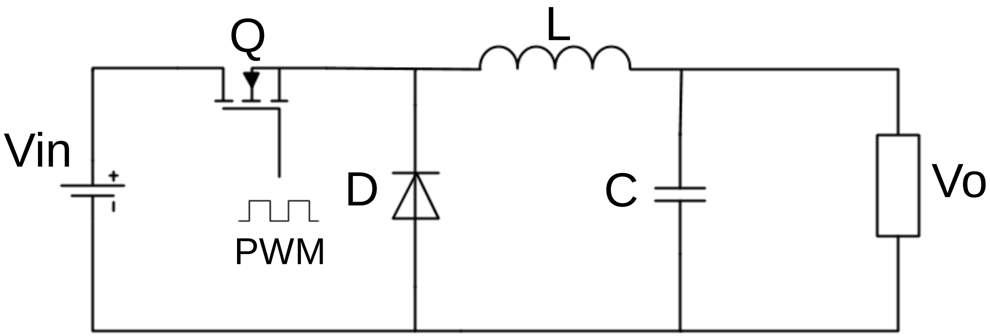
Vin＜Vo



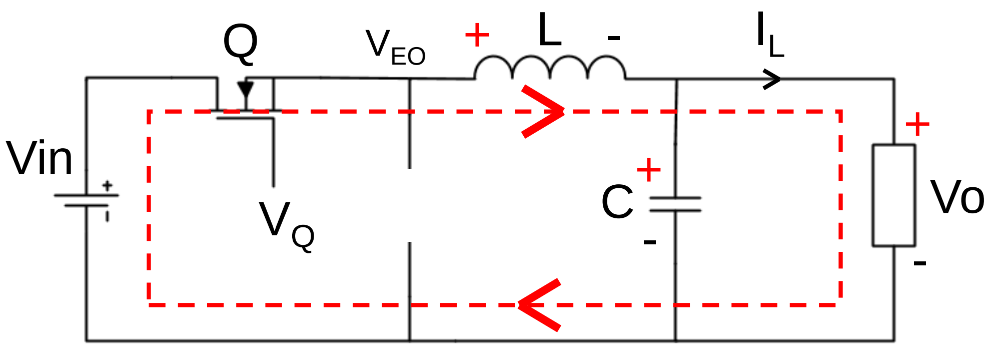
Buck-Boost

Vin $\gtreqless$ Vo

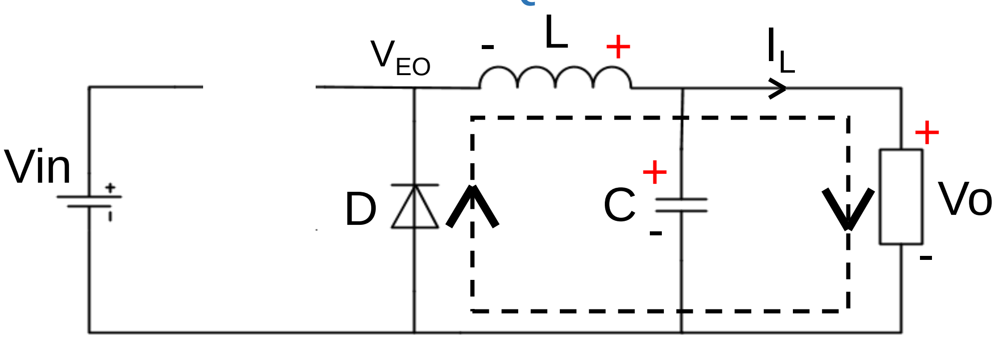
Operation of Buck Converter



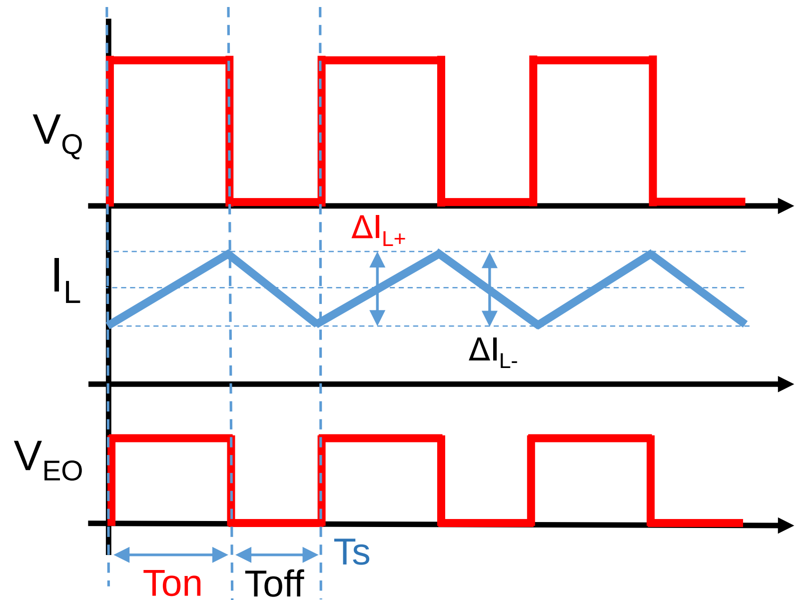
Buck Converter



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

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

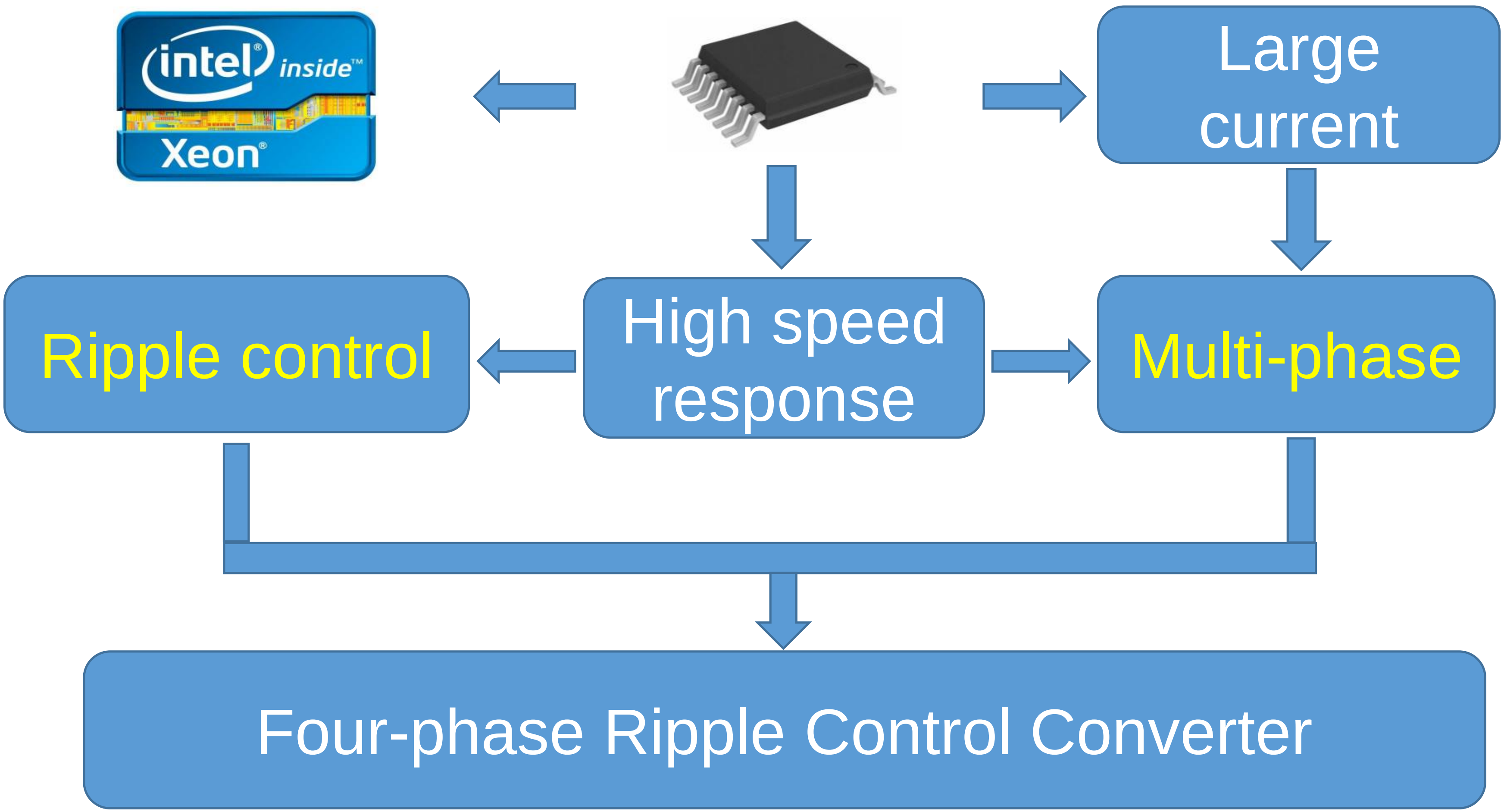
Volt-second balance

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

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

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



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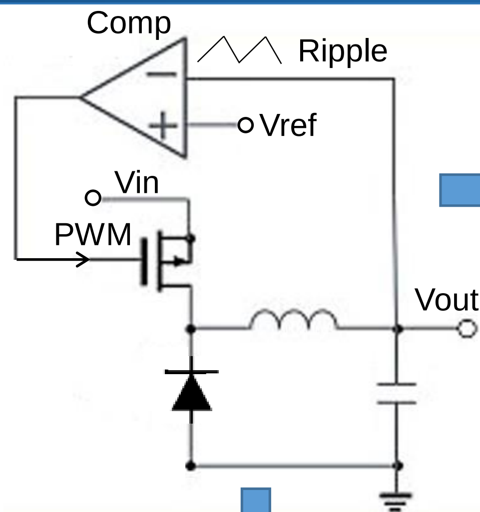
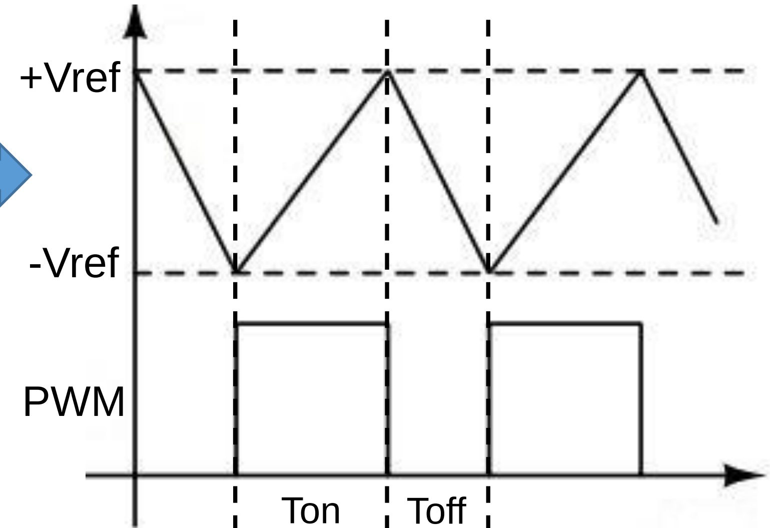
Merit of Constant on-time control

Ripple Control

Hysteresis window control



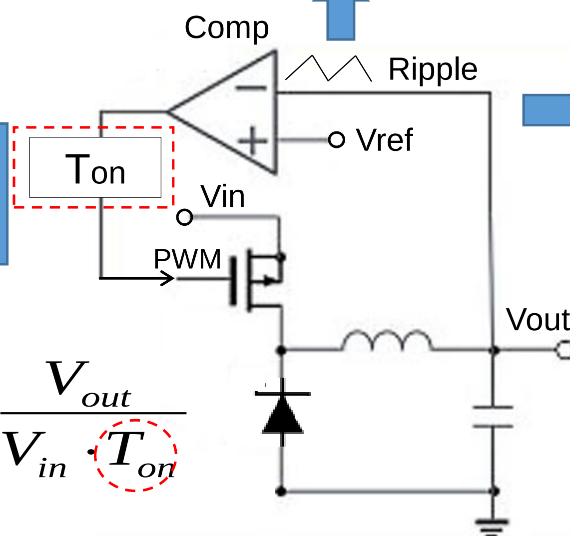


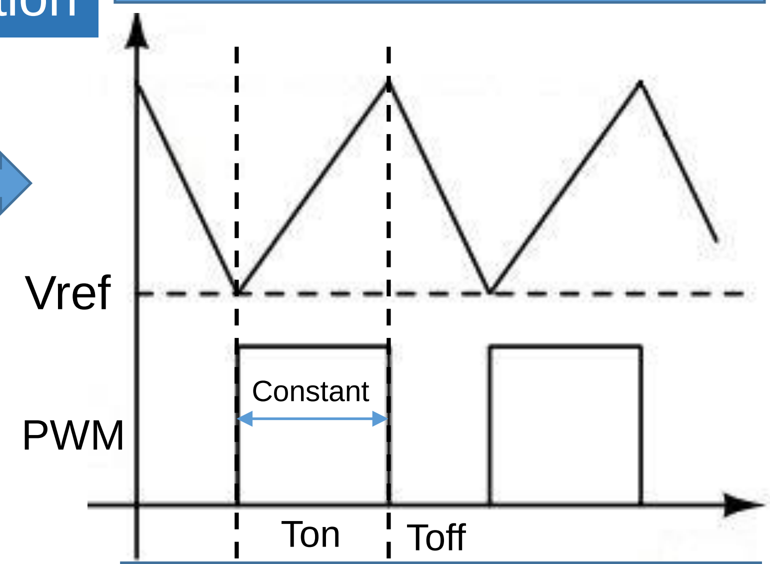
Frequency swings usually

No phase compensation

Extreme fast response

Constant on-time control





Frequency keeps stable

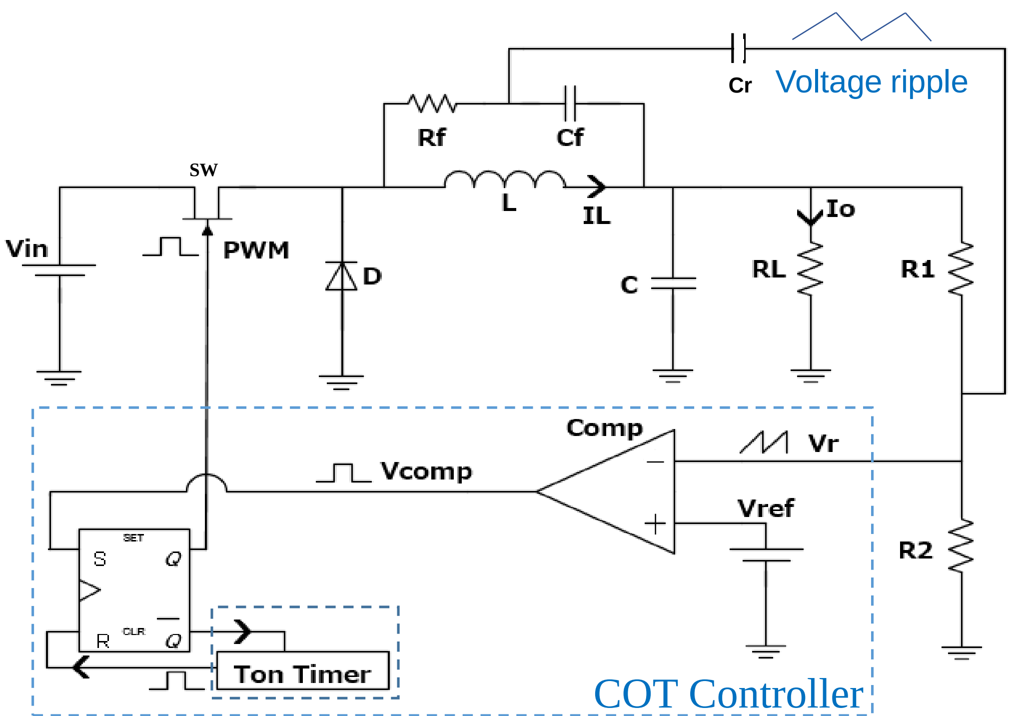
$$V_{out} = V_{in} \frac{T_{on}}{T_s}$$

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

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

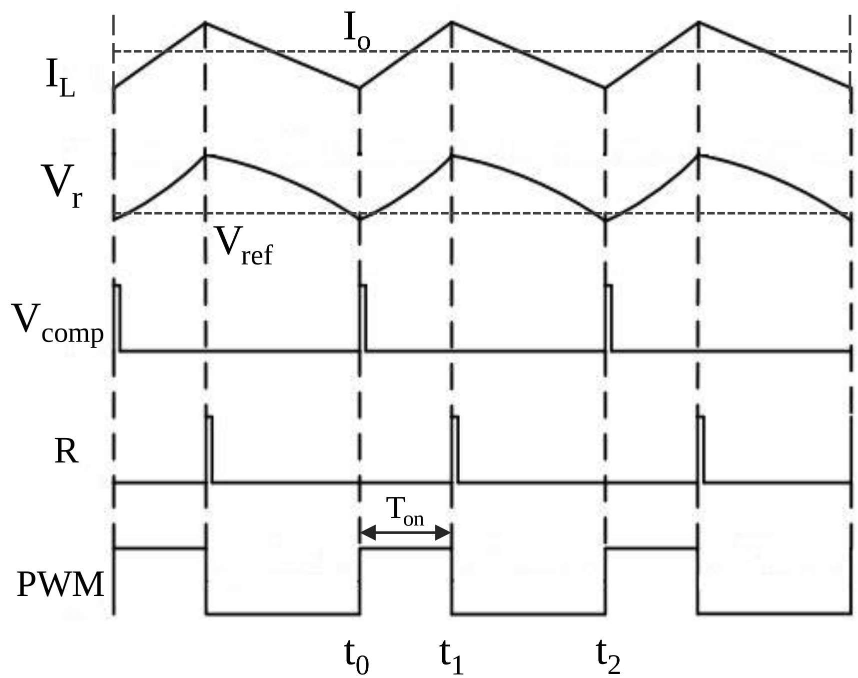
Operation of Constant on-time control

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, Ton timer starts

④ Ton timer is over

⑤ RS flip-flop is reset

⑥ PWM goes to LOW.

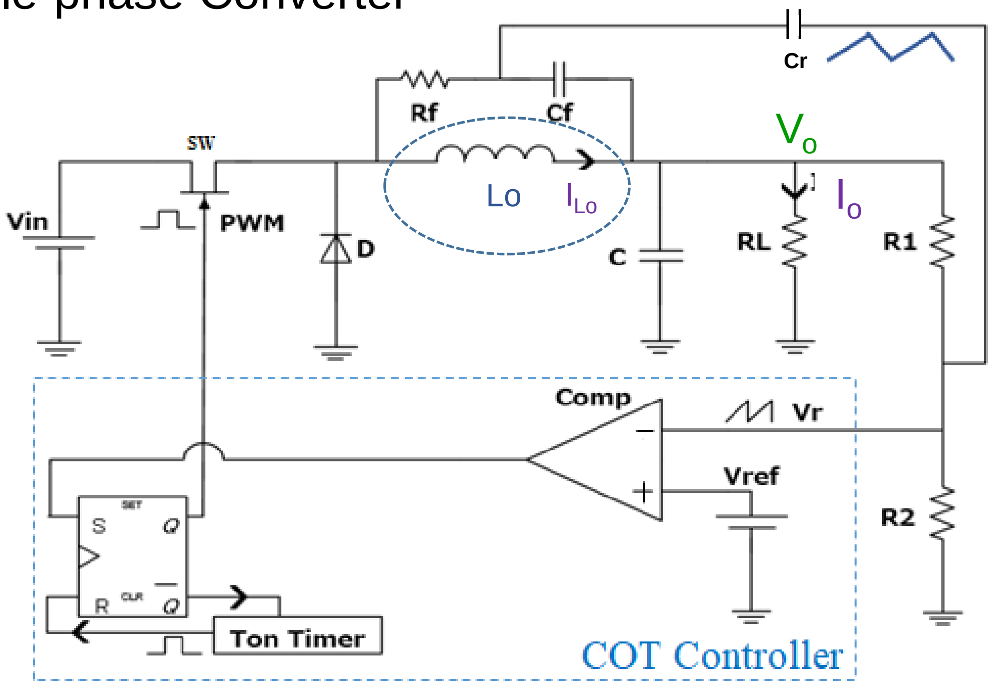
State t_1~t_2

⑦ PWM keeps LOW until next cycle

Contents

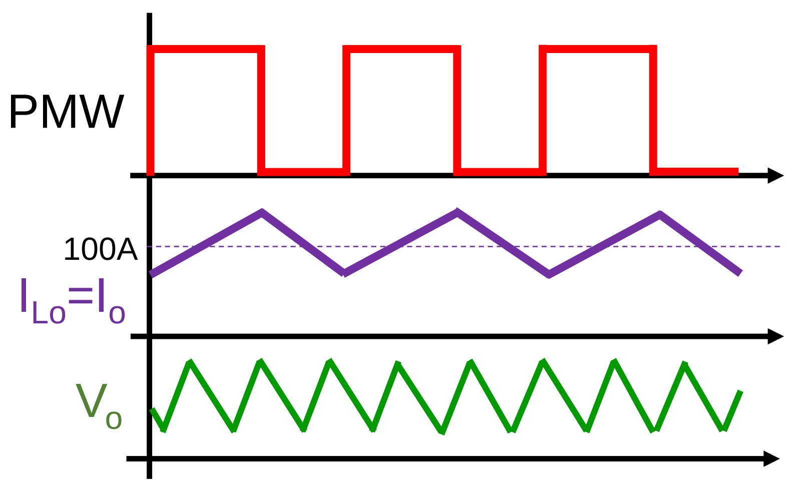
Demerit of Single-Phase Converter

Single-phase Converter

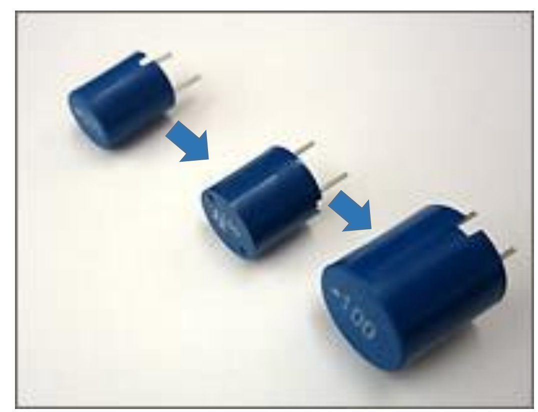


Io flows
only through inductor Lo

Lo large

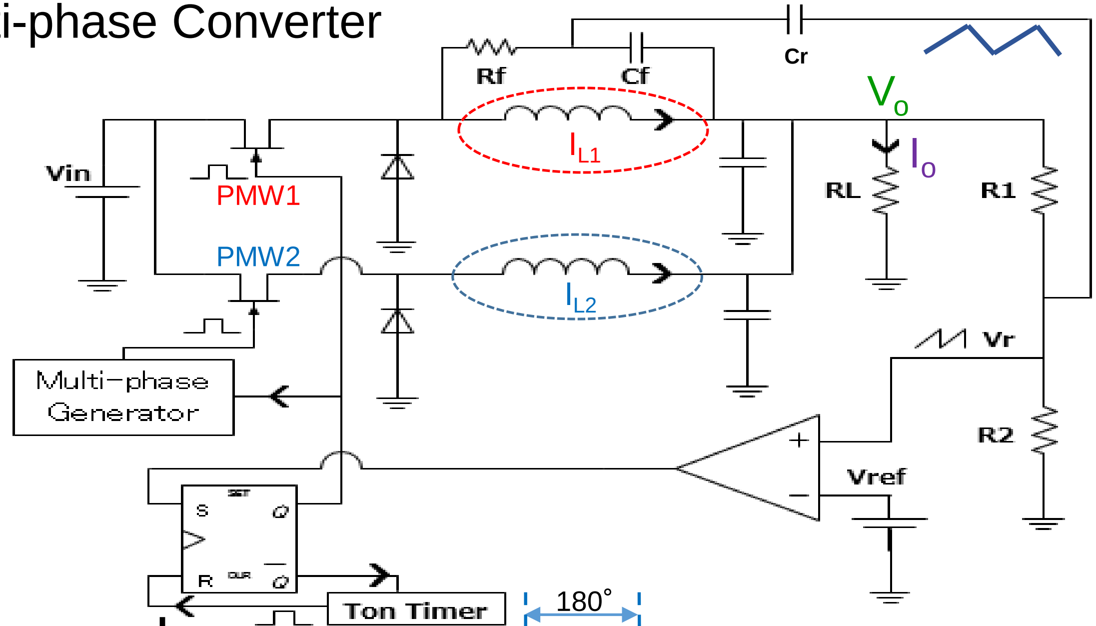


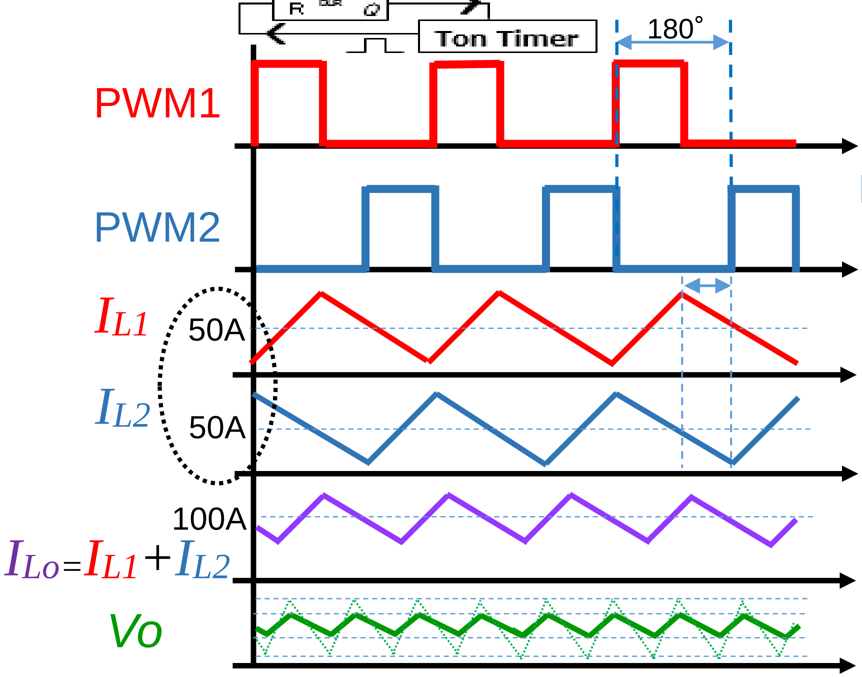
Large load
on inductor Lo



Merit of Multi-Phase Converter

Multi-phase Converter





Tracking PWM2 with PWM1 without clock is demanded

Inductor L1 and L2 will go shares with Io

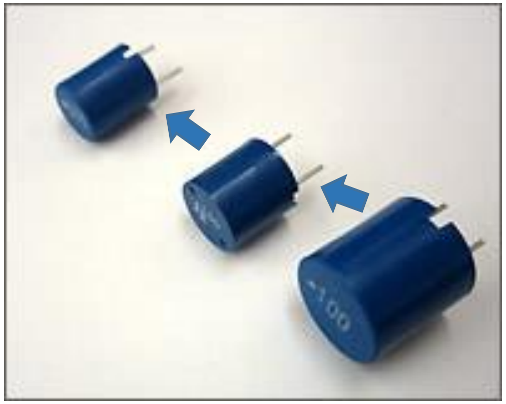
L1 and L2 small

180° phase difference

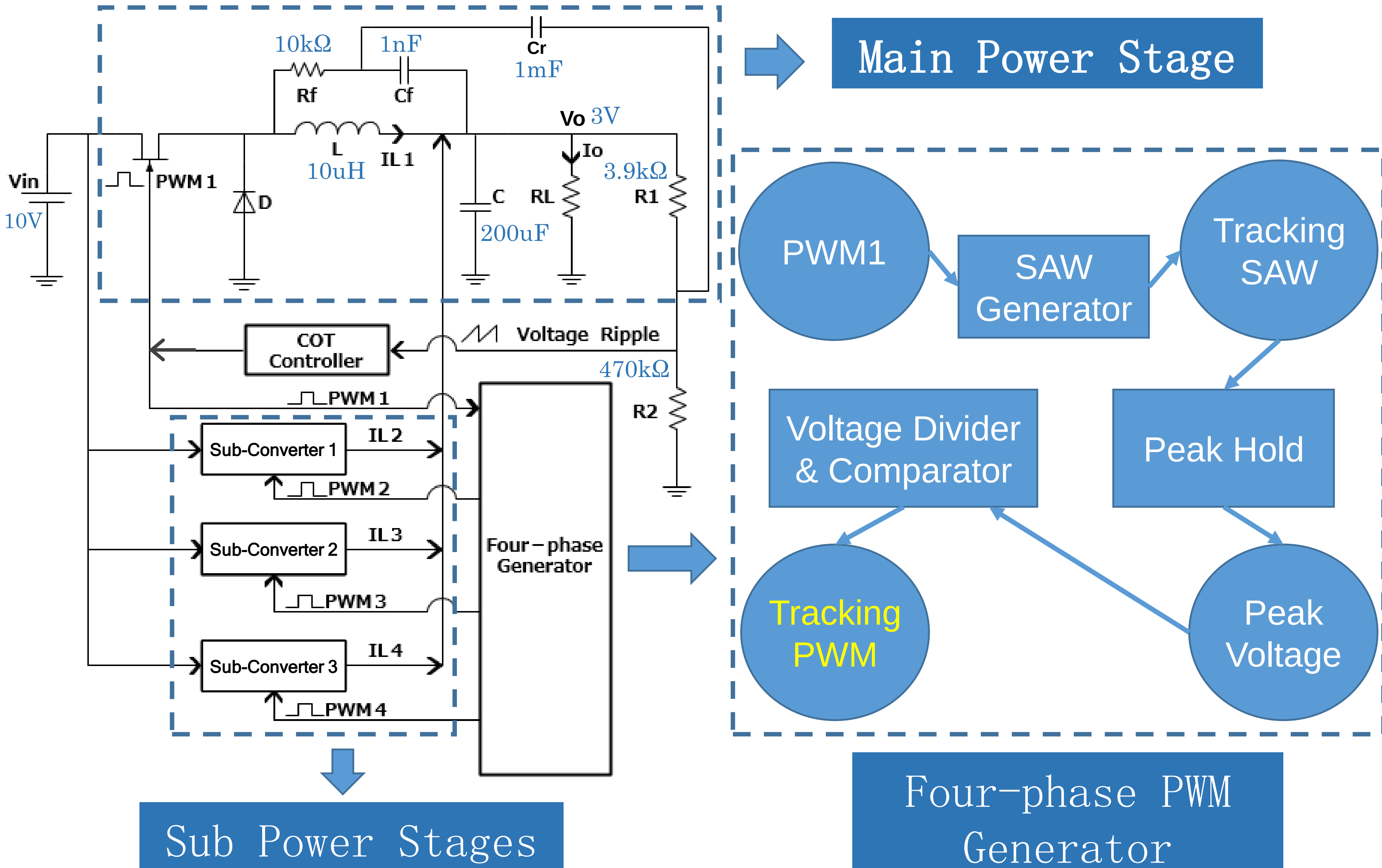
Load of each phase's inductor halved

Simulative frequency multiplication

Low ripple by shifted two-phase peak current

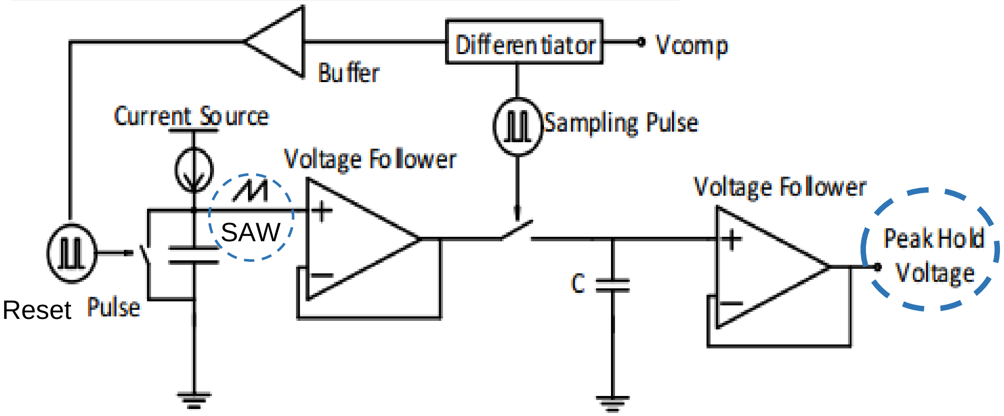


Proposed Four-Phase Converter Solution

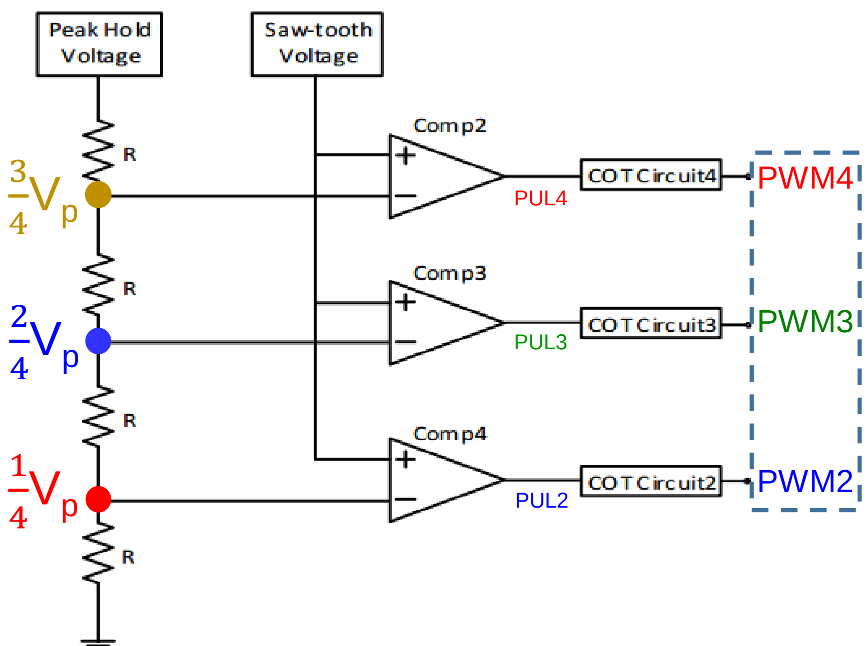


Generation of Four-Phase PWM

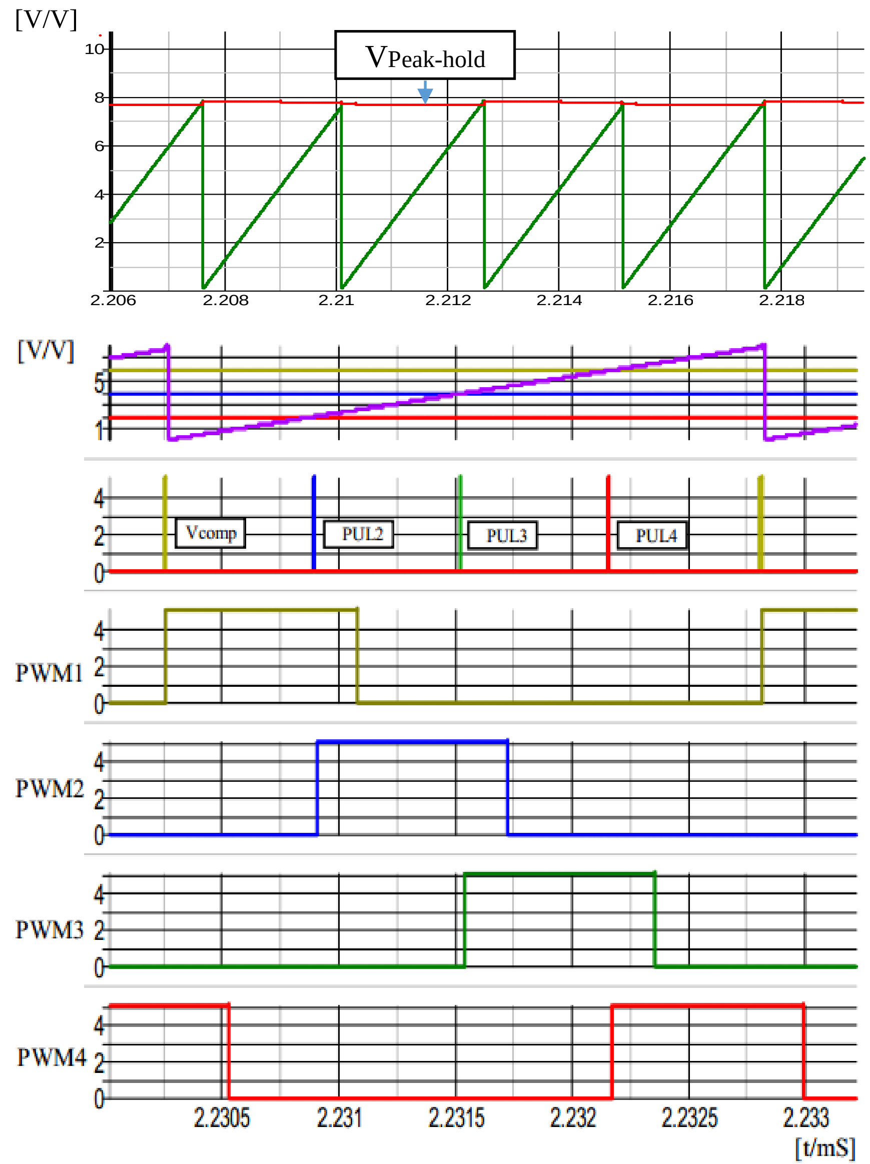
SAW Generator & Peak Hold



Voltage Divider & Comparator



Operation waveform



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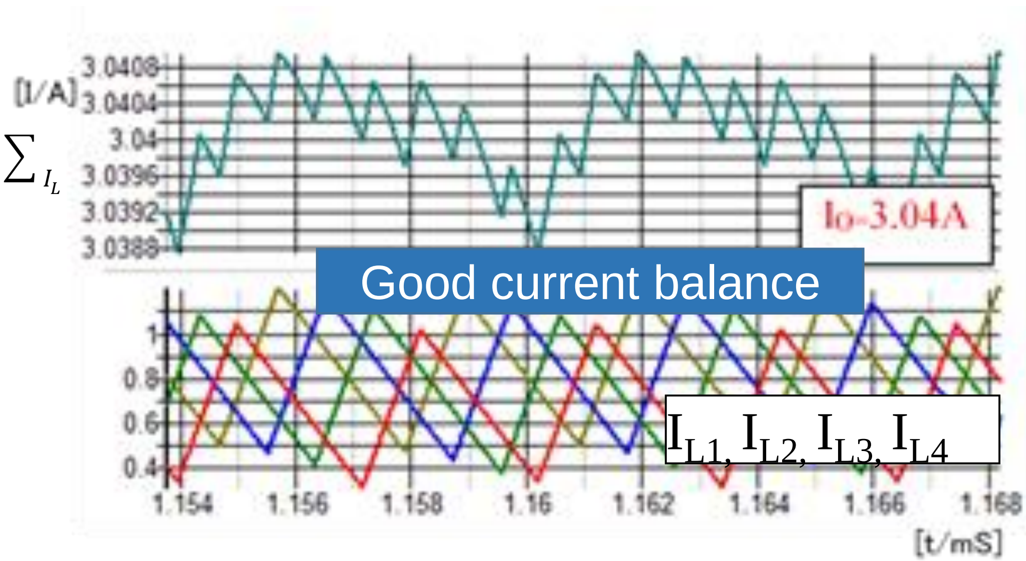
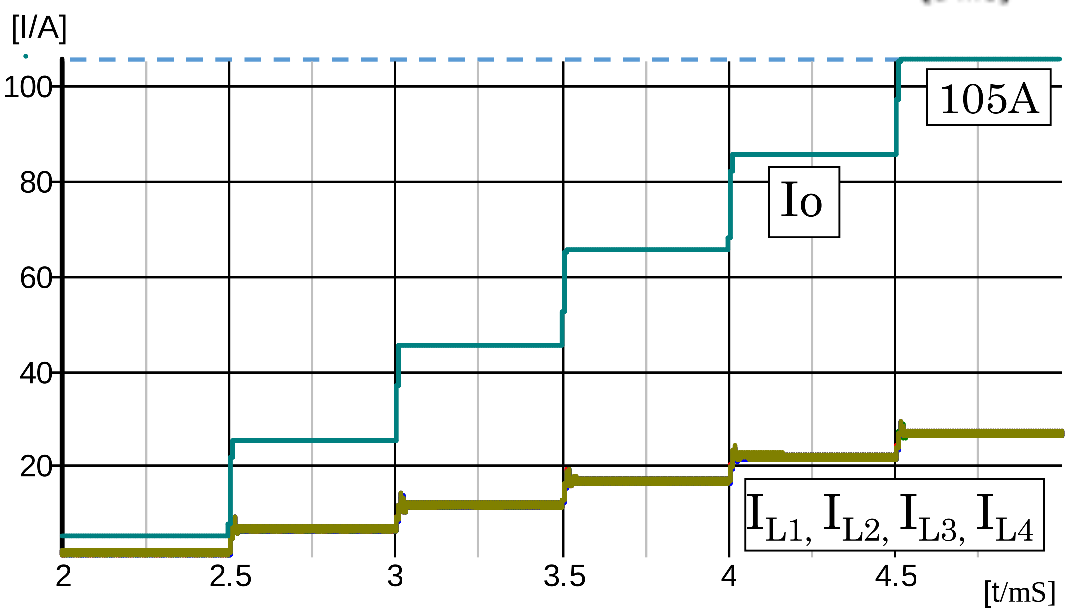
Current Balance





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

$I_o = 3.04A$

I_{L1}, I_{L2}, I_{L3}, I_{L4} = 0.67A ~0.84 A

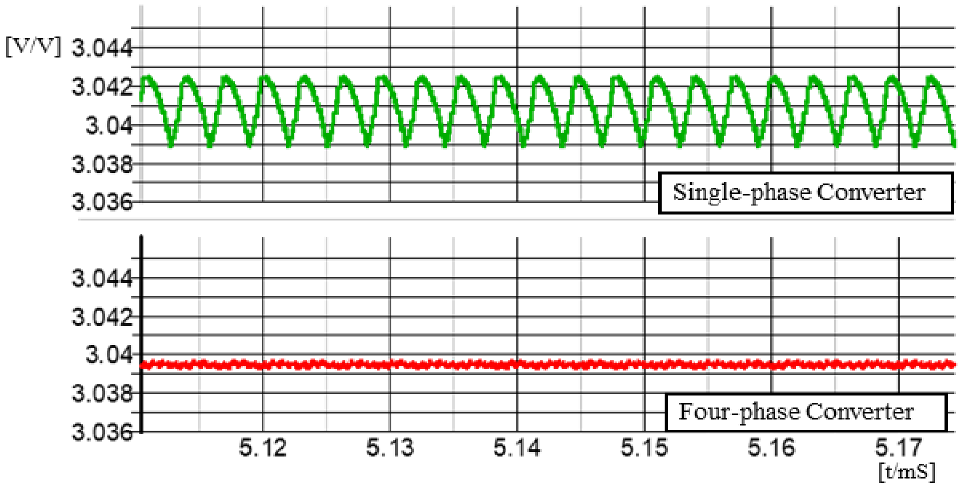
$\Delta I_L = I_L - I_o/4 = 0.09A$

$\delta = 0.09/(3.04/4) \times 100\%$
$= 11.8\%$

Large load current achieved

Good current balance during transient response

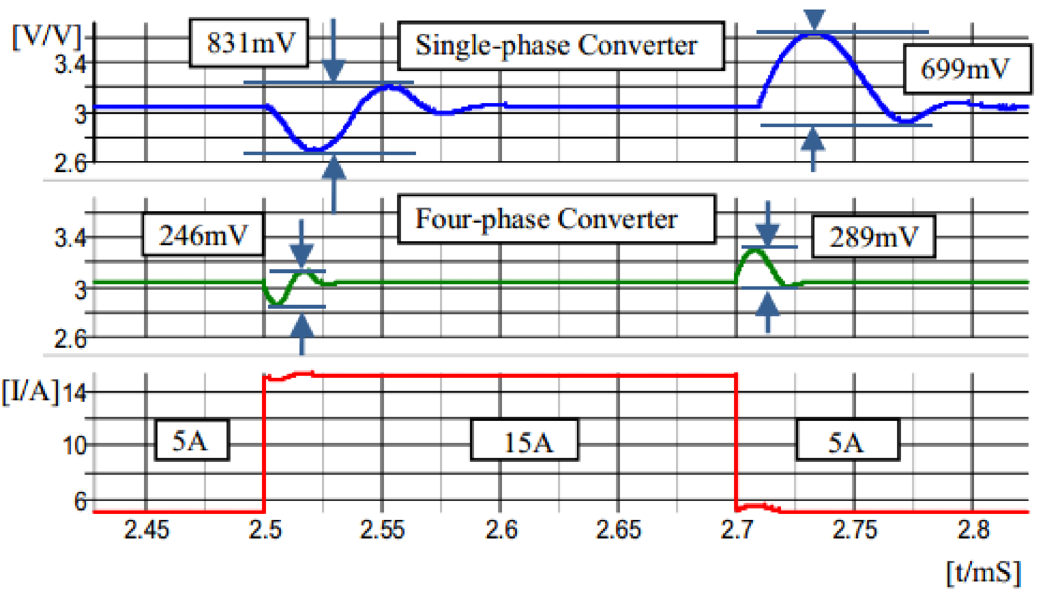
Single and multi-phase Comparison



V_{out} : 3V

Static state characteristic

	Ripple peak to peak	Ripple range
Vout	86%off 35mV⇒5mV	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

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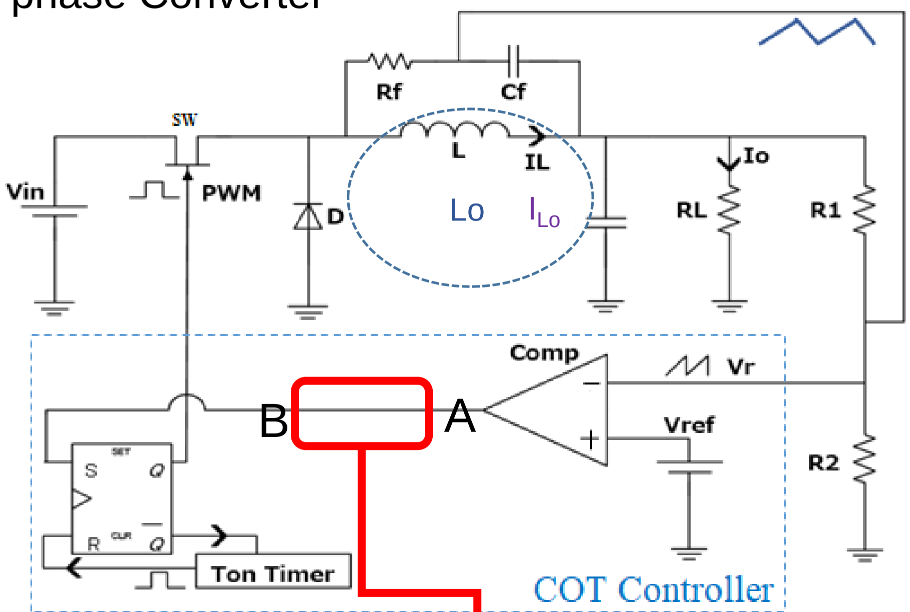
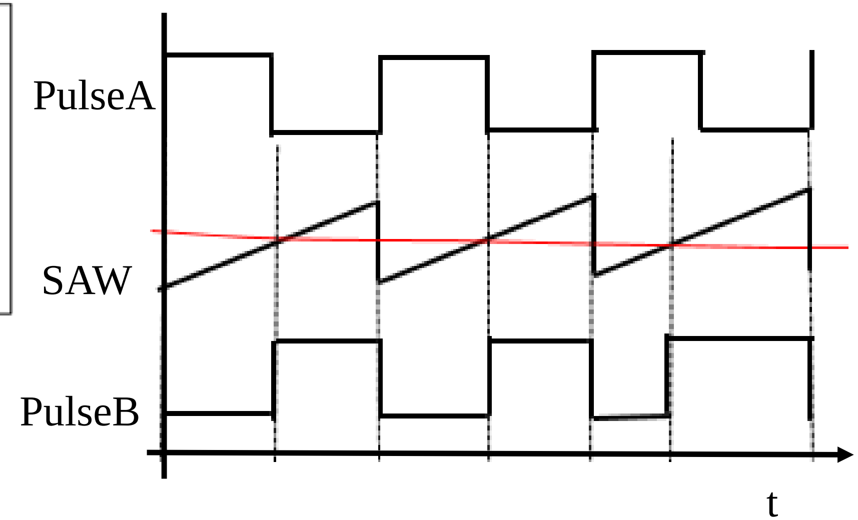
Pulse Phase Modulation

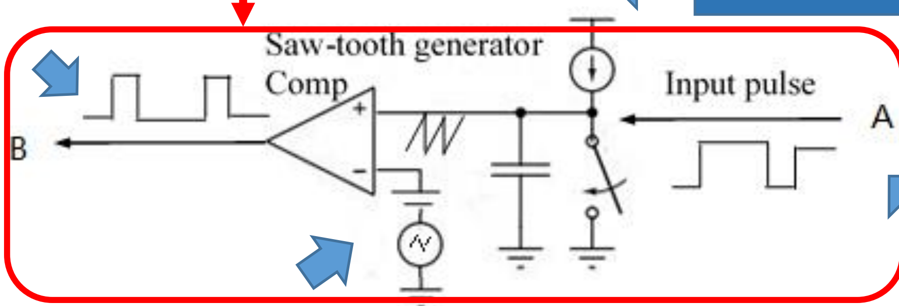
Single-phase Converter





Synchronized SAW signal to V_{comp}

Phase Modulated Pulse



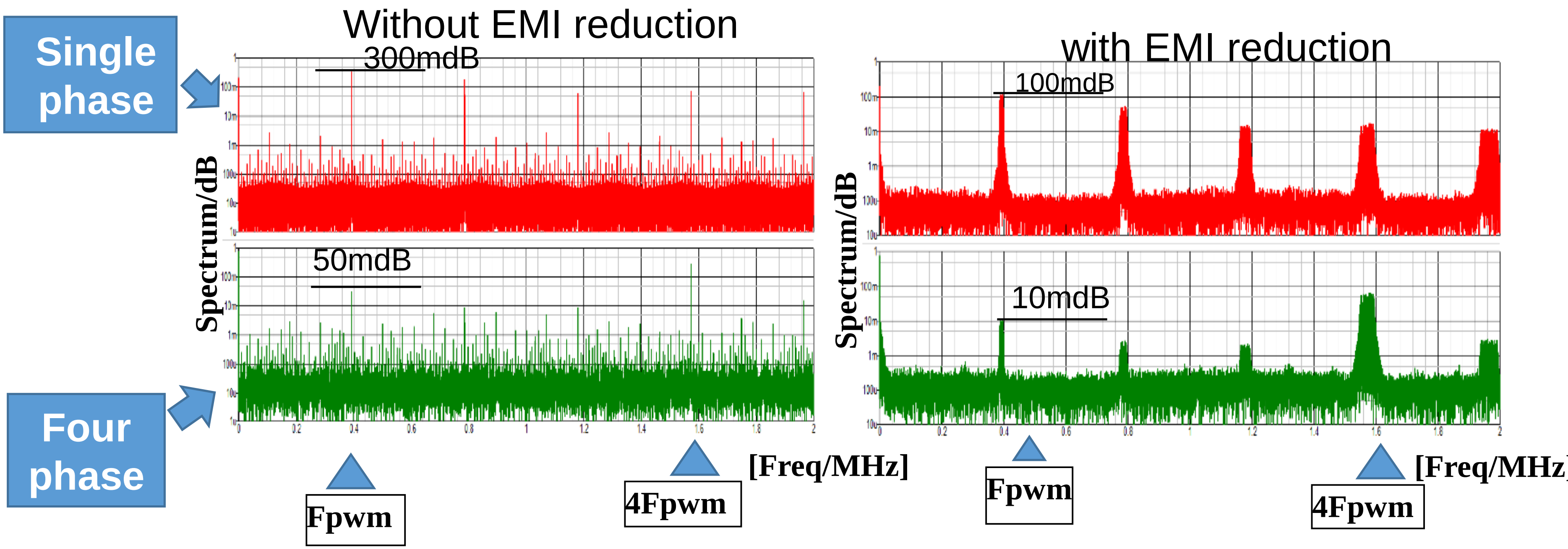
Synchronized pulse signal to PWM

Comparison between SAW & Triangle wave

EMI Reduction Circuit

Spectrum of Conductive Noise

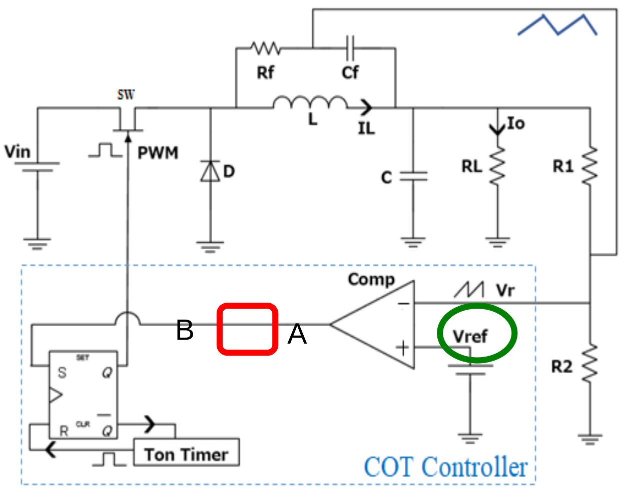
Conductive noise at input side

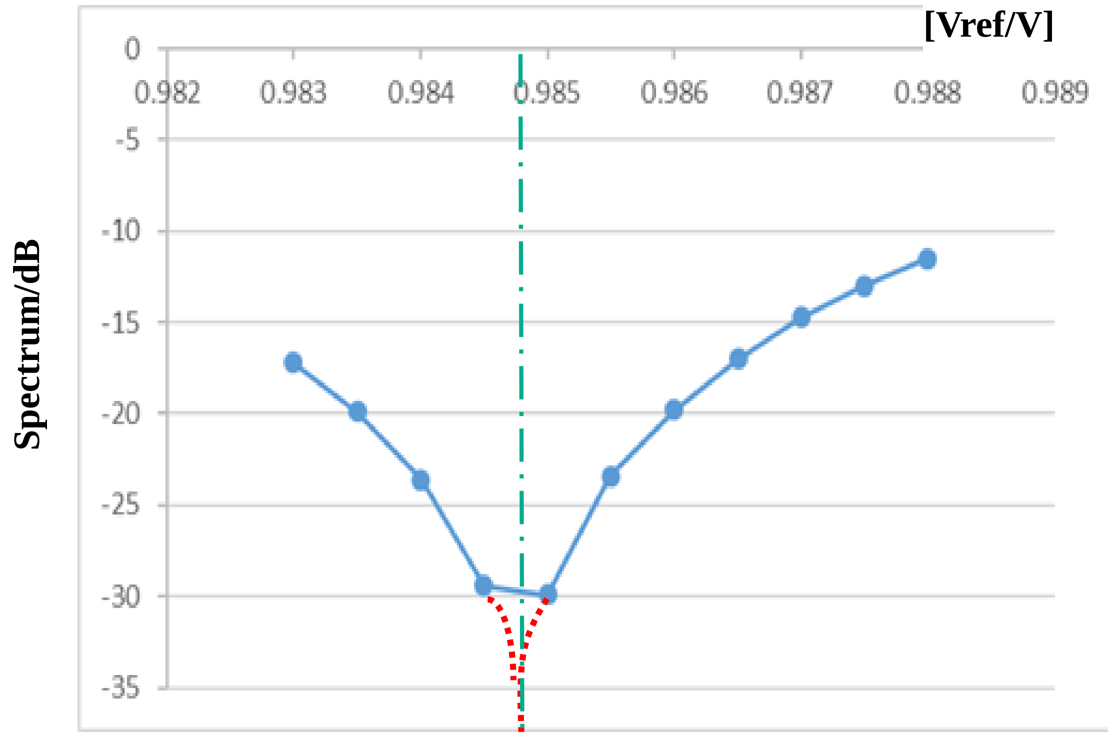


Spectrum level
at clock frequency
(Fpwm=390kHz)

Single phase	**300 mV**	→ 100 mV 9.5 dB reduction
Four phase	**50 mV**	→ 10mV 14 dB reduction

Conductive Noise and Vref





Vref

change

turn-on time of the switch

change

input current noise

input current noise

90 degrees

no spectrum

Theoretically

less level at Vref=0.9848 V

Minimum level of conductive noise

Conclusion

- Design of good relationship between conductive noise and reference voltage for COT pulse is proposed.
- Four-phase ripple controlled converter with EMI reduction is proposed
- Peak level of spectrum at 4Fpwm is reduced
- Low output voltage ripple, Fast response
- Current balance is very good even at large output current

Thank you for your attention