# Multi-Phase Full/Half Wave Type Resonant Converter with Automatic Current Balance against Element Variation

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# Contents


- Research background
- Full/Half wave type soft switching converter
- Multi-phase soft switching converter
- Automatic current balance technology
- Conclusion

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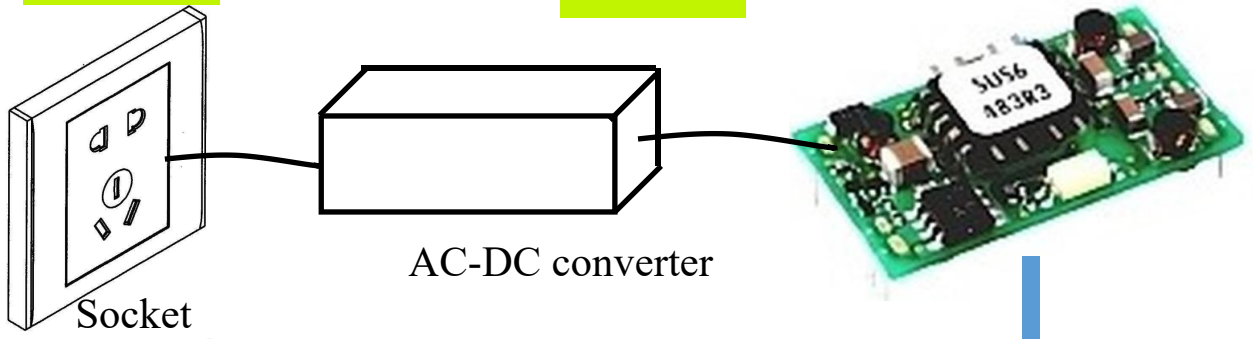
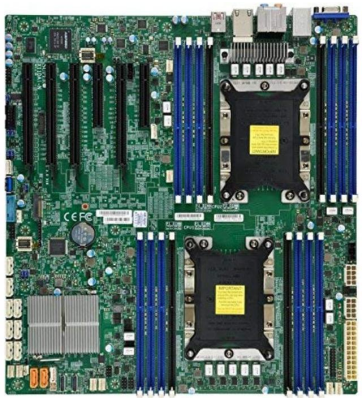
# Research Background



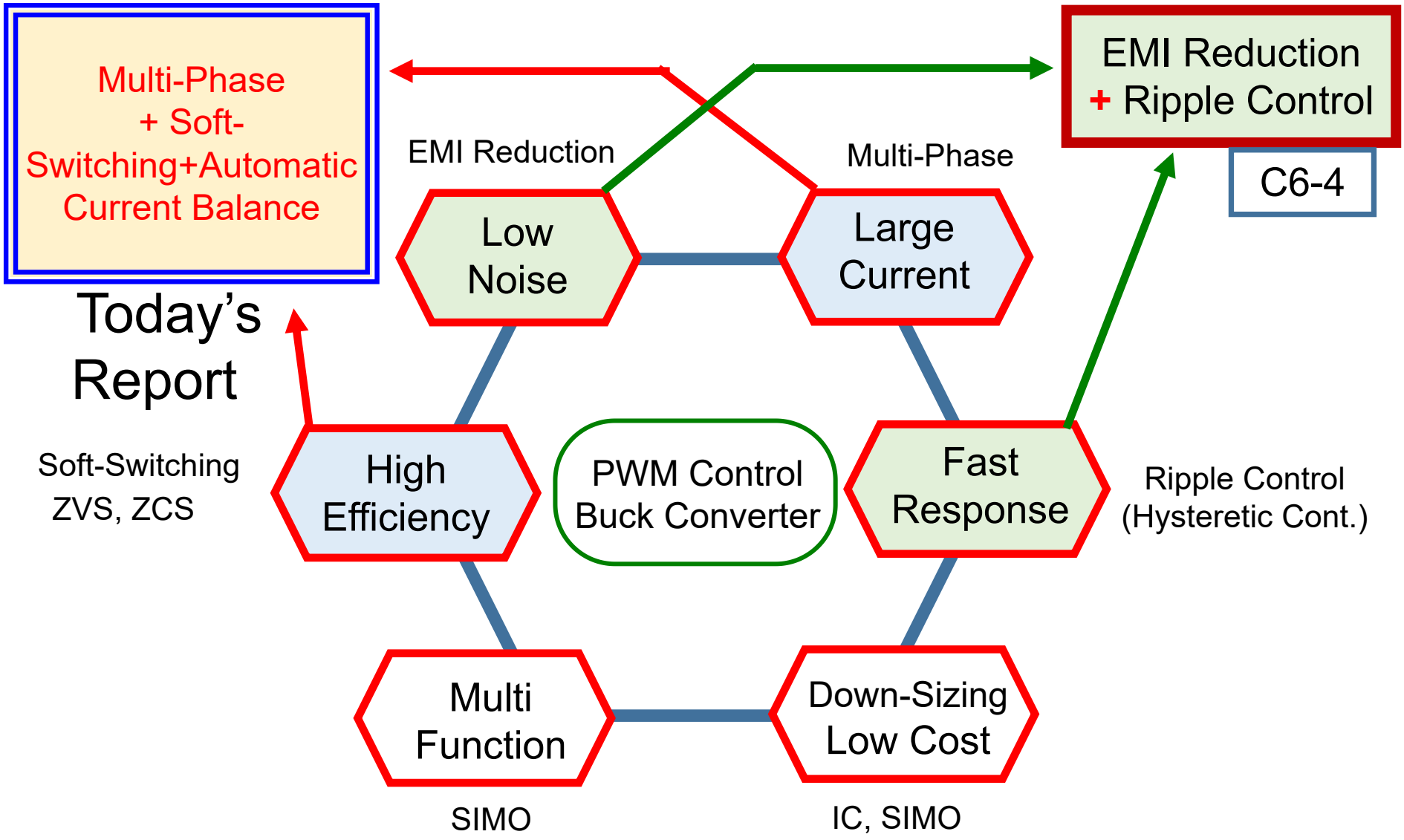

Large Current Fast Response Supplies

DC 1.3V, I >100A

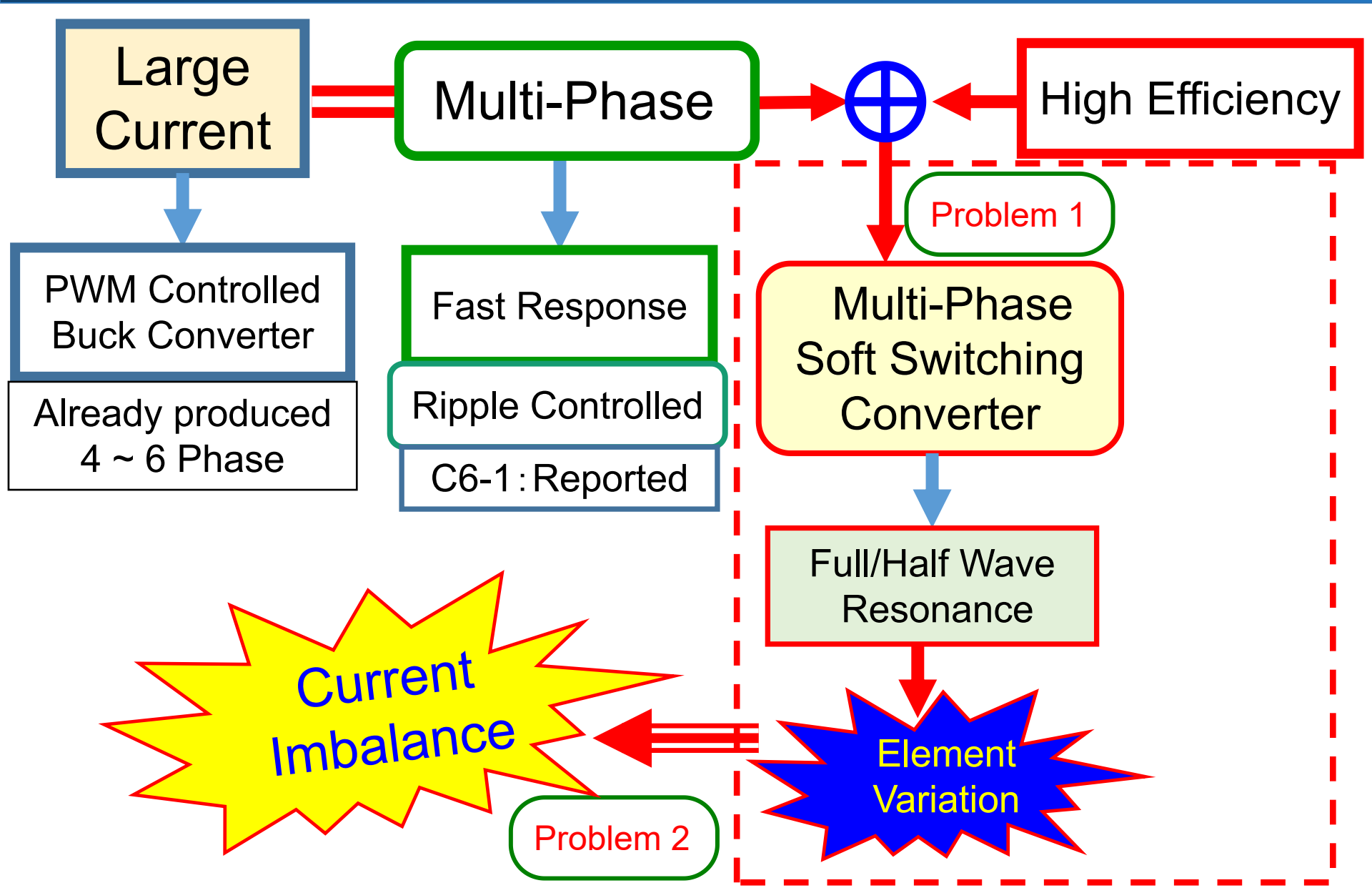
- LED Display
- Digital Camera
- Smartphone
- CPU for server

# Power supply research of Gunma University



# Today's Presentation



# Research Objective

## Objective

Development of power supply with

- Multi-phase soft switching converters with full or half wave resonance
- Automatic current balance technology against resonant element variation

## Technical Problems

1) How to configurate the multi phase constructions when there is no fixed clock pulse?
2) How to control the current balance automatically?

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# Soft Switching Converter (Full Wave)

## Soft Switching Converter with Full Wave Resonance

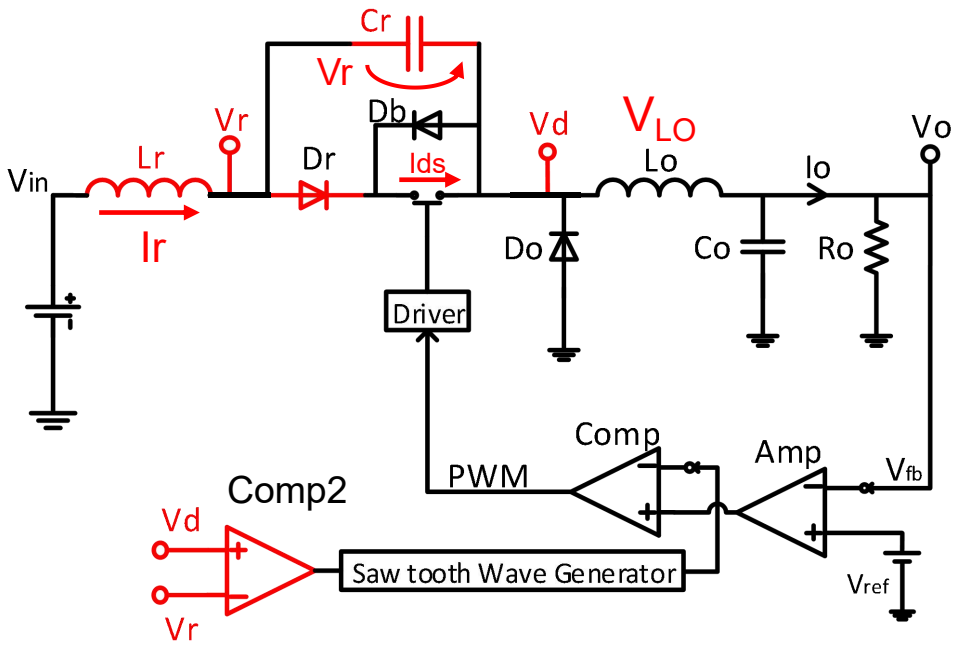


Fig. Full wave soft switching converter

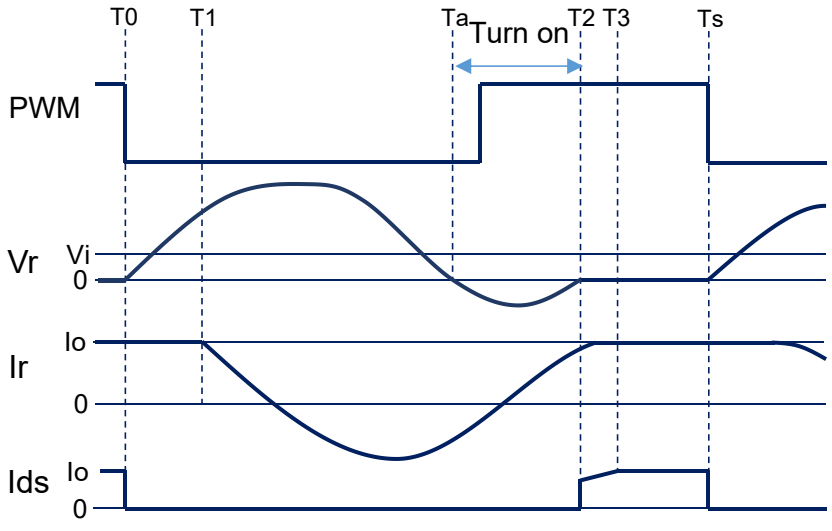


Fig. Signals of full wave converter

* Resonant elements Lr, Cr, Dr are added.
* SW turns ON at Vr=Vd.
* Vo=D·Vi : D is the duty ratio of PWM.

* Conditions: F=760kHz
  Vi=12V, Vo=7.0V, Io=1.0A
  Lo=50μH, Co=470μF
  Lr= 20μH, Cr=100pF

# Soft Switching Converter (Half Wave)

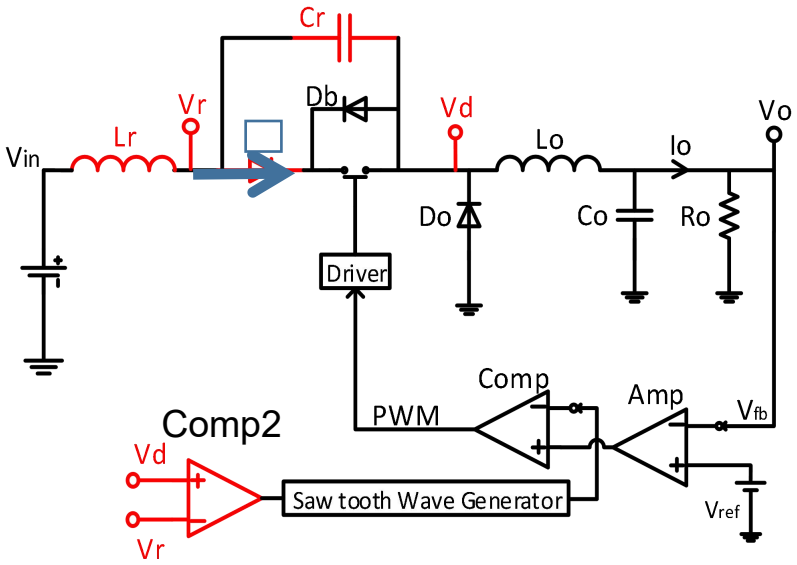


Fig. Half wave soft switching converter

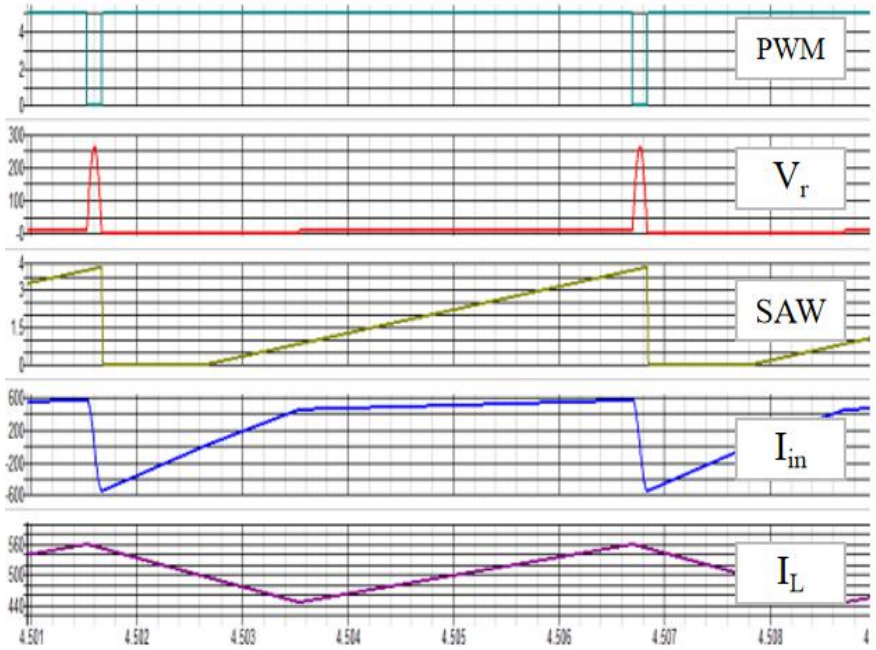


Fig. Signals of half wave converter

* Resonant Dr is deleted.
* SW turns ON at Vr=Vd but
  Vo is not =D·Vi
  (D is duty ratio of PWM)

* PWM Duty shows period of $T_{OFF}$.
* Duty ratio is represented
  by inductor current.
* Operation frequency depends on
  output current Io.

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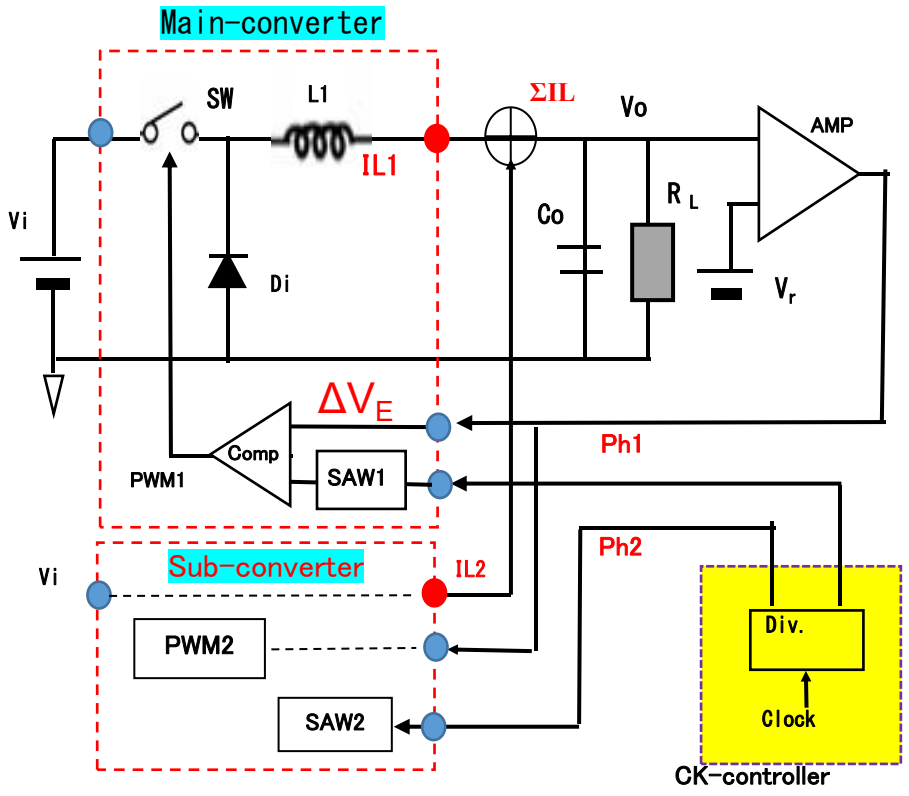
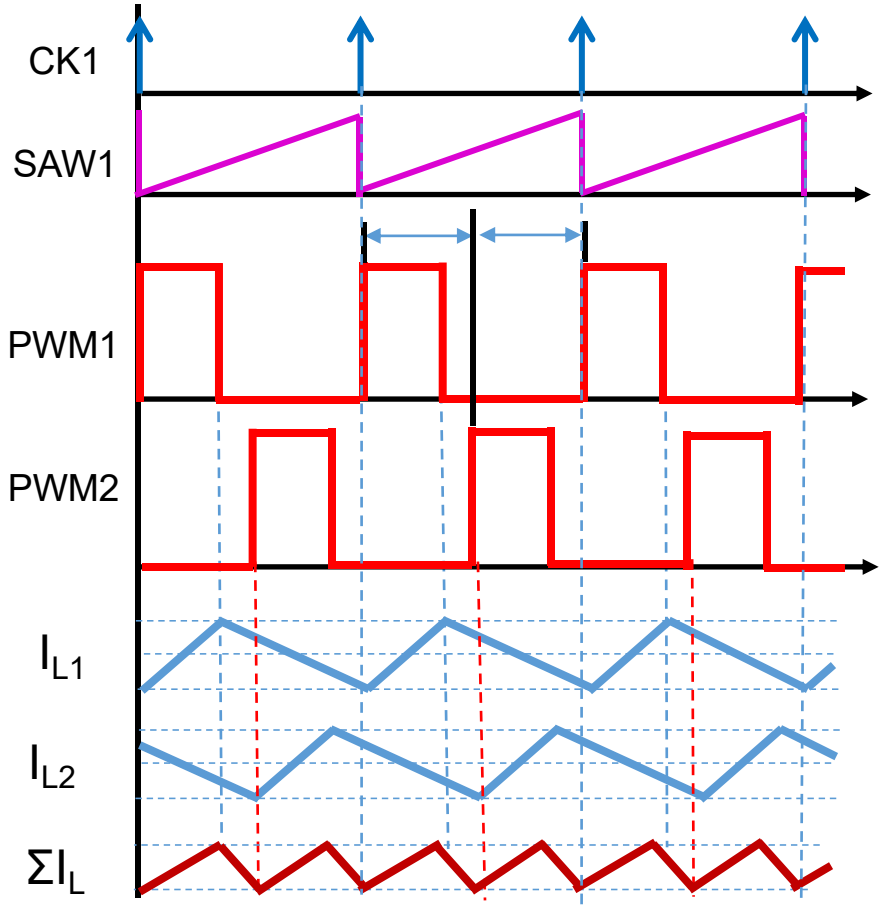
# Multi Phase Buck Converter



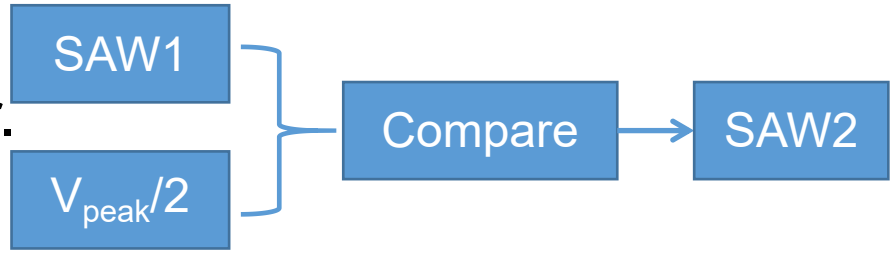




★Two−phase is provided by Flip-Flop which divides the clock pulse.

∗ PWM2 is opposite phase.
∗ Ripple of $\Sigma I_L$ is half of $I_{L1}$ .

# Dual-Phase Soft-switching Converter

- Opposite phase is generated like ripple-controlled converter.



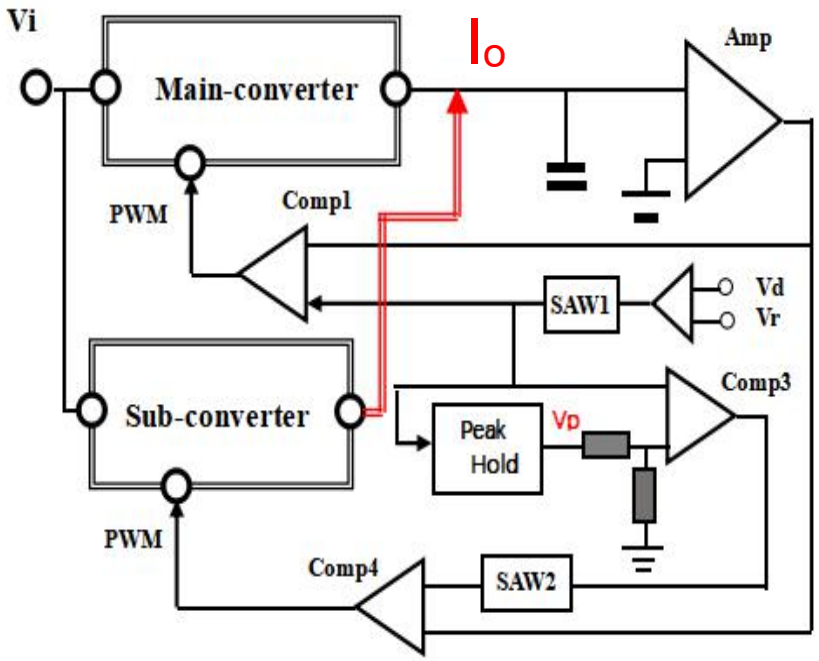




Fig. Dual phase switching converter

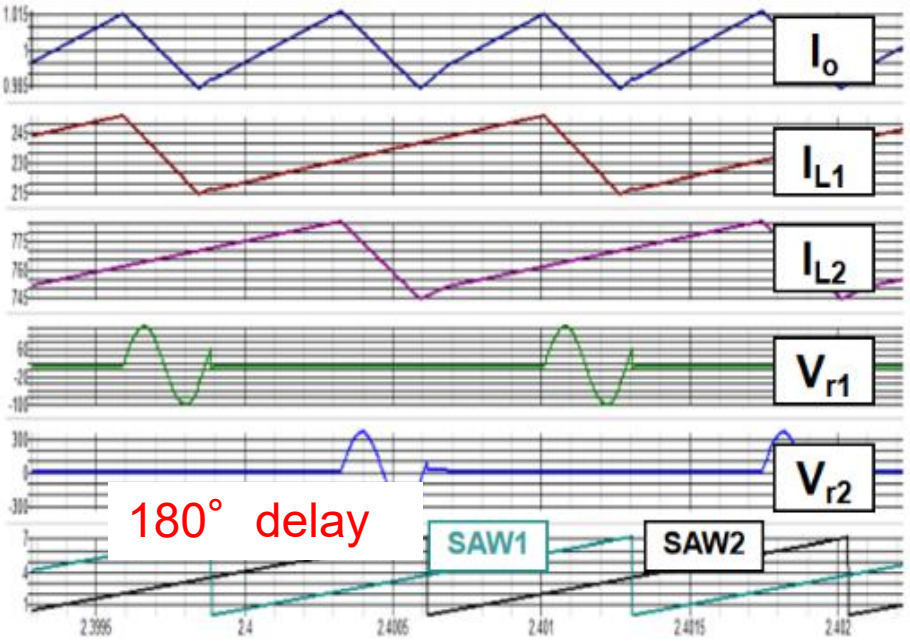



Fig. Signals of dual phase converter

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- Automatic current balance technology

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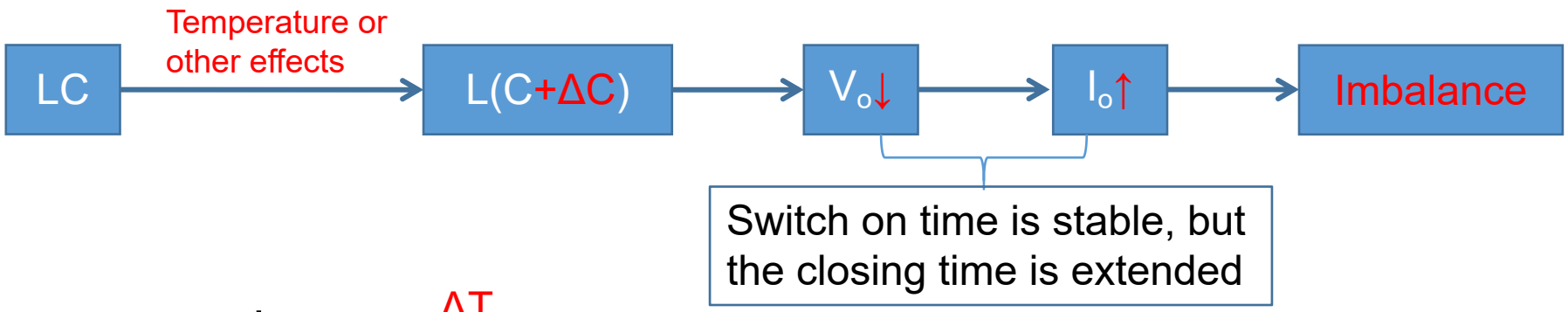
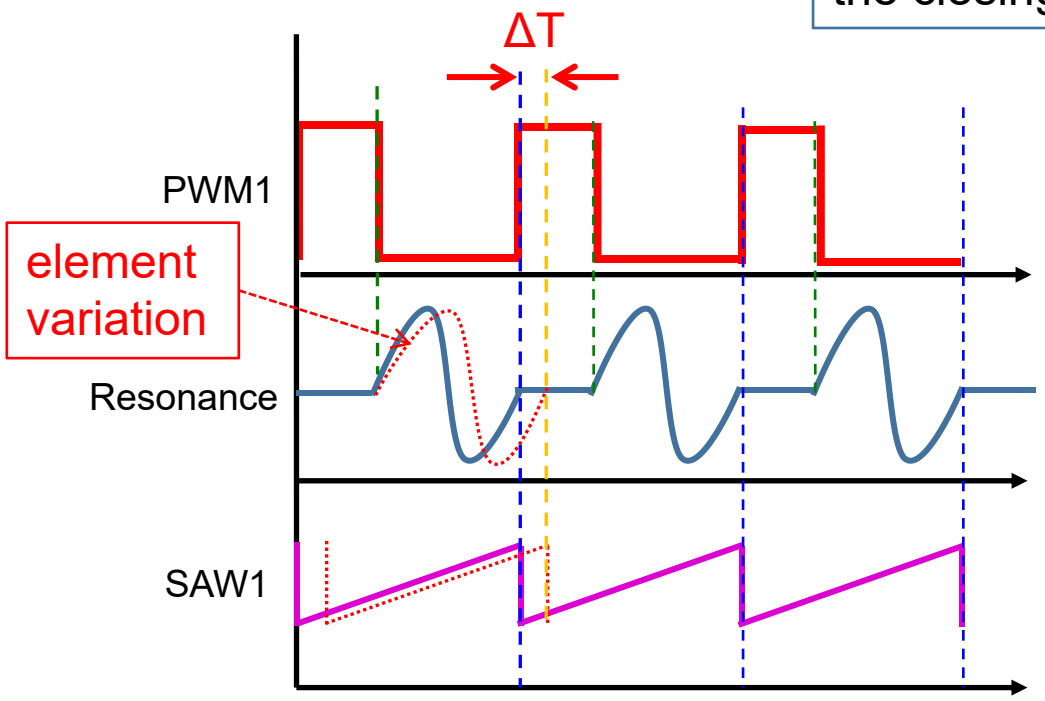
# Imbalance of Dual-Phase Converter



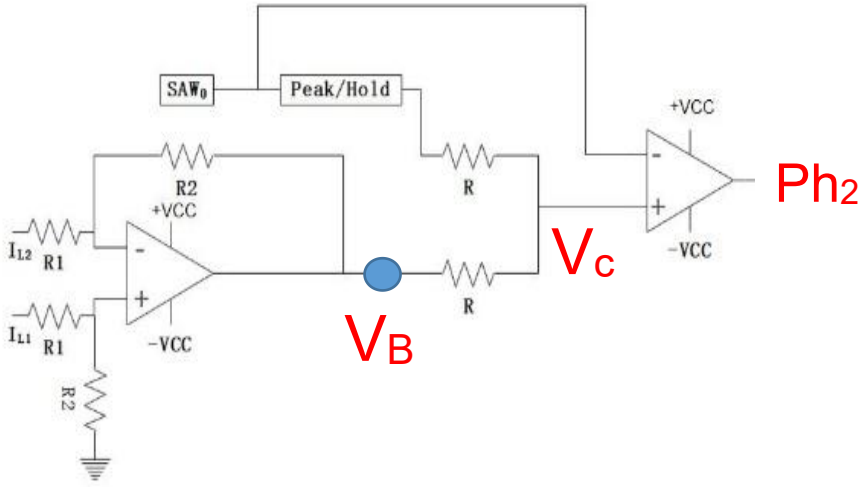



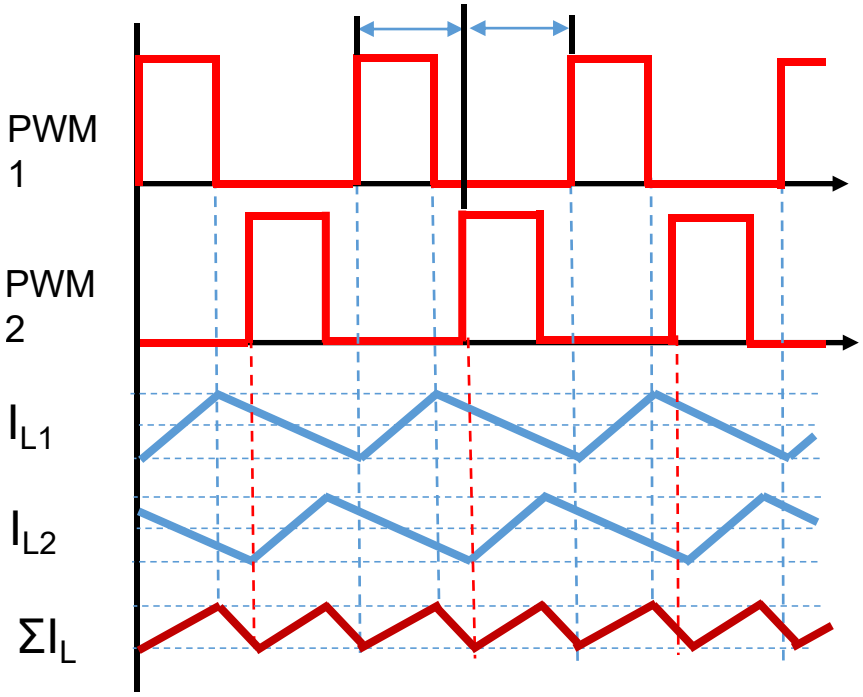

$$V_O \downarrow = V_{in} \bullet \frac{T_{on}}{T_{on} + T_{off} \uparrow}$$

# Automatic Current balance Technology

∗ When phase2 is shift to delay, the current IL2 will decrease.

∗ Detecting the current balance, When IL2 > IL1,
make the bias voltage $V_B$ down.
⇒ Phase 2 shifts delayed and IL2 is decreased.



# Imbalance of Dual-Phase Converter

∗ Current balance

1) Current balance with ideal elements

2) Current imbalance with element variation

●Demerit of current imbalance

1) Output ripple increases!

2) Inductor current increases & loss goes up & heat up.

3) Semiconductor (SW) needs large current & heat capacity

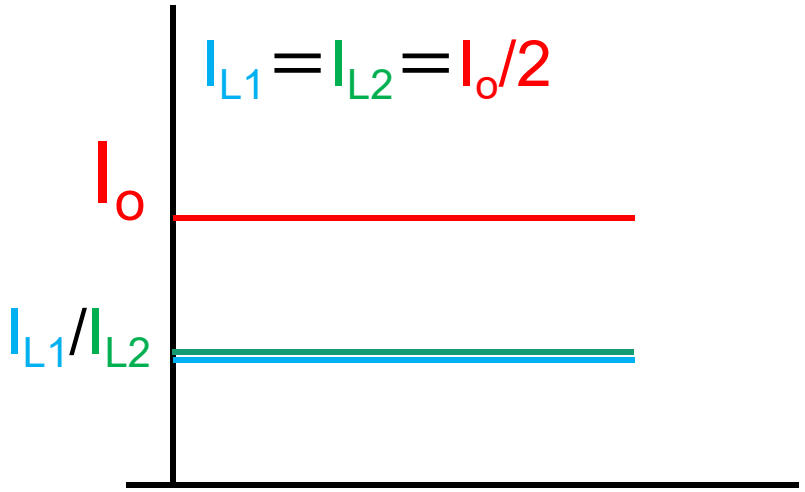



Fig. Current balance with ideal elements

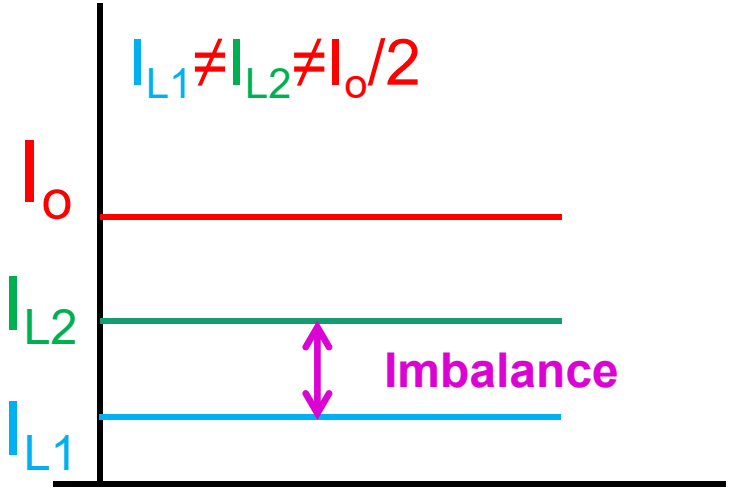
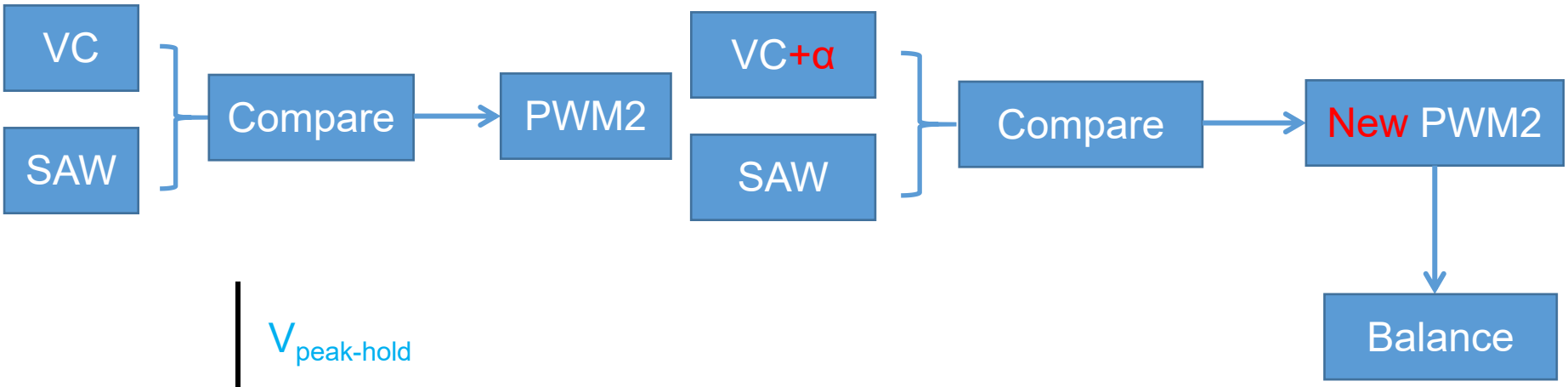
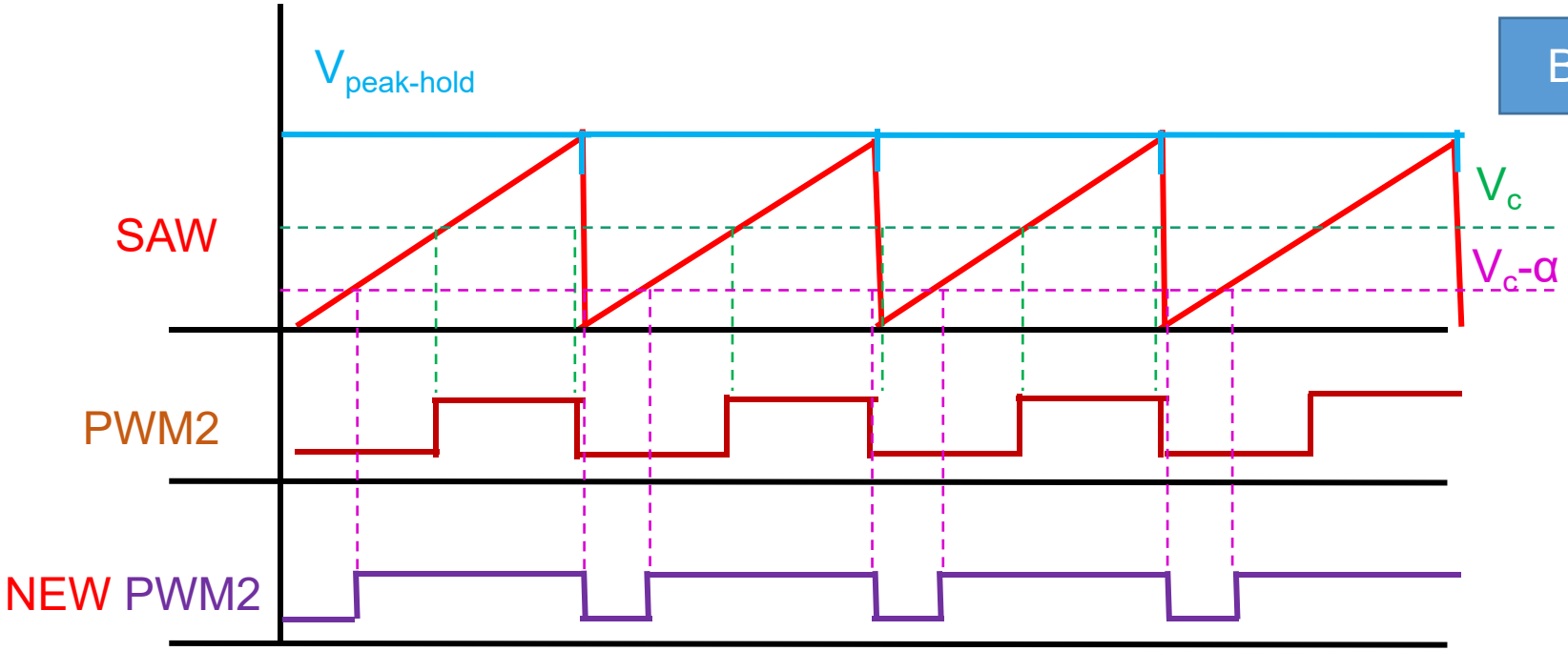



Fig. Current imbalance with element variation

# Automatic Current balance Technology

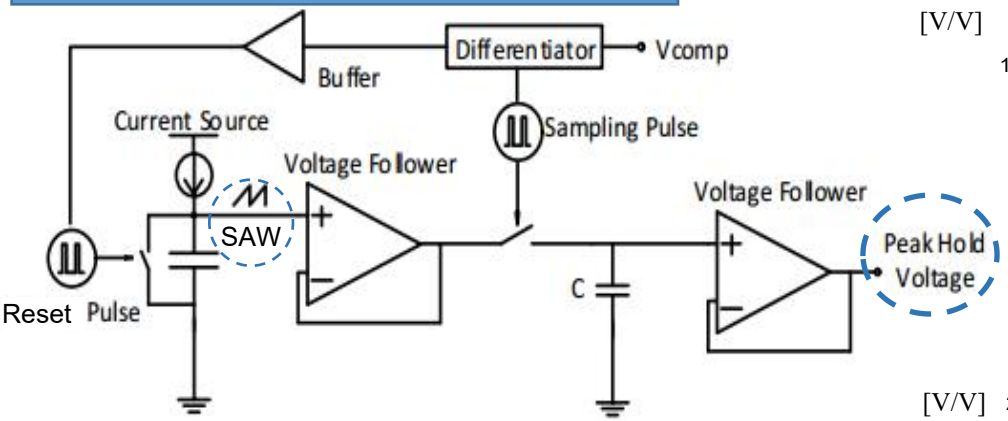


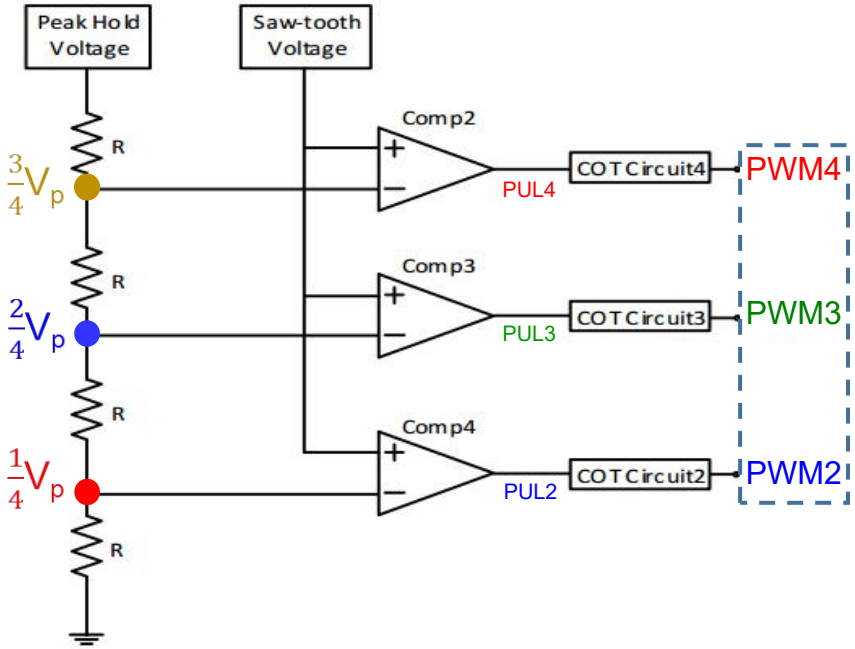

Current balance control signal

# Generation of Four-Phase Pulses

## SAW Generator & Peak Hold




## Voltage Divider & Comparator




## Operation waveform

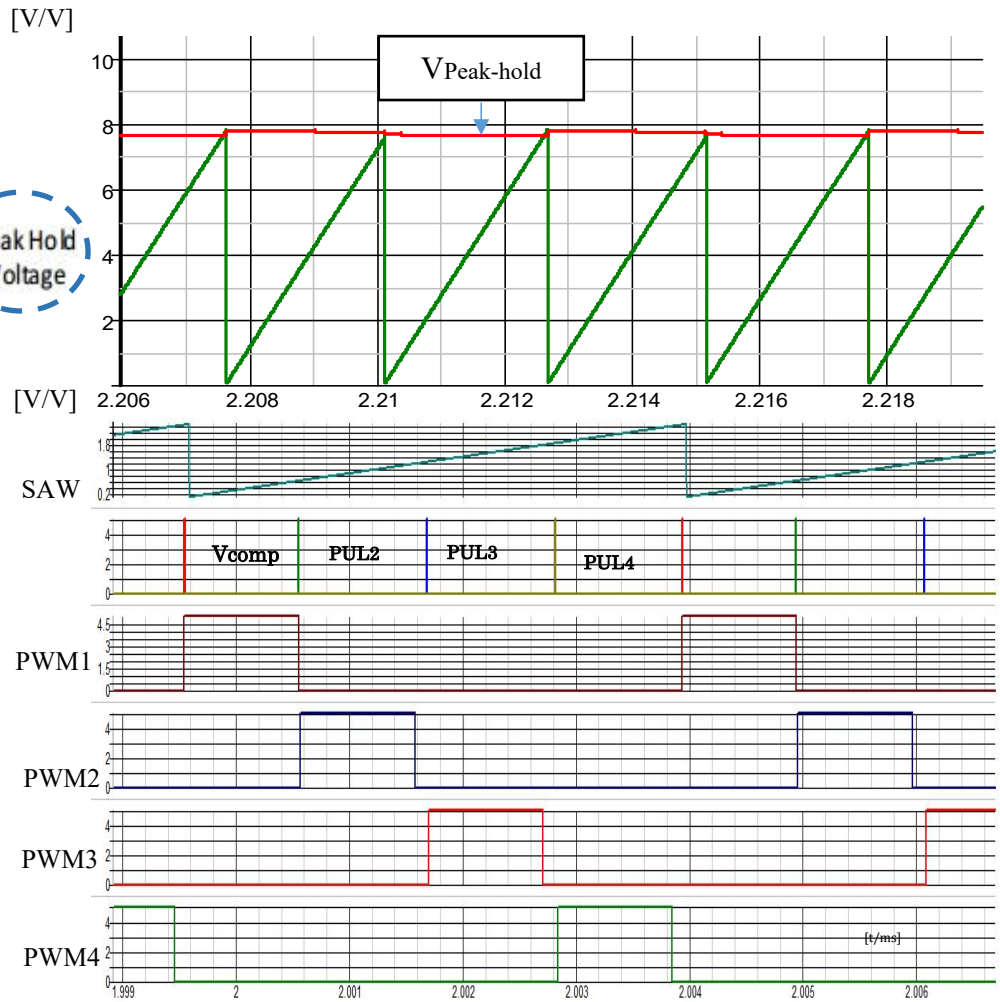
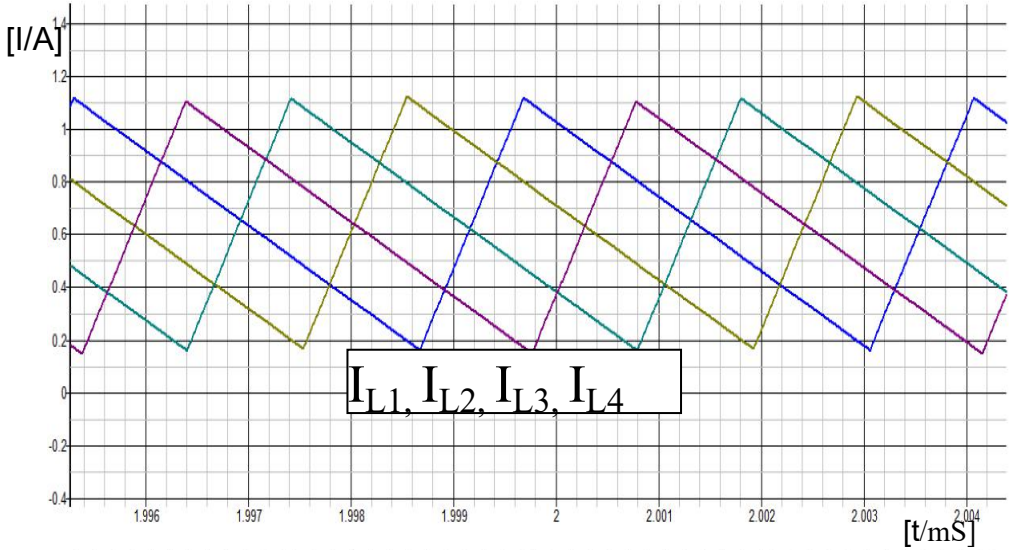
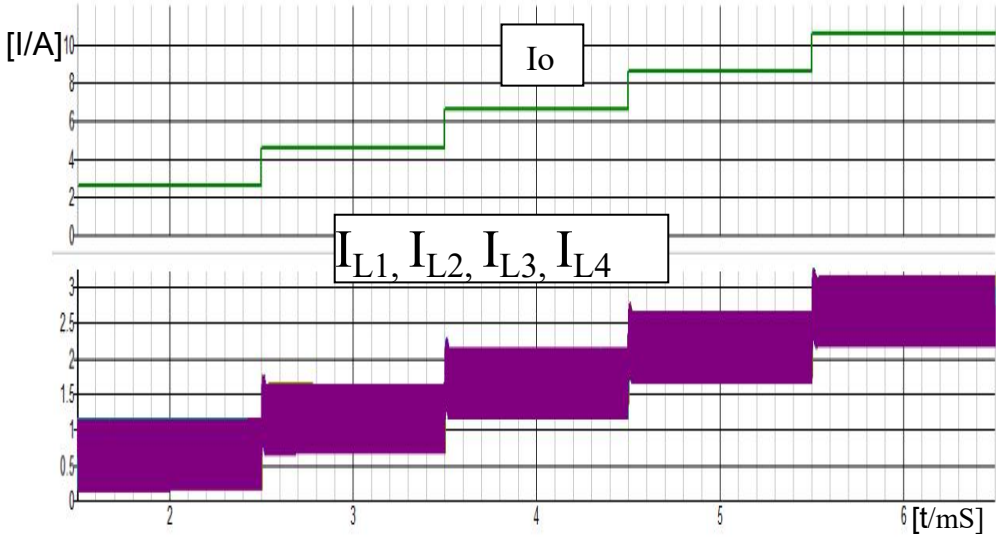



Fig. Signals of Four-phase converter

# Current Balance of four-phase Converter

## ★Simulation Result




Without element variations

$\Delta L$, $\Delta T_{COT}(=\Delta C)$, $\Delta V_{S/H}$

→ **Good current balance**

→ **Large load current achieved**

→ **Good current balance during transient response**

# Imbalance current (Dual-phase)

● Two Phase: With element variation (Inductance)

Inductor

10μH ⇨ 11μH

+ 10%

Main power supply

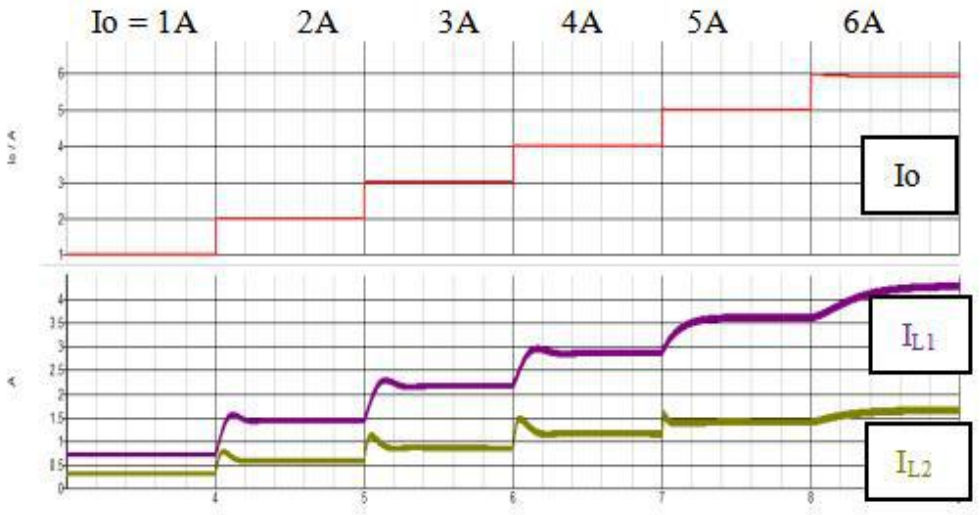



Fig.Dual-phase current imbalance

Io = 6A

$I_{L1}$ =4.3A , $I_{L2}$ =1.7A

$\Delta I_L = (I_{L1} - I_{L2})$ --

= |4.3-1.7|=2.6A

Error Ratio:

δ = (Io/2-In)/Io/2

=(3-1.7)/3=> 43%

☹

# Balance current(Dual-phase)

● Two Phase : Result of proposed method with good current balance

10μH ⇨ 11μH

+ 10%

Inductor

Main power supply

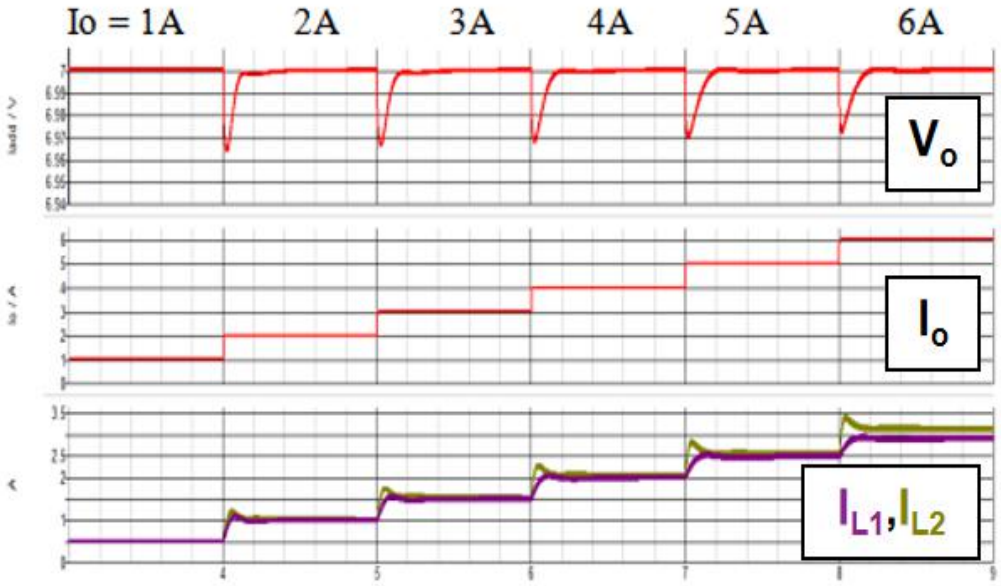



Fig. Multi-phase current balance

⇨ **Good current balance**

Io = 6A

$I_{L1}$ = $I_{L2}$ =3A

# Imbalance current (Multi-phase)

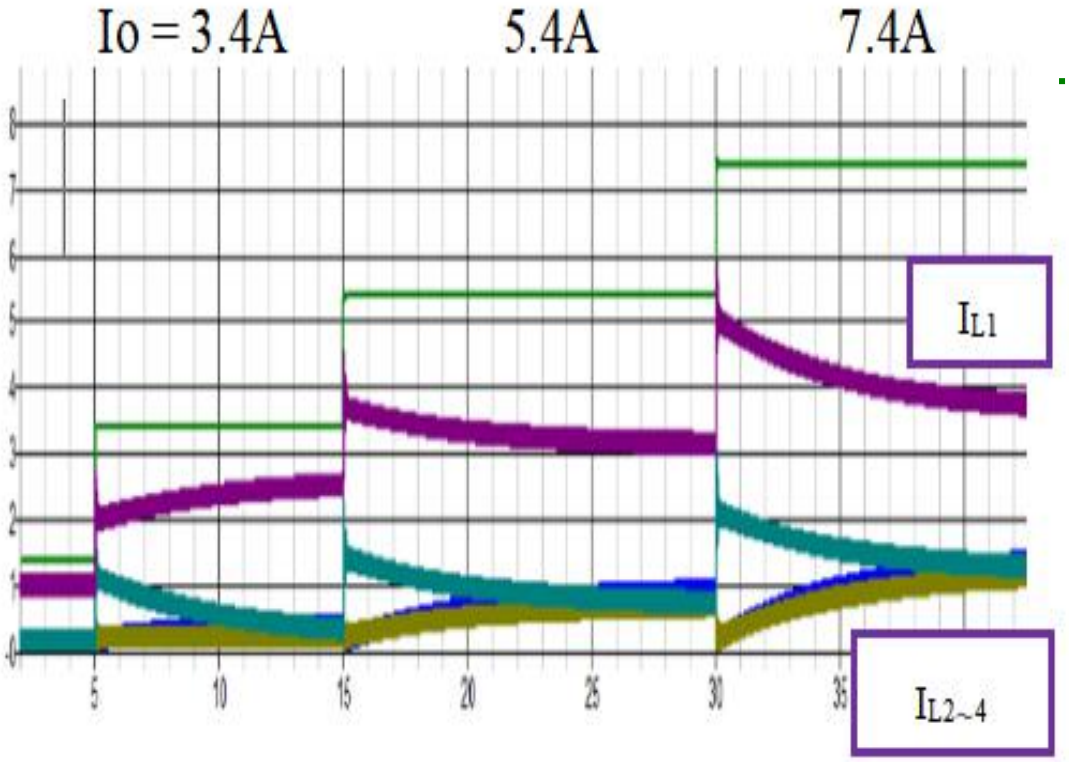
● Four Phase: With element variation (Inductance)

10μH ⇨ 11μH

+ 10%

Inductor

Main power supply




Io = 8.58A

$I_{L1}$ =5.43A , $I_{L2}$ =3.15A

$\Delta I_L = (I_{L1} - I_{L2})$ --

= |5.43-3.15|=2.28A

Error Ratio:

δ = (Io/2-In)/Io/2

=(4.29-3.15)/4.29=> 27 %

☹

Fig. Multi-phase current imbalance

# Balance current(Multi-phase)

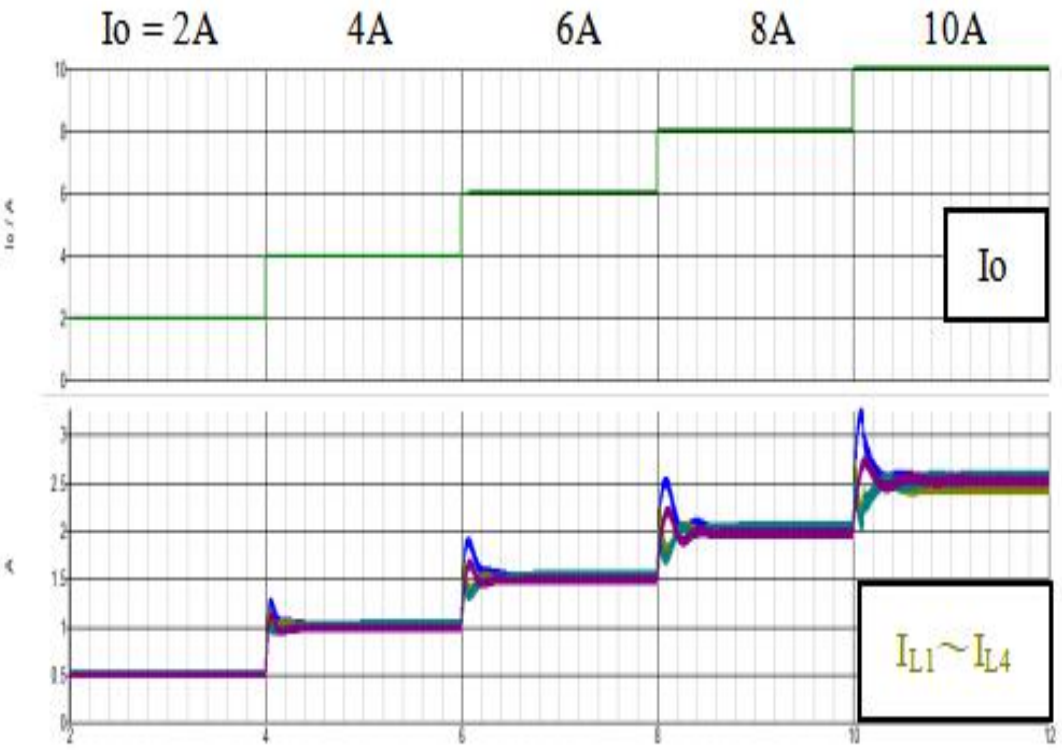
● Four Phase : Result of proposed method with good current balance

10μH ⇨ 11μH

+ 10%

Inductor

Main power supply




Good current balance

Io = 6.81A

$I_{L1}$ =$I_{L2}$ =3.40A

Fig. Multi-phase current balance

# Conclusion

- The peak hold voltage is extracted by the peak hold circuit to compare it with the SAW1 signal, producing a SAW2 signal with a 180° delay, thereby implementing a dual wave converter without a clock signal. This method has automatic adjustment capability and has faster response speed than traditional PLL methods.

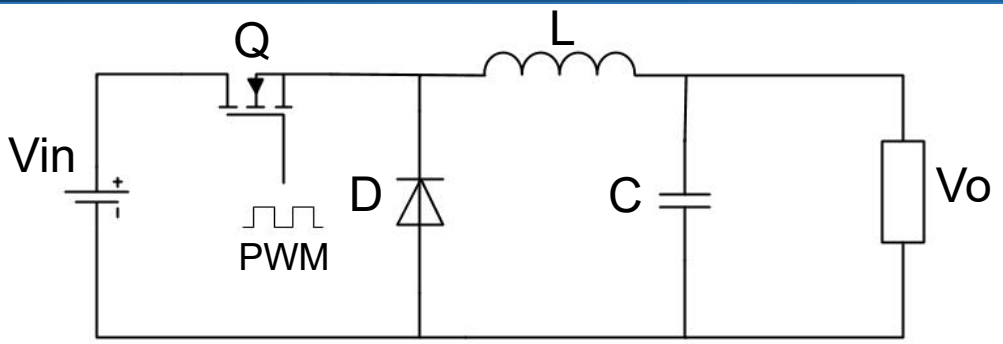
- We have proposed multi-phase full wave and half wave type voltage resonant converters with automatic current balance against the LC elements variation.

# Thank you for your attention

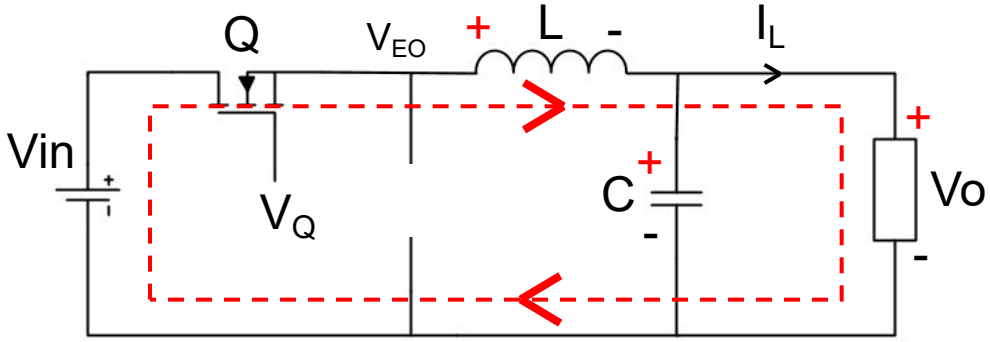
# Q&Aに必要と思われる資料を以下に添付しておくと良い

重庆学会-張諶豪.pdf

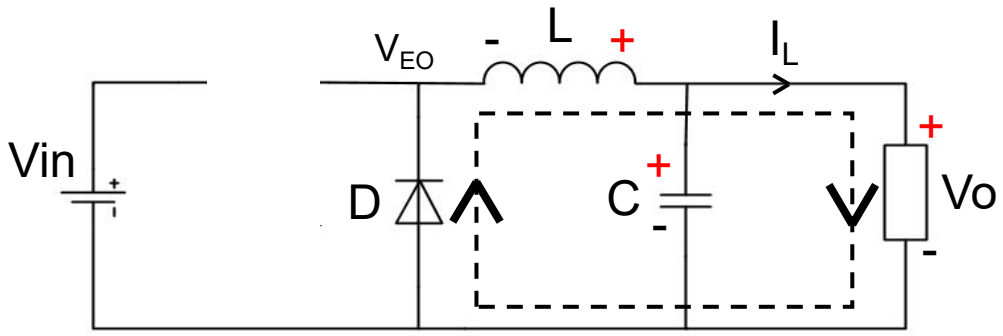
# Operation of Buck Converter



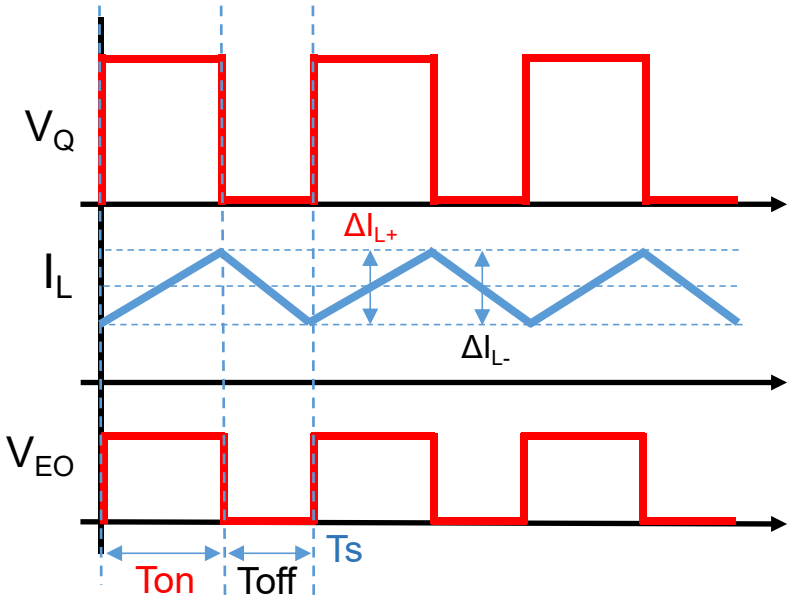

Buck Converter




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**

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

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