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Two-Phase Soft-Switching DC-DC Converter with Voltage-Mode Resonant Switch

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Research Objective

Objective

Development of power supply with

- Low noise
- Fast response
- High efficiency

Approach

- Soft-switching with voltage-mode resonant
- Multi-phase

Contents

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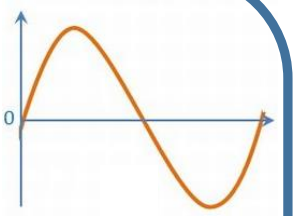
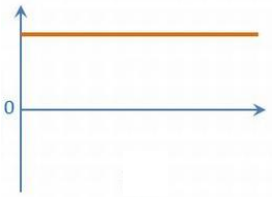
What is Power Supply ?



100～240V AC

AC-DC Converter

Power Supply



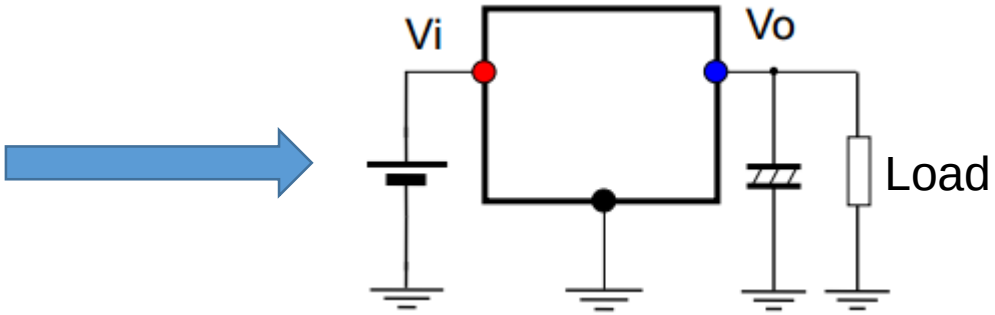
4.2V DC

DC-DC Converter

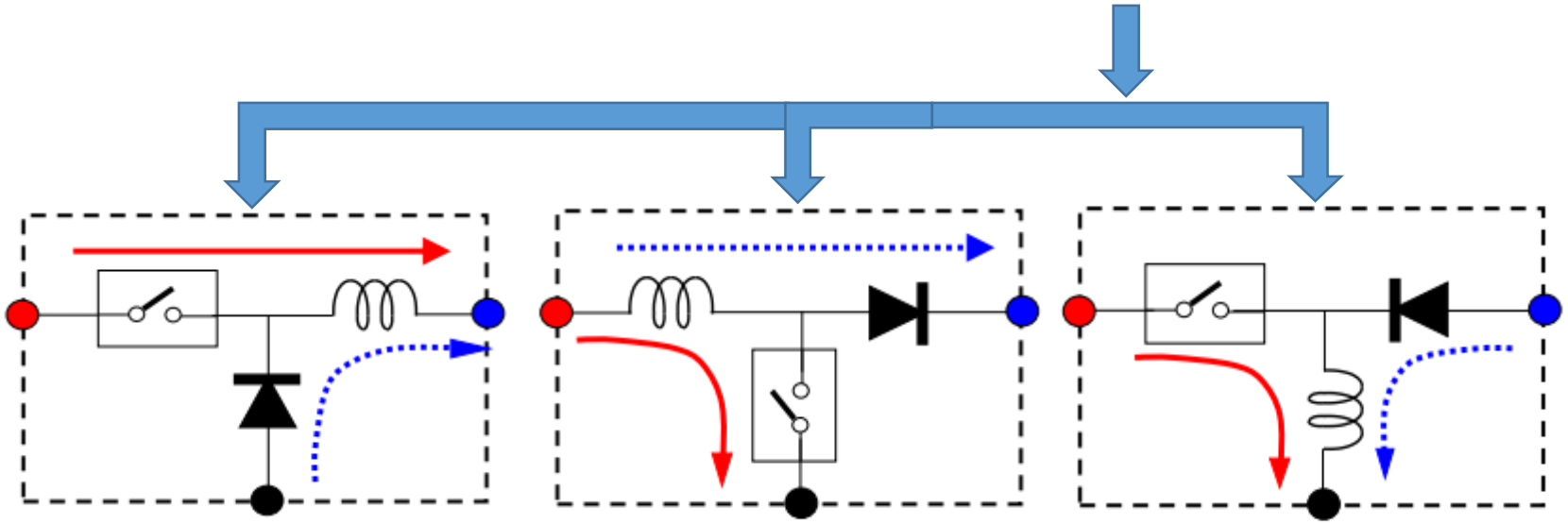
Power supply is demanded everywhere to provide appropriate voltage for electronic device

Classifications of DC-DC Converter

DC-DC converter



Basic configuration



Buck

Vin > Vo

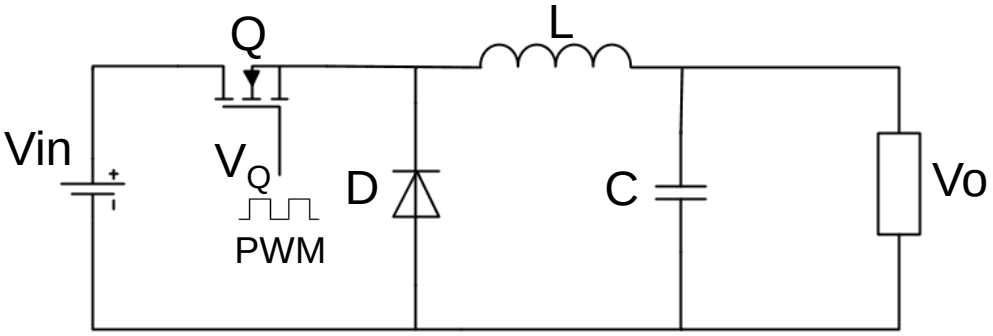
Boost

Vin < Vo

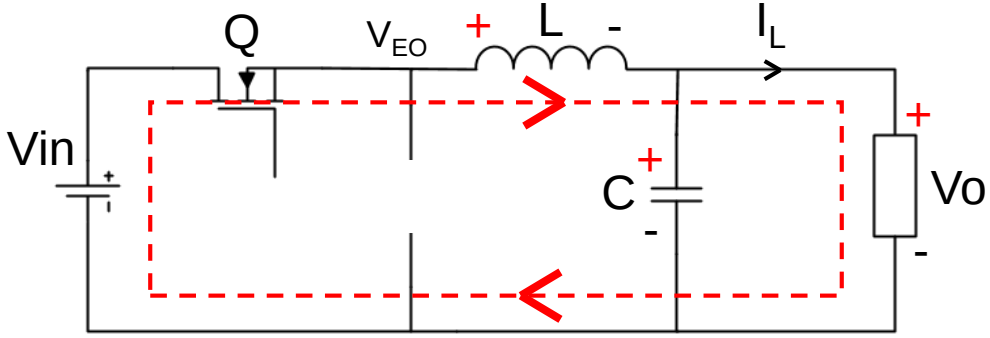
Buck-Boost

Vin ≷ Vo

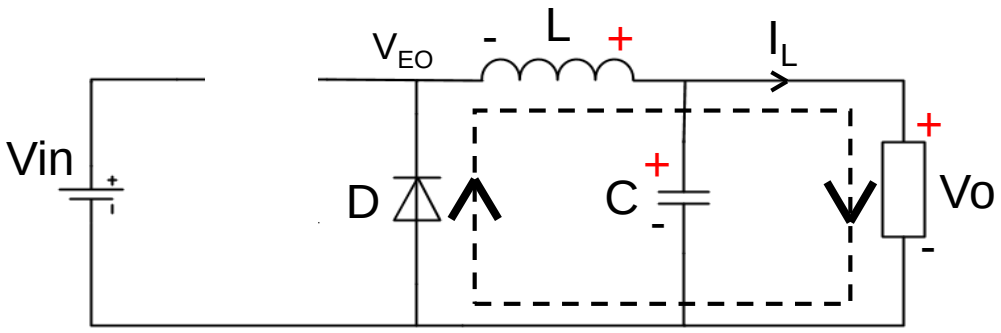
Operation of Buck Converter



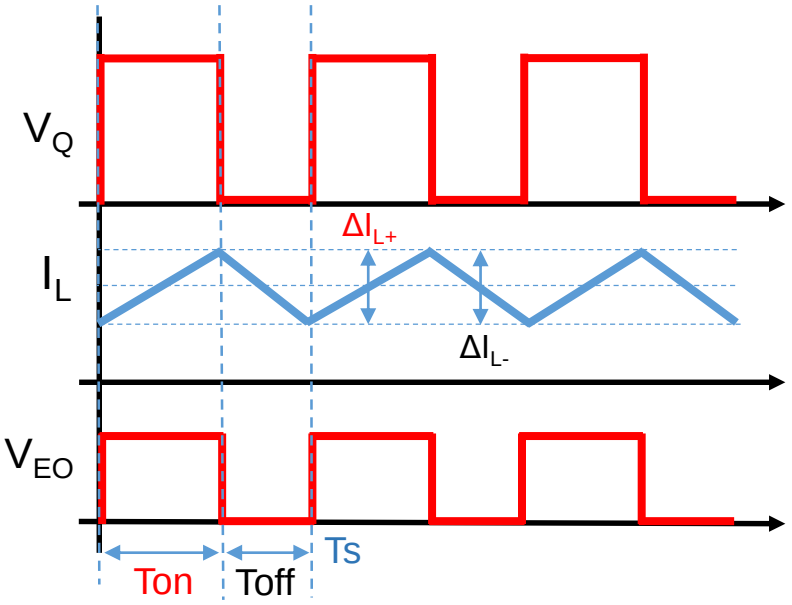
Buck Converter



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

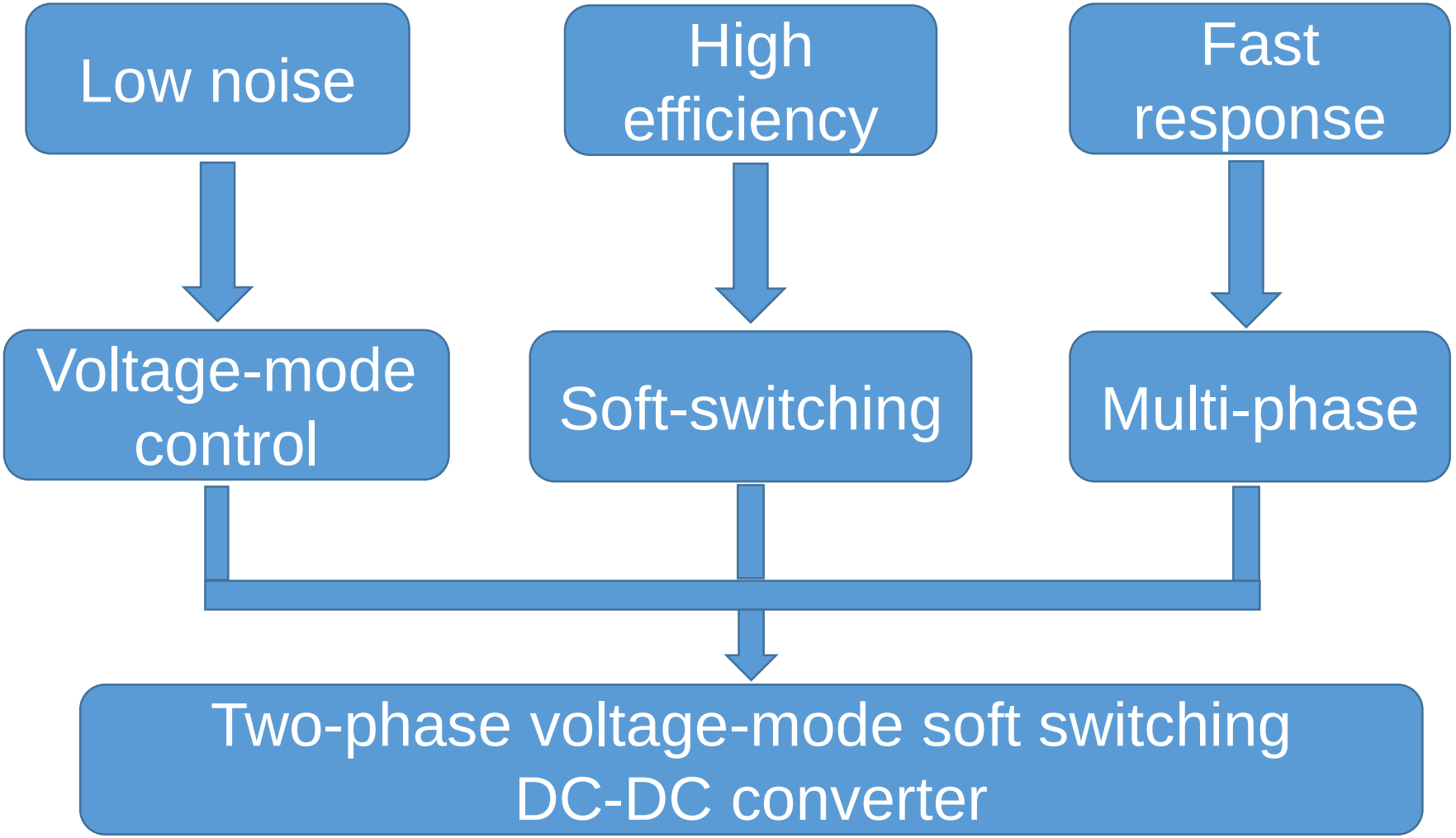
$V_{Loff} = -Vo = L \cdot (\Delta i_{L-} / \Delta t_{off})$

Volt-second Balance

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

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

Demand for Power Supply



Contents

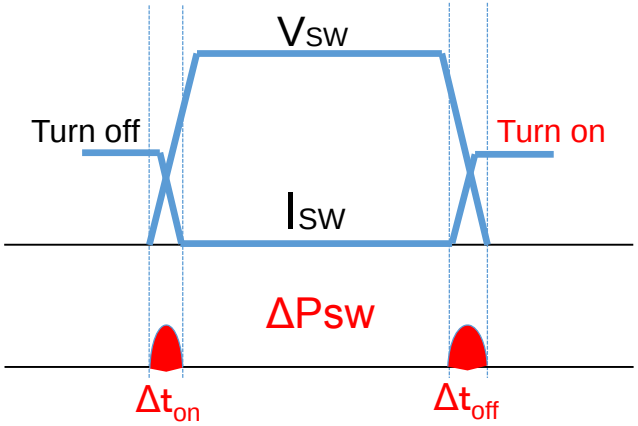
Normal Voltage-mode Control

Saw-tooth signal is generated by external clock

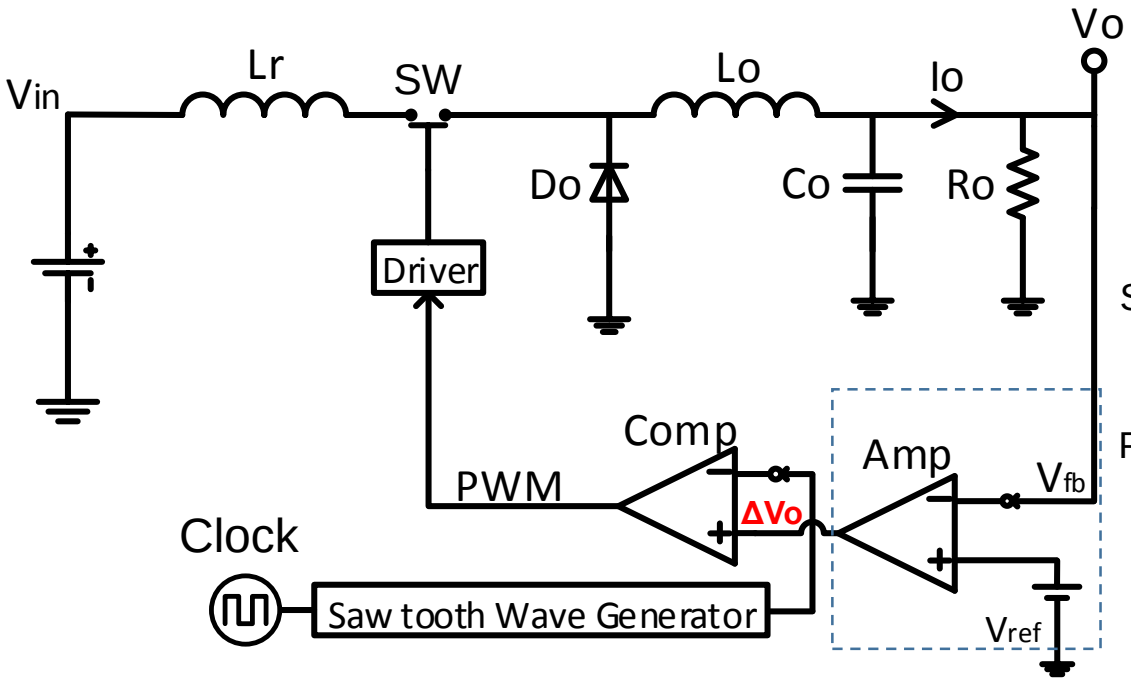
PWM is generated by closed-loop control

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

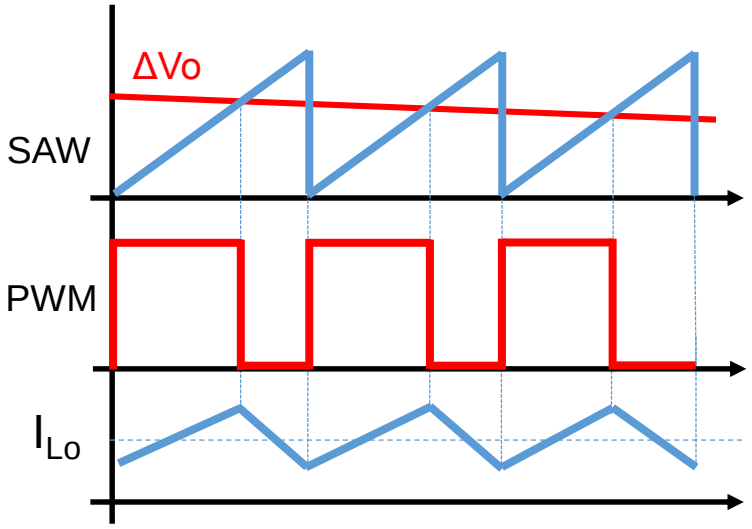
Slow respond



Hard Switching



Voltage-mode Converter

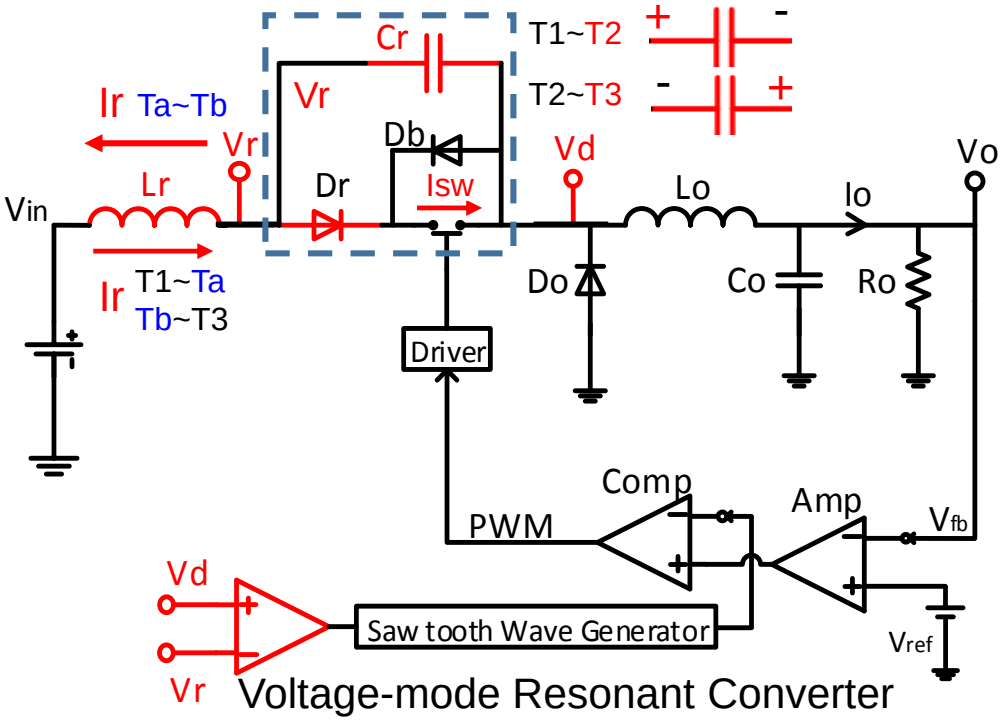


Operation Waveform

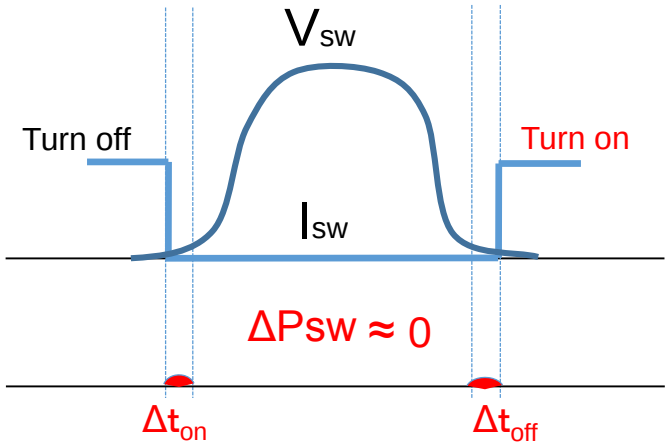
Voltage-mode Resonant Switch

Resonant Inductor Lr & Resonant Capacitor Cr

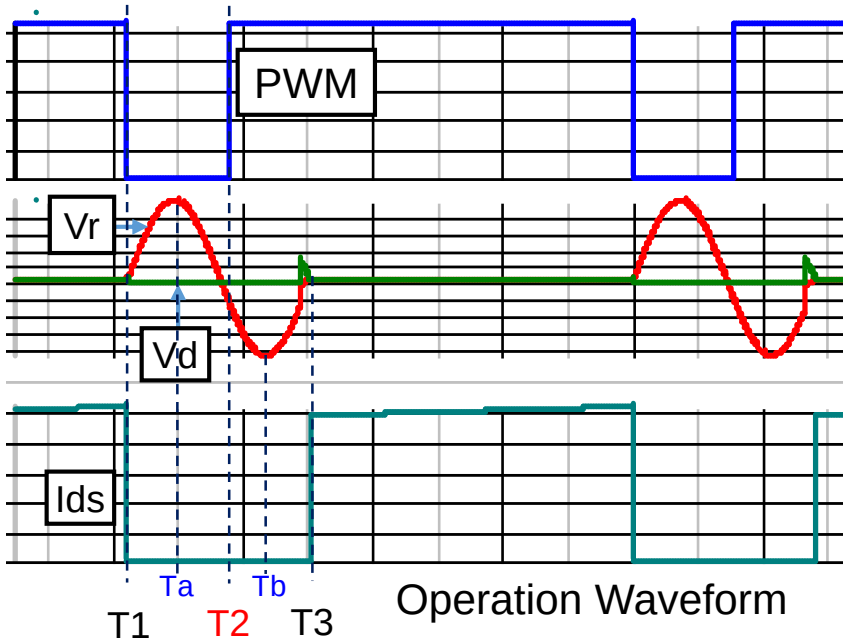
Saw-tooth is generated without clock



Voltage-mode Resonant Converter



Soft Switching



Operation Waveform

T1 The switch turns off when Vr is nearly 0

T2 The switch turns on when Ids is nearly 0

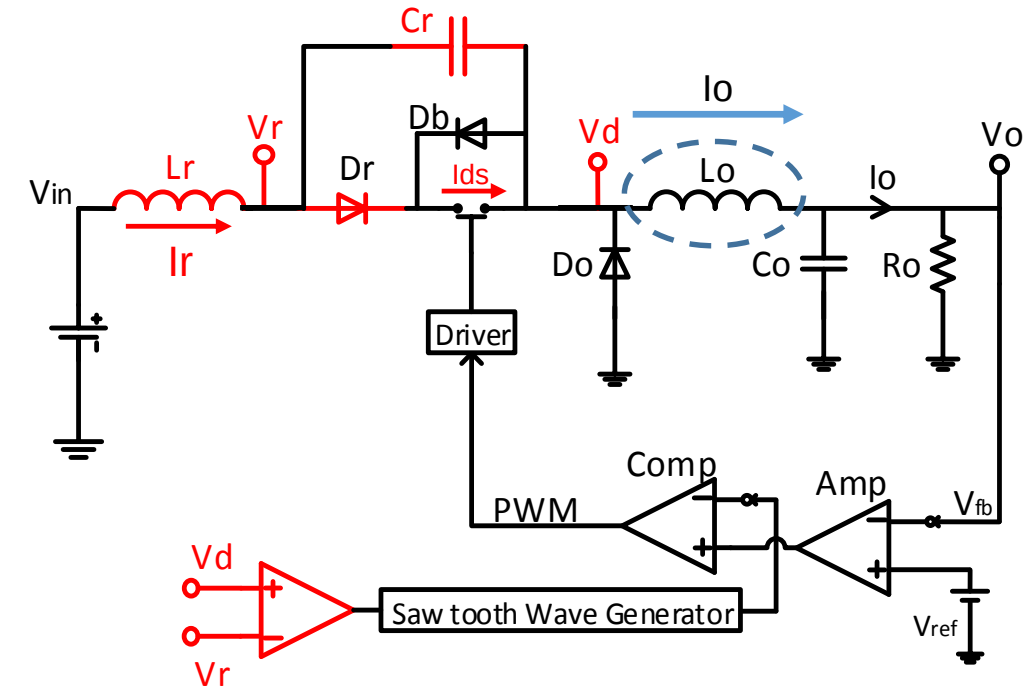
$$P_{sw} = \int_0^{\Delta t} I(t) \cdot V(t) dt \approx 0$$

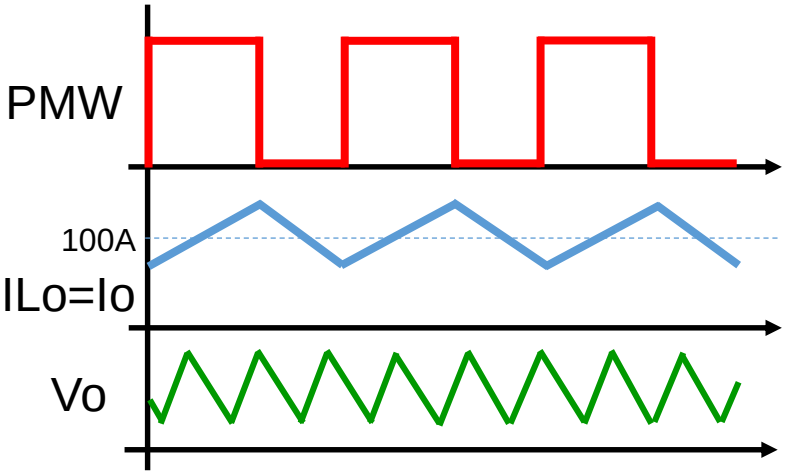
Soft-switching is achieved

Contents

- Research background
- Voltage-mode resonant switch control
- Two-phase DC-DC converter solution
- Simulation result
- Characteristics test
- Conclusion

Demerit of Single-Phase Converter



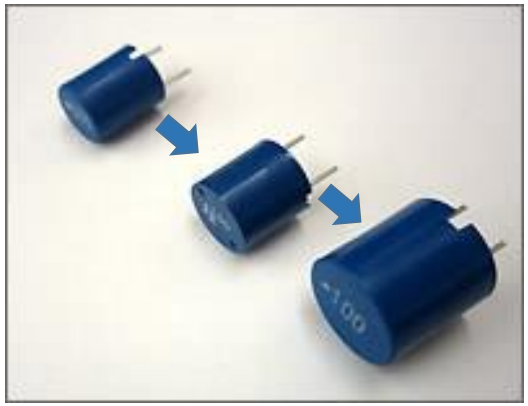


Large load on Inductor Lo

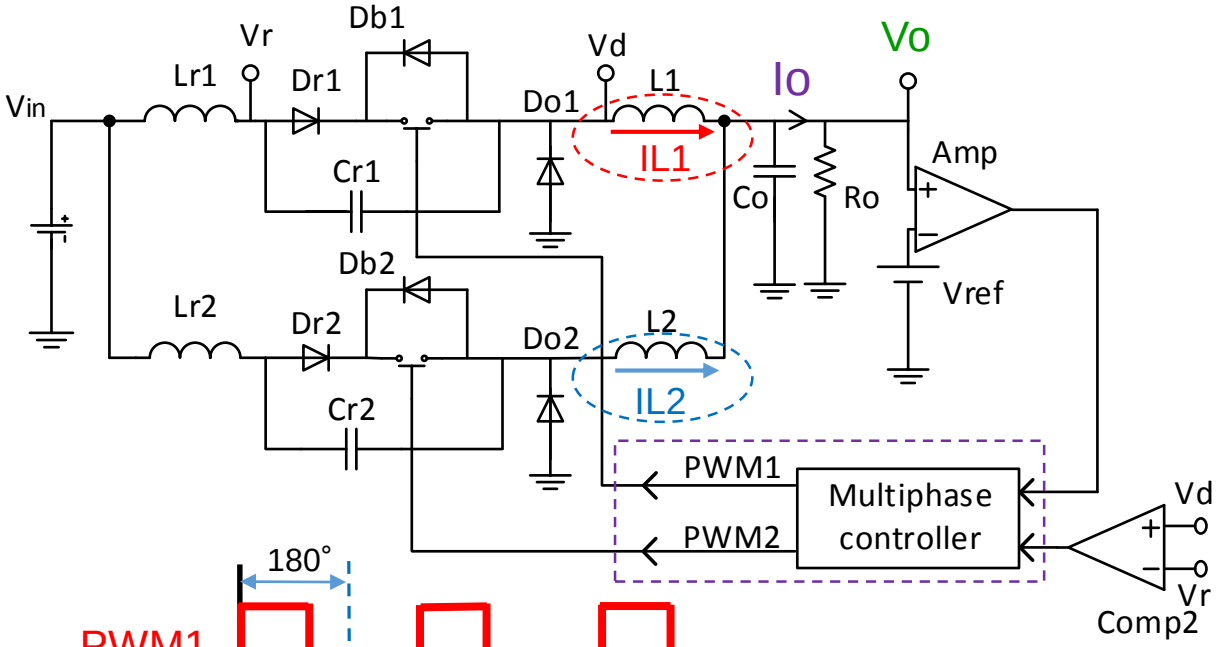
One-phase converter

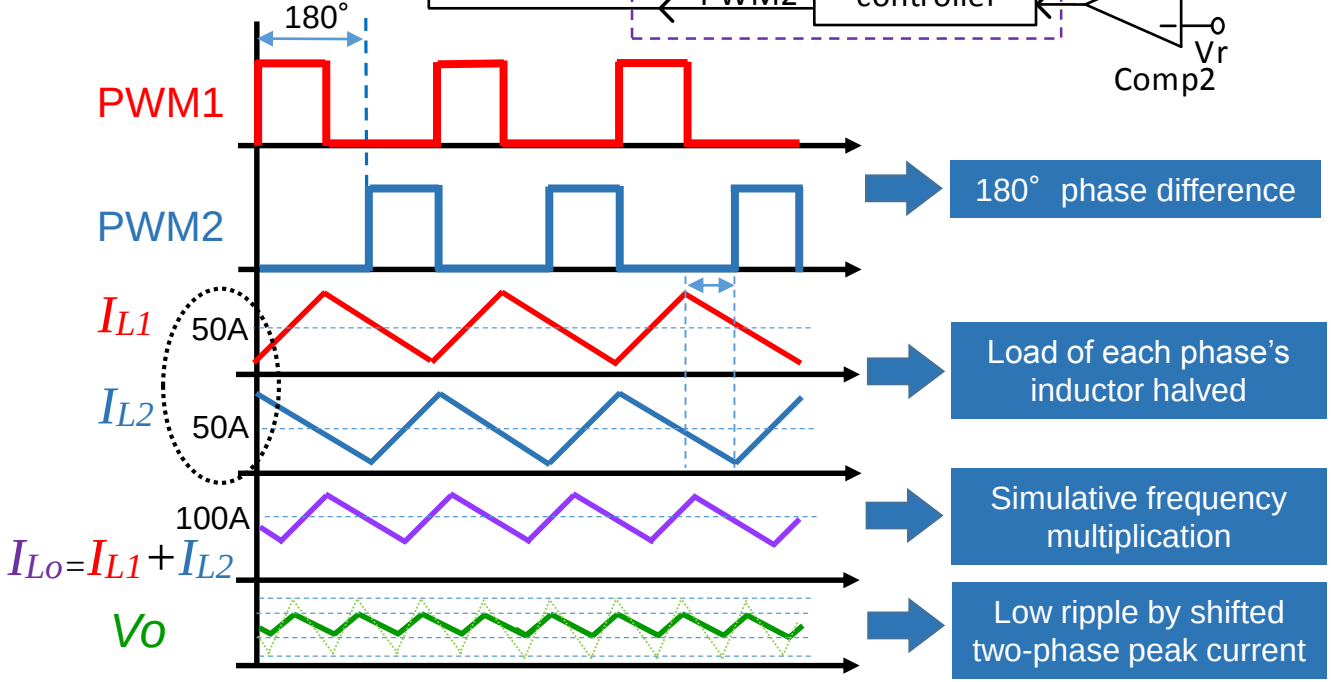
The whole output current Io will flows only through inductor Lo

Lo will be large in size



Merit of Two-Phase Converter





180° phase difference

Load of each phase's inductor halved

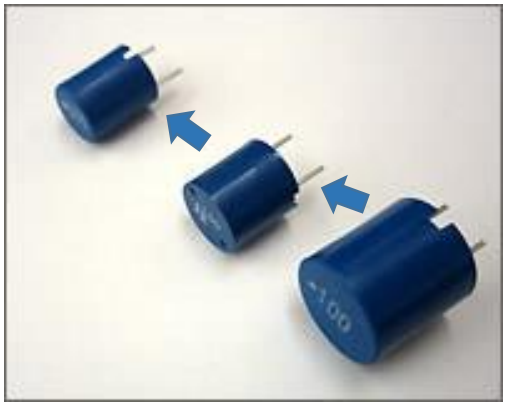
Simulative frequency multiplication

Low ripple by shifted two-phase peak current

Two-phase converter

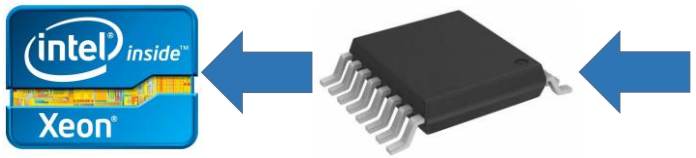
Inductor L1 and L2 will go shares with the Io

L1 and L2 will be small in size

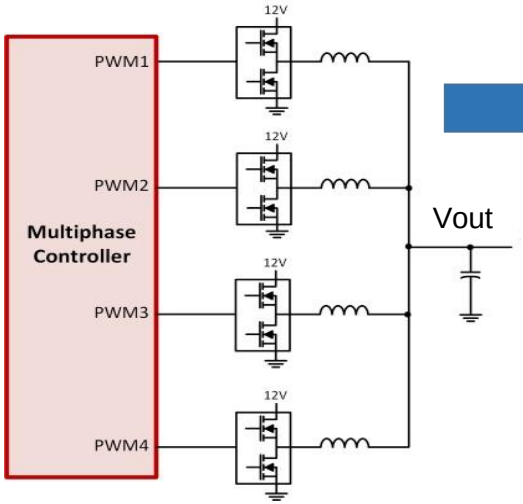


Difficult to get Multi-Phase without Clock

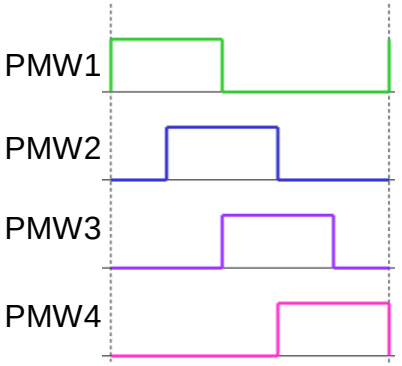
Power supply for sever process



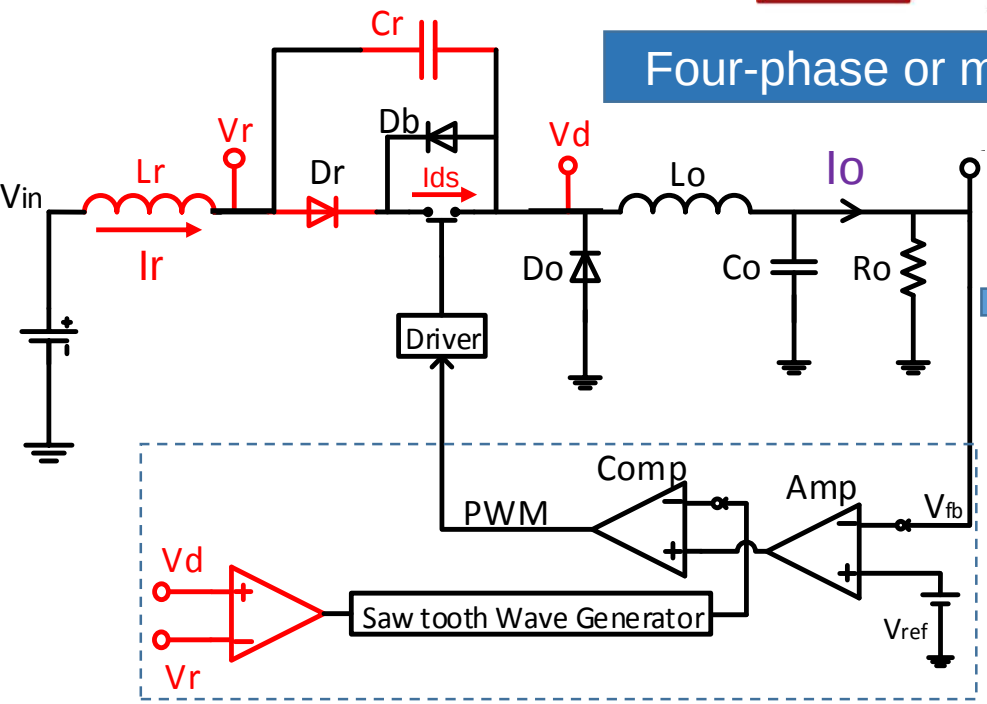
Clock inside



Easy to get multi-phase PWM



Four-phase or more is normal



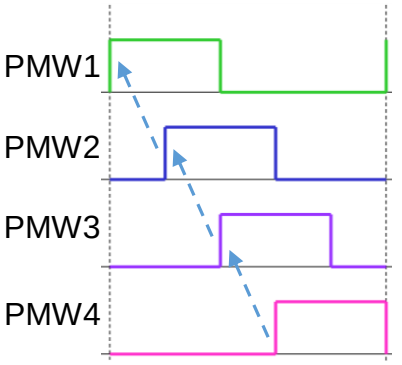
Voltage-mode resonant converter

No clock

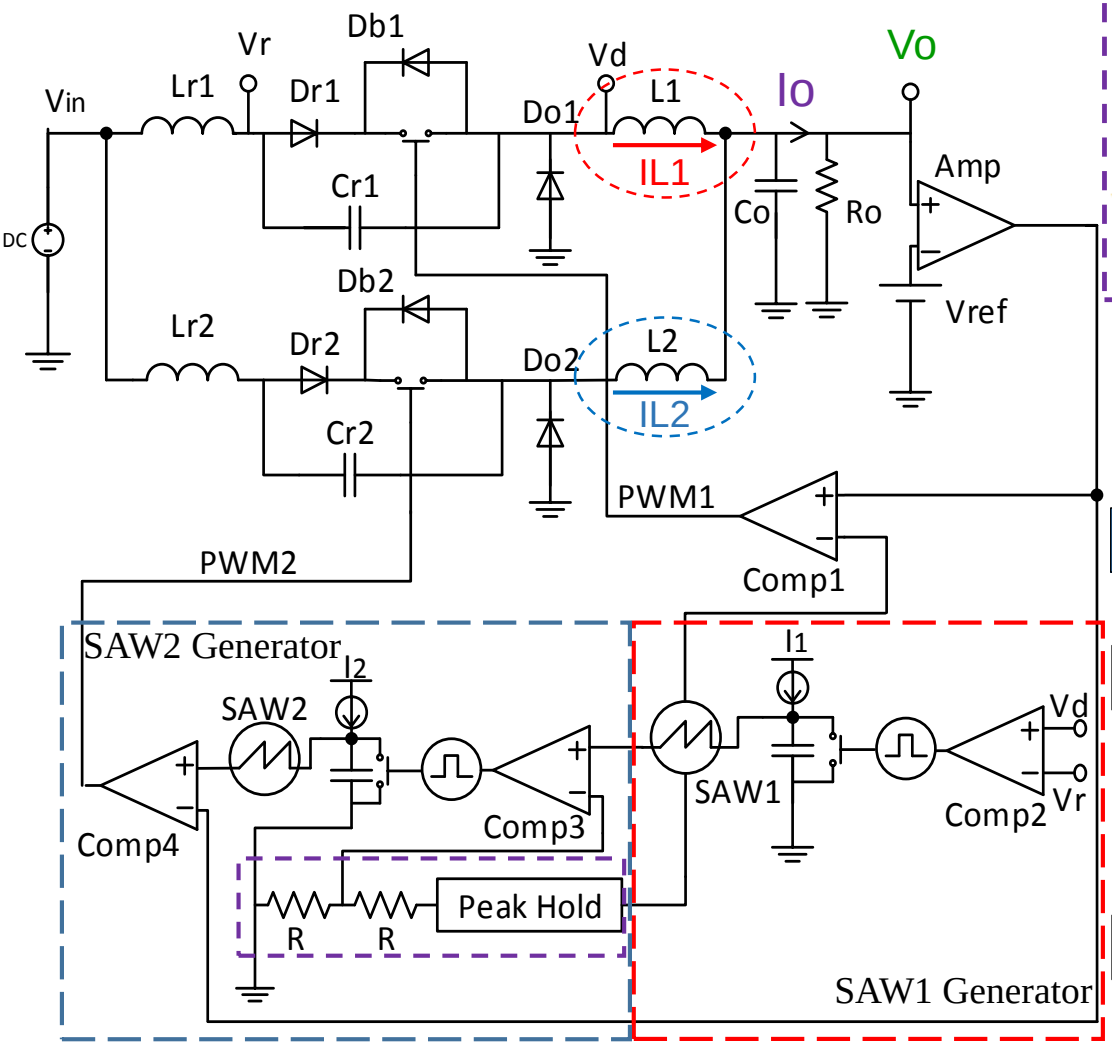
Frequency & phase swinging

Difficult to get multi-phase PWM

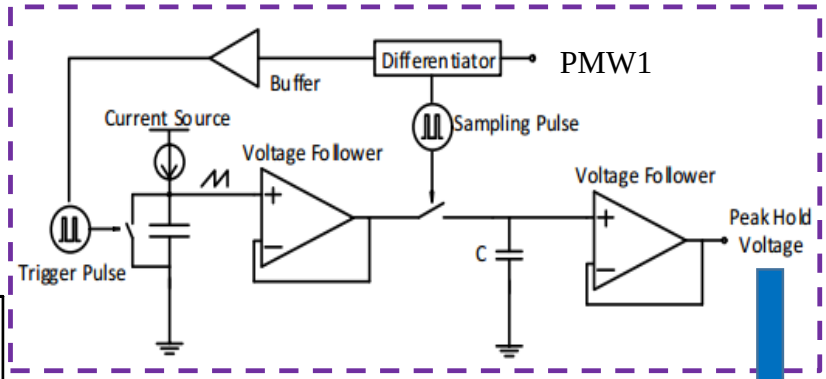
Tracking PWM with PWM1 is demanded without clock



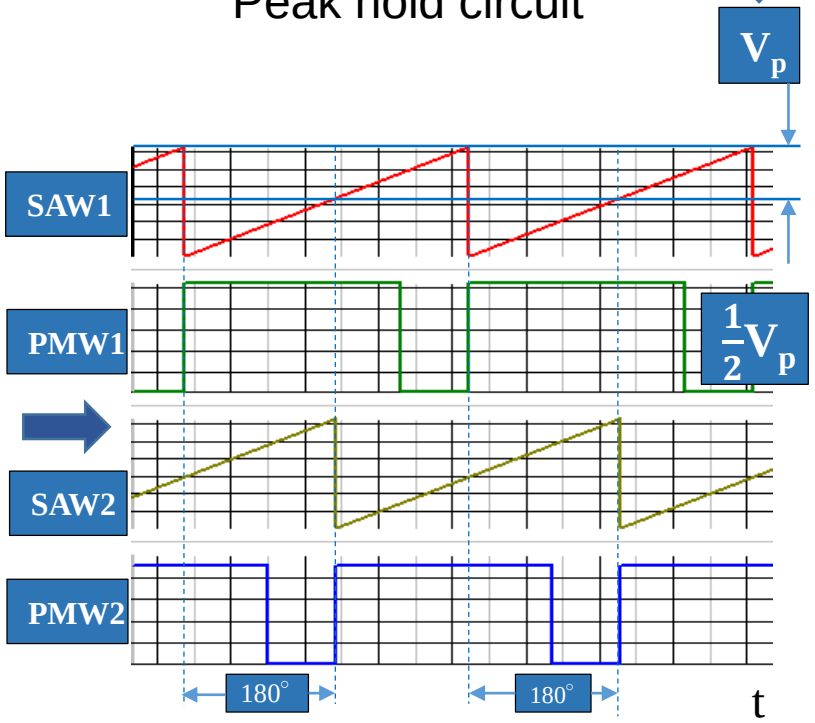
Proposed Two-Phase Converter Solution



Two-phase control



Peak hold circuit



Two-phase PWM simulation result

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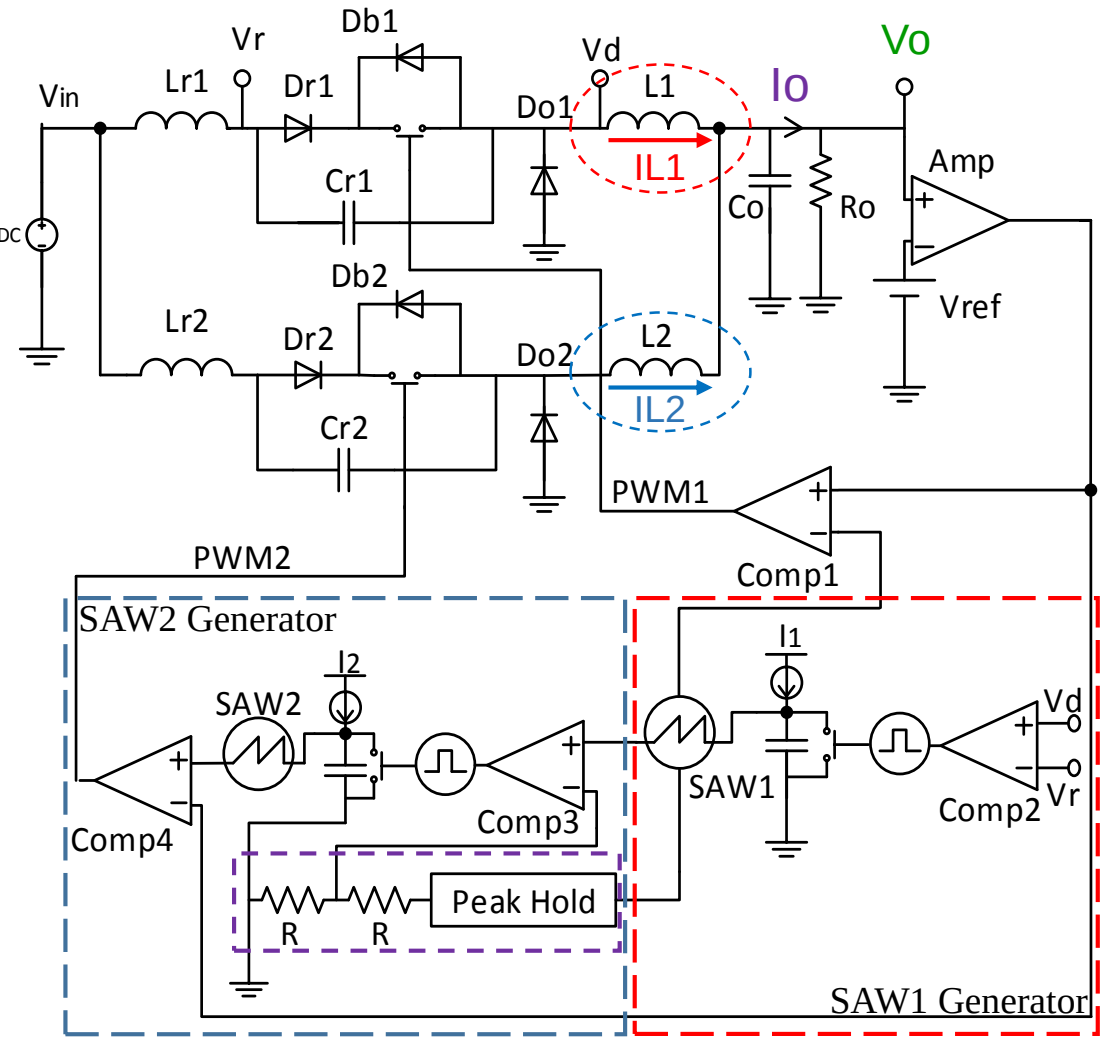
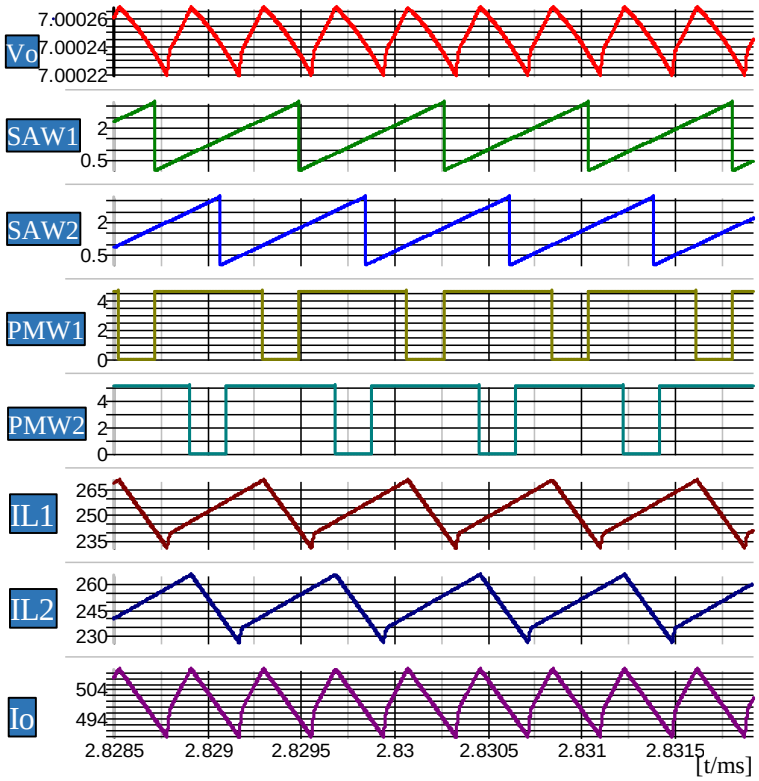
Parameters and Key Waveforms



Two-phase control

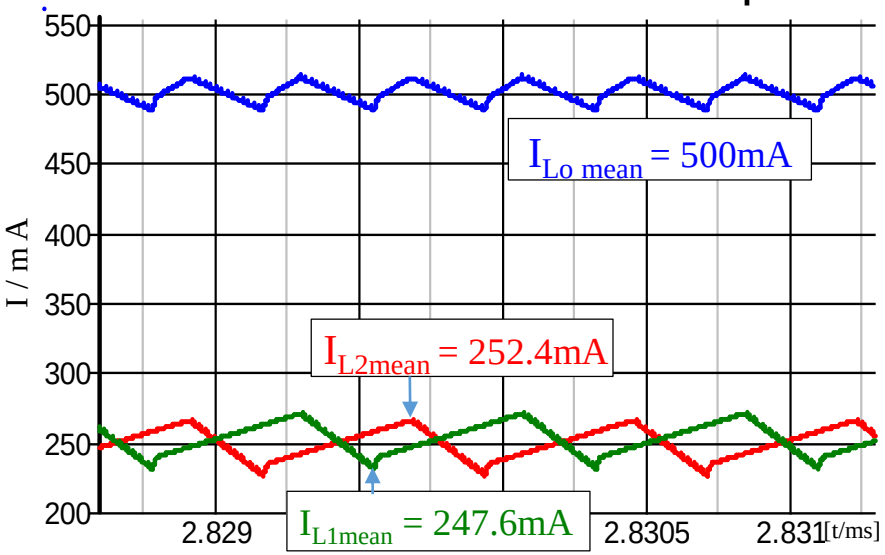
V_{in}	12V
V_o	7V
L_{r1}, L_{r2}	20uH
C_o	200uF
C_{r1}, C_{r2}	100pF
I_o	500mA
F_{op}	1.295MHz

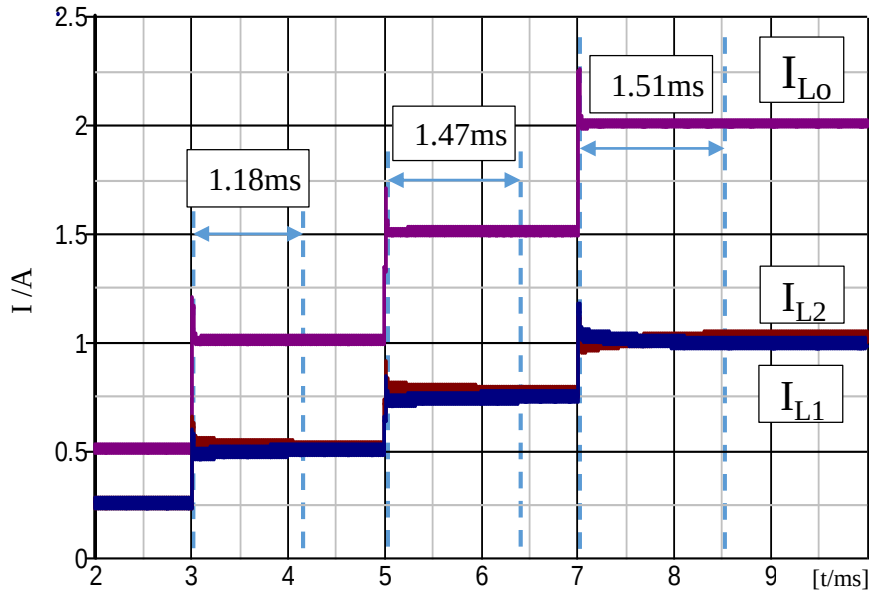
Circuit parameters & simulation



Current Balance

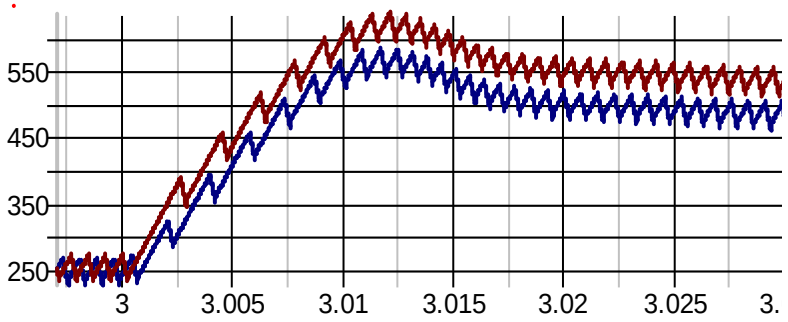
Current balance & transient response





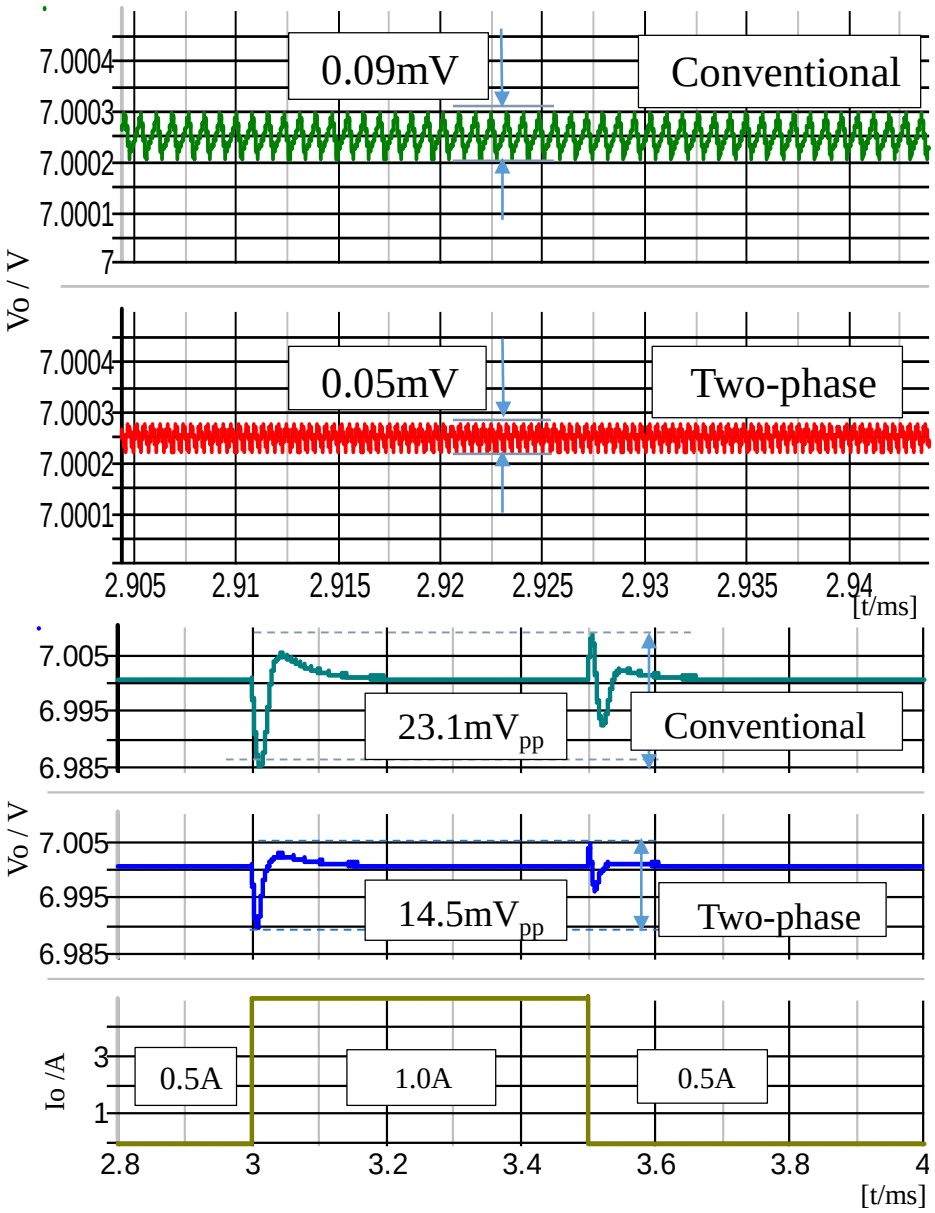
Current balance offset ΔI_L ($\Delta I_L = |I_L - I_o/2|$)

$$\Delta I_{L1} = I_{L1} - I_o/2$$
$$= |247.6-500/2| = 2.4\text{mA}$$
$$\Delta I_{L2} = I_{L2} - I_o/2$$
$$= |252.4-500/2| = 2.4\text{mA}$$
$$\Delta I_{L1} = \Delta I_{L2}$$
$$\delta = 2.4/(500/2) \times 100\% = 0.96\%$$



I_{L2} keeps pace with I_{L1} during the transient response

Comparison



Static State Characteristic

	Conventional	Two-phase
Output Voltage ripple	0.09mV	0.05mV

Output Voltage ripple 44.4% off

Dynamic Load Regulation

	Conventional	Two-phase
Overload V_{pp}	19.8mV	8.8mV
Underload V_{pp}	15.7mV	8.7mV
Recover time	0.27ms / 0.23ms	0.20ms / 0.18ms

Transient response peak to peak voltage 37.2% off

Content

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- Simulation result
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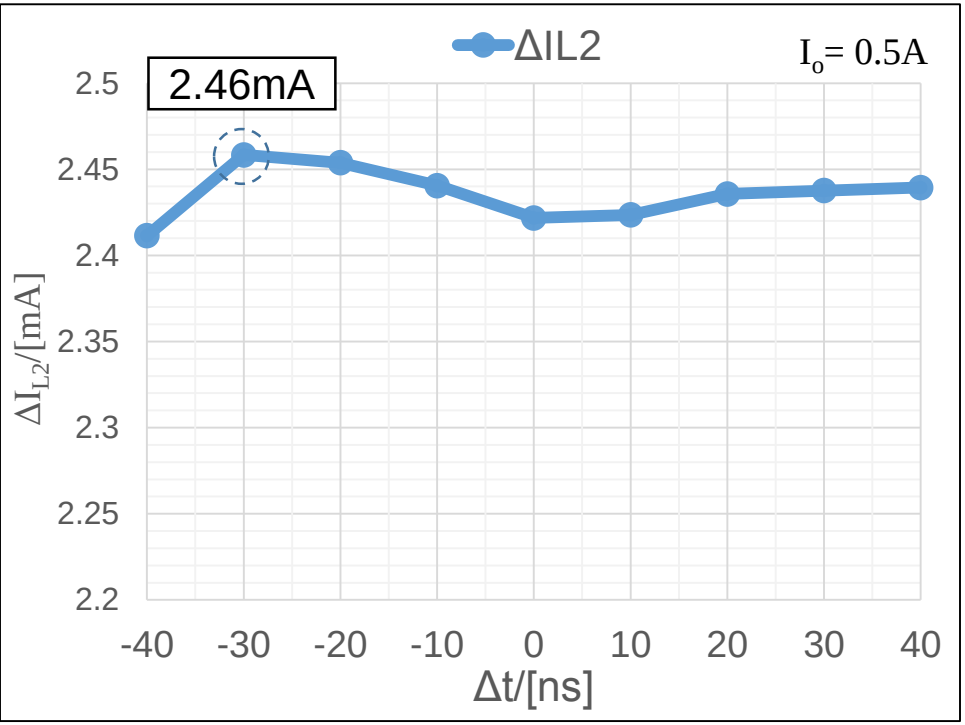
- Conclusion

Characteristics Test 1



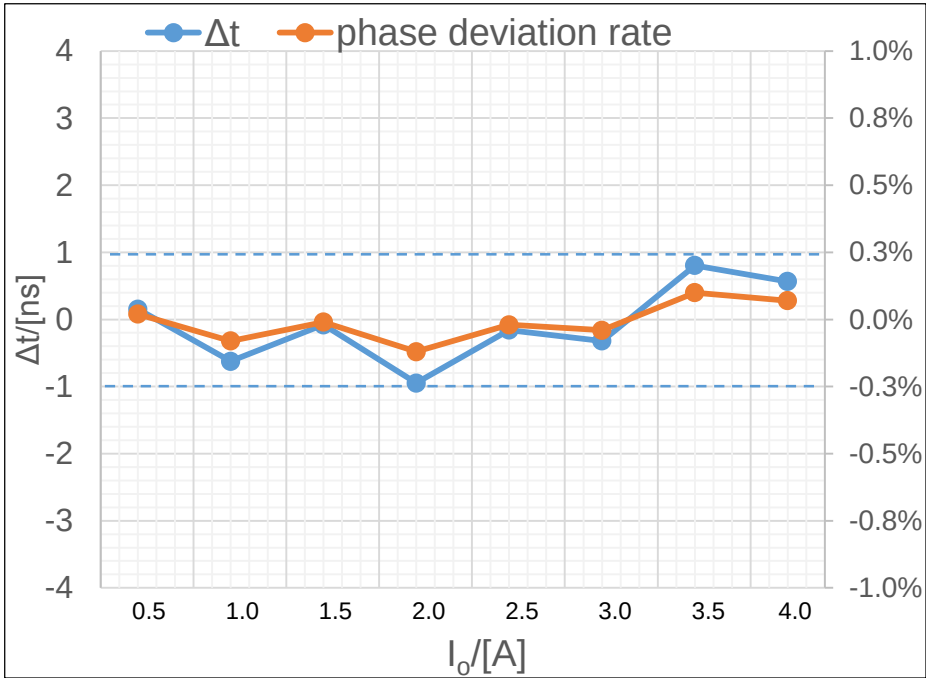
Relationship between
Phase Displacement & Current Balance

Maximum of ΔI_{L2} is 2.46 mA
deviating less than 1%

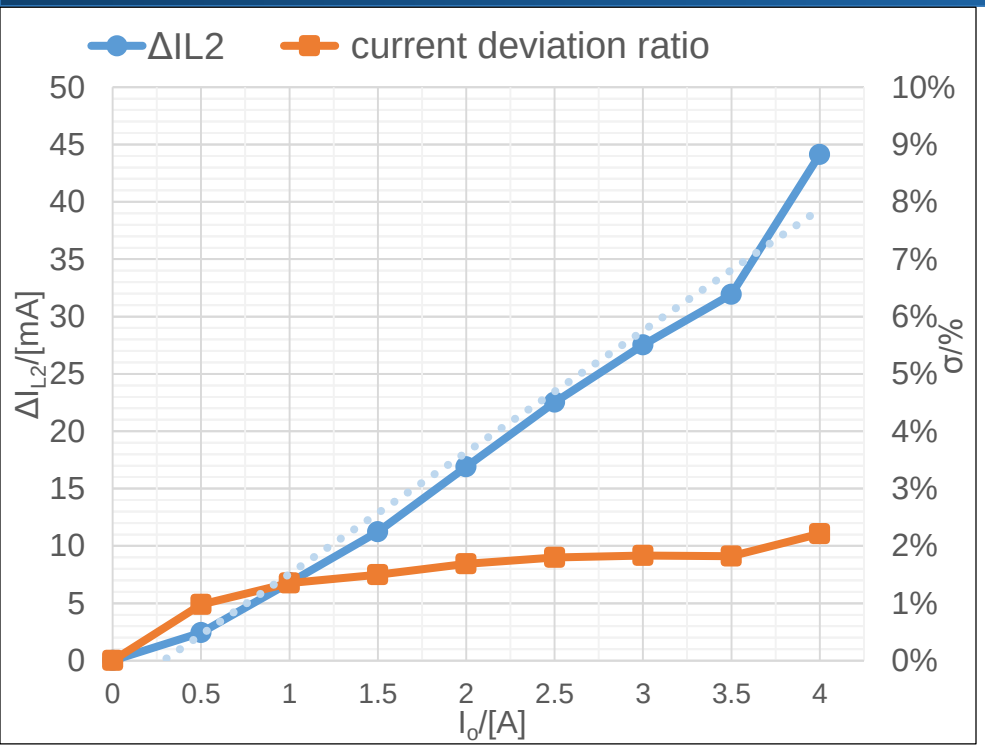
Relationship between

Load Current & Phase Displacement

Phase displacement shifts less than ±1ns
even the load current is 4.0A



Characteristics Test 2

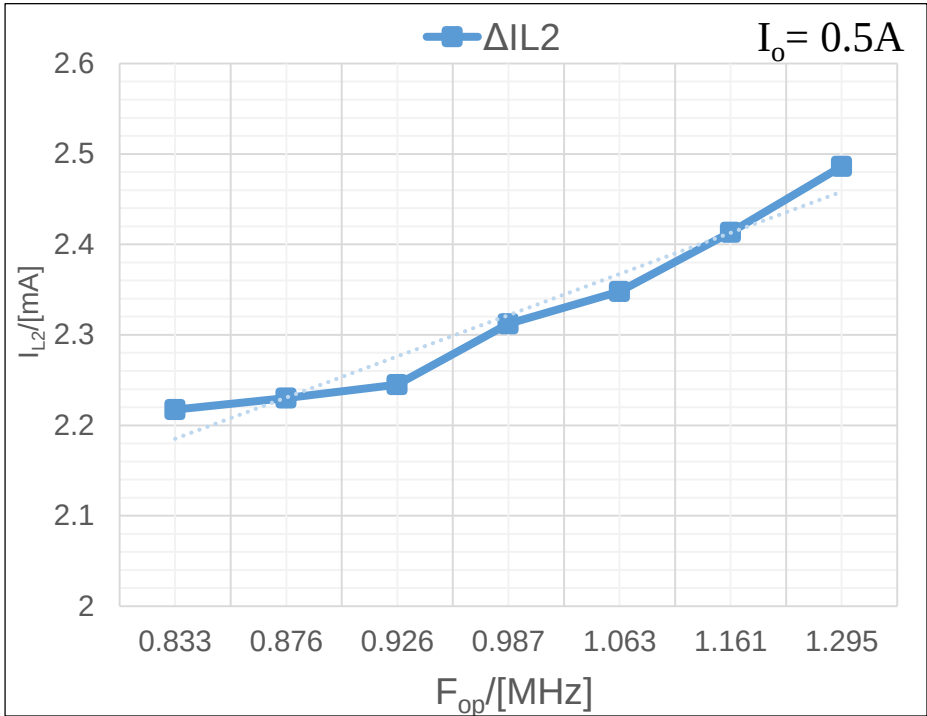


Relationship between Load Current and Current Balance

ΔI_{L2} rises in proportion to increasing load current

Relationship between Load Current and Current Balance

ΔI_{L2} changes a little by varying operation freq., getting little current offset ratio less than 1%



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Conclusion

- We have proposed
  two-phase DC-DC converter
  with voltage-mode resonant switch.

- Low output voltage ripple, fast response are achieved.

- Stable characteristic of current balance is tested.

Thank you for listening
谢谢

Q&A

Q:How many times did you do the simulation until the result coming out.

A：Actually, I did many times for the simulation. As for the voltage resonant switch, there is a necessary condition that $V_{rmax} = I_o Z_n$ to achieve the soft-switching. As for the characteristics of current balance, I also did many times for the simulation to get the necessary data to paint the graph.

Q:What is the difference between convectional and two-phase converter.

A:The output voltage ripple has get off by 44.4%. The voltage step-up and down during the transient response also low, so do the recovery time.