C6-1 10:15-10:30
Nov. 1, 2019 (Fri)

Automatic Correction of Current Imbalance for Multi Phase COT Ripple Based Control Converter

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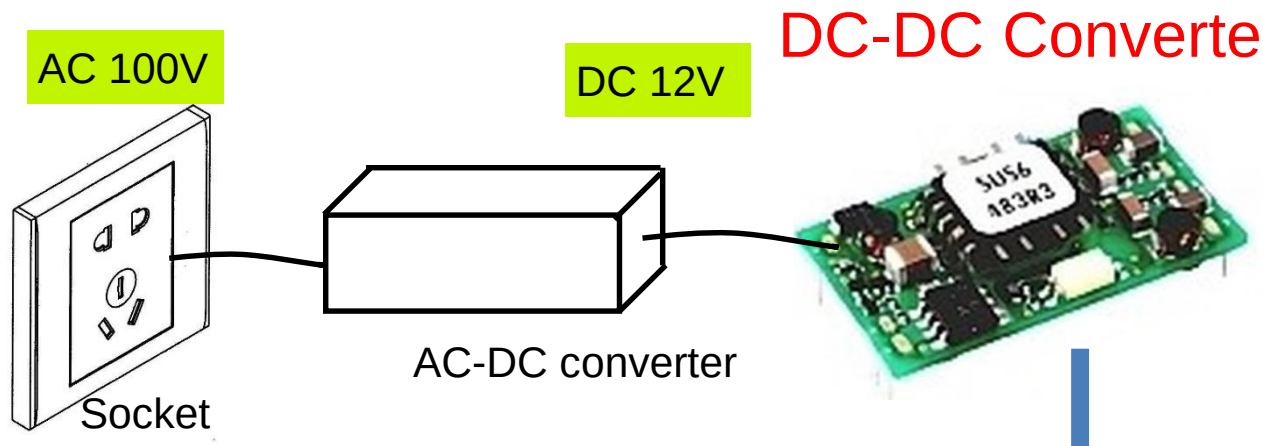
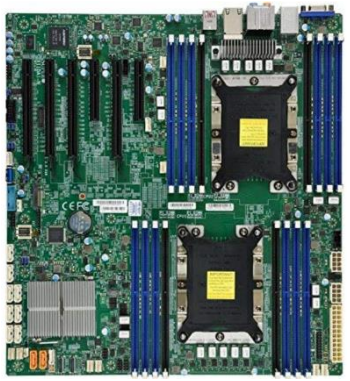
Outline

1. Research Background
2. COT Ripple Based Control Converter
3. Characteristic of Multi-Phase Converter
4. Multi-Phase Configuration of COT Ripple Based Control Converter
5. Automatic Current Imbalance Correction
6. Simulation Verification
7. Conclusion

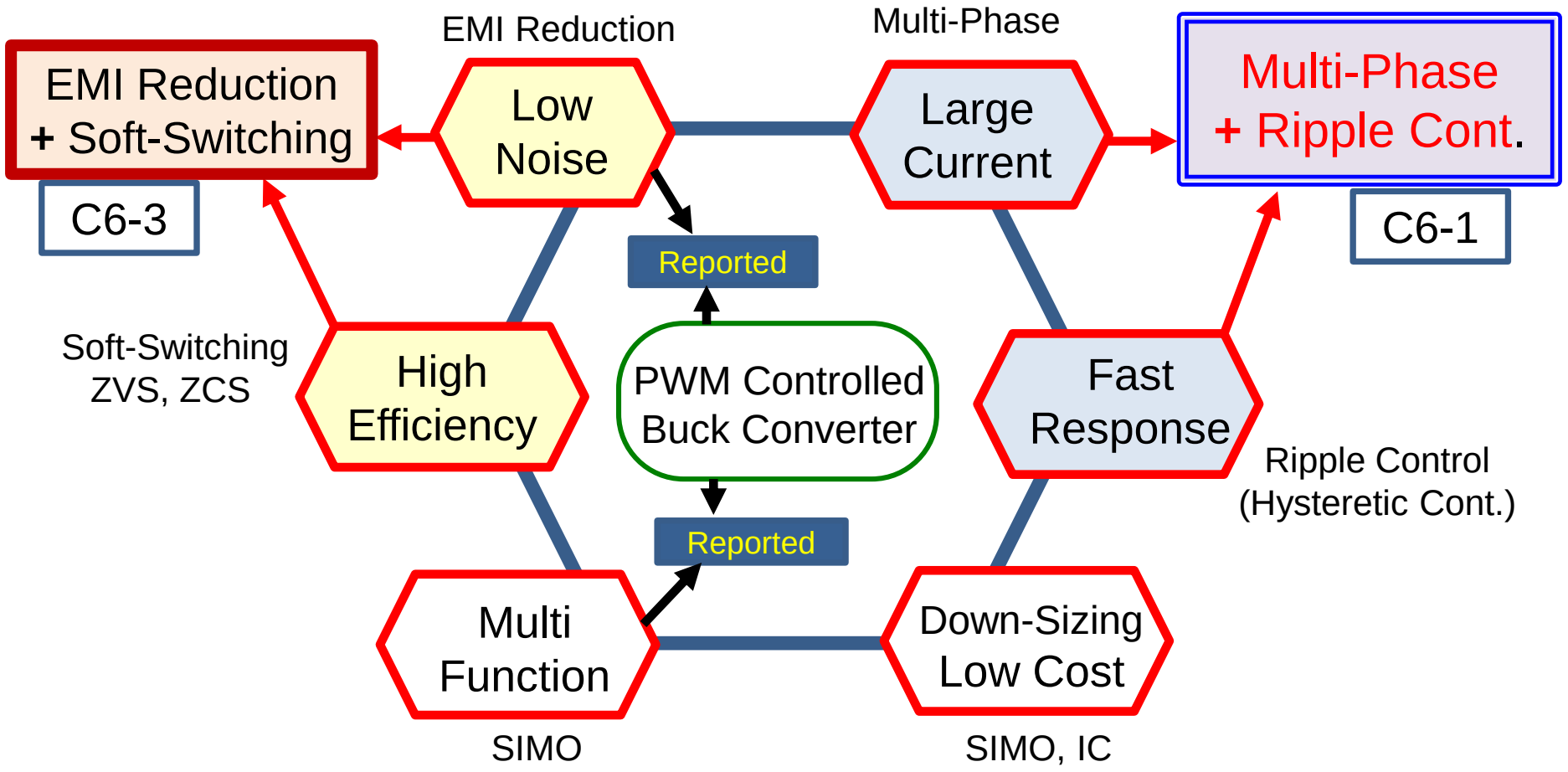
Research Background



LED Display Digital Camera Smartphone CPU for Server



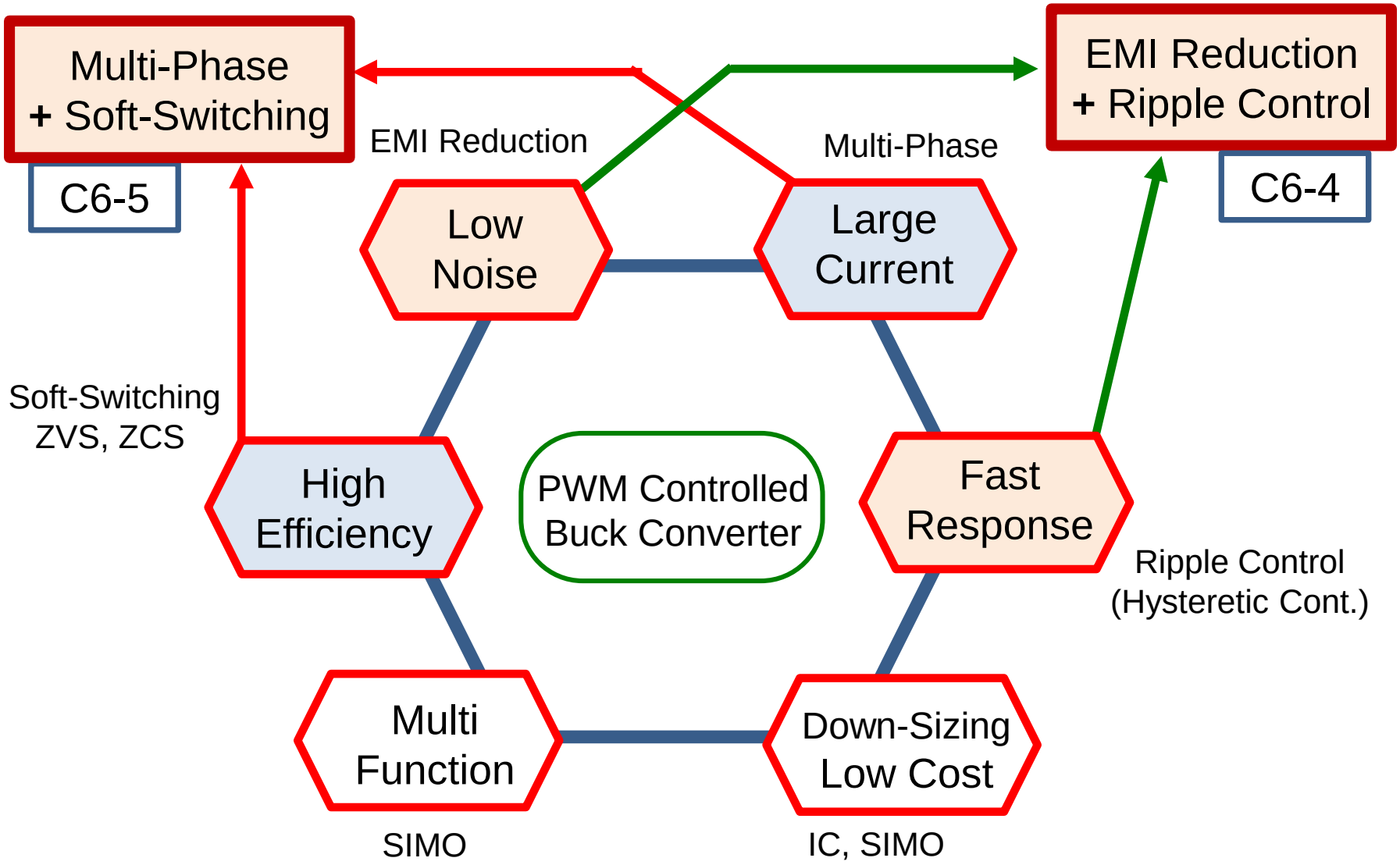
Study of Power Supplies at Gunma University (1/2)



EMI: Electro-Magnetic Interference
SIMO: Single-Inductor Multi-Output

ZVS: Zero Voltage Switching
ZCS: Zero Current Switching

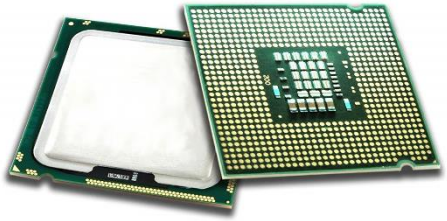
Study of Power Supplies at Gunma University (2/2)



Power Supply as Require Large Current

Power consumption of
electronic information equipment

Increase



CPU for server: More than 100A

Power supply: Use Multi-Phase configuration

Problems with multi-phase converter:
Error of element value / Parasitic component

Inductor current of each channels: Imbalance occur

Control the current to be equal

Objective

COT ripple based control converter

COT: Constant On-Time

- For large load current
  Multi-Phase configuration
- Current imbalance correction
  Automatic current imbalance correction with feedback control
- Simulate proposed circuit

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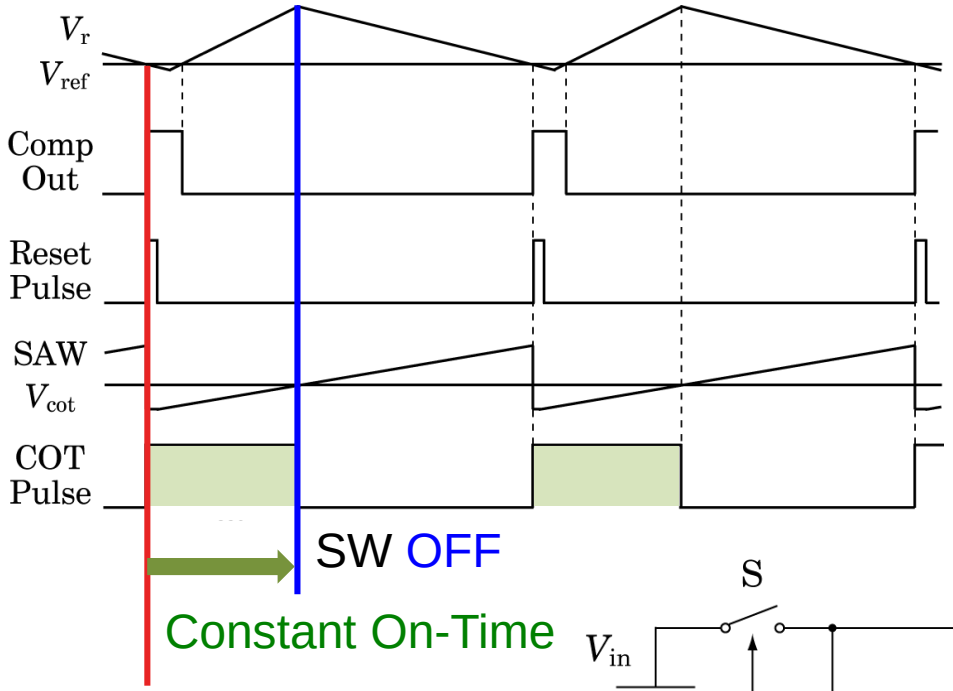
COT Ripple Based Control Converter

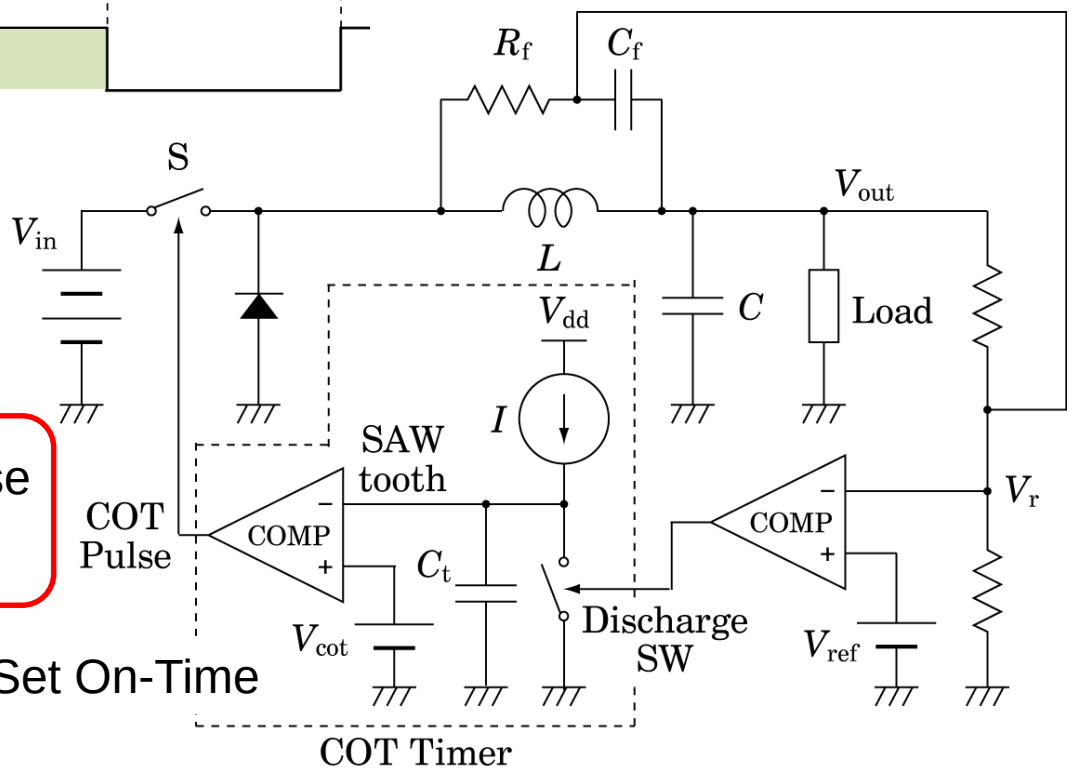


Output voltage < Reference:
SW ON

Suppresses excessive increase in switching frequency

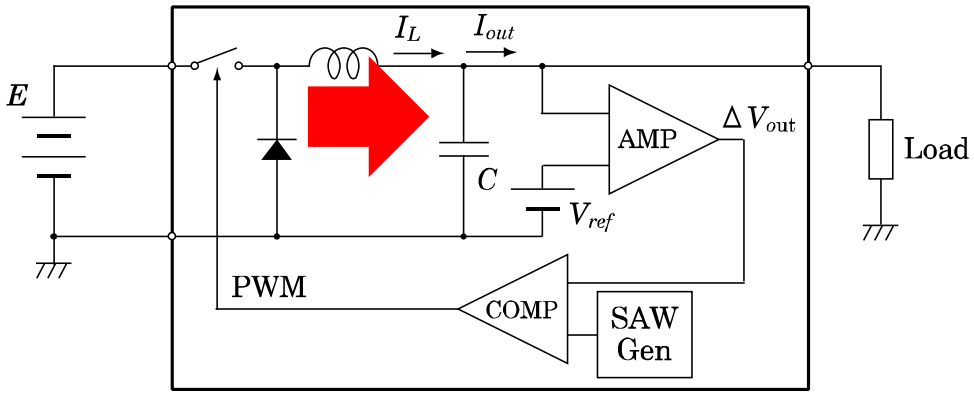
After switch off output voltage drops to the reference

Switch on for a constant time



Problems with Single-Phase Converter

Large current



Increase
load current

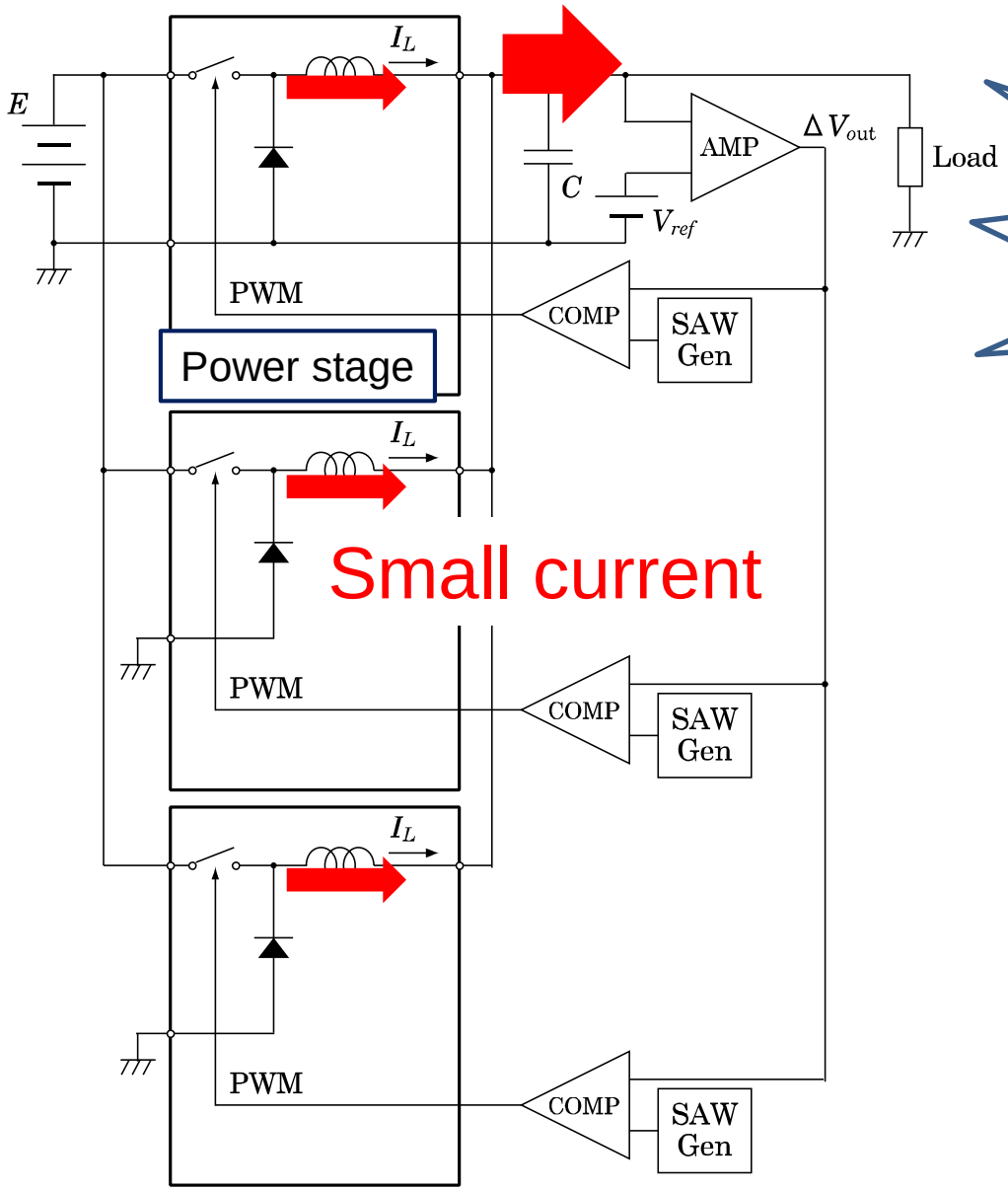
Single-Phase converter

Increase allowable current of switching elements and coils

Increase
gate capacitance

Can not high speed switching

Multi-Phase Configuration



Increase load current

Parallel connection of power stages

Decrease inductor current in each channel

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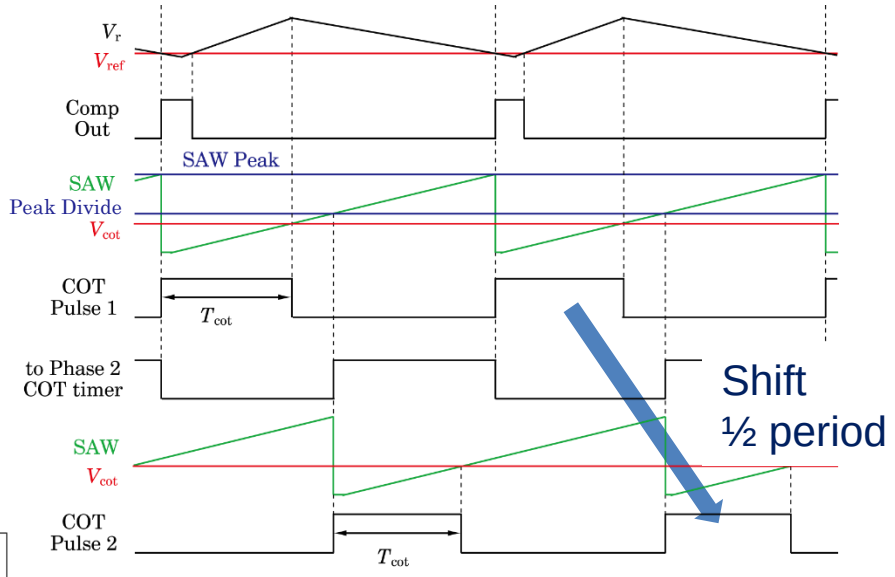
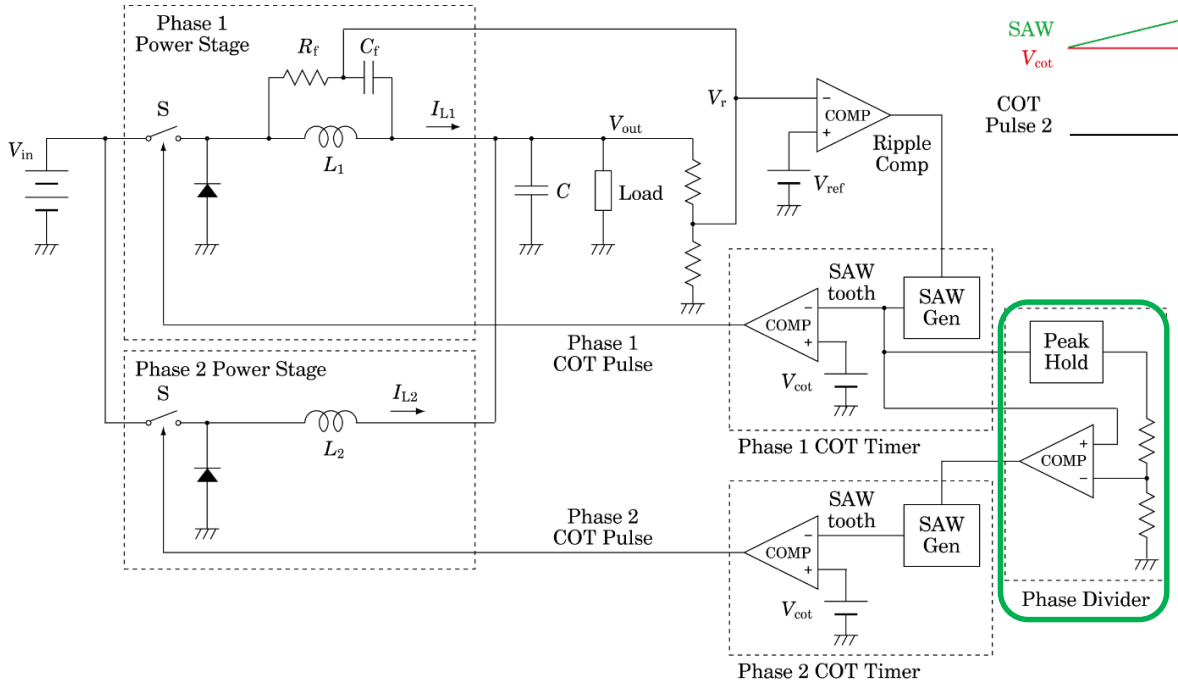
Multi-Phase COT Ripple Based Control Converter

Parallel connection of power stages

Ripple detection: 1st phase only





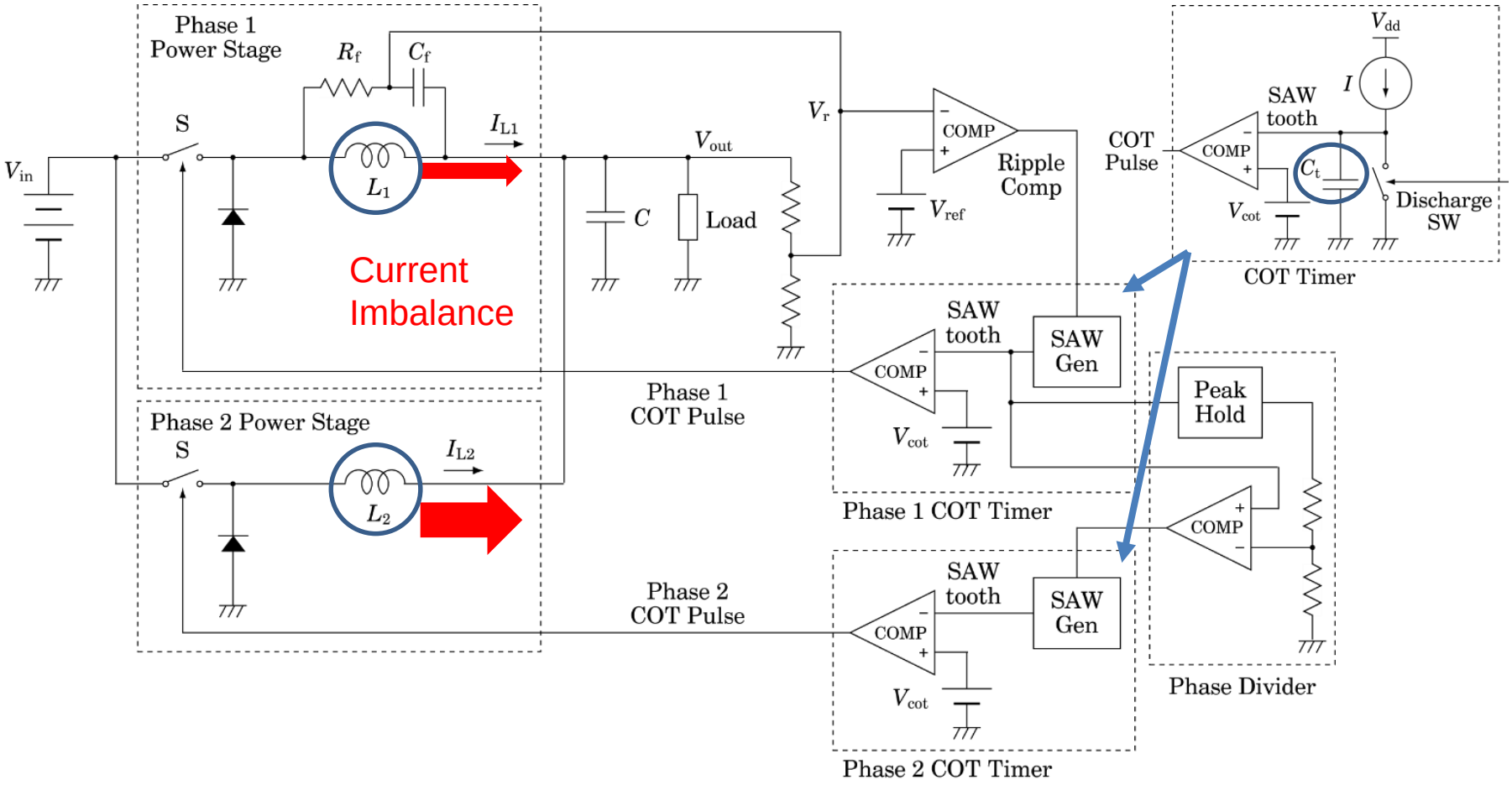
Phase shifted pulse

1st phase COT pulse

Detect amplitude of saw tooth wave & Divide

2nd phase COT pulse

Current Imbalance by Element Variation



Element variation ➡ Current imbalance occur

Causes overcurrent, ripple increase and power loss

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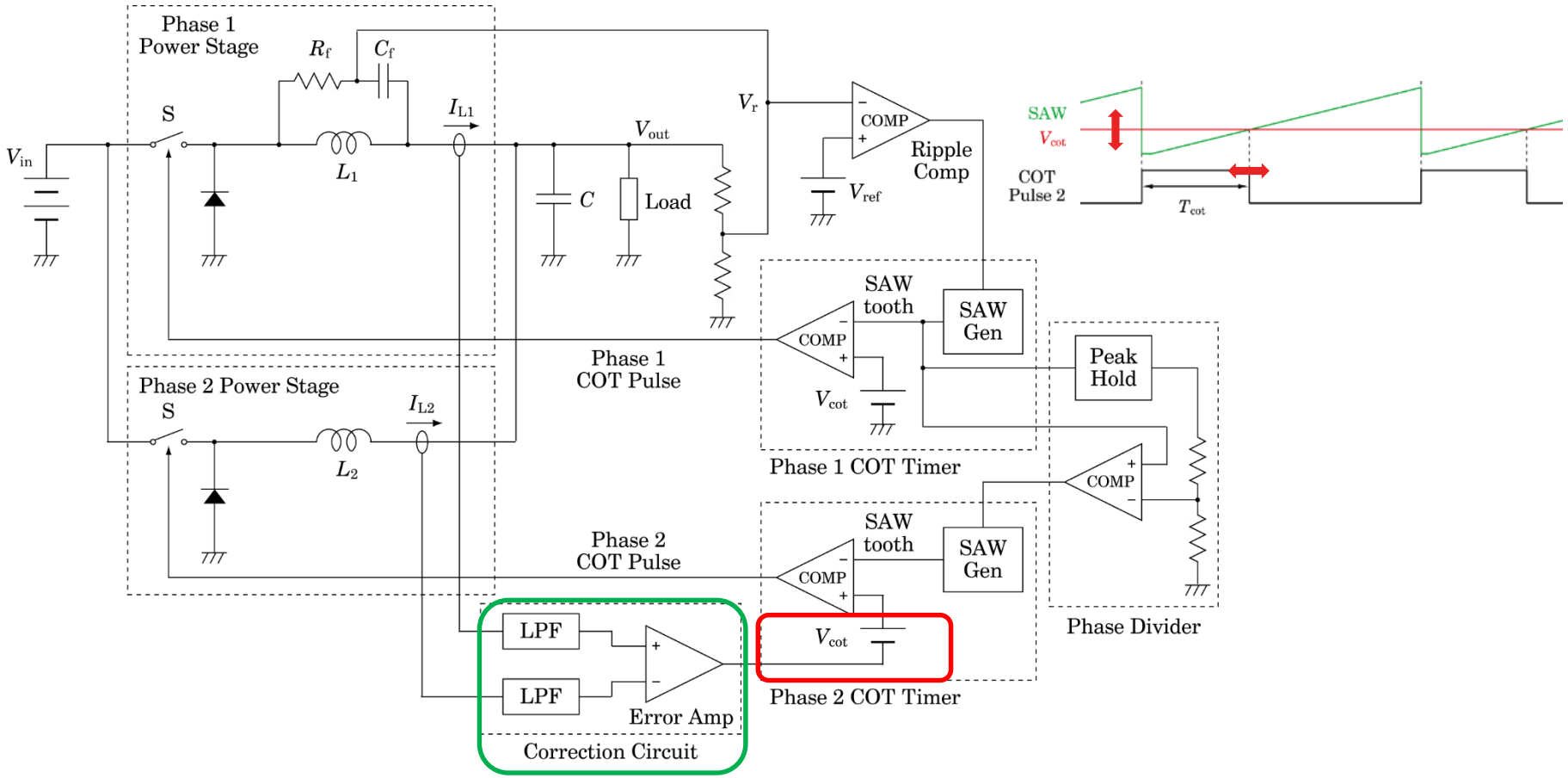
Automatic Current Imbalance Correction (Dual-Phase)



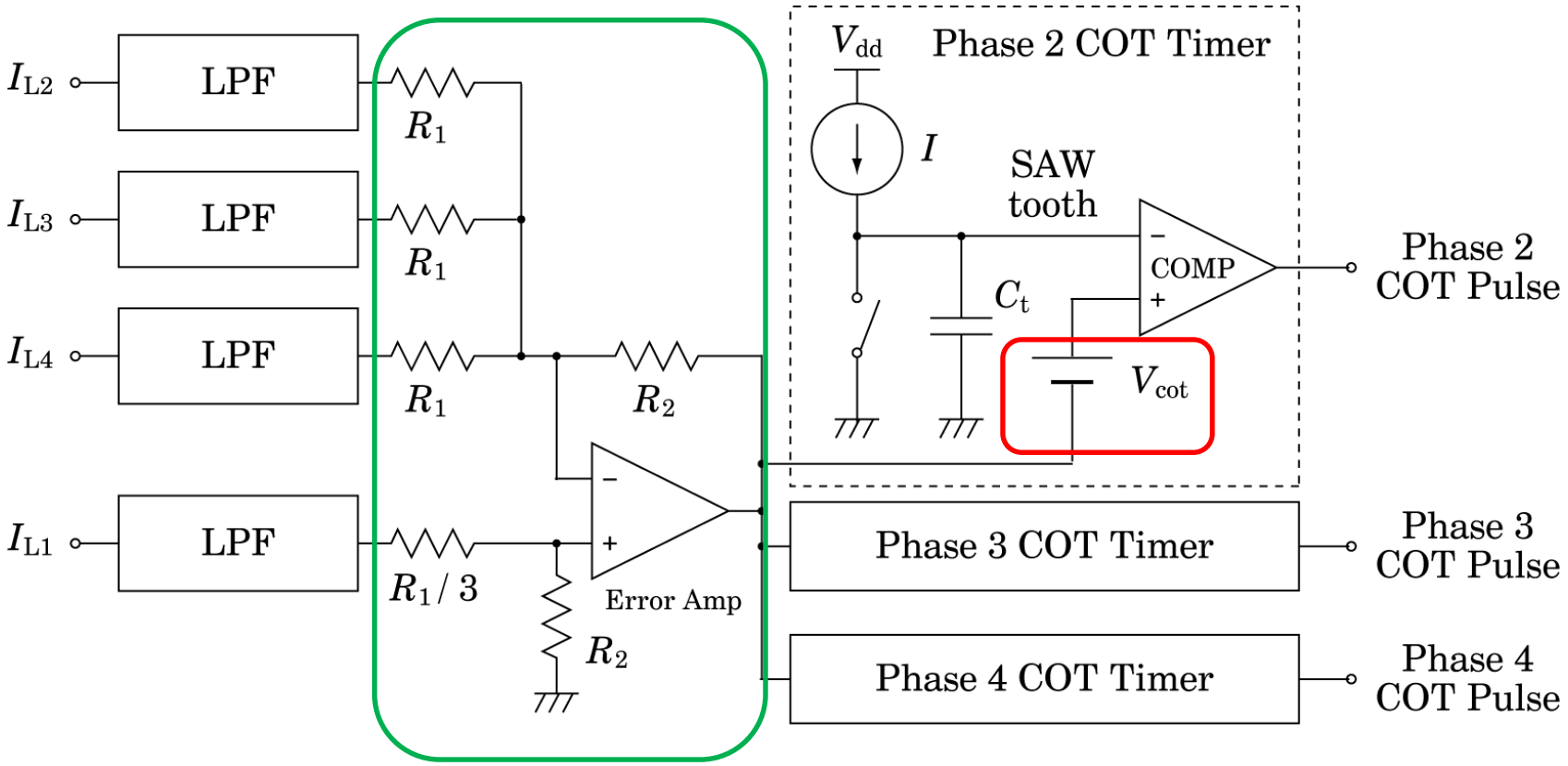
Inductor current difference → On-Time reference

Feedback

$I_{L1} = I_{L2}$

Correct imbalance between two channels

Automatic Current Imbalance Correction (Limitedly)



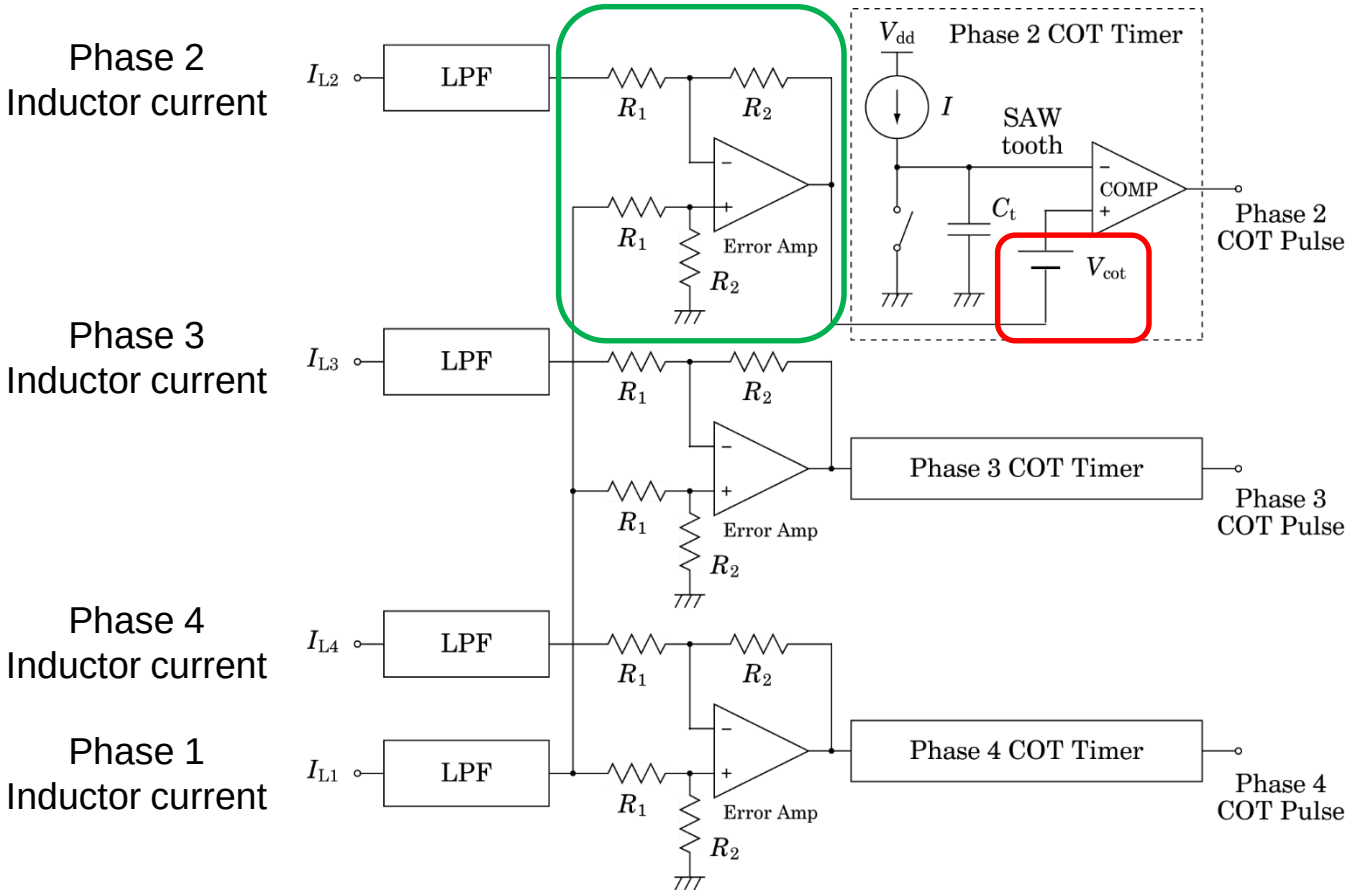
Inductor current difference → On-Time reference

Feedback

$$3I_{L1} = I_{L2} + I_{L3} + I_{L4}$$

Corrects only imbalance between Main-Phase and Sub-Phase

Automatic Current Imbalance Correction Circuit (Completely)



Inductor current difference → On-Time reference

Feedback

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

Fully corrects imbalance between all channels

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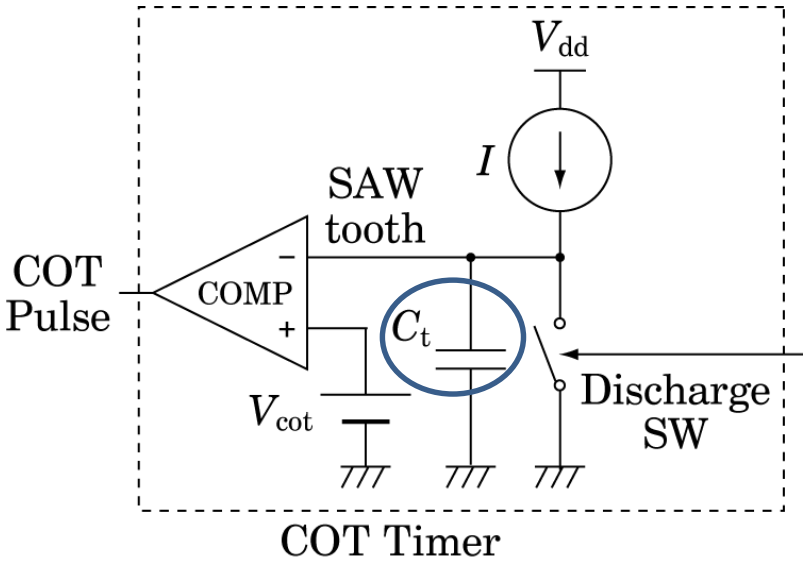
Simulation Conditions

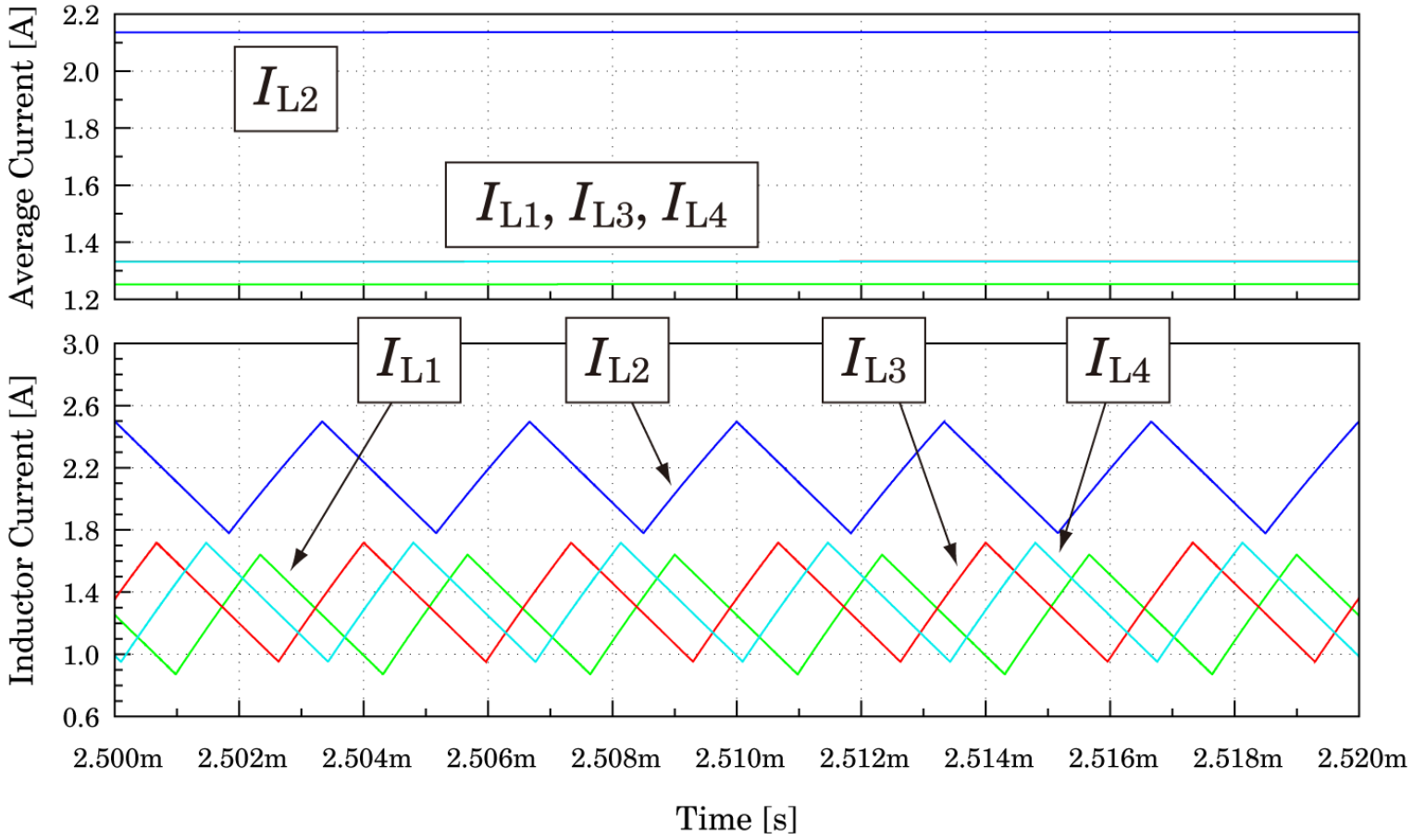
Conditions: Quad-Phase configuration

2nd phase COT timer capacitor C_{t2} increase 10%



Increase C_{t2} ➡ Increase On-Time ➡ Increase inductor current

Simulation Result (Without Correction)

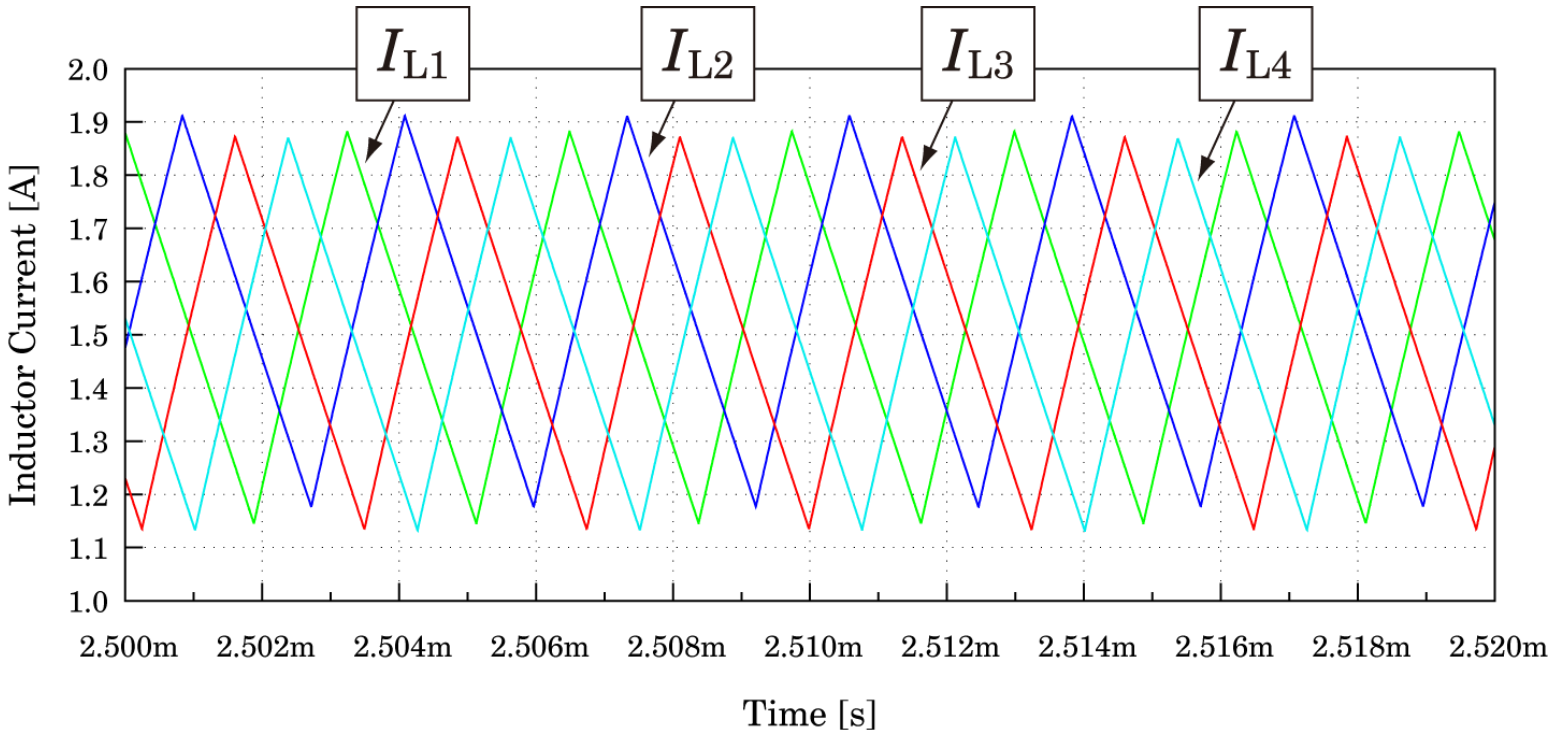


2nd phase COT timer capacitor C_{t2} increase 10%

1st phase inductor current: 1.25A
2nd phase inductor current: 2.13A
3rd phase inductor current: 1.33A
4th phase inductor current: 1.33A

2nd phase increase: 41%

Simulation Result (With Complete Correction)



2nd phase COT timer capacitor C_{t2} increase 10%

1st phase inductor current: 1.51A
2nd phase inductor current: 1.54A
3rd phase inductor current: 1.50A
4th phase inductor current: 1.50A

2nd phase increase: 1%

Imbalance: 41% ➡ 1%

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Conclusion

- Considered Multi-Phase configuration for COT ripple based control converter

- Proposed automatic correction of current imbalance due to element variation

  → **Feedback the current difference to each COT pulse On-Time**

- Simulation

  → **Improved current balance**
  41% ➡ 1%

Thank you for your attention

謝謝

Q & A

Q. 電流アンバランス補正には複数のループが存在するが，安定なのか．

A. 下図に示すように負荷電流をステップ変化させた場合は安定である．
アンバランス発生要因の時間変化については今後検討する．