

### 1. Research Objective

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

● Target Application

- ⇒ Power Supply of Microprocessor
  - Full-wave resonant converter circuit
  - ⇒ PWM Control Circuit
  - ⇒ ZVS Operation
- PWM: Pulse Width Modulation  
ZVS: Zero Voltage Switching

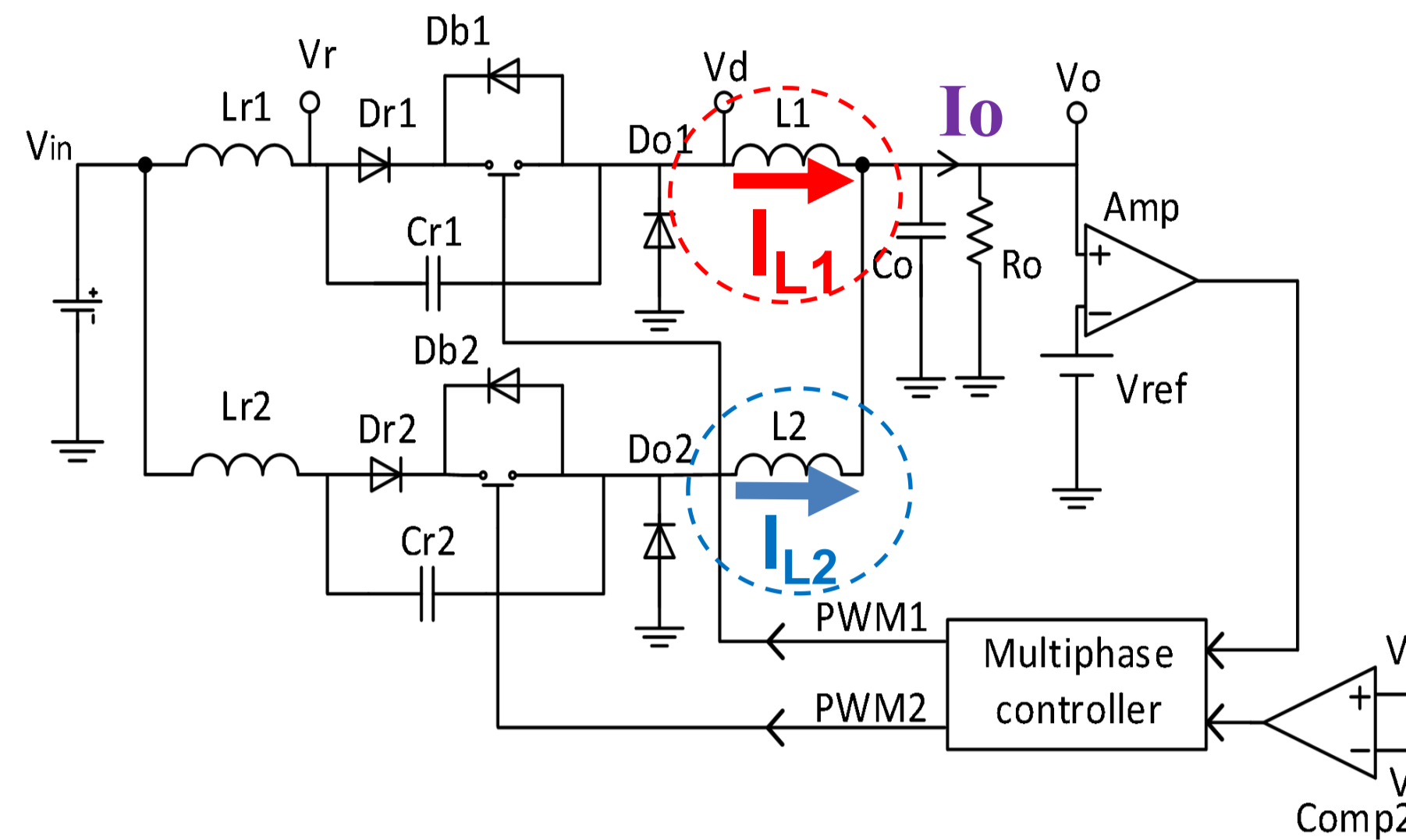
● Current balance of Full/Half wave type dual-phase converter

- ⇒ Automatic Current Balance Circuit

● Current balance of four-phase resonant converter

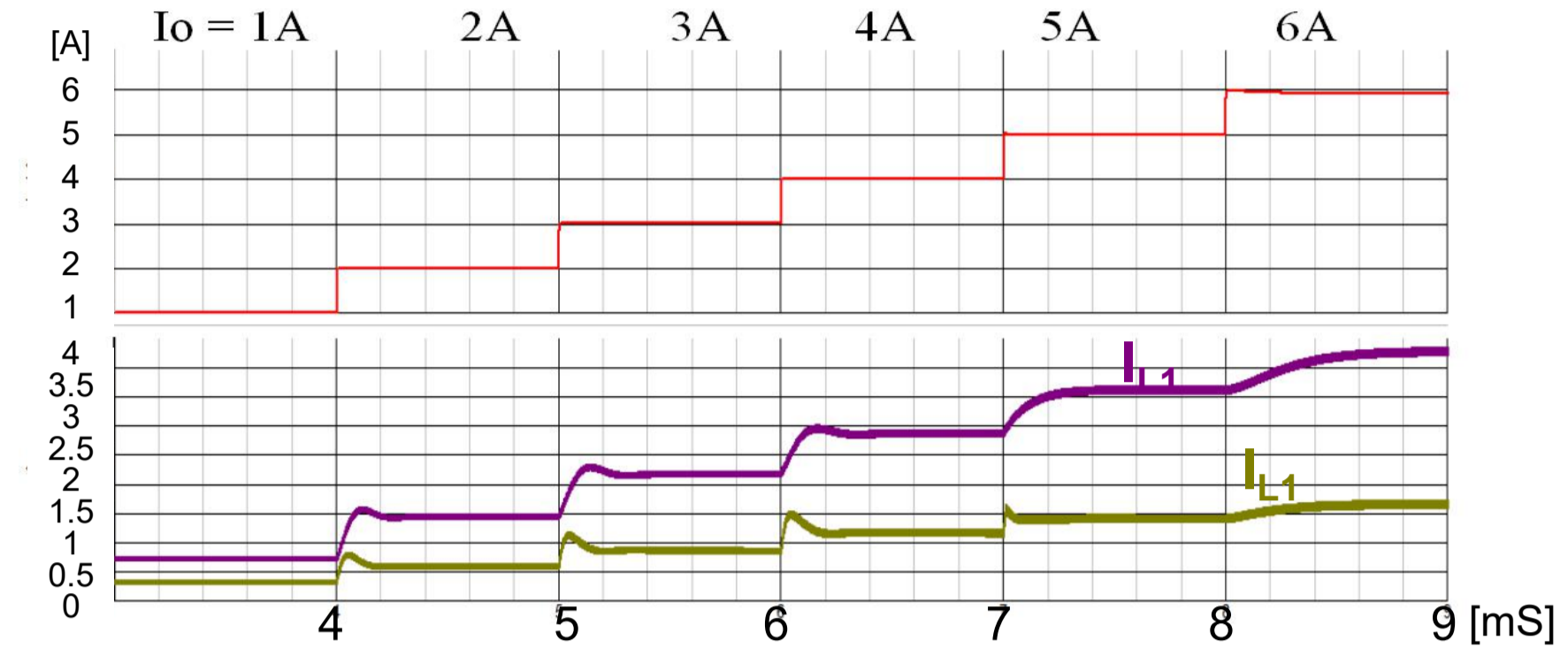
### 2. Background

#### Dual-phase converter

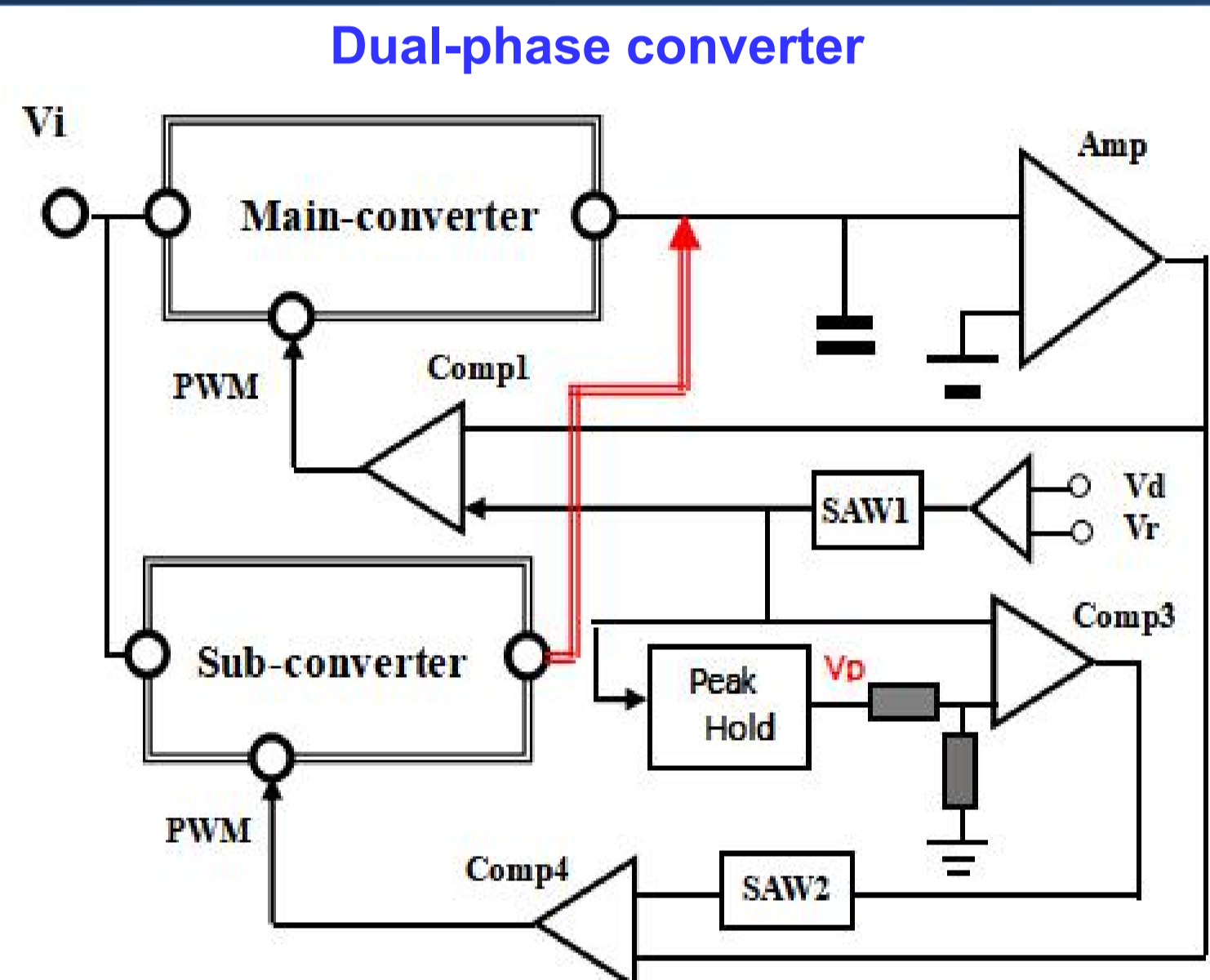


#### Problem

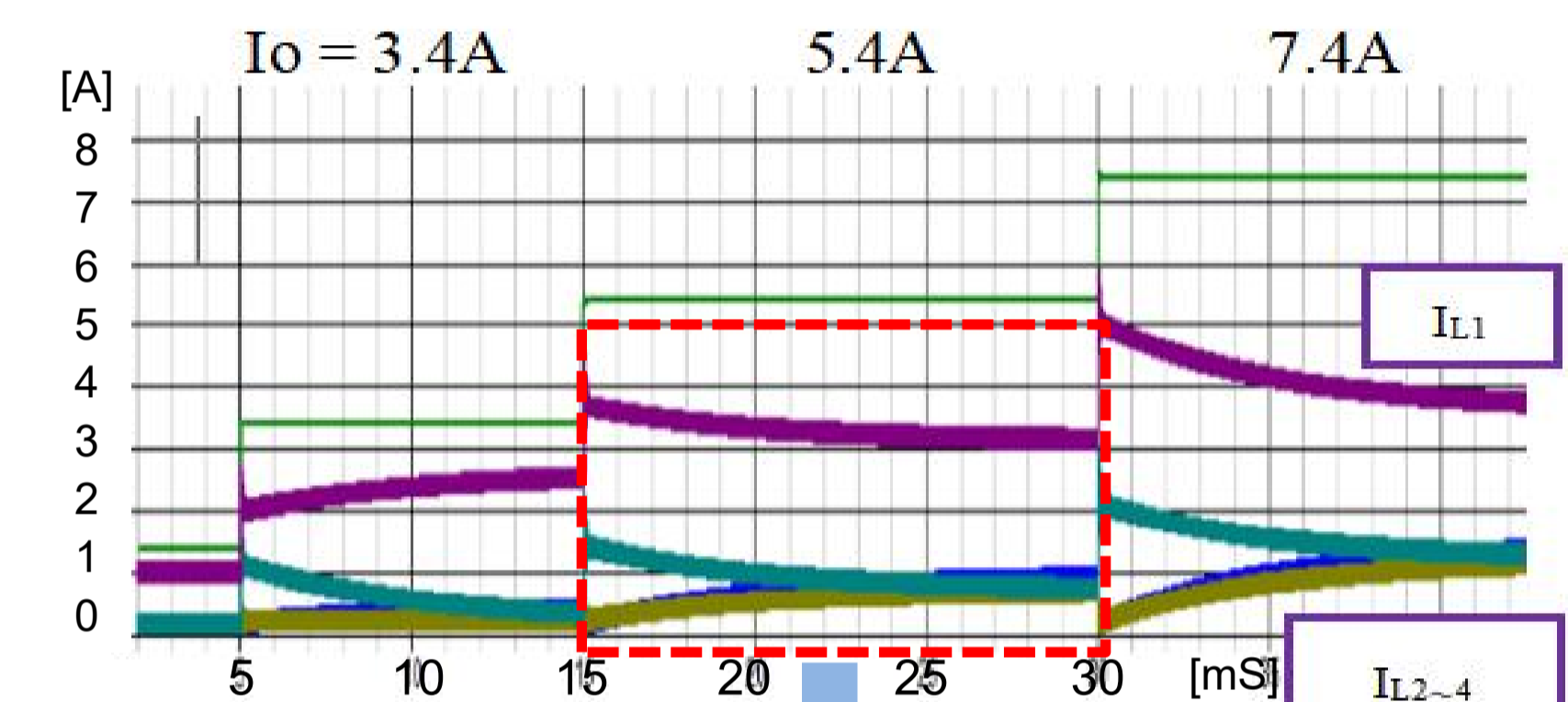
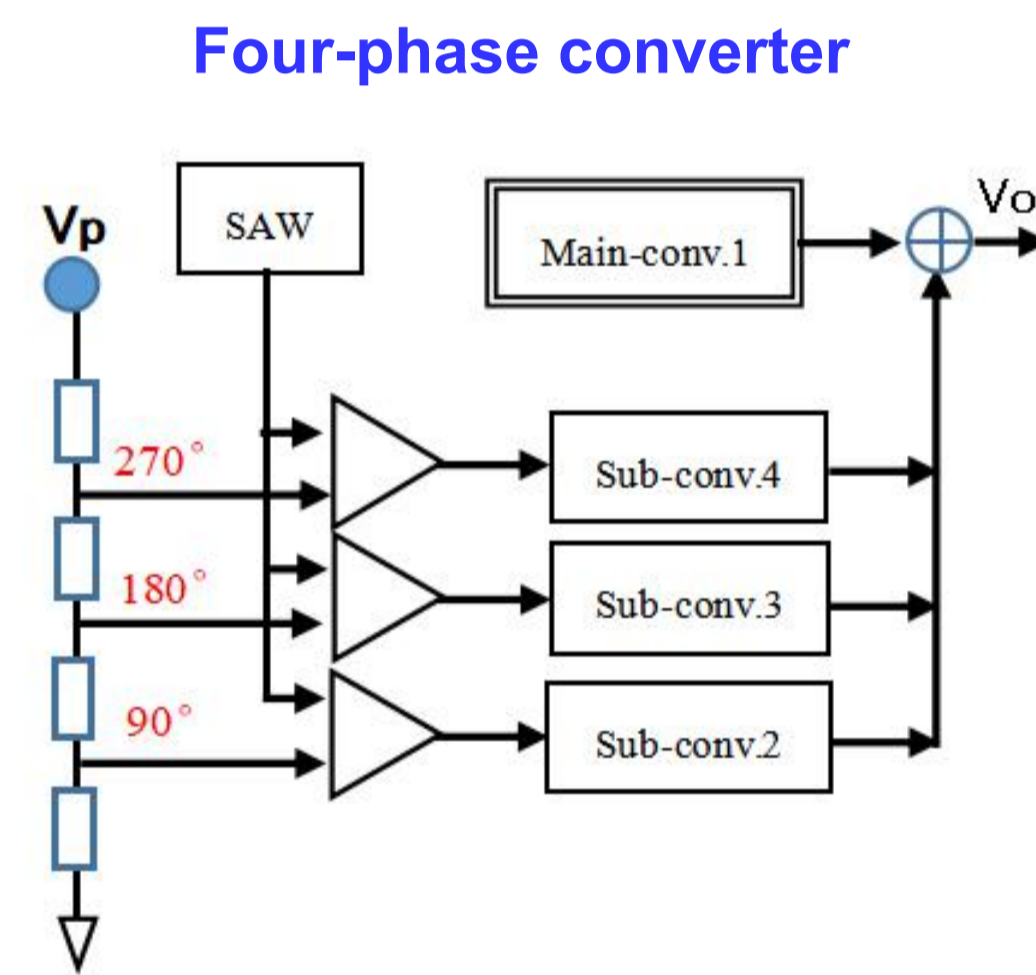
- Dual-phase converter without current balance circuit has imbalance current with element variation
- Imbalance increases with increase of output current  $I_o$ .



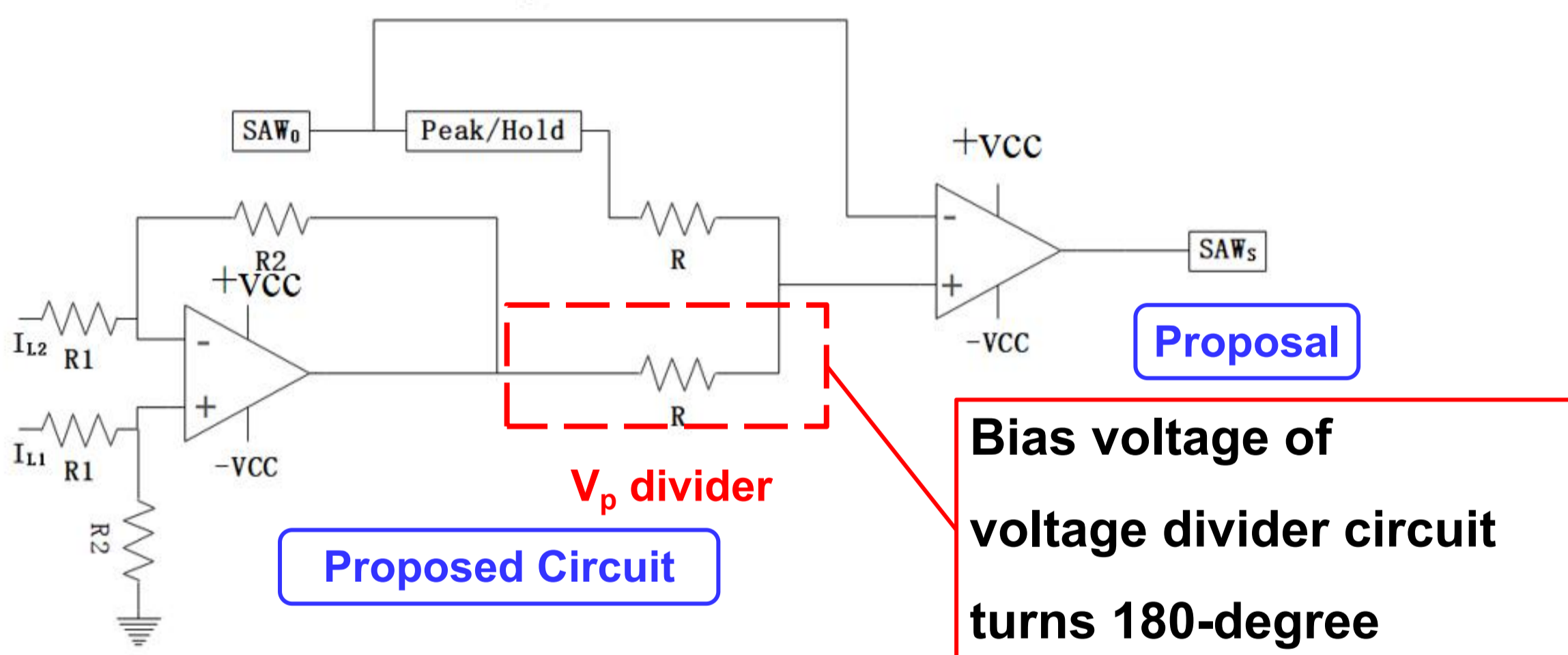
### 3. Proposed Circuit



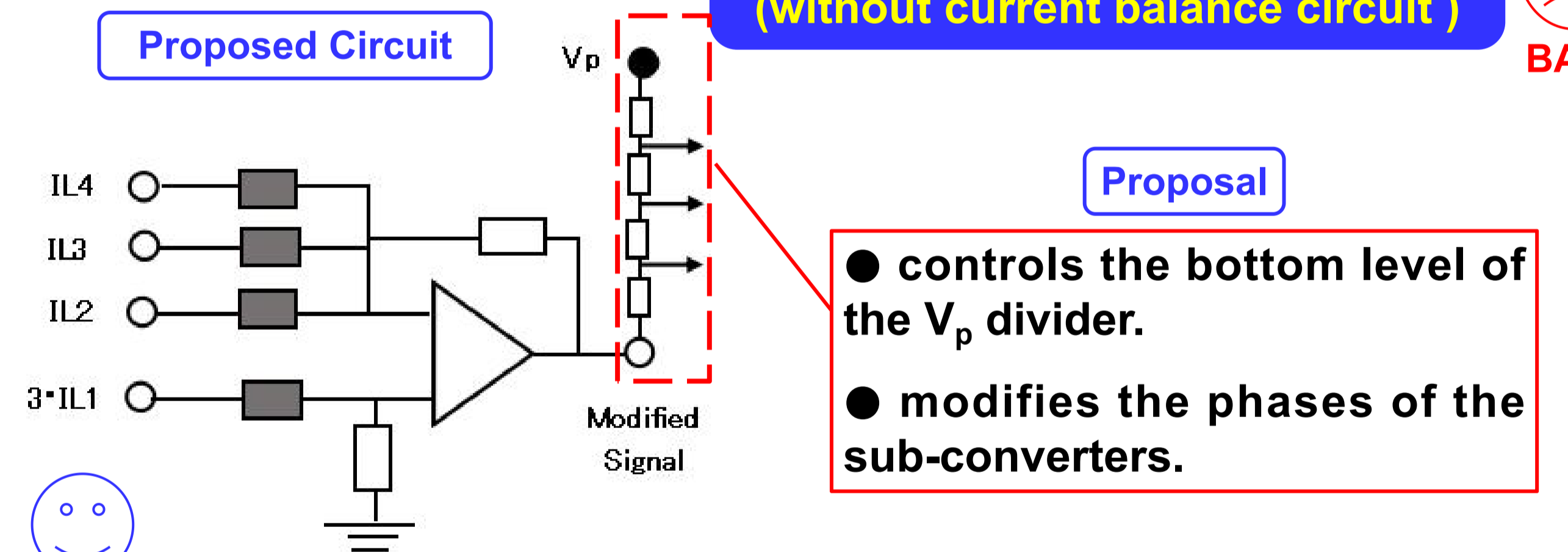
Add two more sub-converters



+185% current imbalance (without current balance circuit) BAD!



Bias voltage of voltage divider circuit turns 180-degree



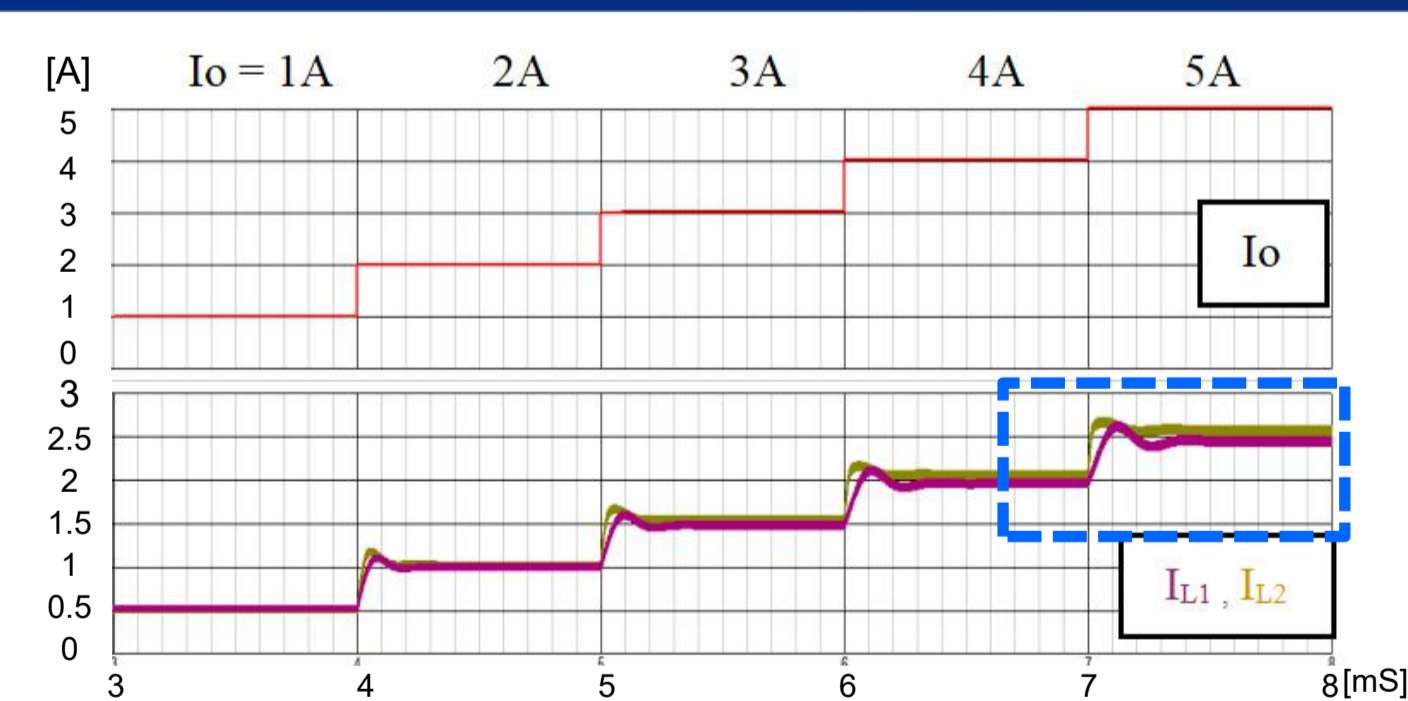
- controls the bottom level of the  $V_p$  divider.
- modifies the phases of the sub-converters.

GOOD!

Circuit of automatic current balance of dual-phase converter

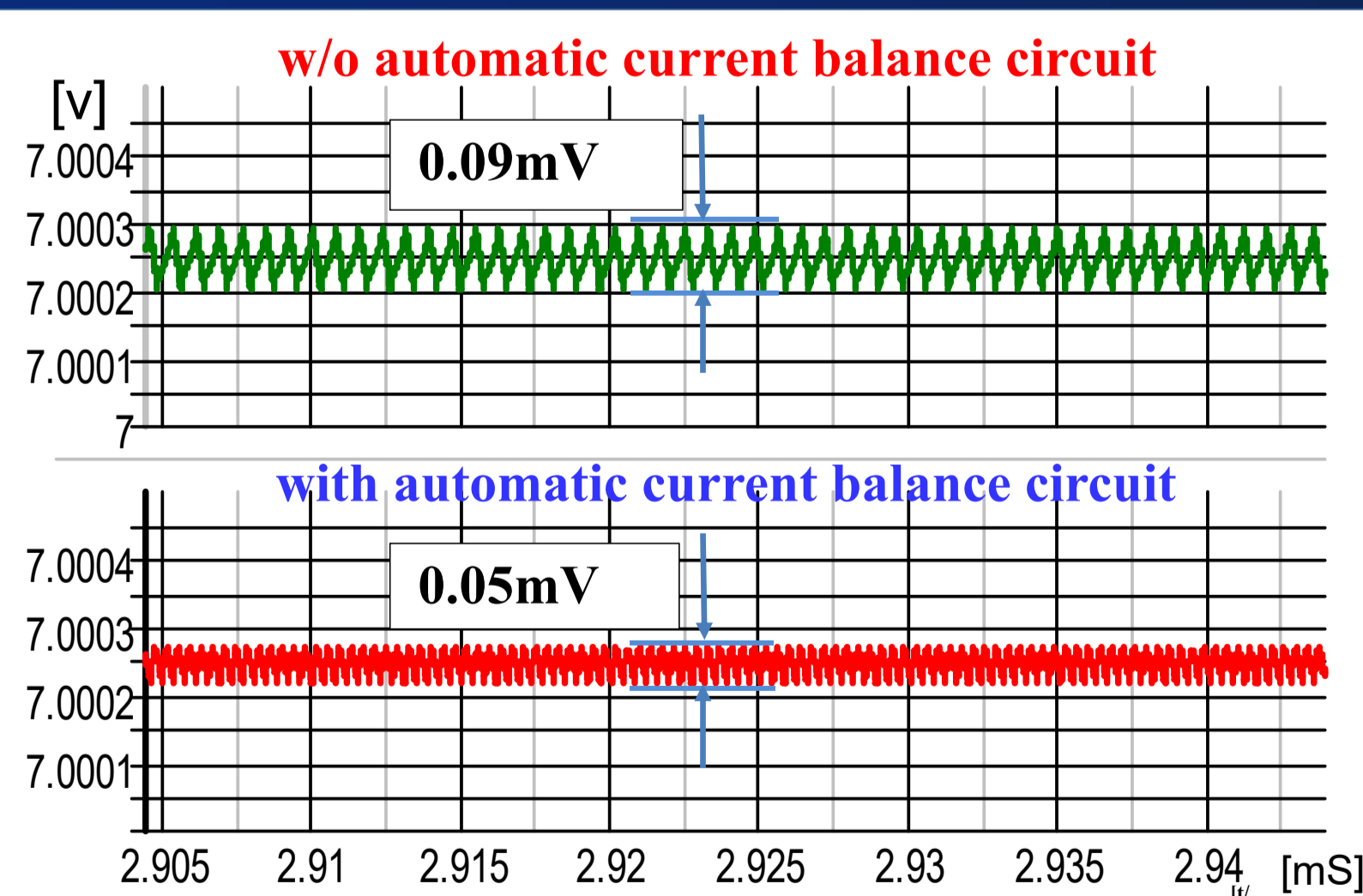
Circuit of automatic current balance of four-phase converter

### 4. Simulation Results

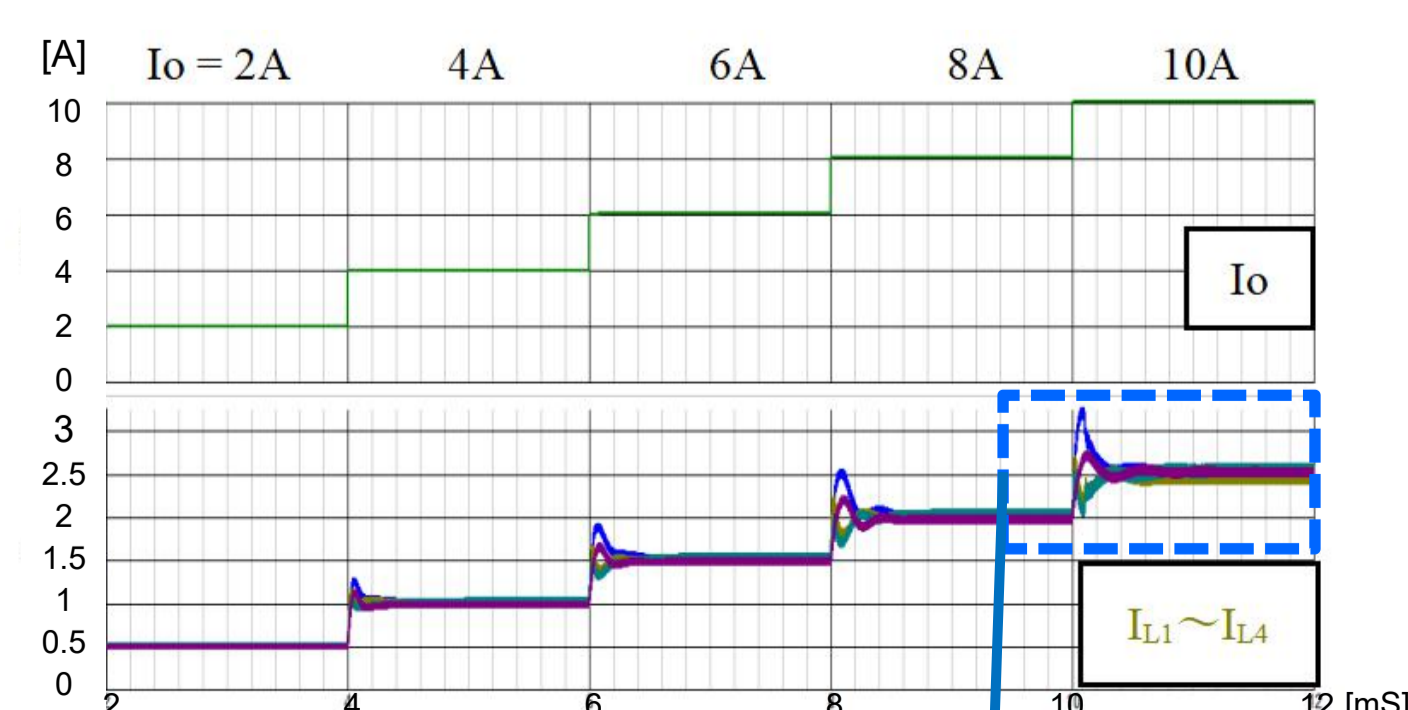


+40% current imbalance (+3.5A) → +0.07% current imbalance (+0.02A)

Current balance of dual-phase converter

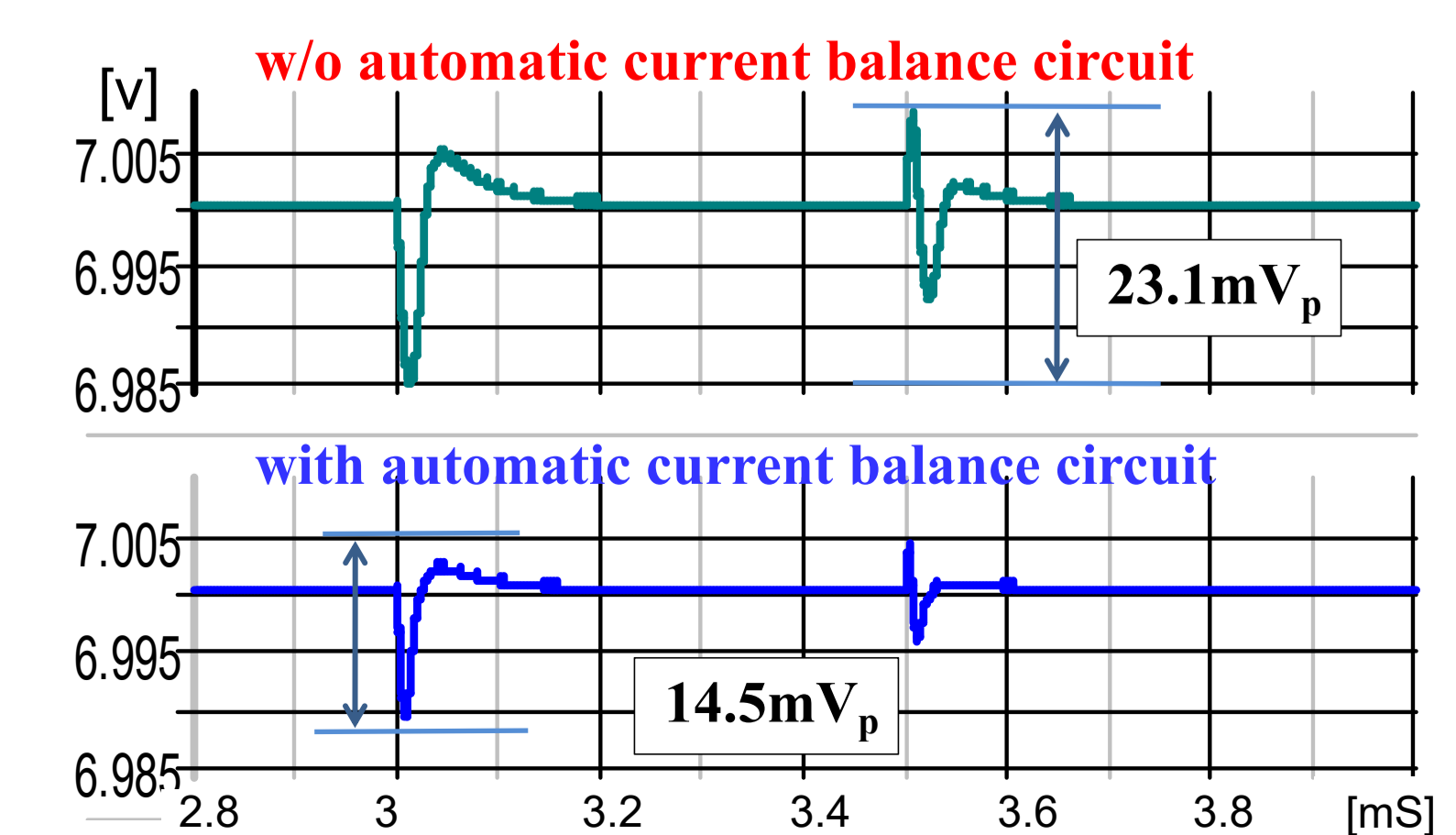


Ripple of output voltage of dual-phase converter



+18% current imbalance → +0.02% current imbalance (+0.05A)

Current balance of four-phase converter



Transient response GOOD!

### 5. Conclusion

- In dual-phase converter with element variation of 10%, current imbalance ratio is very large of 3.5A to 1.5A for output current  $I_o$  of 5.0A. Automatic current balance circuit → Current imbalance < 0.02A.
- In four-phase converter, current imbalance of  $I_{L1}$  is +18% with element variation of 10% for output current  $I_o$  of 5.4A which is reduced to 0.02% with automatic current balance circuit.
- Effective for full wave and half wave type resonant converter with two- or four-phase converter.

### 6. References

[1] H. Kobayashi, T. Nabeshima (Editors), Handbook of Power Management Circuits, Pan Stanford Publishers (2016).  
 [2] K. Asaishi, N. Tsukiji, Y. Kobori, Y. Sunaga, N. Takai, H. Kobayashi, "Hysteresis Control Power Supply with Switching Frequency Insensitive to Input /Output Voltage Ratio", IEEE 13th International Conference on Solid-State and Integrated Circuit Technology, Hangzhou, China (Oct. 2016)  
 [3] Y. Xiong, Y. Sun, N. Tsukiji, Y. Kobori, H. Kobayashi, "Two-phase Soft-switching DC-DC Converter with Voltage-mode Resonant Switch", IEEE International Symposium on Intelligent Signal Processing and Communication Systems, Xiamen, China (Nov. 2017)