ICPET 2014 International Conference on Power Engineering and Technology
Toronto, Canada (Jun 16-17, 2014)

Single-Inductor Multi-Output Converter with Four-level Output Voltages

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Outline

- Research Objective
- SIDO Converter with Exclusive Control
  - SIDO Buck Converter (Simulation & Experimentation)
  - SIDO Boost Converter (Simulation & Experimentation)
- SIMO Converter with Four Output
  - Previous SIMO Converter with Ripple Control
  - Proposed SIMO Converter with Exclusive Control
    - ＊SIMO Buck Converter (Simulation)
    - ＊SIMO Boost Converter (Simulation)
- Conclusion

＊ SIDO : Single-Inductor Dual-Output
＊ SIMO: Single-Inductor Multi-Output

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Background

Many DC-DC Converters in Cell phones, manufacturing machinery, etc.

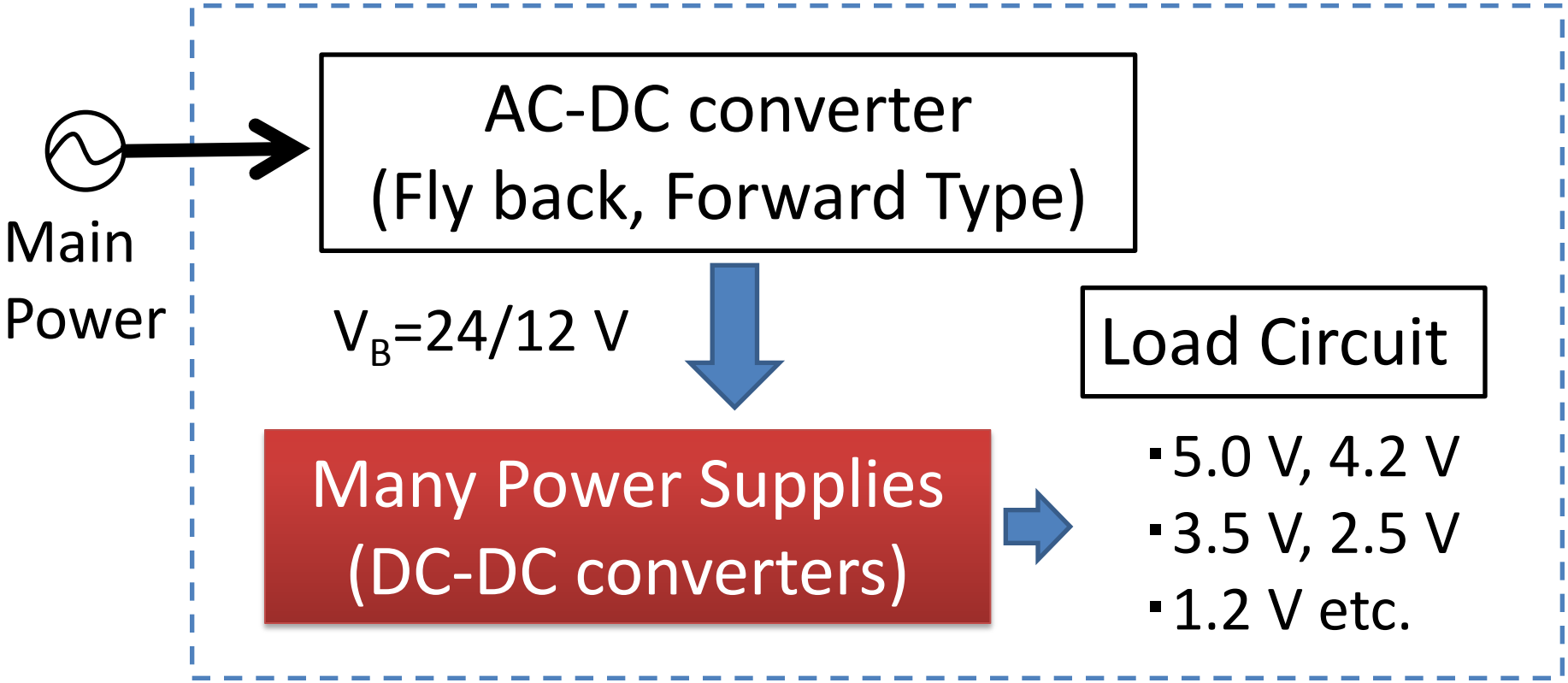
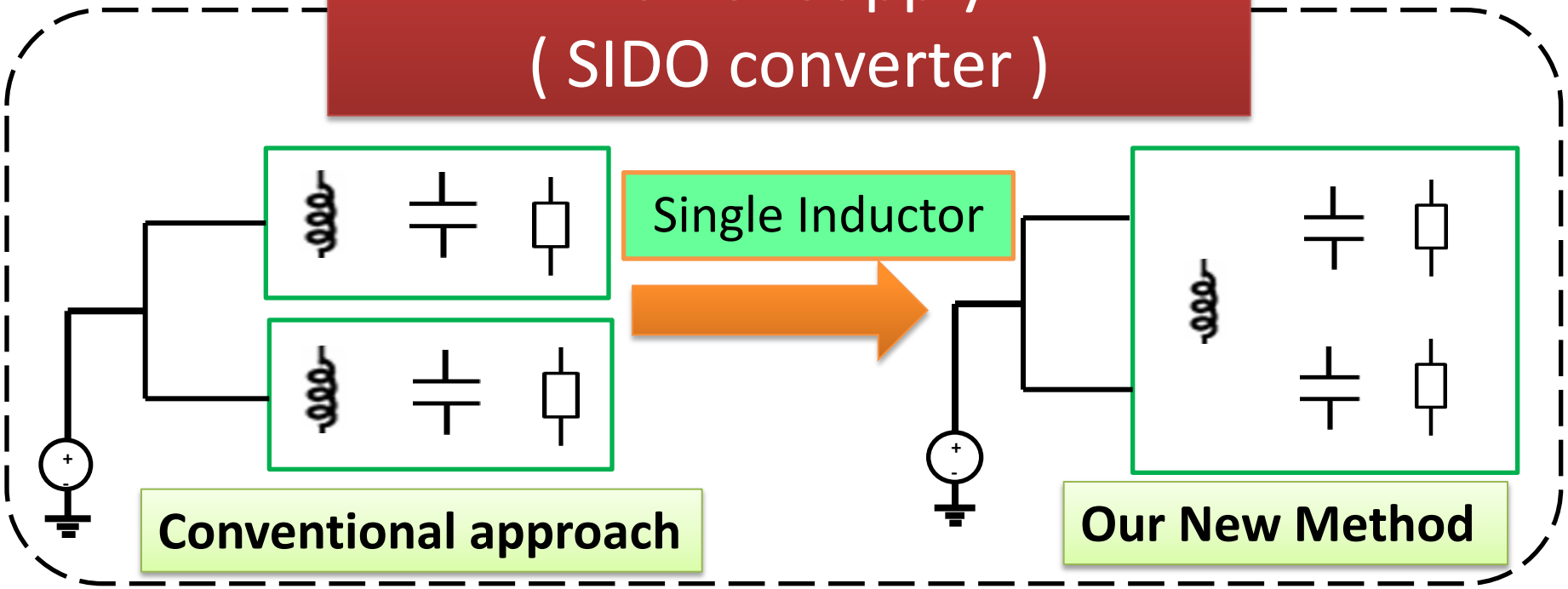


Fig.1 background

Background

Single Inductor Dual Output Power Supply (SIDO converter)



Reduce inductor

Reduce cost
Reduce volume

Fig.2 Background

Research Objective

- Single Inductor Dual Output (SIDO) converter
  - Our Previous SIDO converters with **Exclusive Control**

    buck-buck or boost-boost converter

- New SIMO Converters with Four Sub-Converters

  Four buck or four boost sub-converters
  - How to select the most hungry sub-converter?

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Previous SIDO Converter with Exclusive Control

Vi=9V ⇒ V1=6V, V2=5V

⊿V1＞⊿V2 ⇒ SEL「L」⇒ S2:OFF ⇒ V1
⊿V1＜⊿V2 ⇒ SEL「H」⇒ S2:ON ⇒ V2

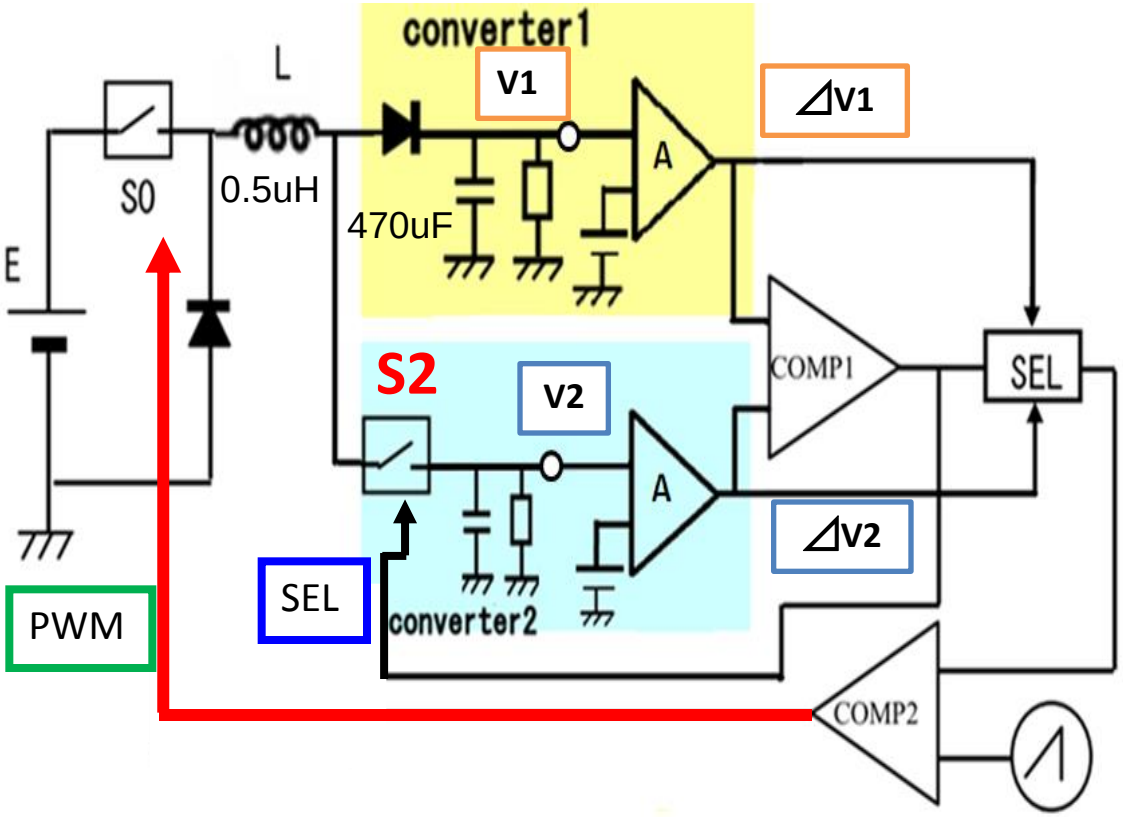


Fig.3 Simulation Circuit of Buck Converter

F=500kHz

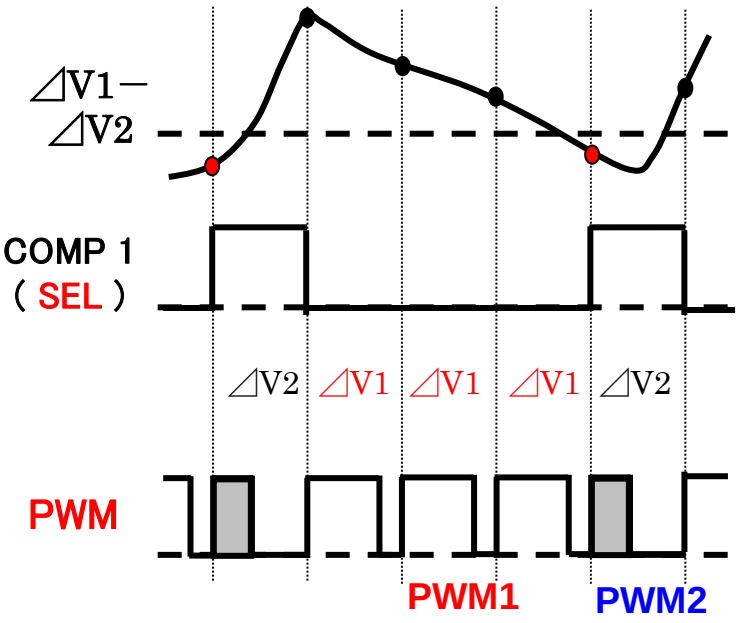


Fig.4 Timing Chart

Previous SIDO Buck Converter

【Simulation Result 1 】

Vi=9V ⇒ V1=6V, V2=5V

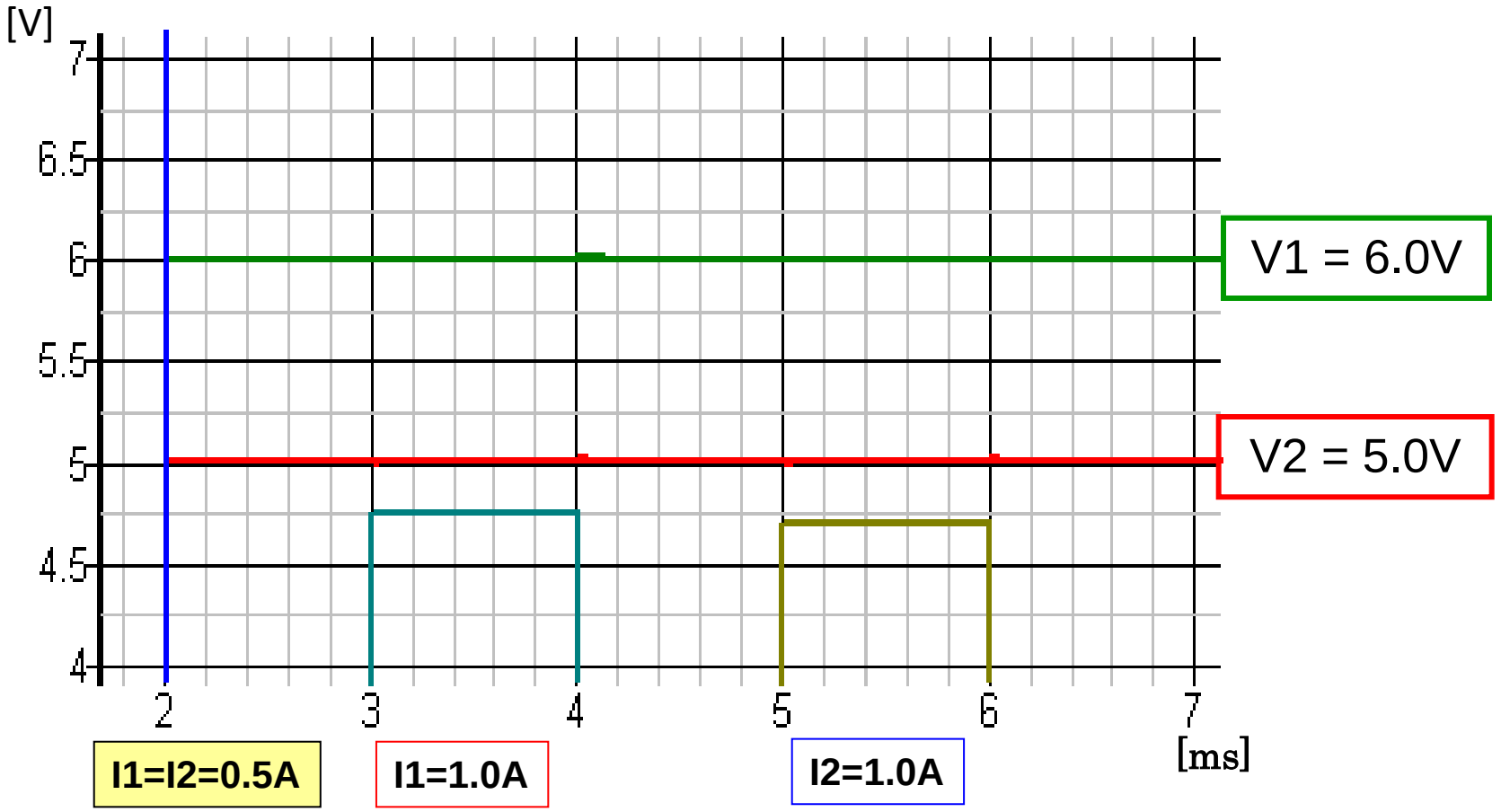


Fig.5 Simulation Results (Buck Converter)

Previous SIDO Buck Converter

【Simulation Result 1 】

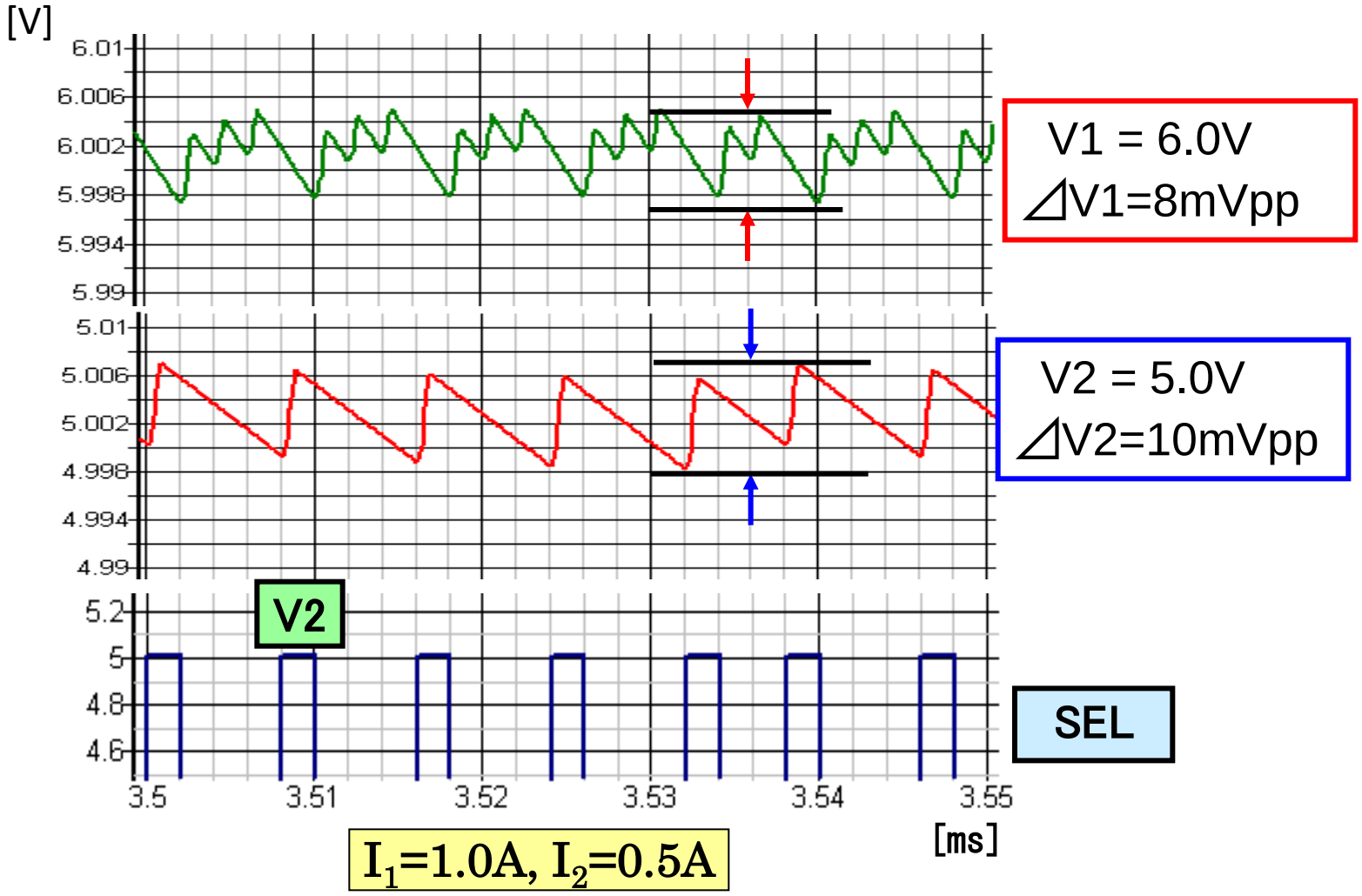
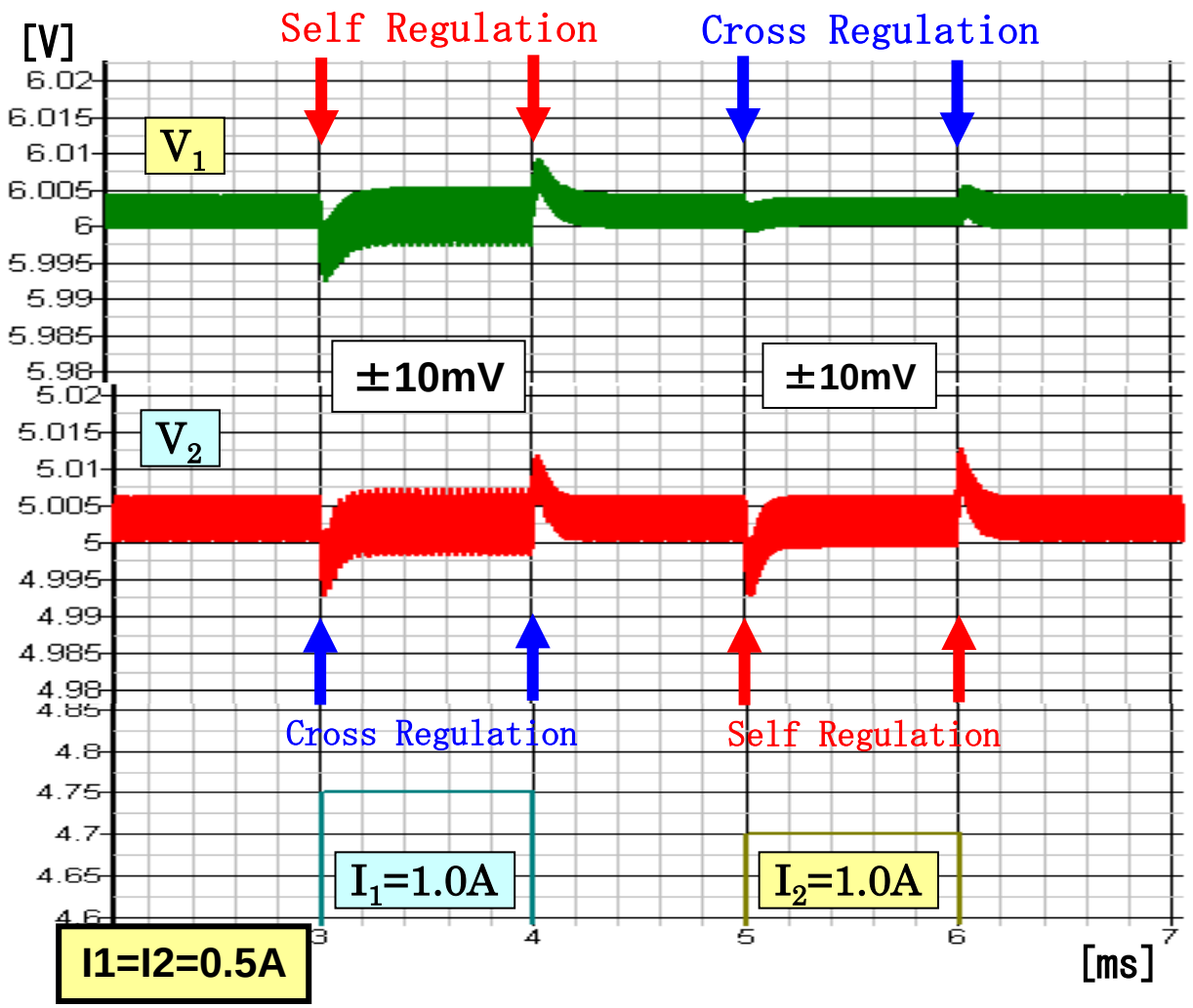


Fig.6 Output Ripples (Buck Converter)

Previous SIDO Buck Converter

【Simulation Result 1 】



Red Arrow:
Self-regulation
Blue Arrow:
Cross-regulation

Fig.7 Ripples & Transient Responses

Previous SIDO Buck Converter

【Experimental Result 1】

● Output Voltage

Vi=9.0V ⇒ V1=6.0V, V2=4.5V, f=200kHz

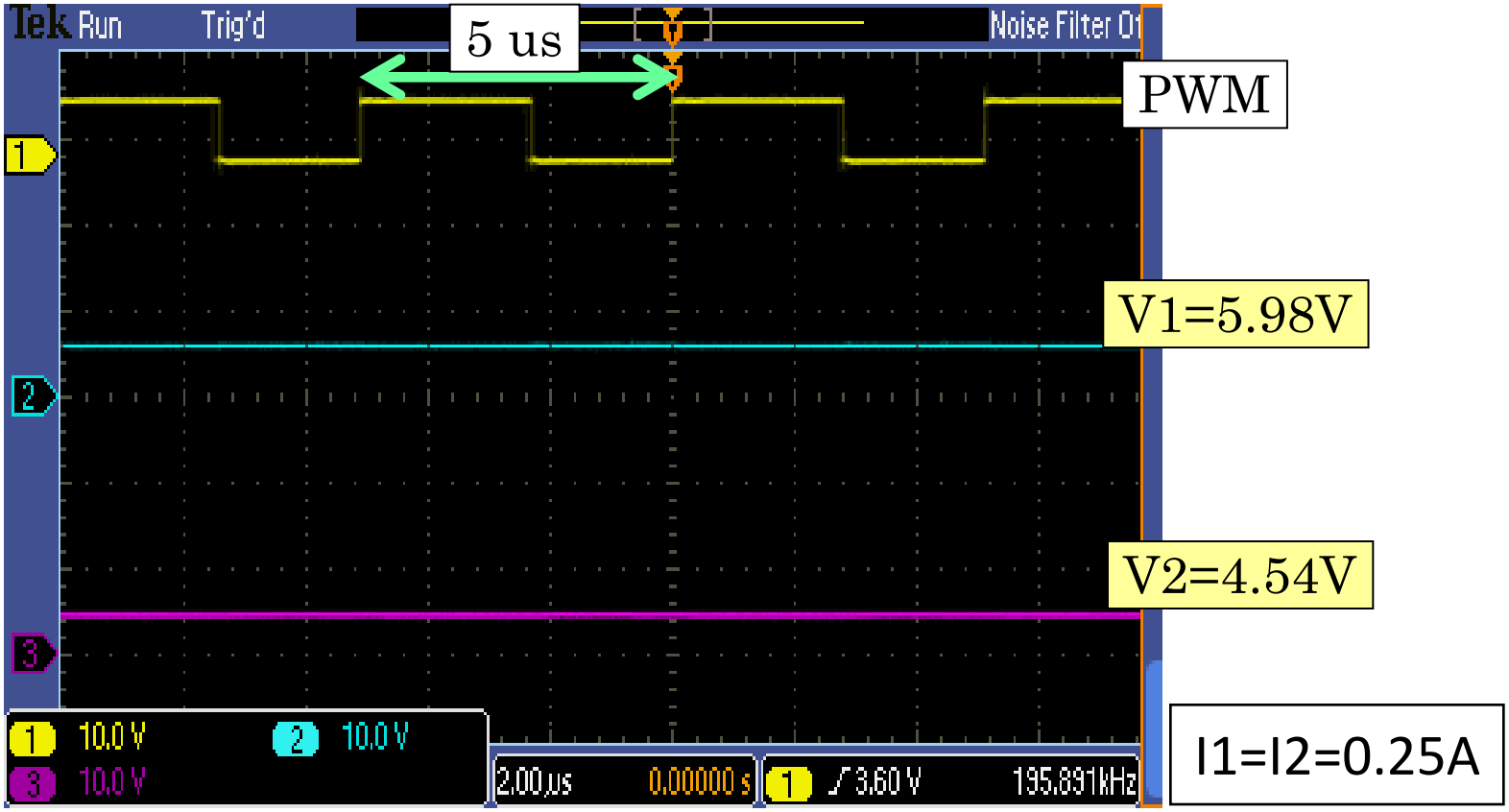


Fig.8 Experimental Result (Output Voltages)

Previous SIDO Buck Converter

【Experimental Result 1】

- Ripples & Transient Responses

I2 = 0.50A／0.25A

Static Ripples: 20 mVpp
Transient Resp.: 10 mVop

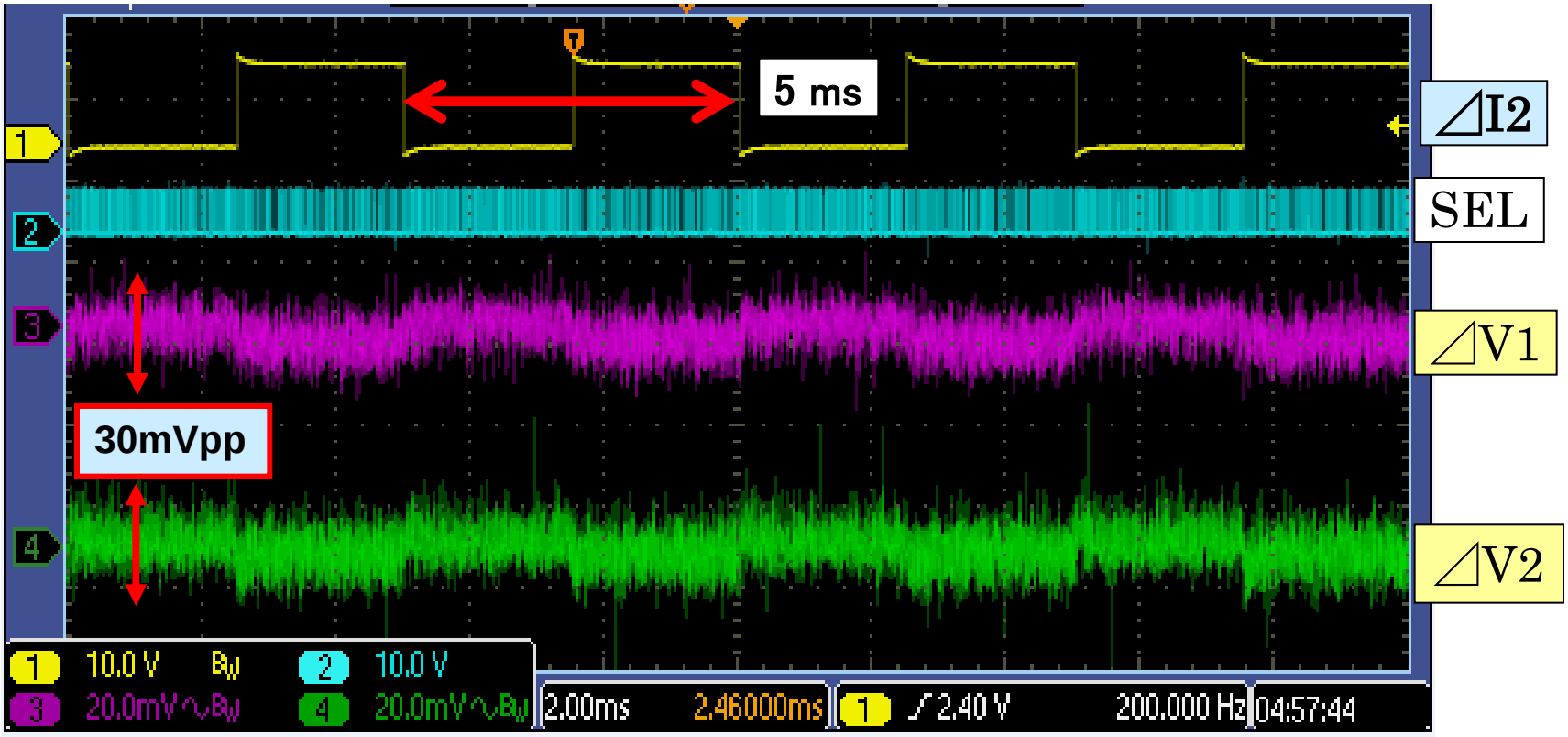


Fig.9 Experimental Result

Previous SIDO Boost Converter

Vi=3V ⇒ V1=5V, V2=4V

⊿V1＞⊿V2 ⇒ SEL「L」⇒ S2:OFF ⇒ V1
⊿V1＜⊿V2 ⇒ SEL「H」⇒ S2:ON ⇒ V2

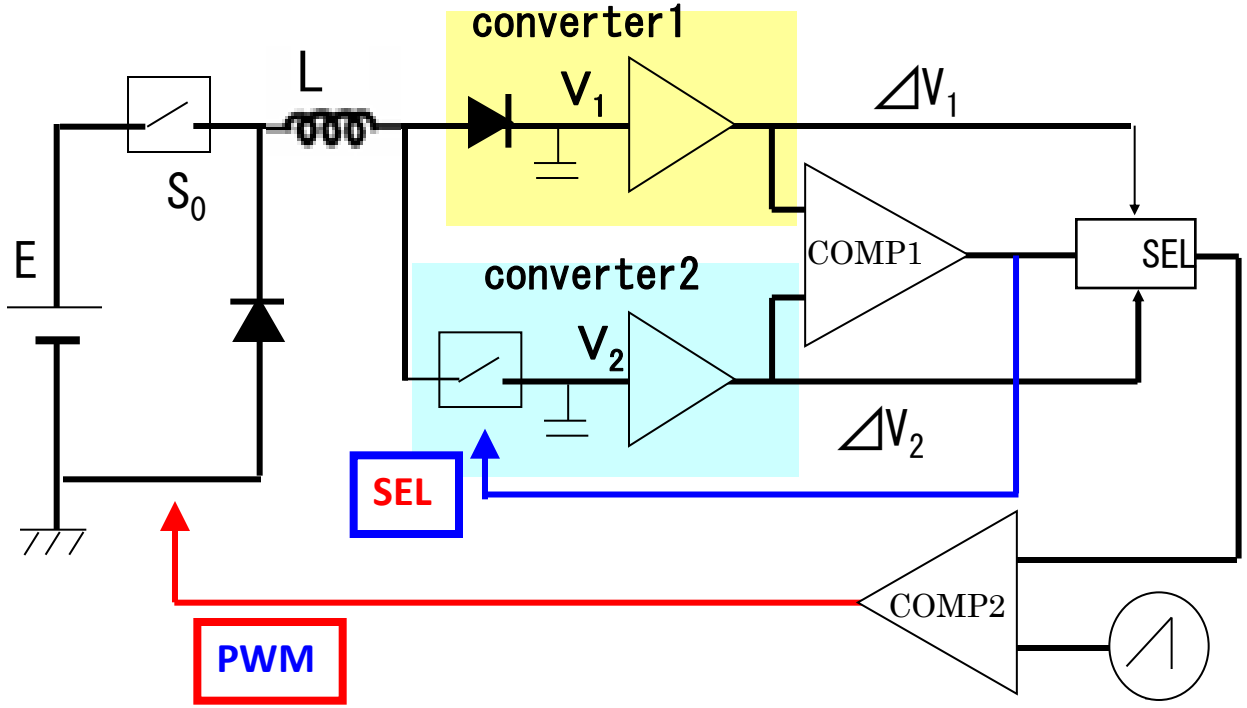


Fig.10 Simulation Circuit of Boost Converter

Previous SIDO Boost Converter

【 Simulation Result 2 】

- Static Ripples: 5mVpp
- Transient Resp.: ±10 mV

- Vi=3.0V ⇒ V1=5.0V, V2=4.0V
- Io1=Io2=0.4A/0.2A
- L=0.5uH, C=470uF, F=200kHz

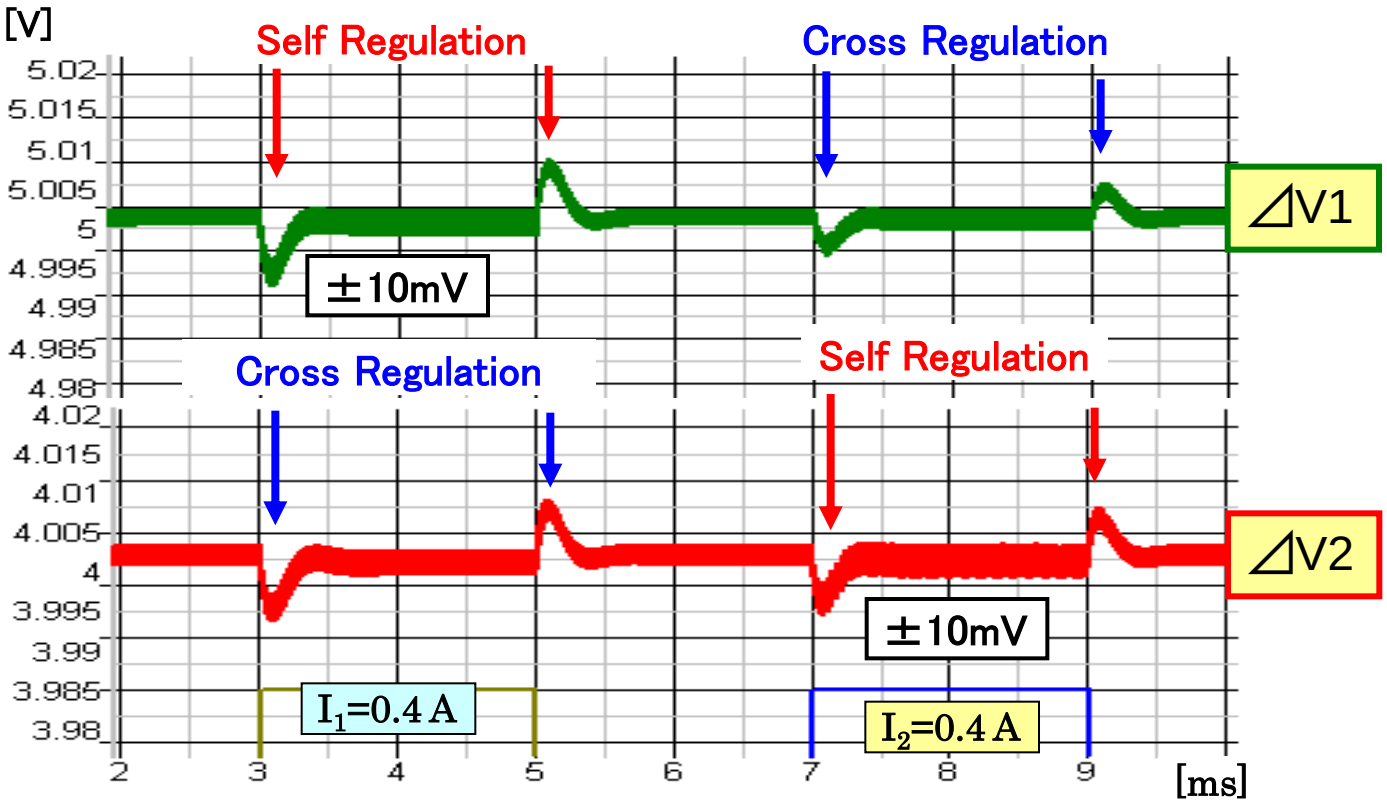


Fig.11 Simulation Result of SIDO Boost Converter

Proposed SIDO Boost Converter

【 Experimental Result 2 】 Vi=3.0V ⇒ V1=5.0V, V2=4.0V, f=200kHz

● Ripples & Transient Responses I1 = 0.40A／0.20A

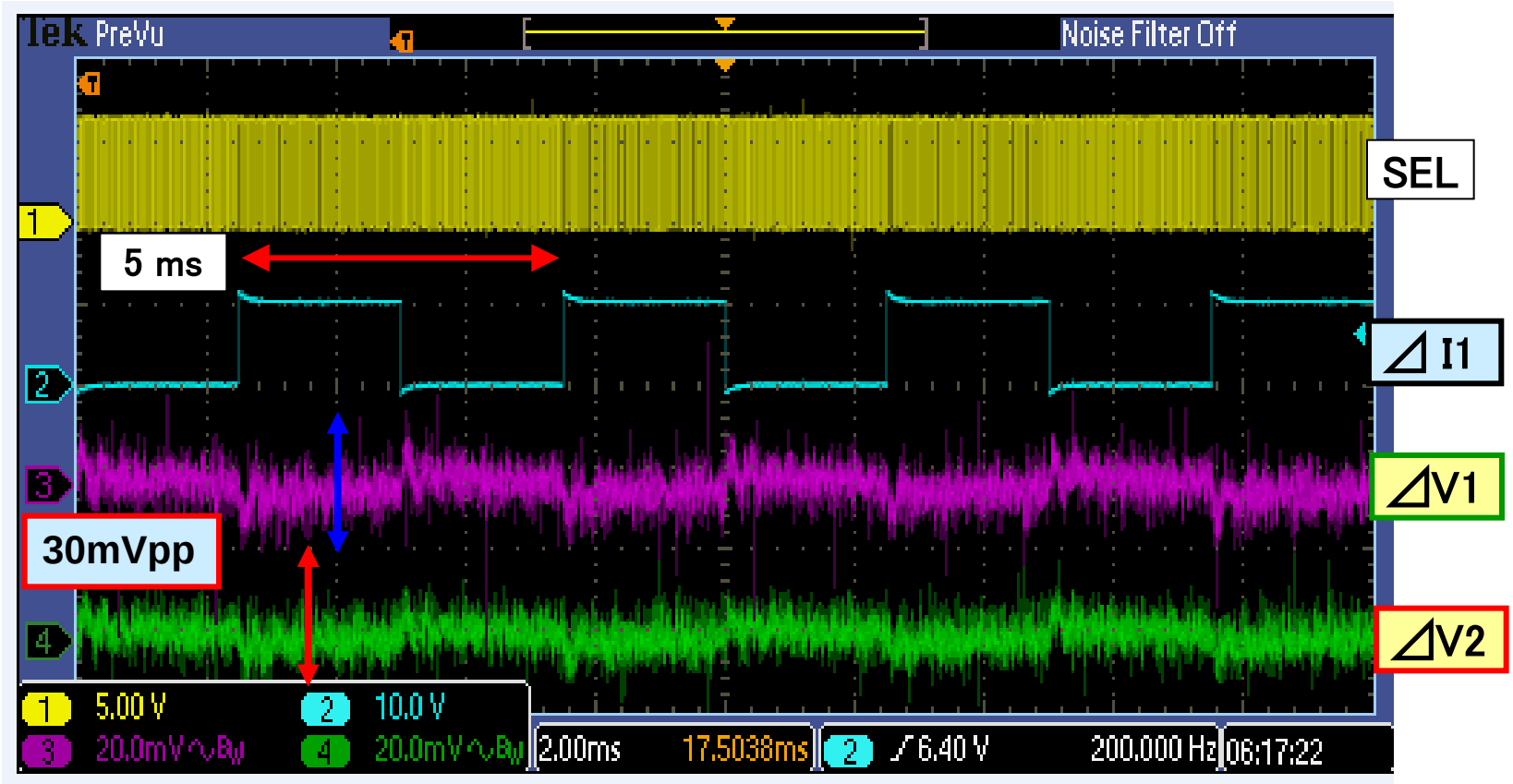


Fig.12 Experimental Result of SIDO Boost Converter

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Previous SIMO Buck Converter with Ripple-Based Control

【 Simulation Circuit 1 】

★ Each sub-converter : **Plug-in type**

- Vi = 10.0V, Vo = 6.0／5.0／4.0／3.0 V
- Hysteretic Control (Buck Converter)
- Priority : V4 > V3 > V2 > V1 (fixed)

∵ V4 < V3 < V2 < V1

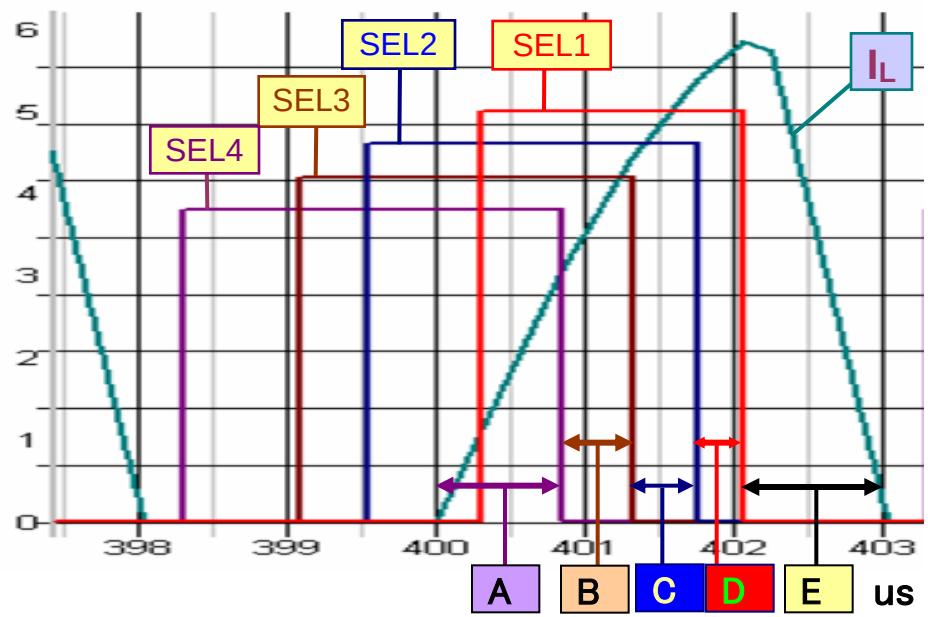


Fig.14 Wave form of SEL signals

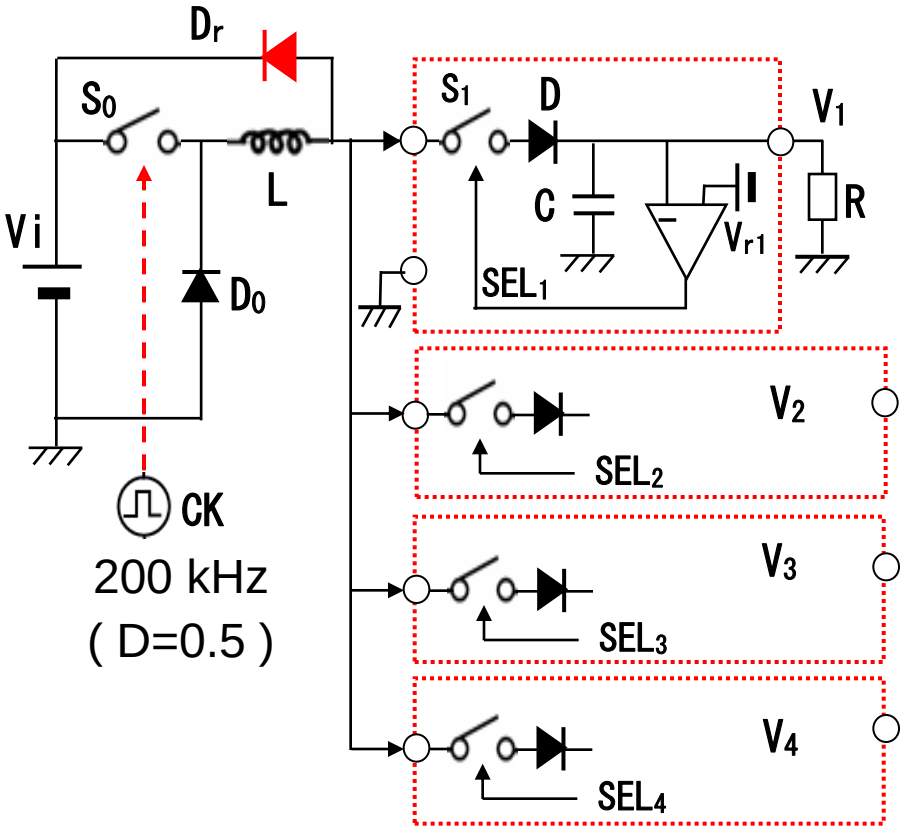


Fig.13 Simulation Circuit 1

Previous SIMO Converter with Ripple-Based Control

【 Simulation Result 1 】Buck Converter

●Ripple-Based Control

Vi=10v, Vo=6, 5, 4, 3V

a) When Io1~Io4=0.5A

⊿V1～⊿V4 ≒ 3mV

b) When Io1=1.0A (Io2~Io4=0.5A)

・⊿V1=7mV＞⊿V2≒⊿V3≒⊿V4

∵ Priority is fixed.

: V4 > V3 > V2 > V1

V1 is served last.

★Improve the priority order!

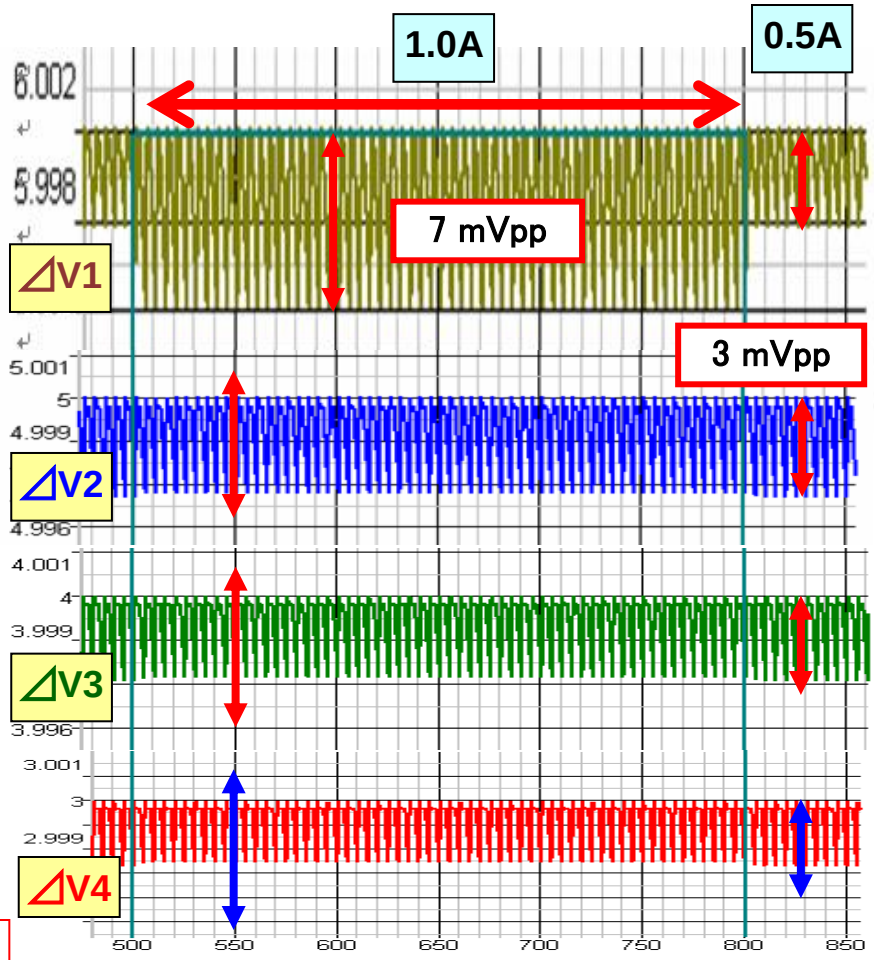


Fig.15 Simulation Result 1

Previous SIMO Converter

【 Simulation Result 2 】Boost Converter

- Vi = 4.0V, Vo = 6.0／5.5／5.0／4.5 V
- Io1=0.5A/0.25A, Io2~Io4=0.25A

● ⊿V1=4mV＞⊿V2～⊿V4

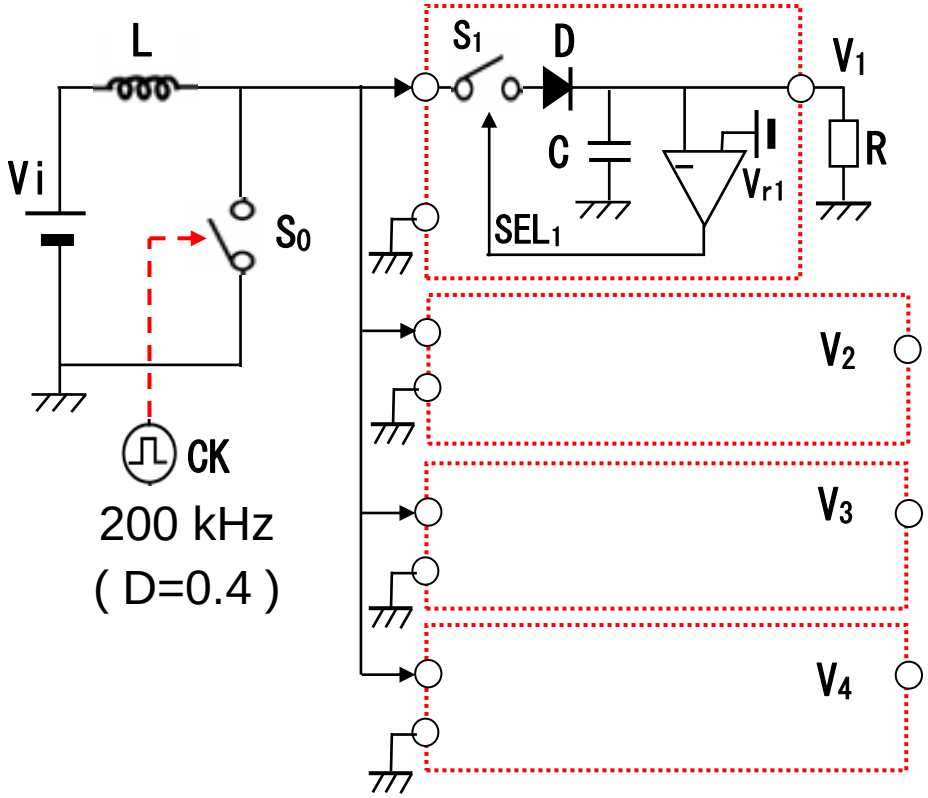


Fig.16 Simulation Circuit 2

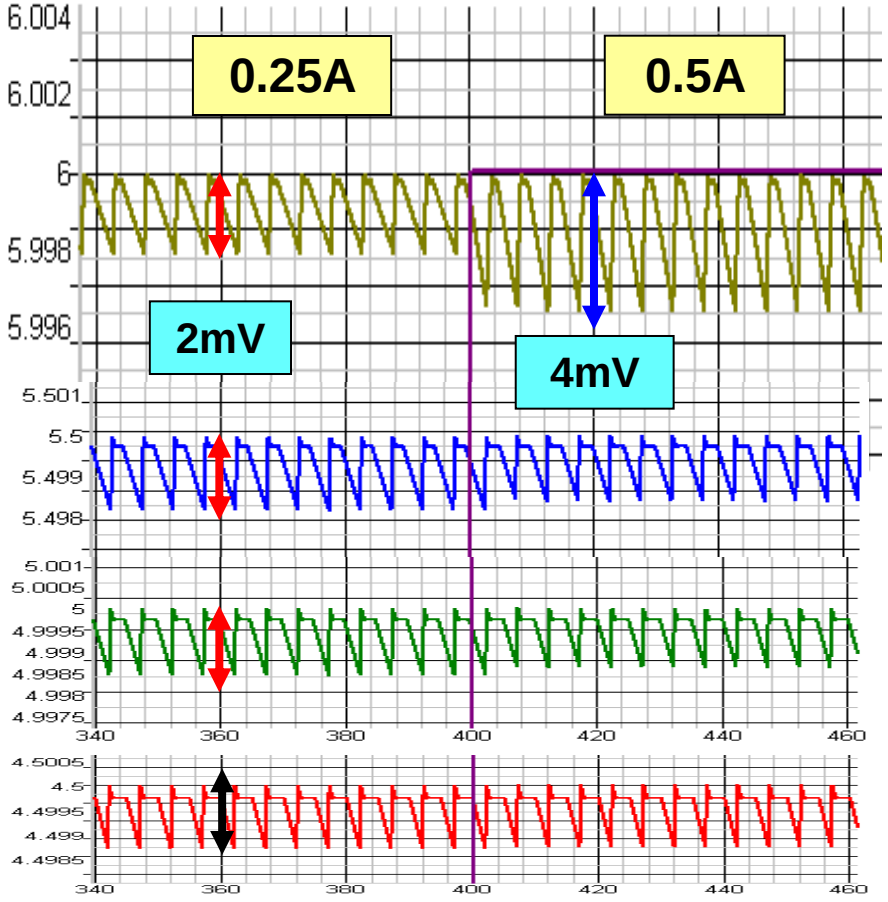
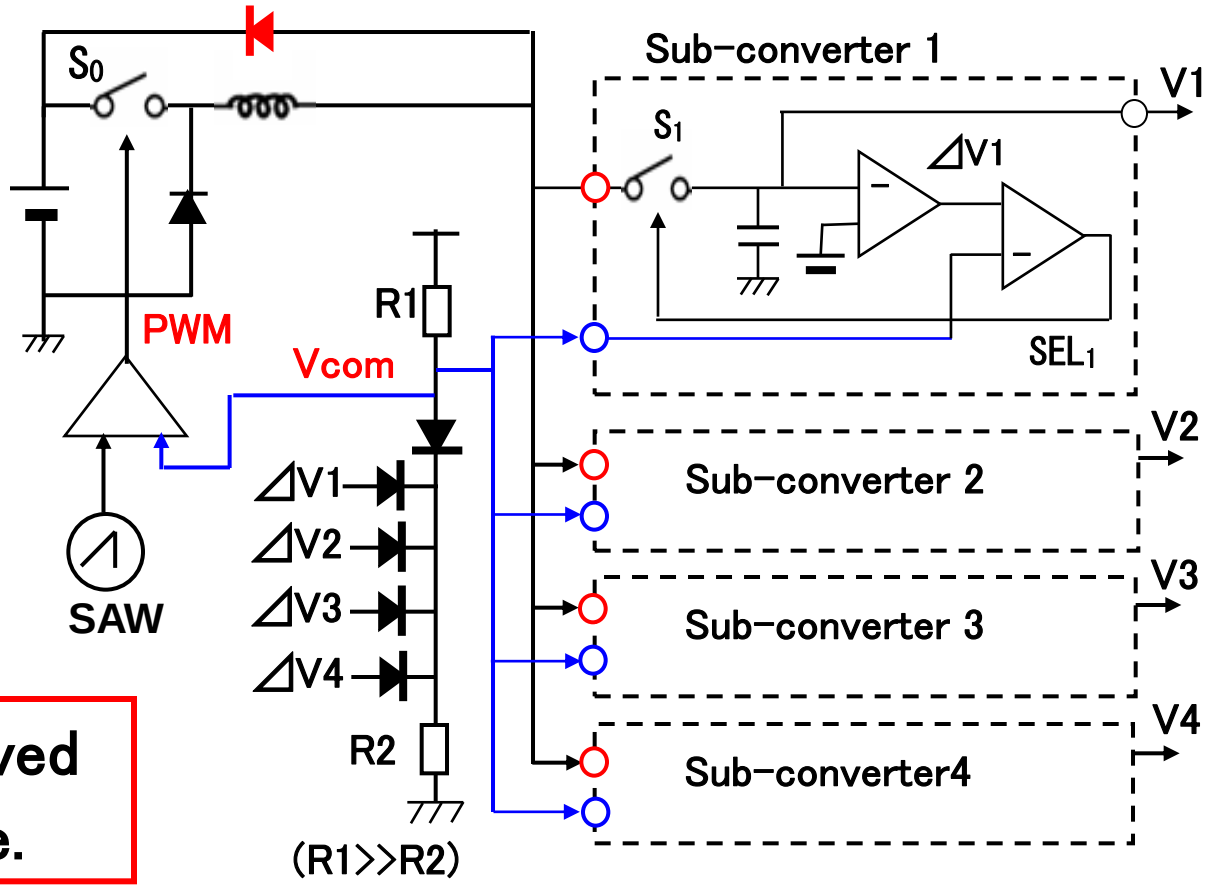


Fig.17 Simulation Result 2

Proposed SIMO Converter with Exclusive Control

【 Simulation Circuit 1 】 Buck Converter

- PWM & SEL signal is generated using common ⊿V.
- When output V is lower, ⊿V is higher.
- Usually single SEL is「H」exclusively.



The highest ⊿V is served for next control cycle.

Fig.18 Proposed SIMO Circuit (Buck)

SIMO Converter with Exclusive Control

【 Simulation Results 1 】Buck Converter

- Vi = 10V, Vo = 6.0／5.5／5.0／4.5 V
- Io=0.5A each, I1=I4=1.0/0.5A
- L=0.2uH,
  C=470uF each
- F=500kHz

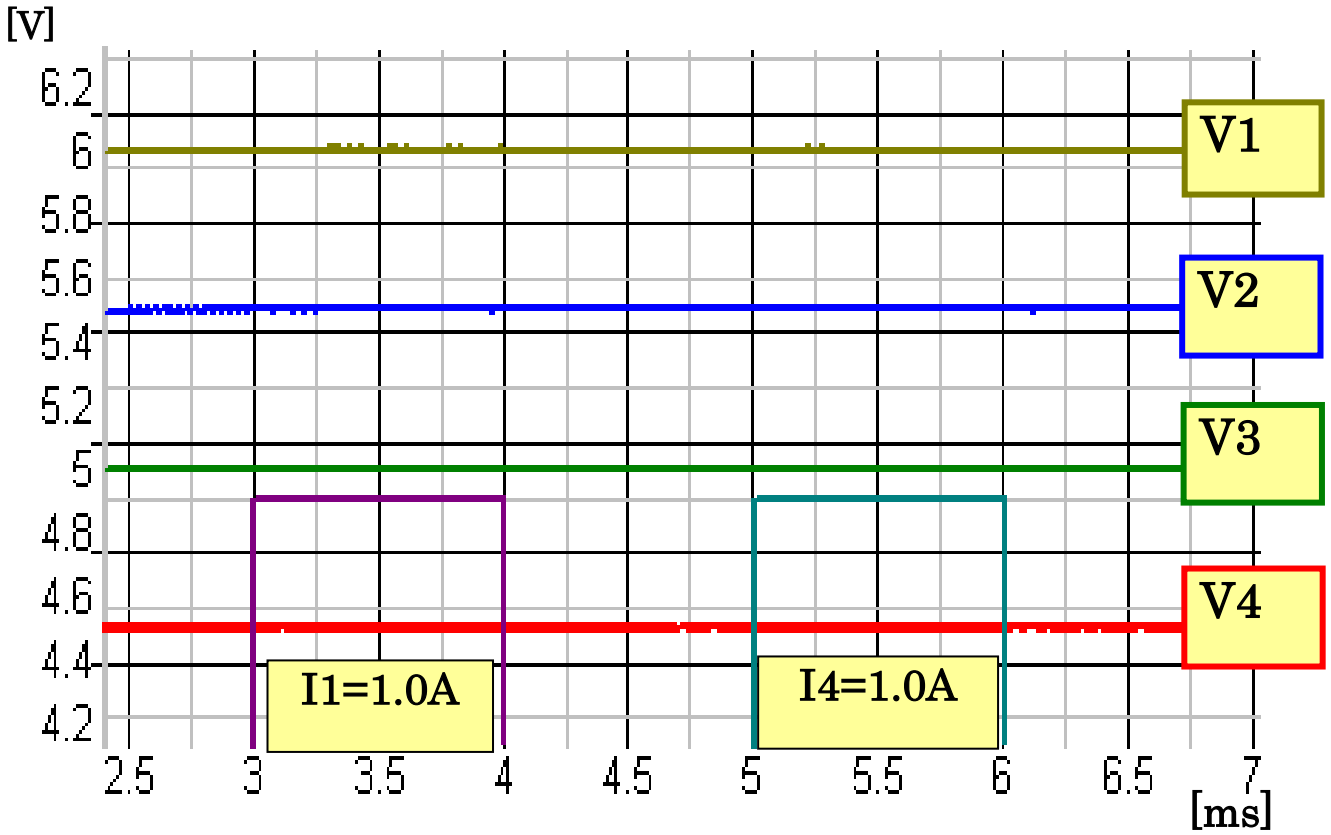


Fig.19 Simulation Results (Buck Converter)

SIMO Converter with Exclusive Control

【 Simulation Results 1 】 Buck Converter

- **When all SEL signals are 「L」,**
  Inductor Current is regenerated to the voltage source.

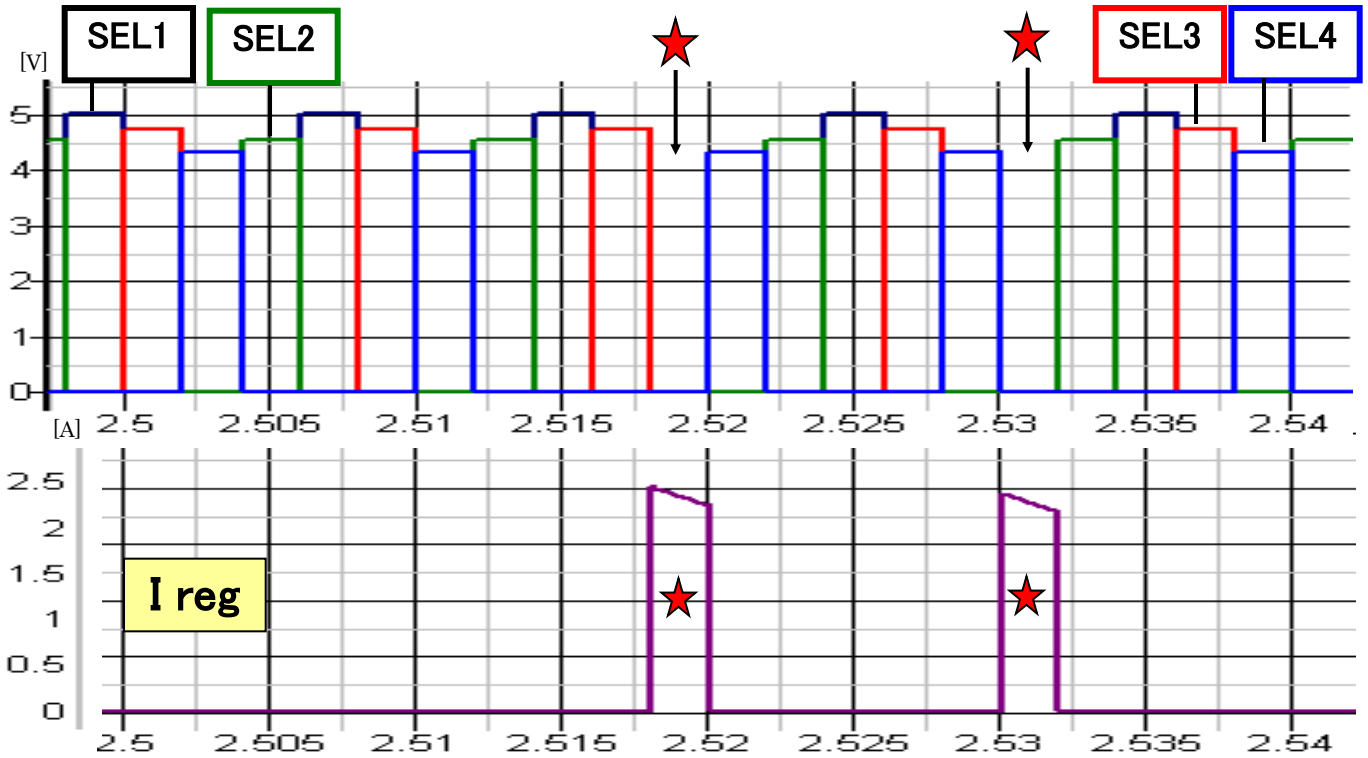


Fig.20 SEL signals and Regenerated current

SIMO Converter with Exclusive Control

【 Output ripples 】

Buck Converter

- Vi=10V
  Vo = 6.0/5.5/5.0/4.5 V
- Ripples:
  ⊿V <20mVpp
- Transient Response:
  Shoot < ±10mV
  @⊿I=0.5A

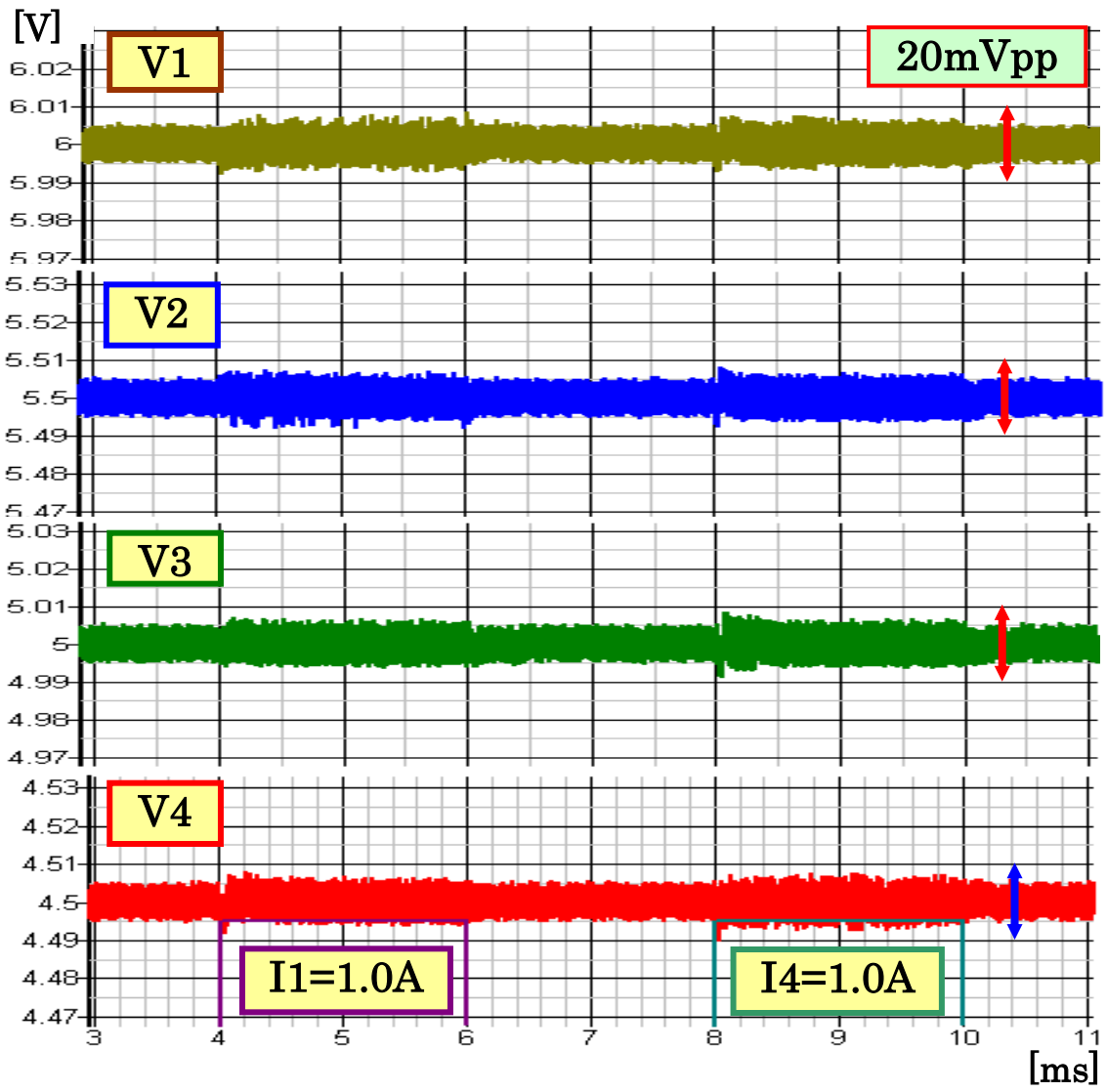


Fig.21 Output ripples (Buck Converter)

SIMO Converter with Exclusive Control

【 Simulation Results 1 】Boost Converter

- Vi = 4.0V, Vo = 6.0／5.5／5.0／4.5 V
- Io=0.1A each, I1=I4=0.2/0.1A
- L=1.0 uH, C=470 uF each
- F=500 kHz

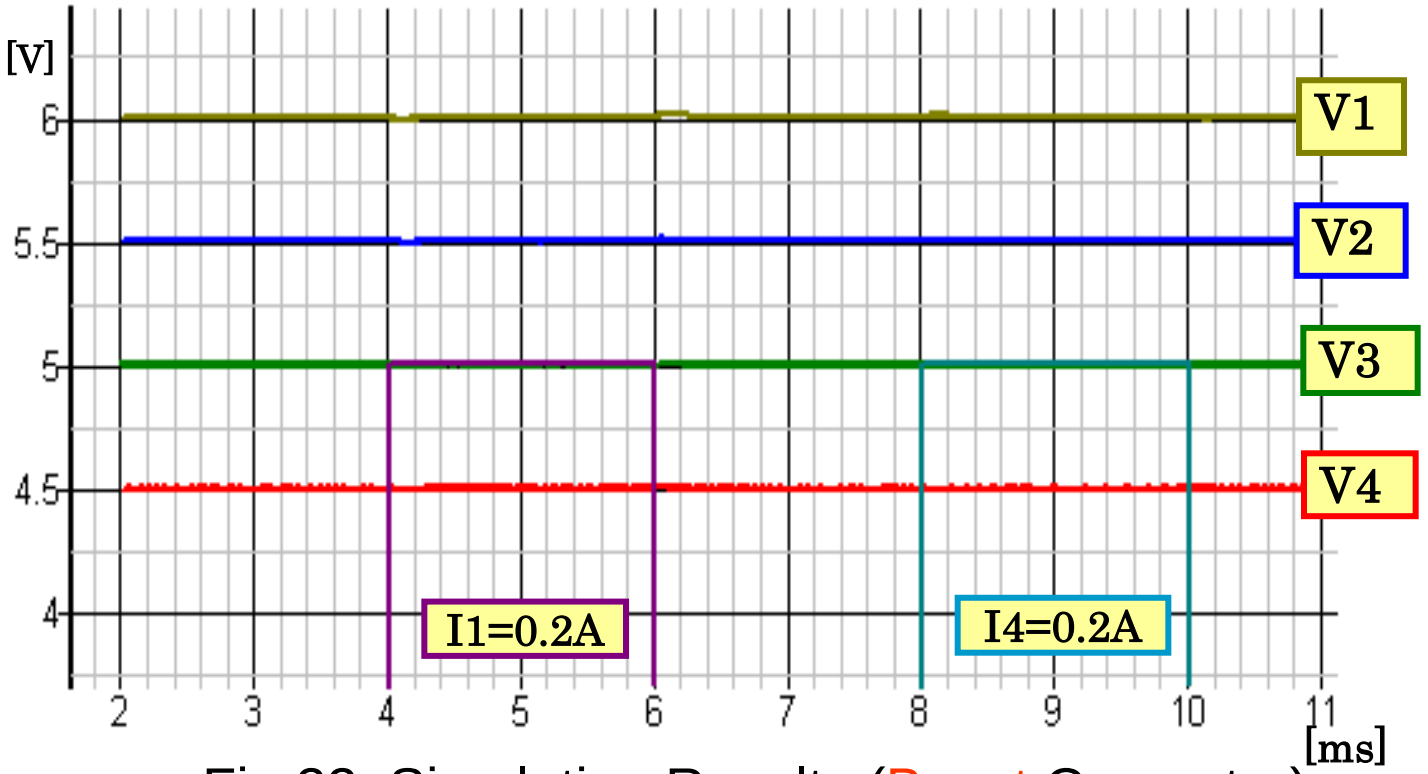


Fig.22 Simulation Results (Boost Converter)

SIMO Converter with Exclusive Control

【 Output ripples 】

Boost Converter

- Ripples:
  ⊿V <5mVpp
- Transient Response
  Shoot < ±15mV
  @⊿I=0.1A

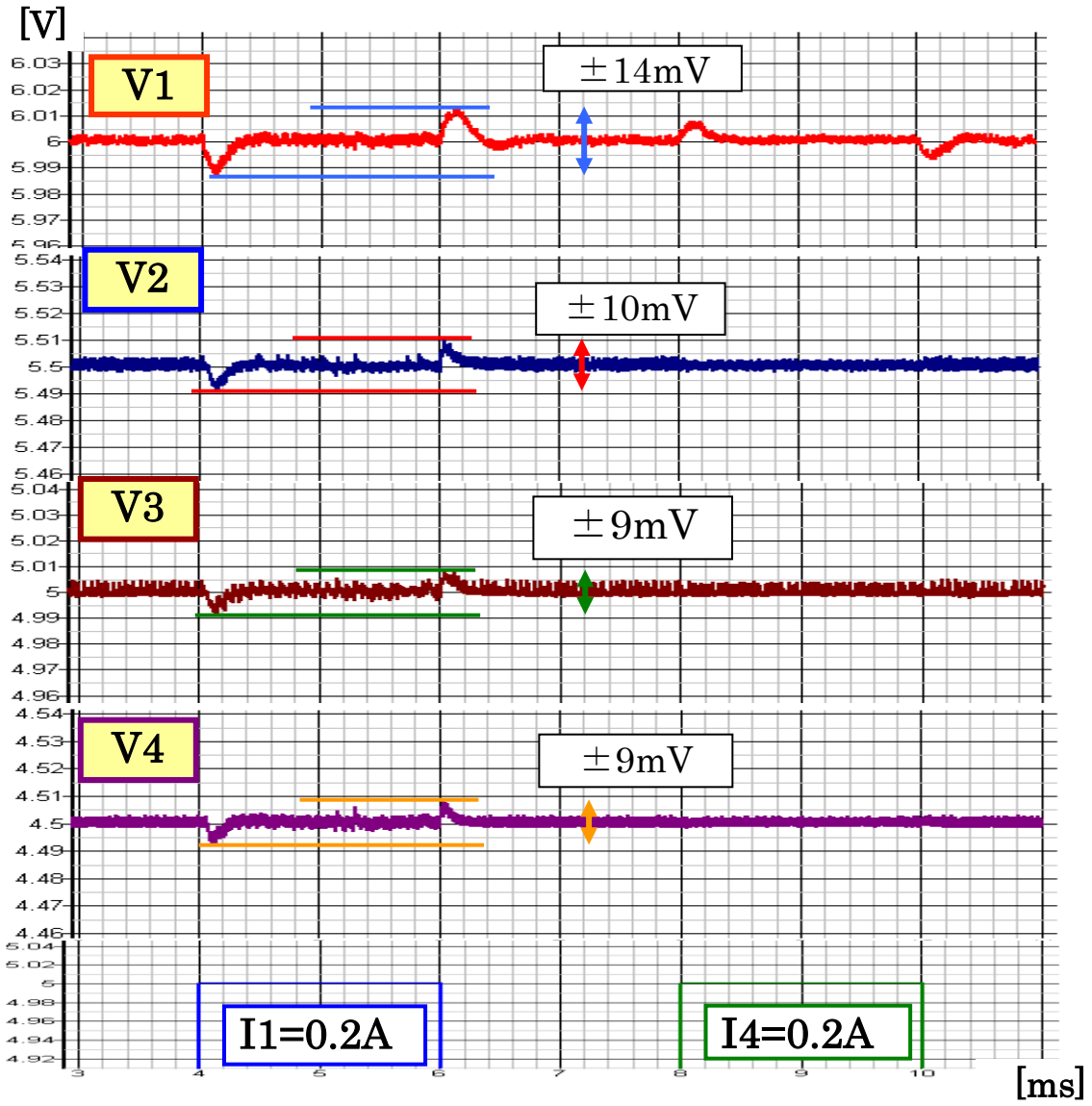


Fig.23 Output ripples (Boost Converter)

Conclusion

SIMO Buck/Boost Converter with Four-level Output Voltages using Exclusive Control and New Priority Circuit.

a) New priority circuit using wired OR voltage Vcom .
Sub-converter of most different from reference voltage has the priority to be served for next cycle.

b) Simulation Results:

1)Buck Converter (Vi=10V, Vo=6.0, 5.5, 5.0 4.5V)

- Output Ripples: $\Delta Vo <$ 20 mV @ Io=0.5A each
- Transient Response: $\Delta Vo < \pm 10$ mV @ΔIo=0.5A

2) Boost Converter (Vi=4.0V, Vo=6.0, 5.5, 5.0, 4.5V)

- Output Ripples: $\Delta Vo <$ 5 mV @ Io=0.1A each
- Transient Response: $\Delta Vo < \pm 15$ mV @ ΔIo=0.1A

Thank you
for your attention.

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