PEEE 004

High-Speed Response Single Inductor Multi Output DC-DC Converter with Hysteretic Control

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Outline

- Research Objective
- SIDO Converter with Exclusive Control
  - Circuit and Operation
  - Simulation and Experimental Results
- Proposed SIDO Converter with Hysteretic Control
  - Basic Converter with Hysteretic Control
  - Circuit and Operation of Proposed Converter
  - Simulation and Experimental Results
- Proposed SIMO Converter with Hysteretic Control
- Conclusion

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Background

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

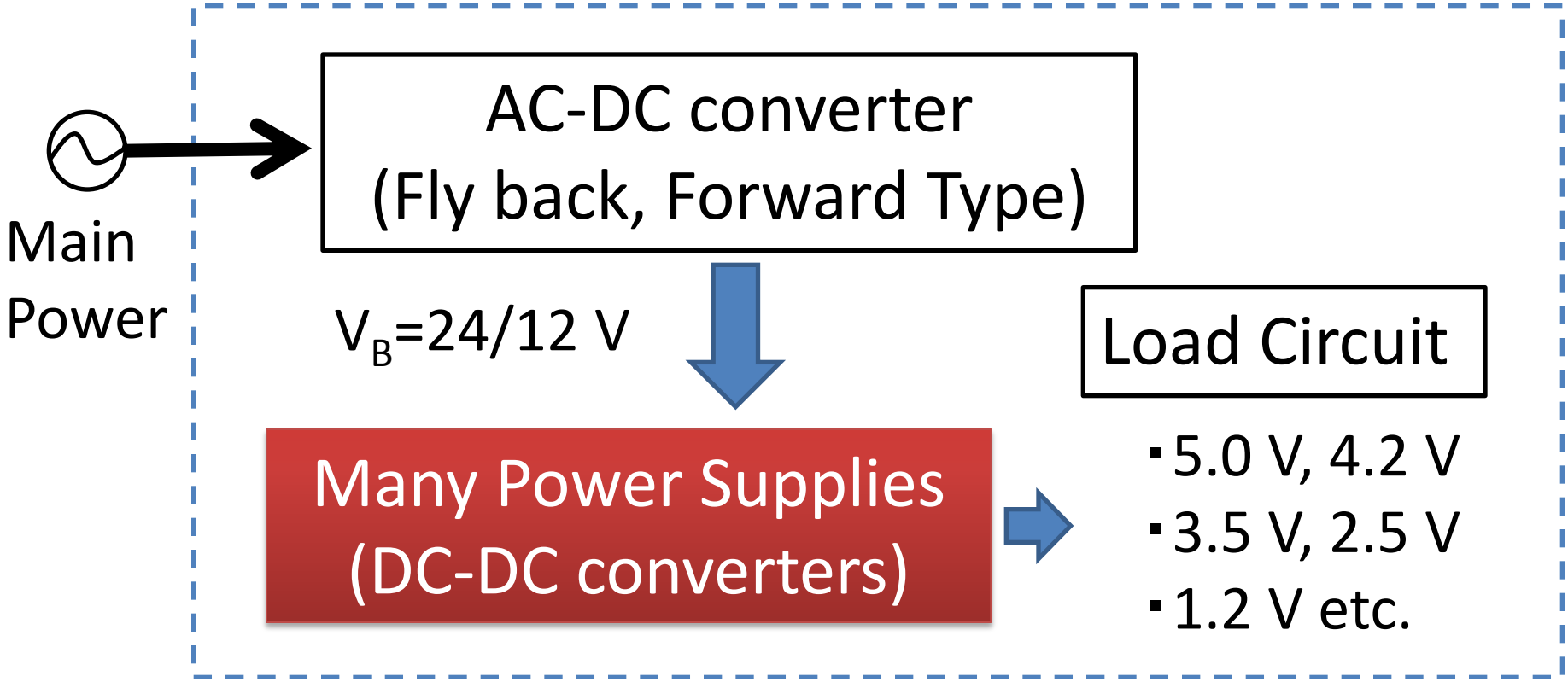
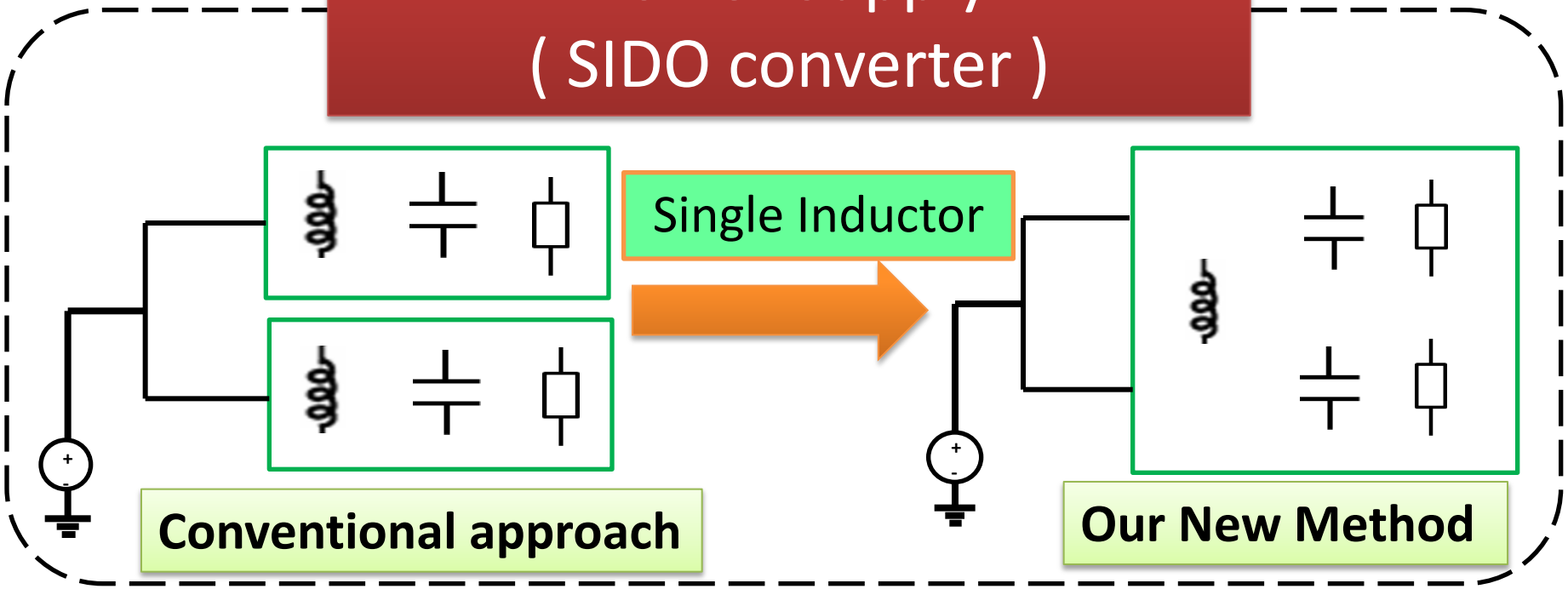


Fig.1 background

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 converter with **Exclusive Control**

    buck-buck or boost-boost converter
  - Control Speed becomes slow

    because of sharing a Inductor and a switch

- New SIDO/SIMO Converter with **Hysteretic Control**
  - Using few additional components, no current sensor
  - Does not depend on the value of Vo or Io.

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Previous SIDO Converter with Exclusive Control

Vi=9V ⇒ V1=6V, V2=4V

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

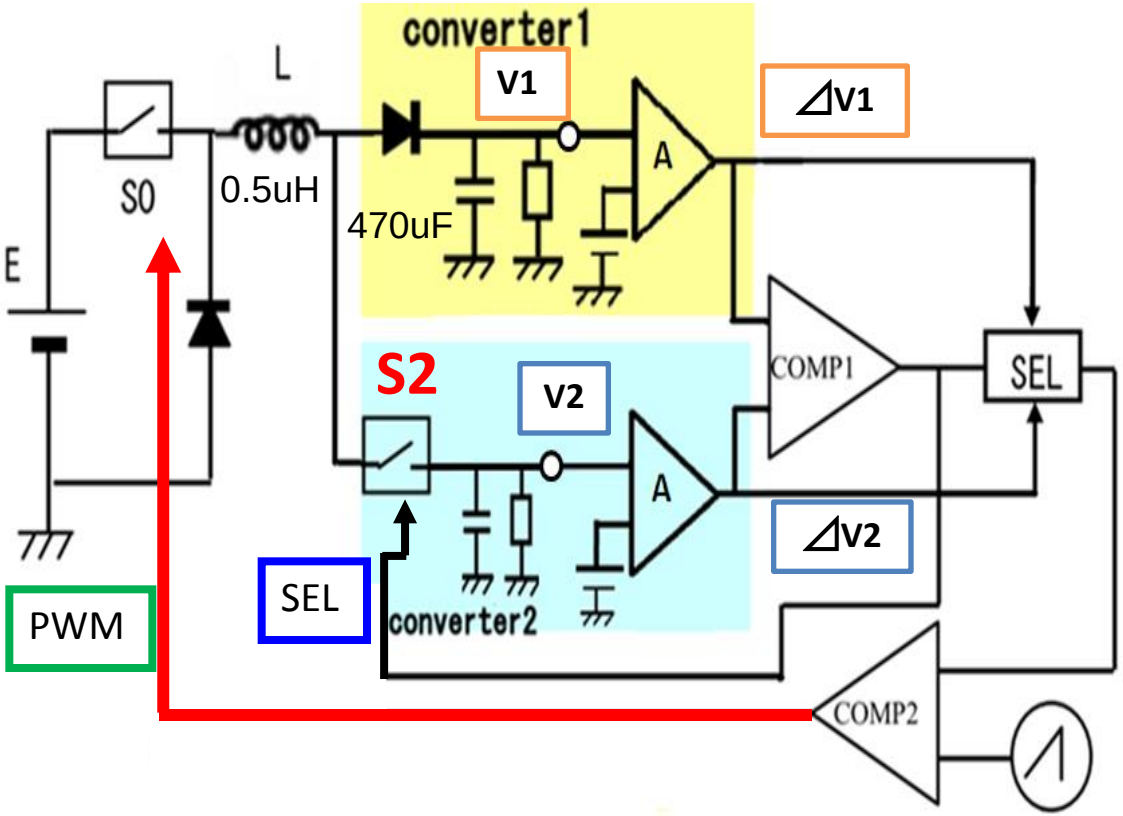


Fig.3 Simulation Circuit

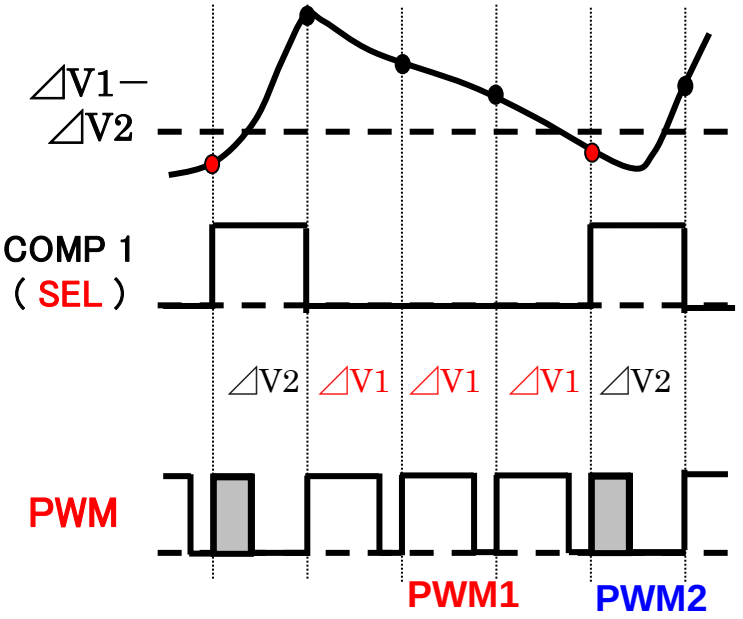
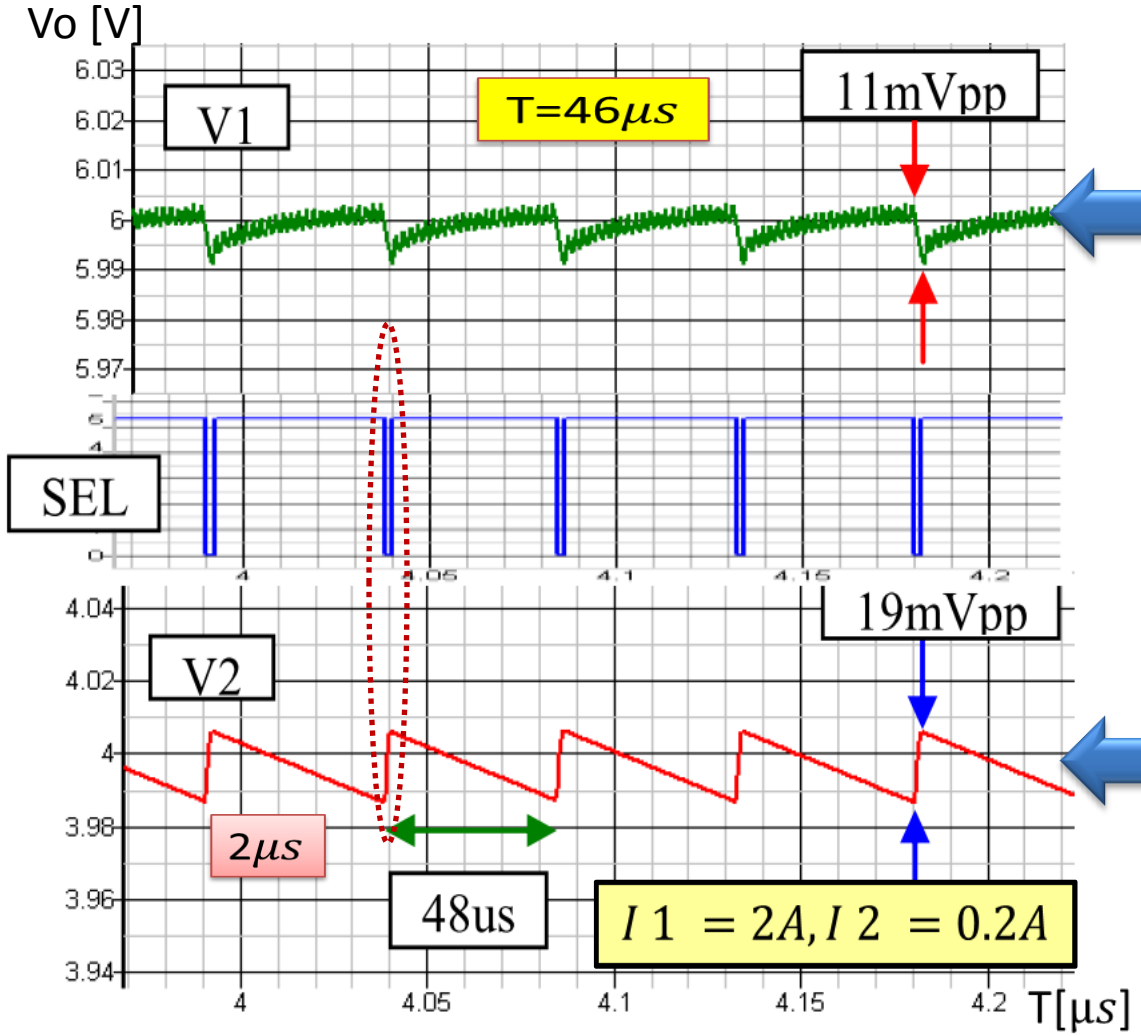


Fig.4 Timing Chart

Previous SIDO Converter

【Simulation Result 1 】Output Ripple



V1 = 6.0V
⊿V1=11mVpp

(Io Ratio： 10×)
$I1/I2 = 2A/0.2A$=10

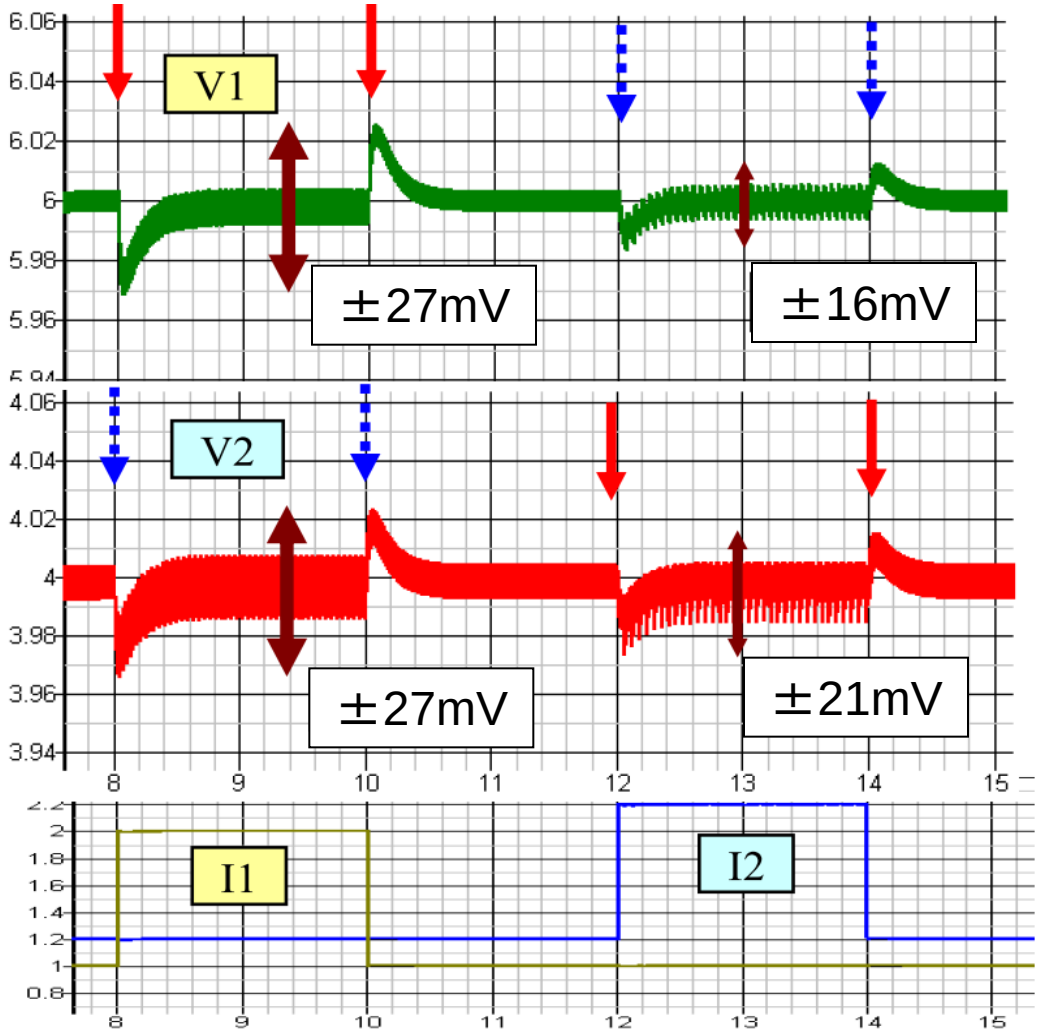
V2 = 4.0V
⊿V2=19mVpp

$\Delta V1, \Delta V2 < 0.5\%V_o$

Fig.5 Simulation Result (Output Ripple)

Previous SIDO Converter

【Simulation Result 2 】(Transient Response)



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

$\Delta V_{SR}, \Delta V_{CR} < 27mV$

- I1=2.0A／1.0A
- I2=2.2A／1.2A

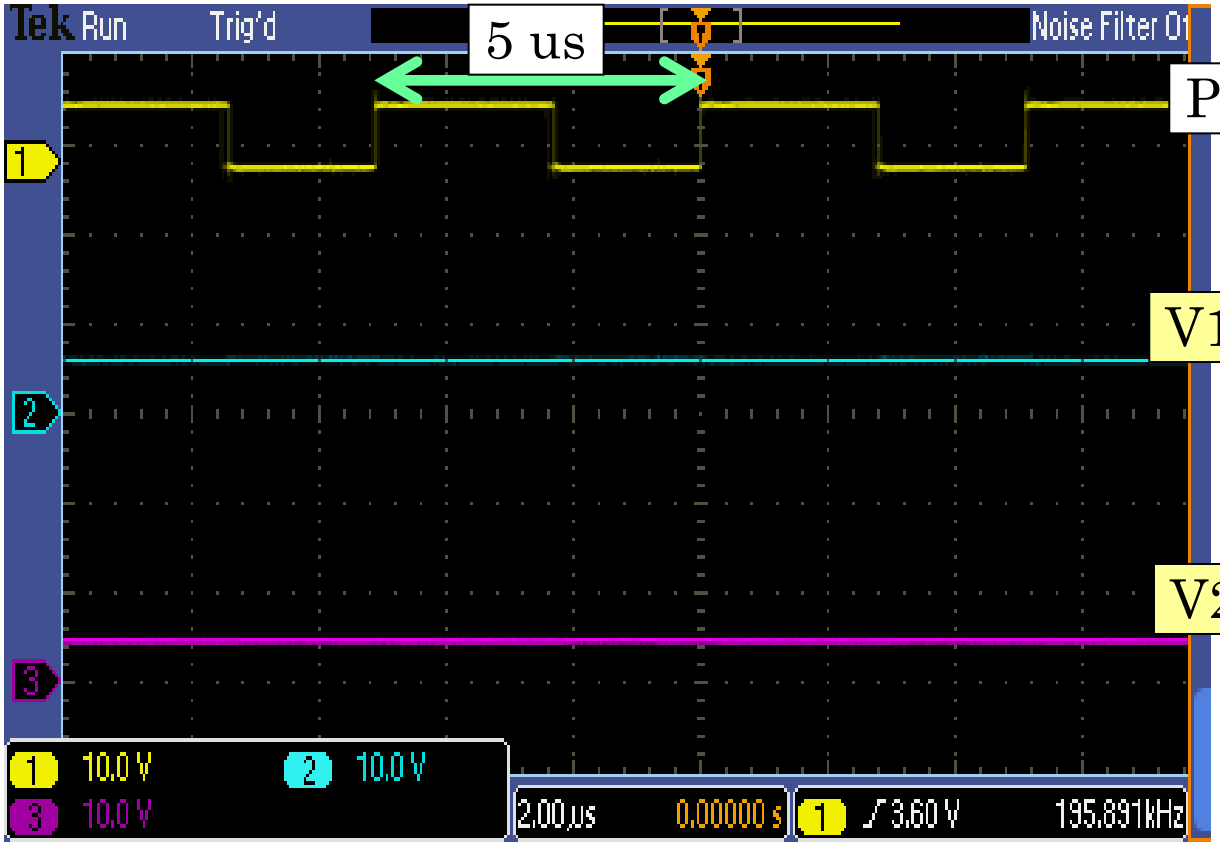
Fig.6 Simulation Result (Dynamic Load Regulation)

Previous SIDO Converter

【Experimental Result 1】

● Output Voltage

Vi=9.0V ⇒ V1=6.0V, V2=4.5V, f=200kHz



I1=0.25A
I2=0.36A

Fig.7 Experimental Result (Static Load Regulation)

Previous SIDO Buck Converter

【Experimental Result 2】

● Dynamic Load Regulation

I2 = 0.60A／0.36A

⊿V1 = 10 mVpp (Cross Regulation)
⊿V2 = 12 mVpp (Self Regulation)

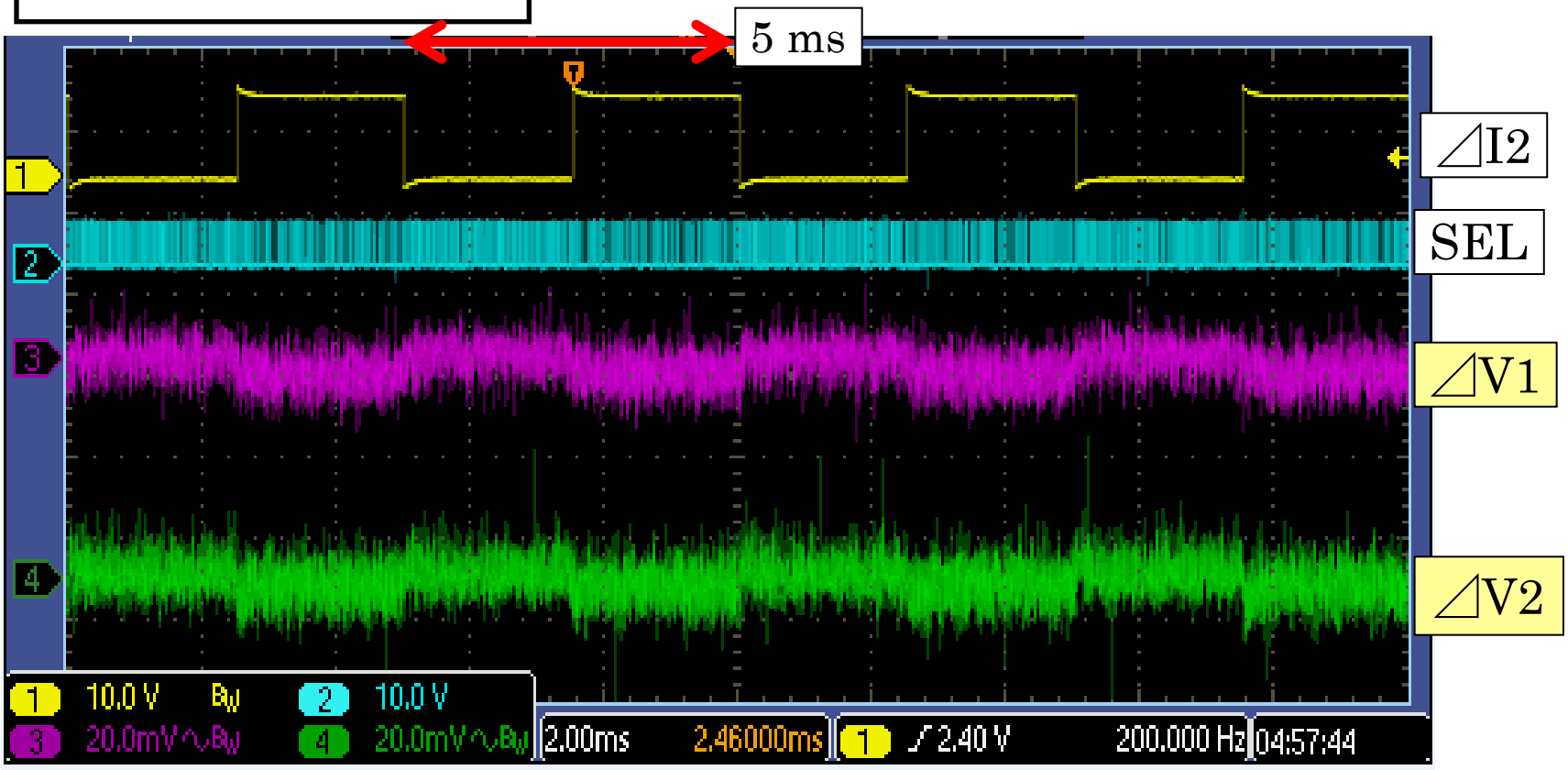


Fig.8 Experimental Result (Dynamic Load Regulation)

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  - Simulation and Experimental Results
- Proposed SIDO Converter with Hysteretic Control
  - Basic SISO Converter with Hysteretic Control
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  - Simulation and Experimental Results
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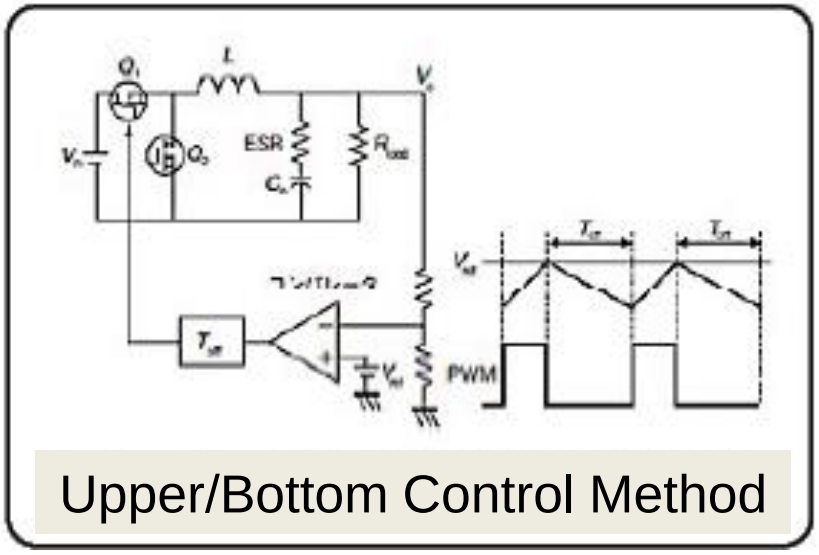
Proposed SIDO Converter with Hysteretic Control

【Basic SISO Converter】(Future)

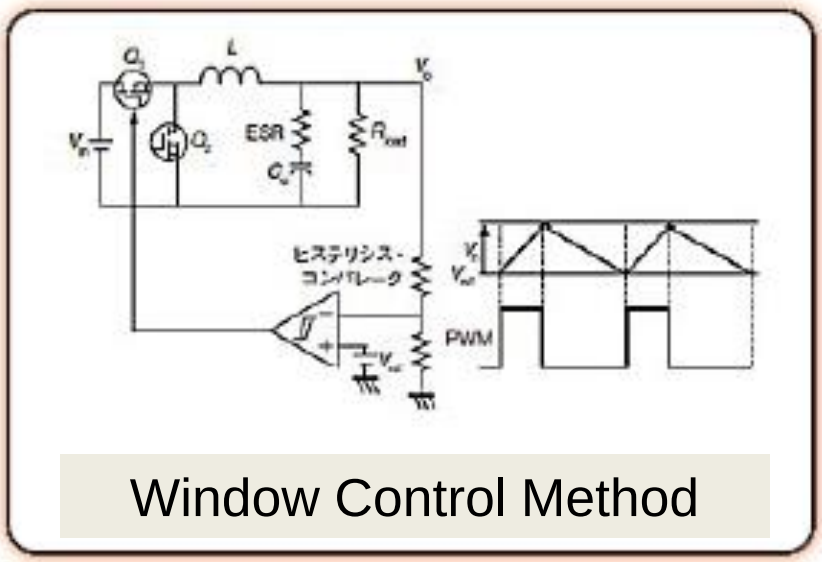
SISO: Single Inductor Single Output

- Non-Linear Control (High-Speed Control)
- Simple Circuit (Comparator only)

(Window Control Method is called Bang-Bang Control)



Upper/Bottom Control Method



Window Control Method

Fig.9 Basic Hysteretic Control Method

Proposed SIDO Converter with Hysteretic Control

【Basic SISO Converter】(Circuit)

- Upper Level Control Method (Energy supply control)
- Simple Circuit (Comparator only. No clock, no PWM signal)
- Control frequency is depend on Loop Delay, Load Current etc.

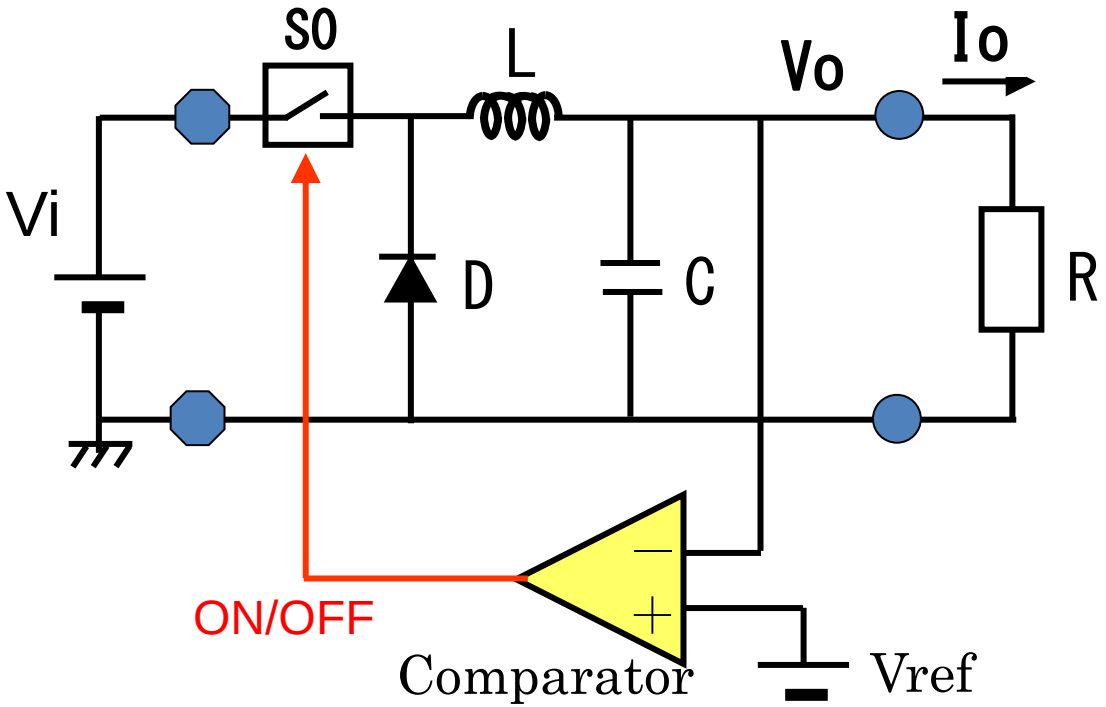


Fig.10(a) Circuit of Upper Level Control

★ T_{ON} depends on Delay, Io etc.

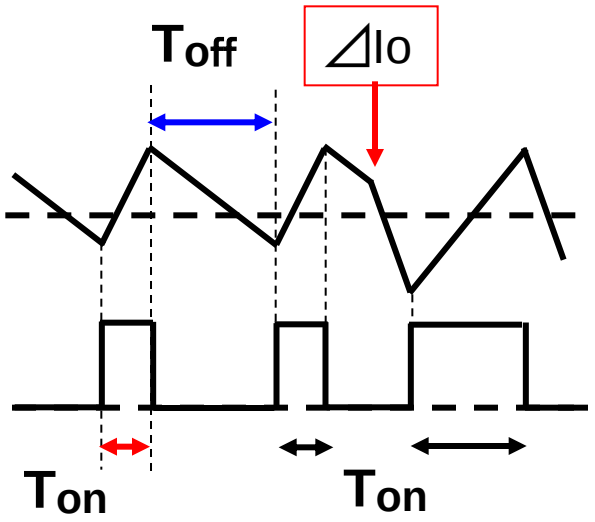


Fig.10(b) Timing Chart

Proposed SIDO Converter with Hysteretic Control

【Basic SISO Converter】(Simulation Result)

- Vi=9.0V, Vo=5.0V
- ⊿Io＝1.0A／0.5A

- F ≒ 1 MHz
- ⊿Vo＝2.5 mVpp
- Overshoot:± 6.0 mV

★ Parameters
L=10uH, C=470uF

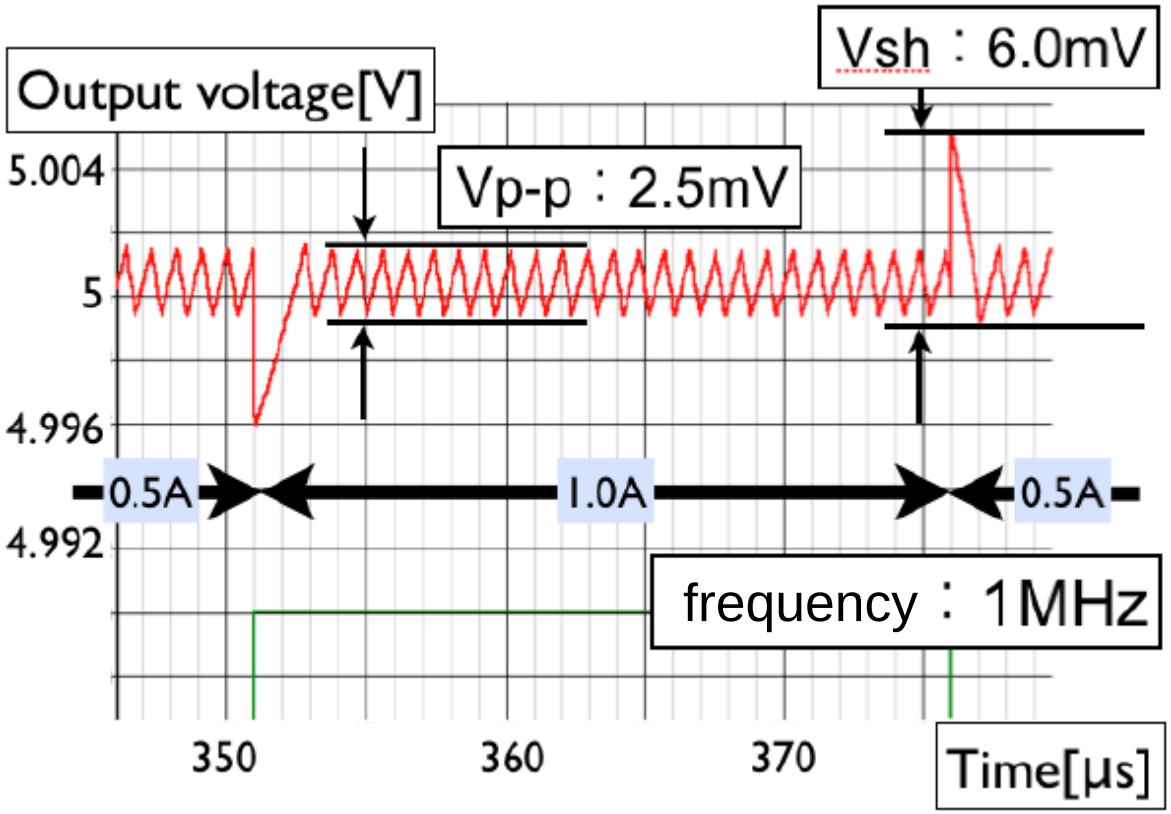


Fig.11 Simulation Result of SISO Converter

Proposed SIDO Converter with Hysteretic Control

【 Circuit of **Buck** Converter 】

- Vi=9.0V ⇒ V1=5.0V, V2=3.0V, Io=0.25A
- L=1uH, C=470uF

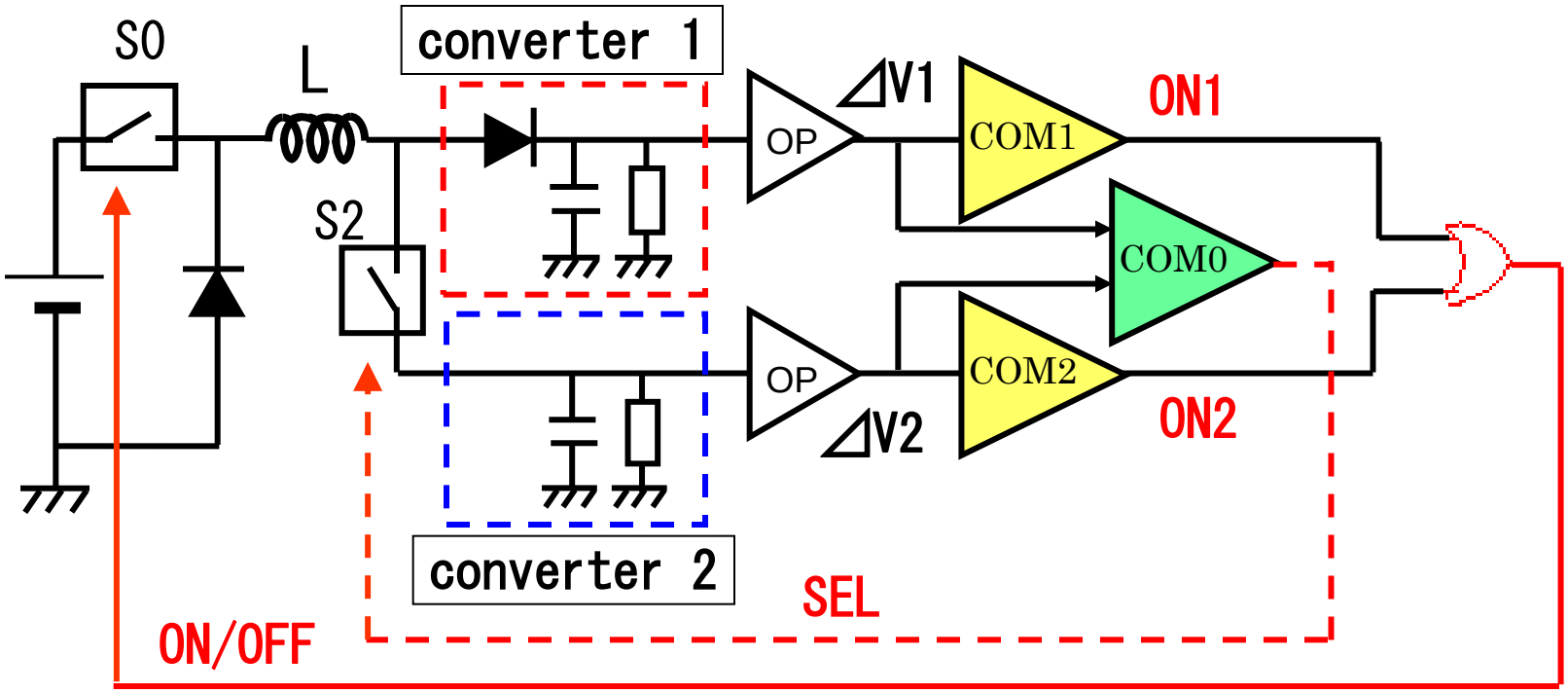


Fig.12 Proposed SIDO Circuit with Hysteretic Control

Proposed SIDO Converter with Hysteretic Control

【 Simulation Result 】

- ⊿V1, ⊿V2＜10mV
- Overshoot≒0 mV

- Vi=9.0V ⇒ V1=6.0V, V2=4.0V
- Io1=1.0A/0.5A, Io2=0.5A
- L=0.5uH, C=470uF

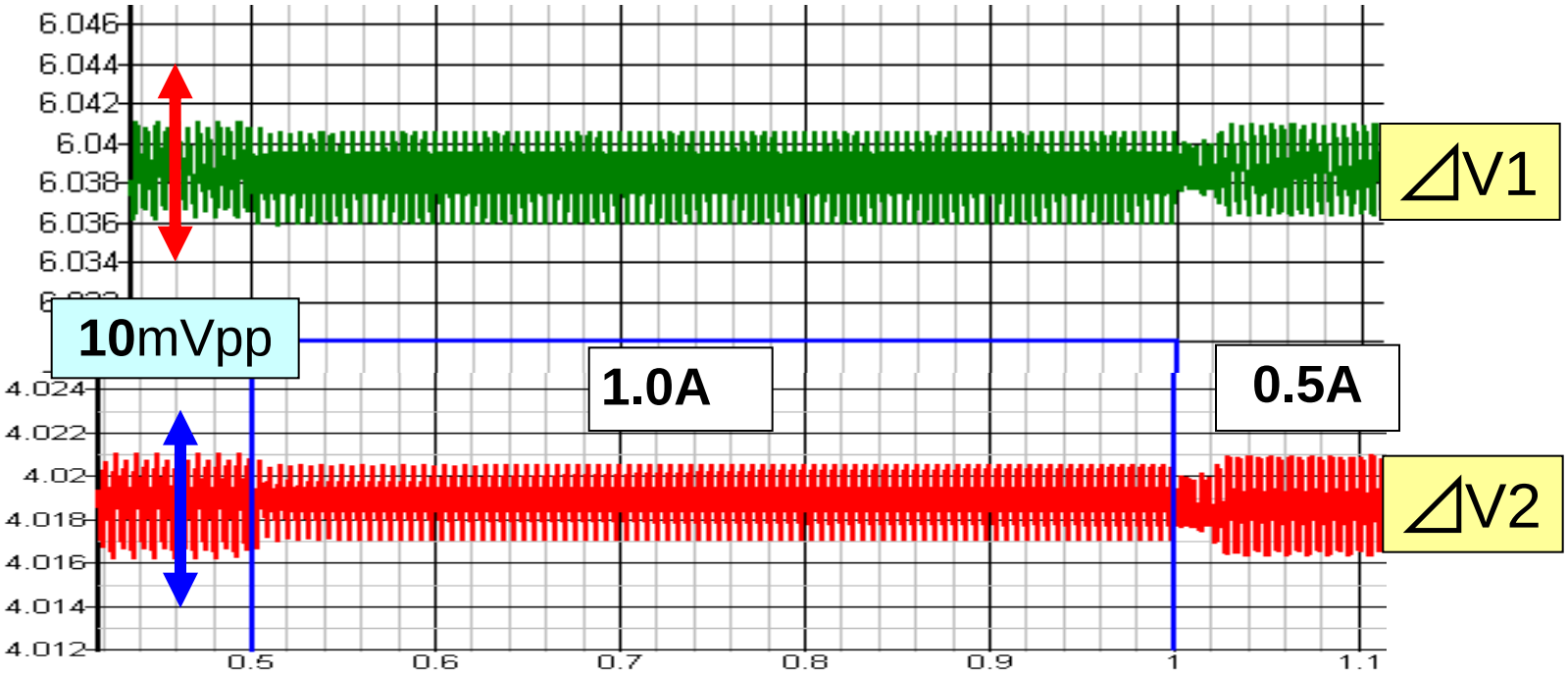


Fig.13 Simulation Result of SIDO Buck Converter

Proposed SIDO Converter with Hysteretic Control

【Circuit and Operation】(**Boost** Converter)

- Vi=3.0V ⇒ V1=5.0V, V2=4.0V
- Io1=1.0A/0.5A, Io2=0.5A
- L=1uH, C=470uF
- Clock is used for starter.

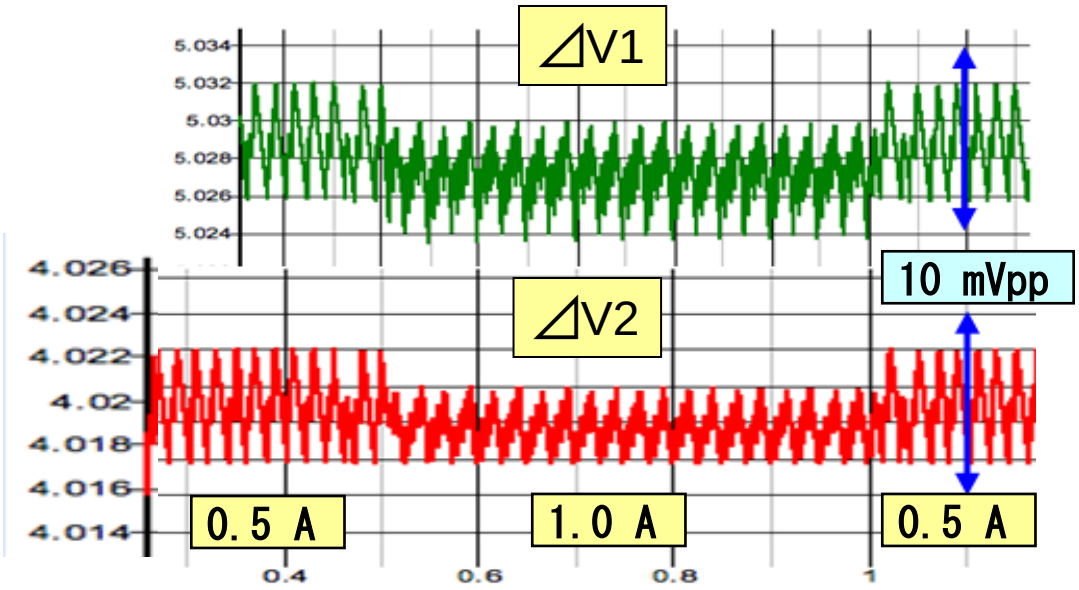


Fig.15 Simulation Result

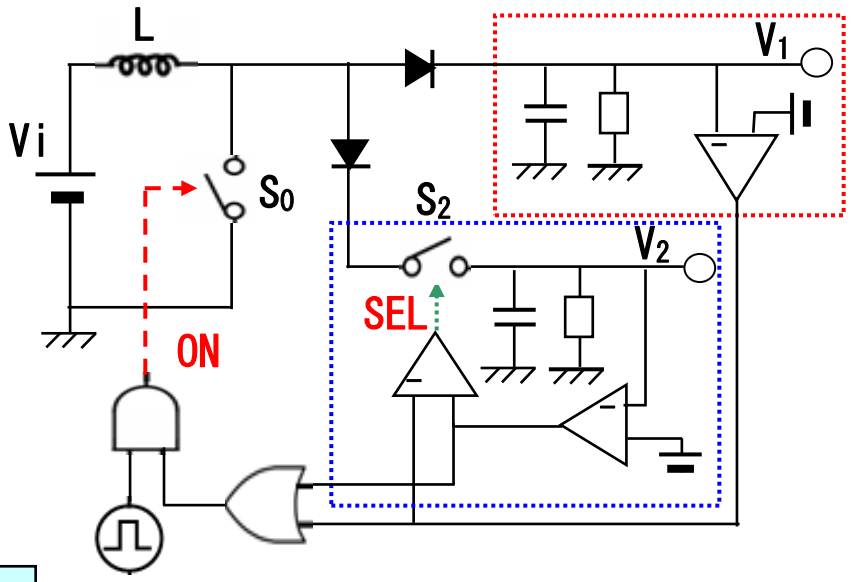


Fig.14 Simulation Circuit

【 Simulation Result 】

- ⊿V1=⊿V2 < 10mVpp
- Little Overshoot

Proposed SIDO Converter with Hysteretic Control

【 Experimental Result 】
(Buck Converter)

- Static Load Regulation
  (Output Ripple)
  ⊿V1=20mV, ⊿V2=15mV
  F=850 kHz
  @ Io1=0.50 A, Io2=0.20 A

- Dynamic Load Regulation
  (Transient Response)
  ⊿V1=25 mV : Self Regulation
  ⊿V2= 5 mV : Cross Regulation
  @ Io1=0.35A／0.18A
  Io2=0.10A

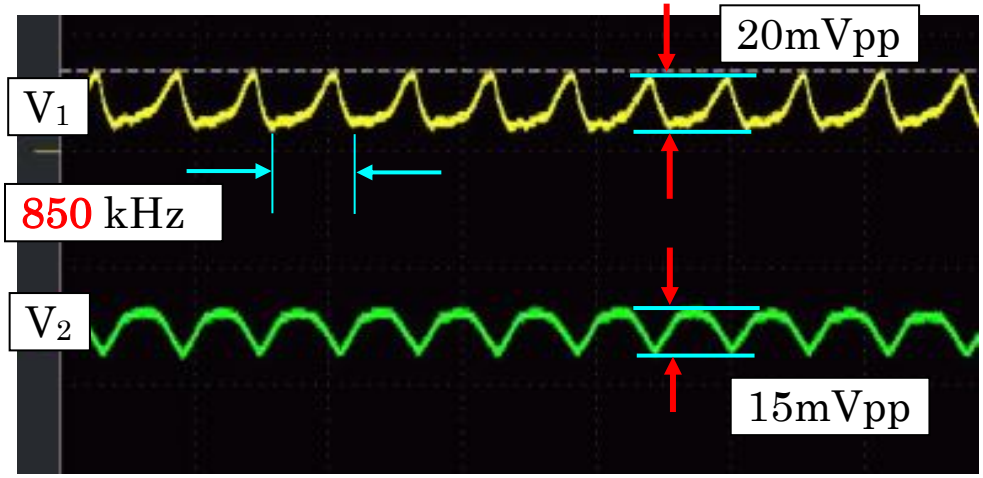


Fig.16 Experimental Result 1

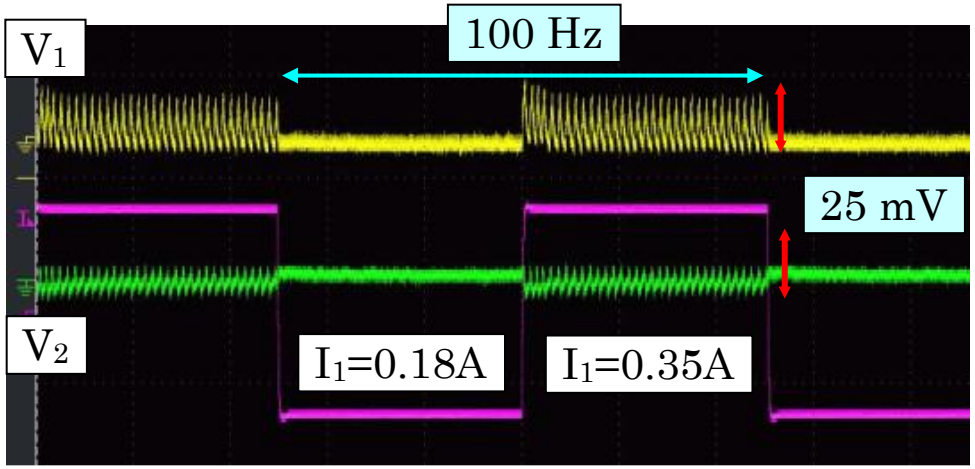


Fig.17 Experimental Result 2

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SIMO Converter with Hysteretic Control

SIMO: Single Inductor Multi Output

【 Circuit of **Buck** Converter 】

- Vi = 9.0V, Vo = 6.0／5.0／4.0／3.0 V
- Priority : V4 > V3 > V2 > V1

  ∵ V4 < V3 < V2 < V1
- Period E : I_L is back to source.

★ **Each converter : Plug-in type**

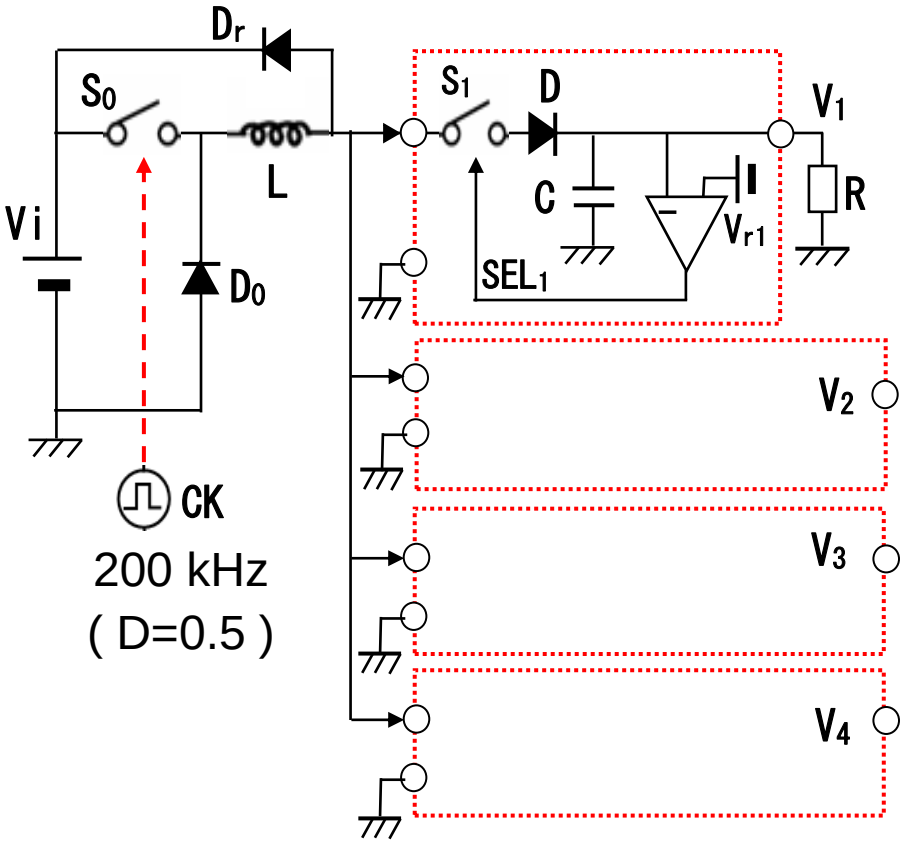

Fig.18 Simulation Circuit

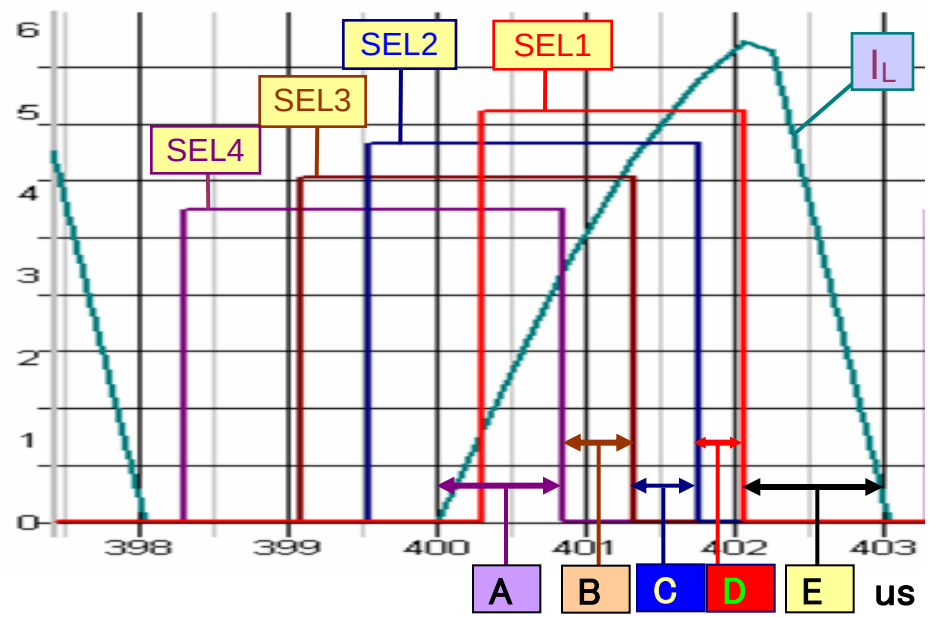

Fig.19 Timing Chart

SIMO Converter with Hysteretic Control

【 Simulation Result 】
(**Buck** Converter: 4 outputs)

a) Io1= 0.5A (Io2~Io4=0.5A)

- 3mV=⊿V1≒⊿V2≒⊿V3≒⊿V4

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

- 7mV=⊿V1＞⊿V2≒⊿V3≒⊿V4

∵ Priority : V4 > V3 > V2 > V1

- F= 200 kHz (D=0.5)

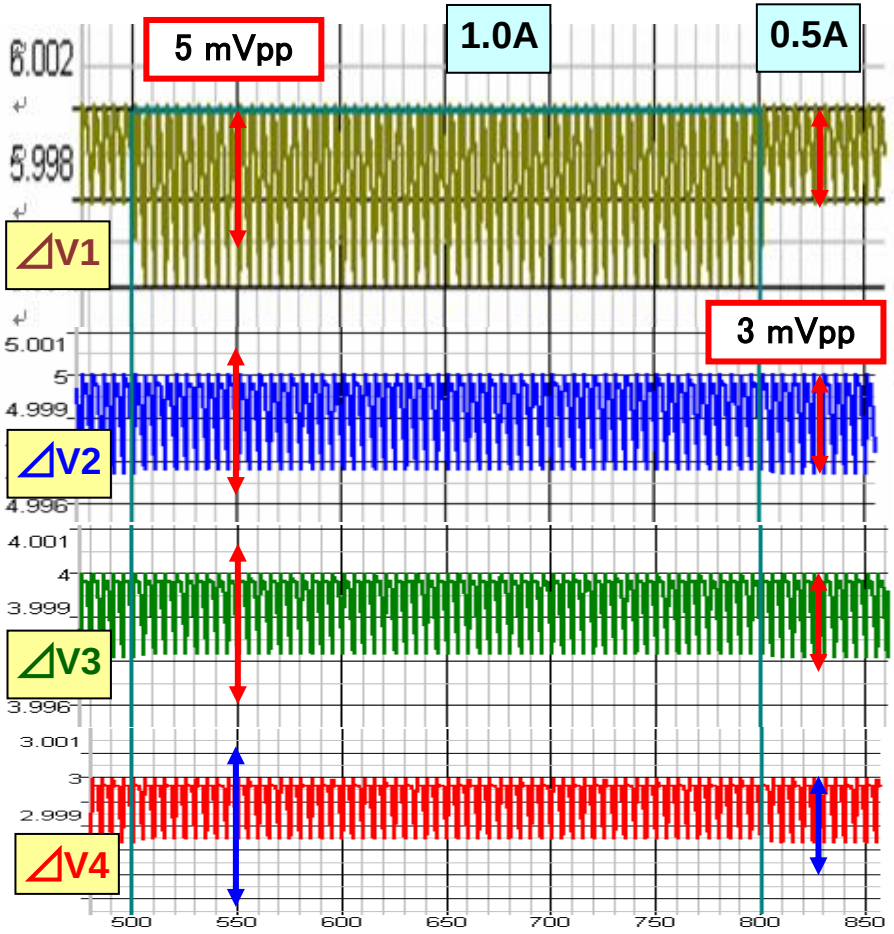

Fig.20 Simulation Result

SIMO Converter with Hysteretic Control

【 Circuit of **Boost** Converter 】

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

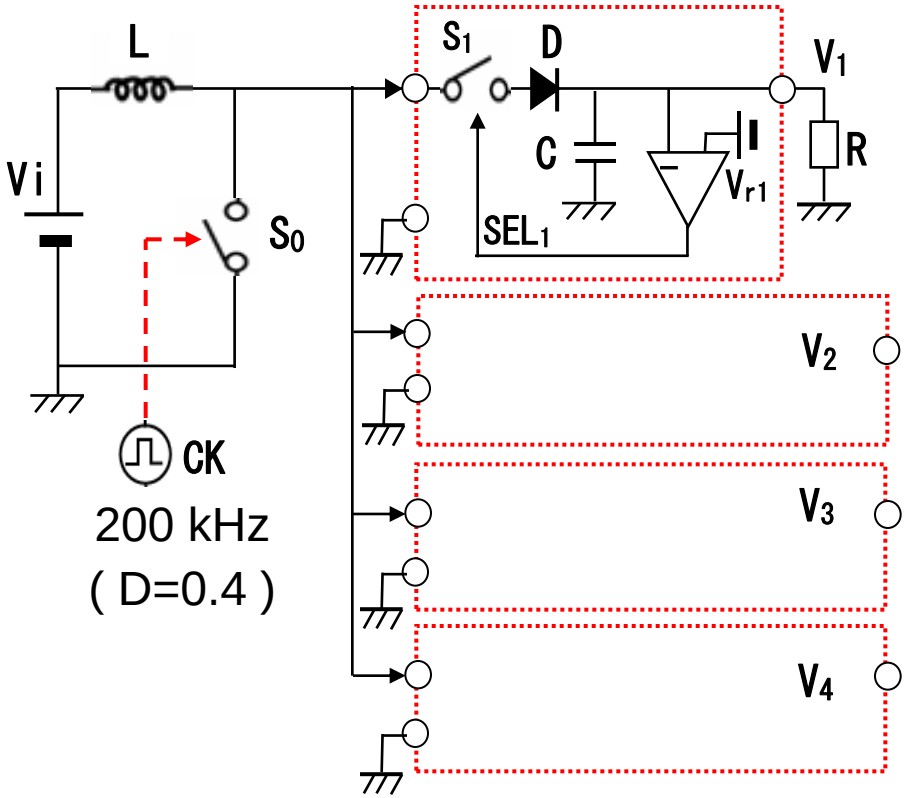

Fig.21 Simulation Circuit

● 4mV=⊿V1＞⊿V2≒⊿V3≒⊿V4

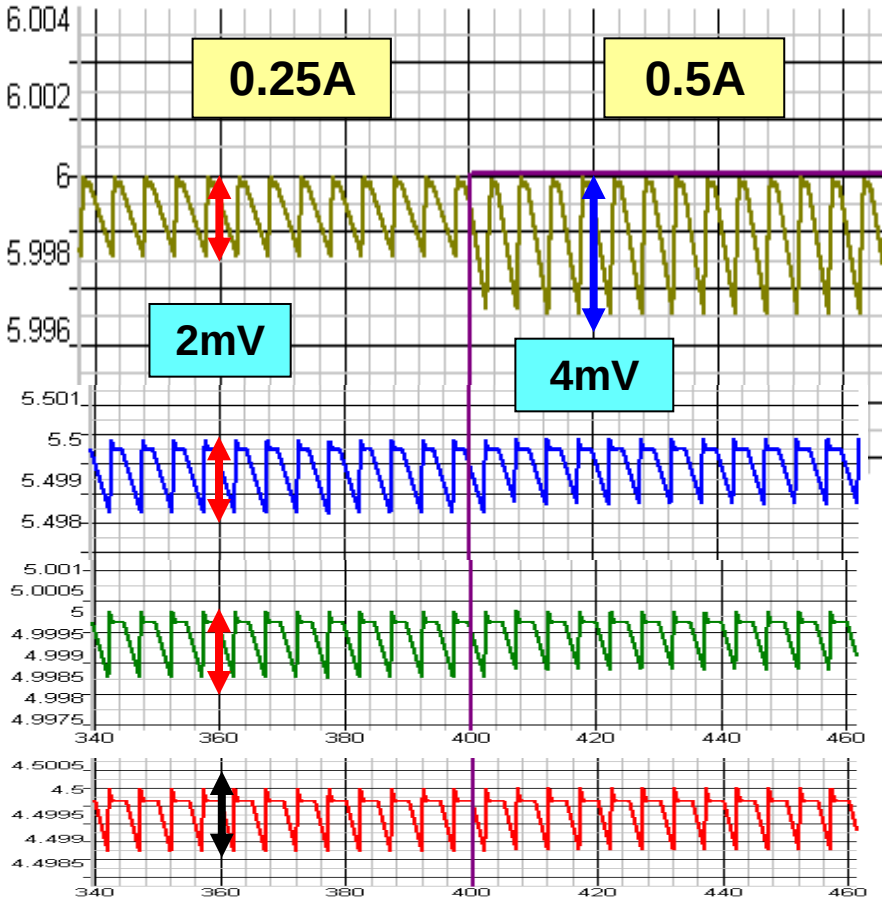

Fig.22 Simulation Result

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Conclusion

1. SIDO Converter with Hysteretic Converter

a) Simulation Result (Buck : 9.0V ⇒ 6.0V, 4.0V)

⊿Vo＜10 mV (Boost : 3.0V ⇒ 5.0V, 4.0V)

@ Io1=1.0A／0.5A, Io2=0.50A

b) Experimental Result (Buck Converter)

⊿Vo＜25mV @ Io1=0.35A／0.18A, Io2=0.10A

⊿Vo＜20mV @ Io1=0.18A, Io2=0.20A／0.10A

2. Simulation Result of SIMO Converter (4 outputs)

a) Buck Converter: (Io2~Io4=0.5A)

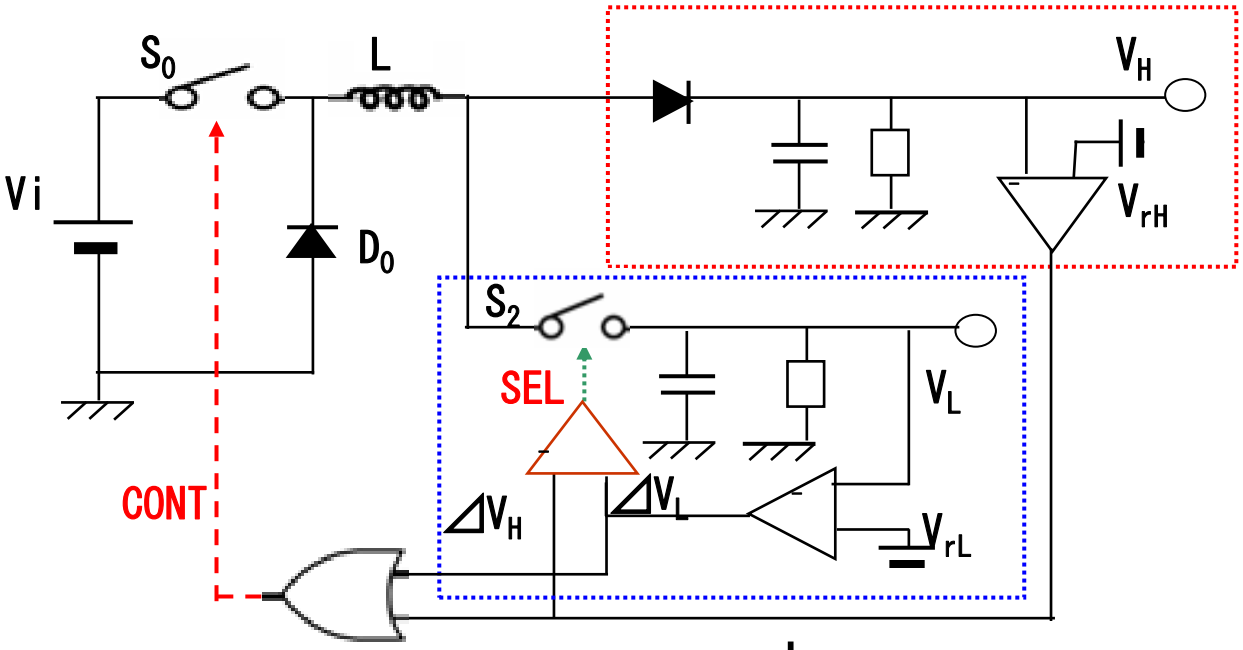
- ⊿Vo＜7mV (Io1=1.0A／0.5A)

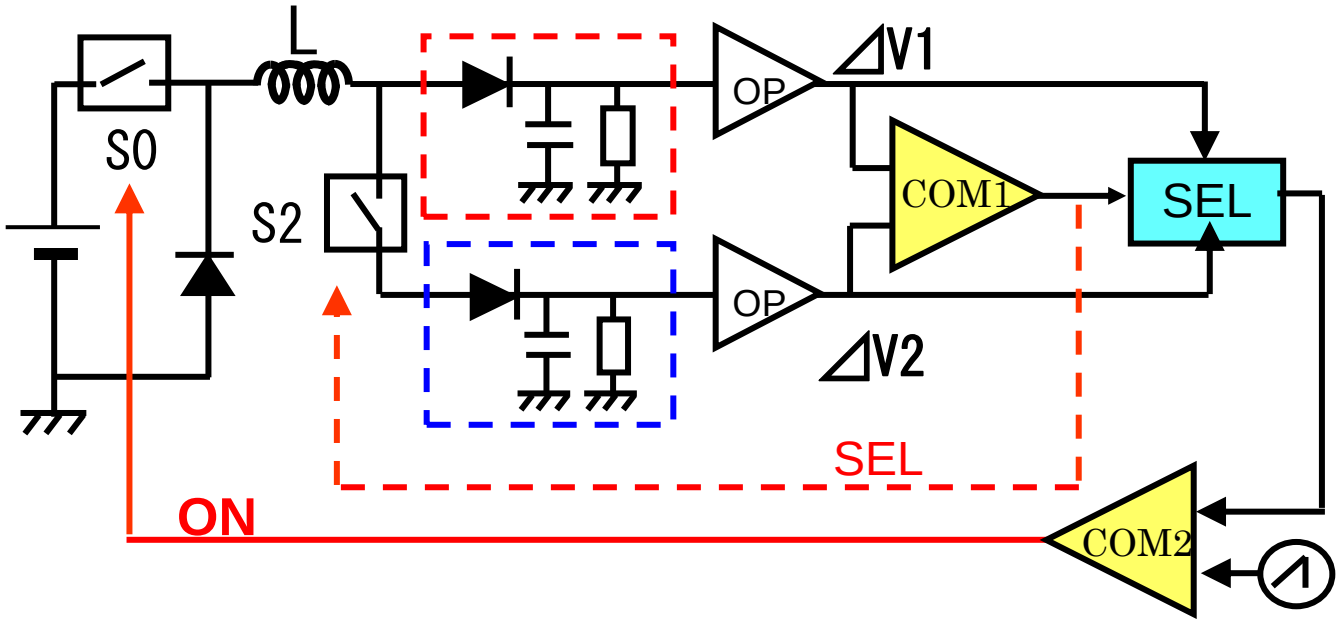
b) Boost Converter: (Io2~Io4=0.25A)

- ⊿Vo＜4mV (Io1=0.5A／0.25A)

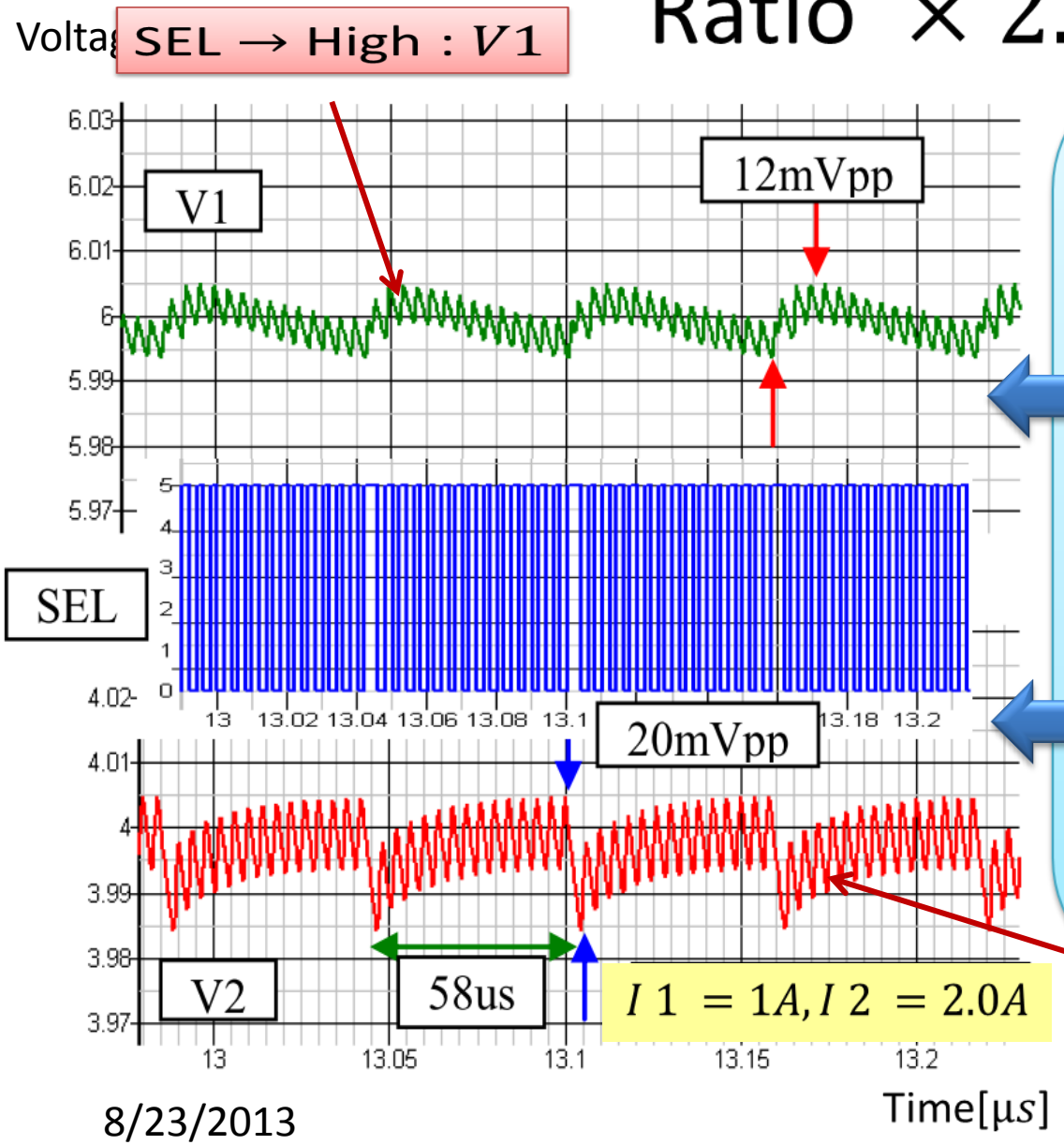
Thank you
for your kind attention.

【 Circuit of SIDO Buck Converter 】





Output Ripple ΔV 1 and ΔV 2 Ratio $\times$ 2.2



$I\,1 = 1A,$
$I\,2 = 2.2A$

$\Delta V1 = 12mVpp$

$\Delta V2 = 20mVPp$

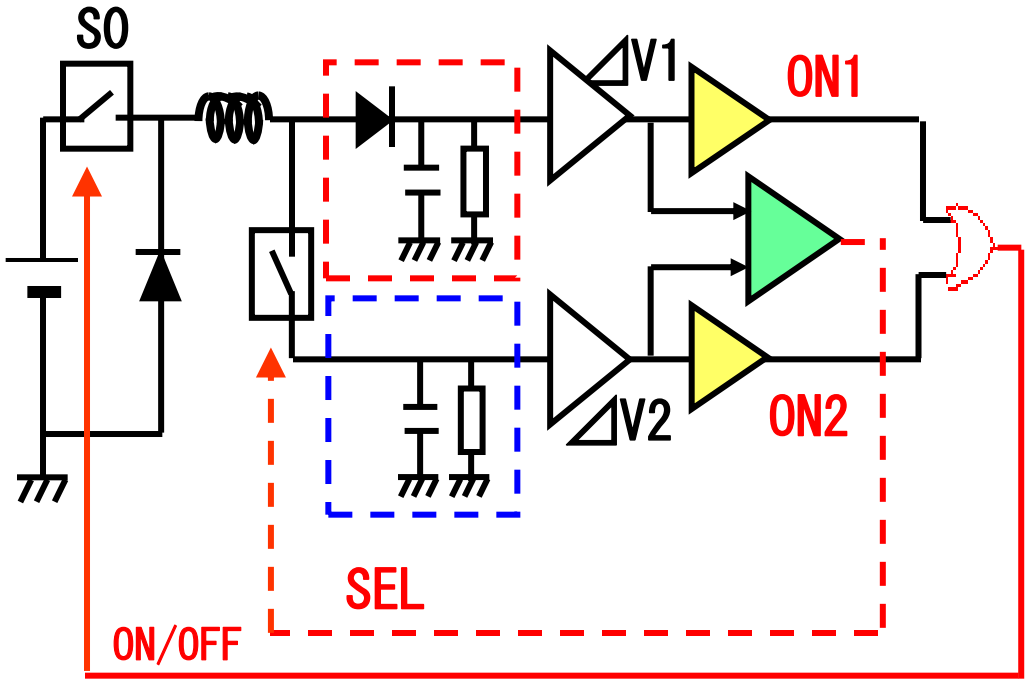
$\Delta V1, \Delta V2 < 0.5\%V_o$

SEL → Low : $V2$

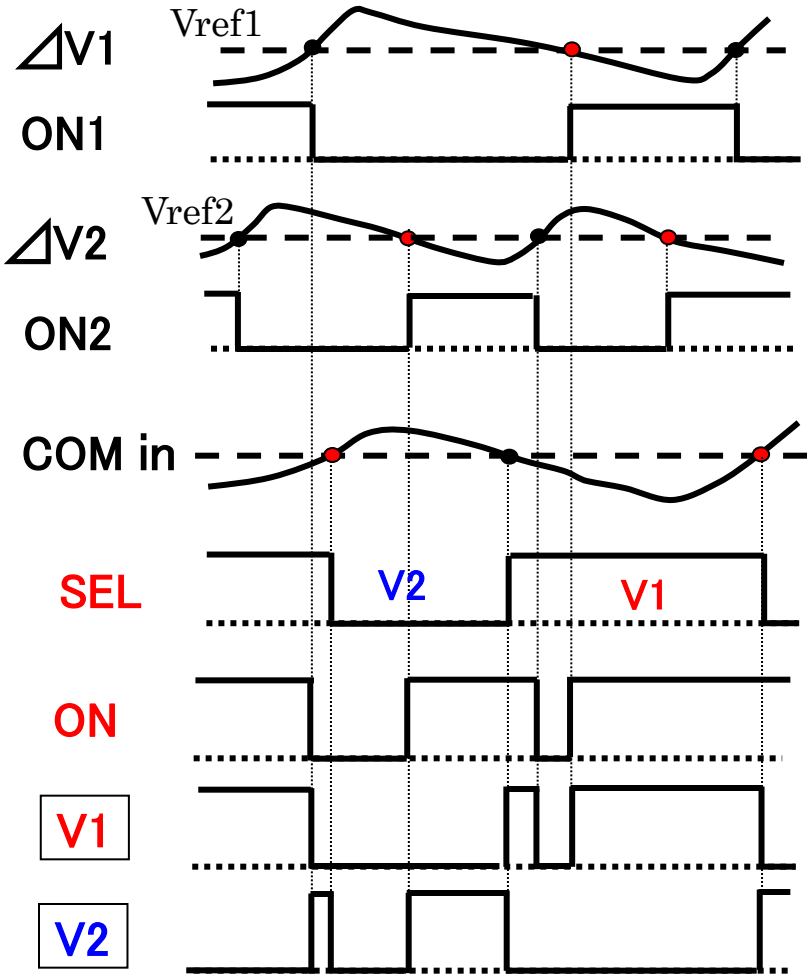
Proposed SIDO Converter with Hysteretic Control

【 Operation of **Buck** Converter】

- ON/OFF signal: ON1+ON2
- SEL signal: Compare (⊿V2＞⊿V1)



Proposed SIDO Buck Circuit



Timing Chart

Proposed SIDO Converter with Hysteretic Control

【 Experimental Result 1 】

(Buck Converter)

● Output Ripple

(Static Load Regulation)

(a) ⊿V1=25mV, ⊿V2=20mV

F=950 kHz

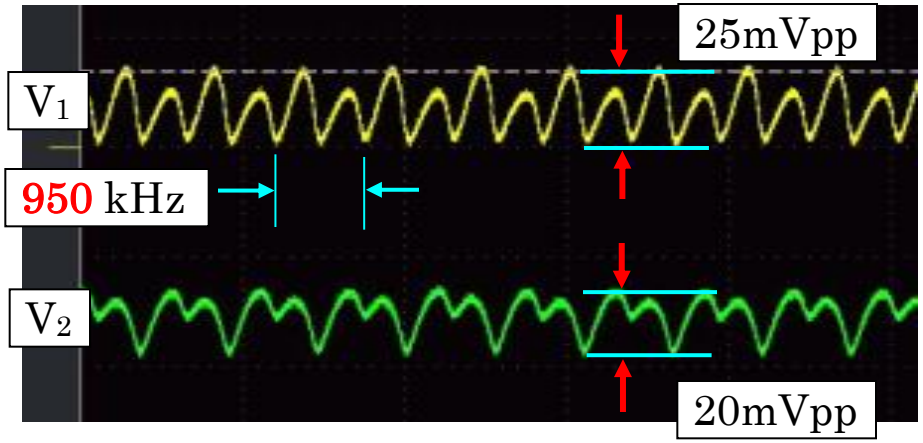
@ Io1=0.35 A, Io2=0.20 A

(b) ⊿V1=20mV, ⊿V2=15mV

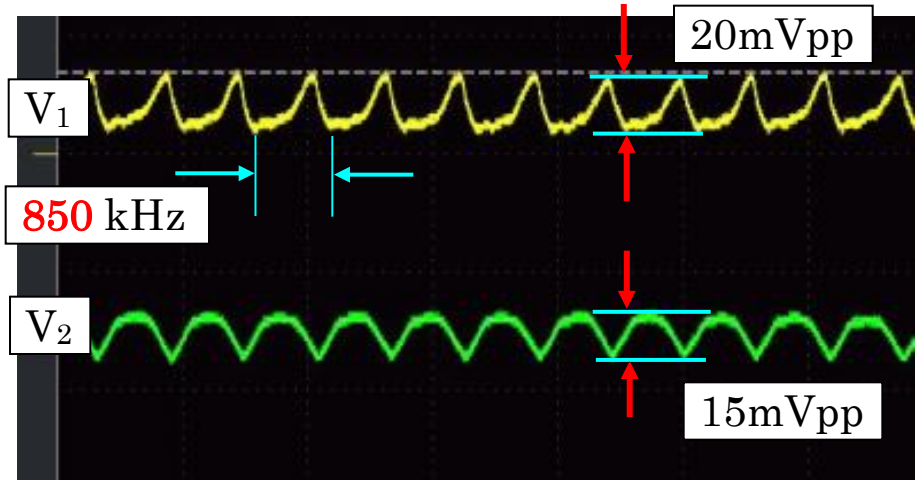
F=850 kHz

@ Io1=0.50 A, Io2=0.20 A

● Polarity of each ripple is complementary



Experimental Result 1



Experimental Result 2

Proposed SIDO Converter with Hysteretic Control

【 Experimental Result 2 】

(Buck Converter)

● Dynamic Load Regulation

(a) ⊿V1=25 mV : Self Regulation

⊿V2=5 mV : Cross Regulation

@ Io1=0.35A／0.18A

Io2=0.10A

(b) ⊿V1=30mV : Cross Regulation

⊿V2=15mV : Self Regulation

@ Io1=0.18A

Io2=0.20A／0.10 A

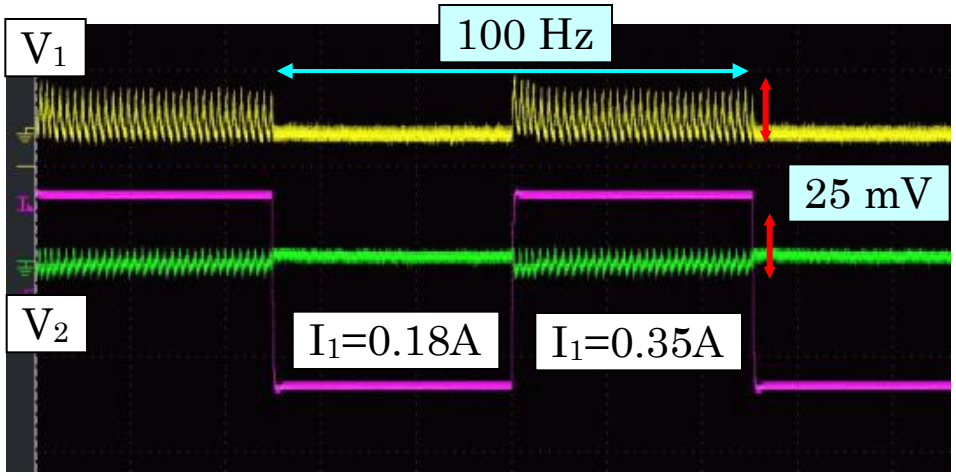


Fig.17(a) Experimental Result 1

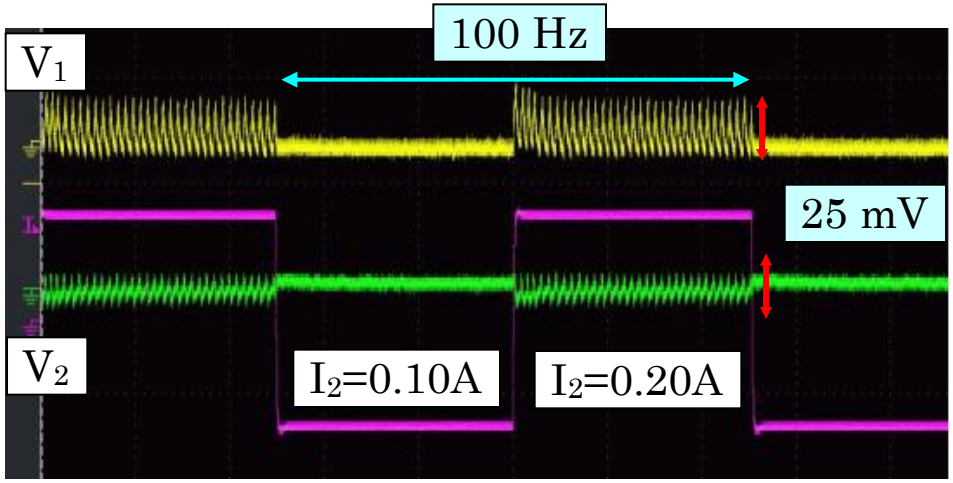
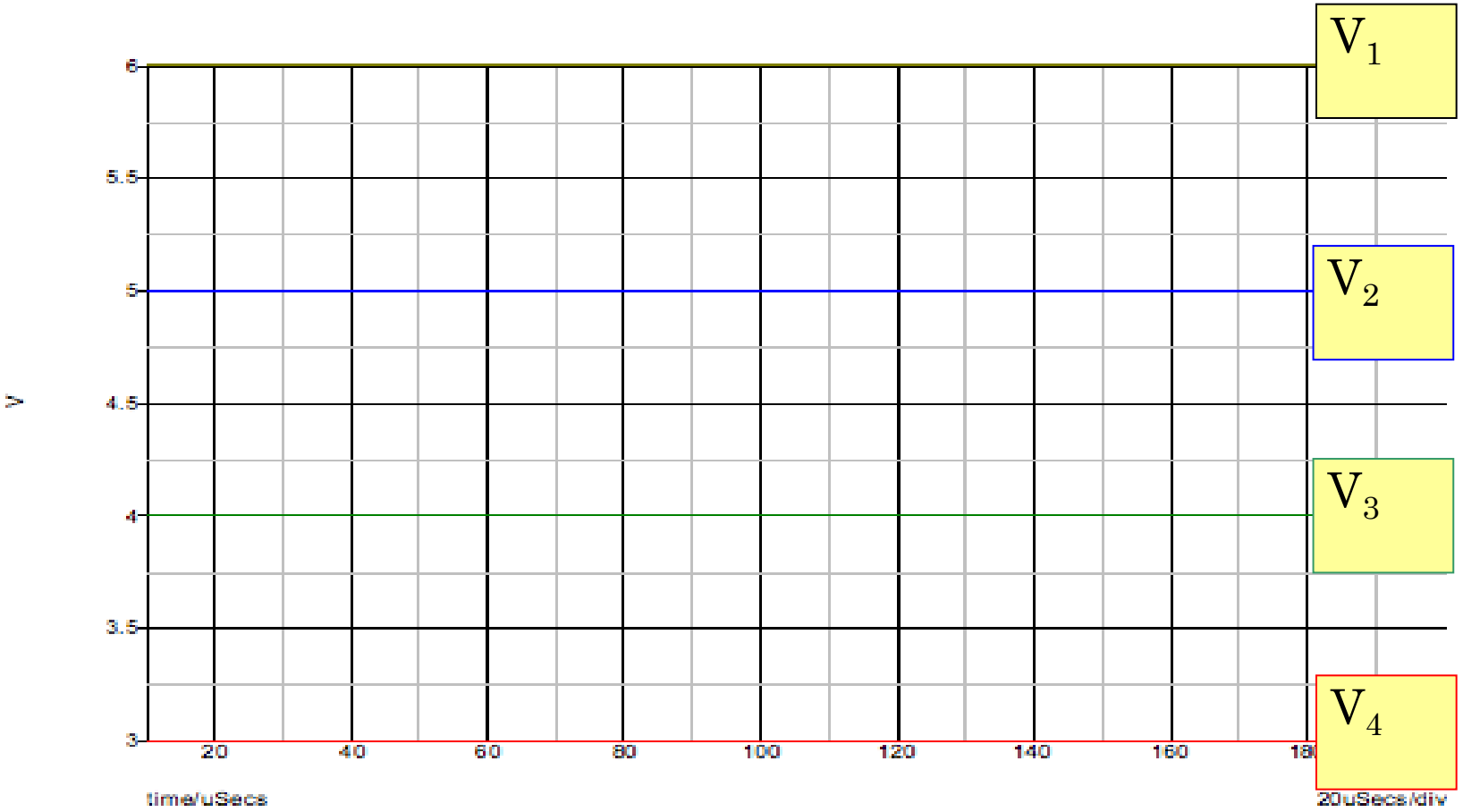


Fig.17(b) Experimental Result 2

【 Simulation Result of SIMO Converter 】4 outputs

Vo = 6.0V, 5.0V, 4.0V, 3.0V



SIMO Converter with Hysteretic Control

【 Simulation Result 】

(**Boost** Converter: 4 outputs)

a) Io1= 0.25A (Io2~Io4=0.25A)

- 2mV=⊿V1≒⊿V2≒⊿V3≒⊿V4

b) Io1= 0.5A (Io2~Io4=0.25A)

- 4mV=⊿V1＞⊿V2≒⊿V3≒⊿V4

∵ Priority : V4 > V3 > V2 > V1

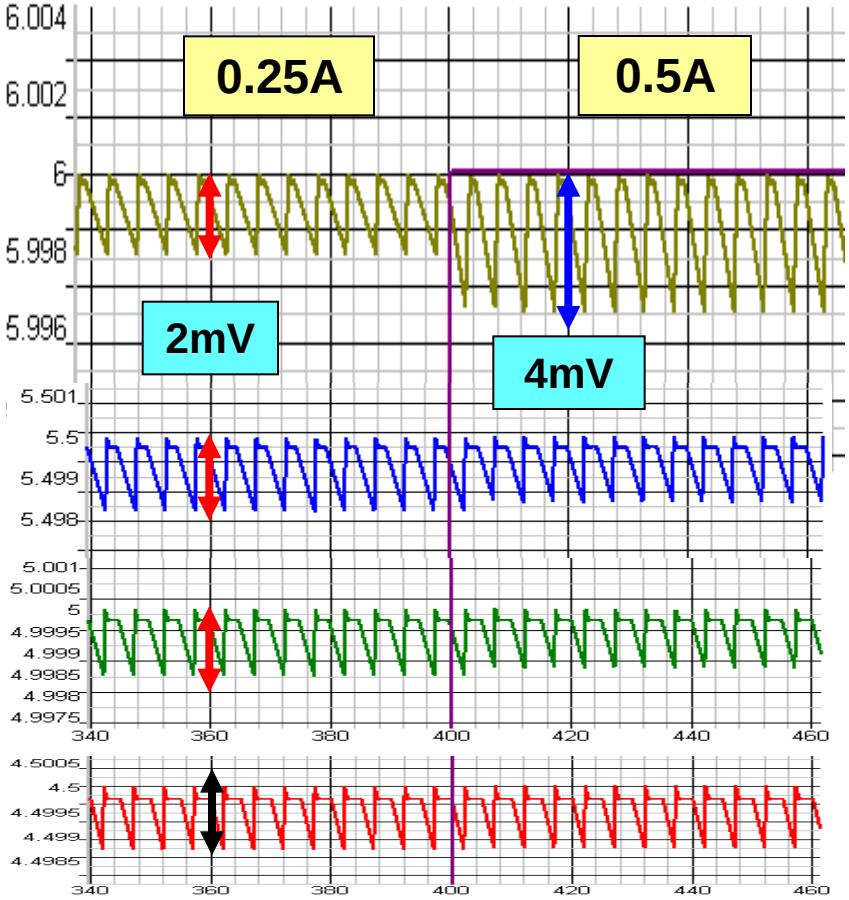
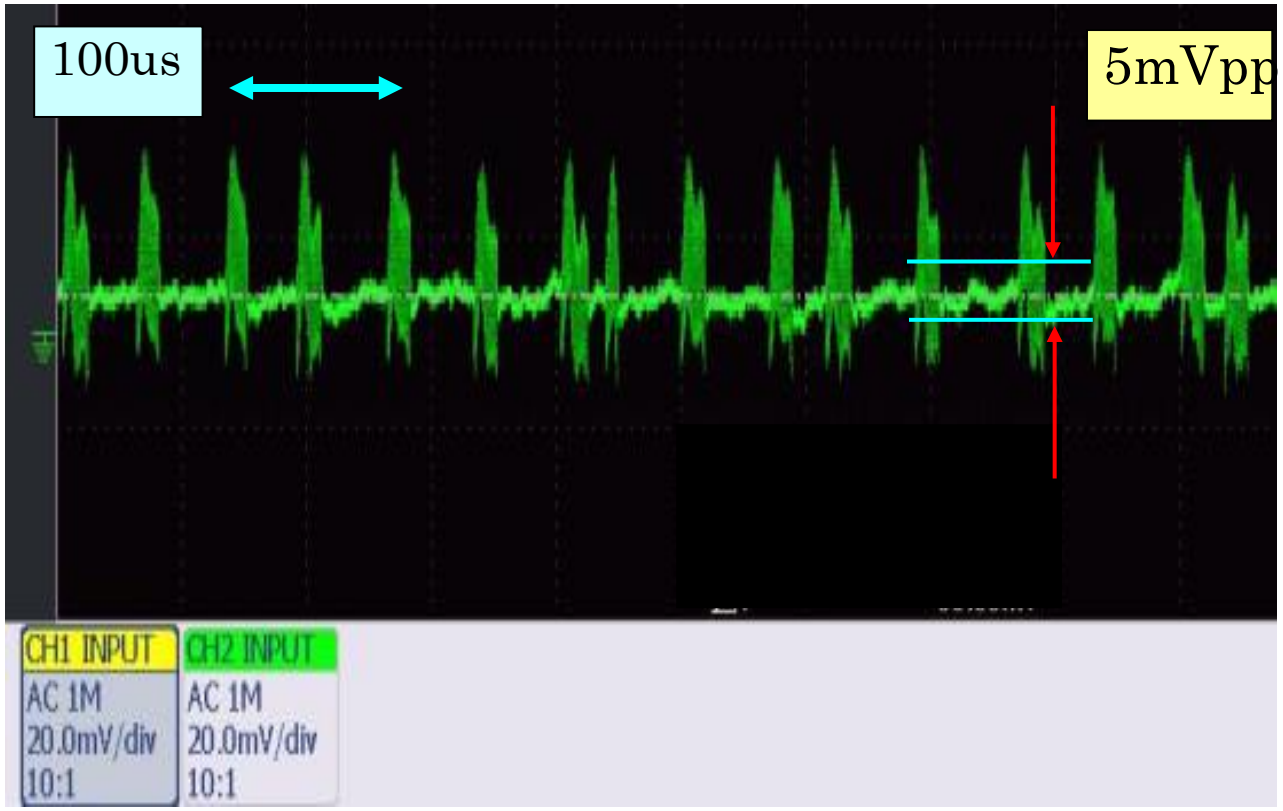


Fig.22 Simulation Result

【 Experimental Result of SISO Converter 】

Vo=4V, Io=0.35A (on Universal Board)

Pulse Noises because of Z of GND line

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