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

Y. Kobori (NIT, Oyama College/Gunma Univ. Japan)
S. Tanaka, N. Tsukiji, N. Takai, H. Kobayashi (Gunma Univ.)
Outline

• Background, Research Objective
• Previous **SIDO** Converter with Exclusive Control
• Basic **SISO** Converter with Hysteretic Control
• **SISO** Converter with New Hysteretic Controls
• Proposed **SIDO** Converters (Two Types)
• Experimental Results of Proposed Converters
• Conclusion

**SISO**: Single-Inductor Single-Output
**SIDO**: Single-Inductor Dual-Output
Many DC-DC Converters in Cell phones, manufacturing machinery, etc.

**AC-DC converter**
(Fly back, Forward Type)

\[ V_B = 24/12 \text{ V} \]

**Output Voltages**
- 5.0 V, 4.2 V
- 3.3 V, 2.5 V
- 1.2 V etc.

**Many Power Supplies**
(DC-DC converters)

---

**Fig. 1 background**
Research Objective

Fig. 2 Research Objective

- SISO: Single-Inductor Single-Output
- SIDO: Single-Inductor Dual-Output

Approach

High Speed & Low cost, volume

Reduce cost & volume
Outline

• Background, Research Objective
• Previous SIDO Converter with Exclusive Control
• Basic SISO Converter with Hysteretic Control
• SISO Converter with New Hysteretic Controls
• Proposed SIDO Converter (Two Types)
• Experimental Results of Proposed Converters
• Conclusion
Previous SIDO Converter with Exclusive Control

\[ \Delta V_1 > \Delta V_2 \Rightarrow \text{SEL}['L'] \Rightarrow S2:OFF \]
\[ \Delta V_1 < \Delta V_2 \Rightarrow \text{SEL}['H'] \Rightarrow S2:ON \]

Fig.3 Simulation Circuit with Exclusive Control

\[ V_i=9V \]
\[ V_1=6V, V_2=4V \]

Fig.4 Timing Chart
**Previous SIDO Buck Converter**

**Simulation Result**

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

\[
\Delta V_{SR}, \Delta V_{CR} < 27\text{mV}
\]

- **I1** = 2.0A/1.0A
- **I2** = 2.2A/1.2A

**Fig.5 Simulation Result (Ripple & Load Regulation)**
Previous SIDO Buck Converter

【Experimental Result】

- Output ripple
  \[ I_2 = 0.60A/0.36A \]
  \[ ∆V1 = ∆V2 < 15 \text{ mVpp} \]
  \[ \text{Over/Under-shoot} < 10\text{mV} \]

Fig.7 Experimental Result (Ripple & Load Regulation)
Outline

• Background, Research Objective
• Previous SIDO Converter with Exclusive Control
• Basic SISO Converter with Hysteretic Control
• SISO Converter with New Hysteretic Controls
• Proposed SIDO Converters (Two Types)
• Experimental Results of Proposed Converters
• Conclusion
Basic SISO Converter with Hysteretic Control

【Basic Hysteretic Control】

- Non-Linear Control, High-Speed Control
- Simple Circuit (Comparator only)
  (Window Control Method is called Bang-Bang Control)

Fig.8 Basic Hysteretic Control Method
**Basic SISO Converter with Hysteretic Control**

【Circuit of SISO Converter】(Without Triangular signal)

- Simple Circuit (Comparator only. No clock, no SAW-tooth signal)
- Comparator has slight Hysteresis level (< 10 mV).
- Control frequency depends on Loop Delay, Load Current etc.

★ Vulnerable to a noise

---

**Fig.9(a) Circuit of Upper Level Control**

**Fig.9(b) Timing Chart**
Outline

• Background, Research Objective
• Previous SIDO Converter with Exclusive Control
• Basic SISO Converter with Hysteretic Control
• SISO Converter with New Hysteretic Controls
• Proposed SIDO Converters (Two Types)
• Experimental Results of Proposed Converters
• Conclusion
SISO Converter (Type 1) with New Hysteretic Controls

- Triangular signal with CR circuit across Inductor (> 0.1 V)
- OP-Amp to get high Gain
- High Speed, High Gain and Stable against noise

Fig. 10(a) New SISO Converter (Type 1)

Fig. 10(b) Wave form

\[ \star T_{on} \text{ mostly depends on } CR, \text{ Hysterisis etc.} \]
SISO Converter (Type 1) with New Hysteretic Controls

Simulation Results:
- \( V_i = 9.0 \text{V}, \ V_o = 5.0 \text{V}, \ \Delta I_o = 1.0 \text{A} / 0.5 \text{A} \)
- \( \Delta V_o = 5.0 \text{mVpp} \)
- Overshoot: \( \pm 5.0 \text{mV} \)
- \( F \approx 360 \text{kHz} \)

Parameters:
- \( L = 10 \text{uH}, \ C = 470 \text{uF} \)

Fig. 11 Simulation Result of SISO Converter (Type 1)
SISO Converter (Type 2) with New Hysteretic Controls

- Triangular signal with CR circuit across OP amp.
- \((V_o + \text{triangular signal})\) is compared with \(V_{\text{ref}}\).

Fig. 12(a) New SISO Converter (Type 2)  
Fig. 12(b) Wave form
**SISO Converter (Type 2)**

with **New Hysteretic Controls**

【Simulation Results】

a) Output Ripples

\[ \Delta V_o < 10 \text{ mVpp @ } i_o = 0.5 \text{ A} \]
\[ \Delta V_o < 15 \text{ mVpp @ } i_o = 1.0 \text{ A} \]

b) Over/Under-shoot

\[ \Delta V_o < 20 \text{ mV @ } \Delta i_o = 0.5 \text{ A} \]

C) \( F_{op} = 1.3 \text{MHz @ } i_o = 0.5 \text{ A}, \quad F_{op} = 0.93 \text{MHz @ } i_o = 1.0 \text{ A} \)

Fig. 13  Simulation Result of SISO Converter (Type 2)
Outline

• Background, Research Objective
• Previous SIDO Converter with Exclusive Control
• Basic SISO Converter with Hysteretic Control
• SISO Converter with New Hysteretic Controls
• Proposed SIDO Converters (Two Types)
• Experimental Results of Proposed Converters
• Conclusion
Proposed **SIDO** Converter (Type 1) with Hysteretic Control

**Buck SIDO Converter** (Type 1)
- $V_i=9.0\,\text{V} \Rightarrow V_1=5.0\,\text{V}, V_2=3.0\,\text{V}, I_o=0.25\,\text{A}$
- $L=1\,\mu\text{H}, C=470\,\mu\text{F}$

![Proposed SIDO Converter Circuit](image)

Fig.14  Proposed SIDO Circuit with Hysteretic Control
Proposed **SIDO Converter (Type 1)** with Hysteretic Control

**Simulation Result**
- $\Delta V_1, \Delta V_2 < 5$ mVpp
- Overshoot $< 5$ mV
- $V_i=9.0V$
- $V_1=5.0V, V_2=4.5V$
- $I_{o1}=I_{o2}=0.5A/1.0A$
- $L=1.0\mu H, C=470\mu F$

**Fig. 15** Simulation Result of SIDO Converter (Type 1)
Proposed SIDO Converter (Type 2) with Hysteretic Control

【Proposed SIDO Converter】(Type 2)
- \( V_i = 5.0V, V_o = 2.5/2.0, \)
  \( I_{o1} = 0.5/0.75A, I_{o2} = 0.5A, \)
- \( L = 0.9 \mu H, C = 200 \mu F. \)

\[ V_2 = \frac{R_2}{R_1 + R_2} \cdot V_1 \]

Fig. 16  Simulation Circuit of SIDO Converter (Type 2)
Proposed SIDO Converter (Type 2) with Hysteretic Control

Simulation Result

a) Output Ripples
\[ \Delta V_o < 5 \text{ mVpp} \]
@ \( I_o = 0.5/0.75 \text{ A} \)

b) Over/Under-shoot
< 10 mV
@ \( \Delta I_o = 0.25 \text{ A} \)

Fig. 17 Simulation Result of SIDO Converter (Type 2)
Outline

• Background, Research Objective
• Previous SIDO Converter with Exclusive Control
• Basic SISO Converter with Hysteretic Control
• SISO Converter with New Hysteretic Controls
• Proposed SIDO Converters (Two Types)
• Experimental Results of Proposed Converters
• Conclusion
Experimental Results of Proposed Converters

【SISO Converter (Type 2)】

a) Output Ripples
   \[ \Delta V_o < 20 \text{ mVpp} \] at \( I_o = 0.71 \text{ A} \)

b) \( F_{op} = 250 \text{ kHz} \)

- \( V_i = 9.0 \text{ V}, V_o = 2.5 \text{ V} \)

Fig. 18 Simulation Result of SISO Converter

(Type 2)
Experimental Results of Proposed Converters

【SIDO Converter (Type 1)】

a) Output Ripples
\[ \Delta V_0 < 20 \text{ mVpp} \]

b) Fop = 60 kHz
Too slow!

◆ Pulse noise
about 350mV

Fig.19 Simulation Result of SIDO Converter (Type 1)
Experimental Results of Proposed Converters

【SIDO Converter (Type 1)】

* PWM signal & Triangular Signal

● $F_{op} = 60 \text{ kHz}$
   Too slow!

* P-MOSFET
  Off timing is delayed

Fig. 20 Wave forms of SIDO Converter (Type 1)
Conclusion

Two Types of SIDO Converter with Hysteretic Control

● Simulation Result
  Type 1: Ripple <10 mVpp @ Io=1.0 A
  Shoot < 5 mV @ ∆Io=0.5A
  Type 2: Ripple <5 mVpp @ Io=0.5 A
  Shoot < 10 mV @ ∆Io=0.25A

★ Experimental Result
  Type 1: Ripple <20 mVpp @ Io=0.4 A
  (SIDO) Shoot <5 mV @ ∆Io=0.2A
  Type 2: Ripple <20 mVpp @ Io=0.7 A
  (SISO) - - - - -

* Our future work is to experiment SIDO converter of type 2.
Thank you for your attention.
Amplitude level of output ripple mainly depends on Hysteresis level and the delay time

$$\Delta V_{rip} = V_{hys} + V_{delay}$$

$$= V_{hys} + (V_{ON} + V_{OFF})$$

Here,

$$V_{ON} = I_L \cdot \Delta T_{ON}/C$$

$$\therefore V_{delay} = I_L (\Delta T_{ON} + \Delta T_{OFF})/C$$

Fig. X Timing Chart