Design of a Simple Feed-Forward Controller for DC-DC Buck Converter

Shu Wu, Yasunori Kobori, Tetsuji Yamaguchi,
Zachary Nosker, Murong Li, Eiji Shikata,
Feng Zhao, Li Quan, Tsuyoshi Kaneko,
Qiulin Zhu, Nobukazu Takai,
Haruo Kobayashi

Gunma University, Japan

AKM Technology Corporation

Kimio Ueda

Asahi Kasei Microdevices

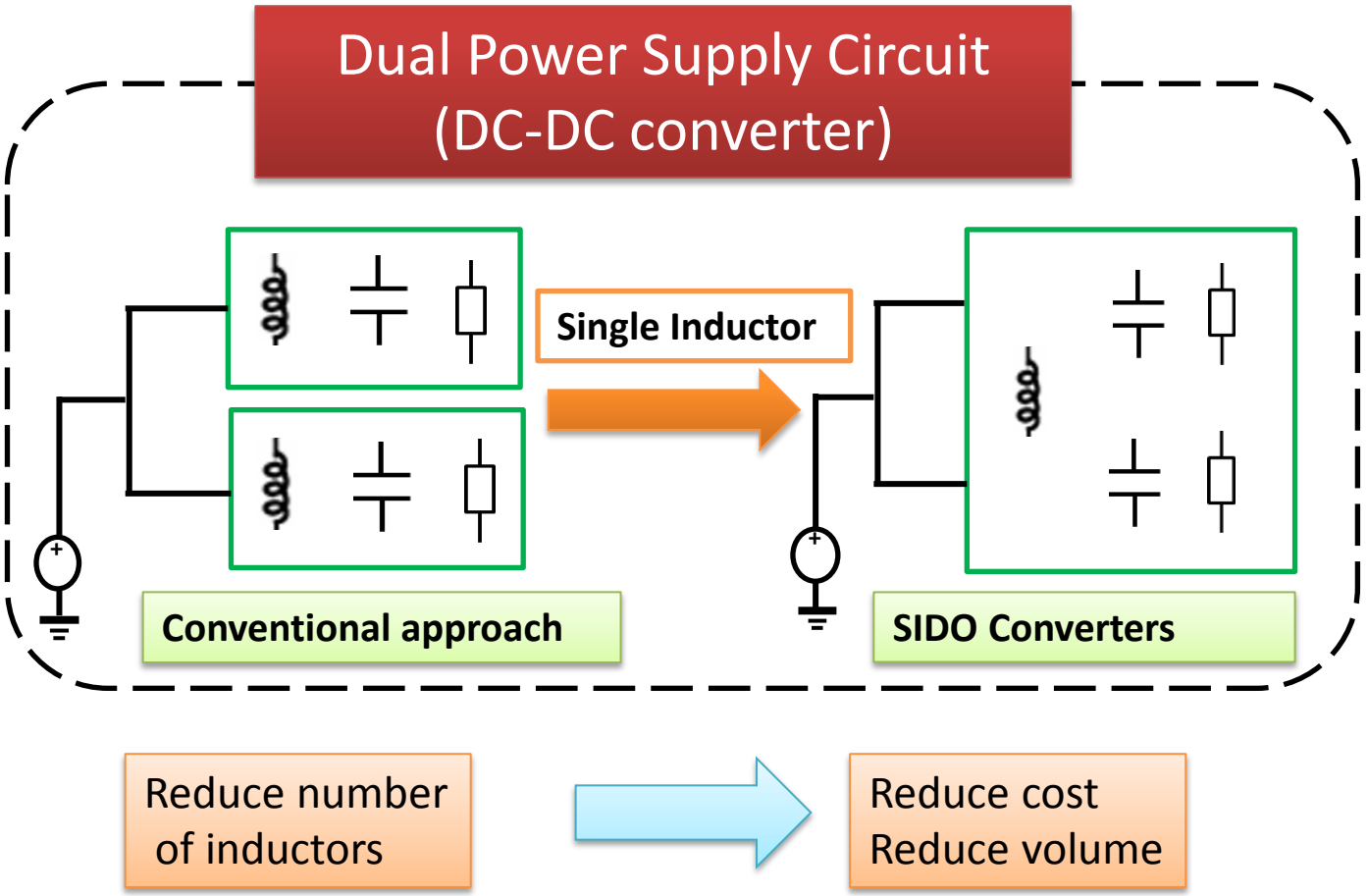
Outline

- Research Objective
- Proposed Feed-forward Control Method
  - Capacitor Charge Balance
  - Proposed Feed-forward Controller
- Simulation Results
  - SISO Buck Converter Simulation
  - SIDO Buck Converter Simulation
- Conclusion

Outline

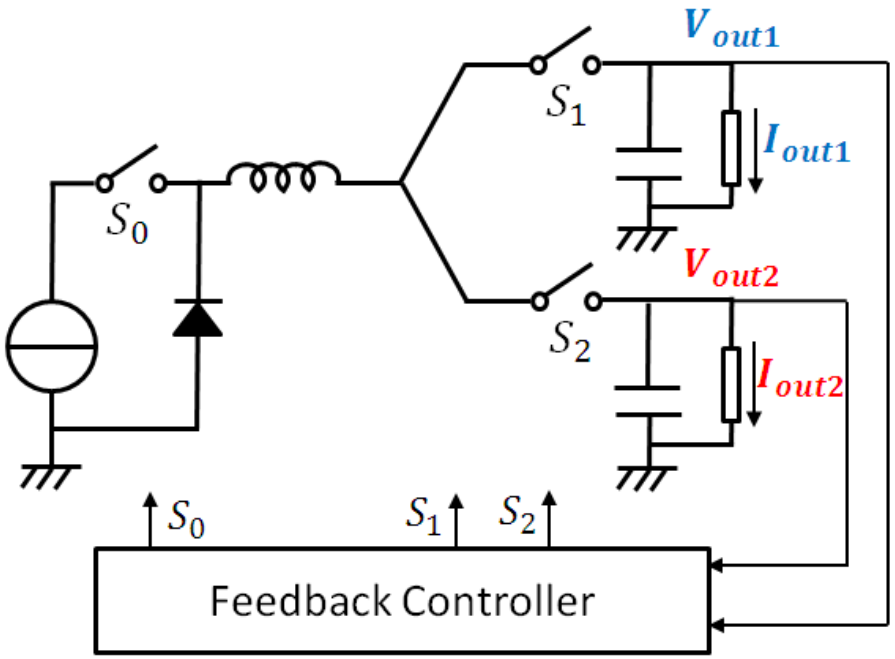
- Research Objective
- Proposed Feed-forward Control Method
  - Capacitor Charge Balance
  - Proposed Feed-forward Controller
- Simulation Results
  - SISO Buck Converter Simulation
  - SIDO Buck Converter Simulation
- Conclusion

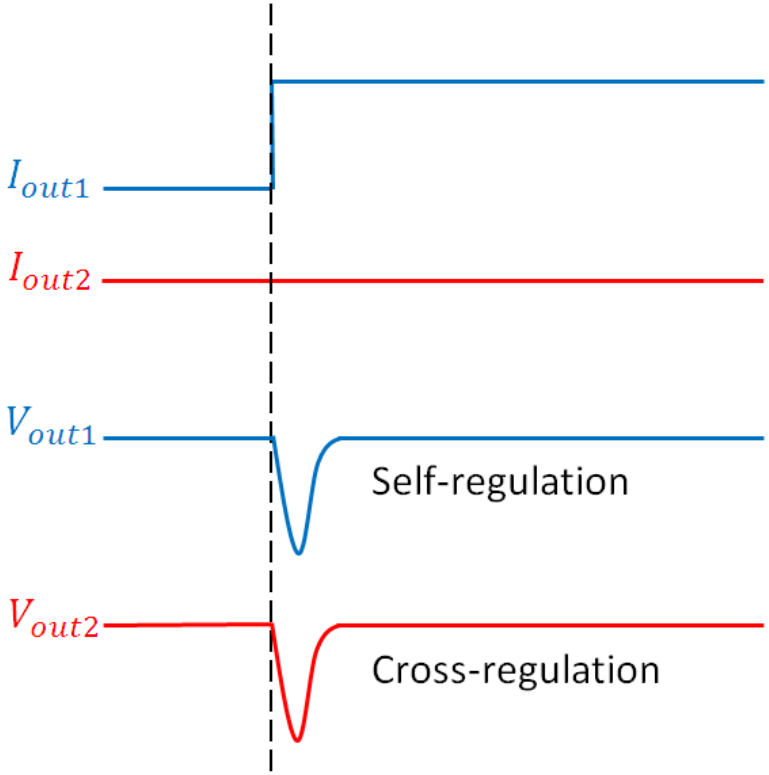
Background



SIDO: Single Inductor Dual Output

Cross-Regulation





SIDO buck converter with feedback control

Essential problem: transient response

Conventional Method

- **Feed-back control**

  Control Delay

- **Feed-forward + Feed-back control**

Accurate control variables modulation are required

digital non-linear feed-forward control

- **Complicated for SIDO converter**
- **Not cost-effective**

Research Objective

- **Principle**

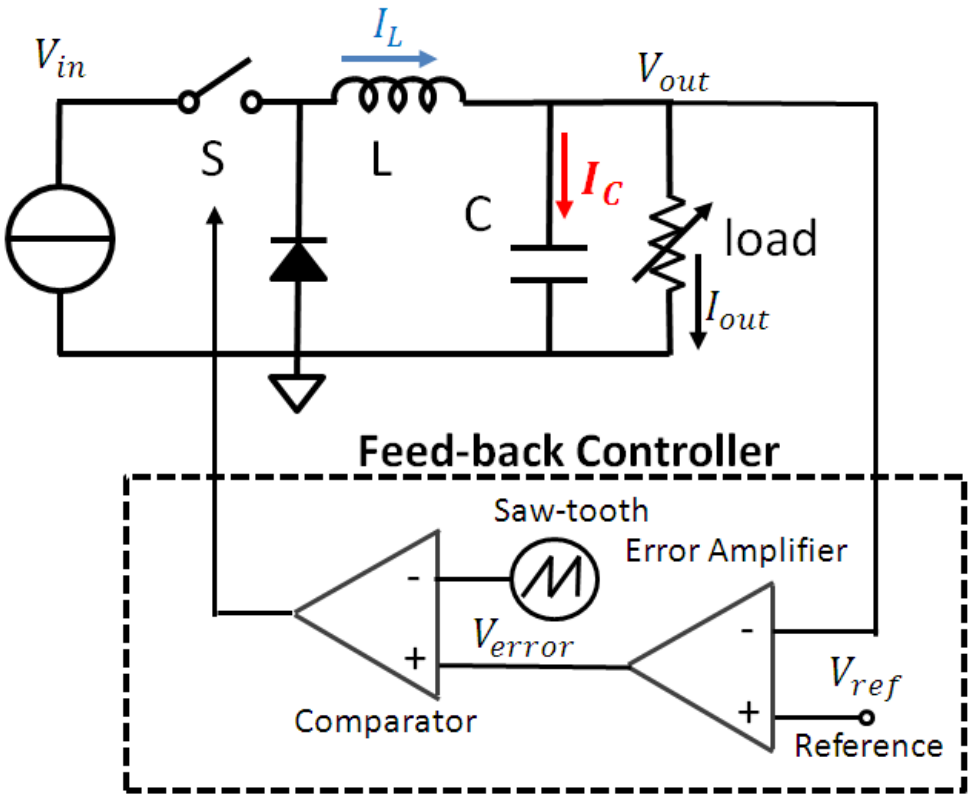
  Charge balance of output capacitor

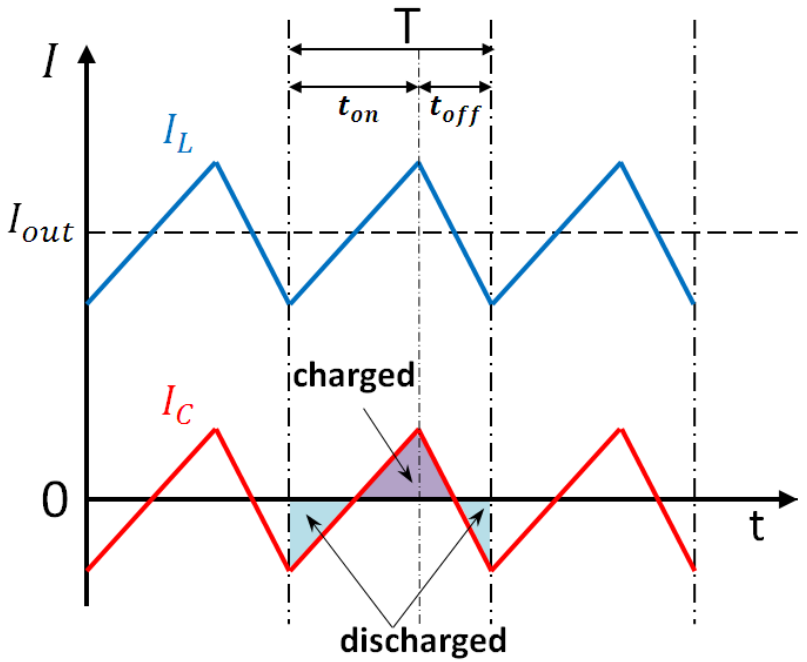
- **Advantage**
  - Simple
  - Fast transient response
  - Cross-regulation improvement for SIDO buck converter

Outline

- Research Objective
- Proposed Feed-forward Control Method
  - Capacitor Charge Balance
  - Proposed Feed-forward Controller
- Simulation Results
  - SISO Buck Converter Simulation
  - SIDO Buck Converter Simulation
- Conclusion

Charge Balance (1)

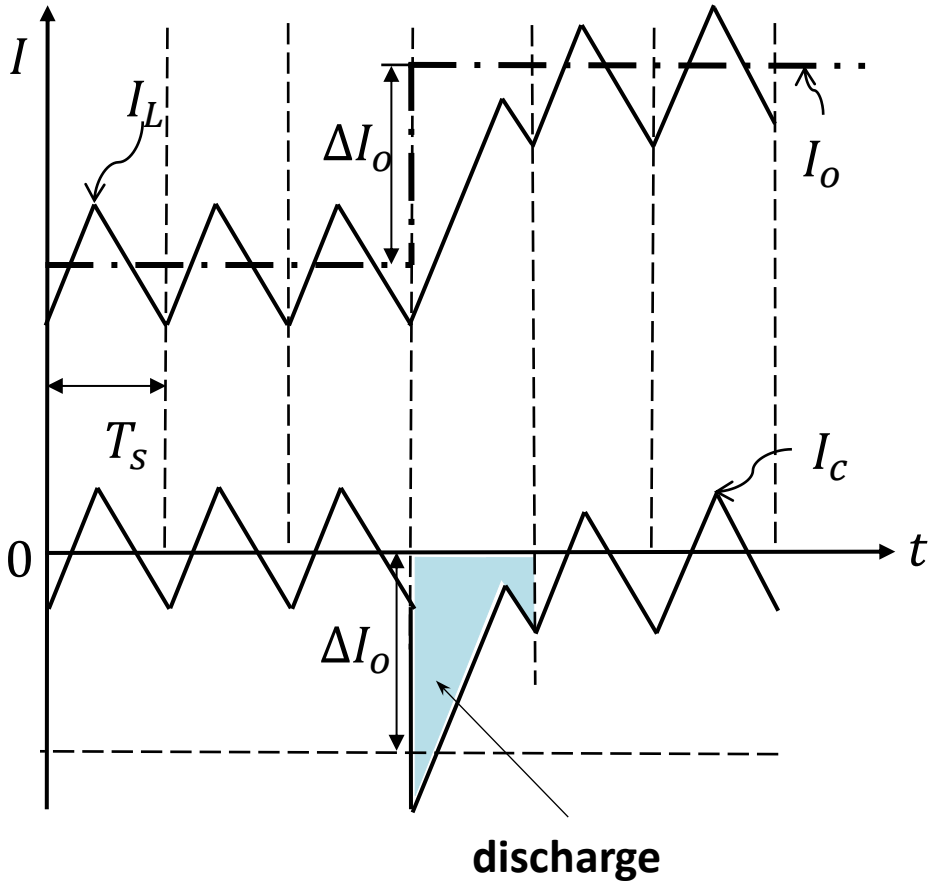




SISO buck converter

- Charge by input and inductor
- Discharge to output

Charge Balance (2)



Steady State

I_C Charge=Discharge

$$\int_0^{T_s} I_C \, dt = 0$$

Load is changed

I_L can't step change

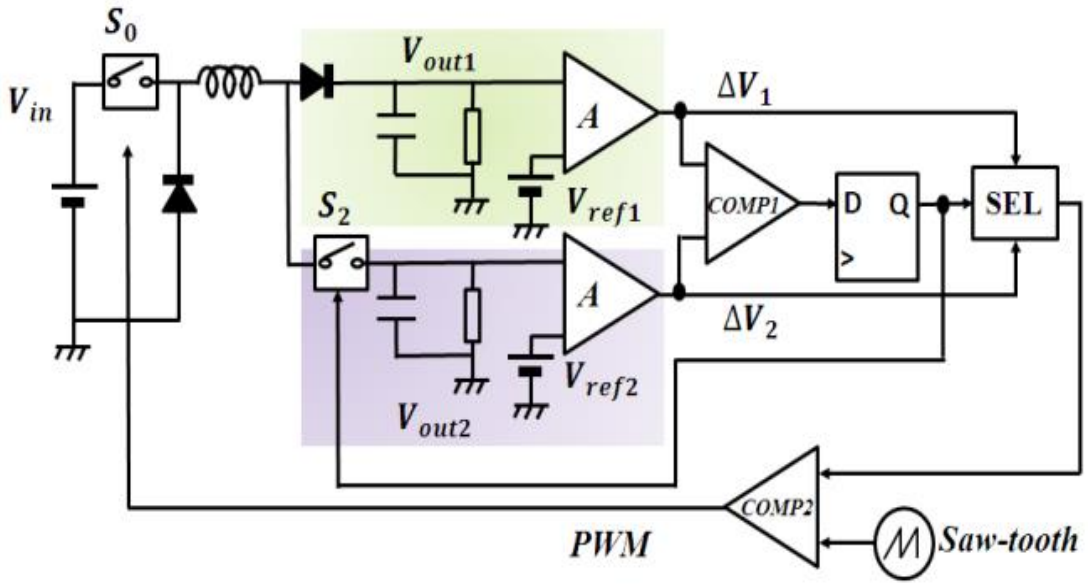
⇓

Capacitor more discharge

⇓

I_C Charge≠Discharge

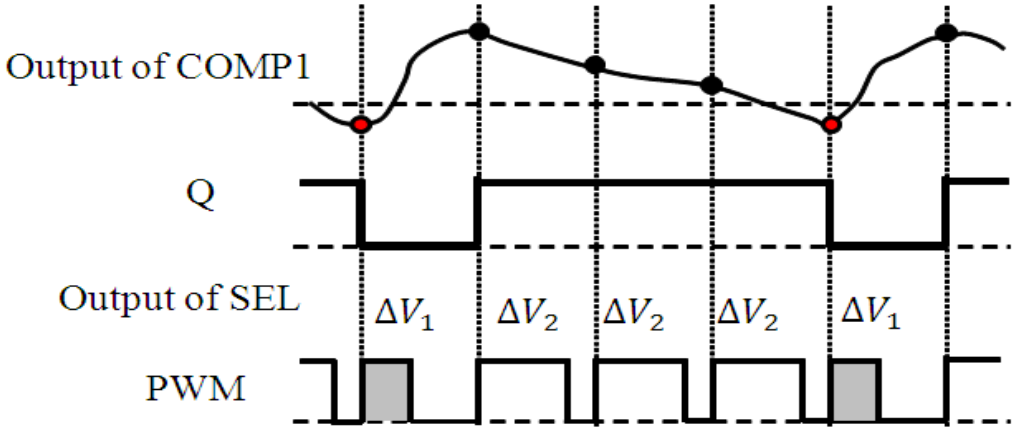
Charge Balance (3)



S_0 decides
how much power is supplied

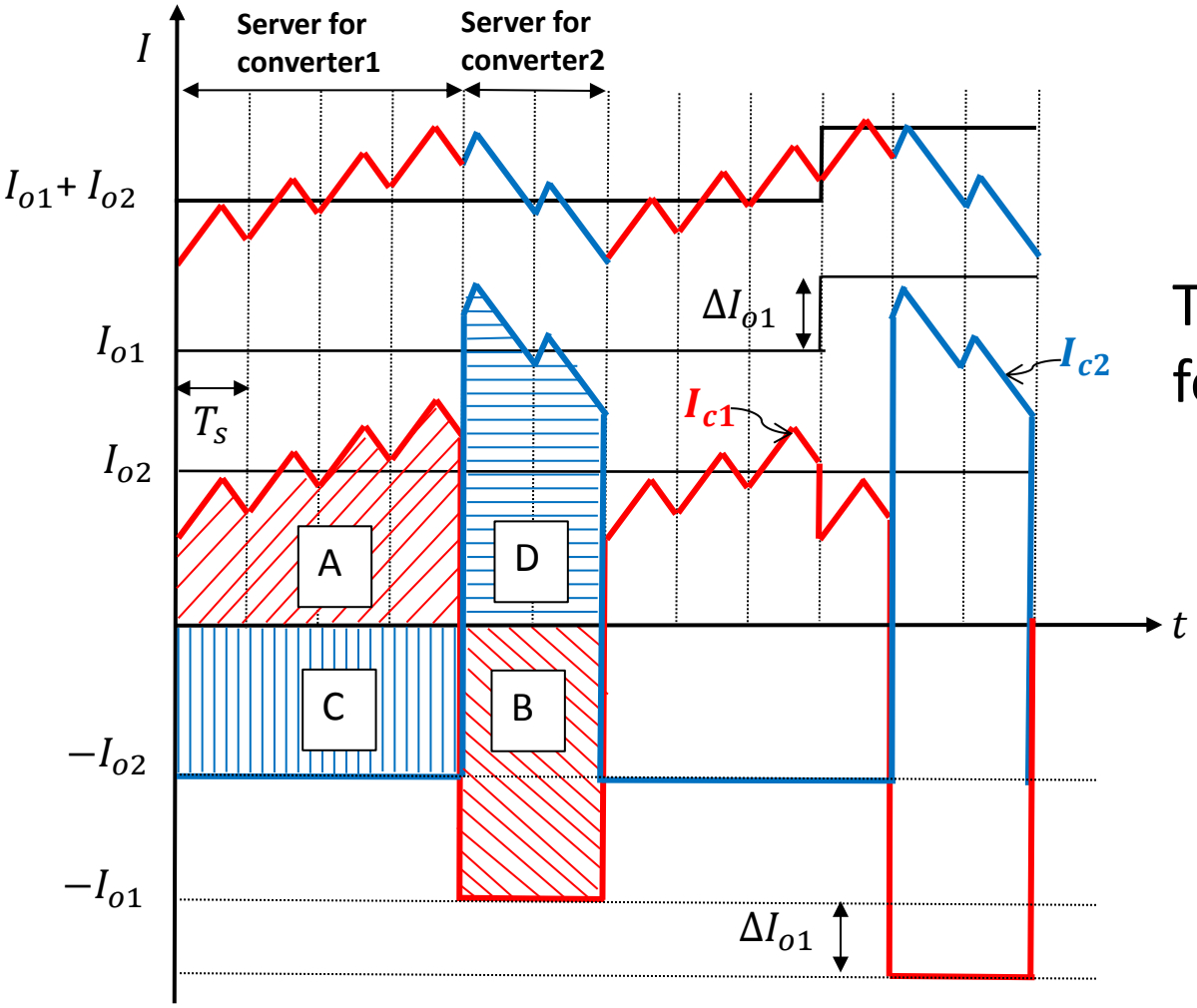
S_2 decides
which converter is served

SIDO buck converter with exclusive control



Timing chart

Charge Balance (4)



Steady State

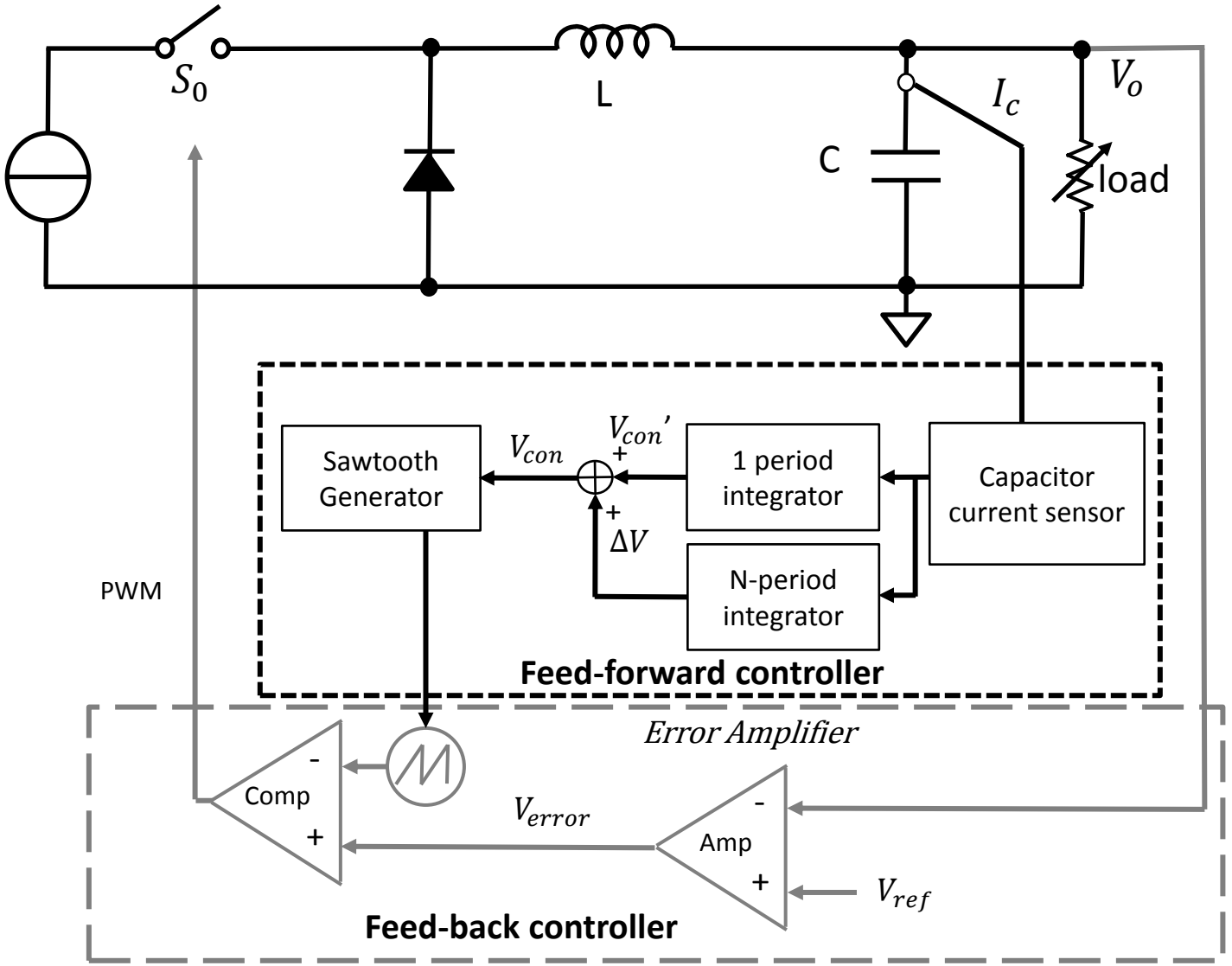
A=B = C=D

This balance is **useless** for feed-forward control

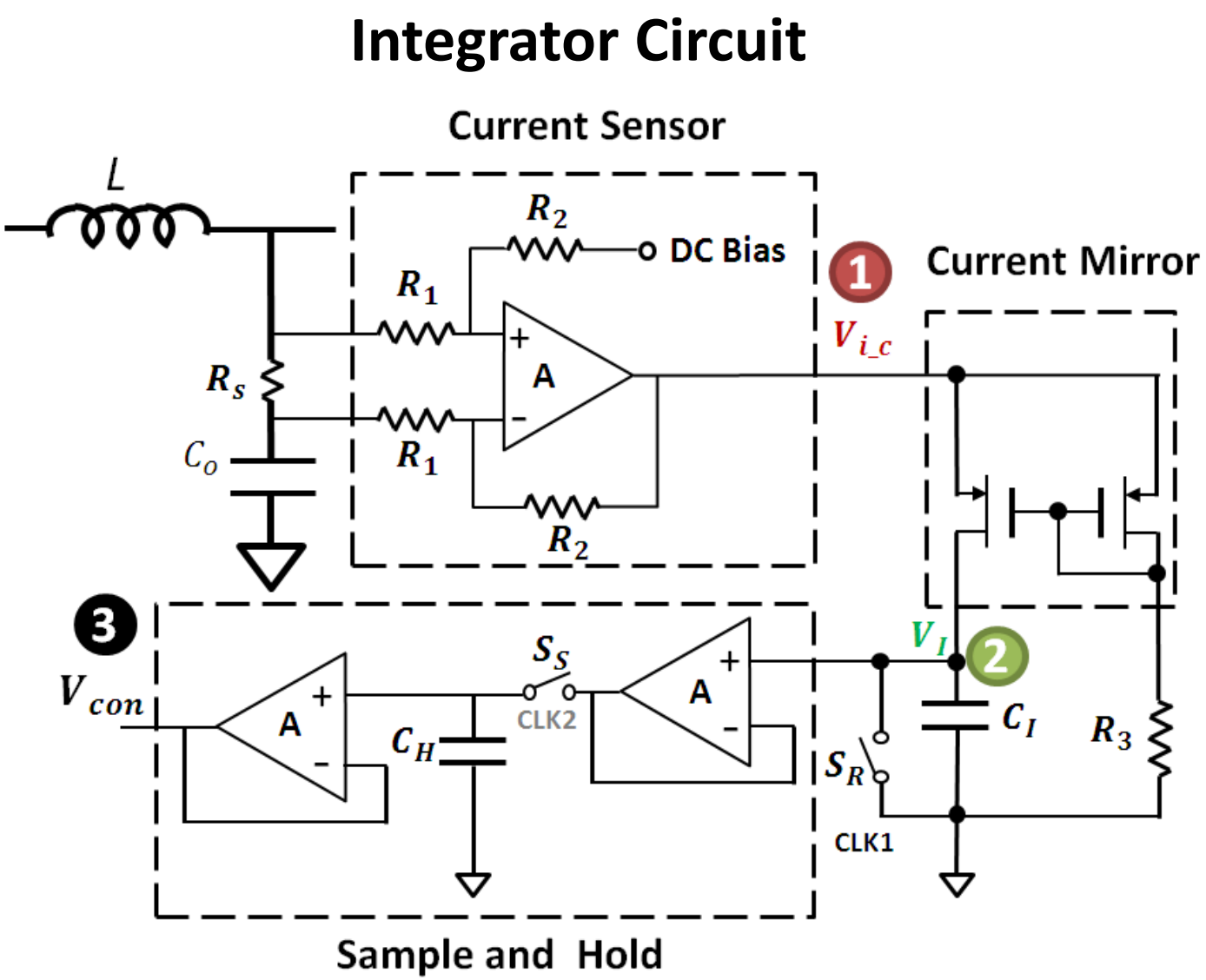
Approximate Balance

$$\int_0^{T_s} (I_{C1} + I_{C2})\, dt \approx 0$$

System Block Diagram

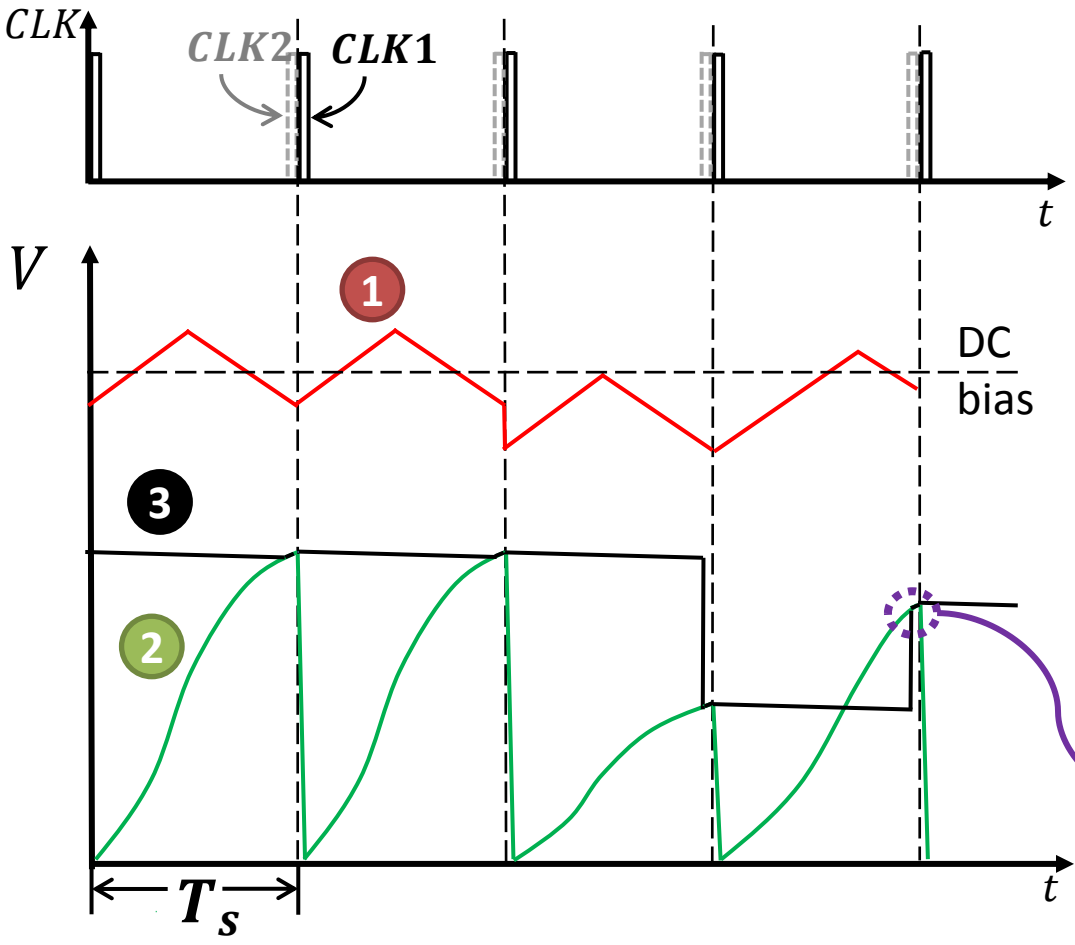


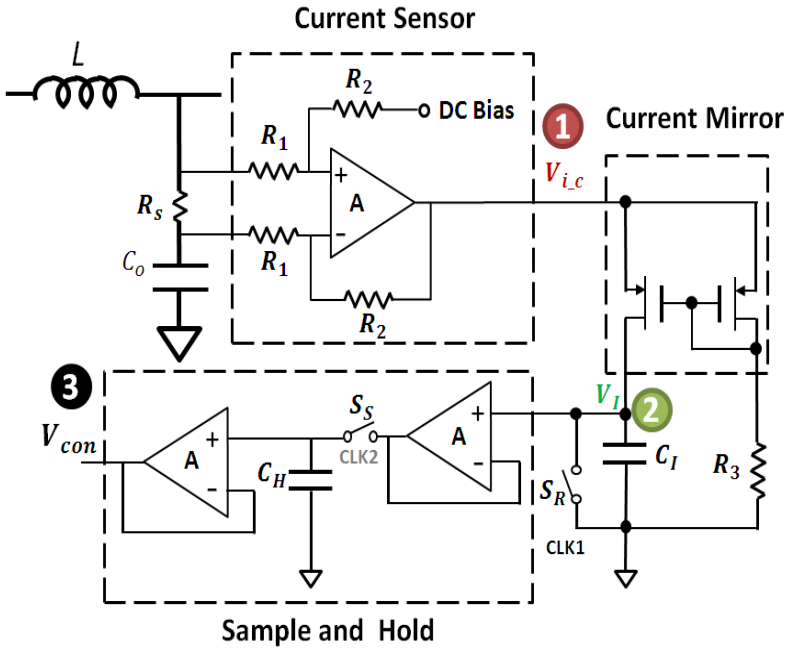
Integrate the current of output capacitor (1)



Integrate the current of output capacitor (2)

Integrator Timing Chart

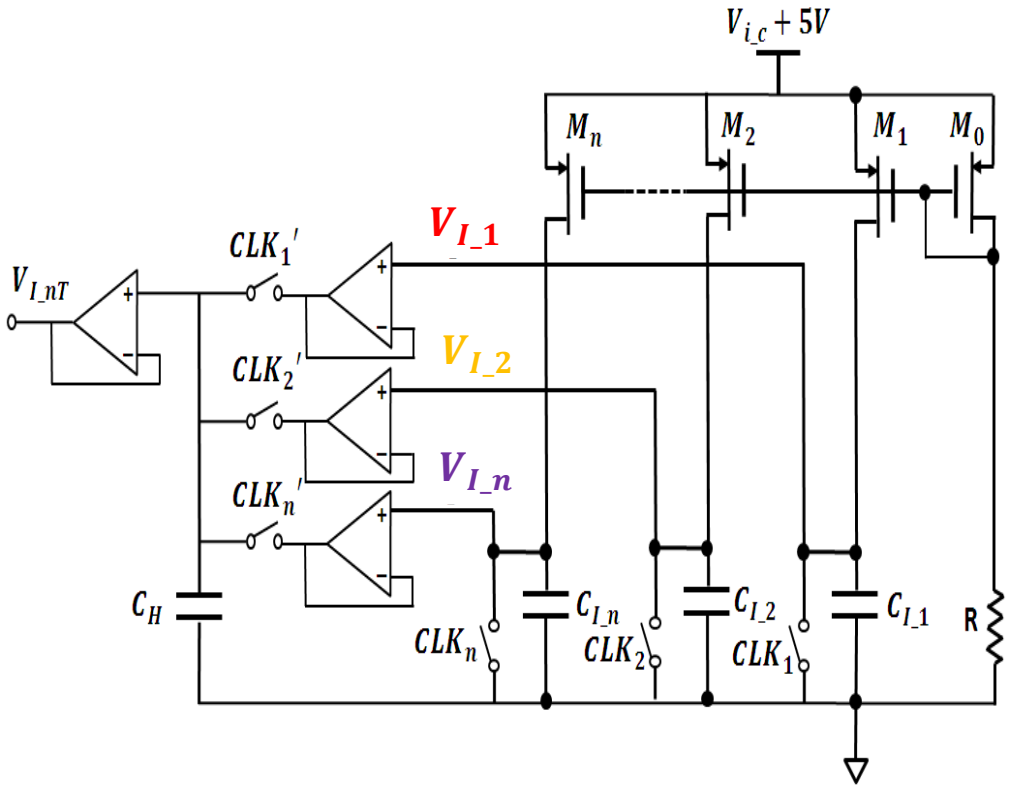




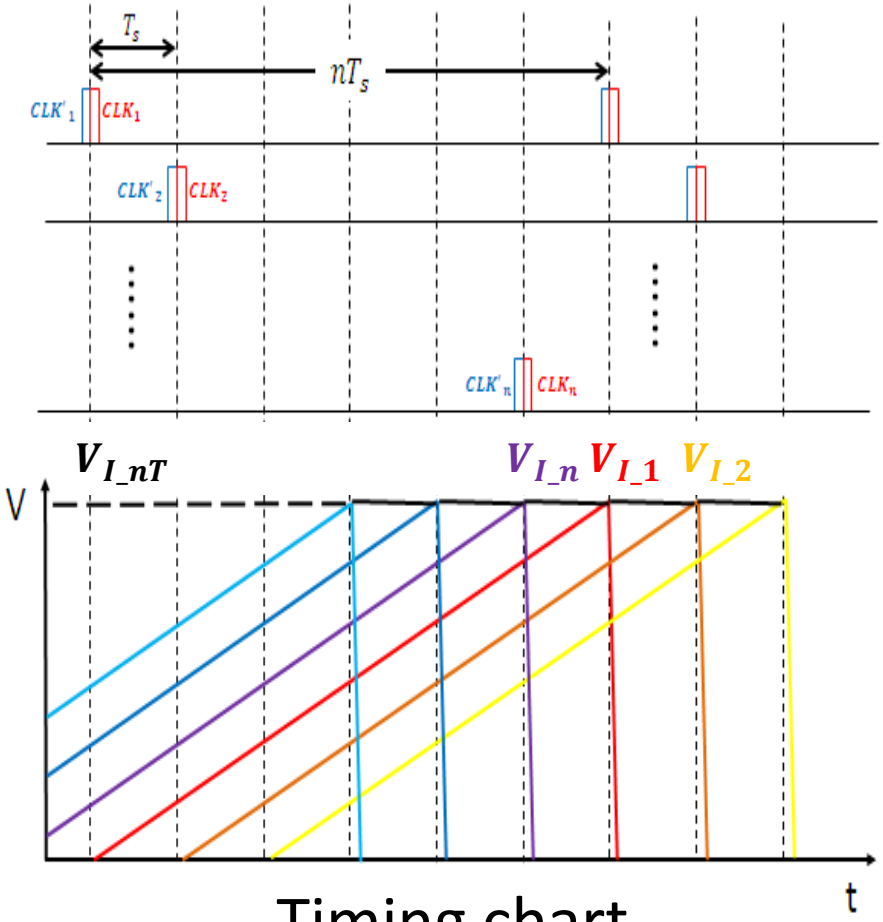
$$V_{I\_peak} = \frac{1}{R_3 C_I} \int_0^{T_s} V_{i\_c}(t)dt$$

Control Variable Compensation (1)

N-period integrator

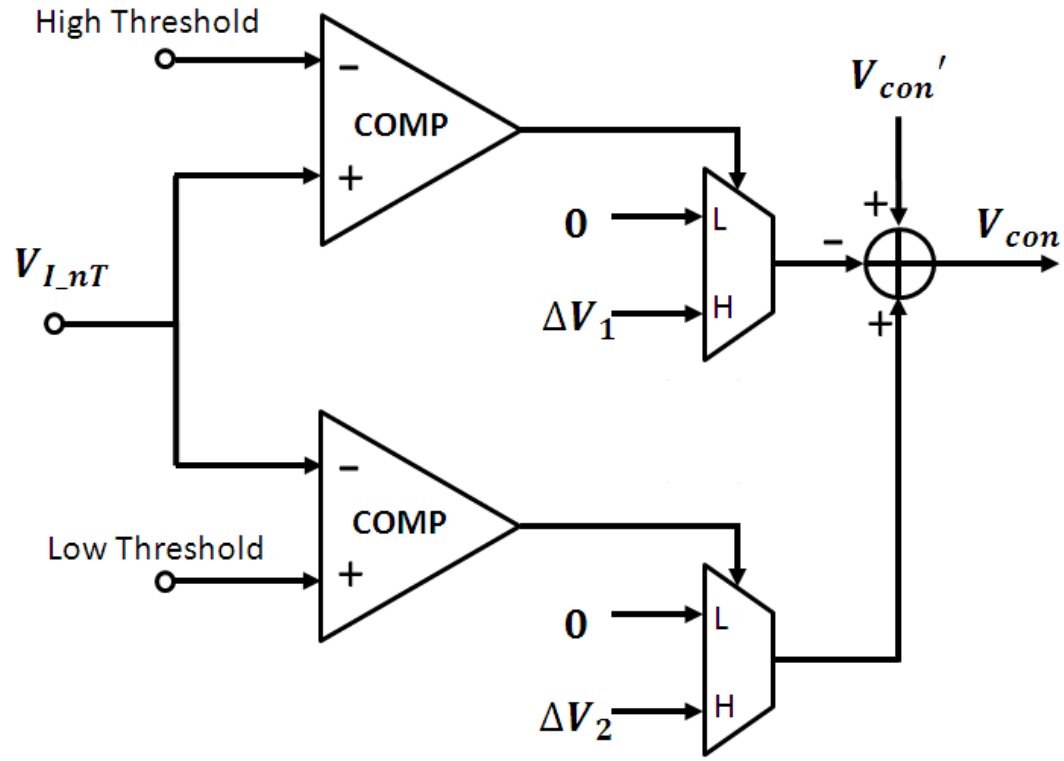


N-period integrator



Timing chart

Control Variable Compensation (2)

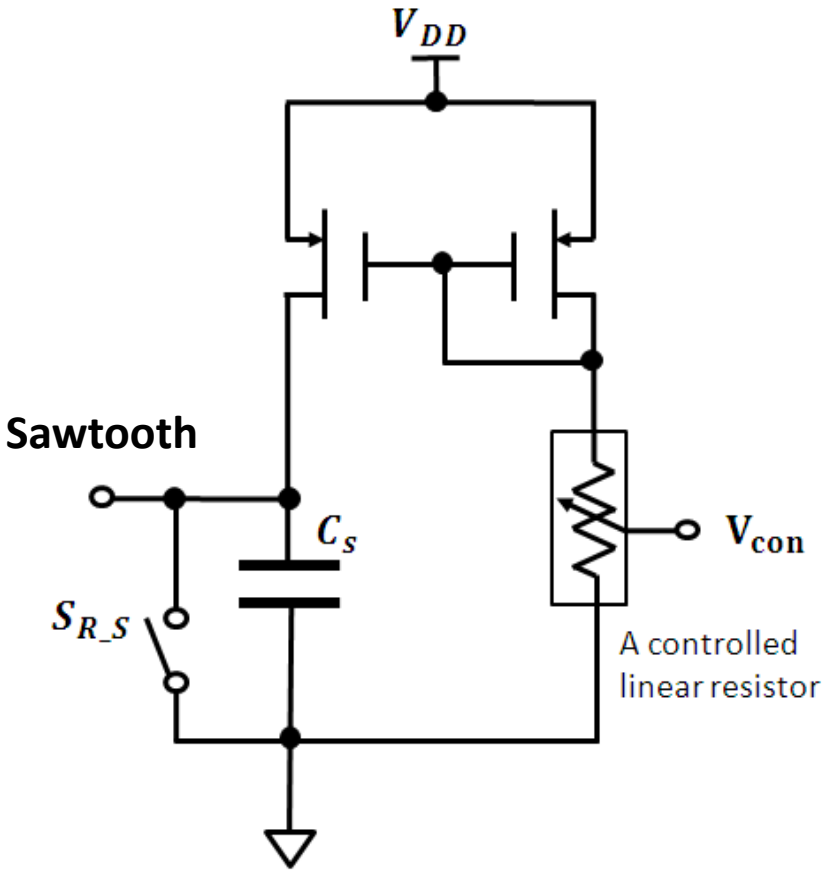


V_{I_nT} ---output of N-period integrator

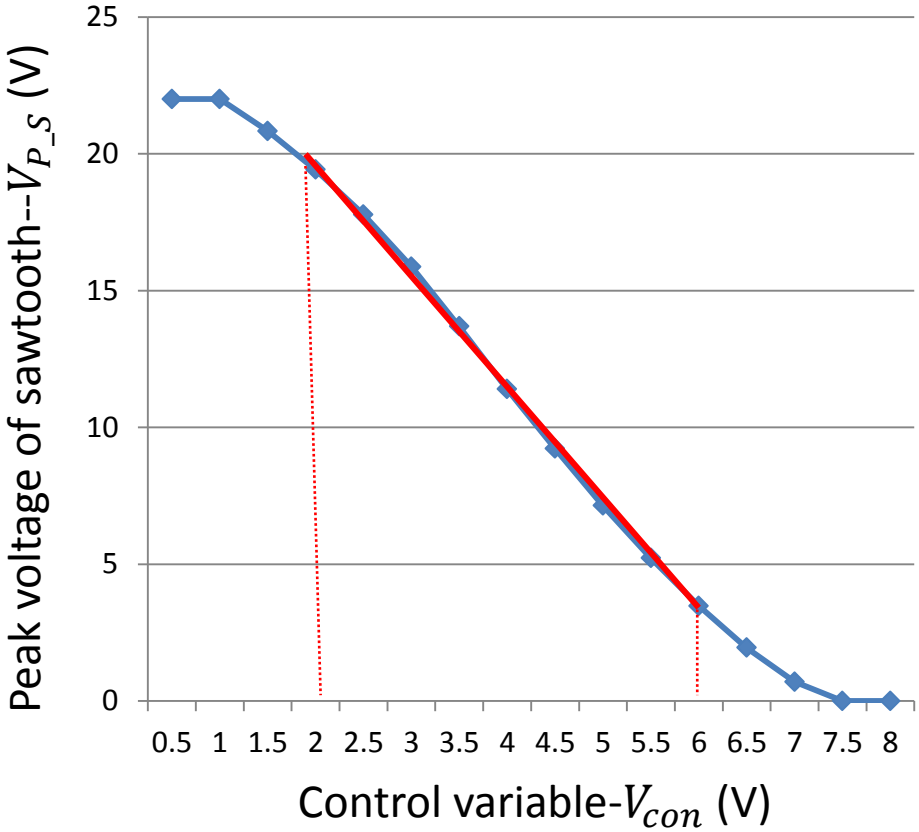
$V_{con}{}'$ ---single period integration control variable

ΔV ---constant compensation

Saw-tooth Generator



Sawtooth Generator



Outline

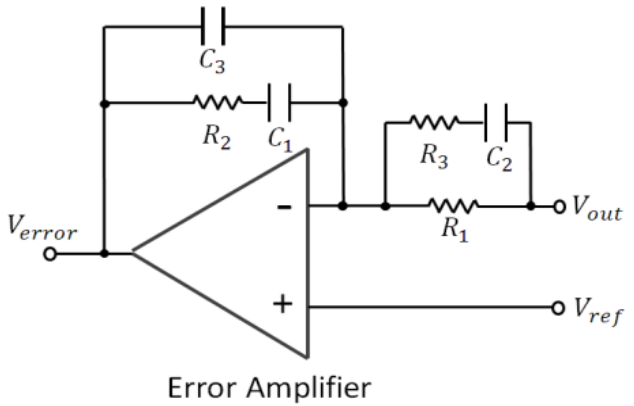
- Research Objective
- Proposed Feed-forward Control Method
  - Capacitor Charge Balance
  - Proposed Feed-forward Controller
- Simulation Results
  - SISO Buck Converter Simulation
  - SIDO Buck Converter Simulation
- Conclusion

Parameters and Phase Compensation

Converter Parameters

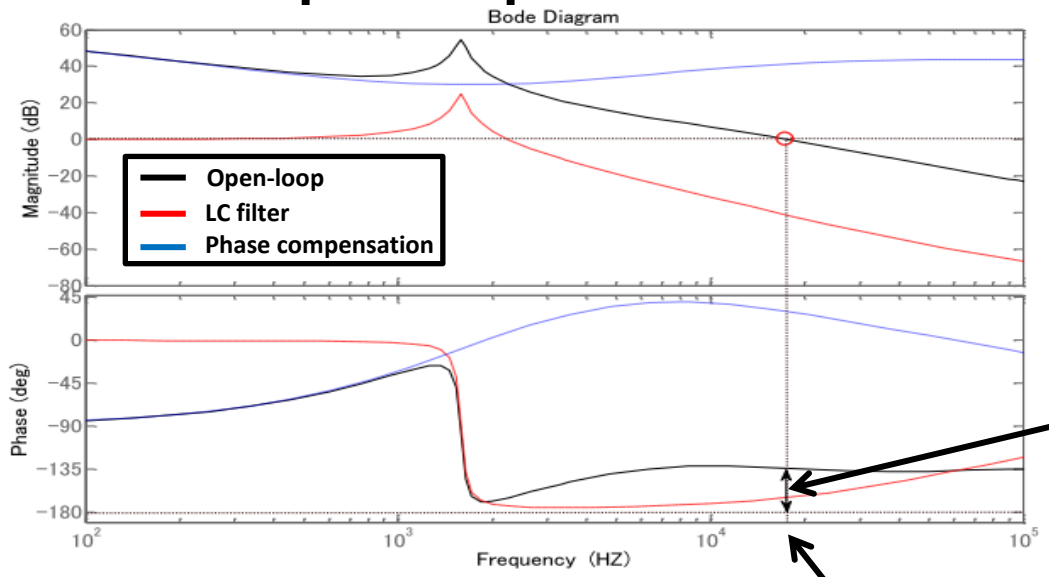
V_{in}	Input voltage	12V	
V_{out}	Output voltage	SISO	SIDO
		6V	6V, 4V
L	Inductor	20μH	
C	Output capacitor	500μF	
ESR	Equivalent Series Resistance	5mΩ	
f_{switch}	Switching frequency	500kHz	

Phase Compensation



Error Amplifier

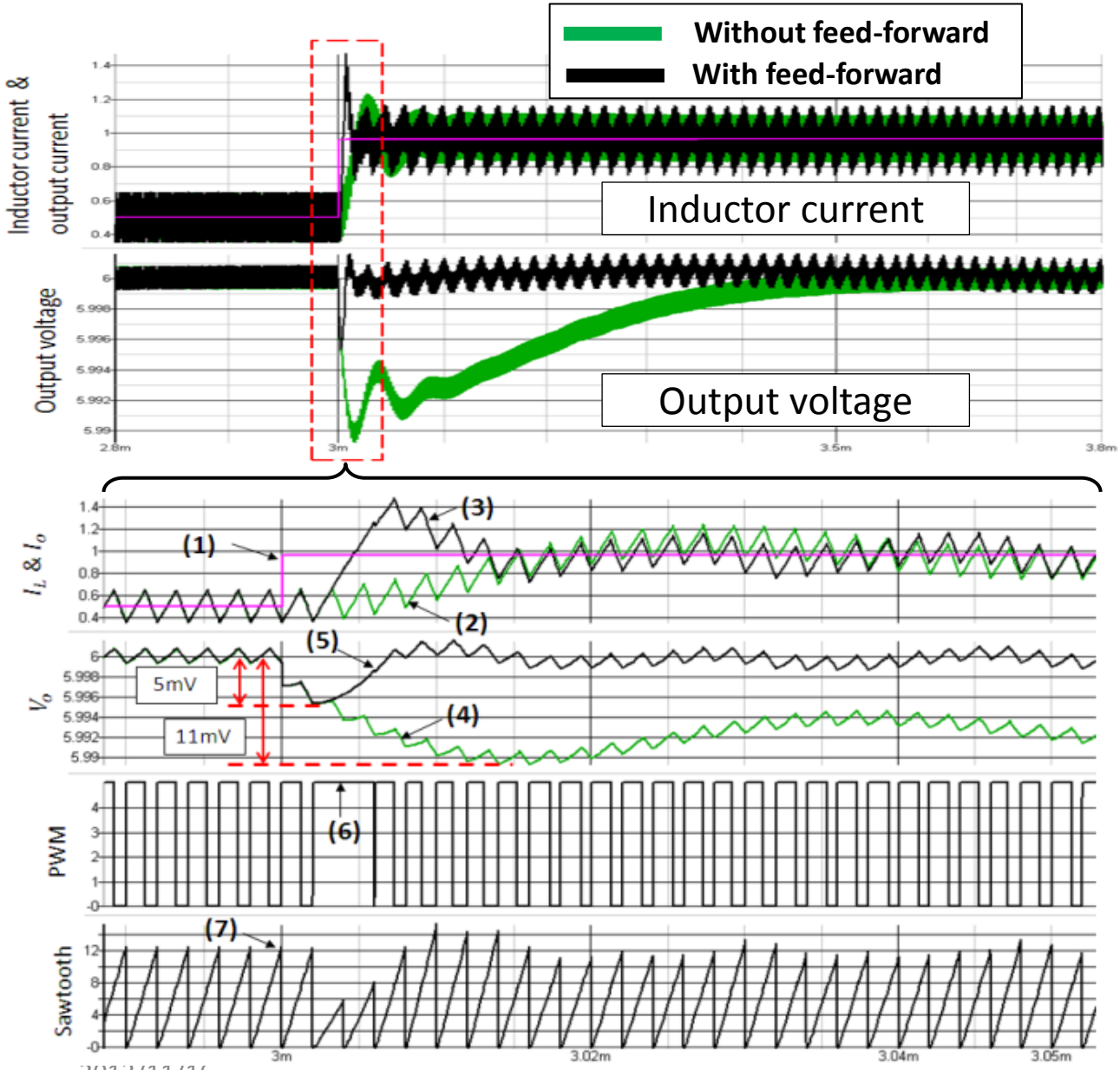
Open-loop Bode Plot



Phase Margin≈ 45°

$f_{cross} = 20KHz$

SISO buck converter(1)



$I_o: 0.5A \rightarrow 1A$

Output under-shoot:

Decrease

11mV→5mV

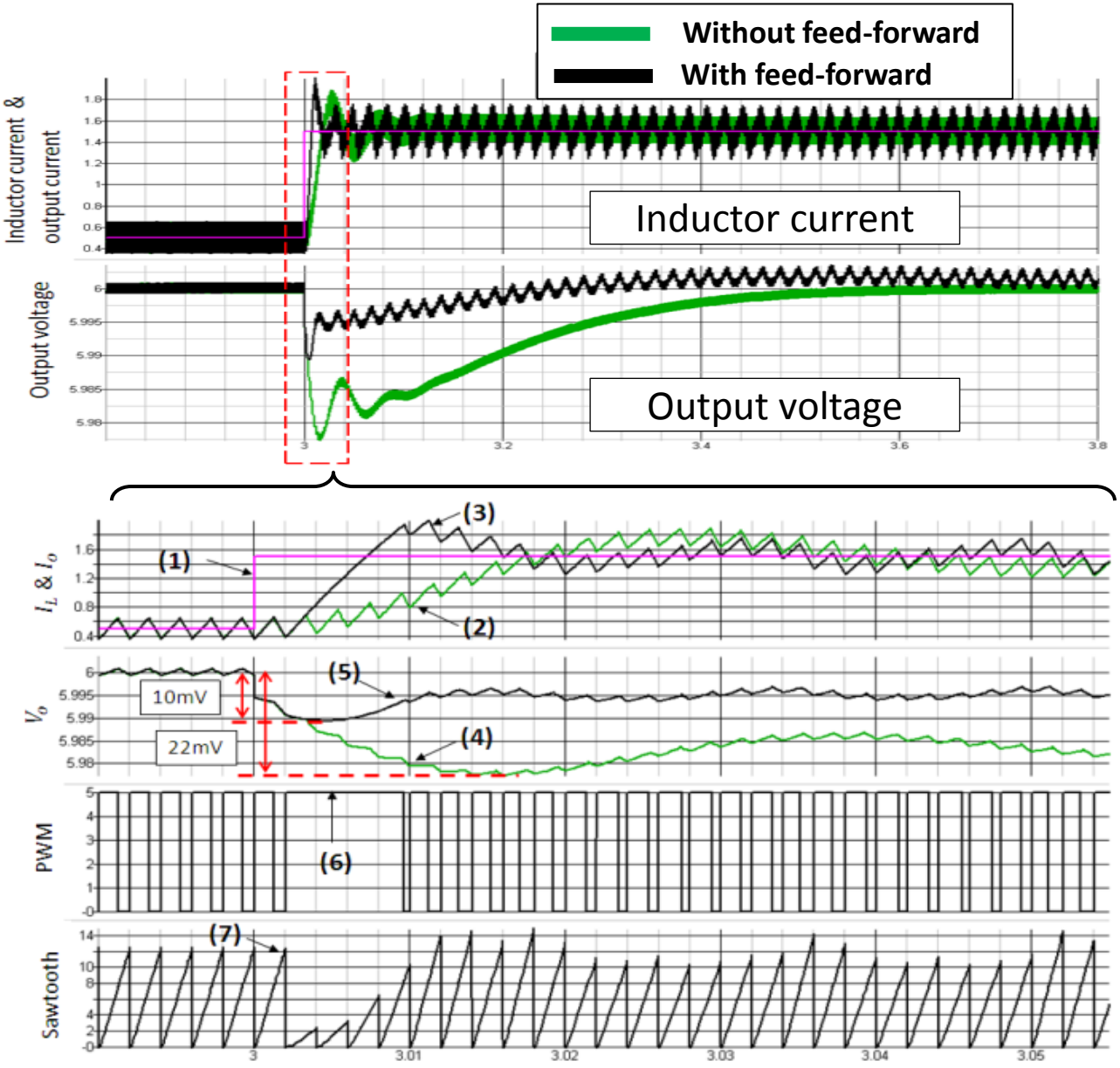
Response time:

Decrease

500μ s→8 μ s

(1) load current
(2) inductor current (FB)
(3) inductor current FF
(4) output voltage (FB)
(5) output voltage
(6) PWM signal
(7) saw-tooth signal

SISO buck converter(2)

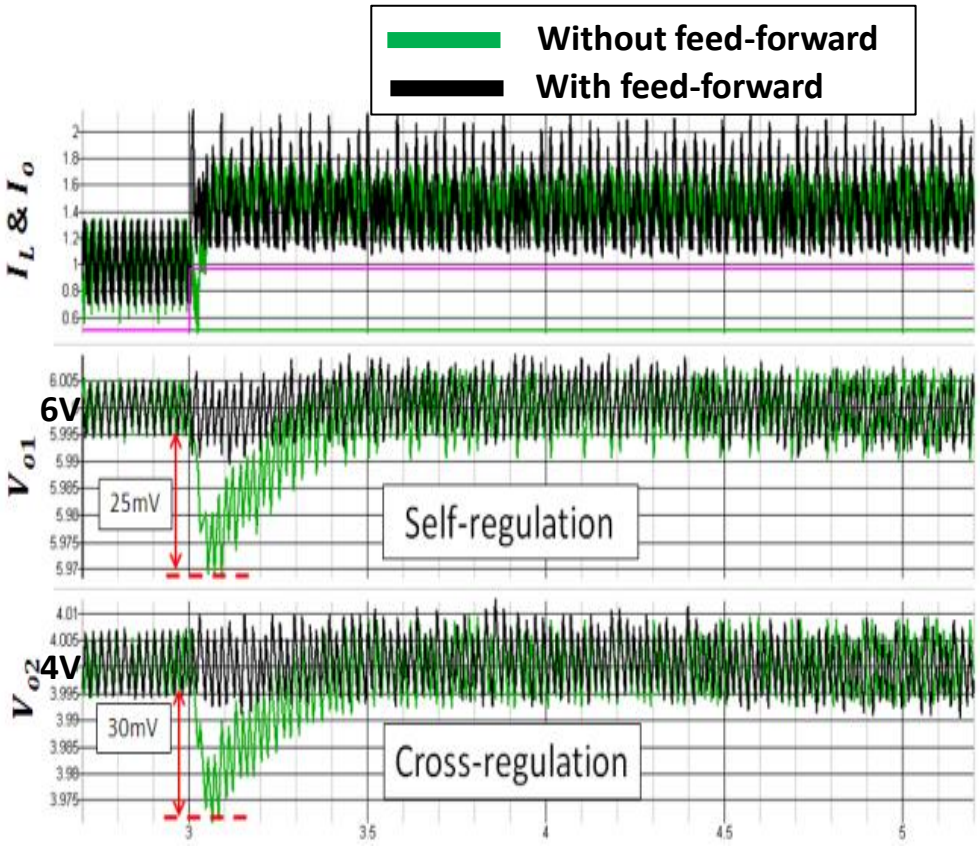


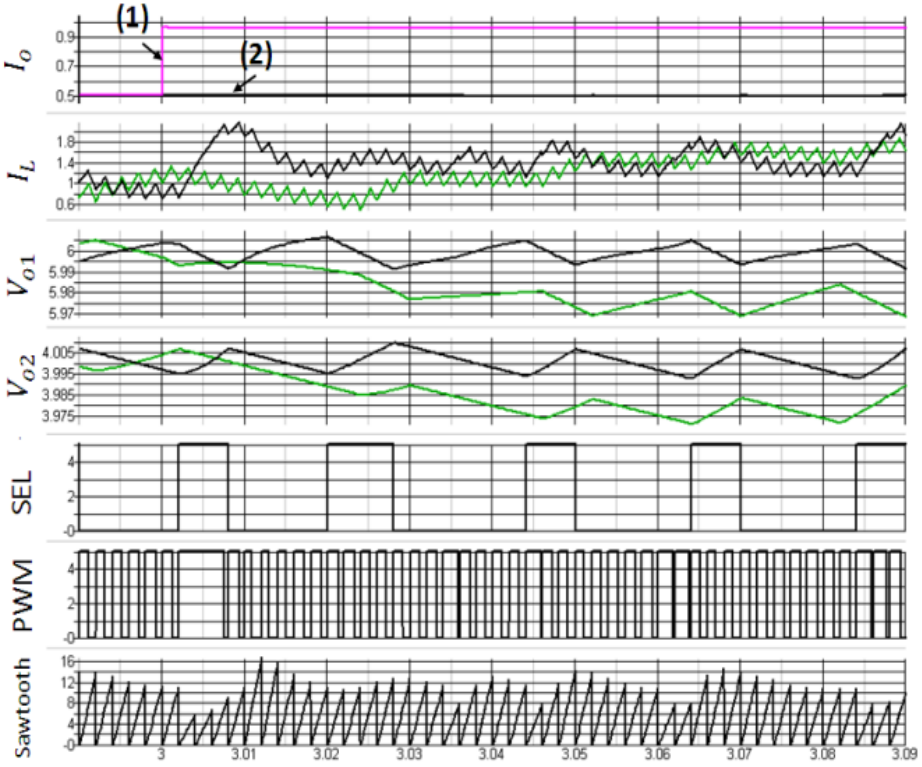
$I_o: 0.5A \rightarrow 1.5A$

(1) load current
(2) inductor current (FB)
(3) inductor current FF
(4) output voltage (FB)
(5) output voltage
(6) PWM signal
(7) saw-tooth signal

SIDO buck converter(1)

$I_{o1}: 0.5A \rightarrow 0.96A,$ $I_{o2}: 0.5A$



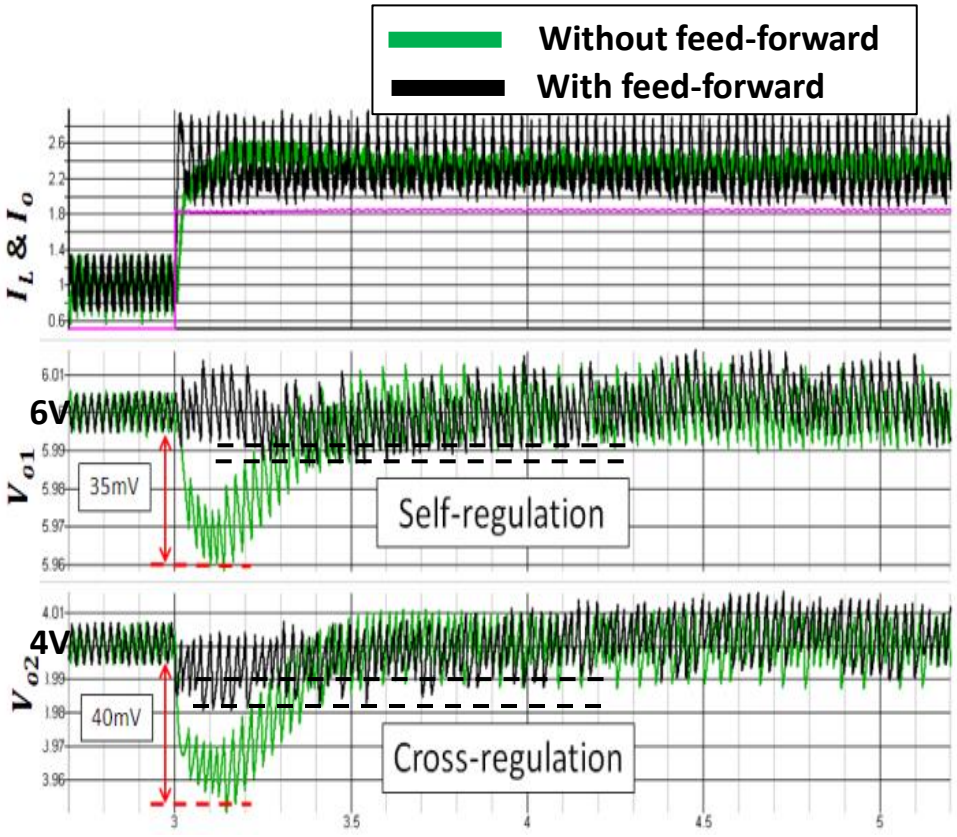


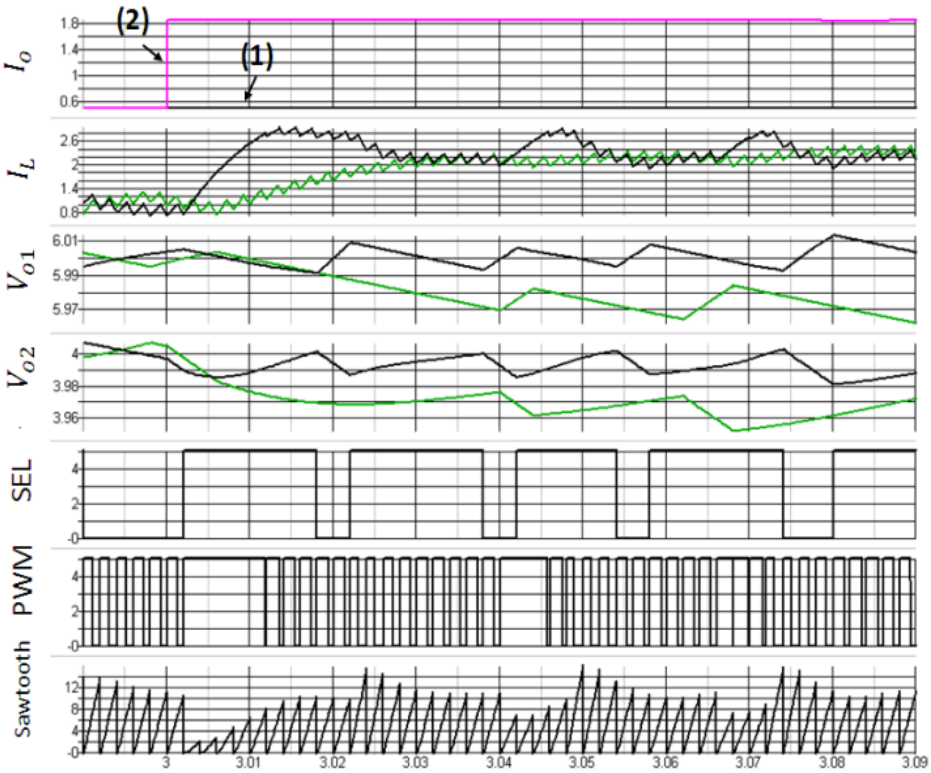
Feed-forward	With	Without
Self-regulation	--	25mV
Cross-regulation	--	30mV

(1) load current of sub-converter1
(2) load current of sub-converter2

SIDO buck converter(2)

$I_{o1}: 0.5A, \qquad I_{o2}: 0.5A \rightarrow 1.85A$





Feed-forward	With	Without
Self-regulation	5mV	35mV
Cross-regulation	10mV	40mV

(1) load current of sub-converter1
(2) load current of sub-converter2

Outline

- Research Objective
- Proposed Feed-forward Control Method
  - Capacitor Charge Balance
  - Proposed Feed-forward Controller
- Simulation Results
  - SISO Buck Converter Simulation
  - SIDO Buck Converter Simulation
- Conclusion

Conclusion

- Proposed new feed-forward controller

  Simple:

  Only output capacitor current is detected

  Digital nonlinear calculation not required

  ↓

  Applicable to SIDO converter

  Cost-effective

Available:

Transient response is Significantly improved

↓

Cross-regulation of SIDO converter is improved

The End

Thanks for your attention

Presented by 吳澍（Wu Shu）

Q&A


ĐẢNG CỘNG SẢN VIỆT NAM QUAN
SỐNG, CHIẾN ĐẤU, LAO ĐỘNG VÀ HỌC TẬP THEO GƯƠNG CHỦ TỊCH HỒ CHÍ MINH VĨ ĐẠI
The 4th International
Integrated Circuits, Desig
(ICDV 201
Ho Chi Minh city, Novemb
Organized by
SISO buck converter(1)
Output under-shoot:
Decrease
11mV->5mV
Response time:
Decrease
ĐOÀN KẾT, THỐNG NHẤT, TẬP TRUNG TRÍ TUỆ QUYẾT TÂM THỰC HIỆN THẮNG CÔNG NGHỊ QUYẾT ĐẠI HỘI V ĐẢNG BỘ TRƯỜNG ĐH KHTN

Question and Answer 1

- The simulation result in page 21 and 22, there is oscillation in output voltage after transient response. Is it a right result?

- No, it is not a good result. This oscillation is caused by qualitatively multi-period integration compensation. But feed-forward require accurate control variable modulation. This problem will be improved in further.

Question and Answer 2

- Normally when we talk about the voltage control mode and the current control mode of switching power supplies, they belong to feedback control scheme. What is the different between your proposed method and current control mode?

- Current control mode is feedback control. Inductor current is detected and compared with error signal. By this comparison, duty cycle is regulated.
  While our proposed method use capacitor current to regulate sawtooth signal. When transient response happen, we don’t need wait until error signal is changed, then regulate duty cycle.