Gunma University
Analog Circuit
Takai Laboratory

Single Inductor DC-DC Converter with Bipolar Outputs using Charge Pump

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Outline

①Introduction

②SIMO DC-DC Converter

③Simulation Results

④Conclusion

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Introduction

Industry Demands

High Efficiency and Extremely Small System Solution

Conventional Power Supply Circuits

Linear Regulator	Efficiency 30～60%	Circuit Size：Small
Switching Regulator	Efficiency 70～90%	Circuit Size：Large

Optimize Efficiency

Switching Regulator

Introduction

Switching Regulator

Multi Output Power Supply Circuit

Digital Camera

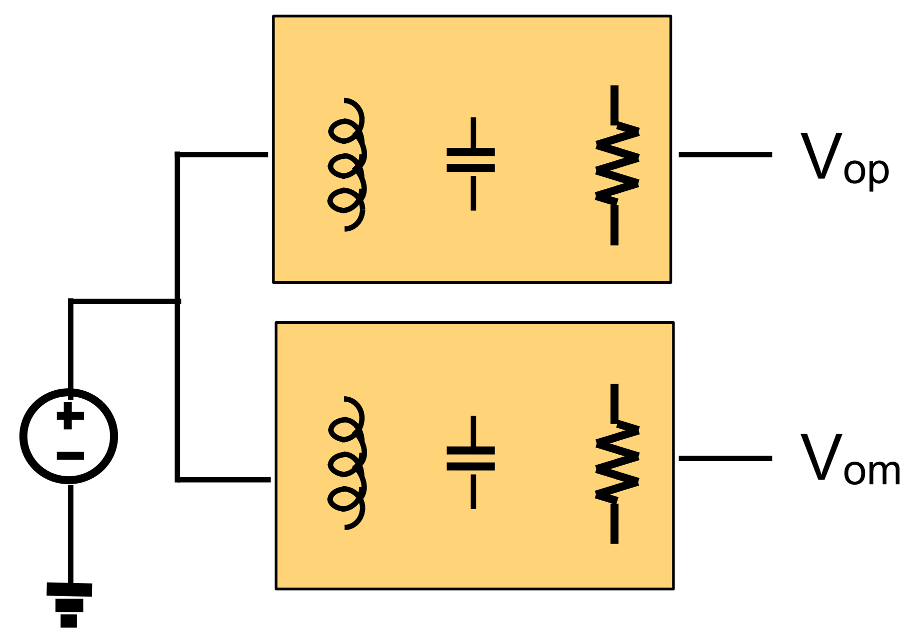
Positive　Voltage：１５V

Negative Voltage：－８V

OLED Display

Positive Voltage：５V

Negative Voltage：－２V



Multi Output Power Supply Circuit

Introduction

Multi Output Power Supply Circuit

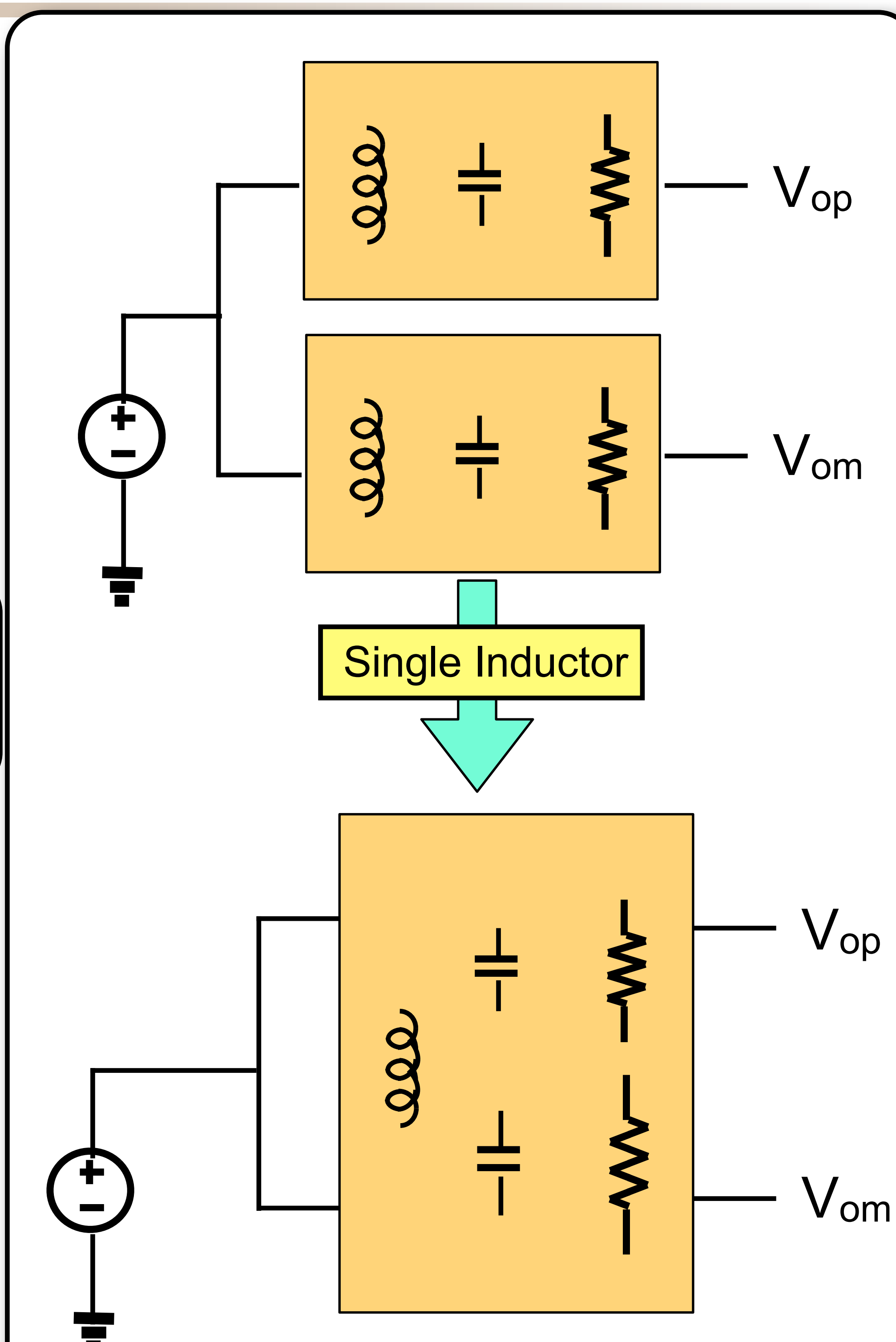
Industry Demands

High Efficiency and Extremely Small System Solution

One Inductor is Removed

SIMO DC-DC Converter

SIMO:single inductor multi output



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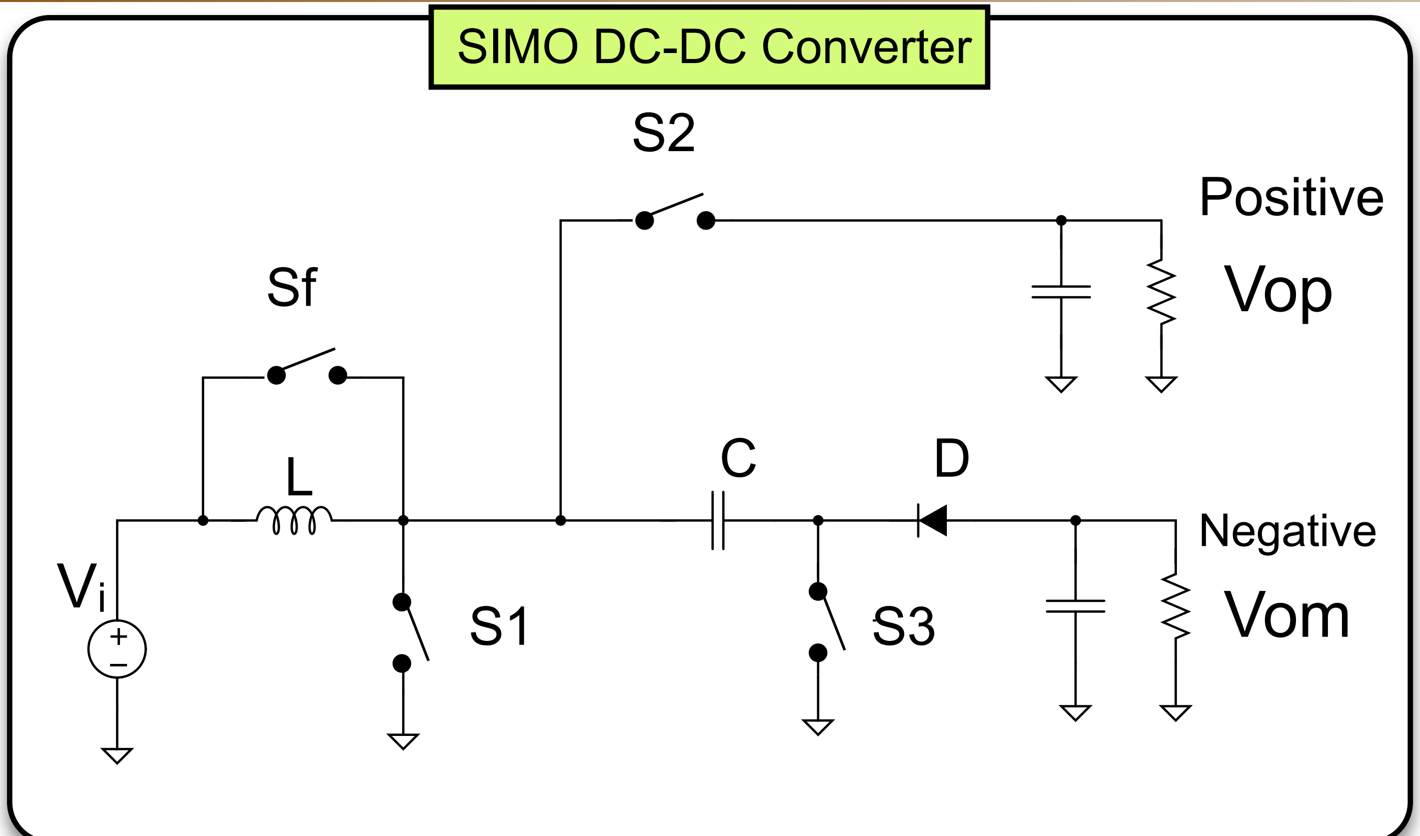
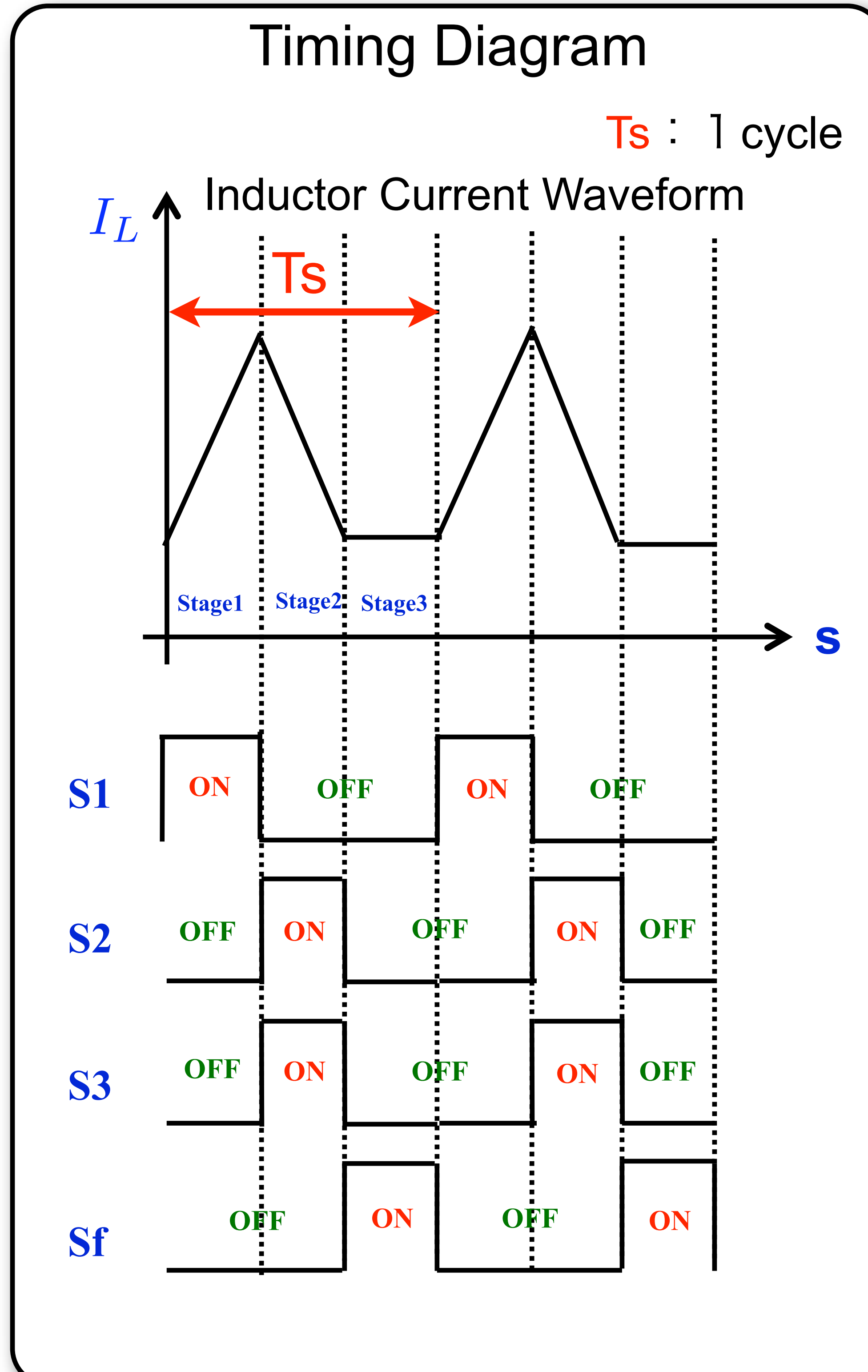
Conventional Circuit



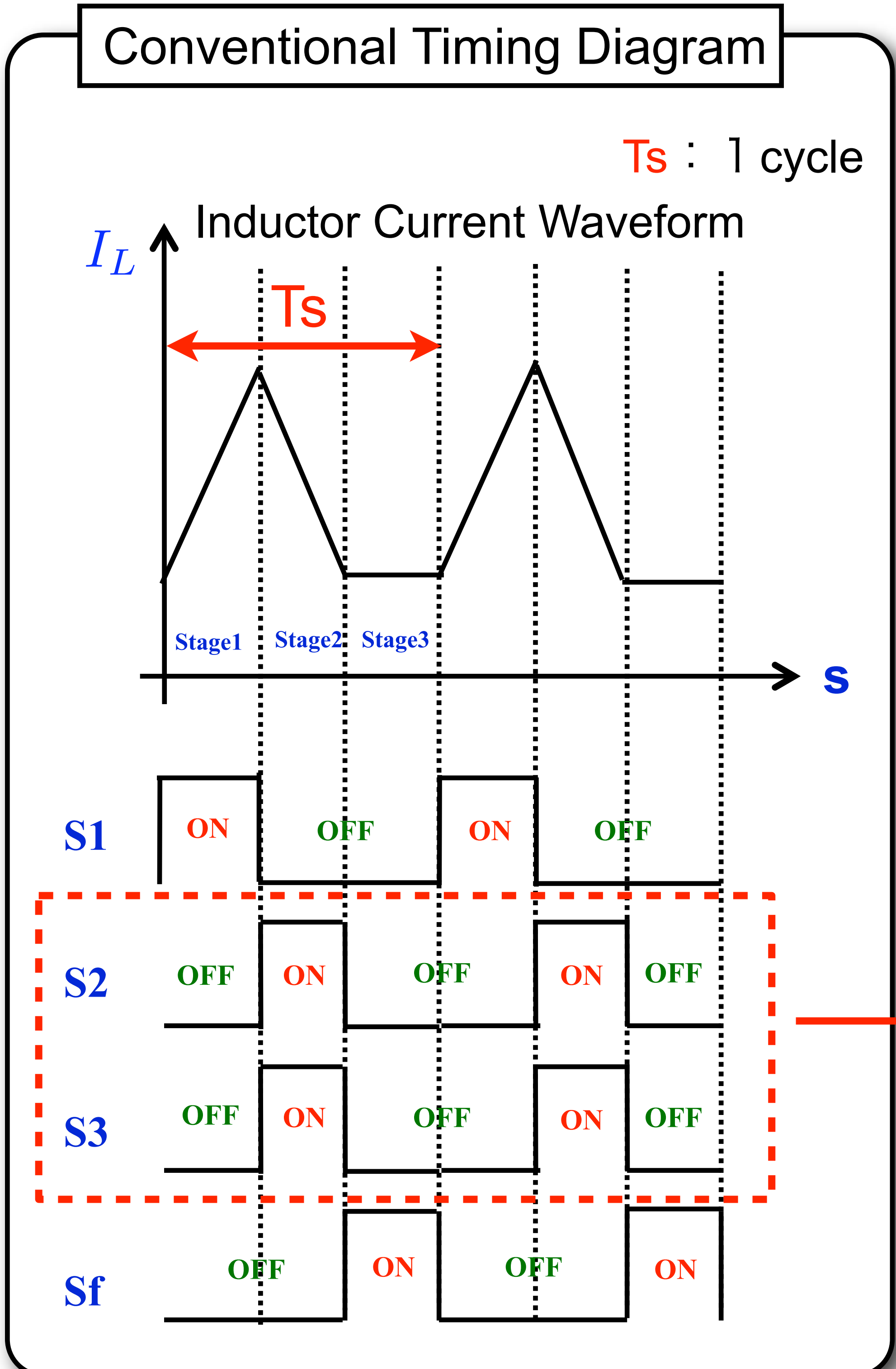


Negative Voltage : $V_{om} = -V_{op} + V_F$

Negative Output Depends on Positive Output

Cause : S2 & S3 are on Simultaneously

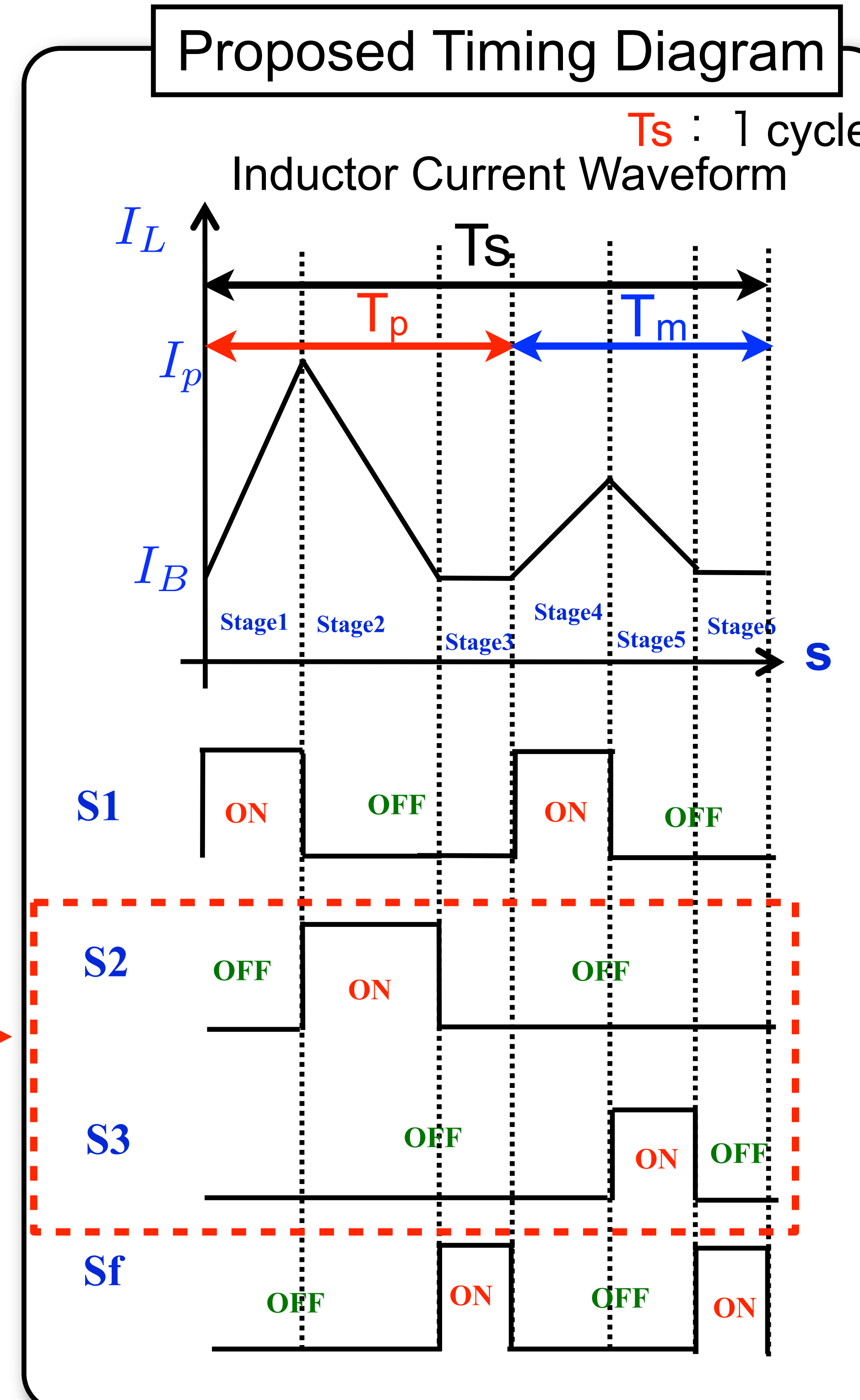
Change of Timing Diagram



Inductor Current is Changed

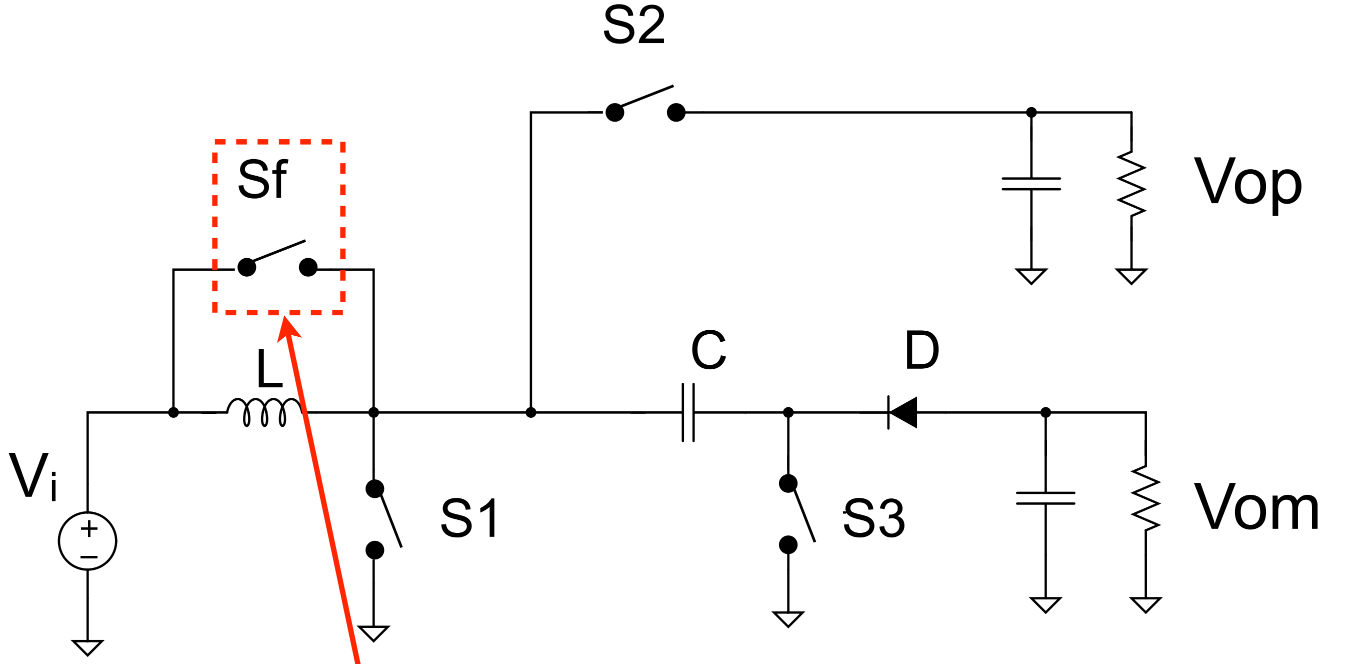
The duty ratio of each switch is fixed

Change!



Change of Timing Diagram

SIMO DC-DC Converter

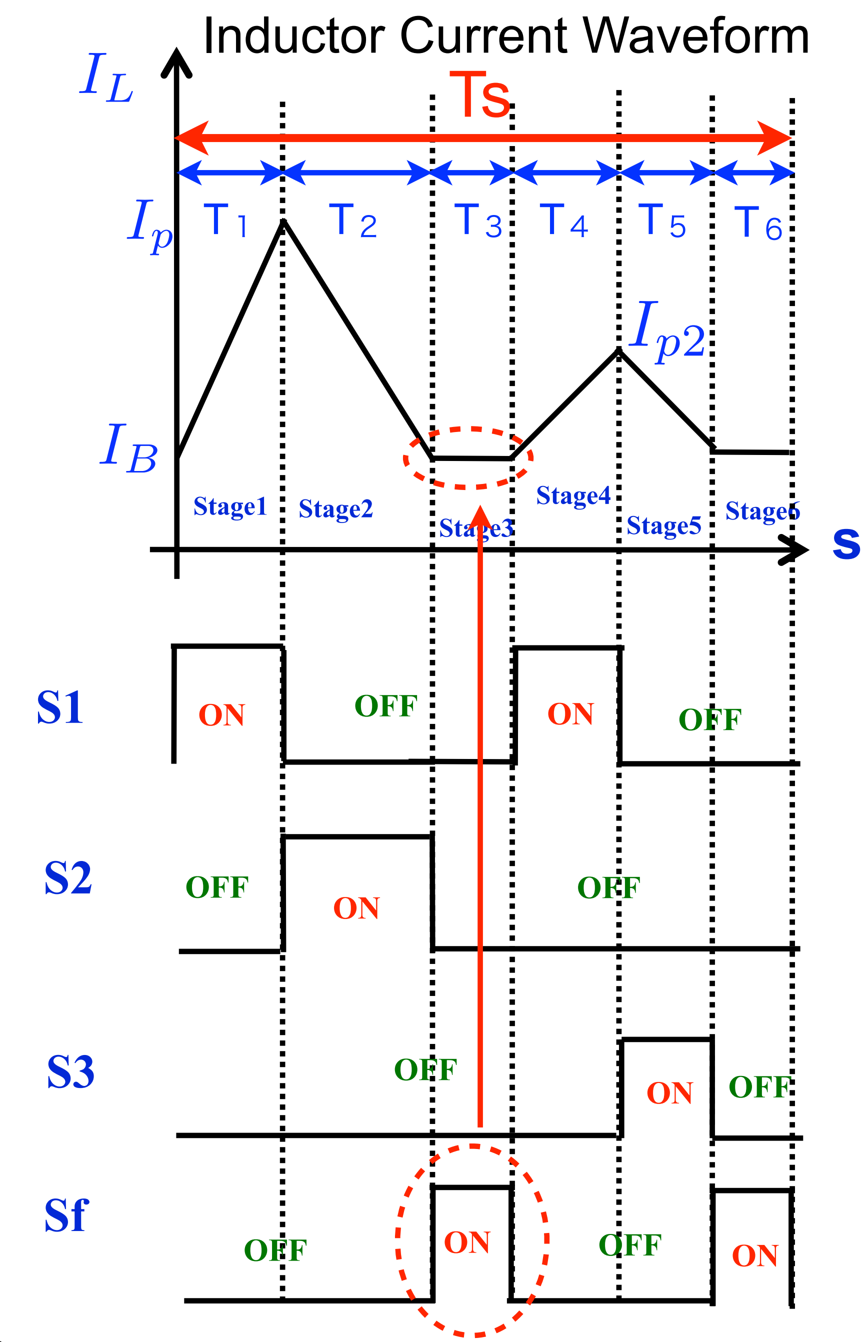


Operation of Switch Sf

Maintains the value of the current in the inductor.

Proposed timing diagram

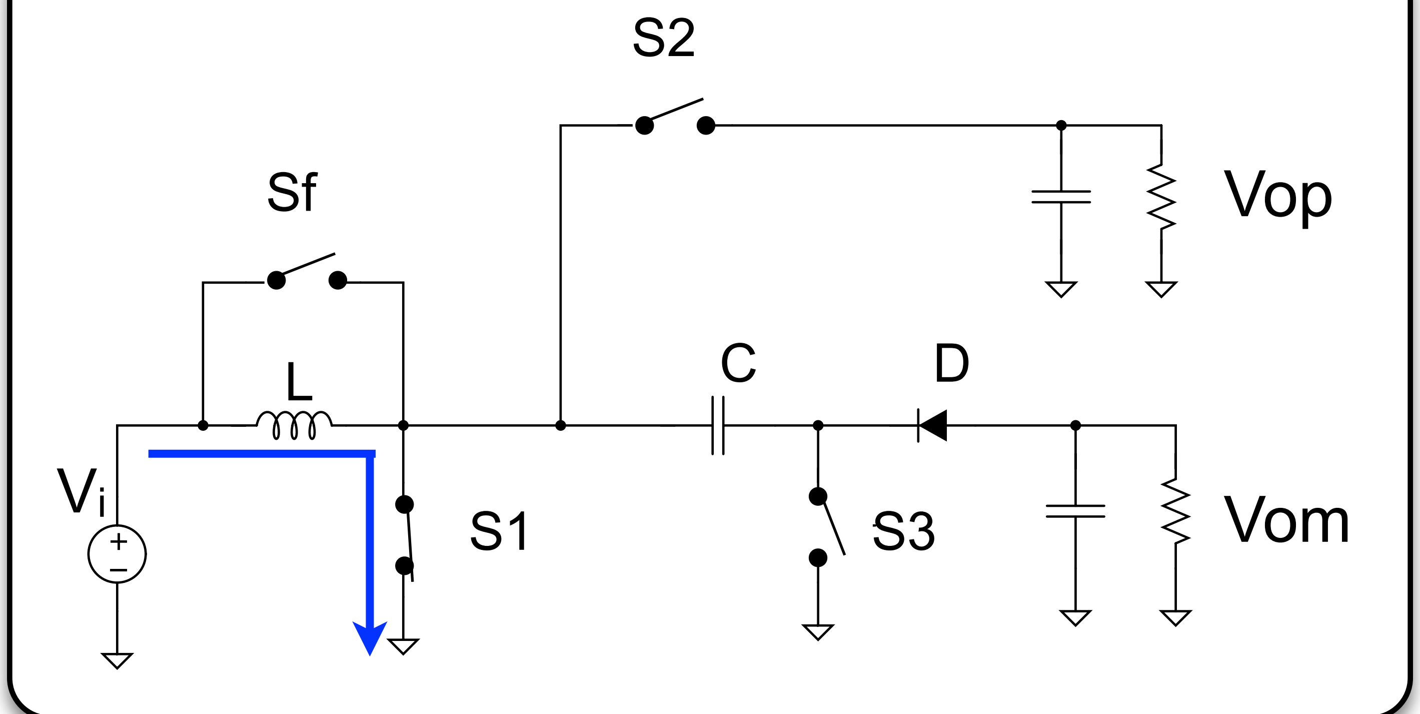
Ts : 1 cycle



2010年12月13日月曜日

Change of Timing Diagram

SIMO DC-DC Converter



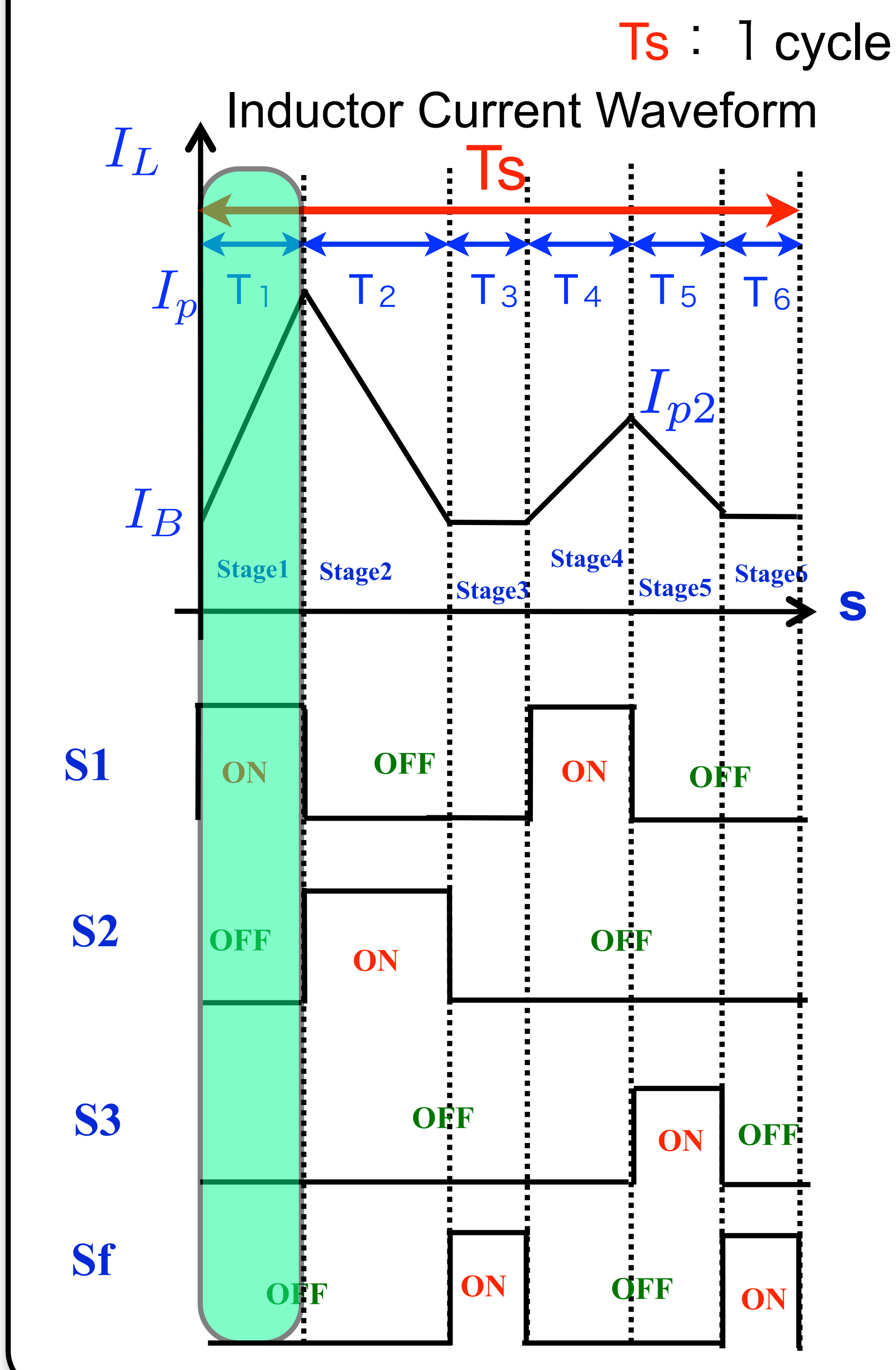
Stage1

S1: Turns on ☞ Inductor L stores energy from voltage V_{in}

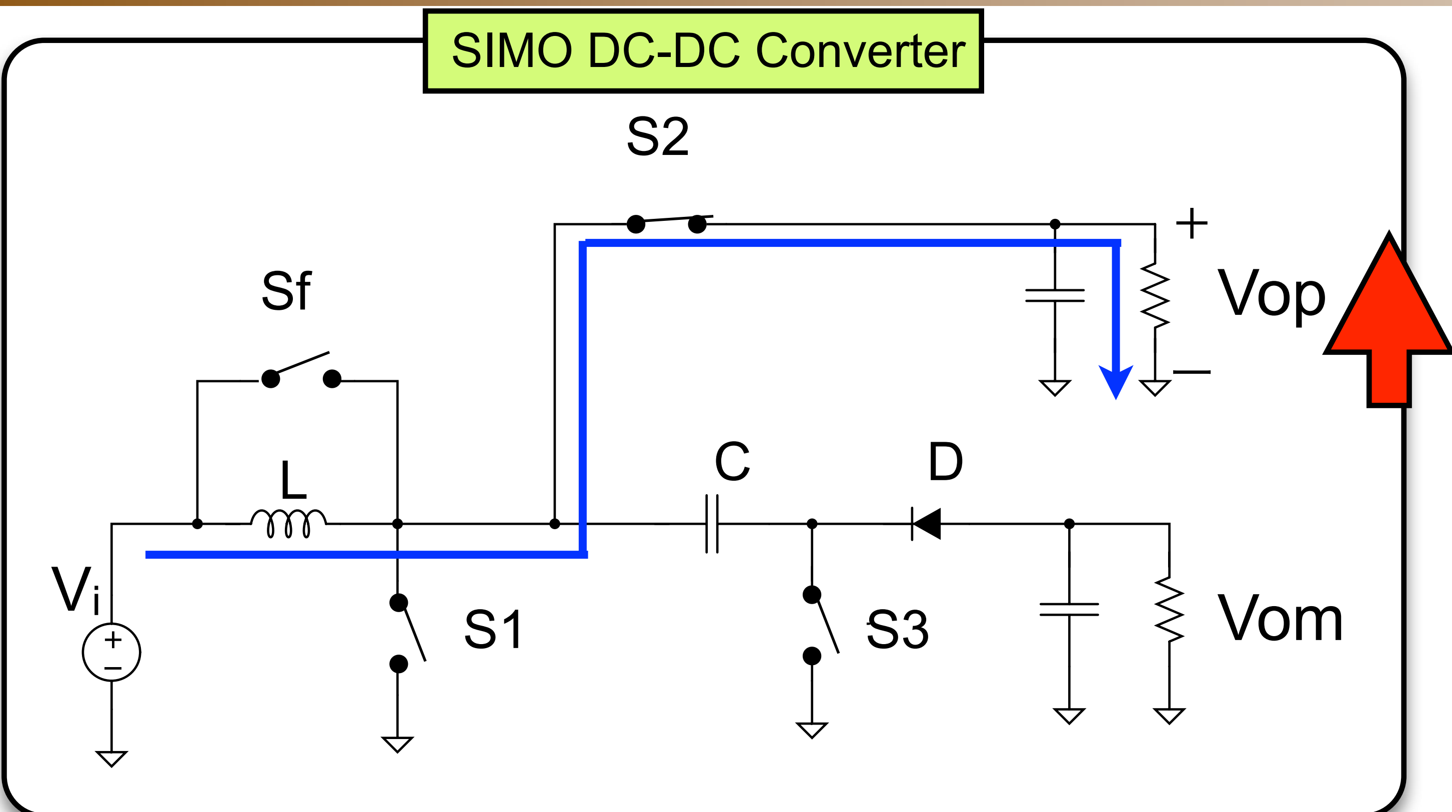
Current that flows to inductor L

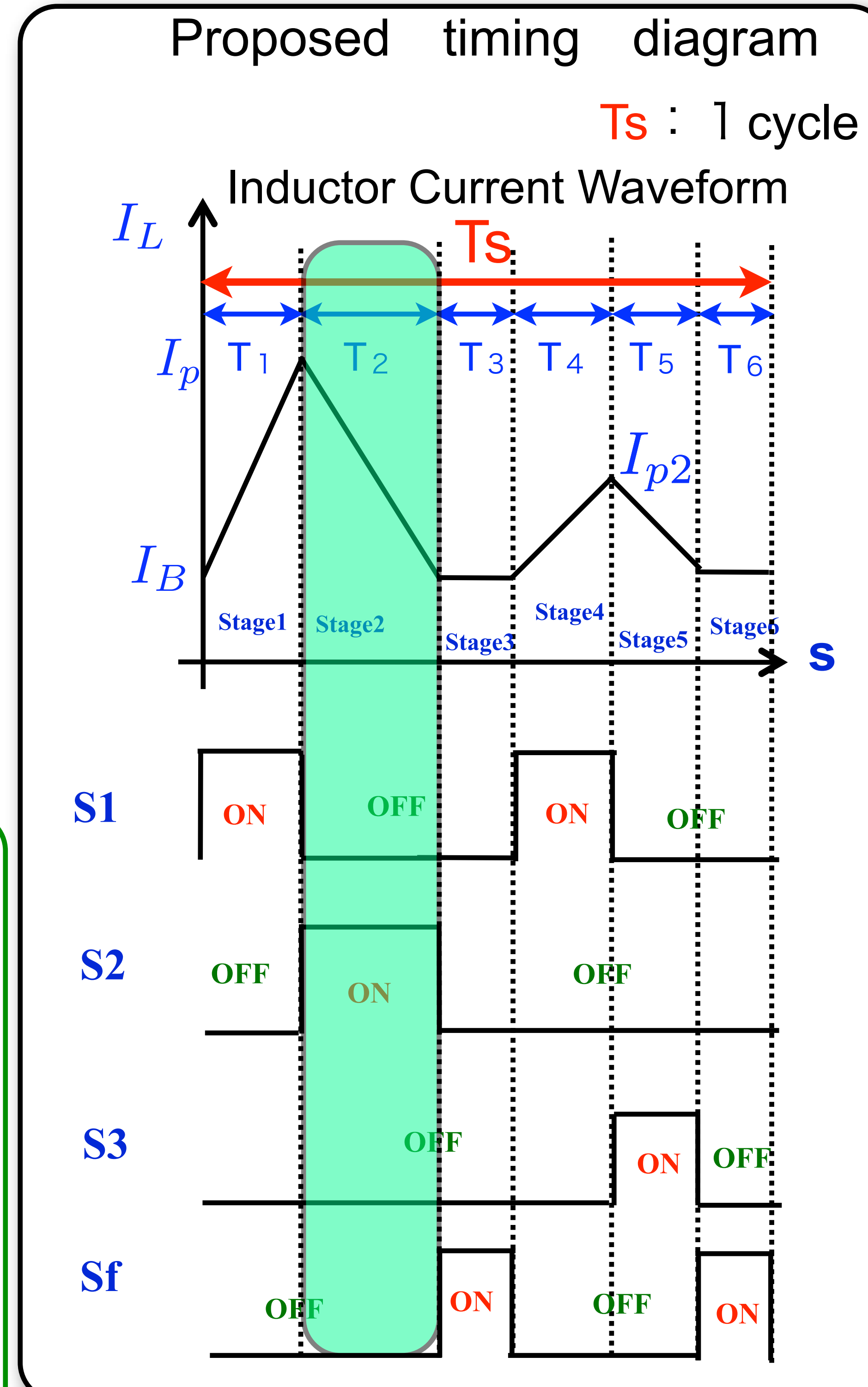
$$I_L = \frac{V_i}{L}t = \frac{I_p - I_B}{T1}t$$

Proposed timing diagram



Change of Timing Diagram





Stage2

S2 : Turn on・・・Inductor L supplies its energy to output terminal of V_{op}

$$I_L = \frac{V_{op} - V_i}{L} t = \frac{I_p - I_B}{T2} t$$

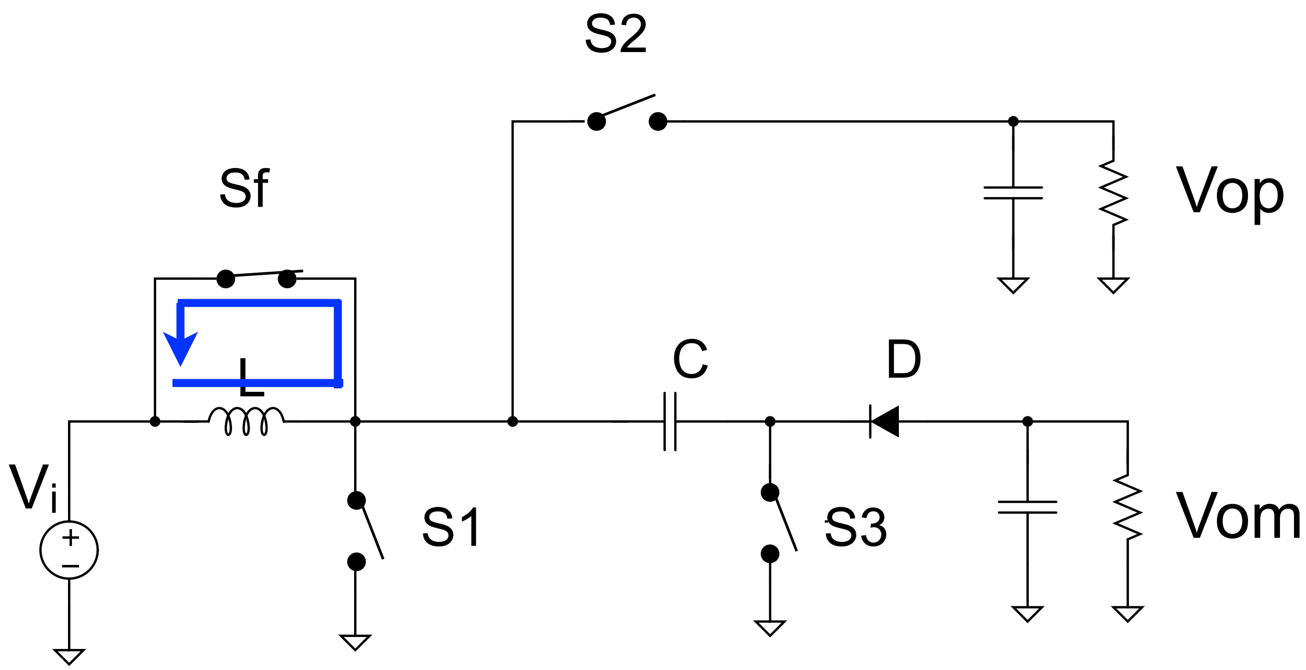
Equation of Stage1

$$I_L = \frac{V_i}{L} t = \frac{I_p - I_B}{T1} t$$

$$V_{op} = \frac{T1 + T2}{T2} V_i$$

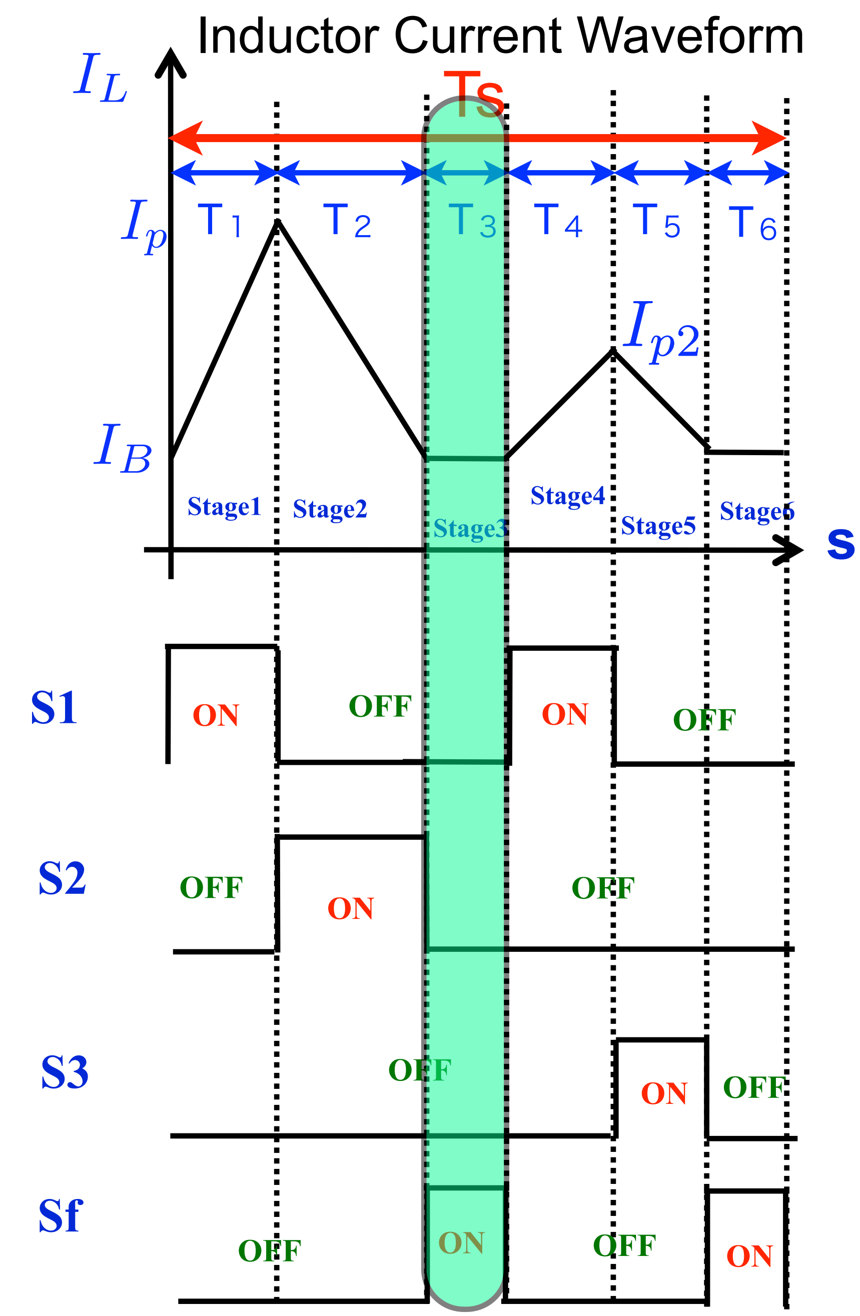
Change of Timing Diagram

SIMO DC-DC Converter



Proposed timing diagram

Ts : 1 cycle

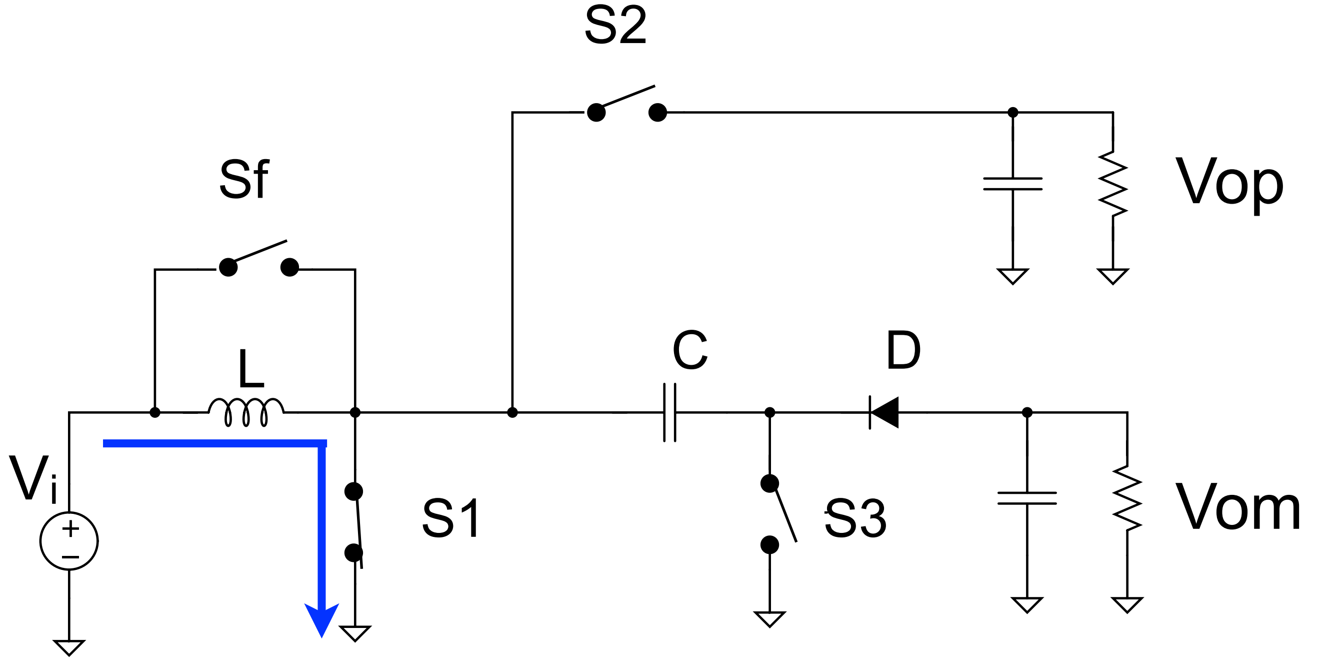


Stage3

Sf : Turn on ・・・ The current of the inductor is maintained with the free wheel switch

Change of Timing Diagram

SIMO DC-DC Converter



Stage4

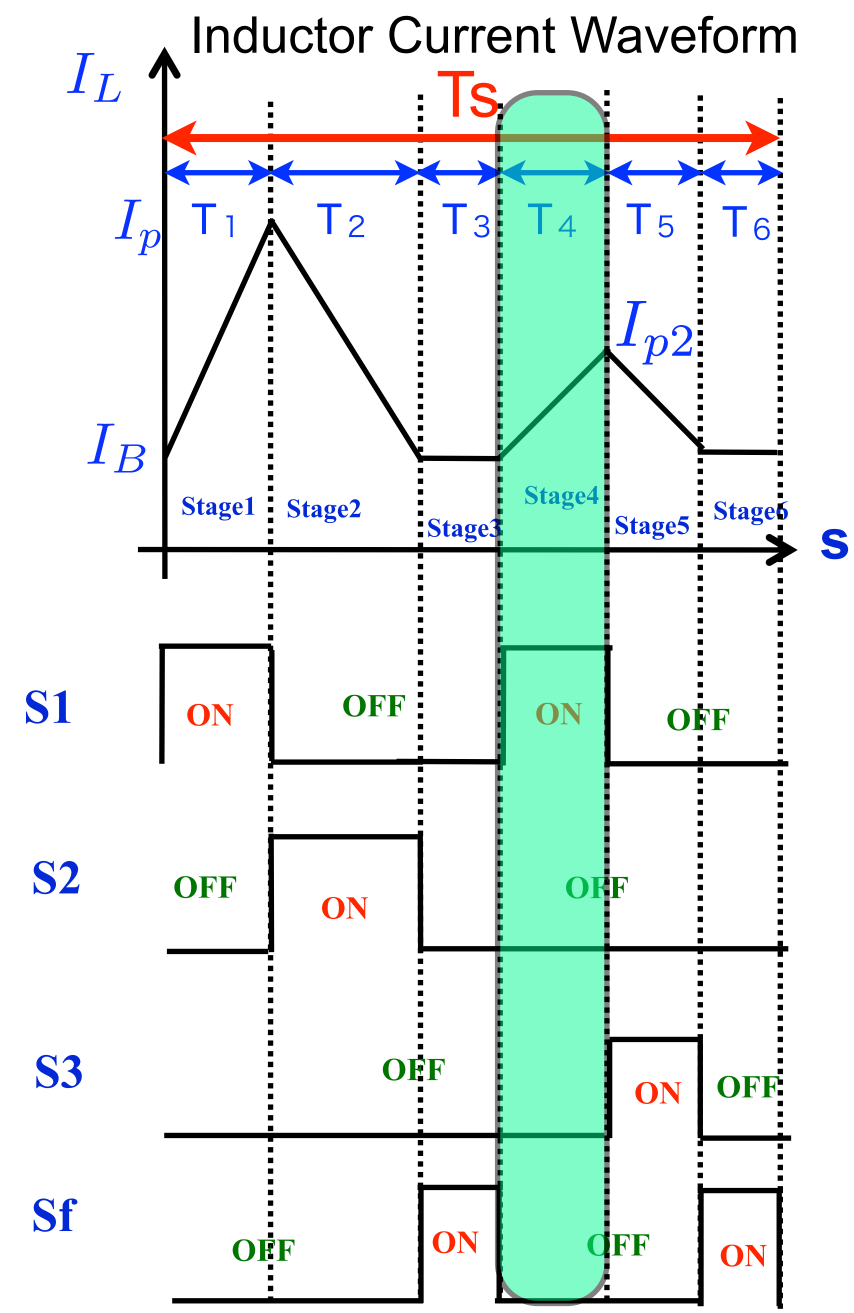
S 1 :Turn on・・・Inductor L stores energy from voltage V_{in}

Current that flows to inductor L

$$I_L = \frac{V_i}{L}t = \frac{I_{p2} - I_B}{T4}t$$

Proposed timing diagram

Ts : 1 cycle



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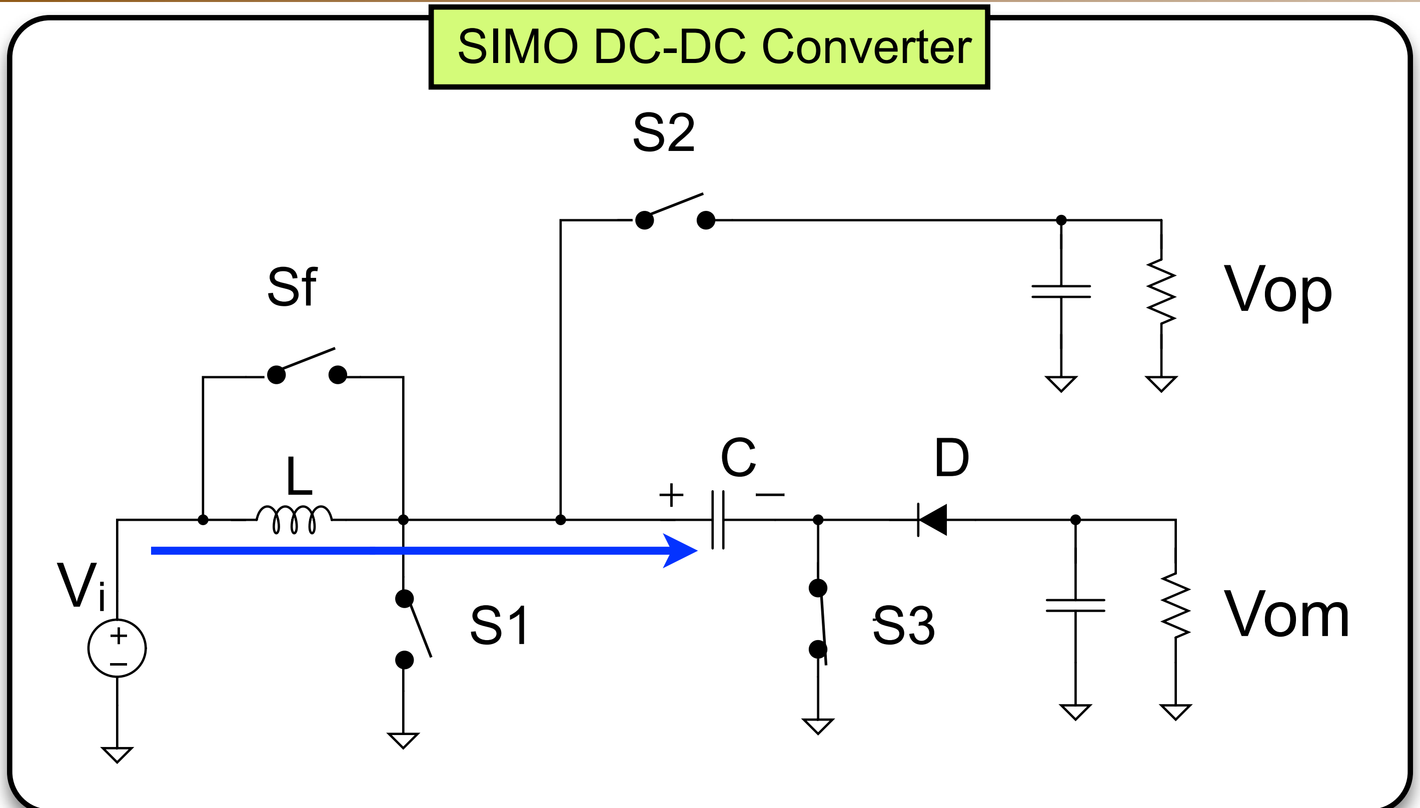
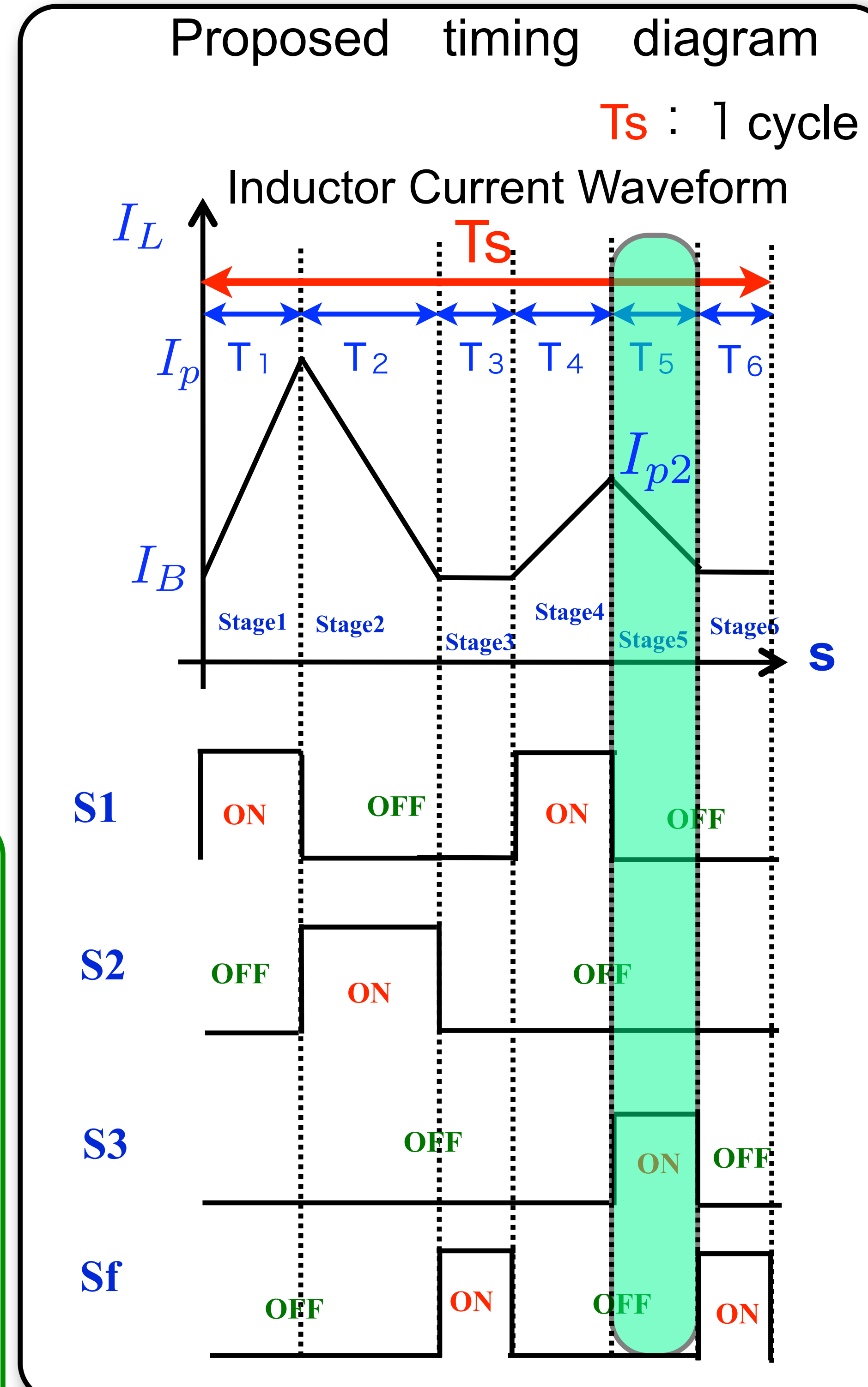
Change of Timing Diagram





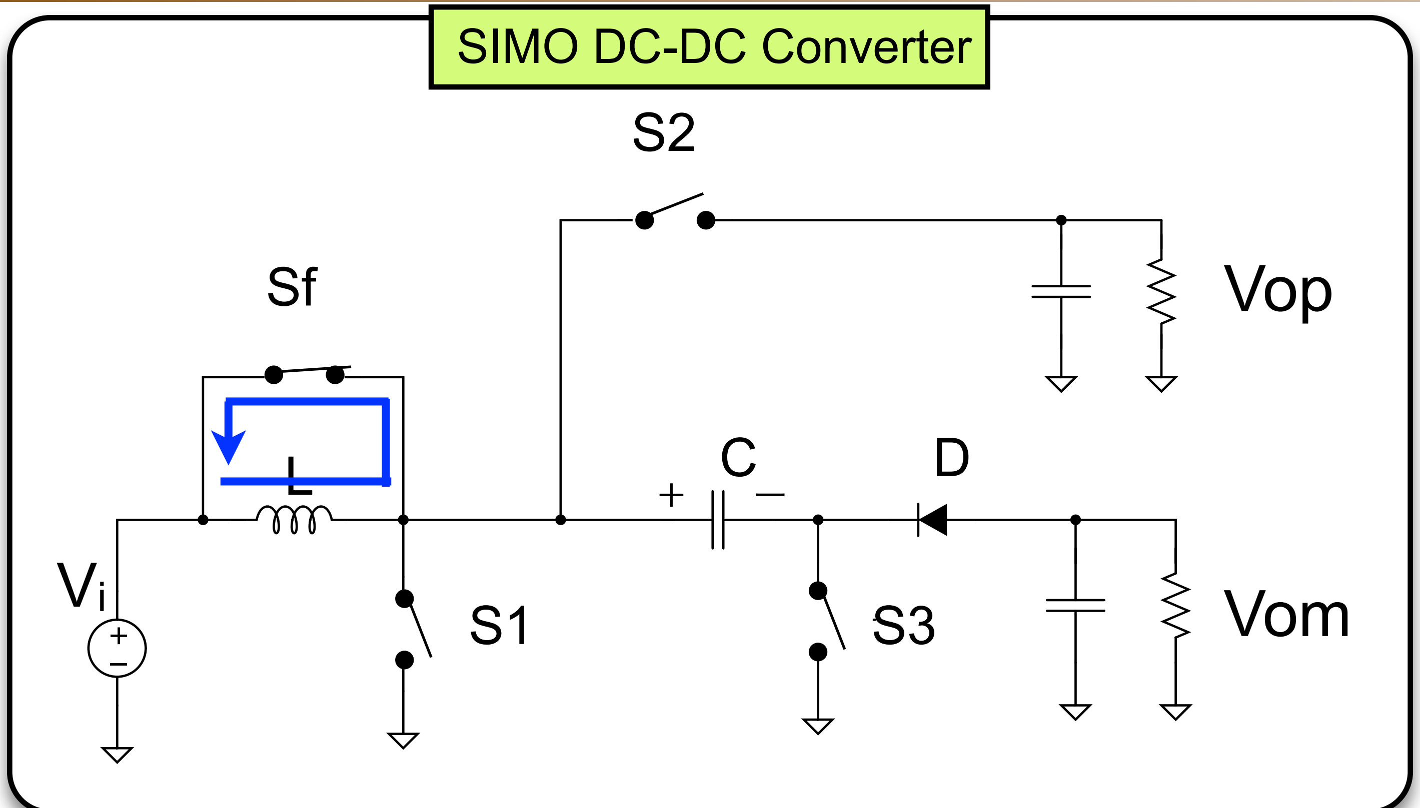
Stage5

S3 : Turn on・・・Charge pump capacitor C_c charges energy from the inductor

Current that flows to inductor L

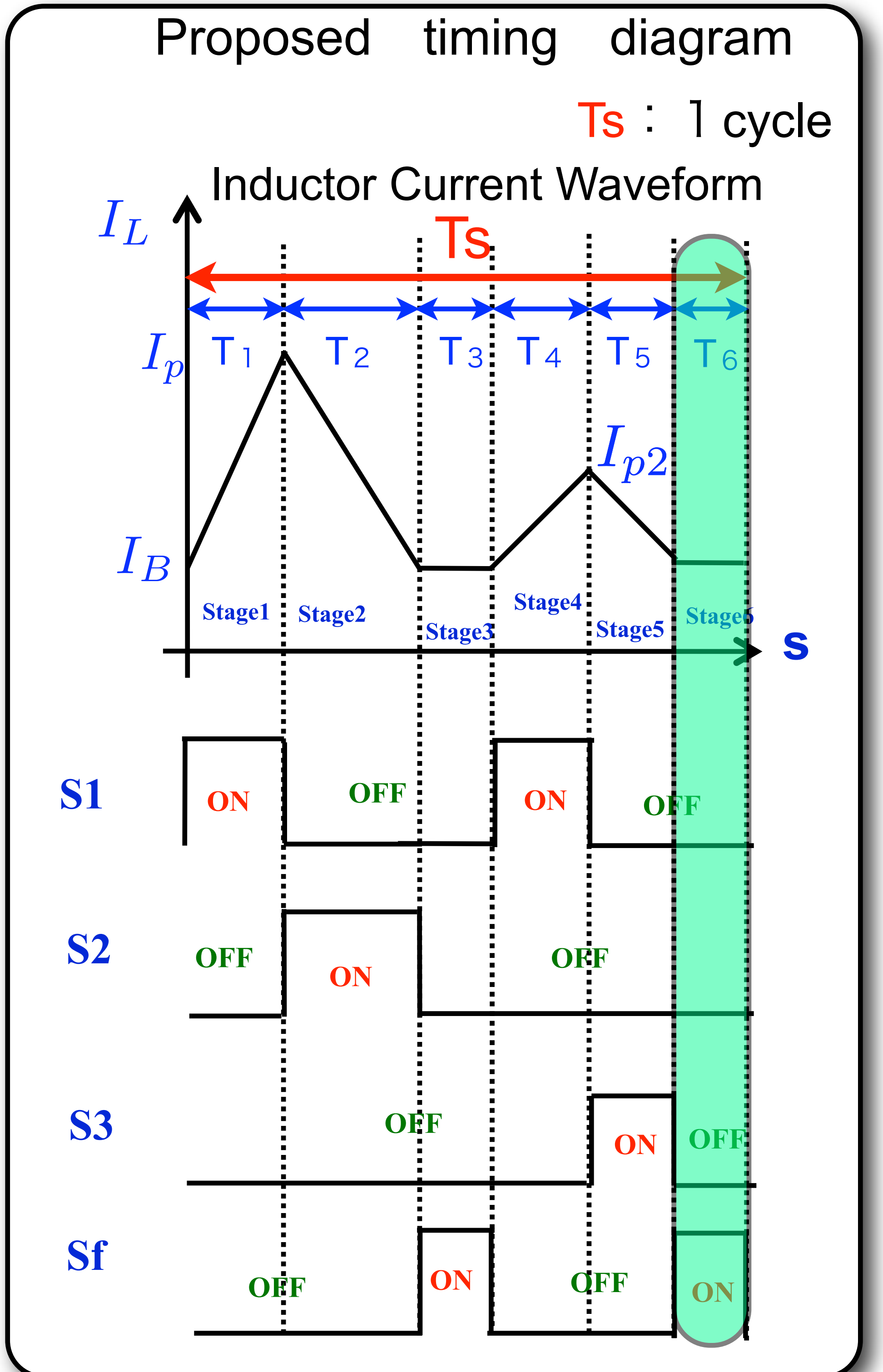
$$I_L = -\frac{V_i - V_c}{L}t = -\frac{I_{p2} - I_B}{T5}t$$

Change of Timing Diagram



Stage6

Sf：Turn on・・・The current of the inductor is maintained with the free wheel switch



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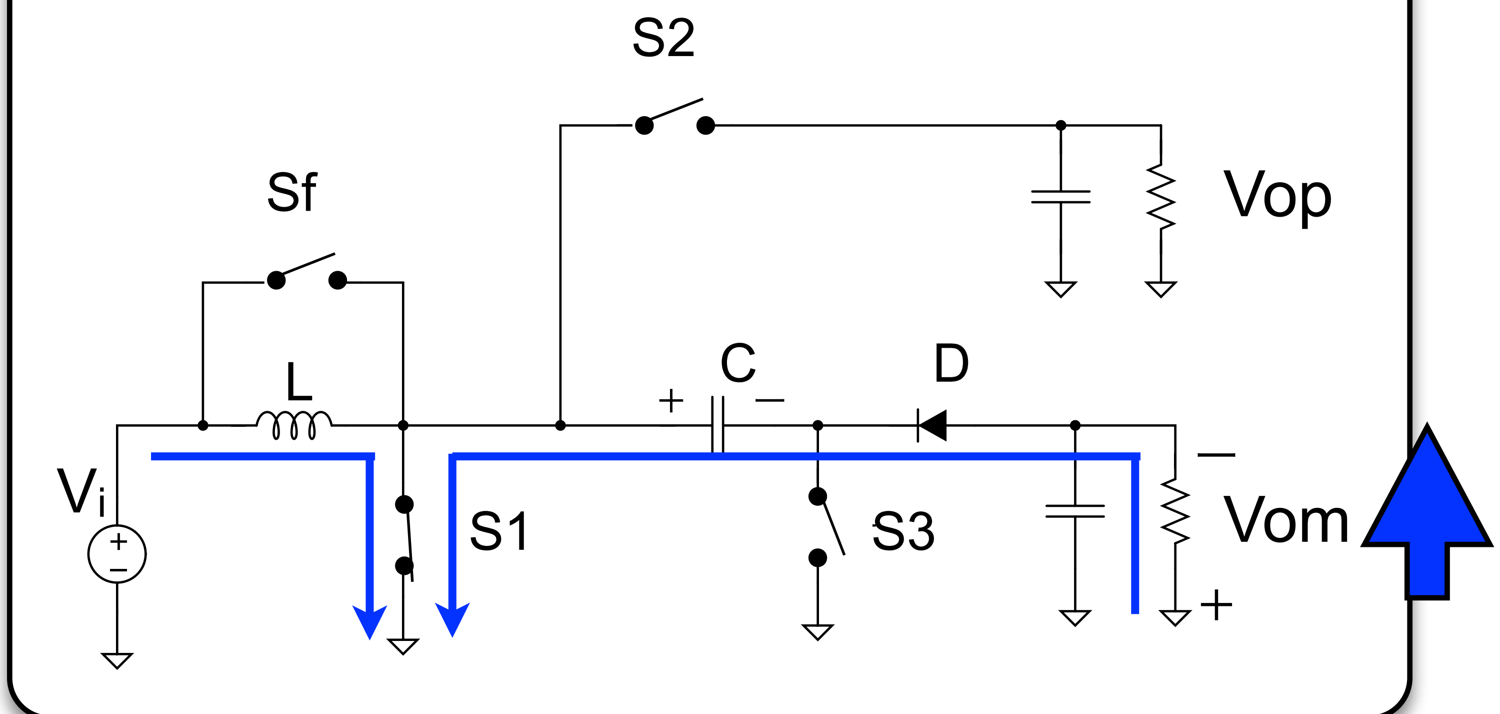
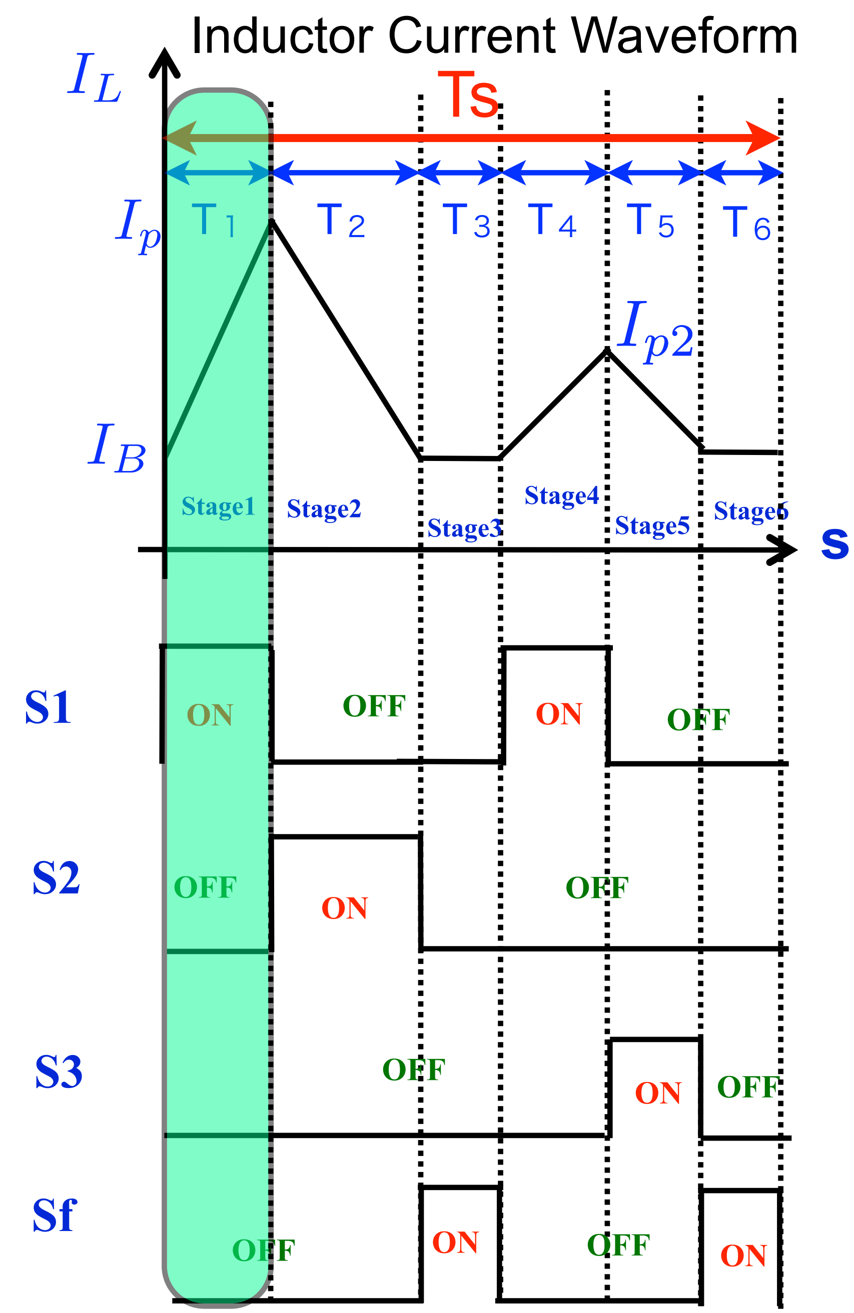
Change of Timing Diagram

SIMO DC-DC Converter



Proposed timing diagram

Ts : 1 cycle



Stage1

S1 : Turn on・・・Energy of capacitor is discharged and negative voltage V_{om} are given

Equation of Stage4

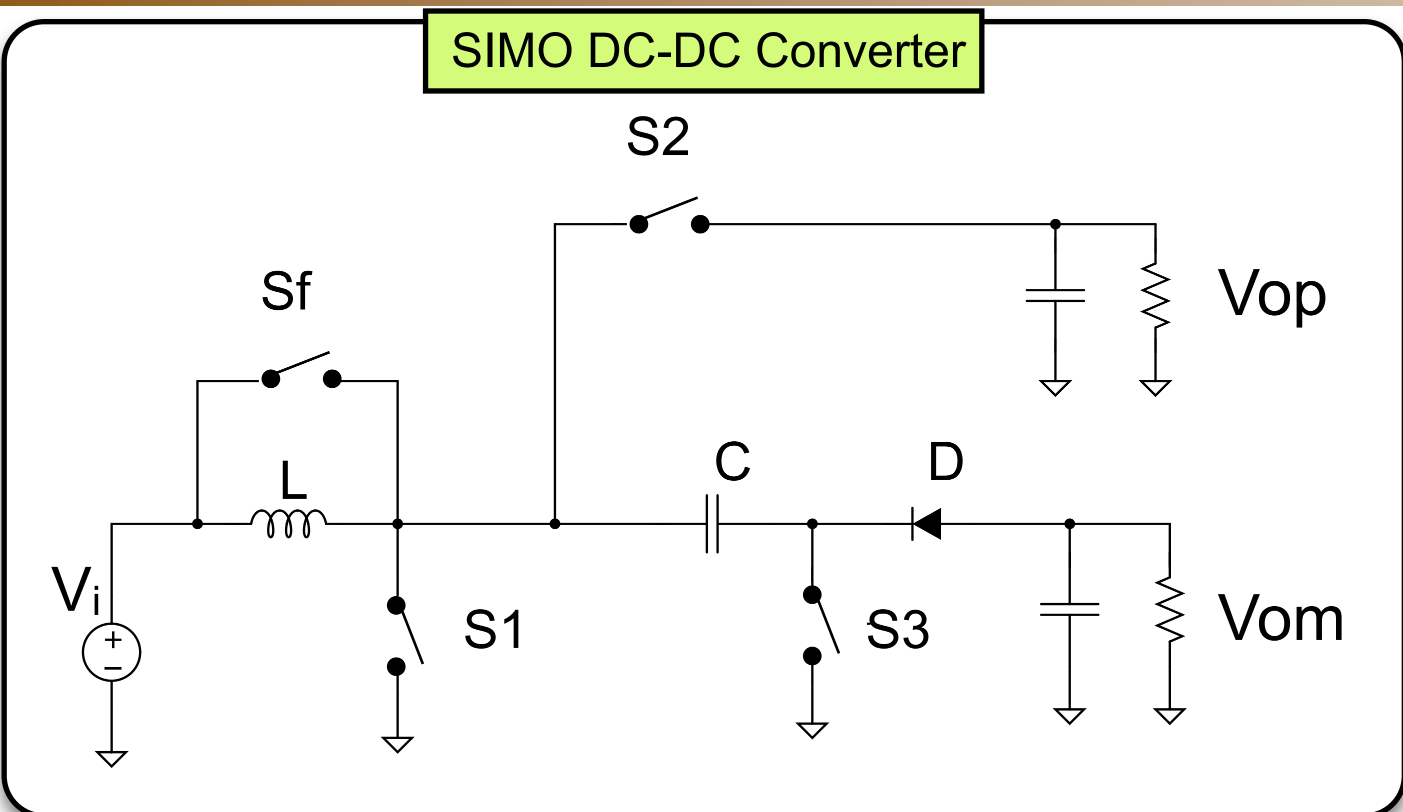
$$I_L = \frac{V_i}{L}t = \frac{I_{p2} - I_B}{T4}t$$

Equation of Stage5

$$I_L = -\frac{V_i - V_c}{L}t = -\frac{I_{p2} - I_B}{T5}t$$

$$V_{om} = -\frac{T4 + T5}{T5}V_i$$

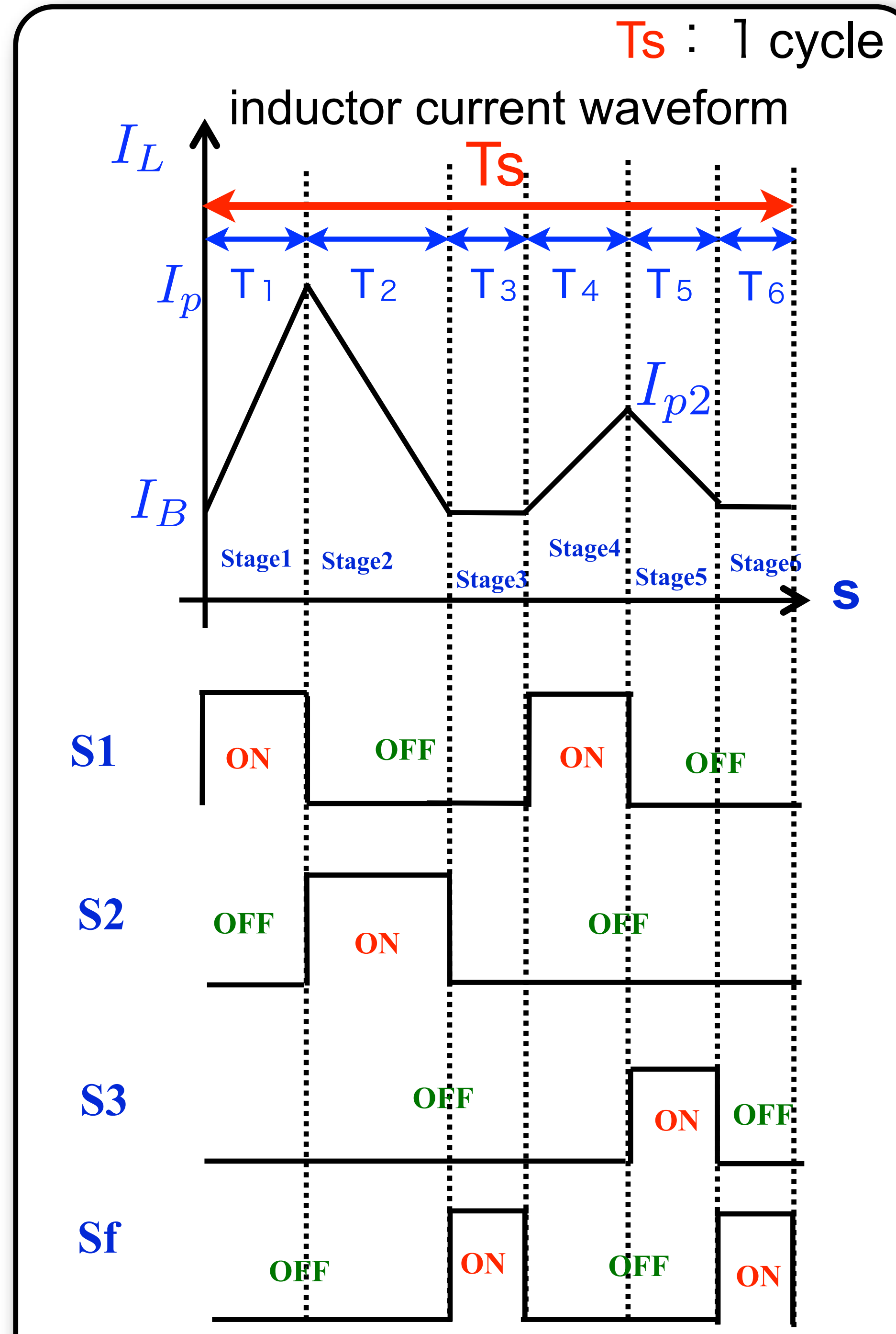
Change of Timing Diagram



$$V_{op} = \frac{T1 + T2}{T2} V_i = \frac{D1 + D2}{D2} V_i$$

$$V_{om} = -\frac{T4 + T5}{T5} V_i + V_F = -\frac{D4 + D5}{D5} V_i + V_F$$

Negative output voltage can be changed independently



Propose timing diagram

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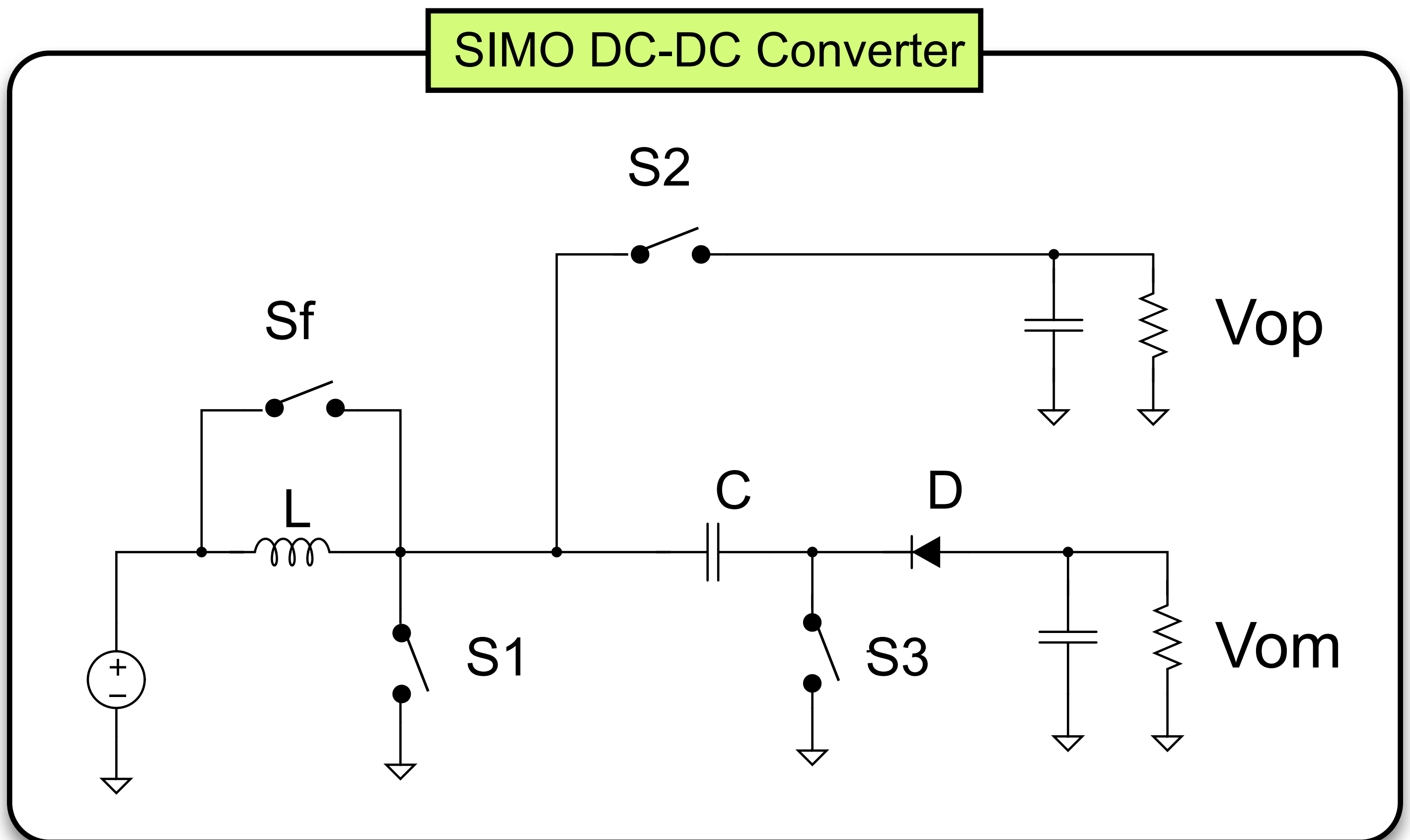
Simulation Results



Simulation Condition

Switching Frequency：500kHz

Input Voltage Vin：3.5V

Inductor L：2u

Output Capacitor Cout：10u

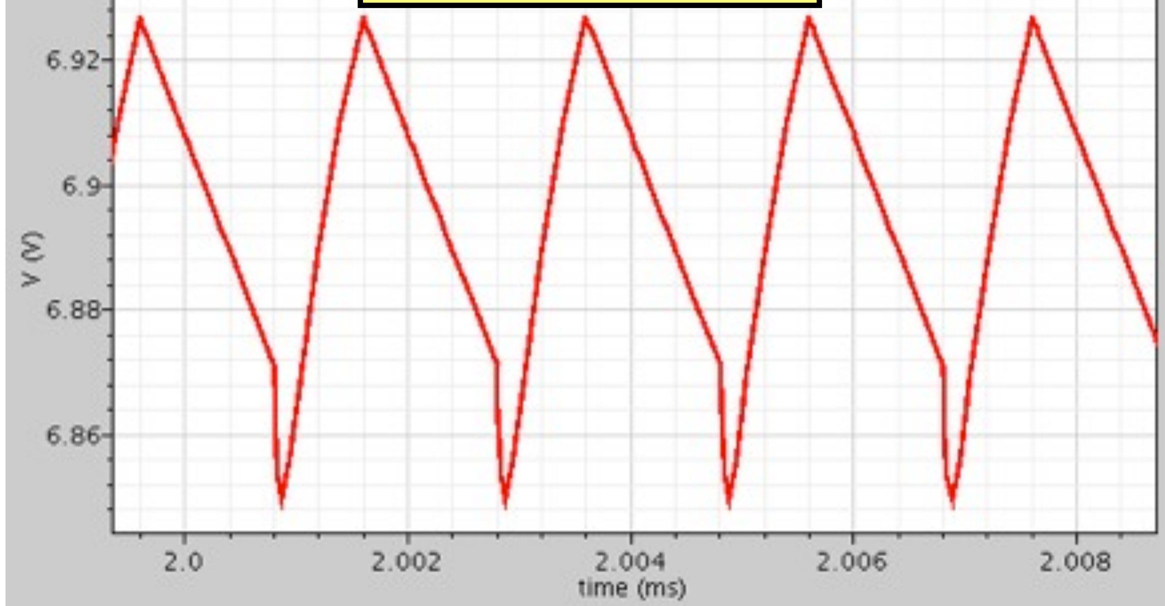
Load Resistance Ro：15Ω

Charge Pump Capacitor Cc：5u

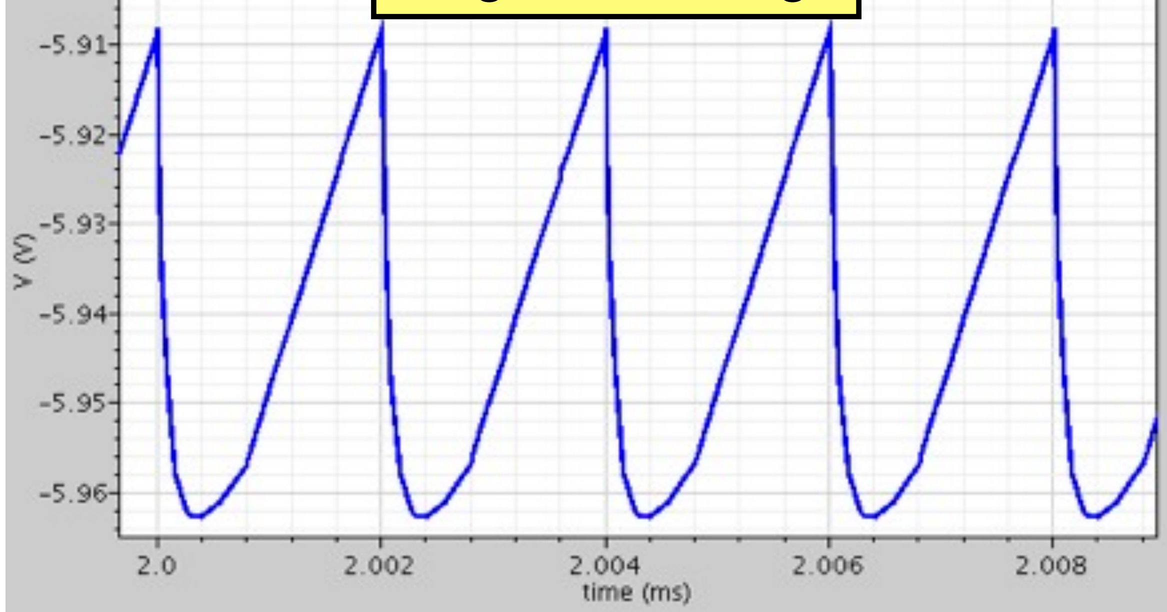
Simulation Results(Conventional)

Positive Output Voltage:7V

Positive Voltage



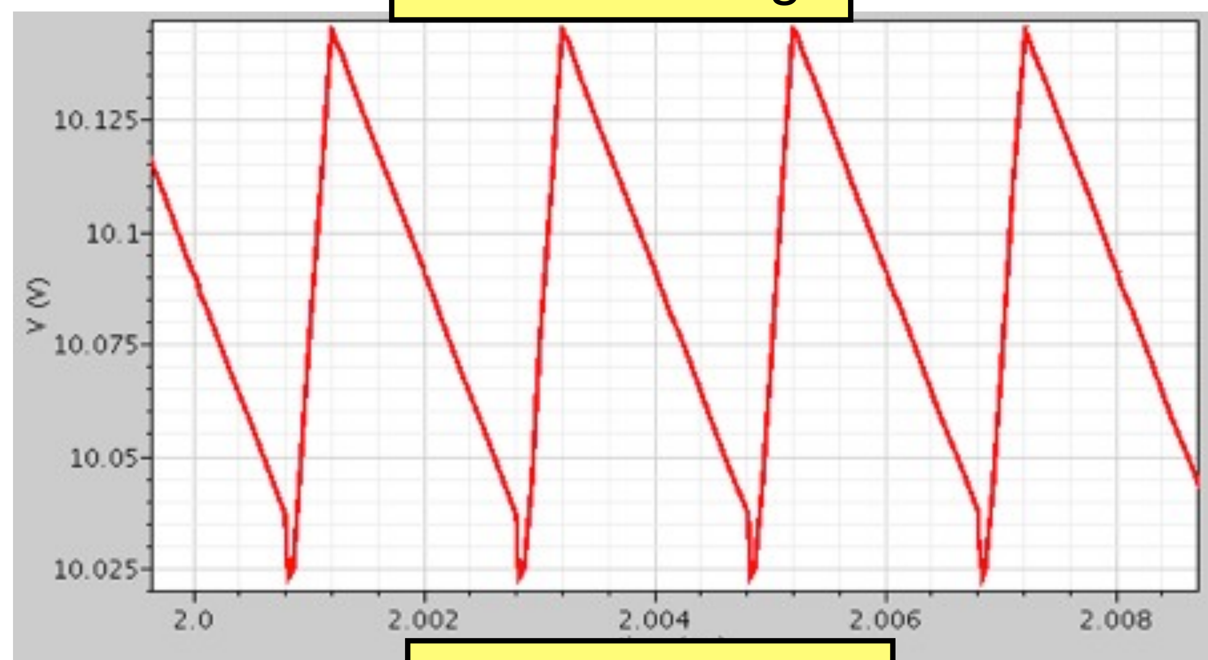
Negative Voltage



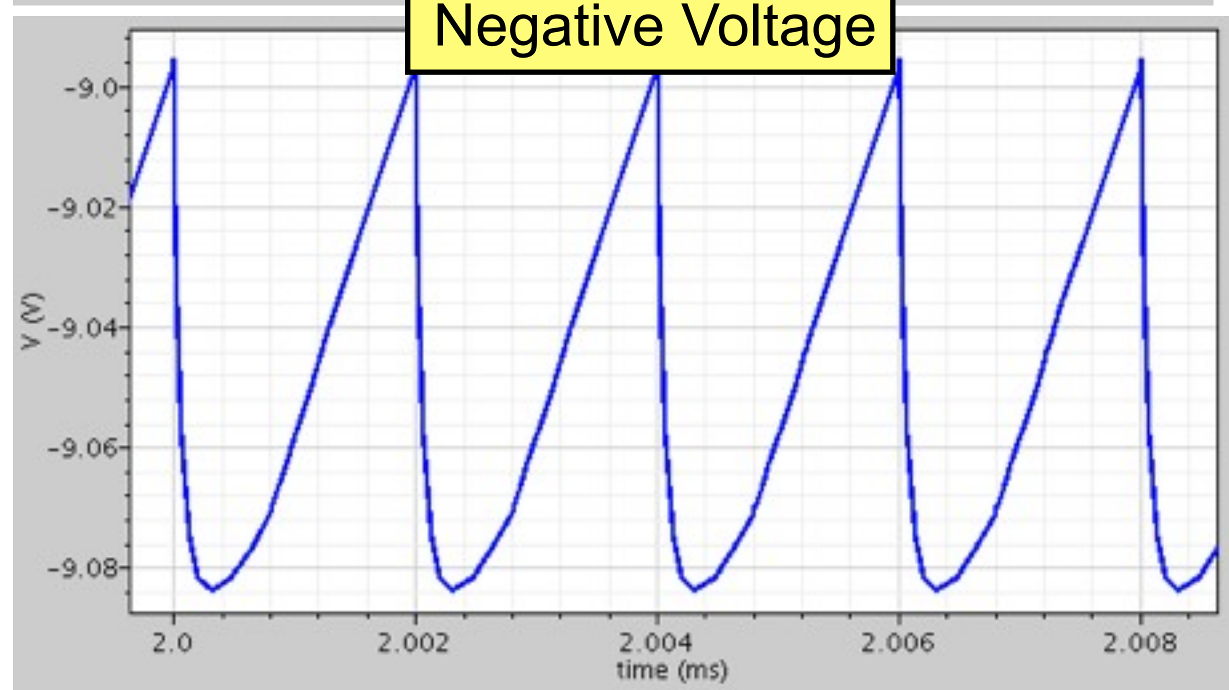
Negative Output Voltage:-5.93V

Positive Output Voltage:10.5V

Positive Voltage



Negative Voltage



Negative Output Voltage:-9V

Simulation Results(Conventional)

Positive Voltage	Positive Voltage Ripple (Vpp)	Negative Voltage	Negative Voltage Ripple (Vpp)
6.89V	75.5mV	-5.9V	54.3mV
10.1V	119.7mV	-9.1V	87.9mV

Negative Voltage : $V_{om} = -V_{op} + V_F$

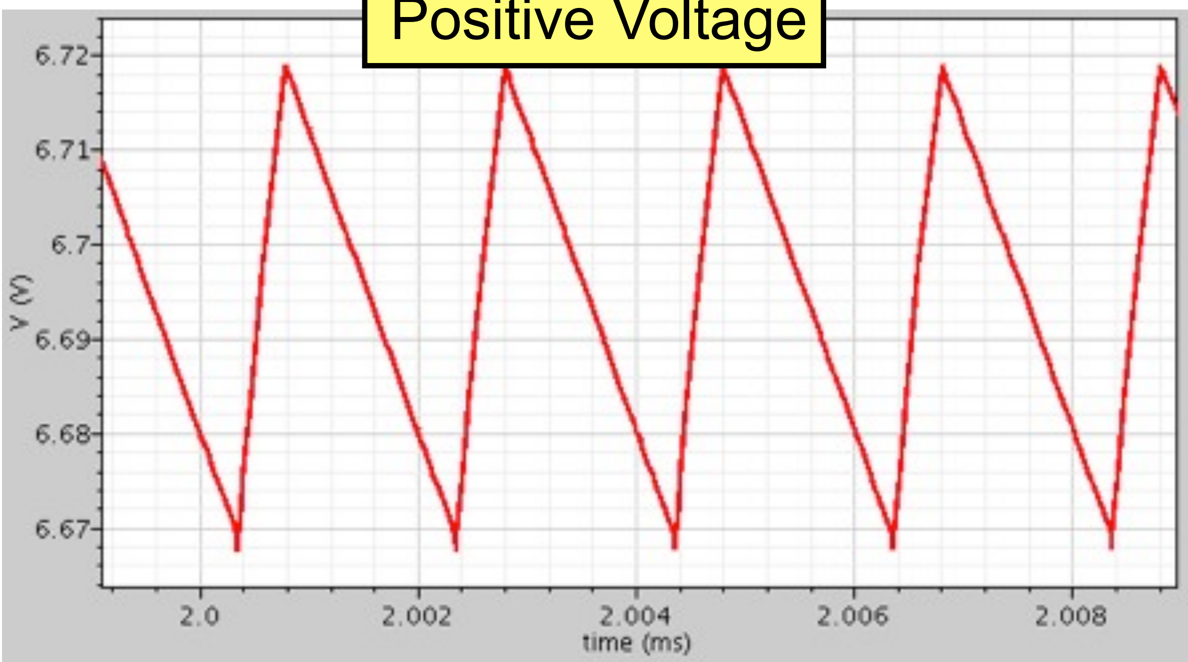
Conventional Circuit

A negative voltage depends on a positive voltage

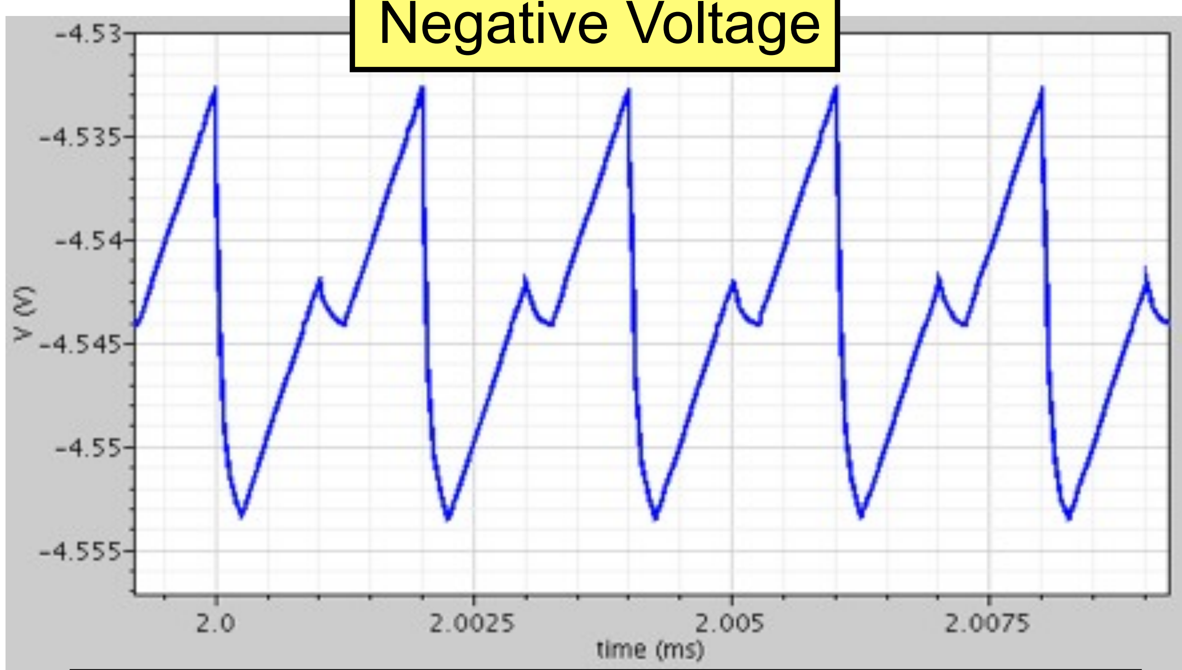
Simulation Results(Proposed)

Positive Output Voltage:6.7V

Positive Voltage



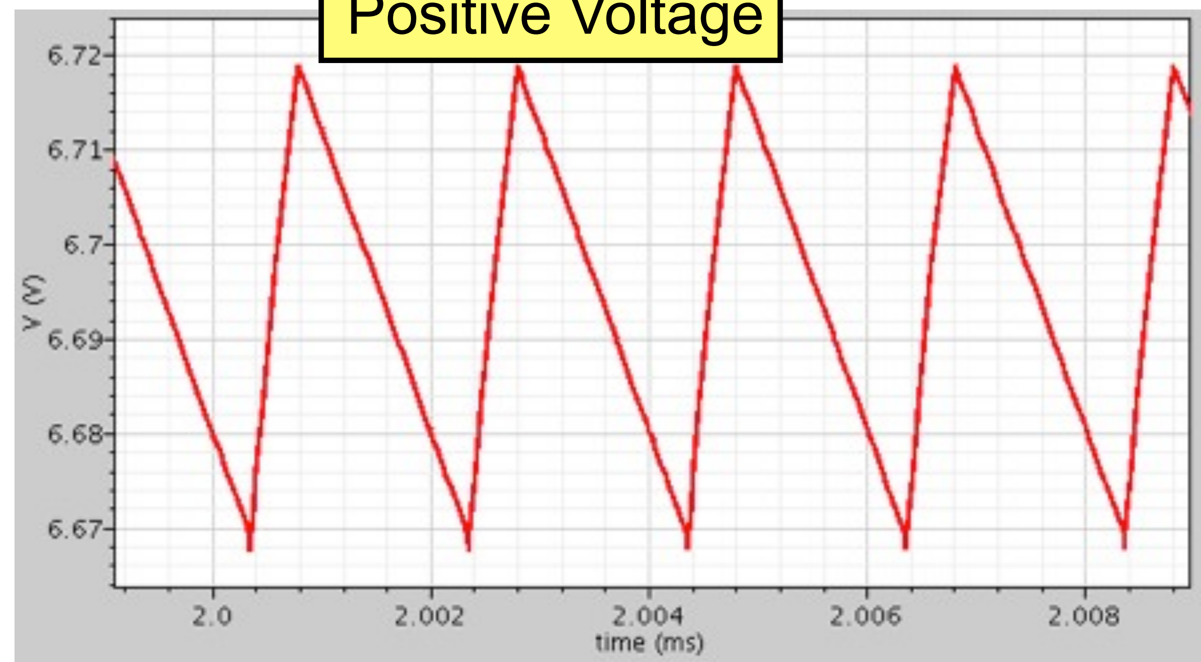
Negative Voltage



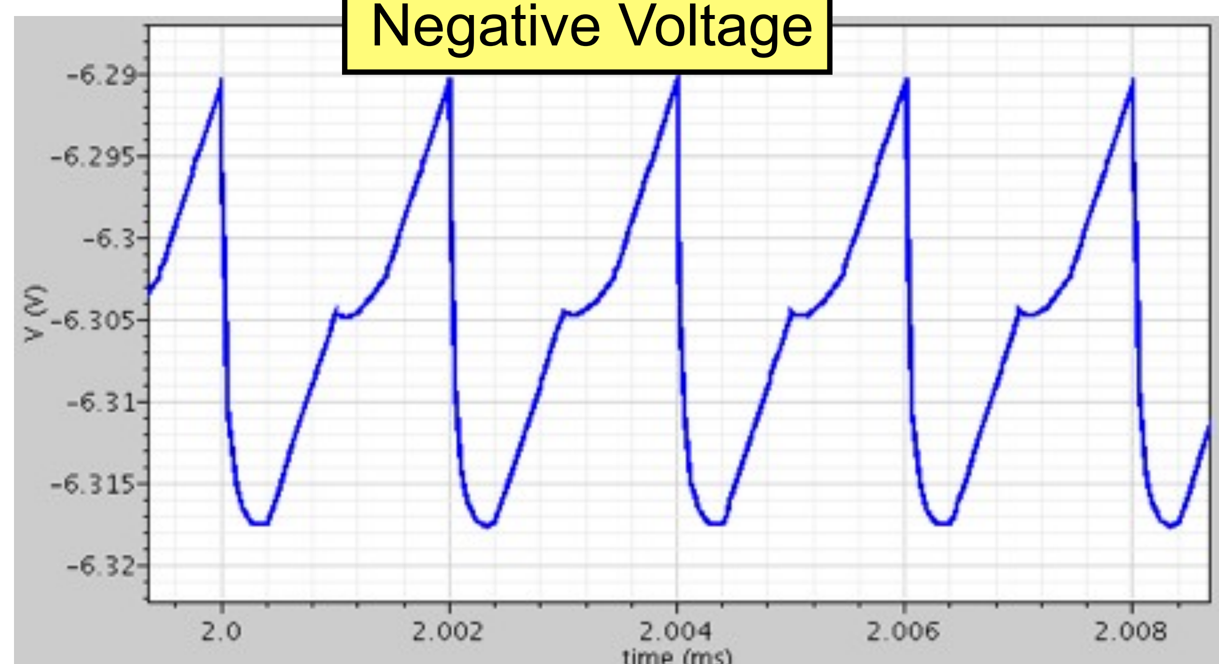
Negative Output Voltage:-4.54V

Positive Output Voltage:6.7V

Positive Voltage



Negative Voltage



Negative Output Voltage:-6.3V

Simulation Results

Proposed Timing Daigram

Positive Voltage	Positive Voltage Ripple (Vpp)	Negative Voltage	Negative Voltage Ripple (Vpp)
6.7V	50.8mV	-4.5V	20.8mV
6.7V	50.8mV	-6.3V	27.1mV

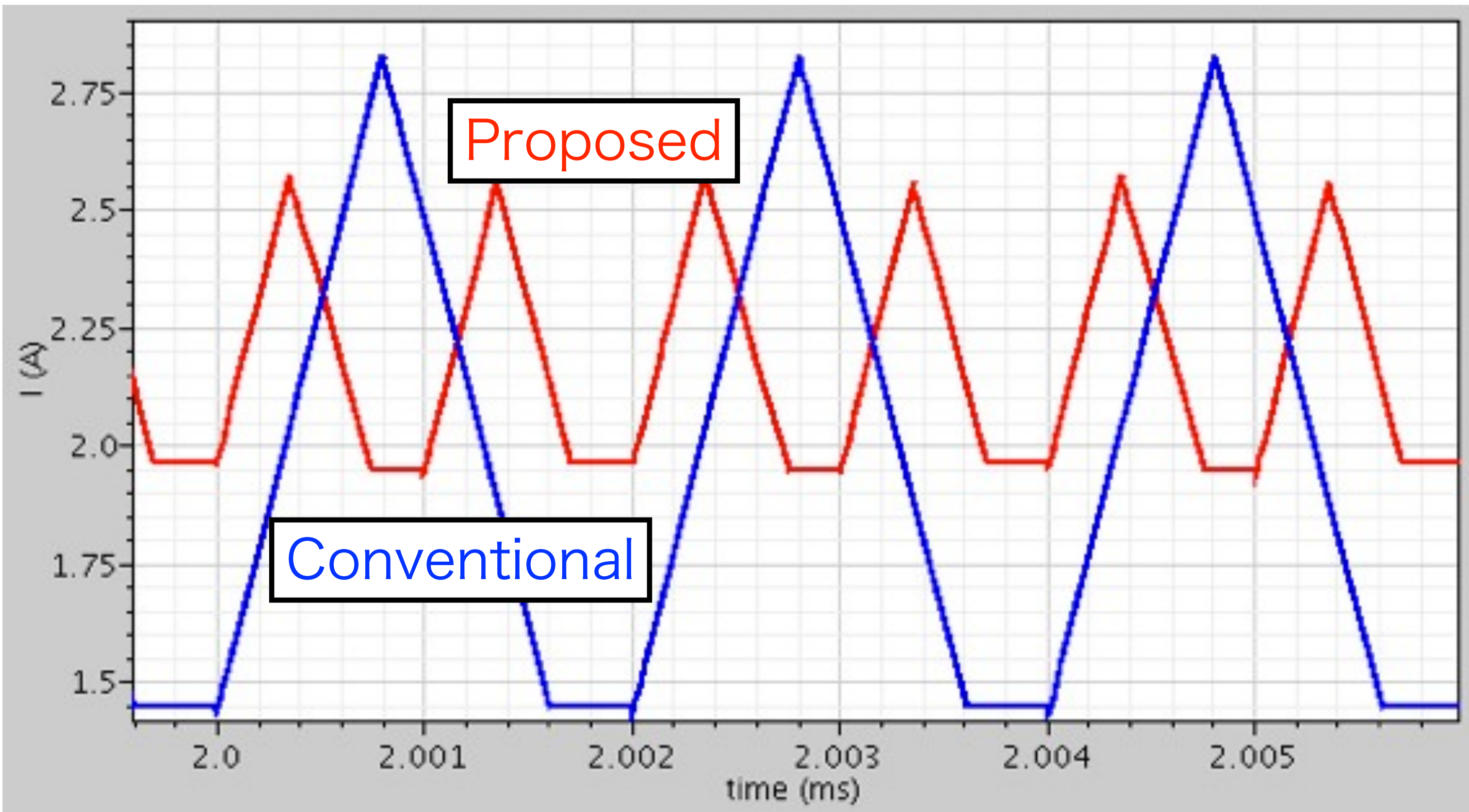
Conventional Timing Daigram

Positive Voltage	Positive Voltage Ripple (Vpp)	Negative Voltage	Negative Voltage Ripple (Vpp)
6.9V	75.5mV	-5.9V	54.2mV
10.1V	119.7mV	-9.1V	87.9mV

Voltage Ripple has Decreased

Inductor Current Waveform

Inductor Current Waveform



At The One Cycle

Conventioanl

Inductor L is
one charge ＆discharge

Proposed

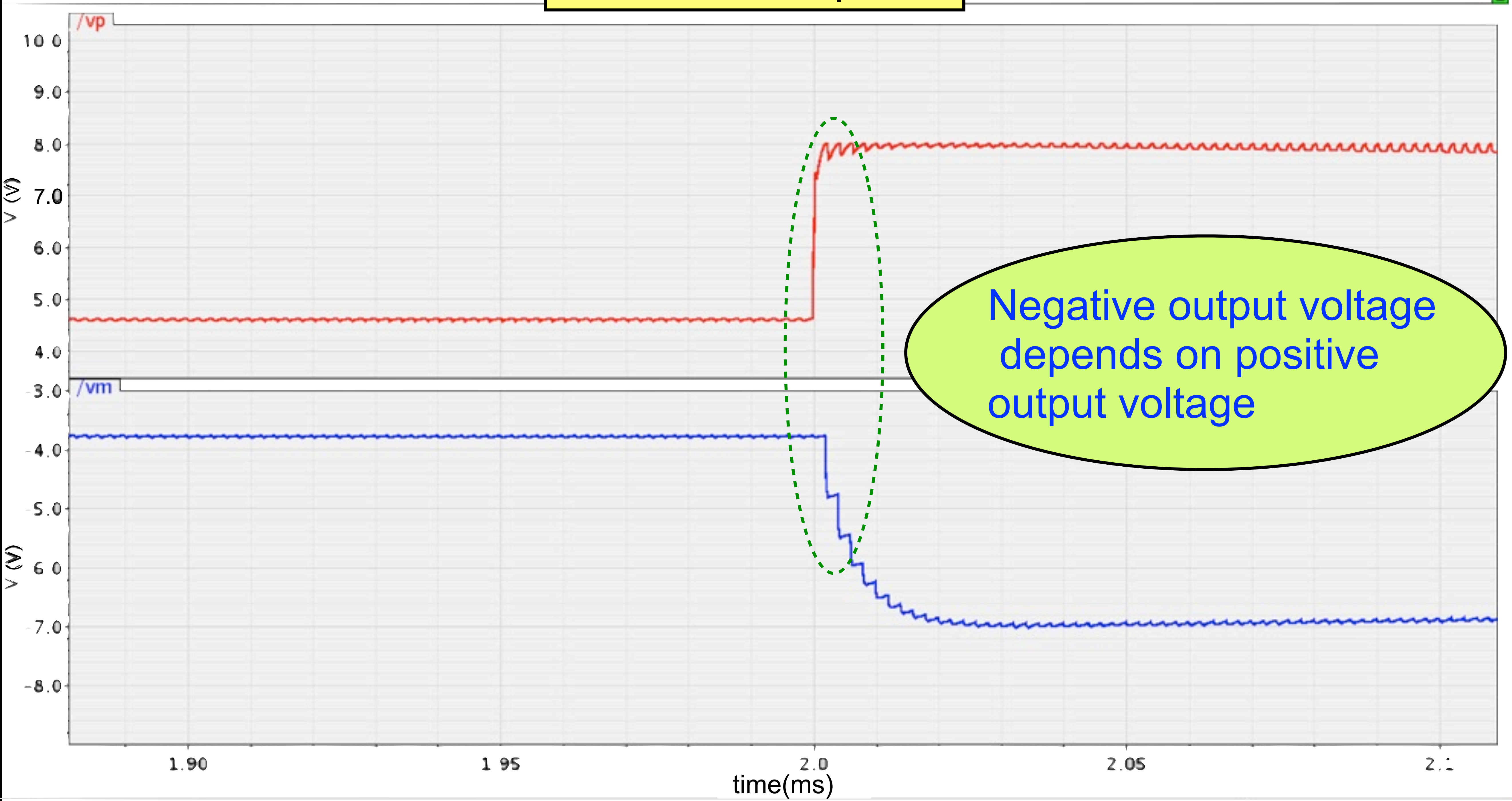
Inductor L is
two charge ＆discharge

	Current Ripple (Vpp)
Conventional	1.35 A
Proposed	630.4mA

Inductor Current Ripple is Reduced by 50%

Transient Response (Conventional)

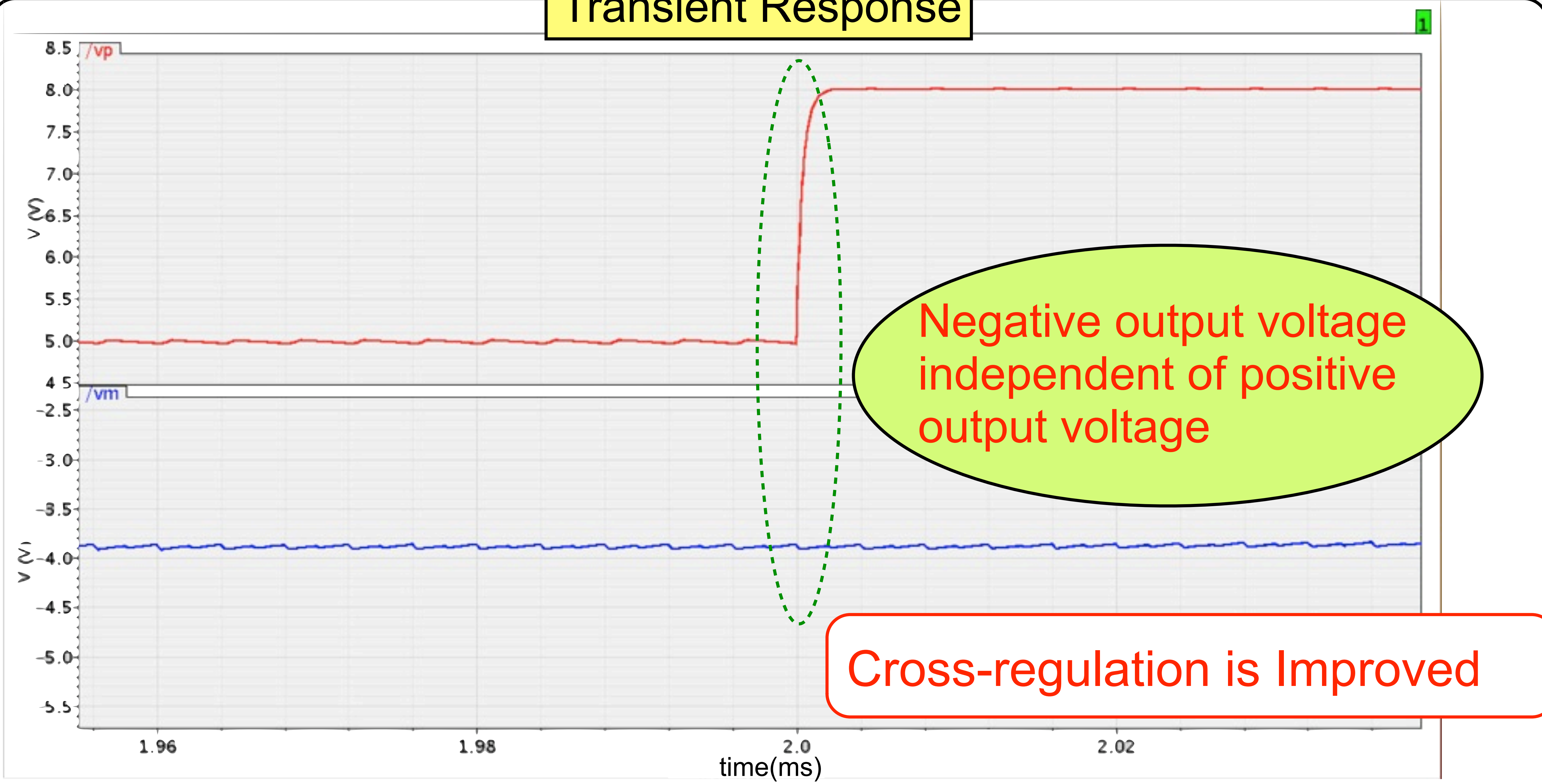
Transient Response



Output Voltage Waveform

Transient response(Proposed)

Transient Response



Output Voltage Waveform

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Conclusion

A new timing diagram is proposed

- Independent positive and negative output voltage
- Voltage ripple and inductor ripple less than conventional timing diagram
- Cross-regulation is improved