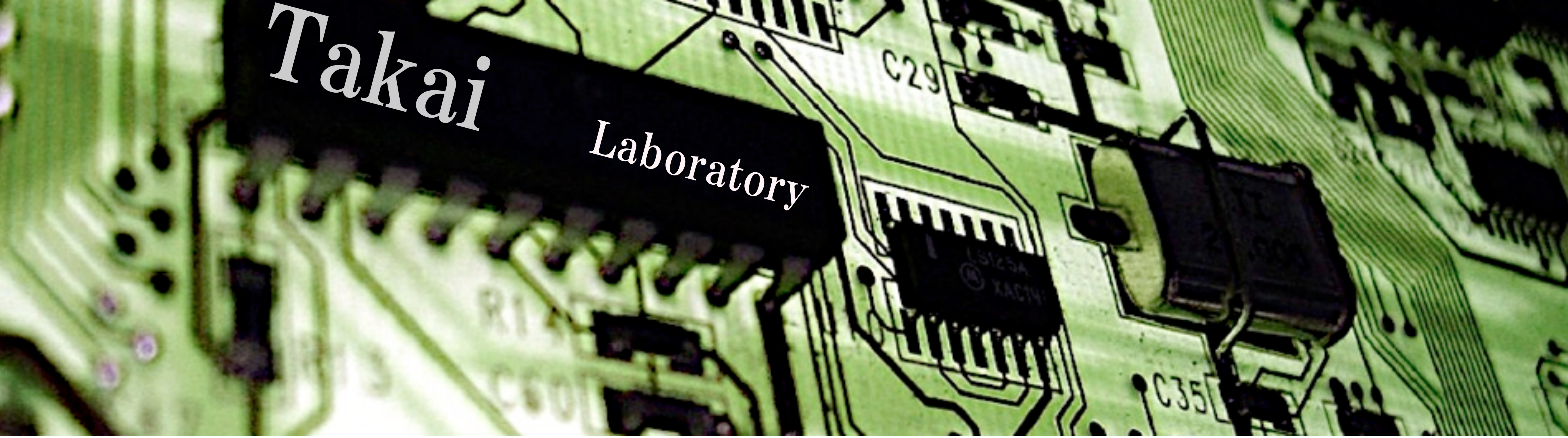

High Efficiency Single-Inductor Dual-Output DC-DC Converter with ZVS-PWM Control

Gunma University, Japan

Yoshiki Sunaga, N.Shiraishi, K.Asaishi,
N.Tsukiji, Y.Kobori, N.Takai, H. Kobayashi

2015/11/4

OUTLINE

- Background and Objective
- Boost Converter with ZVS-PWM Control
- Conventional SIDO Boost Converter
- Simulation results
- Implementation of SISO Boost Converter with ZVS-PWM Control
- Conclusion and Future works

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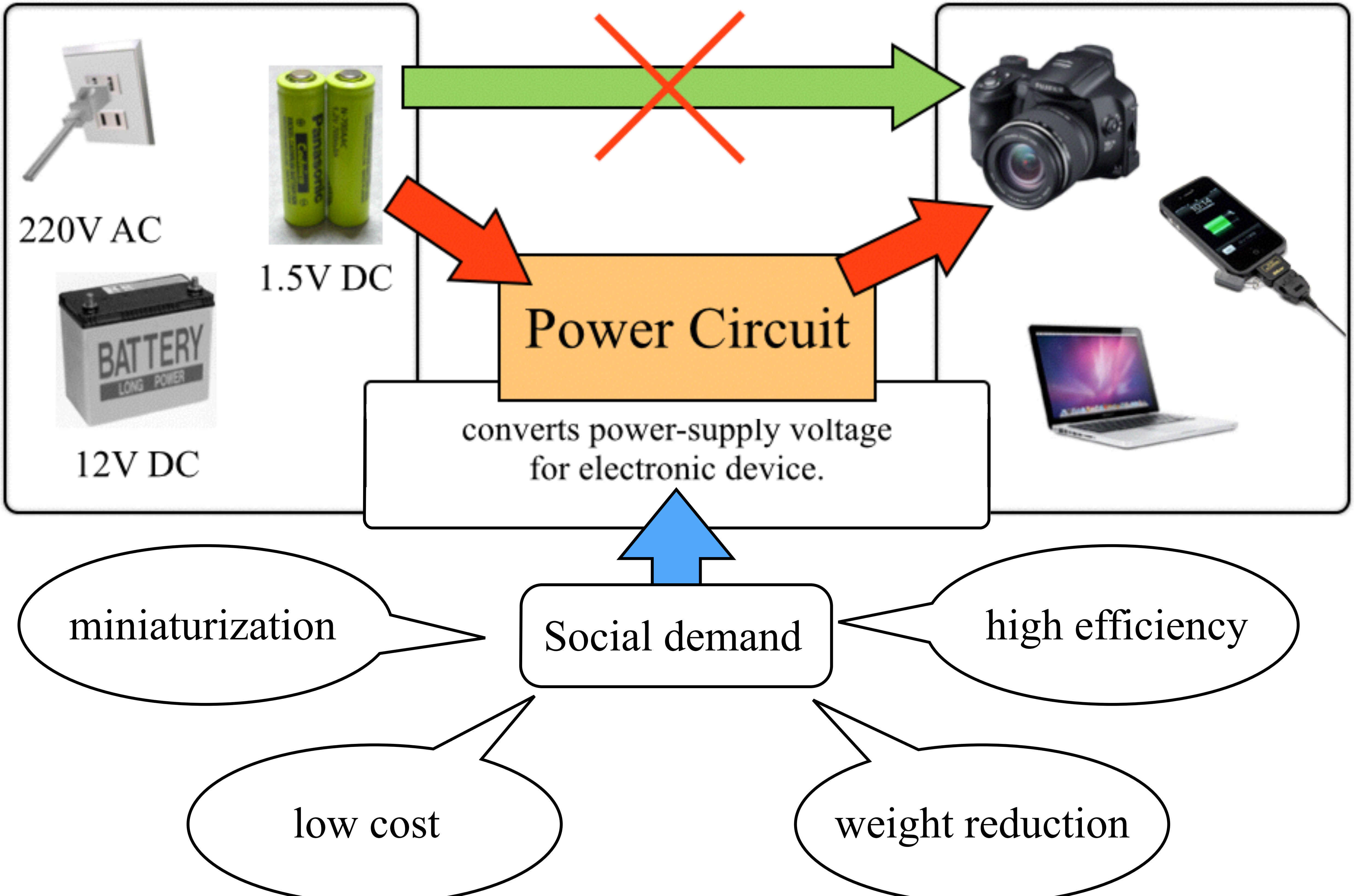
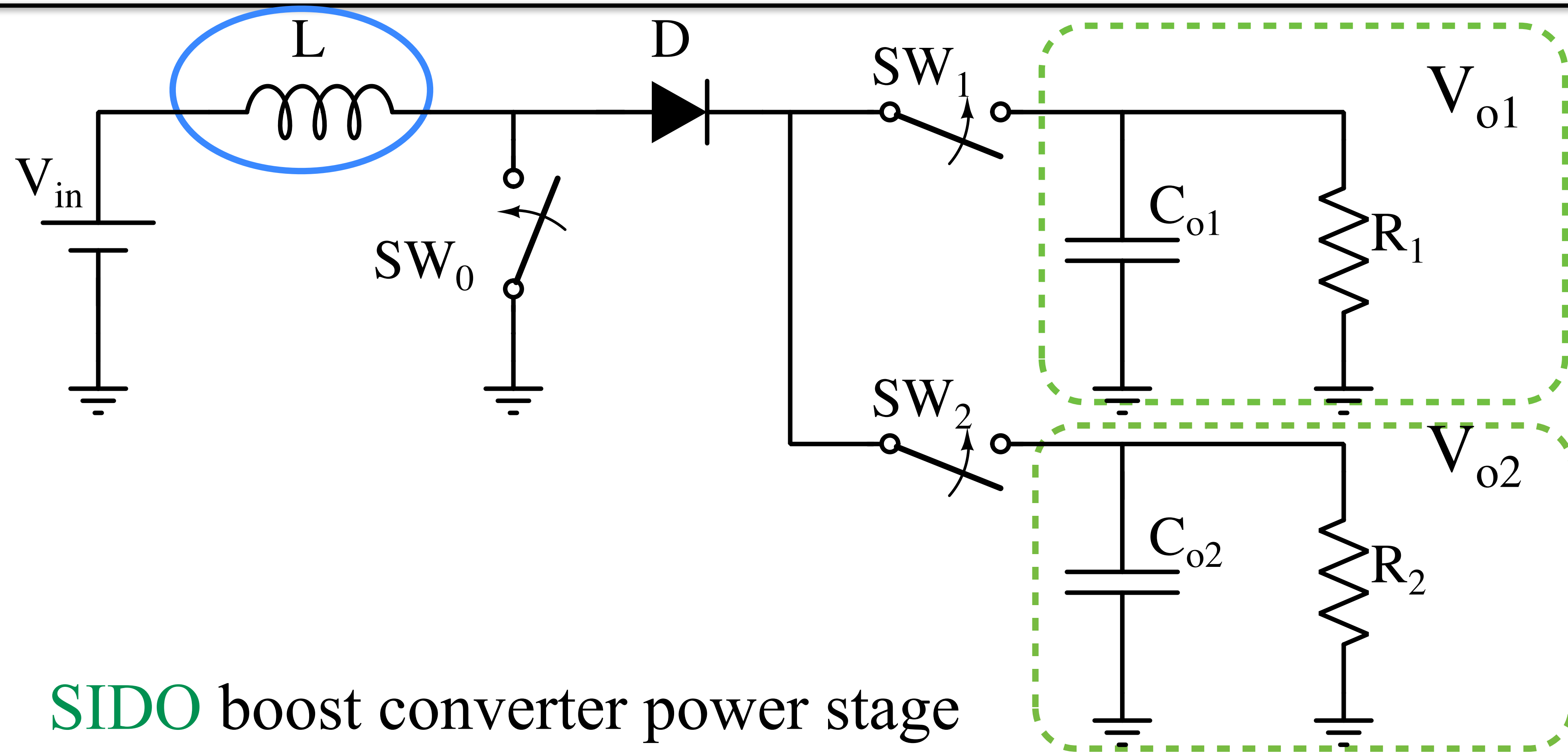


Background and Objective



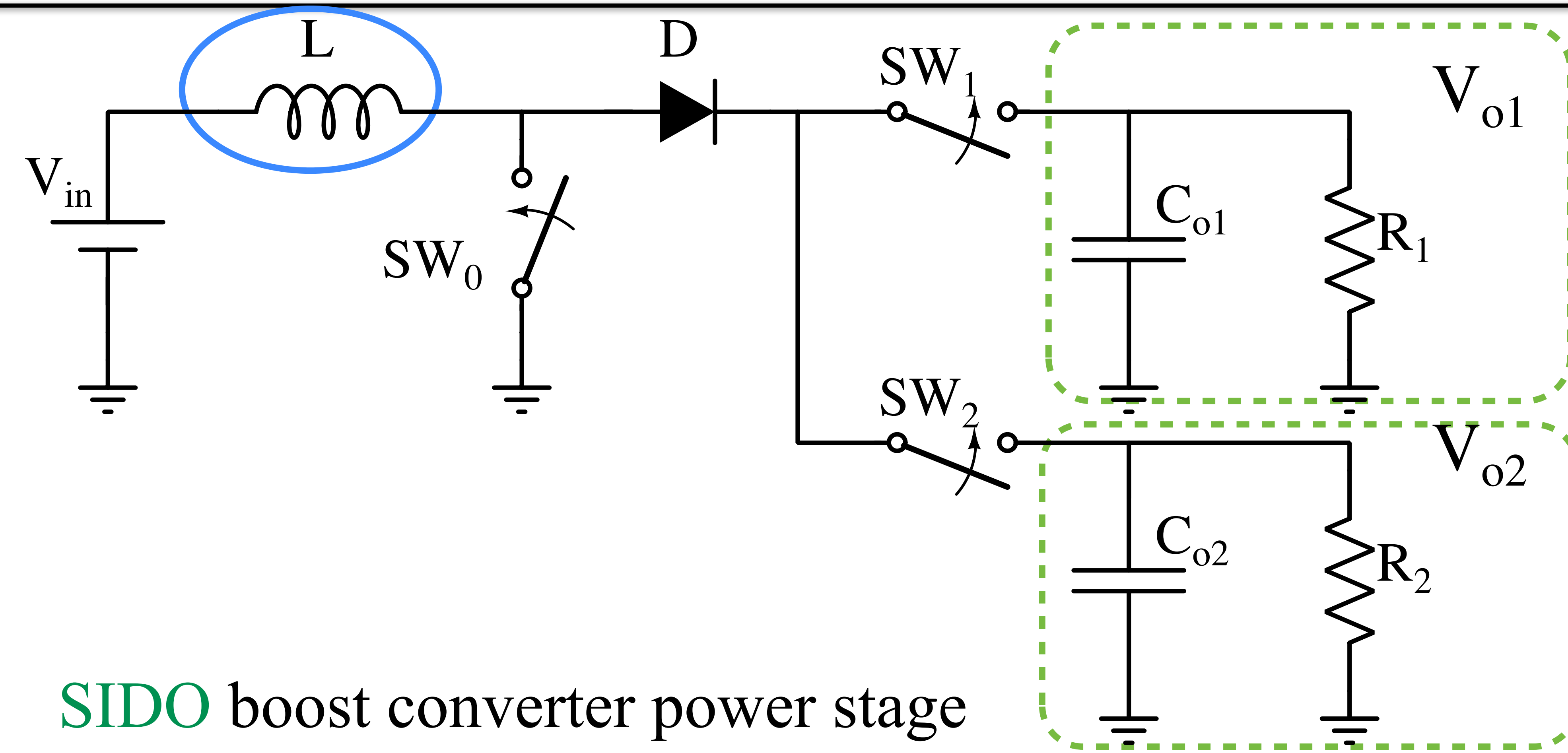
SIDO boost converter power stage

SIDO means…
Single Inductor Dual Output

Dual Output
and
Single Inductor

→ **miniaturization**

Background and Objective



SIDO boost converter power stage

Proposal!

ZVS is one of the soft-switching methods for switching loss reduction
(ZVS:Zero Voltage Switching)

apply → **high efficiency**

OUTLINE

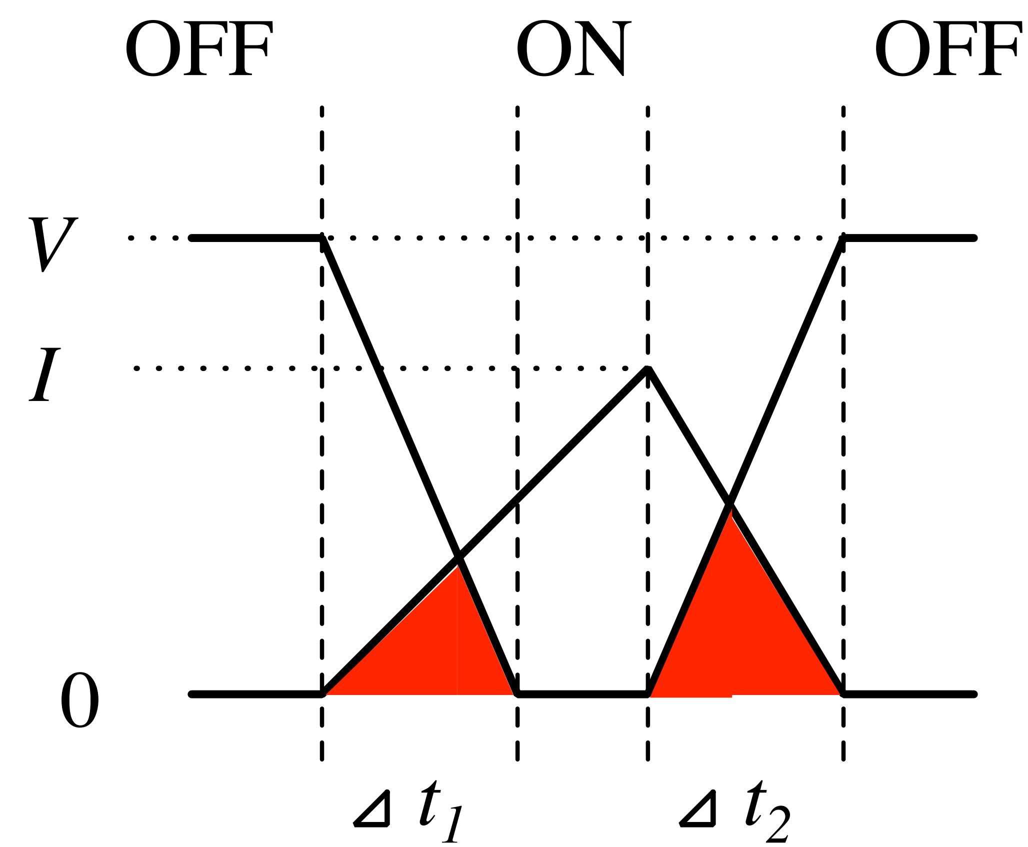
Switching loss

Switching loss

when the switch is turned ON/OFF,
The switch transistor suffers from an electrical loss.

Its expression is given as follows:

$$P_{sw} = \int_0^{\Delta t} I(t) \cdot V(t) dt$$
$$= \frac{1}{6} \cdot V \cdot I \cdot \Delta t$$

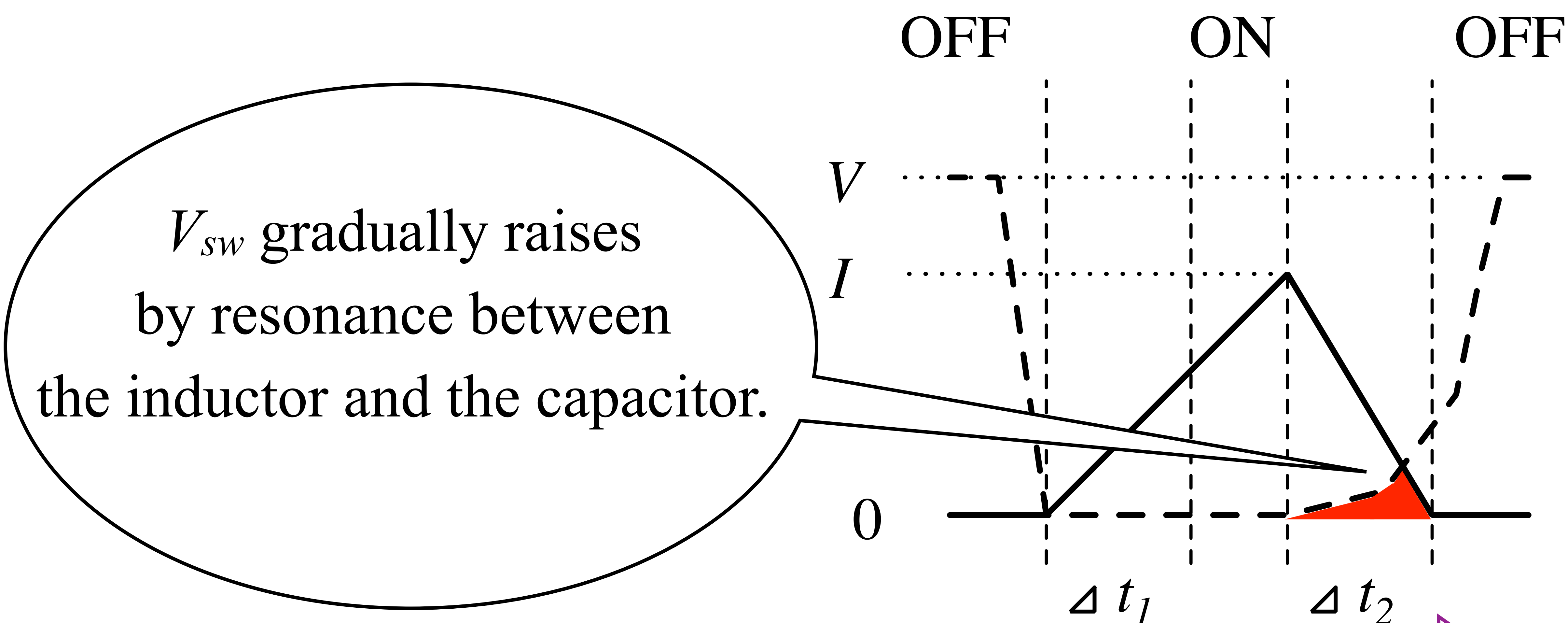


switch OFF > switch ON

ZVS(Zero Voltage Switching)

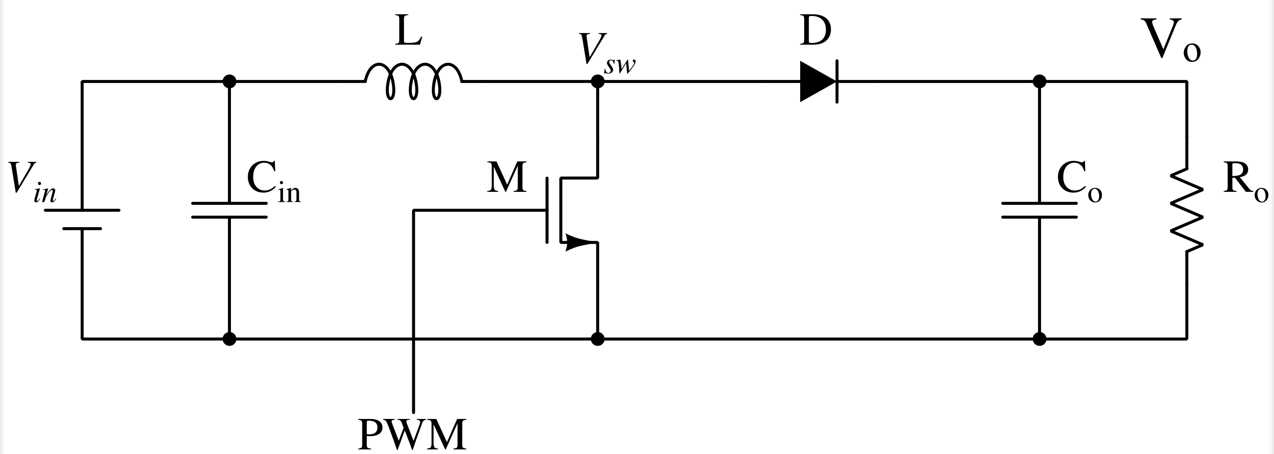
ZVS mean... → Switching method for the switching loss reduction.
Use the resonance between the inductor and the capacitor.

V_{sw}=GND → Switch ON & OFF! → P_{sw} reduction

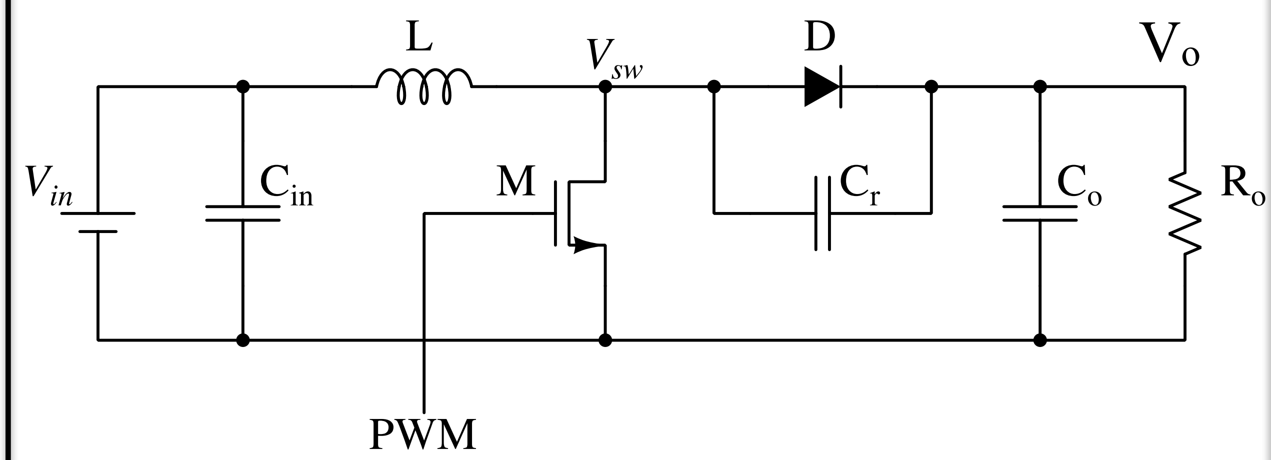


SISO Boost Converter with ZVS-PWM Control

Power Stage



SISO Boost Converter

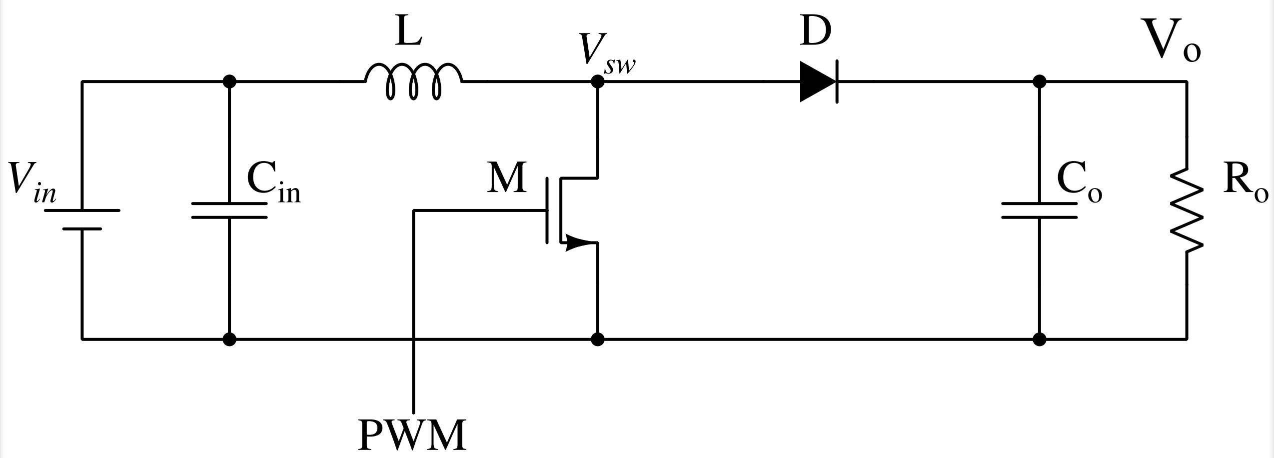


SISO Boost Converter
with ZVS-PWM Control

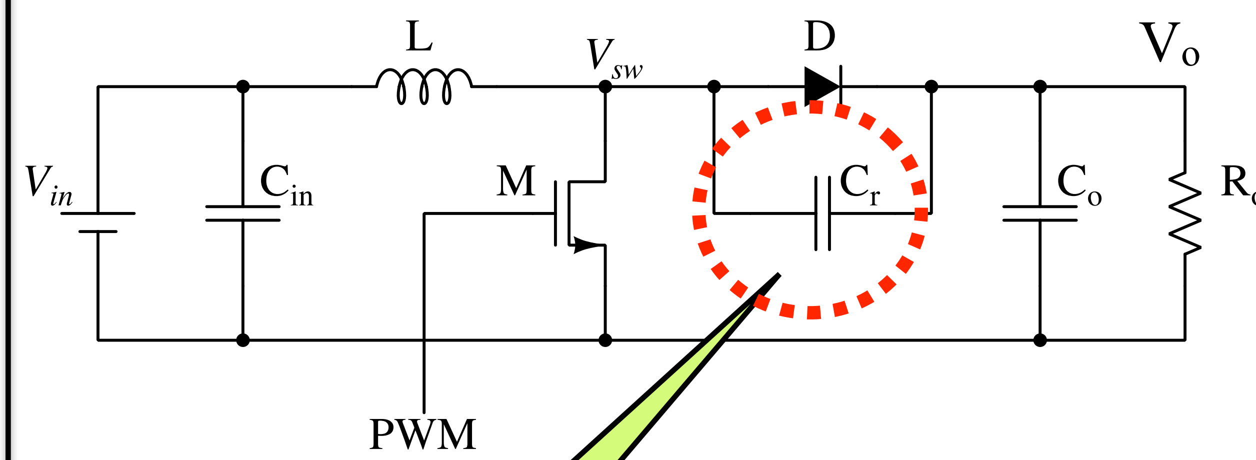
SISO:Single Inductor Single Output

SISO Boost Converter with ZVS-PWM Control

Power Stage



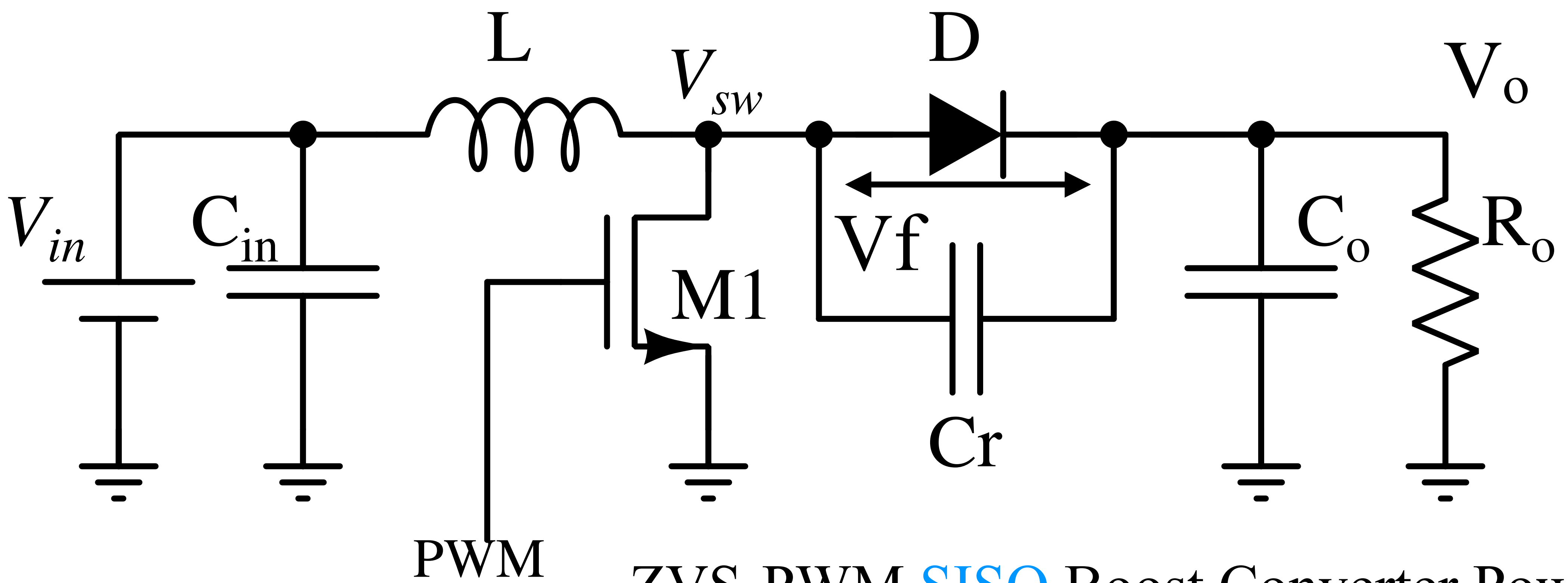
SISO Boost Converter



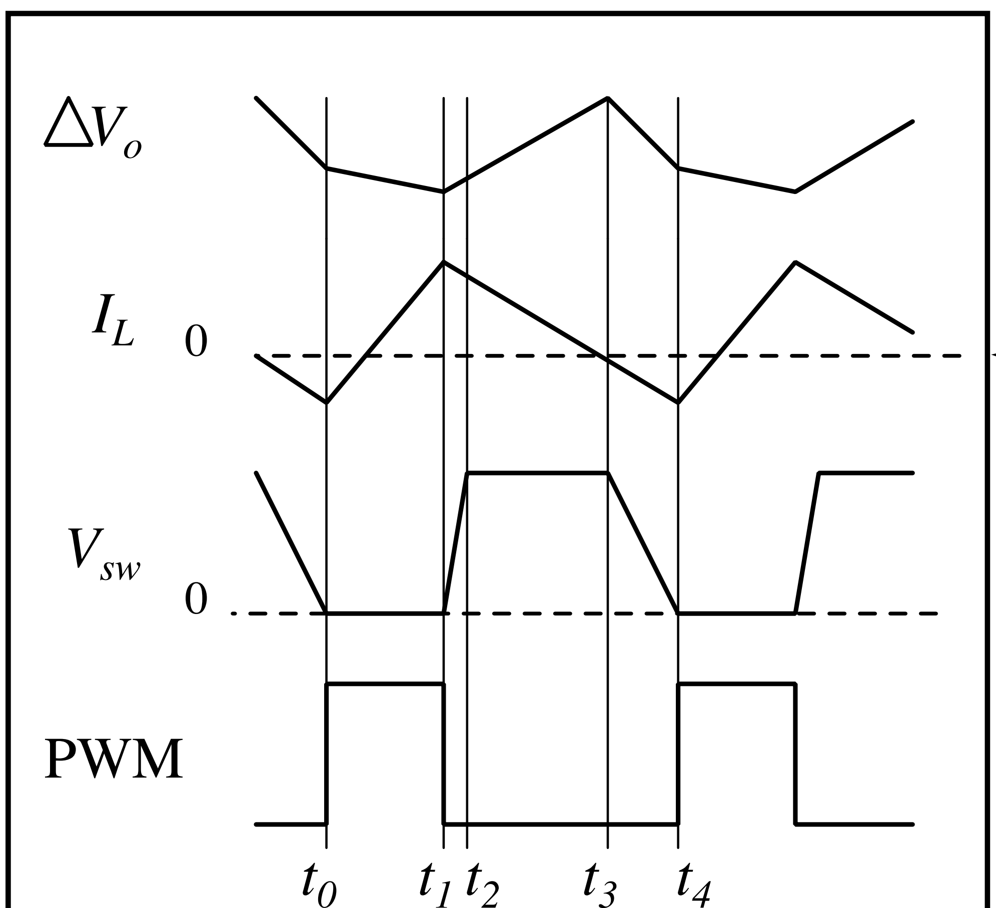
SISO Boost Converter with ZVS-PWM Control

Only add the resonance capacitor Cr!

SISO Boost Converter with ZVS-PWM Control



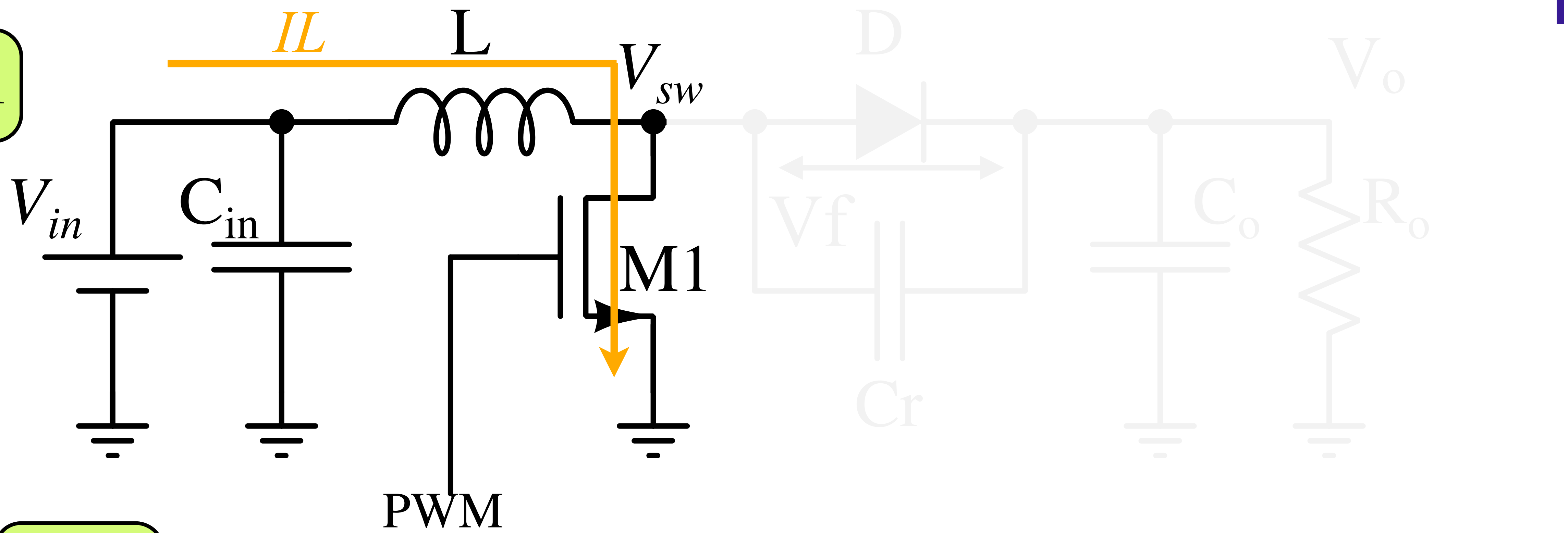
ZVS-PWM SISO Boost Converter Power stage

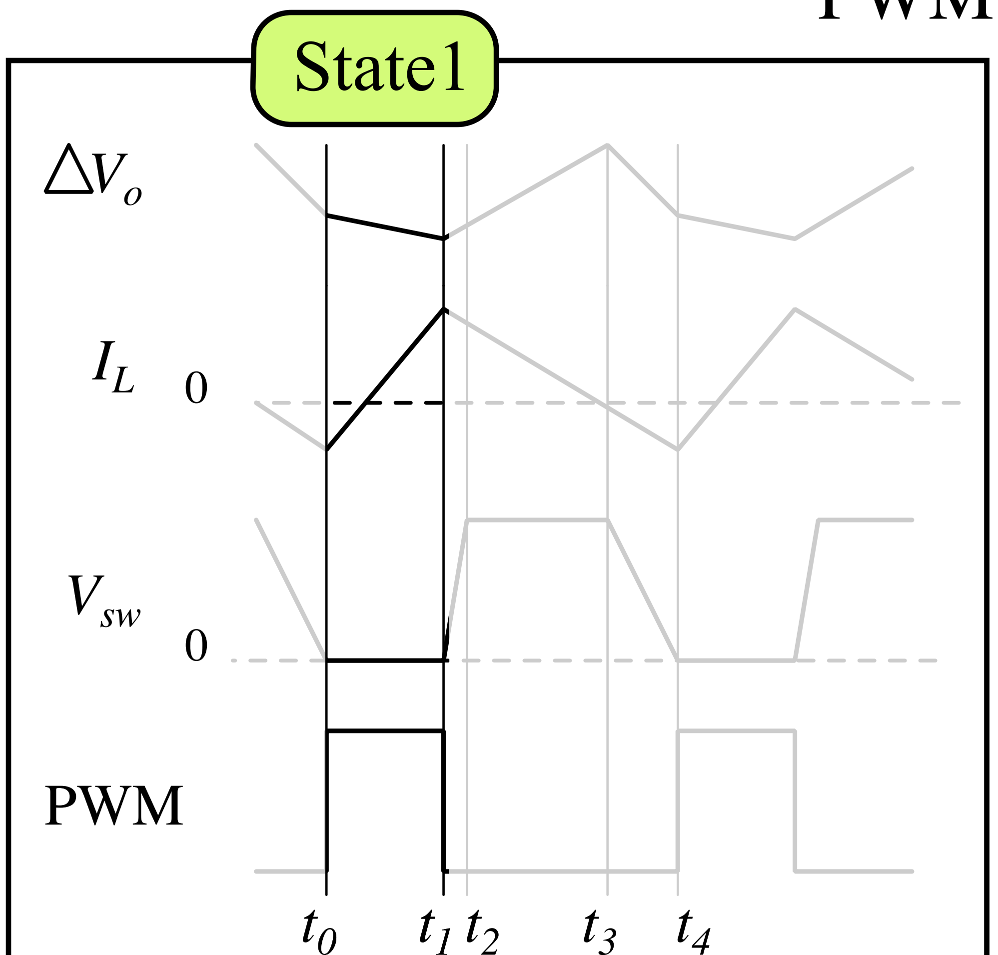


simulation result of SISO Boost Converter with ZVS-PWM control in steady-state. Its operation can distribute in 4 states.

SISO Boost Converter with ZVS-PWM Control

State1





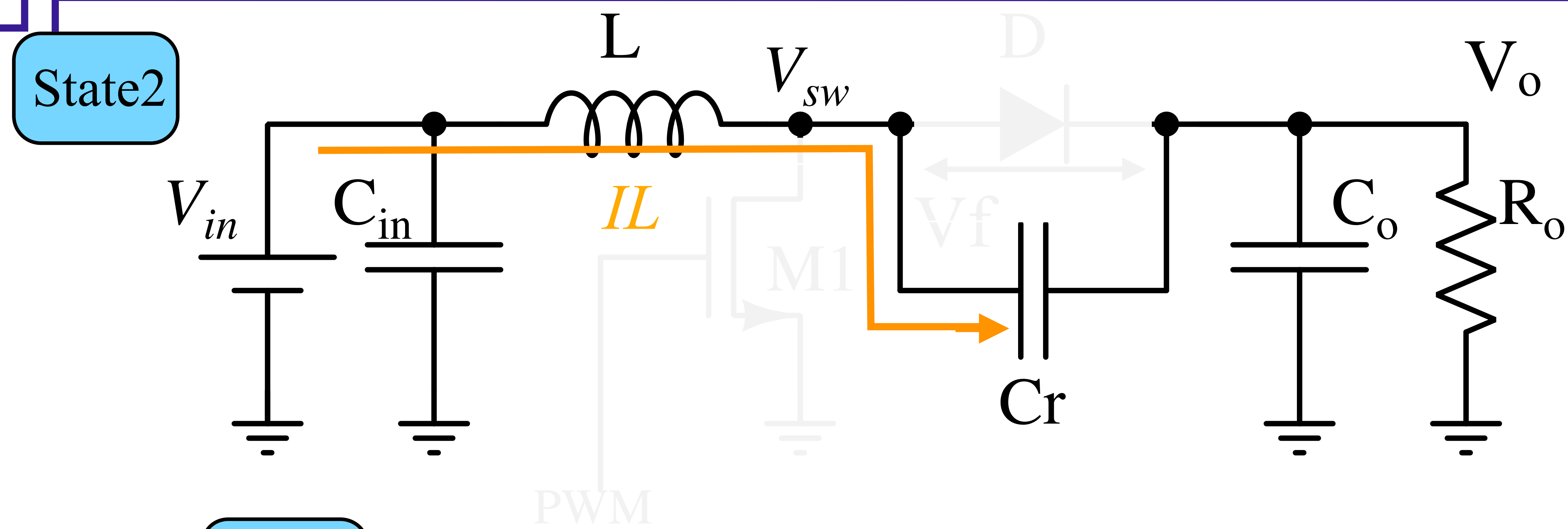
PWM:Hi M1:ON D:OFF

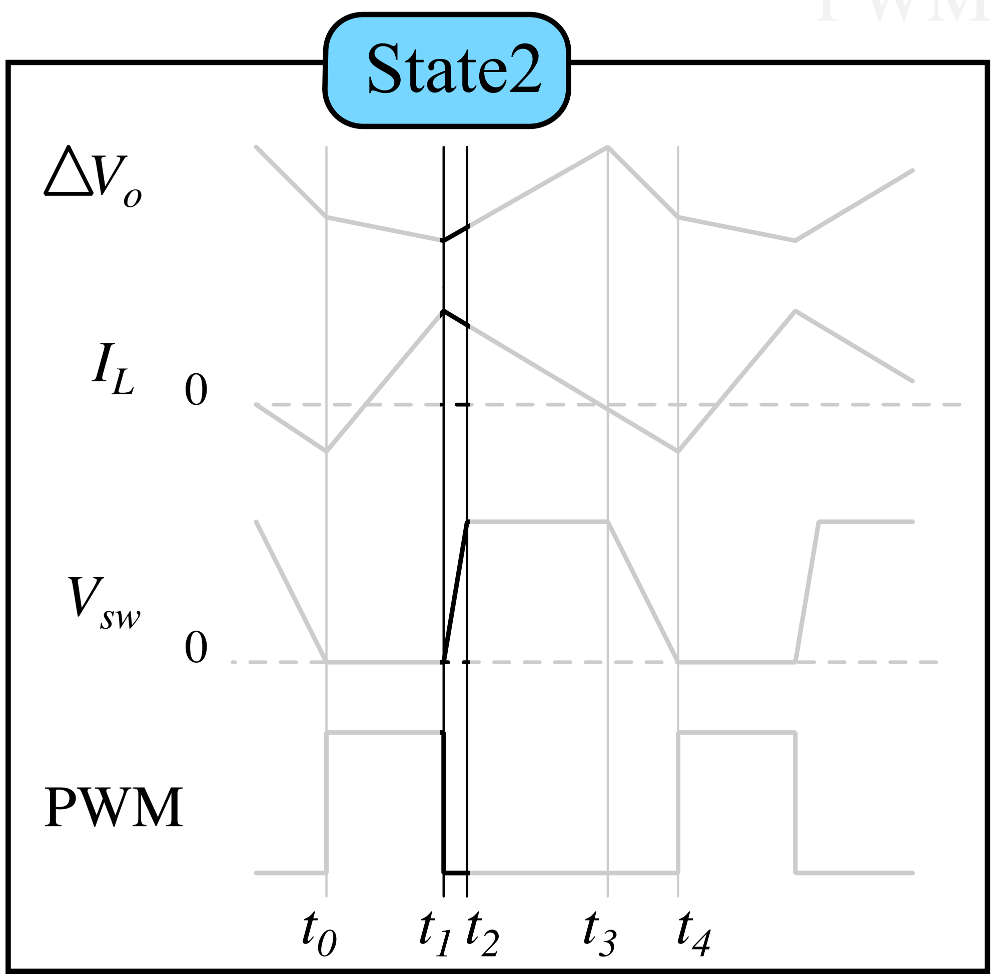
Terminal voltage V_{sw}=0V.

I_L is increased at the rate of V_{in}/L.

C_r is charged to V_o during this period.

SISO Boost Converter with ZVS-PWM Control





PWM:Lo M1:OFF D:OFF

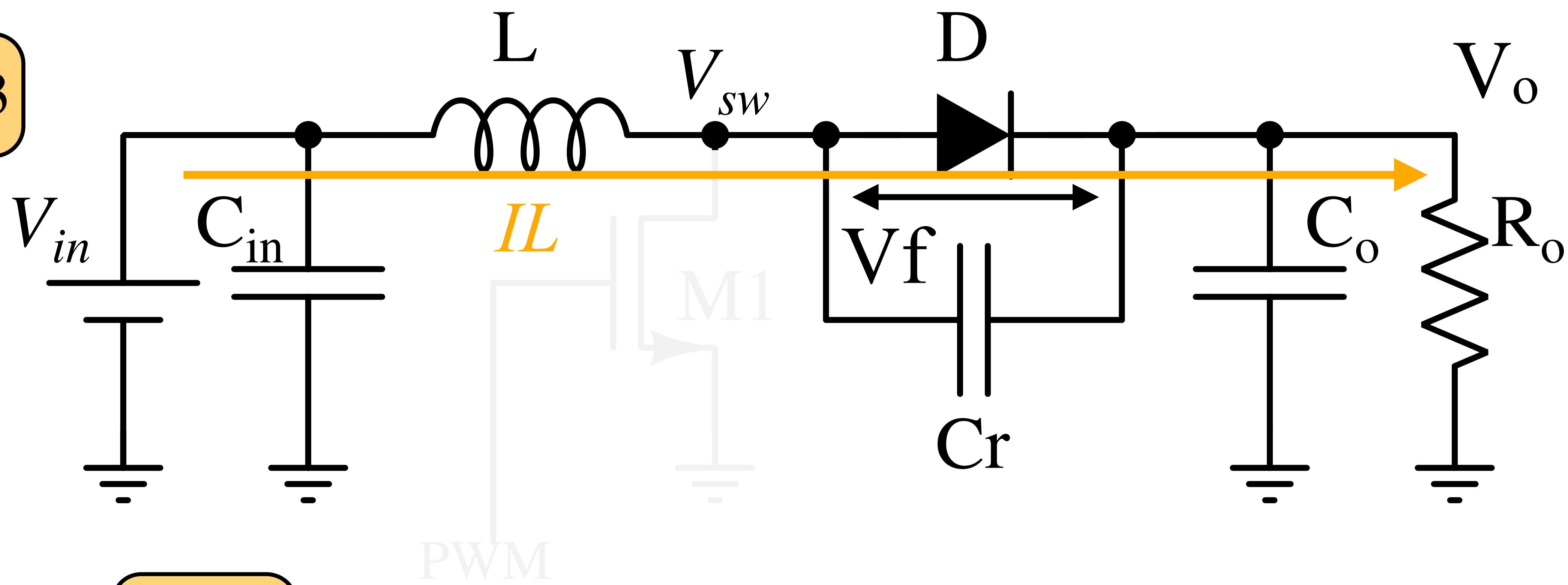
I_L is supplied to output by C_r.

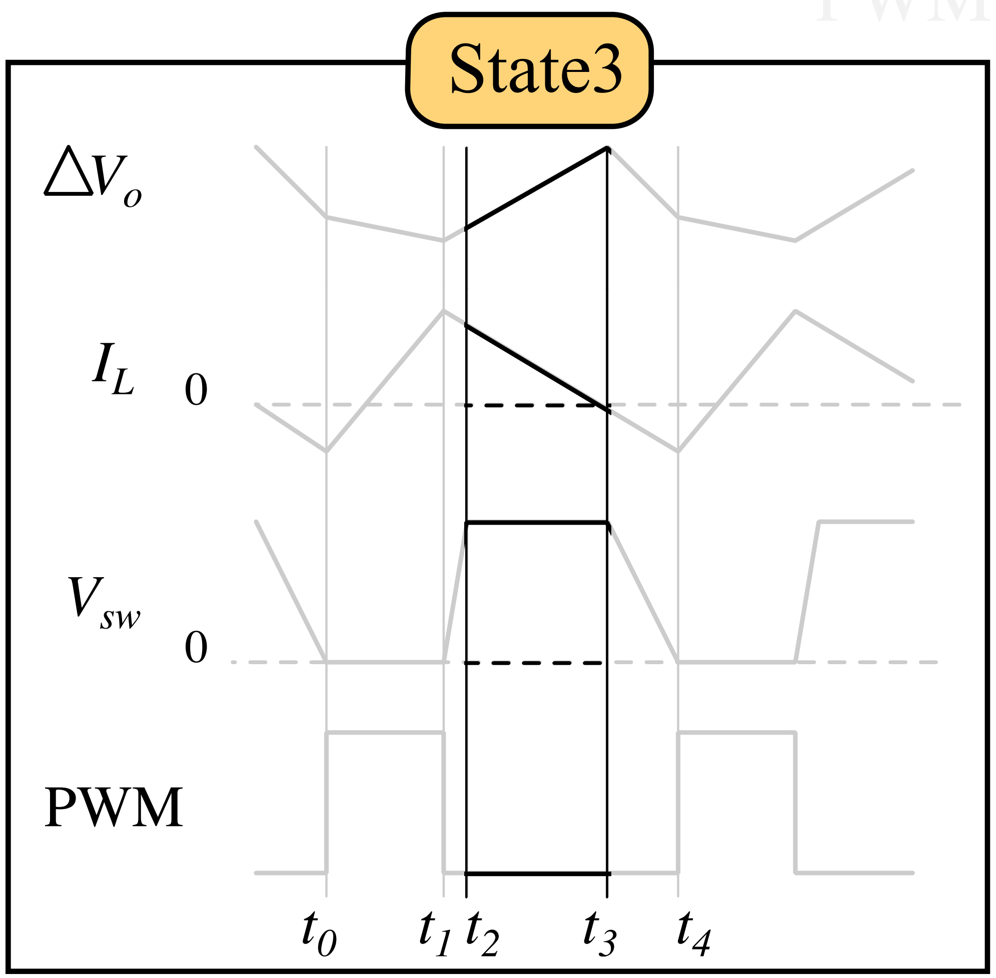
V_{sw} drastically increases due to current supply to C_r.

Finally, V_{sw} increases to V_o+V_f until diode is turned ON.

$\color{#0099ff}{SISO}$ Boost Converter with ZVS-PWM Control

State3





PWM:Lo M1:OFF D:ON

V_{sw} is V_o+V_f, Diode is turned ON, and resonance stops.

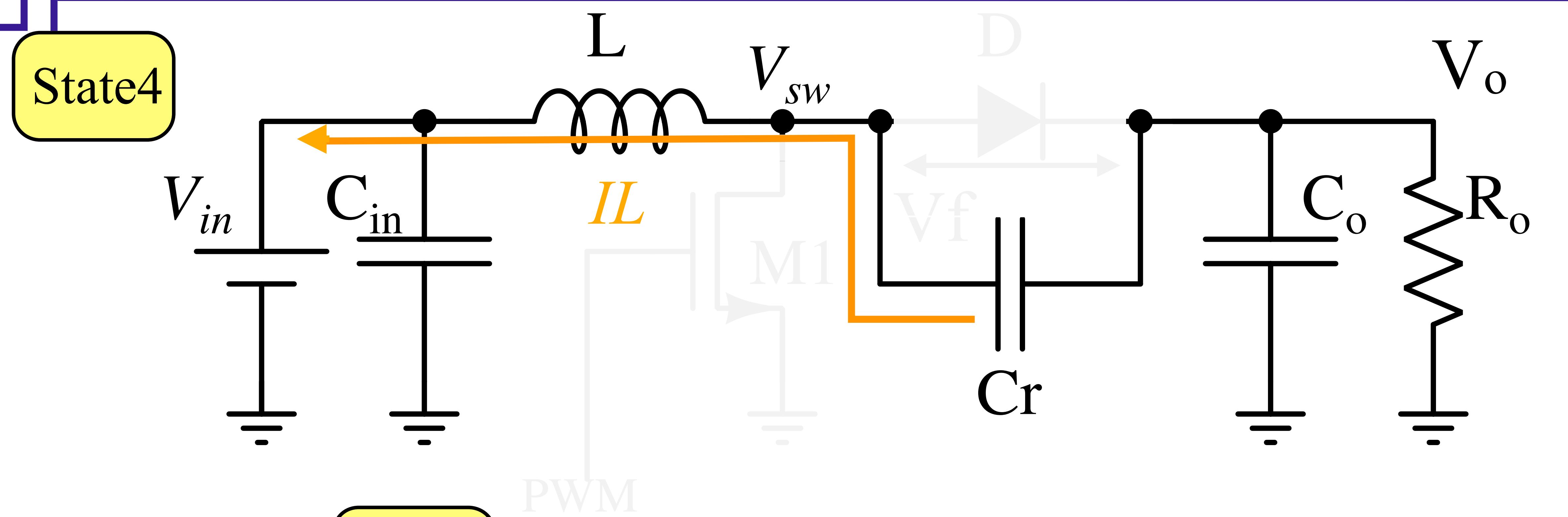
I_L flows through diode from V_{in}.

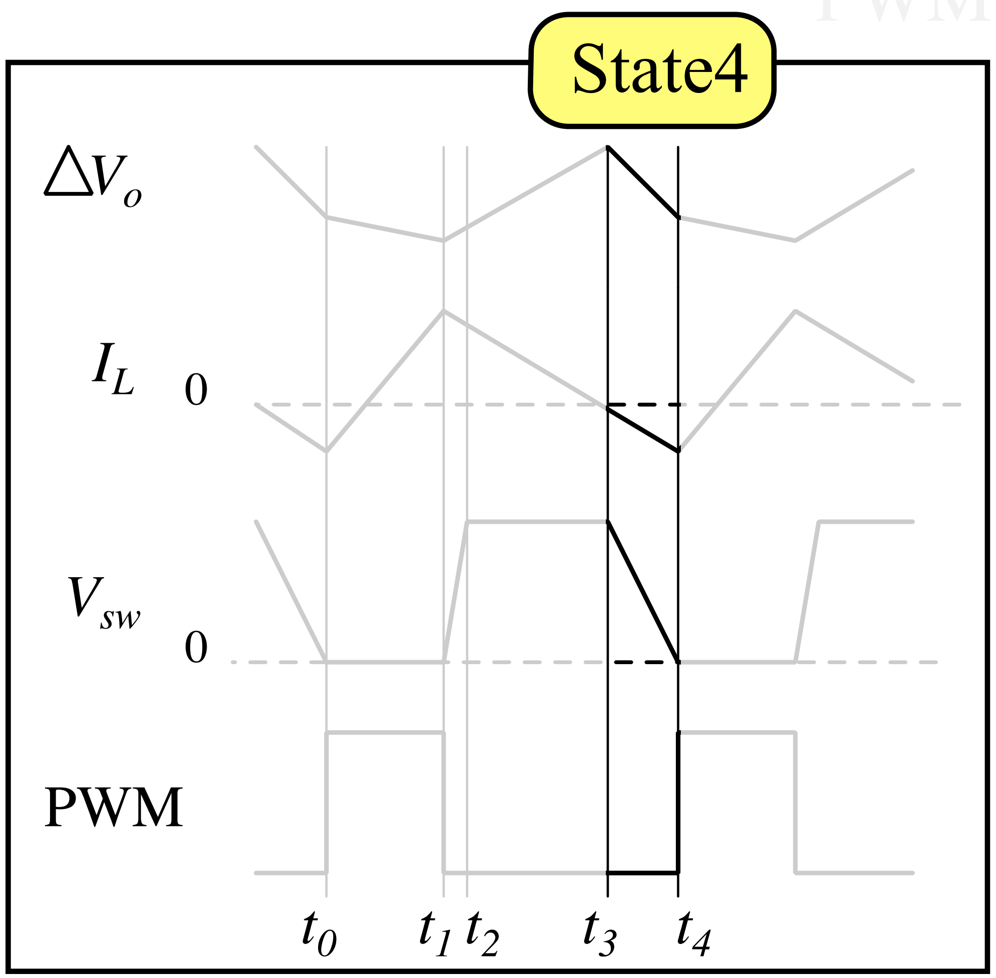
I_L decreases at the rate of (V_{in}-V_o)/L.

Finally, I_L is turned to the opposite direction flow at t_3.

In this period, V_{sw} maintains to V_o+V_f.

SISO Boost Converter with ZVS-PWM Control





PWM:Lo M1:OFF D:OFF

I_L is negative, Diode is turned OFF,

and resonance starts again.

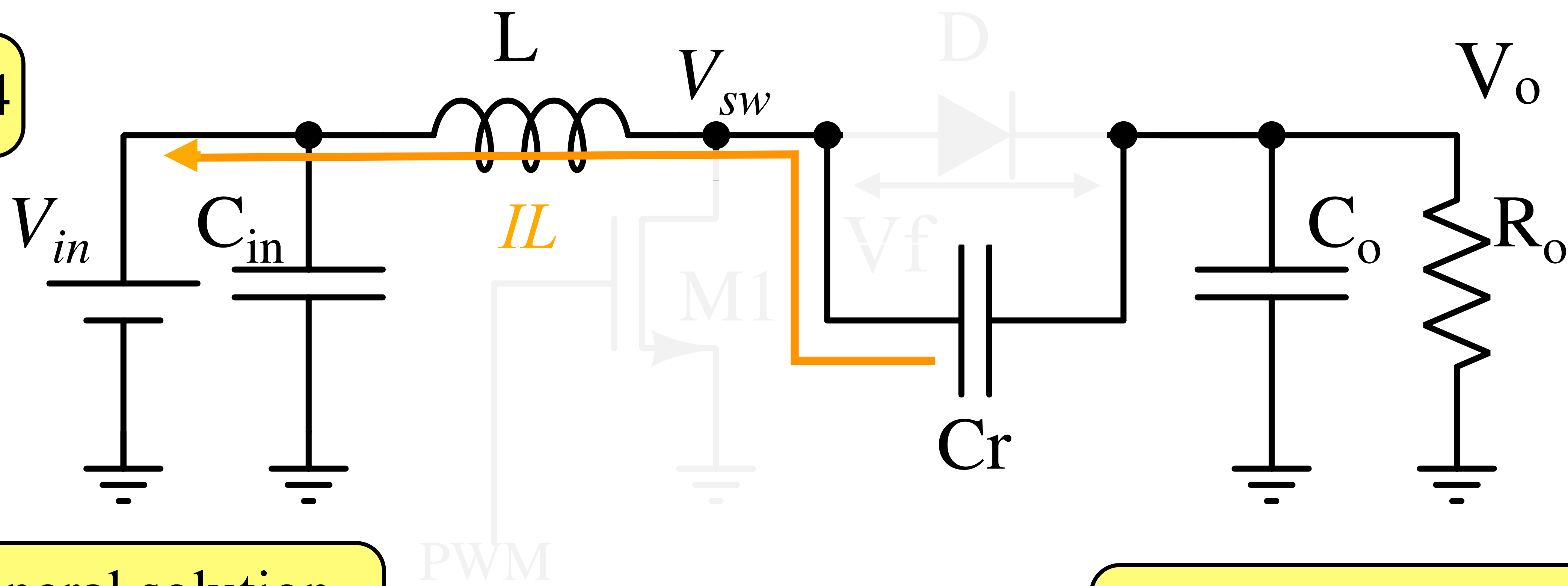
V_{sw} gradually decreases due to I_L supply.

When V_{sw} reaches at 0V,

then M1 is turned ON and state returns to State1.

The input and output voltage condition

State4



General solution

$$I_L(t) = (V_{in} - V_o) \cdot \sqrt{\frac{C_r}{L}} \cdot \sin wt$$

$$V_{sw}(t) = V_o \cdot \cos wt + V_{in}(1 - \cos wt)$$

$$(w : \frac{1}{\sqrt{C_r \cdot L}})$$

$\cos\omega t = -1$

The ZVS condition

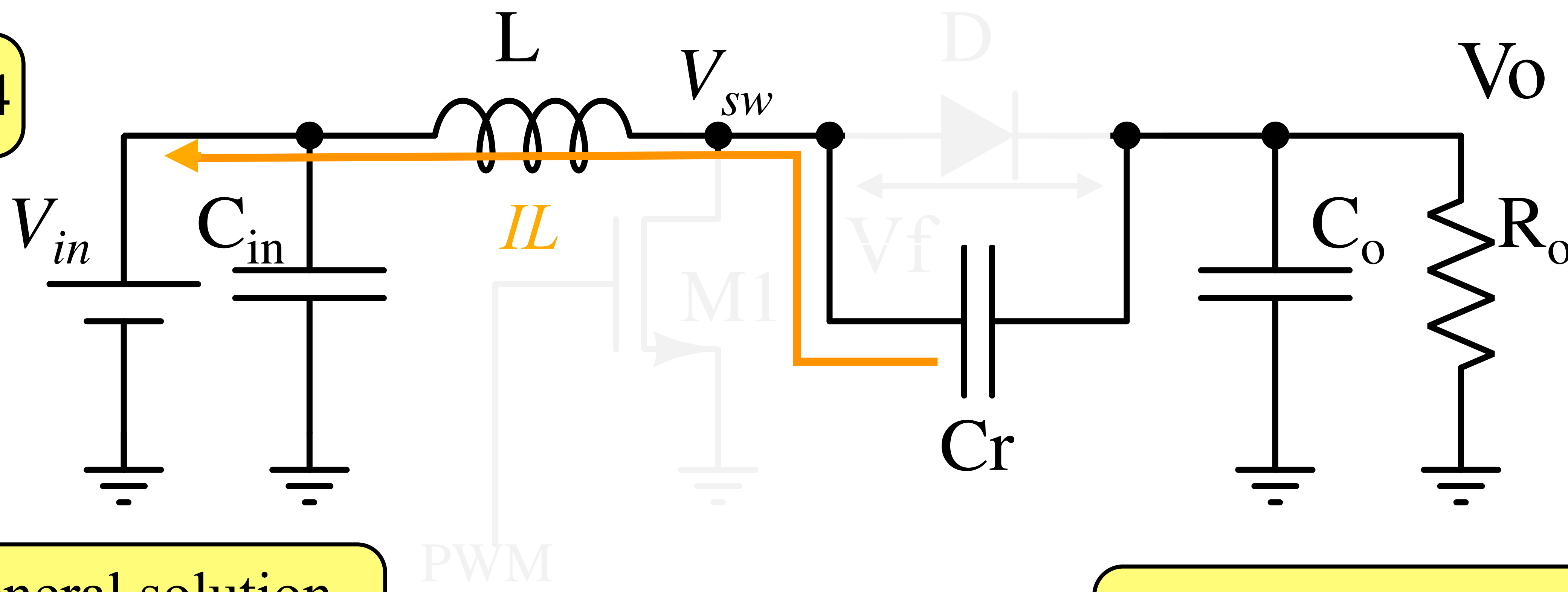
The minimum of $V_{sw}(t)$ ≦ 0V

$$-V_o + 2V_{in} \leq 0V$$

$$V_o \geq 2V_{in}$$

The input and output voltage condition

State4



General solution

$$I_L(t) = (V_{in} - V_o) \cdot \sqrt{\frac{C_r}{L}} \cdot \sin wt$$

$$V_{sw}(t) = V_o \cdot \cos wt + V_{in}(1 - \cos wt)$$

$$(w : \frac{1}{\sqrt{C_r \cdot L}})$$

The ZVS condition

The minimum of $V_{sw}(t)$ ≦ 0V

cosωt=-1

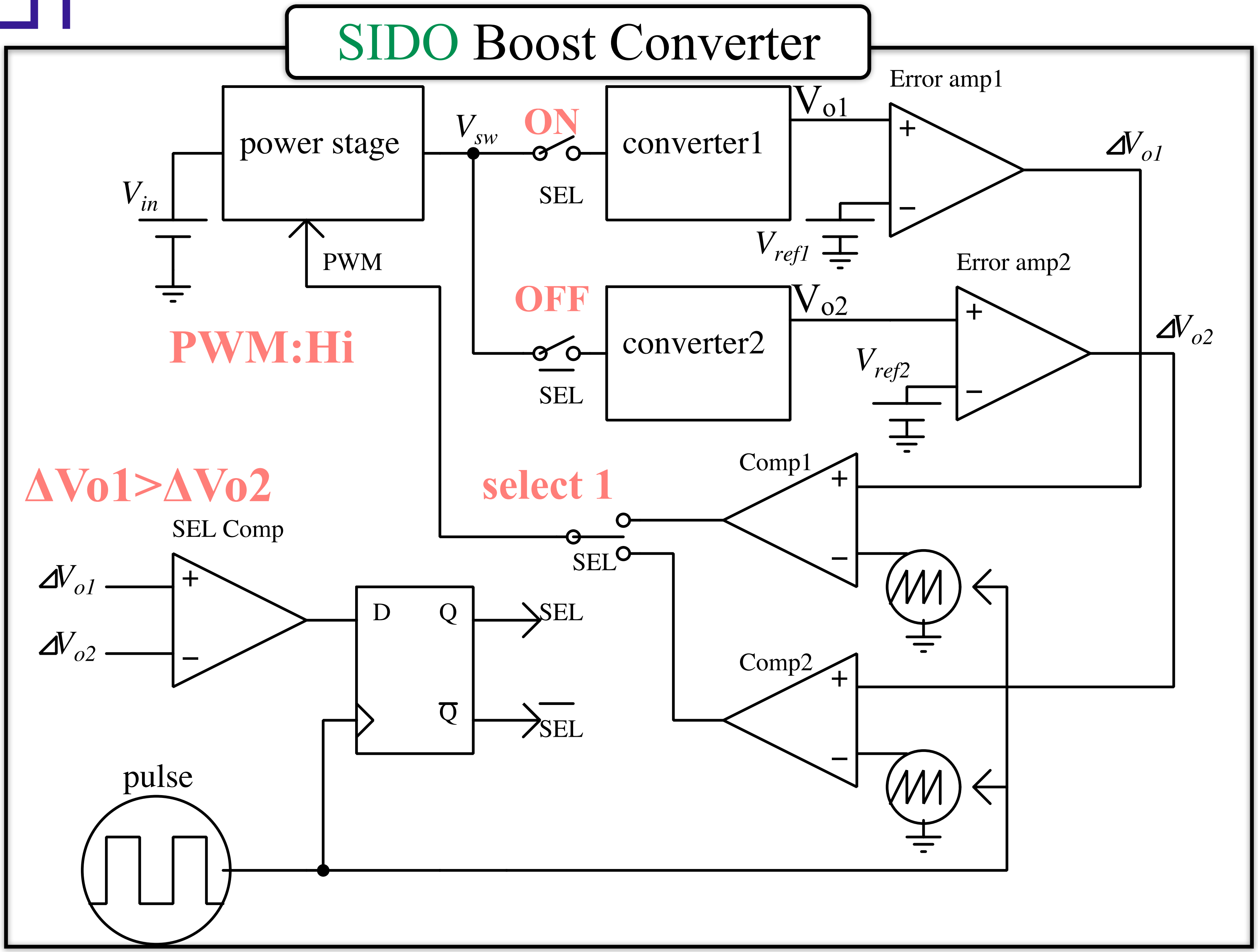
$$-V_o + 2V_{in} \leq 0V$$

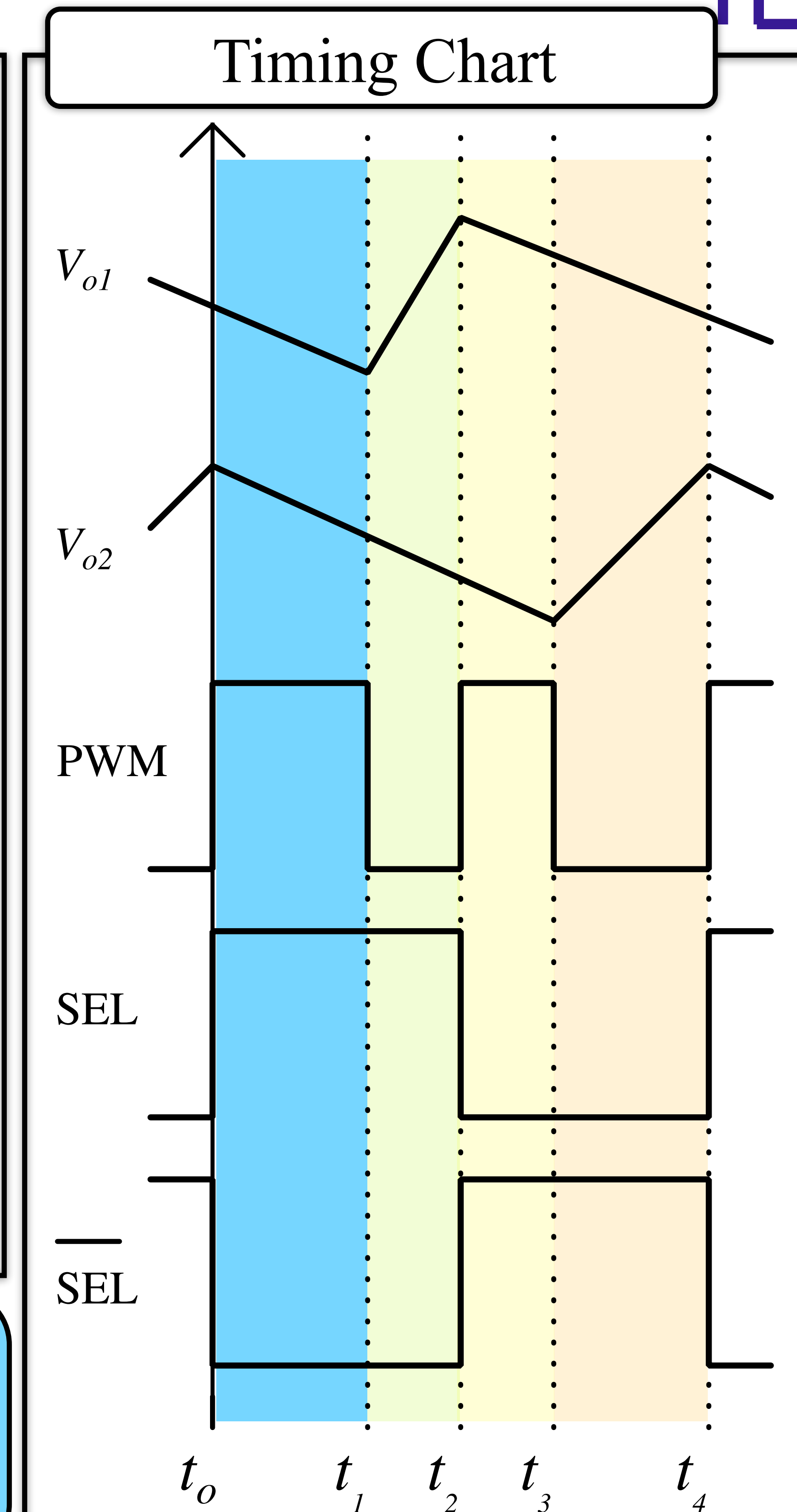
$$V_o \geq 2V_{in}$$

The input and output voltage condition!

OUTLINE

Conventional SIDO Boost Converter

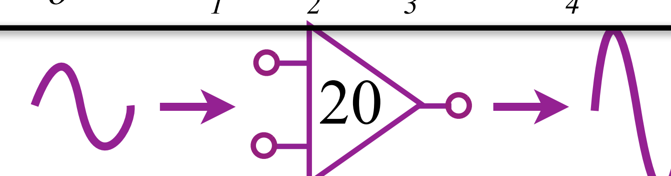




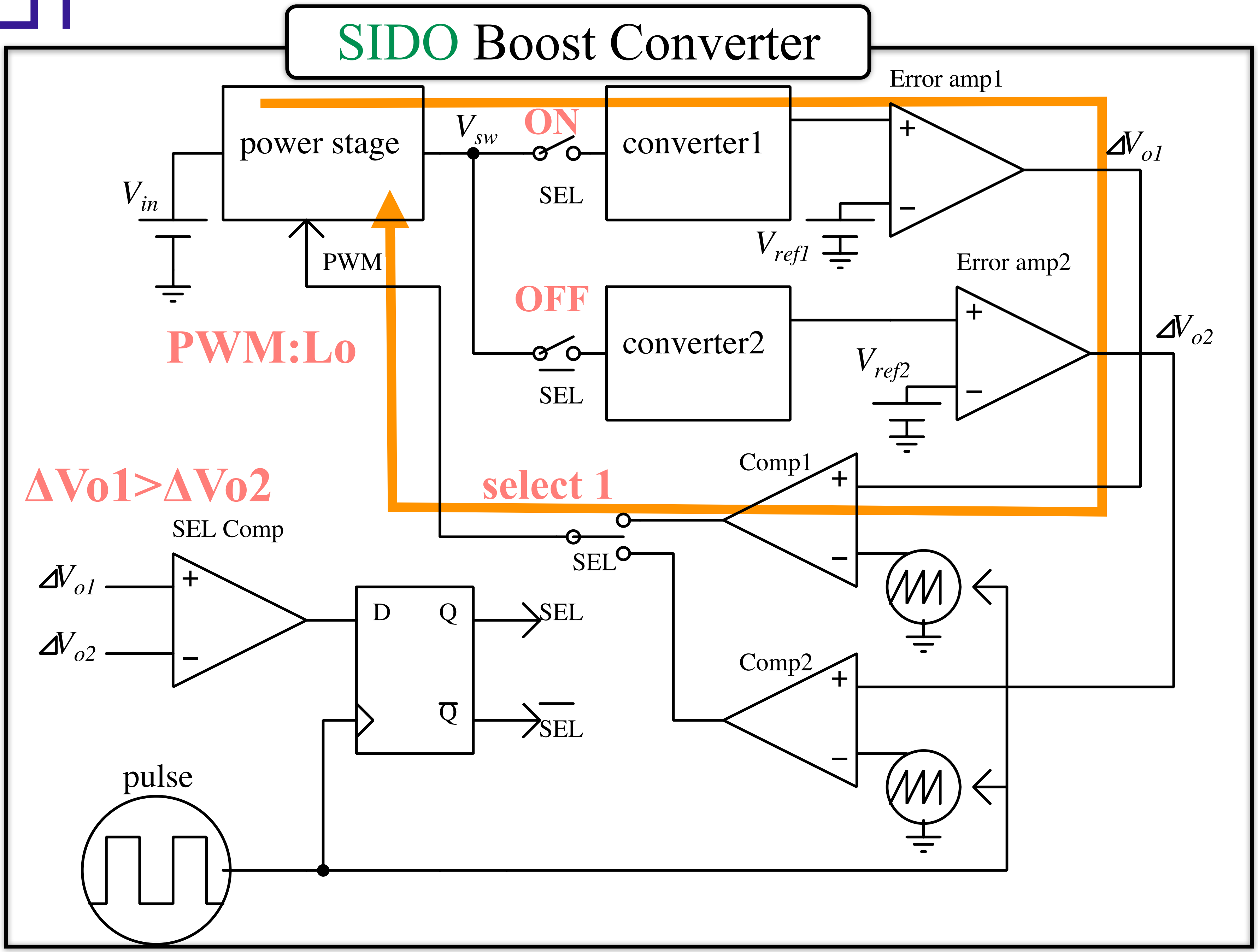
t0〜t1

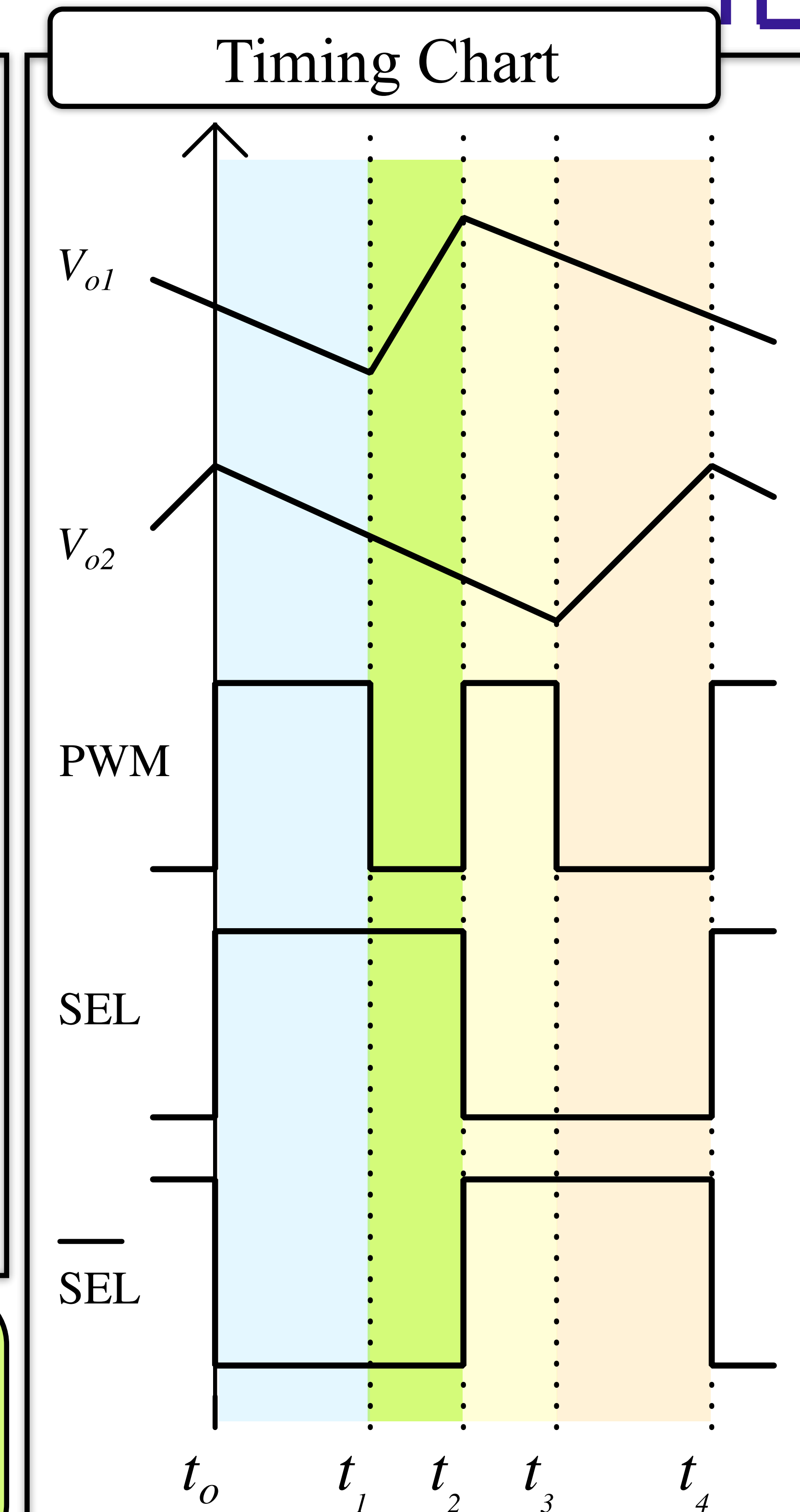
SEL signal is Hi, and Output1 selected.

PWM signal is Hi. V_{o1} is decreased during this period.



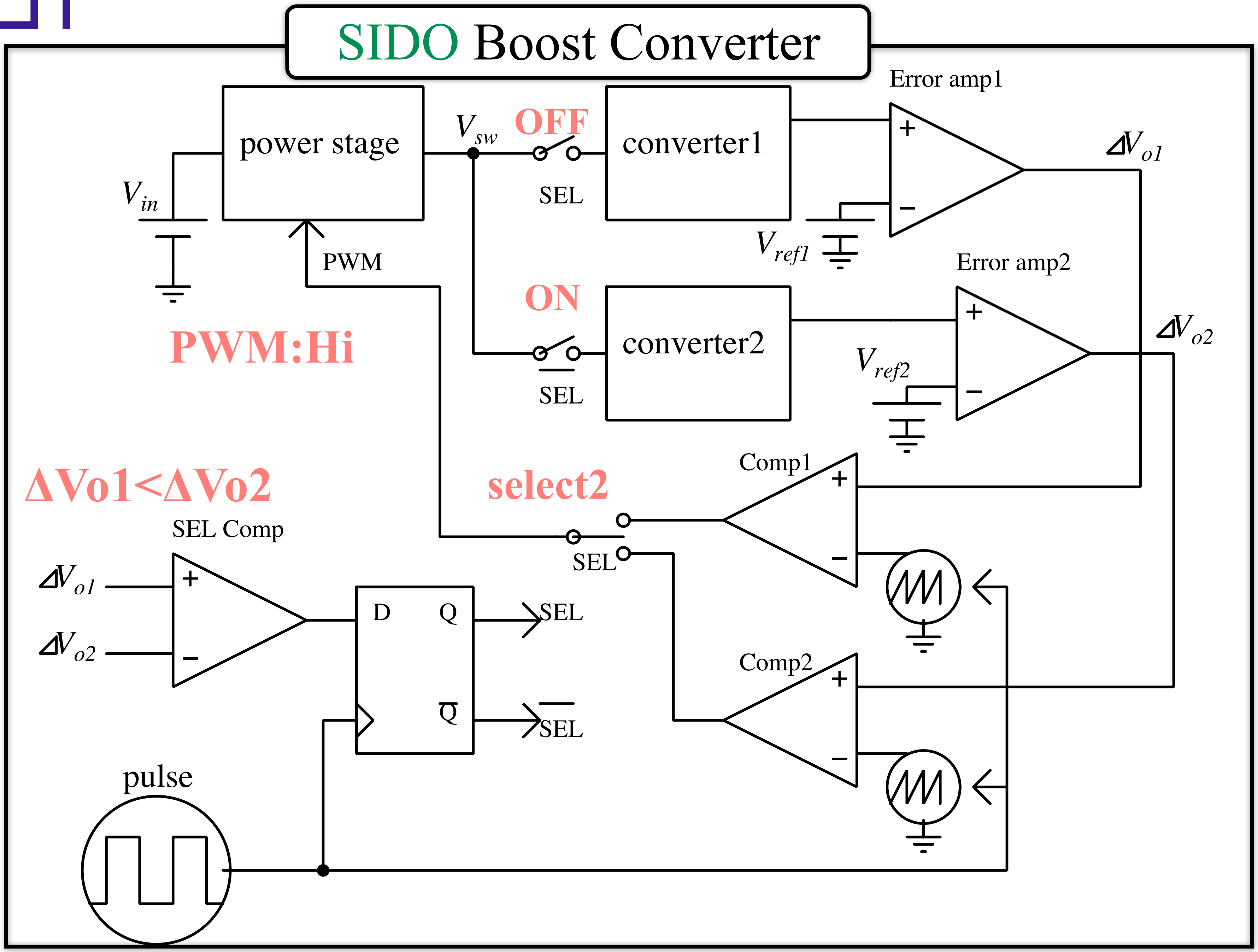
Conventional SIDO Boost Converter

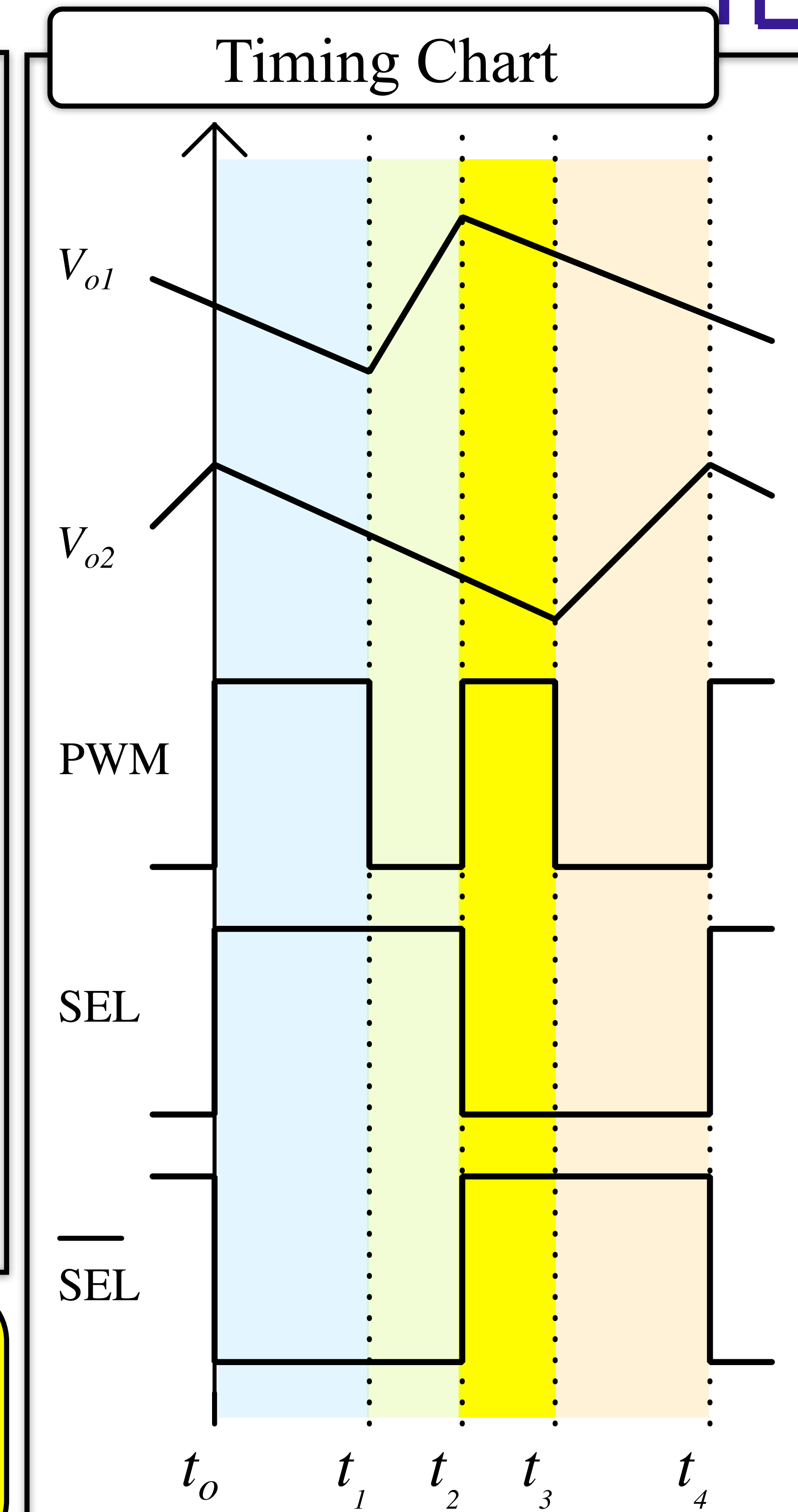




t1～t2 SEL signal is Hi, and Output1 selected.
PWM signal is Lo. V_{o1} is increase during this period.
$\Delta V_{o1} < \Delta V_{o2}$ at t_2, then SEL signal is turned Lo.

Conventional SIDO Boost Converter



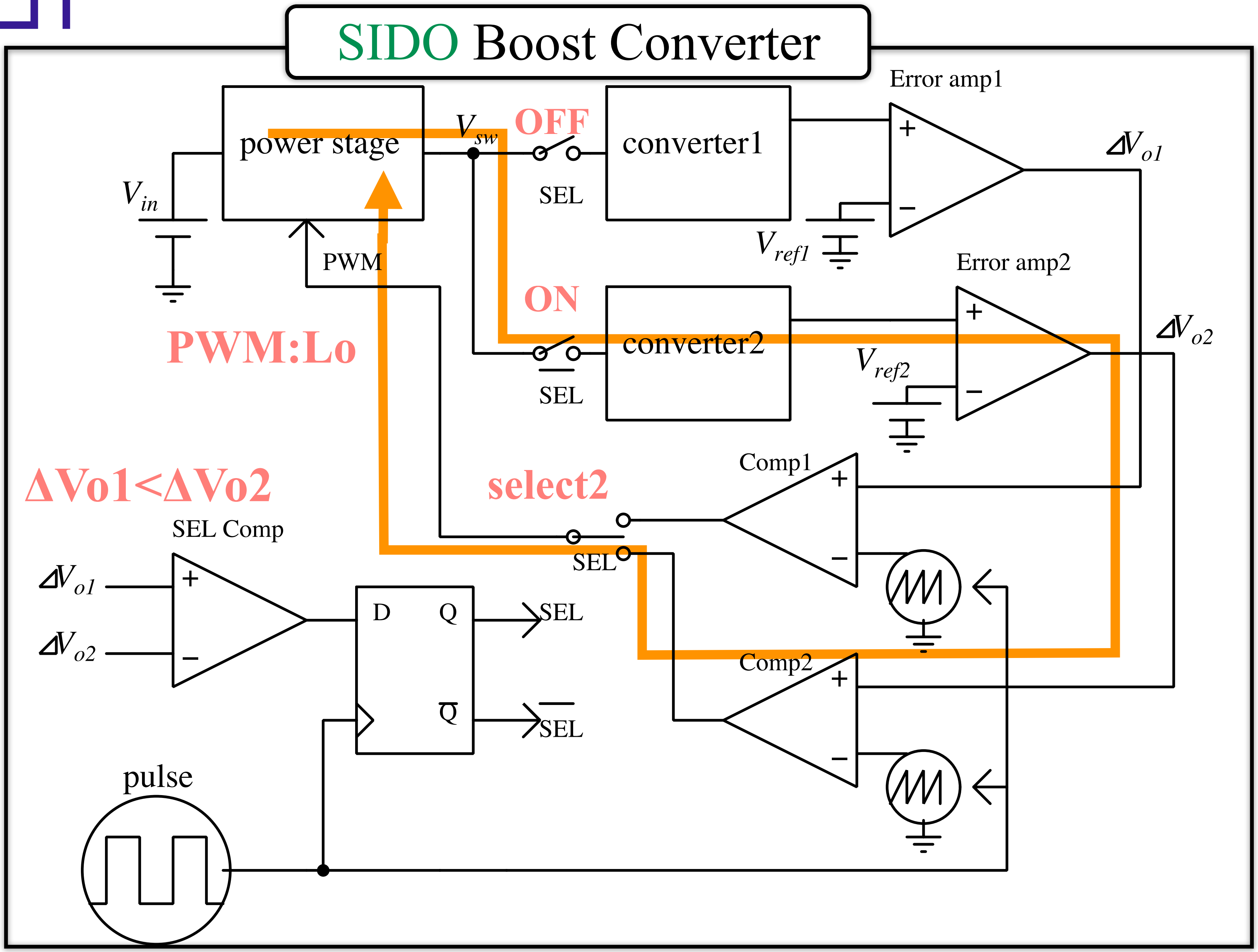


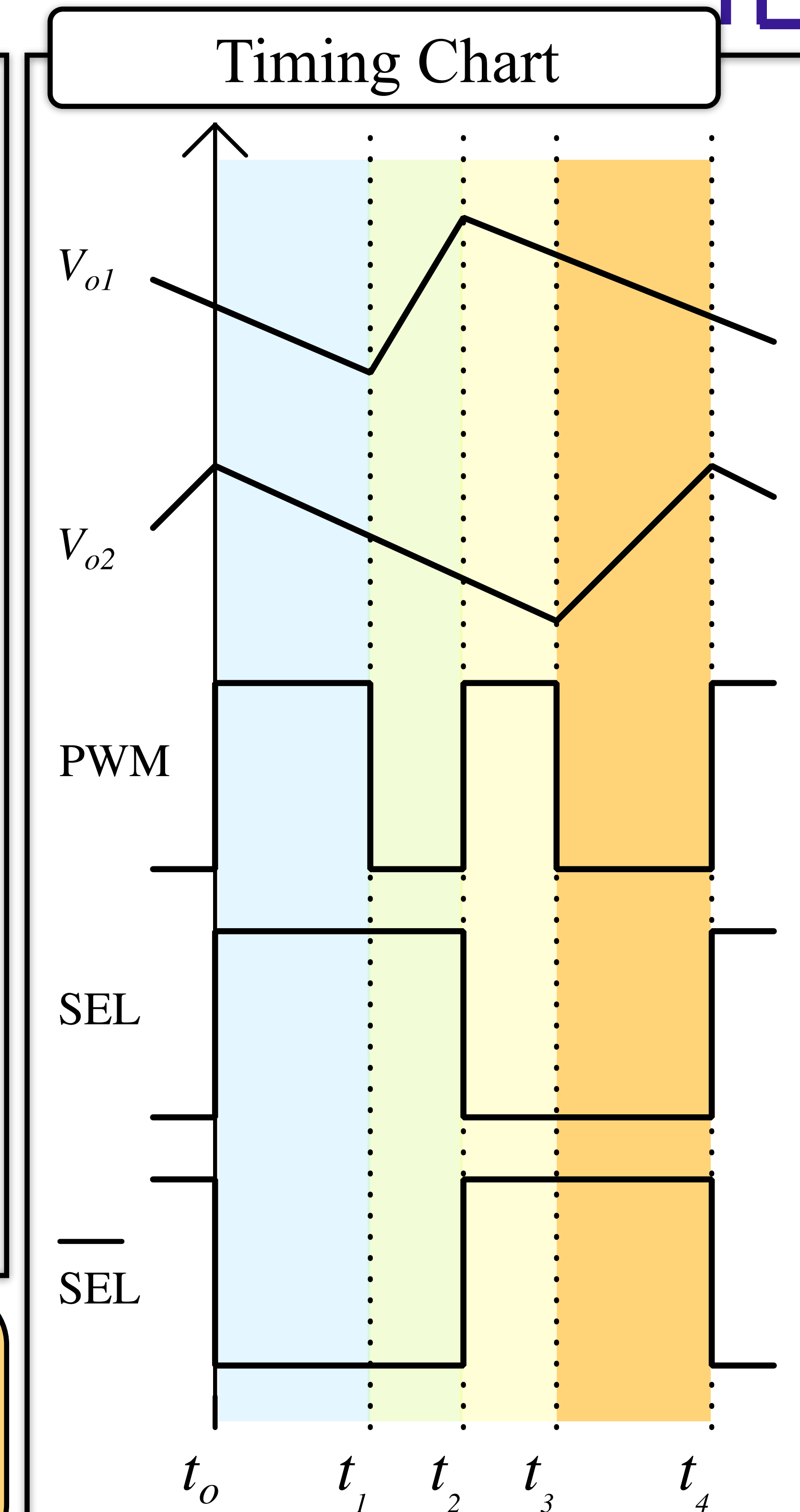
t2～t3

SEL signal is Lo, and Output2 selected.

PWM signal is Hi. V_{o2} is decreased during this period.

Conventional SIDO Boost Converter



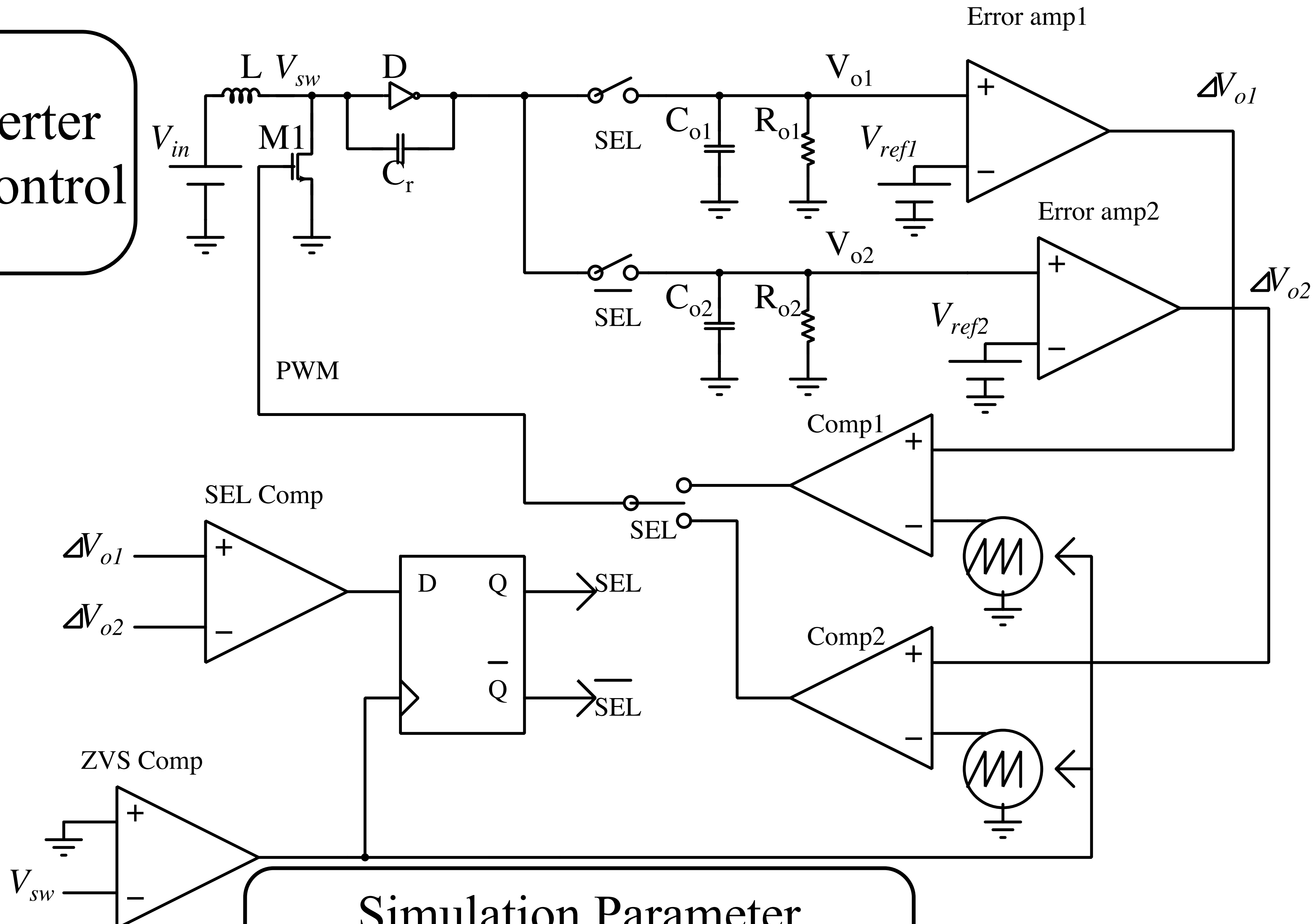


t3～t4 SEL signal is Lo, and Output2 selected.
PWM signal is Lo, V_{o2} is increase during this period.
$\Delta V_{o1} > \Delta V_{o2}$ at t_4, then SEL signal is turned Lo.

OUTLINE

Simulation Circuit (SIDO)

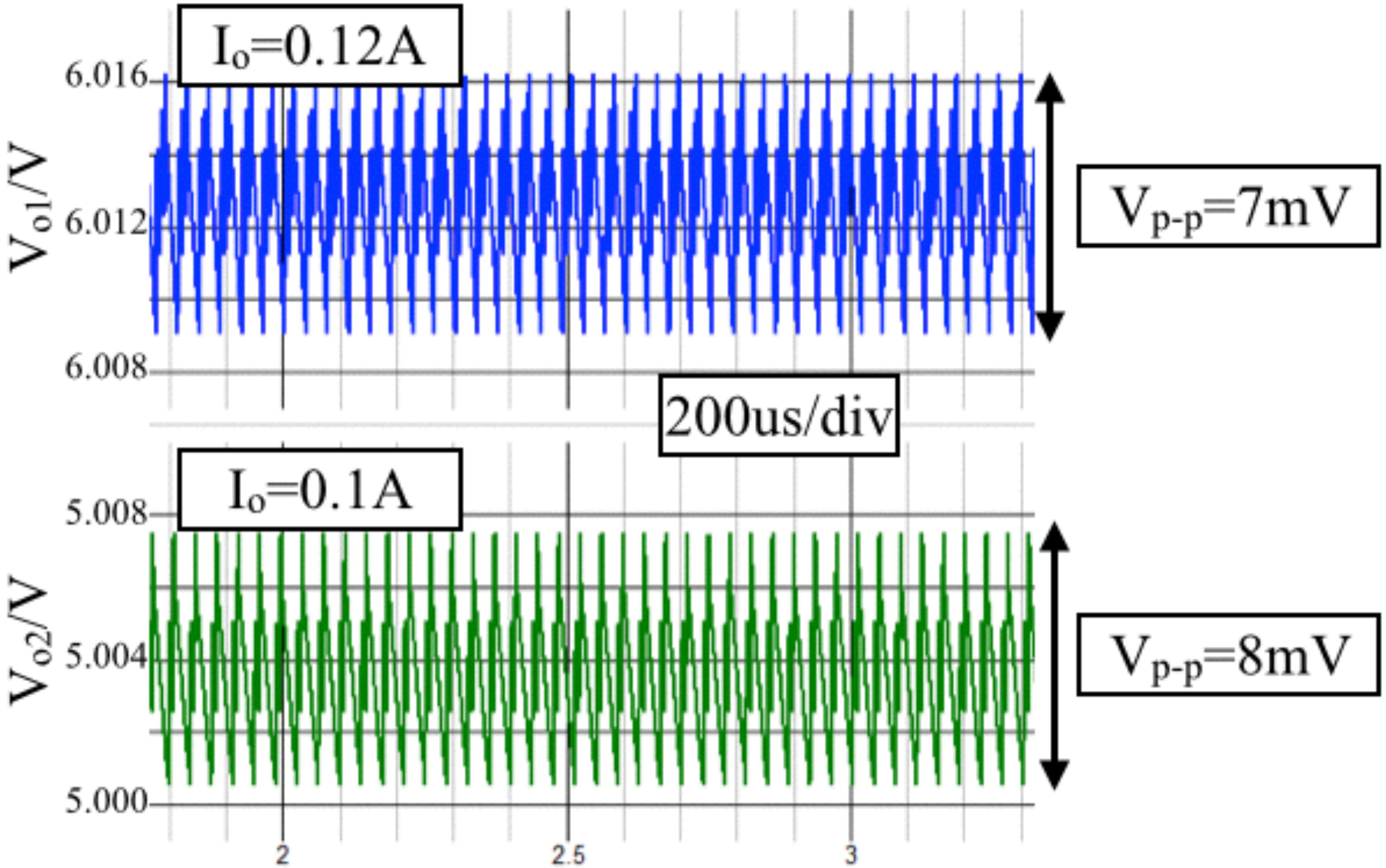
SIDO boost converter with ZVS-PWM control



Simulation Parameter

V	L	C	C	C	R	R	V	V
2.5V	3.9uH	100nF	470uF		50Ω		6V	5V

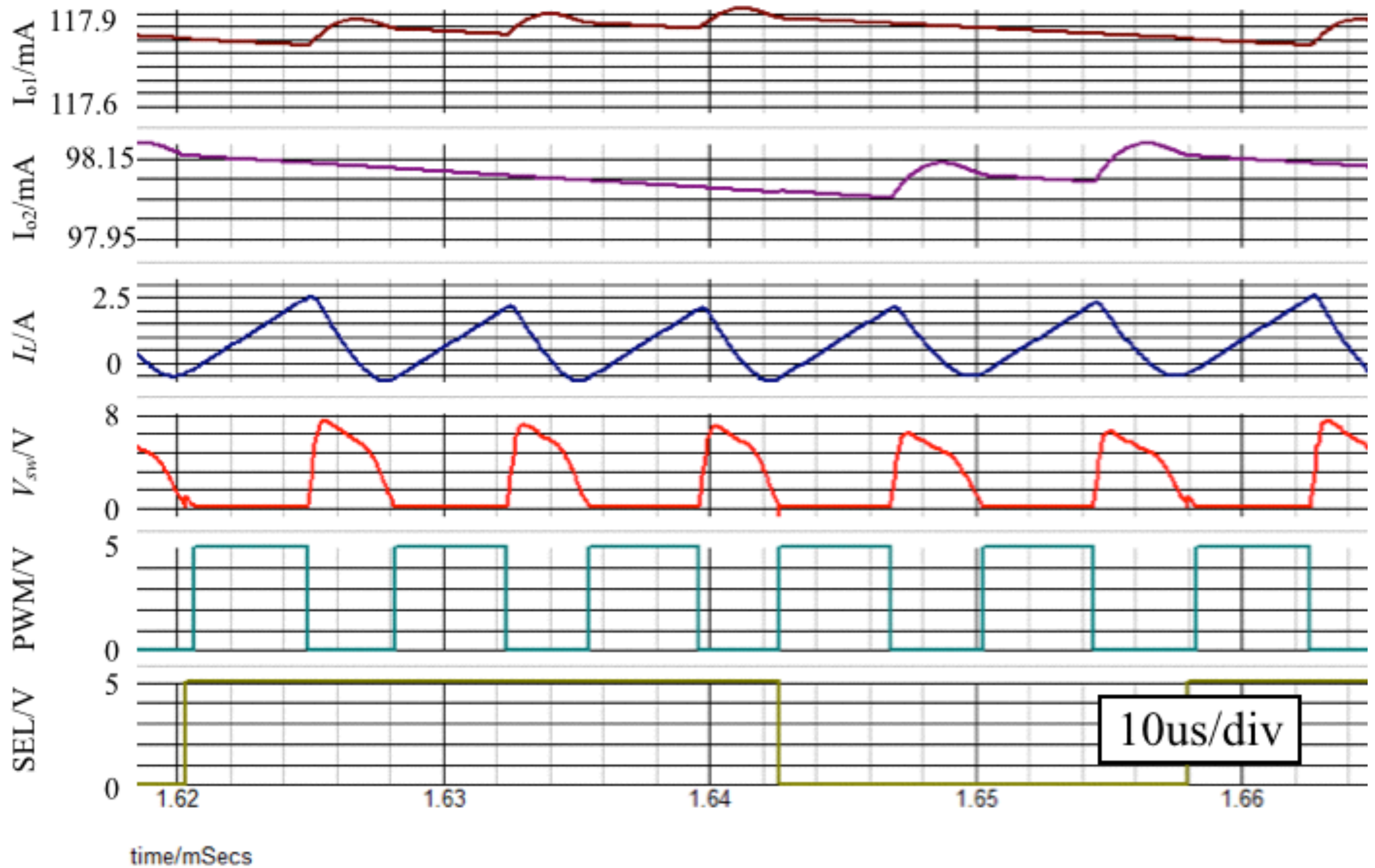
Simulation Circuit (SIDO)



output waveforms

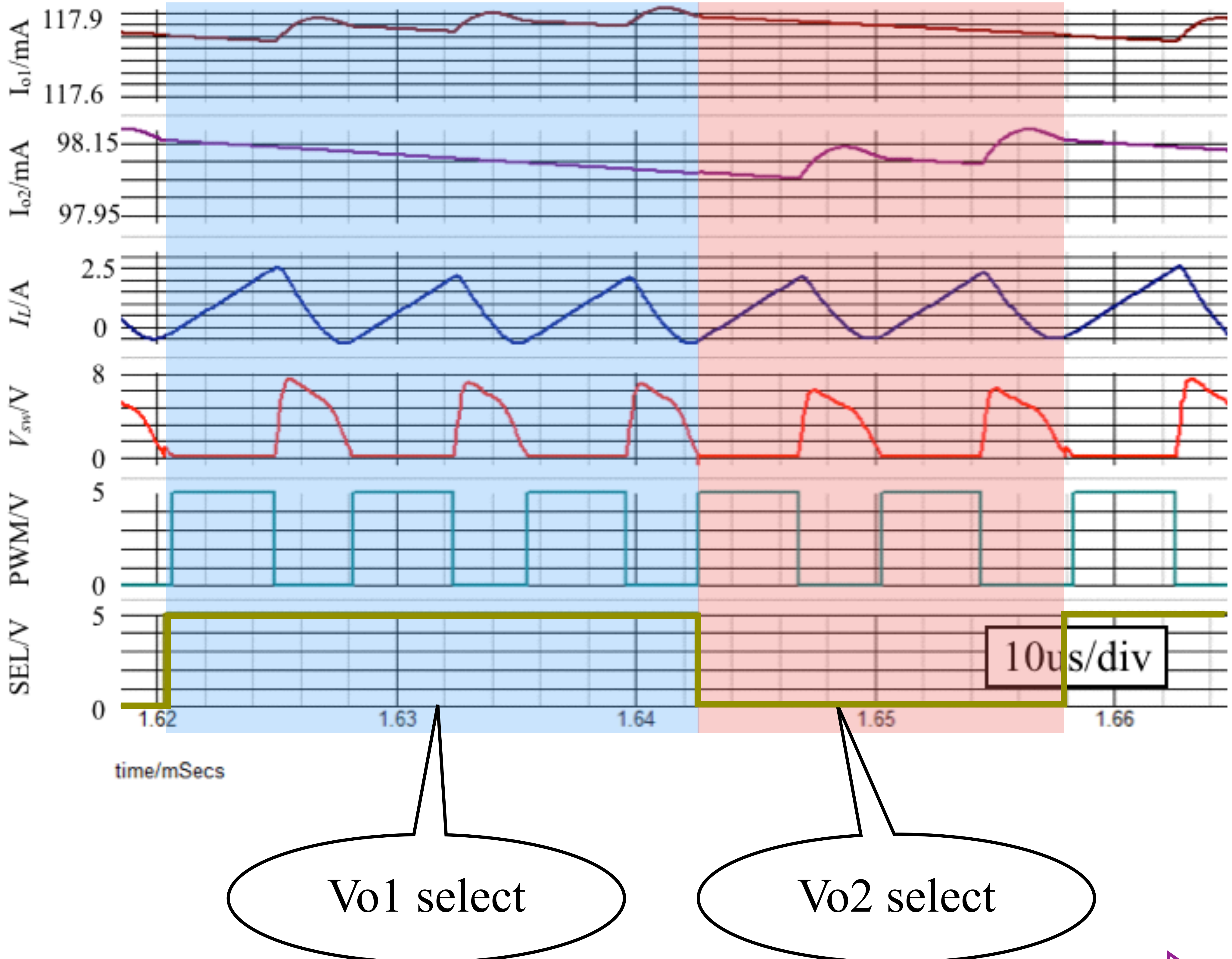
- the output voltage ripples of V_{o1} and V_{o2} are under $10mV_{p-p}$

Simulation Circuit (SIDO)

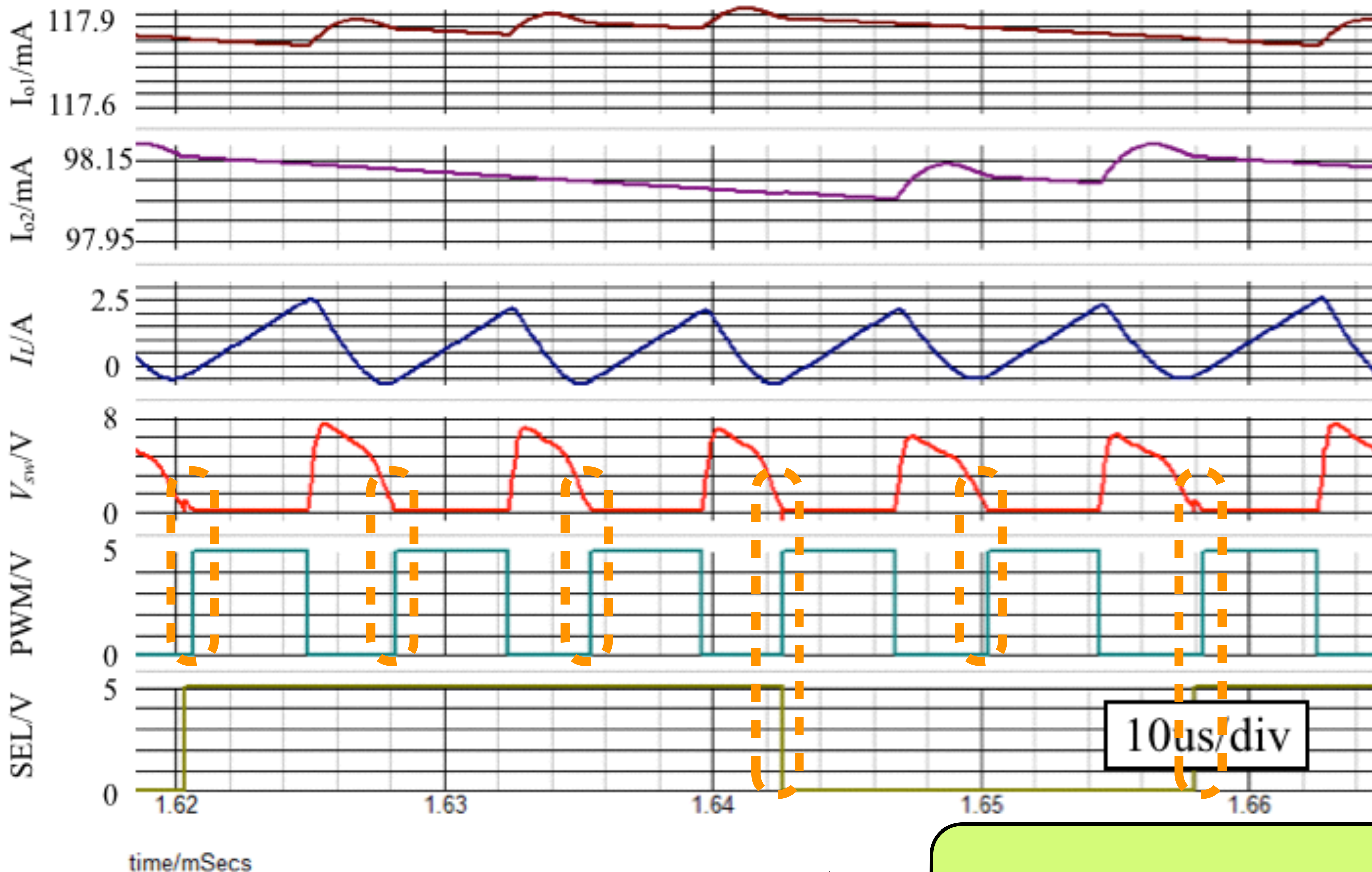


Operation waveforms of SIDO boost converter with ZVS-PWM control

Simulation Circuit (SIDO)



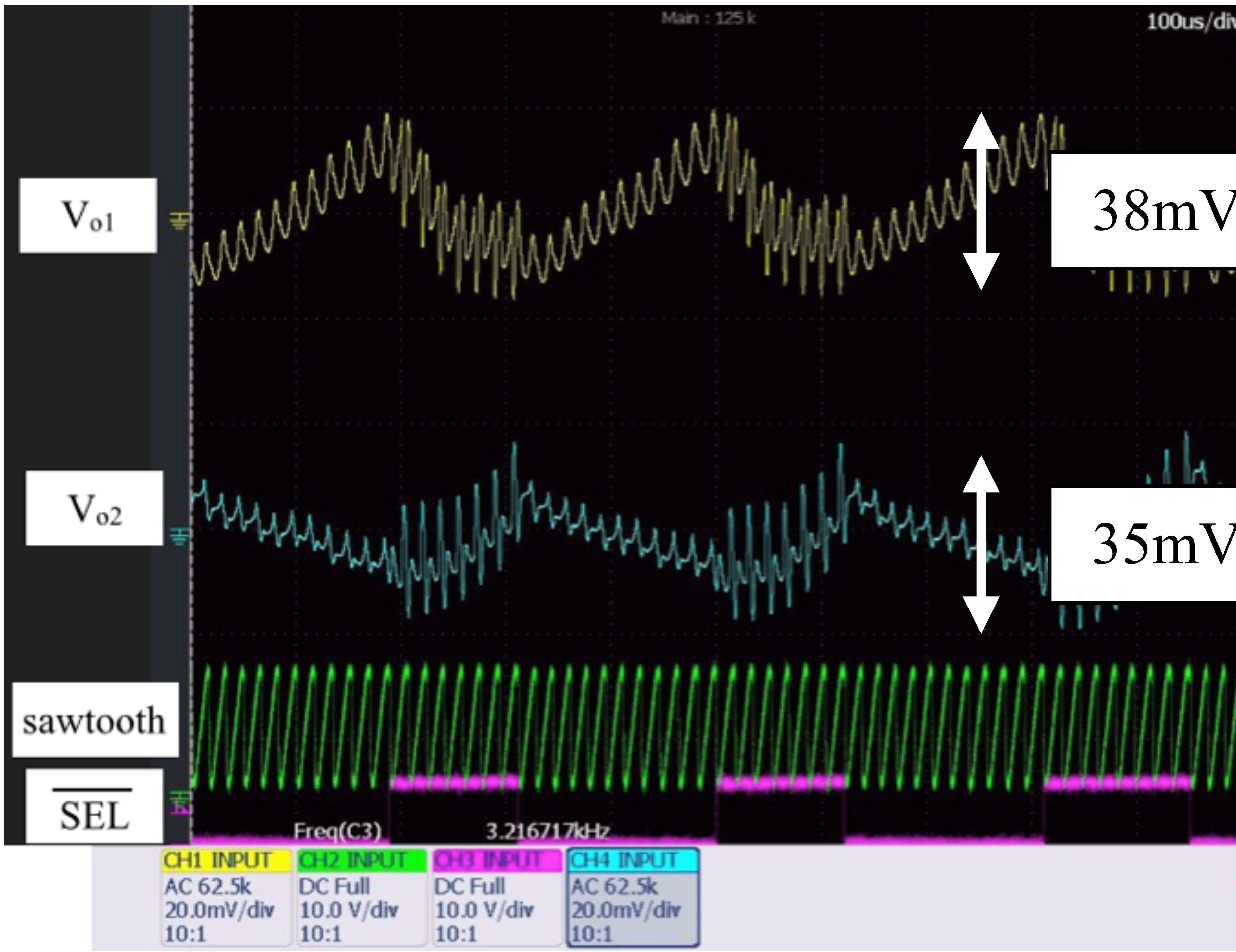
Simulation Circuit (SIDO)



- PWM signal is turned Hi when V_{sw}=0V.
- SEL signal is switched when V_{sw}=0V.

→ **Zero Voltage Switching!**

Impriment Circuit (SIDO)



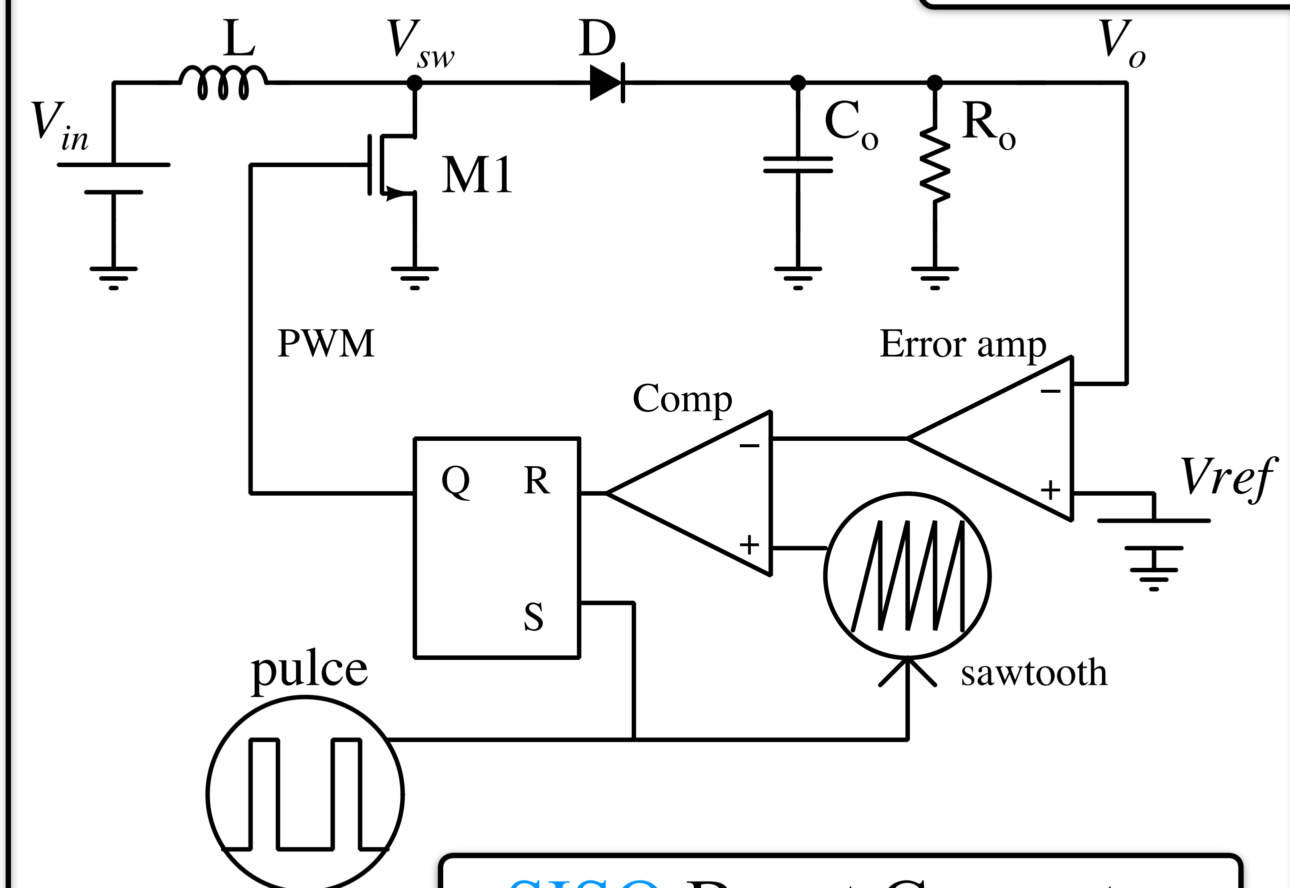
Operation waveforms of the SIDO boost converter with ZVS-PWM control

Implement Parameter

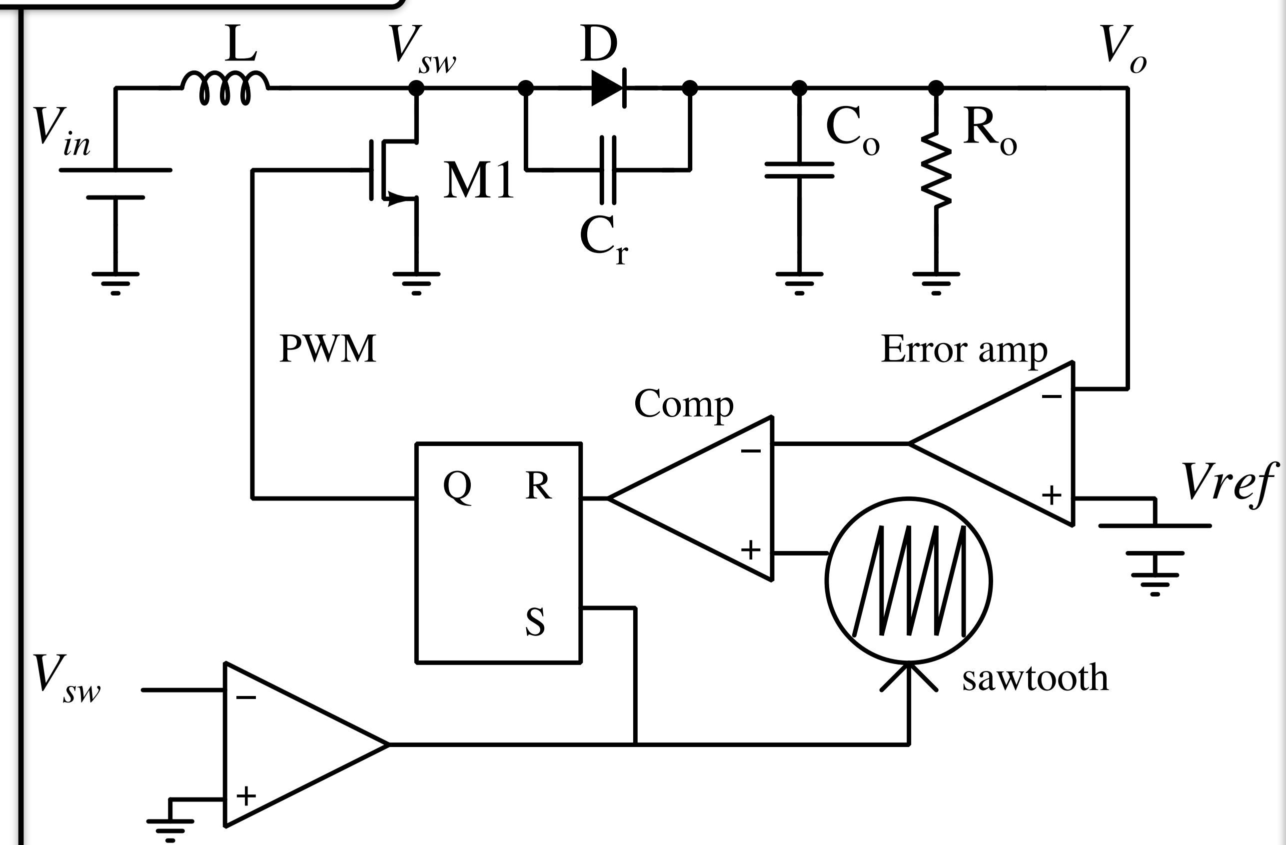
V	2.5V
V	6.03V
V	5.10V
L	6.8uH
C	100nF
C	940uF
R	51Ω

Comparison of Switching Loss (SISO)

Simulation Circuit



SISO Boost Converter



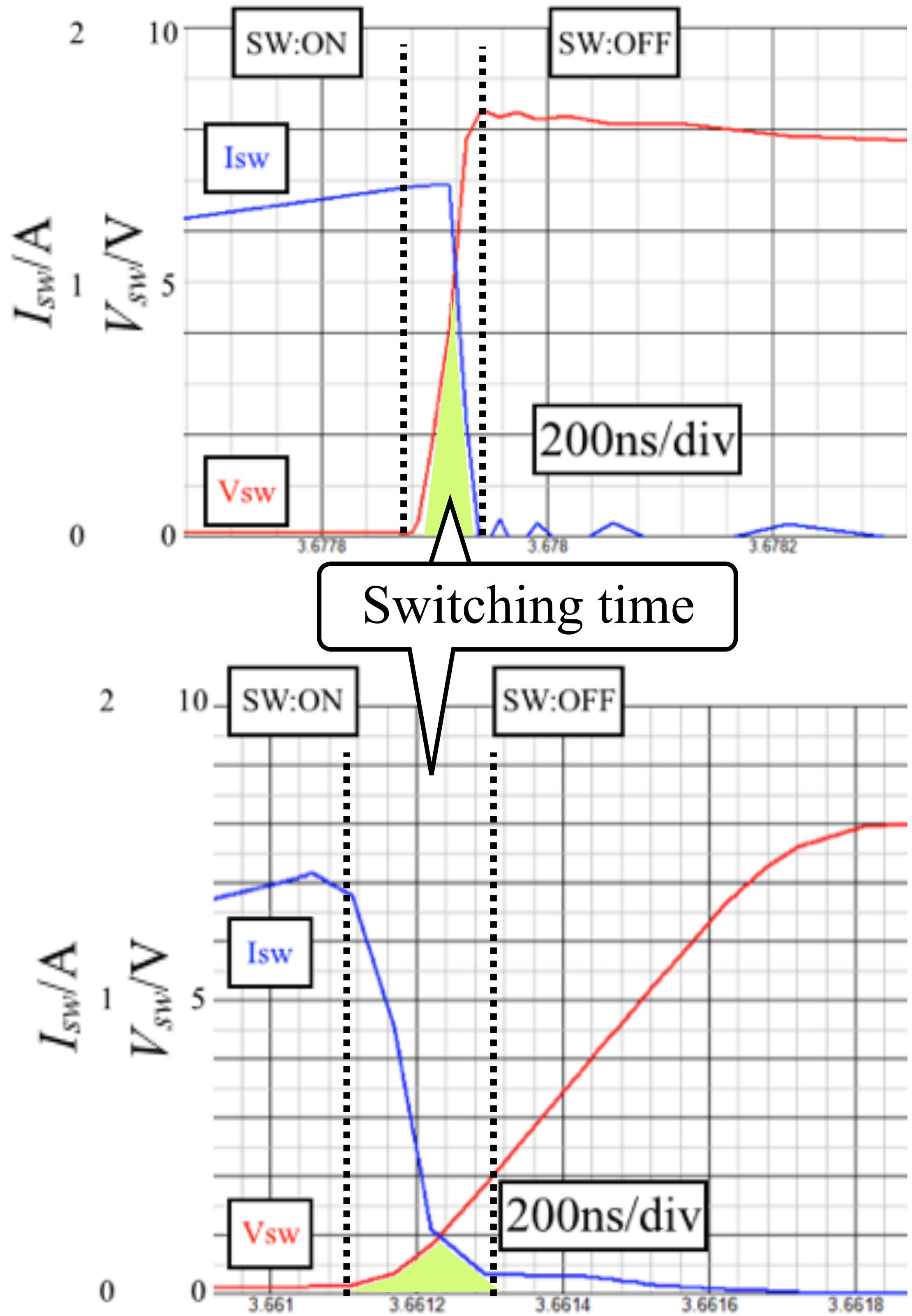
SISO Boost Converter with ZVS

Simulation Parameter

V	L	C	C	R	V	*F*
2.5V	3.9uH	- / 100nF	470uF	20Ω	6V	170.3kHz

F_{op}:Switching Frequency

Comparison of Switching Loss



Conventional

Power loss

P_{sw}=10.3mW/sec

Switching loss P_{sw}

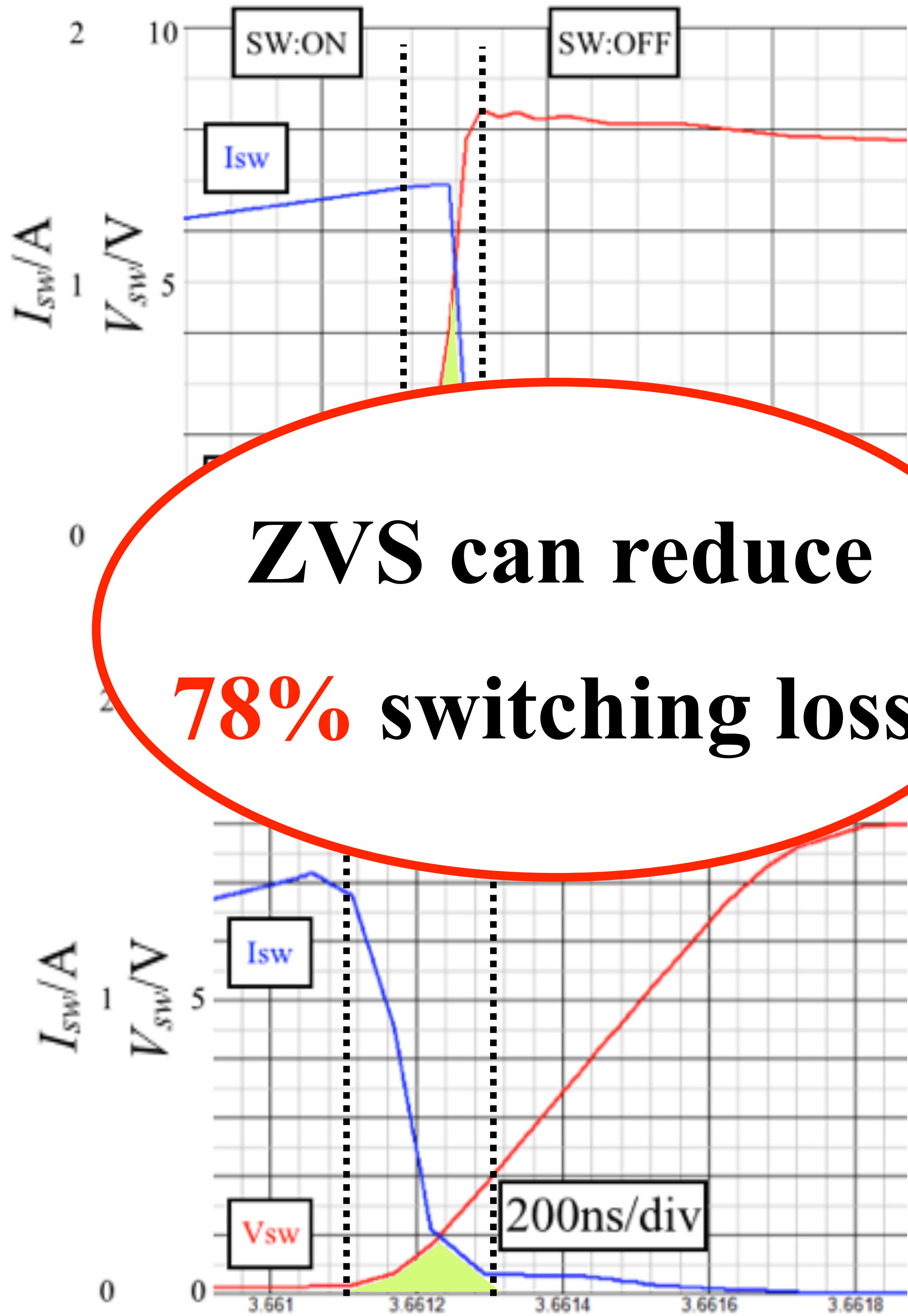
$$P_{sw} = \frac{1}{6} \cdot V \cdot I \cdot \Delta t$$

Propose

Power loss

P_{sw}=2.26mW/sec

Comparison of Switching Loss



ZVS can reduce

78% switching loss!

Conventional

Power loss

P_{sw}=10.3mW/sec

Switchin P_{sw}

P $\cdot V \cdot I \cdot \Delta t$

Propo

Power loss

P_{sw}=2.26mW/sec

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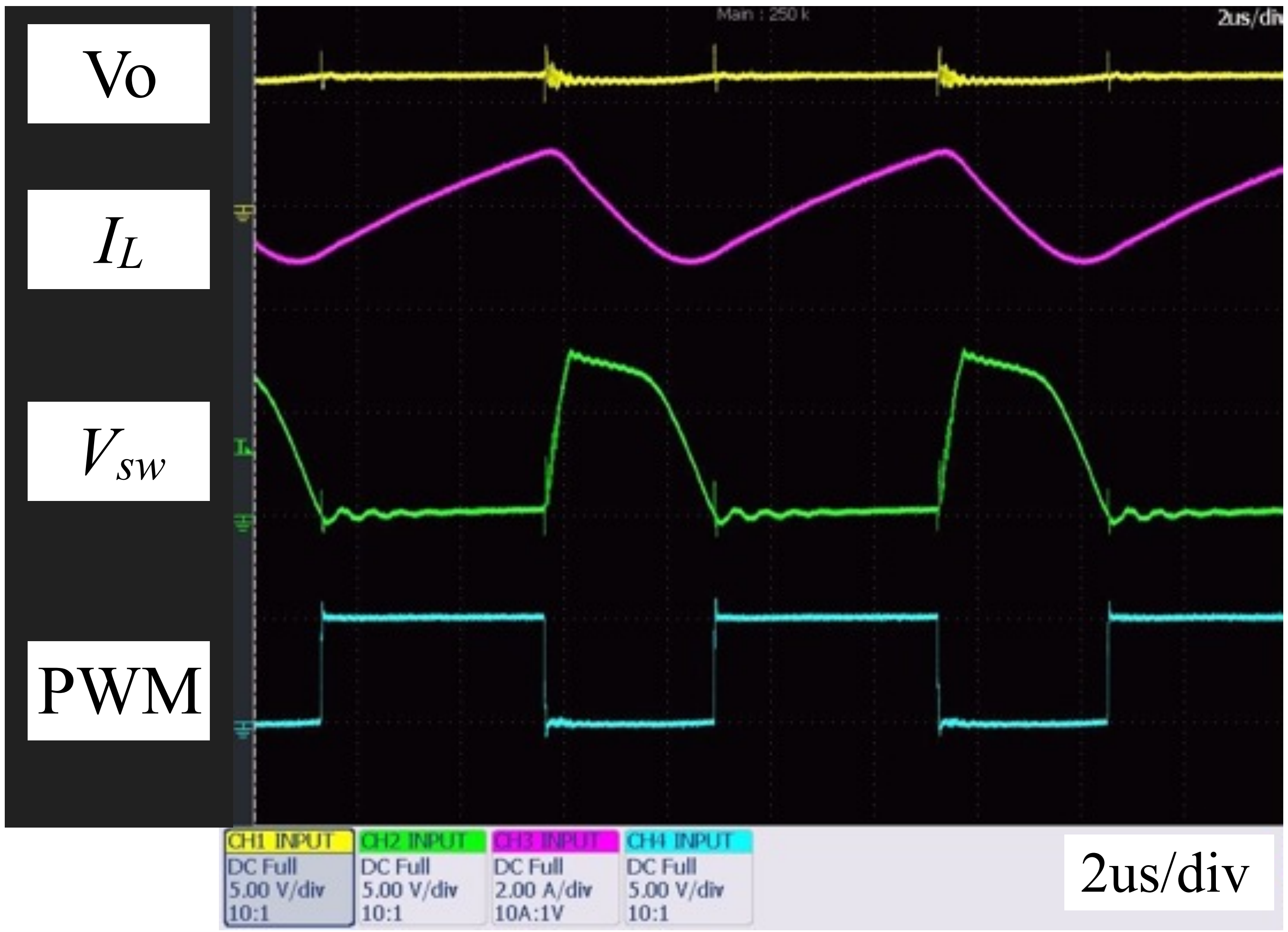
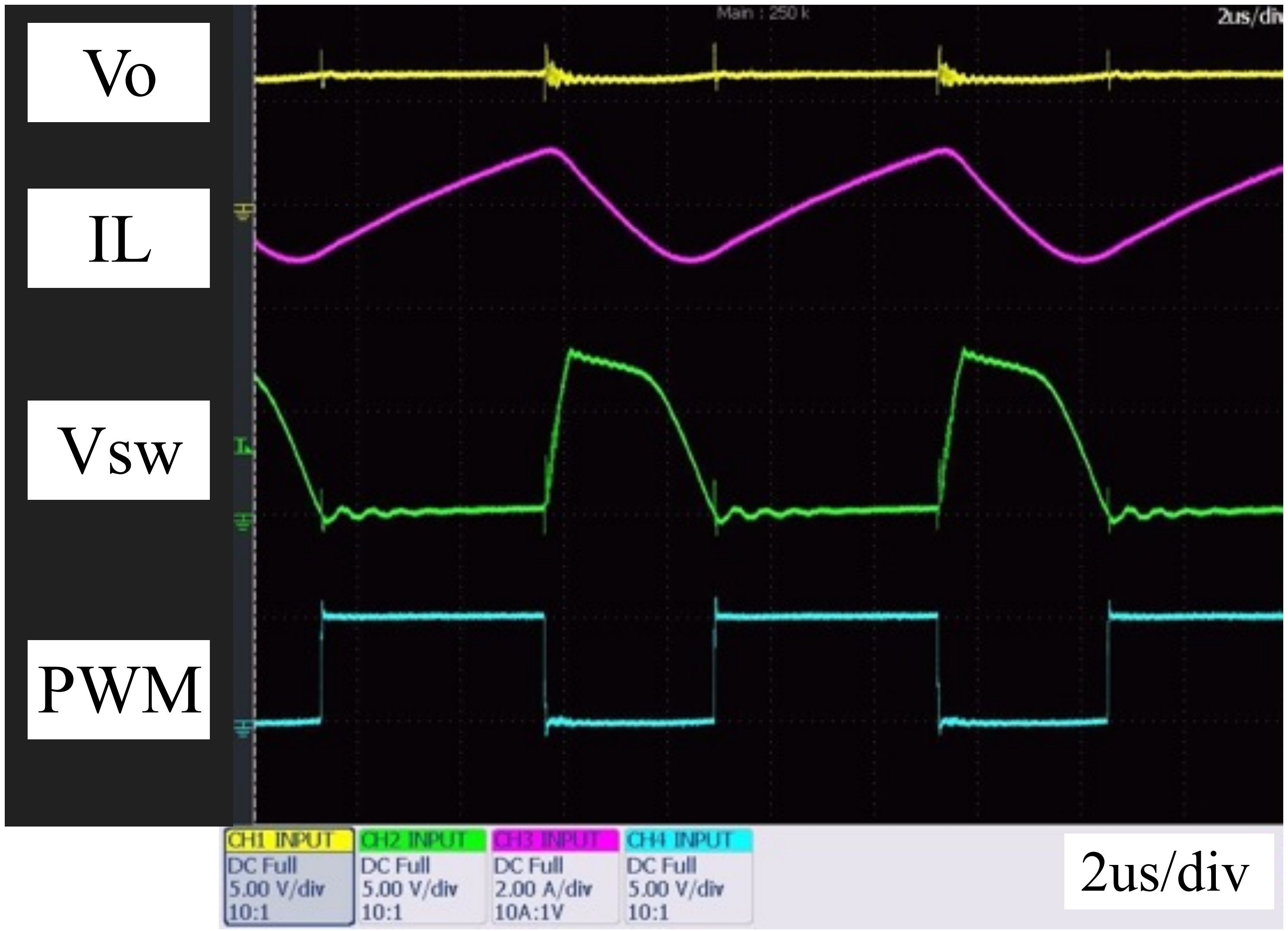
Operation principle

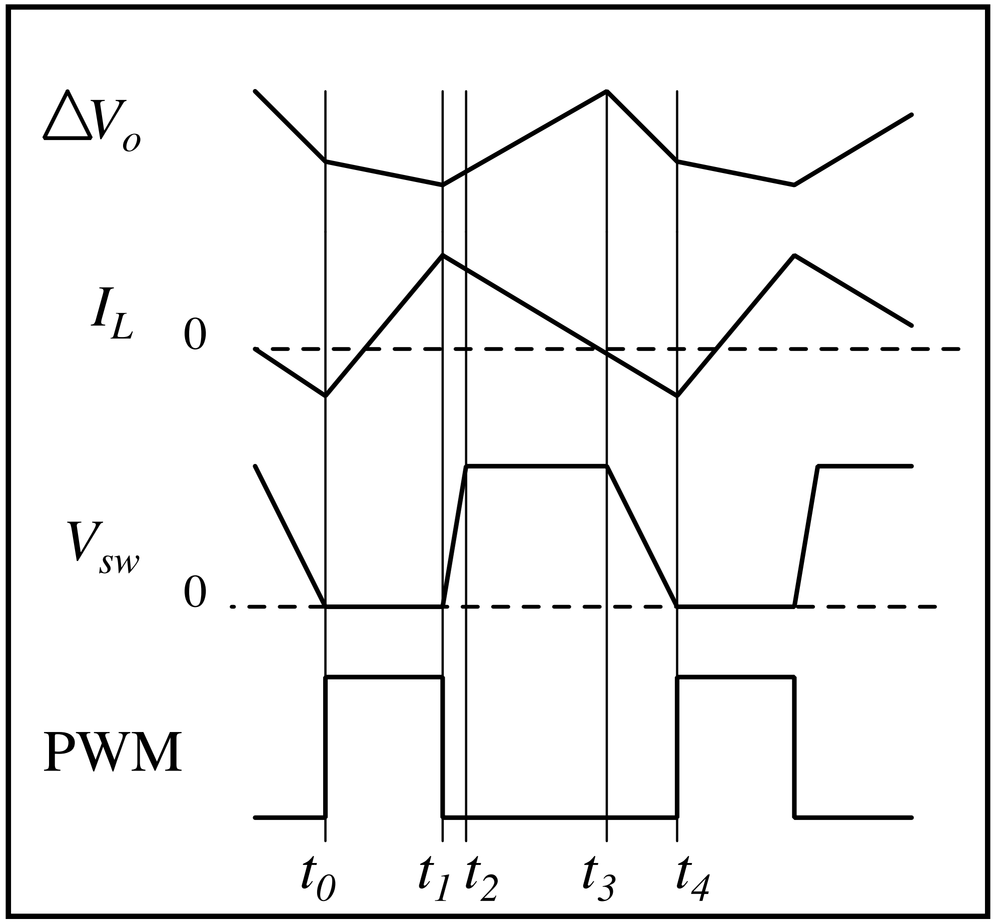


Measured waveforms of the SISO boost converter with ZVS-PWM control

Implement Parameter	
V	2.5V
V	6V
L	3.9uH
C	100nF
C	470uF
R	51Ω
F	129kHz

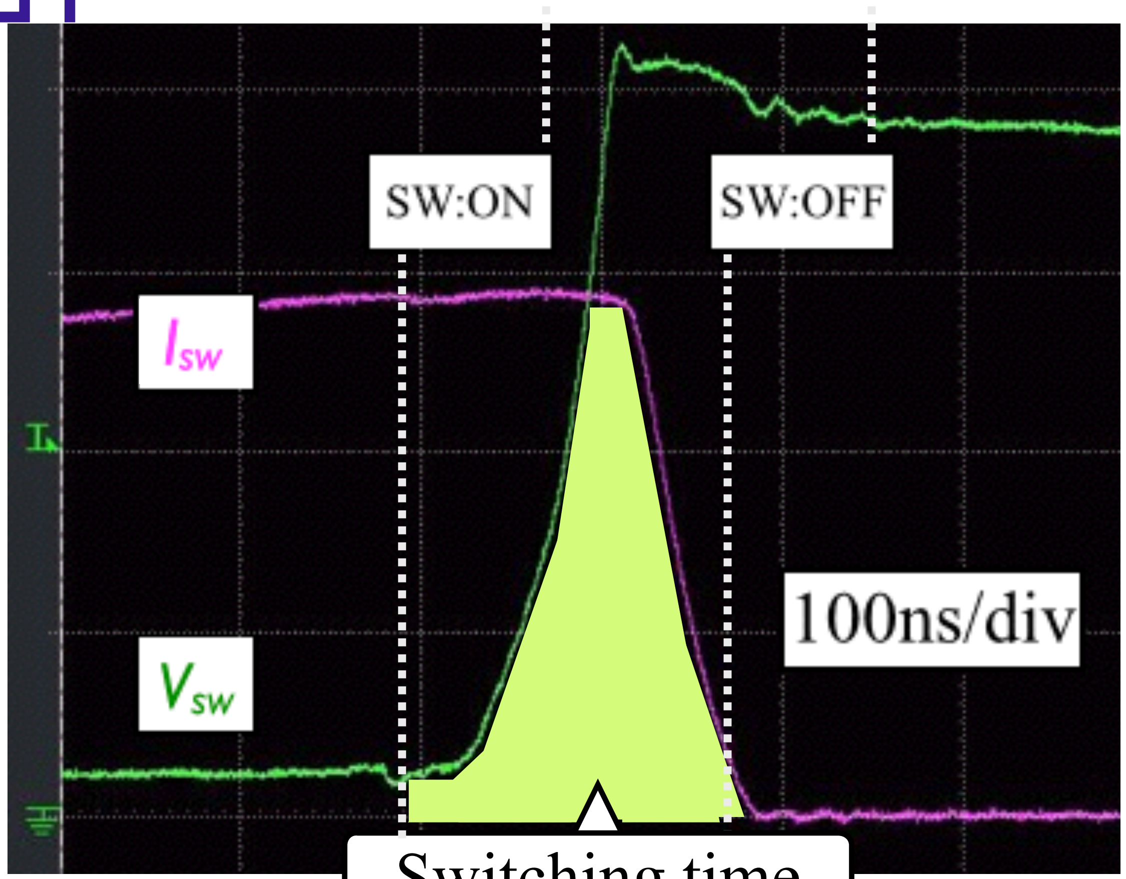
Operation principle

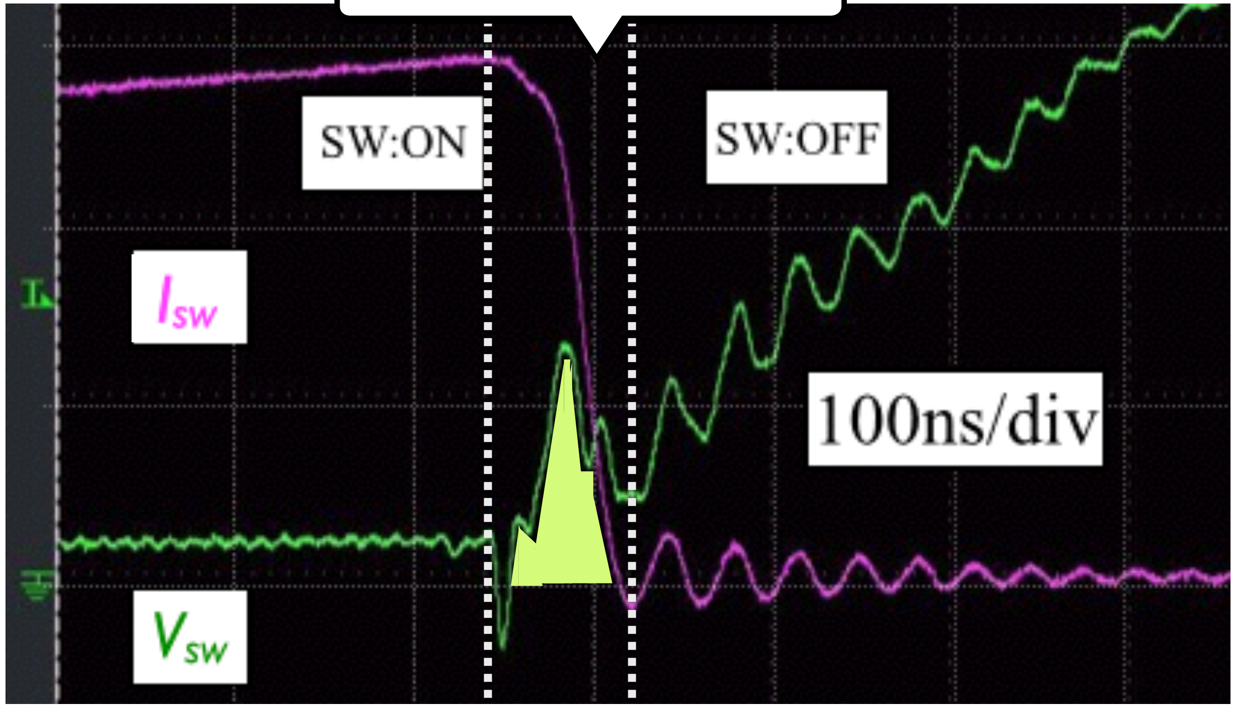




Measured waveforms of the SISO boost converter with ZVS-PWM control

Comparison of Switching Loss





Conventional

Power loss

P_{sw}=102.2mW/sec

Switching loss P_{sw}

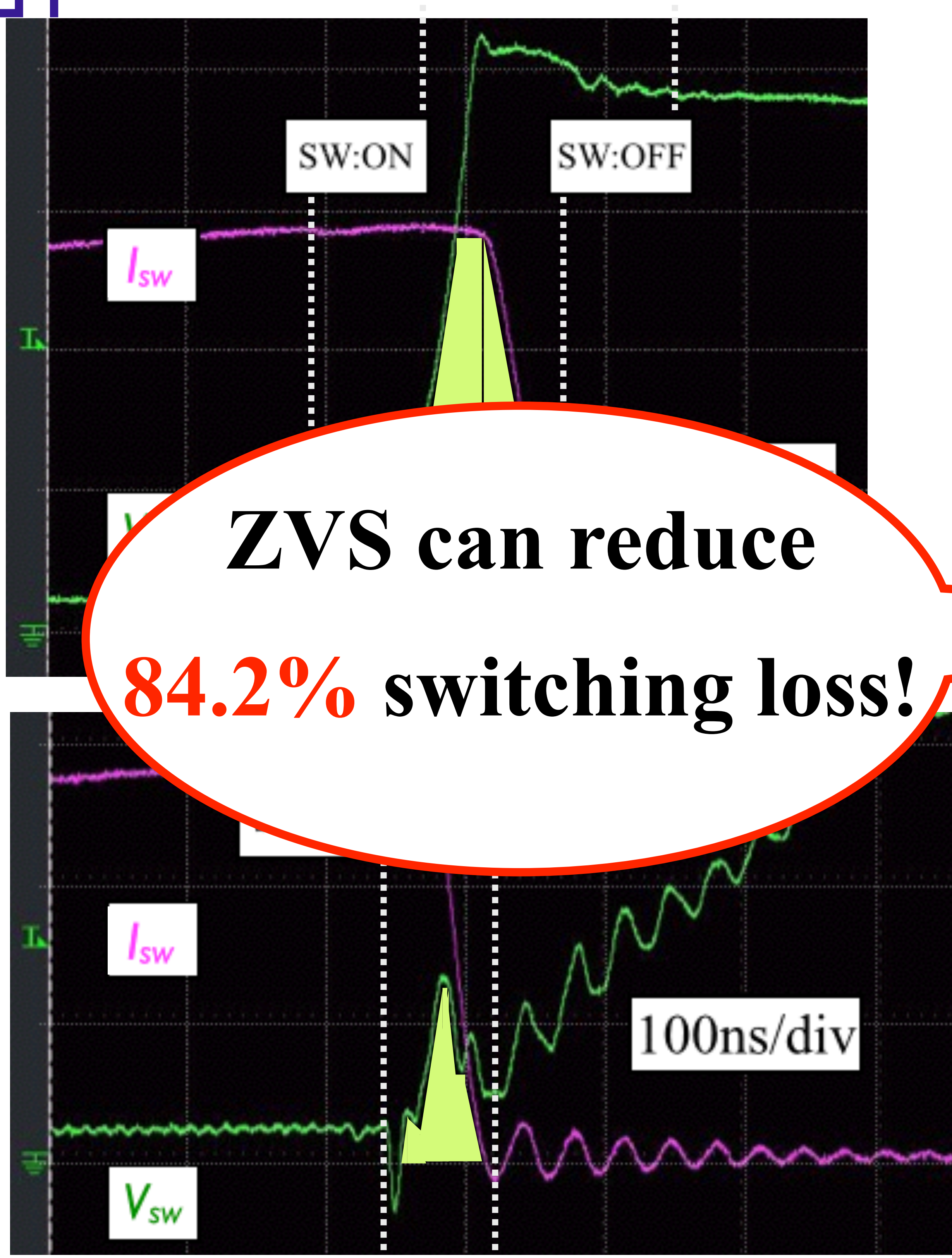
$$P_{sw} = \frac{1}{6} \cdot V \cdot I \cdot \Delta t$$

Propose

Power loss

P_{sw}=16.1mW/sec

Comparison of Switching Loss



Conventional

Power loss

P_{sw}=102.2mW/sec

Switch ss P_{sw}

$\frac{1}{6} \cdot V \cdot I \cdot \Delta t$

Pro

Power loss

P_{sw}=16.1mW/sec

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- Summary and Future works

Summary and Future works

Summary

- We have proposed a SIDO boost converter with ZVS-PWM control for small size and high efficiency.
- We have shown condition of Zero Voltage Switching($V_o \geqq 2V_{in}$).
- ZVS can reduce 78% of switching loss on simulation(SISO).
- ZVS can reduce 84.2% of switching loss on implementation(SISO).

Future works

- We implement SIDO boost converter with ZVS-PWM control.
- The measurement of characteristics of ZVS-PWM control(SISO,SIDO).

Summary and Future works

Thank you for listening.

謝謝

Q&A

Q1.この回路の動作はＣＣＭですか？

A1.いいえ。SIDO ConverterはDCM動作をさせる必要があります。

Q2.SIDOはSISOより出力リプルが大きくなるような気がしますが？

A2.That’s right!