第11回 電気学会東京支部栃木・群馬支所合同研究発表会

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EMI Reduction and Frequency Stabilization in Ripple Injection Type Hysteretic Controlled Switching Converter

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Outline

- Research Background
- Buck switching converter
- Basic hysteretic controlled switching converter
  - DCM state and CCM state
- Hysteretic controlled switching converter with ripple injection
  - Analysis of operating frequency in DCM state
  - How to reduce the minimum current of CCM
- Improvement of operating frequency in DCM state
- Phase modulation method of EMI reduction
- Improvement of ripple of output voltage
- Summary

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Research Background

Applications of DC-DC converters

Switching Converter are widely used in various electronic equipments

Hysteretic Controlled Switching Converter is for high-speed control.

Linear control

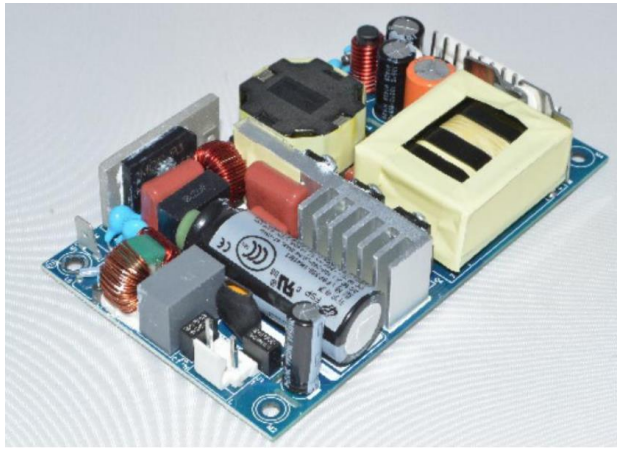
Voltage controlled mode
Current controlled mode

Non-linear control

Hysteretic control

Research Background

How does EMI interfere with electronic systems



EMI ☹

EMI: Electro Magnetic Interference

EMI interferes with
logic level and communication bus.

EMI makes digital logic chaotic, and
causes microcomputer to malfunction

Research Objective

Objective

Requirements of ripple injection type hysteretic controlled switching converter

o Frequency stabilization

o Low EMI noise

o Small output ripple

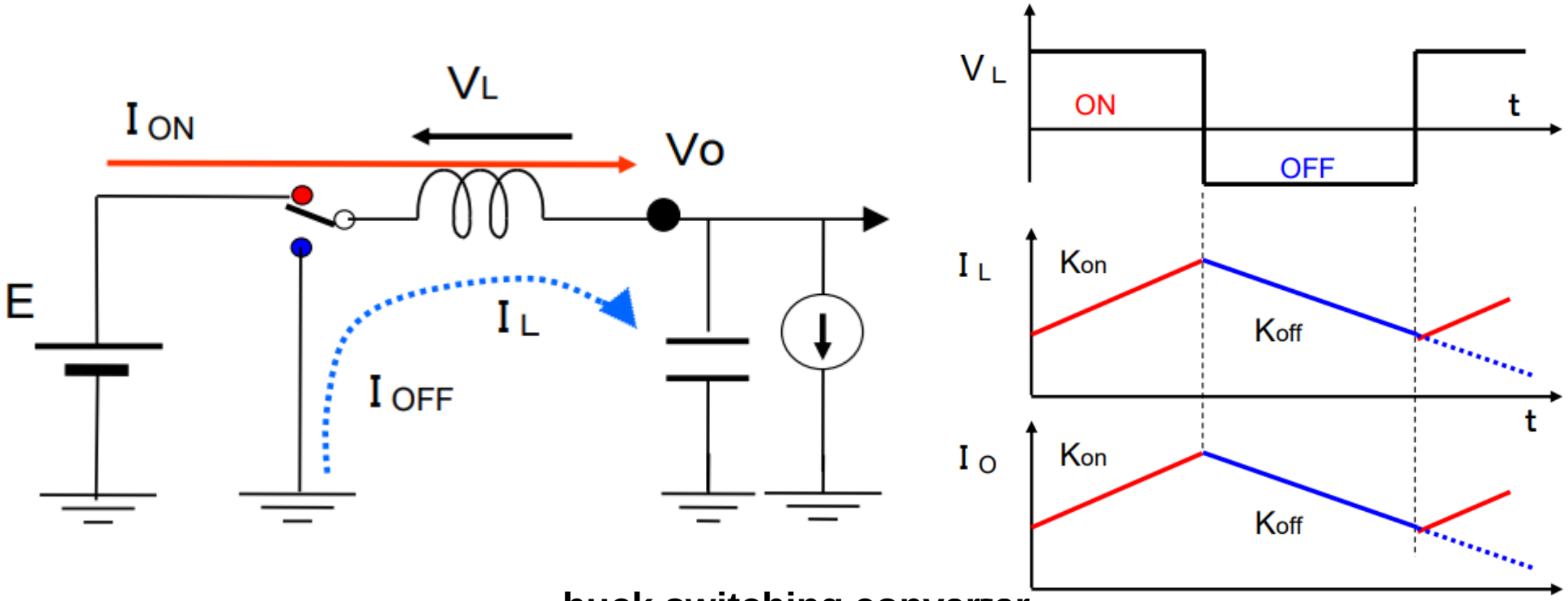
Approach

o Modulation method for frequency stabilization

o EMI noise reduction with phase modulation

o Reduction of output voltage ripple

Buck switching converter



buck switching converter

ON： VL=(E－Vo)、di/dt =(E－Vo) / L ＞0

OFF： VL=－Vo、di/dt=－Vo / L ＜0

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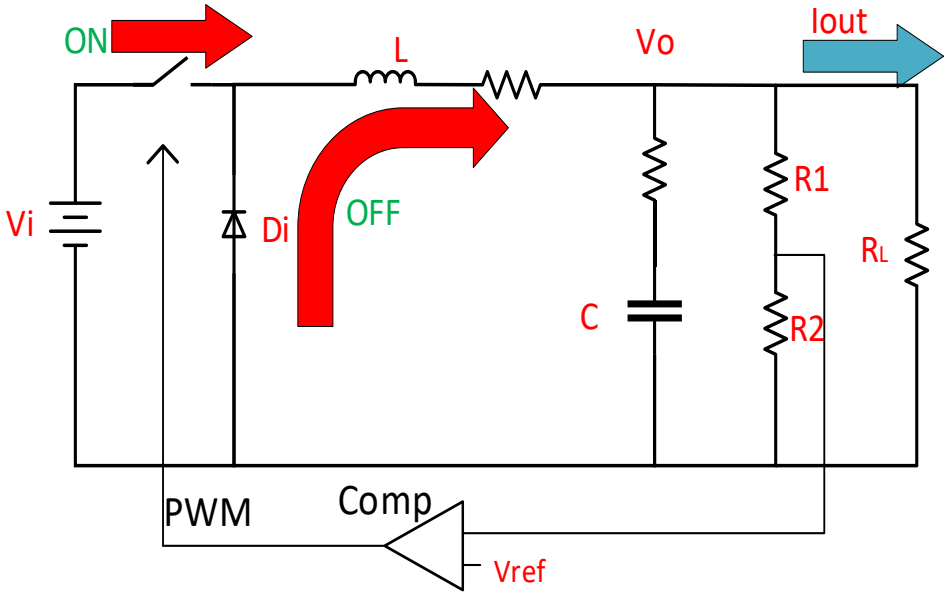
Basic hysteretic controlled switching converter



Basic hysteretic Controlled Switching Converter

Features:

Vo is compared with Vref for fast response

[Advantages]

- Only few circuit elements
- No operational amplifier
- Fast load response
- No phase compensation

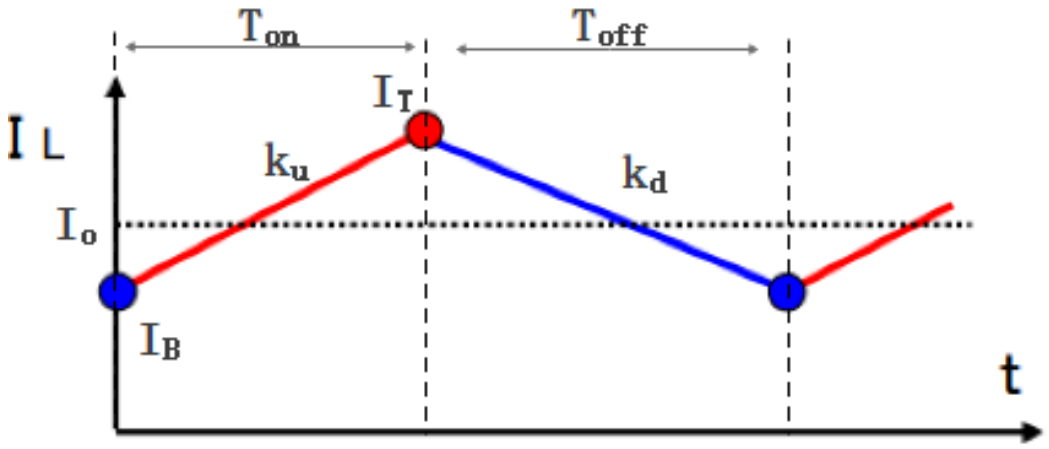
[Disadvantage]

- Output current change
  ⇒ Operating frequency change.
- Comparator needs output voltage ripple.

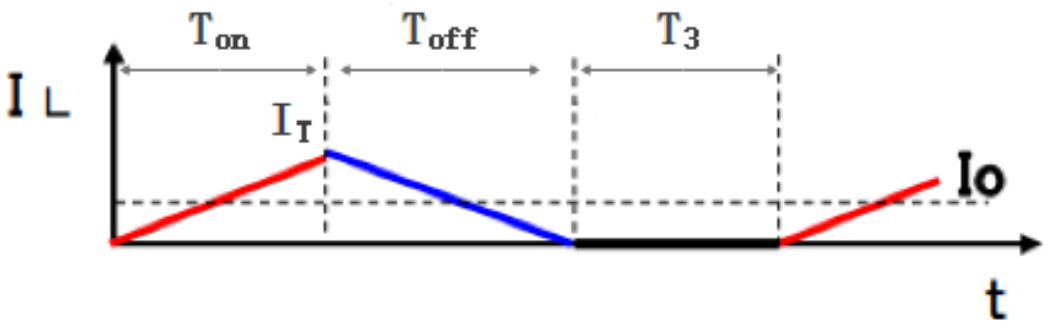
DCM state and CCM state

DCM : Discontinuous Conduction Mode

CCM : Continuous Conduction Mode



CCM



DCM

$$I_{out} = \frac{1}{T}\int_0^T I_L(t)dt$$

$Q = I_o(T_{on} + T_{off})$
$= (I_T + I_B)(T_{on} + T_{off})/2$

$Q = I_o(T_{on} + T_{off} + T_3)$
$= I_T / \{2(T_{on} + T_{off})\}$

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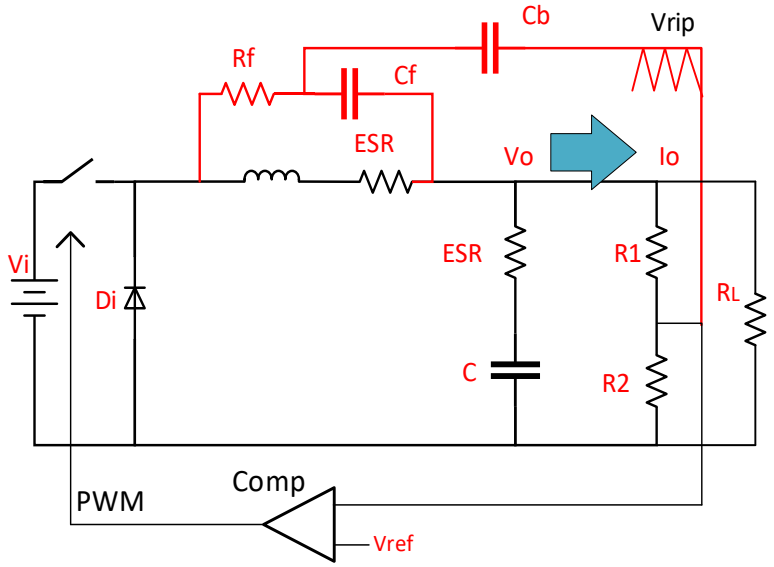
Hysteretic controlled switching converter with ripple injection

Operating frequency:
mainly determined by time constant CR of ripple generation circuit



Hysteretic controlled converter with ripple injection.

V_{in} = 10 V	R1 = 3.9 kΩ
V_{out} = 3 V	R2= 470 kΩ
L = 10 mH	Rf = 470 kΩ
C = 100 uF	Cf = 5 nF,
ESR = 5 mΩ	C_b = 20 uF.

Analysis of operating frequency in DCM state

In DCM state, T_{on} and T_{off} are fixed values (the same as CCM state)

Top current I_T is constant.

$$I_T = T_{ON} \cdot (V_i - V_o)/L$$

Inductor charge Q_L is constant.

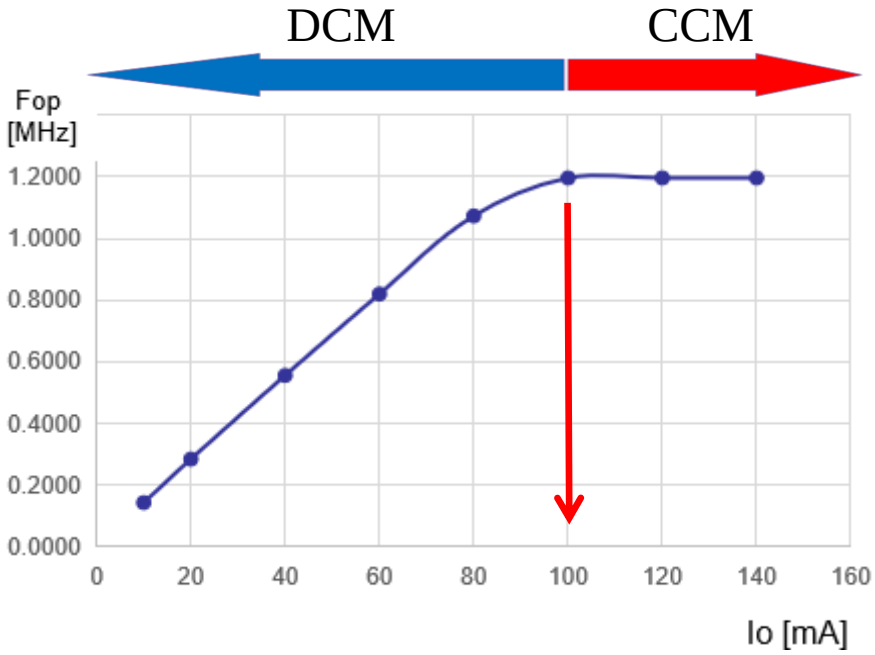
$$Q_L = I_T \cdot (T_{ON} + T_{OFF}) /2$$

$Q_o = Q_L$

$$Q_L = I_o \cdot T_o$$

$$\therefore \quad F_{op} = I_o/Q_L = 1/T_o \quad Q_L = Q_{min}$$

$$\therefore F_{op} = K \cdot I_o$$



No matter how Io changes,
Q_L is unchanged，
Q_{min} is minimum charge in CCM

Operatiing frequency in DCM is proportional to load current

How to reduce the minimum current of CCM

Fo=1/To = Io/Qmin

Qmin decreases in proportion to Io

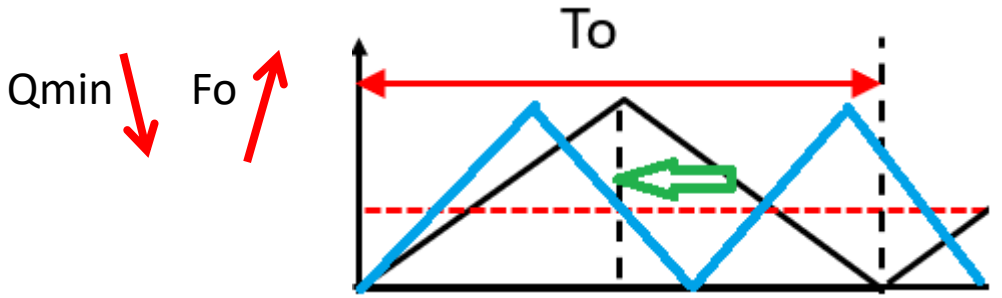
Qmin decreases in proportion to period

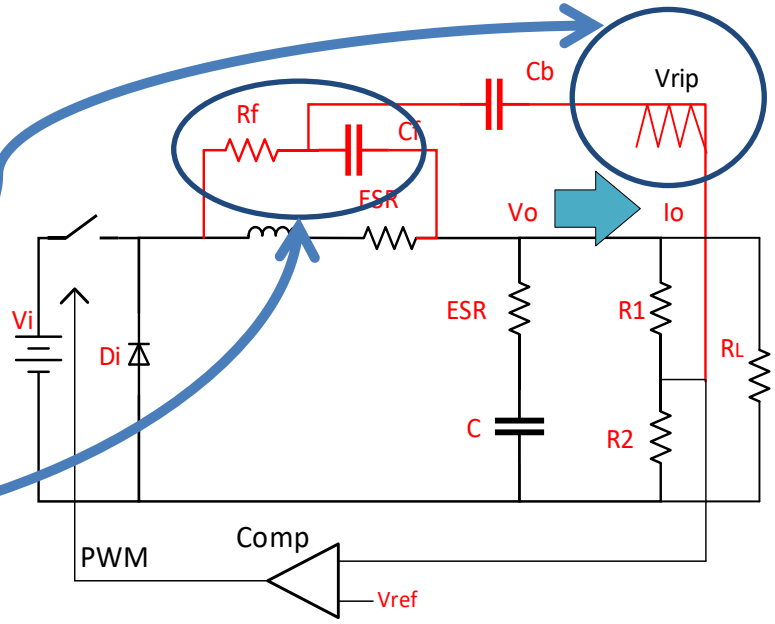
How to reduce Qmin: Reduce Ton

(rising slope of injection ripple ⇒ steeper)

Modulation of time constant for injection ripple generation

Operating frequency is determined by
time constant CR of ripple generation circuit





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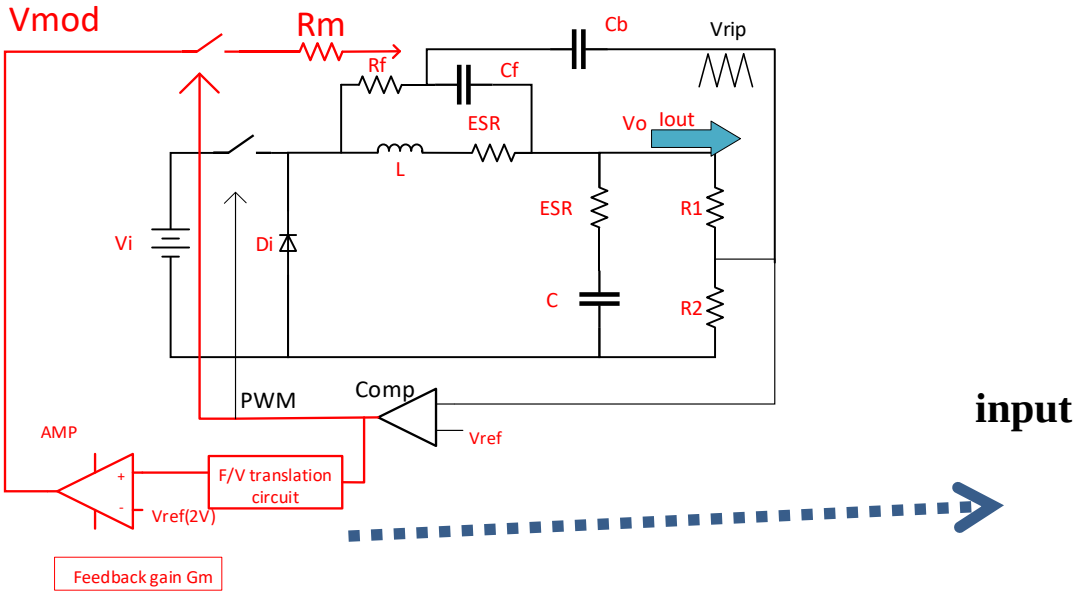
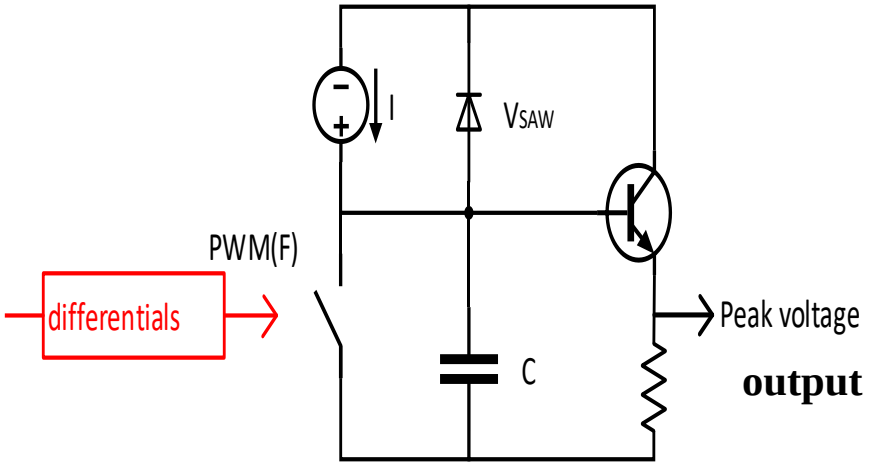
Improvement of operating frequency in DCM state



input



F/V translation circuit

Modulation method of time constant for ripple generation

1) PWM period T ⇒ long
2) Vmod ⇒ high
3) Rising slope of injection ripple ⇒ steep
4) On-time ⇒ short
5) PWM period T ⇒short

Voltage from F/V translation circuit is in proportion to operating period.

⇒ Amplified to generate a modulation voltage Vmod

⇒ Injected into time constant through resistor Rm.

Modulation method of time constant for ripple generation

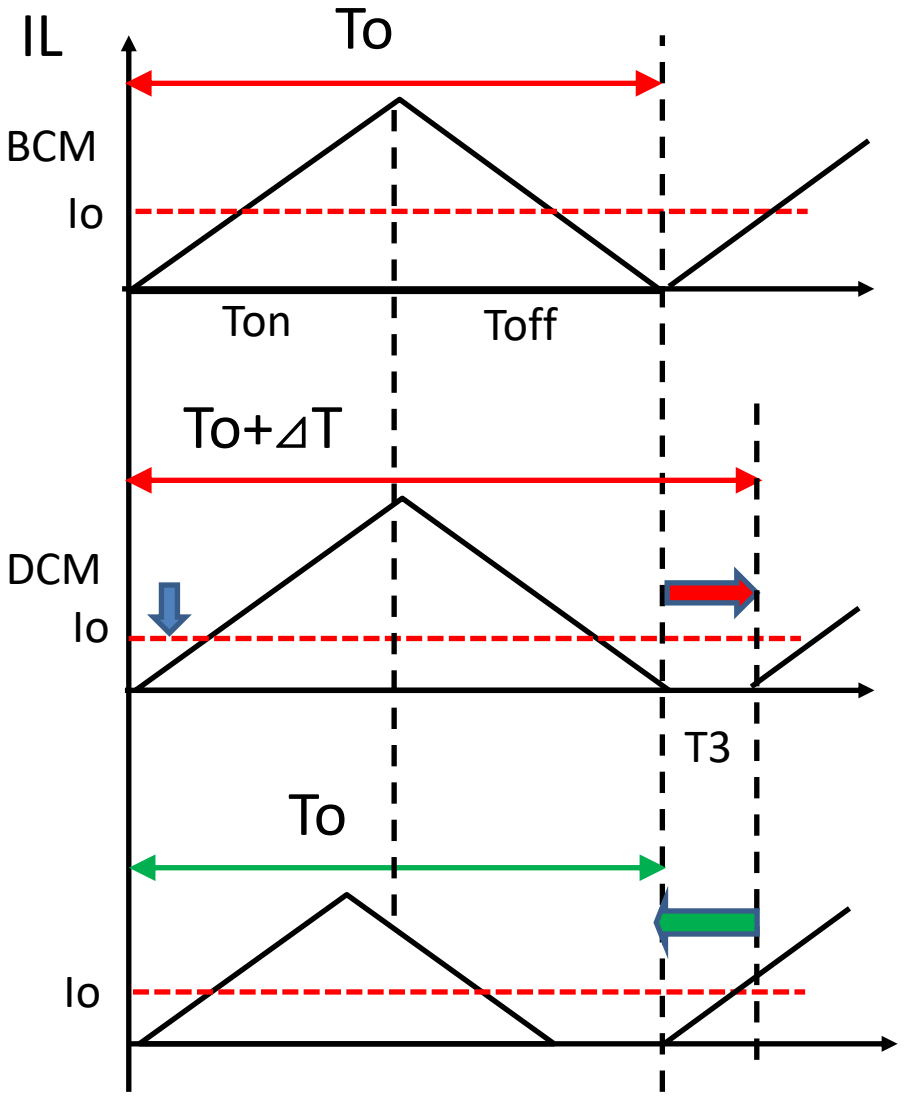
1) Io decreases from BCM state

   BCM: Boundary Conduction Mode

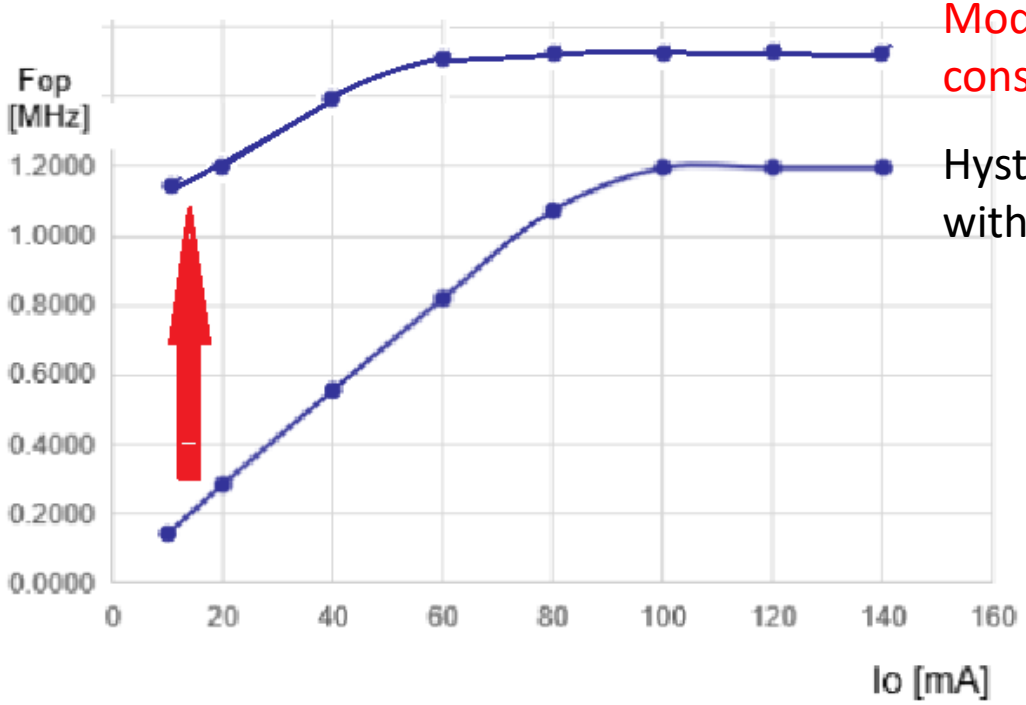
2) It becomes DCM and T3 appears
   ⇒ Period To expands and
   frequency decreases

3) When rising slope of injection ripple is raised⇒ Ton becomes shorter
   (current slope is the same)

4) Ton + Toff + T3 becomes shorter
   ⇒ Period T becomes shorter and
   frequency is raised



Simulation results



Modulation method of time constant for ripple generation

Hysteretic controlled switching converter with ripple injection

- Frequency change width is improved from ⊿F=1.0MHz to 0.3MHz,
- Frequency change rate is improved from 85% to 20%.

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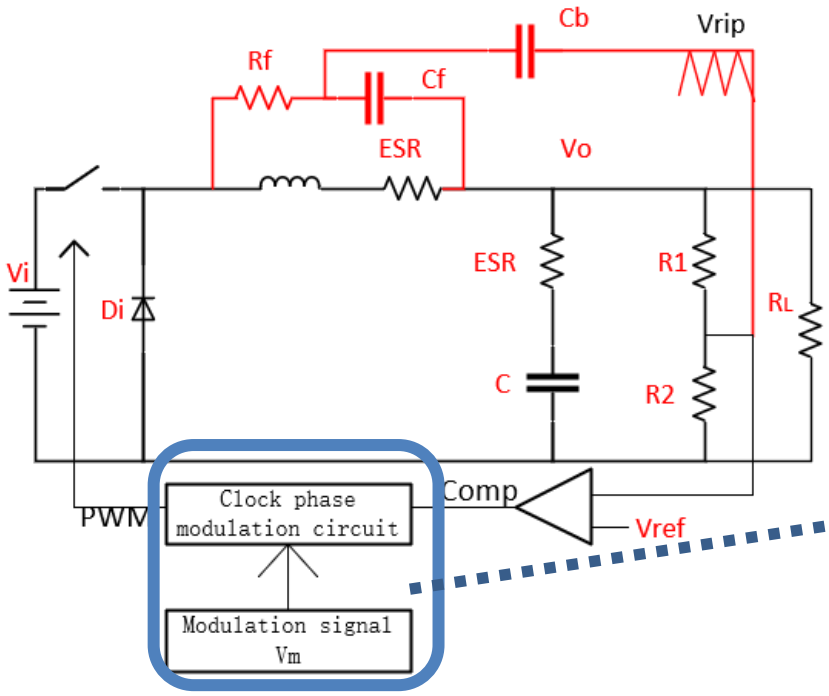
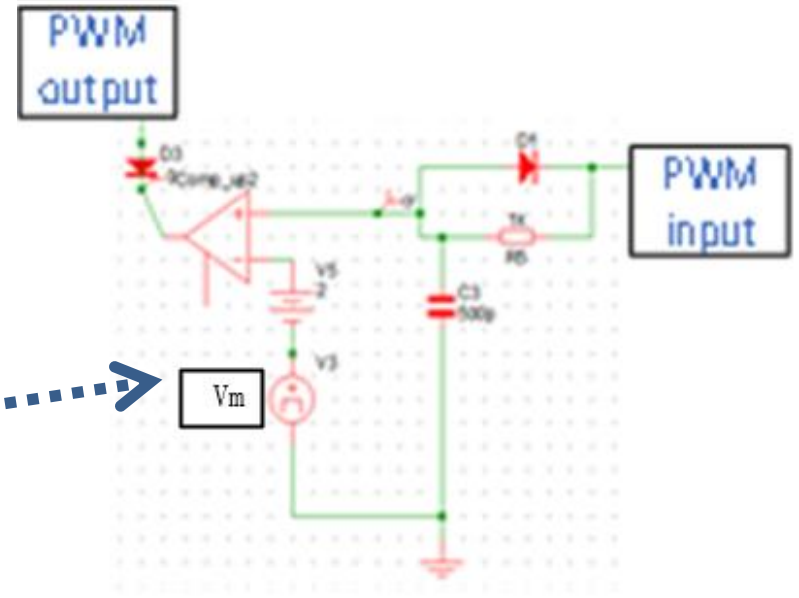
Phase modulation circuit for EMI reduction

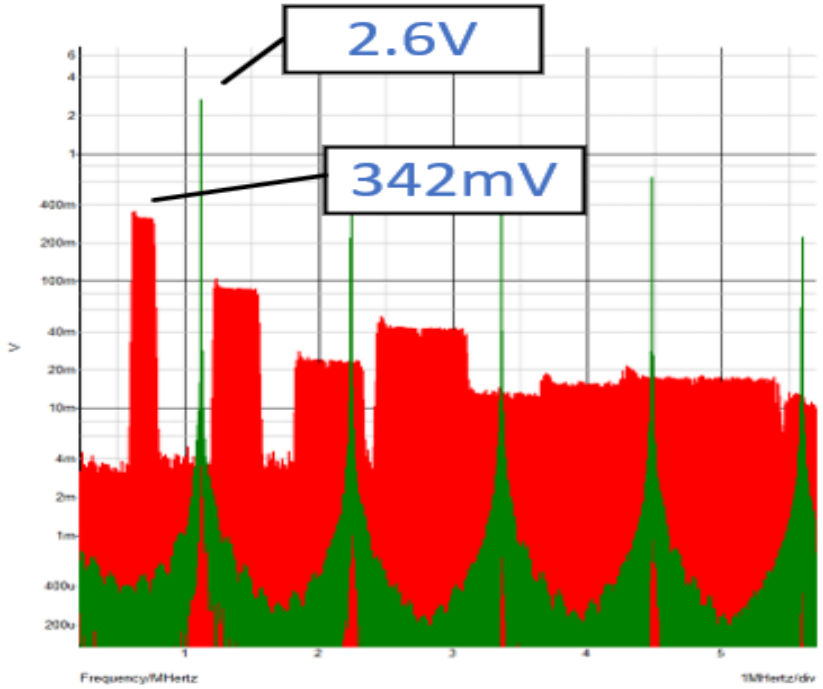


Phase modulation method in ripple injection type hysteretic controlled switching converter



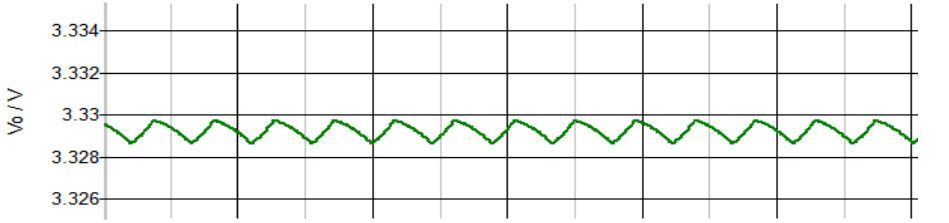
Phase modulation circuit

Simulation results

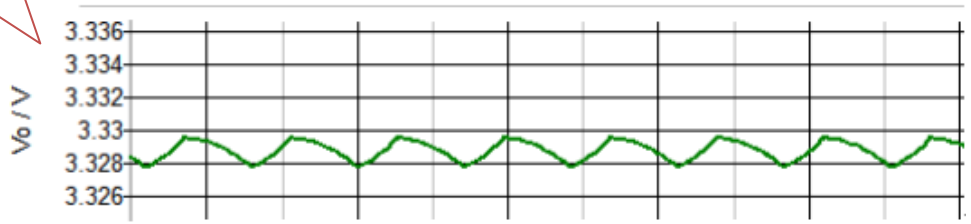


PWM spectrum

BUT



Before phase modulation



After phase modulation

Output voltage ripple 1mV → 2mV

Peak level of the frequency spectrum decreases from 2.6V to 342mV (17.6 dB reduction)

We want a lower ripple , but how….

Output voltage ripple reduction

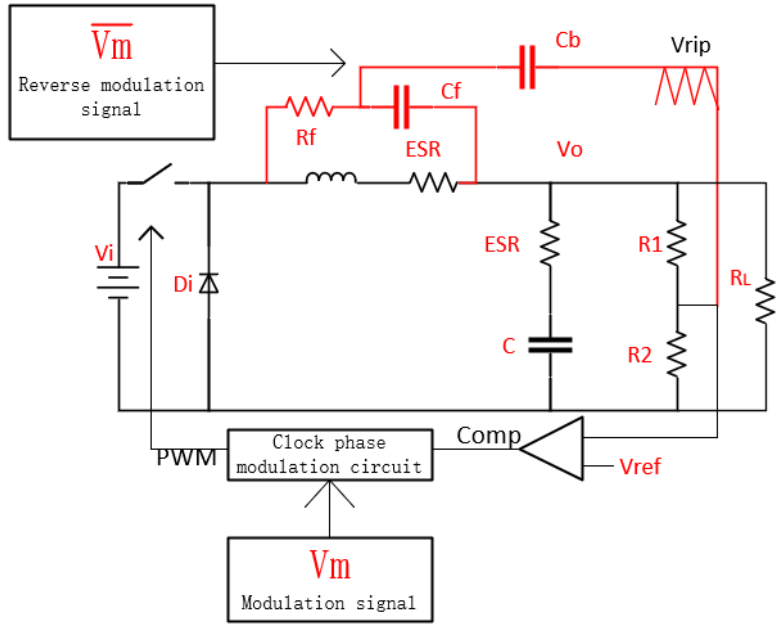
How to reduce output voltage ripple ?

With EMI phase modulation,
PWM is slow at 1 kHz,
so output ripple occurs.

+

Operating frequency can be modulated by DCM frequency correction.

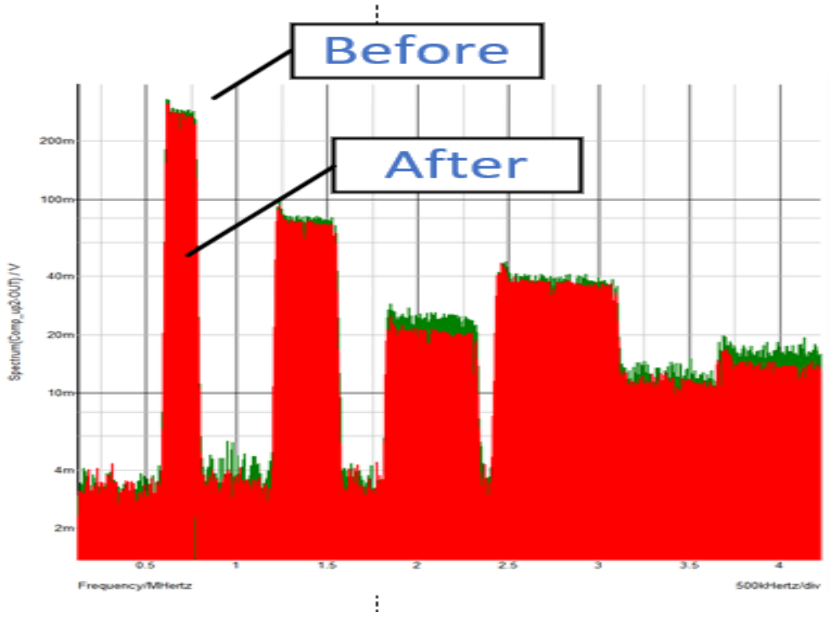
Output ripple can be improved by reverse modulation



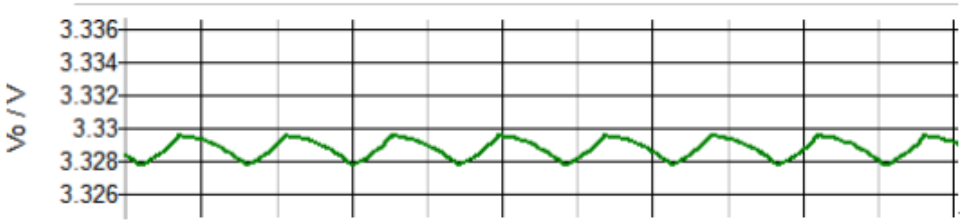
Vm and $\overline{Vm}$ get the same frequency but opposite phase

Proposed circuit for EMI reduction with ripple suppression

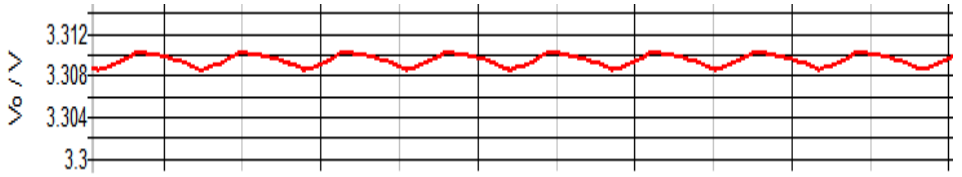
Simulation results



PWM spectrum



Before ripple suppression



After ripple suppression

- PWM spectrum is the same as before
- Lower output voltage ripple 2mV → 1mV

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Summary

- Investigation of
  - Hysteretic controlled switching converter with ripple injection,
  - Modulation method of time constant for ripple generation

- Proposal of time constant modulation circuit for ripple generation
  - Operating frequency improvement in DCM state
  - Stable operating frequency and lower frequency change rate
    ⇒ Beneficial for filtering ripple noise

- Proposal of phase modulation circuit for EMI reduction
  - Peak level suppression of frequency spectrum

- Proposal of output voltage ripple reduction
  - Simultaneous suppression of
    frequency spectrum peak ripple and output voltage ripple

- Simulation results agreed with analysis

Future research

Our future research is

- To stabilize frequency even under 40mA for output current.
- To analyze ripple injection type hysteretic control switching converter using transfer function.