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Analysis and Stability Evaluation of 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**
    - **Modulation method of time constant for ripple generation**
    - **Results of simulation**
- **Summary**

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Research Background

Many DC-DC converters are widely used in electronic devices.

Hysteretic Controlled Switching Converter is known as a typical control method for high-speed control.

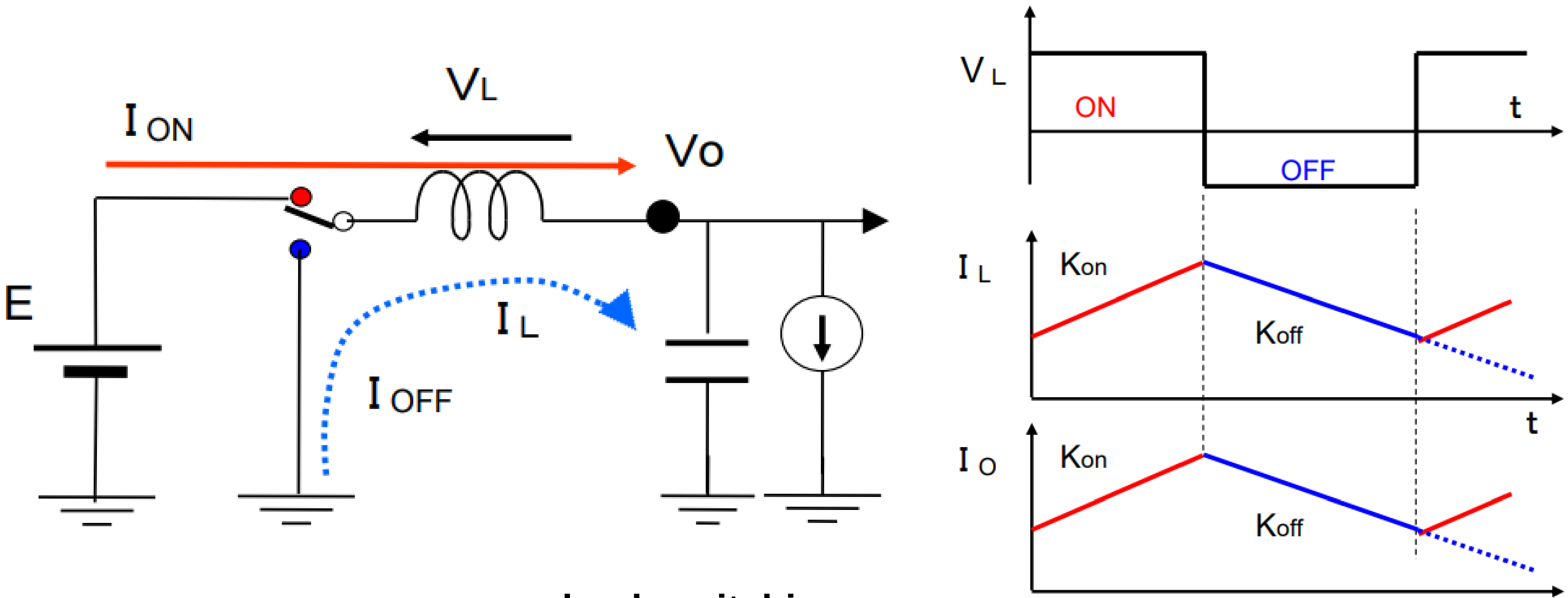
Linear control

Voltage controlled mode
Current controlled mode

Non-linear control

Hysteretic control

Buck switching converter



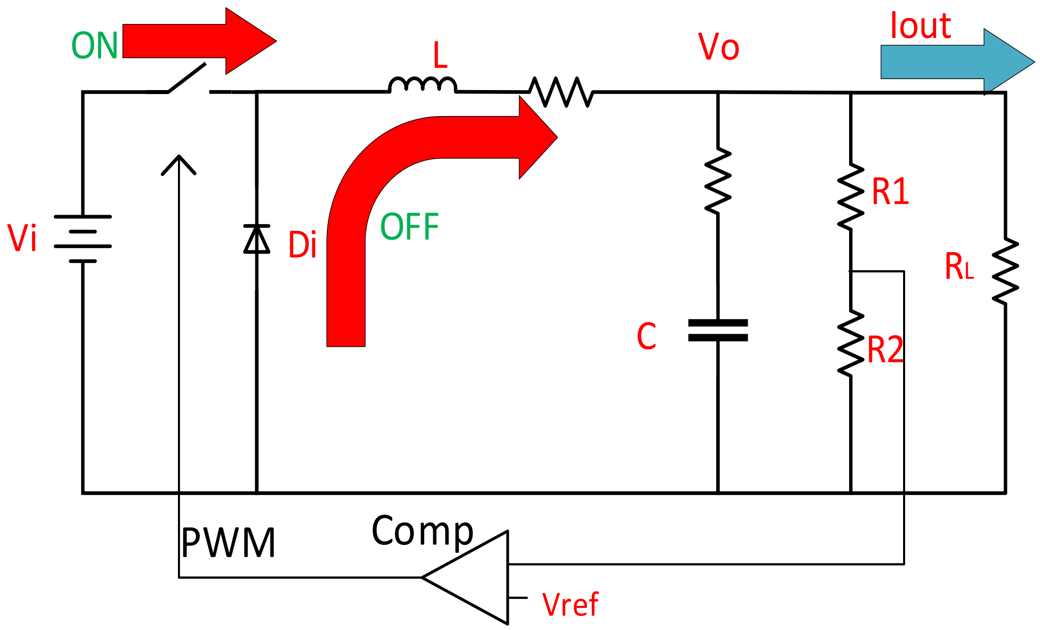
buck switching converter

ON： $V_L=(E-V_o)$、$di/dt=(E-V_o)/L>0$

OFF： $V_L=-V_o$、$di/dt=-V_o/L<0$

Outline

Basic hysteretic controlled switching converter



Features:

Vo is directly compared with Vref

[Advantages]

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

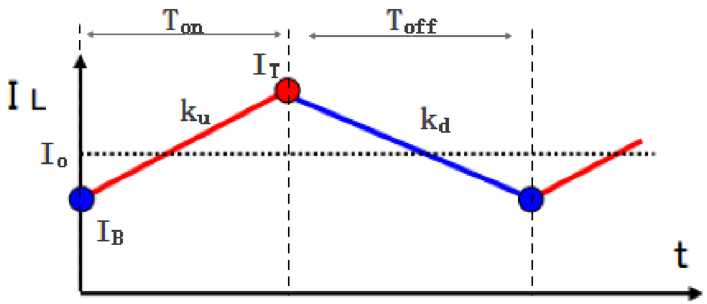
[Disadvantage]

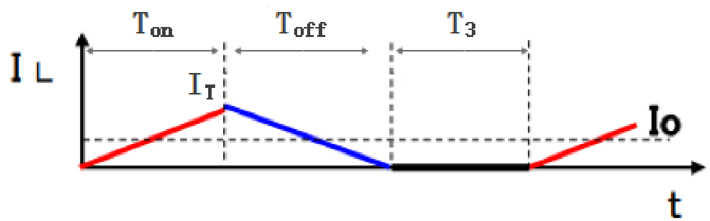
- Output current change ➡ Operating frequency change
- Comparator needs output voltage ripple.

DCM state and CCM state

DCM : Discontinuous Conduction Mode

CCM : Continuous Conduction Mode





(a) CCM state

(b) DCM state

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

$D_o = T_{on}/T_o = V_o/V_i \quad (T_o = T_{on} + T_{off})$

$M = V_o/V_i = D_o$

$D_o = T_{on}/T_o = V_o/V_i \quad (T_o = T_{on} + T_{off} + T_3)$

$M = V_o/V_{in} = T_{on}/(T_{on} + T_{off}) \neq T_{on}/T_o$

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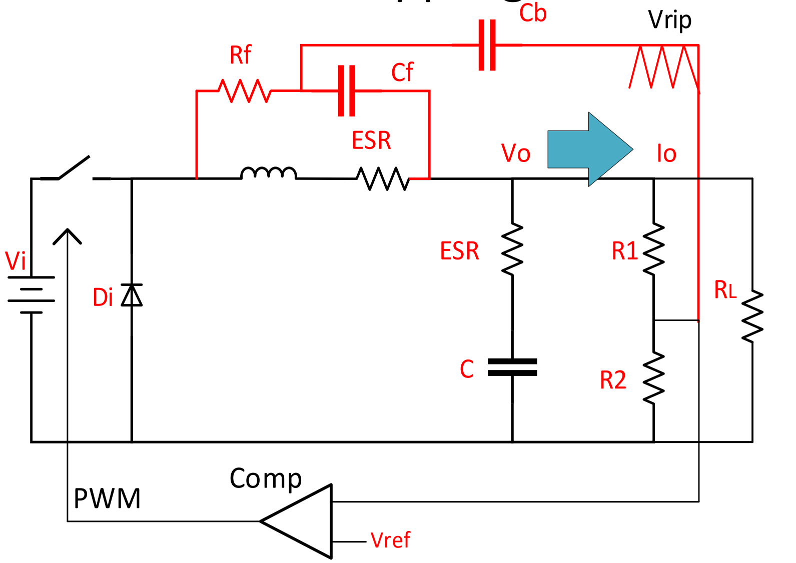
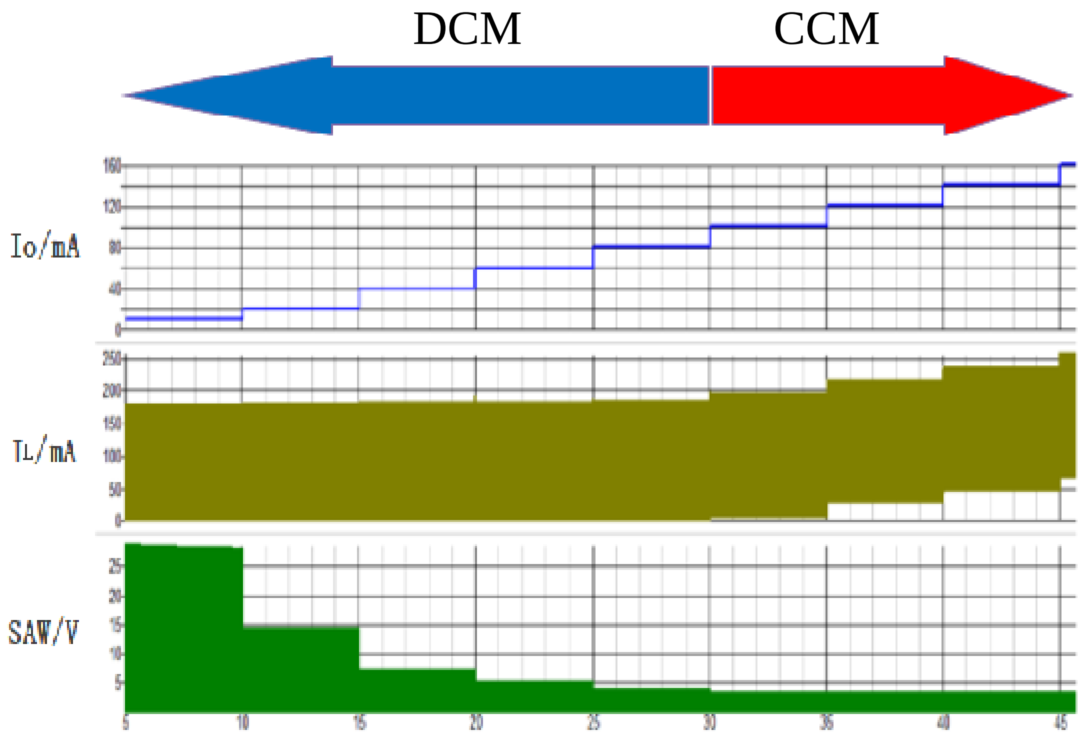
Hysteretic controlled switching converter with ripple injection

Operating frequency ➡ determined by
- Comparator delay
- Hysteresis and loop delay
- Time constant CR of ripple generation circuit



Hysteretic controlled converter with ripple injection.



V_{in} = 10 V
V_{out} = 3 V
L = 10 mH
C = 100 uF
ESR = 5 mΩ

R1 = 3.9 kΩ,
R2= 470 kΩ,
Rf = 470 kΩ,
Cf = 5 nF,
C_b = 20 uF.

SAW voltage is generated in F/V translation circuit.

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.

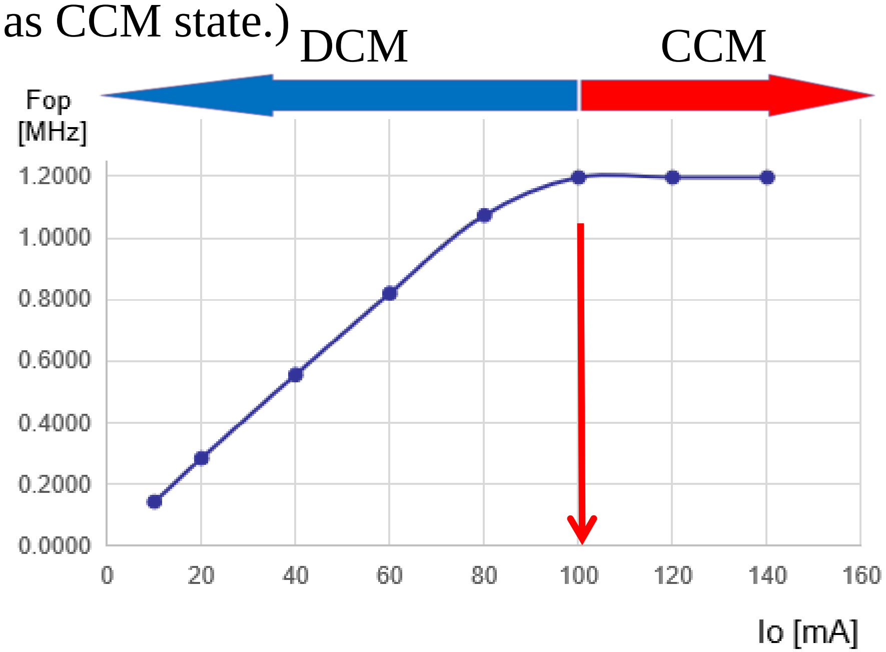
$$Q_L = I_T \cdot (T_{ON} + T_{OFF})/2$$

$Q_o = Q_L$

$$Q_L = I_o \cdot T_o$$

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

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



No matter how Io changes,
Q_L is unchanged,
Q_{min} is the minimum charge.

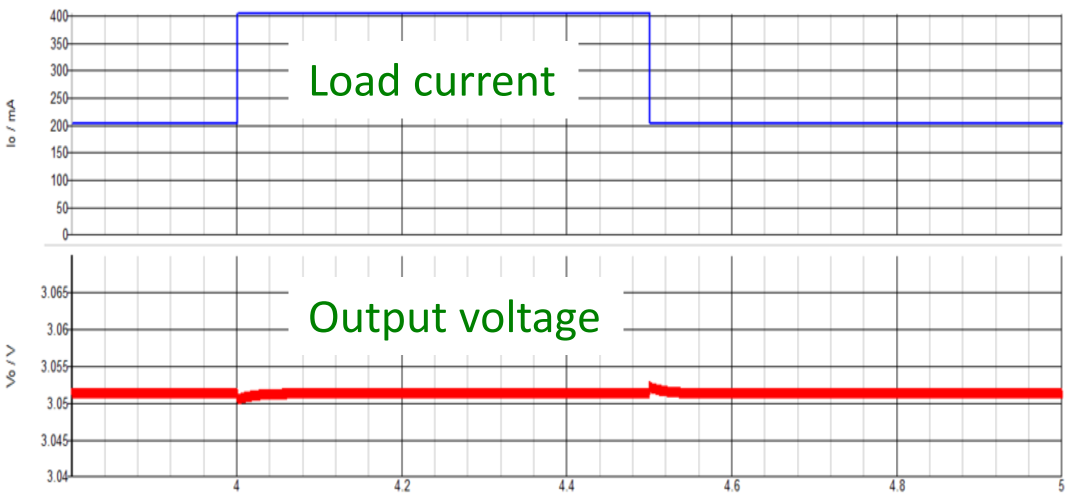
Operation frequency in DCM
is proportional to load current.

How to reduce the minimum current of CCM
Method 1

Increase $L_{o,}$ decrease C_o

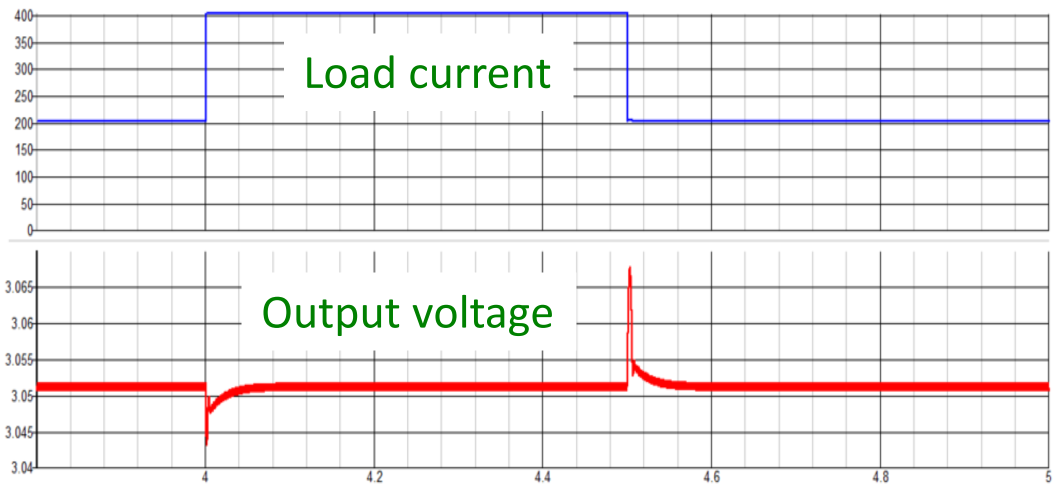
⇨ Transient response deteriorates **NG！！**

Lo= 10 μH ⇒ 50 μH
Co= 100μF ⇒ 20μF



Lo=10μH, Co=100μF

Before



Lo=50μH, Co=20μF

After

How to reduce the minimum current of CCM
Method 2

Qmin ↓ Fo ↑

Fo=1/To = Io/Qmin

Qmin decreases in proportion to Io

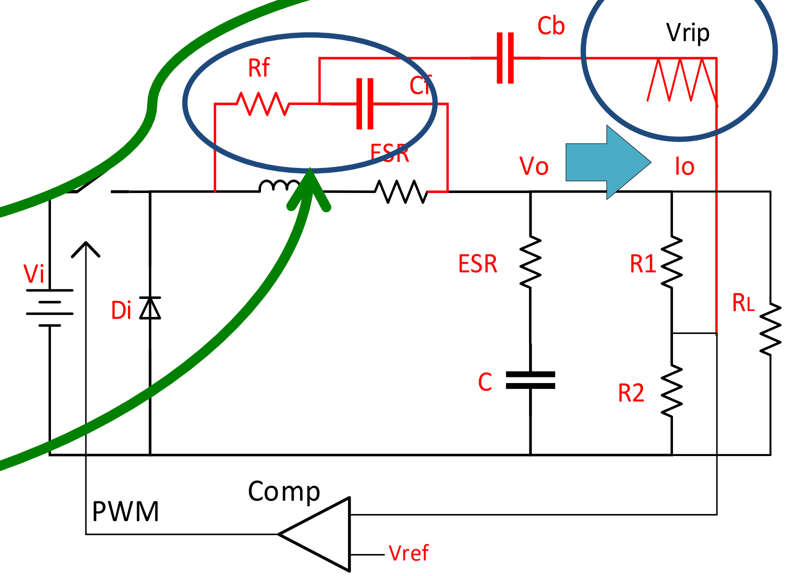
Qmin decreases in proportion to period

How to reduce Qmin: Reduce Ton

Rising slope of injection ripple)

Modulation of time constant for injection ripple generation

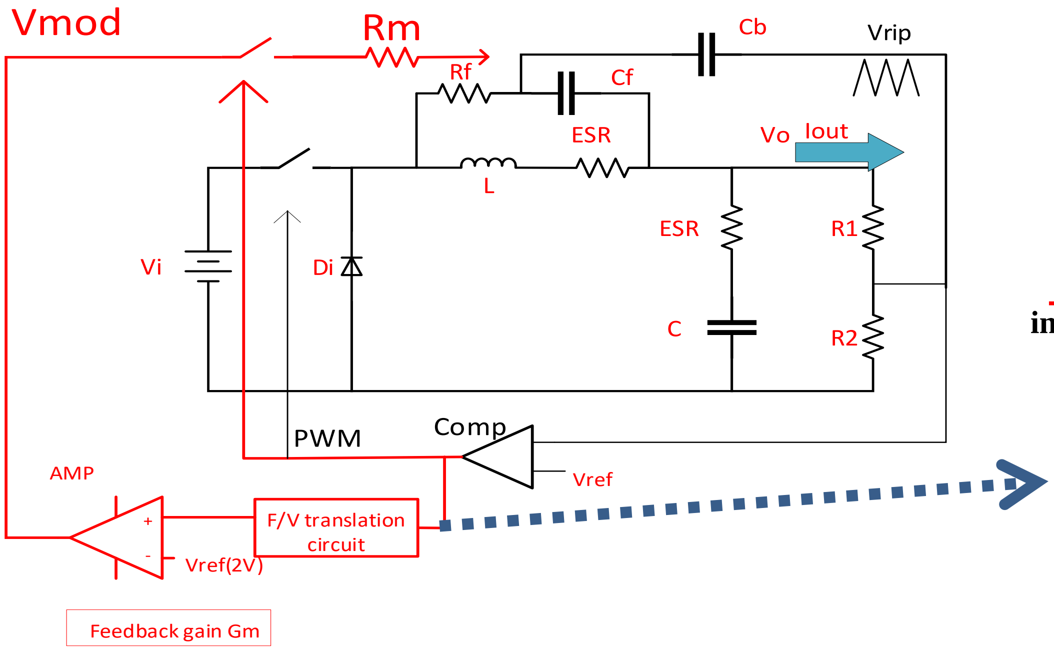
Operating frequency is determined by
time constant CR of ripple generation circuit



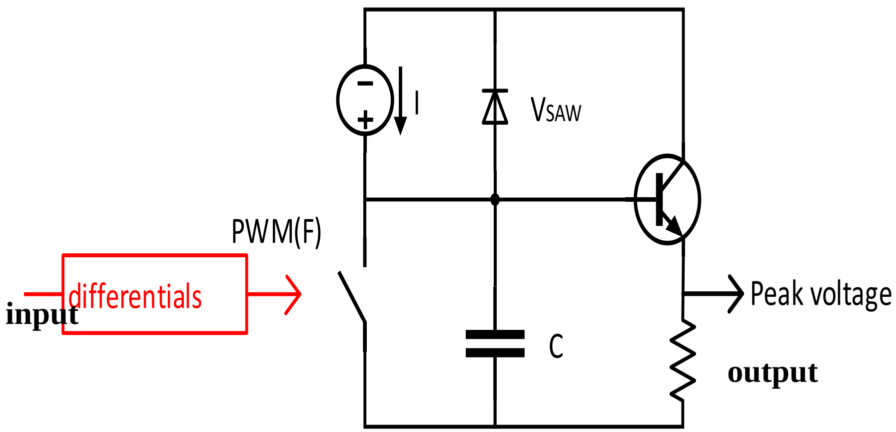
Outline

Improvement of operating frequency in DCM state

Stabilization circuit for ripple injection



Time constant modulation method for ripple generation



F/V translation circuit

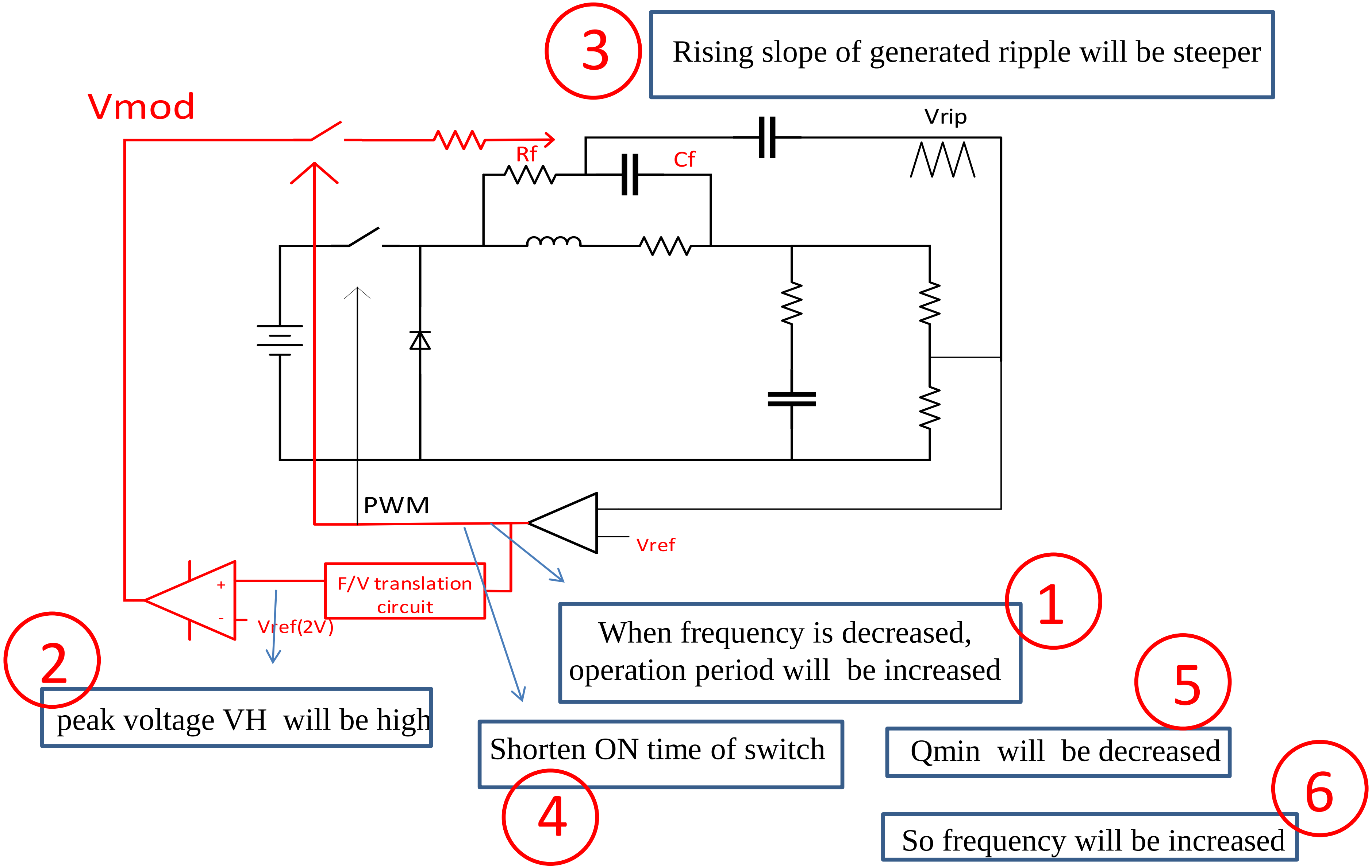
Voltage from F/V translation circuit

➡ in proportion to the operating period.

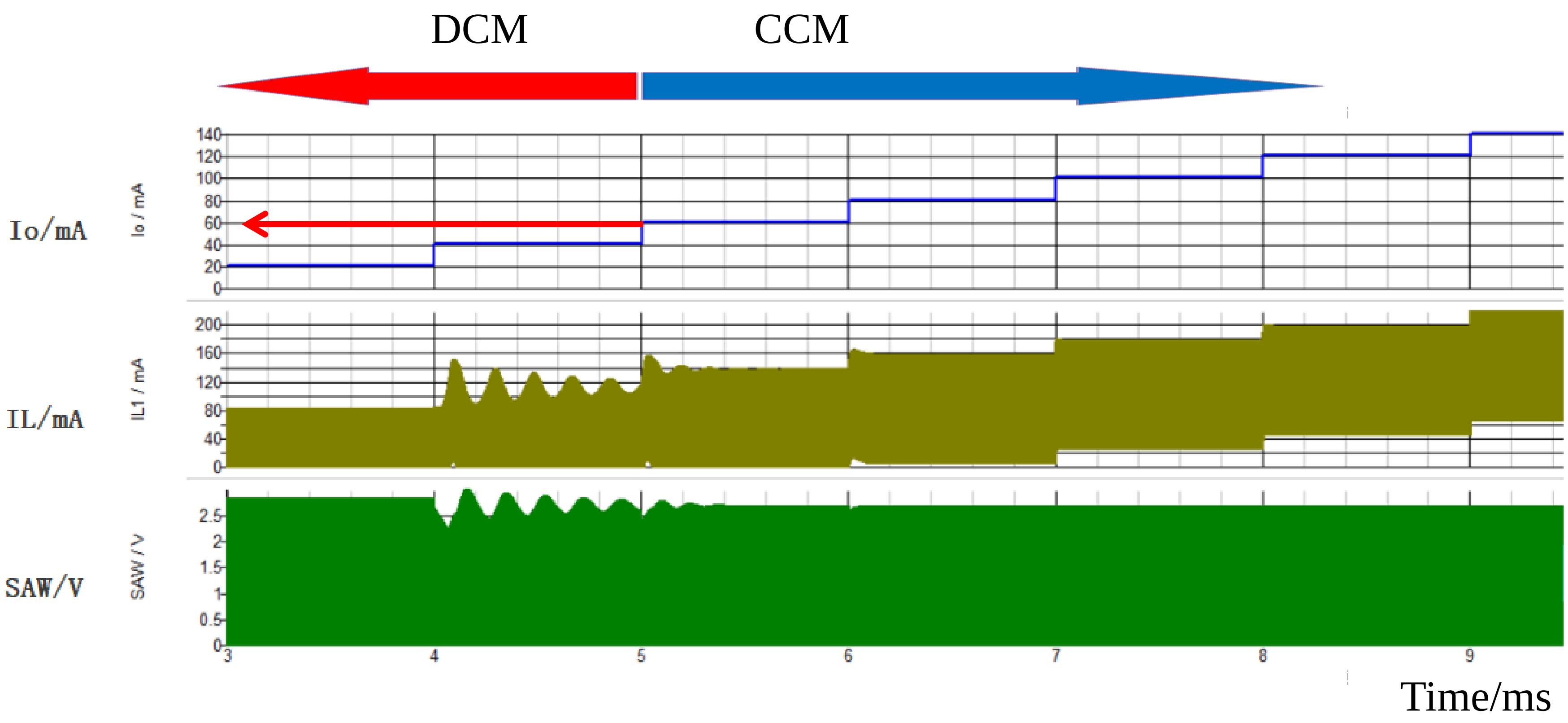
This voltage is amplified to generate a modulation voltage V_m

➡ injected into the ripple.

Modulation method of time constant for ripple generation

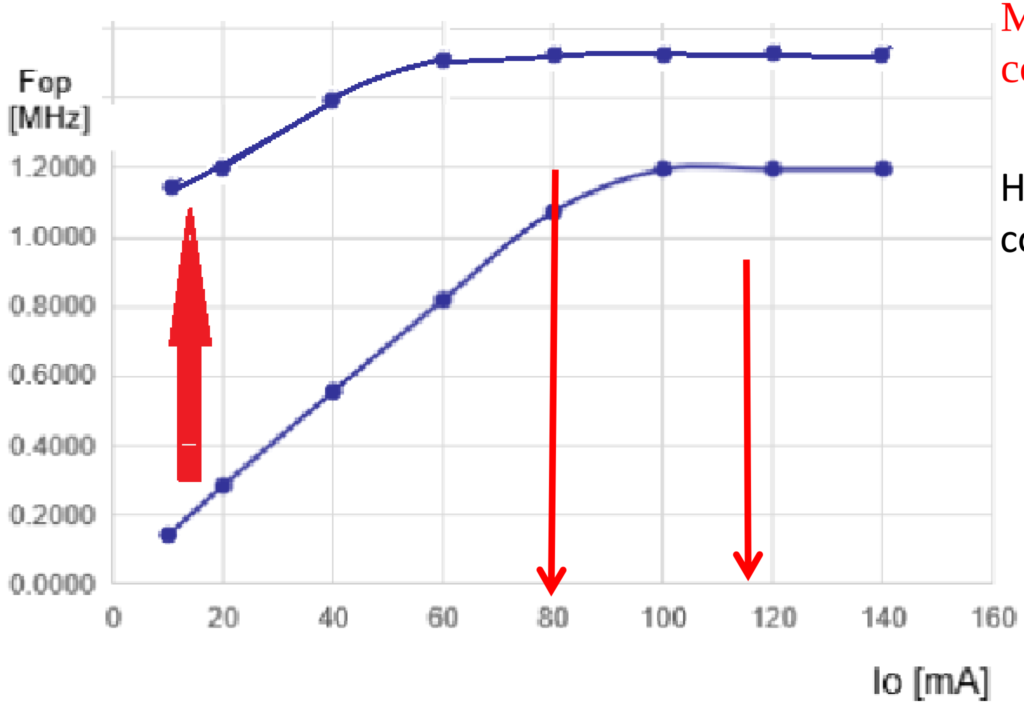


Results of simulation



Constant operating frequency ➡ Iout < 60 mA

Results of simulation



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
  α=85% to 20%.

Summary

- We investigated the basic buck switching converter and hysteretic controlled switching converter with ripple injection, and introduced the modulation method of time constant for ripple generation

- About hysteretic controlled switching converter, we verified and analyzed the relationship between current and frequency and proposed two methods to stabilize the frequency in DCM state.

- We proposed modulation method and circuit of time constant for ripple generation which greatly stabilize the operating frequency in DCM state.
  - ➡ More stable operating frequency and lower frequency change rate.
  - ➡ Beneficial for filtering ripple noise.

- Simulation results qualitatively agreed with analysis.

Future Research

- To stabilize the frequency even under 40mA of the output current.

- To analyze ripple injection type hysteretic controlled converter using the transfer functions.