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Notch Frequency Generation Methods in Noise Spread Spectrum for Pulse Coding Switching DC-DC Converter

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Outline

1. Research Background

- **EMI in switching converter**
- **EMI reduction by noise spectrum spread**

2. Basic Pulse Coding Switching Converters

- **Basic buck DC-DC converter**
- **Notch frequency by pulse coding control**

3. Ripple-Controlled Hysteretic Converter with Band-Select Noise Spectrum Spread

- **Theoretical analysis of PFM method**
- **Pulse coding COT converter**
- **Simulation results**

4. Conclusion

COT: Constant ON/OFF Time

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EMI in switching converter

Many devices use DC-DC switching converters.

⇒ Switching pulses emit much EMI noise.

⇒ Reducing the EMI noise is critical.

EMI

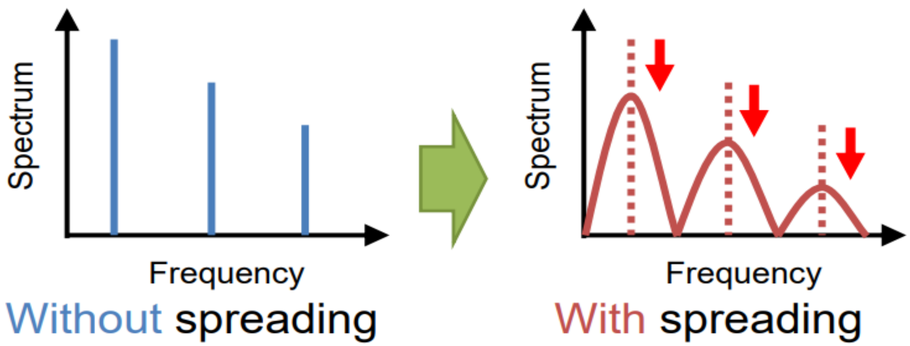
EMI: Electro-Magnetic Interference

EMI Reduction by Noise Spectrum Spread

◆ Spectrum Spread

EMI noise spectrum peak:
Reduced

Noise in Radio signal bands:
Spread



Normal Spectrum Spread method

◆ + Pulse Coding method

Noise spectrum peak:
Reduced

Generate Notch Frequency
in Radio signal bands

- **Next: ripple-controlled COT converter**
(This work)

* How to generate pulses

COT: Constant OFF/ON Time

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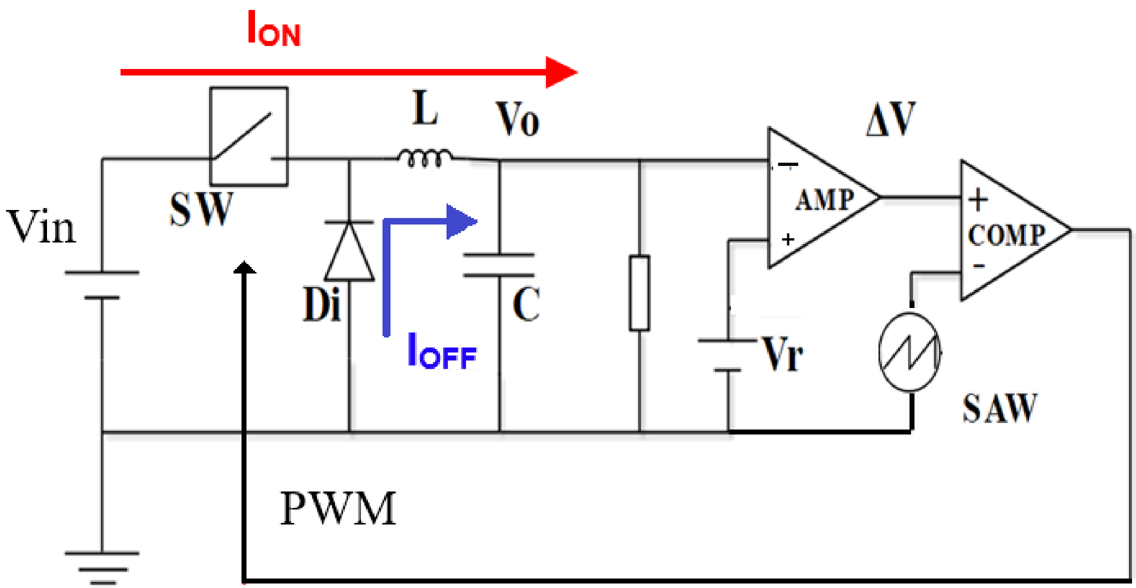
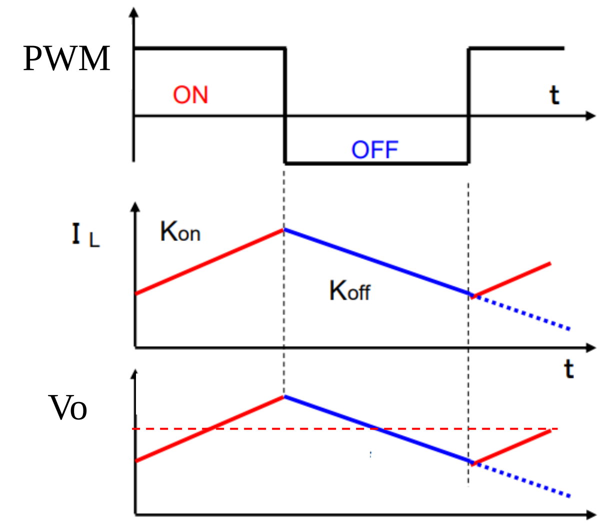
Basic buck DC-DC converter





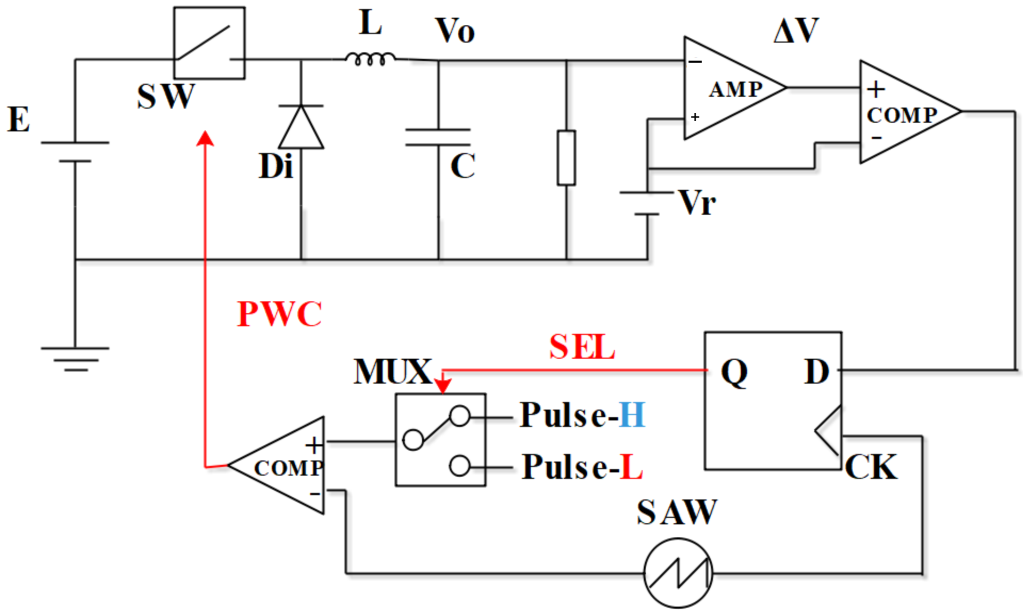
$$V_o = D \cdot V_{in} \qquad (D: \text{PWM Duty})$$

$$I_{ON} = (V_{in} - V_o)/L$$

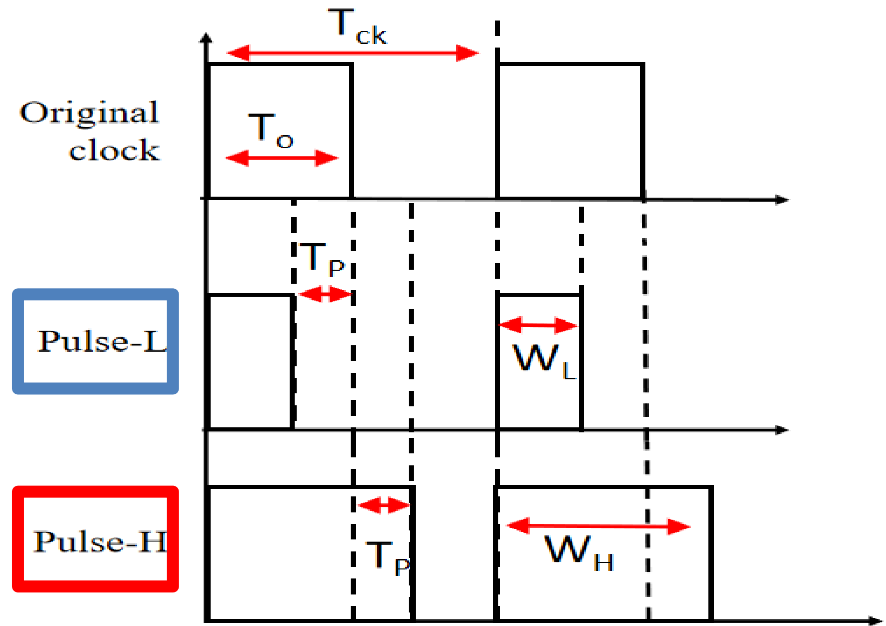
$$I_{OFF} = -V_o/L$$

PWM: Pulse Width Modulation

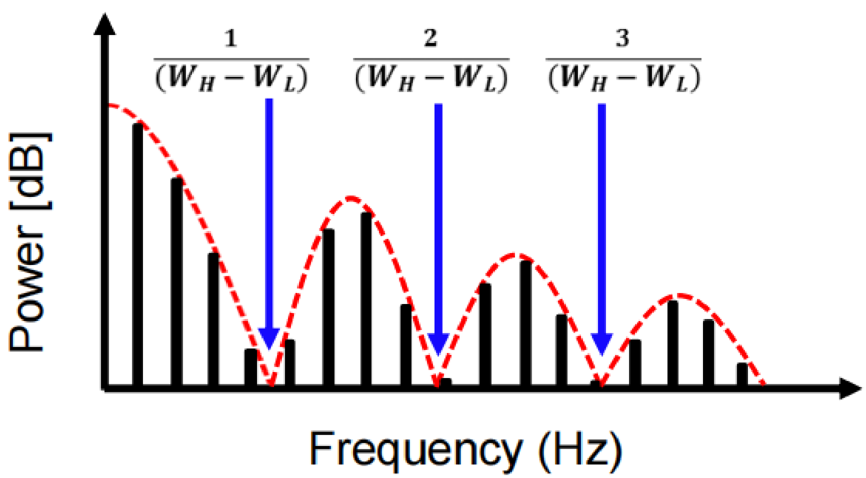
Notch frequency by Pulse Coding Control



PWC method switching converter



Coded pulses of the PWC control



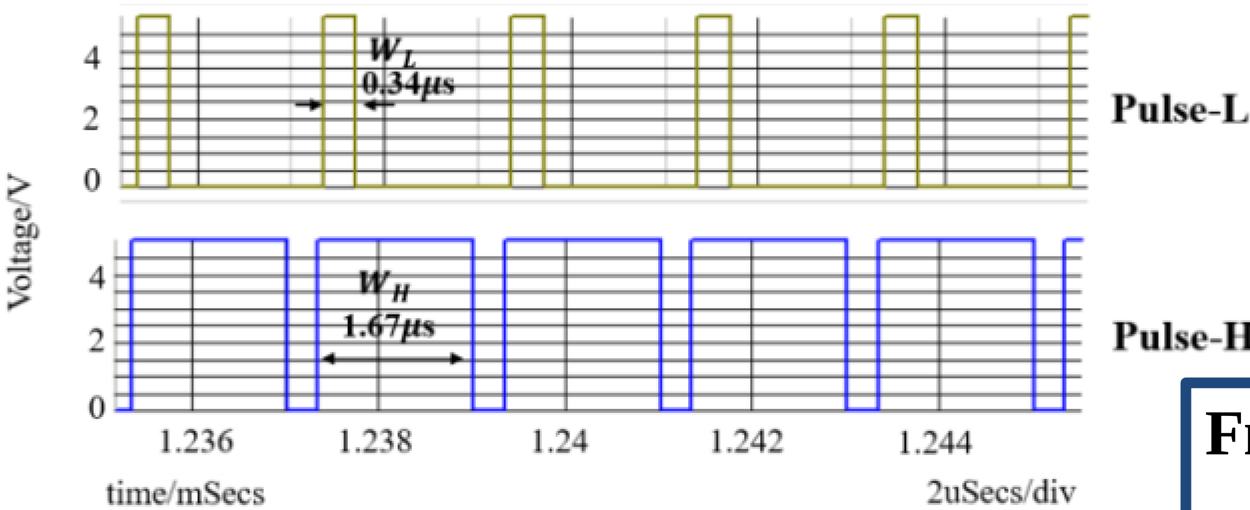
Spectrum of the switching converter with PWC

$$|f(\omega)| = (W_H - W_L)\left|sinc\{\tfrac{\omega}{2}(W_H - W_L)\}\right|$$

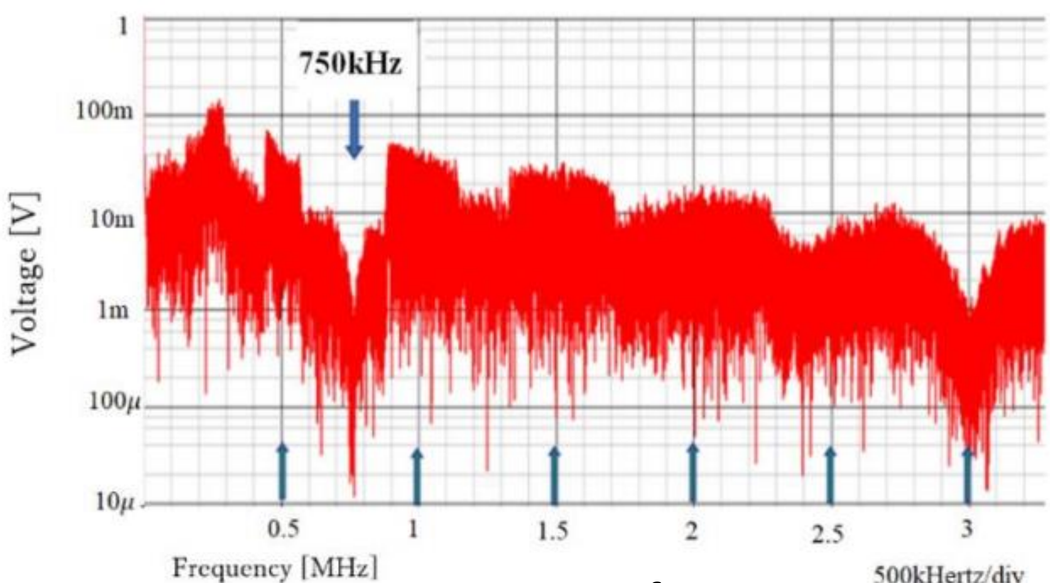
$$F_n = \frac{M}{W_H - W_L}$$

PWC： Pulse Width Coding

Notch frequency by Pulse Coding Control: Simulation



Coded pulse



Spectrum of PWM

Fn =1/(WH-WL)

= 1/(1.67-0.34)μ

= 750 kHz

Fck= 500 kHz

$$F_n = \frac{M}{W_H - W_L}$$

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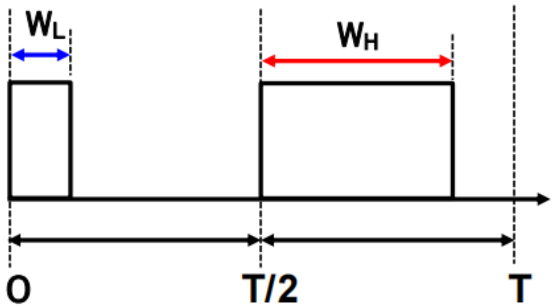
COT: Constant ON/OFF Time

Theoretical analysis of PFM method

PFM : pulse frequency modulation

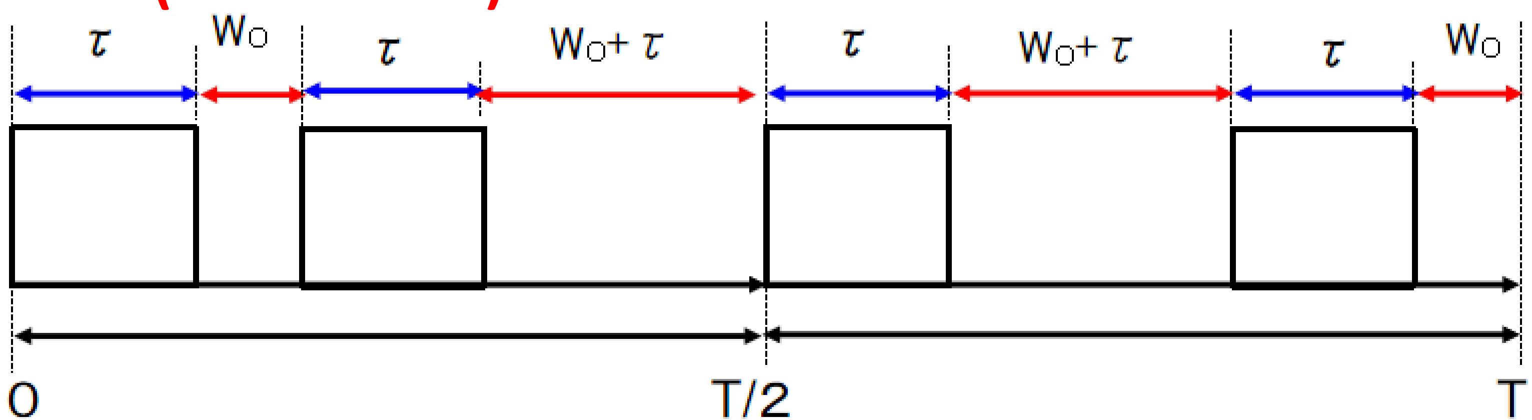
◆ PWC method （Previously proposed）



$$|f(\omega)| = (W_H - W_L)\left|sinc\{\tfrac{\omega}{2}(W_H - W_L)\}\right|$$

$$F_n = \frac{M}{W_H - W_L}$$

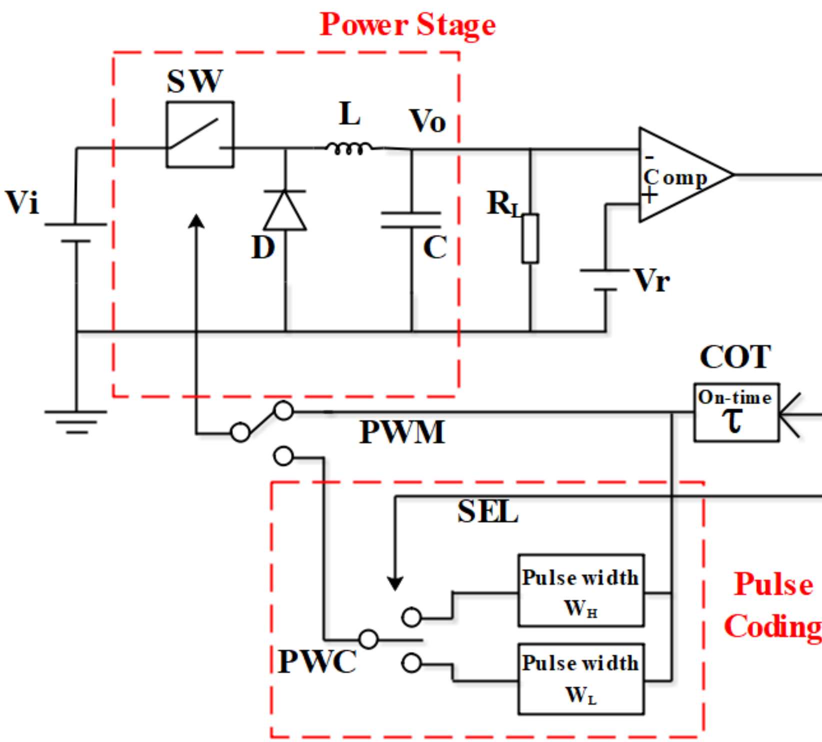
◆ PFM method (COT control)（This time）



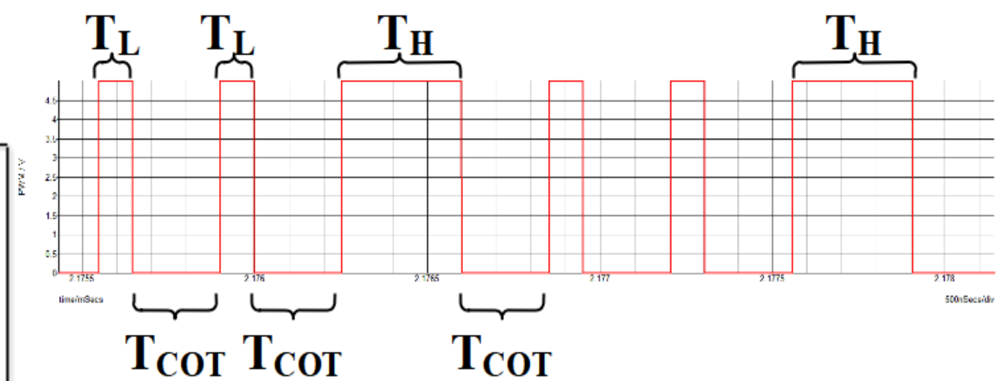
$$|f(\omega)| = \frac{4}{\omega} sin^2\left(\frac{\omega\tau}{2}\right) = 2\tau \sin\left(\frac{\omega\tau}{2}\right) \text{sinc}\left(\frac{\omega\tau}{2}\right)$$

$$\frac{\omega\tau}{2} = n\pi \quad -> \quad F_n = n/\tau$$

Pulse coding COT converter



Ripple controlled PFM pulse coding converter



Pulse of PFM (COT method)

$$T_{COT} = \tau = T_{in}$$

$$D_o \fallingdotseq V_o / V_{in}$$

$$(1-D_o)T_{ck} = T_{cot}$$

$$T_{ck} = T_{cot} + (T_H + T_L)/2$$

Tck : Average period of clock frequency

Tin : Period of input frequency

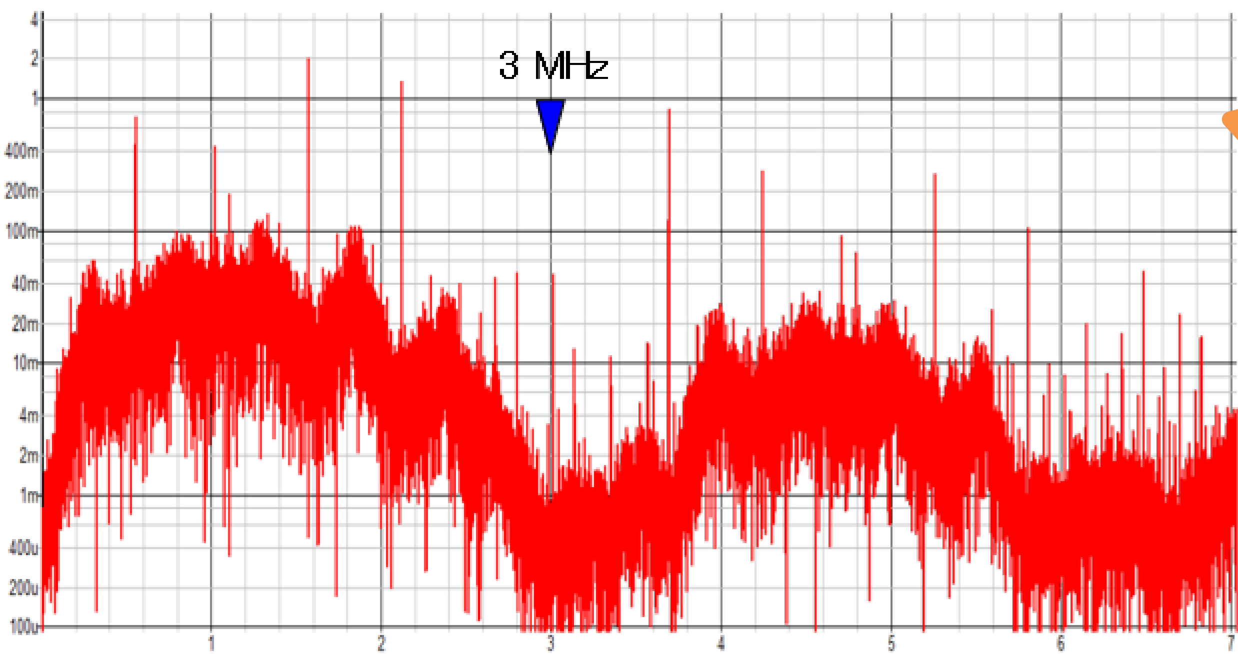
COT: Constant OFF Time

Pulse coding COT converter: Simulation results

Tck=682ns±150ns Fck=1.47MHz（⊿F=−0.27/+0.41MHz）

τ =T_{COT} = 336ns, W_H−W_L= 496−196ns=300ns

F_N ≒ 3.0 MHz ～ 3.3 MHz



Simulation result of analog circuit

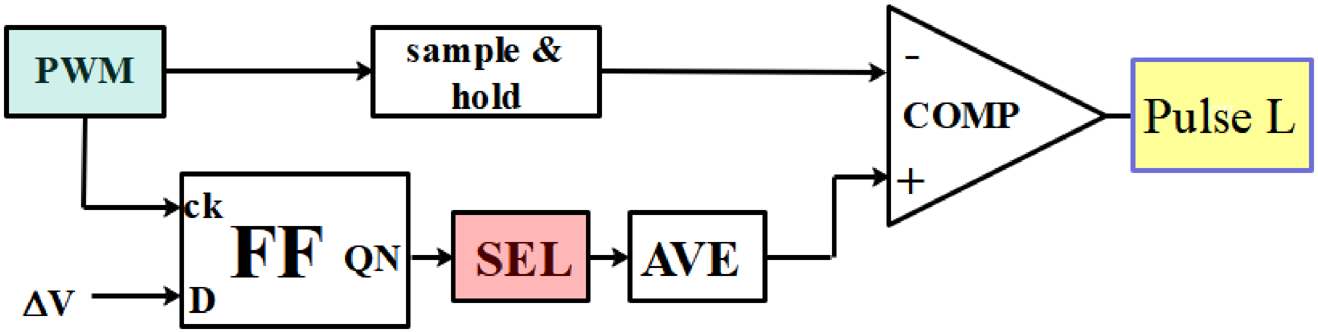
F_n =n/τ

Notch depth:
Shallow

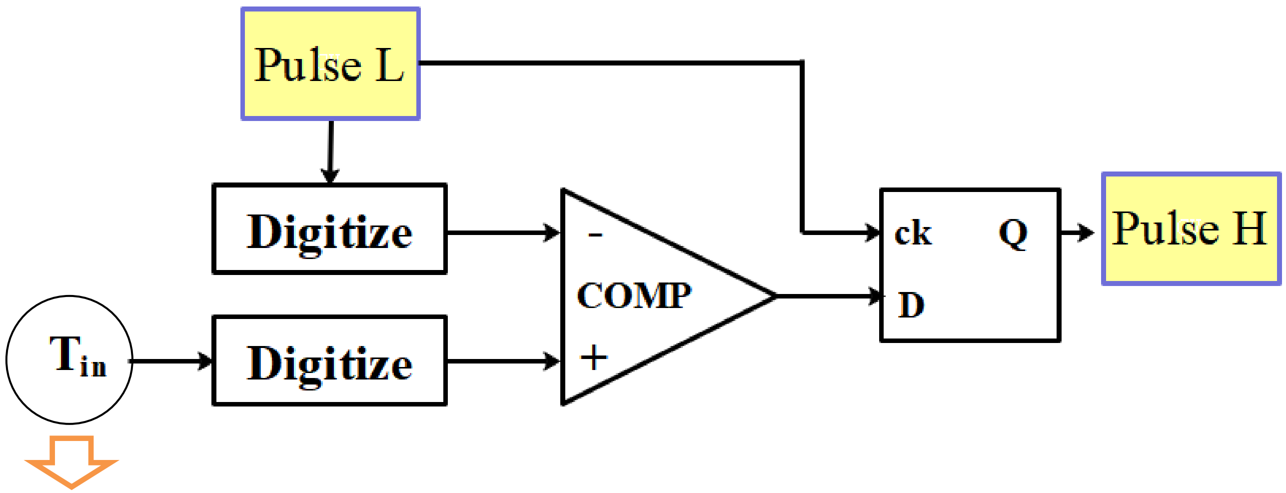
Accuracy :
poor

So we need:
Digital circuit

Pulse coding COT converter: Digital implementation



Blocks of pulse L generation circuit.



Automatic response when Fin(1/Tin) changes

Blocks of pulse H generation circuit.

Simulation results: Waveforms

Fin =4.0 MHz Vin=10V

Vo=4.0V Io=0.4A

Fm= 1 kHz, Vm=100mV

L= 100μH+10mΩ,

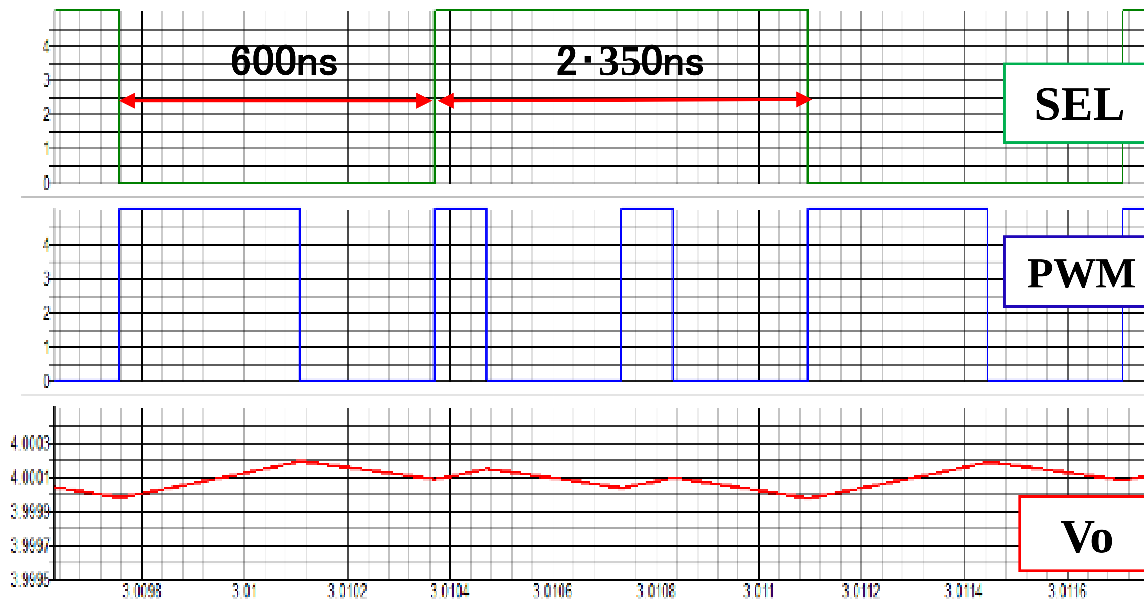
Co=220 μF+10mΩ

Tck=950ns (1.05MHz)

T_{OFF}=Tcot = 258 ns

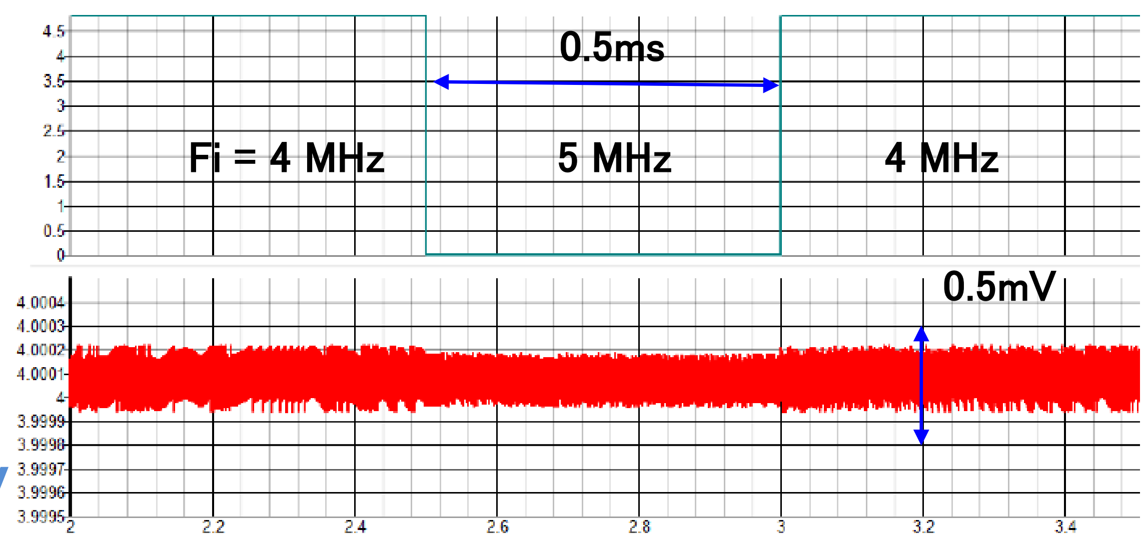
W_H−W_L= 250 ns

⊿Vo= 0.4 mV

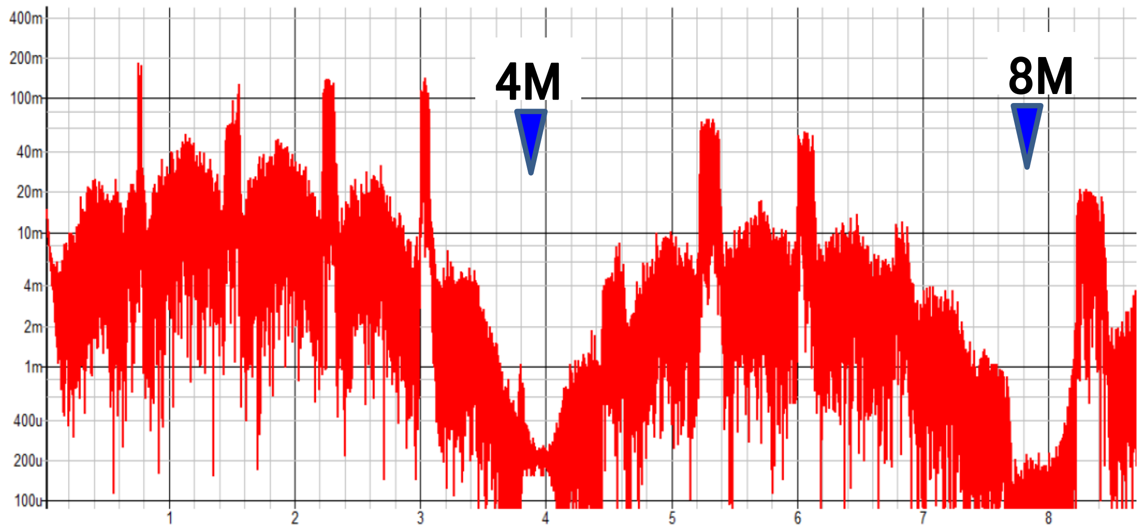


Fin= 4 MHz ⇔ 5 MHz

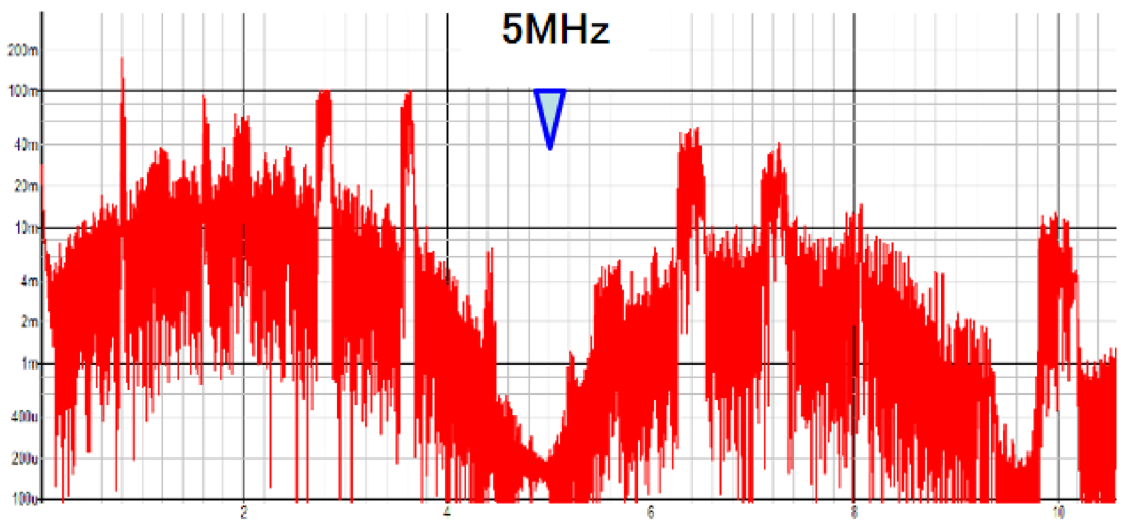
Overshoot:⊿Vs＜0.1mV



Simulation results: Spectrum



F_N = 4.0M. 8.0 MHz



F_N = 5.0MHz

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This work:

- **Introduction** : **Pulse coding switching DC-DC converter**
- **Proposal** : **Ripple-controlled converter with pulse coding method**

Automatically generates notch frequency.
Notch : Deeper!
Overshoot: Smaller!
Transient response : Quicker!

Future work:

- Exploration of **more** methods
- **Hardware experiments** are underway