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Mechanical, Electricaland Medical Intelligent System

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Self-Adjustable Notch Frequency in Noise Spectrum of Pulse Coding DC-DC Converter for Communication Devices

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OUTLINE

- Introduction & Objective
- Conventional Switching Converters with Spread Spectrum
- Pulse Coding Method in Switching Converter
- Automatic Self-Adjusting the Notch Frequency
  - Relationship with the Clock and the Notch
  - Simulation Circuit and the Major Waveform
  - Simulated Noise Spectrum of PWM Signal
- Conclusion

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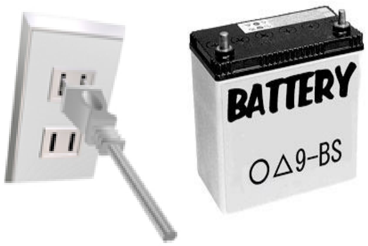
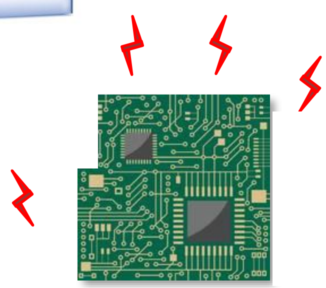
Research Background





EMI

Switching converters

Supply many kinds of voltage by switching power

↓

Power of switching converter has become large

↓

Switching noise has strongly spread in wide frequency range

↓

Important to reduce switching noise by decreasing main spectrum level

EMI:Electro-Magnetic Interference

Research Objective

Usually we reduce clock noise by spread spectrum
with shaking clock phase at random by analog noise

Noise of clock frequency is spread to all frequencies
around clock & its harmonics

Some electronic devices like radio receivers
would not like to be affected at special frequency noise

Research Objective

①Reduction of EMI[1] generated from clock
②**Noise removal** at specific frequency
③Automatic generation notch frequency

[1]EMI:Electro-Magnetic Interference

Research Objective

Proposed method

Spread spectrum method using pulse coding

Design circuit
in order to generate notch frequency automatically

↓

Switching power circuit

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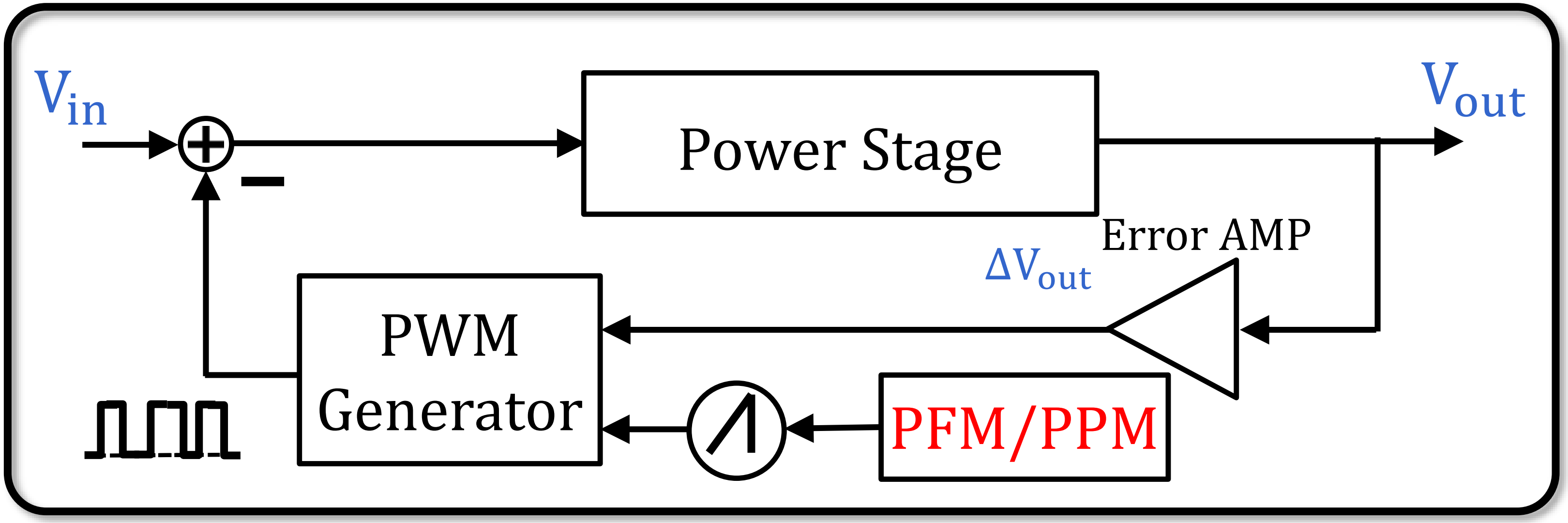
Conventional Switching Converters with Spread Spectrum

Spread Spectrum

Analog modulation of periodic clock
⇒Reduction of electro-magnetic noise concentrating on fundamental frequency

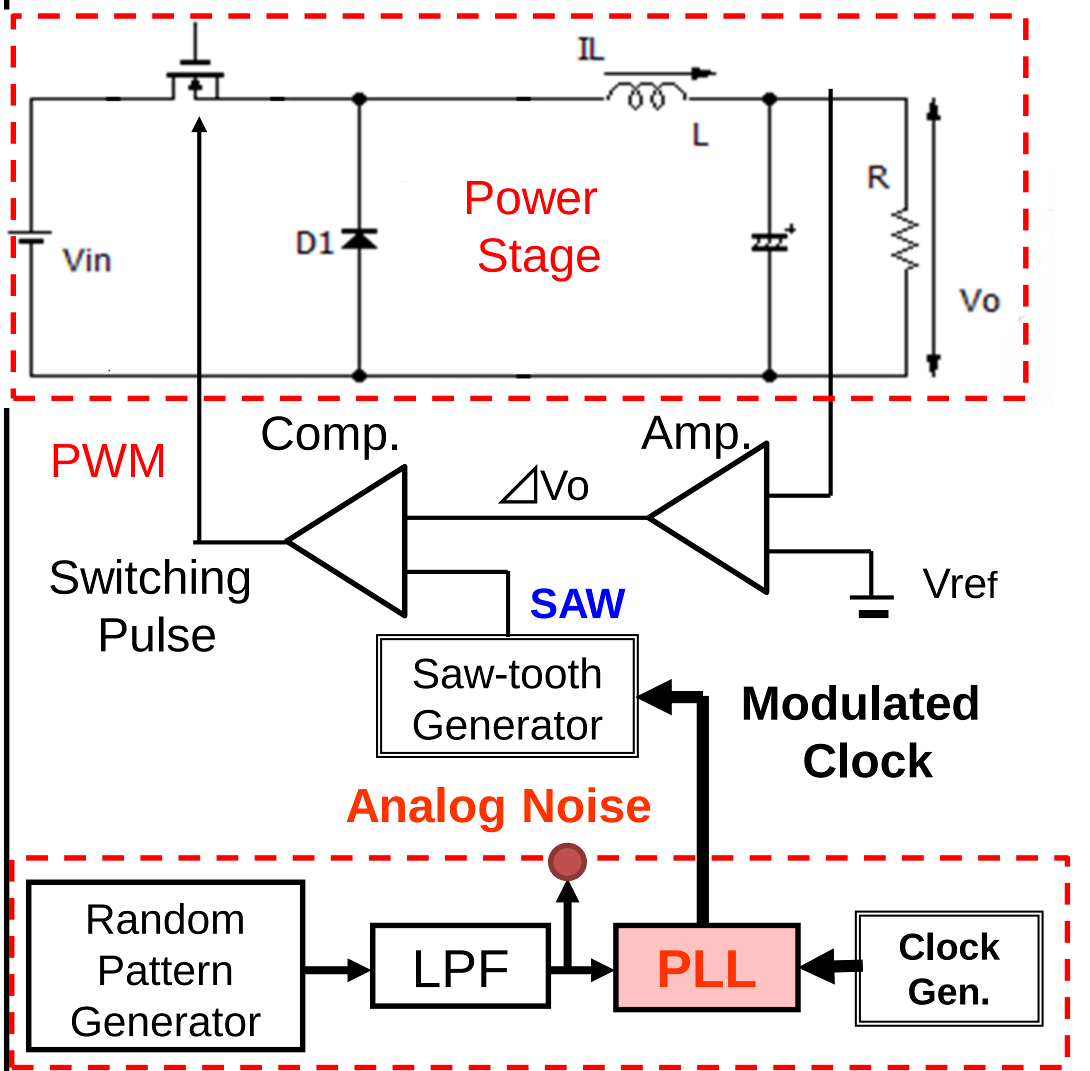


Switching Power

PFM : Pulse Frequency Modulation

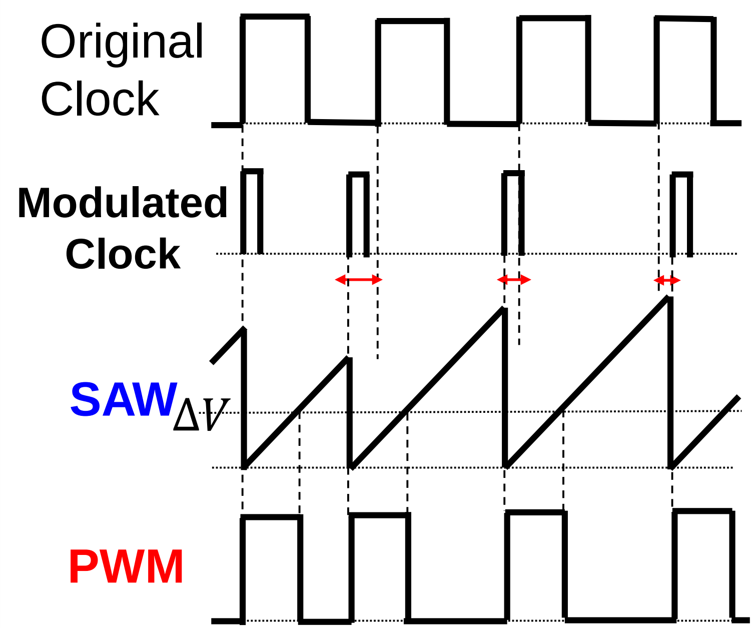
PPM : Pulse Phase Modulation

Spread Spectrum for EMI Reduction



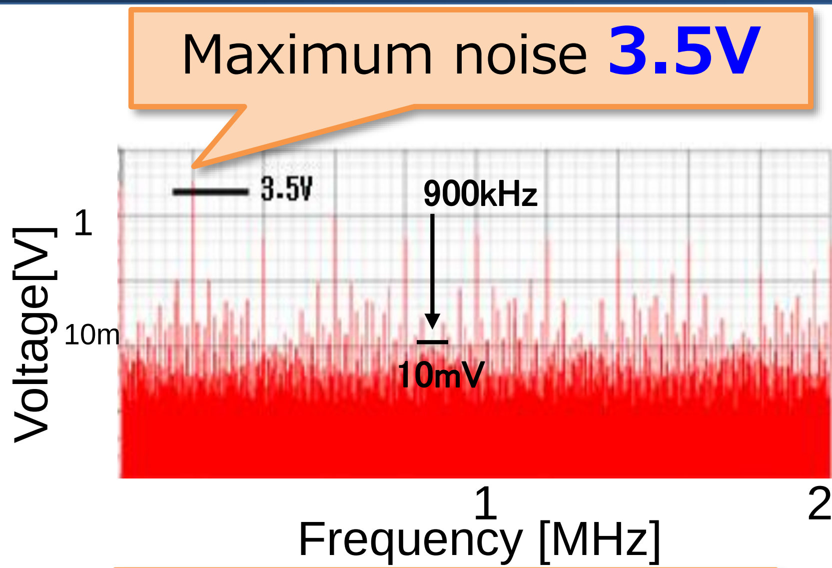
Buck converter with modulated clock

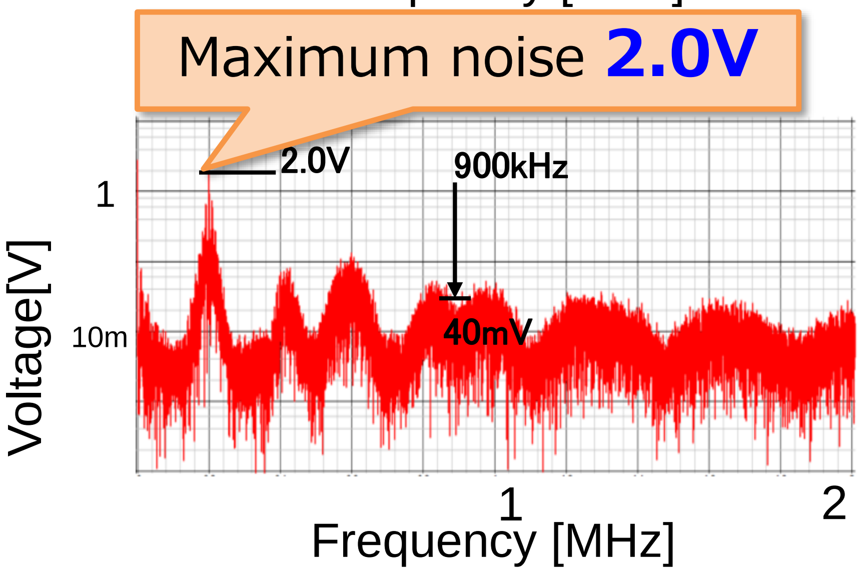
* Clock to SAW generator is modulated by shaking phase of original clock at random using analog noise & PLL
* SW pulse frequency is modulated and reduce EMI noise



Timing Chart

Spread spectrum for EMI Reduction





◎Simulation conditions

Input : 12V

Output : 6V

Clock frequency : 200kHz

Without EMI reduction

➢ Noise is concentrated in basic and harmonic frequencies

With EMI reduction

➢ Peak level of clock frequency is reduced a lot

Noise is concentrated by diffusion

Noise increases depending on frequency

Spectrum ⇐ Fast Fourier Transformation (FFT) of PWM signal

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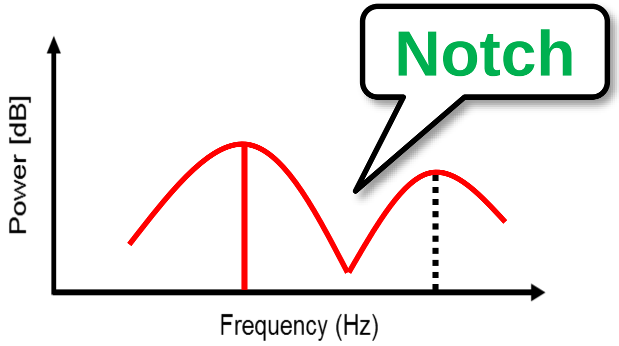
Diffuse Noise to Specific Frequency

Problem

Noise diffusing uniformly



Using digital modulation

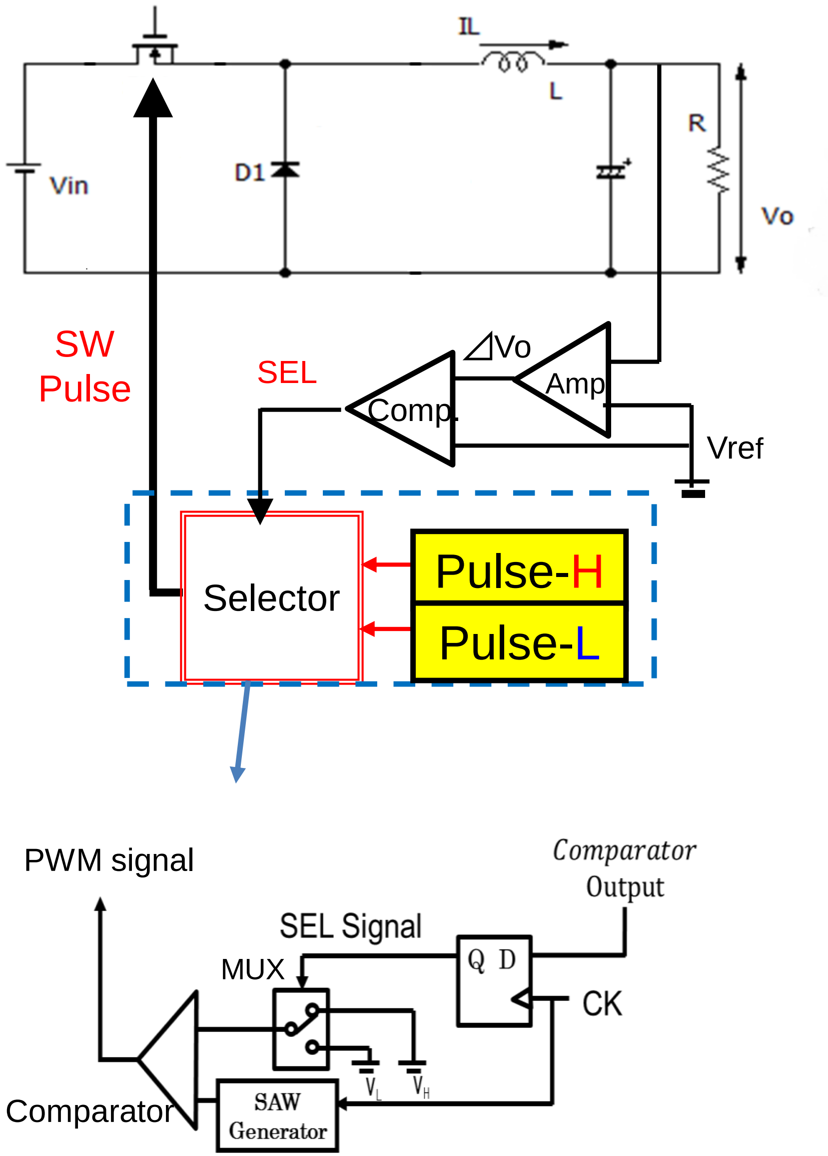
Noise diffuses to specific frequency

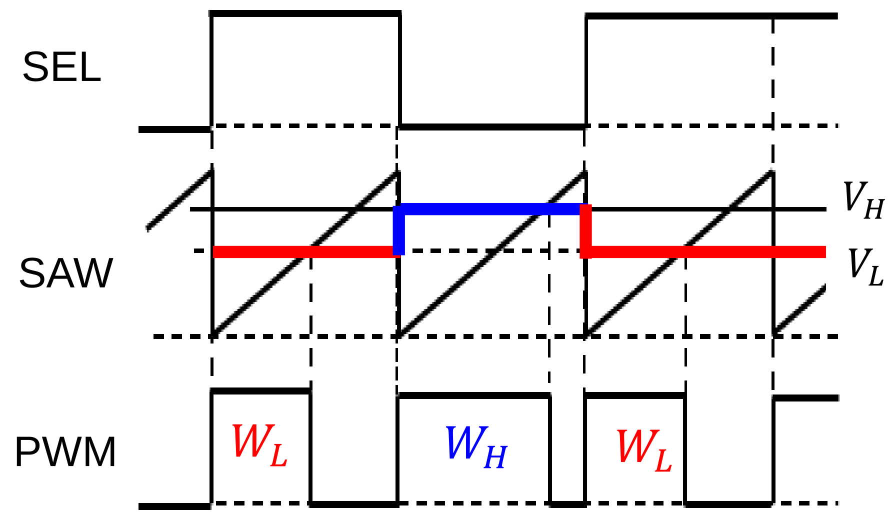
Frequency band where noise does not spread

Notch band created in important frequency band

- Reduction EMI
- Control of diffused noise

Pulse Width Modulation in Switching Converter





Input High

①SEL: High
②MUX select V_H
③Generate pulse with long width in comparator

★ $D_H > D_o > D_L$

$$D_o = V_o / V_{in}$$

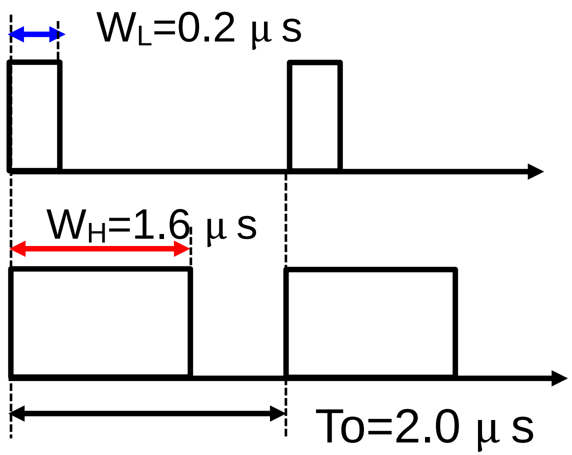
Input Low

①SEL: Low
②MUX select V_L
③Generate pulse with short width in comparator

Simulation Result with PWC & EMI Reduction

◎ Condition

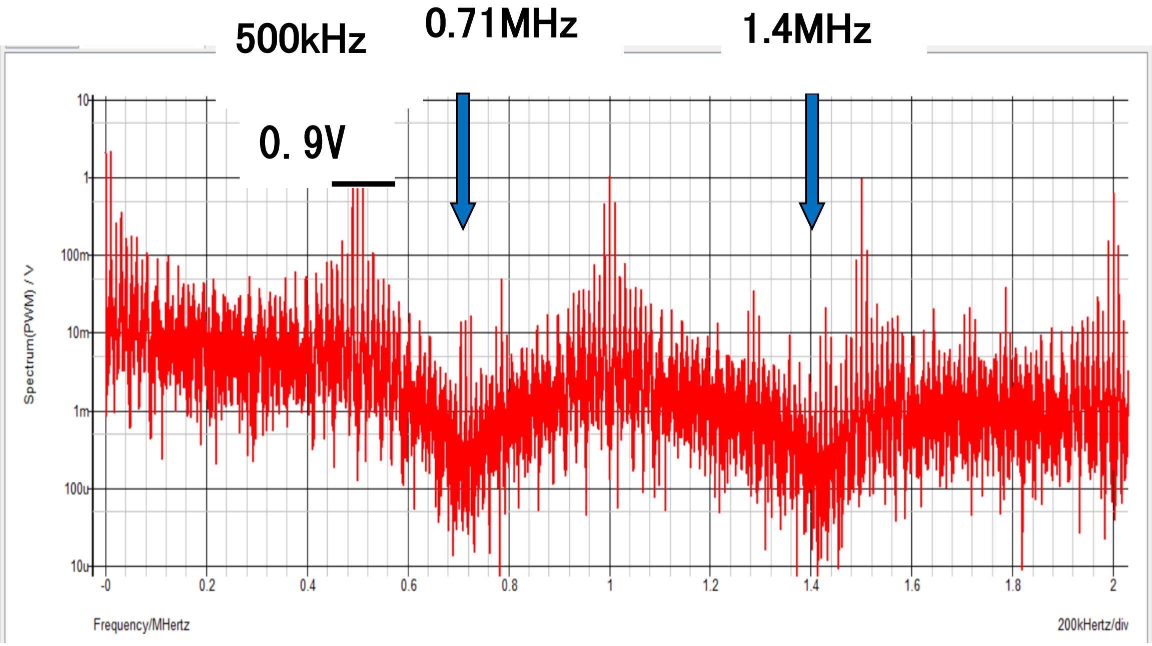
Buck DC-DC converter
V_{in} : 10V
V_{out} : 5V
L : 200 μ H
C : 470 μ F
I_{out} : 0.25A
f_{ck} : 500kHz



Design a clock pulse to determine the notch frequency

$$f_n \cong N \times \frac{1}{(W_H - W_L)} \quad [N = 1,2,3,\cdots,n]$$

$$= N \times \frac{1}{1.6\mu s - 0.2\mu s} = 714\text{KHz}$$



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Application of Automatic Self-Adjusting the Notch Frequency

Switching frequency and harmonics used in in-vehicle DC-DC converter must not overlap reception frequency bands of AM, FM of radio

demand

Reception frequency from radio receiver ≈ Notch frequency ≠ N times clock frequency

Frequency band where noise does not spread

DC-DC converter

Radio receiver

Goal

Automatic generation of notch frequency

It is possible to greatly reduce influence on other electronic devices

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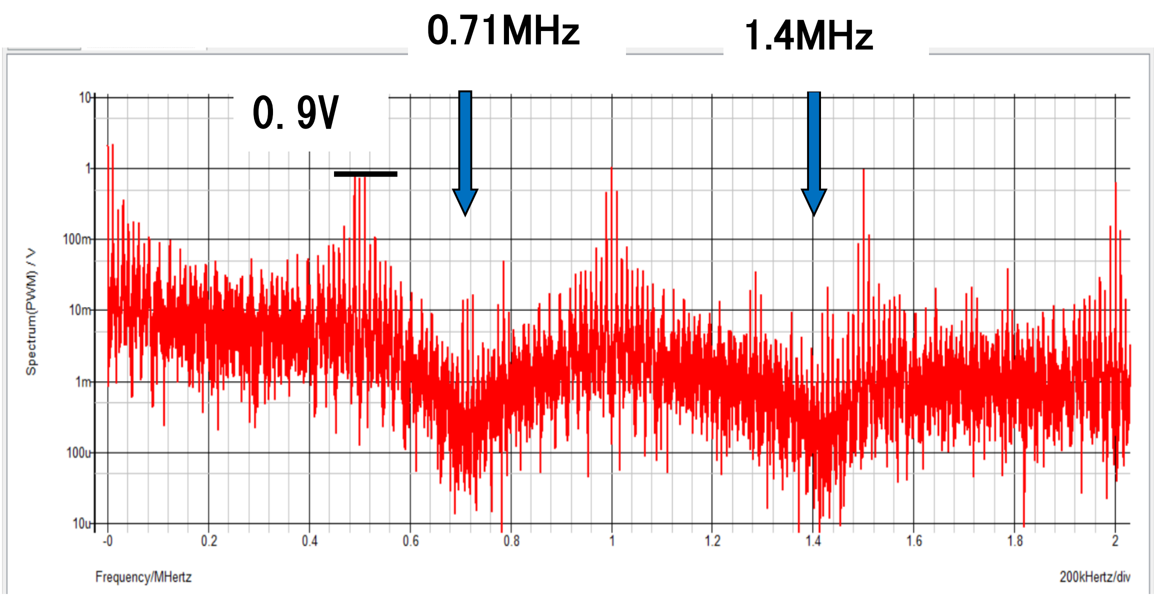
Relationship with Clock and Notch

f_{ck} : 500kHz



It is good for notch frequency Fn to appear at the middle between clock frequency Fck and its twice frequency 2Fck

$$f_{\mathrm{ck}} < f_{\mathrm{in}} < 2f_{\mathrm{ck}}$$

$$\mathrm{N}f_{\mathrm{ck}} < f_{in} < (\mathrm{N}+1)f_{\mathrm{ck}}$$

Optimal

$$f_{\mathrm{in}} = (N+0.5)f_{\mathrm{ck}}$$

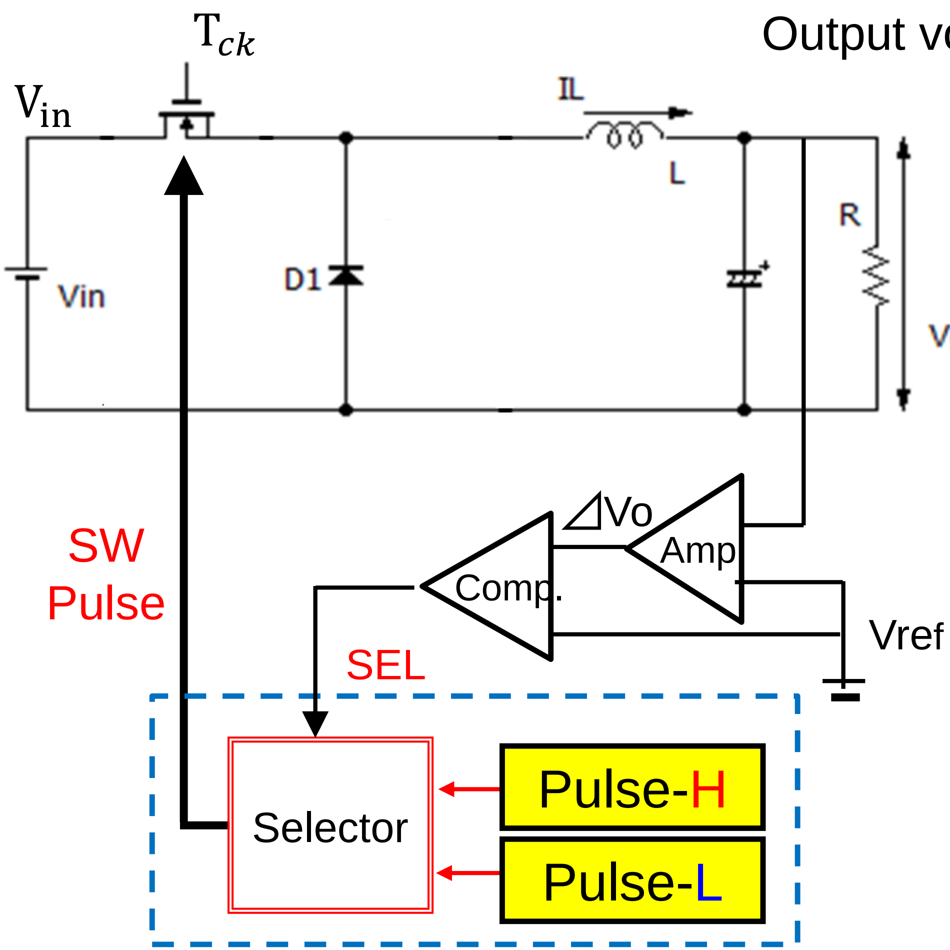
When N=1

Optimal

$$f_{\mathrm{in}} = 1.5f_{\mathrm{ck}}$$

$$\frac{f_{in}}{3} = \frac{f_{ck}}{2}$$

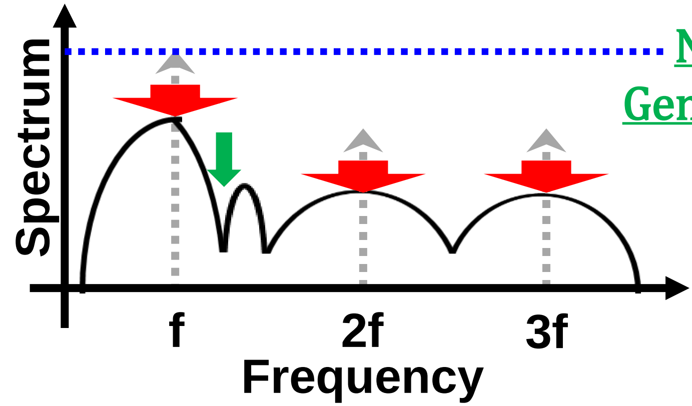
Relationship with Clock and Notch



Output voltage Vo is determined by the clock duty

$$T_{on} = D_o \times T_{ck} = \frac{V_o}{V_{in}} \times T_{ck}$$

Customizing input Fin can self-adjust notch frequency, automatically.



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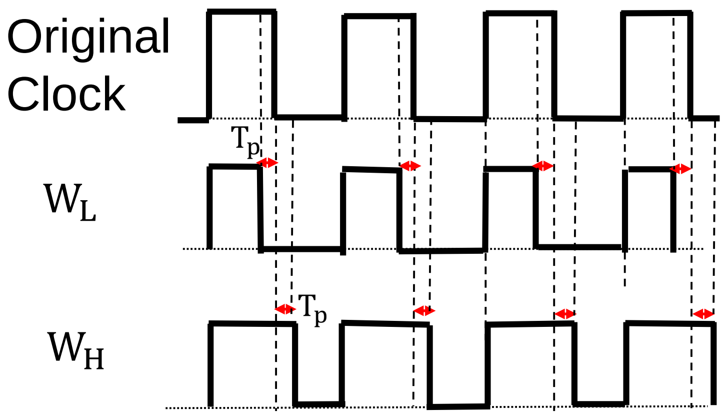
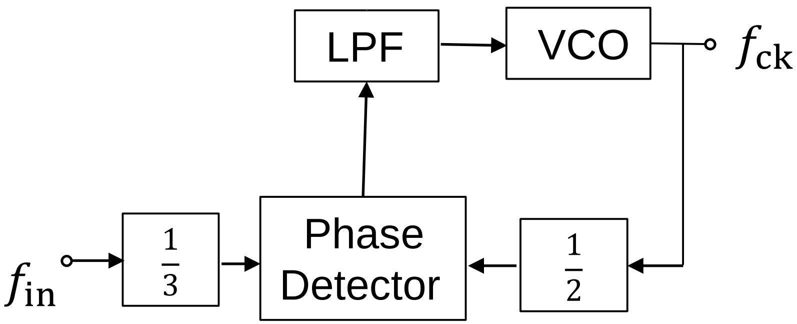
Simulation Circuit and Waveforms of F_{in} and F_{ck}



Timing Chart

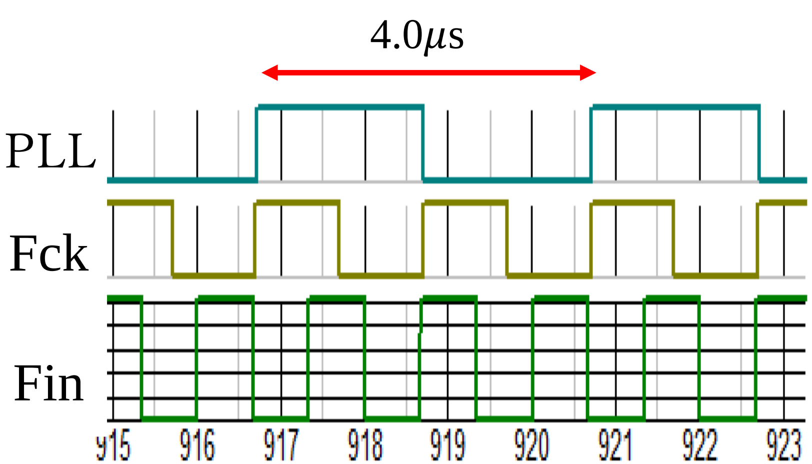
$$W_L = T_o - T_p$$
$$W_H = T_o + T_p$$
$$T_n = W_H - W_L = 2 \times T_p$$

$$T_{on} = D_o \times T_{ck} = \frac{V_o}{V_{in}} \times T_{ck}$$



Generation of PLL synchronized signals

$$f_{ck} = (\frac{2}{3}) f_{in}$$



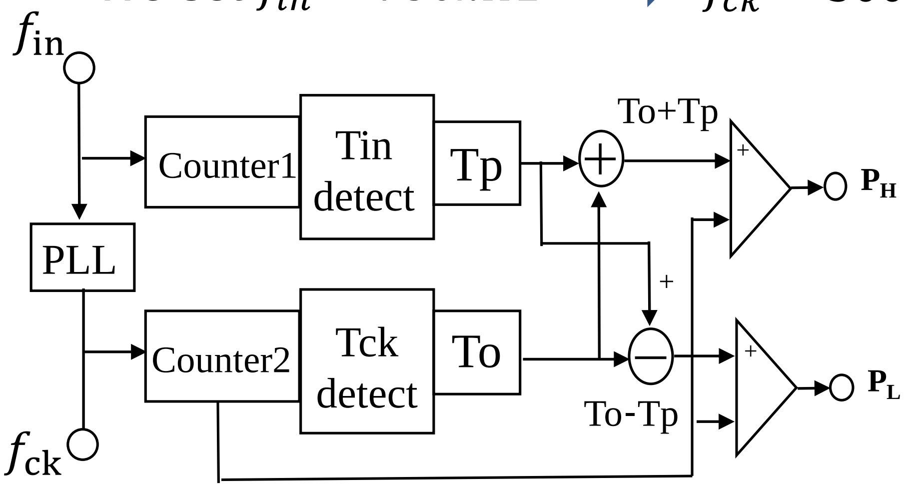
Waveforms of PLL circuit

Simulation Circuit and Waveforms of P_H, P_L Generation

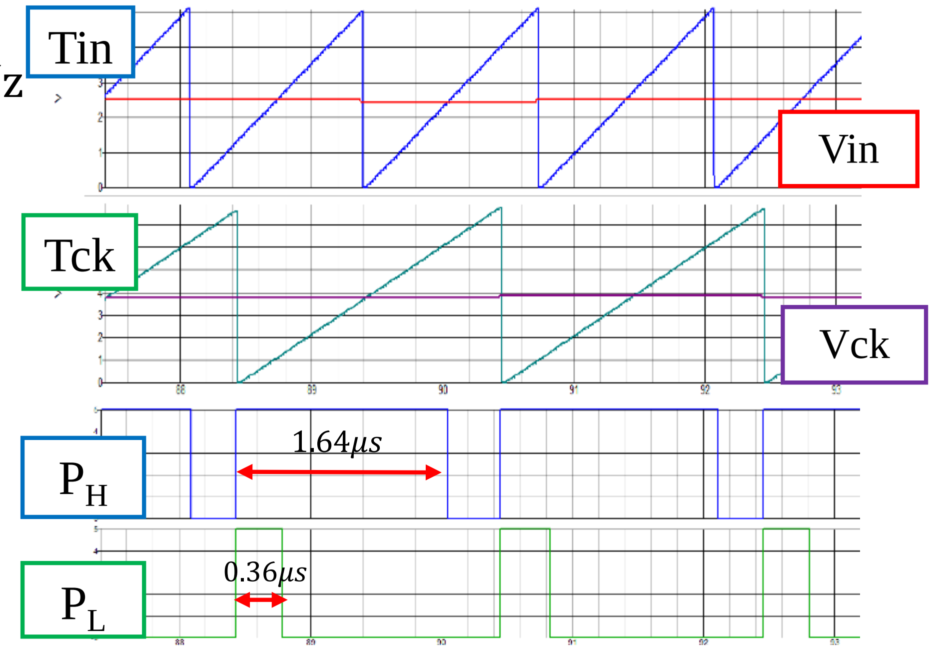
Pulse creation procedure

$f_{in} \Rightarrow f_{ck} \Rightarrow T_o, T_p \Rightarrow W_H, W_L$

We set $f_{in} = 750kHz$ ⇒ $f_{ck} = 500kHz$



Block diagram of P_H, P_L generation



Coding pulses in PWM signal

Theoretical formula

$$W_H = T_o + T_p = 1.67\mu s$$
$$W_L = T_o - T_p = 0.33\mu s$$

Experimental formula

$$W_H = 1.64\mu s$$
$$W_L = 0.36\mu s$$

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Simulated Noise Spectrum of PWM Signal

Formula of notch frequency

$$f_{notch} = \frac{n}{(W_H - W_L)} = \frac{1}{(1.64\mu s - 0.36\mu s)} = 780kHz \approx f_{in} = 1.5 f_{ck}$$

◎ Condition

Buck DC-DC converter

V_{in} : 10V

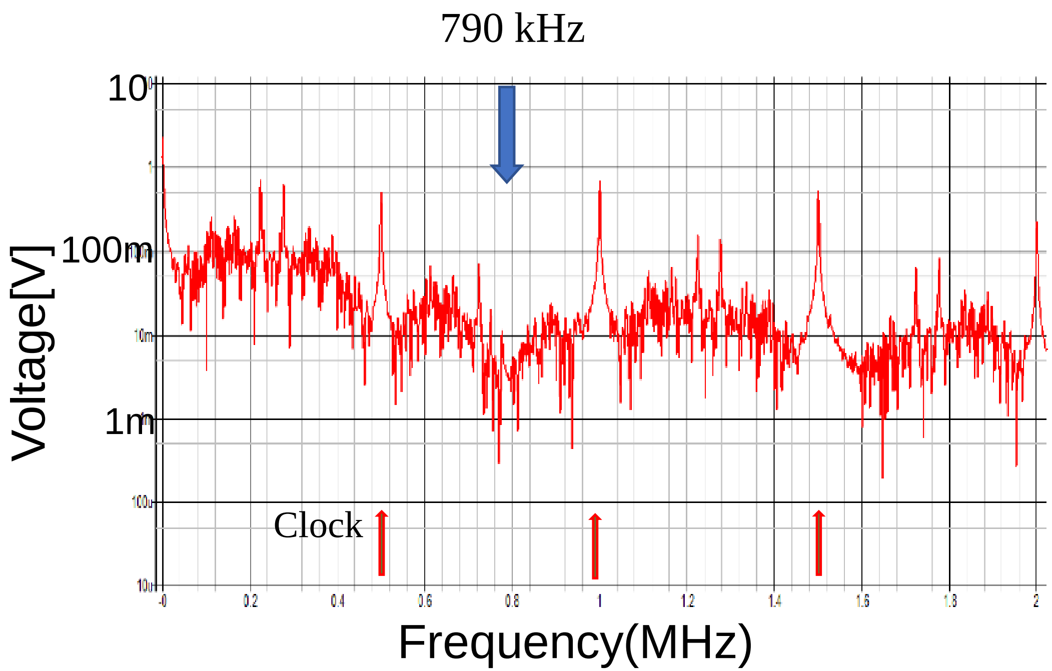
V_{out} : 5V

L : 200 μH

C : 470 μF

I_{out} : 0.25A

f_{in} : 750kHz



Assume to suppress influence on AM radio
⇒A notch was generated around 750kHz

Output Voltage Ripple with $\Delta I_o = \pm 0.5A$

◎ Condition

Current variation I_o : 1 A／0.5A

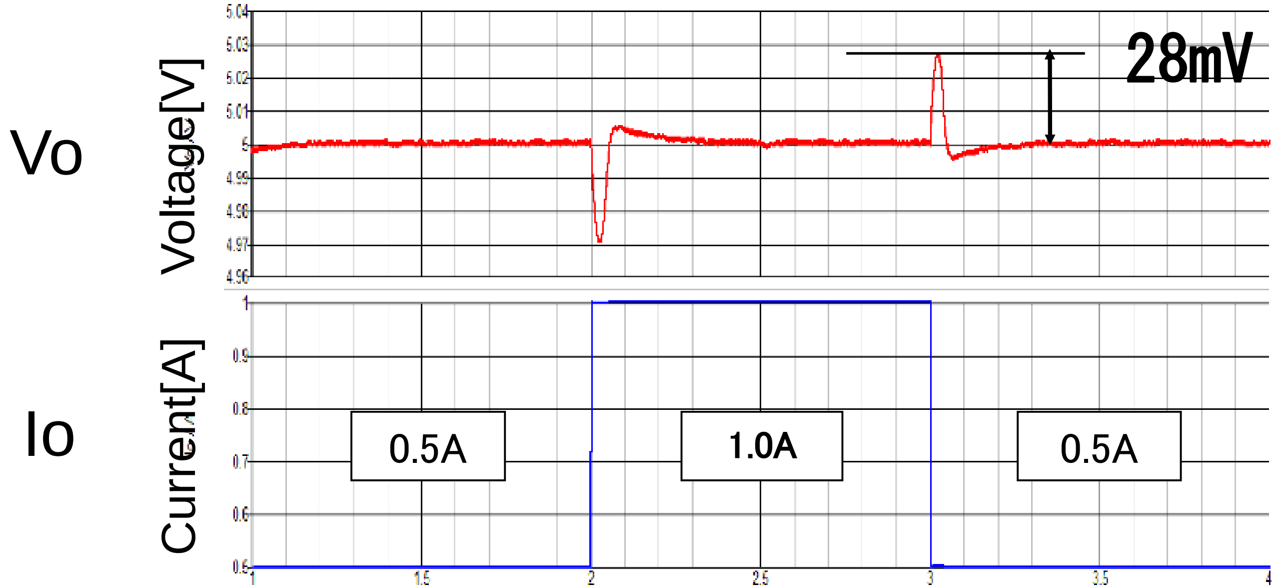
V_{in}=10V

V_o=5V

◎ Output stability

Ripple: $2mV_{pp}$

Overshoot or undershoot: $\pm 28mV$



Simulated EMI Spread Spectrum of PWM Signal

◎ Condition

$f_{\text{in}} = (N + 0.5)f_{\text{ck}}$ When N=1

$f_{in} = 1.5f_{ck} = f_{notch} = 750kHz$

Buck DC-DC converter

V_{in} : 10V

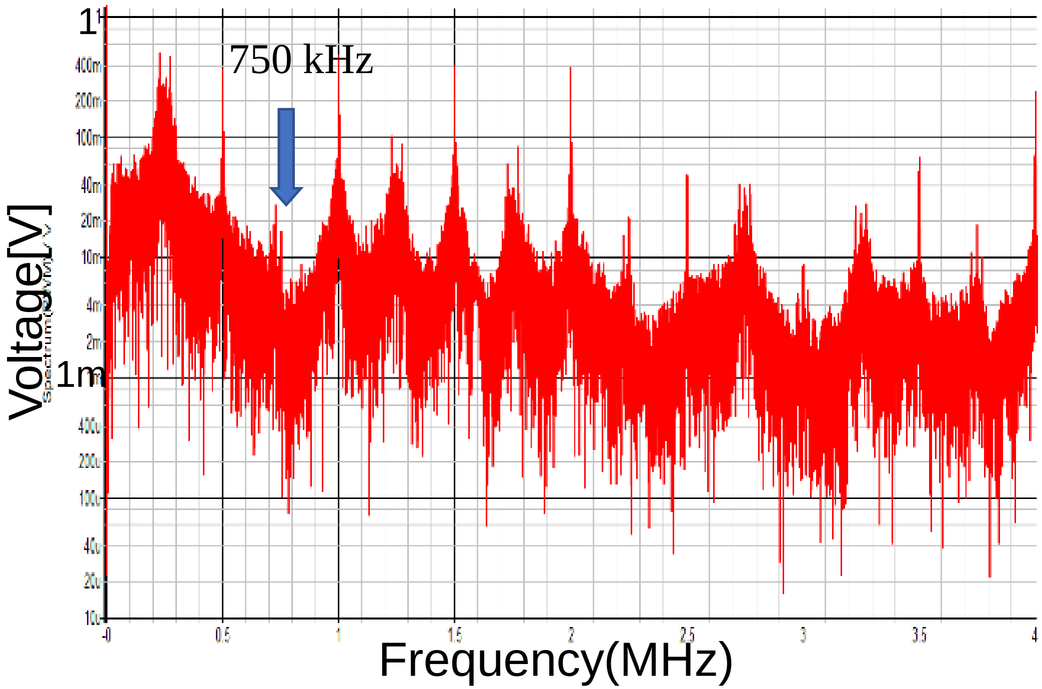
V_{out} : 5V

L : 200 μ H

C : 470 μ F

I_{out} : 0.25A

f_{in} : 750kHz



$f_{\text{ck}} < f_{in} < 2f_{\text{ck}}$

Simulated EMI Spread Spectrum of PWM Signal

◎ Condition

$$f_{\text{in}} = (N + 0.5) f_{\text{ck}}$$

When N=2

$$f_{in} = 2.5 f_{ck} = f_{notch} = 1.25MHz$$

Buck DC-DC converter

V_{in} : 10V

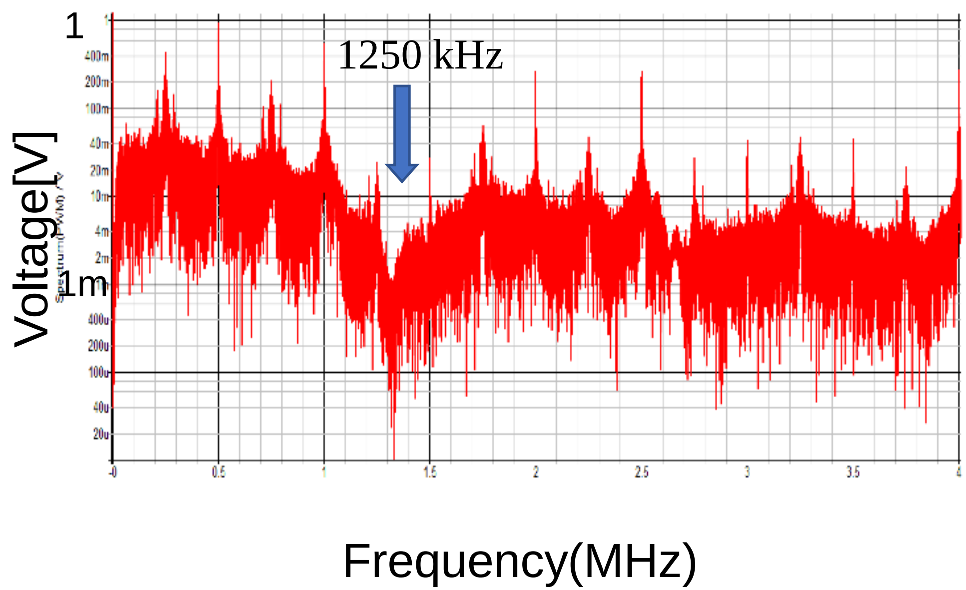
V_{out} : 5V

L : 200 μ H

C : 470 μ F

I_{out} : 0.25A

f_{in} : 1.25MHz



$$2f_{\text{ck}} < f_{in} < 3f_{\text{ck}}$$

Transient Response with F_{in} Change

◎ Condition

$f_{in} = 1MHz \Rightarrow f_{ck} = 667kHz$

f_{in} variation $0.5M / 1.0MHz$

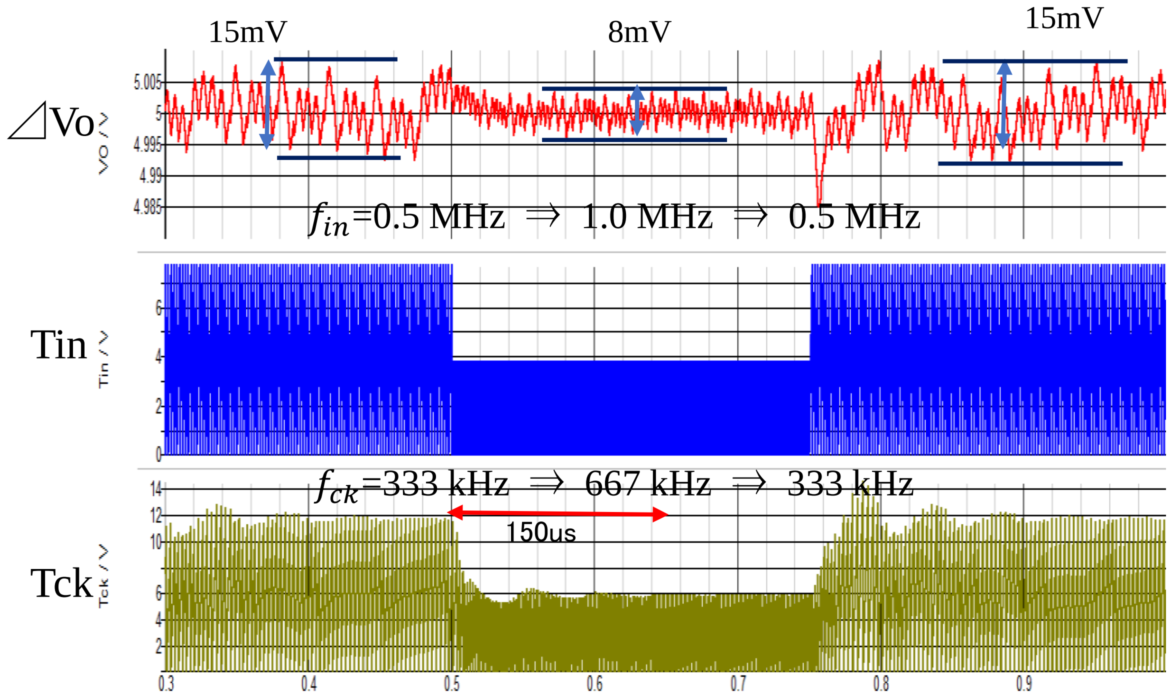
Settling Time: $150\mu s$

◎ Output stability

Ripple: $15mV_{pp}$ at $f_{in} = 0.5MHz$

$8mV_{pp}$ at $f_{in} = 1MHz$

Overshoot : $15mV$



$V_{pp} \propto T_{ck} = 1/f_{ck}$

Response speed when tuning or switching communication channels

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Conclusion

- Realize pulse coding method in switching converter
- Analyze spectrum spreading with notch characteristics
- Automatic self-adjusting the notch frequency

⇓

Create notch characteristics occurred around f_{in}

Using $f_{\mathrm{in}} = (N + 0.5) f_{\mathrm{ck}}$, discussion on generation of notch in N=1,2 situation

Assumed to suppress influence on AM radio
⇒A notch was generated around receive frequency band

Thank you for Listening

Q and A

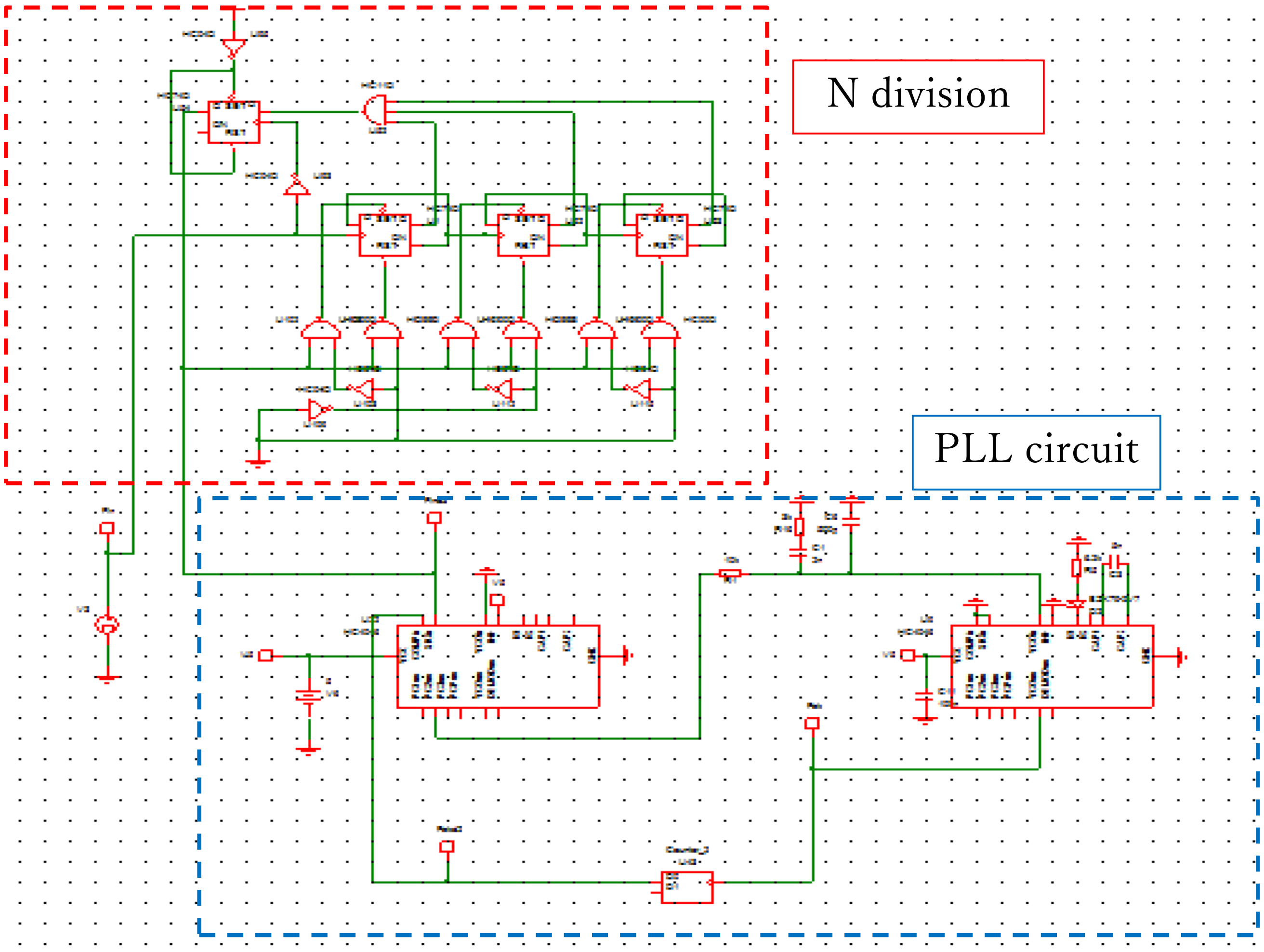
1. Can you realize multiple notch?

Answer: According to spectrum in our realization, it can produce multiple notch. Because f_{in} between Nf_{ck} to $(N+1)f_{ck}$, so notch was happened in these space.

2. Could you change your notch frequency linear?

Answer: I have not consider this question yet, notch frequency has band and I think it is possible.

Appendix PLL Circuit



Appendix EMI Circuit