Nov. 2 S40-6 17:15-17:29

Full Automatic Notch Generation in Noise Spectrum of Pulse Coding Controlled Switching Converter

Yi-Fei Sun, Yasunori Kobori, Haruo Kobayashi
Gunma University
Kobayashi Laboratory
t172d004@gunma-u.ac.jp

群馬大学 GUNMA UNIVERSITY

Kobayashi Laboratory

OUTLINE

- Introduction & Objective
- Conventional Switching Converter
- Pulse Coding Method in Switching Converter
- Full Automatic PWC Control
- Implementation of PWC Converter
- Conclusion and Future work

PWC: Pulse Width Coding

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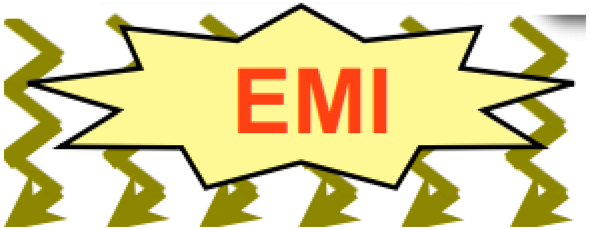
Research Background



Electronic circuits

High density and complication

Problem

Large EMI noise

Focus

EMI reduction ⇒ spread noise spectrum

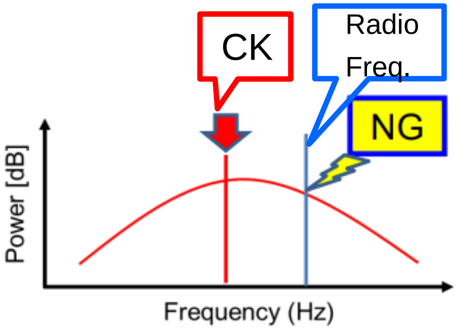
Task

Clock modulation ⇒ diffusion clock noise

EMI: Electro-Magnetic Interference

Research Objective

Problem



Previous Method

Spread spectrum ⇒ shaking clock phase

Problem

F_{ck} noise spread ⇒ Receive frequency

Radio receiver

Research Objective

Spread spectrum :
⇒ EMI reduction & Noise diffusion

Further more

Noise suppression near receive frequency

Research Summary

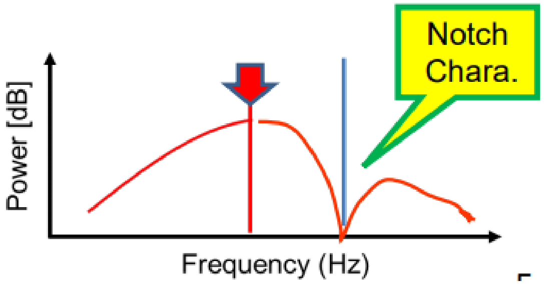
Proposed method

Pulse coding method

⇓

Design modulation circuit
⇒ generate notch frequency automatically

Achievement



① EMI reduction
② Noise removal
③ Automatic generation of F_{notch}

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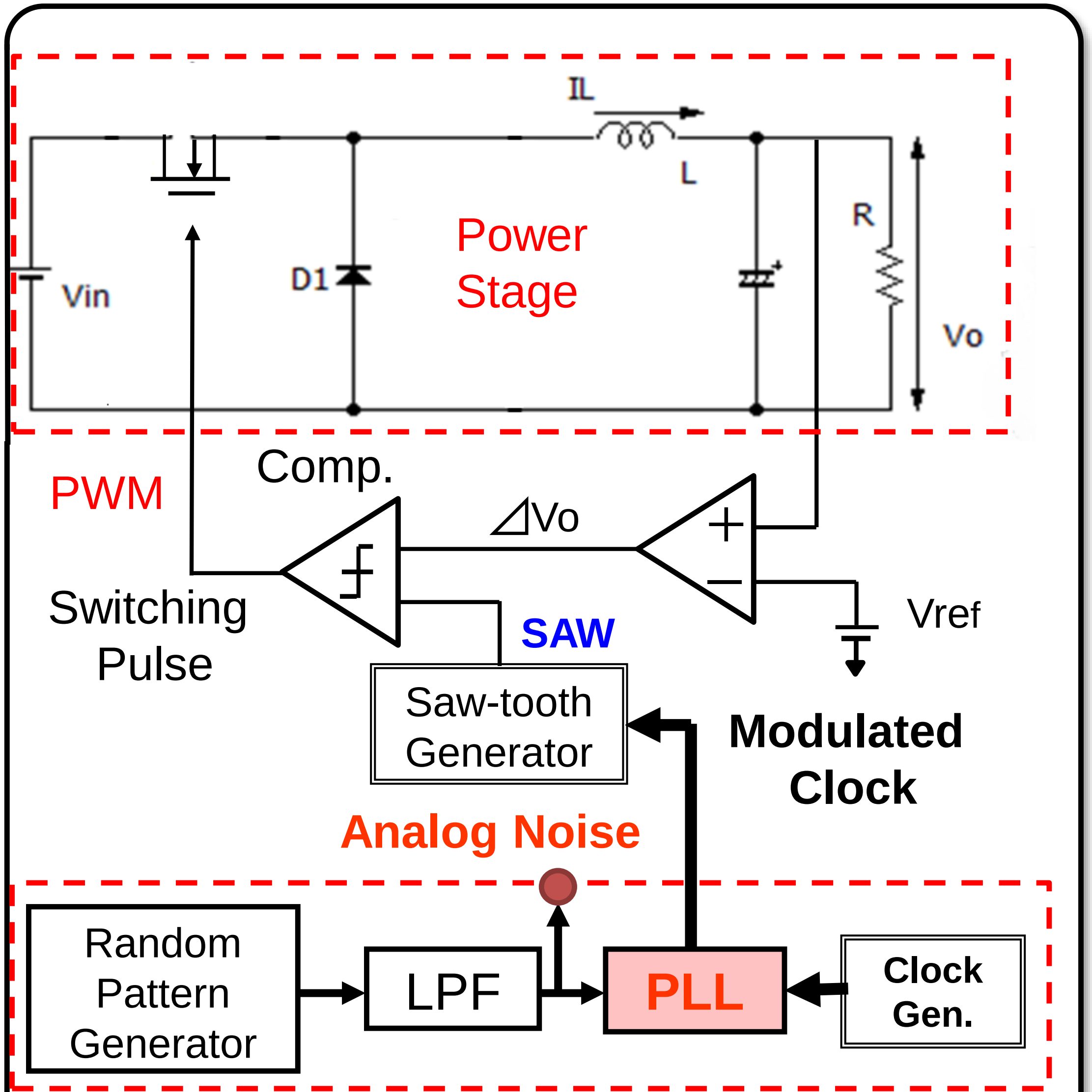
Spread Spectrum Using Pseudo Analog Noise



Buck converter with modulated clock

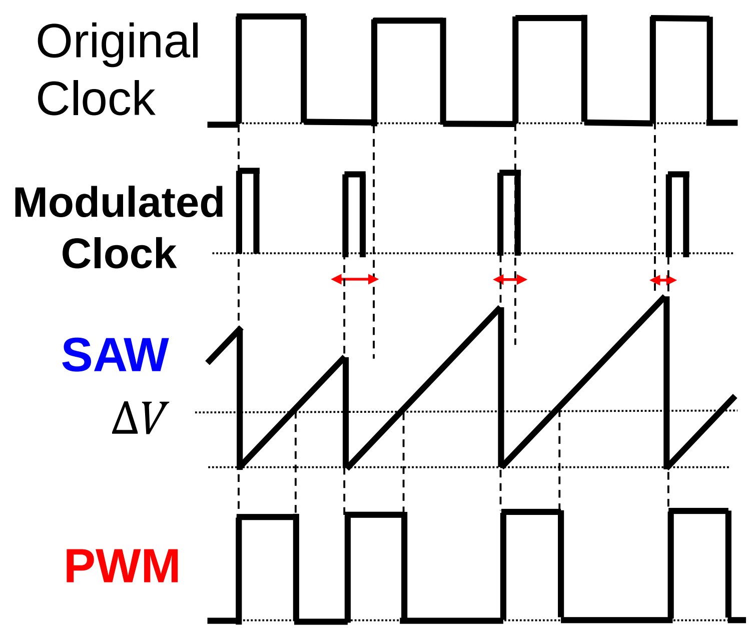
Reduce EMI noise

⬇

modulation clock to SAW

⬇

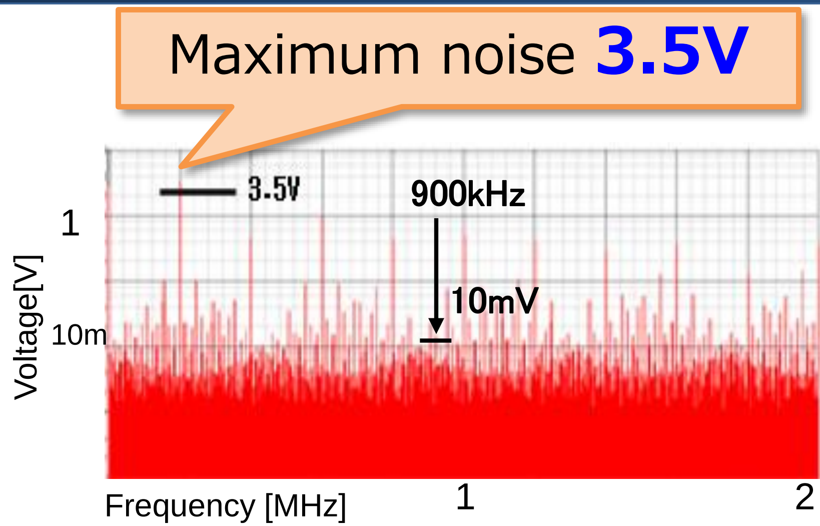
shaking phase using analog noise & PLL



Timing Chart

PLL: Phase Locked Loop

Spread Spectrum for EMI Reduction

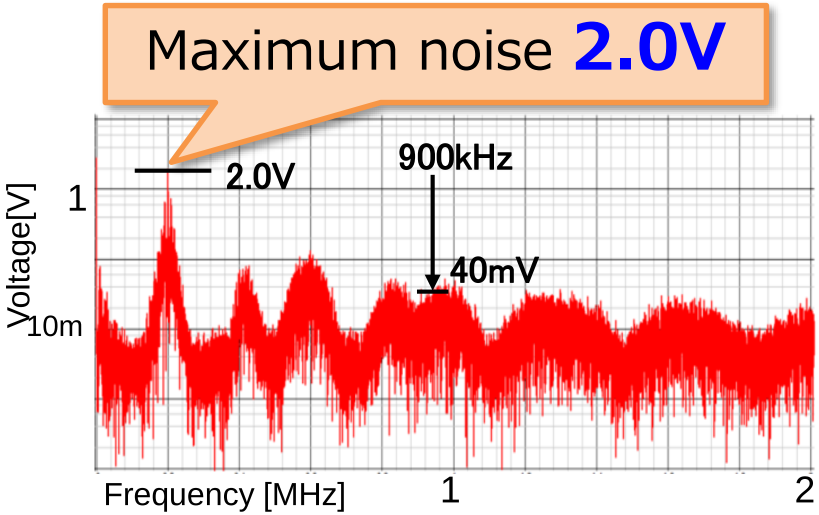


PWM signal spectrum without EMI reduction

◎Simulation conditions
Input : 12V
Output : 6V
Clock frequency : 200kHz

Without EMI reduction

- Noise⇒basic and harmonic frequencies
- Bottom level: 1mV



PWM signal spectrum with EMI reduction

With EMI reduction

- Peak level ⇒ reduced a lot

Noise : concentrated by diffusion

- Bottom level : 10mV
  around the received frequency

Not good

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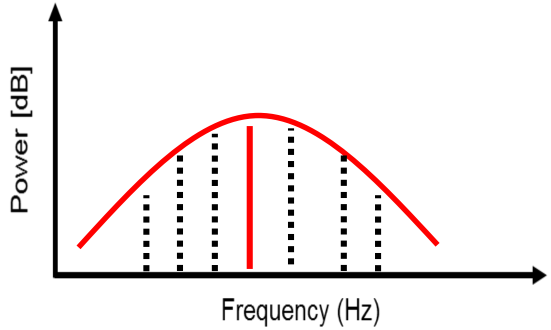
Diffuse Noise to Specific Frequency

Problem

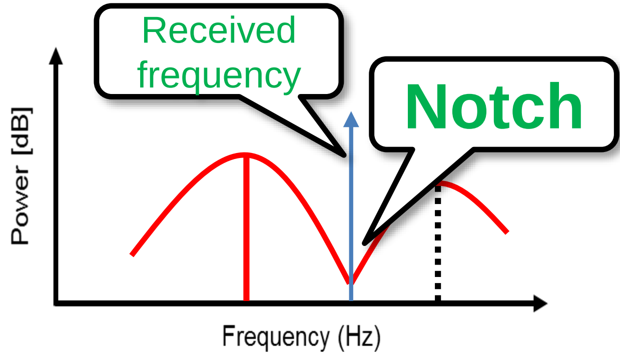
Noise diffusing uniformly
(analog modulation)



Digital modulation

Noise diffuses to specific frequency

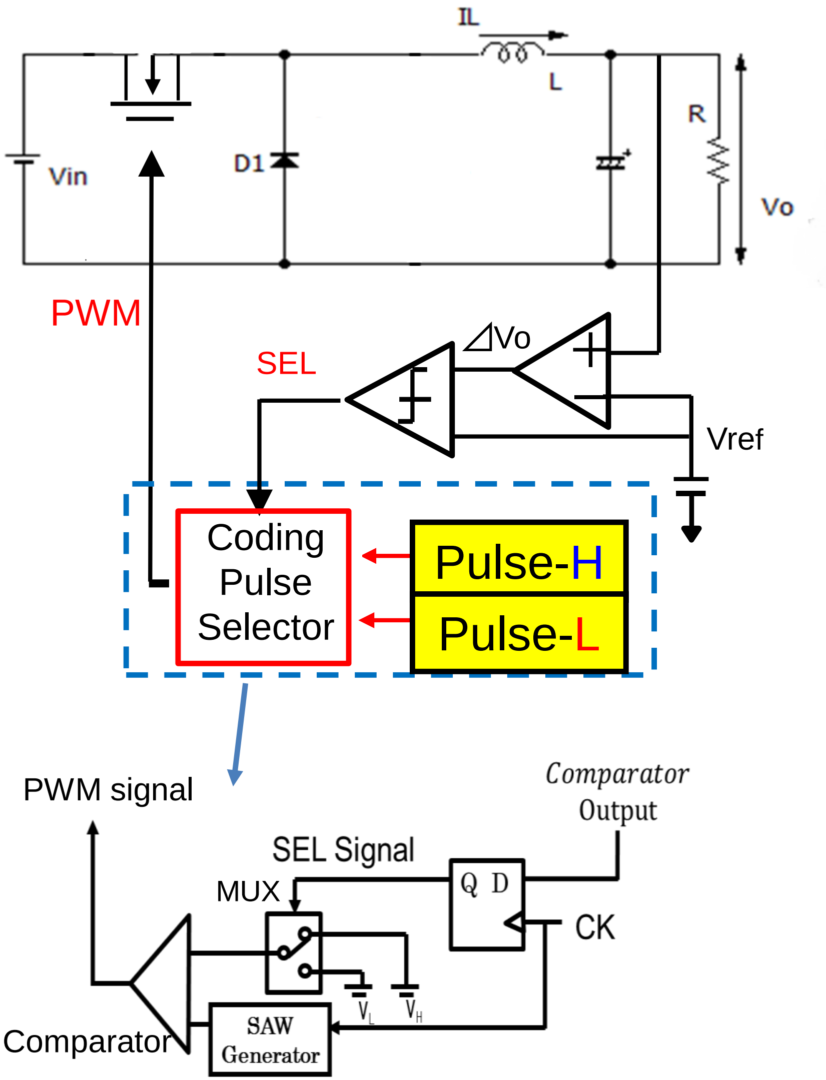
Frequency band where noise does not spread

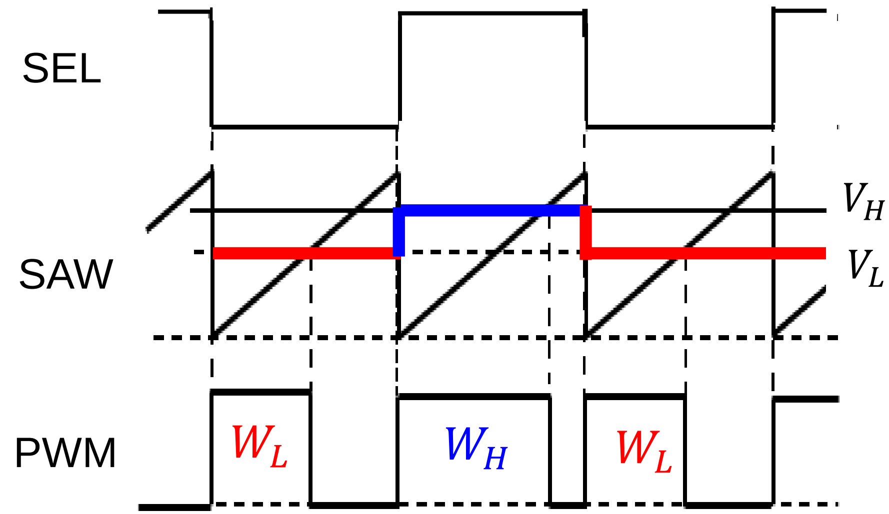


Notch band created in important frequency band

- EMI Reduction
- 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

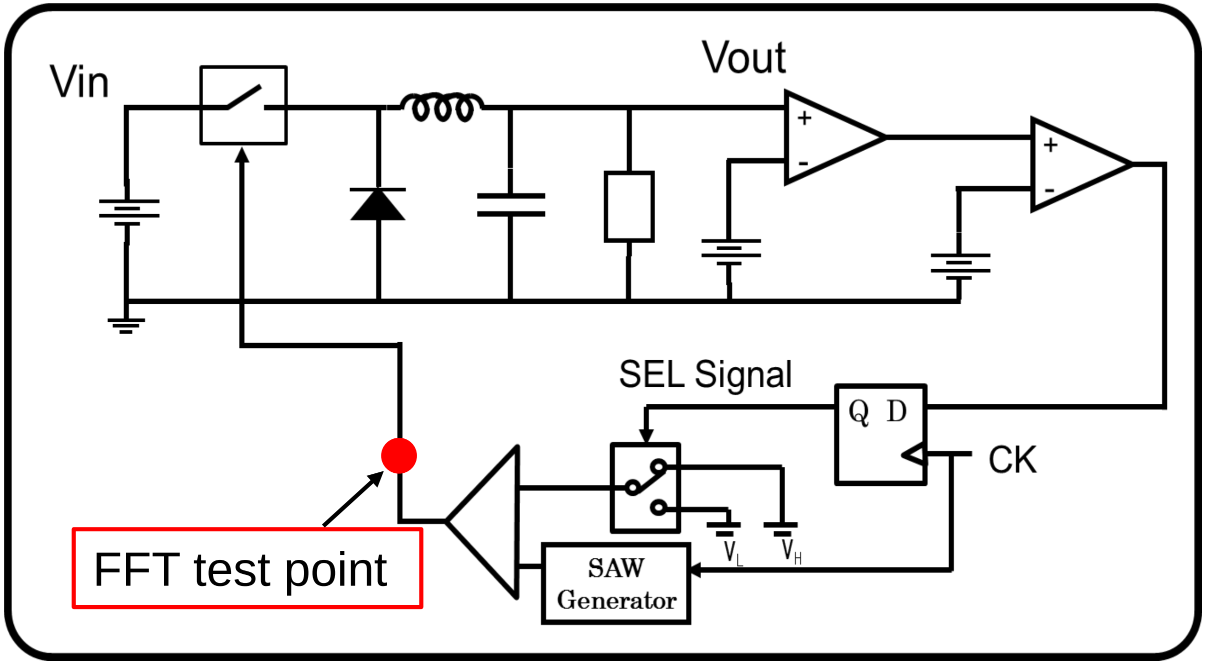
Input Low

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

★ $D_H > D_o > D_L$

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

Simulation Condition



◎ Condition

Buck DC-DC converter

V_{in} : 10V

V_{out} : 5V

L : 200 μ H

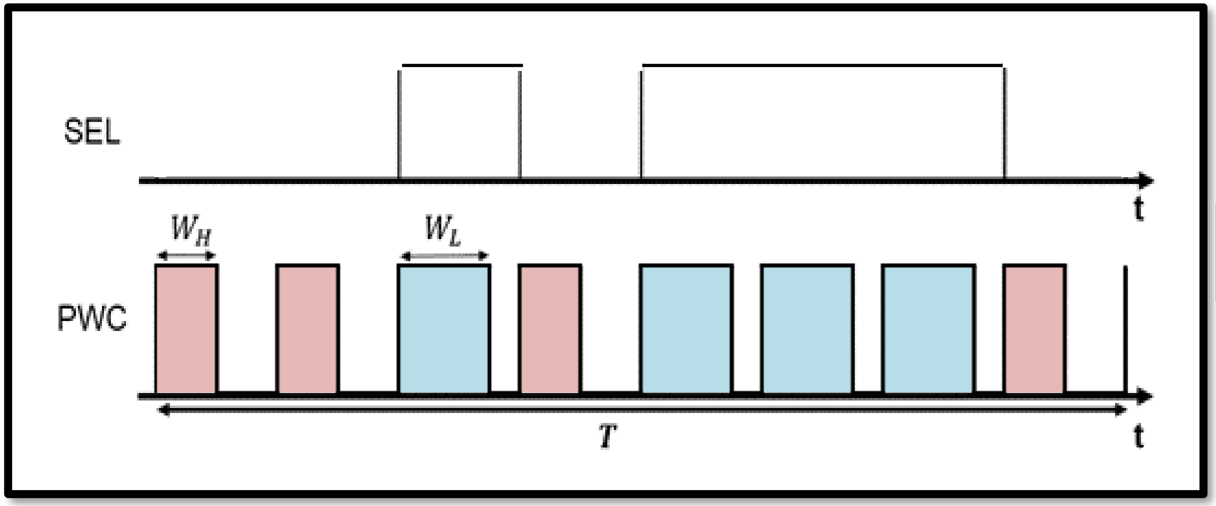
C : 470 μ F

I_{out} : 0.25A

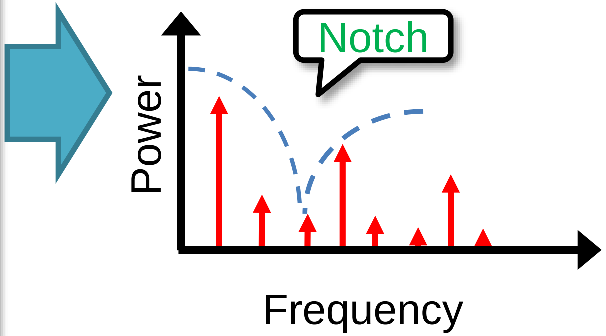
f_{ck} : 500kHz

W_H : 1.6μs

W_L : 0.2μs

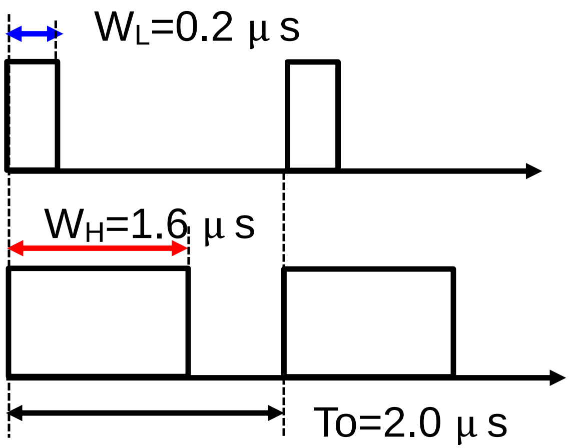


Spectrum of PWC signal



Simulation Result with PWC Control

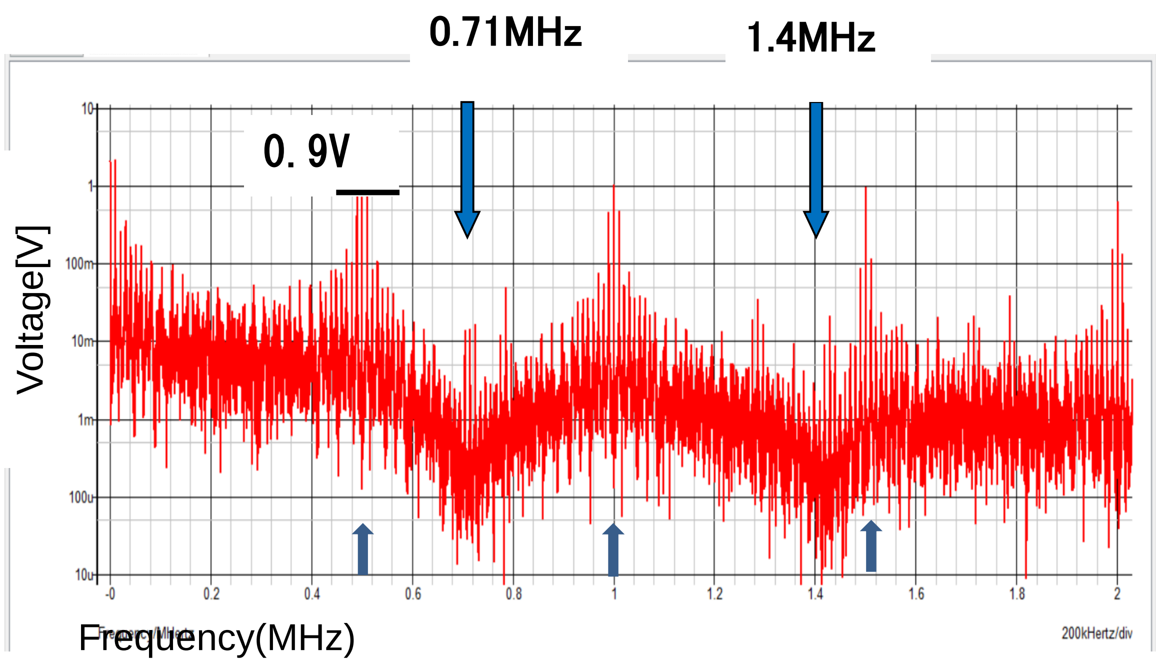
Design clock pulse to determine the notch frequency



Pulse widths of the coding pulses

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

$$= N \times \frac{1}{1.6\mu s - 0.2\mu s} = 0.71\text{MHz}$$



★manually set W_L and W_H

PWM signal spectrum using PWC control

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Automatic PWC Control

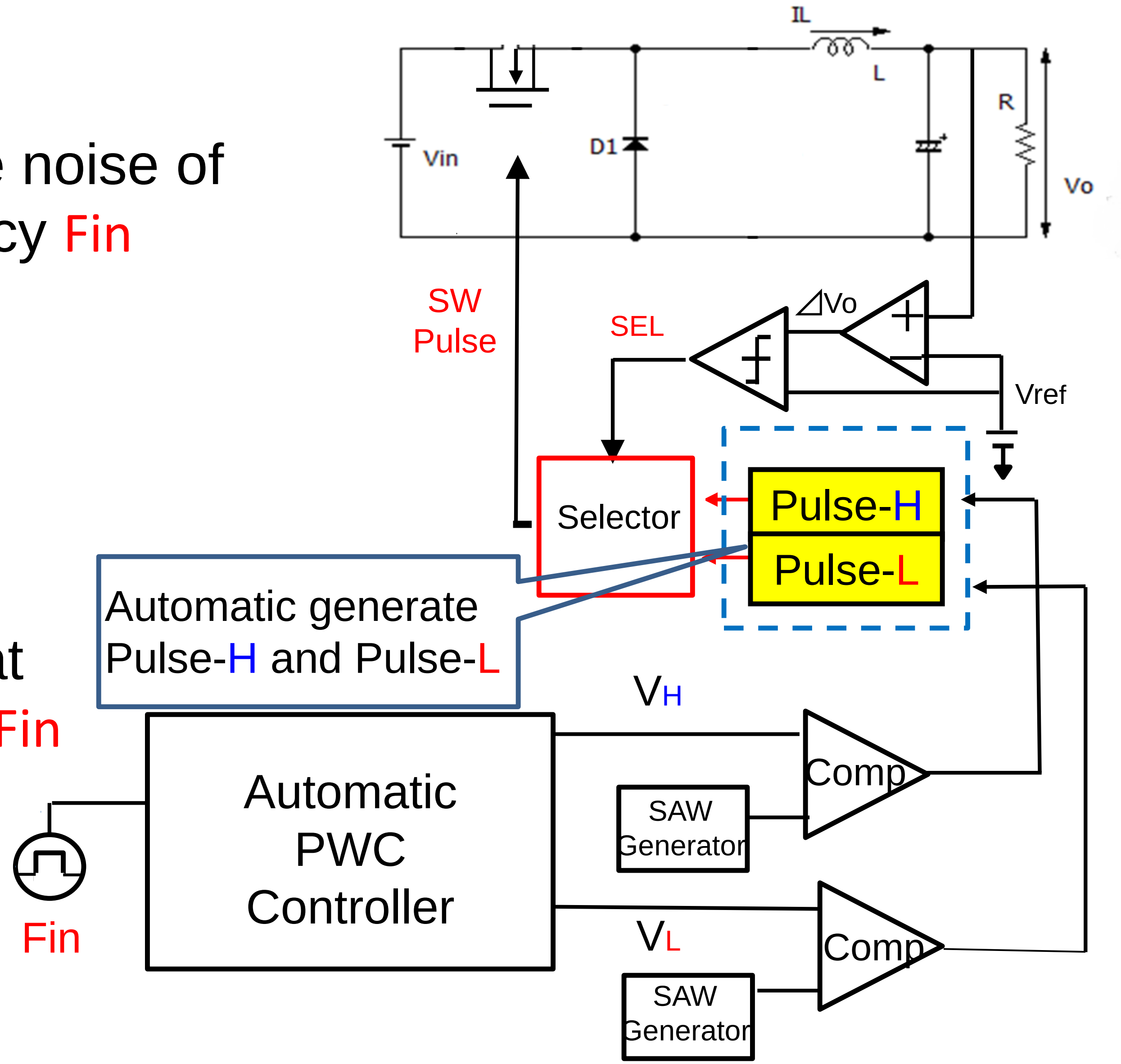
Objective

Reduction generate noise of receive frequency Fin

Method

PWC

generate notch at receive frequency Fin



Research Application

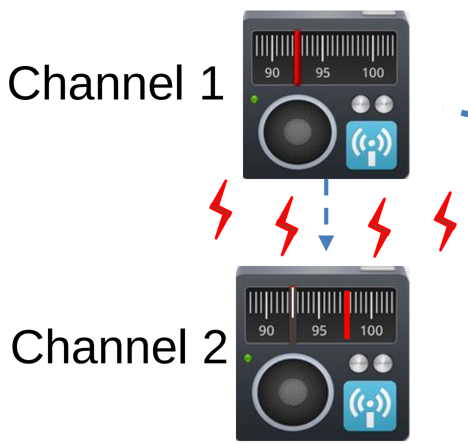
Information equipment switching power supply

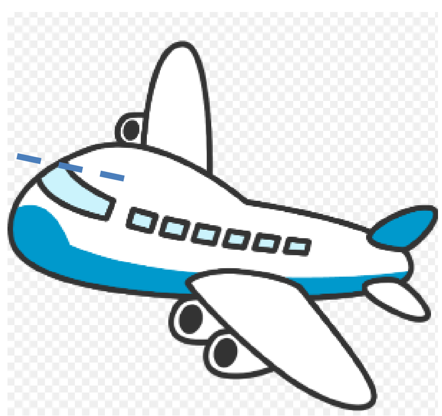
⇩ **feature**

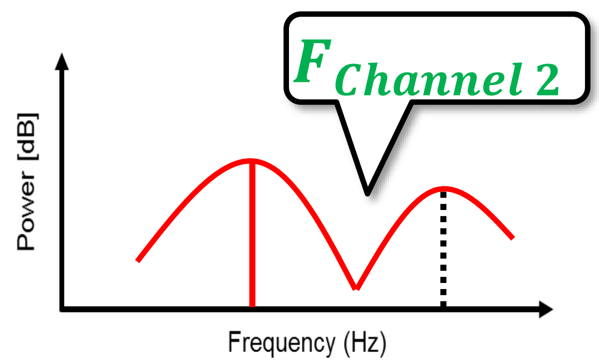
① Receiving weak radio waves

② Noise near receive frequency
⇒ automatically removed

③ Receive frequency change
⇒ Notch frequency automatically change







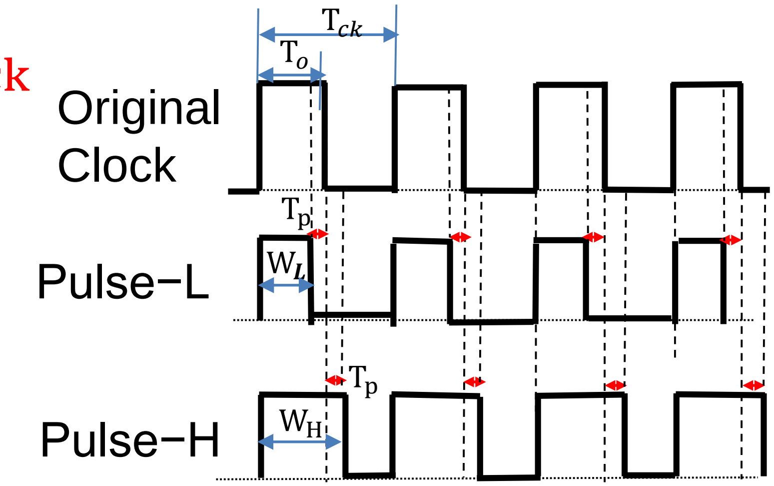
Clock Frequency, Notch Frequency and PWC

The relationship between F_n and F_{ck}

$$NF_{ck} < F_n < (N+1)F_{ck}$$

Optimal

$$F_n = (N + 0.5)F_{ck}$$



Timing Chart

The relationship between F_n and PWC

$$F_n \cong N \times \frac{1}{(W_H - W_L)}$$

When N =1

$$T_n \cong (W_H - W_L)$$

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

$$W_L = T_o - T_p$$

$$W_H = T_o + T_p$$

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

W_H and W_L

Generated at the center of the original clock

Generate Pulse-H and Pulse-L Automatically

Generate T_{ck} from T_{in} using

F_{in}=(N+0.5) ・ F_{ck}

⇩

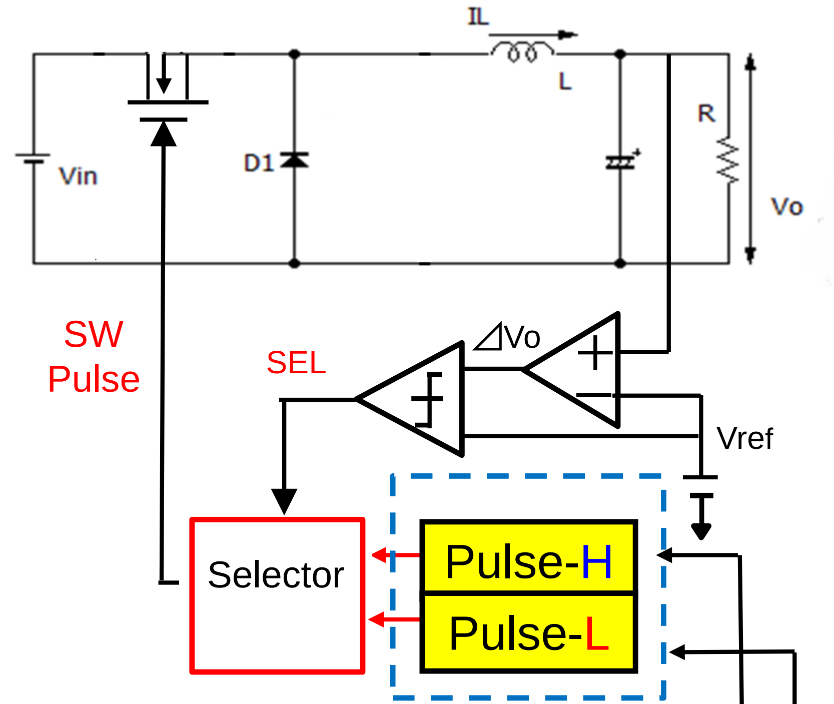
T_{ck}=(N+0.5) ・ T_{in}

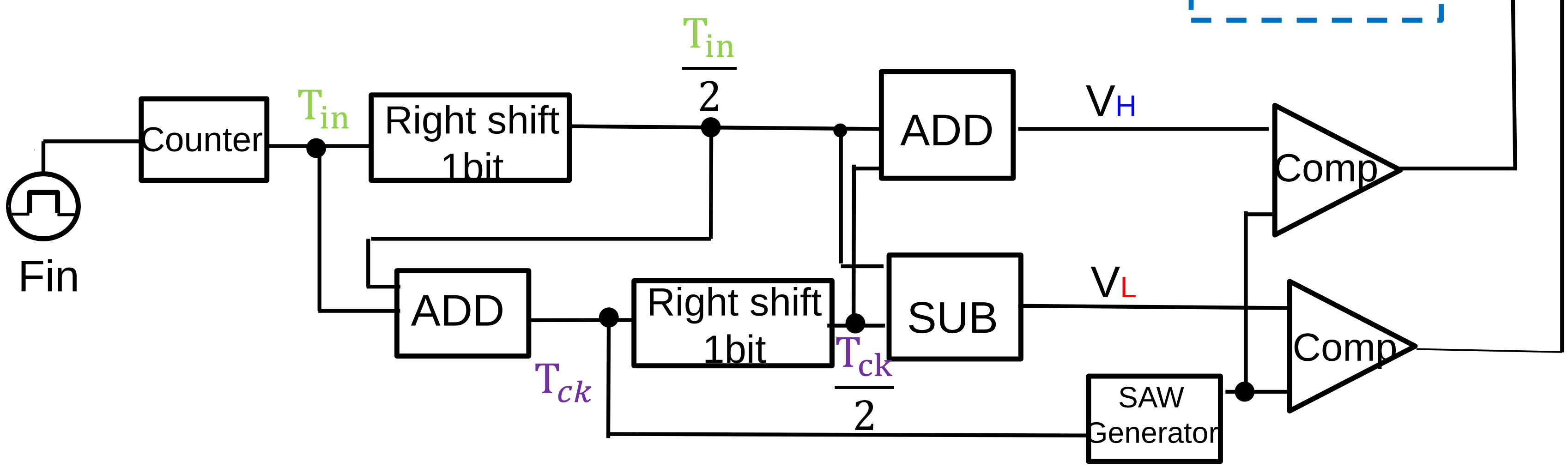
$$W_L = T_o - T_p = D_o \times T_{ck} - \frac{1}{2} T_{in}$$

$$W_H = T_o + T_p = D_o \times T_{ck} + \frac{1}{2} T_{in}$$

$$T_n = 2 \times T_p$$

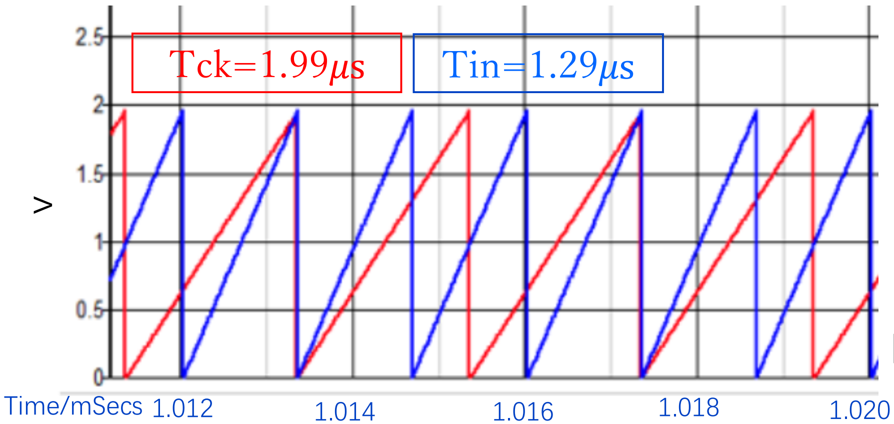
D_o=0.5 N=1 situation





Simulation Waveforms of W_H, W_L Generation

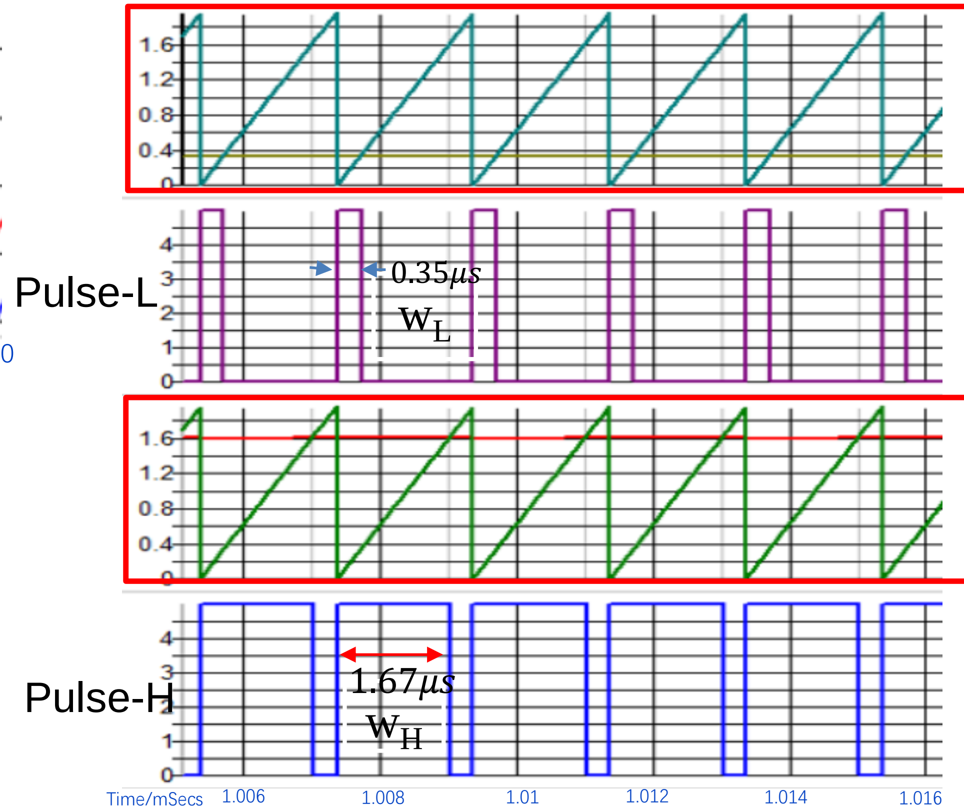
We set $F_{in} = 750kHz$ ➡ Automatic generated $F_{ck} = 500kHz$



Simulation waveform of T_{ck} and T_{in}

$$T_{\mathrm{ck}} = (\mathrm{N} + 0.5)T_{\mathrm{in}} = 1.5T_{\mathrm{in}}$$

T_{ck} compare with V_L or V_H



Simulation waveforms of W_H and W_L

Theoretical formula

$W_H = 1.66\mu s$

$W_L = 0.29\mu s$

Simulation result

$W_H = 1.67\mu s$

$W_L = 0.35\mu s$

Well matched

Noise Spectrum of PWM Signal Case 1

$$F_{in} = (N + 0.5)F_{ck}$$

N=1 Best position : Fck < Fn < 2Fck

Fin=750kHz ⇒Fck=500kHz （ W_H=1.66μs, W_L=0.29μs）

◎Condition

Buck DC-DC converter

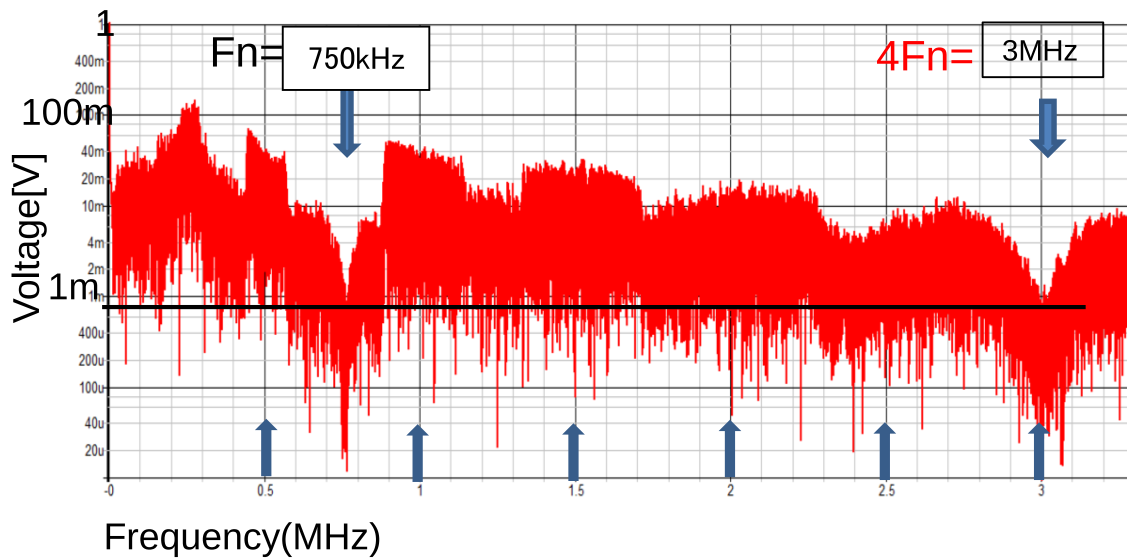
V_{in} ：10V

V_{out} ：5V

L ：200 μ H

C ：470 μ F

I_{out} ：0.25A



Simulated spectrum with EMI reduction

◎Result

Fn=750kHz

4· Fn=3.0MHz

Why appear?

Assume to suppress influence on AM in 750kHz

$F_{in} = 750kHz \Rightarrow F_{notch} = 750kHz$

Noise Spectrum of PWM Signal Case 2

N=2 Best position: 2Fck ＜ Fn ＜ 3Fck

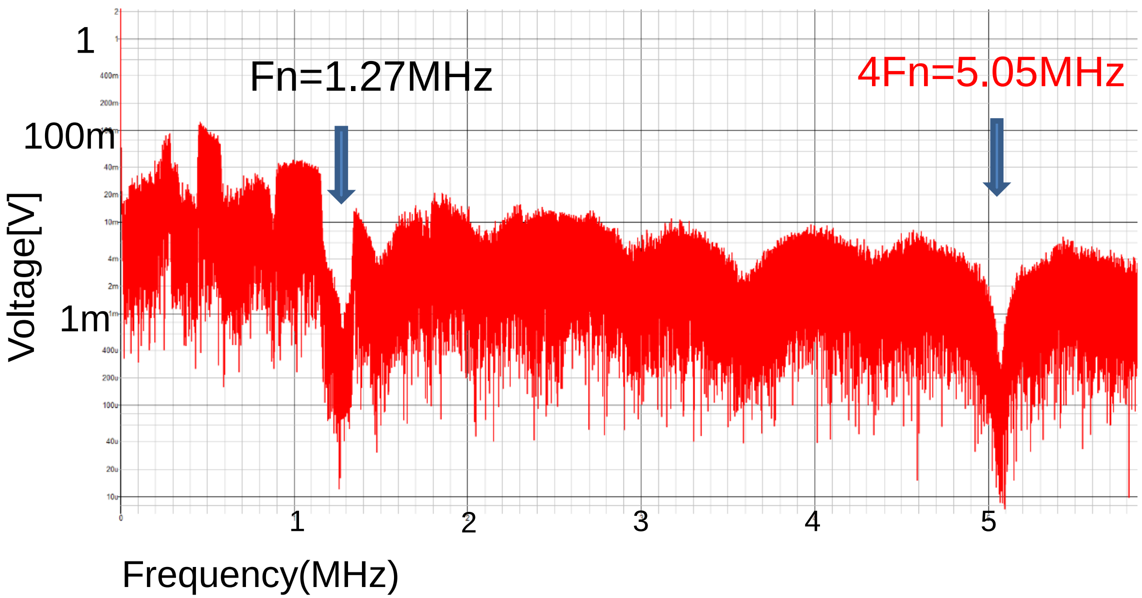
Fin=1.25MHz ⇒ Fck=500kHz (W_H=1.40μs,W_L=0.60 μs)

◎Condition：same

◎Simulation Result

Fn=1.27 MHz

4Fn=5.05 MHz



＊Compare bottom levels

4Fn is deeper than Fn

Simulated spectrum with EMI reduction

Transient Response with F_{in} Change in Case 2

◎ Condition (N= 2)

$F_{in} = 1.25\text{MHz} \Rightarrow F_{in} = 1\,MHz$

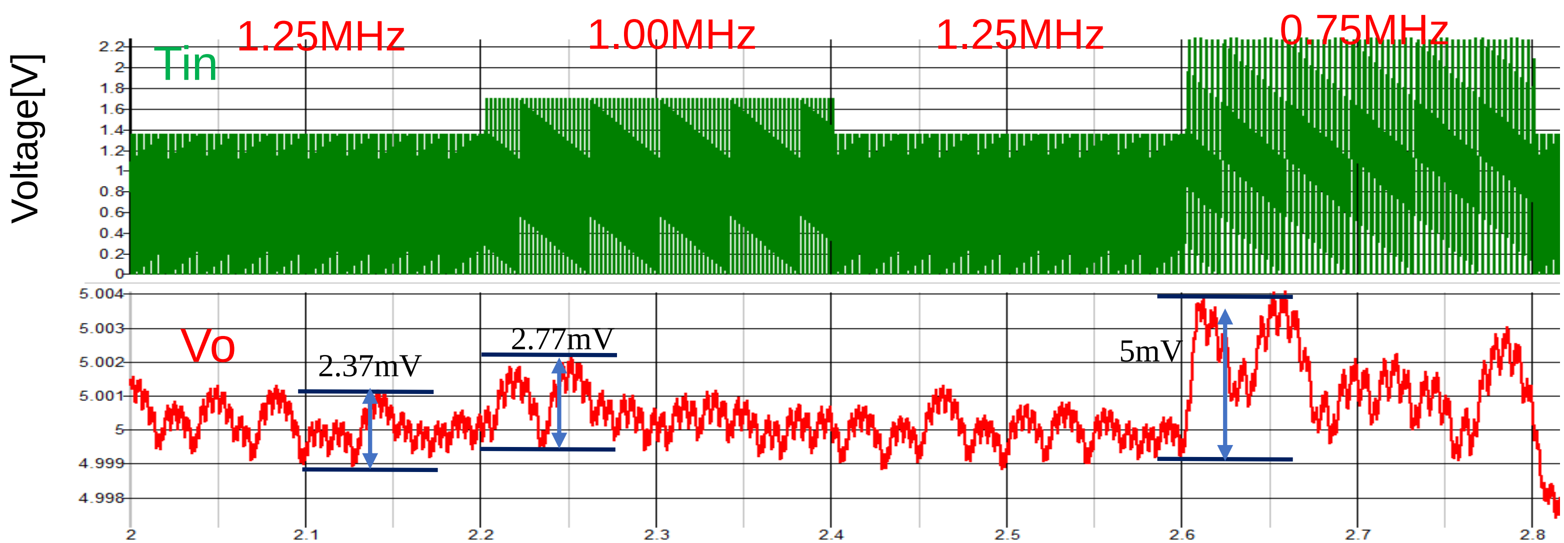
$F_{in} = 1.25\text{MHz} \Rightarrow F_{in} = 750kHz$

Settling Time $< 2T_{in} < 3\mu s$

◎ Output stability

Ripple: $2.37mV_{pp}$ at $F_{in} = 1.25MHz$
$2.77mV_{pp}$ at $F_{in} = 1MHz$
$5mV_{pp}$ at $F_{in} = 750kHz$

Static ripple <5.00mV (0.1%) stable



Transient response with Fin change

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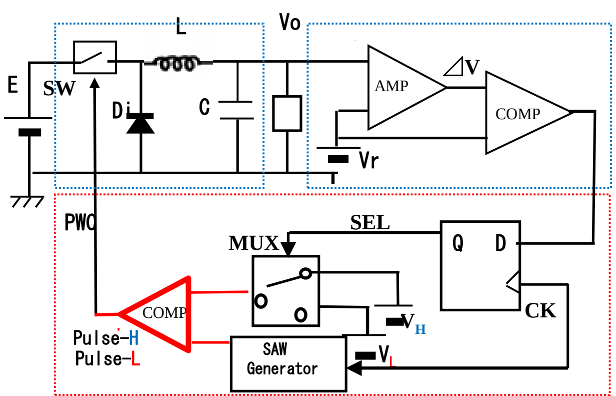
Implementation of PWC Control Switching Converter

Generation of W_H and W_L

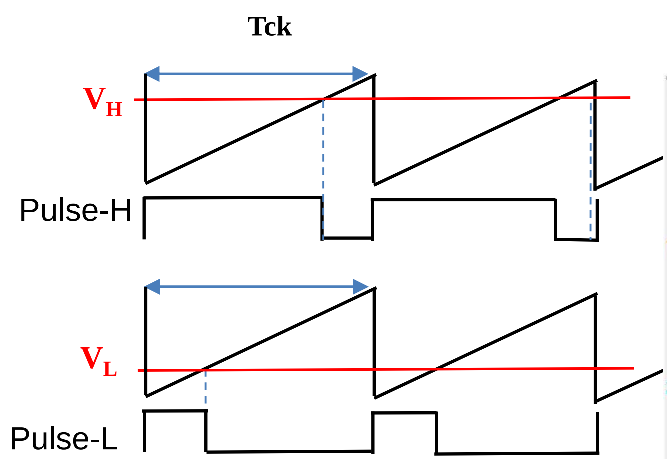
V_o	Op amp output	comparator output	SEL	PWM output	Duty
＞5V	L	L	L	P_L	L
＜5V	H	H	H	P_H	H

◎ Condition

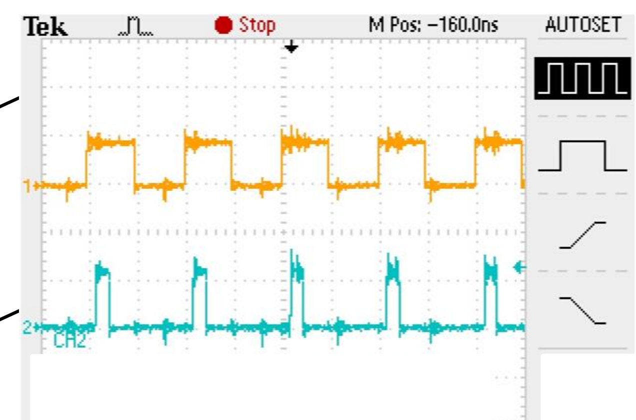
W_H	W_L	f_{notch}
1.0μs	0.4μs	1.66MHz



Converter with PWC control



Theoretical PWM signal



Waveform of W_H and W_L

Spectrum of PWC Control Switching Converter

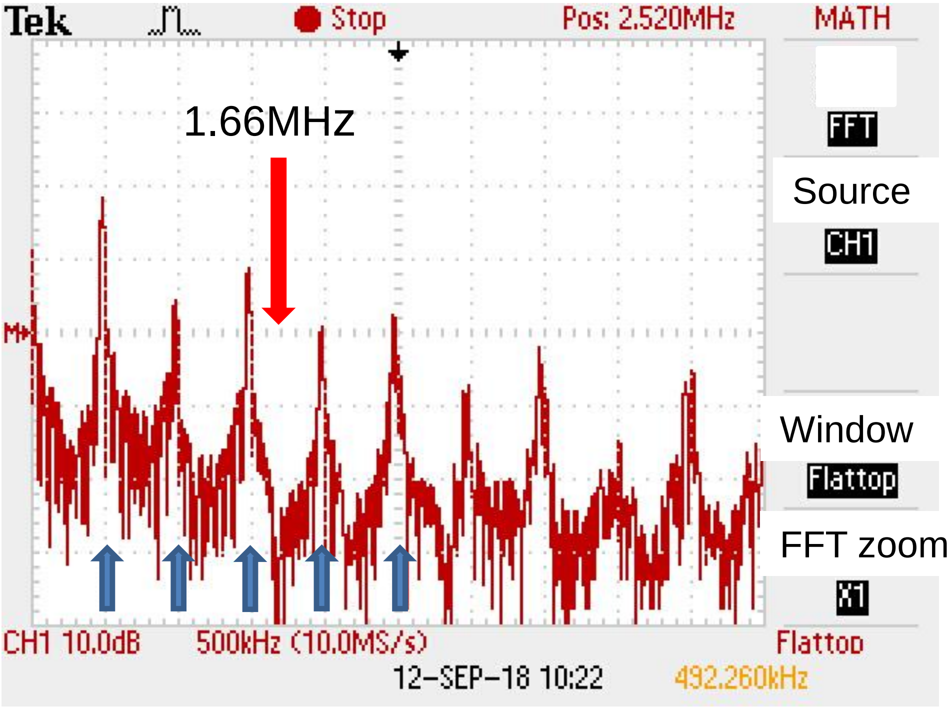
Theoretical formula

$$F_{notch} = \frac{N}{(W_H - W_L)} = \frac{N}{(1.0us - 0.4us)} = 1.66\text{MHz}$$

◎Condition

Buck DC-DC converter
V_{in} : 12V
V_{out} : 5V
L : 22 μ H
C : 100 μ F
I_{out} : 0.4A

$W_H = 1.0\mu s$
$W_L = 0.4\mu s$
$f_{clock} = 1.66\text{MHz}$



Notch between $3f_{ck}$ and $4f_{ck}$

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Conclusion and Future Work

Conclusion

For EMI problem handling in switching power converter

- Developed pulse coding control in order to generate notch characteristics at desired frequency
- Automatic generate the F_{notch} from F_{in}
- Implementation of PWC control switching converter

Future work

- Notch generation using other pulse coding methods
- Investigate why the large notch at $4F_{notch}$ appear.

Thank you for Listening

Q&A

Q1: In your DC-DC buck converter, the inductor value is 200μH. Does this inductor value matters in your design? How you concerned the inductor and capacitor?

A: In buck converter, filter generally consists of inductor and capacitor. By adjusting the duty, the average voltage through output capacitance filtering can be controlled. Capacitor is also related to output voltage ripple.

Q1: How do you think the output current?

A: Output current is related to inductor current and DC component. When switch is on, inductor current increases linearly, the midpoint of the waveform ramp is the output current.