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Pulse Coding Controlled Switching Converter with Generating Automatic Frequency Tracking Notch Characteristics for Radio Receiver

Yifei Sun, Yi Xiong, 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 Converters
- Pulse Coding Method in Switching Converter
- Automatic PWC Control
  - Relationship with the Clock frequency and the Notch frequency
  - Direct generation of clock pulse from input frequency
  - Simulated Noise Spectrum of PWM Signal
- Automatic PWPC Control
- Conclusion and future work

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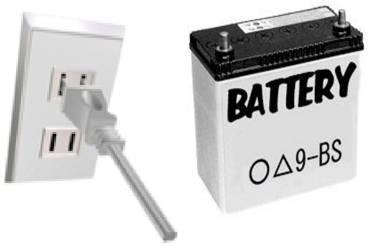
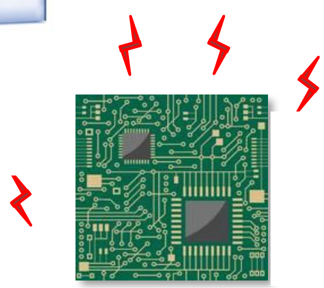
Research Background





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

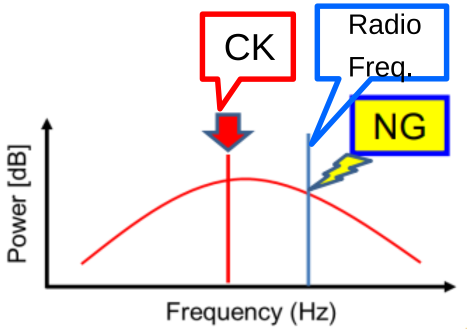
EMI: Electro-Magnetic Interference

Research Objective

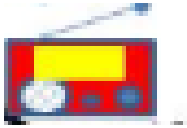
Reduce clock noise by spread spectrum
with shaking clock phase

Trouble

Noise of clock frequency is spread



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



Radio receiver

Research Objective

Spread spectrum with both EMI[1] reduction and
control the diffusion of noise

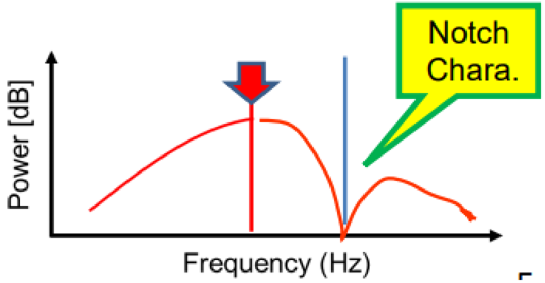
[1]EMI: Electro-Magnetic Interference

Research Summary

Proposed method

Spread spectrum method using pulse coding

Design modulation circuit
in order to generate notch frequency automatically



Achievement

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

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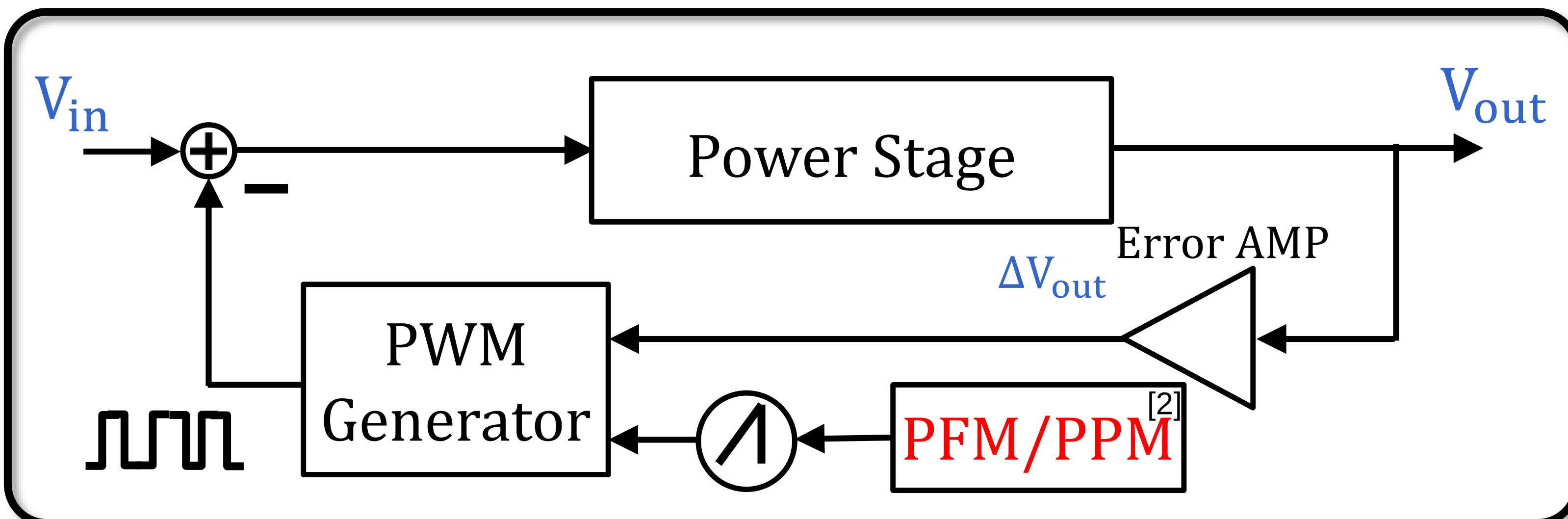
Conventional Switching Converter with Spread Spectrum

Spread Spectrum

Continuous modulation of periodic clock
⇒Reduction of EMI concentrating on fundamental frequency

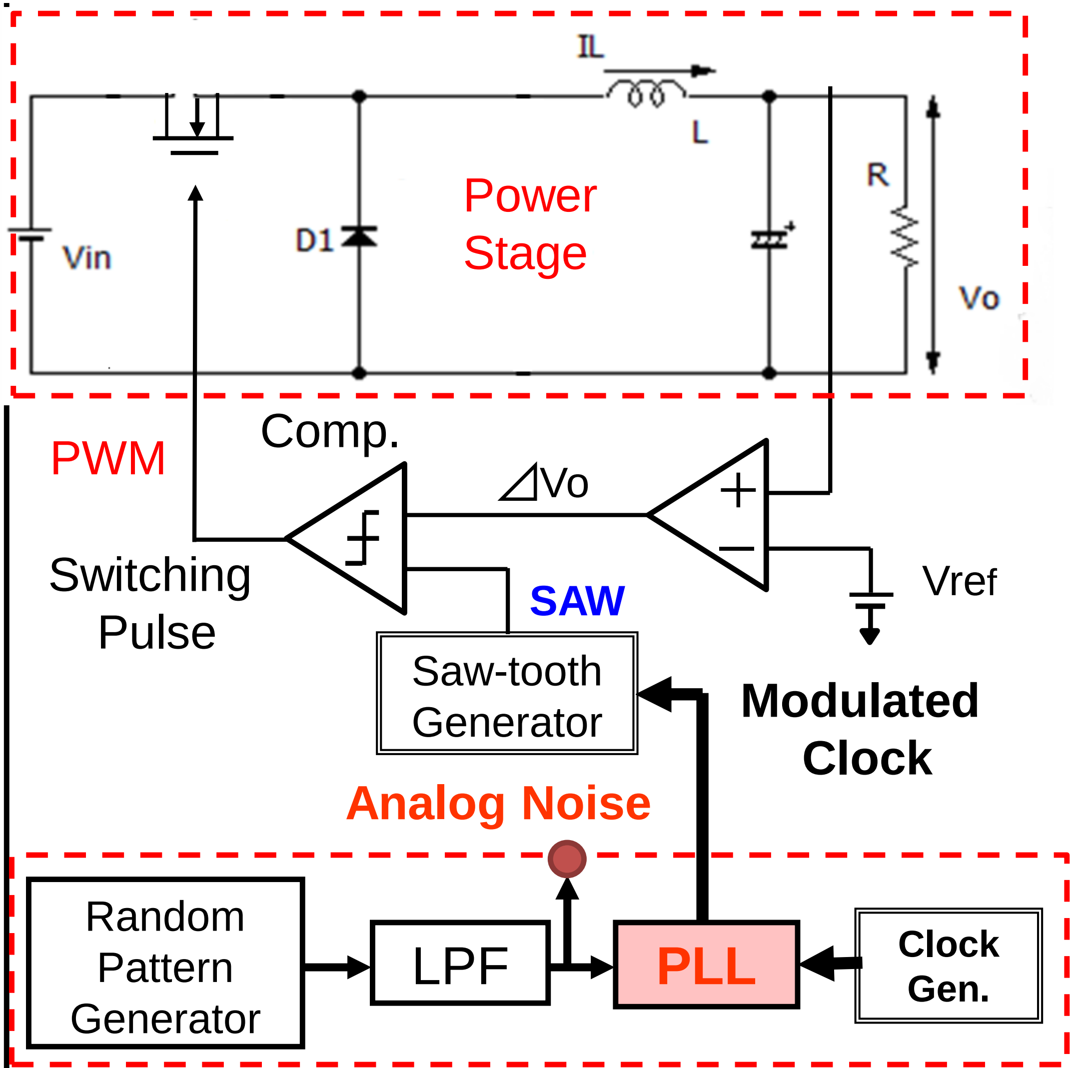


Switching Power

[2] PFM: Pulse Frequency Modulation PPM: Pulse Phase Modulation

Spread Spectrum for EMI Reduction

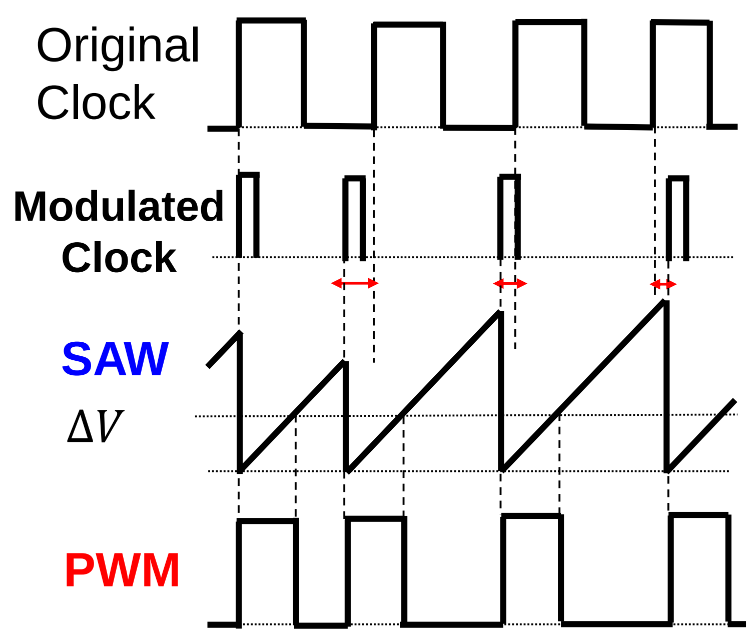
Spread spectrum using pseudo analog noise



Buck converter with modulated clock

Reduce EMI noise

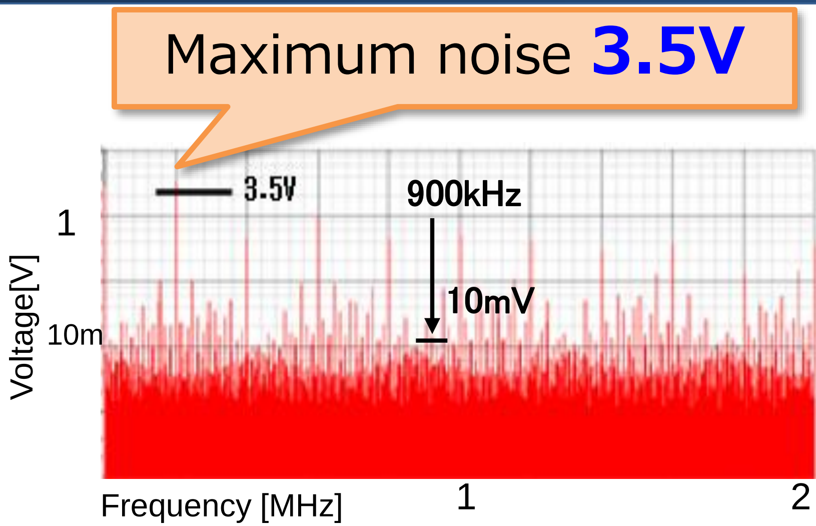
＊Clock to SAW is modulated by shaking phase using analog noise & PLL[3]



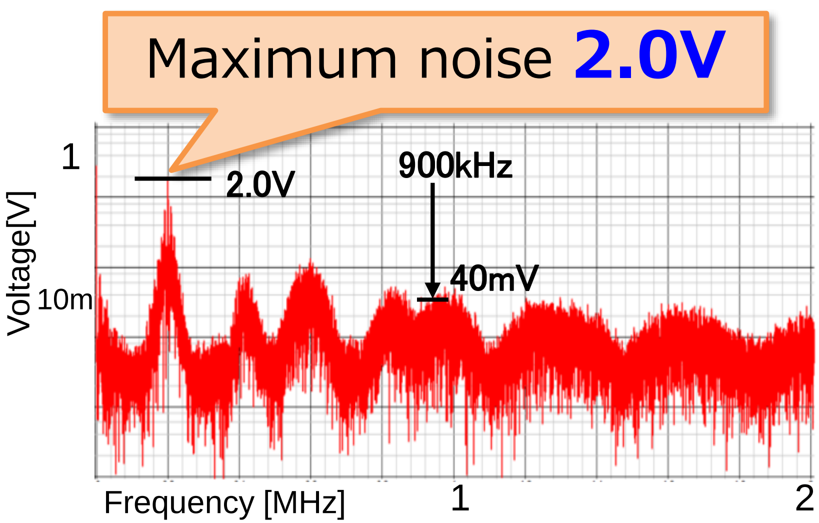
Timing Chart

[3] PLL: Phase Locked Loop

Spread spectrum for EMI Reduction



PWM signal spectrum without EMI reduction



PWM signal spectrum with 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

Bottom levels are increased

Not good

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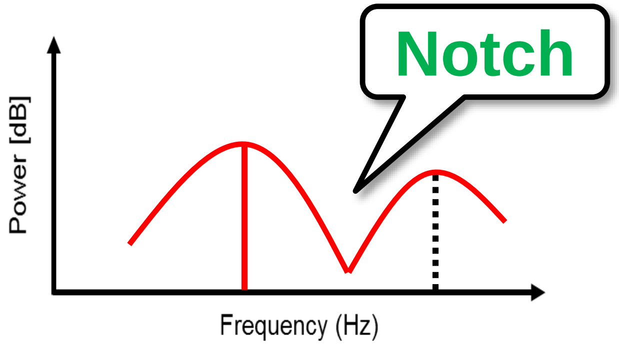
Diffuse Noise to Specific Frequency

Problem

Noise diffusing uniformly
(using analog modulation)



Using 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

Coding Method

Single coding method

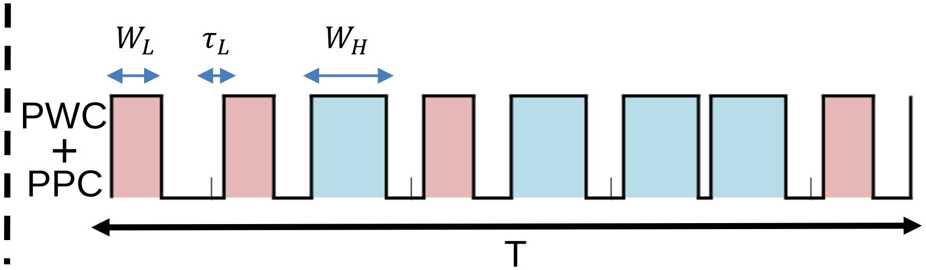
Pulse width・period・position
select one to modulation

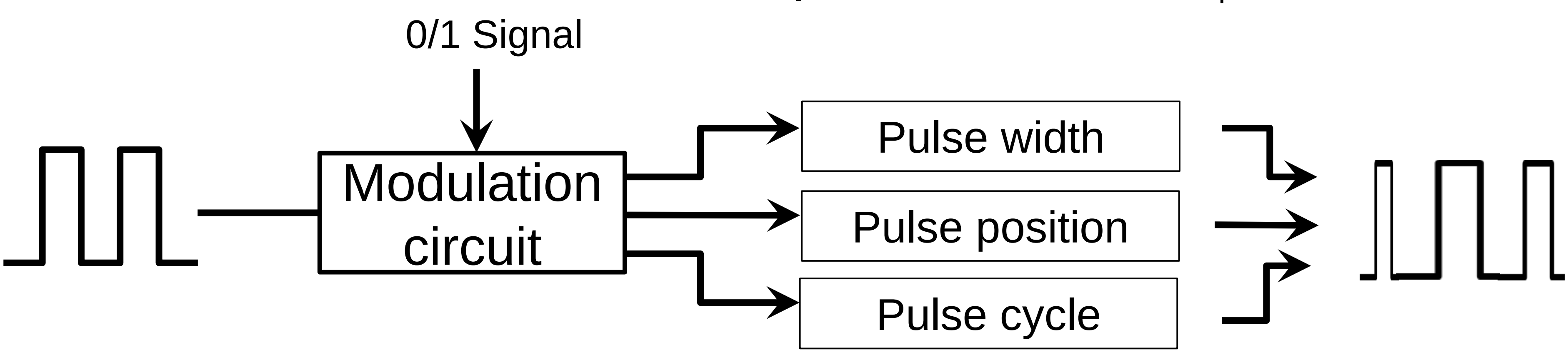
- PWC(Pulse Width coding)method
- PCC(Pulse Cycle coding) method
- PPC(Pulse Phase coding) method

Complex coding method

Pulse width・period・position
select two to modulation

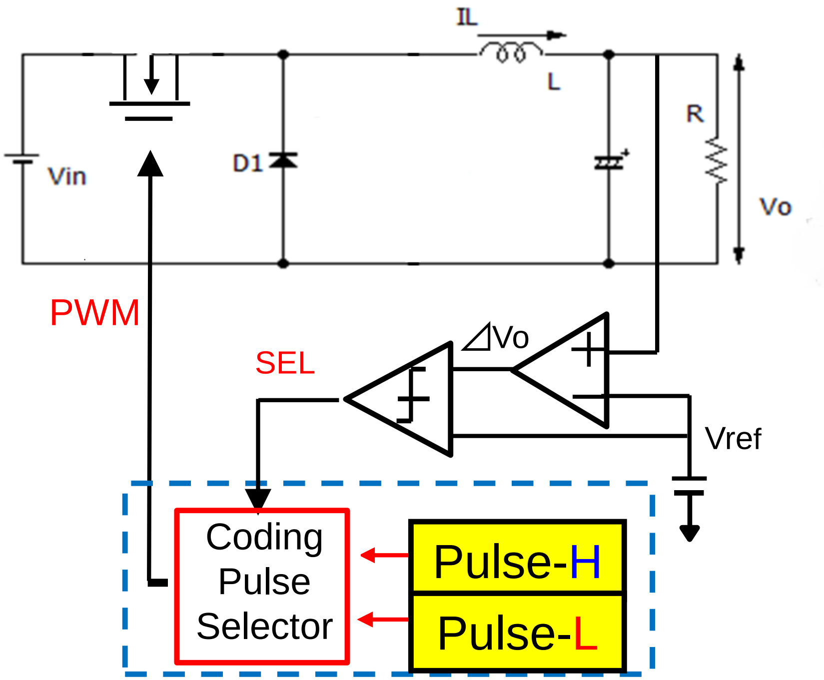
- PWPC（PWC+PPC） method

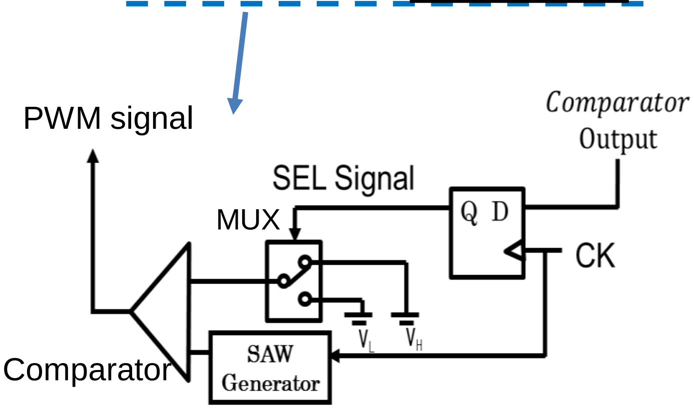


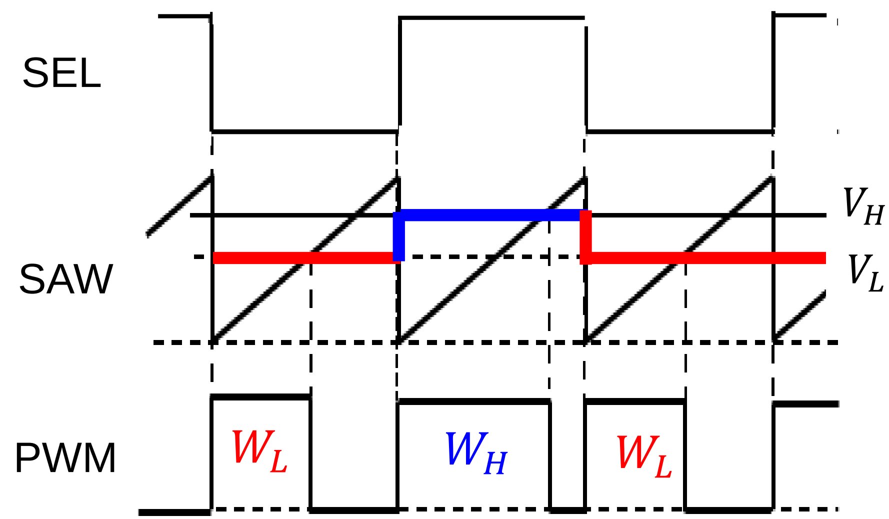


Complex coding method

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 Result with PWC Control

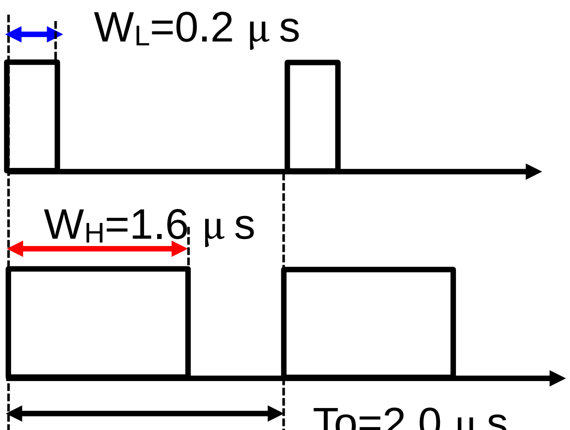
◎ Condition

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

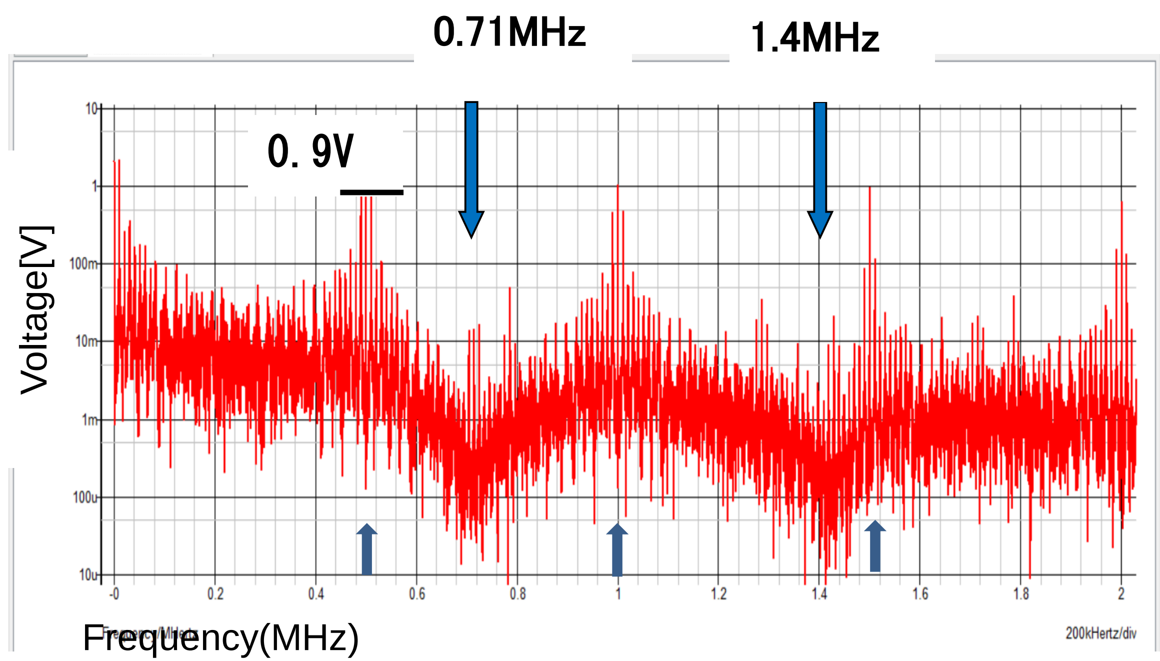
Design clock pulse to determine the notch frequency

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

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



Pulse widths of the coding pulses
★manually set W_L and W_H



PWM signal spectrum using PWC control

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Automatic PWC Control

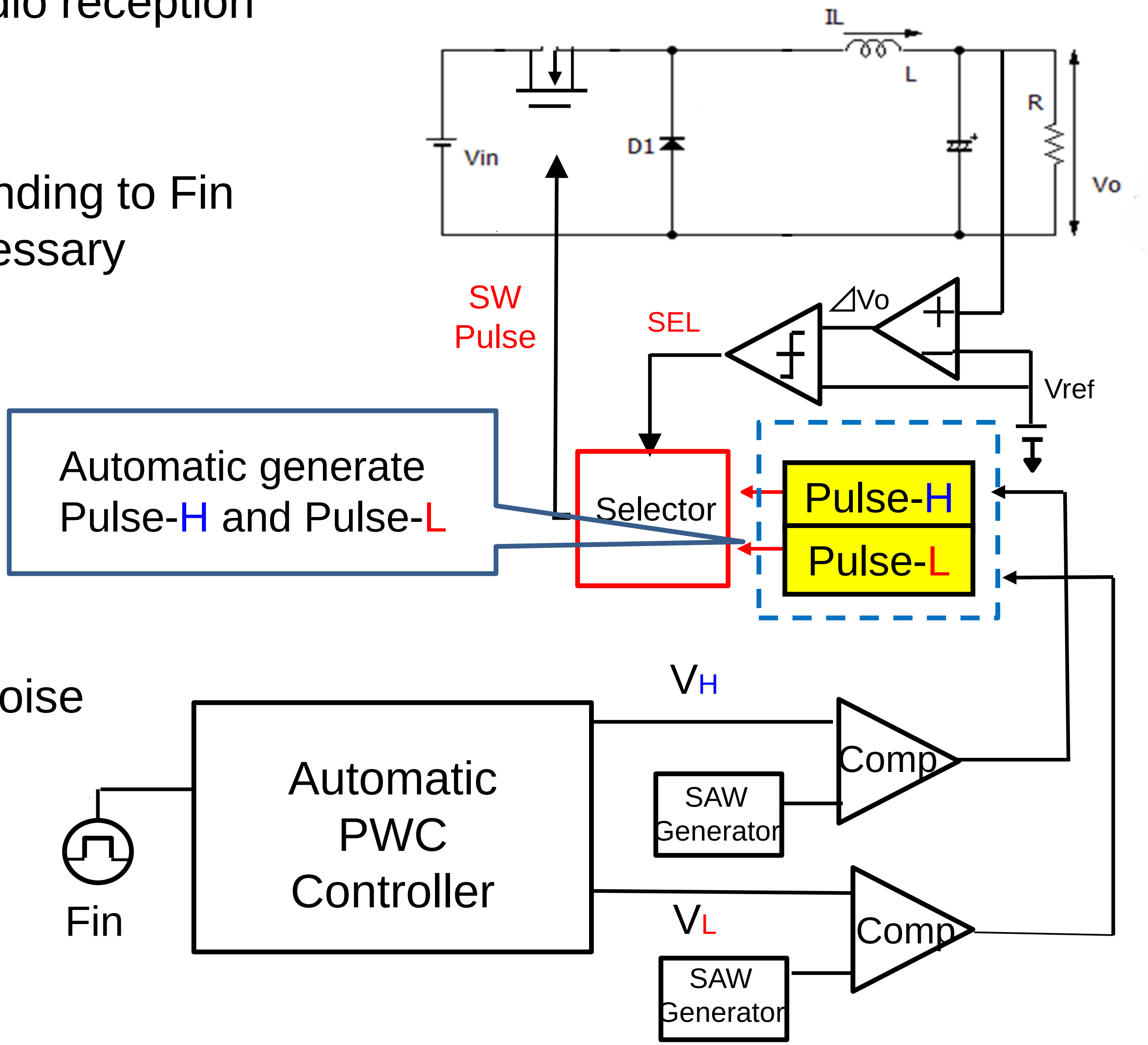
Set frequency of radio reception

Auto corresponding to Fin change is necessary

Notch frequency

Control of diffused noise

Radio receiver



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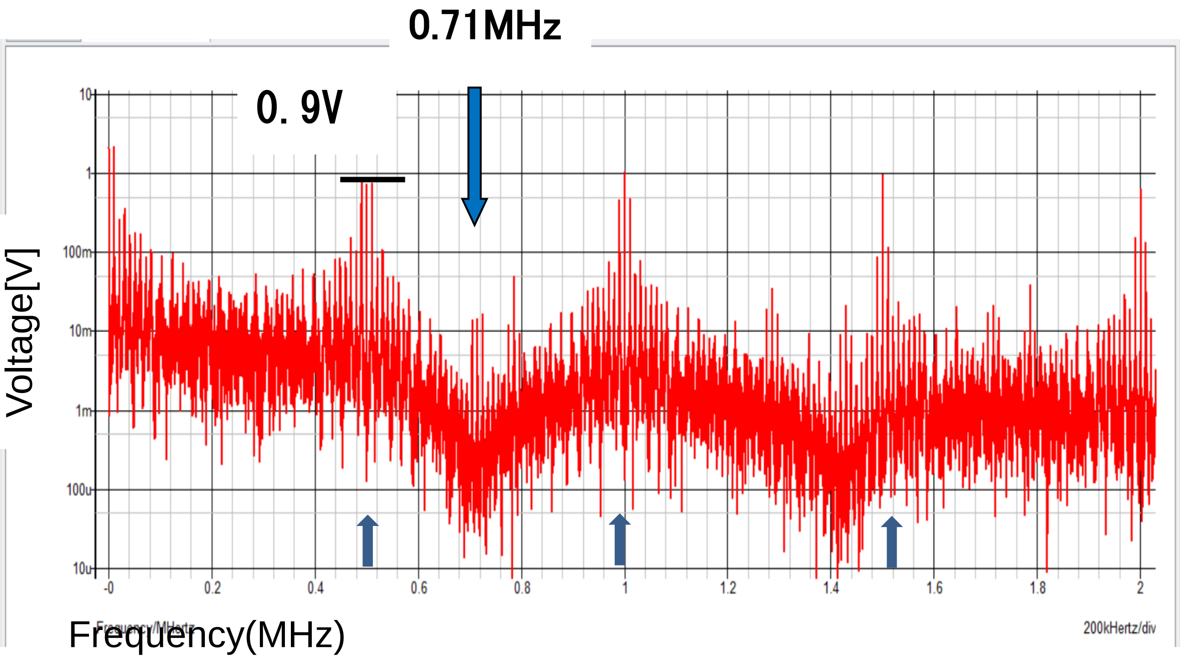
Relationship with Clock and Notch

F_{ck} ：500kHz



PWM signal spectrum using PWC control

Better to generate Fn at middle of Fck

$$F_{ck} < F_n < 2F_{ck}$$

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

Optimal

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

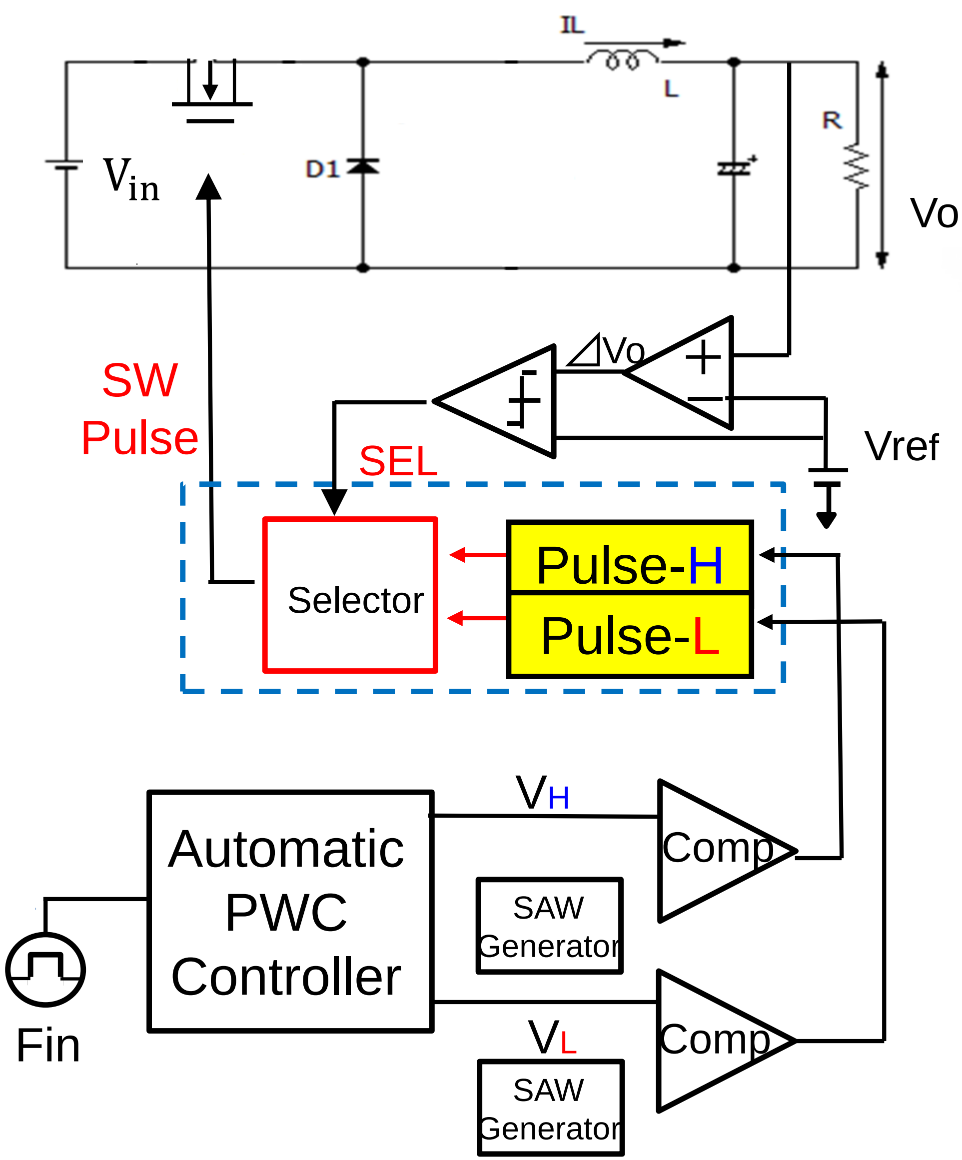
When N=1

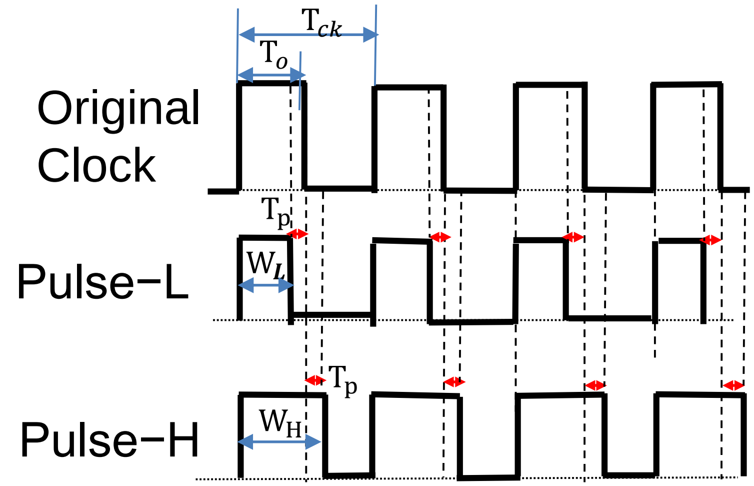
Optimal

$$F_n = 1.5F_{ck}$$

$$\frac{F_n}{3} = \frac{F_{ck}}{2}$$

Relationship between Pulse-H and Pusle-L





Timing Chart

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

$$W_L = T_o - T_p$$

$$W_H = T_o + T_p$$

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

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Generating Tck using Direct Calculation

Generate Tck from Tin using:

F_{in}=(N+0.5) ・ F_{ck}

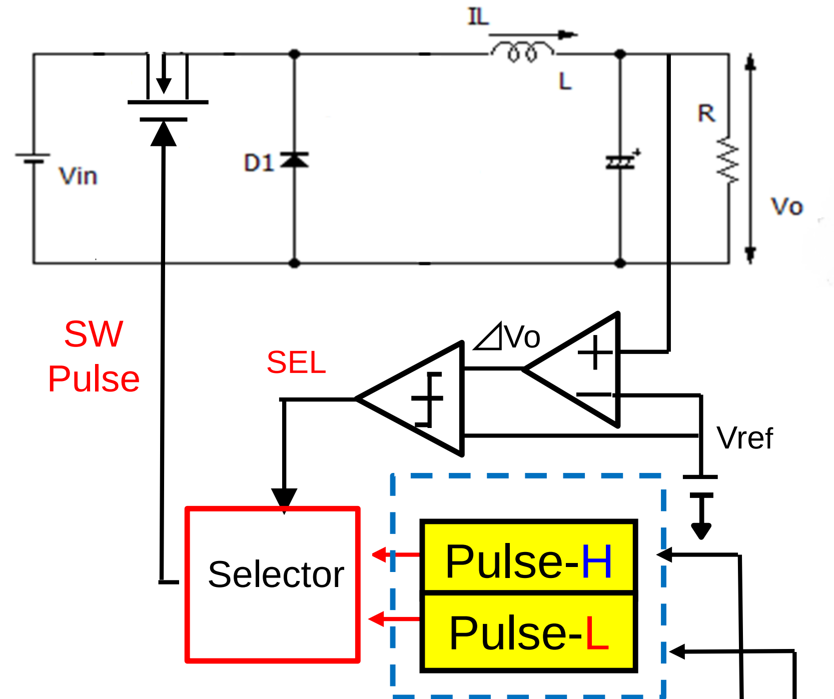
⇩

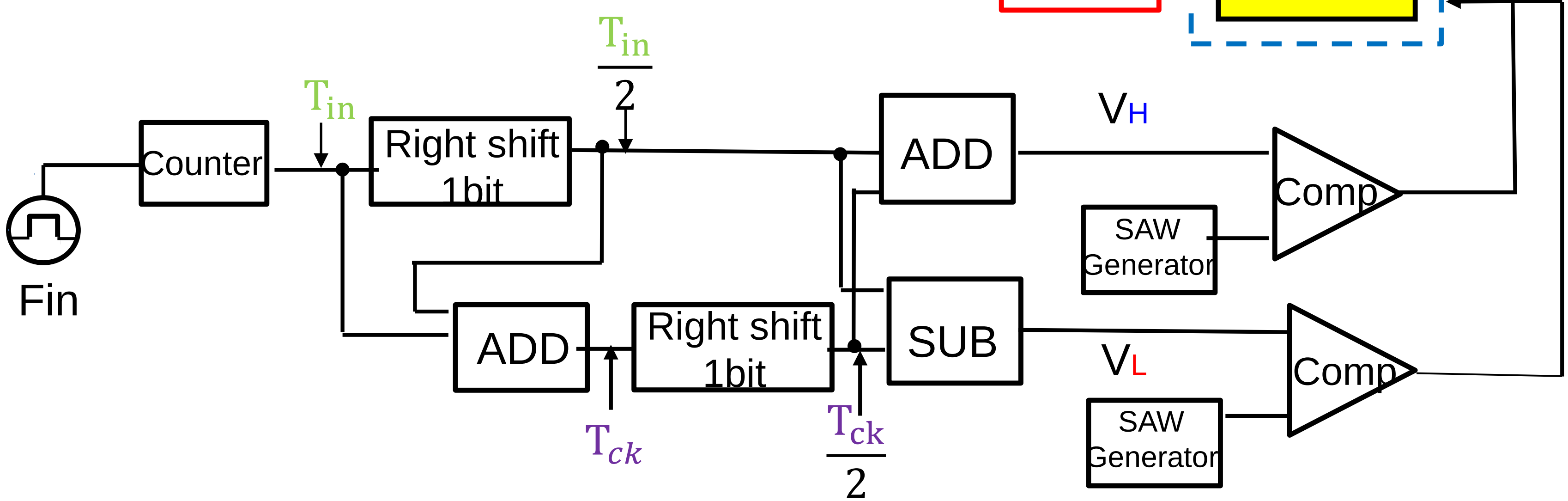
T_{ck}=(N+0.5) ・ T_{in} N=1 D_o=0.5

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

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

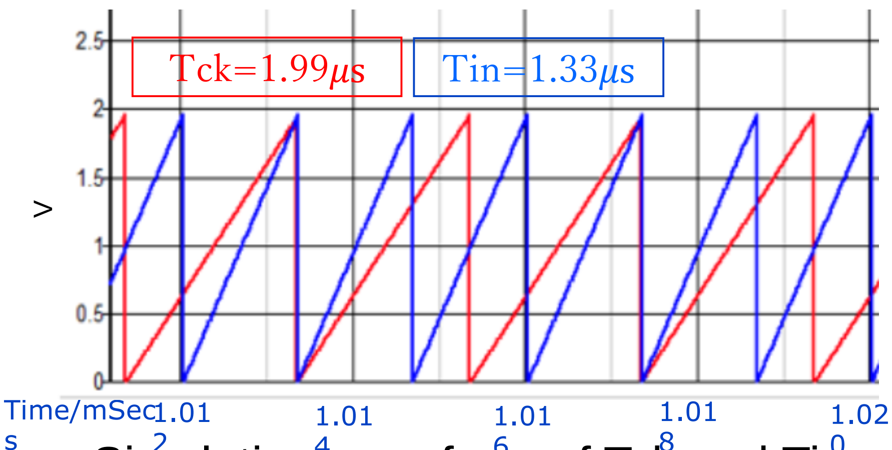
$$T_n = 2 \times T_p$$





Simulation Waveforms of W_H, W_L Generation

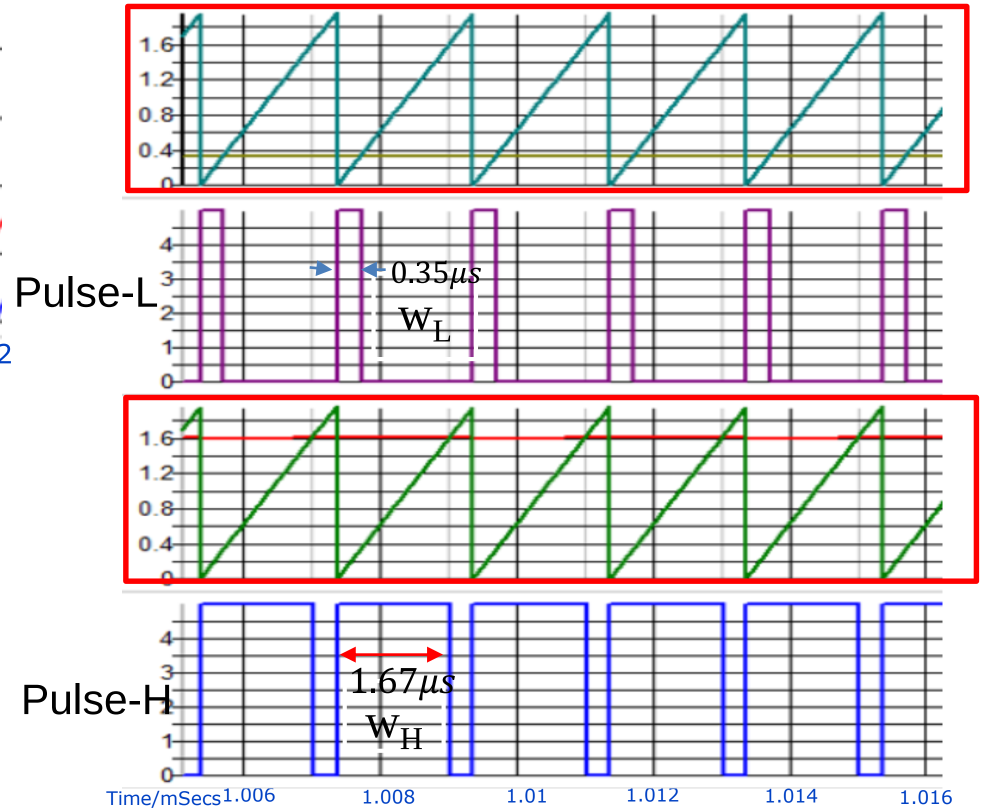
We set $F_{in} = 750kHz$ ➡ Automatic generated $F_{ck} = 500kHz$



Simulation waveform of Tck and Tin

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

Tck compare with VL or VH



Simulation waveform of W_H and W_L

Theoretical formula

$W_H = 1.66\mu s$

$W_L = 0.38\mu s$

Simulation result

$W_H = 1.67\mu s$

$W_L = 0.35\mu s$

Well matched

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Simulated Noise Spectrum of PWM Signal Case 1

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

Case 1 : Fin=750kHz, N=1⇒Fck=500kHz, W_H=1.66μs, W_L=0.38μs

Result：Fn=750 kHz, Fck=500 kHz, Fck ＜ Fn ＜ 2Fck

◎Condition

Buck DC-DC converter

V_{in} ：10V

V_{out} ：5V

L ：200 μ H

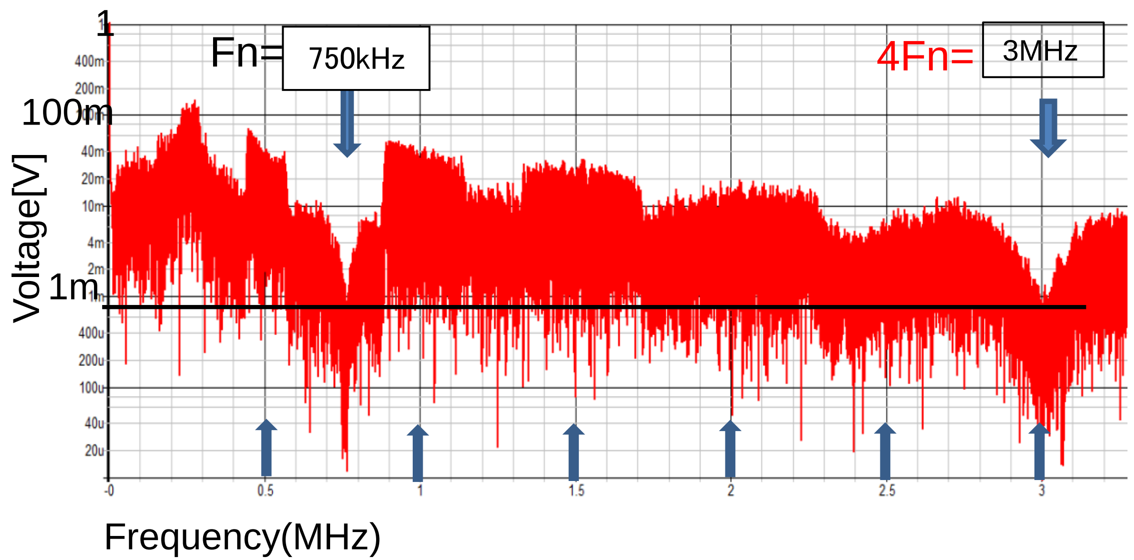
C ：470 μ F

I_{out} ：0.25A

◎Result

Fn=750kHz

4• Fn=3.0MHz



Simulated spectrum with EMI reduction

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

Simulated Noise Spectrum of PWM Signal Case 2

Case 2:Fin=1.25MHz,N=2 ⇒ Fck=500kHz,W_H=1.40μs,W_L=0.60 μs

Result：Fn=1.27 MHz, Fck=500 kHz, 2Fck ＜ Fn ＜ 3Fck

◎Simulation Result

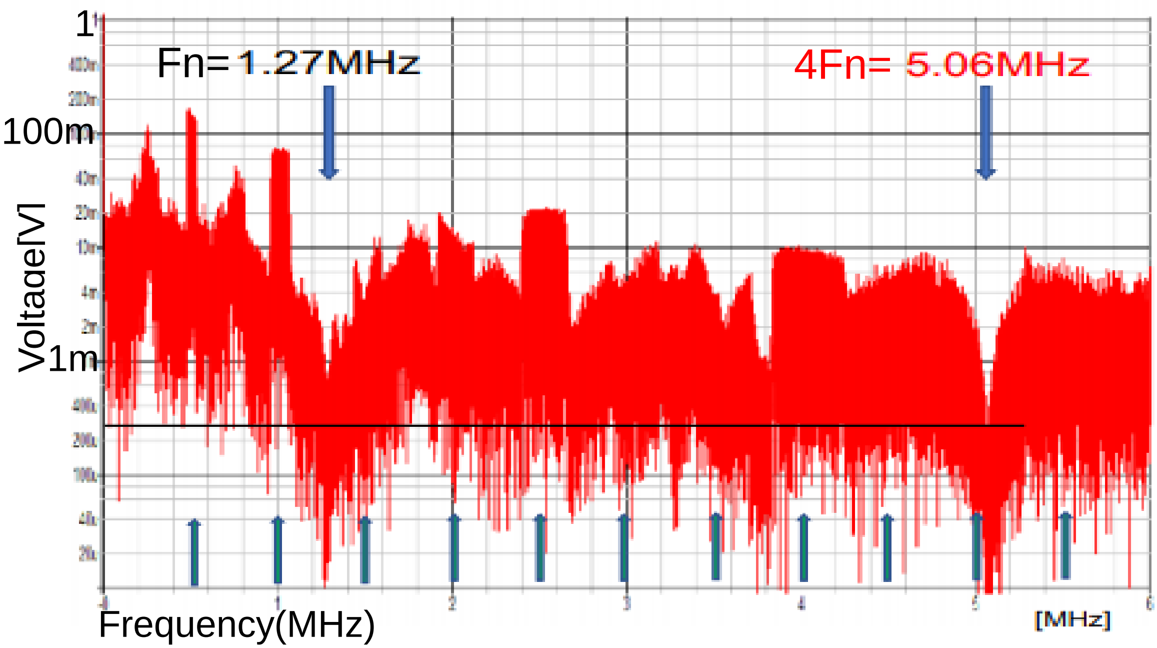
Fn=1.27 MHz

4Fn=5.05 MHz

＊Compare bottom levels

4Fn is deeper than Fn

◎Condition：same



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≈ 0μs

◎ Output stability

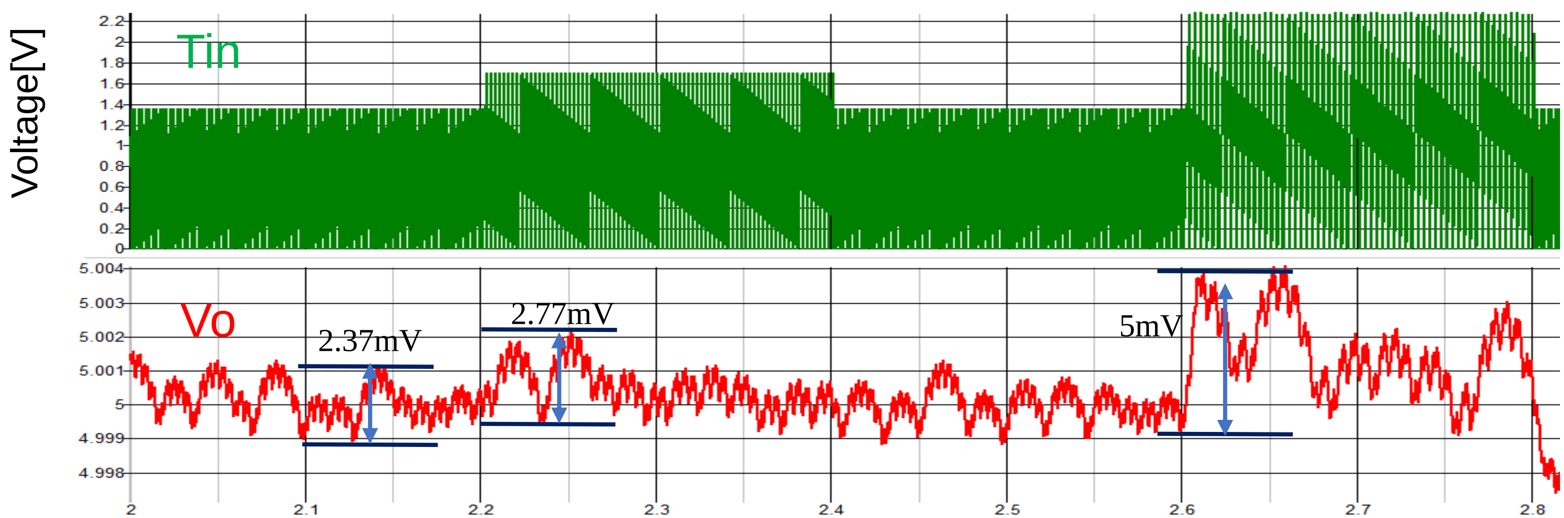
Ripple: $2.37mV_{pp}$ at $F_{in} = 1.25MHz$

$2.77mV_{pp}$ at $F_{in} = 1MHz$

$5mV_{pp}$ at $F_{in} = 750kHz$

Static ripple is about 0.1% of the output voltage V_o

stable



Transient response with Fin change

Response speed is important when tuning or switching communication channels

Simulated Noise Spectrum of PWM Signal Case 3

Case3 : Fin=1.75MHz, N=3⇒Fck=500kHz, W_H=1.29μs,W_L=0.72μs

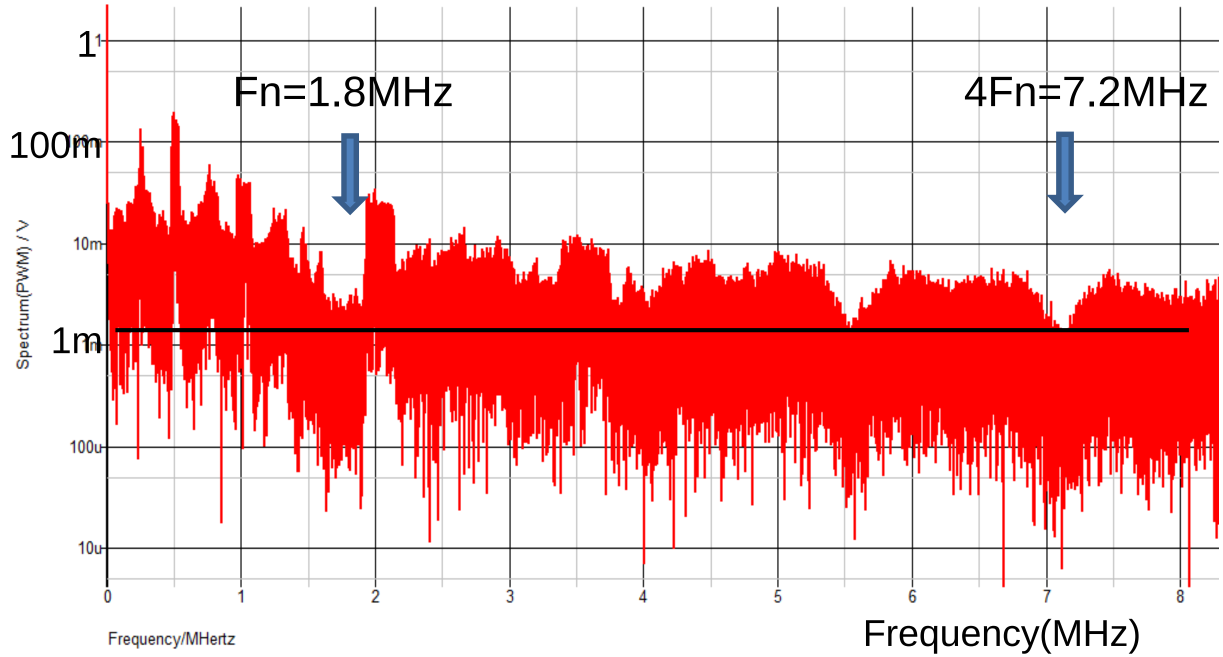
Result：Fn=1.8 MHz, Fck=500 kHz, 3Fck ＜ Fn ＜ 4Fck

◎Simulation Result

Fn=1.8 MHz
4Fn=7.2 MHz

∗Compare bottom levels
Almost equal

◎Condition：same



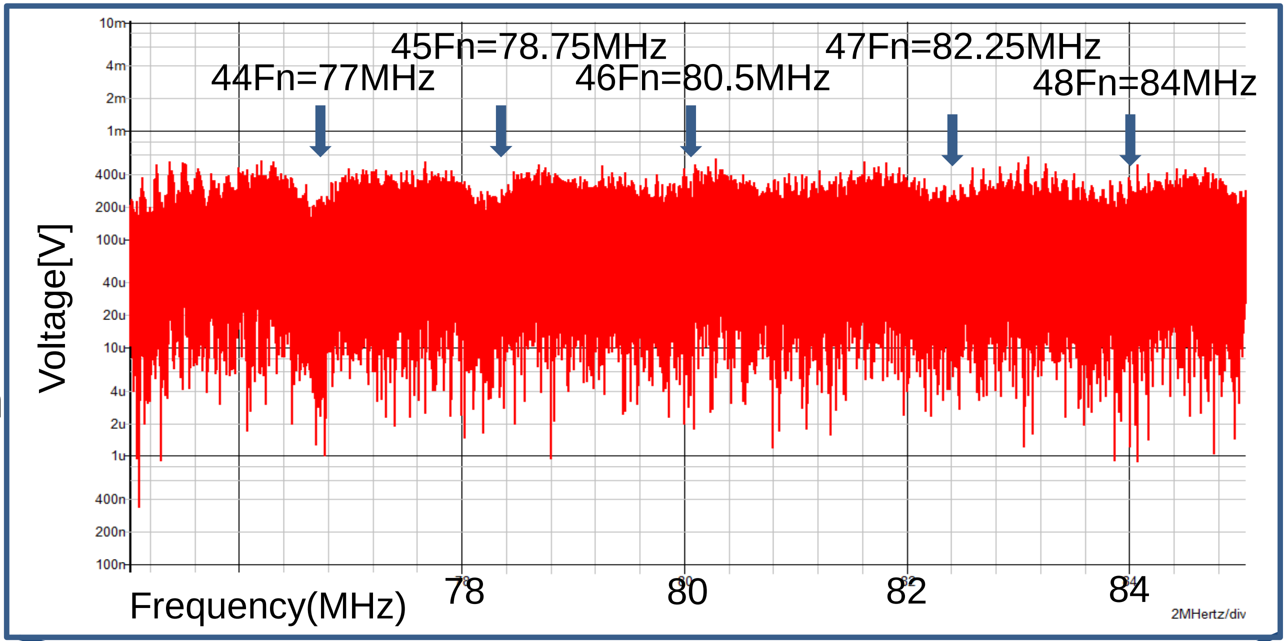
Simulated spectrum with EMI reduction

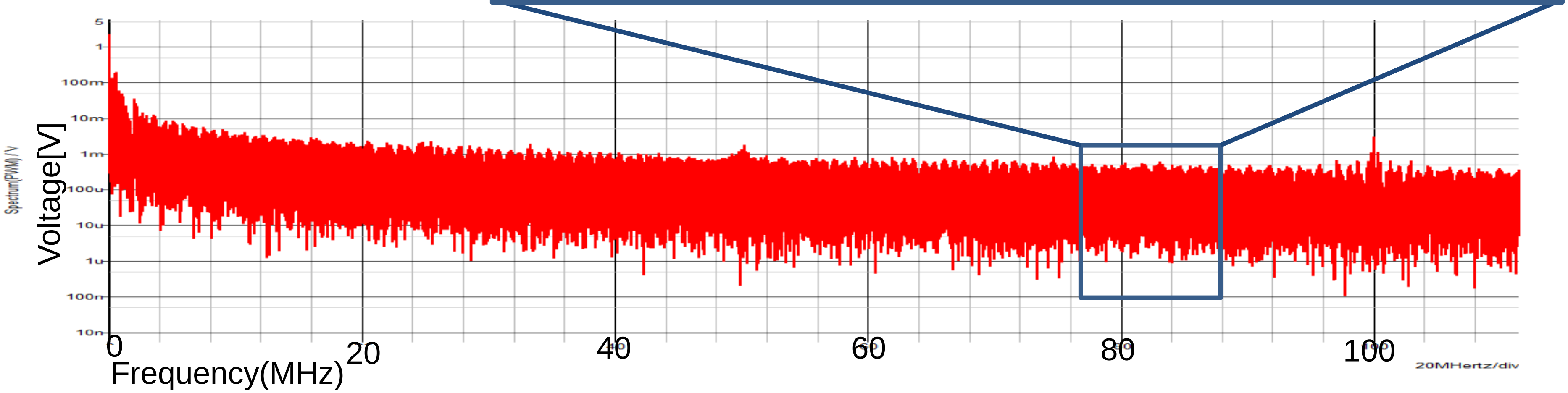
Simulated Noise Spectrum of PWM Signal Case 3

∗ High frequency harmonics is not clear!

∗ But it is good for AM radio receiver.(< 2MHz)

●It needs to generate Notch at higher than 80MHz (FM)





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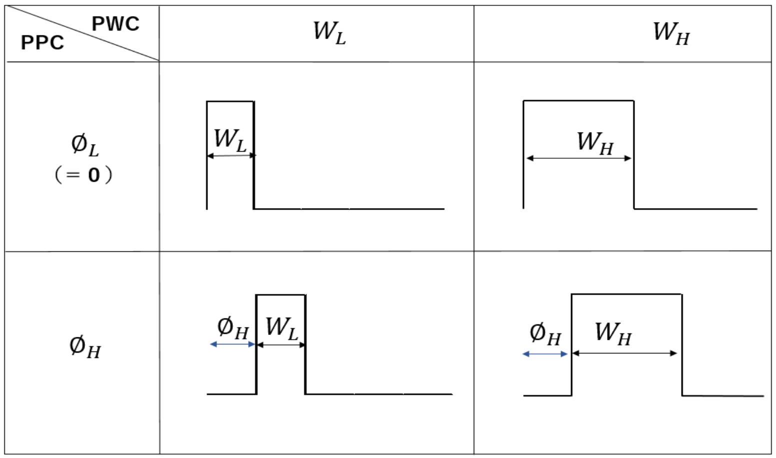
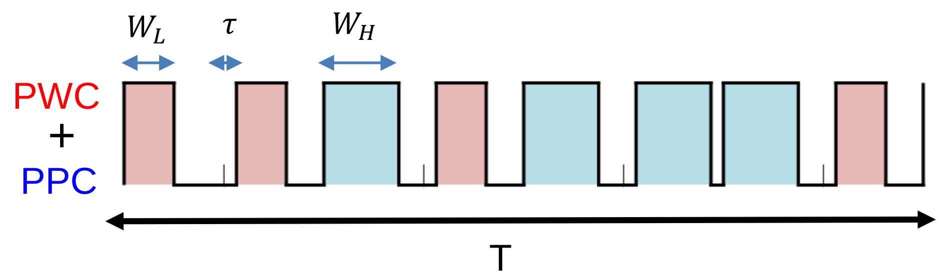
- Conclusion and future work

PWPC Method

Complex coding method

PWPC (Pulse width coding + Pulse phase coding) method





Theoretical formula

$$f_{notch1} = \frac{n}{(W_H - W_L)}$$

$$f_{notch2} = \frac{n}{2|\tau_H - \tau_L|}$$

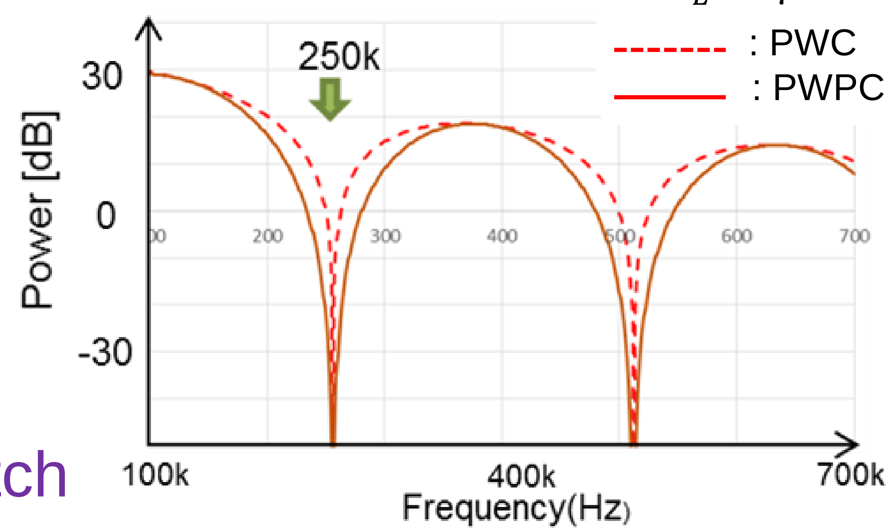
Set $f_{notch1} = f_{notch2}$ ➡ Big Notch

Expect

Condition:

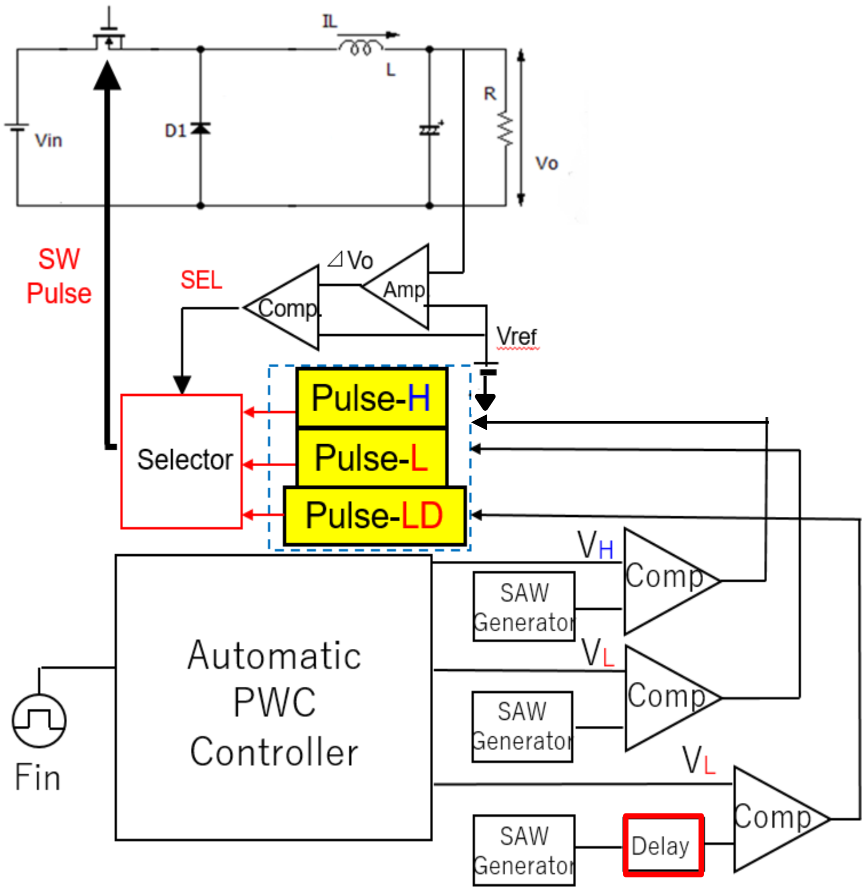
$W_H = 7\mu s$

$W_L = 3\mu s$

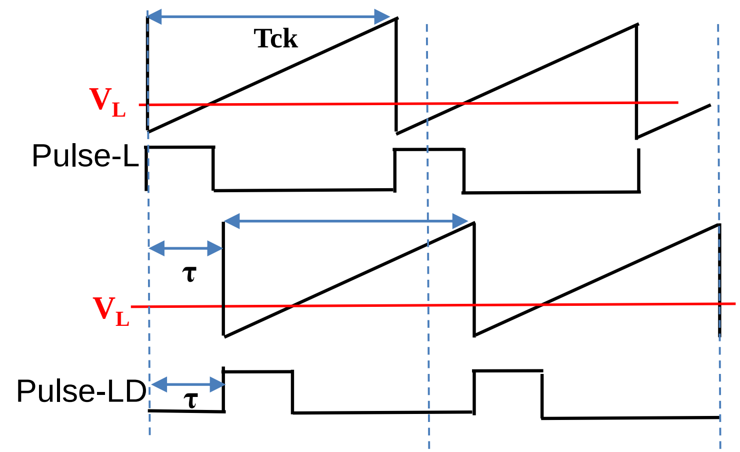


Automatic Generation of Notch Frequency with PWPC Control

Automatic pulse generation



Pulse coding of PWPC method



Design timing in PWPC method

$$W_H = To + Tp = Do \times Tck + 0.5Tin$$

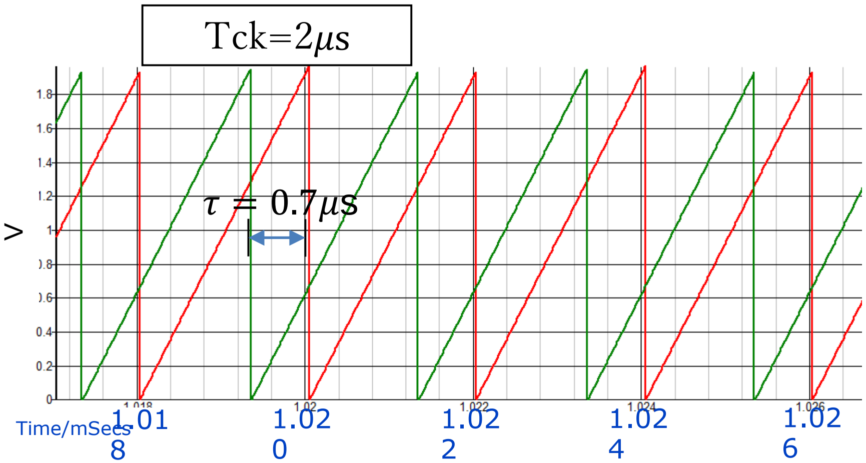
$$W_L = To - Tp = Do \times Tck - 0.5Tin$$

$$\tau = (W_H - W_L)/2 = 0.5 \times Tin$$

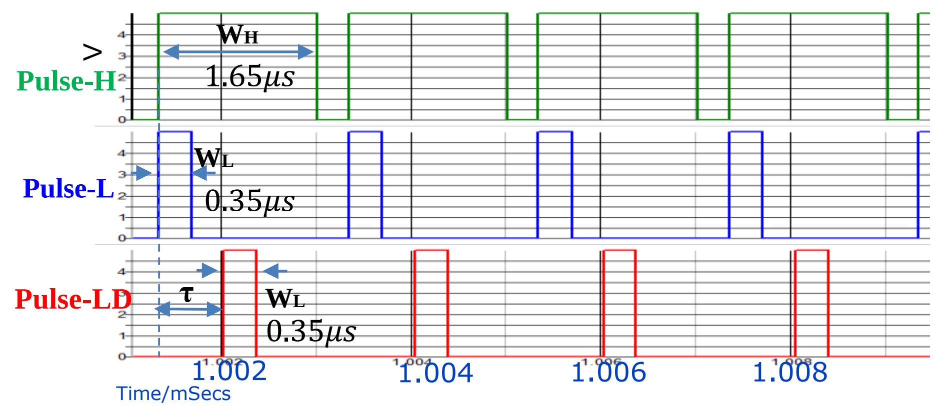
Simulation Waveforms of W_H, W_L Generation

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

$f_{notch1} = f_{notch2}$ ➡ $\frac{n}{(W_H - W_L)} = \frac{n}{2|\tau_H - \tau_L|}$ ➡ $\tau_H - \tau_L = \tau = \frac{W_H - W_L}{2} = \frac{T_{in}}{2}$



Simulation waveform of Tck and delay Tck



Simulation waveform of Pulse-H, Pusle-L and delay Pulse-L

Theoretical formula result

$W_H = 1.67\mu s$
$W_L = 0.33\mu s$
$\tau = 0.67\mu s$

Well matched

Simulation result

$W_H = 1.66\mu s$
$W_L = 0.38\mu s$
$\tau = 0.70\mu s$

Simulated Noise Spectrum of PWPC Control

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

Fin=750kHz , N=1⇒ Fck=500kHz,W_H=1.67μs,W_L=0.33 μs

Fn=750 kHz, Fck=500 kHz, Fck < Fn < 2Fck

◎ Condition

Buck DC-DC converter

V_{in} : 10V

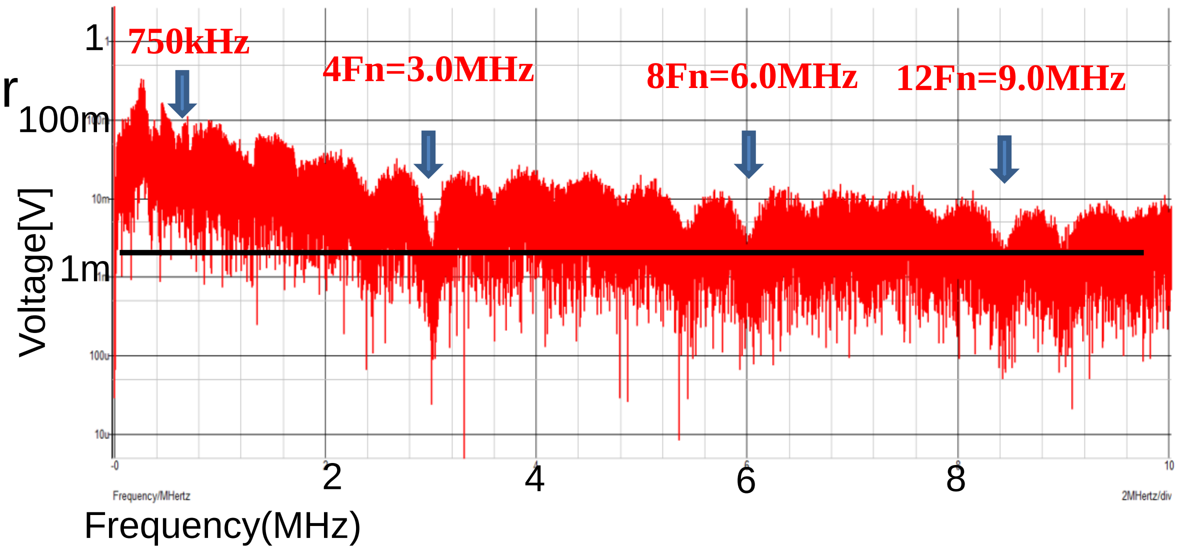
V_{out} : 5V

L : 200 μ H

C : 470 μ F

I_{out} : 0.25A

F_{in} : 750kHz



Simulated spectrum with EMI reduction

PWPC characteristic: There are many harmonics of 4NFn

（N ＝1,2,3・・・）

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- Pulse Coding Method in Switching Converter
- Automatic PWC Control
  - Relationship with the Clock frequency and the Notch frequency
  - Direct generation of clock pulse from input frequency
  - Simulated Noise Spectrum of PWM Signal in the higher frequency range
- Automatic PWPC Control
- Conclusion and future work

Conclusion

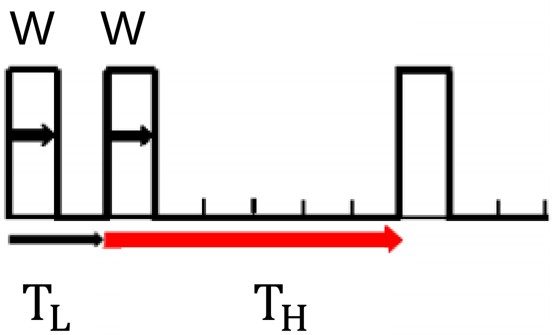
- Developed pulse coding control in order to generate notch characteristics at desired frequency
- Analyze spread spectrum with notch characteristics
- Automatic generate the notch frequency from Fin

Using $F_{\mathrm{in}} = (N + 0.5)F_{\mathrm{ck}}$, discussion on direct generation of notch in N=1,2,3 situation using PWC control

Automatic generating of notch frequency with PWPC control

Future Work

- Notch generation using PCC(Pulse Cycle Coding) method



- Investigate why the large notch at 4Fn appear.
- Extend 4Fn in order to high frequency notch generation using PWPC method

Thank you for Listening

Q&A

Q1. I want to know the purpose of this research, you want reduce some noise at some special frequency?
A : In my research, I want to spread spectrum with both EMI reduction and control the diffusion of noise. Usually, in order to reduce EMI noise, we let the clock signal be randomly modulated, but the diffused noise diffuses into the forbidden zone. For example, in in-vehicle DC-DC converter must not overlap reception frequency bands of AM, FM of radio. If let reception frequency from radio receiver equal to notch frequency, it is possible to greatly reduce influence on other electronic devices. So we proposed a algorithm that the notch frequency can be generated arbitrarily.

Q2. How do you defined Fn?
A : Fn is notch frequency in PWM signal spectrum. The PWM signal of spectral characteristics of square wave depend on sinc function, maybe the notch is the zero point of sinc function and we also tested it.

Q&A

Q3. In slide page 26, why there is a deviation between Fin and Fn?
A : When the frequency is becoming higher, the speed of the transistor respond when turn on and off in switching will be come fast, and will create error.

Q4. How the 500kHz signal is used to switching converter?
A : At first, basic clock signal is generated, during the counter can create Tin, than using the relationship equation between Tck and Tin, W_L and W_H can create V_H and V_L. The saw-tooth signal is generated by using the basic clock, compared with V_H and saw-tooth, V_L and saw-tooth can create Pulse-H and Pulse-L. Using Pulse-H and Pulse-L can create switching pulse.

Q5. What is the characteristics of your generated notch?
A : I think the characteristics of notch is this equation $F_{\mathrm{in}} = (N + 0.5)F_{\mathrm{ck}}$
The notch frequency is between the clock frequency.