The Institute of Electronics, Information and Communication Engineers

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Automatic Notch Generation in Noise Spectrum of Switching Converter with Pulse Coding Method

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OUTLINE

- Introduction & Objective
- Conventional Switching Converters with Spread Spectrum
- Pulse Coding Method in Switching Converter
- Automatic PWC Control
    - Relationship with the Clock frequency and the Notch frequency
    - Direct generation the clock pulse from input frequency
    - Simulated Noise Spectrum of PWM Signal
    - Discussion about Do
- Conclusion and future work

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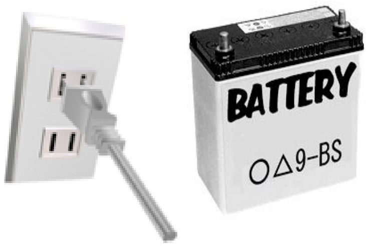
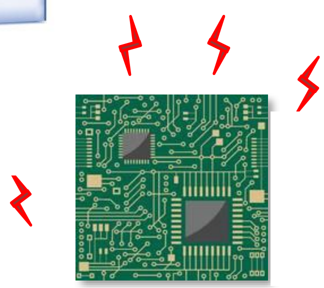
Research Background





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

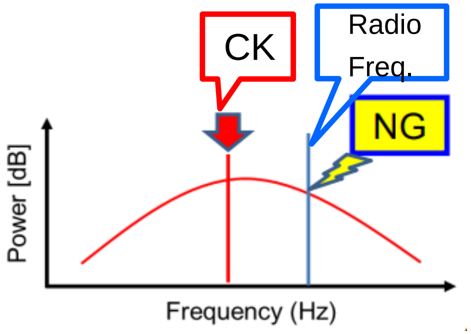
EMI:Electro-Magnetic Interference

Research Objective

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

Trouble

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

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

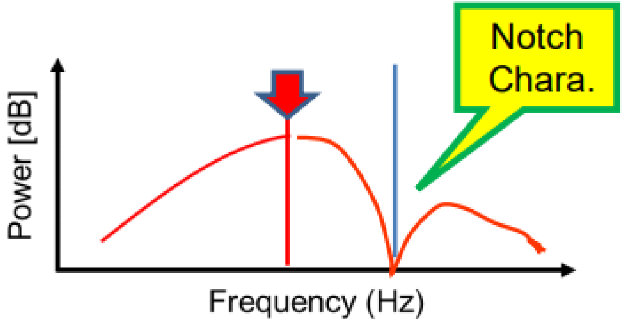
[1]EMI: Electro-Magnetic Interference

Research Summary

Proposed method

Spread spectrum method using pulse coding

Design modulation circuit
in order to generate notch frequency automatically



Achievement

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

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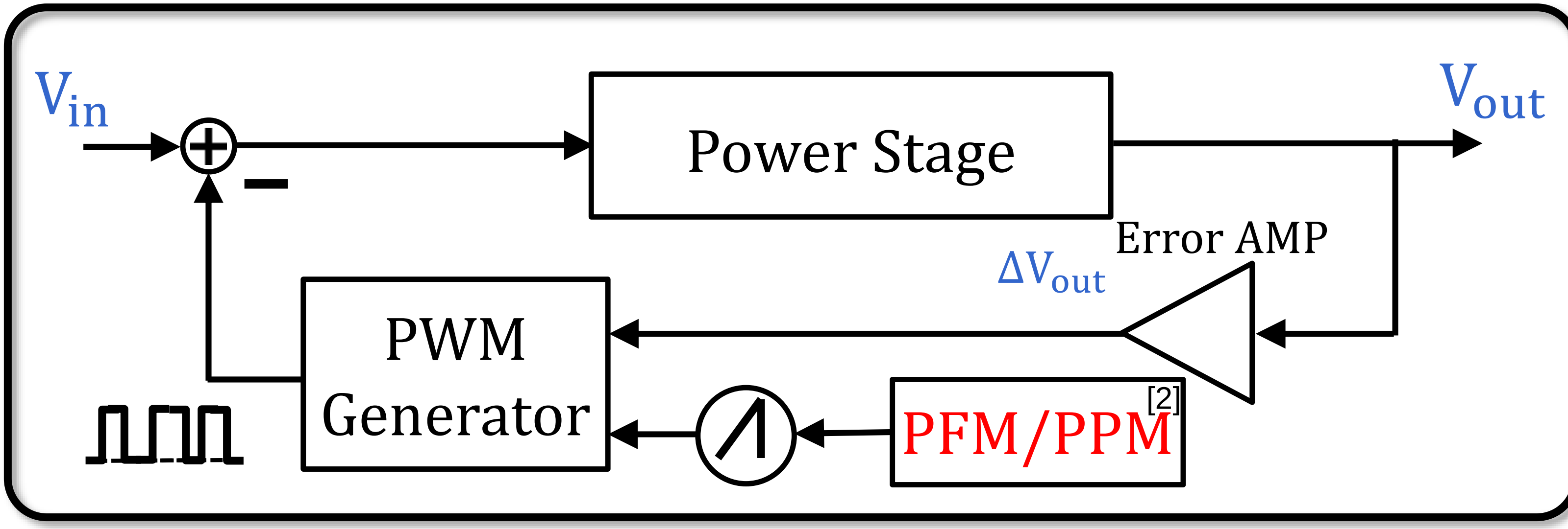
Conventional Switching Converter with Spread Spectrum

Spread Spectrum

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

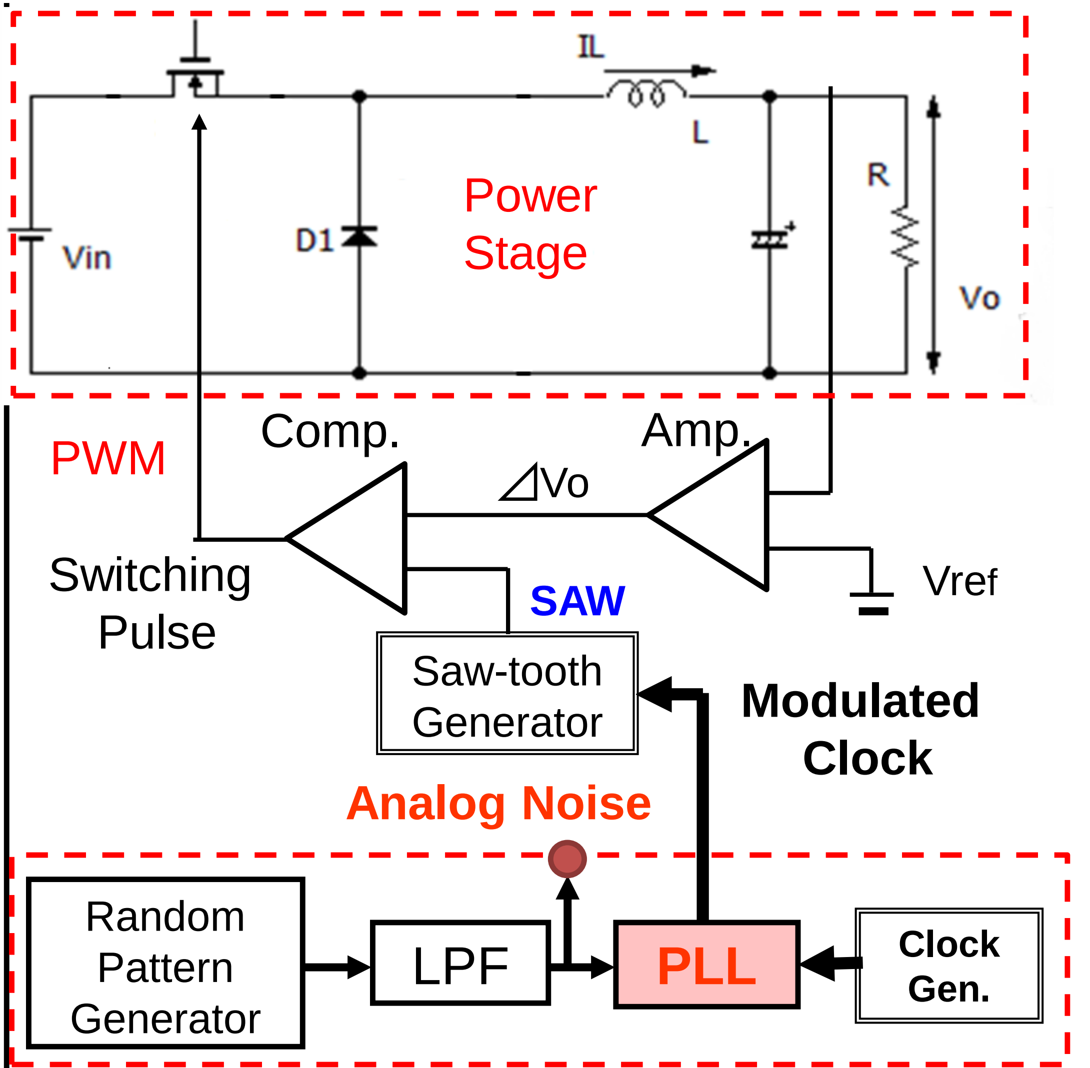


Switching Power

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

Spread Spectrum for EMI Reduction

Spread spectrum using pseudo analog noise

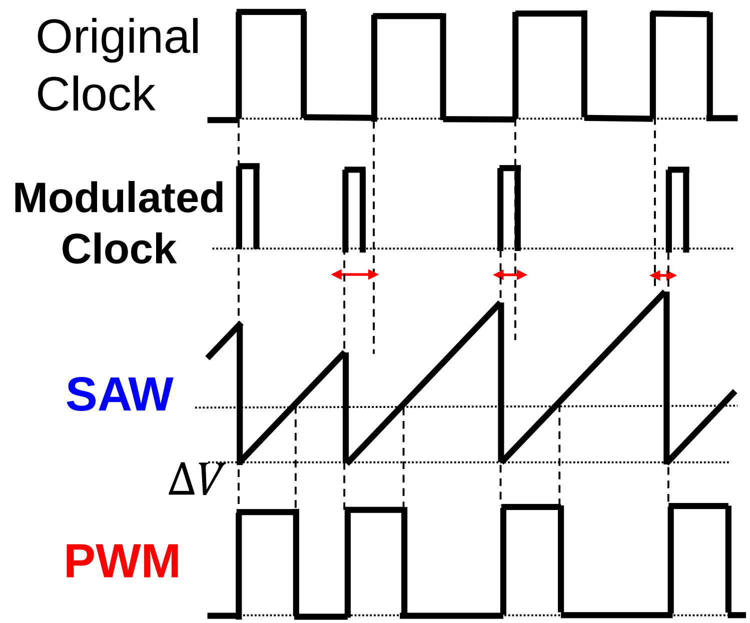


Buck converter with modulated clock

To reduce EMI noise, clock pulse is modulated

∗ Clock to SAW generator is modulated by shaking phase of original clock at random using analog noise & PLL[3]

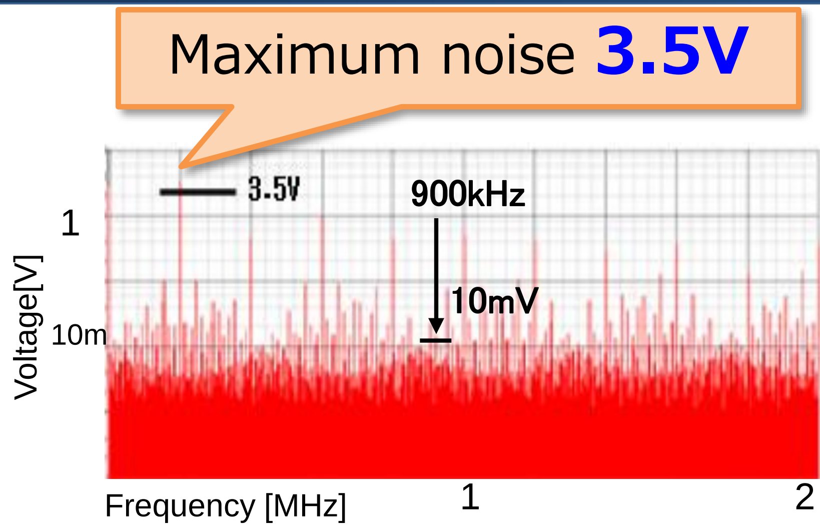
∗ SW pulse frequency is modulated and reduce EMI noise



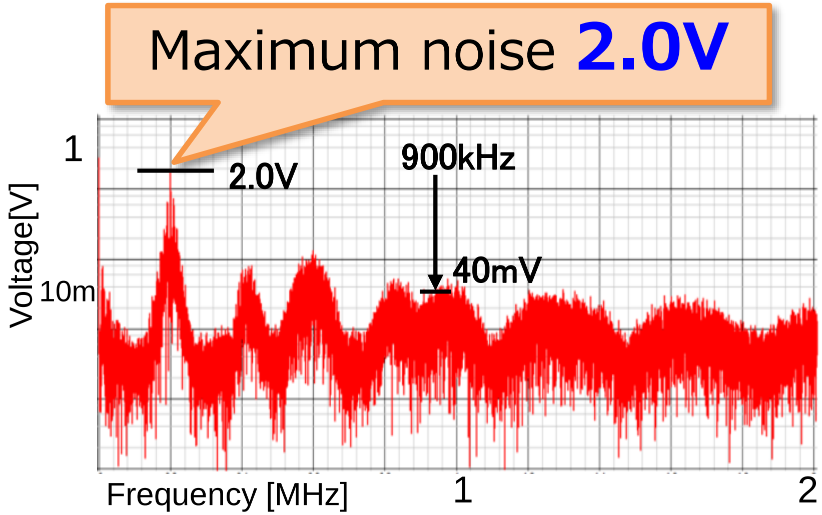
Timing Chart

[2] 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 NG

Spectrum → Fast Fourier Transformation (FFT) of PWM signal

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Coding Method

Single coding method

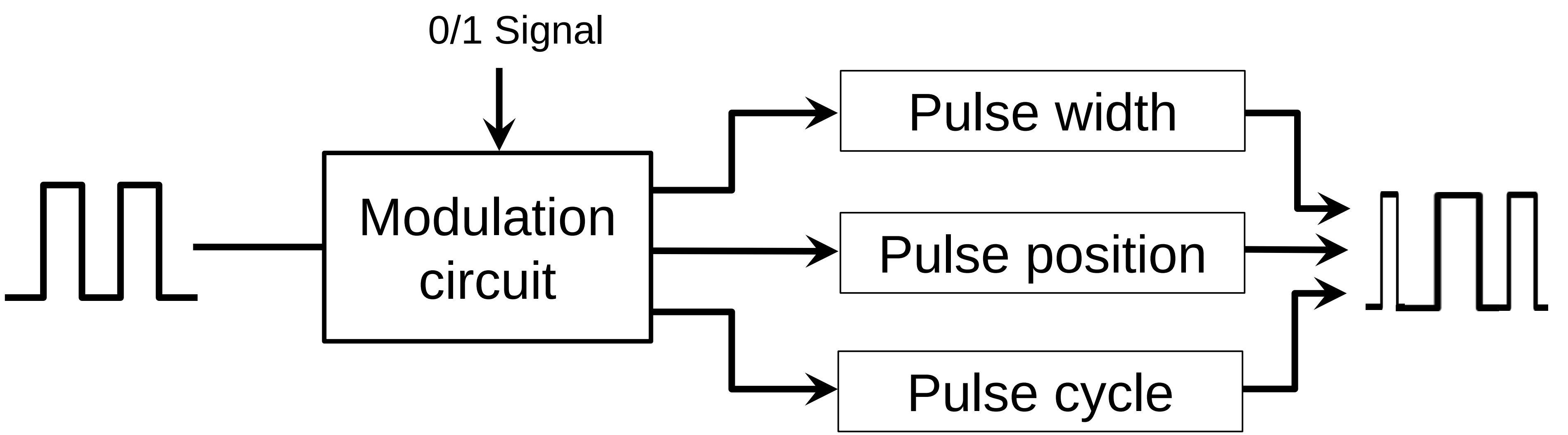
Pulse width · period · position
select one to modulation

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

Complex coding method

Pulse width · period · position
select two to modulation

- ASM（PWC+PCC） method
- DPM（PPC+PCC) method
- PWPC（PWC+PPC） method

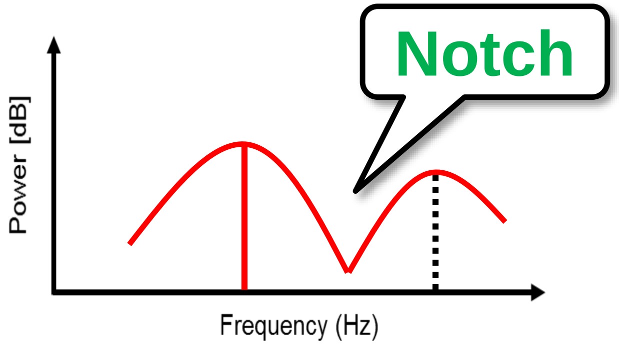


Complex coding method

Diffuse Noise to Specific Frequency

Problem

Noise diffusing uniformly



Using digital modulation

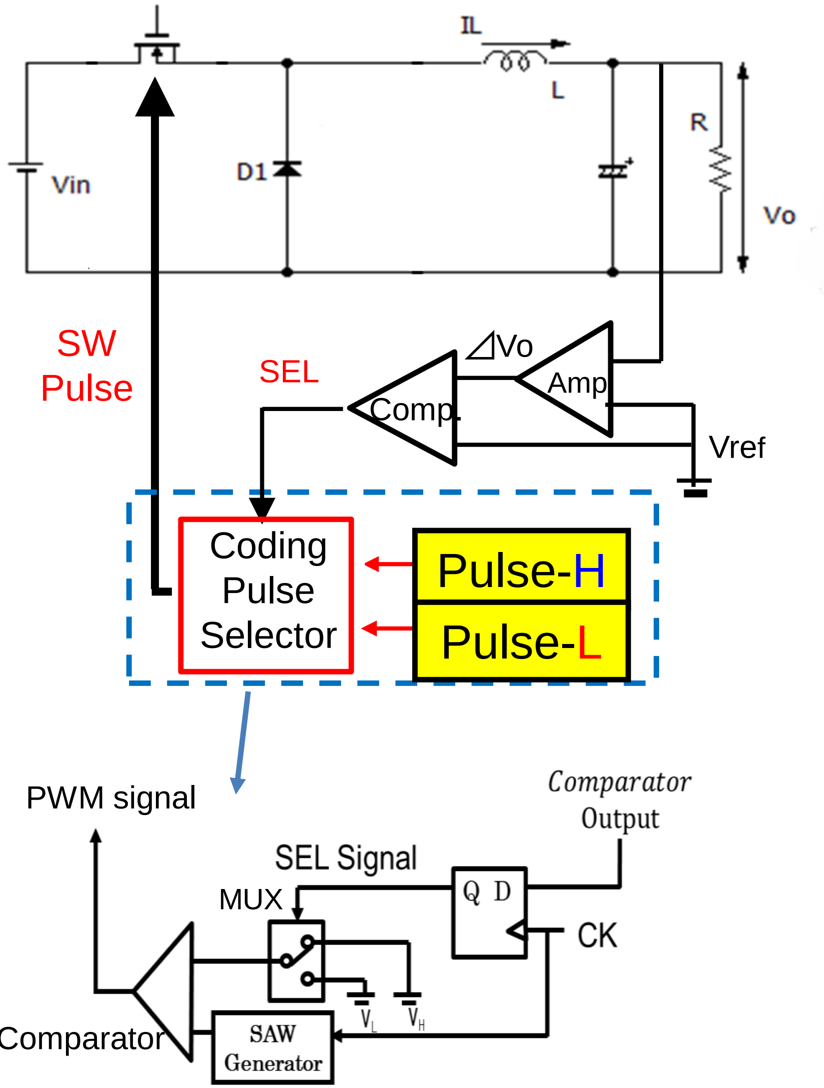
Noise diffuses to specific frequency

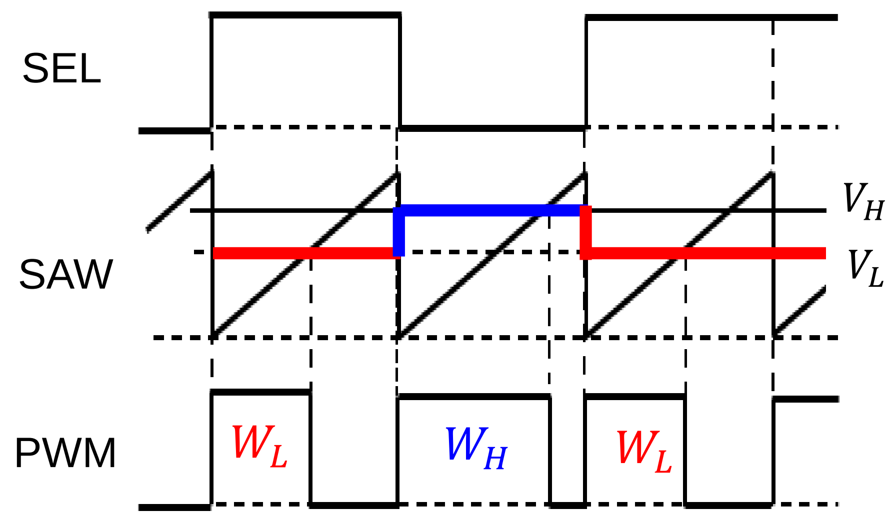
Frequency band where noise does not spread

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

Input Low

①SEL: Low

②MUX select V_L

③Generate pulse with short width in comparator

★ $D_H > D_o > D_L$

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

★In this situation, manually set W_L and W_H

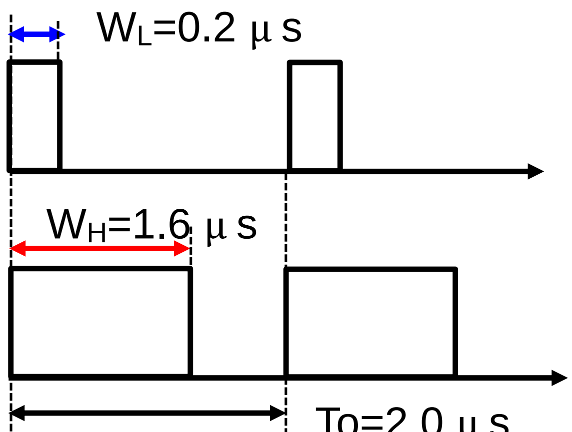
Simulation Result with PWC Control

◎ Condition

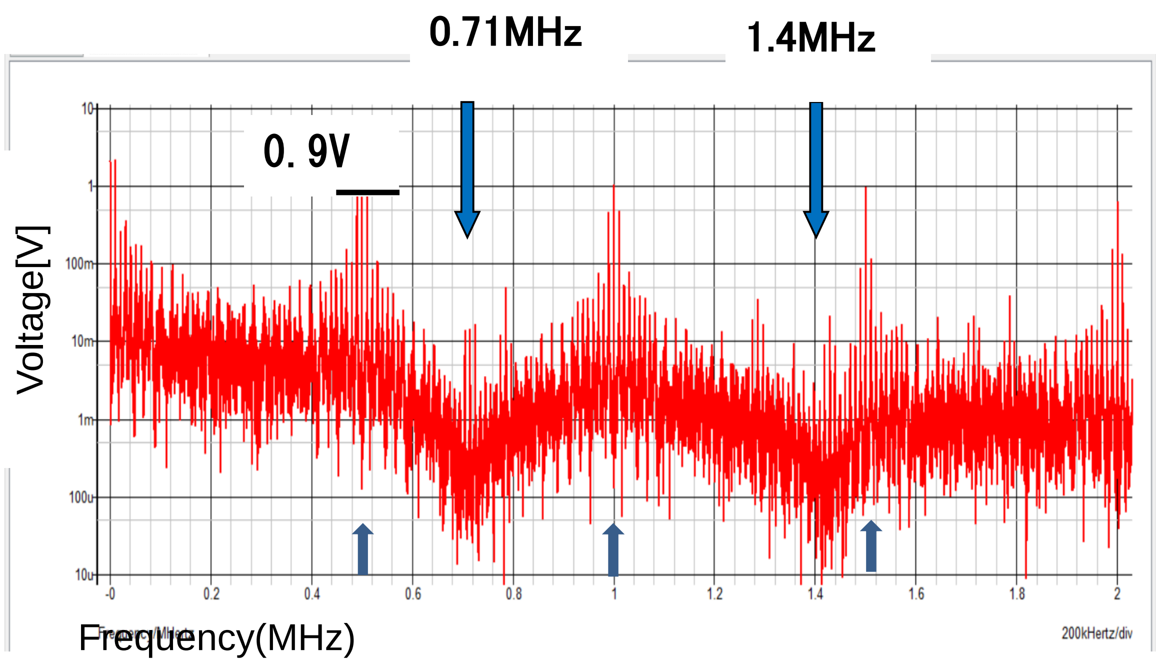
Buck DC-DC converter
V_{in} : 10V
V_{out} : 5V
L : 200 μ H
C : 470 μ F
I_{out} : 0.25A
f_{ck} : 500kHz

Design a clock pulse to determine the notch frequency

$$f_n \cong N \times \frac{1}{(W_H - W_L)} \quad [N = 1,2,3,\cdots,n]$$
$$= N \times \frac{1}{1.6\mu s - 0.2\mu s} = 0.71\text{MHz}$$



Pulse widths of the coding pulses



PWM signal spectrum using PWC control

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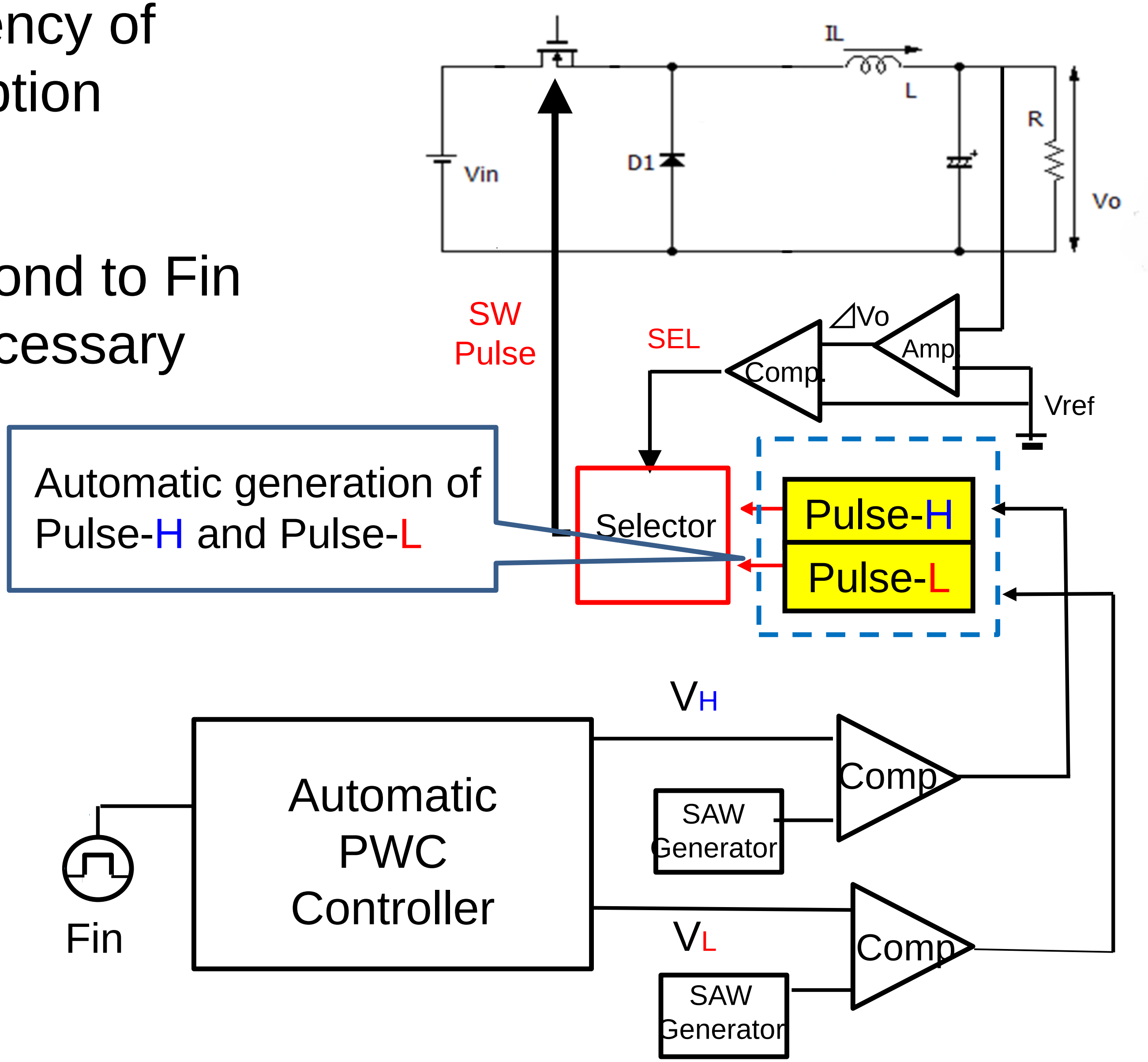
Automatic PWC Control

Set frequency of radio reception

Auto correspond to Fin change is necessary

Radio receiver



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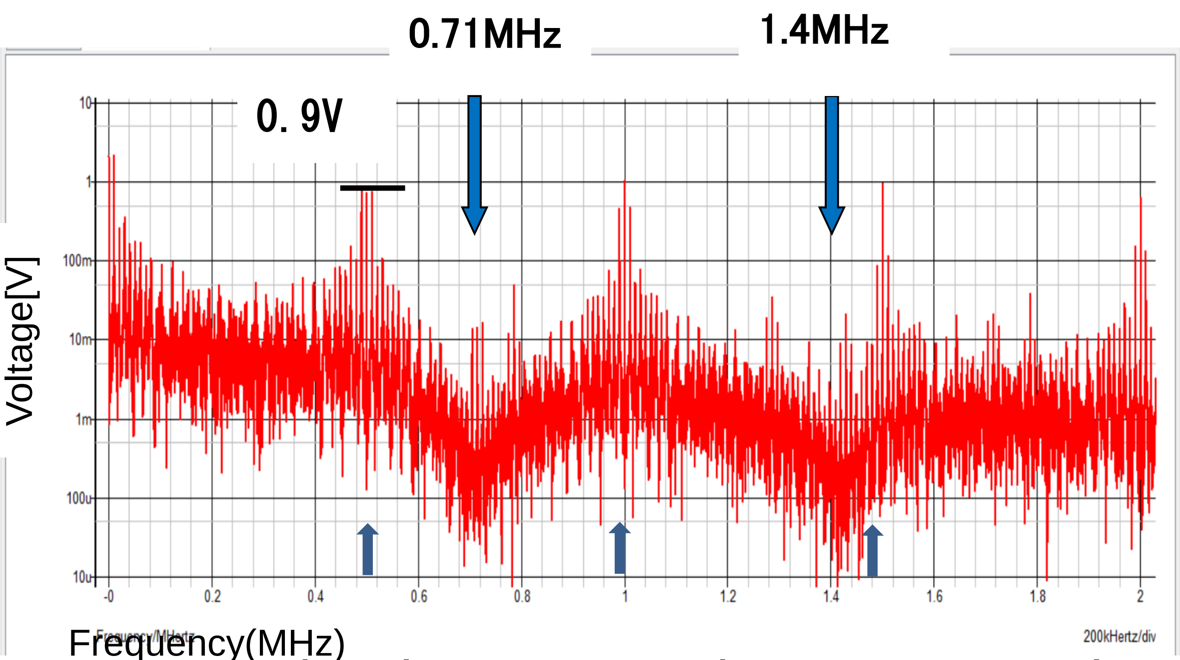
Relationship with Clock and Notch

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

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

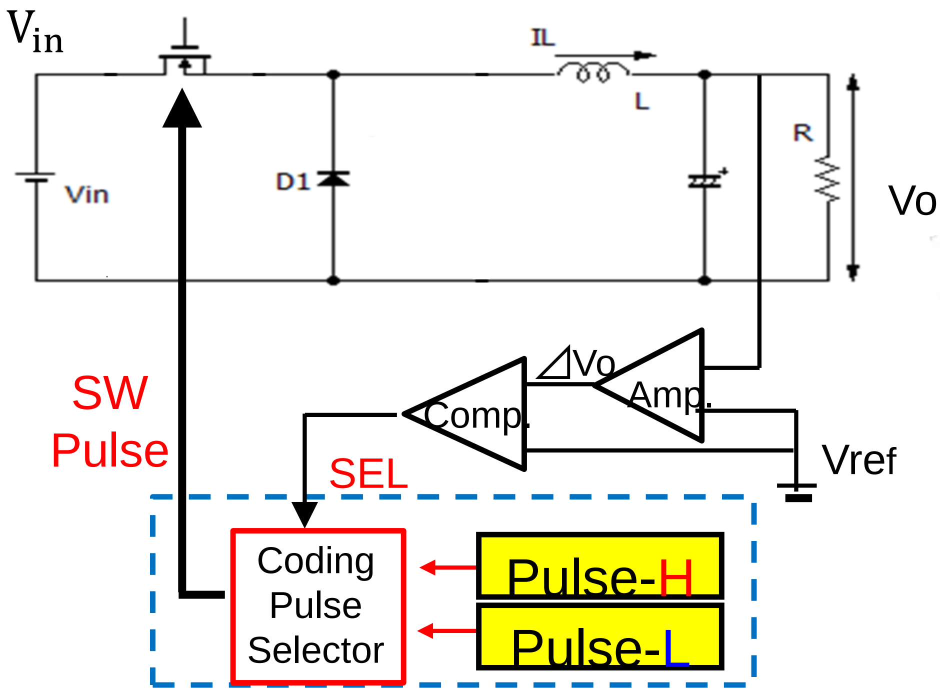
When N=1

Optimal

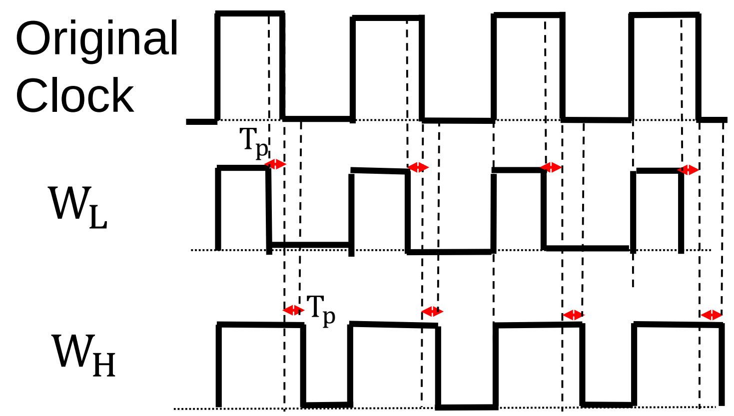
$$F_n = 1.5F_{ck}$$

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

Relationship with Clock and Notch



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



Timing Chart

$$W_L = T_o - T_p$$

$$W_H = T_o + T_p$$

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

Output voltage Vo is determined by the clock duty

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Generating Tck using Direct Calculation

Generate Tck from Tin using:

F_{in}=(N+0.5) ・F_{ck}

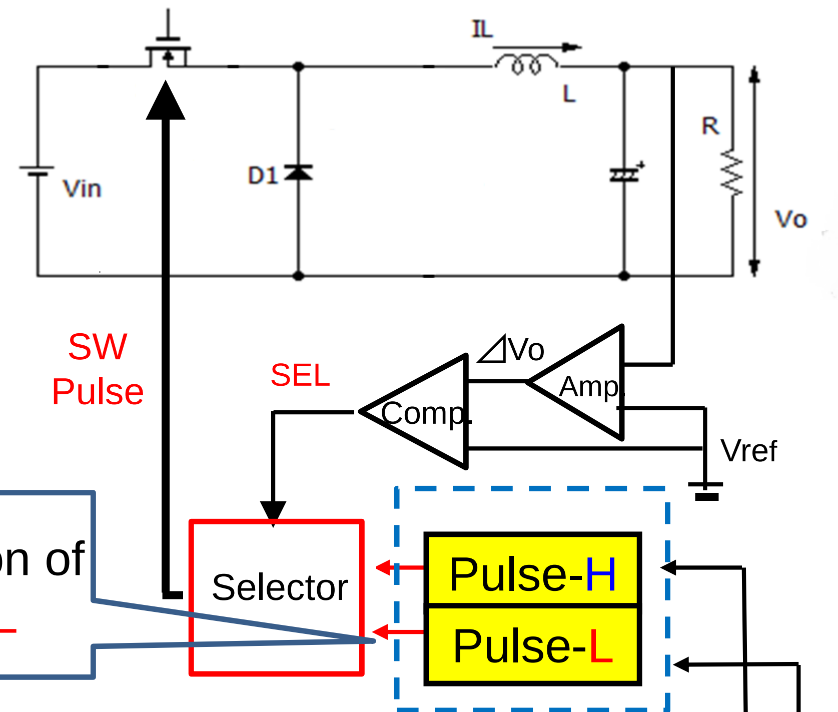
⇩

T_{ck}=(N+0.5) ・T_{in} N=1

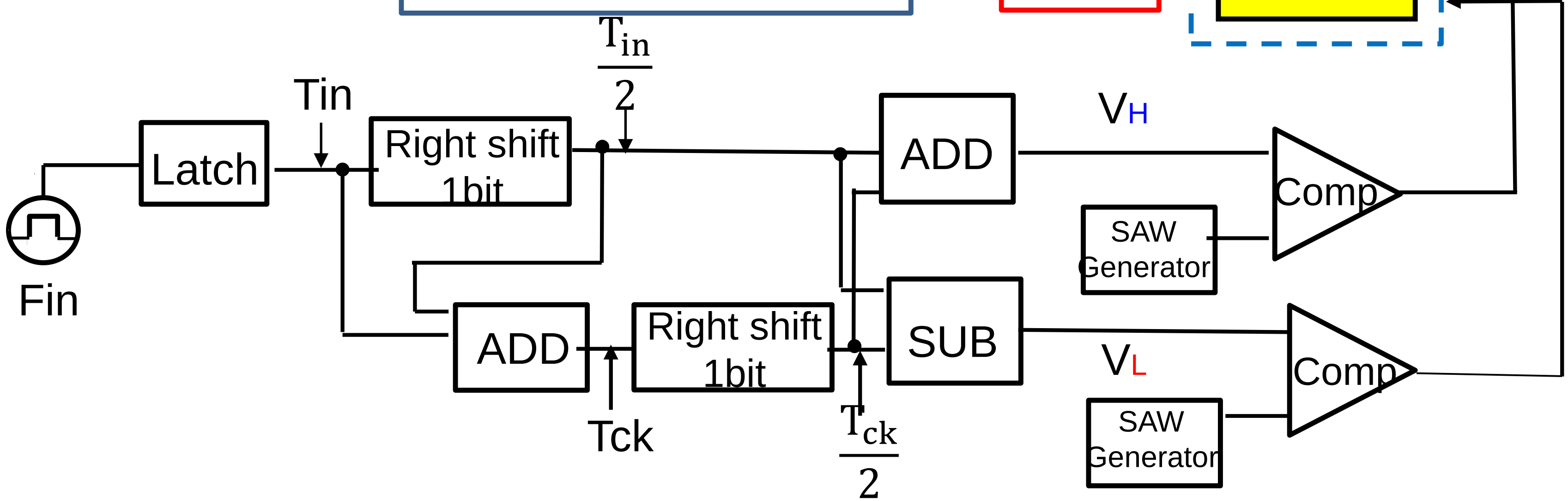
$W_L = T_o - T_p$ =Do×Tck+$\frac{1}{2}$Tin

$W_H = T_o + T_p$ =Do×Tck- $\frac{1}{2}$Tin

$T_n = 2 \times T_p$

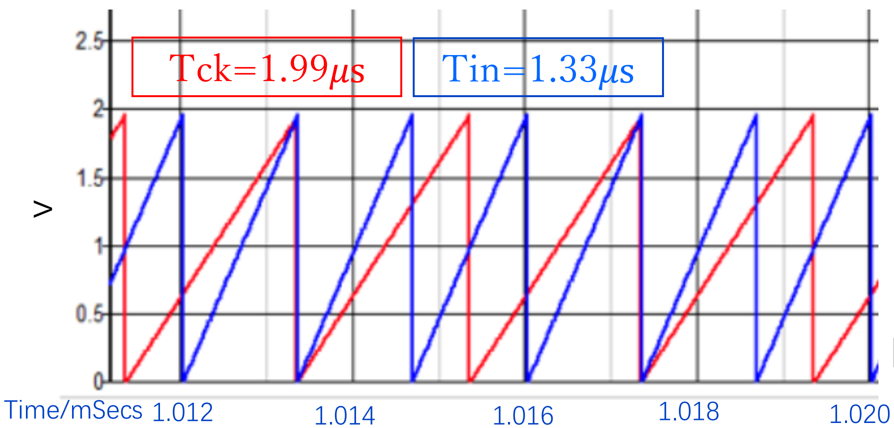


Automatic generation of Pulse-H and Pulse-L



Simulation Waveforms of W_H, W_L Generation

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



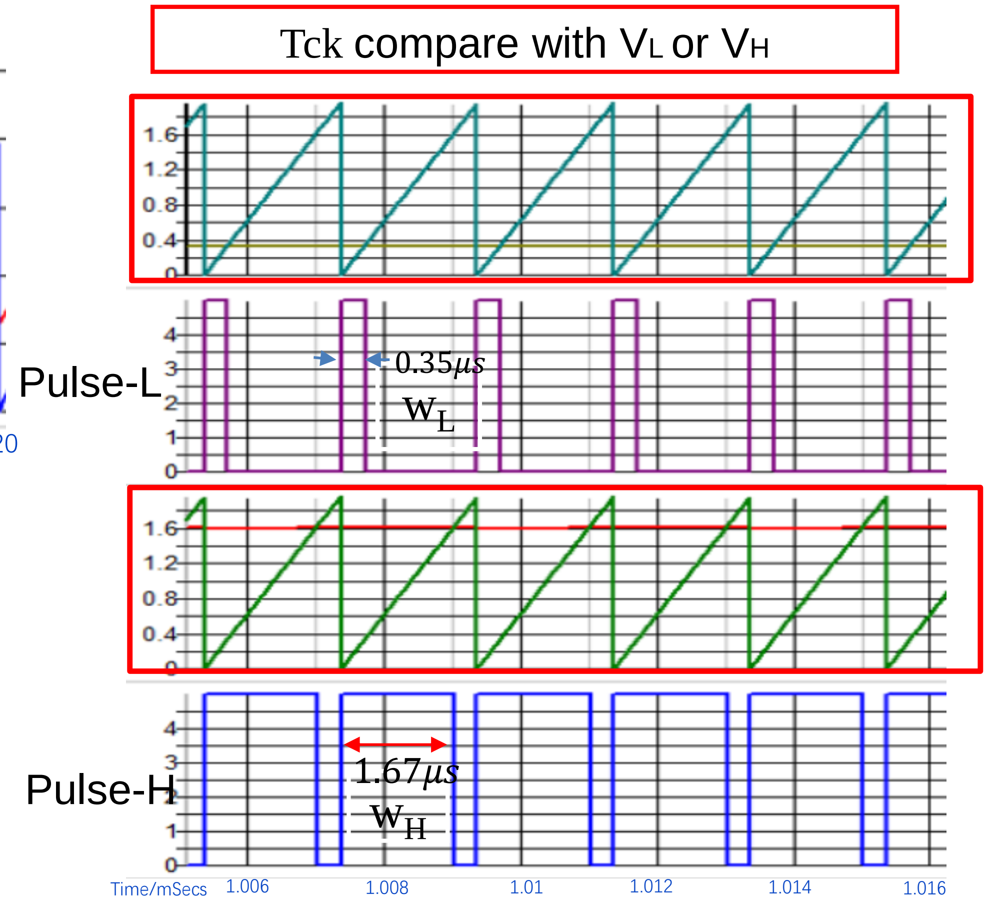
Simulation waveform of Tck and Tin

Theoretical formula

$W_H = 1.66\mu s$
$W_L = 0.34\mu s$

Experimental result

$W_H = 1.67\mu s$
$W_L = 0.35\mu s$



Simulation waveform of W_H and W_L

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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

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

◎ Condition

Buck DC-DC converter

V_{in} ：10V

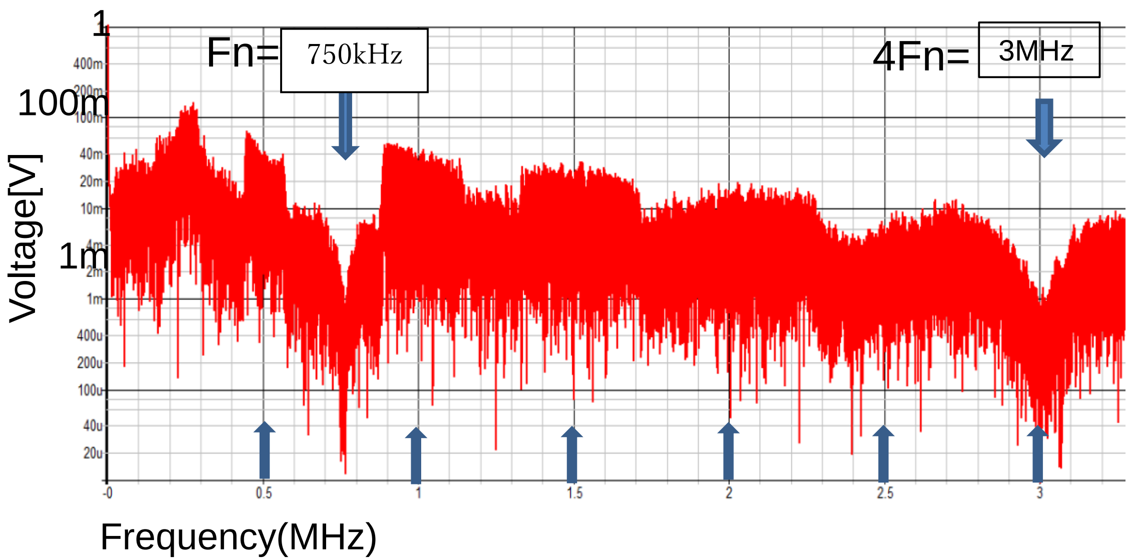
V_{out} ：5V

L ：200 μ H

C ：470 μ F

I_{out} ：0.25A

F_{in} ：750kHz



Simulated spectrum with EMI reduction

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

Simulated Noise Spectrum of PWM Signal Case 2

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

Case 2 : Fin=1.25MHz , N=2

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

◎ Condition

Buck DC-DC converter

V_{in} ：10V

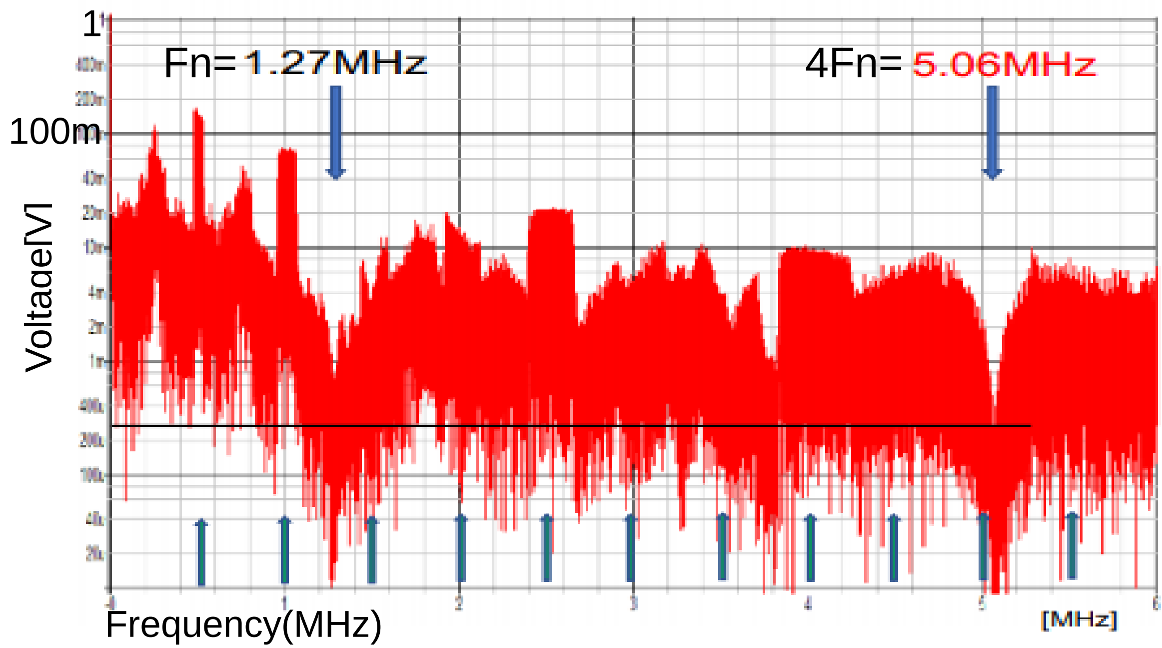
V_{out} ：5V

L ：200 μ H

C ：470 μ F

I_{out} ：0.25A

F_{in} ：1.25MHz



Simulated spectrum with EMI reduction

Transient Response with F_{in} Change

◎ Condition

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

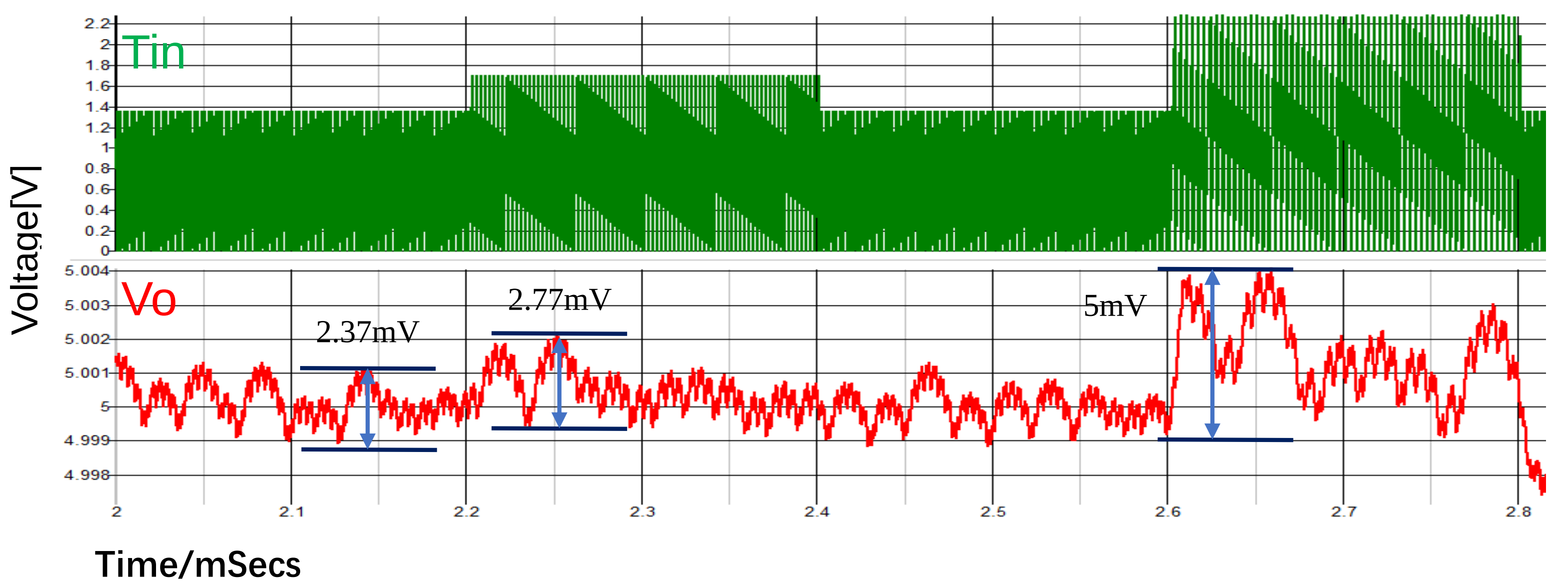
$F_{in} = 1.25\text{MHz} \Rightarrow F_{in} = 750kHz$

Settling Time $\approx 0\mu s$

◎ Output stability

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

Overshoot : $5mV$



Transient response with Fin change

Response speed when tuning or switching communication channels

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Discussion about Do

- When Vin=17v, Vout=5v, Fin=750kHz situation
- $D_o = \frac{V_{out}}{V_{in}} = 0.3$ ⇨ $W_H = 0.3T_{ck} + 0.5T_{in}$
  $W_L = 0.3T_{ck} - 0.5T_{in}$
- When N=1 ⇨ $W_L = 0.3T_{ck} - 0.5T_{in} = -0.065$ NG

The relationship between the input frequency Fin and the static duty ratio Do

$T_{ck} = (N + 0.5) \times T_{in}$ $\quad T_{ck} > W_{H,L} = (N + 0.5)T_{in}D_o \pm 0.5T_{in} > 0$

$$\therefore 2N \cdot \frac{T_{in}}{(2N+1)} > D_o > \frac{T_{in}}{(2N+1)}$$

When N=1, $\frac{1}{3} < D_o < \frac{2}{3}$

N=2, $\frac{1}{5} < D_o < \frac{4}{5}$

Processing Method in Do<$\frac{1}{3}$ or Do>$\frac{2}{3}$ Situation

When Vin=17v, Vout=5v, Fin=750kHz, PWC situation

D_o=0.3

Theoretical formula

$$W_H = \ \ 0.7T_{ck}$$

$$W_L = -0.1T_{ck}$$

$0\mu s$

Duty of select pulse

50%

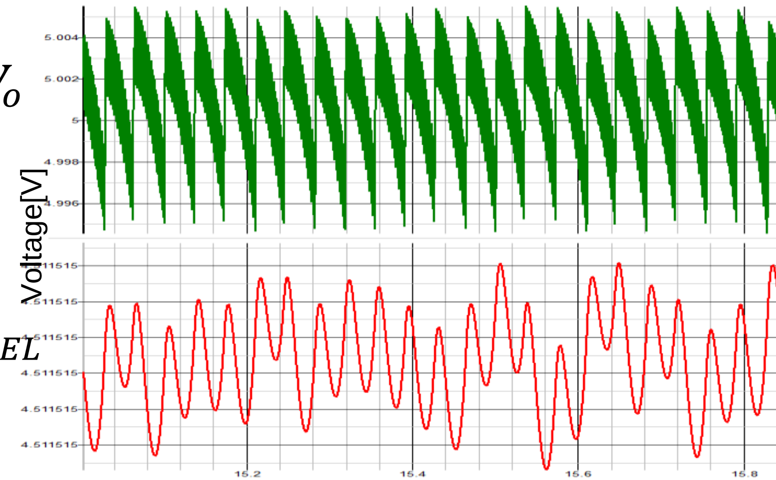
42.86%

The ripple of Vo will be change?

ΔV_o is a little bigger

V_o

V_{SEL}



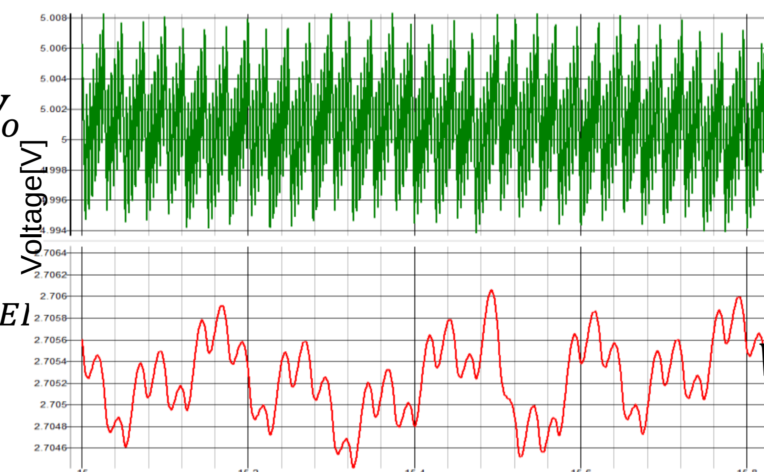
ΔV_o=10mV

$V_{SEL} = 4.51V$

The duty of select signal is 50% situation

V_o

V_{SEL}



ΔV_o=14mV

$V_{SEL} = 2.70V$

The duty of select signal is 42.86% situation

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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

Create notch characteristics occurred around F_{in}

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

Discussion about Do

Future Work

- Automatic notch generation using complex pulse coding

PWPC: PWC(Pulse Width Coding)+PPC(Pulse Phase Coding)

PWC: $F_n = \frac{1}{T_H - T_L}$ PPC: $F_n = \frac{1}{2(T_H - T_L)}$

- Notch generation using PCC(Pulse Cycle Coding) method

- Investigate why the large notch at 4Fn appear.

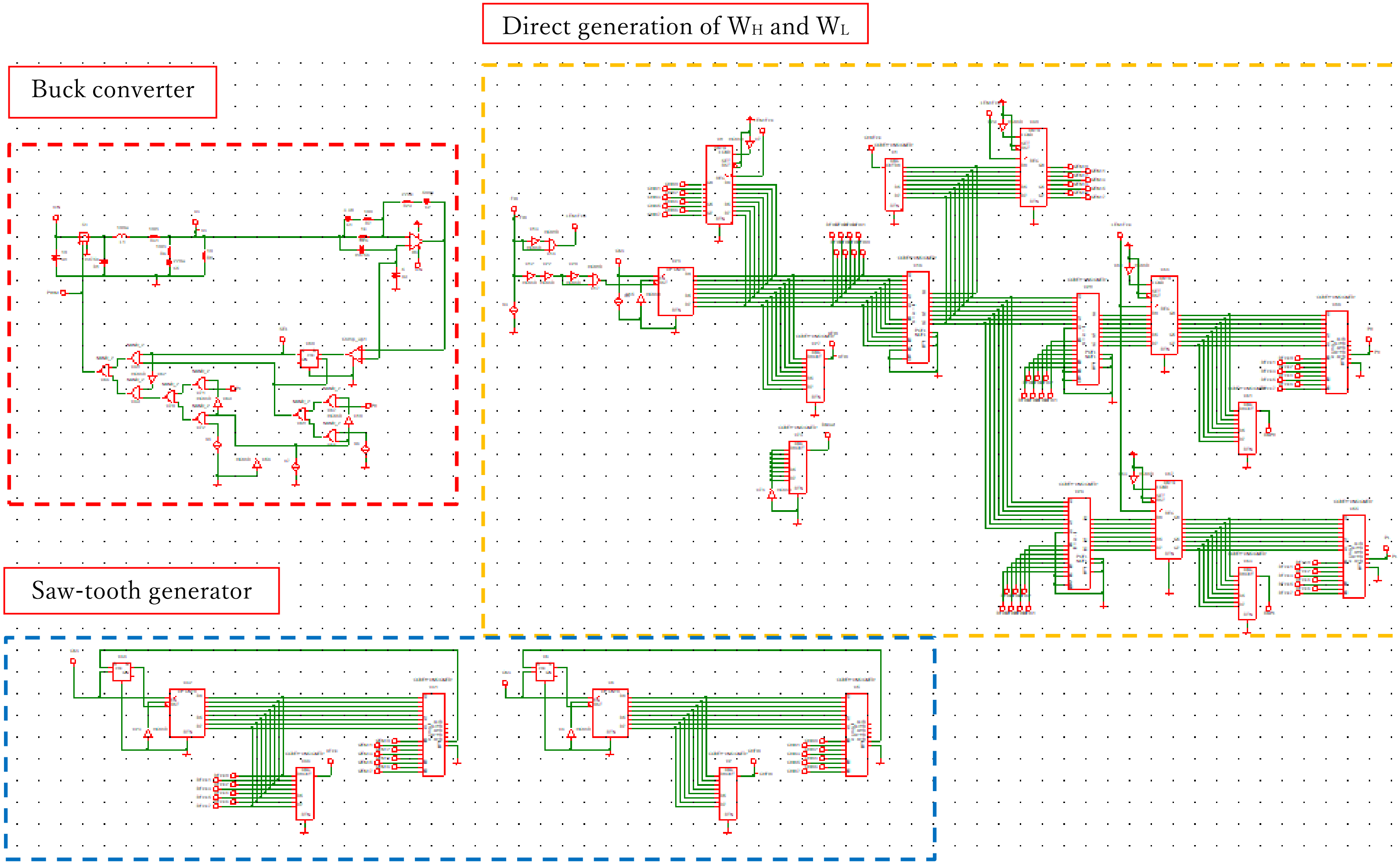
Thank you for Listening

Q&A

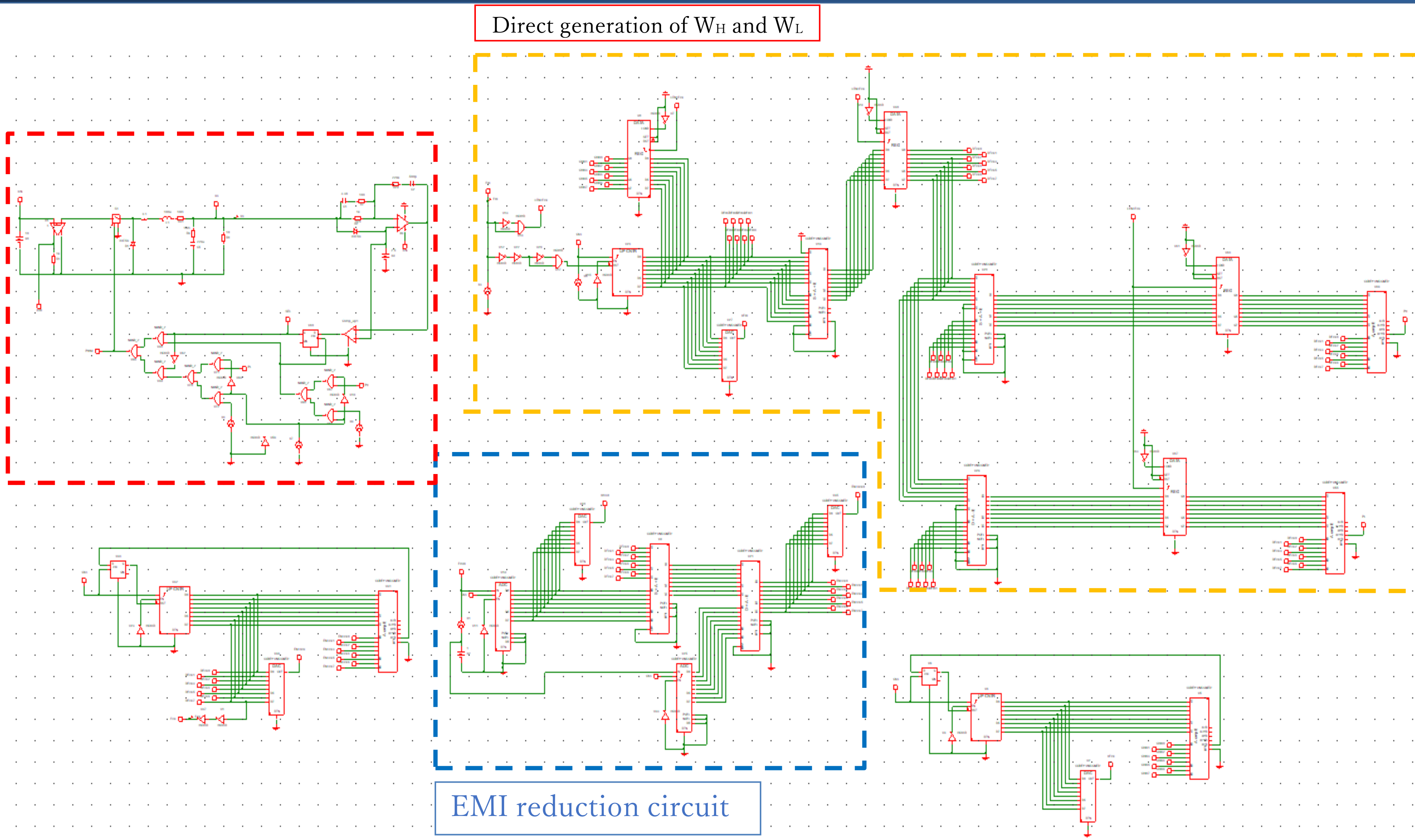
Q1: Does the efficiency of the power supply change by pulse coding?
A:Only coding the PWM signal of the power stage, Since its frequency and average pulse width are the same, the efficiency does not change.

Q2: Can this coding method and calculation formula be applied to other control methods?
A:It can be applied similarly in the control method that can perform PWM modulation.

Automatic Notch Generation using Direct method（N=1)

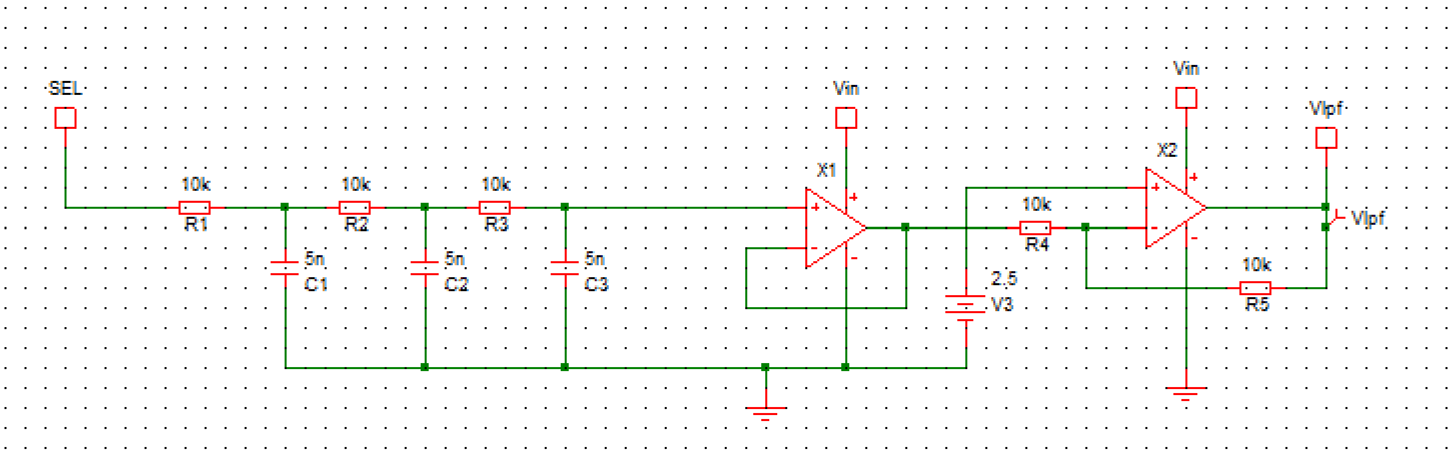


Automatic Notch Generation using Direct method with EMI Reduction (N=2)



Processing Method in Do<$\frac{1}{3}$ or Do>$\frac{2}{3}$ Situation

- D_o = 0.3
  W_L is set to 0, design W_H only
- Simulation about the V_{SEL}



Application of Automatic Generation of 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

Frequency band where noise does not spread

Goal

↓

Automatic generation of notch frequency

↓

It is possible to greatly reduce influence on other electronic devices

DC-DC converter

Radio receiver

Set frequency of radio reception

↓

Auto correspond to Fin change is necessary