Pulse Coding Control Switching Converter with Adjustable Conversion Voltage Ratio Notch Frequency Generation in Noise Spectrum

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OUTLINE

- Introduction & Objective
- Pulse Coding Method in Switching Converter
- Automatic Notch Frequency Generation with Pulse Width Coding (PWC) Control
- Conversion Voltage Ratio Analysis
- Conclusion and future work

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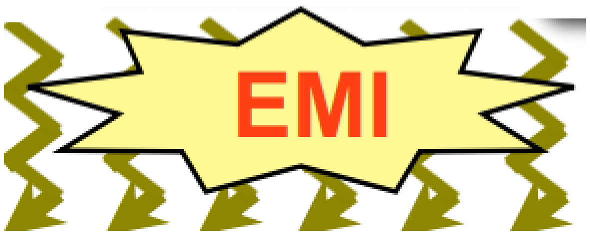
Research Background



Electronic circuits

High density and complication

Problem

Large EMI[1] noise

Focus

EMI reduction ⇒ spread noise spectrum

Task

Clock modulation ⇒ diffusion clock noise

[1] EMI: Electro-Magnetic Interference

Research Objective

Research Objective

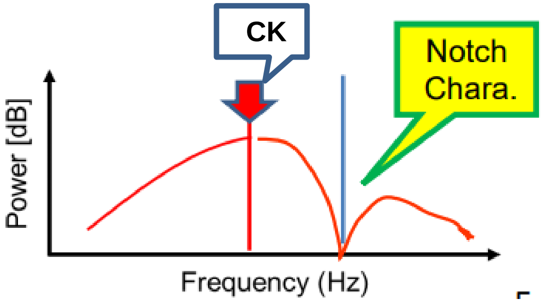
Spread spectrum : EMI reduction & Noise diffusion

Further more

Full automatic notch frequency generation noise suppression near receive frequency

Proposed method

Pulse coding method



Design modulation circuit & Conversion voltage ratio analysis
⇒ generate notch frequency automatically

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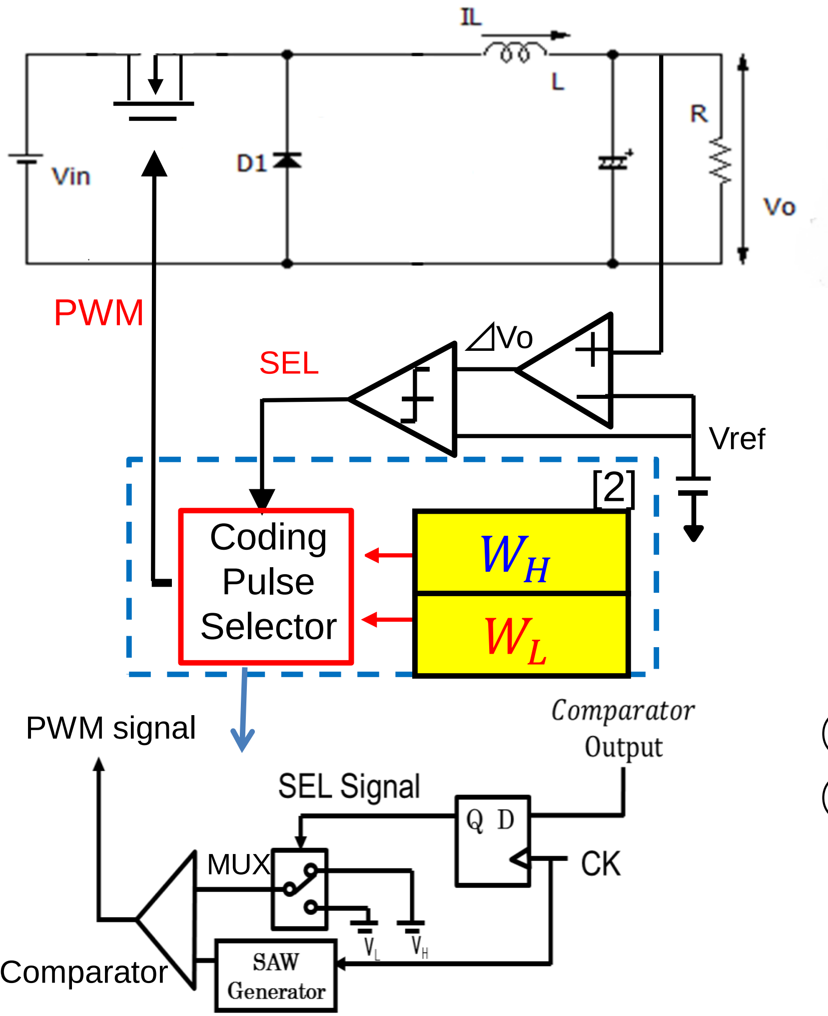
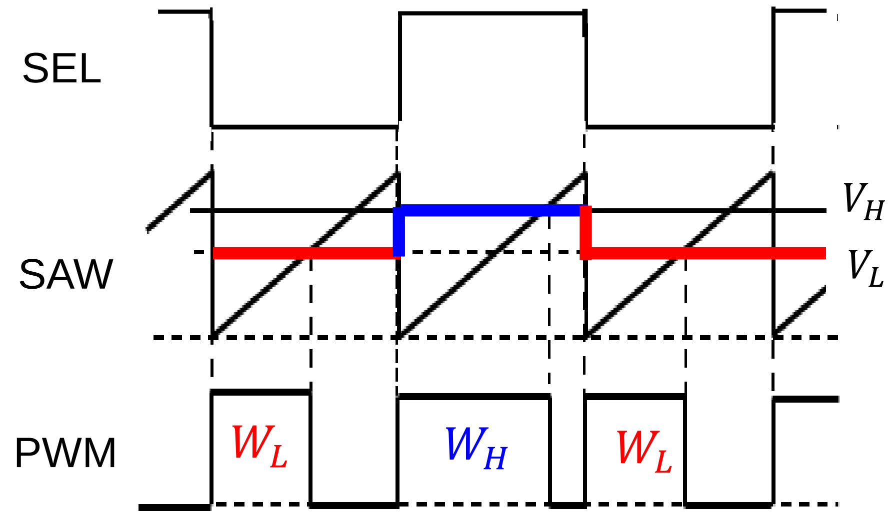
Pulse Width Coding in Switching Converter



8-1 Switching converter with PWC control



8-2 Timing chart of PWM signal

SEL High

① MUX select V_H
② Generate pulse with wide width in comparator

SEL Low

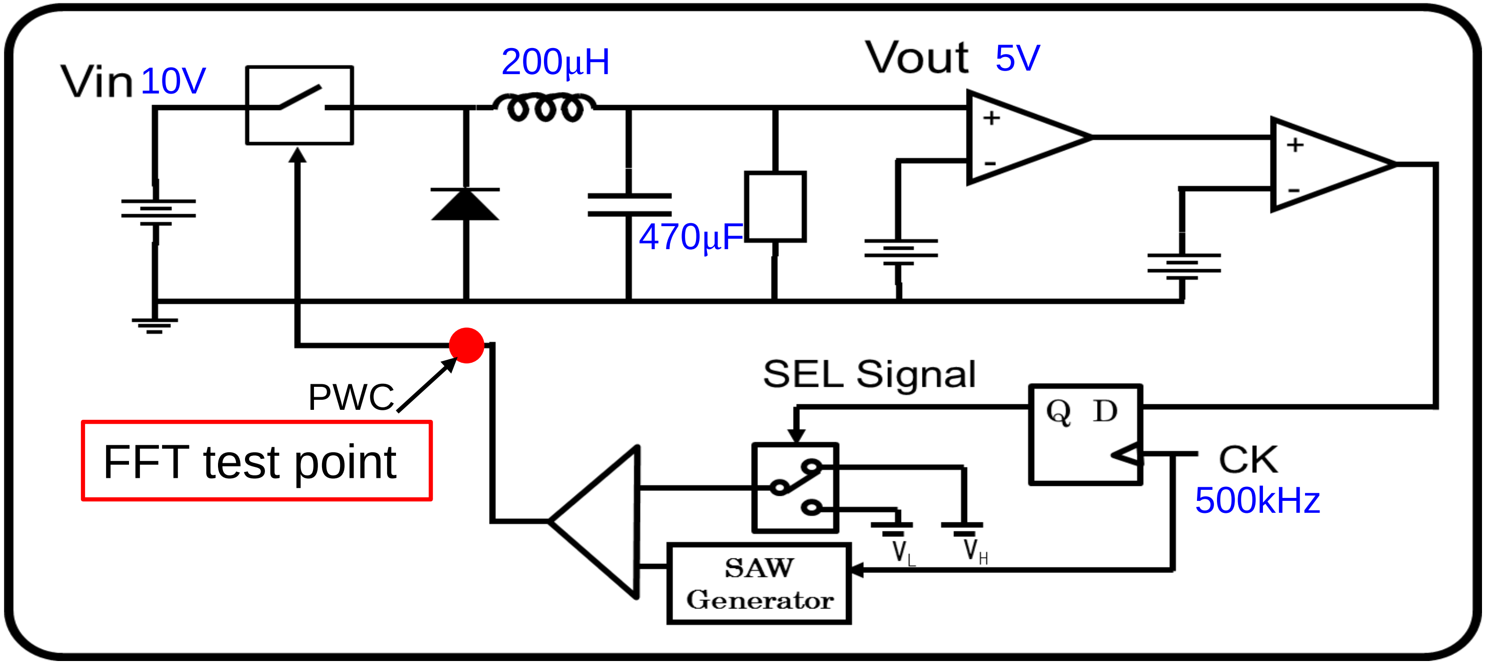
① MUX select V_L
② Generate pulse with narrow width in comparator

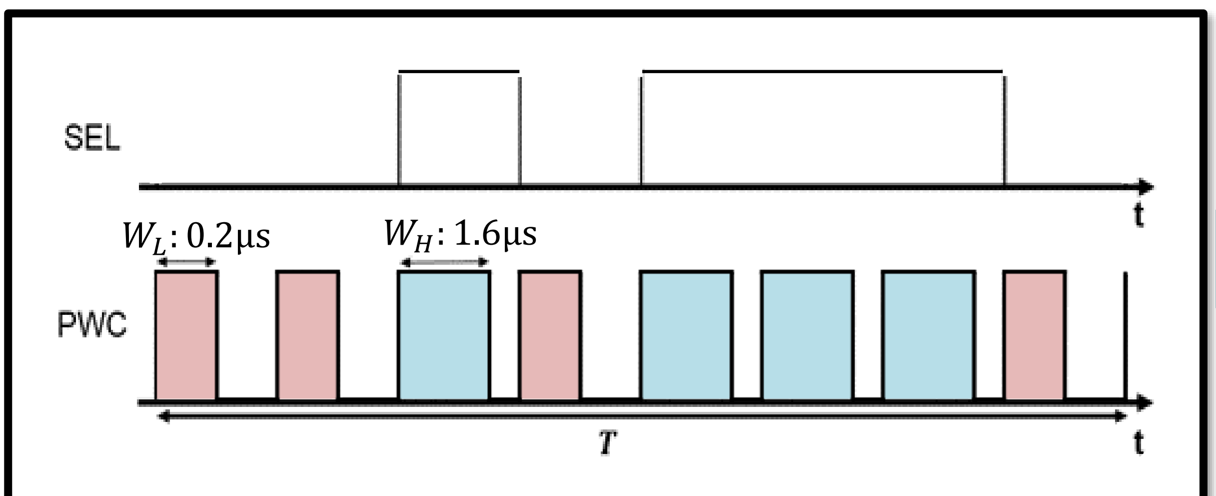
[2] W_H: Wide width of PWM signal (High duty ratio)
W_L: Narrow width of PWM signal (Low duty ratio)

★ $D_H > D_o > D_L$

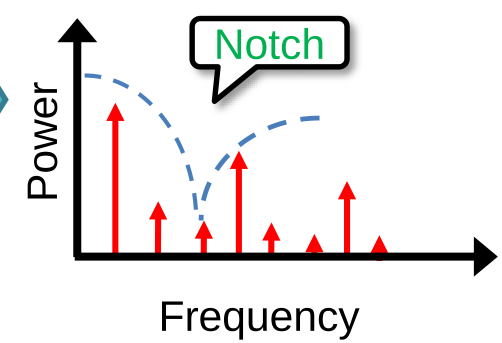
$$D_o = V_o / V_{in}$$

Simulation Condition



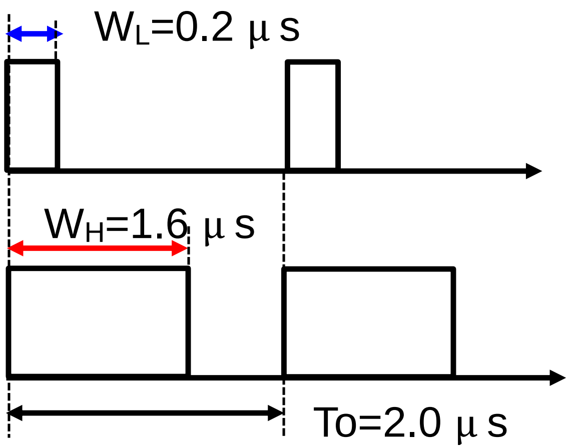


Spectrum of PWC signal



Simulation Result with PWC Control

Design clock pulse to determine the notch frequency F_n

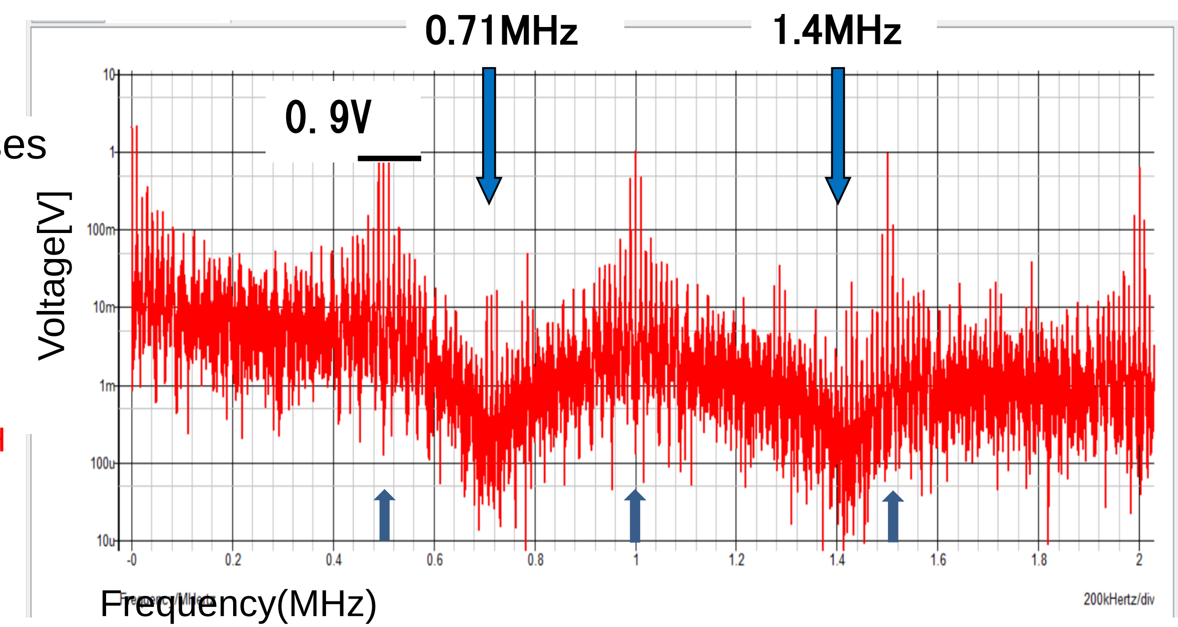


10-1 Pulse widths of the coding pulses

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

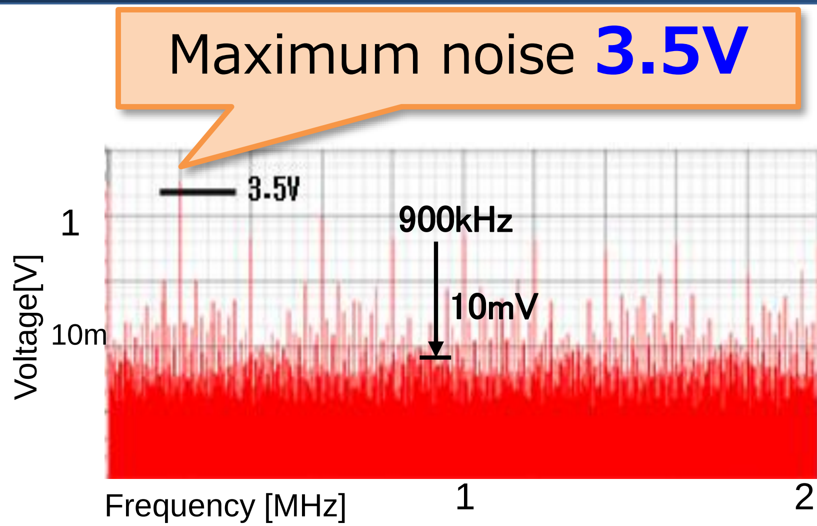
$$= N \times \frac{1}{1.6\mu s - 0.2\mu s} = 0.71\mathbf{MHz}$$

★manually set W_L and W_H (without feedback)

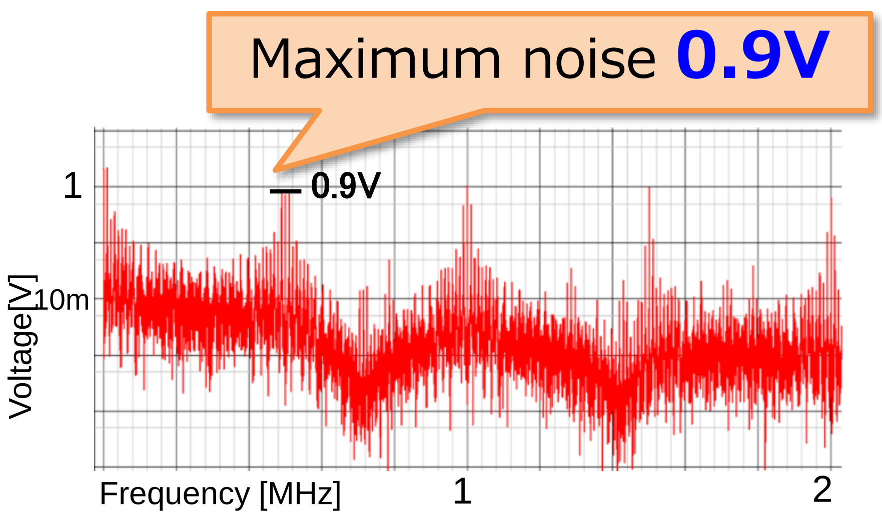


10-2 PWM signal spectrum using PWC control

Spread Spectrum for EMI Reduction



11-1 PWM signal spectrum without EMI reduction



11-2 PWM signal spectrum using PWC control

◎Simulation conditions (without EMI reduction)

Input : 10V
Output : 5V
Clock frequency : 200kHz

Without EMI reduction

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

With EMI reduction

- Peak level ⇒ reduced a lot
- Noise : diffusion
- Notch created

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Research Application

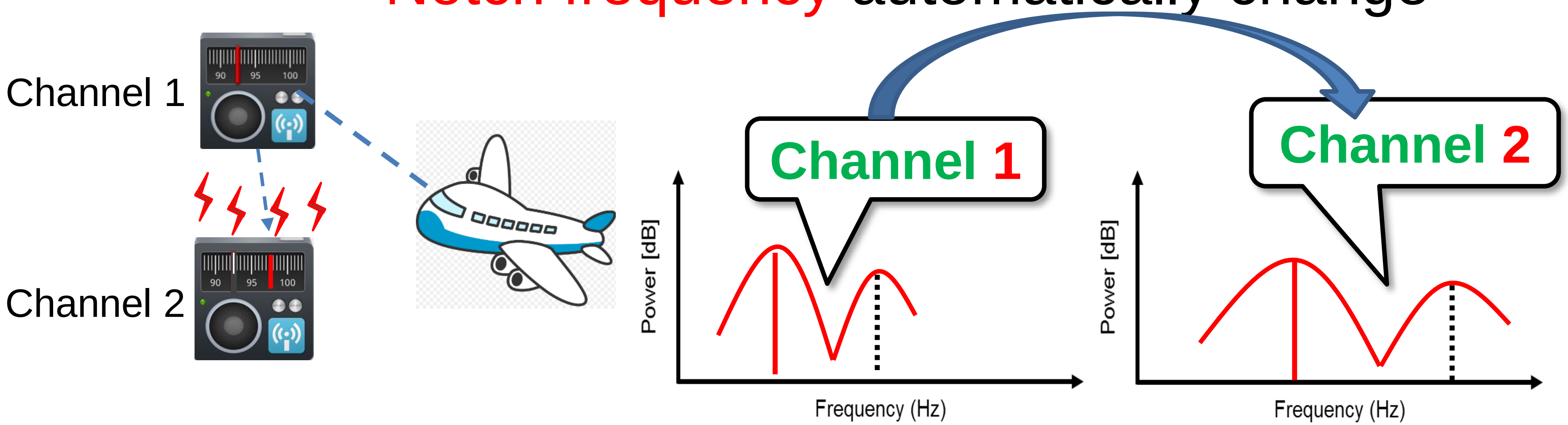
Information equipment switching power supply

feature

① Receiving weak radio waves

② Noise near receive frequency
⇒ automatically removed

③ Receive frequency change
⇒ Notch frequency automatically change



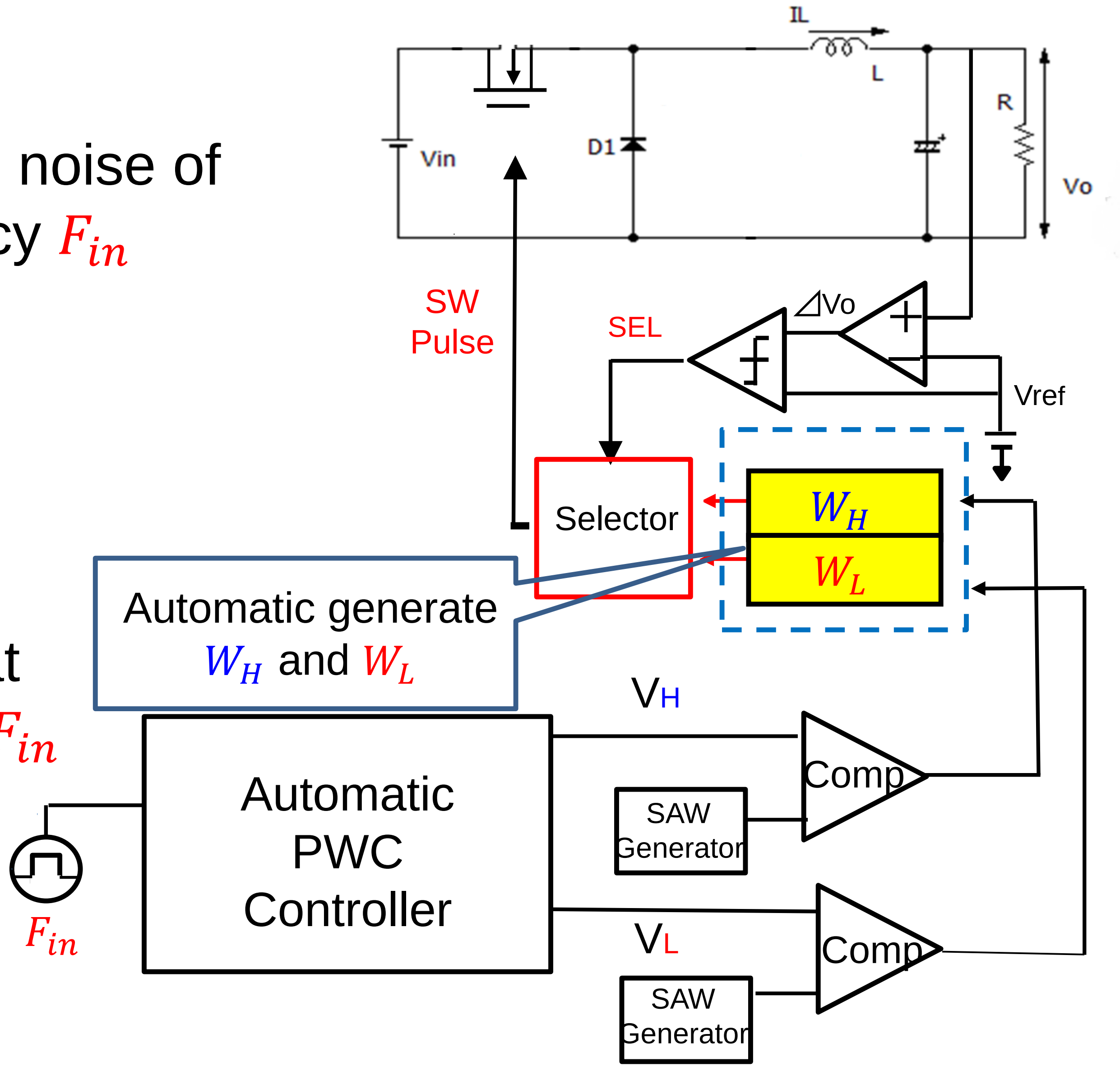
Automatic PWC Controller

Objective

Reduction generate noise of receive frequency F_{in}

Method

PWC control generate notch at receive frequency F_{in}



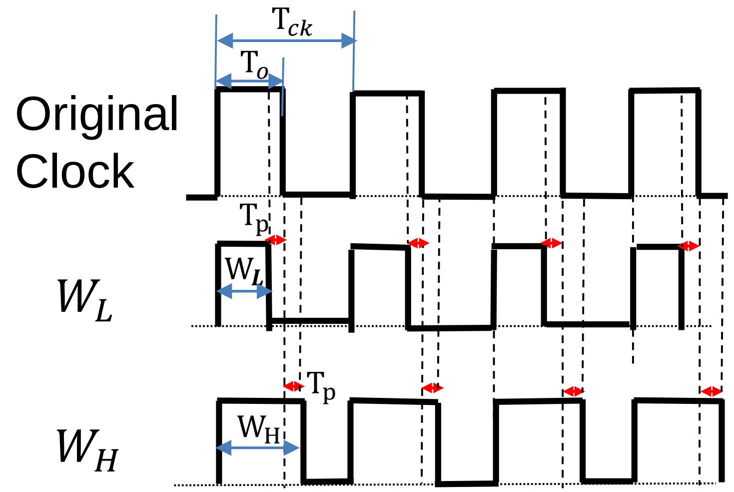
PWC Pulse with Clock Frequency F_{ck} and Notch Frequency F_n

The relationship between F_n and F_{ck}

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

Optimal

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



14-1 Timing chart of PWM signal

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

Automatic Pulse Generation

Generate T_{ck} from T_{in} using

F_{in}=(N+0.5) ・F_{ck}

T_{ck}=(N+0.5) ・T_{in}

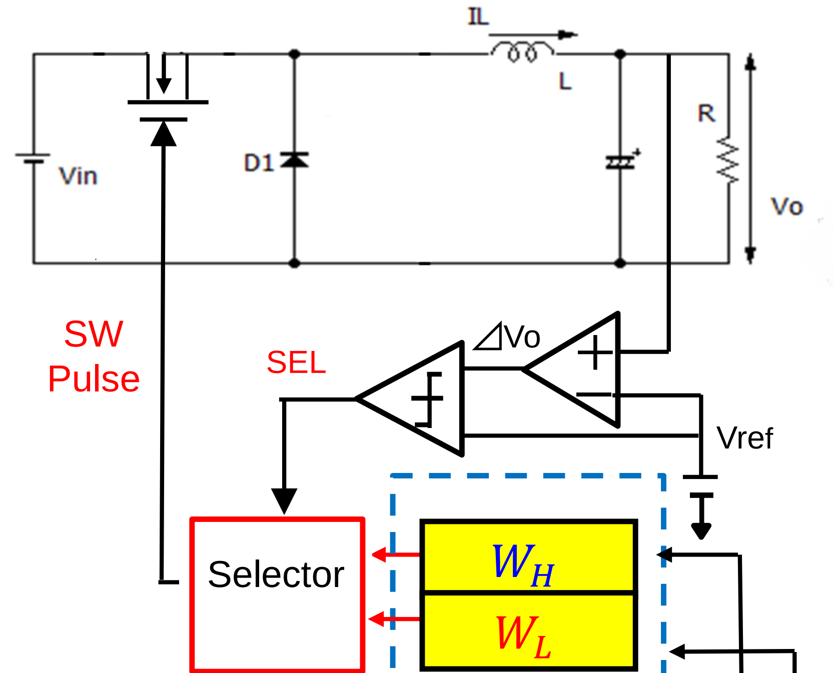
$$W_L = T_o - T_p = D_o \times T_{ck} - \frac{1}{2} T_{in}$$

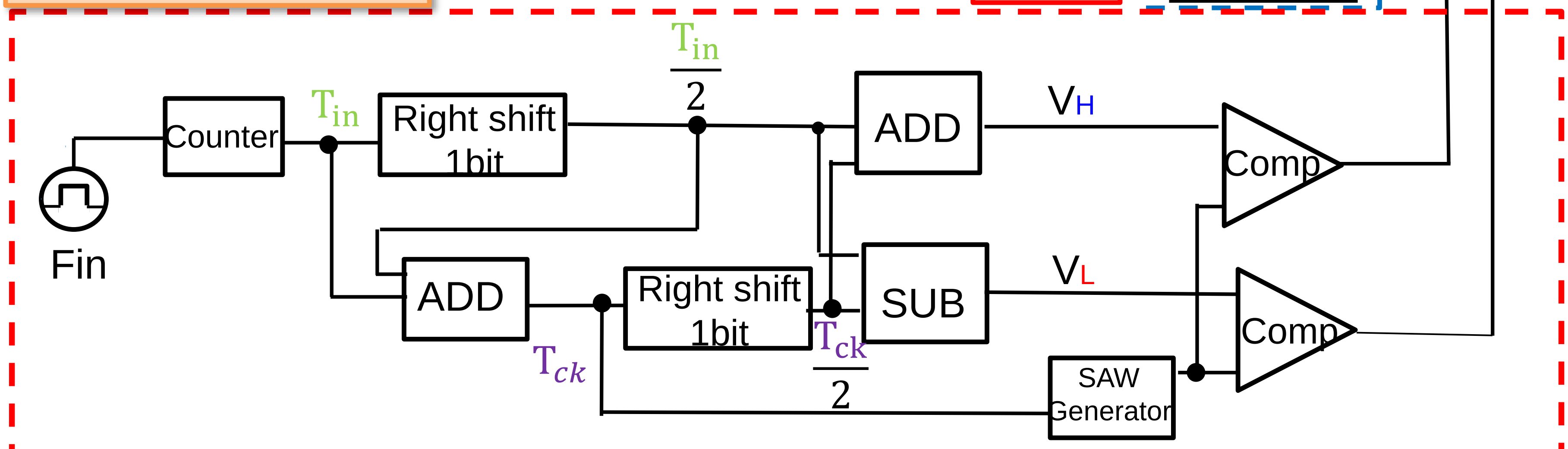
$$W_H = T_o + T_p = D_o \times T_{ck} + \frac{1}{2} T_{in}$$

$$T_n = 2 \times T_p$$

D_o set to 0.5

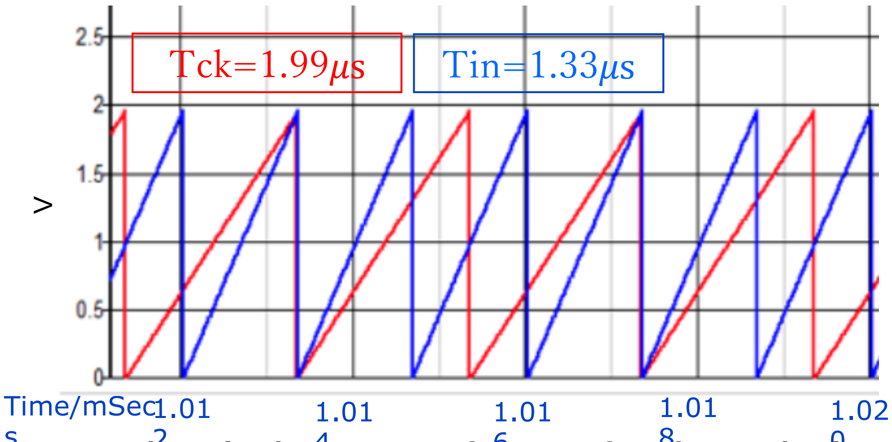
N=1 situation





Simulation Waveforms of W_H, W_L Generation

$F_{in} = 750kHz$ ⇨ Automatic generated $F_{ck} = 500kHz$



16-1 Simulation waveform of Tck and Tin

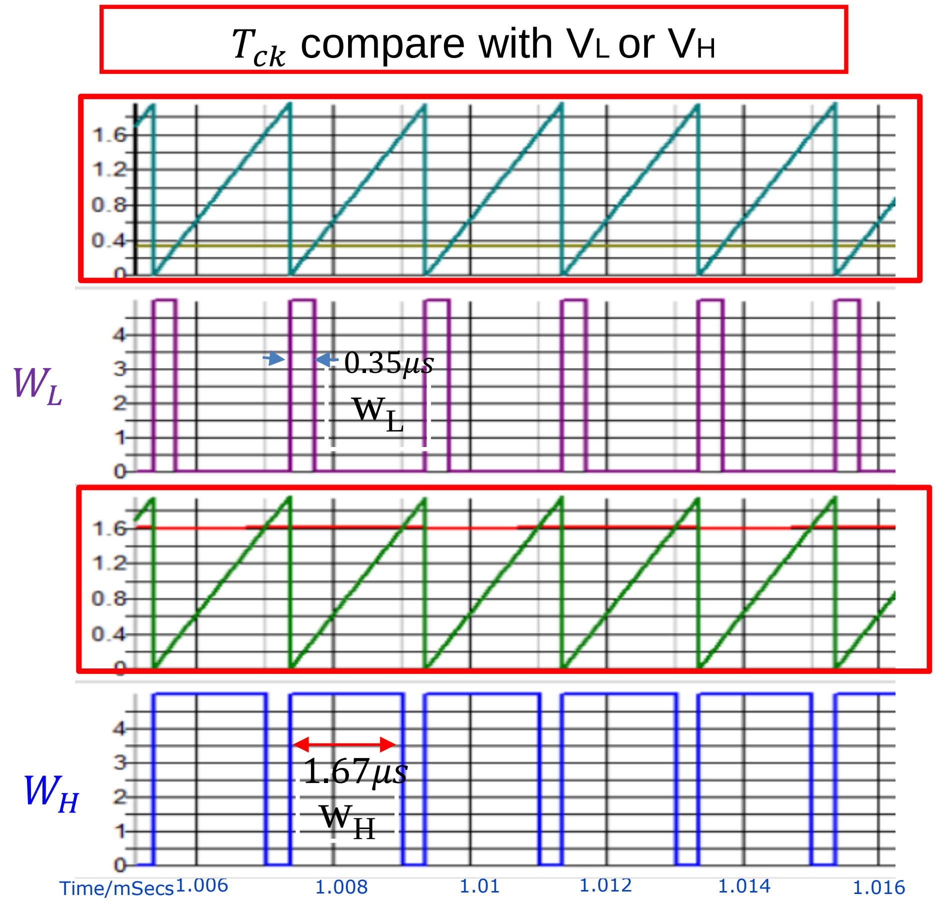
Theoretical formula

$W_H = 1.66\mu s$
$W_L = 0.26\mu s$

Experimental result

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

Well matched



16-2 Simulation waveform of W_H and W_L

Noise Spectrum of PWC Signal

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

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

Fin=750kHz ⇒Fck=500kHz （ W_H=1.66μs, W_L=0.26μs）

◎Condition

Buck DC-DC converter

V_{in} ：10V

V_{out} ：5.0V

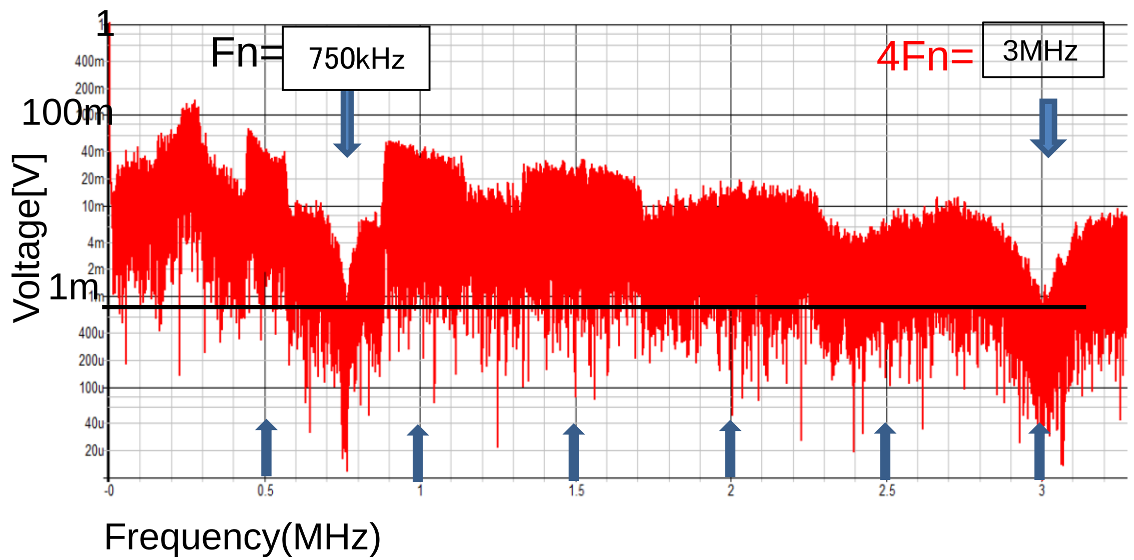
L ：200 μ H

C ：470 μ F

I_{out} ：0.25A

◎Result

Fn=750kHz



17-1 Simulated spectrum with EMI reduction

Assume to suppress influence on AM in 750kHz

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

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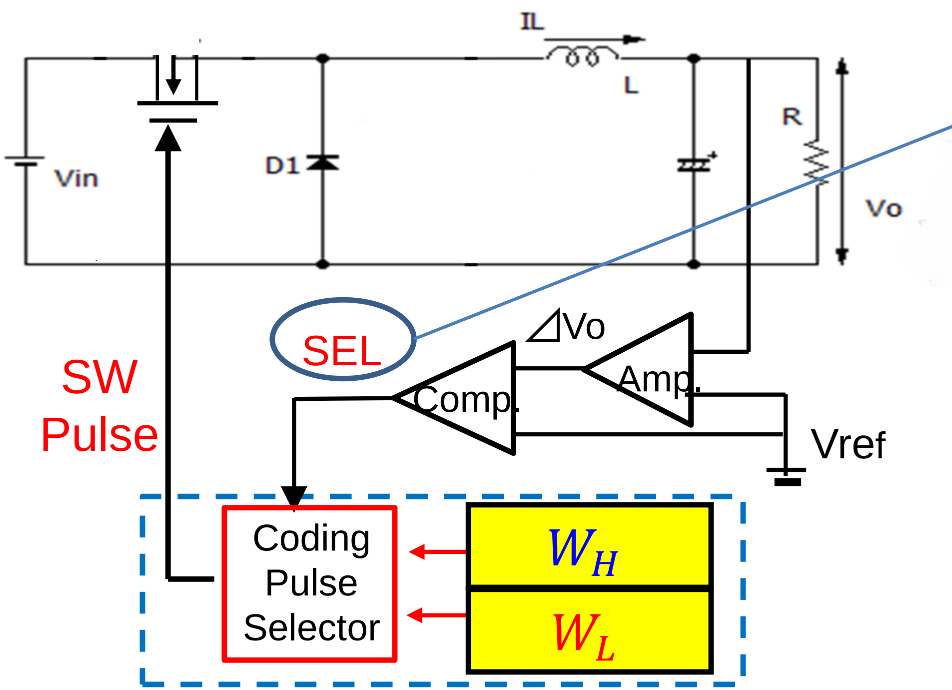
Necessity of Conversion Voltage Ratio Analysis

- Conversion voltage ratio : $D_o = \frac{V_o}{V_i}$
- Duty of SEL signal (high and low ratio) : D_s
- In ideal condition (D_o not shift)

$$W_H: (D_o + D_H)\, T_{ck} = D_o T_{ck} + \frac{T_{in}}{2} = (D_o + \tfrac{1}{3})T_{ck}$$

$$W_L: (D_o - D_L)\, T_{ck} = D_o T_{ck} - \frac{T_{in}}{2} = (D_o - \tfrac{1}{3})T_{ck}$$

($D_H = D_L = D_P$: shift value of D_o)



When D_o is accurate

Duty of SEL signal D_s will be balance ⇒0.5

Average voltage of SEL signal will be $\frac{V_{cc}}{2}$

When D_o shift

Duty of SEL signal D_s will be affected

Influence: output voltage ripple

Influence of Input Voltage Change

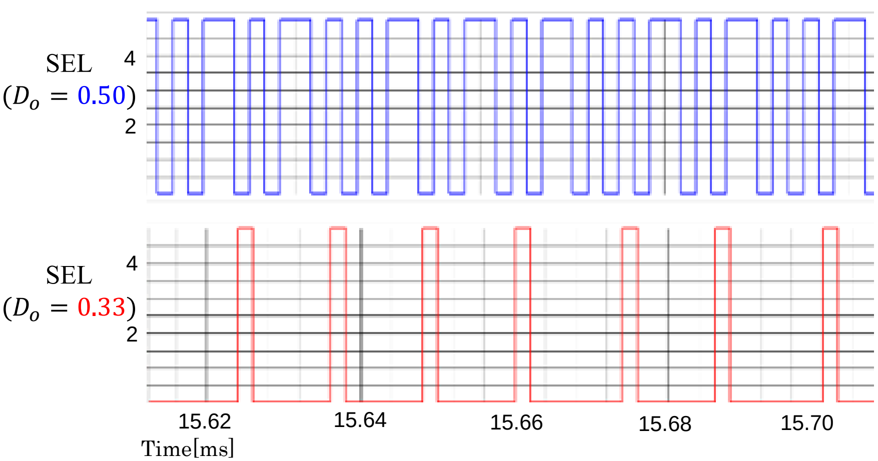
$$D_o = \frac{V_o}{V_i}$$ ⇒ Change Vi = 10V / 15V / 18V ⇒

$$D_{o1} = \frac{V_o}{V_i} = \frac{5}{10} = 0.5$$

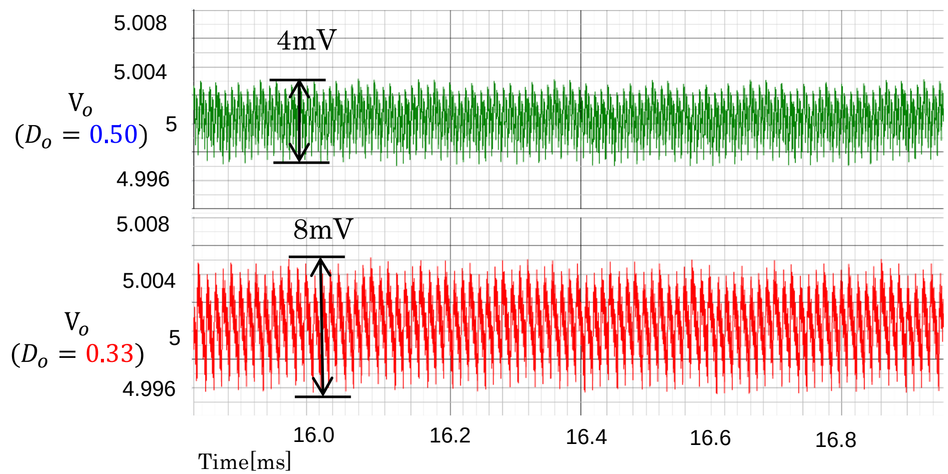
$$D_{o2} = \frac{V_o}{V_i} = \frac{5}{15} = 0.33$$

⇒

$$D_{o3} = \frac{V_o}{V_i} = \frac{5}{18} = 0.28$$



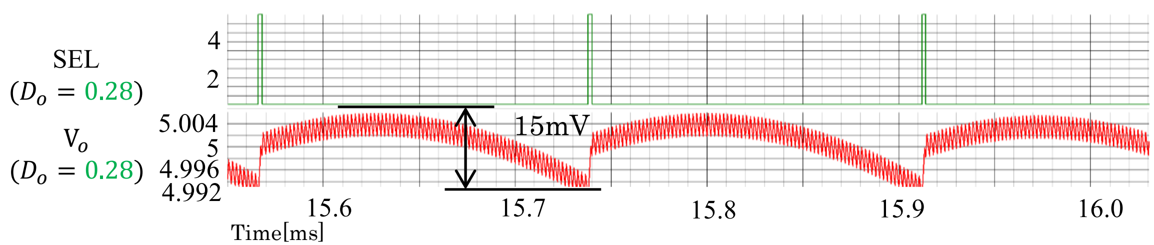
21-1 Waveforms of select signal



21-2 Change of output ripple

★ D_o shift⇒output voltage ripple effected & become bigger

Ex. D_{o3}=0.28
⊿Vo= 15mVpp



21-3 Change of output ripple($D_o = 0.28$)

D_o Setting Method

The relationship between T_{in} and D_o （N=1）

$$W_H：D_oT_{ck} + \frac{T_{in}}{2} < T_{ck}$$

$$W_L：D_oT_{ck} - \frac{T_{in}}{2} > 0$$

$$T_{ck} = 1.5T_{in}$$

$$\Rightarrow 0.33 < D_o < 0.67$$

Consider about:

$$D_{o3} = \frac{V_o}{V_i} = \frac{5}{18} = 0.28 \Rightarrow \begin{cases} W_H = T_{in} \\ W_L = 0 \end{cases}$$

$$(W_H - W_L = T_{in})$$

$$D_{o4} = \frac{V_o}{V_i} = \frac{5}{7} = 0.71 \Rightarrow \begin{cases} W_H = 1 \\ W_L = 1 - T_{in} \end{cases}$$

This time:

F_{notch} shift, duty of SEL signal : D_s also shift → Ripple become bigger

What should we do when D_o smaller than 0.33 or bigger than 0.67?

Method of Ripple Reduce in D_o Setting

The relationship between T_{in} and D_o (N=2)

$$W_H: D_o T_{ck} + \frac{T_{in}}{2} = (D_o + \frac{1}{5}) T_{ck} < T_{ck}$$

$$W_L: D_o T_{ck} - \frac{T_{in}}{2} = (D_o - \frac{1}{5}) T_{ck} > 0$$

$$T_{ck} = 2.5 T_{in}$$

$$0.2 < D_o < 0.8$$

Early consider :

$$D_{o3} = \frac{V_o}{V_i} = \frac{5}{18} = 0.28$$

$$D_{o4} = \frac{V_o}{V_i} = \frac{5}{7} = 0.71$$

Simulation Result of PWM Signal When N=2

$$\mathrm{F}_{\mathrm{in}} = (N + 0.5)\mathrm{F}_{\mathrm{ck}} = 2.5\mathrm{F}_{\mathrm{ck}}$$

N=2　Best position : 2Fck ＜ Fn ＜ 3Fck

Fin=1.25MHz ⇒Fck=500kHz

◎Condition

Buck DC-DC converter

V_{in} ：10V

V_{out} ：2.5V

D=0.25

L：200μH

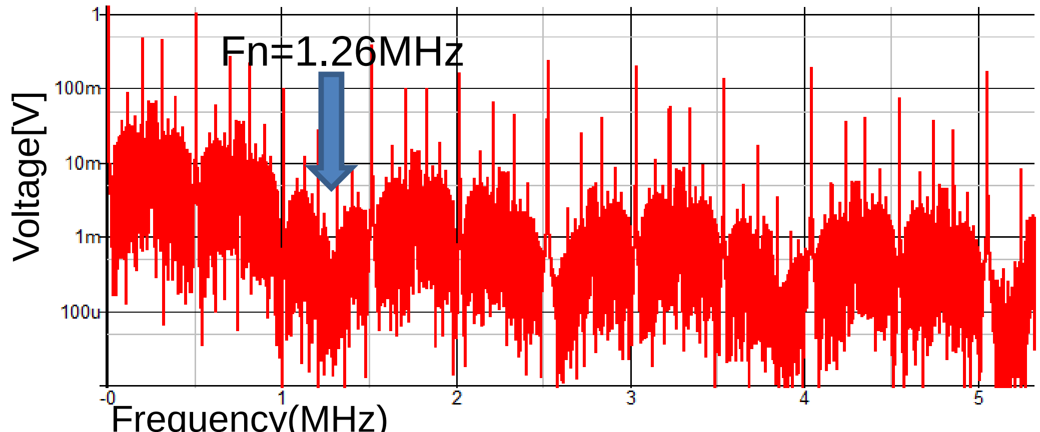
C：470μF

◎Result

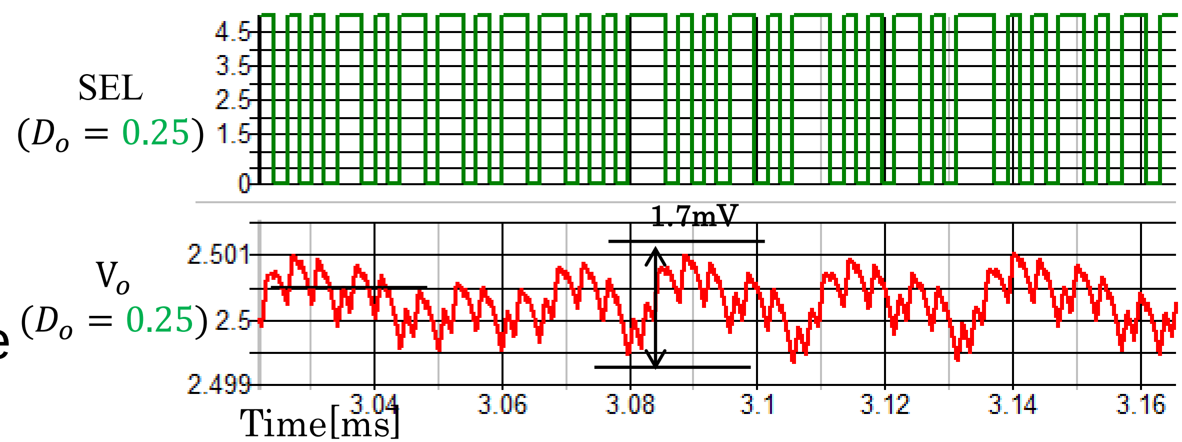
Fn=1.26MHz

Output ripple: 1.7mV

Duty of SEL signal: keep in balance



24-1 Simulated spectrum in N=2 situation



24-2 Waveforms of select signal and output ripple

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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}
- Conversion voltage ratio D_o analysis and the improvement of conversion rate is designed

Future work

- Implementation of automatic PWC control switching converter

Thank you for Listening