平成30年度　第9回　電気学会東京支部栃木・群馬支所　合同研究発表会
於　小山高専　2019年3月4日(月),5日(火)

Mar. 4　ETG-19-14　10:30-10:45

# Implementation Evaluation on Pulse Coding Controlled Switching Converter with Notch Frequency Generation in Noise Spectrum

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# OUTLINE

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

PWC: Pulse Width Coding

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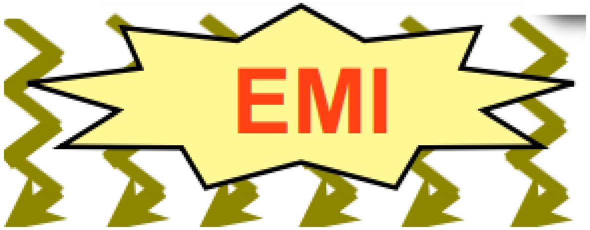
# Research Background




Electronic circuits

High density and complication

Problem

Large EMI noise

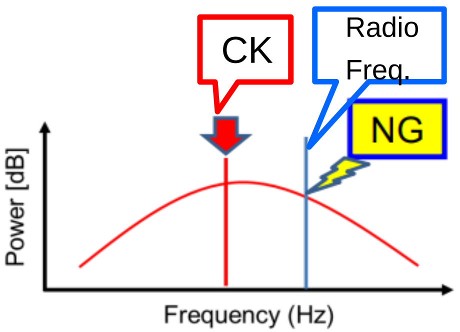
Focus

EMI reduction ⇒ spread noise spectrum

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

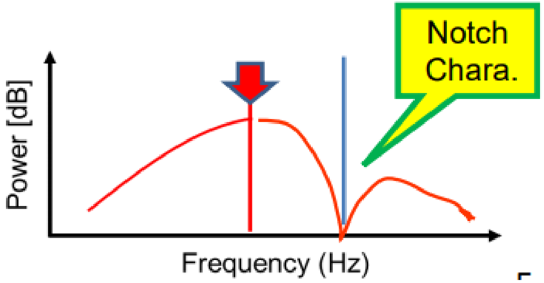
## Proposed method

Pulse coding method

⇓

Design modulation circuit
⇒ generate notch frequency automatically

## Achievement




① EMI reduction
② Noise removal
③ Automatic generation of $F_{notch}$
④ Implementation of PWC control switching converter

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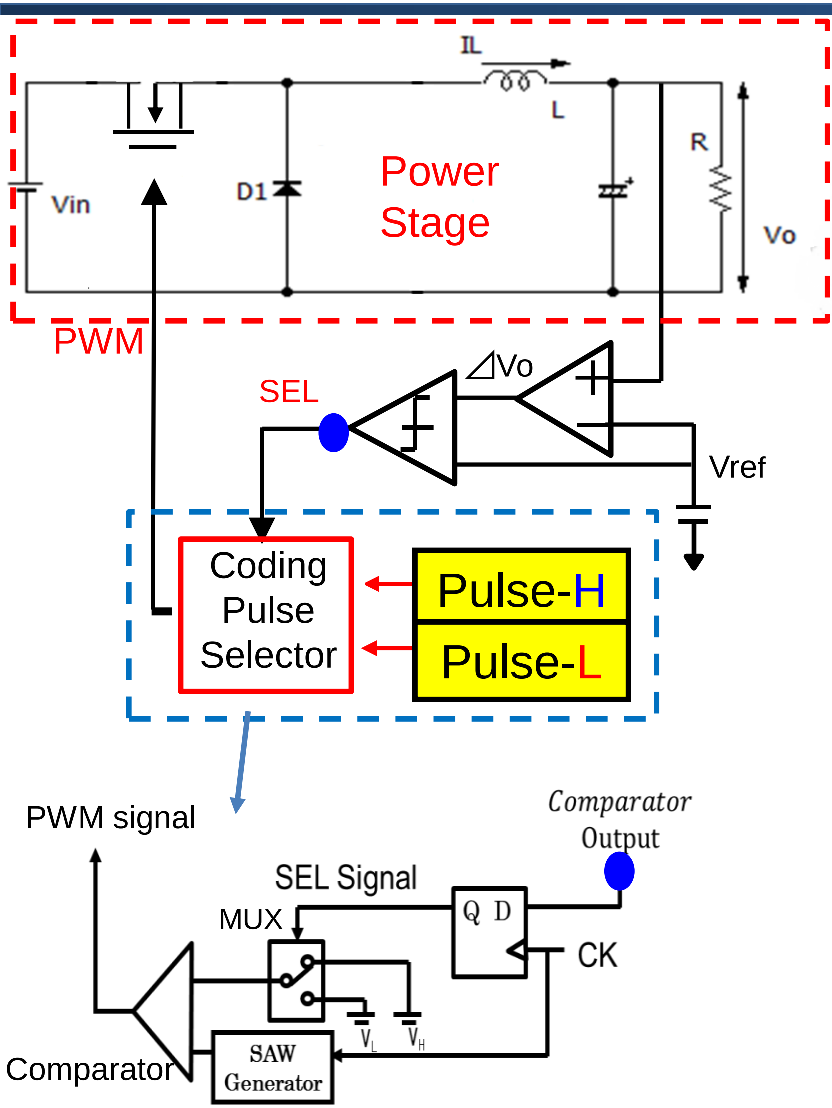
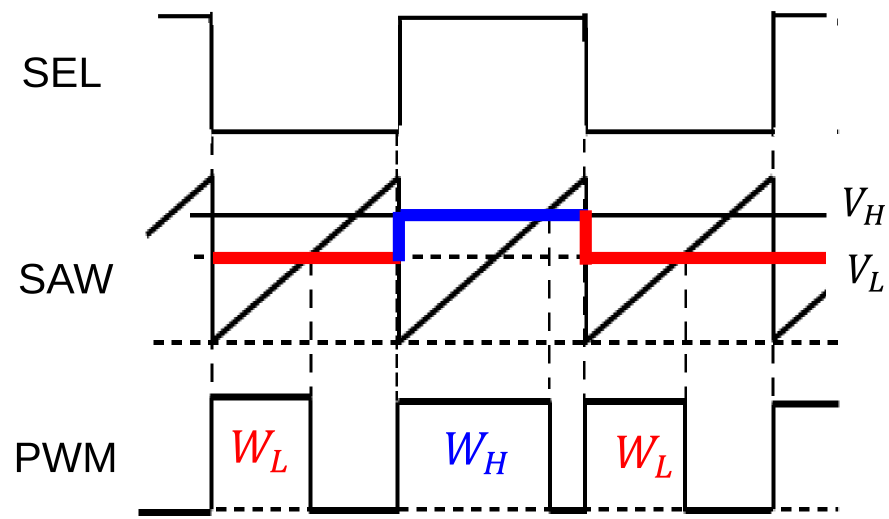
# Pulse Width Modulation in Switching Converter



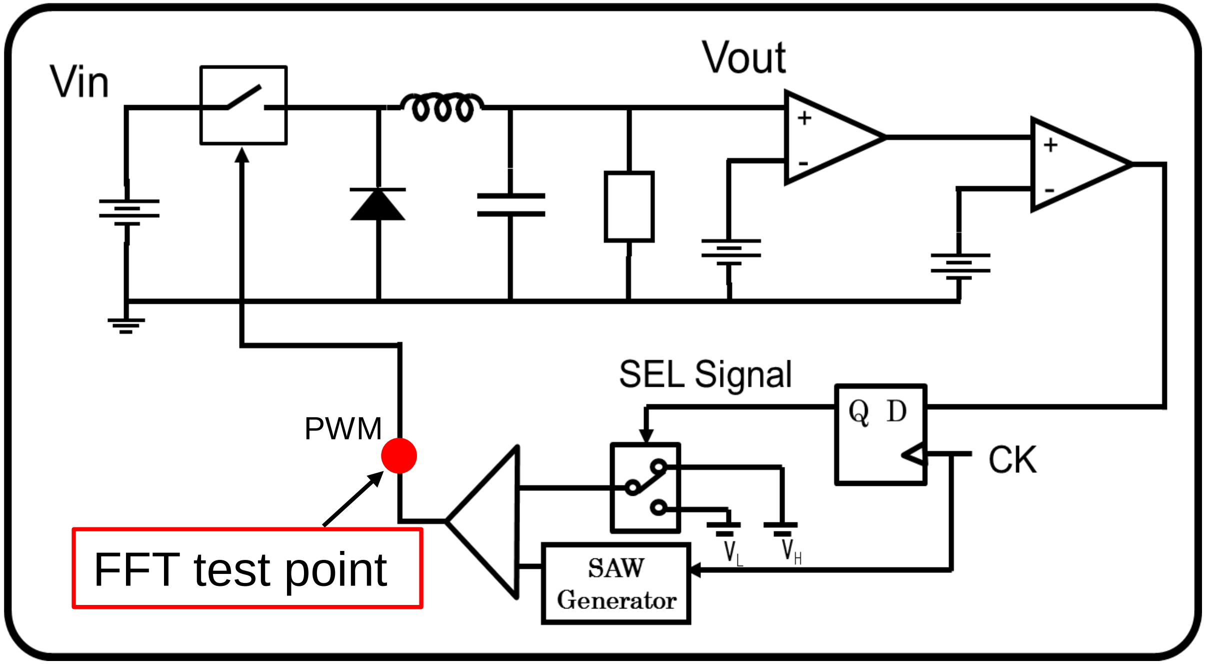

## Input High

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

# Simulation Condition




◎ Condition

Buck DC-DC converter

$V_{in}$ : 10V

$V_{out}$ : 5V

L : 200 μH

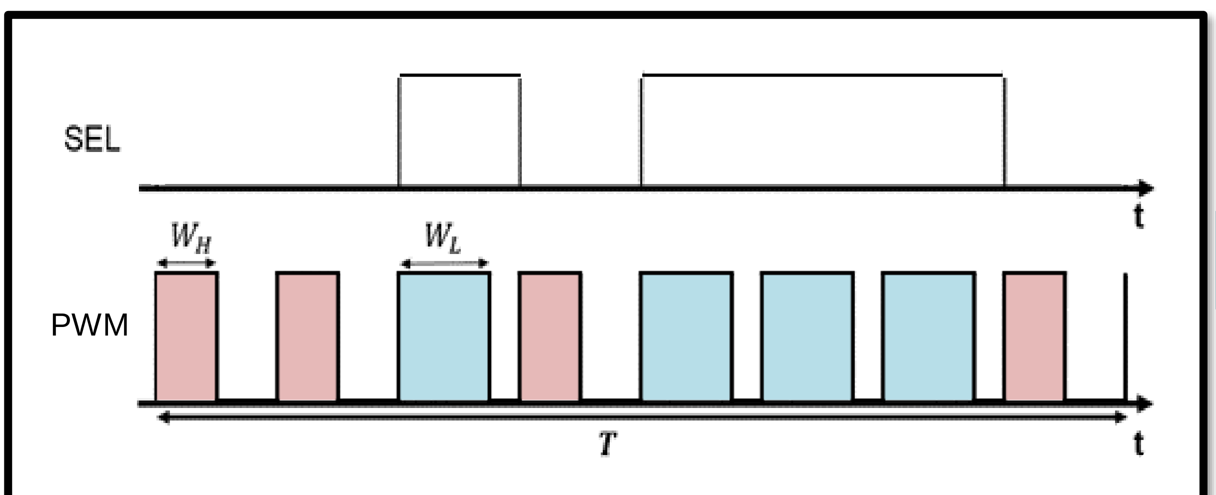
C : 470 μF

$I_{out}$ : 0.25A

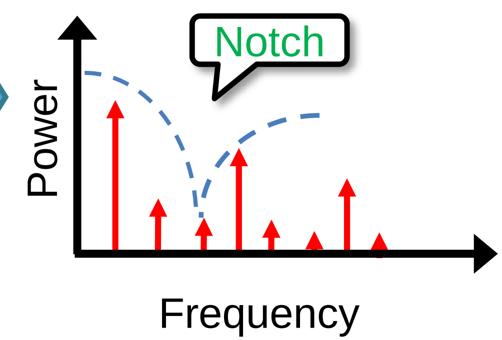
$f_{ck}$ : 500kHz

$W_H$ : 1.6μs

$W_L$ : 0.2μs

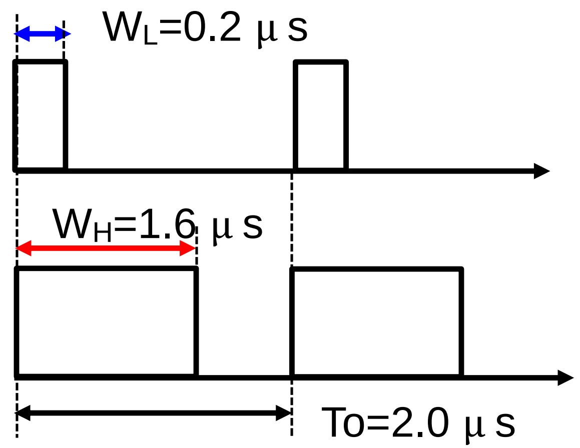



Spectrum of PWM signal



# Simulation Result with PWC Control

Design clock pulse to determine the notch frequency

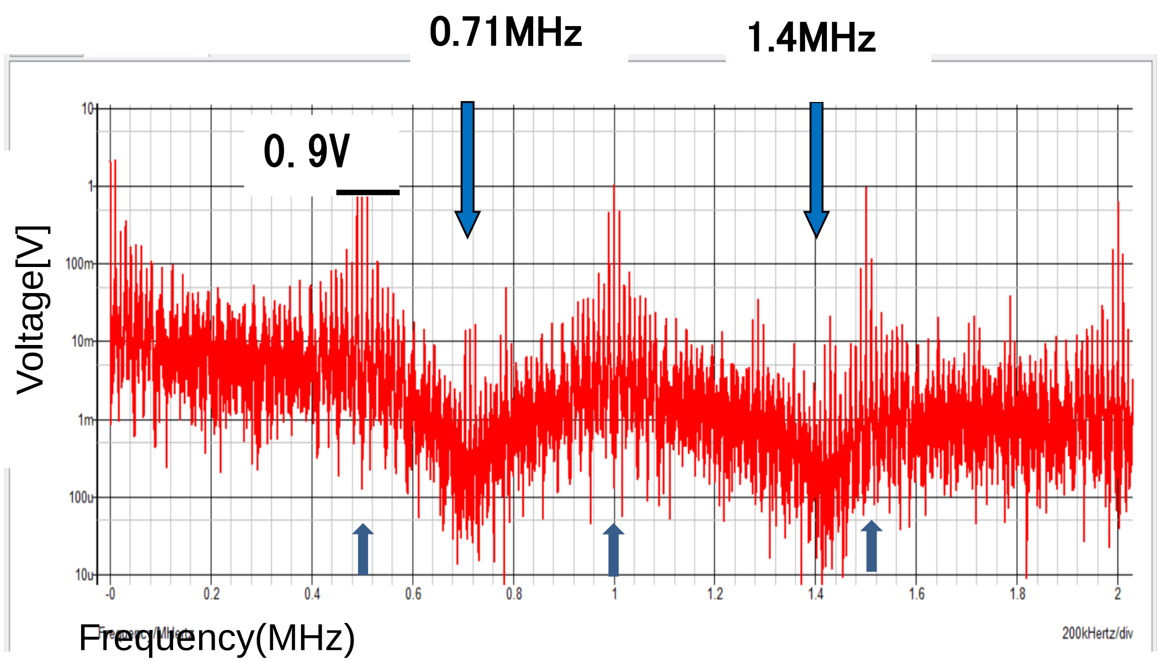



Pulse widths of the coding pulses

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

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

★manually set $W_L$ and $W_H$




PWM signal spectrum using PWC control

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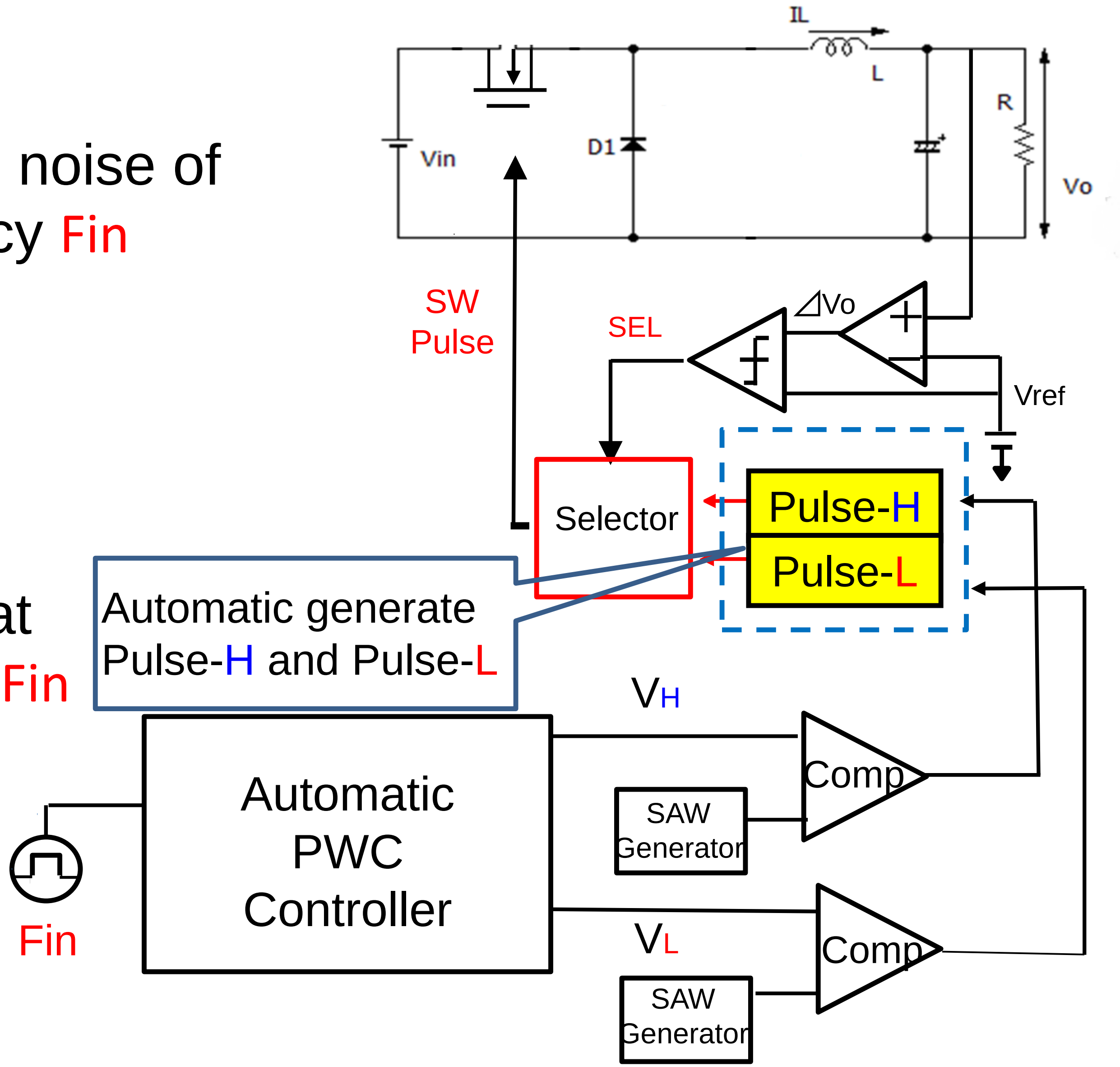
# Automatic PWC Control

## Objective

Reduction generate noise of receive frequency Fin

## Method

generate notch at receive frequency Fin



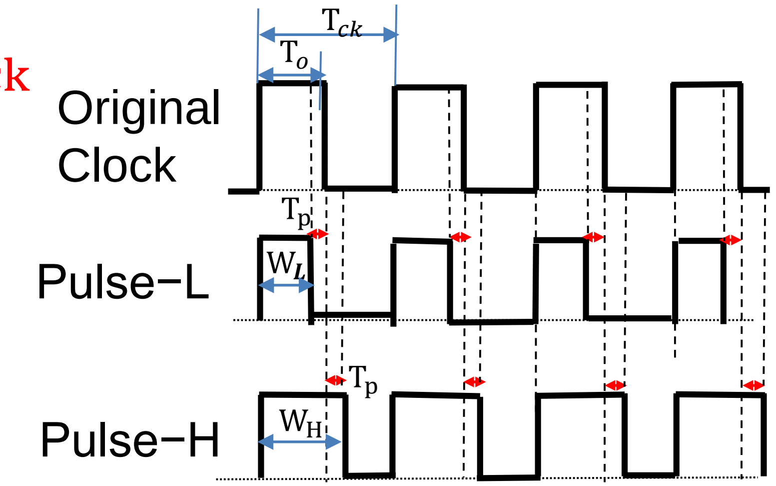
# Clock Frequency, Notch Frequency and PWC

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 PWM signal

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

When $N$ =1

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

$W_H$ and $W_L$

Generated at the center of the original clock

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

$$W_L = T_o - T_p$$

$$W_H = T_o + T_p$$

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

# Generate Pulse-H and Pulse-L Automatically

Generate $T_{ck}$ from $T_{in}$ using

$F_{in}$=($N$+0.5) ・ $F_{ck}$

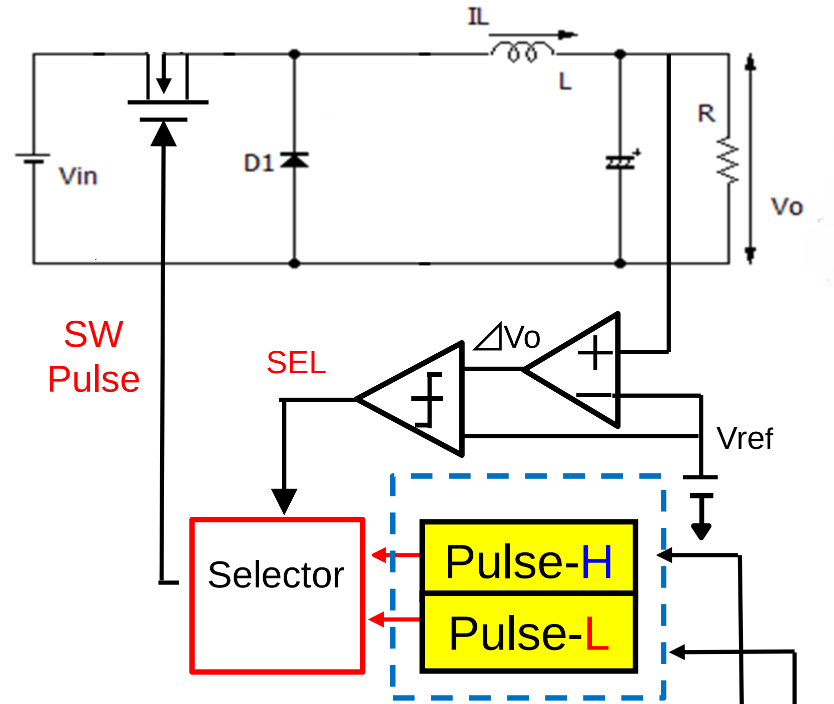
$T_{ck}$=($N$+0.5) ・ $T_{in}$

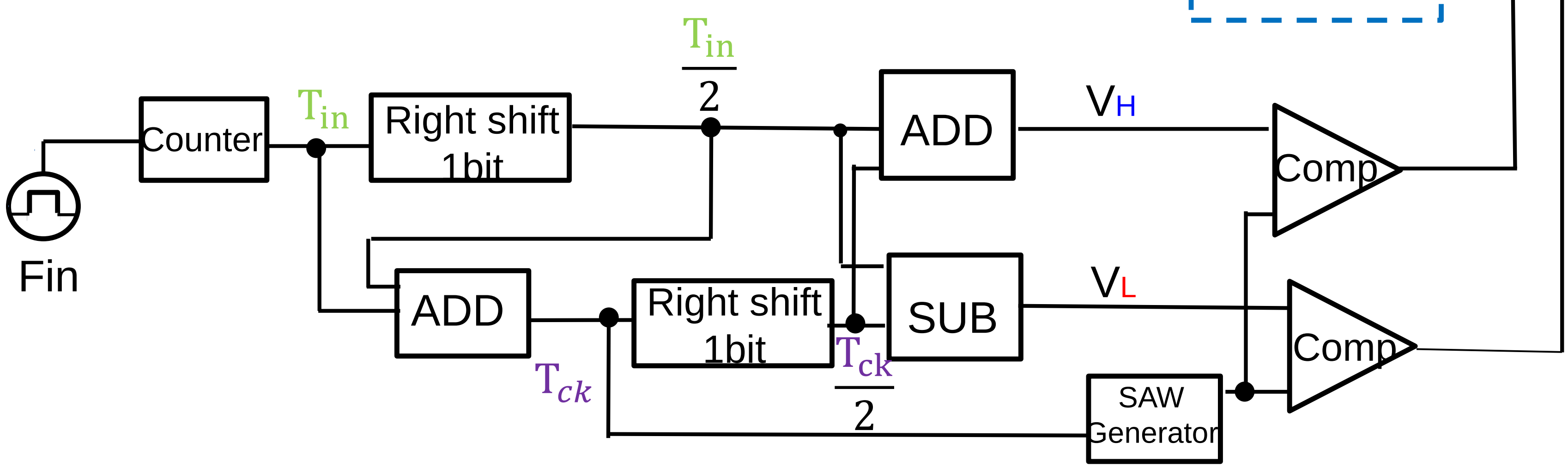
$$W_L = T_o - T_p = D_o \times T_{ck} - \frac{1}{2} T_{in}$$

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

$$T_n = 2 \times T_p$$

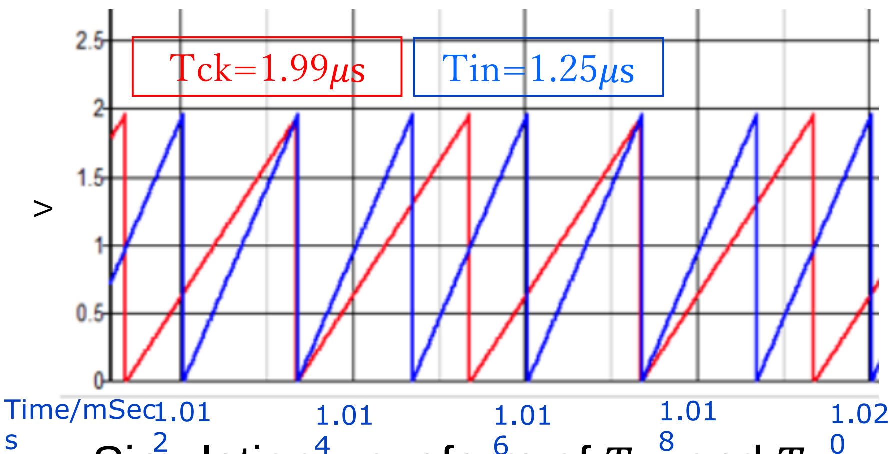
$D_o$=0.5 $N$=1 situation



# Simulation Waveforms of $W_H$, $W_L$ Generation

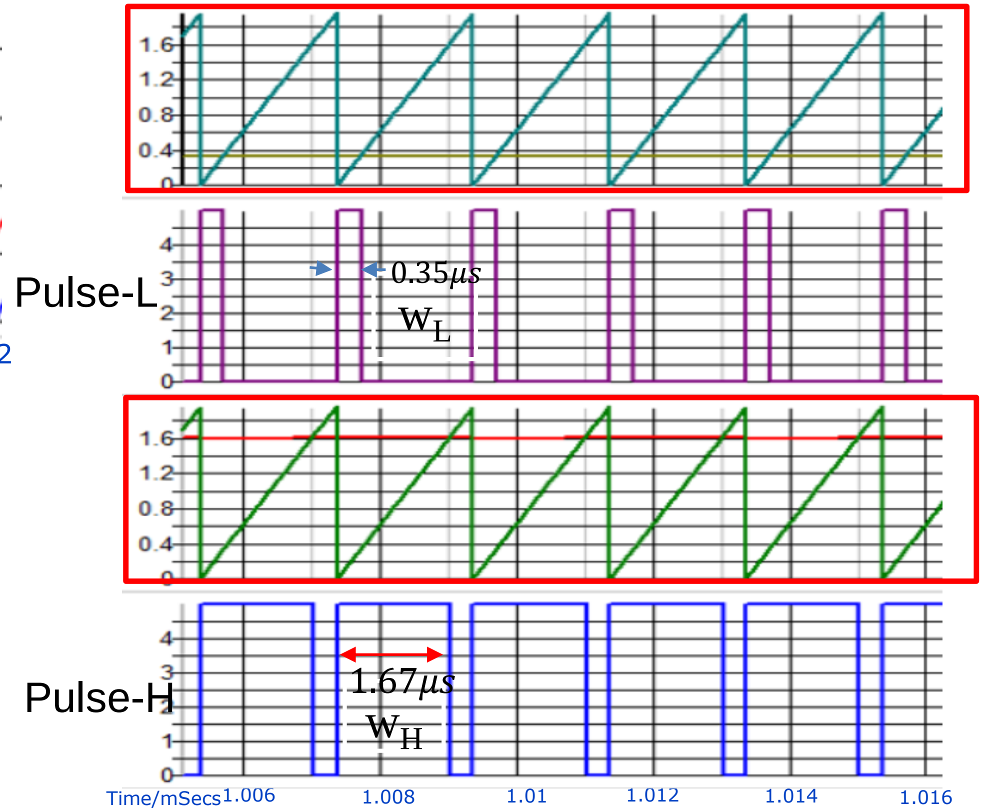
We set $F_{in} = 750kHz$ ➡ Automatic generated $F_{ck} = 500kHz$




Simulation waveform of $T_{ck}$ and $T_{\text{in}}$

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

$T_{ck}$ compare with VL or VH




Simulation waveforms of $W_H$ and $W_L$

Theoretical formula

$W_H = 1.66\mu s$

$W_L = 0.25\mu s$

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, $W_L$=0.25μs）

## ◎Condition

Buck DC-DC converter

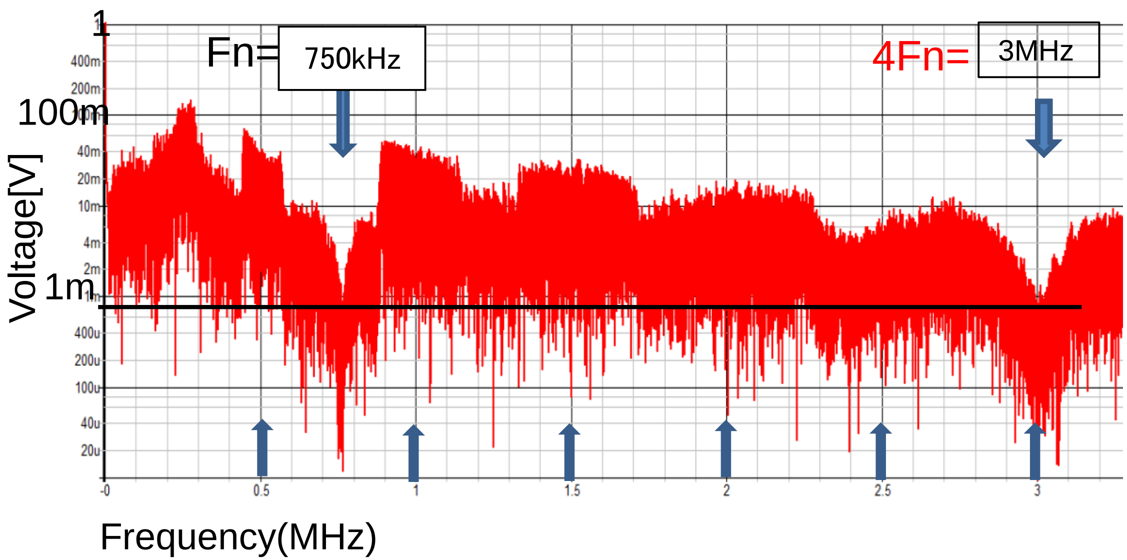
$V_{in}$ ：10V

$V_{out}$ ：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

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

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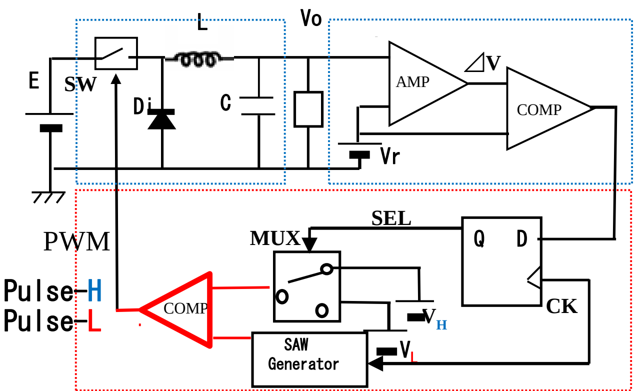
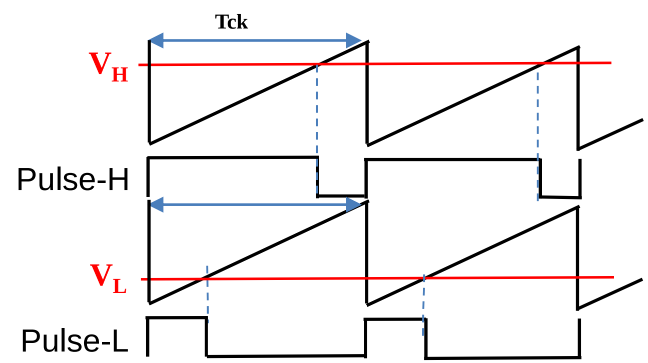
# Implementation of PWC Control Switching Converter

## Generation of $W_H$ and $W_L$

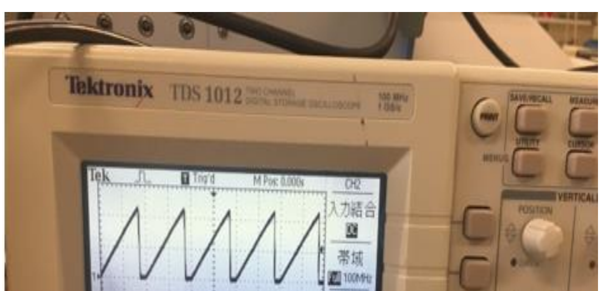
| $V_o$ | Op amp output | comparator output | SEL | PWM output | Duty |
|---|---|---|---|---|---|
| ＞5V | L | L | L | $P_L$ | L |
| ＜5V | H | H | H | $P_H$ | H |



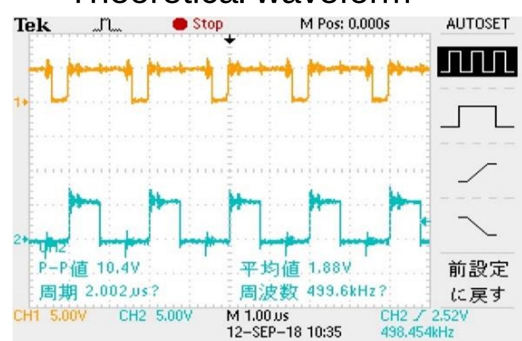

Converter with PWC control




Theoretical waveform




Saw-tooth waveform
(Period: 2 μs)




Implementation pulse of
Pulse-H and Pulse-L

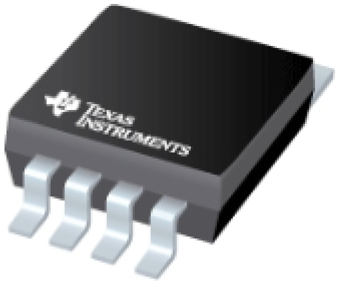
# IC Selection and Measurement Items

## IC selection

LMR23630 36V 3A synchronous step-down converter

**Features:**

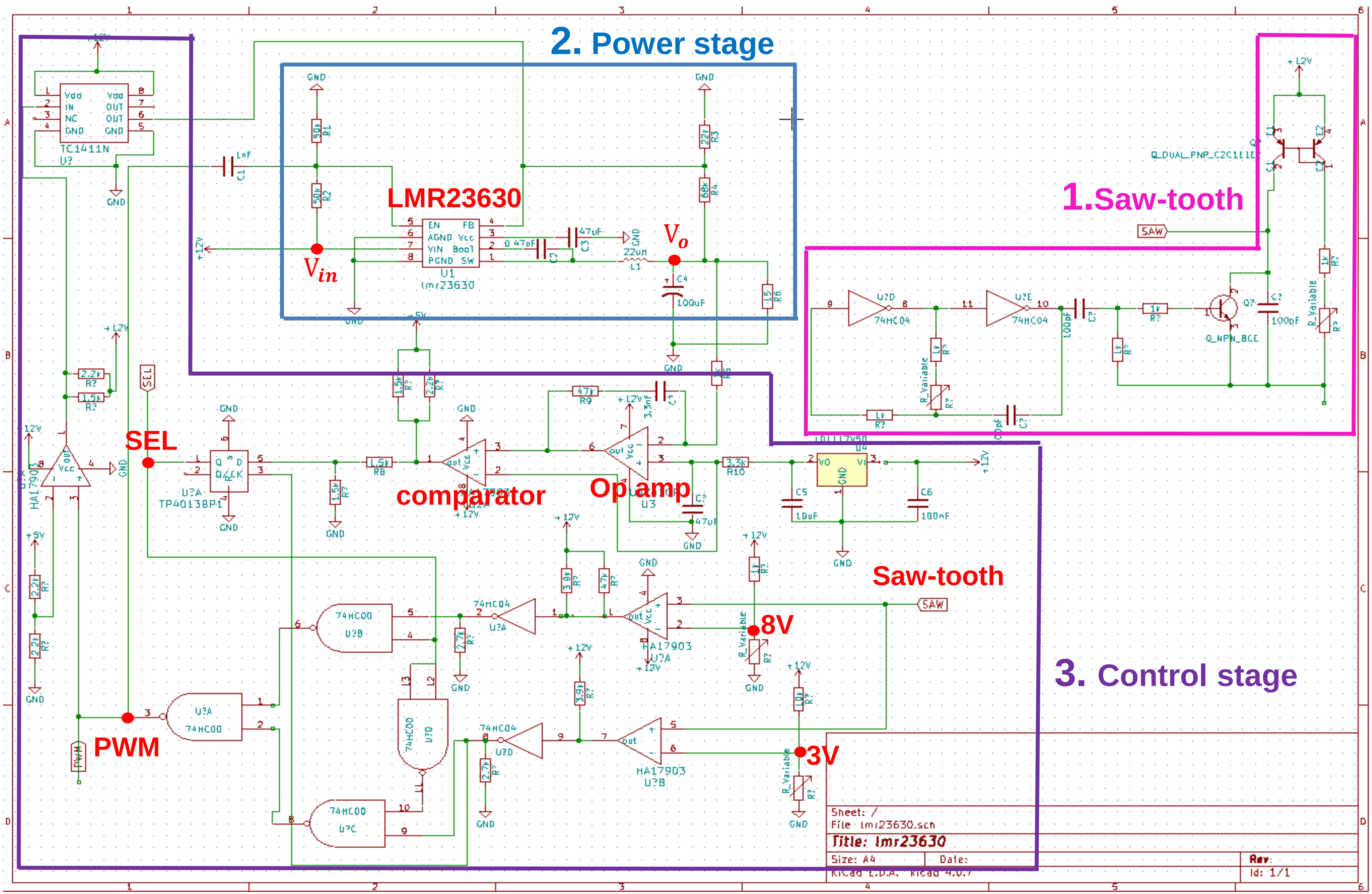
1. 4-V to 36-V input range
2. Current-mode control
3. 400-kHz switching frequency and adjustable frequency options
4. Frequency synchronization to external clock
5. PFM and forced PWM mode options




## Measurement Items

Output voltage : Vo
Waveform of Pulse-H and Pulse-L
Waveform of Saw-tooth
Spectrum of PWM signal

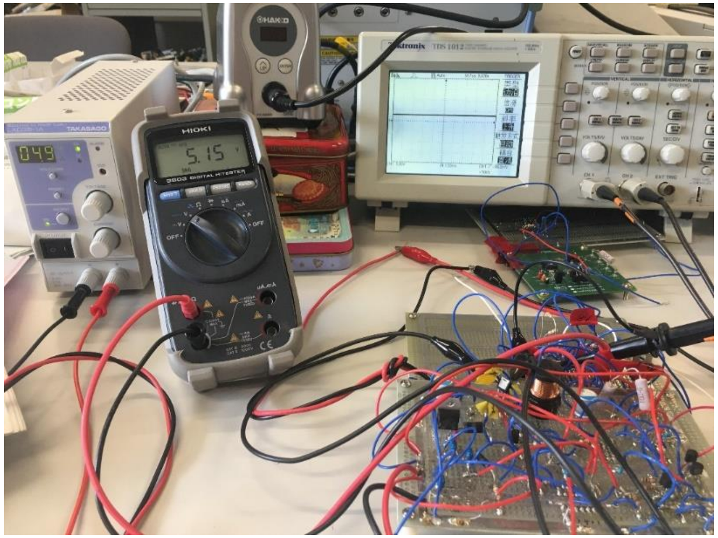
# Implementation Circuit Diagram



# Parameter Setting

| | |
|---|---|
| Vin | 12V |
| Vo | 5V |
| L | 100uH |
| C | 47uF |
| Vref | 5V |
| fclk | 500kHz |

Pulse generator can generate clocks of 250kHz or less
Using pulse generation circuit




Implementation

# Spectrum of PWC Control Switching Converter

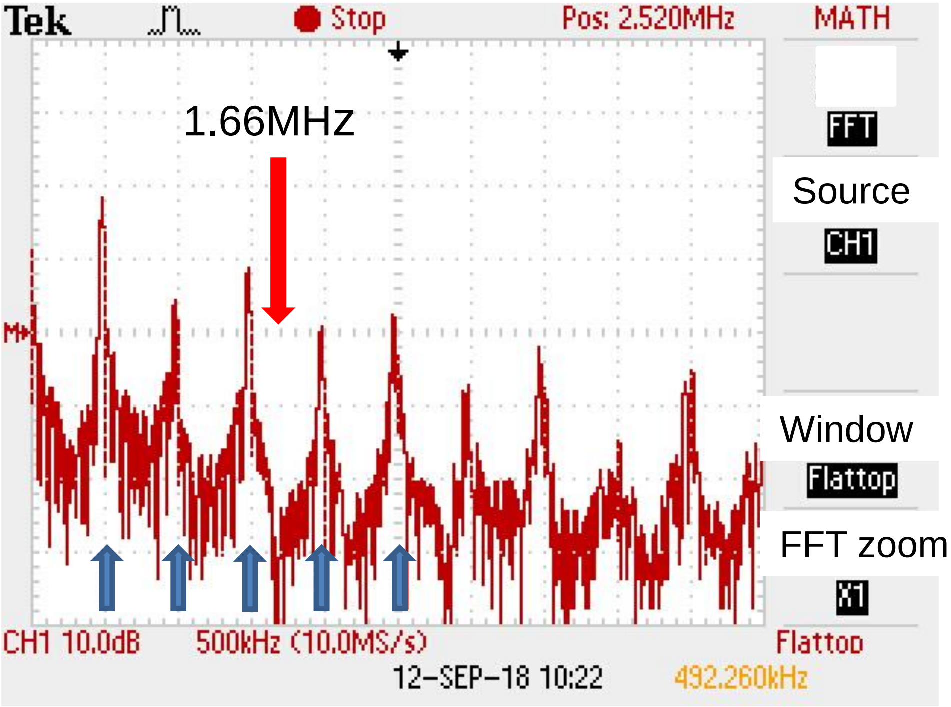
Theoretical formula

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

## ◎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 3$f_{ck}$ and 4$f_{ck}$**

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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

- Implementation of full automatic PWC control switching converter

Thank you for Listening

# Q&A

Q1: If using this device, the noise of the spectrum will be decreased?
A: If using the pulse coding method as I mentioned early in switching converter, the noise of the spectrum will be decreased. In implementation, the IC which I choose can create the step-down conversion function from 12V to 5V. And the pulse coding function is realized in the control part of the circuit.

Q2: The frequency of PWM was a fixed frequency?
A: Yes, the frequency of PWM was set by ourselves and it is always 500kHz.