Spread Spectrum with Notch Frequency using Pulse Coding Method

for Switching Converter of Communication Equipment

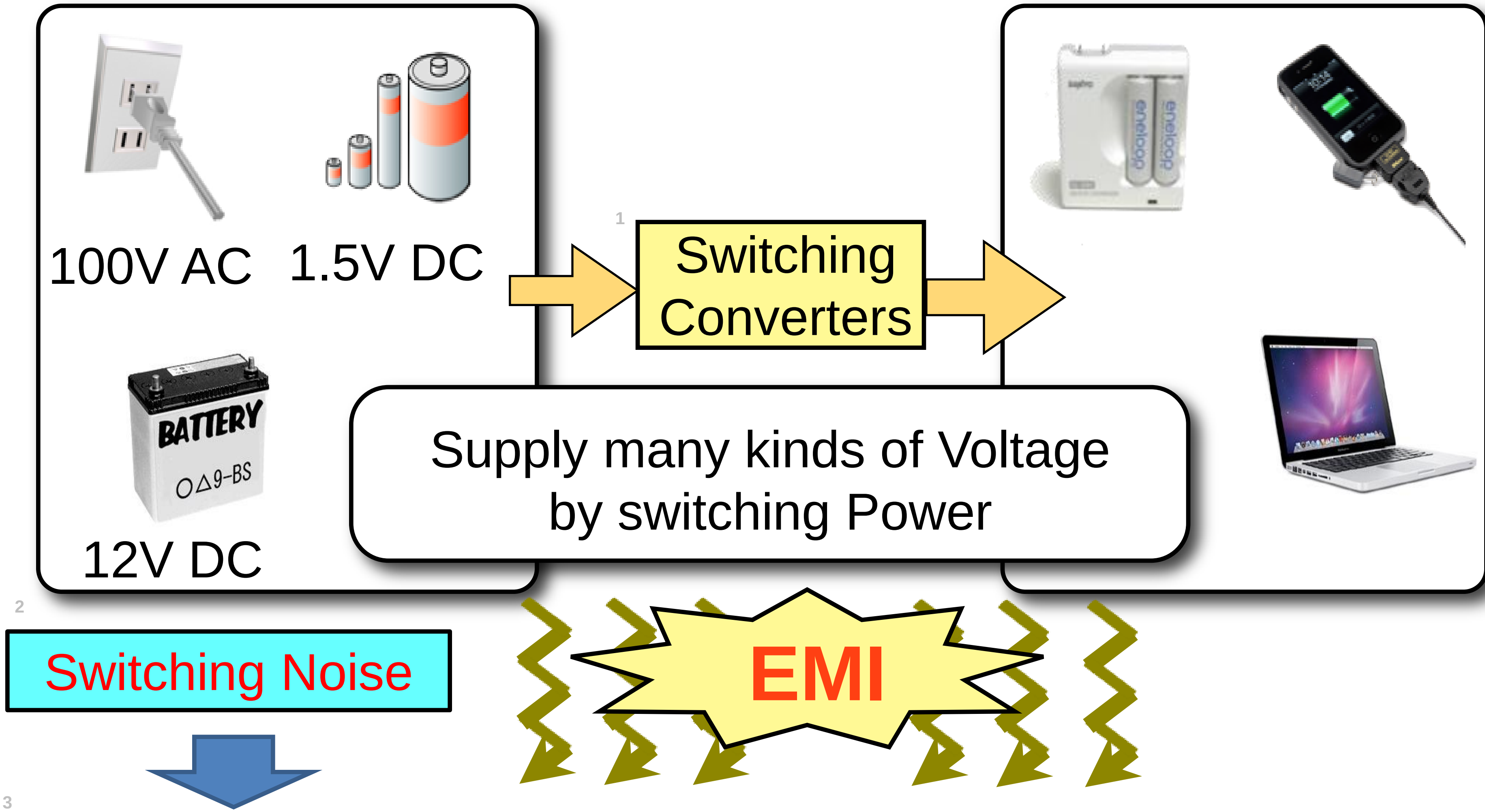
Yasunori Kobori[1*], Futoshi Fukaya[1],
Takuya Arafune[2], Ensi Li[2], Nobukazu Tsukiji[2], Nobukazu Takai[2], Haruo Kobayashi[2]

1) National Institute of Technology, Oyama College
2) Gunma University
Japan

Outline

1. Introduction & Objective
2. Spread Spectrum for EMI Reduction
3. Pulse Coding Method in Switching Converter
   3-1 Pulse Width Coding (PWC) with Notch Frequency
   3-2 Pulse Cycle Coding (PCC) with Notch Frequency
4. Experimental Result with PWC Method
5. Conclusion

1. Introduction & Objective



Important to reduce SW noise by decreasing main spectrum level

Fig.1-1 background (EMI)

EMI: Electro-Magnetic Interference

1. Introduction & Objective

- We have reduced the clock noise by spread spectrum with shaking clock phase at random by analog noise.

↓

- Noise of clock frequency is spread to all frequencies around the clock & its harmonics.

↓

- Some electronic devices like radio receivers would not like to be affected at special frequency noise.

↓

★ Spread Spectrum Method is required to reduce noise with notch characteristics at special frequency.

- **Objective:**

1) Clear the relationship between
   notch frequencies and pulse coding conditions.

2) Simulate the notch frequency in spread spectrum
   with PWC and PCC method in switching converters.

3) Experiment PWC method and notch frequencies
   with some conditions in the buck converter.

Outline

1. Introduction & Objective
2. Spread Spectrum for EMI Reduction
3. Pulse Coding Method in Switching Converter
   3-1 Pulse Width Coding (PWC) with Notch Frequency
   3-2 Pulse Cycle Coding (PCC) with Notch Frequency
4. Experimental Result with PWC Method
5. Conclusion

2. Spread Spectrum for EMI Reduction

★ EMI reduction method.

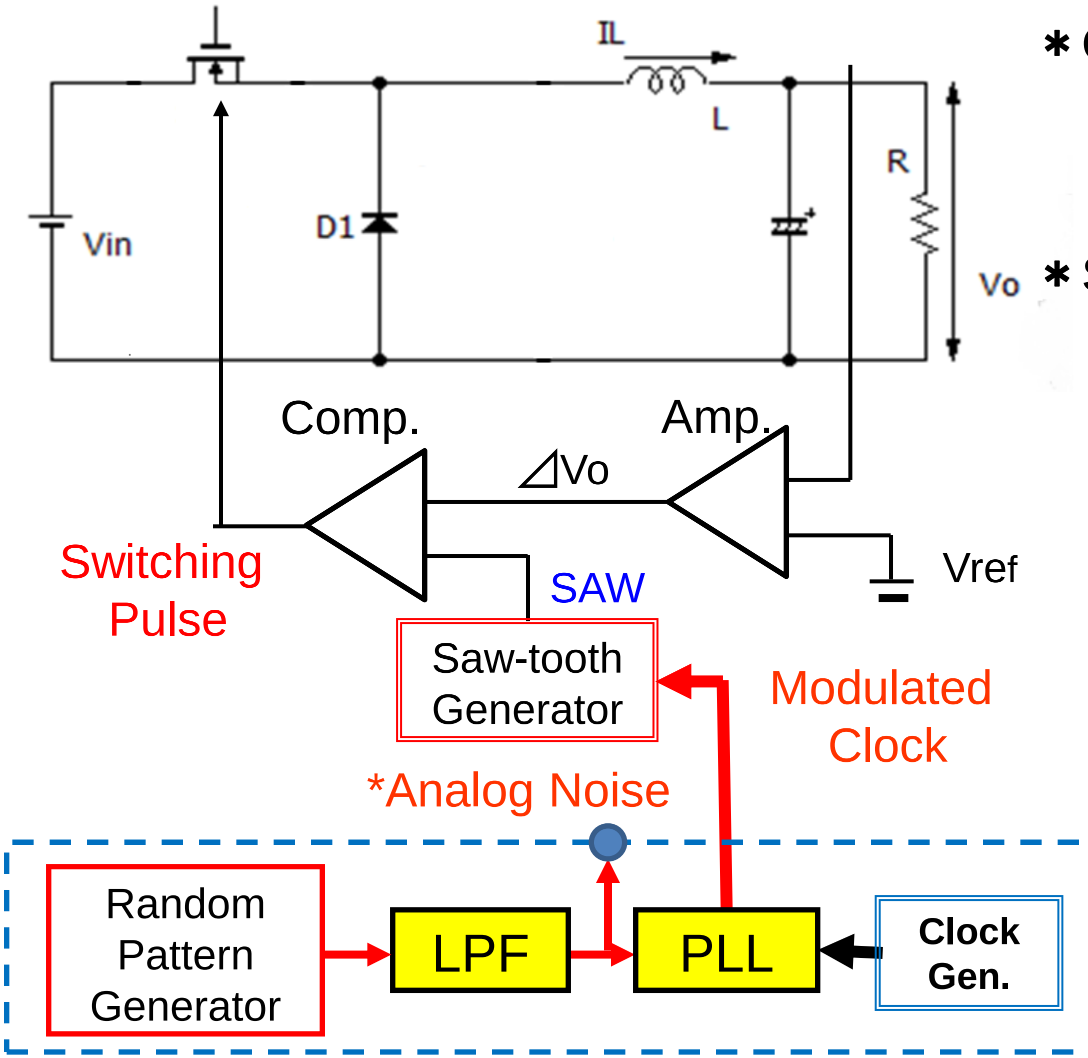


Fig.2-1 Buck converter with modulated clock

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

∗ SW pulse frequency is modulated and reduce the EMI noise.

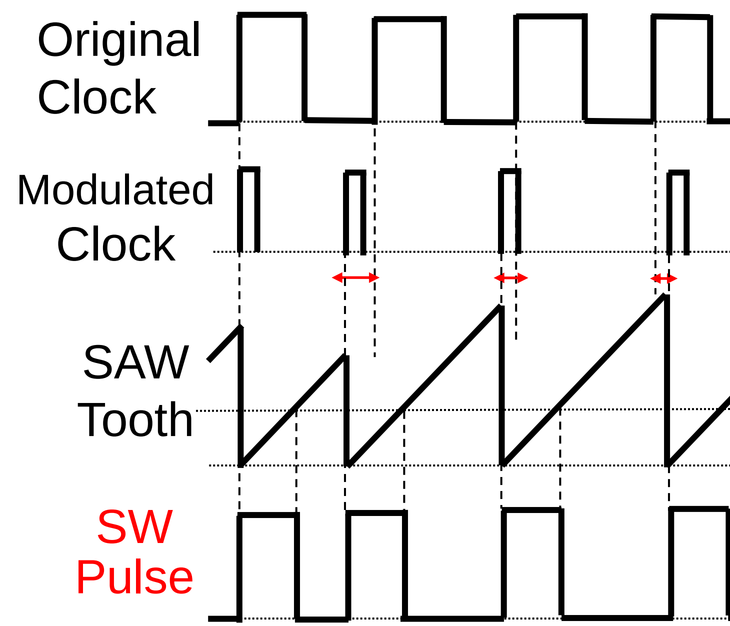


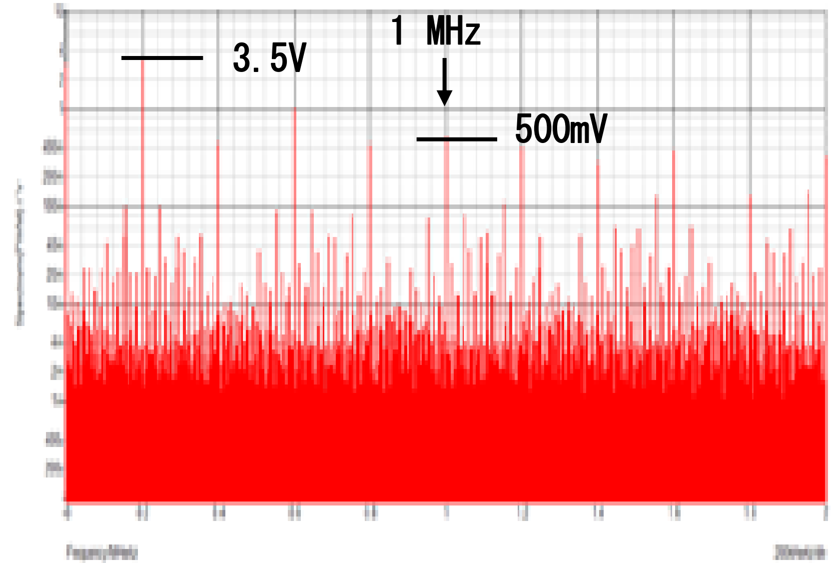
Fig.2-2 Timing Chart

★ Simulation results
of spread spectrum
with EMI reduction.

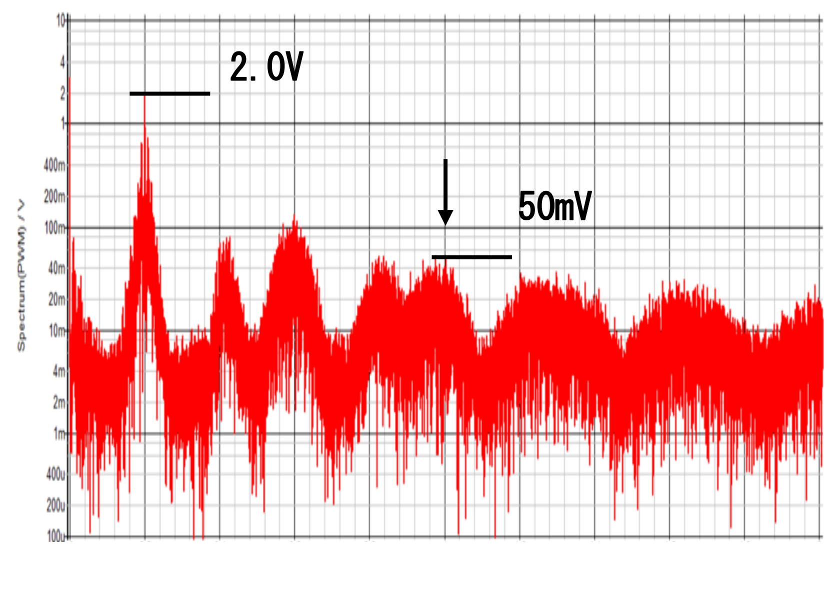
- ●Clock Frequency (200kHz)
  Peak level is reduced
  from 3.5V to 2.0V (-2.4 dB)
- ● Harmonic frequency (1 MHz)
  from 500mV to 50mV (-10 dB)

◆ Peak level of clock frequency
is reduced a lot, but
other frequency level is
increased about 10 mV.

★ No good for radio receivers.



(a) Without EMI reduction



(b) With EMI reduction

Fig.2-3 Comparison of Spectrum

Outline

1. Introduction & Objective
2. Spread Spectrum for EMI Reduction
3. Pulse Coding Method in Switching Converter
   3-1 Pulse Width Coding (PWC) with Notch Frequency
   3-2 Pulse Cycle Coding (PCC) with Notch Frequency
4. Experimental Result with PWC Method
5. Conclusion

3. Pulse Coding Method in Switching Converter

3-1 Pulse Width Coding PWC with Notch Frequency

★ Switching Converter with Pulse Coding

＊Make SEL signal
by comparing ⊿Vo w Vr.

・Select Pulse-H or Pulse-L.

Pulse-H： with H-Duty ratio

＊In order to control Vo,
duty ratios of coding pulses
are very important.

★ $V_H > V_O > V_L$ ・・・(3)

Vo= Vo／Vin

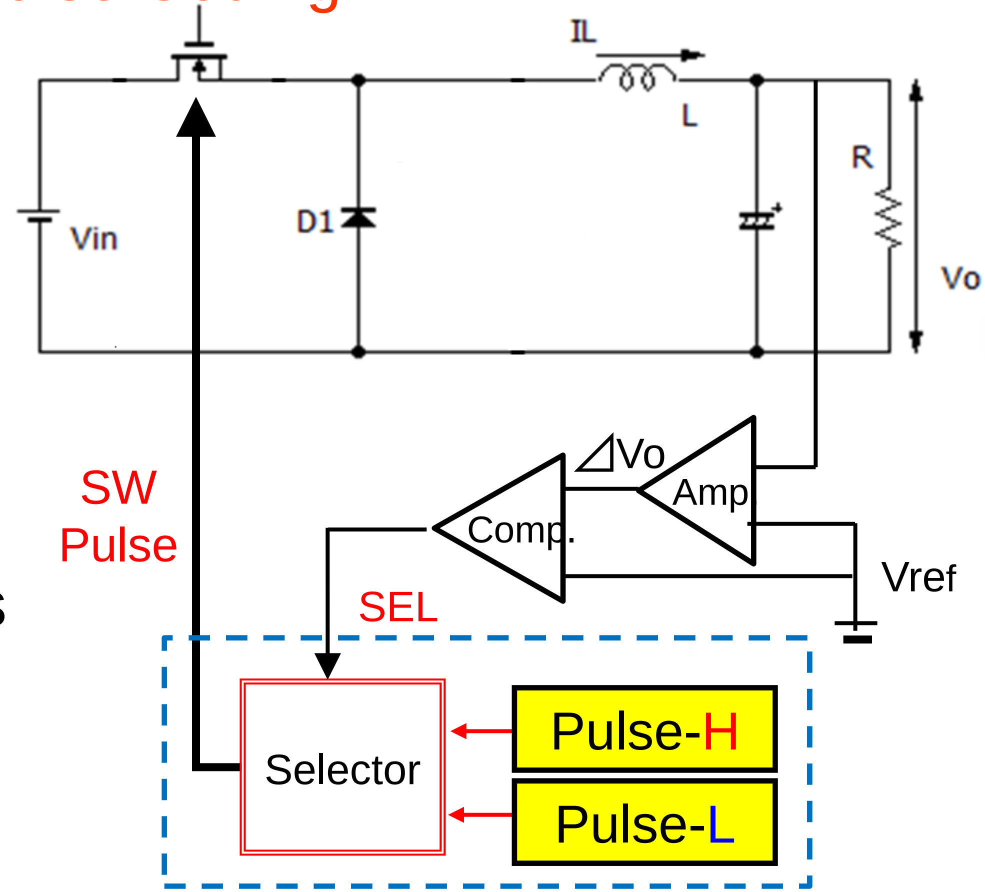


Fig.3-1 Switching Converter with Pulse Coding

★ Simulation results with PWC & EMI reduction

- ∗ Duty: D_H =0.8, D_L =0.1
- ∗ F_N =k/1.4us=0.71, 1.43 MHz
- ∗ Clock Level: 3.5V⇒ 0.9V (−5.9dB)

Table 3-1 Parameters of buck converter

Vin	10.0 V
Vo	5.0 V
Io	0.25 A
L	200uH
Co	470μF
Fck	500kHz

● Spectrum of SW pulse

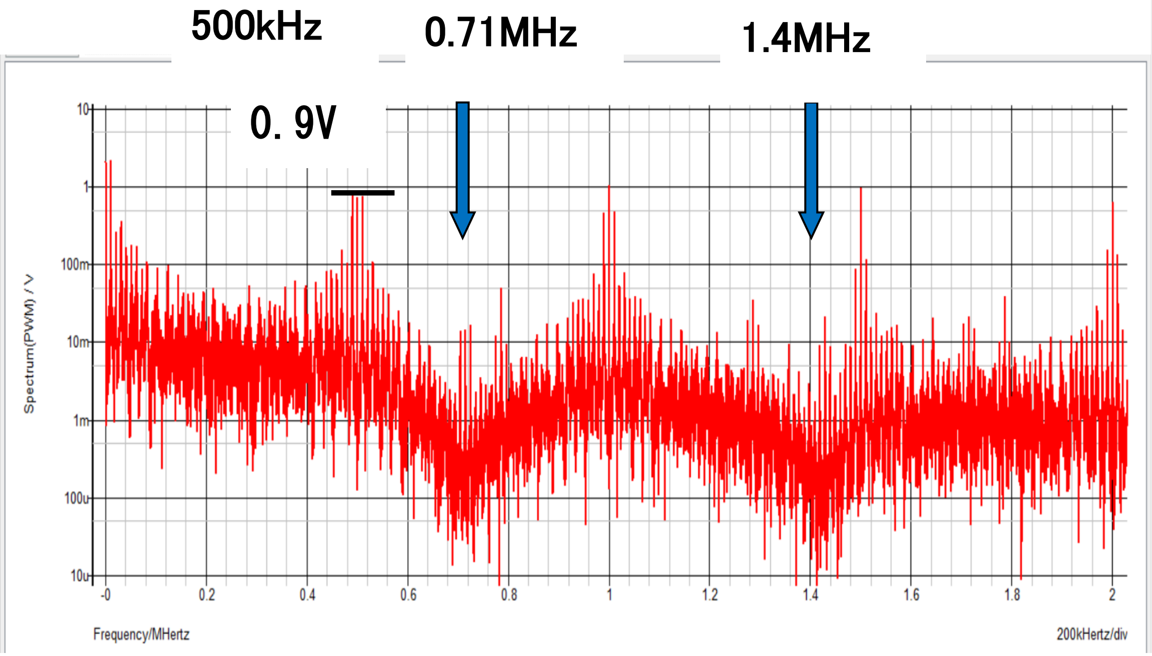


Fig.3-3 Spread Spectrum with PWC

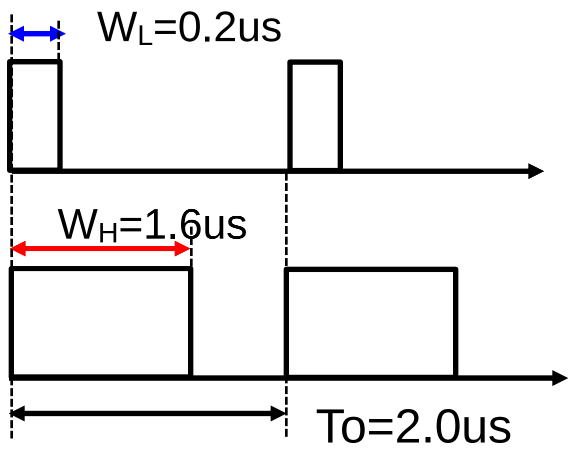


Fig.3-2 PWC Pulse 2

3-2 Pulse Cycle Coding PCC with Notch Frequency

* Two coding pulses supplied from PCC pulse generator.
* Pulse period : T_H or T_L. Pulse width is constant: Wo.

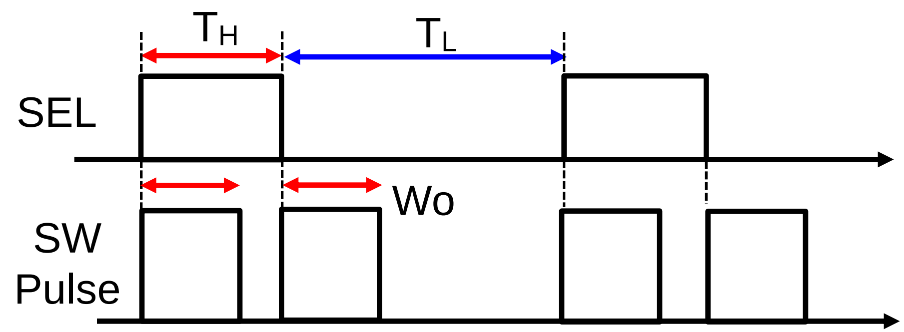


Fig.3-4 PCC pulses

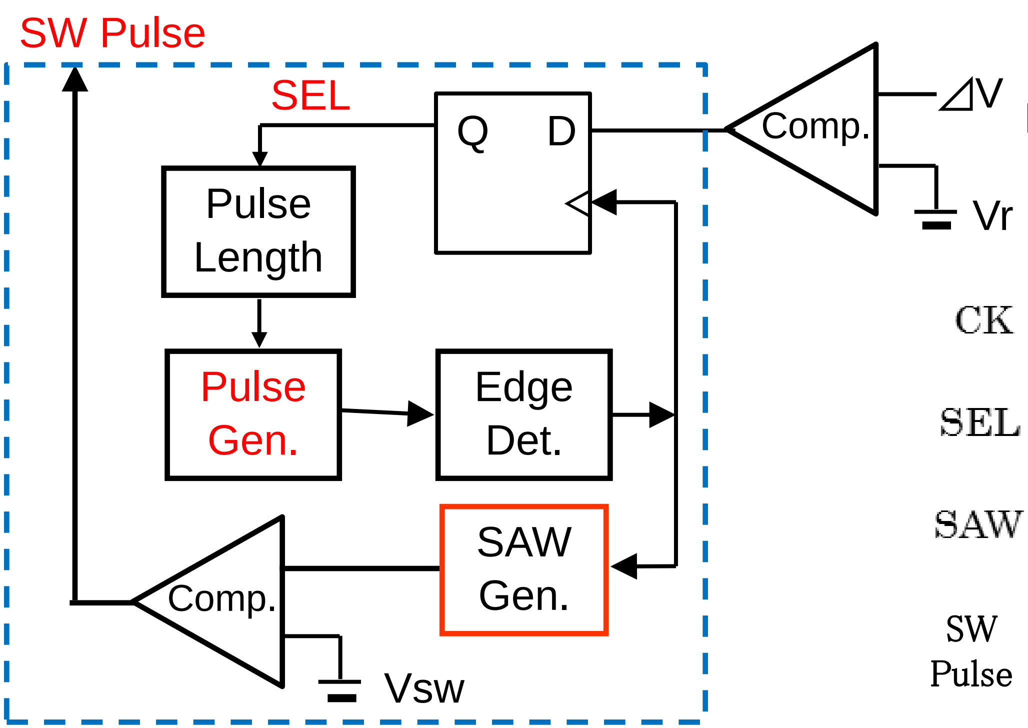


Fig.3-5 PCC Pulse Generator

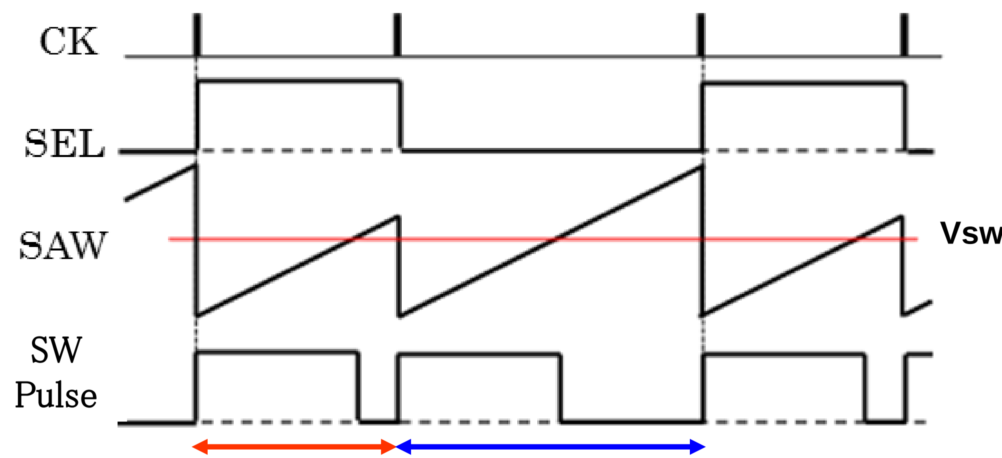


Fig.3-6 Timing Chart

- Simulation Results with PCC (without EMI rejection)
  - Parameters: T_L = 3.5us, T_H = 2.0us (Wo =1.3us)
  - F_N = N／(3.5－2.0)us = 0.667･N [MHz]

＊Highest spectrum level: 3.5V ⇒ 2.0V (－2.4dB)

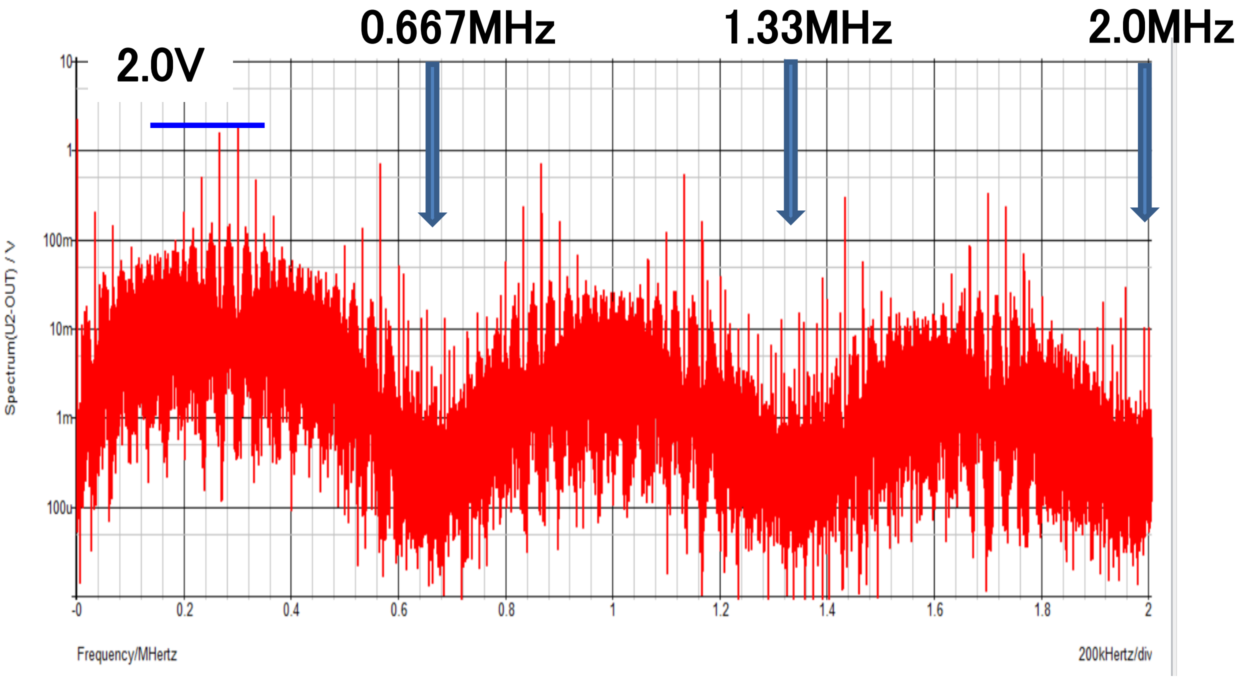


Fig.3-7 Spread Spectrum (PCC method)

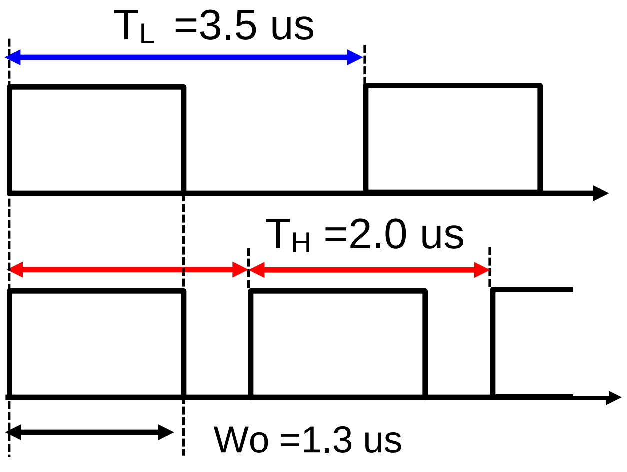


Fig.3-8 PCC Pulses

● Simulation Results (PCC method)

∗ Duty Ratios: D_H = 1.3／2.0 = 0.6, D_L=1.3／3.5 = 0.38

∗ Output Voltage Ripple： 10 mVpp (0.2 % of Vo)

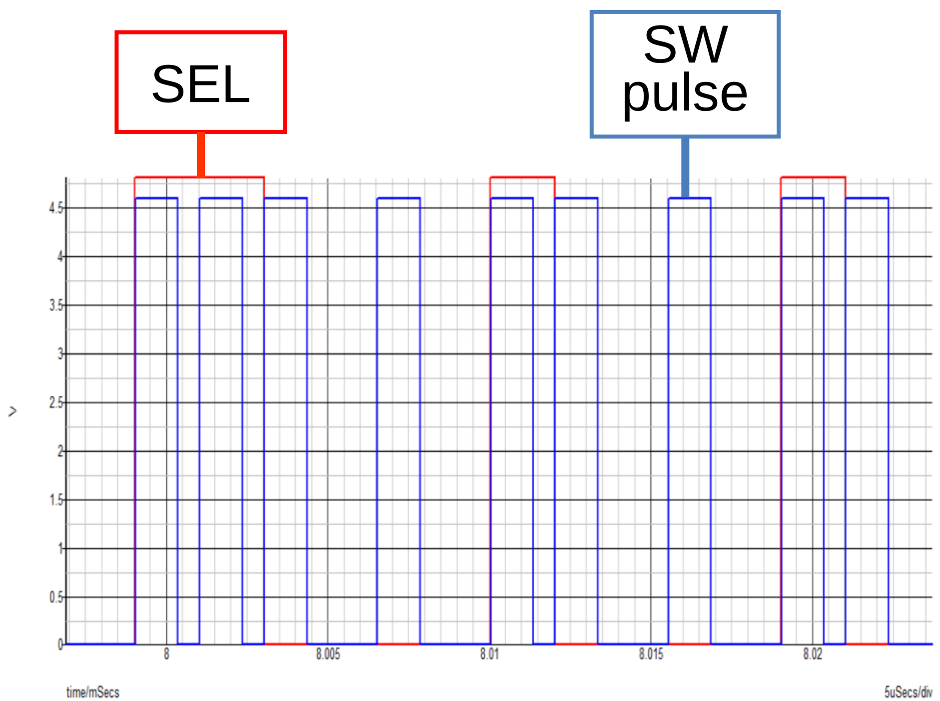


Fig.3-9 SEL and SW Pulses

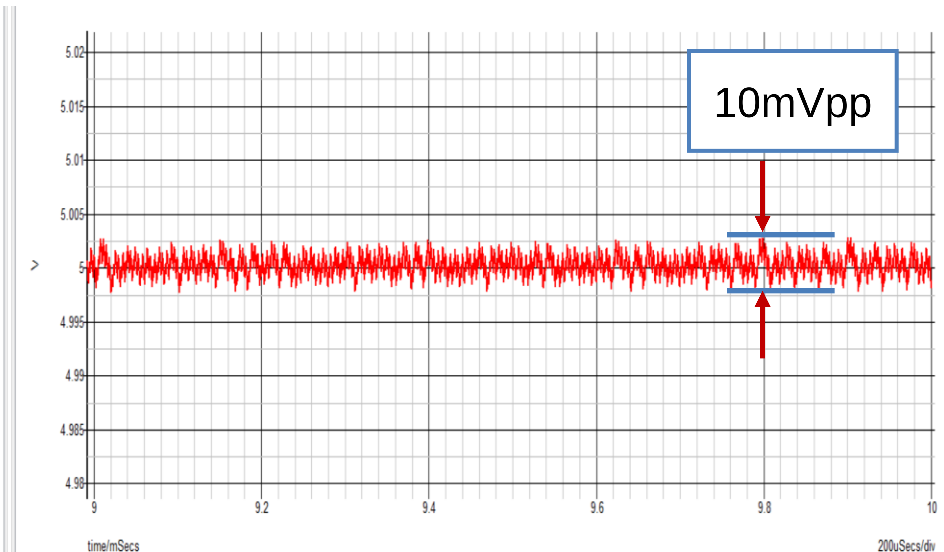


Fig.3-10 Output Ripple

Outline

1. Introduction & Objective
2. Spread Spectrum for EMI Reduction
3. Pulse Coding Method in Switching Converter
   3-1 Pulse Width Coding (PWC) with Notch Frequency
   3-2 Pulse Cycle Coding (PCC) with Notch Frequency
4. Experimental Result with PWC Method
5. Conclusion

4. Experimental Result with PWC Method

● PWC method in the buck converter

＊Parameters

Vi=10 V, Vo=5.0V, Io= 0.25 A

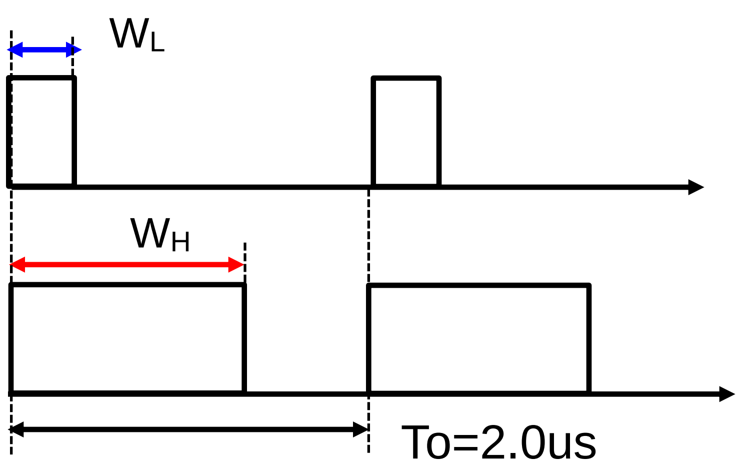
L=1 mH, C=470 uF

F≒160 kHz

＊Pulse Width Coding

Notch Frequencies

$F_n = k / (W_H - W_L)$



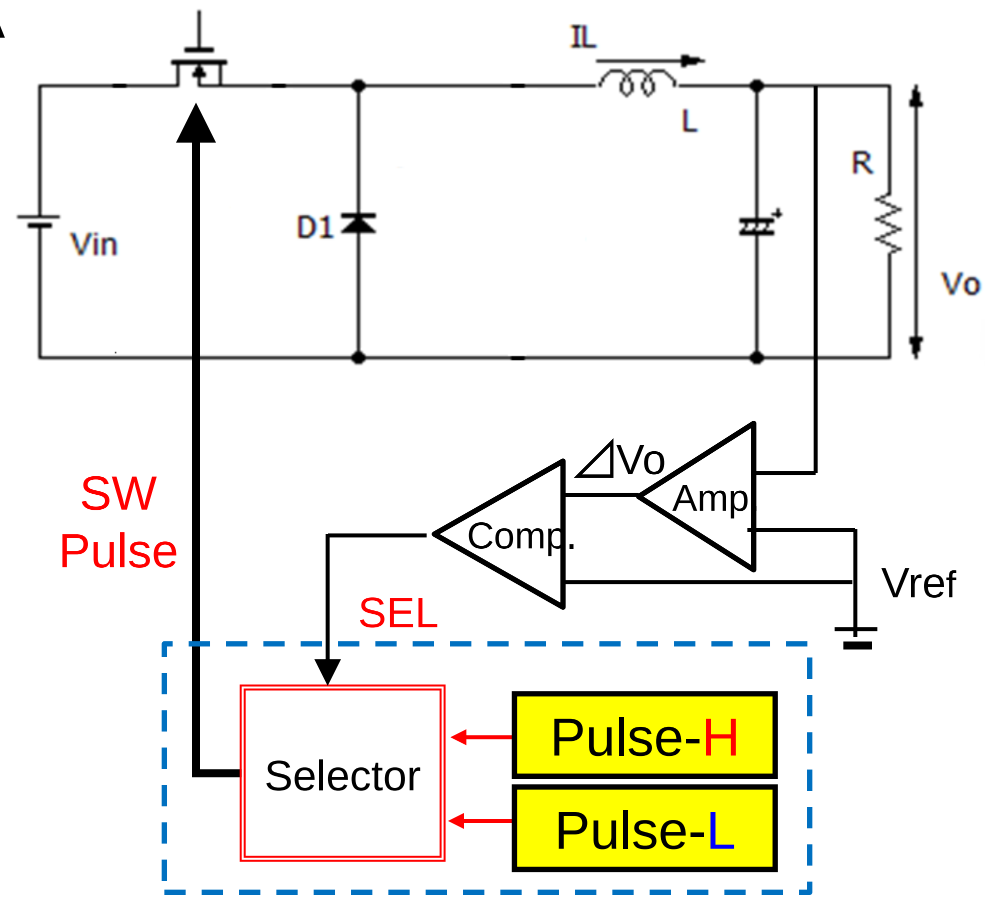


Fig.4-1 Buck converter with PWC

● Experimental result of PWC method in buck converter

＊Conditions of PWC

W_H = 5.0 ns, W_L = 1.0 ns, T ≒ 6.2 us (160 kHz)

＊Notch Frequency： Fn=1／(5.0−1.0) us = 250 kHz

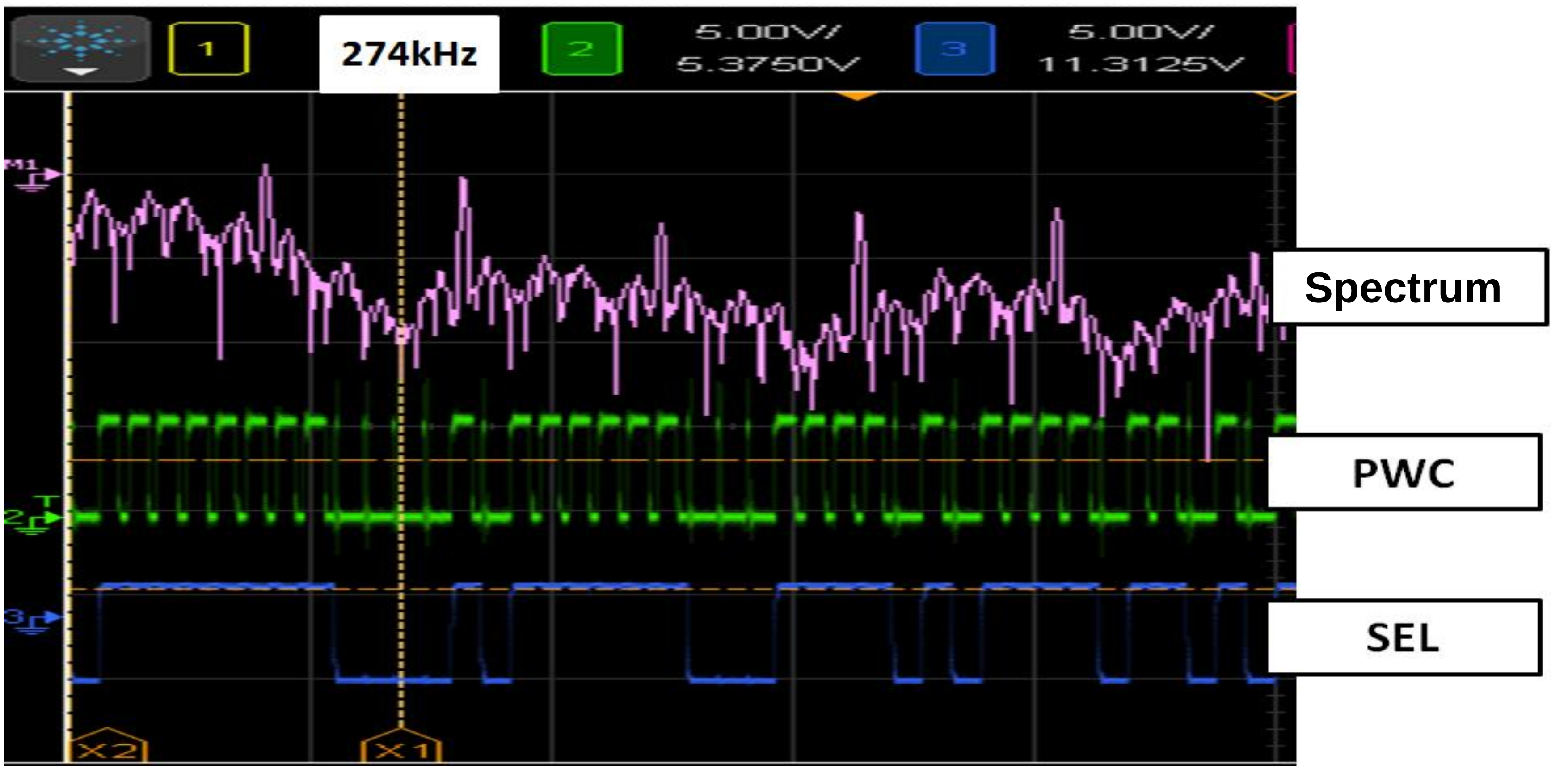


Fig.4-2 Spectrum & major signals of buck converter with PWC

● Experimental result 2 with PWC

∗ Conditions of PWC

$W_H = 4.0$ ns, $W_L = 1.1$ ns, $T ≒ 6.2$ us

∗ Notch Frequencies: Fn=1／(4.0－1.1)us = 345, 690 kHz

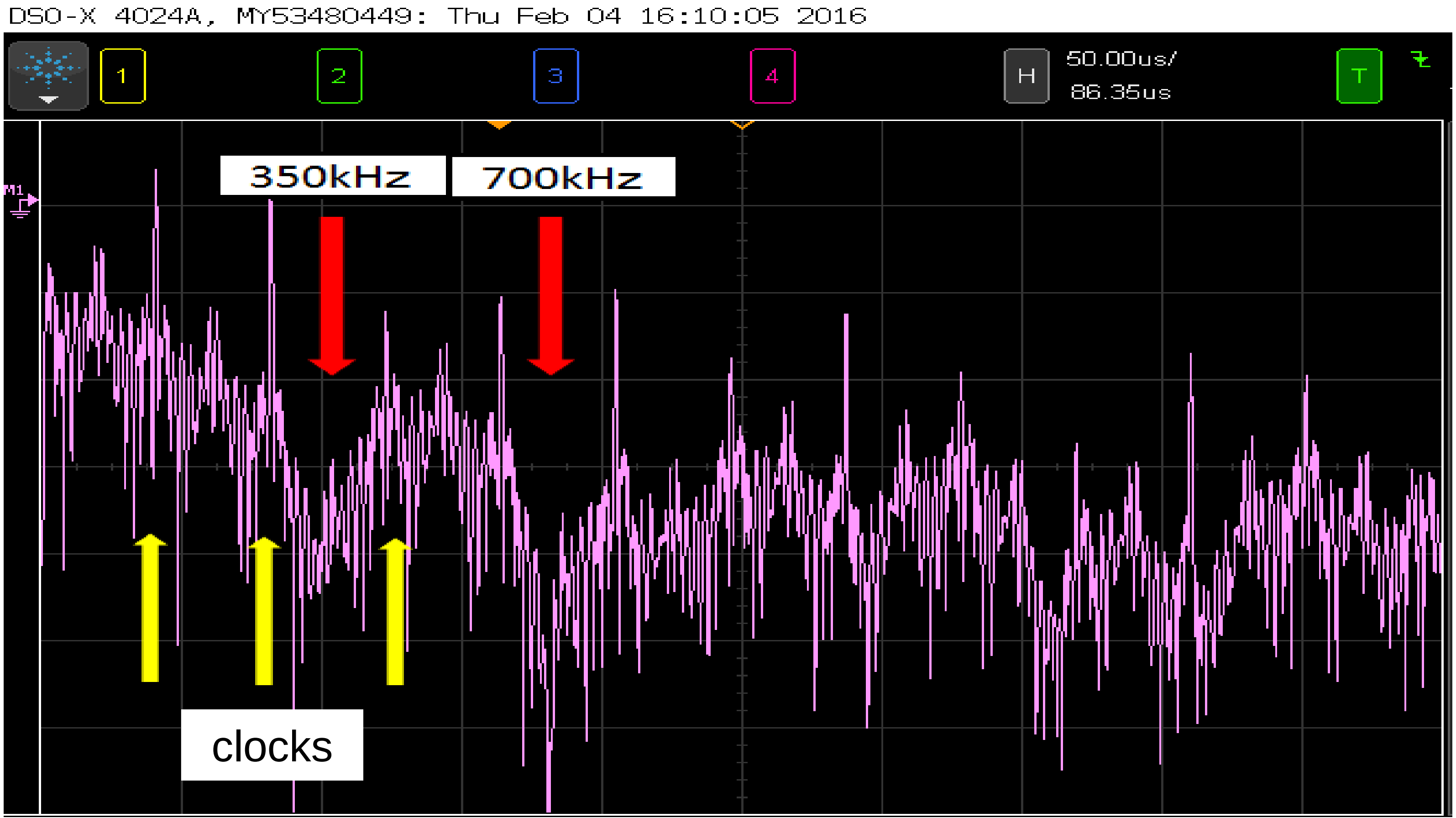


Fig.4-3 Another spectrum with PWC

● Experimental result 3 with PWC

∗ Conditions of PWC (with high frequency)

W_H = 2.0 ns, W_L = 1.0 ns, T ≒ 2.4 us（420 kHz）

∗ Notch Frequency： Fn=1／(2.0－1.0)us = 1.0 MHz

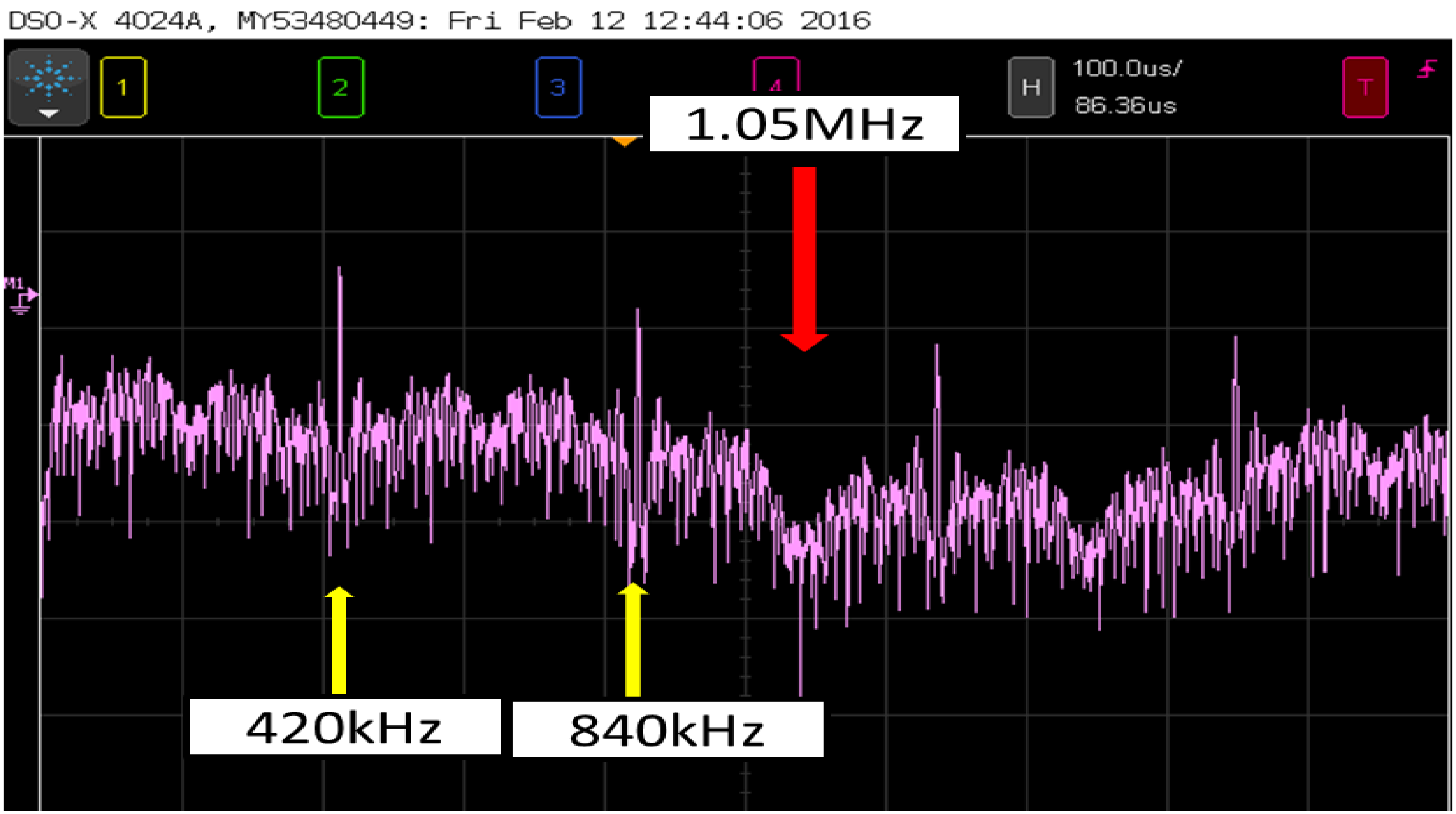


Fig.4-4 Another spectrum with high frequency

Conclusion

★ Pulse Coding Method with notch frequencies in the switching converters.

1. Notch Frequencies with pulse coding:
   - $F_N = K／(W_H－W_L)$ with PWC method
   - $F_N = K／(T_L－T_H)$ with PCC method
2. Simulation results with Pulse Coding:
   1) PWC method: $F_N = 0.71$ MHz
      $W_H = 1.6$ ns, $W_L = 0.2$ ns
   2) PCC method: $F_N=0.67$ MHz
      $T_H = 2.0$ ns, $T_L = 3.5$ ns
3. Experimental result with PWC method (Exp. Fn)
   1) $W_H = 5.0$ us, $W_L = 1.0$ us, $F_N = 254$ kHz (274 kHz)
   2) $W_H = 4.0$ us, $W_L = 1.1$ us, $F_N = 345$ kHz (350 kHz)
   3) $W_H = 2.0$ us, $W_L = 1.0$ us, $F_N = 1.0$ MHz (1.05MHz)

Thank you for your kind attention!

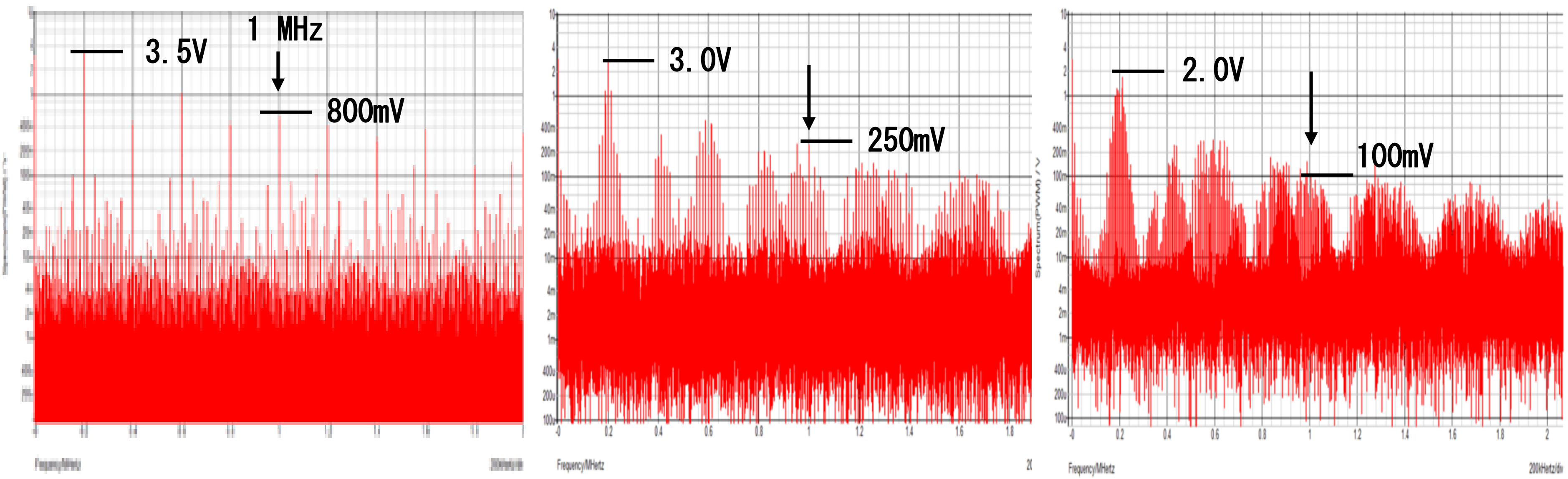
Is there any question?

★ Simulation Results with EMI Reduction

●I Spread Spectrum (Fo=200kHz)

Peak level of basic frequency is reduced (-2.4 dB)

Harmonic frequency is widely spread (-9.0 dB @1MHz).



(a) Without Spread Spectrum (b) Digital Spread Spectrum (c) Analog Spread Spectrum

Fig. A-1 Comparison of Spread Spectrum