IEEE International Symposium on Intelligent Signal Processing and Communication Systems 2017

NOVEMBER 6-9, 2017, XIAMEN, CHINA

NP-L5， Paper ID: 8

Noise Spread Spectrum with Adjustable Notch Frequency in Complex Pulse Coding Controlled DC-DC Converters

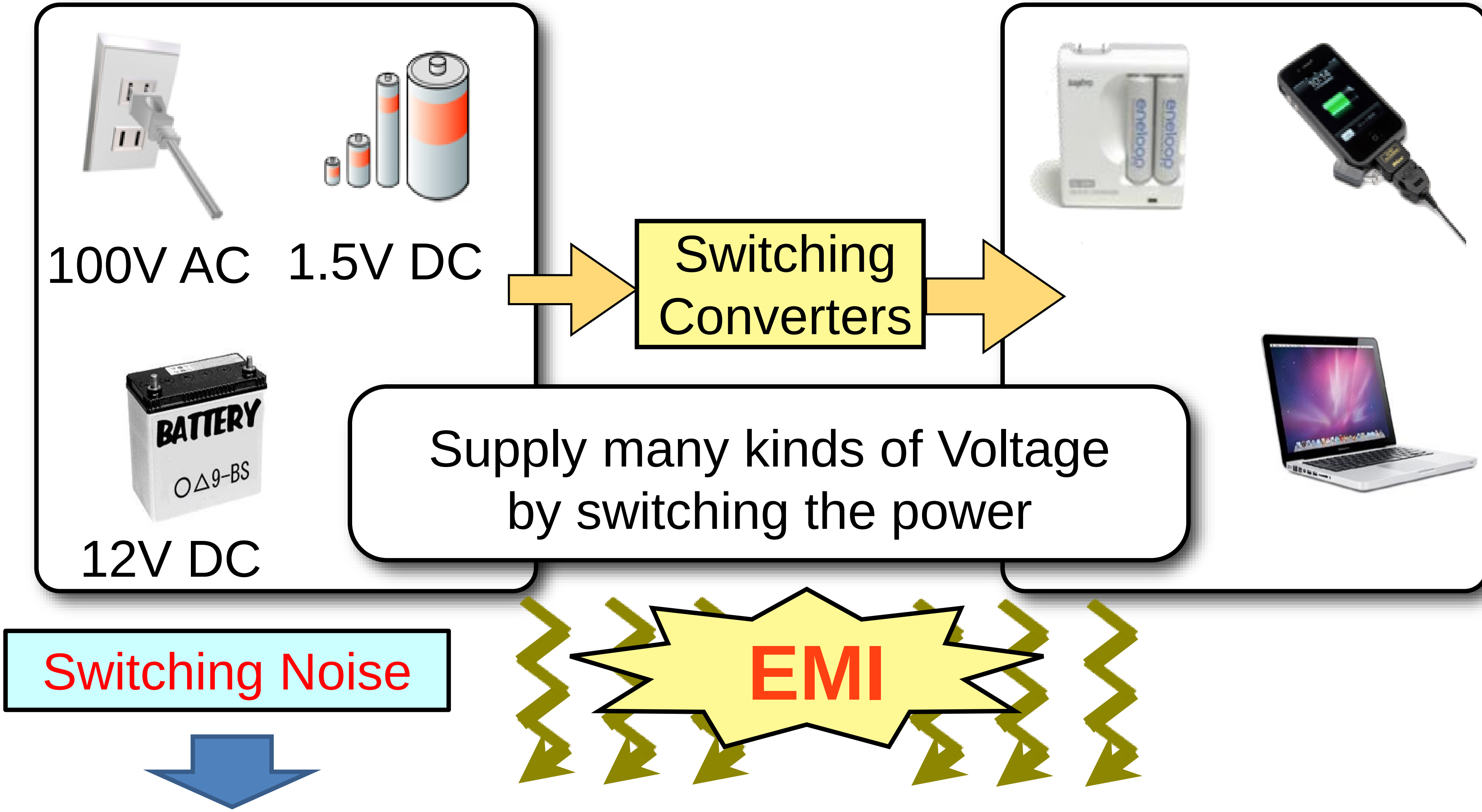
Yasunori Kobori*, Nobukazu Tsukiji, Takuya Arafune,
Manimel Wadu Sahan Dulara, Yifei Sun,
Nobukazu Takai and Haruo Kobayashi

Gunma University, Japan

Outline

1. Introduction & Objective
2. Spread Spectrum for EMI Reduction
3. Pulse Coding Method in Switching Converter
4. Experimental Result with PWC
5. Conclusion

1. Introduction & Objective



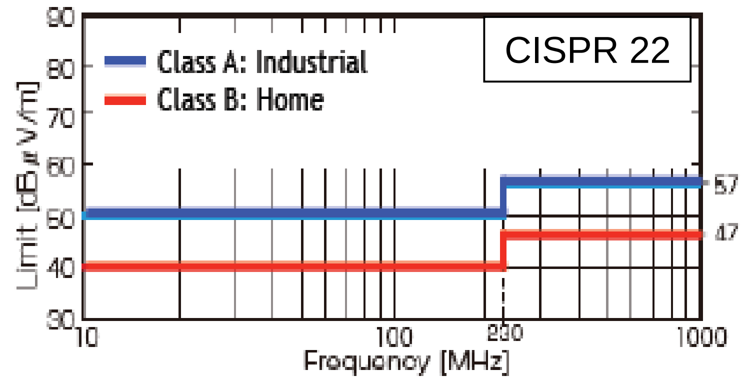
Important to reduce SW noise & to decrease main spectrum level

Fig.1-1 background (EMI)

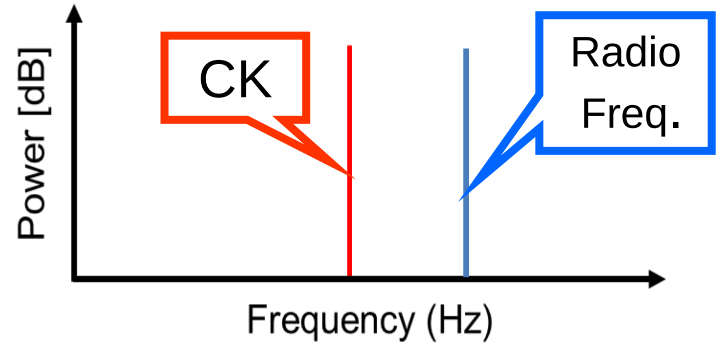
EMI: Electro-Magnetic Interference

research process

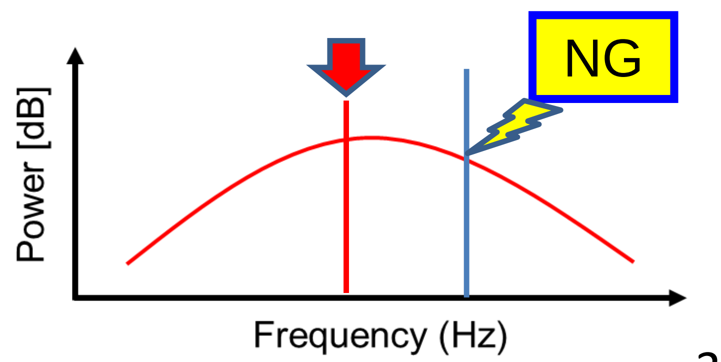
● Reduced clock noise spectrum
below the Standard Level



▲ By shaking the clock phase/frequency,
spread the clock noise around
clock frequency and harmonics.



◆ Radio receivers would not like
to be affected by spread noise.



※ Our Objective

★ Develop Spread Spectrum Method
both to reduce the EMI noise and

research process

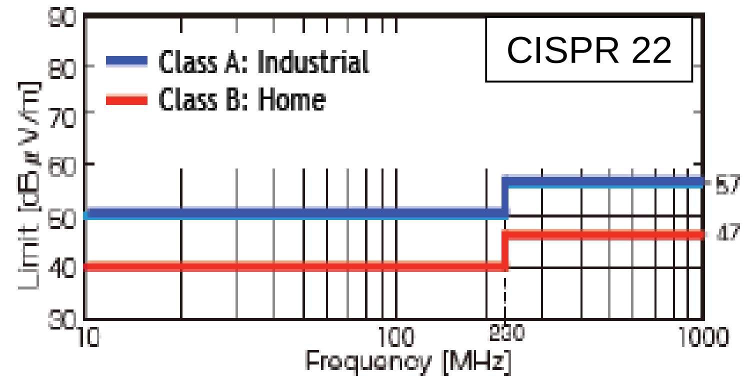
● Reduce clock noise spectrum level below the Standard Level

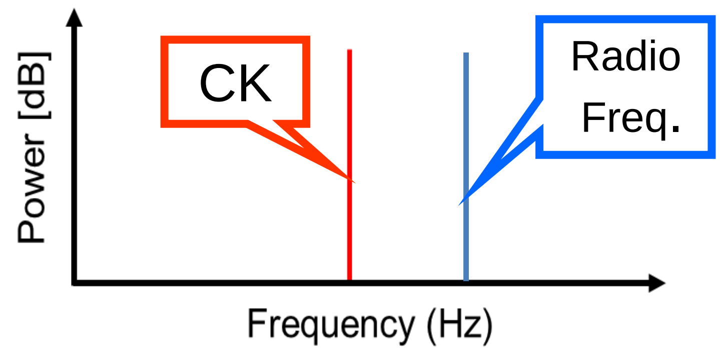
▲ By shaking the clock phase/frequency, spread the clock noise around clock frequency and harmonics.

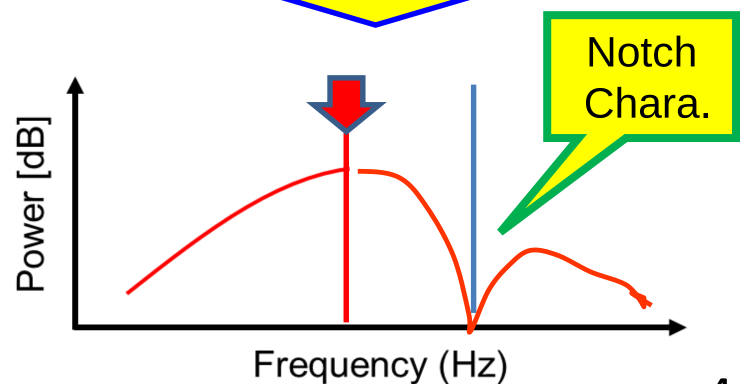
◆ Radio receivers would not like to be affected by spread noise.

※ Our Objective

★ Develop Spread Spectrum Method both to reduce the EMI noise and to reject noise at desired frequency with Notch Characteristics.







Outline

1. Introduction & Objective
2. Spread Spectrum for EMI Reduction
3. Pulse Coding Method in Switching Converter
4. Experimental Result with PWC
5. Conclusion

2. Spread Spectrum for EMI Reduction

★ Conventional switching converter

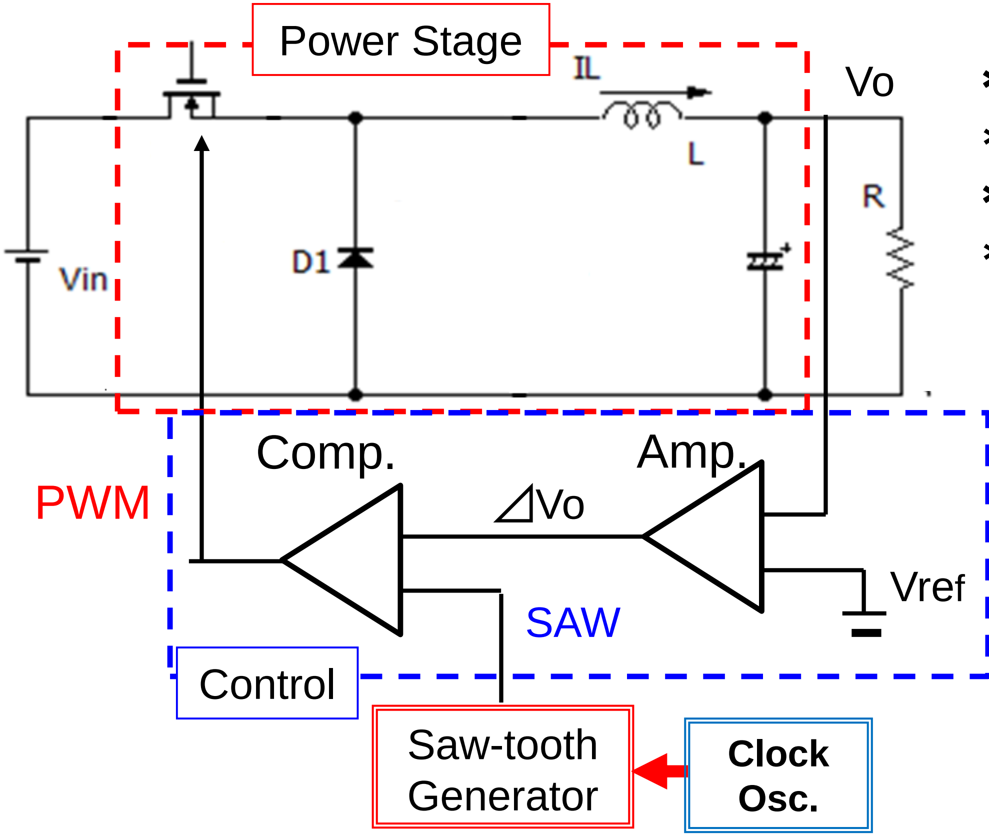


Fig.2-1 Buck type switching converter

* Consist of Power Stage and Control.
* Vo is compared with Vref and Amp.
* SAW-tooth is generated from clock.
* PWM pulse is generated by comparing SAW signal with ⊿Vo.

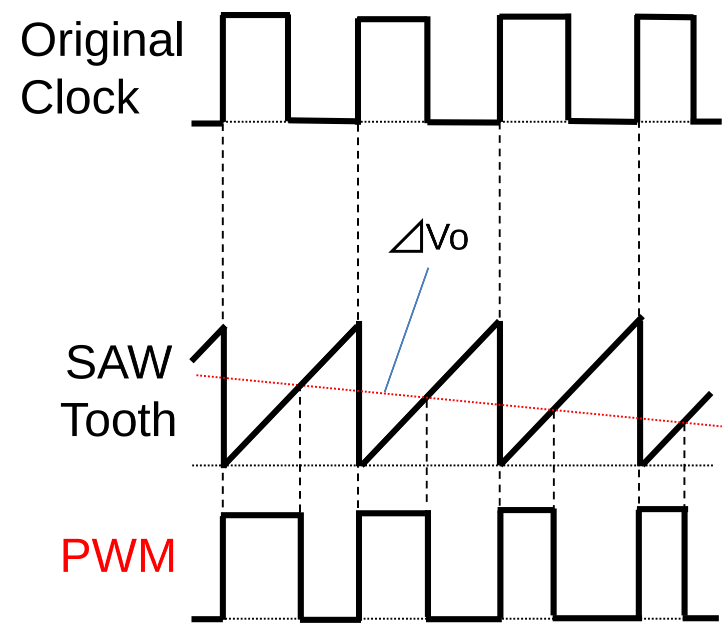


Fig.2-2 Timing Chart

2. Spread Spectrum for EMI Reduction

★ Switching converter with EMI reduction

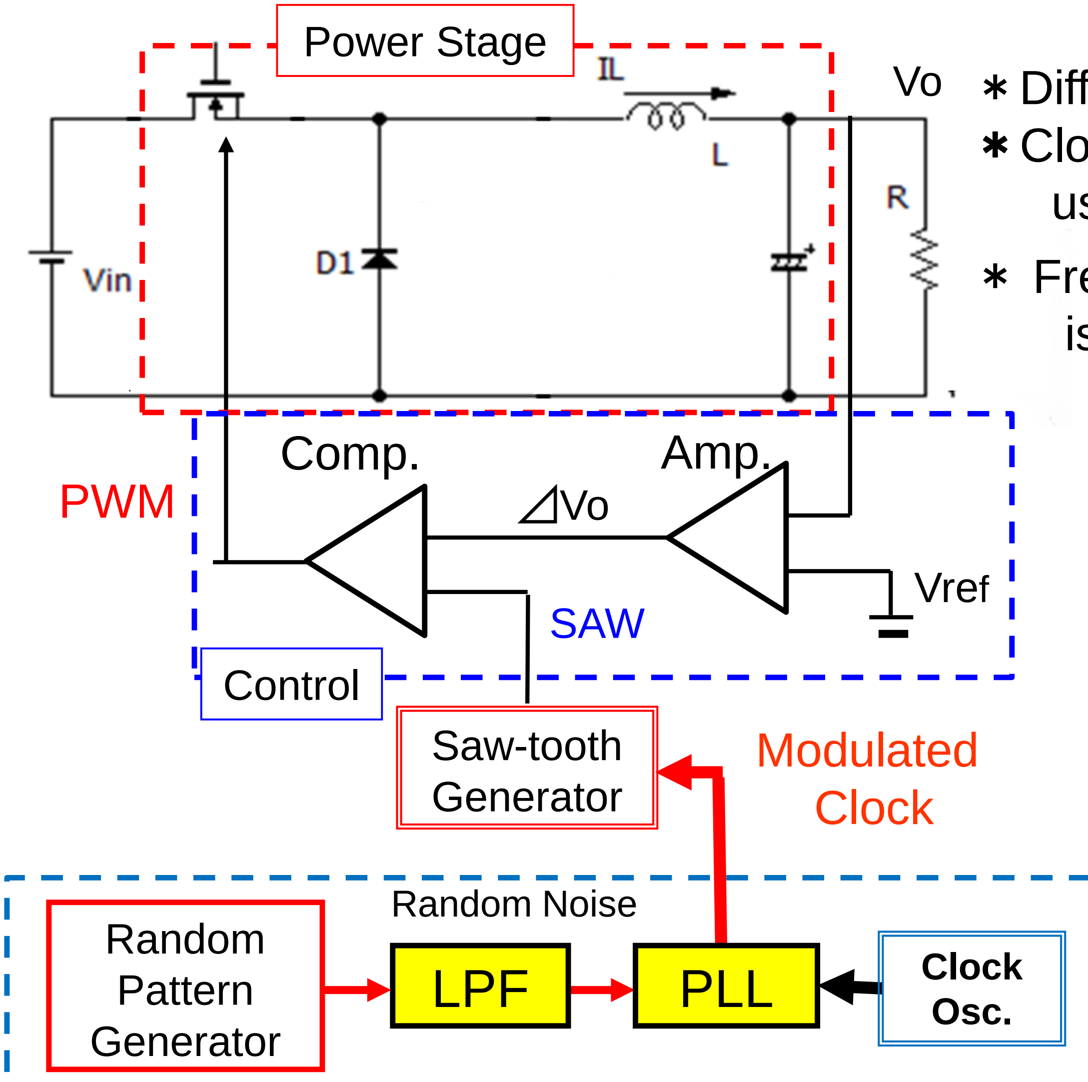


Fig.2-1’ Buck converter with modulated clock

* Difference is only the modulated clock.
* Clock is modulated by shaking frequency using PLL circuit & random noise.
* Frequency of SAW signal or PWM pulse is modulated & reduce EMI noise.

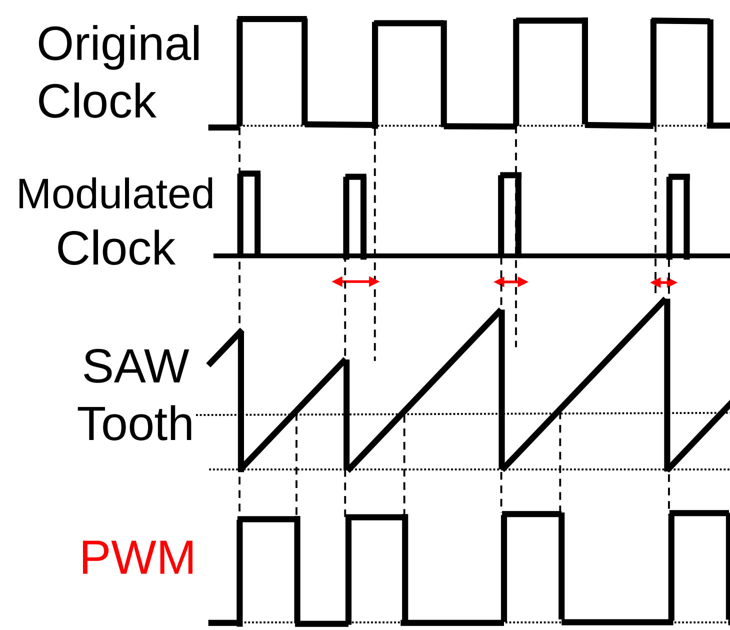


Fig.2-2’ Timing Chart

★Simulation results & spectrum

(spectrum of PWM pulse)

＊ Clock Frequency is 200kHz

● Without EMI reduction

＊Many line spectra

- Peak level of clock F. is 3.5V
- Level of 1MHz is 500mV

● With EMI reduction

＊ Clock level is reduced

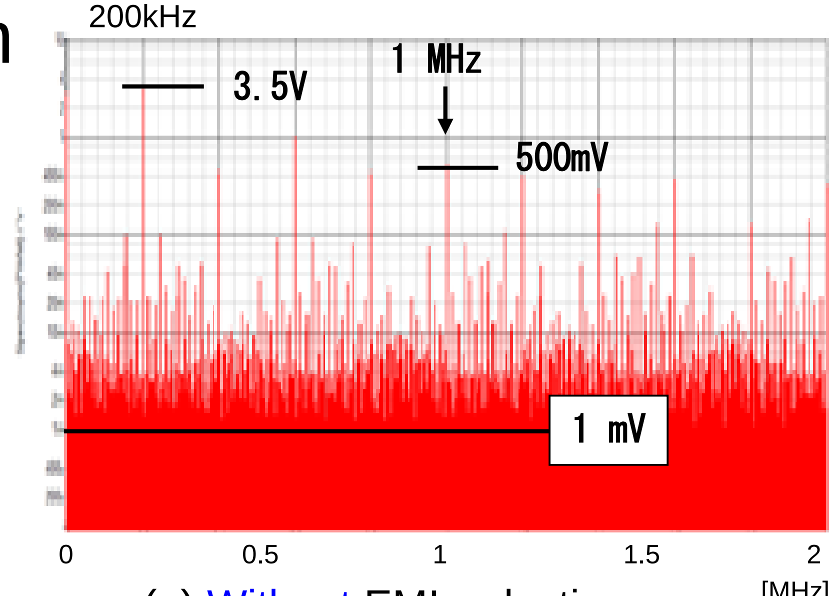
3.5V ⇒ 2.0V (-4.9 dB)

＊Harmonics is much reduced

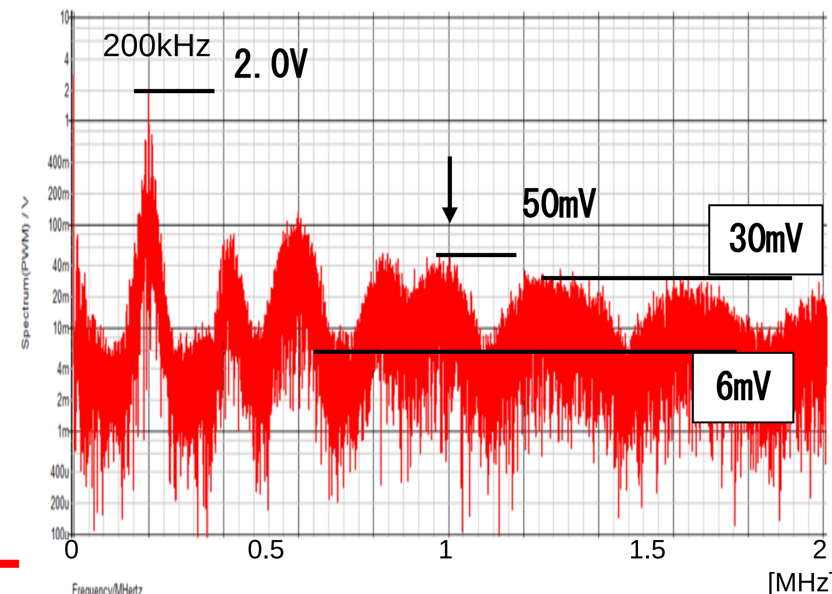
1MHz: 500mV ⇒ 50mV (-20 dB)

◆Bottom levels are increased (6mV)

★ 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) control
    - 3-2 Improved PWC control
    - 3-3 Complex Pulse Coding control
4. Experimental Result with PWC
5. Conclusion

3. Pulse Coding Method in Switching Converter

★ Switching Converter with Pulse Coding

＊Power stage is same.

＊In the control circuit,
SEL signal is generated
by comparing ⊿Vo with Vref.

･PWM pulse is selected from
Pulse-H or Pulse-L
according to SEL signal.

＊To control output voltage Vo,
relationship of pulse duty ratio is

$$D_H > D_O > D_L \qquad (1)$$

Here, D_H is D of Pulse-H
D_L is D of Pulse-L
$D_O = V_o/V_{in}$ (V conversion R.)

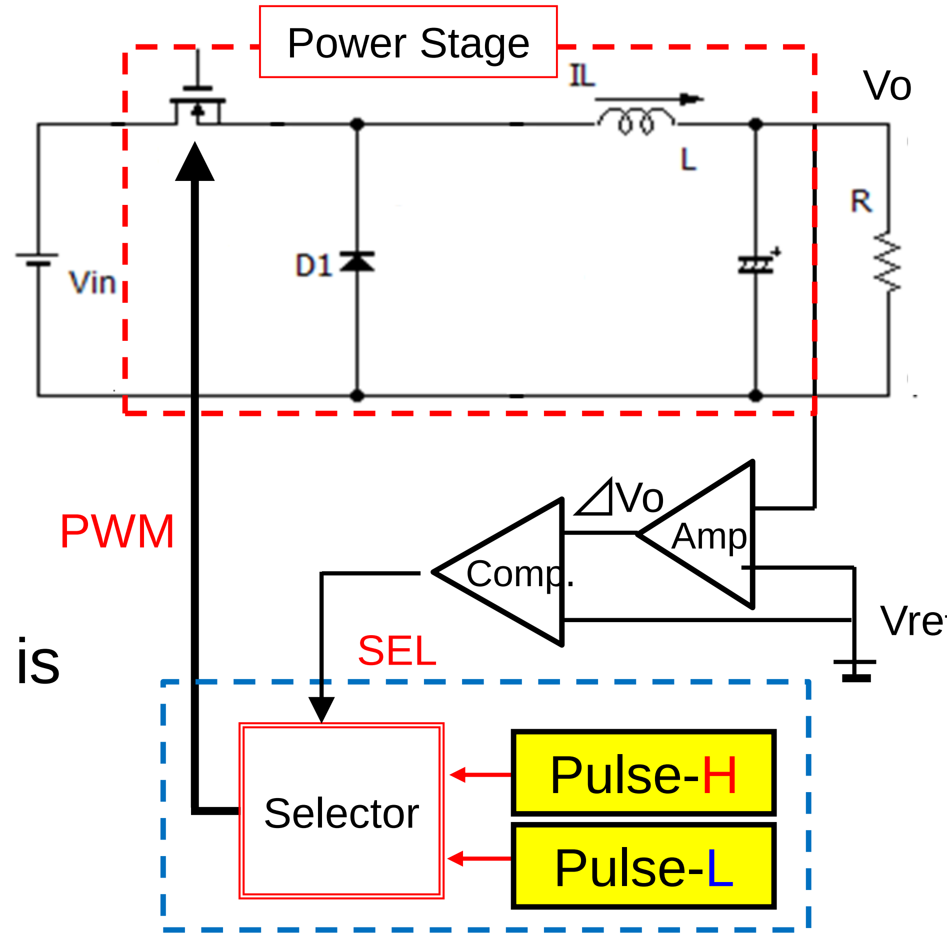


Fig.3-1 Converter with Pulse Coding

3-1 Pulse Width Coding (PWC)

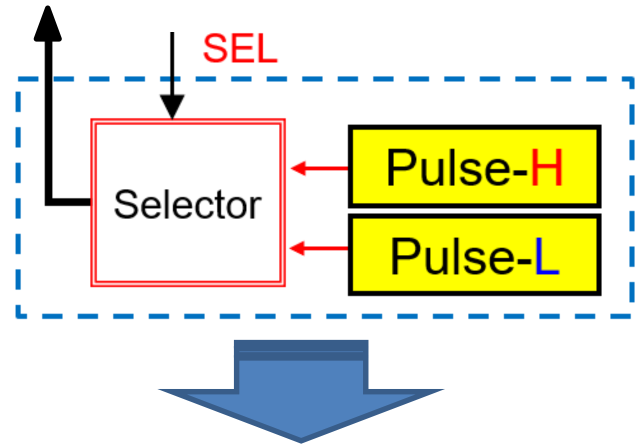
∗ Conditions: Vi=10V, Vo=5V, Fck=500kHz

∴ Do = Vo/Vi = 0.5

★ Coding pulses of PWC control

Pulse-H : W_H =1.7us, D_H =0.85

Pulse-L : W_L =0.4us, D_L =0.20



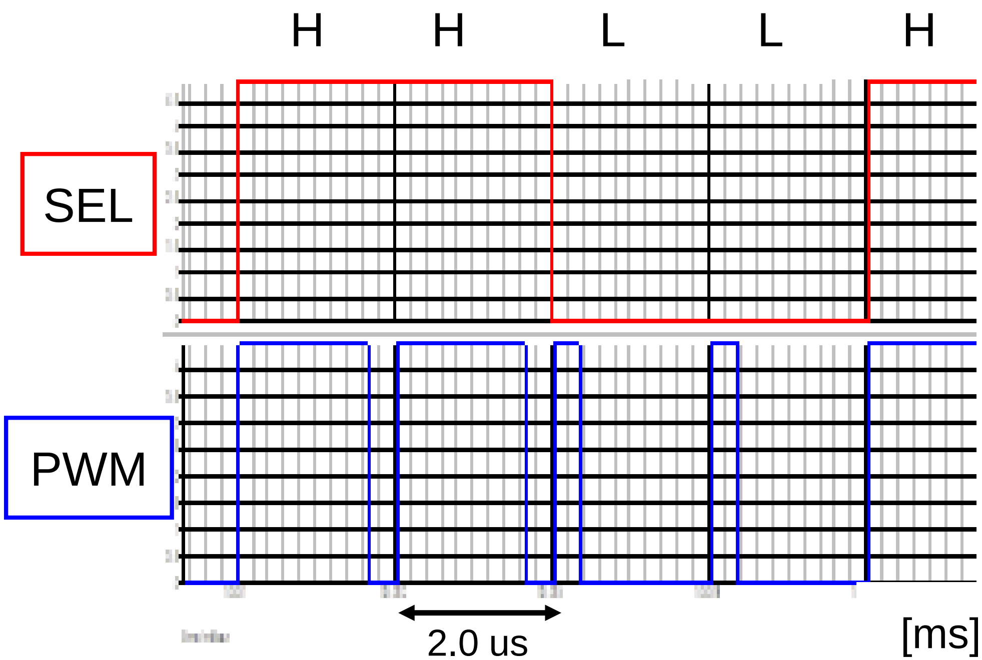


Fig.3-3 SEL signal & PWM pulses

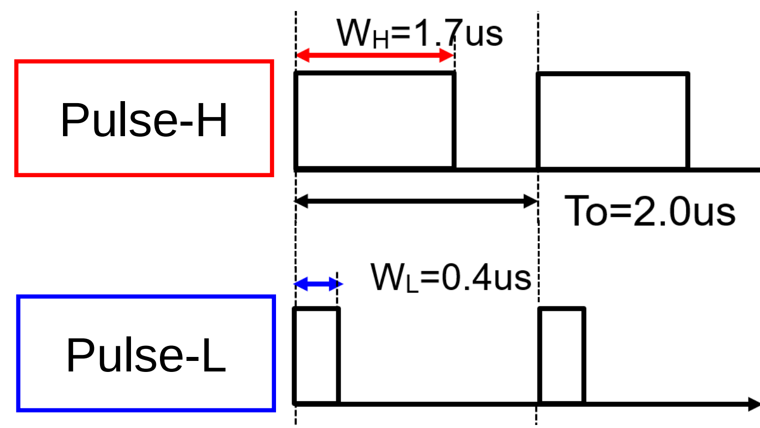


Fig.3-2 PWC Pulses

●Simulation results with PWC

(1) Output Voltage Ripple

- Static ripple < 2 mVpp @Io=0.25A
- Overshoot = 2.5 mV @⊿Io=0.125A

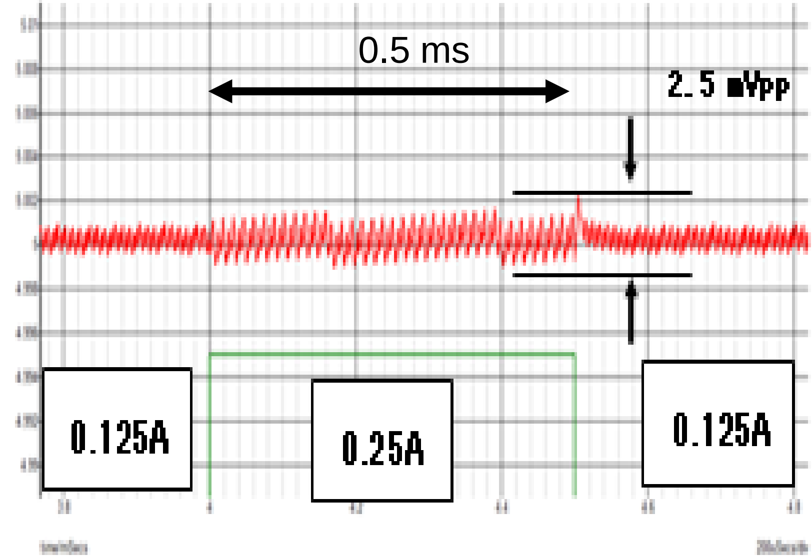


Fig.3-4 Output ripple with PWC

(2) Spectrum of PWM pulse

＊ Theoretical Notch Frequency

$F_N = N/(W_H - W_L)$ (2)

=N/1.3us=770kHz, 1.5MHz

（N: natural number)

- Peak Level Reduction:

  3.5V ⇒ 0.9V (－11.8 dB)

＊ Bottom Leve is deeper:

V_B =－45dB ⇒－65 dB (－20dB)

Control notch frequency!

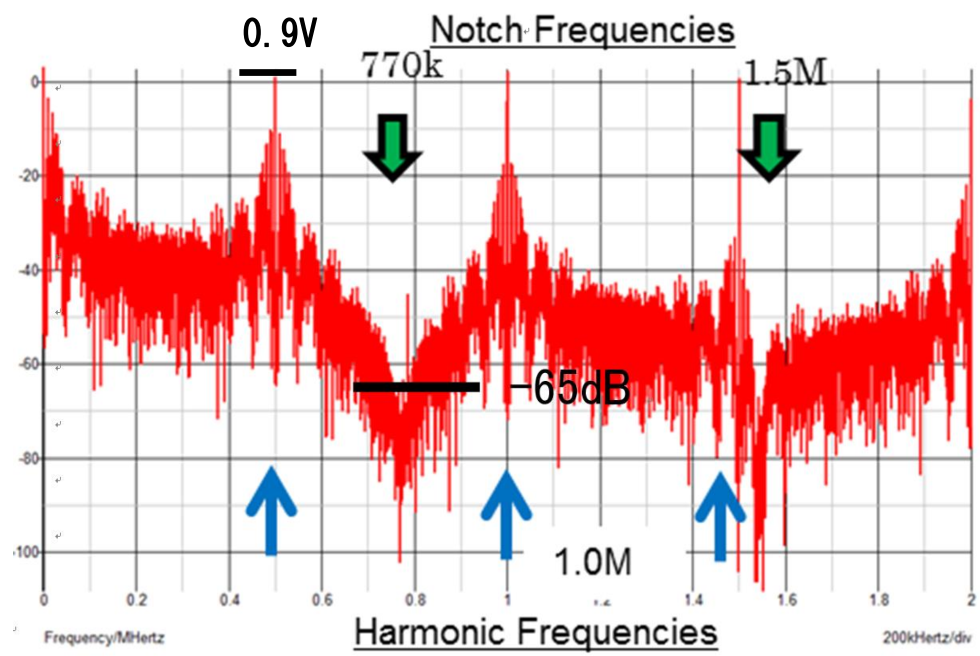


Fig.3-5 Spectrum with PWC

3-2 Improved PWC Control

＊Voltage conversion ratio Do=Vo/Vi < 0.3,
W_L is set 0 us & design W_H only.

＊When Do > 0.7, W_H is 1 (always H) & design W_L only.

● Simulation result

＊When Do= 3V/10V = 0.3

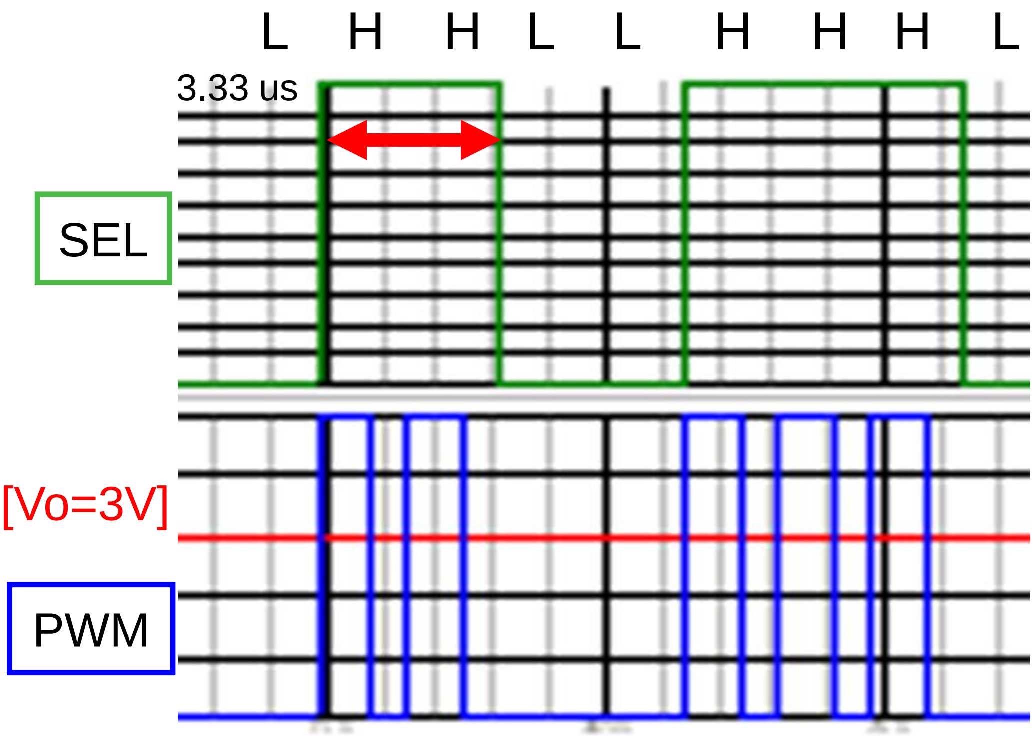


Fig.3-8 Signals of Improved PWC

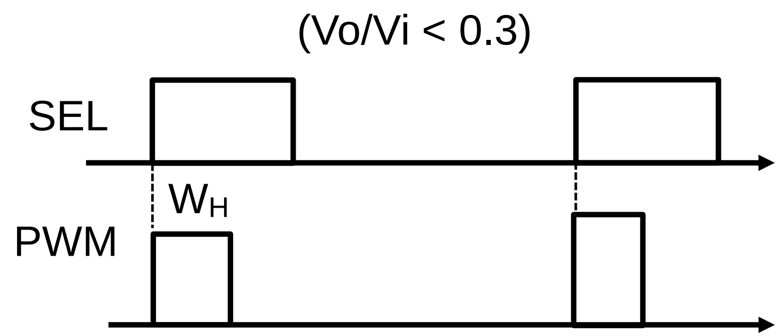


Fig.3-6 Improved PWC 1

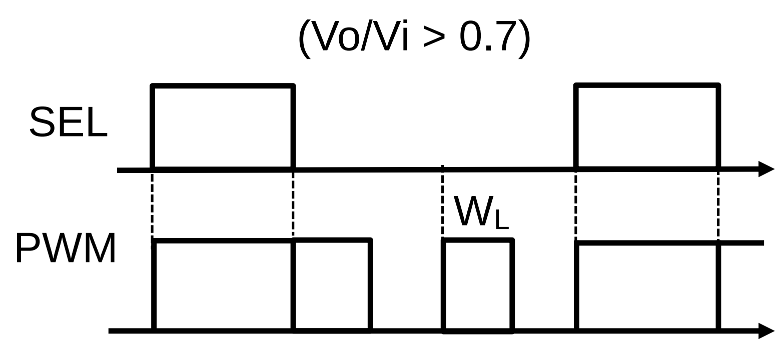


Fig.3-7 Improved PWC 2

● Noise Spectrum of Improved PWC control

∗ Duty Ratio: Do = 3.0V／10V = 0.3, Fck=600kHz（Tck=1.67us）

∗ W_H =1.39 us (D_H = 0.46), W_L = 0 us (Low)

∗ Notch Freq.: F_N = N/1.39= 0.72, 1.44, 2.16, 2.88 MHz, ・・・

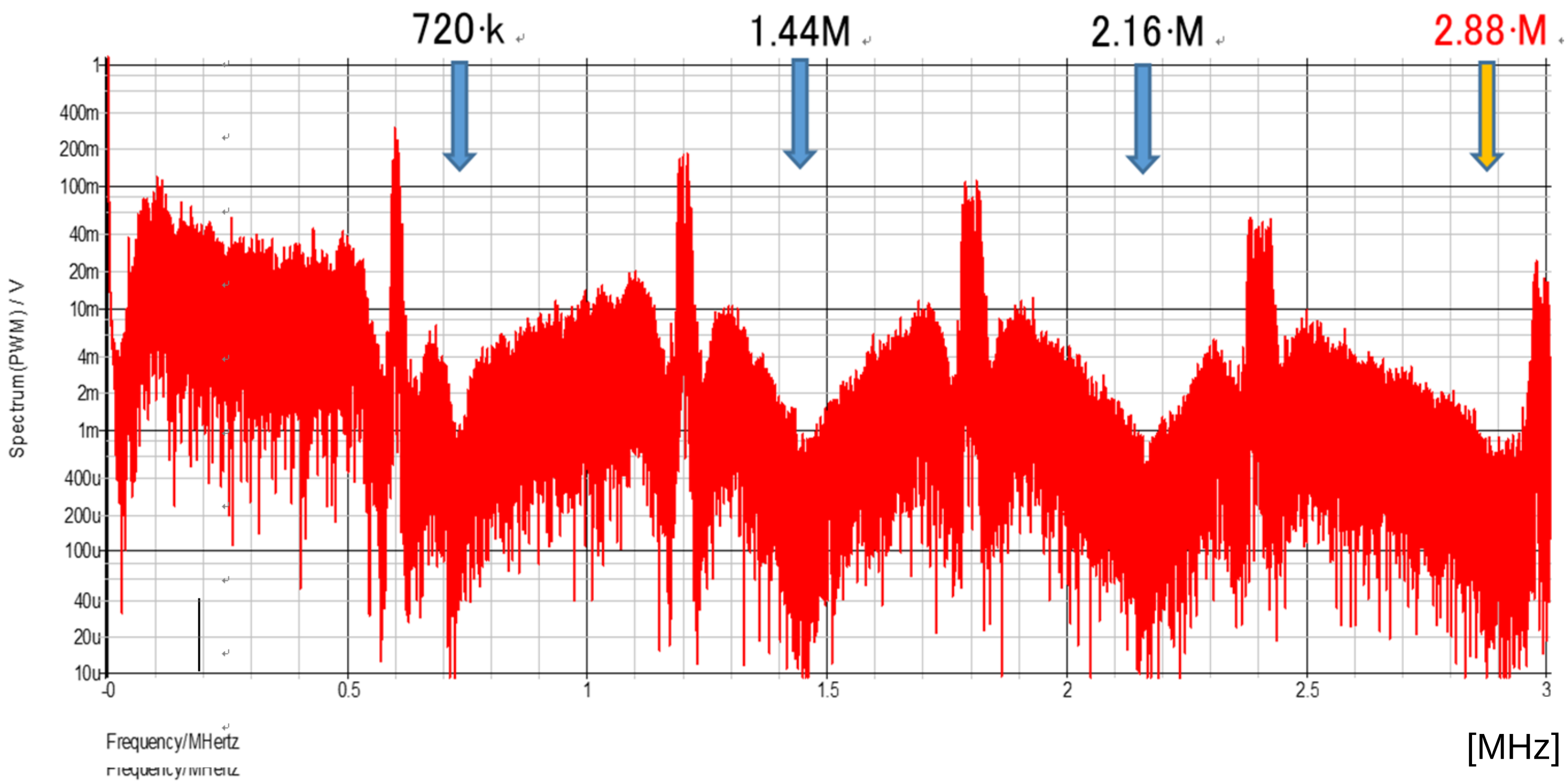


Fig.3-9 Noise Spectrum of Improved PWC control 1

3-3 Complex Pulse Coding Control

- Pulse Phase Coding (PPC) control

∗ Pulse width W is same
but phase is different with time τ .

∗ Theoretical Notch Frequency

$$F_N = N/(2 \cdot \tau) \qquad (3)$$

∗ But this coding is NG for Vo control
because duty ratios are not different.

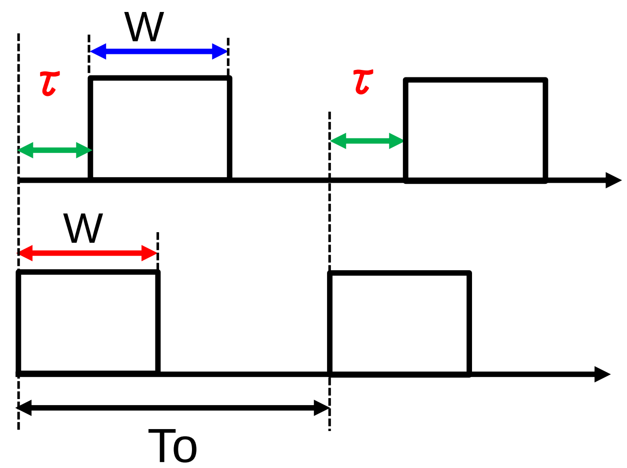


Fig.3-10 Pulse Phase Coding

- Complex Pulse Coding control

∗ Mix PWC+PPC ⇒ PWPC control

∗ Theoretical Notch Frequencies

$$Fn_1 = N / (2\tau) , \quad Fn_2 = M / (W_H - W_L)$$

(N,M : natural number)

◆ $Fn_1 = Fn_2$ ⇒ Large Notch

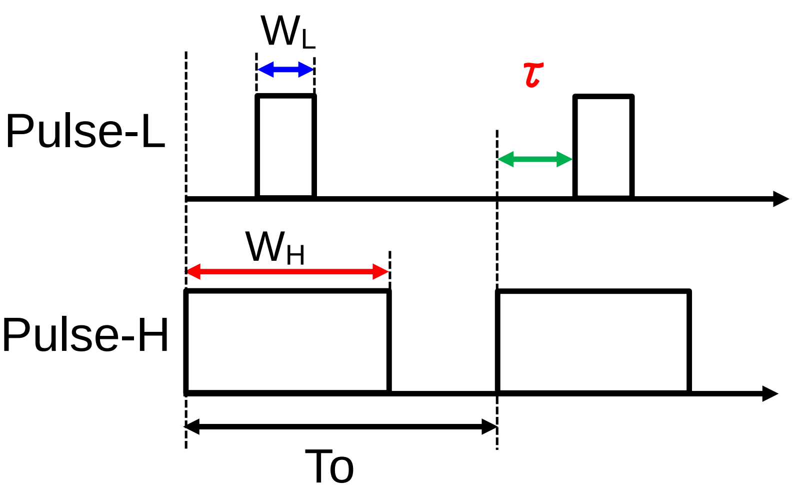


Fig.3-11 Complex Pulse Coding

● Noise Spectrum of PWPC control:

＊Conditions: Vi=10V, Vo=5.0V, Fck=1.4 MHz (Tck=714 ns)

W_H =480 ns, W_L = 320 ns, $\tau = (W_H - W_L)/2$ = 80 ns

＊Notch Frequency: F_N = 1/160ns= 6.25 MHz

Bottom Level: V_B : −65dB ⇒ −75 dB (−10dB)

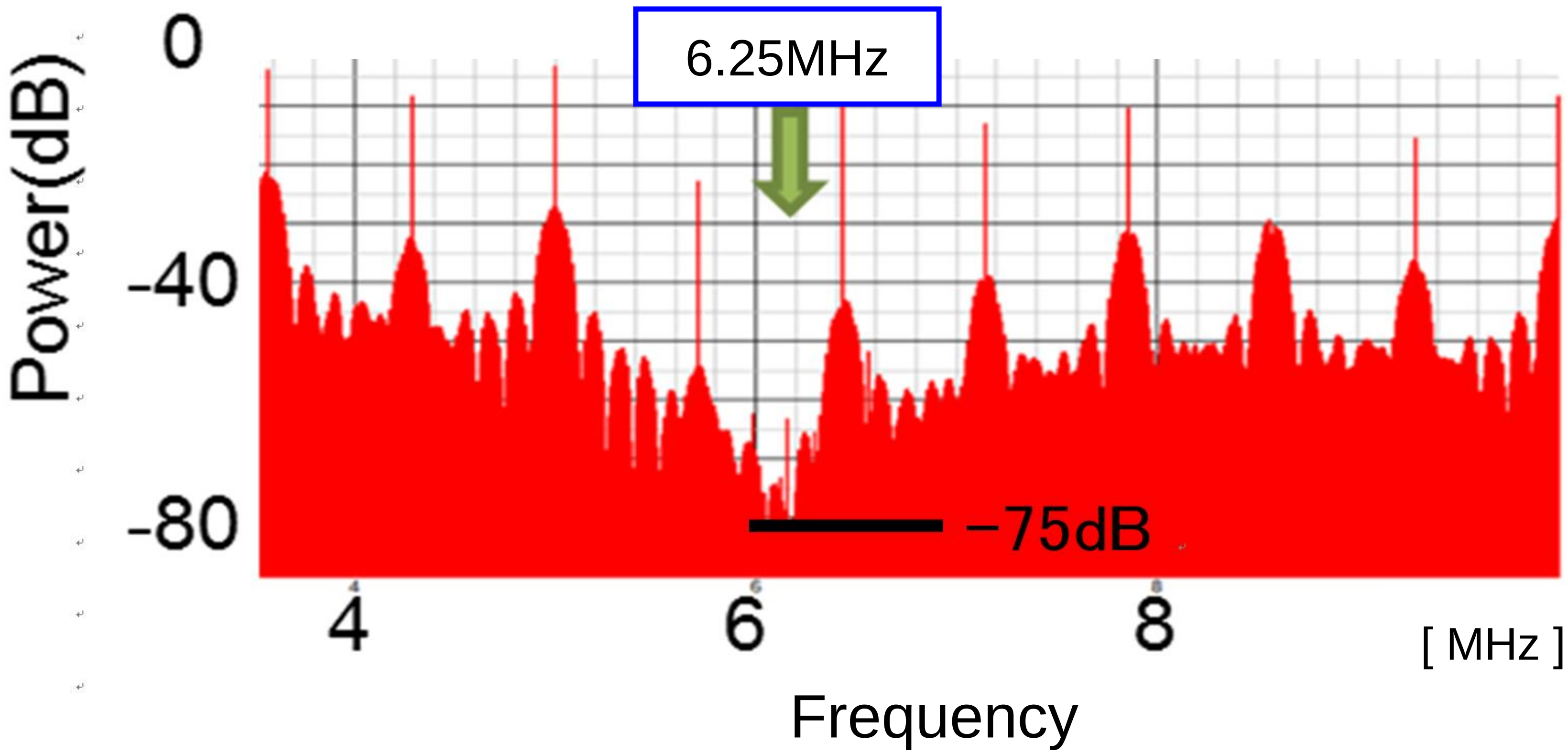


Fig.3-12 Noise Spectrum of PWPC control

Outline

1. Introduction & Objective
2. Spread Spectrum for EMI Reduction
3. Pulse Coding Method in Switching Converter
4. Experimental Result with PWC
5. Conclusion

4. Experimental Result with PWC

- Experimental noise spectrum with PWC

∗ Conditions: Vi=10 V, Vo=5.0V, Io= 0.25 A,
W_H =1.46us, W_L =0.40us, Fck=600 kHz

∗ Notch Freq. : F_N = 1/1.06us = 920kHz (Fck ＜ F_N ＜ 2·Fck)

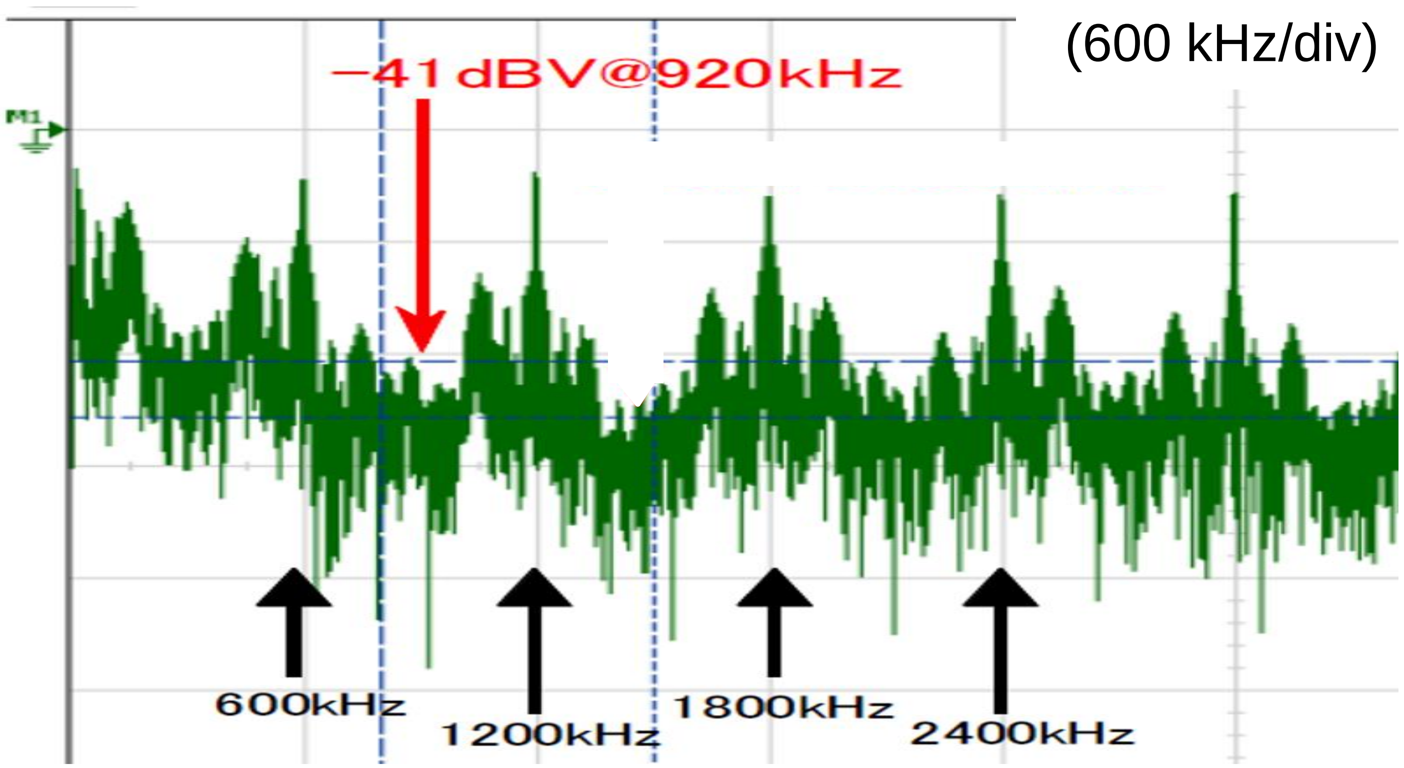


Fig.4-1 Noise Spectrum with PWC control

●Output Voltage Ripple with PWC control

- Static ripple = 8mVpp @ Io=530 mA (0.2% of 5V)
- Overshoot/Undershoot = 18mV (Include offset)

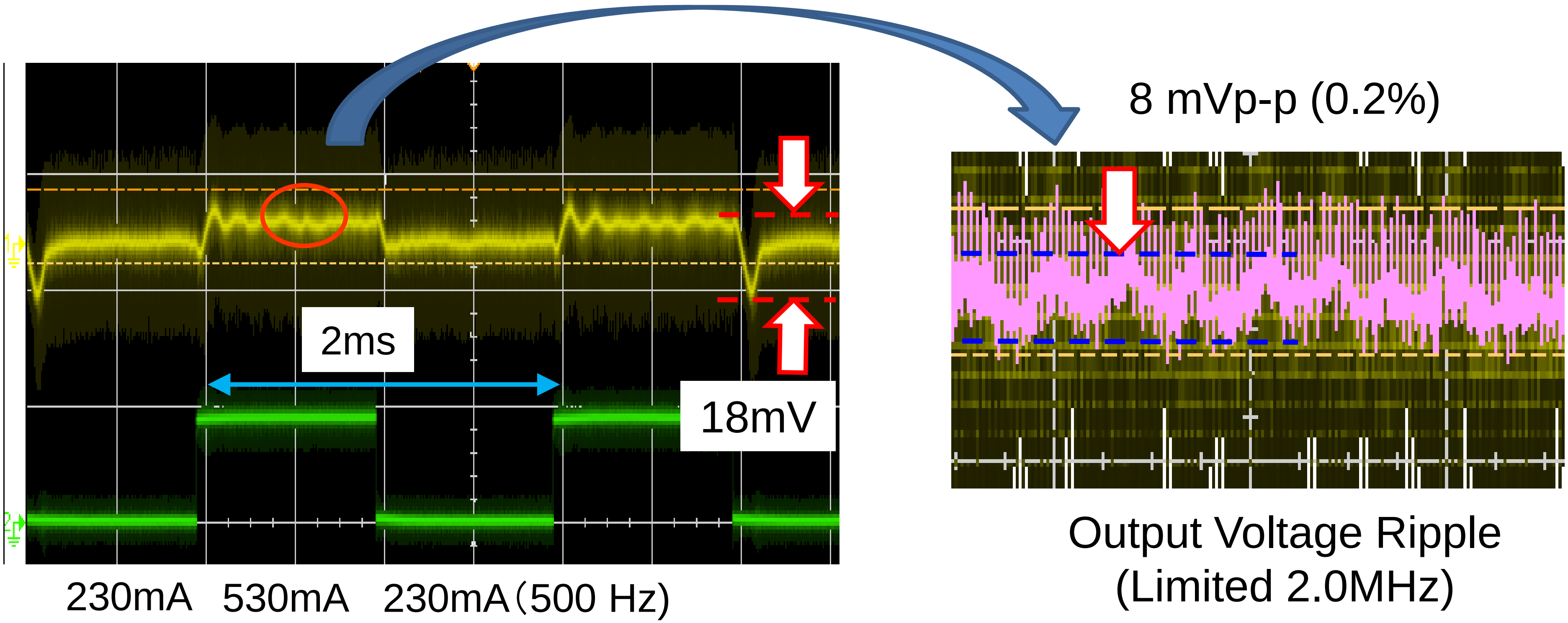


Fig.4-2 Output Voltage Ripple of experimental PWC converter

● Another Experimental noise spectrum with PWC

∗ Conditions

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

∗ Notch Freq.：F_N =1／(2.0－1.0)us = 1.0 MHz

(2·Fck ＜ F_N ＜ 3·Fck)

DSO-X 4024A, MY53480449: Fri Feb 12 12:44:06 2016

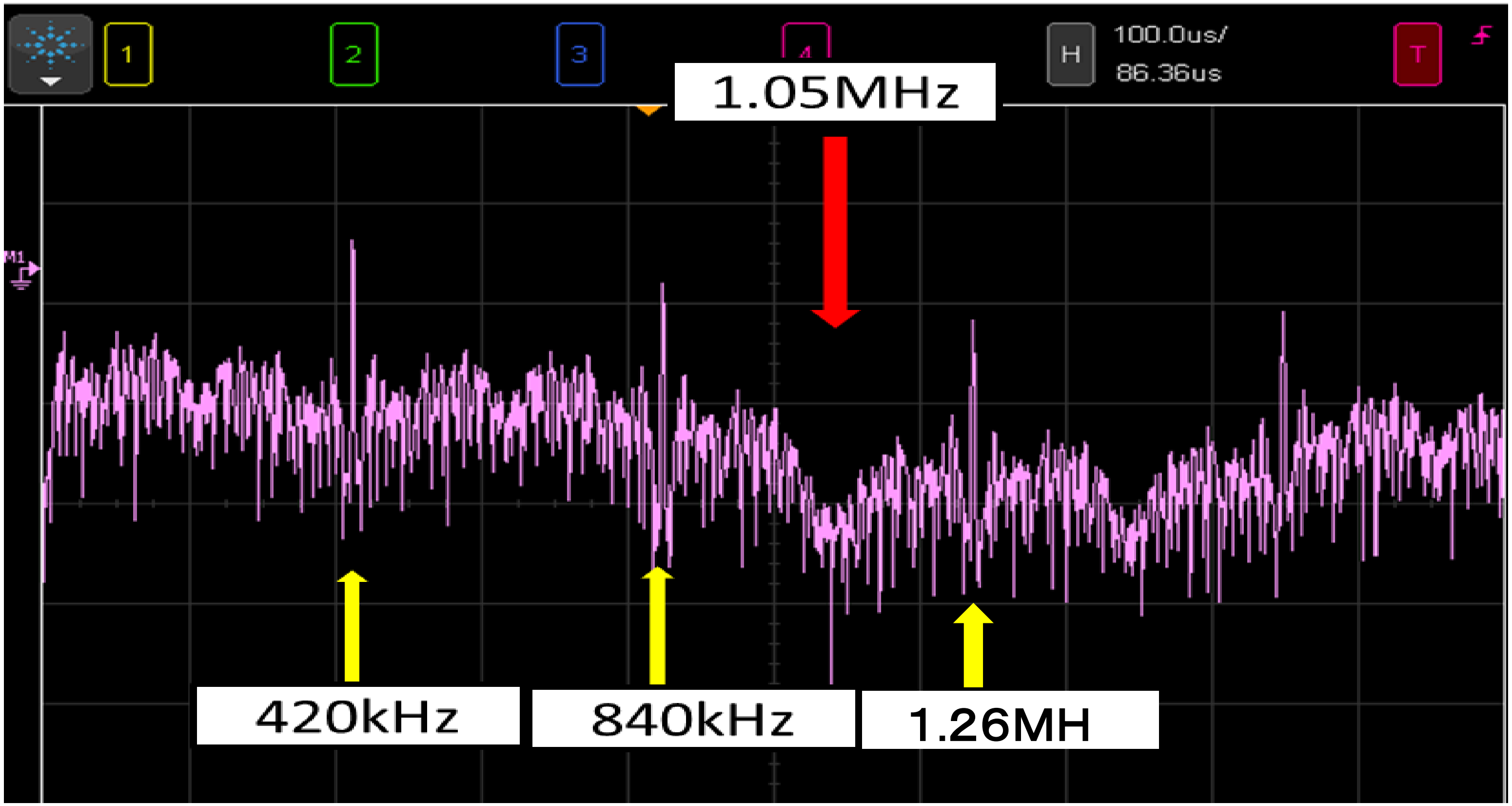


Fig.4-3 Another spectrum with high frequency

● Experimental noise spectrum with improved PWC

∗ Conditions: Fck=600kHz (T=1.67us)

W_H = 1.32 ns (D_H =0.8), W_L = 0.0 ns [Do=0.5]

∗ Notch Freq.: F_N =N／1.32us = 0.76, 1.5, 2.3 MHz

⇒ There appear 1.5MHz (2･F_N) & 2.3MHz (3･F_N)

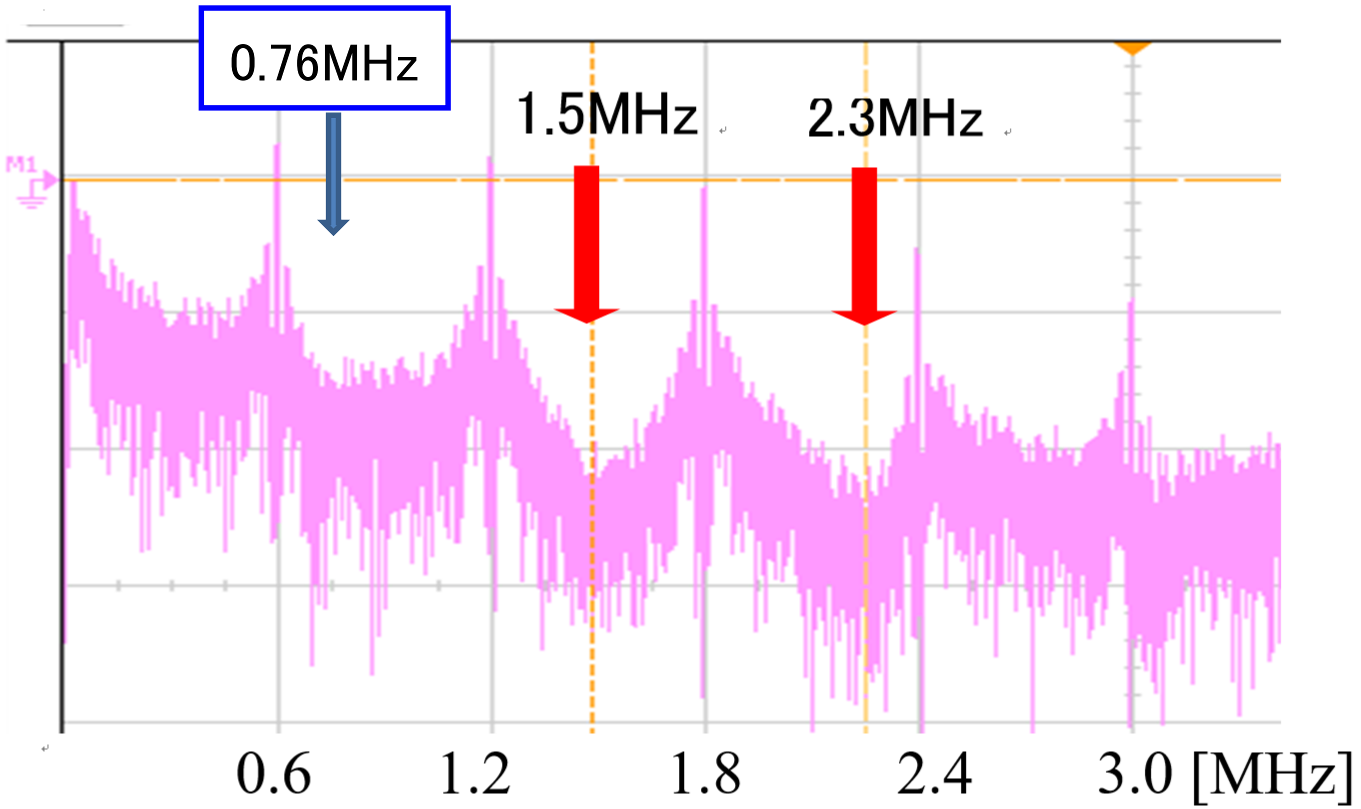


Fig.4-4 Noise Spectrum with Improved PWC

Conclusion

★ Pulse Width Coding (PWC) control with notch characteristics at a desired frequency

1. Notch Frequencies with pulse coding:
   - $F_N = N / (W_H - W_L)$ with PWC,
   - $F_N = M / (2\tau)$ with PPC

   ∗ $V_{peak} = 3.5V \Rightarrow 0.9V$ (−11.8 dB)

2. Simulated Noise Spectrum with Complex Pulse Coding:
   - ∗ PWC : $F_N = 0.77$ MHz : $V_{bottom} = -65$dB
   - ∗ Impr. PWC: $F_N = 0.72$, 1.44MHz
   - ∗ PWPC : $F_N = 6.25$ MHz : $V_{bottom} = -75$dB

3. Experimental Noise Spectrum with PWC
   1) PWC(1) : $F_N = 940$kHz ($Fck < F_N < 2 \cdot Fck$)
   2) PWC(2) : $F_N = 1.00$MHz ($2 \cdot Fck < F_N < 3 \cdot Fck$)
   3) Impr. PWC : $F_N =$(0.76), 1.5, 2.3 MHz

Thank you for your kind attention!

Any question?