Selectable Notch Frequencies of EMI Spread Spectrum Using Pulse Modulation in Switching Converter

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**Gunma University

Outline

1. Introduction & Objective
2. Spread Spectrum for EMI Reduction
3. Pulse Coding Method in DTC
    3-1 PWM Pulse Coding with Notch Frequency
    3-2 PCM Pulse Coding with Notch Frequency
4. Spread Spectrum in Switching Converter
    4-1 Spread Spectrum with PWM Coding
    4-2 Spread Spectrum with PCM Coding
5. Conclusion

DTC : Digital to Time Converter
PWM: Pulse Width Modulation
PCM: Pulse Cycle Modulation

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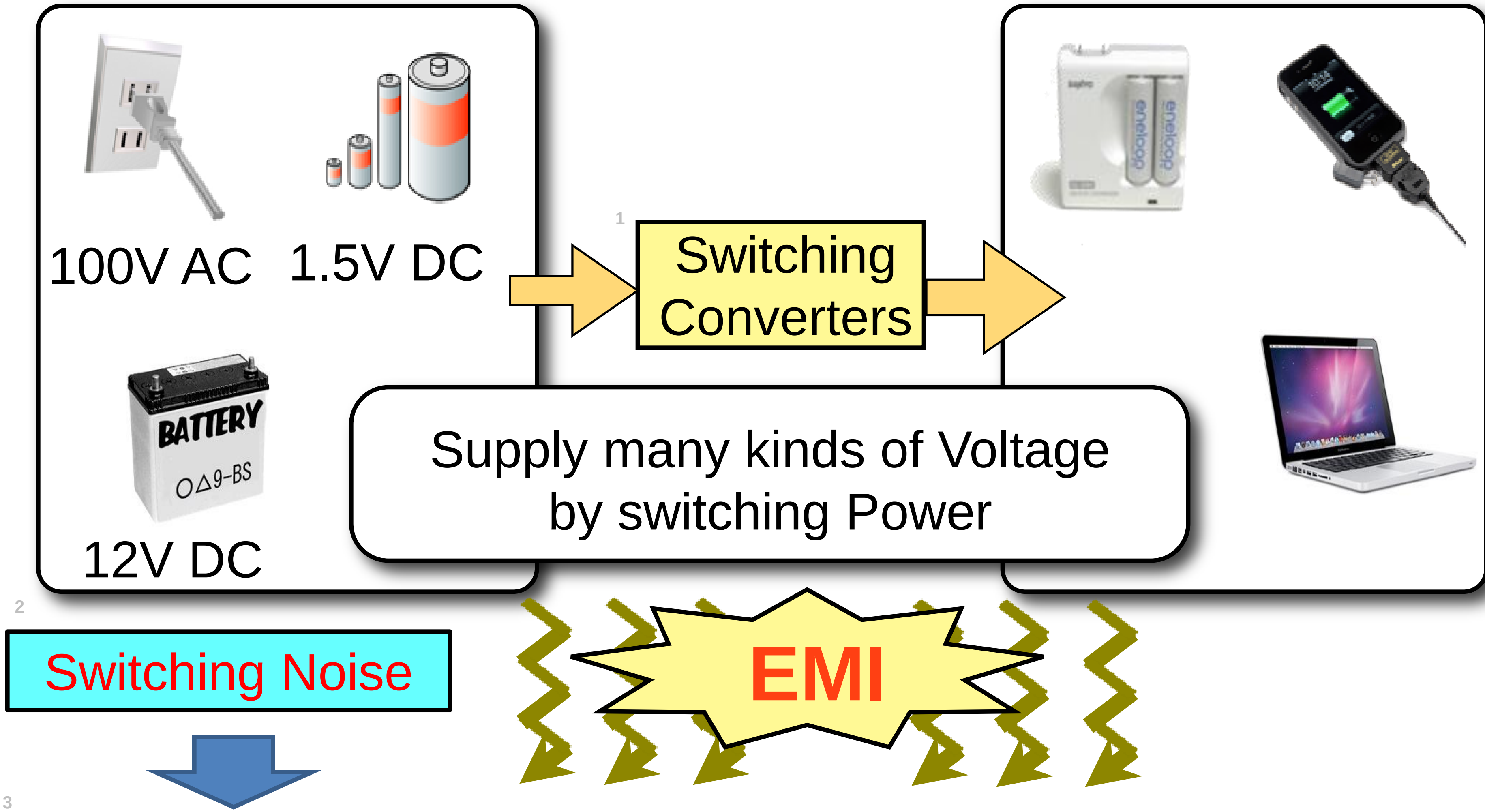
1. Introduction & Objective



Important to reduce SW noise by decreasing main spectrum level

Fig.1-1 background (EMI)

EMI: Electro-Magnetic Interference

1. Introduction & Objective

● We reduce the clock noise by spread spectrum
with shaking the clock phase at random.

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

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

★ Spread Spectrum Method is required
with notch frequency and noise reduction.

- Objective:

1) Clear the relationship between
notch frequencies and parameters of coding pulses.

2) Simulate the notch frequency in spread spectrum
with PWM and PCM pulse coding.

3) Check the notch frequencies in the switching converter
with pulse coding and EMI reduction.

Outline

2. Spread Spectrum for EMI Reduction

★Developed EMI reduction method as previous presentation.

＊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.

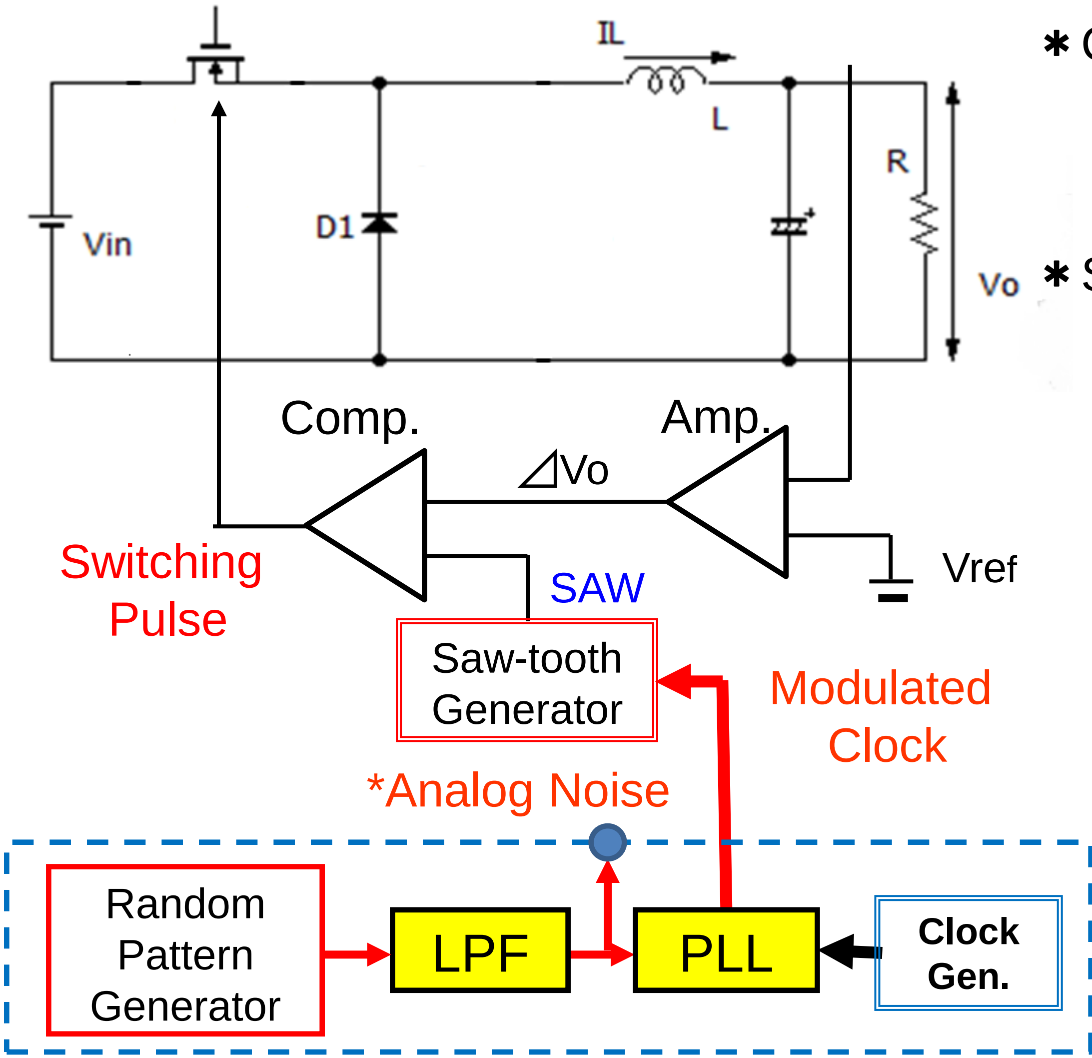


Fig.2-1 Buck converter with modulated clock

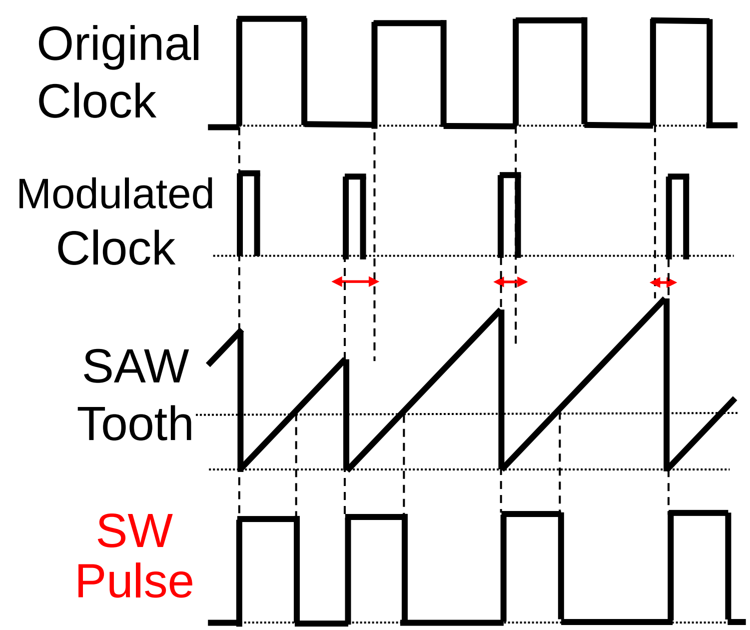


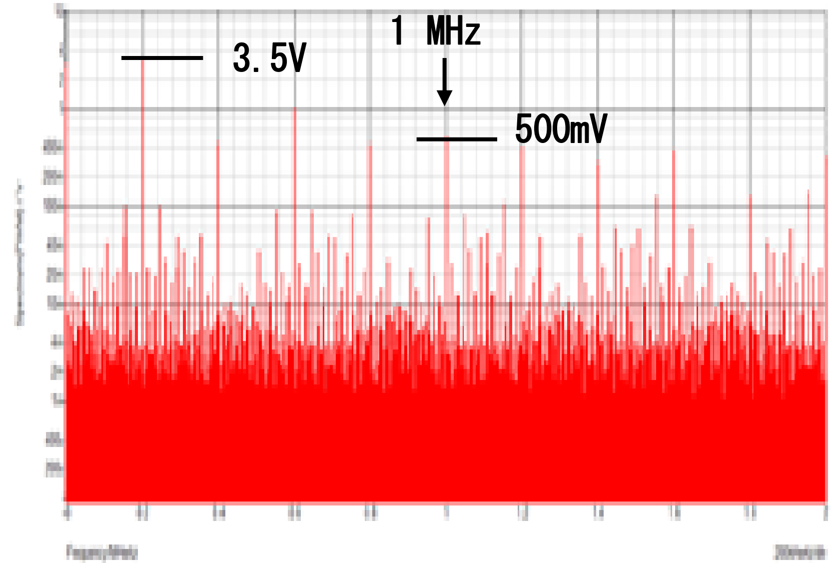
Fig.2-2 Timing Chart

★ Simulation results of spread spectrum with EMI reduction.

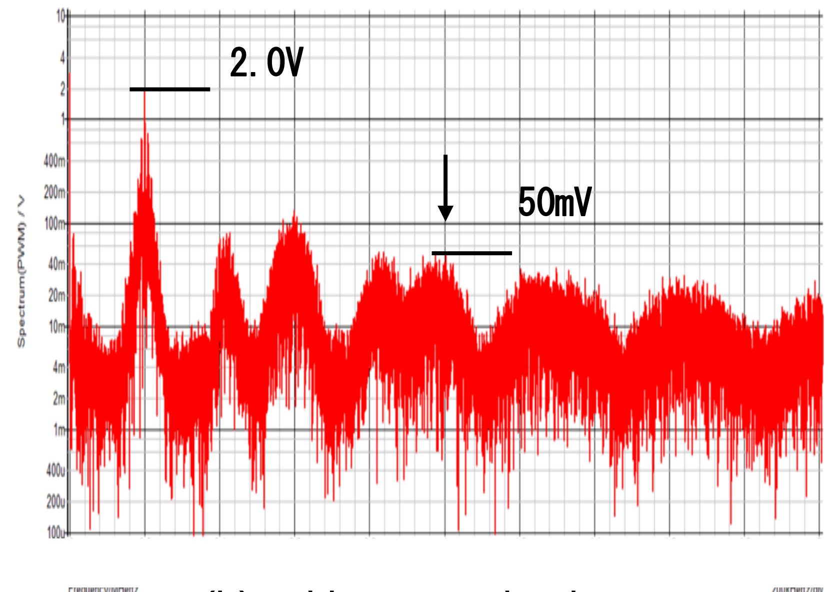
- ●Clock Frequency (200kHz) Peak level is reduced from 3.5V to 2.0V (-2.4 dB)
- ● Harmonic frequency (1 MHz) from 500mV to 50mV (-10 dB)

◆ 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

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3. Pulse Coding Method in DTC
   3-1 PWM Pulse Coding with Notch Frequency
   3-2 PCM Pulse Coding with Notch Frequency

4. Spread Spectrum with Noise Reduction & Notch Frequency
   4-1 Spread Spectrum with PWM Coding
   4-2 Spread Spectrum with PCM Coding

5. Conclusion

DTC : Digital to Time Converter
PWM: Pulse Width Modulation
PCM: Pulse Cycle Modulation

3. Pulse Coding Method in DTC

3-1 PWM Pulse Coding with Notch Frequency

● Pulse Coding in Digital-to-Time Converter (DTC)

Digital Signal ⇒ 3 Pulse Coding (PWM, PPM, PCM)

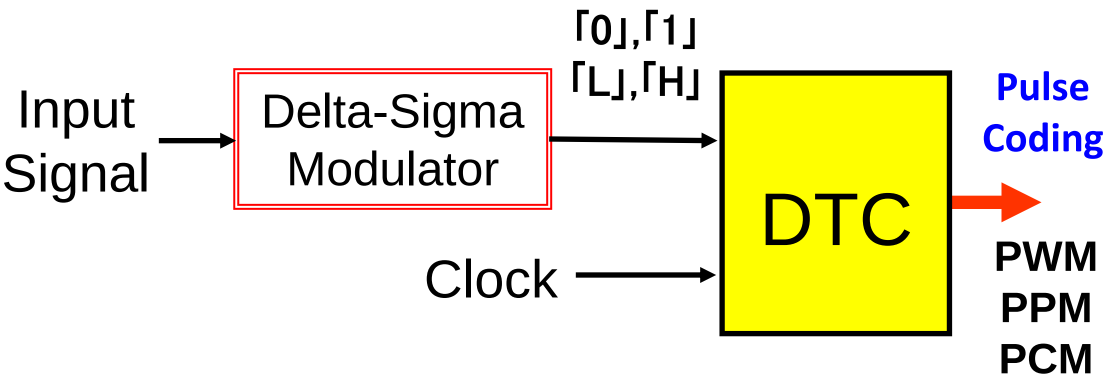

Fig.3-1 Digital to Time Converter (DTC)

PWM: Pulse Width Modulation
PPM : Pulse Position Modulation
PCM : Pulse Cycle Modulation

★ PWM Coding

∗ Period is constant. : To

∗ Pulse Width is different.

・Select " W_L pulse " when 「L」 comes.

・W_L means width of Low-duty pulse.

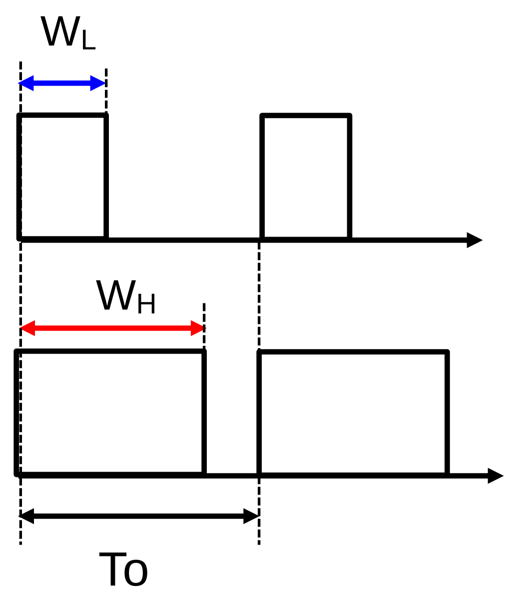

Fig.3-2 PWM Coding Pulse

★ Simulation Result with PWM Coding

∗ Parameters of coding pulses:

W_L = 200us , W_H = 600us (To=1.0 ms)

∗ Notch Frequency: $F_N = k／(W_H - W_L)$ ・・・ (1)

Here, F_N is independent on the period.

∗ F_N = k／400us = 2.5, 5.0, 7.5 ・・・[kHz]

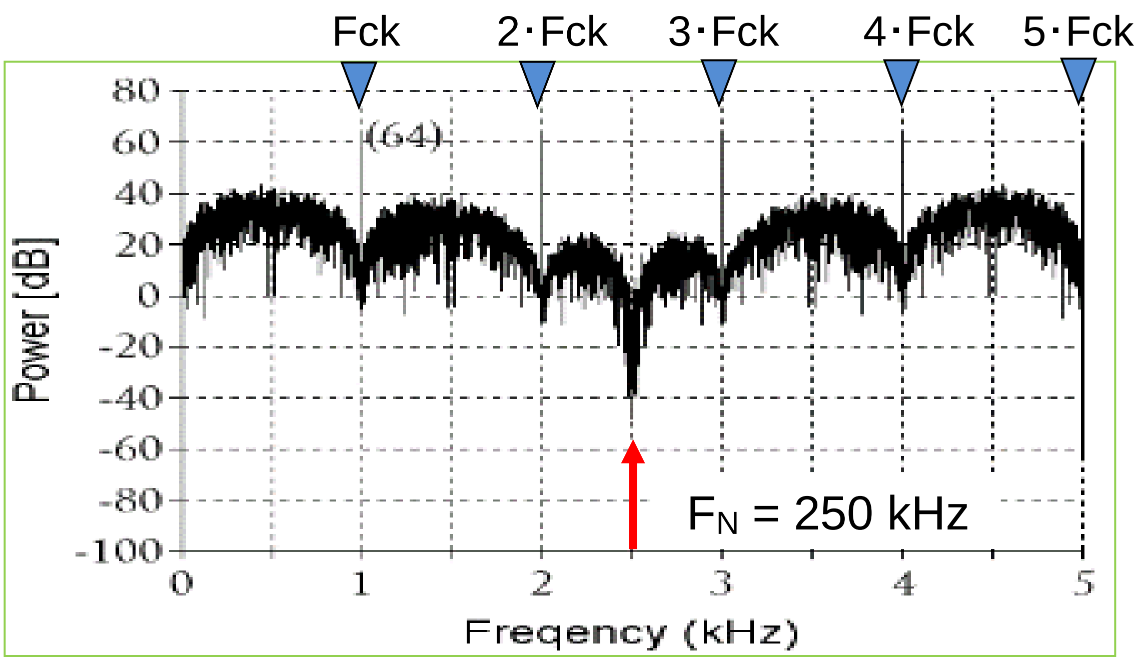

Fig.3-3 Notch Frequency with PWM Coding

∗

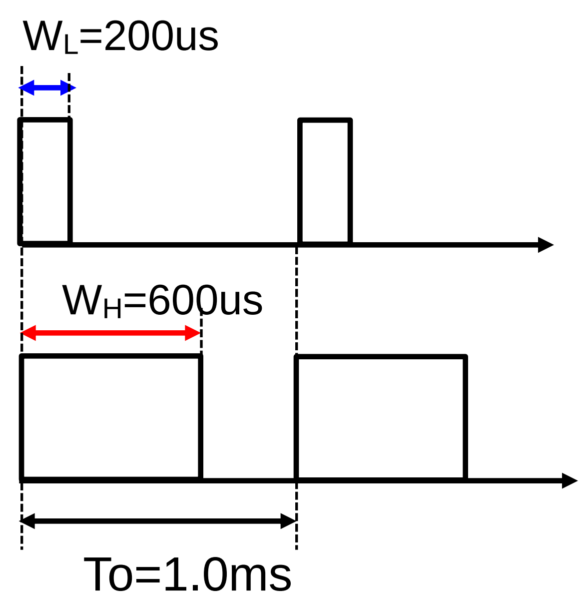

Fig.3-4 PWM Coding Pulse

● Simulation Result (2) with PWM Coding

＊ W_H = 800us, W_L = 200us (To=1.0 ms)

F_N = k／600us = 1.67, 3.33, 5.0 ･･･ [kHz]

★Set F_N by adjusting pulse width difference with setting the clock frequency not overlapped with F_N.

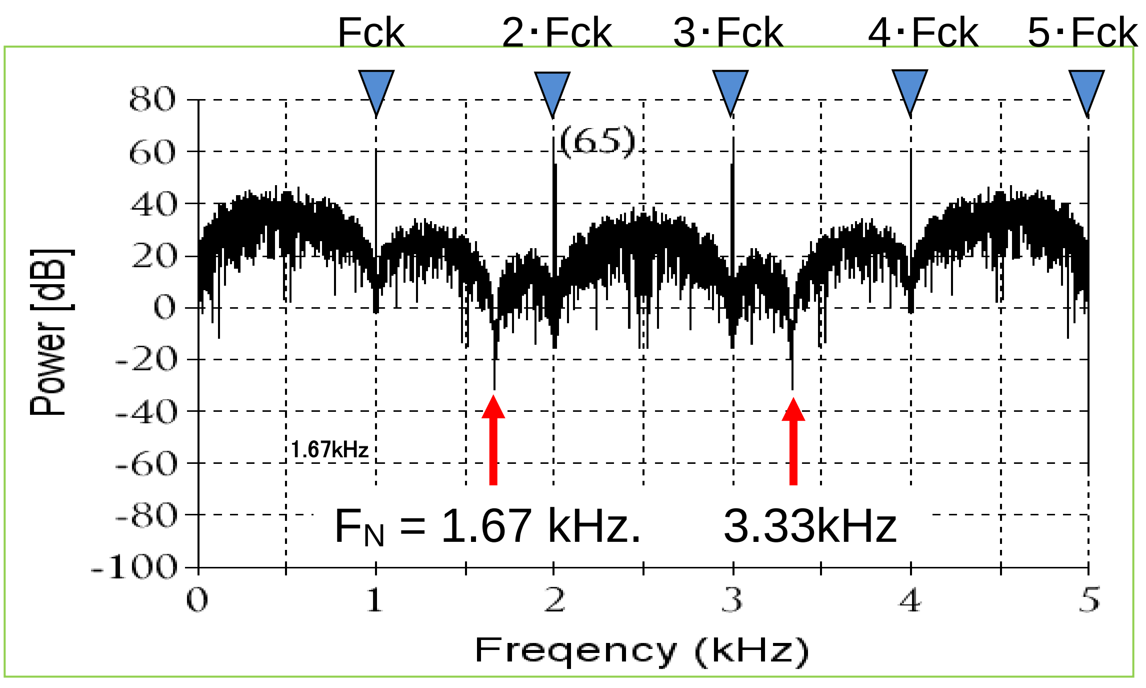

Fig.3-5 Notch Frequency with PWM Coding

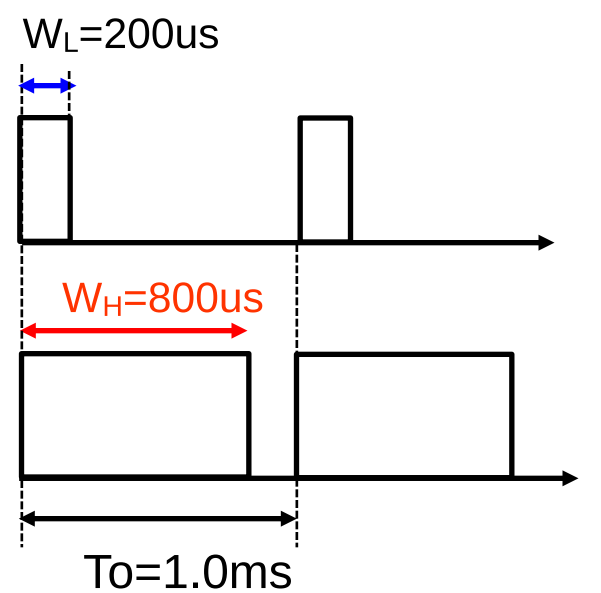

Fig.3-6 PWM Coding Pulse

3. Pulse Coding Method in DTC

3-2 PCM Pulse Coding with Notch Frequency

★ Parameters of PCM Coding

∗ Pulse Width is constant. : Wo

∗ Pulse Cycle (Period) T is different.

・Select “ T_L “ when 「L」 comes.

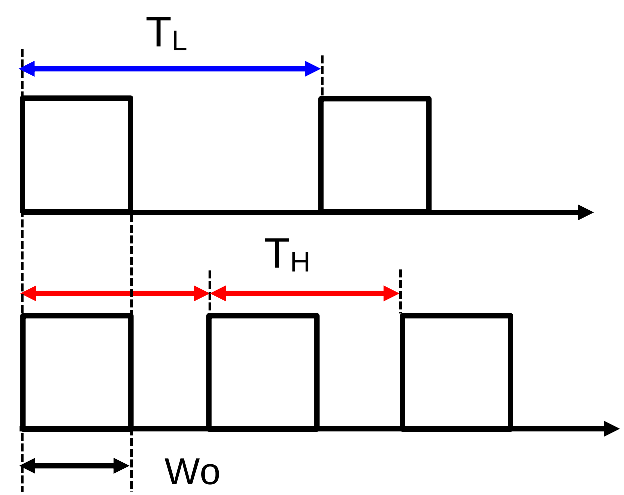

Fig.3-7 PCM Coding Pulse

●Notch Frequency:

$F_N = k ／ (T_L − T_H)$ ・・・ (2)

It’s derived from pulse cycle difference.

PCM : Pulse Cycle Modulation

★ Simulation results with PCM Coding

- Parameters: T_L = 600us, T_H = 200us (Wo = 100us)

  F_N = k／400us = 2.5, 5.0, 7.5 ･･･[kHz]

  ∗ Fck_H=5.0 kHz

  Fck_L=1.67kHz

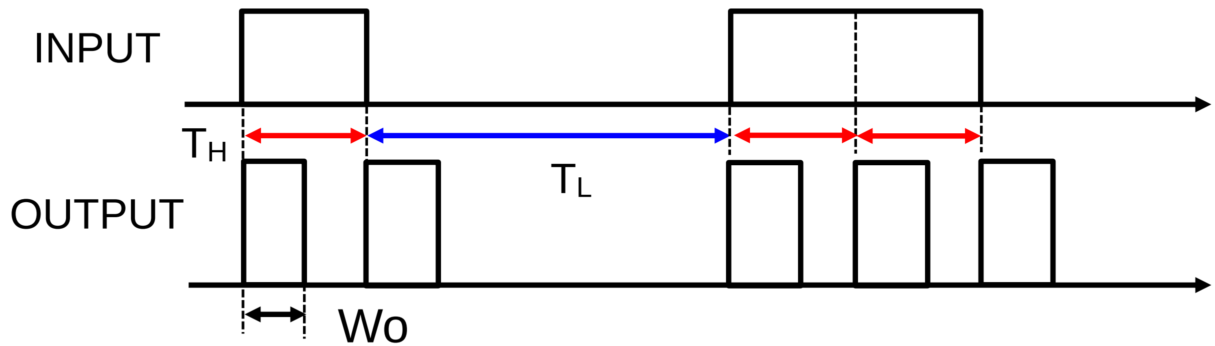

Fig.3-9 Input & Output Pulses

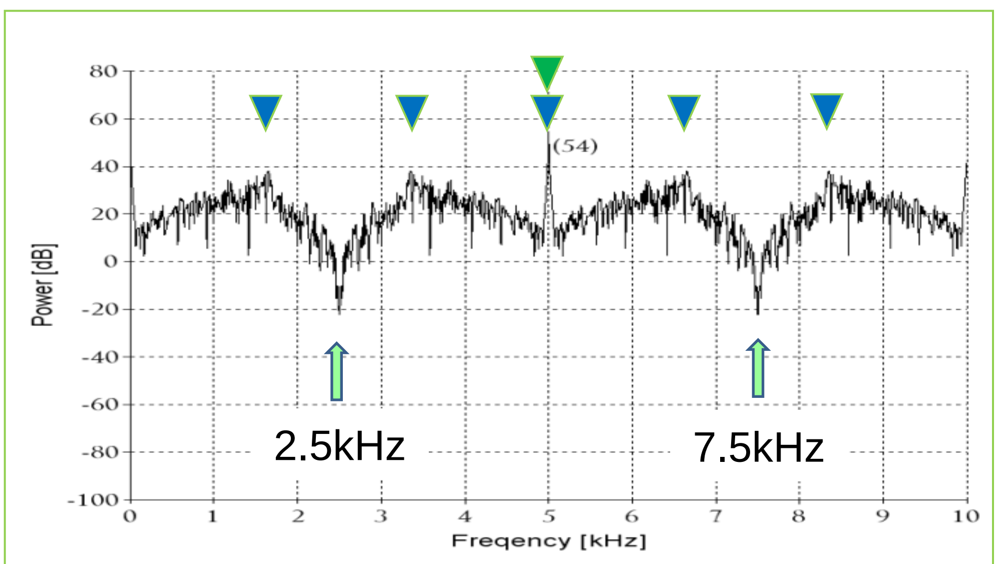

Fig.3-10 Notch Frequency with PCM Coding

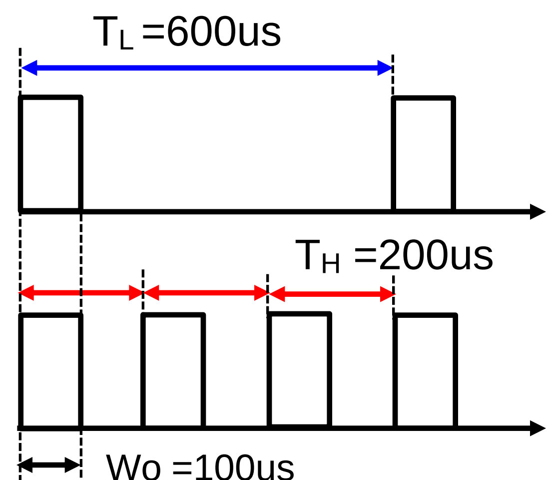

Fig.3-8 PCM Coding Pulse

- simulation result (2) with PCM Coding
  - ∗ T_L = 800us, T_H = 200us (Wo = 100us)
  - ∗ F_N = k／600us = 1.67, 3.33, 5.0, 6.67, 8.33 ･･･[kHz]
  - ∗ Fck_H= 5.0 kHz , Fck_L=1.25kHz

★Set F_N by adjusting pulse period difference with setting the clock frequency not overlapped with F_N.

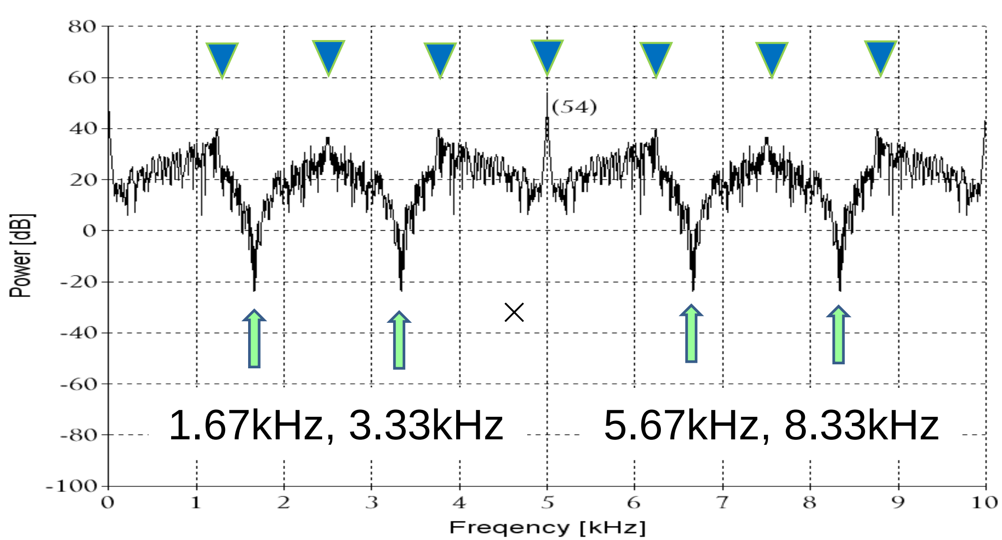

Fig.3-12 Notch Frequency with PCM Coding

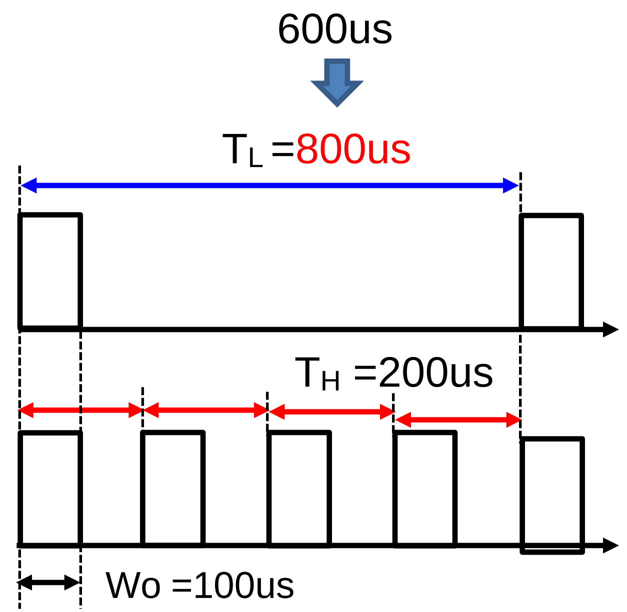

Fig.3-11 PCM Coding Pulse

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2. Spread Spectrum for EMI Reduction

3. Pulse Coding Method in DTC
   3-1 PWM Pulse Coding with Notch Frequency
   3-2 PCM Pulse Coding with Notch Frequency

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   4-1 Spread Spectrum with PWM Coding
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5. Conclusion

PWM: Pulse Width Modulation
PCM: Pulse Cycle Modulation

4. Spread Spectrum in Switching Converter

4-1 Spread Spectrum with Pulse Coding

★ 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

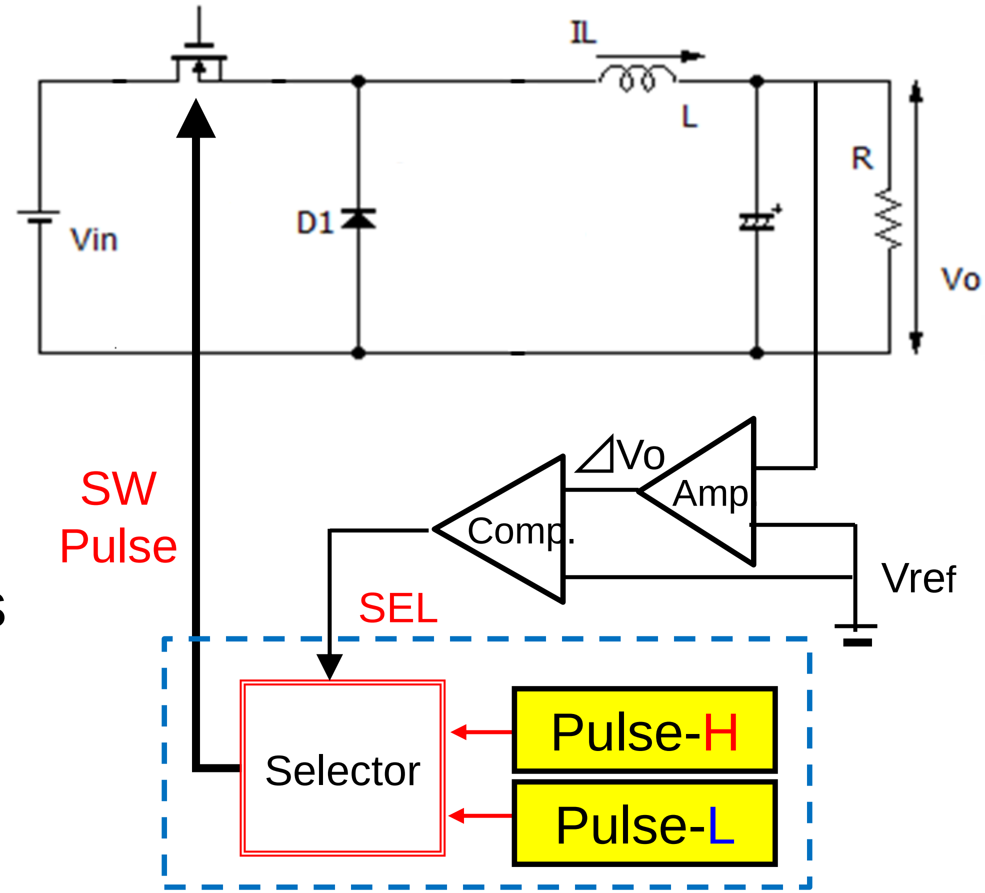


Fig.4-1 Switching Converter with Pulse Coding

★ Simulation results with PWM Coding & 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 4-1 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

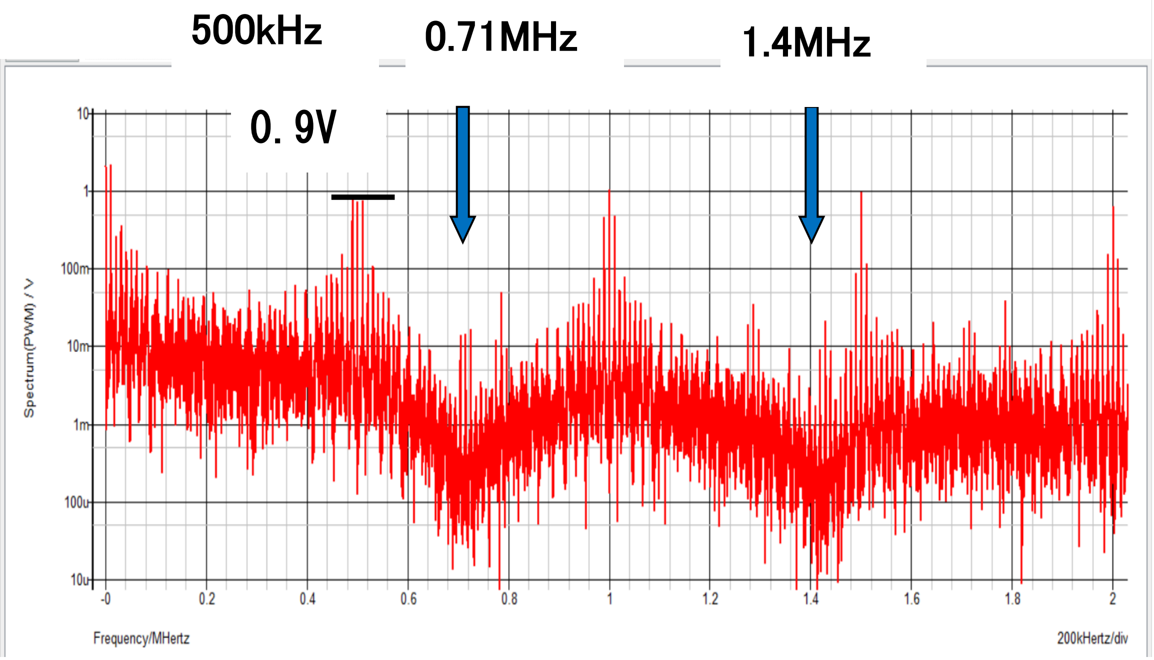


Fig.4-3 Spread Spectrum with PWM Coding

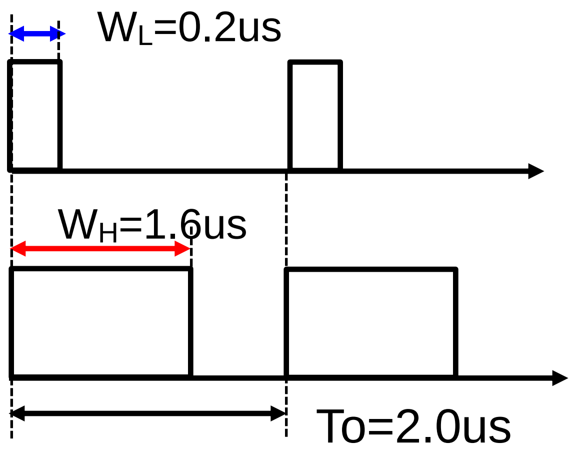


Fig.4-2 PWM Coding Pulse 2

4. Spread Spectrum in Switching Converter

4-2 Spread Spectrum with PCM Coding in SW converter

∗ Two coding pulses supplied from PCM pulse generator.

∗ Pulse period : T_H or T_L.
Pulse width is constant: Wo.

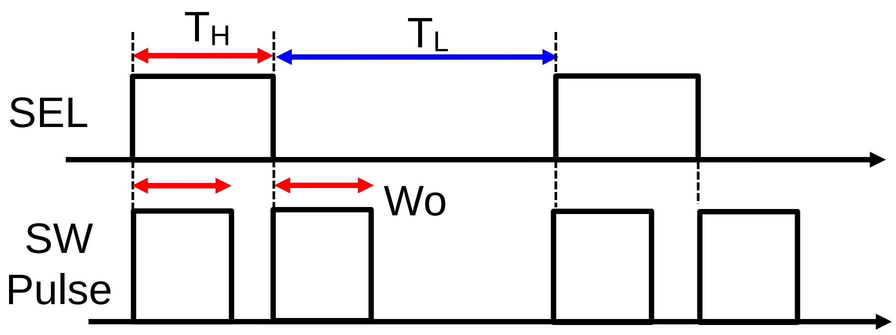


Fig.4-4 Ideal PCM Coding

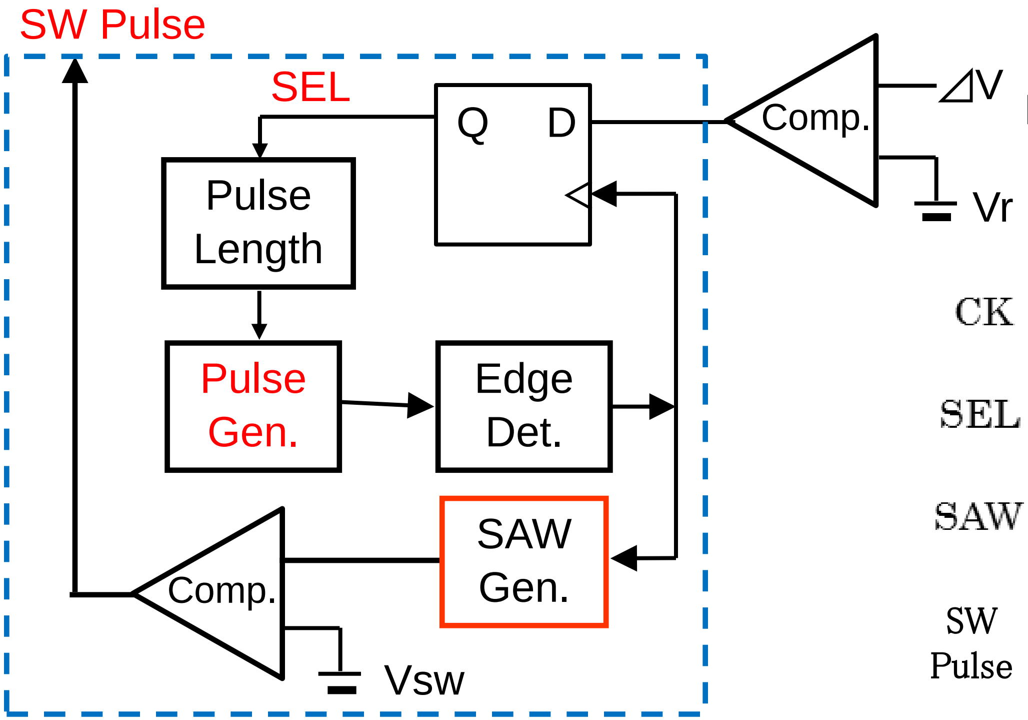


Fig.4-5 PCM Pulse Generator

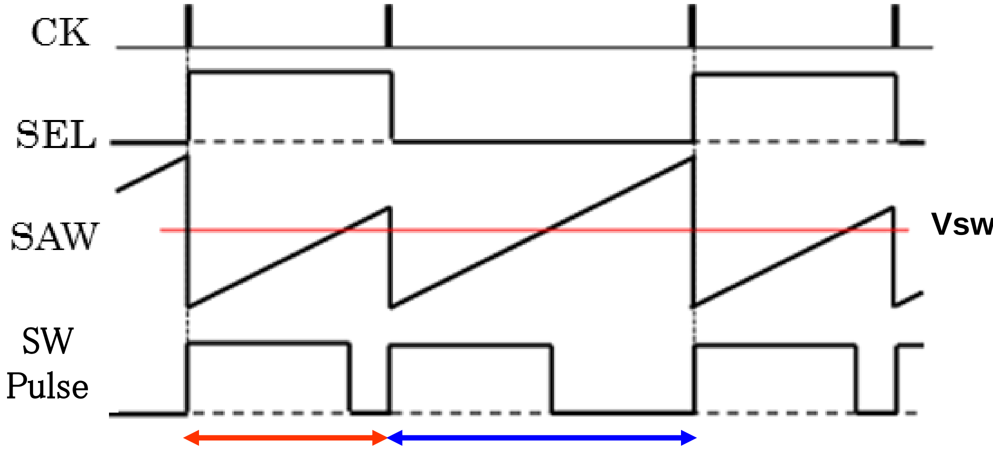


Fig.4-6 Timing Chart

● Simulation Results with PCM Coding (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)

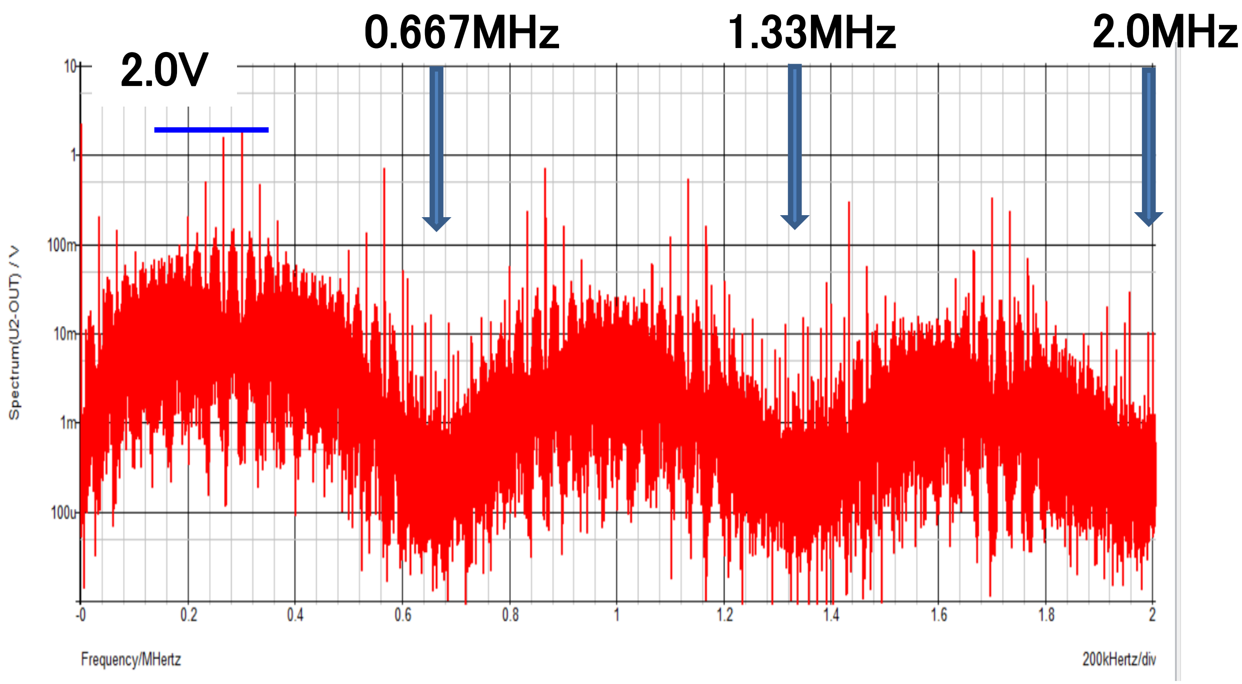


Fig.4-7 Spread Spectrum (PCM)

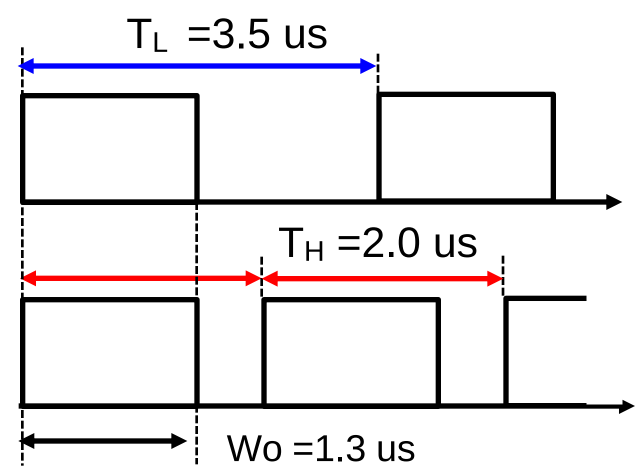


Fig.4-8 PCM Coding Pulse

● Simulation Results (PCM Coding)

∗ 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)

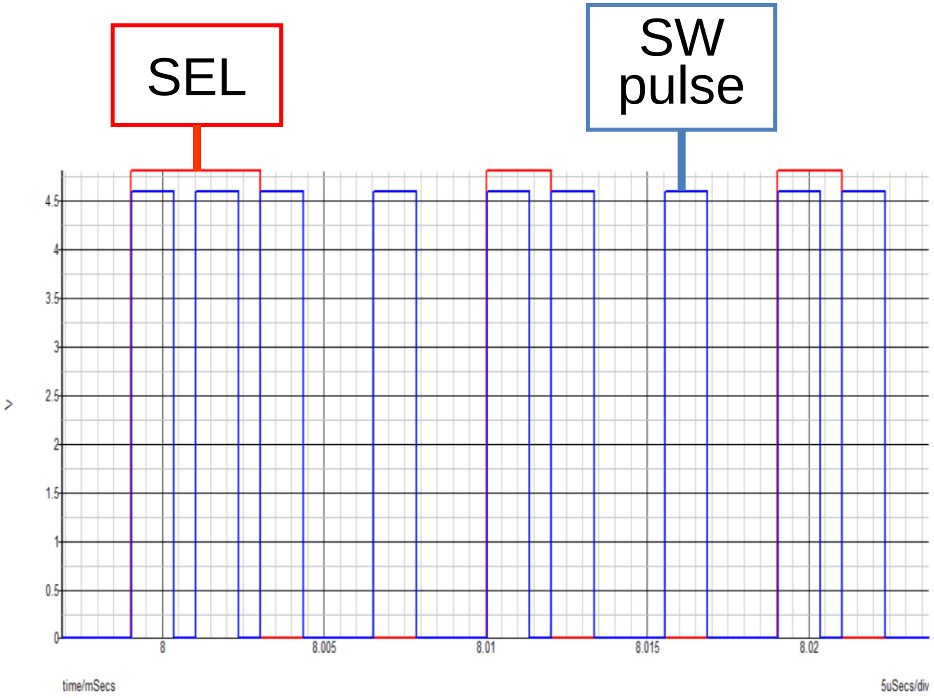


Fig.4-9 SEL and PWM Pulses

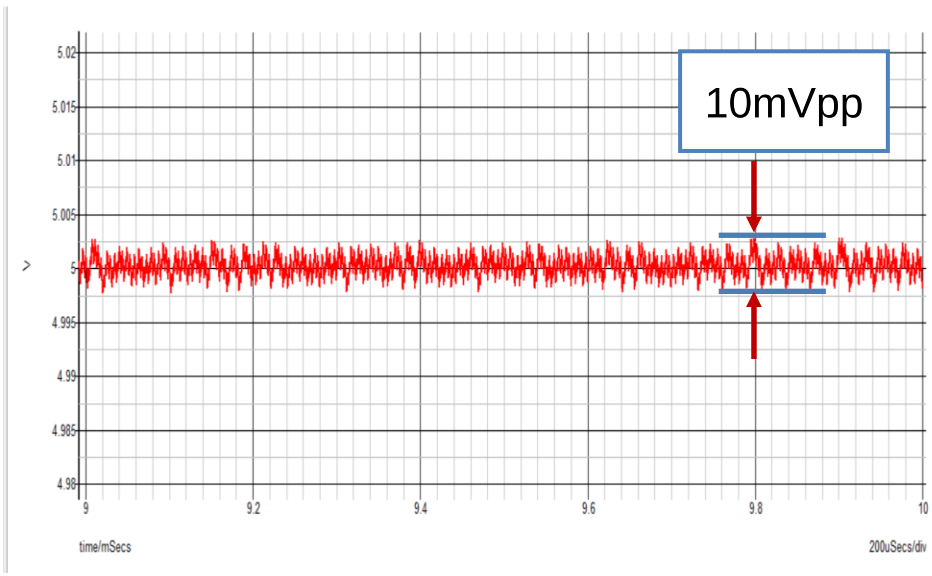


Fig.4-10 Output Ripple

Conclusion

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

1. Notch Frequencies with pulse coding:
   - $F_N = K / (W_H - W_L)$ @ PWM coding
   - $F_N = K / (T_L - T_H)$ @ PCM coding
2. Simulation results with Pulse Coding:
   1) PWM Coding with EMI reduction:
      - Notch Frequency: $F_N = 0.71$ MHz
      - Peak level of Fck: −5.9 dB (Ripple : 15 mVpp)
   2) PCM Coding without EMI reduction:
      - Notch Frequency: F_N=0.67 MHz
      - Peak level of Fck: −2.4 dB (Ripple : 10 mVpp)

★ We can set the Notch frequency freely by adjusting the coding pulse parameters.

Future Research

1. Simulation of spread spectrum
   with PCM pulse coding and EMI rejection.

2. Implementation of the buck converter
   with notch frequencies and EMI rejection.

3. Applications to another converters
   which use no clock pulse
   like ripple controlled converters.

Thank you for your kind attention!

謝 謝

We thank STARC for their support.

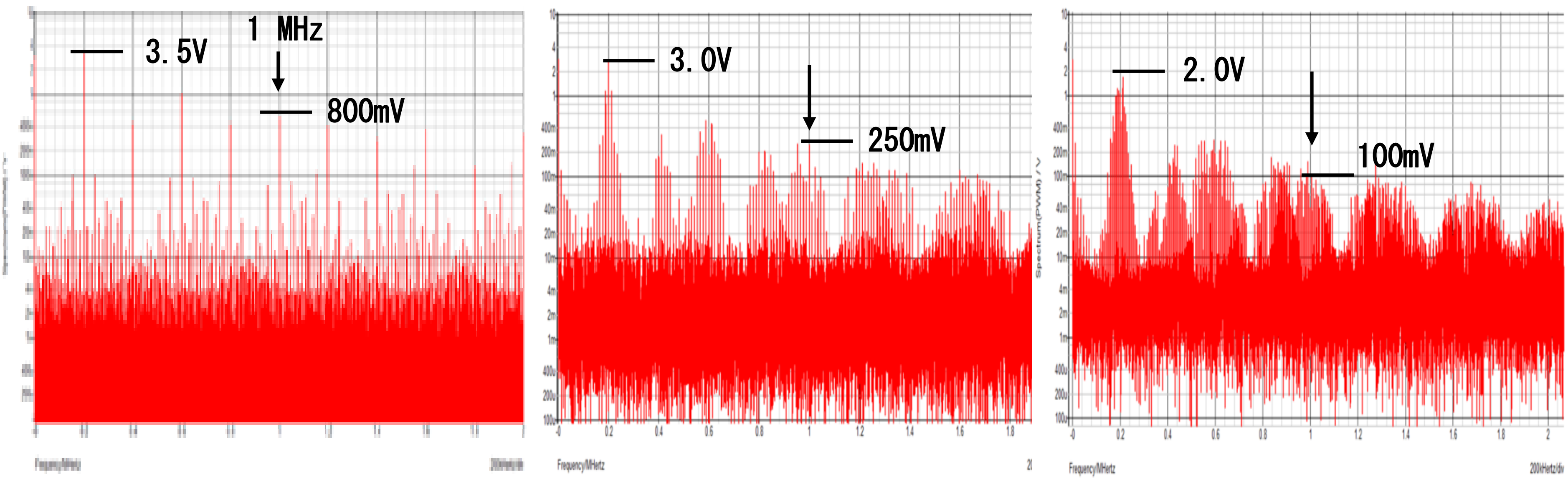
(STARC: Semiconductor Technology Academic Research Center, Japan)

★ 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).

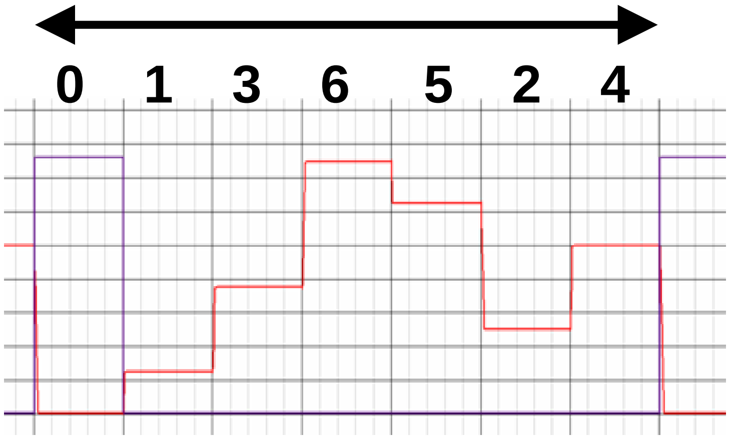


(a) Without Spread Spectrum (b) Digital Spread Spectrum (c) Analog Spread Spectrum

Fig. A-1 Comparison of Spread Spectrum

★ Primitive polynomials

- 3 degree
  (a) $G(s) = x^3 + x^2 + 1$
  (b) $G(s) = x^3 + x + 1$
- 4 degree
  (a) $G(s) = x^4 + x^3 + x^2 + x + 1$
  (b) $G(s) = x^4 + x^3 + 1$
  (c) $G(s) = x^4 + x + 1$
- 5 degree
  (a) $G(s) = x^5 + x^4 + x^3 + x + 1$
  (b) $G(s) = x^5 + x^4 + x^2 + x + 1$
  (c) $G(s) = x^5 + x^3 + x^2 + x + 1$
  (d) $G(s) = x^5 + x^3 + 1$
  (e) $G(s) = x^5 + x^2 + 1$



(a) $x^3 + x^2 + 1$

★ PCM Coding

∗ Ideal coding like Fig. 3-7 is difficult,
because of difference of the period.

∗ Pseudo PCM Coding. Period of the SEL signal is constant.

- Output 3 D_H pulses when SEL=H.
- Output 2 D_L pulses when SEL=L.

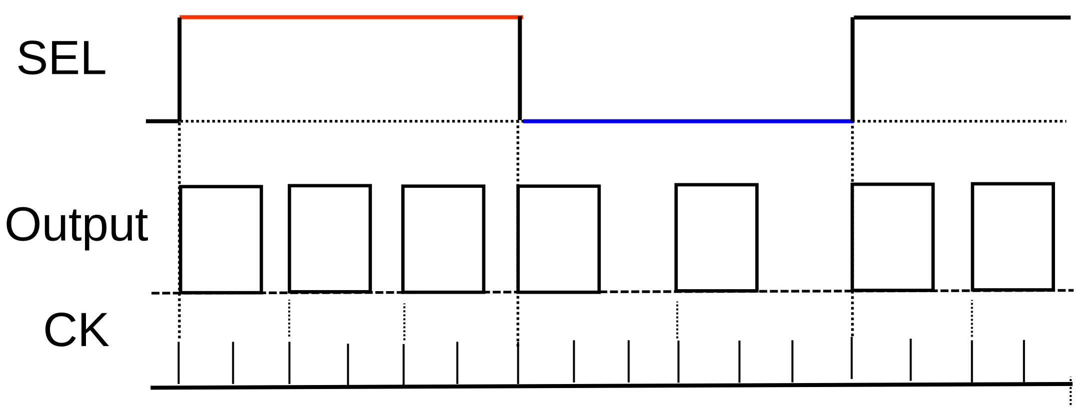


Fig.4-5 Pseudo PCM Coding

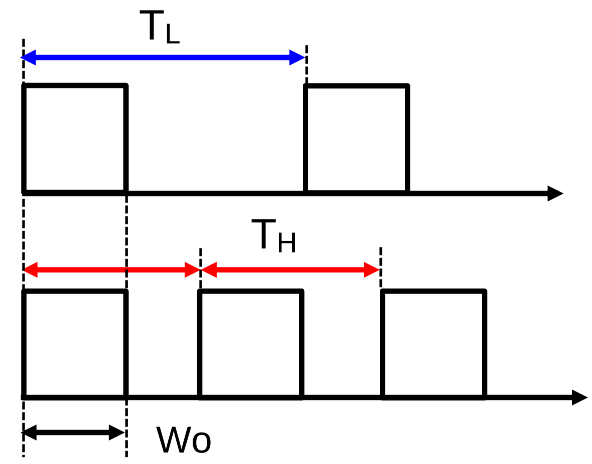


Fig.4-6 PCM Coding

4. Spread Spectrum with Switching Converter

4-2 Spread Spectrum with PCM Coding

★ PCM Coding

∗ Ideal coding like Fig. 3-7 is difficult, because of difference of the period.

∗ Pseudo PCM Coding. Period of SEL signal is constant.

- Output 3 T_H pulses when SEL=H.
- Output 2 T_L pulses when SEL=L.

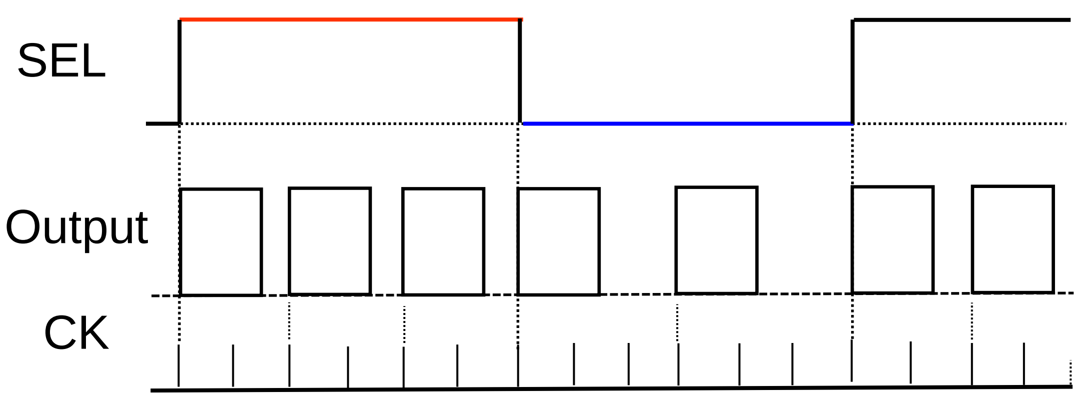


Fig.4-7 Pseudo PCM Coding

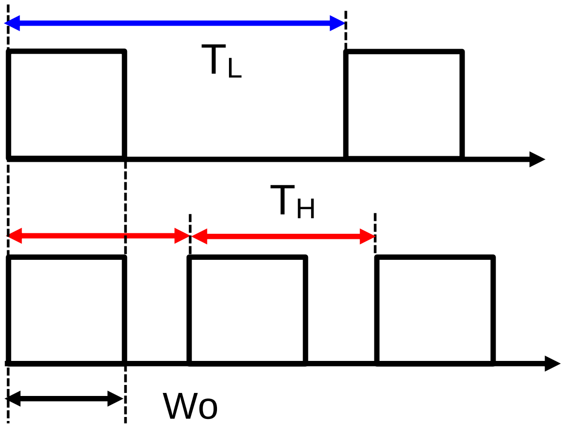


Fig.3-7 Ideal PCM Coding

● Simulation results (Pseudo PCM)

∗ Parameters: $T_{SEL} = 6 \cdot Tck = 12us$ (Fck=500kHz, Tck=2us)

$T_H = 4us$, $T_L = 6us$, Wo =2.8us ($D_H = 0.7$, $D_L = 0.467$)

∗ Spread Spectrum

- Many line frequencies:

  167kHz,333kHz (=N·500/3=167·N kHz), 500k∓55kHz ?

- Notch Frequency is not clear.

  $F_N = k/(6-4)us = 0.5 \cdot k$ MHz (= N·Fck) : No good!

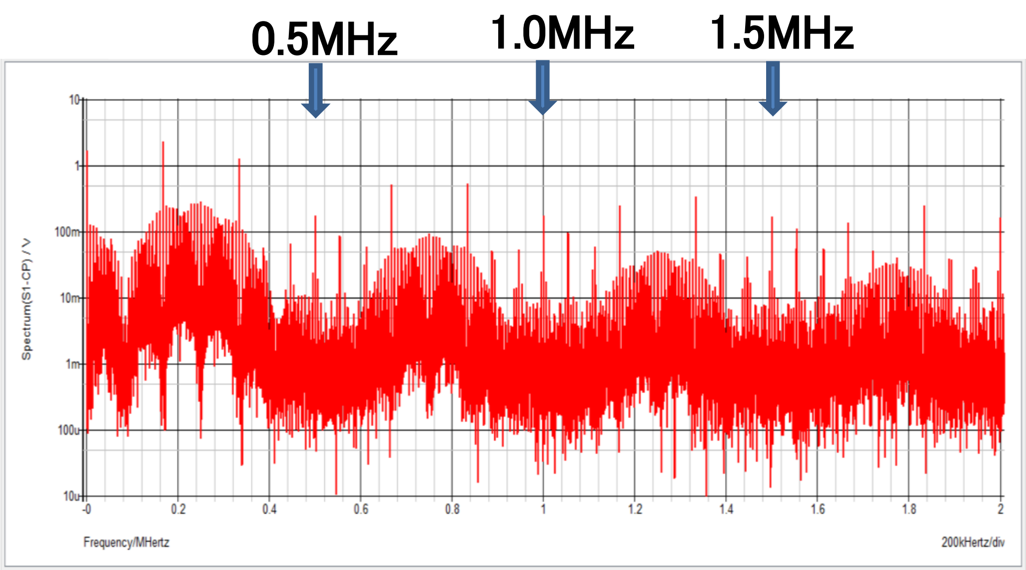


Fig.4-8 Spread Spectrum (Pseudo PCM)

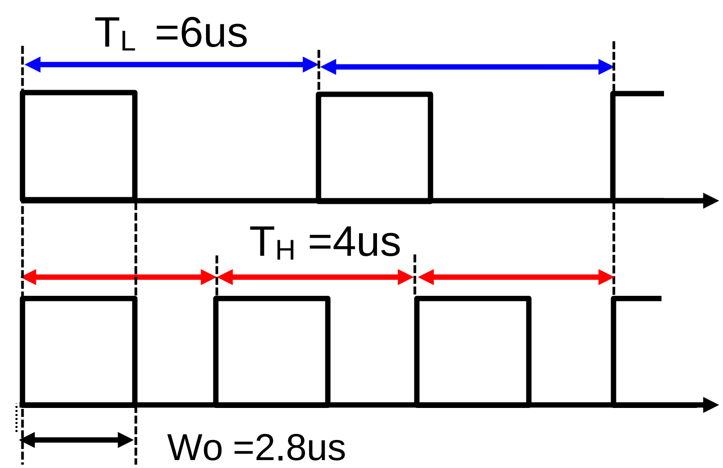


Fig.4-9 Pseudo PCM Coding

- Duty of coding pulses
  - ∗ Steady state: $Do = Vo / Vi$
  - ∗ Duty relation with coding pulses,

$$D_H > Do > D_L \quad \cdots (4\text{-}1)$$

- Ex. (PWM Coding, Fig. 3-4)

$D_H = 0.6$, $D_L = 0.2$

@ Vi=10V, Vo=5.0V: Do=0.5

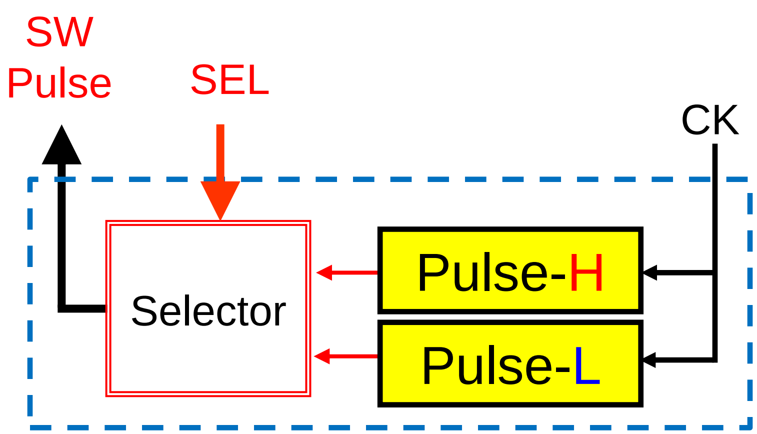


Fig.4-2 Coding Pulse Generator

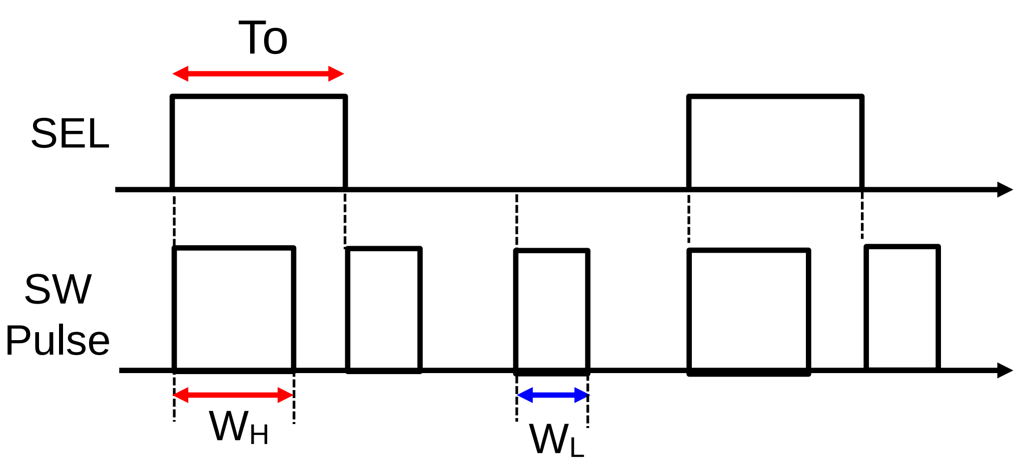


Fig.4-3 SW Pulses with PWM Coding

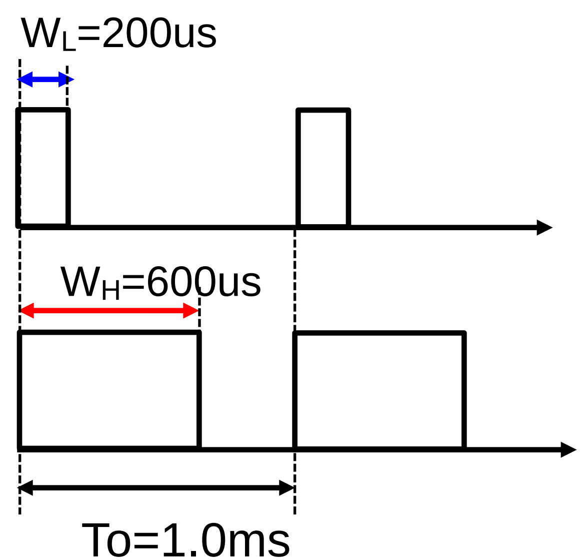


Fig.4-4 PWM Coding Pulse