EMI Reduction by Extended Spread Spectrum in Switching Converter

(EMCJ WS 2015, Bangkok)

Yasunori Kobori*

Nobukazu Tsukiji**, Nobukazu Takai**, Haruo Kobayashi**

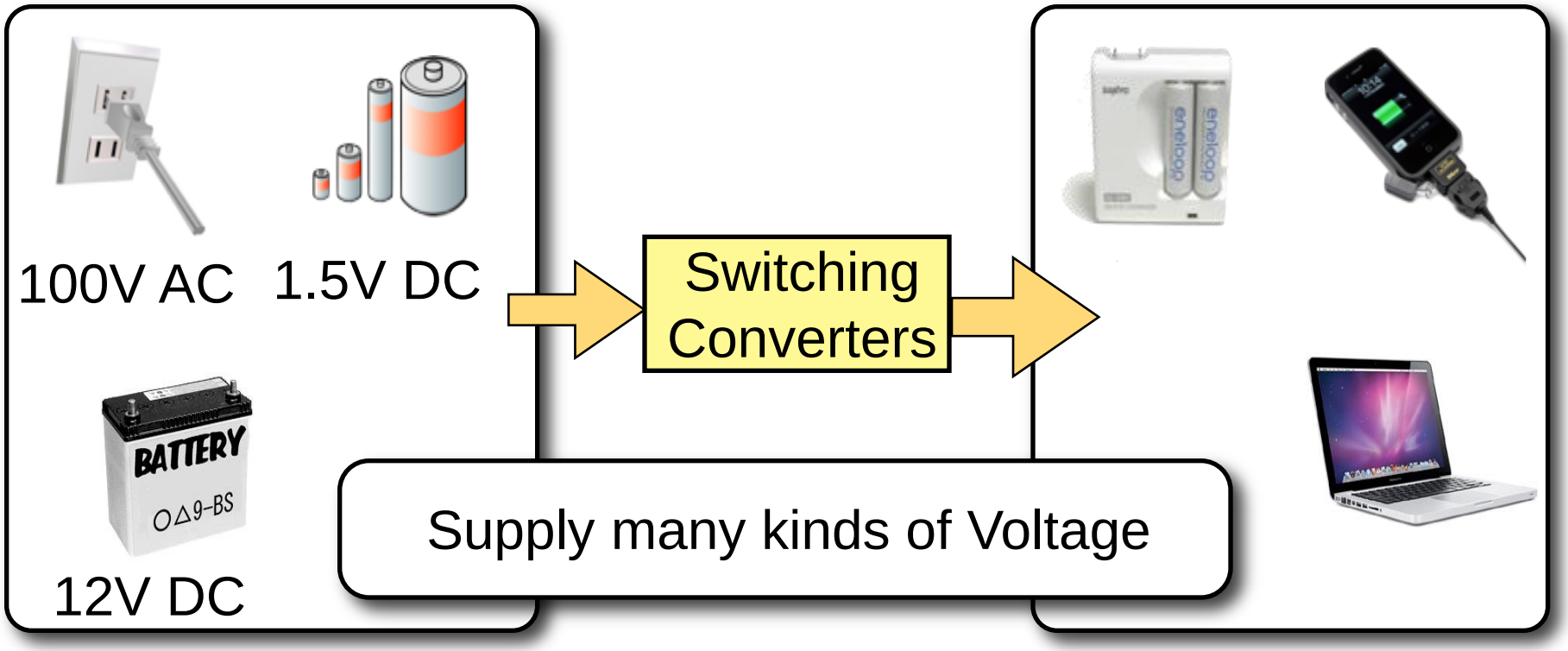
* National Institute of Technology, Oyama College

**Gunma University

Outline

1. Background
2. Conventional Spread Spectrum
   - 2-1 Switching Converter
   - 2-2 Digital Spread Spectrum
3. Proposed Spread Spectrum
   - 3-1 M-sequence circuit
   - 3-2 Pseudo Analog Noise Generator
   - 3-3 Simulation Results
4. Advanced Spread Spectrum
   - 4-1 Extended Bit Pattern with Bit Inverse
   - 4-2 Extended Bit Pattern with Bit Exchage
5. Conclusion

1. Background



- Many switching converters in equipment

Fig.1 background

1. Background

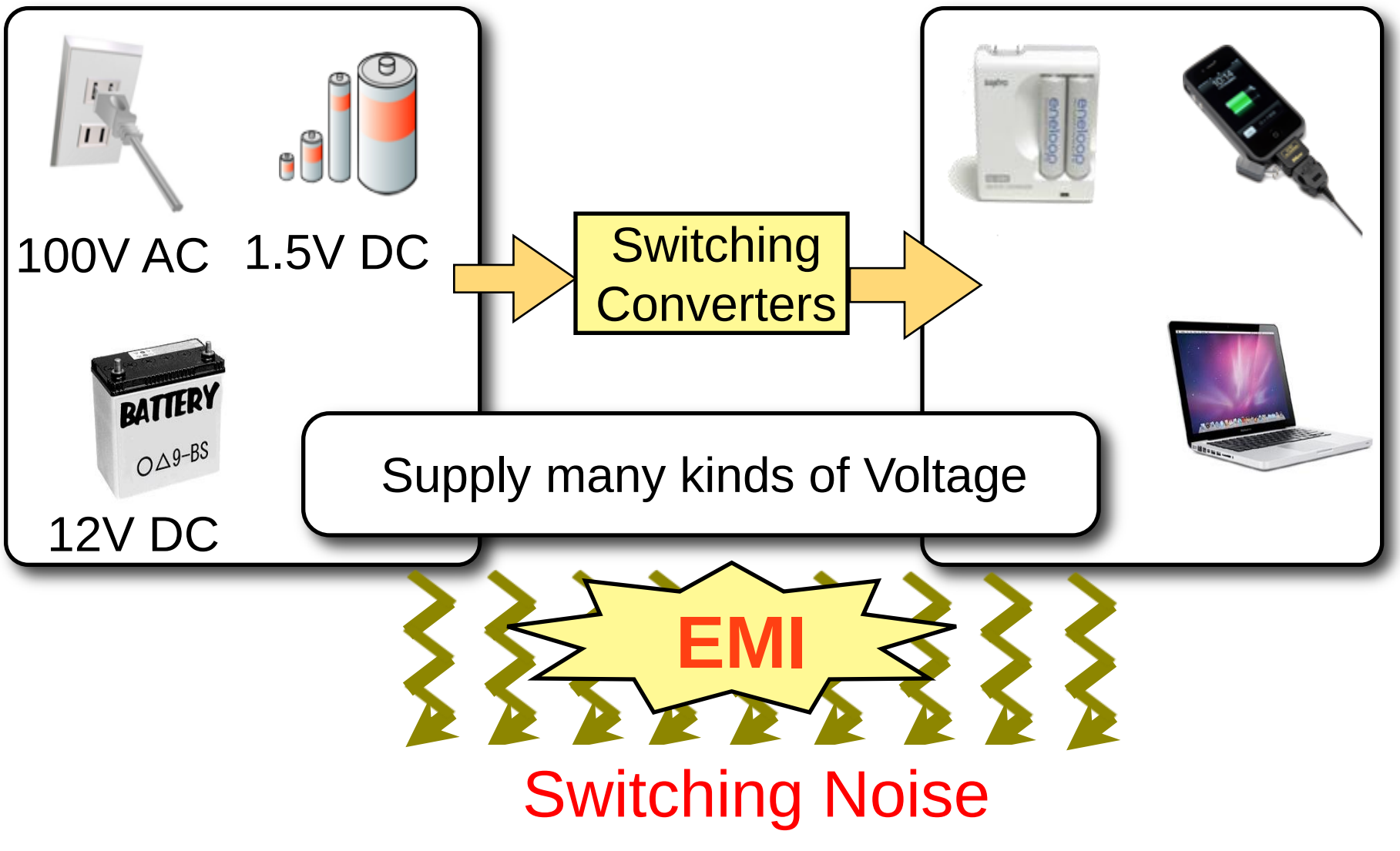


Fig.2 background (EMI)

EMI: ElectroMagnetic Interference

Outline

1. Background
2. Conventional Spread Spectrum
   - 2-1 Switching Converter
   - 2-2 Digital Spread Spectrum
3. Proposed Spread Spectrum
   - 3-1 M-sequence circuit
   - 3-2 Pseudo Analog Noise Generator
   - 3-3 Simulation Results
4. Advanced Spread Spectrum
   - 4-1 Extended Bit Pattern with Bit Inverse
   - 4-2 Extended Bit Pattern with Bit Exchange
5. Conclusion

2. Conventional Spread Spectrum

2-1 Switching Converter

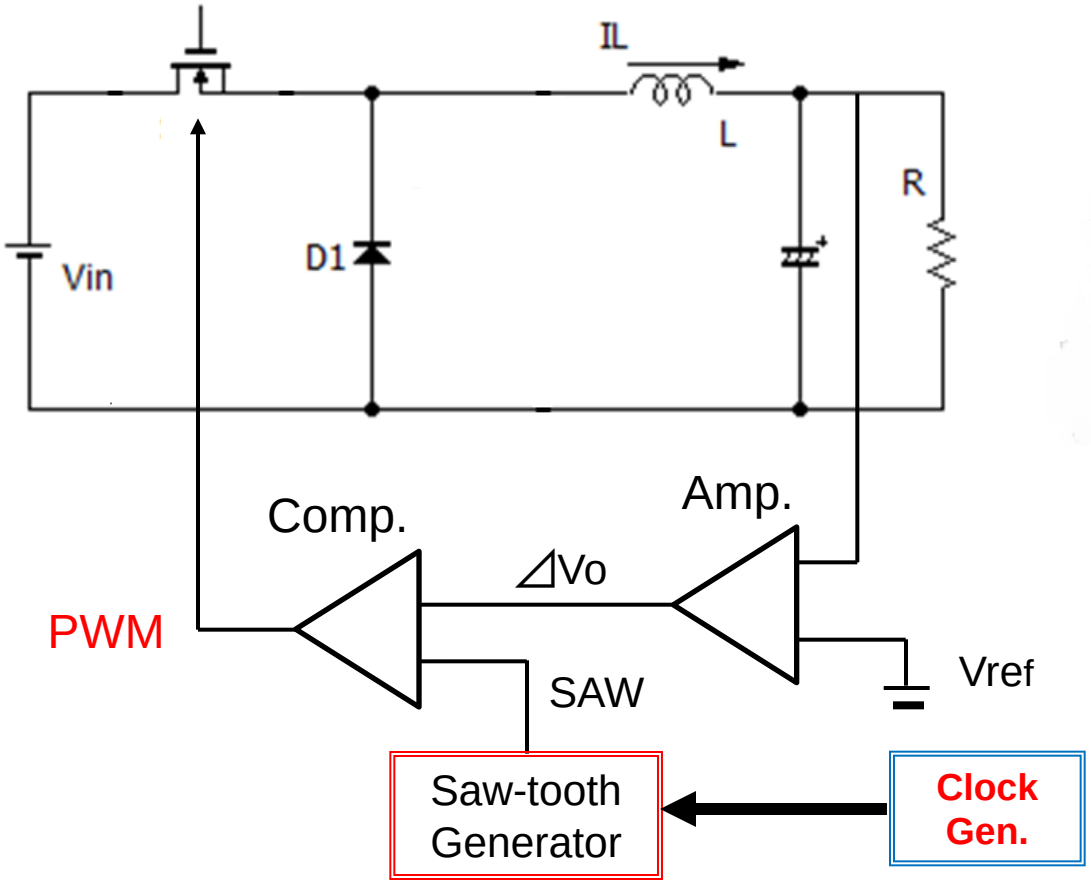


Fig.3 DC-DC Buck Converter

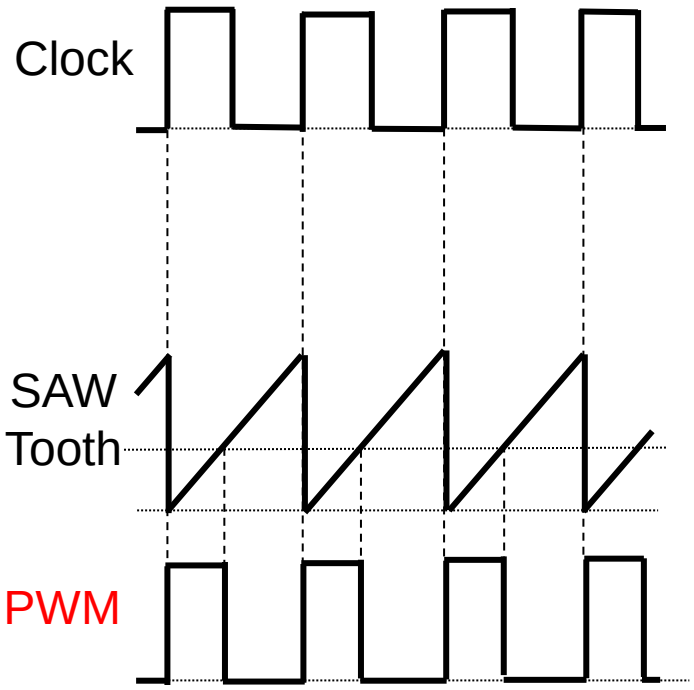


Fig.4 Timing Chart

2. Conventional Spread Spectrum

- Spectrum of PWM signal

  Energy concentration at basic & harmonic frequencies

  fo, 2·fo, 3·fo, ···

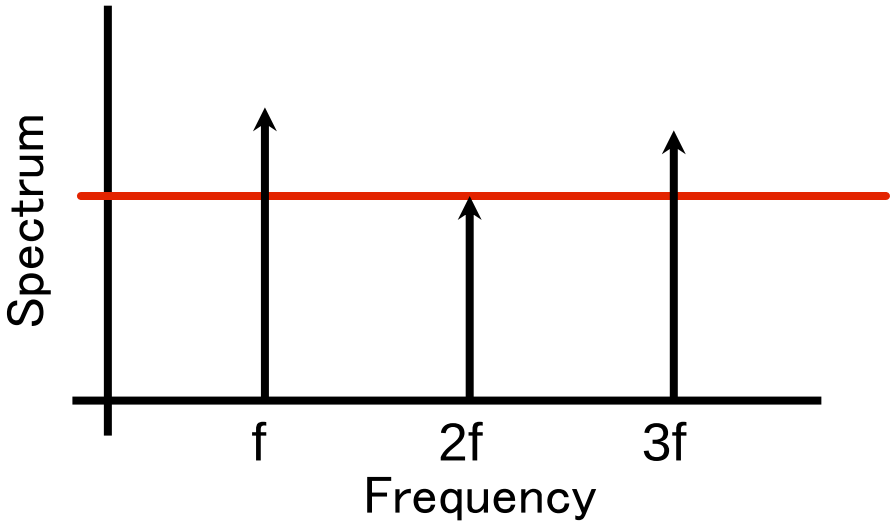


Fig.5 Spectrum of PWM

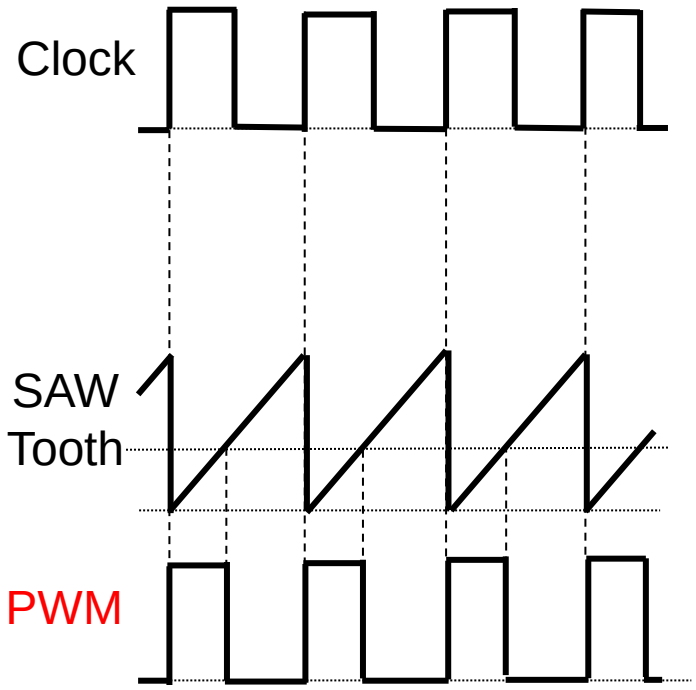


Fig.4 Timing Chart

2. Conventional Spread Spectrum

2-2 Conventional Spread Spectrum

∗ Digital Spread Spectrum

- Phase or Position Modulation of PWM

⇒ Spread the spectrum and
Reduce the power of fo spectrum

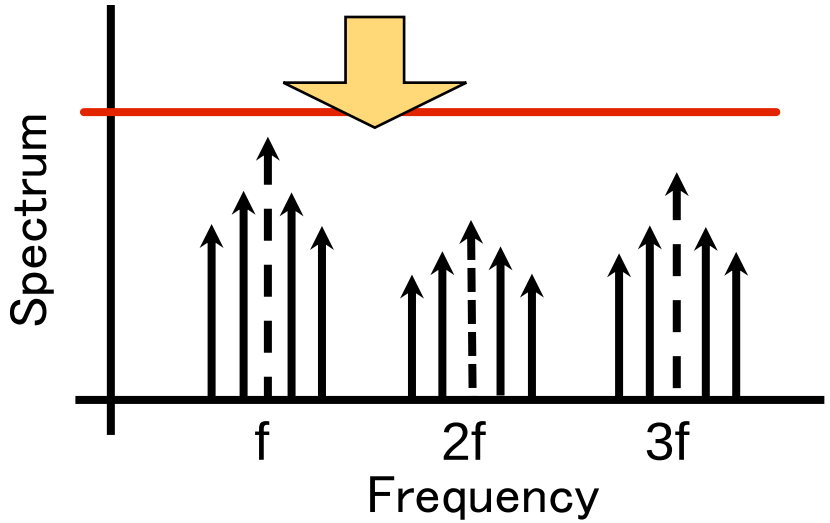


Fig.6 Spectrum of PWM (Image)

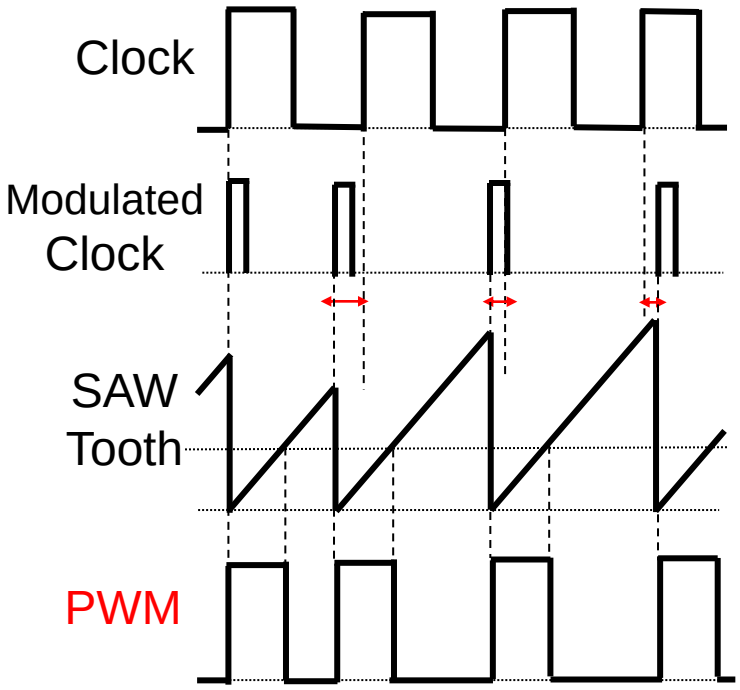


Fig.7 Timing Chart

2. Conventional Spread Spectrum

＊Digital Spread Spectrum

- 8～12bit Random Noise Generator (M-sequence circuit)
- More than one hundred of Shift Resistors and Selectors

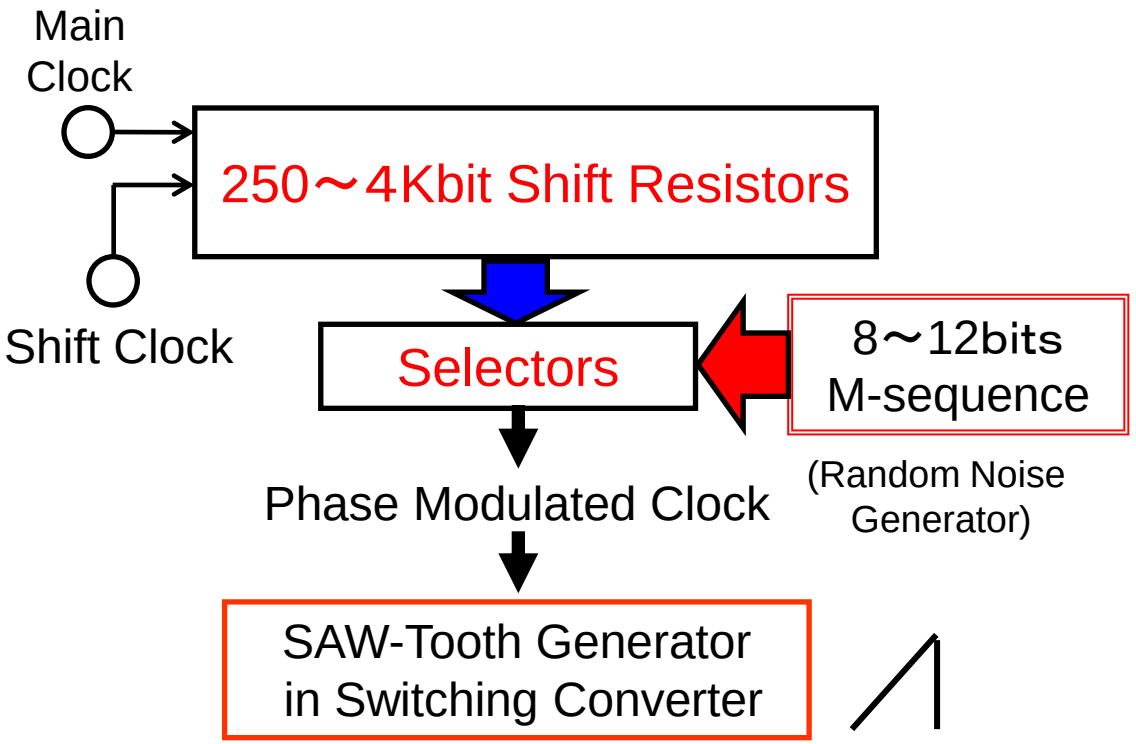


Fig.8 Digital Modulation Circuit

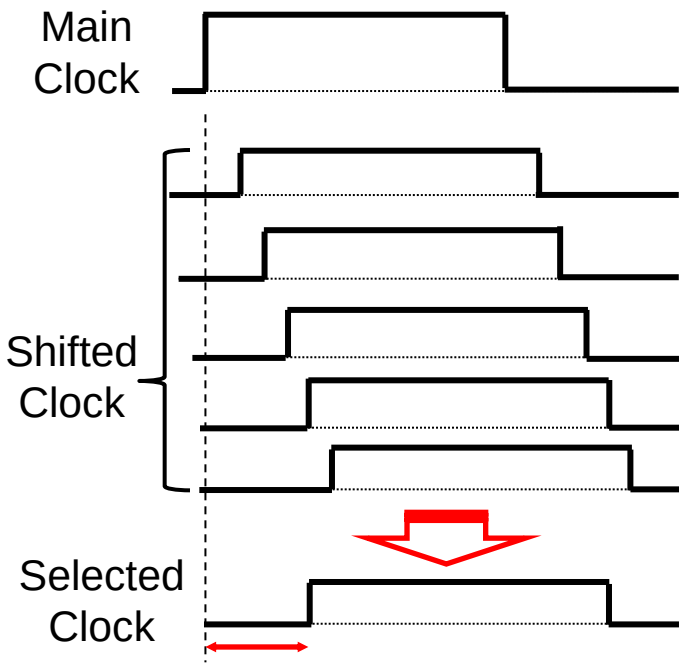


Fig.9 Modulated Clock

Outline

1. Background
2. Conventional Spread Spectrum
   - 2-1 Switching Converter
   - 2-2 Digital Spread Spectrum
3. Proposed Spread Spectrum
   - 3-1 M-sequence circuit
   - 3-2 Pseudo Analog Noise Generator
   - 3-3 Simulation Results
4. Advanced Spread Spectrum
   - 4-1 Extended Bit Pattern with Bit Inverse
   - 4-2 Extended Bit Pattern with Bit Exchange
5. Conclusion

3. Proposed Spread Spectrum

3-1M-Sequence Circuit

- Digital Random Noise Generator
- Consist of n-bit counters
  and some Ex-OR gates
- The number of pulse levels is $N=2^n-1$
- Primitive polynomials (ex. 3 degrees)
  (a) $G(s) = x^3+x^2+1$
  (b) $G(s) = x^3+x+1$

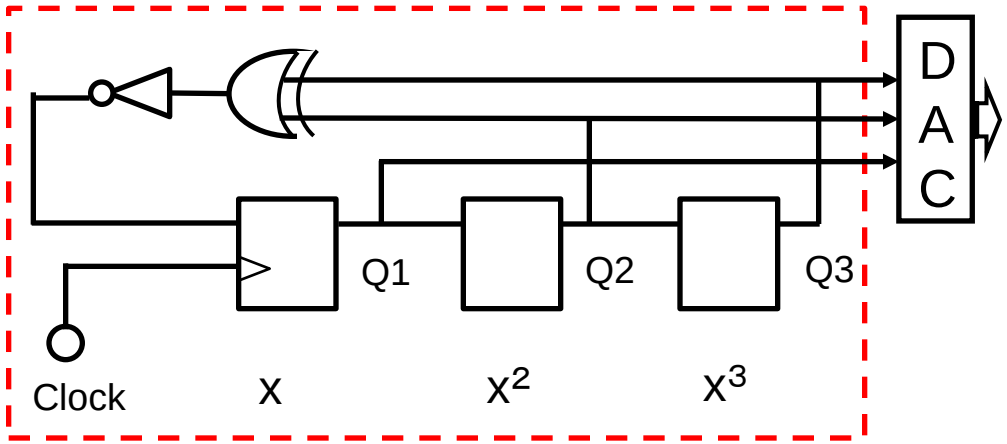
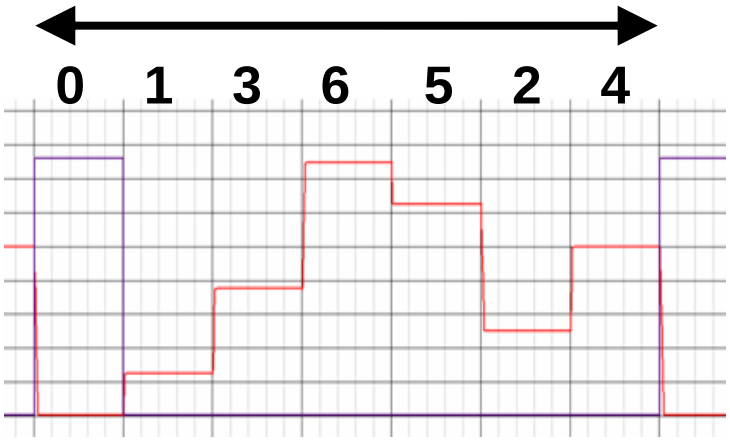
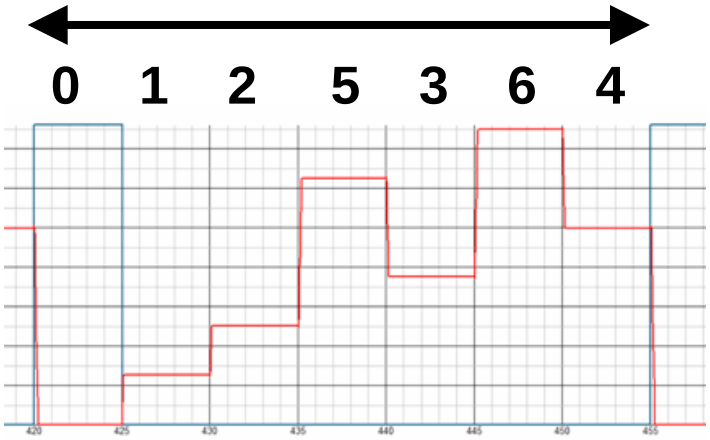


Fig.10 3-bit M-sequence Circuit (3 bit)



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



(b) x^3+x+1

Fig.11 Output Waveforms

3. Proposed Spread Spectrum

3-2 Pseudo Analog Noise Generator

∗ Random Noise with LPF & PLL

- Random Pattern from Digital Noise Generator

⇩ + **LPF**

Periodic Analog Signal

⇩ + **PLL**

Pseudo Analog Noise (Non-periodic)

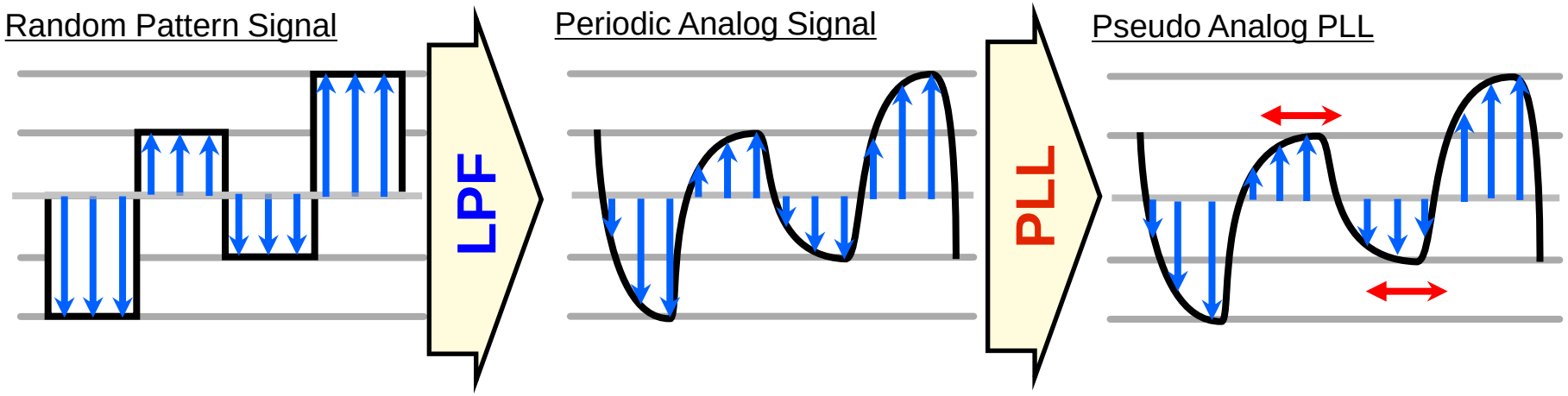
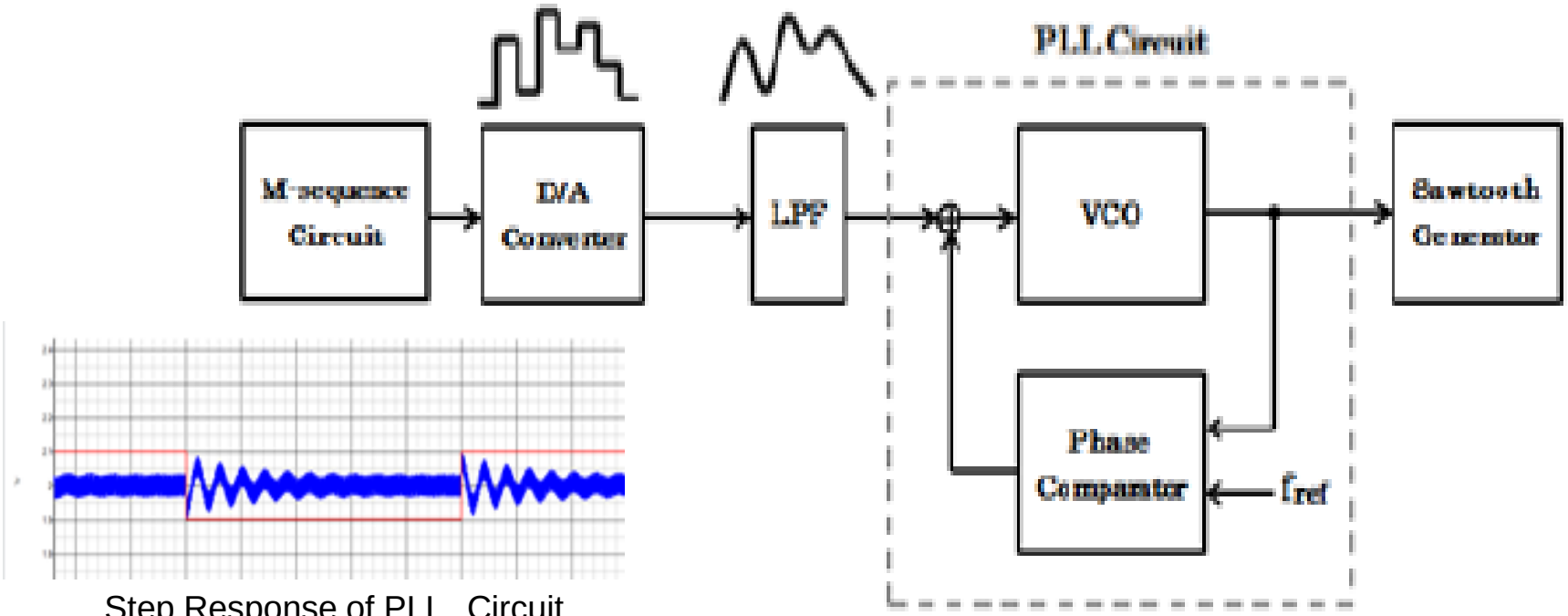


Fig.12 Frequency Modulation with Analog Noise (Image)

3. Proposed Spread Spectrum

3-2 Pseudo Analog Noise Generator

- ∗ M-sequence + DAC ⇒ Random Pattern Generator
- ∗ LPF ⇒ Analog Smooth Signal (Periodic)
- ∗ PLL ⇒ Pseudo Analog Noise (Non-Periodic)



Step Response of PLL Circuit

Fig.13 Pseudo Analog Noise with LPF & PLL

3. Proposed Spread Spectrum

● Switching Converter with Analog Spread Spectrum

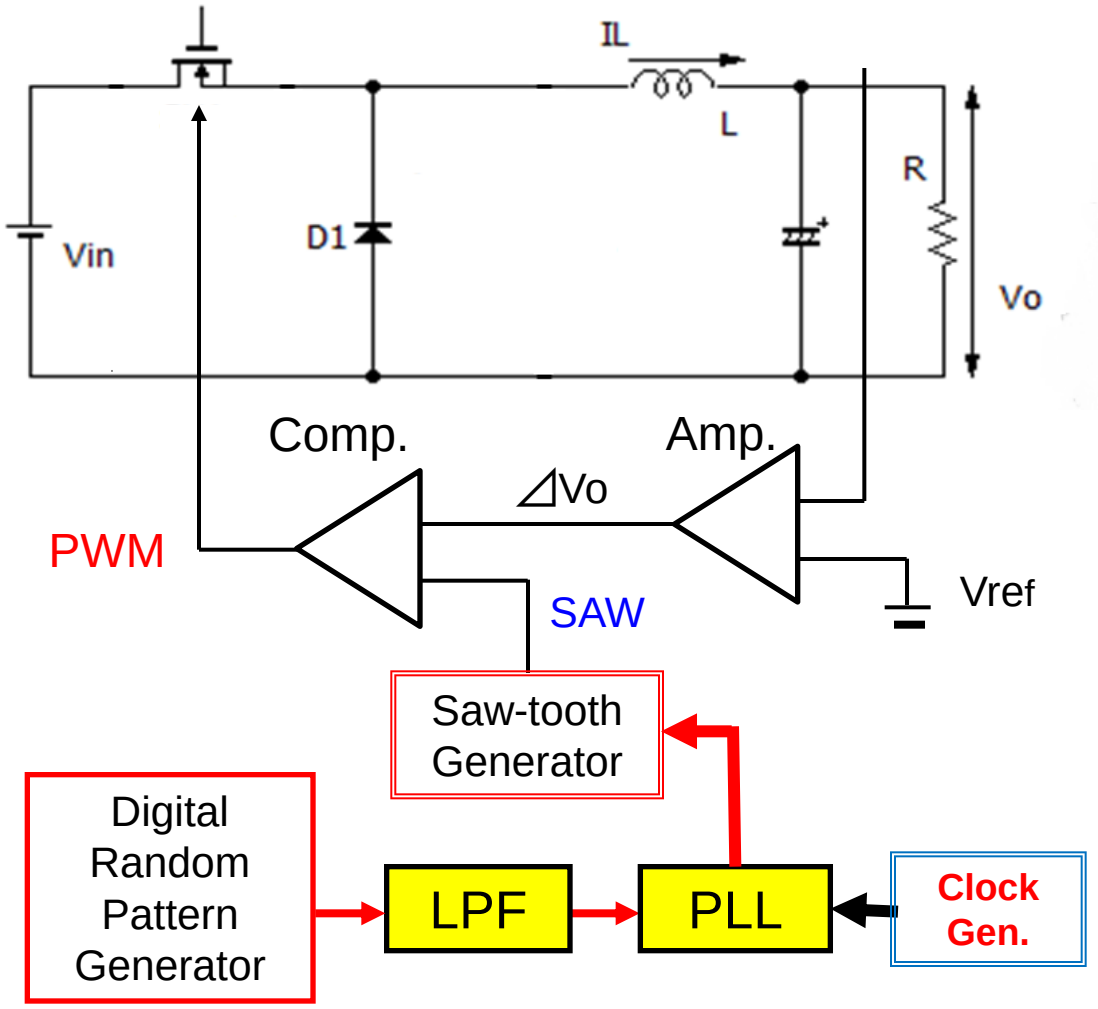


Fig.14 Converter with Analog Spread Spectrum

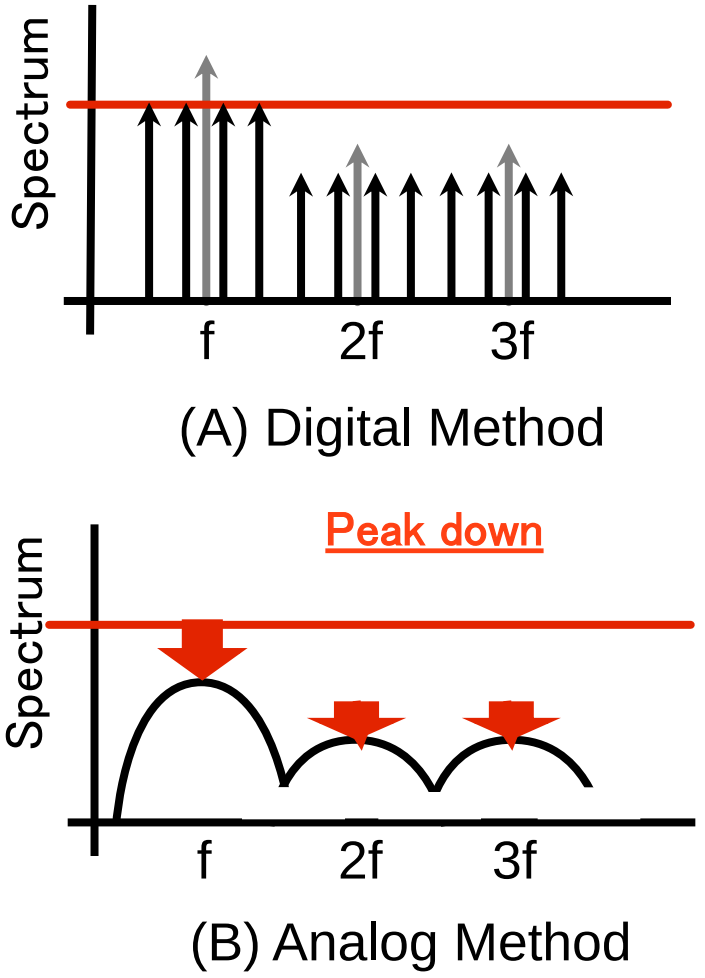
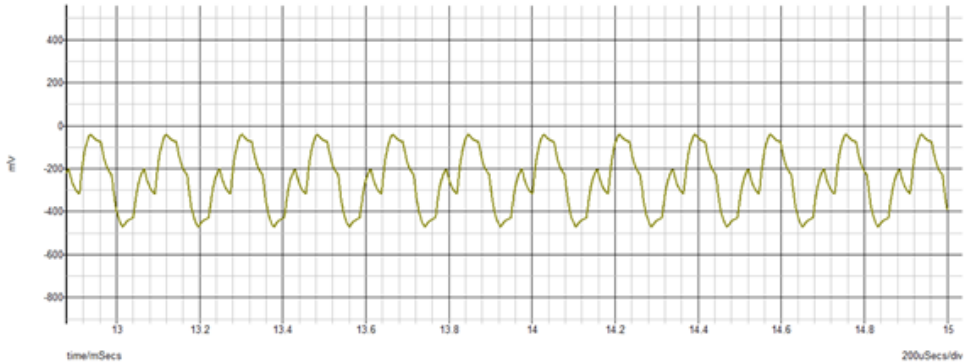


Fig.15 Spread Spectrum (Image)

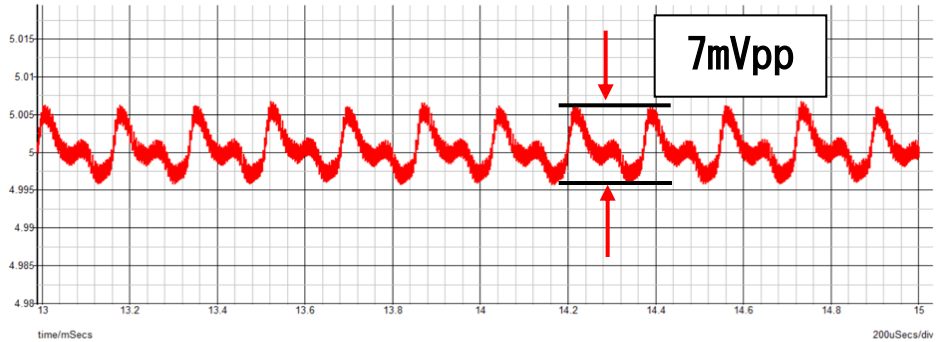
3. Proposed Spread Spectrum

●Waveform of LPF Output & Voltage Ripple

- Output ripple is 7 mVpp (＜ 0.2 % of Vo)
- Waveform of ripple is similar to Output of LPF



(a) Waveform of Analog Noise



(b) Waveform of Output Ripple

Fig.16 Output Voltage Ripple

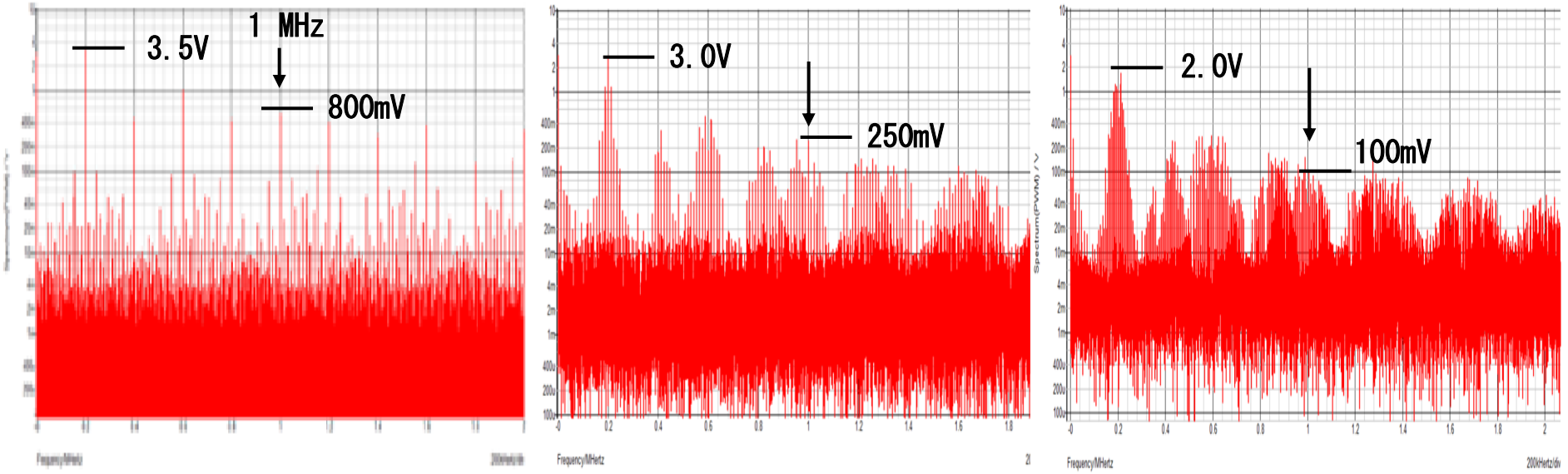
Table 1 Parameters of Switching Converter

Vin	9.0 V
Vo	5.0 V
Io	0.5 A
L	10uH
Co	470μF
Fck	200kHz

3. Proposed Spread Spectrum

3-3 Simulation Results

- ●Fundamental Spread Spectrum (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.17 Comparison of Spread Spectrum

Outline

1. Background
2. Conventional Spread Spectrum
   - 2-1 Switching Converter
   - 2-2 Digital Spread Spectrum
3. Proposed Spread Spectrum
   - 3-1 M-sequence circuit
   - 3-2 Pseudo Analog Noise Generator
   - 3-3 Simulation Results
4. Advanced Spread Spectrum
   - 4-1 Extended Bit Pattern with Bit Inverse
   - 4-2 Extended Bit Pattern with Bit Exchange
5. Conclusion

4. Advanced Spread Spectrum

4-1 Extended Bit Pattern with Bit Inverse

- Bit Operation with Bit Inverse
  Each Bit Pattern is different ⇒ ×8 Patterns

Table 2 Bit Reverse Results

0)	$Q_1Q_2Q_3$:	0-1-3-6-5-2-4-	(3)
1)	$\overline{Q_1}Q_2Q_3$:	1-0-2-7-4-3-5-	(4)
2)	$Q_1\overline{Q_2}Q_3$:	2-3-1-4-7-0-6-	(5)
3)	$\overline{Q_1}Q_2Q_3$:	3-2-0-5-6-1-7-	(6)
4)	$Q_1Q_2\overline{Q_3}$:	4-5-7-2-1-6-0-	(7)
5)	$\overline{Q_1}Q_2\overline{Q_3}$:	5-4-6-3-0-7-1-	(8)
6)	$Q_1\overline{Q_2Q_3}$:	6-7-5-0-3-4-2-	(9)
7)	$\overline{Q_1Q_2Q_3}$:	7-6-4-1-2-5-3-	(10)

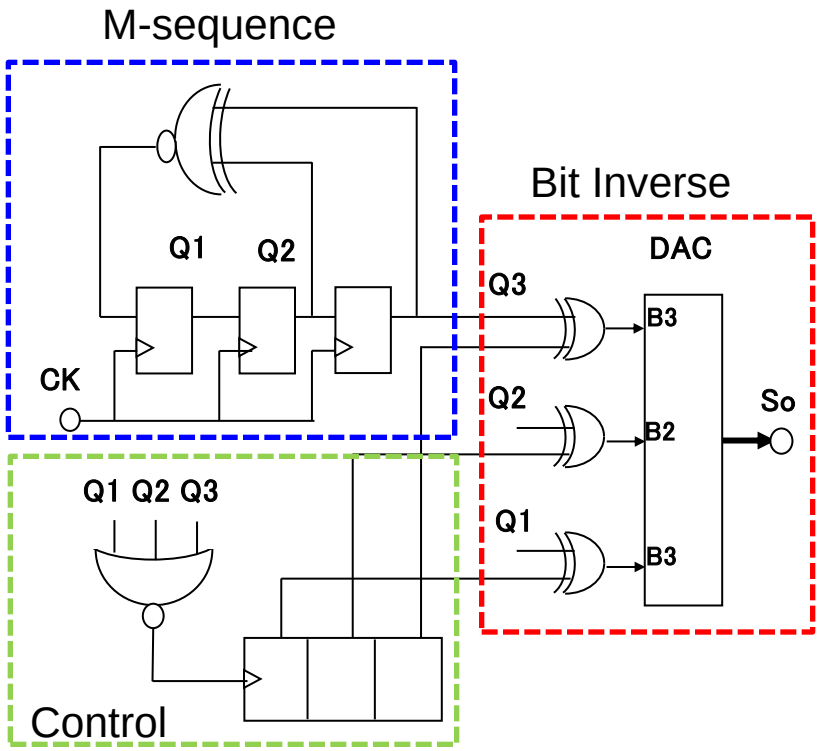


Fig.18 Bit Inverse Circuit

4. Advanced Spread Spectrum

4-1 Extended Bit Pattern with Bit Inverse

- Output noise pattern with Bit Inverse
  Periodic Length = 7 × 8 = 56 Clocks
- Harmonic Frequency Spectrum is reduced -12dB and smooth

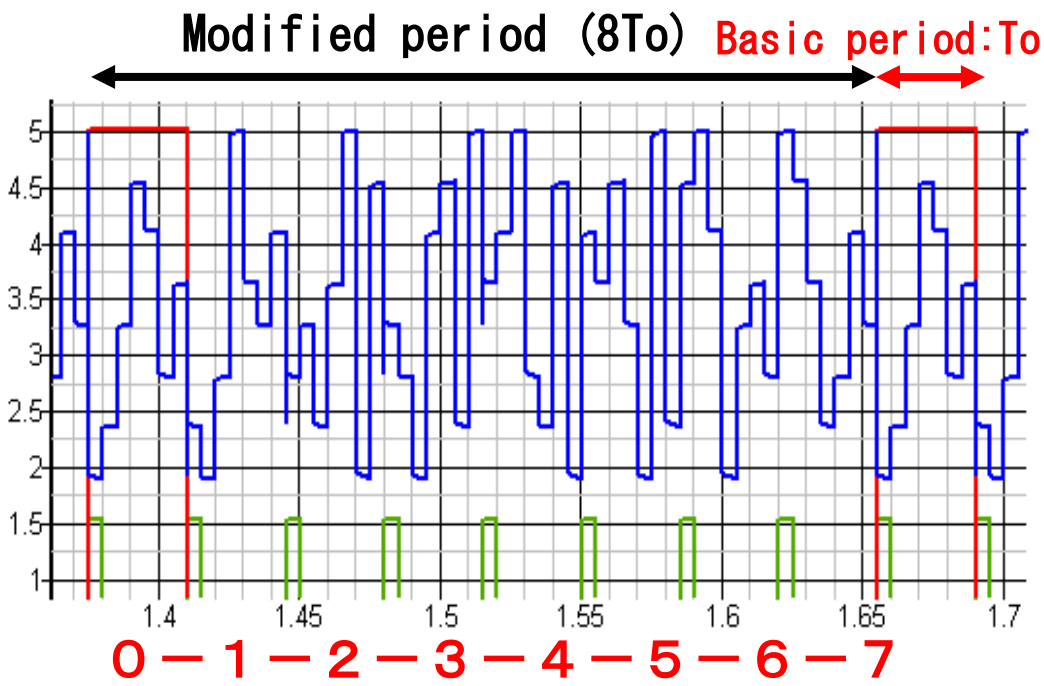
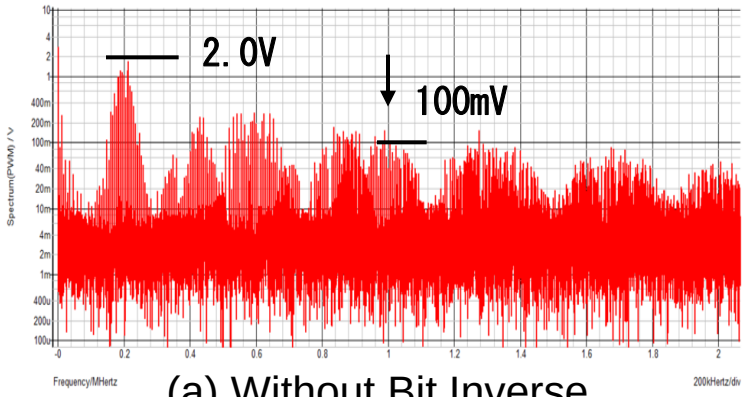
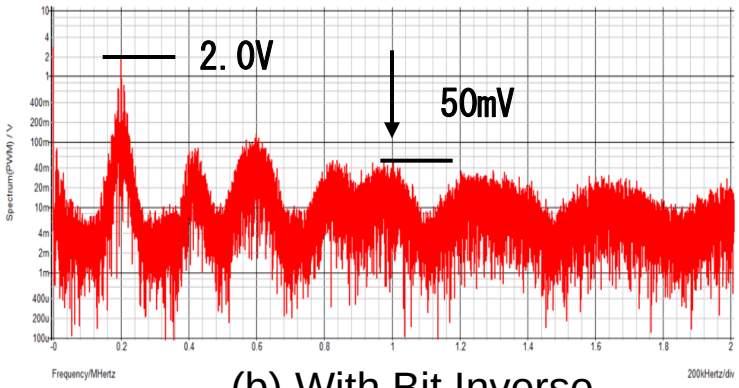


Fig.19 Waveform of Bit Pattern Inverse



(a) Without Bit Inverse



(b) With Bit Inverse

Fig.20 Spread Spectrum

4. Advanced Spread Spectrum

4-2 Extended Bit Pattern with Bit Exchange

- Output Noise Pattern with Bit Exchange
  Each Bit Pattern is different ⇒ ×6 Patterns
- Bit Inverse & Bit Exchange ⇒ 8×6 = 48 Patterns

Table 3 Bit Exchange Results

0) $Q_1Q_2Q_3$:	0-1-3-6-5-2-4-	(3)
A) $Q_1Q_3Q_2$:	0-1-5 -6-3-4-2-	(11)
B) $Q_2Q_1Q_3$:	0-2-3-5-6-1-4-	(12)
C) $Q_2Q_3Q_1$:	0-4-5-3-6-1-2-	(13)
D) $Q_3Q_1Q_2$:	0-2-6-5-3-4-1-	(14)
E) $Q_3Q_2Q_1$:	0-4-6-3-5-2-1-	(15)

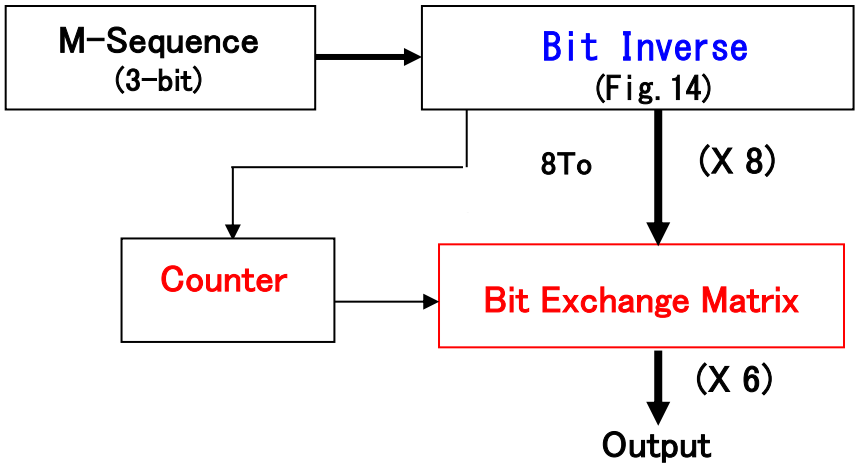


Fig.21 Bit Exchange Circuit

- Output noise pattern
  with Bit Inverse & Exchange
  Periodic Length = 48 × 7 = 336 Clocks
- Peak level of fo : −3.7 dB
- Output Ripple is 13 mVpp (< 0.3 %)

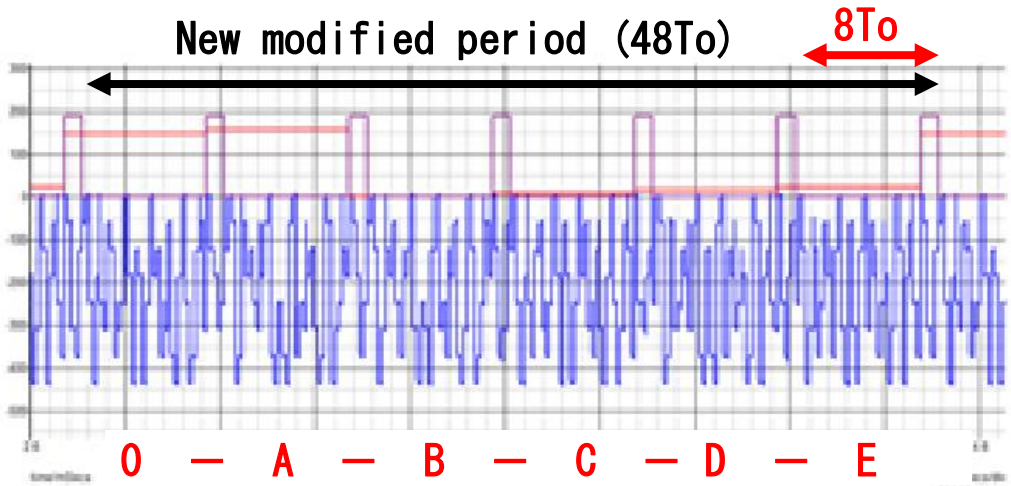


Fig.22 Output Noise Pattern with Inv. & Exc.

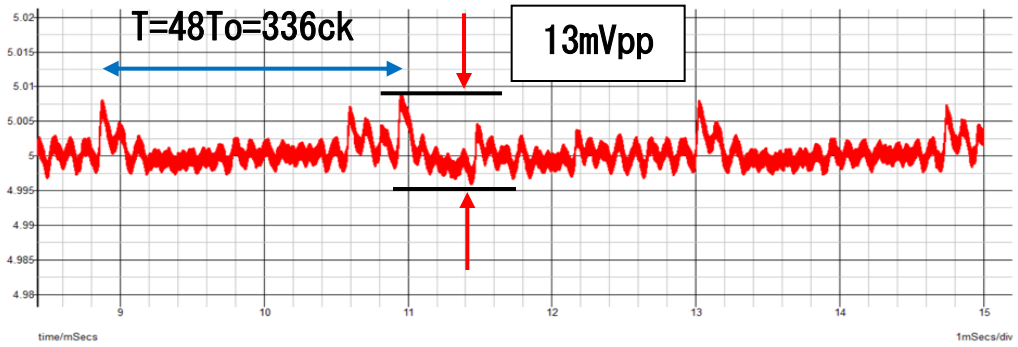
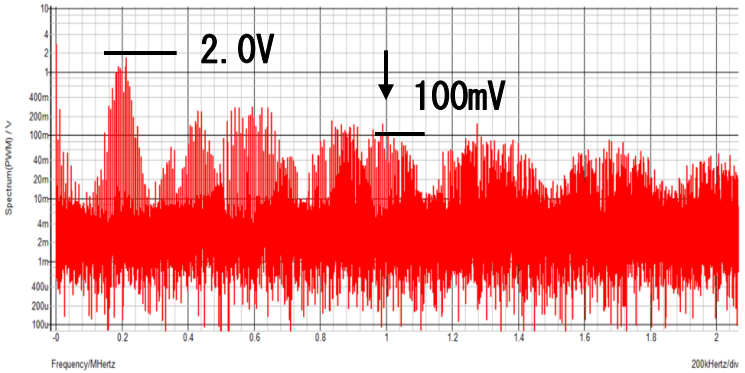
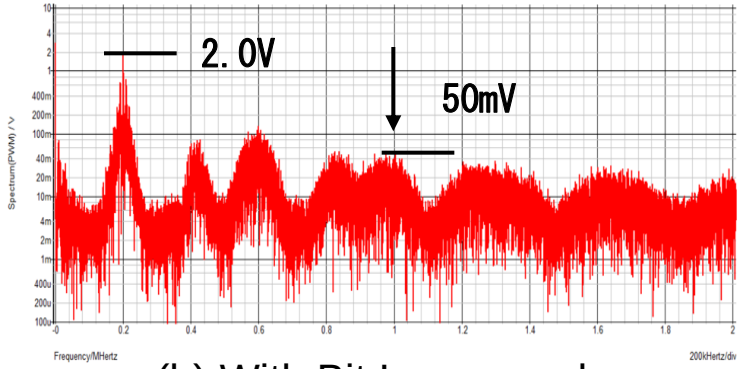


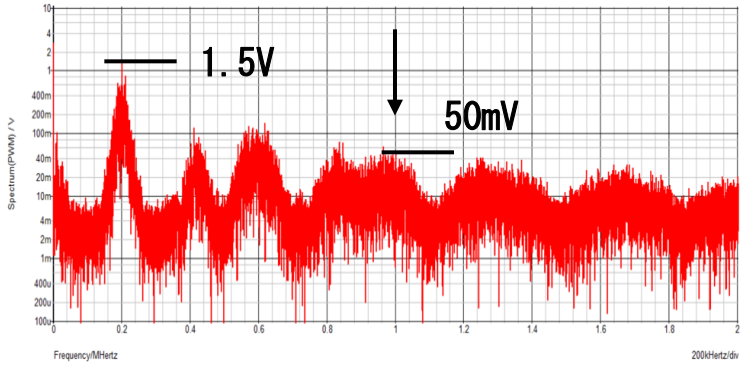
Fig.23 Output Ripple of Switching Converter



(a) Without Bit Exchange



(b) With Bit Inverse only



(c) With Bit Inverse & Exchange

Fig.24 Spread Spectrum

Conclusion

- New EMI reduction method by extended spread spectrum with pseudo analog noise using LPF and PLL circuit

a) Pseudo Analog Noise Generator:

- 3-bit M-sequence circuit for random pattern generator
- Extended pattern generator with Bit Inverse & Exchange

b) Simulation Results:

1) with pseudo analog noise [Period = 7 clock length]

- Peak level of fo(200kHz): −2.4 dB (Ripple : 7 mVpp)
- Harmonic levels (1MHz) : −9.0 dB

2) with Extended pseudo analog noise [Period = 336 clock]

- Peak level of fo(200kHz) : −3.7 dB (Ripple : 13 mVpp)
- Harmonic levels (1MHz) : −12 dB

Thank you
for your attention.