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 Exchange
5. Conclusion
1. Background

Switching Converters

Supply many kinds of Voltage

- 5.0 V, 4.2 V, 3.5 V,
- 2.5 V, 1.2 V etc.

Many switching converters in equipment

Fig.1 background
1. Background

Switching Converters

Supply many kinds of Voltage

EMI

Switching Noise

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
  $f_0$, $2 \cdot f_0$, $3 \cdot f_0$, \cdots

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 $f_0$ 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)

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)
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

![Waveform of Analog Noise](image1)
![Waveform of Output Ripple](image2)

Table 1 Parameters of Switching Converter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vin</td>
<td>9.0 V</td>
</tr>
<tr>
<td>Vo</td>
<td>5.0 V</td>
</tr>
<tr>
<td>Io</td>
<td>0.5 A</td>
</tr>
<tr>
<td>L</td>
<td>10uH</td>
</tr>
<tr>
<td>Co</td>
<td>470μF</td>
</tr>
<tr>
<td>Fck</td>
<td>200kHz</td>
</tr>
</tbody>
</table>

Fig.16 Output Voltage Ripple
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).

Fig. 17 Comparison of Spread Spectrum

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

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Bit Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0-1-3-6-5-2-4-</td>
</tr>
<tr>
<td>1</td>
<td>1-0-2-7-4-3-5-</td>
</tr>
<tr>
<td>2</td>
<td>2-3-1-4-7-0-6-</td>
</tr>
<tr>
<td>3</td>
<td>3-2-0-5-6-1-7-</td>
</tr>
<tr>
<td>4</td>
<td>4-5-7-2-1-6-0-</td>
</tr>
<tr>
<td>5</td>
<td>5-4-6-3-0-7-1-</td>
</tr>
<tr>
<td>6</td>
<td>6-7-5-0-3-4-2-</td>
</tr>
<tr>
<td>7</td>
<td>7-6-4-1-2-5-3-</td>
</tr>
</tbody>
</table>

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

Fig.20 Spread Spectrum

(a) Without Bit Inverse

(b) With Bit Inverse

Modified period (8To) Basic period:To
4. Advanced Spread Spectrum

4-2 Extended Bit Pattern with Bit Exchange

- Output Noise Pattern with Bit Exchange
  Each Bit Pattern is different \( \Rightarrow \times 6 \) Patterns
- Bit Inverse & Bit Exchange \( \Rightarrow 8 \times 6 = 48 \) Patterns

Table 3 Bit Exchange Results

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Bit Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>0) ( Q_1Q_2Q_3 )</td>
<td>0-1-3-6-5-2-4- (3)</td>
</tr>
<tr>
<td>A) ( Q_1Q_3Q_2 )</td>
<td>0-1-5-6-3-4-2- (11)</td>
</tr>
<tr>
<td>B) ( Q_2Q_1Q_3 )</td>
<td>0-2-3-5-6-1-4- (12)</td>
</tr>
<tr>
<td>C) ( Q_2Q_3Q_1 )</td>
<td>0-4-5-3-6-1-2- (13)</td>
</tr>
<tr>
<td>D) ( Q_3Q_1Q_2 )</td>
<td>0-2-6-5-3-4-1- (14)</td>
</tr>
<tr>
<td>E) ( Q_3Q_2Q_1 )</td>
<td>0-4-6-3-5-2-1- (15)</td>
</tr>
</tbody>
</table>

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 %)

New modified period (48To)

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

T=48To=336ck

13mVpp

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): $-2.4 \text{ dB} \ (\text{Ripple : 7 mVpp})$
      - Harmonic levels (1MHz) : $-9.0 \text{ dB}$
   2) with Extended pseudo analog noise [Period = 336 clock]
      - Peak level of fo(200kHz) : $-3.7 \text{ dB} \ (\text{Ripple : 13 mVpp})$
      - Harmonic levels (1MHz) : $-12 \text{ dB}$
Thank you for your attention.