Automatic High Frequency Notch Generation in Noise Spectrum of Switching Converters with Pulse Coding Method

Yifei Sun*, Yi Xiong, Nobukazu Tsukiji, Yasunori Kobori, Haruo Kobayashi

Division of Electronics and Informatics, Graduate School of Science and Technology, Gunma University
1-5-1 Tenjin-cho, Kiryu-shi, Gunma, 376-8515 Japan
E-mail: *t172d004@gunma-u.ac.jp

Abstract

EMI noise can be reduced by properly shaking the clock of the switching power supply. In addition, we are investigating a method of controlling the power supply by coding pulses with different pulse widths and generating a notch characteristic with less noise in the EMI spread spectrum. In this pulse coding method, a clock and coding pulse is generate automatically with respect to the reception frequency, and this method can generate notch characteristic at set frequency. We also consider to generating notch frequency in the higher frequency range.

Keyword: Switching Converter, Noise spectrum, Notch frequency, Pulse Coding, Communication Device

1. Introduction

In recent years, with the acceleration of high-speed and high-frequency electronic equipment, the fluctuation of the switching noise has strongly spread in the wide frequency range. So it is very important to reduce an Electro Magnetic Interference (EMI) noise by suppressing the peak levels at the fundamental frequency and its harmonic frequencies.

On the other hand, for the communication equipment including the radio receiver, it is very important to reduce the radiation noise at the specific frequencies, such as the receiving frequency, by suppressing diffusion of power supply noise. We have proposed the pulse coding technique to have the notch characteristics at the random frequency in the noise spectrum of the switching converter[3]-[5].

In this paper, we spread spectrum with both EMI reduction and suppressing diffusion of power supply noise using PWC method by the notch characteristics. The notch frequency is automatically set to that of the received signal by adjusting the clock frequency using the equation Fn=(N+0.5)Fck. Than investigated the direct generating method of the clock and the coded pulses to automatic generation of the notch frequency and also consider to generating this notch frequency in the higher frequency range.

2. Switching Converters with Spread Spectrum

2.1. Basic DC-DC switching converters

Fig. 1 shows the basic block diagram of the buck type DC-DC converter[1],[2] with the PWM (Pulse Width Modulation) signal control and Fig.2 shows its main signals. This converter consists of the power stage and the control stage. The power stage contains a main power switch, a free-wheel diode, an inductor and an output capacitor. The main switch is controlled by the PWM signal from the control stage, which consists of an operational amplifier, a comparator and a reference voltage source. The comparator generates the PWM signal compared a saw-tooth signal and the amplified error voltage like Fig2. In the buck type DC-DC converter, the output voltage Vo can be expressed by the following equation using the input voltage Vi and the ON/OFF ratio D (Duty).

$$V_o = D \times V_i \qquad (1)$$

Here, as the switching signal of high power is increase in speed, large EMI were generated.

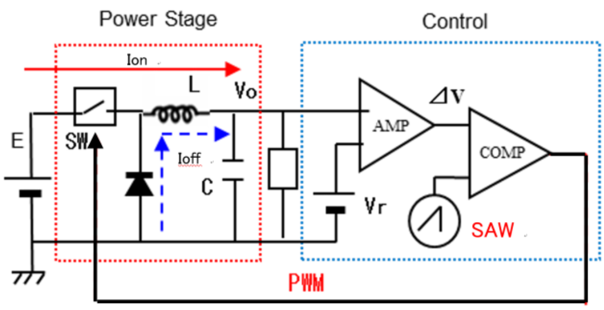


Fig.1 Switching buck converter with PWM signal

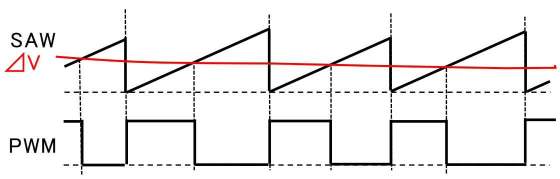


Fig.2 Waveform of switching buck converter

2.2. EMI reduction with clock modulation

In order to reduce the EMI noise, modulation of the clock pulse is usually use by shaking the phase or frequency of the clock in Fig.1. The spectrum of the PWM signal without the clock modulation is shown in Fig.3.

There is the line spectrum at the frequency of the clock (0.2MHz) and there appear many harmonic spectra. Fig.4 shows the spectrum with the clock modulation. The peak level of the clock spectrum is reduced from 3.5V to 2.0V which is about 4.9dB reduction. There is no line spectrum but the bottom levels of the spectrum are higher than 8mV. That is not so good for the communication devices which receive weak radio waves.

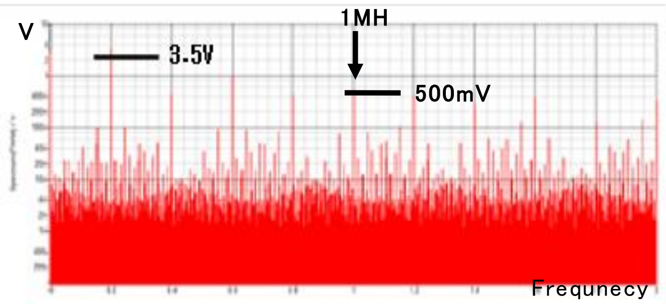


Fig.3 Simulated spectrum without EMI reduction

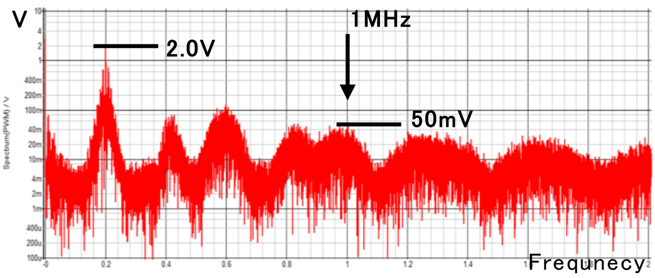


Fig.4 Simulated spectrum with EMI reduction

2.3. Pulse width coding (PWC) method

In the proposed PWC method, the analog output voltage error is convert to a digital signal. By appropriately switching and controlling the pulse width with this signal, the output voltage of the switching power supply is stabilize.

Parameters is defined to show the empirical formula of the notch frequency of the PWC method. Let W be the width of pulse period, W_H be the longer modulation width and W_L be the shorter one. N is represents a natural number. At this time, the notch frequency Fn is expressed by the following equation obtained by a numerical experiment.

$$F_n = \frac{N}{(W_H - W_L)} \quad (2)$$

From the above equation, it can be seen that the notch frequency depends only on the difference in the pulse width of the coding signal and does not depend on the clock frequency. Also by adjusting the pulse width, the notch frequency can be arbitrarily set.

3. PWC Method Switching Converter

3.1. Configuration of PWC method switching converter

Fig.5 shows the control circuit for the PWC method switching converter. The amplified error voltage of the output voltage is compared with the reference voltage Vr and its output logic level is kept in the D-type flip-flop FF by the clock for synchronizing with the clock. The output of this FF is called select signal SEL which choices one of the two pulses input to the selector. These two pulses are the coding pulses generated using the modulated clock.

In this simulation, the pulse width coding PWC pulses are used to generate the notch frequency in the spectrum of the modulate clock. Fig. 6 shows the conditions of the PWC control and the other conditions are Vi=10V, Vo=5.0V, Io=0.2A and Fck=500kHz. And we manually set W_H and W_L.

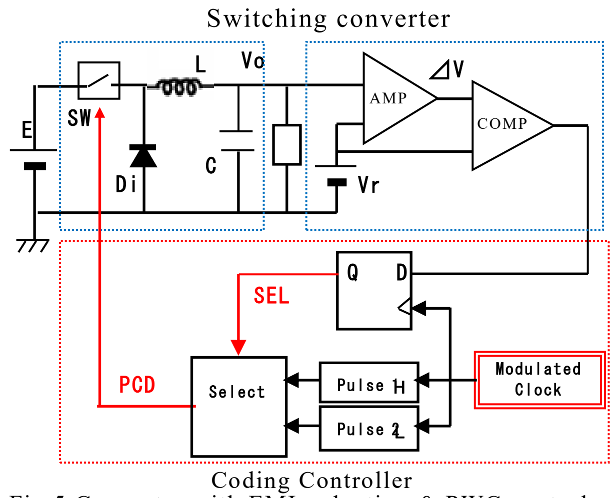
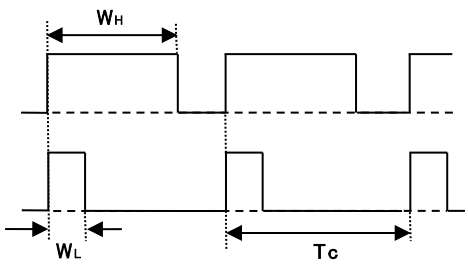


Fig.5 Converter with EMI reduction & PWC control



●Conditions ★Pulse 1 ★Pulse 2

Tck=2.0μs W_H=1.6μs W_L=0.3μs

$D_H=W_H/T_{ck}=0.80$ $D_L=W_L/T_{ck}=0.15$

Fig.6 Coded pulses of PWC control

3.2. Simulation result with PWC control

Fig.7 shows the spectrum of the coded pulses of the PCD signal. There appear the notch characteristics at the frequency of 770 kHz and 1.5MHz, which are the theoretical frequencies by calculating from the coded pulses shown in Fig.6.

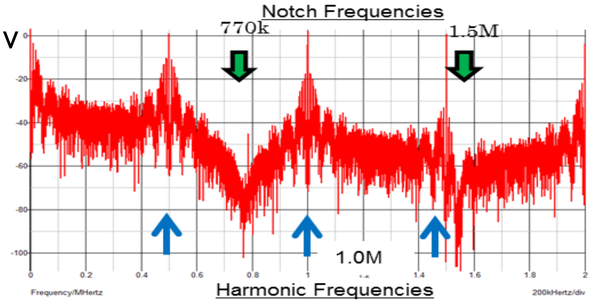


Fig.7 Simulated spectrum with PWC control

4. Automatic Generation of the Notch Frequency

When set frequency of communication equipment like the radio receiver, auto correspond to input frequency change is necessary. We consider about automatic generation of Pulse-H and Pulse-L (in Fig.5) to realize automatic PWC control.

4.1. Analysis of relationship with Fck and Fn

Generally speaking, it is good for the notch frequency Fn to generate at middle of Fck (as shown in Fig.7). Fn is the frequency of the receiving signal Fin. The relationship is shown in the next equation.

$$\text{Fin} = (\text{N}+0.5)\times\text{Fck} \qquad [\text{N=natural number}] \qquad (6)$$

On the other hand, the duty Do of the PWM signal in the switching converter is usually represented like Do=Vo/Vin, here Vo is the output DC voltage and Vin is the input DC voltage respectively. Hence the pulse width To of the PWM signal is represented shown in the Eq. (7).

According to the Eq. (2), the period of the notch frequency Tn is derived from the difference between the pulse width of W_H and W_L. In this case, W_H, W_L and To should have the relation shown in the Eq. (8) in order to control the output voltage Vo stable. Here, Tp is the pulse difference between W_H and To or To and W_L, and 2×Tp is equal to Tn and it means the gain of the pulse coding control.

$$\text{To} = \text{Do}\times\text{Tck} = (\text{Vo/Vin})\times\text{Tck} \qquad (7)$$

$$W_H=\text{To}+\text{Tp}, \quad W_L=\text{To}-\text{Tp} \qquad (8)$$

$$\therefore \text{Tn}=W_H-W_L=2\times\text{Tp} \qquad (9)$$

4.2. Direct generating the clock pulse (N=1)

In order to make the response quick for changing the input frequency, we have investigated the direct generating method of the clock and the coded pulses. In the Eq. (6), the period of clock Tck is able to be generated by measuring the period of the input pulse Tin like the following Eq. (10). It is easy to make Tck with a shifter and the digital adder in the digital circuit. Fig.8 shows the block diagram of proposed circuit of the direct method (in the case that N=1). And the Fig.9 is automatic PWC method pulse coding circuit.

$$\text{Fin} = (\text{N}+0.5)\times\text{Fck} \quad \Rightarrow \text{Tck} = (\text{N}+0.5)\times\text{Tin} \qquad (10)$$

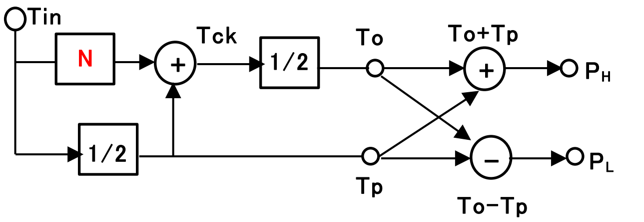


Fig.8 Block diagram of direct generating the clock pulse and the coding pulse

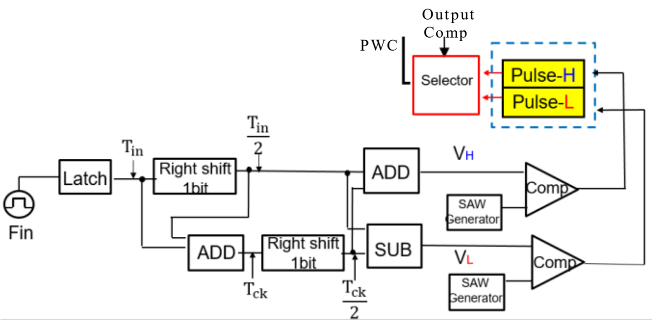


Fig.9 Automatic PWC method pulse coding circuit

4.3. Simulated results of the direct method

In the simulated spectrum of the direct method shown in Fig.10, the generated clock is modulated with EMI reduction. The notch characteristics clearly appears and its frequency is just 750kHz which is equal to Fin. The bottom level of the notch frequency is about 1mV. There appears another big notch at F=3.0MHz, which is the 4th harmonic of the fundamental notch frequency Fn.

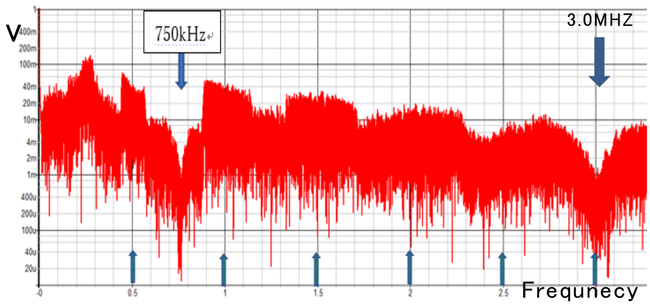


Fig.10 Simulated spectrum with EMI reduction

4.4. Direct generating the clock pulse (N=2)

When N=2 and Fin=1.25MHz are set in Eq. (10), the clock frequency is automatically calculated as

Fck=500kHz and the notch frequency appears at F=1.27MHz between the 2nd and the 3rd harmonics of the clock frequency shown in Fig.11. The relationship between the period of the clock pulse and that of the input signal is as the next equation.

$$Tck = 2.5 \times Tin \qquad (10')$$

In the communication devices, there are many changes of the receiving signal and the input frequency. Response speed is important when tuning or switching communication channels. Here let input change from 1.25MHz to 1MHz and 750kHz. The clock frequency is changed according to the change of Fin. Fig.12 shows the change of the peak of the sawtooth signal of Fck.

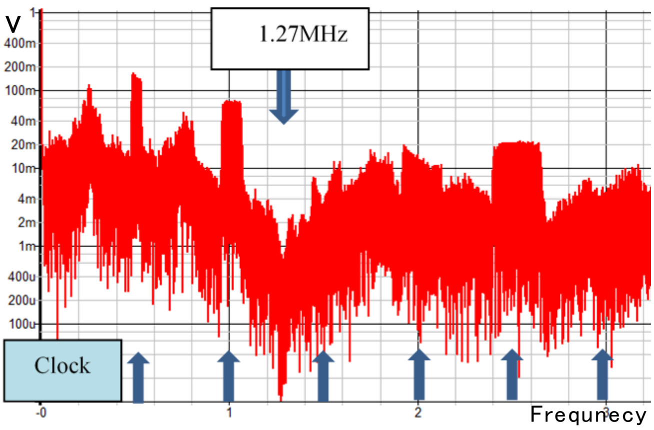


Fig.11 Simulated spectrum with N=2

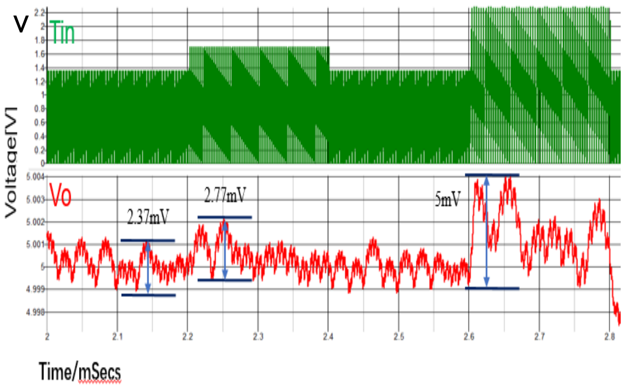


Fig.12 Transient response for Fin change (N=2)

4.5. Direct generating the clock pulse (N=3)

When N=3 and Fin=1.75MHz are set in Eq.(10), the clock frequency is automatically calculated as Fck=500kHz and the notch frequency appears at F=1.80MHz between the 3rd and the 4th harmonics of the clock frequency shown in Fig.13. It is a little higher than input frequency.

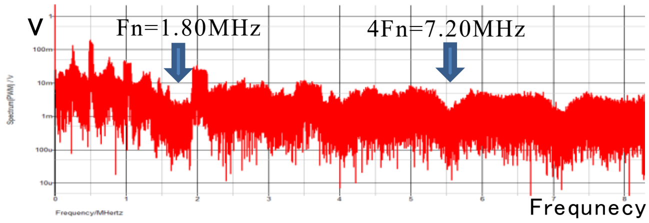


Fig.13 Simulated spectrum with N=3

Conclusion

This paper has proposed the technique to generate the notch characteristics at the desired frequency in the noise spectrum of the switching converter. The clock pulse and the coding pulses are automatically generated and the notch characteristic automatically appears at the input frequency where the notch frequency Fn appears between the clock frequency Fck and its 2nd harmonic or the 2nd and the 3rd harmonics. Automatic High Frequency Notch Generation in Noise Spectrum of Switching Converters with Pulse Coding Method has already been achieved. It is good for radio receiver to receiving high frequency signal without other communication devices interference.

References

[1] H. Kobayashi, T. Nabeshima, Handbook of Power Management Circuits, Pan Stanford Publisher (2016)

[2] Y. Kobori, T. Arafune, N. Tsukiji, N. Takai, H. Kobayashi, "Selectable Notch Frequencies of EMI Spread Spectrum Using Pulse Modulation in Switching Converter", IEEE ASICON, B8-8, Chengdu, China (Nov. 2015)

[3] Y. Kobori, N. Tsukiji, T. Arafune, M. W. S. Dulara, Y. Sun, N. Takai, H. Kobayashi, "Noise Spread Spectrum with Adjustable Notch Frequency in Complex Pulse Coding Controlled DC-DC Converters", IEEE International Symposium on Intelligent Signal Processing and Communication Systems 2017, Xiamen, China (Nov. 2017)

[4] Y. Sun, Y. Xiong, N. Tsukiji, Y. Kobori, H. Kobayashi, "Self-adjustable Notch Frequency in Noise Spectrum of Pulse Coding DC-DC Converter for Communication Devices", ICMEMIS2017, IPS01-03, Kiryu, Japan (Nov. 2017)

[5] Y. Sun, Y. Xiong, Y. Kobori, H. Kobayashi, "Automatic Notch Generation in Noise Spectrum of Switching Converter with Pulse Coding Method", Technical Committee on Circuits and Systems, IEICE Engineering Sciences Society, 2018IEICJ-115, Tokyo Japan (Jan.2018)