Proceedings of International Conference
Technology and Social Science 2018 (ICTSS 2018)

Pulse Coding Controlled Switching Converter with Generating Automatic Frequency Tracking Notch Characteristics for Radio Receiver

Yifei Sun[1,a], Yi Xiong[1,b], Yasunori Kobori[1,c] and Haruo Kobayashi[1,d]

[1]Division of Electronics and Informatics, Faculty of Science and Engineering, Gunma University
1-5-1 Tenjincho, Kiryu-shi, Gunma, 376-8515, Japan

[a]< t172d004@gunma-u.ac.jp >, [b]<t161d601@gunma-u.ac.jp>,

[c]<kobori@gunma-u.ac.jp>, [d]<koba@gunma-u.ac.jp>

Keywords: spread spectrum, EMI reduction, notch frequency, pulse coding

Abstract. This paper proposes an EMI spread spectrum technique with automatic notch frequency tracking using the pulse coding controlled method of the DC-DC switching converter for the communication equipment. This proposed EMI spread spectrum technique does not distribute the switching noise into some specified frequency bands. In other words, the noise spread spectrum characteristics have selective notches. We can automatically prevent the noises from spreading into important frequencies (such as AM, FM bands). The notches in the spectrum of the switching pulses appear using two types of pulse coding method (PWC and PWPC). The notch frequency is automatically set to that of the received signal by adjusting the clock frequency using the equation $\mathrm{F_n} = (\mathrm{N} + 0.5)\mathrm{F_{ck}}$. Here $\mathrm{F_n}$ is a notch frequency, $\mathrm{F_{ck}}$ is a clock frequency, N is a positive integer. We have confirmed with simulation that the proposed technique is effective for EMI reduction and notch generation.

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 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 in the noise spectrum of the switching converter [1].

In this paper, we propose a spread spectrum technique for EMI reduction with suppressing diffusion of power supply noise using Pulse Width Coding (PWC) and Pulse Width/Pulse Phase Coding (PWPC) methods, based on the notch characteristics design. The notch frequency is automatically set to that of the received signal by adjusting the clock frequency using the equation $\mathrm{F_n} = (\mathrm{N} + 0.5)\mathrm{F_{ck}}$. Then we investigate the direct generation method of the clock and the coded pulses for automatic generation of the notch frequency and also consider this notch frequency generation in the higher frequency range.

2. Switching Converters with Spread Spectrum

2.1 Basic DC-DC Switching Converters

Fig. 1 shows a basic block diagram of the buck type DC-DC converter [2,3] with the Pulse Width Modulation (PWM) signal control and Fig. 2 shows its main signals. The comparator generates the PWM signal by comparing a saw-tooth signal and the amplified error voltage as shown in Fig. 2. 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).

$$V_o = D \times V_i \tag{1}$$

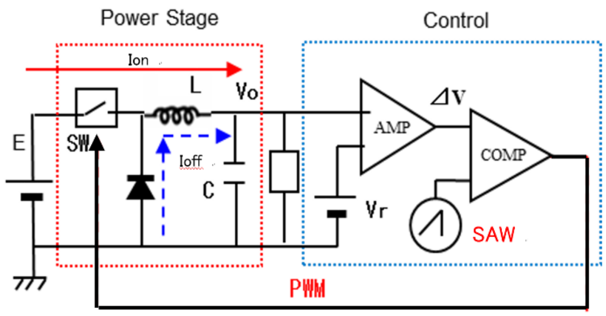


Fig.1 Switching buck converter with PWM signal

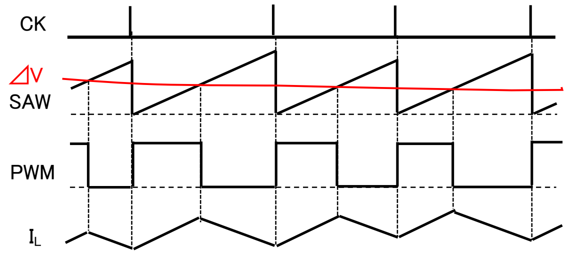


Fig.2 Waveform of switching buck converter

2.2 EMI Reduction and Pulse Width Coding (PWC) Method

In order to reduce the EMI noise, modulation of the clock pulse is usually used 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 4.9dB reduction. There is no line spectrum but the bottom levels of the spectrum are higher than 8mV. In Japan's AM radio broadcasting, 0.5~1.6MHz are used as the carrier frequency band, the occupied bandwidth of each broadcast station is 15kHz. In other words, AM radio channel also diffuses noise to selected frequency. It is not good for the communication devices which receive weak radio waves.

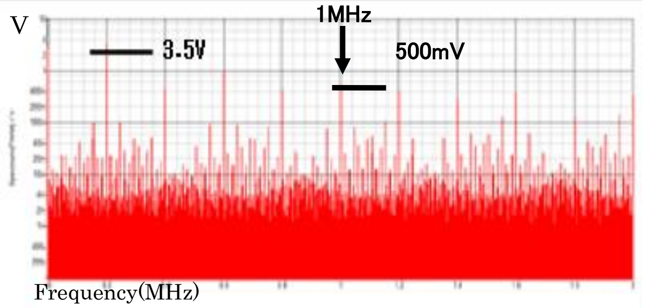


Fig.3 Simulated spectrum without EMI reduction

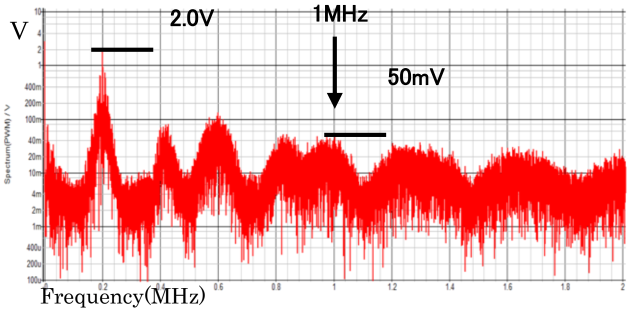


Fig.4 Simulated spectrum with EMI reduction

In PWC method, the analog output voltage error is converted to a digital signal. By appropriately switching and controlling the pulse width of this signal, the output voltage of the switching power supply is stabilized. Parameters are 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 represents a positive integer. At this time, the notch frequency Fn is expressed by the following equation obtained by a numerical experiment.

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

3. Automatic Notch Frequency Generate with PWC Control

Fig.5 shows the control circuit for the PWC method switching converter. The output of this FF is called a select signal (SEL) which selects one of the two pulses to the selector. These two pulses are the coding pulses generated using the modulated clock. Here we manually set the value of W_H and W_L. When tuning or switching communication channels, automatic adjustment to the input frequency change is necessary. So we consider about automatic generation of Pulse-H and Pulse-L to realize automatic PWC control.

3.1 Analysis of Relationship with Fck and Fn

Generally speaking, it is good for the notch frequency Fn to generate at the middle of Fck. When the received signal frequency from a radio receiver is equal to the notch frequency, it is possible to greatly reduce influence on other electronic devices. So we set the notch frequency equal to the received signal frequency from radio receiver, that is input frequency Fin. The relationship is shown in the next equation.

$$F_{in} = (N + 0.5) \times F_{ck} \qquad [N = natural\ \ number] \tag{3}$$

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 as shown in Eq. (5). The period of the notch frequency Tn is derived from the difference between the pulse widths of W_H and W_L. In this case, W_H, W_L and To should have the relation shown in Eq. (6) in order to control the output voltage Vo to be stable. Here, Tp is the pulse difference between W_H and To or To and W_L, and 2×Tp is equal to Tn; this means the gain of the pulse coding control.

$$T_o = D_o \times T_{ck} = \frac{V_o}{V_{in}} \times T_{ck} \tag{4}$$

$$W_H = T_o + T_p,\ W_L = T_o - T_p \tag{5}$$

$$T_n = W_H - W_L = 2 \times T_p \tag{6}$$

3.2 Direct Generation of Clock Pulse (N=1)

In the Eq. (3), the period of clock Tck is able to be generated by measuring the period of the input pulse Tin. It is easy to make Tck with a shifter and a digital adder in digital circuit. Fig. 6 is automatic PWC method pulse coding circuit according to Eq. (4)~(6) when $D_o = 0.5$ situation.

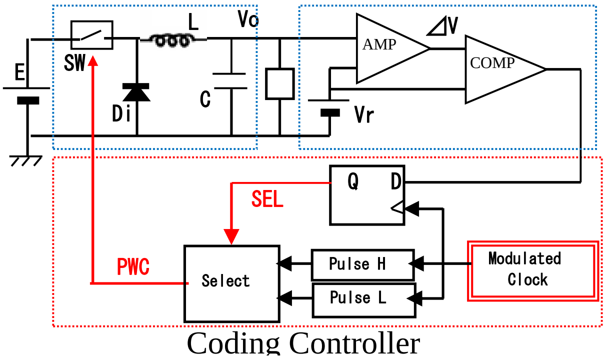


Fig.5 Converter with PWC control

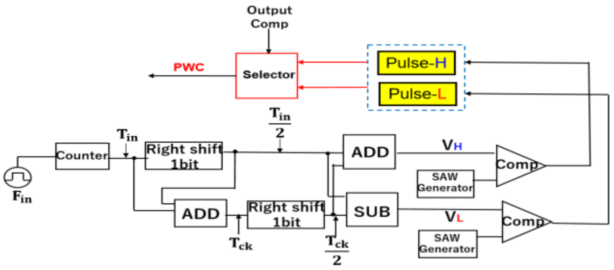


Fig.6 Automatic PWC method of the direct method

3.3 Simulation Result of the Direct Method (N=1)

Fig. 7 shows the simulation waveforms of P_L and P_H if we just set Fin equal to 750kHz. Tck is the saw-tooth, compared with V_L and V_H can produce Pulse-L and Pulse-H automatically. The simulated spectrum of the direct method is shown in Fig. 8. The notch characteristics can be clearly reflected. The frequency is 750kHz which is equal to Fin. The bottom level of the notch frequency is 1mV. There appears another big notch at F=3.0MHz, which is the 4th harmonic of the fundamental notch frequency.

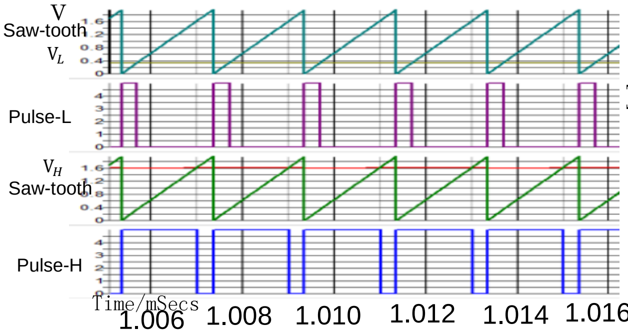


Fig.7 Simulation waveform of P_L and P_H

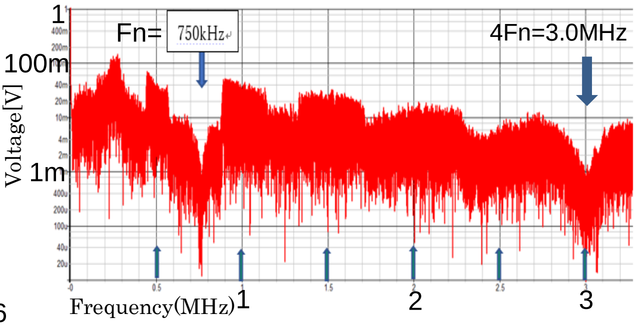


Fig.8 Simulated spectrum with EMI reduction

3.4 Direct Generation of the Clock Pulse (N=2)

When N=2 and Fin=1.25MHz are set in Eq. (3), 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 as shown in Fig. 9. 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 frequency change from 1.25MHz to 1MHz and 750kHz. The clock frequency is changed according to the variety of Fin. Fig. 10 shows the change of the peak of the saw-tooth signal of Fck.

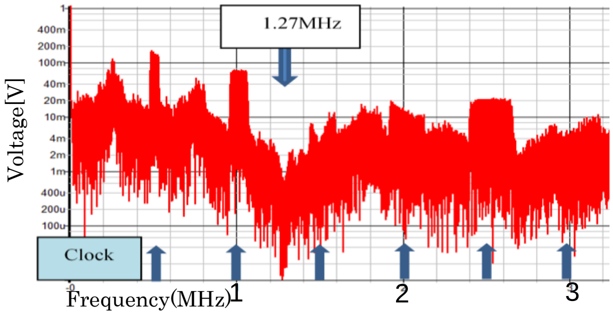


Fig.9 Simulated spectrum with N=2

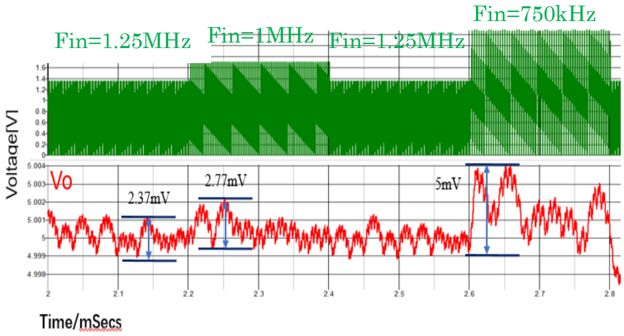


Fig.10 Transient response for Fin change (N=2)

3.5 Direct Generation of the Clock Pulse (N=3)

When N=3 and Fin=1.75MHz are set in Eq. (3), 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. 11. In Fig. 12, let input frequency change from 1.75MHz to 1.5MHz, we can find the steady-state ripple is 0.05% of the output voltage when $V_o=5V$. This fluctuation rate is very small, which means that stable DC-DC conversion is possible.

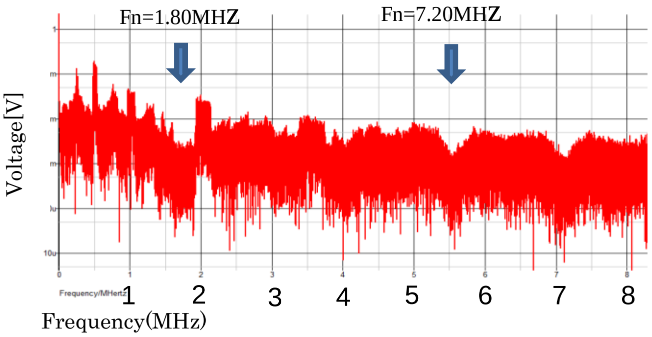


Fig.11 Simulated spectrum with N=3

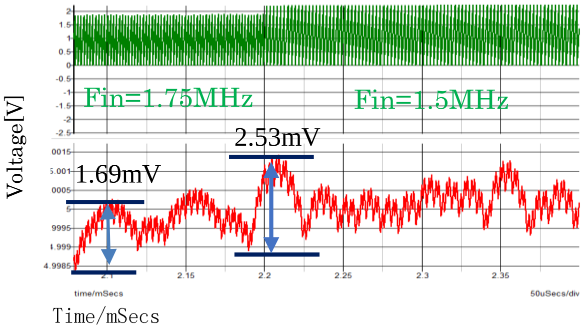


Fig.12 Transient response for Fin change (N=3)

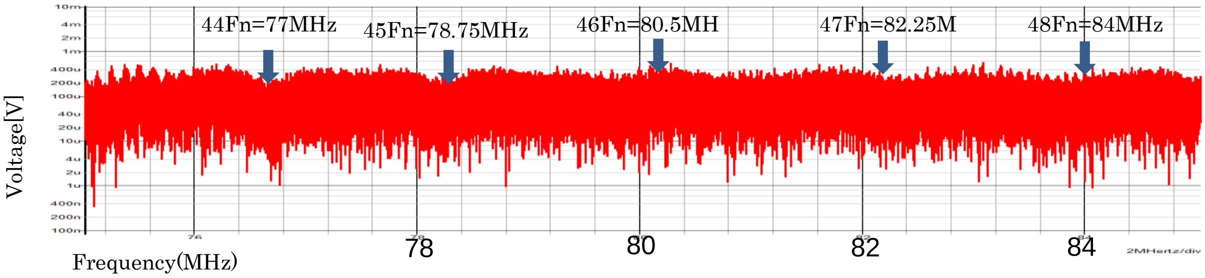


Fig.13 Simulated spectrum in high frequency (N=3)

Fig.13 shows simulated spectrum in high frequency regions from 75MHz to 85MHz situation. In high frequency regions, the harmonics notch is not clear, but it is still good for AM radio receiver as we mentioned earlier because in AM radio broadcasting, 0.5~1.6MHz are used as the carrier frequency band. In order to generate notches at high frequency, we come up with PWPC method.

4. Automatic Generating of Notch Frequency with PWPC Control

The PWPC method is a modulation method combined with PWC (Pulse Width coding) and PPC (Pulse Phase Coding) methods. We consider the automatic generation of Pulse-H and Pulse-L and Pulse-LD (Fig.14) to realize an automatic PWPC control.

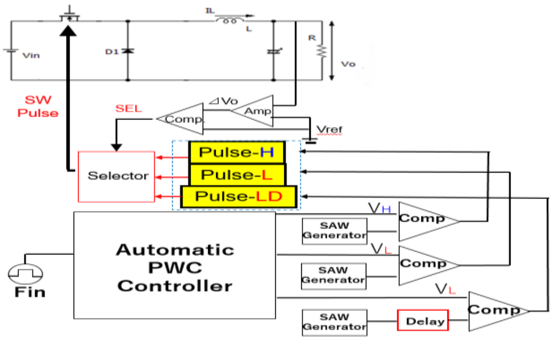


Fig.14 Pulse coding of PWPC method

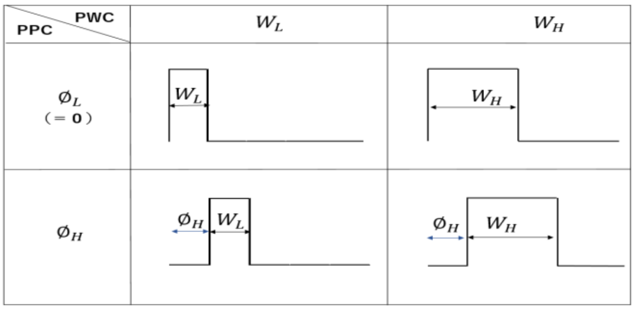


Fig.15 Coding pulse list

From Fig. 15, parameters are defined to show the empirical formula of the notch frequency. Let τ be the delay of pulse coding, τ_H be the longer delay and τ_L be the shorter one. N is represents a positive integer. At this time, the notch frequency Fn is expressed by the following equation obtained by a numerical experiment

$$F_n = \frac{N}{2(\tau_H - \tau_L)} \tag{7}$$

4.1 Analysis of PWPC Method

In PWPC method, the notch frequency can be realized by the Eq. (2) and Eq. (7), these two equations are made to obtain a big notch. Fig.14 shows a configuration of PWPC system. Using PWPC method, we want to produce delay saw-tooth compared with V_L to create Pulse-LD.

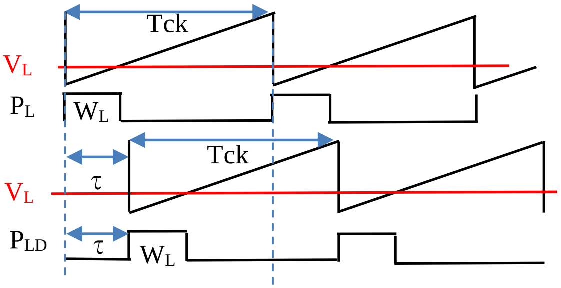


Fig. 16 Design timing in PWPC method

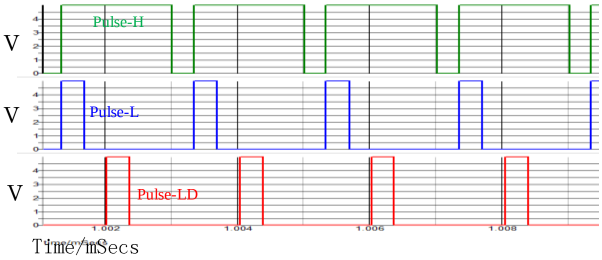


Fig. 17 Main waveforms of Fig. 14

Fig.16 shows the designed timing in PWPC method, where the phase shift τ is equal to 0.5Tin if Eq.(2) is equal to Eq.(7) in order to create big notch.

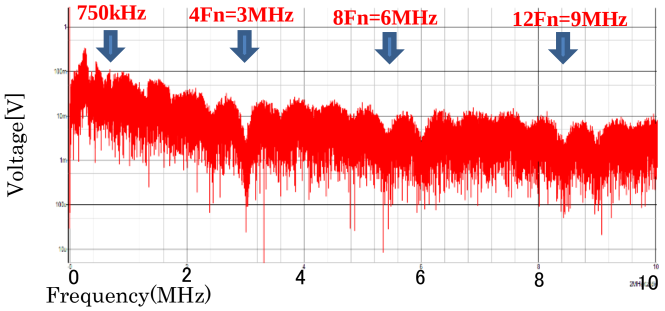
$$\tau = (W_H - W_L)/2 = 0.5 \times Tin \tag{8}$$

4.2 Automatic Generation of Notch Frequency with PWPC Control

Fig.17 shows major signal waveforms in Fig. 14. The coding pulses P_H, P_L or P_{LD} are generated by comparing the voltage $(To + Tp)$, $(To - Tp)$ or $(\tau + To - Tp)$ with the saw-tooth signal Tck.

In the proposed system, the input/output voltage are Vin=10V and Vo=5V, so that the theoretical duty ratio of the signal is Do=0.5. When the frequency of the input signal is set at Fin=750kHz, and in N=1 situation, the frequency of the clock is guided at Fck=500kHz by Eq. (3). In order to set the notch frequency at Fin=750kHz, the calculated pulse widths are chosen as W_H=1.67μs, W_L = 0.33μs, and the delay time is τ=0.67μs.

Seeing the simulation results, the simulated widths of the coded pulses are set to W_H=1.65μs,W_L = 0.35μs, τ=0.67μs as shown in Fig. 17. In this case, the simulated notch frequency appears at Fn=750kHz shown in Fig.18, which is almost equal to the theoretical notch frequency Fin=750kHz. There appears a big notch at F=3.0MHz, which is the 4th harmonic of the fundamental notch frequency Fn. The output voltage ripple is 3.98mV as shown in Fig. 19.



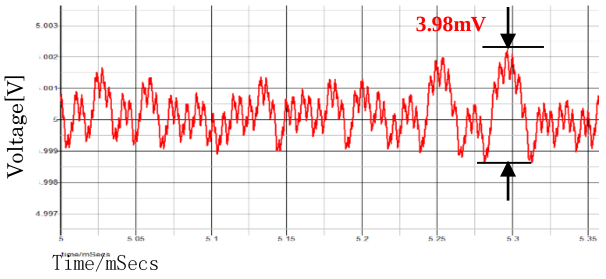


Fig.18 Simulation spectrum with PWPC control (N=1) Fig.19 Simulated output voltage ripple

5. Conclusion

This paper has proposed a 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. We have confirmed with simulation that automatic notch generation in noise spectrum of switching converters with PWC and PWPC methods can be achieved. It is good for radio receivers to receive high frequency signal without other communication device interferences.

References

[1] H. Kobayashi, T Nabeshima, ***Handbook of Power Management Circuits***, Pan Stanford Publishers, 2016.

[2] Y. Kobori, N. Tsukiji, N 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, NP-L5, Xiamen, China (Nov. 2017)

[3] 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”, International Conference on Electrical and Medical Intelligent System (ICMEMIS), IPS01-03, Kiryu, Japan (Nov. 2017)