Automatic Notch Frequency Tracking Method with EMI Noise Reduction of Pulse Coding Controlled Switching Converter for Communication Devices

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Abstract

This paper proposes a new EMI spread spectrum technique with automatic notch frequency tracking using the pulse coding controlled method of DC-DC switching converter for the communication equipment. This new EMI spread spectrum technique does not distribute the switching noise into some specified frequencies. In the PWC (Pulse Width Coding) method, the fundamental notch frequency is concerned with the pulse width difference between two coded pulses. In the complex PWPC (Pulse Width and Phase Coding) method, the notch frequency is calculated by the pulse width and phase. In this paper, 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.

Keyword: Switching converter, spread spectrum, EMI reduction, notch frequency, pulse width coding, phase coding

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 the 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]-[6].

In this paper, we spread spectrum with both EMI reduction and suppressing diffusion of power supply noise using PWC and PWPC methods 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. Then we investigate 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. At the end, we use complex conversion PWPC method to automatic generation of the notch frequency and improve notch characteristics.

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 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 by comparing a saw-tooth signal and the amplified error voltage as shown in 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).

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

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

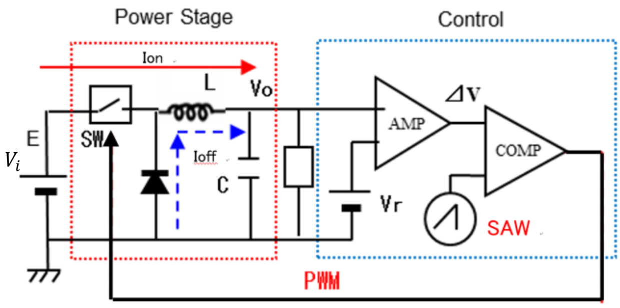


Fig.1 Switching buck converter with PWM signal

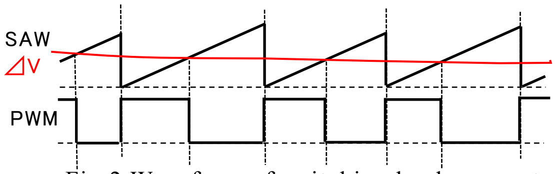


Fig.2 Waveform of switching buck converter

2.2. EMI reduction with clock modulation

In order to reduce the EMI noise, modulation of the clock pulse is usually 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 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.

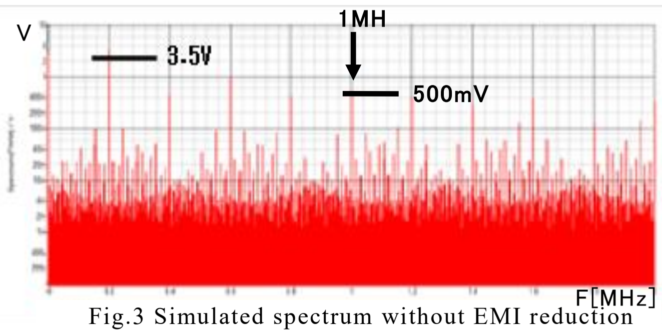


Fig.3 Simulated spectrum without EMI reduction

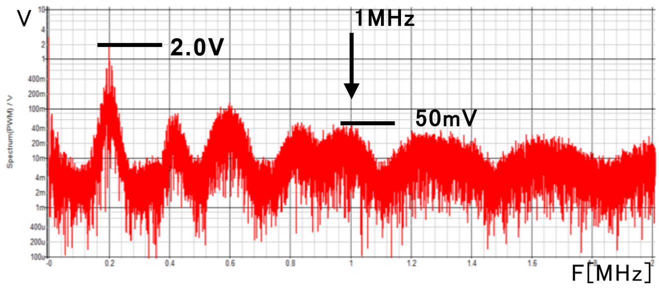


Fig.4 Simulated spectrum with EMI reduction

2.3. Pulse width coding (PWC) method

In the proposed PWC method, the analog output voltage error is 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 is represents a natural number. At this time, the notch frequency Fn is expressed by the following equation obtained by a numerical experiment.

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

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 compared with the reference voltage Vr and its output logic level were 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 order to perform stable control, it is necessary to control the increase and decrease of the output voltage by satisfying the following conditions.

$$D_L < D_O = \frac{V_{out}}{V_{in}} < D_H \qquad (3)$$

Here, D_L, D_H are the duty of pulses generated when the digital signals are low and high.

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 there we manually set $W_H = 1.6\mu s$, $W_L = 0.3\mu s$. The other conditions are Vi=10V, Vo=5.0V, Io=0.2A and Fck=500kHz.

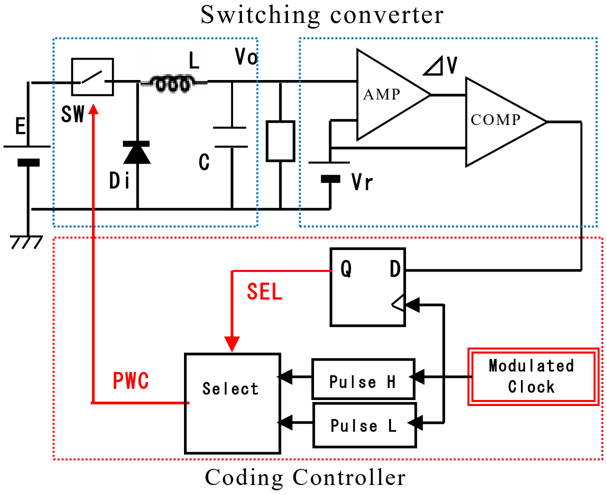
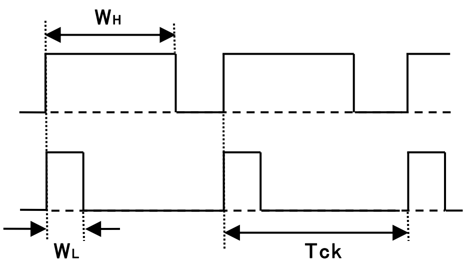


Fig.5 Converter with EMI reduction & PWC control



●Conditions ★Pulse H ★Pulse L

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

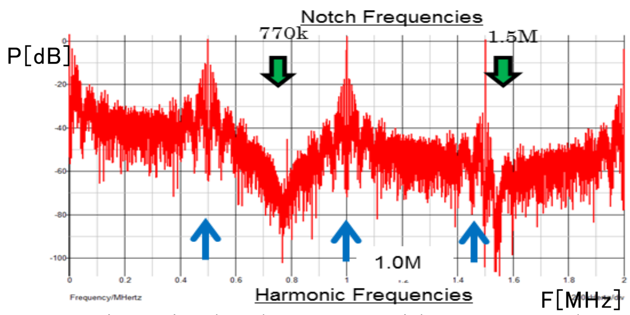


Fig.7 Simulated spectrum with PWC control

4. Automatic Notch Frequency Generate with PWC control

When the frequency of communication equipment like the radio receiver is set, automatic corresponding to input frequency change is necessary. We consider about automatic generation of Pulse-H and Pulse-L (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 the 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.

$$\mathrm{Fin} = (N+0.5)\times \mathrm{Fck} \quad [N=\text{natural number}] \tag{4}$$

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 the Eq. (5).

According to the Eq. (2), 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 the Eq. (6) 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.

$$\mathrm{To} = \mathrm{Do}\times \mathrm{Tck} = (\mathrm{Vo}/\mathrm{Vin})\times \mathrm{Tck} \tag{5}$$

$$W_H=\mathrm{To}+\mathrm{Tp},\quad W_L=\mathrm{To}-\mathrm{Tp} \tag{6}$$

$$\therefore \mathrm{Tn}=W_H-W_L=2\times \mathrm{Tp} \tag{7}$$

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. (4), the period of clock Tck is able to be generated by measuring the period of the input pulse Tin like the following Eq. (8). It is easy to make Tck with a shifter and a digital adder in digital circuit. Fig.8 shows the block diagram of the proposed circuit of the direct method (in the case that N=1). Fig.9 is automatic PWC method pulse coding circuit.

$$\mathrm{Fin} = (N+0.5)\times \mathrm{Fck} \quad \Rightarrow \mathrm{Tck} = (N+0.5)\times \mathrm{Tin} \tag{8}$$

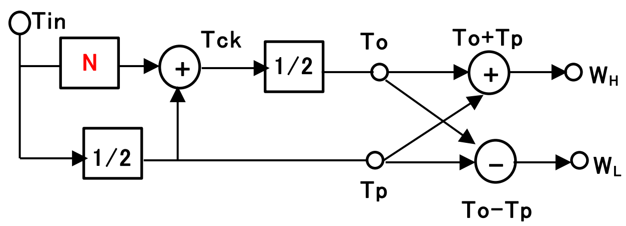


Fig.8 Block diagram of direct generating the clock pulse and the coding pulse

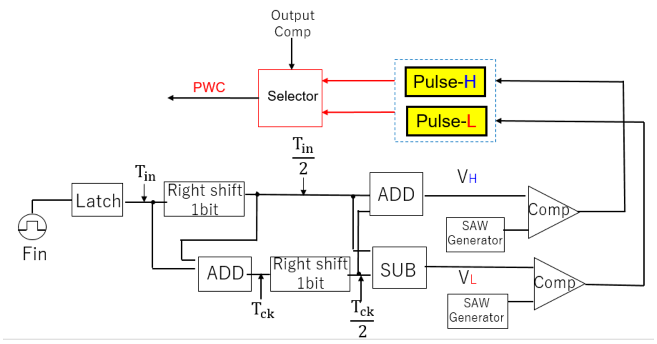


Fig.9 Automatic PWC method pulse coding circuit

4.3. Simulated results of the direct method

In the simulated spectrum of the direct method shown in Fig.10, the generated clock modulates 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.

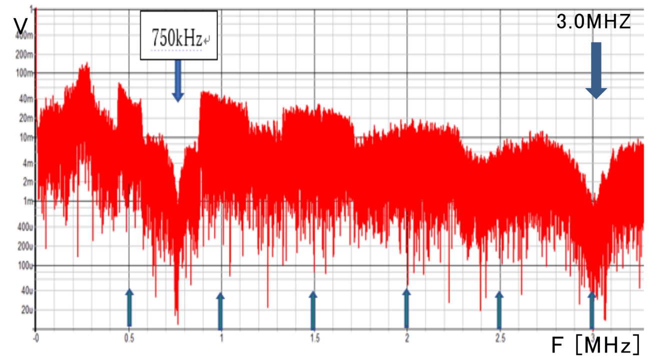


Fig.10 Simulated spectrum with EMI reduction

4.4. Direct generation of the clock pulse (N=2)

When N=2 and Fin=1.25MHz are set in Eq. (8), 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.11. The relationship between the period of the clock pulse and that of the input signal is given as follows:

$$Tck = 2.5\times Tin \qquad (8')$$

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 variety of Fin. Fig.12 shows the change of the peak of the saw-tooth signal of Fck.

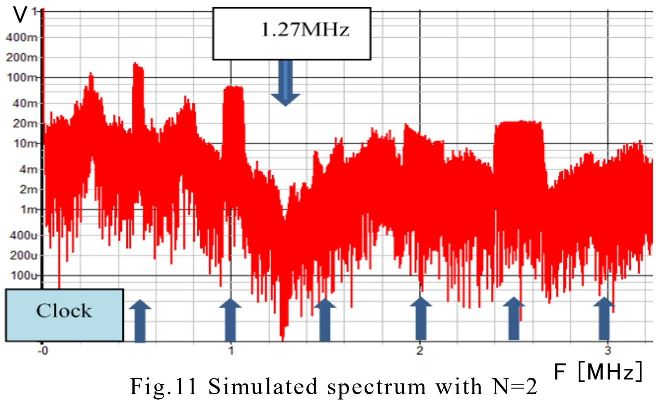


Fig.11 Simulated spectrum with N=2

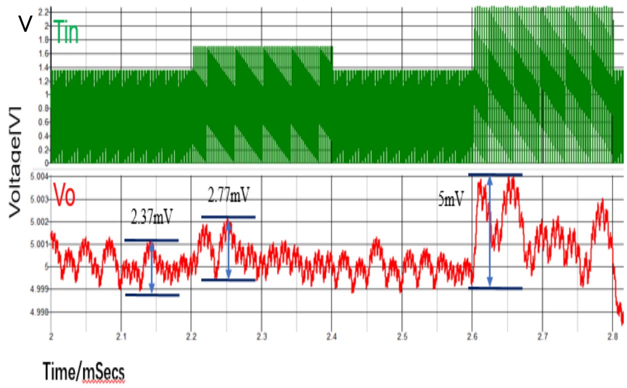


Fig.12 Transient response for Fin change (N=2)

4.5.Direct generation of the clock pulse (N=3)

When N=3 and Fin=1.75MHz is set in Eq. (8), 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.

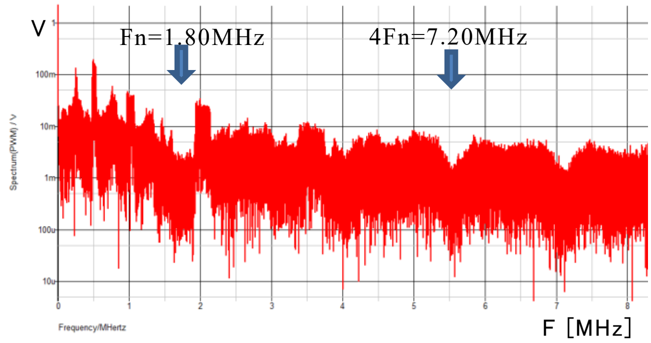


Fig.13 Simulated spectrum with N=3

5. Automatic Generating of Notch Frequency with PWPC Control

Now we consider about PWPC method to control switching in order to reduce EMI noise. PWPC method is a modulation method combined with PWC (Pulse Width coding) method and PPC (Pulse Phase Coding) method. We also consider about automatic generation of Pulse-H and Pulse-L and Pulse-LD (Fig.15) to realize automatic PWPC control.

5.1 Analysis of Pulse Phase Coding (PPC) method

PPC circuit can be simply realized by a delay circuit and a multiplexer. Since the duty ratio of the pulse does not change, it is difficult to satisfy the stability control condition of Eq. (3). Therefore, it is inappropriate for the power supply circuit by this system alone, but it can be used for a power supply circuit by using this method with the PWC method combined system.

Parameters are defined to show the empirical formula of the notch frequency of the PPC method. 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 natural number. At this time, the notch frequency Fn is expressed by the following equation obtained by a numerical experiment [7].

$$F_n = \frac{N}{2(\tau_H - \tau_L)} \tag{9}$$

From this equation, the notch characteristic depends on the twice of difference in pulse phase. Fig.14 is the comparison with PWC method and PPC method.

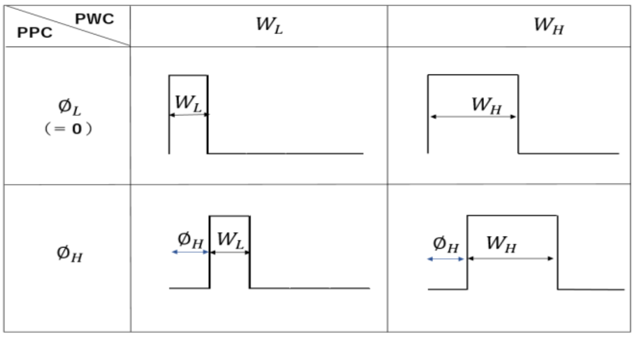


Fig.14 Coding pulse list

5.2 Analysis of PWPC method

In PWPC method, the notch frequency can be realized by the Eq. (2) and Eq. (9), these two equations are made to obtain a large notch. Fig.15 is the configuration of PWPC system. Automatic PWC controller can create V_H and V_L, these two voltages are compared with saw-tooth, and Pulse-H and Pulse-L are produced. Using PWPC method, we also want to produce delay saw-tooth compared with V_L to create Pulse-LD. Fig.16 shows designed timing in PWPC method, where the phase shift τ is equal to 0.5Tin if Eq.(2) is equal to Eq.(9) in order to create big notch.

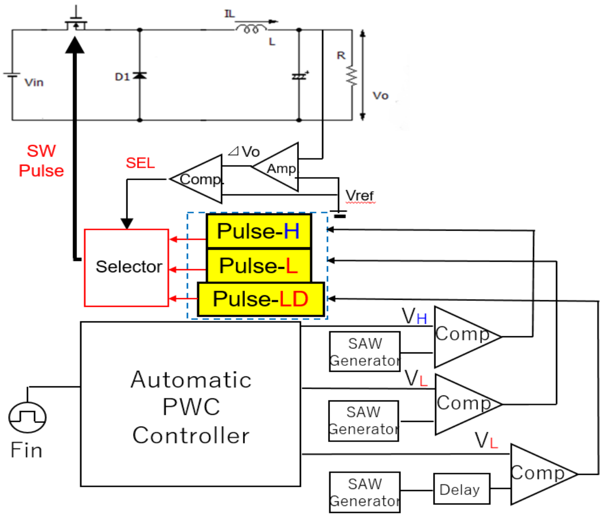


Fig.15 Pulse coding of PWPC method

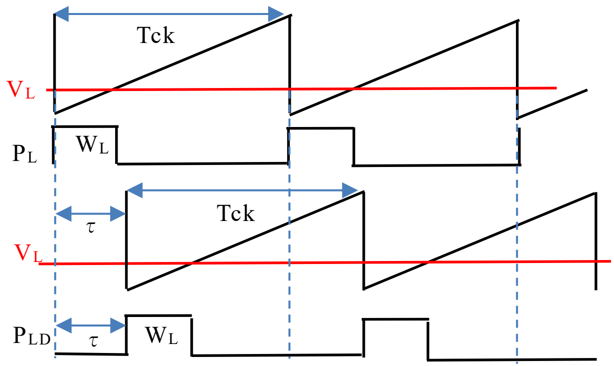


Fig.16 Design timing in PWPC method

The relationship between Fck and Fn are shown in Eq. (4). And according to Eq. (6), the following equations can be obtained. P_{LD} is timing of rear end of P_L.

$$W_H = To + Tp = Do \times Tck + 0.5Tin$$
$$W_L = To - Tp = Do \times Tck - 0.5Tin$$
$$P_{LD} = \tau + To - Tp = \tau + Do \times Tck - 0.5Tin \tag{10}$$

5.3 Automatic generation of notch frequency with PWPC control

Fig.17 shows the major signal of Fig.15. The coding pulse 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 the theoretical duty ratio of the signal is Do=0.5 from the Eq. (3), (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.(8). In order to set the notch frequency

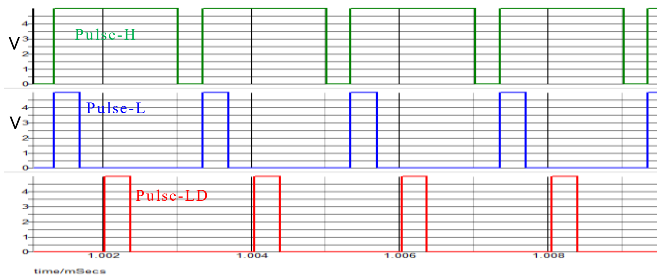


Fig.17 Main waveforms of Fig.15

at Fin=750kHz, the calculated pulse width is W_H=1.67µs,W_L = 0.33µs, τ=0.67µs according to Eq. (10).

Seeing the simulation results, the simulated widths of the coded pulses are set to about W_H =1.65 µs , W_L = 0.35µs, τ=0.67 µs 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 big notch at F=3.0MHz, which is the 4th harmonic of the fundamental notch frequency Fn (6.0MHz) which is the 8th harmonic of the fundamental notch frequency Fn. The output voltage ripple is about 3.98mV as shown in Fig.19.

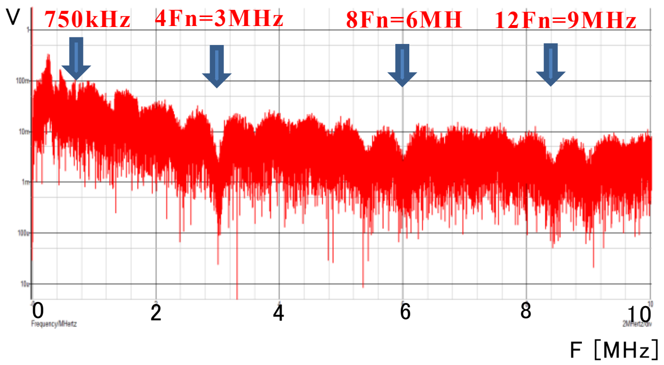


Fig. 18 Simulation spectrum with PWPC control with EMI reduction (N=1)

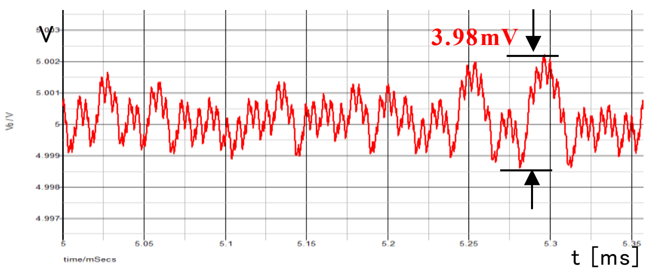


Fig. 19 Simulated output voltage ripple of the switching converter with PWPC coding

6. 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. Automatic notch generation in noise spectrum of switching converters with PWC and PWPC methods have already been achieved. It is good for radio receivers to receive high frequency signal without other communication devices interference.

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