Implementation Evaluation on Pulse Coding Controlled Switching Converter With Notch Frequency Generation in Noise Spectrum

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Abstract

This paper proposes an EMI spread spectrum technology with automatic setting of the notch frequency using the pulse coding controlled method in 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. The notch in the spectrum of the switching pulses was represented by the Pulse Width Coding (PWC) method. Notch frequency was automatically set to the frequency of the received signal by adjusting the clock frequency using the equation $F_n = (N + 0.5)F_{ck}$. Here F_n is the notch frequency, F_{ck} is the clock frequency, N is a positive integer. We have confirmed with the simulation that the proposed technique is effective for EMI reduction and notch generation. In addition, we have confirmed the notch frequency by the prototype circuit.

Keyword: Switching Converter, Noise spectrum, Notch frequency, Pulse Coding, EMI reduction

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 important to reduce the radiation noise at the specific frequencies (such as receiving frequency of the radio receiver) by suppressing diffusion of power supply noise.

In this paper, we propose a spread spectrum technique for EMI reduction with suppressing diffusion of power supply noise using Pulse Width Coding methods, based on the notch characteristics design. The notch frequency is automatically set to the received signal by adjusting the clock frequency and we also have confirmed the notch frequency by the prototype circuit.

2. Switching Converters with Spread Spectrum

2.1. Basic DC-DC switching converter

Fig.1 shows a basic block diagram of the buck type DC-DC converter[1] with the Pulse Width Modulation (PWM) signal control. This converter consists of the power stage and the control stage. The main switch is controlled by the PWM signal from the control stage, and a comparator generates the PWM signal by comparing a saw-tooth signal and the amplified error voltage ΔV. In the buck type DC-DC converter, the output voltage V_o can be expressed by Eq. (1) using the input voltage V_i and the duty ratio D. Here, as the switching signal of high power is increased in speed, large EMI noises are generated.

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

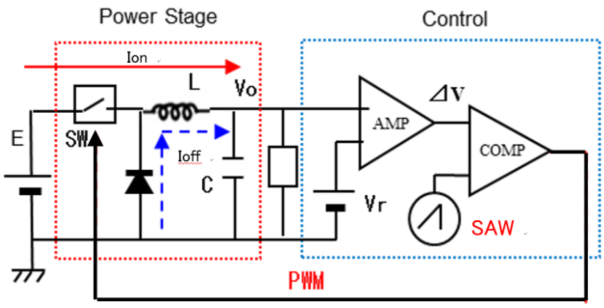

Fig.1 Switching buck converter with the PWM signal

2.2. EMI reduction with spread spectrum

The radiation from the PWM switching pulses is well known as the EMI noises. Fig.2 shows the spread spectrum with the EMI reduction. In this spectrum, the frequency of the clock is 0.2MHz. The peak level of the clock spectrum is quite low around 2.0V. But the bottom levels of the spectrum are higher than 8mV[2]. In Japan's AM radio broadcasting, 0.5~1.6MHz are used as the carrier frequency band, and the occupied bandwidth of each broadcast station is 15kHz. In other words, the AM radio channel also diffuses noise to selected frequency. It is not good for the communication devices which receive weak radio waves.

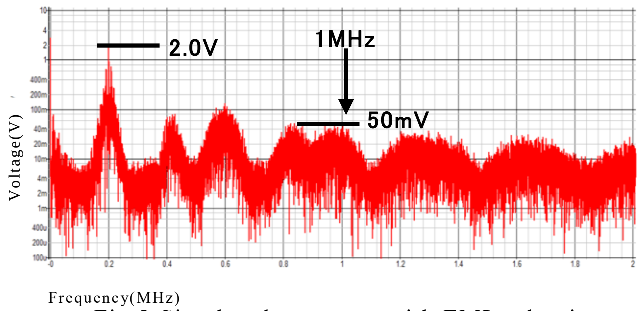

Fig.2 Simulated spectrum with EMI reduction

3. Automatic Notch Frequency Generation with Pulse Width Coding (PWC) Control

3.1. 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 the 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 F_{n1} is expressed by the following Eq. (2)[3].

$$F_{n1} = \frac{N}{(W_H - W_L)} \quad (2)$$

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. By adjusting the pulse width, the notch frequency can be arbitrarily set. Fig.3 shows the control circuit for the PWC method switching converter. The output of D-type flip-flop is called select signal 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 values of W_H and W_L. When tuning the communication channels, automatic adjustment to the input frequency change is necessary. Hence we consider about automatic generation of Pulse-H and Pulse-L to realize automatic PWC control.

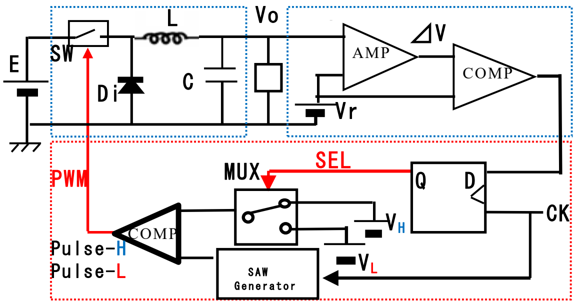

Fig.3 Converter with the PWC control

3.2. Analysis of the relationship between F_{ck} and F_n

Generally speaking, it is good for the notch frequency F_n to generate at the middle of F_{ck}. 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 the radio receiver, that is input frequency F_{in}. The relationship between F_{in} and F_{ck}, T_{in} and T_{ck} were shown as follows:

$$F_{in} = (N + 0.5) \times F_{ck} \;\; [N\text{: } positive \;\; integer] \quad (3)$$

$$T_{ck} = (N + 0.5) \times T_{in} \;\; [N\text{: } positive \;\; integer] \quad (4)$$

On the other hand, the duty D of the PWM signal is usually represented such as by Eq. (1). Moreover, the pulse width T_o of the PWM signal is shown in Fig. 4. It corresponds to Eq. (5), here we set duty of PWM signal is 0.5. We can create Pulse-H and Pulse-L respectively according to T_o shown in Fig.4. It also corresponds to Eq. (6), here T_p is the pulse difference between W_H and T_o or T_o and W_L. The period of the notch frequency T_n is derived from the difference between the pulse widths of W_H and W_L. In this case, W_H, W_L and T_o should have the relation as shown in Eq. (7) in order to control the output voltage V_o, to be stable. Here $2 \times T_p$ is equal to T_n, which means the gain of the pulse coding control.

$$T_o = D_o \times T_{ck} = \frac{V_o}{V_{in}} \times T_{ck} \quad (5)$$

$$W_H = T_o + T_p,\; W_L = T_o - T_p \quad (6)$$

$$T_n = W_H - W_L = \;\; 2 \times T_p \quad (7)$$

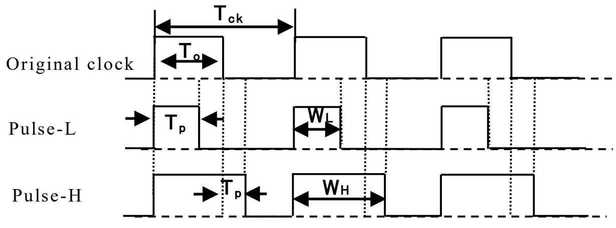

Fig.4 Timing chart of the PWM signal

3.3. Direct generation of clock pulse T_{ck} in fundamental frequency

In Eq. (4), the period of clock T_{ck} can be generated by measuring the period of the input pulse T_{in}. When N=1, the notch frequency can be arbitrarily created between F_{ck} and $2F_{ck}$ as shown in Fig.5. In this case, $T_{ck} = 1.5 \times T_{in}$, and it is easy to realize T_{ck} with a shifter and a digital adder in digital circuit. Fig.6 shows automatic PWC method pulse coding circuit according to Eq. (5)~(7) when $D_o = 0.5$ situation. In this case, $W_H = 0.5T_{ck} + 0.5T_{in}$, and $W_L = 0.5T_{ck} - 0.5T_{in}$.

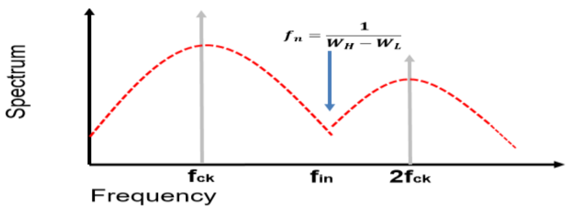

Fig.5 Notch frequency in N=1 situation

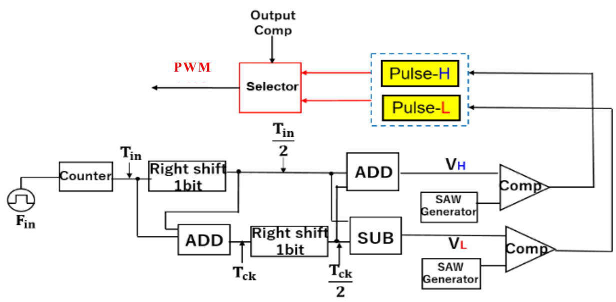

Fig.6 Pulse coding of the automatic PWC method (N=1)

3.4. Simulated results of the clock pulse direct generation

Fig.7 shows the simulated waveforms of Pulse-H and Pulse-L when we just set F_{in} equal to 750kHz. The period of saw-tooth is T_{ck}, and comparison between 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 at

750kHz which is equal to F_{in}.

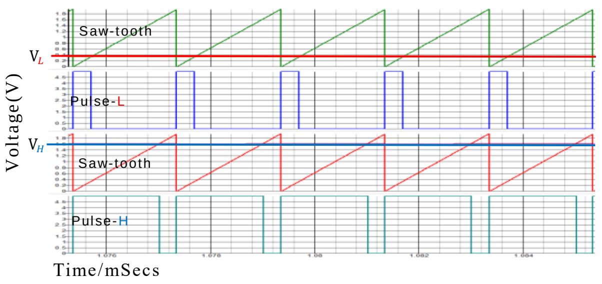

Fig.7 Simulated waveforms of P_L and P_H

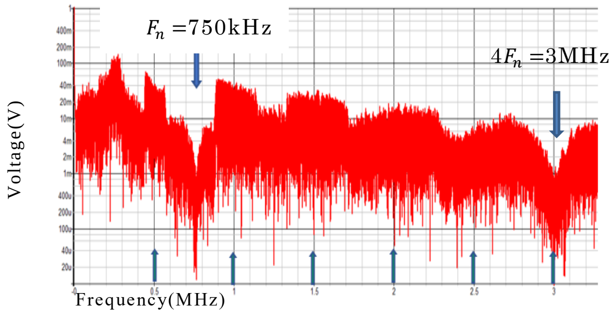

Fig.8 Simulated spectrum with EMI reduction (N=1)

4. Implementation Evaluation on Pulse Coding Controlled Switching Converter with Notch Frequency Generation

We have implemented the circuit in Fig.3. The error voltage ΔV between the output voltage and the reference voltage V_r is amplified and its output logic level is 1-bit high/low signal using D-type flip-flop. This select signal selects one of the two pulses to the selector. Then we need to generate pulse W_H and W_L using V_H and V_L compared with the saw-tooth as shown in Fig.9. Here we manually set the values of V_H and V_L. If the select signal selects high, the PWM signal will output W_H, if the select signal selects low, the PWM signal will output W_L.

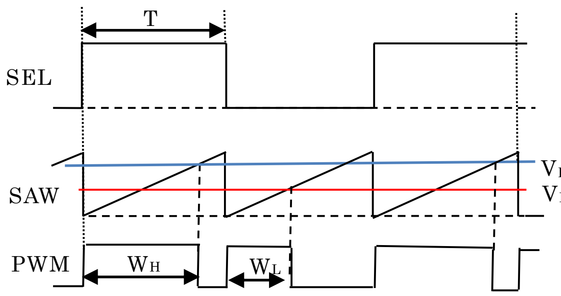

Fig.9 Waveforms of the PWC method

We have implemented the circuit and measured the waveforms of W_H and W_L as shown in Fig.10 as well as spectrum of the PWC control switching converter as shown in Fig.11. The clock frequency was 500kHz, and the pulse widths were set to $W_H = 1.0\mu s$ and $W_L = 0.4\mu s$. Clock frequency appears between the clock and 2nd harmonics of the clock frequency, or between 2nd and 3rd harmonics of the clock frequency. Substitute the parameter values into Eq. (2), 1.66MHz is calculated, which matches the measured result.

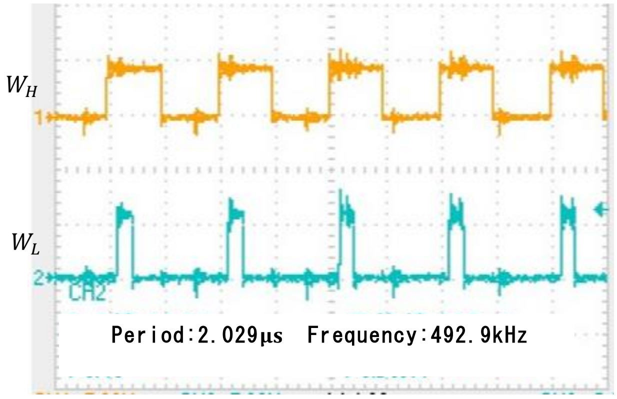

Fig.10 Waveforms of W_H and W_L

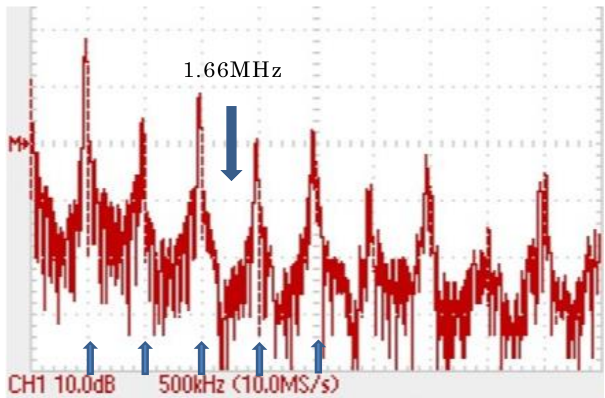

Fig.11 Spectrum of the PWC control switching converter

5. 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 F_n appears between the clock frequency F_{ck} and its 2nd harmonic, or between 2nd and 3rd harmonics. We have confirmed with simulation that the automatic notch generation in noise spectrum of switching converters with PWC method can be achieved. We also have confirmed the notch frequency by the prototype circuit.

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