Selectable Notch Frequencies of EMI Spread Spectrum Using Pulse Modulation in Switching Converter

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Abstract This paper proposes a novel EMI spread spectrum technique to enable to set notch frequencies using pulse modulation in switching converters. The notches appear at the frequencies obtained from empirically derived equations with the proposed spread spectrum technique using the pulse coding methods, the PWM (Pulse Width Modulation) coding or the PCM (Pulse Code Modulation) coding. This technique would be useful for the communication equipment which receives standard radio waves, without being affected by noise from the switching converters.

In our proposed technique, the notch frequencies in the spread spectrum depend on the pulse coding method. We have investigated this technique to apply to the switching converters and found that there is good relationship agreement between the notch frequencies and the empirical equations. The notch frequency in the PWM coding is equal to the equation $F=k/(W_M-Wo)$. In the PCM coding, that is equal to the equation $F=k/(T_M-To)$.

1. Introduction

In recent years, expansion of the mobile device usage has been accelerated by the progress in an information society. There the switching power converter is well known for its downsizing, light weight and high efficiency. As for the Pulse Width Modulation (PWM) control method is usually used for the switching converters and it is very important to reduce an Electro Magnetic Interference (EMI) problem, mainly by suppressing the peak level of the fundamental frequency and its harmonic frequencies.

On the other hand, for the communication equipment including the radio, it is very important to reduce the radiation noise at the particular frequencies by suppressing diffusion of power supply noise.

This paper proposes a new technique in order to reduce the EMI noise at the particular frequencies in the switching converters using the pulse coding technology together with the delta-sigma modulation.

2. Switching Converters and Spread Spectrum

2.1 Switching converters

Figure 1 shows the block diagram of a buck converter, and Fig.2 shows its major signals. The converter consists of the power stage and the control part. The power stage contains a main power switch, a free-wheel diode, an inductor and a bulk capacitor. The main switch is controlled by the PWM pulse from the control part. The control part consists of an operational amplifier, a comparator, a saw-tooth generator and a reference voltage source.

The current flows are shown in Fig.1, where the red solid line shows the direction of the current flow when the inductor is charged (the switch is ON), and the blue dashed line shows the current flow when the inductor is discharged (the switch is OFF). The output voltage is compared with the reference voltage and the error voltage is amplified with the phase compensation. The amplified error voltage is compared in order to supply the PWM pulse with the saw-tooth signal which is generated from the clock pulse.

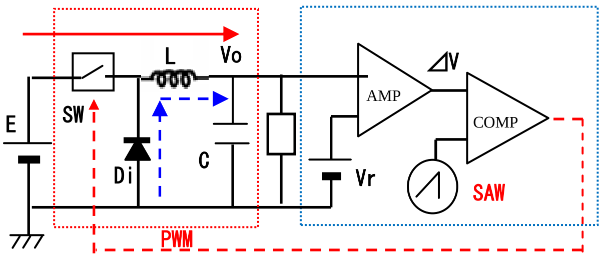

Figure 1. Block diagram of a buck converter.

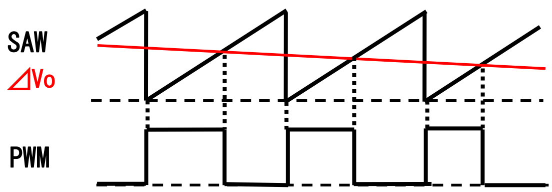

Figure 2. Waveforms of the major signals.

2.2 EMI reduction with spread spectrum

The radiation from the PWM pulses is well known as the EMI noises. Figure 3 shows the spectrum of the PWM pulse of the buck converter in Fig.1 without spread spectrum where the peaks at the basic frequency (3.5V at 200 kHz) and its harmonic frequencies are very large. Figure 4 shows the spread spectrum with the analog noise [1] which modulates the phase or frequency

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of the saw-tooth signal. In Fig.4, the peak levels of the line spectrums are reduced but there are many side-bands around the harmonic frequencies. There is no notch frequency whose level is less than 10 mV, which would not be desired for the communication equipment like the radio.

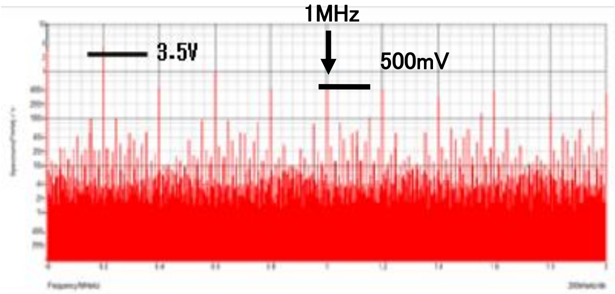

Figure 3. Simulated spectrum of the PWM pulse of the buck converter without pulse modulation.

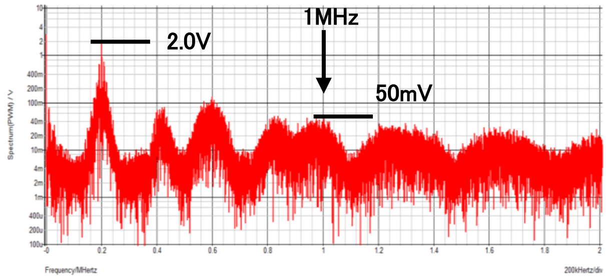

Figure 4. Simulated spread spectrum of the PWM pulse of the buck converter with pulse modulation.

3. Delta-Sigma Modulation with Notch Frequency

3.1 Pulse width modulation (PWM) converter

When the input signal into the delta-sigma modulator is sine wave, its output data is a bit-stream of 1 or 0. Modified pulses are generated according to the input data 1 or 0. Figure 5 shows the pulse width modulation (PWM) in the Digital-to-Time Converter (DTC)[2]. In this system, when the input data from the delta-sigma modulation is "0", the output of this converter is the normal output where the pulse width is Wo=200us and the period is T=1ms. When the input data is "1", the pulse width of the output Wo is changed to 600us.

In this case, the spectrum is shown in Fig.6, and we see that the basic notch appears at 2.5 kHz. The equation of the notch frequency is shown below. According to this equation, notches do not appear at the clock frequency or its integer-multiple frequencies but peaks appear there.

$$Fn = K/(W_M - Wo) = 2.5 \cdot K \text{ [kHz]} \qquad (1)$$

$$\text{Where} \quad K = 1, 2, 3, \cdots$$

When the pulse width W_M is changed to 800us, then the notch frequencies are 1.67kHz, 3.33kHz, ･･･ according to the equation (1) and the spectrum is shown in Fig.7.

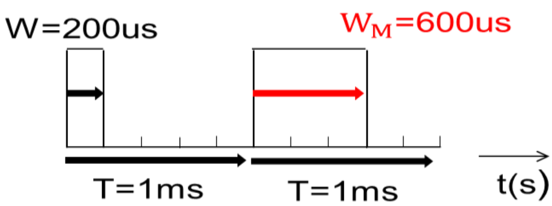

Figure 5. Pulse coding with PWM

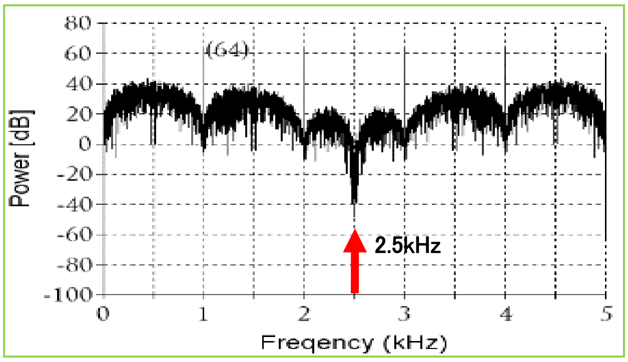

Figure 6. Spectrum of output pulses in PWM (1)

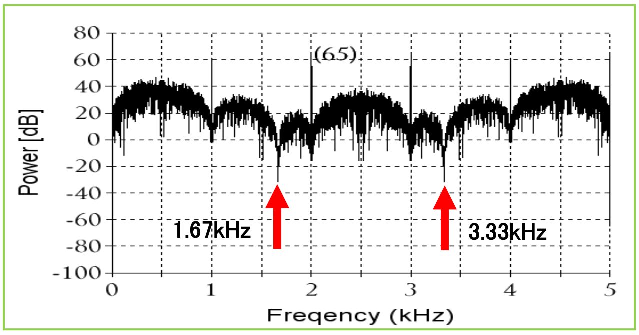

Figure 7. Spectrum of output pulses in PWM (2)

3.2 Pulse cycle modulation (PCM) converter

According to the input data 1 or 0, the output pulse of the PCM converter is modified as shown in Fig. 8. When Di=0, the output pulse width is 100us and the period To=400us. When Di=1, the pulse period is changed from To=400us to T_M=600us.

In this case, the spectrum is shown in Fig.9, and we see that a notch appears at 5.0 kHz. Equation (2) of the notch frequency is shown below. According to this equation, notches do not appear at the clock frequency or its integer-multiple frequencies but peaks appear there.

$$Fn = K/(T_M - To) = 5.0 \cdot K \text{ [kHz]} \qquad (2)$$

$$\text{Where} \quad K = 1, 2, 3, \cdots$$

When the period T is changed from To=400us to 800us and T_M=600us to 1,200us, then the notch frequencies are 2.5kHz, 5.0kHz, ･･･ according to the equation (2) and the spectrum is shown in Fig.10.

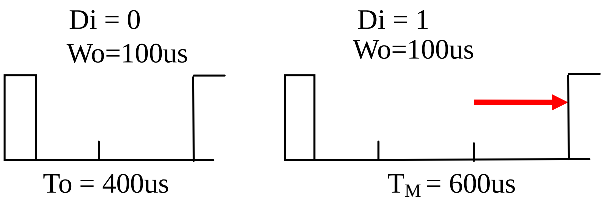

Figure 8. Pulse coding with PCM.

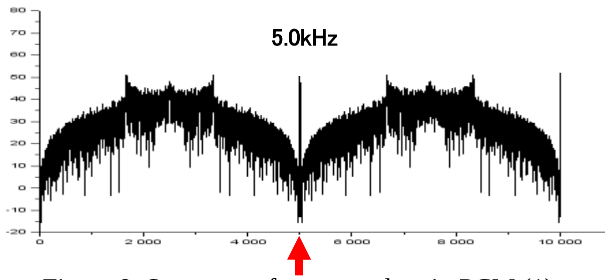

Figure 9. Spectrum of output pulses in PCM (1).

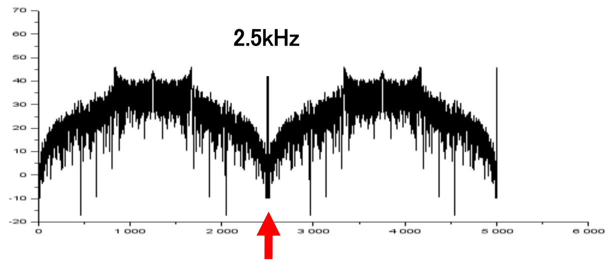

Figure 10. Spectrum of output pulses in PCM (2).

4. Switching Converters with Pulse Coding

4.1 Switching converter with PWM coding

In order to adopt the pulse coding technology shown above, the clock pulses supplied to the saw-tooth generator should be modified as PWM or PCM. Note that there is no need of the saw-tooth signal, because the PWM pulses controlling the main switch are supplied from the coding controller.

Figure 11 shows a buck converter with a PWM coding and its parameter values are shown in Table 1. In Fig.11, the period of the clock is To=2.0us (F=500kHz) and there are two pulse generators, which are connected to the selector, and whose pulse widths are Wo=1.6us and W_M =0.2us with duties of 0.8 or 0.1.

The output voltage ripple is about 15mVpp as shown in Fig.12. Figure 13 shows the spectrum of the switching pulses, where the peak level of the basic frequency is 0.80V and the notches appear at around 700kHz and 1.4MHz because the difference of the pulse widths is 1.4us. These notch frequencies are easily controlled by changing the duty of the control pulses in order to adjust the difference of W_M-Wo to the desired notch frequency.

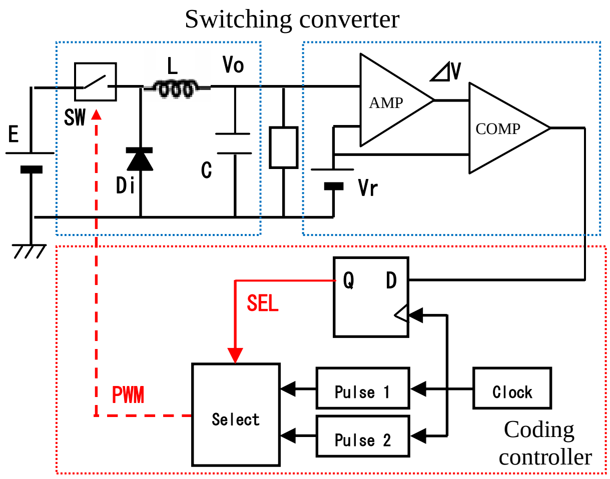

Figure 11. Switching converter with PWM coding.

Table 1. Parameters of switching converter

Vin	10.0 V
Vo	5.0 V
Io	0.25 A
L	200uH
Co	470 μ F
Fck	500kHz

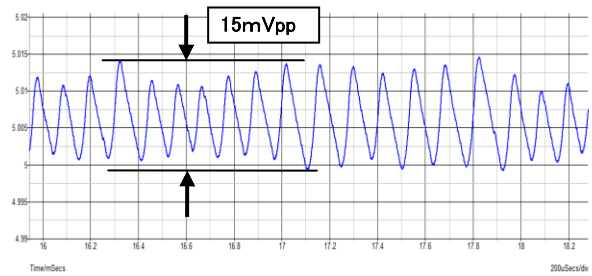

Figure 12. Simulated output voltage ripple of the switching converter with PWM coding.

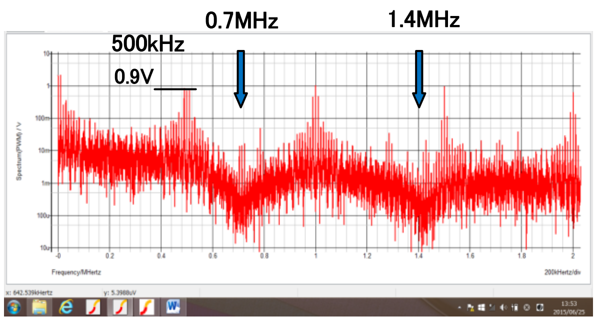

Figure 13. Simulated output voltage spectrum of the switching converter with PWM coding.

4.2 Switching converter with PCM coding

Operation according the timing chart shown in Fig.8 is very difficult, and we consider another operation as shown in Fig.14. Using this operation, the switching converter operates with the modulation of the PCM coding. In this case, the period of the switching pulse is changed according to the select signal SEL whose pulse length is 6・Tck (=12us). The fundamental clock is Fck=500 kHz (Its period is 2.0us.) and each pulse width is set to be 1.9us and the pulse periods are T_0=4us and T_1=6us (Duties are 0.95 and 0.475.)

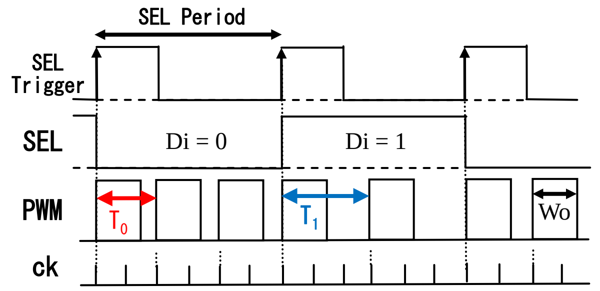

Figure 14. Refined pulse coding with PCM.

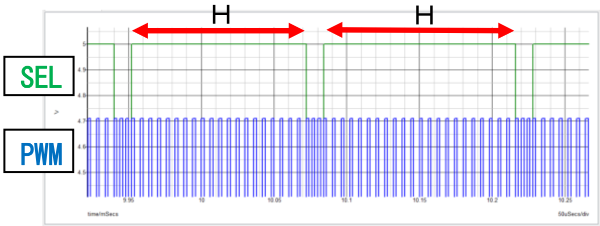

Figure 15. Waveforms of SEL and PWM signals.

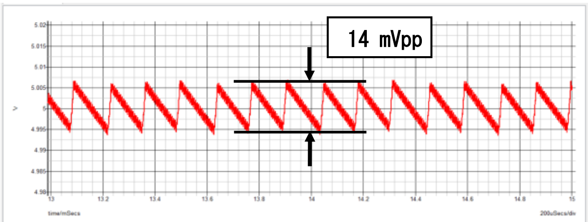

Figure 16. Simulated output voltage ripple of the switching converter with PCM coding.

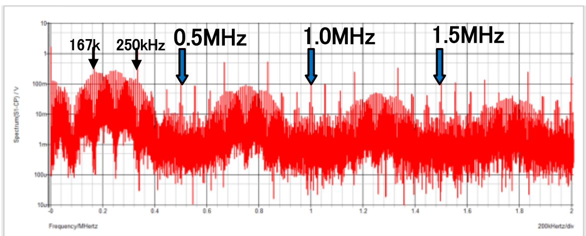

Figure 17. Simulated output voltage spectrum of the switching converter with PCM coding.

Figure 15 shows the simulation results of the SEL signal and the PWM signal, and we see in Fig.16 that the output voltage is just 5.0V and the ripple is about 14mVpp. Considering the equation (2), the notch frequency is fn=K/(6-4)us=K・500kHz. In this case, the fundamental frequency is 500kHz and the two clock frequencies are F1=Fck/2=250kHz and F2=Fck/3 =167kHz. Figure 17 shows the spectrum of the switching pulses, where the notch frequency is appeared at Fn=0.5MHz, 1.0MHz, 1.5MHz・・・. The peak pulses are at 167kHz, 250kHz and 500kHz. Here, the notch frequencies are not so clear like Fig.9 because the switching pulse is the feedback signal in the switching converter. Here, it is the item that the peak frequency of the fundamental clock is equal to the notch frequency, and it is our future work to investigate this relationship.

5. Summary

We have proposed a new spread spectrum technique to select the notch frequencies by coding the PWM pulses in the switching converters. We have shown the equation of the notch frequency using the pulse period or the pulse width. By the PWM coding, the notch frequencies are set based on equation Fn = K/(W_M－Wo) which is selected by changing the pulse width. By the PCM coding, the notch frequency are set based on the equation Fn = K/(T_M－To) which is controlled to change the pulse period. Our simulation results have validated these relationships.

Acknowledgments

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References

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