EMI Reduction by Analog Noise Spread Spectrum In New Ripple Controlled Converter

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Abstract

This paper proposes a new ripple controlled switching converter and a new spread spectrum technique for EMI reduction. The new ripple controlled converter includes a flip-flop after the output of the comparator. The new spread spectrum technique uses a PLL circuit modulated by pseudo analog noise. The PLL circuit modulates a reference clock with non-periodic analog noise. This modulated clock is provided to a flip-flop trigger in order to generate the switching pulses, and the spectrum of the switching pulse is widely spread; our simulation results show that the peak levels of the spectrums of the fundamental and the harmonic frequencies can be significantly reduced.

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.

The ripple controlled switching converter[1]~[3] is attractive for its fast transient response and small circuitry without a clock and a saw-tooth signal generator, and hence the ripple controlled method is widely used for the high speed switching converter. There the frequency of its switching pulse depends on the output voltage and current as well as the parameters of the control circuit. However the EMI trouble is exposed in the stable state there. It is difficult to reduce an Electro Magnetic Interference (EMI) problem; it is realized mainly by suppressing the peak level of the fundamental frequency and its harmonic frequencies of the clock[4]~[6], but the ripple controlled switching converter does not use the clock. Wide bandwidth usage of its output spectrum is desirable in the ripple controlled switching converter for its EMI reduction.

This paper proposes a new technique in order to reduce the EMI noise in the ripple controlled switching converter using the spread spectrum method; we use the new ripple controlled converter and pseudo analog noise for adding fluctuation to a reference voltage and then modulating the switching pulse frequency.

2. Ripple Controlled Converter and Spread Spectrum

2.1 Principle of ripple controlled converter

Figure 1 shows simulation circuits of a conventional ripple controlled buck converter and Fig.2 shows its simulated output voltage ripple in the stable state and the step responses when the output current changes with +-0.25A step. In Fig.1, the converter consists of a power stage and a 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 switching pulse from the control part. The control part consists of an operational amplifier, a comparator and a reference voltage source. The comparator has the hysteresis level of about 20mV and the frequency of the control pulse is from 120k to 180kHz. The output voltage ripple is less than 5 mVpp (0.1 % of the output voltage) which is very small.

Figure.3 shows the simulated spectrum of the switching pulse of the conventional ripple controlled converter. We see that the highest peak level is about 3.0V at the frequency of 185 kHz and there are many harmonic components. Here, this basic frequency is varied by the hysteretic level which is 20mV.

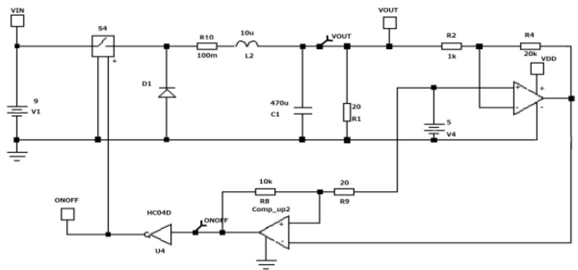

Figure 1. Conventional ripple controlled converter

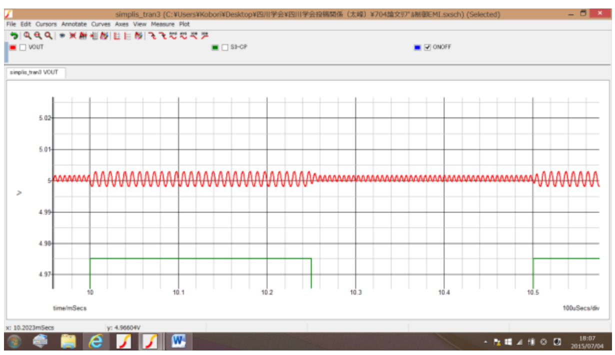

Figure 2. Output voltage ripple and step response

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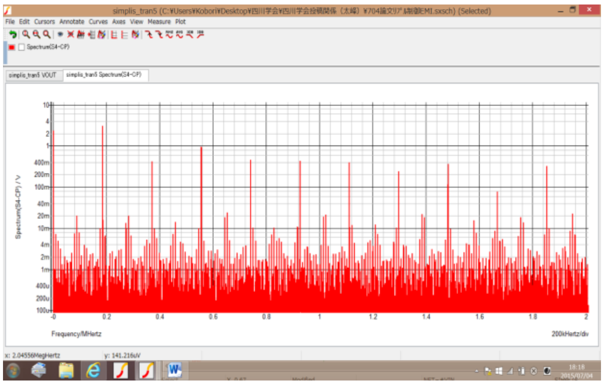


Figure 3. Simulated spectrum of the switching pulse of the conventional ripple controlled converter

2.2 New ripple controlled converter

Figure 4 shows a new ripple controlled buck converter using a clock pulse and a flip-flop. The output pulse from the comparator is latched in the flip-flop which is triggered by the clock pulse. That is, the output of the comparator dose not directly control the main switch, but after synchronization with the clock pulse, the output of the flip-flop controls the main switch. In this case, the frequency of the clock is usually higher than 500 kHz. By this control method, the frequency of the control pulse is constantly fixed; its characteristics stabilization is relatively easy, however, the usage of the clock with a constant frequency would cause an EMI problem.

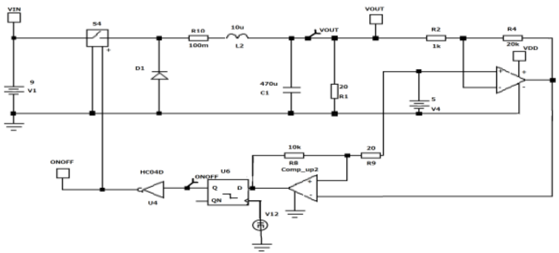


Figure 4. New ripple controlled converter using a flip-flop and clock pulse

Table 1. Simulation parameters of the new ripple controlled converter

Vin	10.0 V
Vo	5.0 V
Io	0.50 A
L	10 uH
Co	470 μF
Fck	1.0 MHz

Figure 5 shows the simulated output voltage ripple and control pulse waveforms in the stable state for the converter in Fig.2; the ripple is very small (about 8mVpp). Simulation parameters are shown in Table 1. Figure 4 shows the simulated step response of the output ripple when the output current is changed as +- 0.5A step. There is no overshoot or undershoot, however the ripple level is a little bit large (about 13 mVpp) when the output current is changed to 1.0 A.

Figure 6 shows the spectrum of the control pulse which controls the main switch ON/OFF without analog modulation. In this case, the output voltage ripple is about 8 mVpp and the clock frequency is 1.0 MHz. The major period of the control pulse is about 3us or 6us. The ripple frequencies of the control pulse are 500 kHz, 250 kHz and 125 kHz and their peak levels are 450 mV, 900 mV and 2,500 mV. We observe that many side-band spectrums appear.

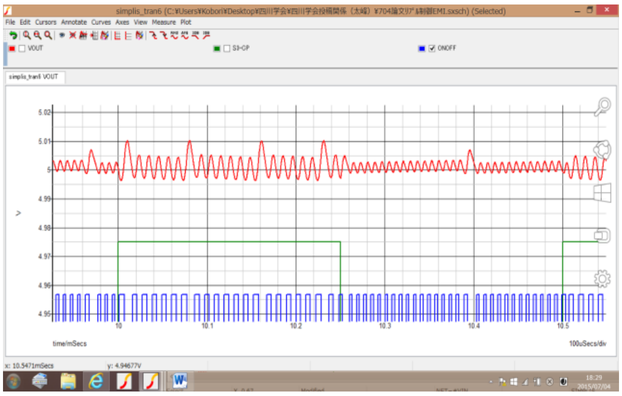


Figure 5. Simulated outpu ripple and switching pulse and its step response of new ripple controlled converter

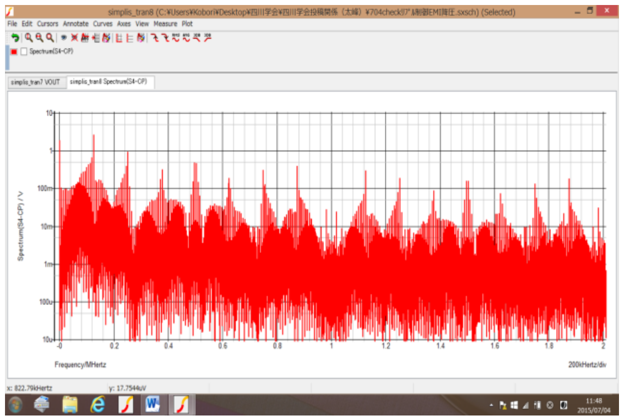


Figure 6. Simulated spectrum of the control pulse without analog noise modulation

3. Spread Spectrum with Analog Noise Generator

3.1 Digital and analog spread spectrum techniques

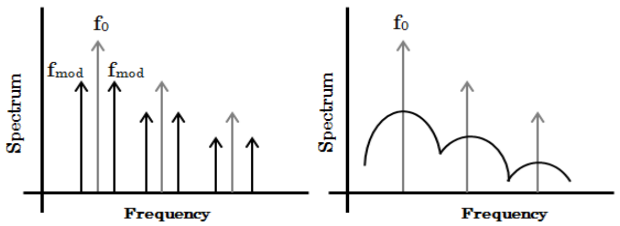
Figure 7 illustrates the spread spectrum with digital and analog methods. In the conventional digital spread method of Fig.7 (a), the number of the generated line spectrum is proportional to that of the modulations, and its noise power is spread discretely in frequency domain. Also the fundamental frequency spectrum turns into the modulated spectrums in its both sides when the number of the modulation frequencies is only one. The analog spread in Fig.7 (b) is expected to reduce the spectrum level more than the digital spread, because it spreads the noise spectrum in a wide range of the frequency through the continuous phase fluctuation.

3.2Analog noise generator

An M-sequence circuit in Fig.8 is widely used to generate pseudo random digital noise. It is composed of a shift register and an exclusive OR gate. It generates digital output of N=(2^n-1) levels based on the number n of the primitive polynomial (here n is the number of the flip-flops in the M-sequence circuit). There are two primitive polynomials for n=3 as follows:

$$G(x) = x^3 + x^2 + 1 \quad (1)$$

$$G(x)= x^3 + x + 1 \quad (2)$$



(a)Digital Spread (b)Analog Spread

Figure 7. EMI reduction with digital and analog spread spectrum techniques.

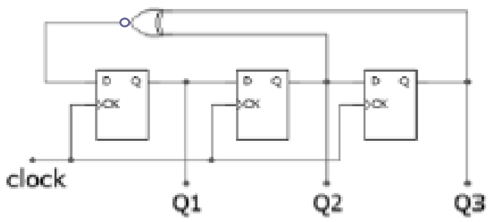


Figure 8. M-sequence circuit (n=3) with G(x)=x^3+x^2+1

Figure 9 shows the output analog step whose levels are converted from the digital binary code of the M-sequence circuit output based on Eq. (1). There are cyclic pattern of 7 levels with 0-1-3-6-5-2-4 (shown in negative).

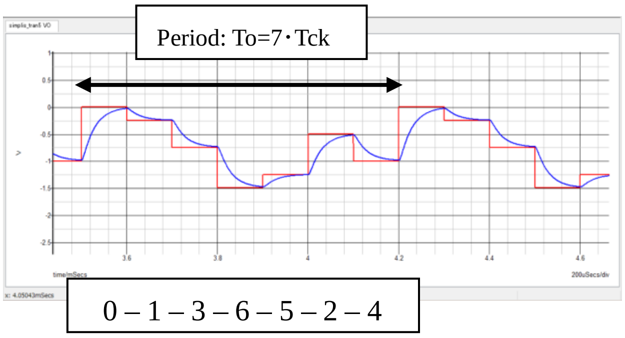


Figure 9. Output waveform of the M-sequence circuit

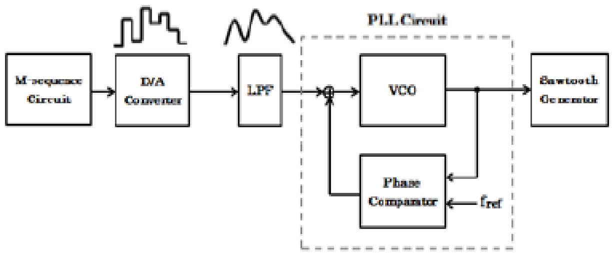


Figure 10. Proposed analog noise generator

4. Ripple Converter with Analog Noise Modulation

4.1 Proposed analog noise generator

Figure 10 shows the proposed analog noise generator with an M-sequence circuit, a low pass filter (LPF) and a phase locked loop (PLL) circuit. The LPF is employed in order to convert the step noise to the smoothed analog noise. In this case, the analog noise is periodic because the output of the M-sequence circuit is periodic, and then the frequency of the PLL circuit is modulated by the analog noise.

4.2 Simulation results with analog noise modulation

The modulated clock is supplied as a reference clock as shown in Fig.4, and then the rippled controlled converter operates with its control clock modulated with the analog noise. Figure 11 shows the simulated output voltage ripple and the step response when the output current changes by +- 0.5A. Figure 12 shows its spread spectrum with the analog noise modulation. We see that the output ripple is less than 10 mVpp which is almost equal to that of Fig.5.

The highest peak level of the spread spectrum is 700 mV at 125 kHz which is reduced by 1.8V (-5.5dB). At the frequency at 250 kHz, the peak level is reduced by 700 mV (-6.5dB). The peaks of all harmonic frequencies are reduced and there is no line spectrum. In this case, the output signal is sampled and held at the flip-flop and there is no spectrum at the frequency 1 MHz.

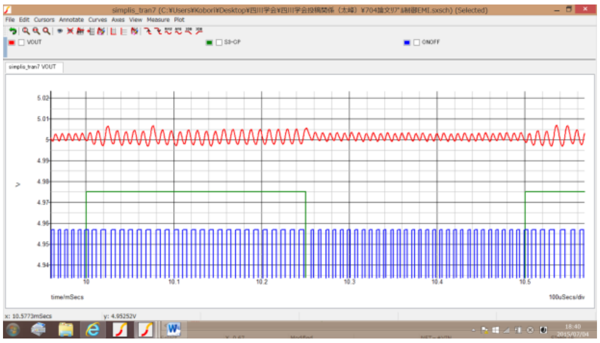


Figure 11. Simulated output ripple with the proposed analog noise modulation

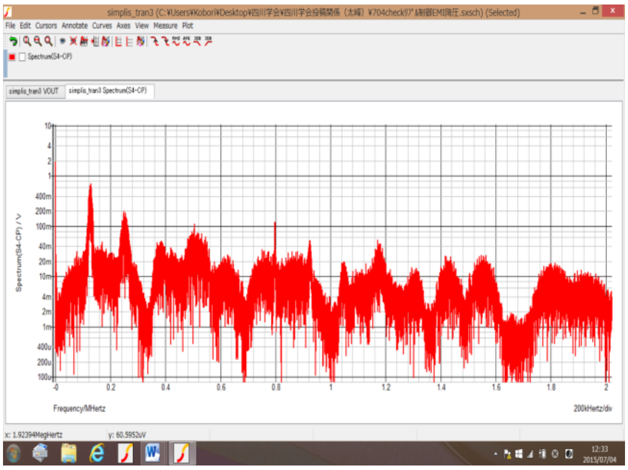


Figure 12. Simulated spread spectrum of new ripple controlled converter with analog noise modulation

5. Summary

This paper proposes a new EMI reduction technique in the ripple controlled converter; it uses analog spread spectrum circuit using low-pass-filtered analog noise generated by an M-sequence circuit. Since the ripple controlled converter is difficult to realize spread spectrum due to no clock usage, we have added the analog noise to the reference voltage of the converter.

Our simulation results showed that the peak level of the spectrum at the fundamental frequency (about 125 kHz) is reduced by 6 dB and that of its second-order harmonics is reduced by 10dB. The output voltage ripple is only 10 mVpp and the step response by the current step +-0.5 A is about 15 mV over/under shoot.

The experimental verification of the proposed method is underway.

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