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Electromagnetic Interference of Switching Mode Power Regulator with Chaotic Frequency Modulation

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Abstract: In this work, we propose an improved switching scheme (called chaotic frequency modulation (CFM)) for switched-mode power supplies to suppress the electromagnetic interference (EMI) noise source. The basic principle of CFM is to use a chaotic signal to modulate the switching signal so that the harmonics of noise power is distributed evenly over the whole spectrum instead of concentrated at the switching frequency. When compared with the conventional pulse width modulation (PWM) scheme, significant improvements in both conducted and radiated EMI noise levels were found with the proposed CFM method. For conducted EMI, the peak noise level was reduced by 25 dBμV. For radiated EMI, we found that the noise was found mainly in the frequency range of 30 MHz to 230 MHz and the CFM scheme would help to reduce the peak noise level in this frequency range by 22 dBμV.

Keywords: Electromagnetic interference, switching mode pover regulator, chaotic frequency modulation, pulse width modulation.

1 Introduction

Switching power supply is now one of the key building blocks for modern electronic products for its high efficient in power conversion. However, it was found to have large electromagnetic interference (EMI) and needs careful design and particular attentions in shielding and casing are needed. The

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EMI becomes critical important because many countries now call for more stringent requirements on the electronic products. All electronic products now have to comply with Federal Communications Commission (FCC) and EC EMC Directive in US and Europe markets, respectively. However, the EMI in power supply is difficult to eliminate because its large power and wide spectrum (up to 100 MHz). In addition, the noise could even conduct to other parts of the system via the power lines. Unfortunately, EMI generations and conductions are too difficult to be modeled [1]. These difficulties have resulted in considerable increase in development and production cost because of product re-design, insertion of extra components, and replacement of casing. These in turn give rise to the delay in lunching the product to market.

EMI noise can be reduced by three ways: suppression of noise source, isolation of coupling path, and filter/shielding. These methods may need to be adopted at the same time in some electronic products (see Fig. 1).

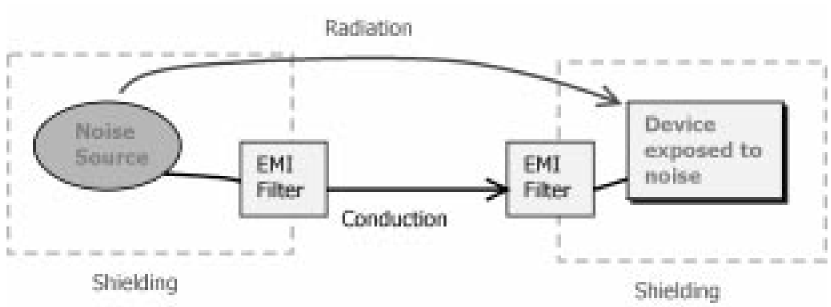


Fig. 1. The common EMI noise coupling paths and the conventional noise suppression methods.

The last two measures are passive and are difficult task [2]. Extra cost is indispensable for these measures. Yet the first one is the most fundamental and the most effective measure but other specifications for the product may limit the noise reduction level. For example, we cannot lower the voltage or change the frequency of the switching mode power supply. With this connection, this work aims to reduce the EMI noise generation in switching model power regulator. Lin and Chen found that the EMI noise in SWPR could be reduced by about 10 dBμV by modulating the switching frequency [3]. Further improvements were obtained by randomized the modulation to spread the discrete harmonics at the multiples of switching frequency to the whole spectrum in order to reduce EMI emission [4-6]. However, it is unavoidable that the spectra of the power supply output signals under most of these schemes still have high harmonic power at the switching frequency since a fixed switching frequency is employed in the schemes. Using a varied switching frequency is a possible method to distribute the switching frequency harmonics over the whole spectrum evenly [3].

In this work, we propose an improved switching scheme: *chaotic frequency modulation* CFM for reducing the EMI in switched-mode power supplies. Preliminary simulation results had been reported [6]. With the chaotic signal modulation, the power of the high order harmonics can be distributed evenly in a wide spectrum and the EMI effects can be minimized [6]. This work provides detailed experimental validation for this method.

2 Chaotic Frequency Modulation

A typical FM signal contains a carrier with frequency f_c and a modulation signal with frequency f_m as following

$$A \sin(2\pi f_c t + mx(t)) \tag{1}$$

where A is the amplitude of the FM signal, m is the modulation factor and $x(t)$ is the modulation signal (typically $x(t) = \sin(2\pi f_m t)$). In power conversion applications, the switching signal must be a square wave and the FM switching signal should be

$$ASQ(2\pi f_c t + mx(t)) \tag{2}$$

where SQ( ) is a square wave function. When a modulation signal with frequency f_m is employed to modulate the switching signal with switching frequency f_c, the harmonics will distribute at the multiples of f_c and $f_c \pm f_m$. As shown in [6], this switching technique can reduce power supply EMI emission by a fair amount. With chaotic frequency modulation (CFM), the harmonic power will be distributed more evenly over the whole spectrum (i.e. the harmonic at f_c will be greatly reduced).

3 Chaotic Frequency Modulation

To verify the applicability of the proposed scheme, a DC-DC boost converter shown in Fig. 2 was constructed. The boost converter was designed to operate in continuous mode and to convert 12 V DC to 24 V DC with 20 W output power. The converter could be either switched with pulse modulation signal (PWM) and CFM. Switching the transistor on and off causes the generation of high frequency EMI noise and the noise level becomes even more higher as the switching frequency increases for reducing the sizes of transformer and capacitors. The major origin of the noise is from the drain-to- source voltage of the transistor that has a high value of $\mathrm{d}v/\mathrm{d}t$ during the switching. This effect becomes even more severe because the noise can be radiated via the package tab and heat-sink of the power transistor.

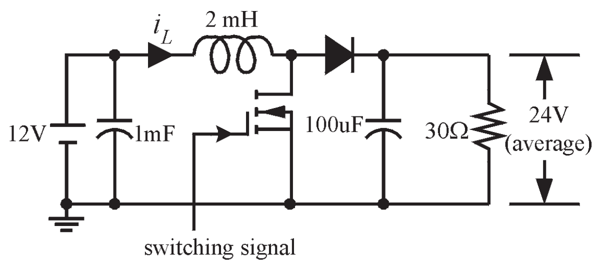
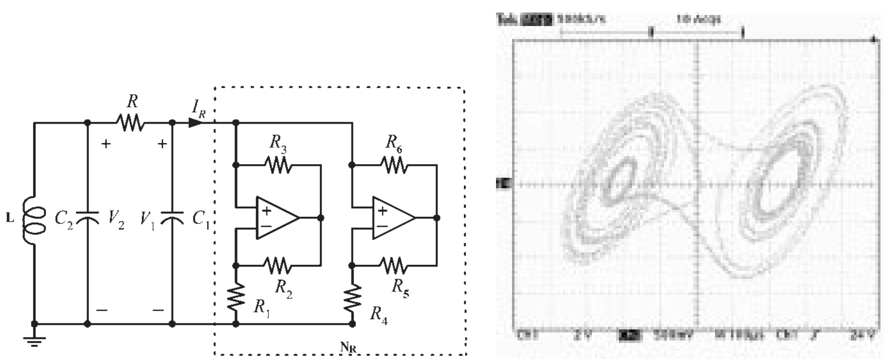


Fig. 2. Boost converter used in this work.

Regarding the CFM scheme, a Chua's circuit [7] was constructed. Figure 3 shows Chua's circuit used in this work for generating chaotic signal. With this circuit, chaotic signal can be generated for center frequency up to 80 kHz using commonly available components. A typical chaotic signal generated by the circuit is shown in lower part of Fig. 3. By using this signal, a CFM square wave with central frequency of 1 MHz is then generated and applied to the switching the MOSFET in Fig. 2.



(a) (b)

Fig. 3. Dual op-amp implementation of Chua's circuit (a). Double-scroll chaotic attractor generated by Chua's circuit and was used as a modulation signal for the boost converter (b).

3.1 Conducted EMI

The conducted EMI noise is the current that coupled to the power, input as well as the output lines. Details of testing apparatus and methodology are governed by the various EMI regulations. We used EN55011 Class B Equipment Under Test (EUT) standard [8] that regulates the conducted emission back to the AC power line for frequency ranging from 450 kHz to 30 MHz for the testing. The conducted EMI was measured by using a computer-controlled HP8590A spectrum analyzer and a detector. After connected all the equipment, the power cord of the power supply is put into the compartment of the detector (see Fig. 4). The detector was then moved along the length of the cord to obtain a position with the worst EMI readings. Then measurements can be made at that position for different types of switching schemes.

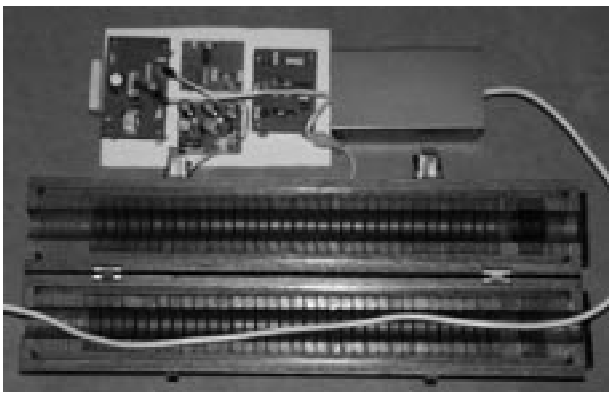
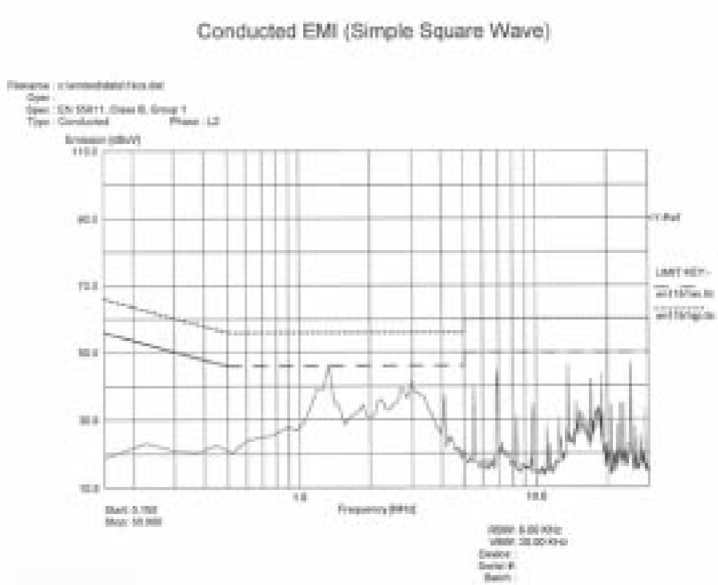
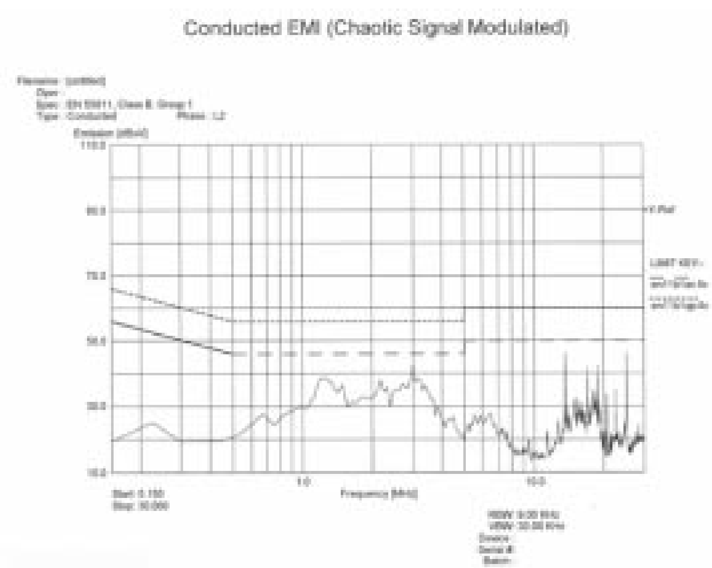


Fig. 4. Compartment with detector used for conducted EMI measurement.

Figure 5 shows the measured conducted EMI for PWM and CFM modulating schemes. There are three lines in the figure. The upper solid line and the dashed line are the average and quasi-peak limit of the standard, respectively. The lowest line is the measured value of conducted EMI of the regulator. Both PWM and CFM scheme of the EUT comply with the standard but CFM scheme is found to have the much lower peak value of the conducted EMI. At around 1.2 MHz, the noise level was reduced by 5 dBμV and in the range of 4 to 10 MHz the noise level was reduced as larger as 25 dBμV. This result coincident with the relationship we obtained from the output terminals. Note that the Equipment Under Test (EUT) is classified as Class B (Group 1) of EN55011 (domestic use), which is the most stringent requirement within the standard.



(a)

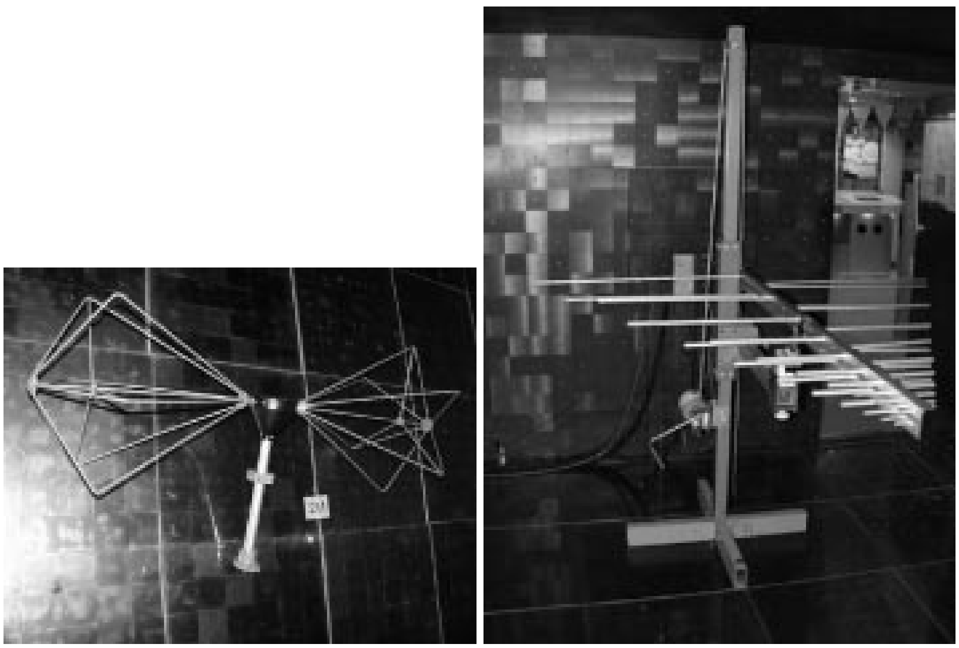


(b)

Fig. 5. Measured conducted EMI for the converter with (a) simple square wave modulating; and (b) chaotic signal modulating.

3.2 Radiated EMI

The radiated EMI were measured with two antennas and an HP8591EM EMC analyzer. The two antennas responding for measuring EMI in frequency ranges of 30 MHz to 230 MHz and 230 MHz to 1 GHz are shown in Fig. 6(a) and Fig. 6(b) respectively. During the measurement, the switching mode power supply, without any casing and shielding, was put on a turntable in a Type 7851 EMI shield enclosure. By adjusting the altitude of the antenna and the angle of the turntable (see Fig. 7), a position with the largest EMI emission was obtained.



(a) (b)

Fig. 6. Antenna for detecting radiation in the frequency range of (a) 30 MHz to 230MHz; and (b) 230 MHz to 1 GHz.

Figures 8 and 9 show the measured radiated EMI for the two modulating schemes in different frequency ranges. The dotted straight lines are the peak limit governed by EN55011 standard. For frequency ranging from 30 MHz to 230 MHz, when compared to the conventional PWM scheme, significant improvement for the new scheme is found at frequencies of 79.5 MHz and 159.5 MHz where the EMI noise was reduced by 22 dBμV and 12 dBμV, respectively. For frequency ranging from 230 MHz to 1 GHz, no significant

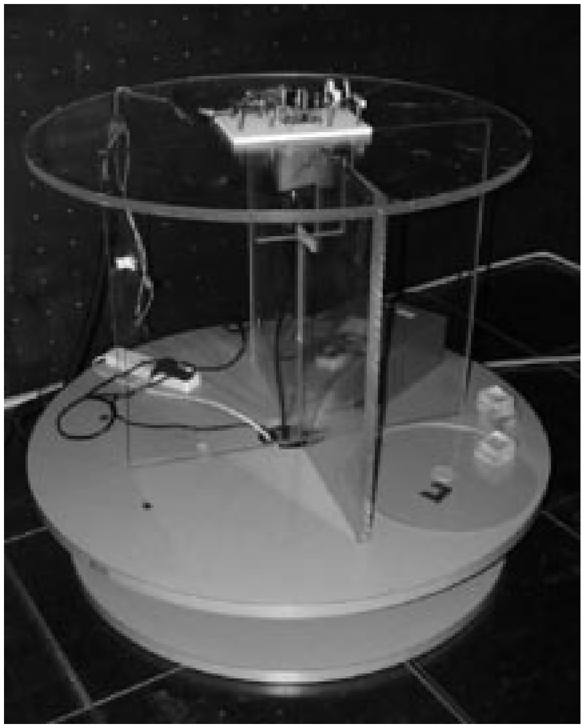
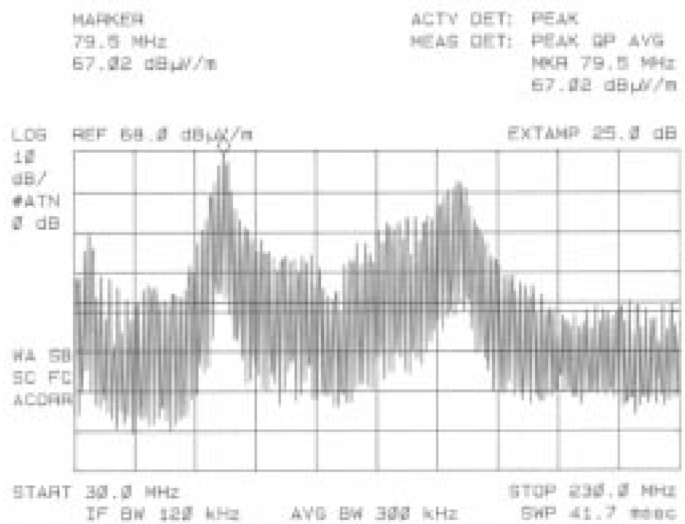


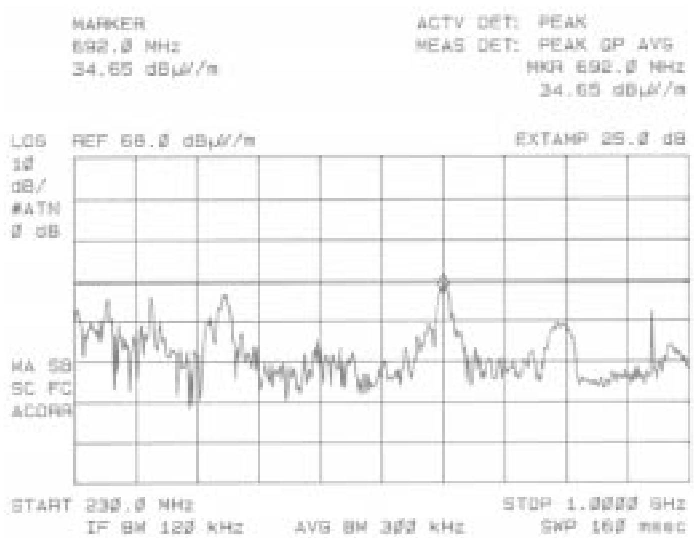
Fig. 7. Part of setup for radiated EMI measurement. The switching mode power supply without any casing and shielding was put on a turntable. The background is a Type 7851 EMI shielding room.

improvement could be found and the wave shapes of both switching schemes are very similar. These observations imply that the radiated EMI in this frequency range should be due to some fundamental radiation sources rather than the switching signals. By monitoring the noise spectrum at the output terminal of the regulator, we found that the harmonics (due to the switching) were attenuated rapidly at frequency around 200 MHz.

Note that the radiated EMI measurements were conducted on EUT without any casing, shielding, filtering or noise isolation. Under this situation, the noise level still marginally passes the radiated EMI requirement of EN55011 in the frequencies ranging from 230 MHz to 1G Hz. However, in frequency range of 30 MHz to 230 MHz, they all failed to meet the requirements. However, the peak noise CFM scheme is 22 dBμV lower than that of the PWM scheme and allow much easier and less expensive ways to further reduced the noise level to below the limit of the standard.

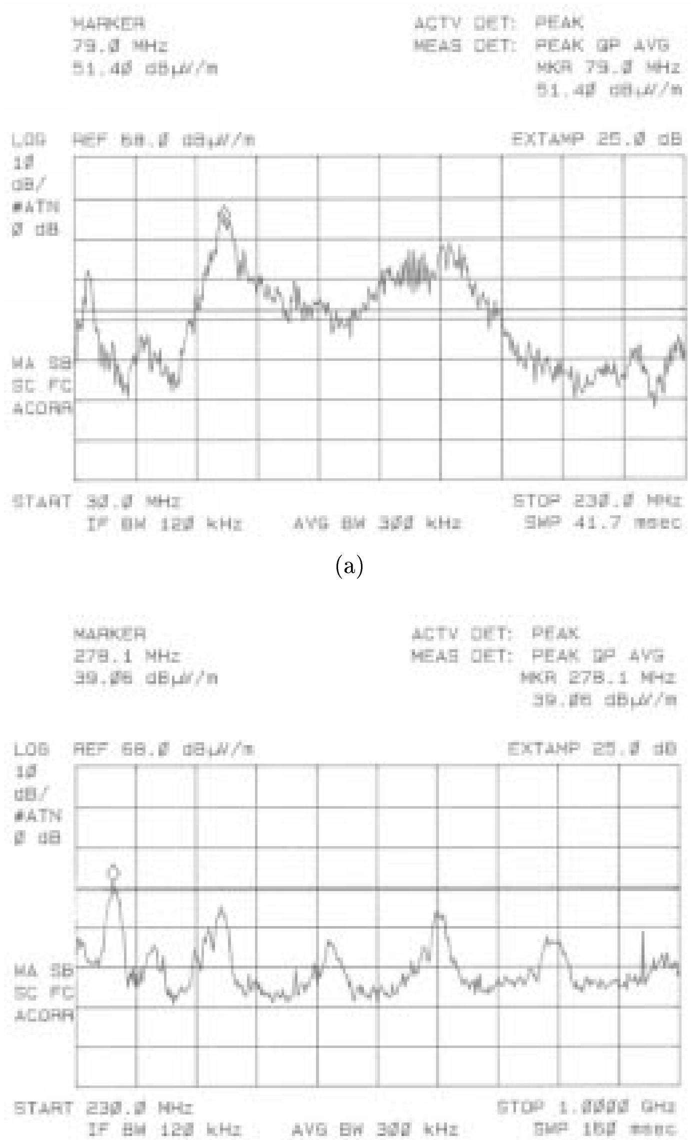


(a)



(b)

Fig. 8. Measured radiated EMI for regulator with for simple square wave switching scheme for frequency ranging from 30 MHz to 230 MHz (a) and frequency ranging from 230 MHz to 1 GHz (b).



(b)

Fig. 9. Measured radiated EMI for converter with chaotic signal modulating. Frequency ranging from 30 MHz to 230 MHz (a) and frequency ranging from 230 MHz to 1G Hz (b).

4 Conclusion

In this work, significant improvements in conducted and radiated EMI noise levels were found with chaotic modulation of the switching signal. For conducted EMI, the peak noise level was reduced by 25 dBμV by employing the CFM scheme. For radiated EMI, we found that the noise was found mainly in the frequency range of 30 MHz to 230 MHz and the CFM scheme would help to reduce the peak noise level in this frequency range by 22 dBμV. According to Lin and Chan [3], the reduction of the EMI emission by switching frequency modulation is determined by the modulation parameter (the ratio of the range of frequency variation and the center modulation frequency, i.e. $\beta = \Delta f / f_m$). The larger value of β, the more even is the resultant spectrum and the degree of noise level reduction the larger. With FM modulation, about 10 dBμV noise reduction was found. The chaotic signal generated from Chua's circuit is in fact an energy re-distribution process. Instead of discrete distribution in the frequency spectrum, chaotic signal has a continuous spectrum that spreads over a large frequency band, i.e $\Delta f \rightarrow \infty$. As a result, the harmonics of the EMI noise due to the switching signal is spread out and the principle components are attenuated. The significant improvements in both conducted and radiated EMI noise would allow much easier and less expensive ways to further reduced the noise level to below the limit of the standard and reduce the design and production costs of electronic products.

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