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Junying Niu, M. Sc.,
Shanxi / China

Suppressing Electromagnetic Interference in Switching-Mode Power Supplies by Chaotic Carrier Frequency Modulation



FernUniversität in Hagen
Schriften zur Informations-
und Kommunikationstechnik

Suppressing Electromagnetic Interference in Switching-Mode Power Supplies by Chaotic Carrier Frequency Modulation

**DISSERTATION
zur Erlangung des akademischen Grades
DOKTOR-INGENIEURIN**

**der Fakultät für Mathematik und Informatik
der FernUniversität in Hagen**

**von
Junying Niu, M.Sc.
Yangquan/China**

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Due to the unpredictable and random-like features of chaotic signals, chaotic carrier frequency modulation (CCFM) technique, by which the spectra of input and output signals can be spread over a wide frequency band without changing the total energy, has been used to suppress electromagnetic interference (EMI) of switching mode power supply (SMPS). So far, the study on CCFM was focused on theoretical analyses, simulations, and experimental verifications, lacking of a practical consideration of applying CCFM in real power supplies, which will be main concern of this dissertation. To provide efficient and economical EMI suppression solutions, a CCFM module is proposed to serve as a plug-in component for power supplies with standard PWM ICs, and for designing a chaotic frequency PWM IC, it is necessary to integrate a chaotic frequency oscillator into the standard PWM IC, which is to be realized both in analogue and digital manners for various practical applications.

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Preface

It was a day in the winter of 2010, when my colleague, Dr. Ping Li, invited Prof. Halang to visit our lab, where I got to know Prof. Halang. After that meeting, I got a wonderful opportunity to study for Ph.D. in Germany, a country famous for its rigor and diligence, where I joined the team led by Prof. Wolfgang A. Halang and Prof. Zhong Li, and began to work on a practical topic since August 2012: applying chaos to reduce electromagnetic interference (EMI) in commercial electrical products.

Switching mode power supply (SMPS), with the features of high energy conversion efficiency and small size, is increasingly widely used in modern electronic equipments. However, severe EMI is caused by high-frequency switching action of semiconductor devices, which threatens the functions of other electric and electronic devices and health of human beings in the environment, and thus poses a big challenge for scientists and engineers to fight EMI. Traditionally, filtering and shielding techniques have been well deployed in various devices, but they have many drawbacks in cost, size, and efficiency, and new solutions are always desired. Owing to the pseudo-randomness and the continuous spectrum features of chaos, chaotic carrier frequency modulation (CCFM) technique can be well employed to fight EMI on the emission source by spreading the spectra of input and output signals over the entire frequency band. Thus, it has attracted great research interest in the past two decades.

Although there have been a lot of the theoretical and experimental research done on the application of CCFM for EMI reduction, commercial SMPSs with chaotic modulation have not yet been seen on the market. Hence, schemes to implement CCFM in the commercial power supplies are of great practical significance. Then, the mathematical analysis and the experimental research on the schemes have been carried out in the framework of this dissertation.

This dissertation agglomerates painstaking efforts of many persons. Without their help, I would not have been able to complete this dissertation.

First, a great appreciation is due to my supervisor, Prof. Zhong Li, for his instruction with patience. In the meantime, thanks for the concern and consideration of Prof. Li's family members, his wife, Mrs. Juan Mei, and his son, Yifan. With the warm help of Prof. Li and his family both in my work and daily life, I could live and work without worries behind. Additionally, it is worth learning from Prof. Li's humor, the attitude to life and good intention toward others.

Also, I owe my thanks to Prof. Halang for his supervision and kindly help in my work. I was deeply influenced by his scientism and academic consciousness. Thanks also go to Mrs. Halang for her kindness and encouragement.

My special thanks are owed to Dr. Ping Li for recommending me to Prof. Li and Prof. Halang. I would thank Prof. Herwig Unger and Dr. Panchalee Sukjit for their kind help. Thanks also go to my colleagues: Mrs. Yuhong Song, Dr. Guidong Zhang, and Mrs. Jutta During, and my friends around: Mr. Ditter Dannet, Mrs. Ulrike Danner, Mr. Ulrisch Fisher, Mrs. Ulrike Fisher, Mrs. Bing Xiao, Mr. Jiameng Luo and Dr. Yajun Li.

Cordial thanks also go to my parents and parents-in-law for their love and concern from time to time. I would thank my husband, Zongzheng You, for his care for the family and our son, Zhijin, for bringing me a lot of pleasure.

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Junying Niu
August 2016

Contents

Abstract	VII
1 Introduction	1
1.1 Power Supply	1
1.2 EMI and EMC	2
1.3 EMI Suppression Techniques	5
1.4 Spread-Spectrum Techniques	7
1.4.1 Periodic Carrier Frequency Modulation	7
1.4.2 Randomized Carrier Frequency Modulation	8
1.4.3 Chaotic Carrier Frequency Modulation	10
1.5 Motivations and Innovations	11
1.6 About the Dissertation	15
2 Chaotic Carrier Frequency Modulation Module	17
2.1 Introduction	17
2.2 Oscillator of PWM IC	18
2.3 Implementation of CCFM	20
2.3.1 Operation Principle of CCFM	20
2.3.2 Chua's Circuit	21
2.3.3 CCFM Module	24
2.4 Simulations	27
2.4.1 Implementation of UC3842-based CCFM	27
2.4.2 Implementation of UCC3895 and NCL30001 based CCFM	30
2.5 Summary	32
3 Power Spectral Characteristics of CCFM-based Switching Converters	34
3.1 Introduction	34
3.2 Statistical Characteristics of Switching Period	36
3.3 Power Spectrum of Switching Signal with Chaotic Frequency	38
3.4 Evaluation of EMI Reduction	40
3.4.1 Effect of Switching Period's Modulation Degree on EMI Reduction	41
3.4.2 Effect of Switching Period's PDF on EMI Reduction	42
3.5 Simulations	43
3.6 Summary	43
4 Application of CCFM in LED Drivers	45
4.1 Introduction	45
4.2 Implementation of CCFM Module	47
4.3 Flyback Converter-Based LED Driver	48
4.3.1 Working Principle	48
4.3.2 EMI Test	51
4.3.3 Electrical Characteristics Measurements	51

4.3.4	Test of Key Elements' Temperature	53
4.3.5	Harmonics Current Measurement.....	56
4.4	Push-pull Converter-Based LED Driver.....	56
4.4.1	Working Principle	56
4.4.2	EMI Test	58
4.4.3	Electrical Characteristics Measurements.....	59
4.4.4	Test of Key Elements' Temperature	60
4.4.5	Harmonics Current Measurement.....	61
4.5	Summary	61
5	Analogue Chaotic Frequency PWM IC	64
5.1	Introduction.....	64
5.2	Analogue PWM IC	65
5.3	Design of CCFM-Based Oscillator.....	68
5.3.1	System Design.....	68
5.3.2	Chaotic Threshold Voltage	68
5.4	Simulations	71
5.4.1	Chaotic Frequency PWM IC Controlled Flyback Converter	71
5.4.2	Chaotic Frequency PWM IC Controlled Shift-Phased Full Bridge Converter.....	74
5.5	Summary	76
6	Digital Chaotic Frequency PWM IC	78
6.1	Introduction.....	78
6.2	Digitally Controlled SMPS	78
6.2.1	Diagram of Digitally Controlled SMPS.....	78
6.2.2	DPWM	79
6.3	DPWM with Chaotic Frequency	80
6.3.1	Working Principle of CDPWM	80
6.3.2	Logistic Map Based Digital Chaotic Signal Generator	81
6.3.3	Tent Map Based Digital Chaotic Signal Generator.....	82
6.3.4	Shift Map Based Digital Chaotic Signal Generator	83
6.3.5	Circuit Design of CDPWM.....	84
6.4	Simulations	87
6.5	Experiments.....	89
6.6	Summary	91
7	Conclusion	93
References		95

Abstract

Due to its high efficiency, a switching mode power supply (SMPS) has been increasingly widely applied in electric industry. However, rapid switching action of semiconductor devices, which results in high change rates of voltage and current, leads to severe electromagnetic interference (EMI) problems.

Many engineering techniques have been proposed to suppress EMI of SMPS by taking measurements on interference sources, victims or EMI coupling paths, respectively. The conventional techniques for EMI reduction are shielding and filtering, which are methods to cut off the coupling path and enhance the interference immunity of the victim. However, they have the disadvantage of increasing size and cost of the products, which restrains their application, especially in portable equipments. Moreover, those methods, just fighting the generated interference, can't prevent the generation of EMI at the source. Hence, more efficient and economic techniques are desired.

In recent years, the spread-spectrum technique, which can reduce EMI at the source by spreading the spectra of input and output signals over a wide frequency band without changing the total energy, has received great research interest. Periodic carrier frequency modulation, randomized carrier frequency modulation and chaotic carrier frequency modulation (CCFM) are commonly used spread-spectrum techniques. The chaotic and randomized modulation techniques are more effective for EMI suppression than the periodic one. Moreover, as a nonlinear deterministic system to generate pseudo-random signals, a chaotic system is easier to control and manufacture than a random system, posing promising potentials in industrial applications. So far, the study on CCFM was focused on theoretical analyses, simulations, and experimental verifications, lacking of a practical consideration of applying CCFM in real power supplies, which will be main concern of this dissertation.

First, for power supplies with standard PWM ICs, a CCFM module is proposed to serve as a plug-in component for suppressing EMI, without changing the original circuit, thus, saving the development process and cost caused by the re-design of the product. The module is used to modulate the switching frequency of the standard PWM ICs by providing a chaotically dithering current for the frequency setting component. It is noted that the CCFM module is adjustable via its parameters to reach a trade-off between EMI suppression and ripples caused by chaotic modulation.

Secondly, for designing a chaotic frequency PWM IC, it is necessary to integrate a chaotic frequency oscillator into the standard PWM IC, which is to be realized both in analogue and digital manners for various practical applications. The oscillator of the traditional analogue PWM ICs is normally implemented by a sawtooth generator, of which the produced signal circularly vibrates between two threshold voltages. Therefore, an analogue chaotic driver of a PWM IC is designed to dither either of the threshold voltages chaotically. The digital PWM IC sets the switching frequency by a counter, which counts from 0 to a pre-assigned value at a certain rate during each switching period. Hence, a chaotic switching period counter is designed for the digital CCFM IC by modulating the pre-assigned value chaotically. Chaotic frequency PWM ICs provide an efficient and economical solution for EMI suppression in power supplies, and enable real industrial applications.

Keywords: Chaotic Carrier Frequency Modulation Module, Electromagnetic Interference, Switching Mode Power Supply, Chaotic Frequency Pulse-Width Modulation Integrated Circuit