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Junying Niu, M. Sc.,
Shanxi / China

Nr. 851

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

FernUniversität in Hagen
Schriften zur Informations- und Kommunikationstechnik

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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

Hagen, 2016

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Suppressing Electromagnetic Interference in Switching-Mode Power Supplies by Chaotic Carrier Frequency Modulation
Fortschr.-Ber. VDI Reihe 10 Nr. 851. Düsseldorf: VDI Verlag 2017.
110 Seiten, 89 Bilder, 9 Tabellen.
ISBN 978-3-18-385110-2, ISSN 0178-9627,
€ 43,00/VDI-Mitgliederpreis € 38,70.

Keywords: Chaotic Carrier Frequency Modulation Module – Electromagnetic Interference – Switching Mode Power Supply – Chaotic Frequency Pulse Width Modulation Integrated Circuit – Spread Spectrum

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.

Bibliographische Information der Deutschen Bibliothek
Die Deutsche Bibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliographie; detaillierte bibliographische Daten sind im Internet unter http://dnb.ddb.de abrufbar.

Bibliographic information published by the Deutsche Bibliothek
(German National Library)
The Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliographie (German National Bibliography); detailed bibliographic data is available via Internet at http://dnb.ddb.de.

Schriften zur Informations- und Kommunikationstechnik
Herausgeber:
Wolfgang A. Halang, Lehrstuhl für Informationstechnik
Herwig Unger, Lehrstuhl für Kommunikationstechnik
FernUniversität in Hagen

ISSN 0178-9627
ISBN 978-3-18-385110-2

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 owned 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.

I would thank the support of the project IGF-Vorhaben-Nr.17211 N, "suppressing electromagnetic interference in electronic devices via chaos control", which was funded by the German Federation of Industrial Research Associations. Sincere thanks go to Shunde Polytechnic for supporting my study.

Junying Niu
August 2016

Contents

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 redesign 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