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This book is dedicated to my dear parents Maria and Kazimierz, and my darling children, Anna, Mateusz and Andrzej

Preface

Power electronics circuits are increasingly important in the modern world due to the rapid progress in developments of microelectronics in areas such as microprocessors, digital signal processors, memory circuits, complementary metaloxide-semiconductors, analog-to-digital converters, digital-to-analog converters, and power semiconductors—especially metal–oxide–semiconductor field-effect transistors and insulated gate bipolar transistors.

Specifically, the development of power transistors has shifted the range of applications from a few amperes and hundreds of volts to several thousands of amperes and a few kilovolts, with a switching frequency measured in millions of hertz. Power electronics circuits are now used everywhere: in power systems, industry, telecommunications, transportation, commerce, etc. They even exist in such modern popular devices as digital cameras, mobile phones, and portable media players, etc. They are also used in micropower circuits, especially in energy harvesting circuits.

In the early years of power electronics, in the 1960s and 1970s, analog control circuits were most commonly used, meaning that only the simplest control algorithms could be applied. Some years later, in the 1980s and early 1990s, hybrid control circuits were used, which consisted of both analog and digital components. In subsequent years, there followed a slow transition to fully digitalized control systems, which are currently widely used and enable the application of more complex digital signal processing algorithms.

In this book, the author considers signal processing, starting from analog signal acquisition, through its conversion to digital form, methods of its filtration and separation, and ending with pulse control of output power transistors. The author has focused on two applications for the considered methods of digital signal processing: an active power filter and a digital class D power amplifier.

Both applications require precise digital control circuits with very high dynamic range of control signals. Therefore, in the author's opinion, these applications will provide very good illustrations for the considered methods. In this book, the author's original solutions for both applications are presented. In the author's opinion, the adopted solutions can also be extended to other power electronics devices.

In relation to the first application—active power filters (APF)—to start with there is analysis of first harmonic detectors based on: IIR filter, wave digital filters, sliding DFT and sliding Goertzel, moving DFT. Then, there is a discussion of the author's implementation of classical control circuits based on modified instantaneous power theory. Next, the dynamics of APF is considered. Dynamic distortion of APF makes it impossible to fully compensate line harmonics. In some cases, the line current THD ratio for systems with APF compensation can reach a value of a dozen or so percent. Therefore, the author has dealt with this problem by proposing APF models suitable for analysis and simulation of this phenomena. For predictable line current changes, it is possible to develop a predictable control algorithm to eliminate APF dynamics compensation errors. In the following sections, the author's modification using a predictive circuit to eliminate dynamic compensation errors is described. In this book, control circuits with filter banks which allow the selection of compensated harmonics are described. There are considered filter banks based on: sliding DFT, sliding Goertzel, moving DFT and instantaneous power theory algorithms.

For unpredictable line current changes, the author has developed a multirate APF. The presented multirate APF has a fast response for sudden changes in the load current. So, using multirate APF, it is possible to decrease the THD ratio of line current even for unpredictable loads.

The second application is a digital class D amplifier. Both APFs and the amplifiers are especially demanding in terms of the dynamics of processed signals. However, in the case of a class D amplifier, the dynamics reaches 120 dB, which results in high requirements for the type of algorithm used and its digital realization. The author has proposed a modulator with a noise shaping circuit for a class D amplifier. Interpolators are also considered that allow for the increasing of the sampling frequency while maintaining a substantial separation of signal from noise. The author also presents an original analog power supply voltage fluctuation compensation circuit for the class D amplifier. The class D amplifier with digital click modulation is also given special consideration. Finally, two-way and three-way loudspeaker systems, designed by the author, are presented, where the signal from input to output is digitally processed.

The greater part of the presented methods and circuits is the original work of the author. Listings from Matlab or in C language are attached to some of the considered algorithms to make the application of the algorithms easier. The presented methods and circuits can be successfully applied to the whole range of power electronics circuits.

The issues concerning digital signal processing are relatively widely described in the literature. However, in the author's opinion, there are very few publications combining digital signal processing and power electronics, due to the fact that these two areas of knowledge have been developed independently over the years. The author hopes that this book will, to some extent, bridge the gap between digital signal processing and power electronics. This book may be useful for scientists and engineers who implement control circuits, as well as for students of electrical engineering courses. It may also be of some value to those who create new topologies and new power electronics circuits, giving them some insight into possible control algorithms.

Zielona Gora, Poland, December 2012 Krzysztof Sozański

Acknowledgments

The author has written this book in his endeavor to abide by the following maxim *nulla dies sine linea* ↔ *nie ma dnia bez kreski* ↔ *not a day without a line drawn*. However, this is not always easily achieved.

I would also like to thank everyone who supported me during the writing of this book.

Contents

Acronyms

Abbreviations

AC	Alternating current
A/D	Analog-to-digital converter
ALU	Arithmetic-logic unit
APF	Active power filter
av	Average value of signal
BPF	Band-pass filter
BSF	Band-stop filter
CM	Click modulator, also called zero position coding
DAI	Digital audio interface
D/A	Digital-to-analog converter
dB	Decibel, 20log($U2/U1$), 10log($P2/P1$)
DC	Direct current
DFT	Discrete Fourier transform algorithm
DPWM	Digital pulse width modulation
DSM	Delta sigma modulator
DSP	Digital signal processor
D/t	Digital-to-time converter
e.g.	For example (exempli gratia-Latin)
EMI	Electromagnetic interference
etc.	And other things, or and so forth (et cetera-Latin)
FIR	Finite impulse response digital filter
FFT	Discrete fast Fourier transform algorithm
FLOPS	Floating-point operations per second
FPGA	Field programmable gate array
HPF	High-pass filter
IGBT	The insulated gate bipolar transistor
IC	Integrated circuit
i.e.	This is (id est-Latin)