PREFACE

All real physical systems are nonlinear in nature. This simple observation is true also for electrical and electronic circuits even though many of them are designed to perform linear transformations on signals. Apart from systems designed for "linear signal processing", many systems have to be nonlinear by assumption, for example rectifiers, flip-flops, modulators and demodulators, memory cells. The design procedures for such circuits are in most cases linear and cannot account for nonidealities and nonlinear phenomena. In many cases the designed circuit, when implemented, performs in a very unexpected way, totally different from that for which it was designed. In most cases, engineers do not care about the origins and mechanisms of the malfunction; for them a circuit which does not perform as desired is of no use and has to be rejected or redesigned. Often behavior such as "excess noise", "latch-up", "false locking" etc. is reported without fully understanding the underlying phenomena. We hope that this book will help engineers to recognize and understand many bizarre cases which are encountered in everyday practice. This is the first goal of this book.

It should also be noted that during the last decade there has been significant development in research on the dynamics of nonlinear electrical and electronic circuits and in the study of chaos. This is due to two facts.

Firstly, electrical and electronic circuits constitute a group of real physical systems in which observations and measurements are relatively easy to make. Various types of behavior including numerous types of bifurcations and chaotic phenomena can be observed using general purpose laboratory tools such as oscilloscopes and spectrum analyzers. More sophisticated specialized tools for tracing solution curves in three dimensions and taking Poincaré sections can be used to pursue experimental analysis even further. Also, general purpose circuit simulation programs such as SPICE are available to designers and researchers. Such an "experimental comfort" enabled thorough studies confirming the existence of strange unexpected behavior in almost every type of electronic circuit — oscillators, filters, instrumentation circuits, switched capacitor circuits, digital circuits, power supplies, PLLs, electric machines, microwave circuits, electro-optic systems etc. The main problem remains in interpreting experimental data.

Secondly, electronic circuits offer an unprecedented opportunity for researchers — with the development of IC technology we can build cheap laboratory experimental setups that reflect properties of almost any proposed model and make measurements in real time in a real physical system for a wide range of system parameters. This makes possible experiments that are not available in any other domain of research such as physics, medicine, biology, economics etc.. A good example of such a "universal" research circuit is Chua's circuit which can mimic a large variety of bifurcations and chaotic phenomena when changing just one of the circuit elements; this circuit provides a useful paradigm for understanding these types of behavior. As a historical note let us mention that many scientists working in the field of electrical engineering and electronics made significant contributions to the development of the theory of nonlinear oscillations and chaotic behavior.

Unexpected behavior was probably first observed in the famous experiment of Van der Pol and Van der Mark but had not been recognized as chaos until relatively recently. Milestones in research into nonlinear oscillations were marked by C. Hayashi and his pupil Y. Ueda from Kyoto University who recognized, for the first time, chaotic oscillations in the forced Duffing system. These early experiments were followed by researchers in many universities around the world with a recent boost given by Leon O. Chua and his collaborators.

So far the available literature concerning chaos and complexity concentrated on two subjects: mathematical (analytical and numerical) methods, and the description and analysis of experimental data coming from various domains of science, primarily physics.

During the past decade many papers concerning specific examples appeared also in journals biased towards the area of circuits and systems (both theory and applications) and in the area of electrical engineering and electronics. These articles however do not present any systematic way of treating such phenomena and are of limited use for engineers. To our knowledge, there is no textbook available on the market which treats this subject from the viewpoint of electronic circuits.

This book is not meant either to repeat mathematical tools or to compete with the results of other authors. Except in very few places, we do not review results published by other authors. Providing basic knowledge of the mathematical notions which are needed to understand nonlinear phenomena, this book guides the reader through several encounters with chaos and complexity studied by the author himself during the past decade, from the analysis of an RC oscillator circuit and digital filters to applications using synchronized chaotic circuits and chaos control techniques.

We concentrate on specific methods for recognizing and analyzing complexity and chaos in electronic circuits. There are many specific experimental and simulation tools available for analyzing electronic and electrical circuits. These tools in some cases might be useful also in other disciplines.

We do not aim to present an in-depth study of mathematical methods. We intend rather to provide a guide for researchers and engineers in the domain of electronic circuits how to deal with bizarre phenomena, how to distinguish them among other types of behavior and how to identify the underlying mechanisms. For this purpose we give a brief review of basic notions used and mathematical tools available as it seems that many phenomena cannot be discovered and understood without introducing more abstract mathematical concepts.

We hope that readers looking at the thorough analysis of examples (employing various available analytical and experimental tools) will be able to apply the approach and tools presented here in their own fields of study. Also having an extensive list of references they will be able to find what is not included in the book but might be of interest.

Organization of the book

The basic mathematical apparatus and notions used throughout the book are introduced in Chapter 1. This should permit an interpretation and analysis of the experimental results. Further, we aim to give some insight into basic problems: how nonlinear circuits differ from linear ones, where the sources of nonlinearity arise in real circuit implementations. We introduce the notions of steady state (asymptotic) behavior and discuss various concepts for defining chaos and complex behavior. Finally a brief discussion of experimental results versus simulation results is given.

A large part of this book can be considered as "The electronic engineers' toolkit for nonlinear dynamics". Using two examples, namely the RC-ladder oscillator and simple digital filter structures, applications of various tools are described. In particular, we describe the interpretation of laboratory and simulation experiments, and some of the available analytical approaches for recognizing and verifying chaotic behavior.

In the last part of the book we discuss issues for avoiding and controlling complex systems. Possible applications in data and signal processing as well as noise generation are considered.

Even before writing the book, I realized that the subject and the underlying theoretical formalisms and models are quite multidisciplinary in nature. While such complexities make the task of presenting the subject rather challenging, they also make it very exciting and hopefully interesting also for specialists from other domains.

The origins of my interest in chaos date back to the period of preparing my PhD thesis, when studying design procedures for sinusoidal oscillators by chance I discovered strange behavior in the RC-ladder oscillator. It was the constant encouragement of my supervisor Prof. Wojciech Mitkowski and the friendly atmosphere of collaboration with the team of Prof. Jacek Kudrewicz at Warsaw University of Technology that resulted in many interesting results. Certainly these two people with exceptional personalities inspired me to become a researcher. The study of chaotic behavior in analog circuits later became my principal research interest for at least five years.

As a novice in the domain of nonlinear dynamics, I wrote a letter to Prof. Leon Chua from the University of California, Berkeley, asking his opinion about my discoveries. His comments and encouragement resulted in the first of my papers published in the IEEE Transactions on Circuits and Systems. Since then, Leon Chua has always been most supportive; in several moments of hesitation and disappointment with results, he was always there to give friendly encouragement and useful comments. Several works of mine would not have been possible without Leon.

During that time I also had the opportunity to visit the Center of Modeling, Nonlinear Dynamics, and Irreversible Thermodynamics (MIDIT) at the Technical University of Denmark, Lyngby, thanks to an invitation from Prof. Erik Mosekilde. During several visits to MIDIT not only did I learn a lot but I also had the chance to meet leading chaos researchers from many laboratories. It was a distinct pleasure for me to share an office with a pioneer in the chaos domain, Prof. Yoshisuke Ueda from Kyoto University. His enthusiasm deeply influenced my research.

During visits to many laboratories engaged in chaos or nonlinear dynamics research and by attending numerous conferences I had the opportunity to meet people who in many ways helped me in carrying out my own studies. My sincere thanks go to Prof. Martin Hasler, dear collaborator and friend, thanks to whom I could profit from excellent laboratories and the nicest possible work environment during several stays as a Visiting Professor at the Chair of Circuits and Systems, Swiss Federal Institute of Technology, Lausanne. To Martin also goes credit for carefully reading parts of this book.

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