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CHAOS IN CIRCUITS AND SYSTEMS

edited by

GUANRONG CHEN & TETSUSHI UETA

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Preface

Circuits, both linear and nonlinear, remain the core components of most electronic and mechatronic equipment and devices to date. As industrial electronics and mechatronics become mature, better functionality and reliability of these technologies require more intriguing use of nonlinear circuits. This calls for thorough investigation of dynamical characteristics and largest possible operating regimes of nonlinear circuits and systems. Of particular interest is the fundamental nonlinear circuit theory that is still in the evolving phase of its development today. In view of the exciting emergence of nano-technology and the attractive quantum-computing future, nonlinear circuits have become even more important and fundamental.

The fact that chaos is ubiquitous in nonlinear circuits has been one of the major motivations for studying nonlinear circuit theory in recent years. A number of workshop and conference proceedings, research monographs and textbooks, special journal issues, and experimental results published previously were focused on analysis and characterization of chaotic phenomena in various nonlinear circuits. There were also many reports on chaos generation via circuit design, mostly performed on platforms of some hypothetical systems such as Chua's circuit. These studies were essential in laying a foundation for further development of both basic theory and engineering design of nonlinear circuits.

Yet, the traditional trend of understanding and analyzing chaos has evolved into the new tasks of ordering and utilizing chaos over the past decade. A new research direction in the field of applied chaos technology not only includes controlling chaos, which means to weaken or completely suppress chaos when it is harmful, but also includes anti-control of chaos, known also as chaotification, which refers to enhancing existing chaos or purposely generating chaos when it is useful and beneficial. One has witnessed increasing interest not only in the traditional chaos analysis and chaos generation via circuitry but also in the new consideration of utilizing chaos in real physical systems. This shows that electronic engineers are really giving chaos more and more serious thought, and it is believed that there is a significant change in attitude of engineers of our generation toward this kind of engineering research. This book aims to bridge the gap between these two phases of development and also to open up some discussion of real applications where chaos can be put to technological use, including communication, power electronics design, and so on.

Chaos, when under control, promises to have a major impact on many novel, time- and energy-critical applications, such as high-performance circuits and devices (e.g., delta-sigma modulators and power converters), liquid mixing, chemical reactions, biological systems (e.g., in the human brain, heart, and in perceptual processes), crisis management (e.g., in jet-engines and power networks), secure information processing (e.g., chaos-based encryption), and decision-making in critical events. This new and challenging research area has embraced both analog and digital technologies and has become a scientific interdiscipline, involving engineers in the fields of controls, systems, electronics, mechanics, and biomedicine, as well as applied mathematicians, theoretical and experimental physicists and, above all, circuit engineers and instrumentation specialists. This book is a collection of some state-of-the-art surveys, tutorials, and overview articles written by some experts in this area.

It is our hope that this book can serve as an updated and handy reference for university professors, graduate students, laboratory researchers and industrial practitioners, as well as applied mathematicians and physicists who are interested in chaos in circuits and systems.

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Contents

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Chaotic Oscillators - Design Principles

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Abstract

An introduction to the design of chaotic oscillators is presented from an electrical engineering point of view. Oscillators are amplifiers with unstable bias points. The basic design principle behind chaotic oscillators is the connection of two electronic circuits which are not in harmony. A number of configurations which may serve as the physical mechanisms behind chaotic behavior are listed. The behavior of an oscillator is explained by means of eigenvalue studies of the linearized Jacobian of the differential equations for the mathematical model of the oscillator. The basic design principle is demonstrated by means of different simple examples.

1.1 Introduction and General Remarks

Radio amateurs and electronic engineers have observed chaotic performance of electronic circuits since the invention of the triode amplifier by Lee de Forest in 1906. The phenomena observed were called noise, nonlinear distortion, parasitic oscillations, intermittent operation or asynchronous heteroperiodic excitation. It was considered unwanted and impossible to investigate analytically. Edwin H. Armstrong (1890-1954) invented the regenerative circuit for HF oscillations in 1912 (superheterodyne 1918, FM 1937). He possibly observed chaos [1, 2]. Balthasar van der Pol (1889-1959) reports about chaos as "an irregular noise" [3–6]. Today (year 2001) we are able to investigate the phenomena by means of computer simulation.

We are interested in *chaos* for two reasons: we want to *avoid chaos* and/or we want to *make use of chaos.* In both cases it is necessary to study chaos in order to understand and master the phenomena. Unfortunately we still need analytical methods for the investigation of nonlinear systems in details. All our analytical design methods are based on linear approximations.

Sinusoidal oscillators are normally considered second order systems. Many topologies have been proposed for sinusoidal oscillators (Colpitts, Clapp, Hartley, Pierce etc.). The design of an oscillator is normally based on the Barkhausen criteria [7] according to which an oscillator is looked upon as an ideal finite gain amplifier with a linear frequency determining feed-back circuit (Fig. 1.5). If the poles of the whole linear circuit are placed on the imaginary axis in the complex frequency plane (s-plane) we have an ideal oscillator. In order to start-up the oscillator some component values are tuned so that the complex pole pair of the circuit is placed in the right half plane (RHP) making the circuit unstable. It is then hoped that the nonlinearities of the amplifier will give rise to a limitation of the signals so that stable oscillations may occur. Possible distortion is smoothed by means of filters. Very little is reported about the mechanism behind the observed stable oscillations. Some authors even claim that the complex pole pair "is brought back to the imaginary axis by the nonlinearities" which of course is nonsense. In short, an oscillator is an amplifier circuit with an unstable DC bias point. Very seldom it is discussed how far out in RHP the poles should be placed in order to optimize the oscillator e.g. with respect to distortion. Due to parasitic memory components, the order of a real oscillator is larger than two i.e. *all oscillators are potentially chaotic.*

If oscillators are coupled in some way so that energy could be exchanged they try to *synchronize* (Fig. 1.1). Even chaotic oscillators try to synchronize. This phenomena is observed everywhere in nature. If you consider a bee, a fish, a bird or a dolphin being a high order chaotic oscillator you may observe how a flock of bees, fish, birds or dolphins may behave as one body. One single orange butterfly is not able to cross the channel from France to England but a "cloud" of thousands of orange butterflies is able to cross. Possibly the first observation of synchronization of man-made oscillators was done by C. Huygens (1629-1695) who invented the pendulum clock in 1656. He reports about synchronous time-keeping of two clocks hung on the same wall [3]. The concept of synchronization might be the base for making use of chaos.

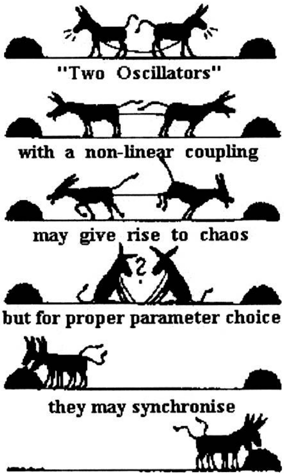

FIGURE 1.1
"COUPLING OF TWO OSCILLATORS" Dansk Standard, Kollegievej 6, DK - 2920 (Aknowledgement: Fig. 1.1 is copied and modified with permission from Dansk Standard, Kollegievej 6, DK - 2920 Charlottenlund, Denmark. http://www.ds.dk/).

Within the last 30 years we have been able to study the nonlinear distortion phenomena by means of computer simulation and to some extent by means of analytical investigation. The concept of chaotic oscillators has been defined by means of a large number of examples. Very little has been reported concerning classification of chaotic oscillators or procedures for design of chaotic oscillators with prescribed attributes.

Amplifiers create power gain (from weak or small signals to strong or large signals). Amplifiers are considered linear circuits having a DC bias point in the left half plane (LHP) of the complex frequency plane.

Oscillators create sine waves as carriers of signals (Radio, TV) or square waves as clock control in digital systems. Oscillators are considered nonlinear circuits having a DC bias point in RHP.

Chaotic oscillators are deterministic systems of order higher than two which apparently behave in a stochastic manner. The behavior of a chaotic system is