Preface

Chaos is a remarkable phenomenon occurring in many nonlinear systems, where the deterministic nature of the structure conjugates with the irregularity of the behavior. This means that, despite the fact that the system is described by a set of ordinary differential equations, where all the terms are perfectly known, its behavior is irregular and very sensitive to initial conditions. The first evidence of unpredictability in deterministic systems is found in the work of the mathematician and scientist Henri Poincaré on celestial motion, while the first formulation of chaos in a mathematical model expressed by a set of ordinary differential equations exhibiting chaos is due to the mathematician and meteorologist Edward Lorenz who was studying a model of air motion in the atmosphere and discovered how small variations in the initial values of the variables of his model resulted in divergent weather predictions.

The discovery of Lorenz was then followed by the introduction of other models showing chaotic behavior. However, at the time of these studies an ultimate *experimental* proof of chaos was lacking. This idea inspired the work of Leon O. Chua who designed the first electronic circuit that intentionally behaves in a chaotic way. On the other hand, it was recognized that chaos was already observed in other known circuits developed in the context of electronic oscillators such as the one used by van der Pol (an oscillating electronic valve with a triode), but often classified or eliminated from those circuits as an irregular noise or an unwanted behavior.

The focus of this book is indeed on experiments on chaos and control of chaos. Chaotic circuits are the main subject of the work as well as their characteristic features and chaotic control and synchronization schemes and experiments. In particular, an approach to realize experiments also on systems initially described by a set of dimensionless equations is dealt with: the idea is to design a circuit which obeys to the same equations of the mathematical model so that experiments on it can be performed. The guidelines for the design of such an *equivalent* electronic circuit are discussed and a gallery of chaotic circuits designed and implemented with off-the-shelf components is presented. The book is conceived in such a way that the reader can easily build the selected circuit, verify whether it is properly working and then perform his/her own experiments. On the contrary, the book does not focus on chaos from a theoretical perspective. There are many wonderful books on this subject and the reader is referred to these books for an introduction to chaos.

From the point of view of our study, chaotic circuits are aperiodic electronic oscillators, that is, circuits able to oscillate with irregular waveforms which never repeat themselves. If two variables of a chaotic circuit are reported one against the other on the oscilloscope, converse to what is found for periodic oscillators, that is, an elliptic Lissajous figure, a complex topological structure, which is the signature of the chaotic attractor of the system, appears. The signals generated by chaotic circuits have a number of remarkable features: they oscillate in a long-term unpredictable fashion; their trend is sensitive to small changes in the initial conditions and in parameter values; they have a sharp autocorrelation function; they are uncorrelated with signals coming from different chaotic systems as well as signals coming from different attractors of the same system or different portions of a signal coming from the same attractor.

At the end of this brief introduction, we mention that different applications of chaotic circuits have been, and some are currently, investigated. They refer to the field of nonlinear control of electronic devices and secure communications with the definition of chaos-based encryption techniques or to applications where chaos enhances the device performance, such as the use of chaos to drive sonar sensors in multi-user scenarios or to improve motion control of microrobots.

The book is organized as follows. Chapter 1 introduces four examples of chaotic circuits which have been designed by exploiting specific features of some electronic components. Chapter 2 describes the main fundamental blocks used to design a chaotic circuit obeying a set of mathematical nonlinear ordinary differential equations and the guidelines for the design. Chapter 3 reports a gallery of chaotic circuits, either autonomous or non-autonomous, realized with operational amplifiers and discrete components. Chapter 4 discusses some examples of chaotic circuits implemented by Field Programmable Analog Arrays. Chapter 5 discusses some examples of control and synchronization experiments between two chaotic circuits.

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