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Series Editor: Leon O. Chua

CHAOS IN CIRCUITS AND SYSTEMS

edited by

GUANRONG CHEN & TETSUSHI UETA

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Guanrong Chen

City University of Hong Kong, China

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CHAOS IN CIRCUITS AND SYSTEMS

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Editor: Leon O. Chua
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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 interdisciplinary, 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.

Guanrong Chen, City University of Hong Kong
Tetsushi Ueta, Tokushima University, Japan

Contents

1	Chaotic Oscillators - Design Principles	1
	E. Lindberg, K. Murali and A. Tamasevicius	
1.1	Introduction and General Remarks	2
1.2	Amplifiers	4
1.3	Oscillators	4
1.4	Conclusions and a Question	18
2	Design Methodology for Autonomous Chaotic Oscillators	23
	A. S. Elwakil and M. P. Kennedy	
2.1	Design Methodology	25
2.2	The Diode-inductor Composite	27
2.3	The FET-Capacitor Composite	38
2.4	Conclusions	47
3	A Design Method for Chaotic Circuits Using Two Oscillators	51
	Y. Hosokawa and Y. Nishio	
3.1	Introduction	52
3.2	The Circuit Model	52
3.3	Linearized Model	53
3.4	Verification	63
3.5	Conclusions	67
4	Chaotic Wandering in Simple Coupled Chaotic Circuits	71
	Y. Nishio	
4.1	Introduction	72
4.2	Circuit Model	73
4.3	Four-Phase Quasi-Synchronization and Chaotic Wandering . .	76
4.4	Analysis of Chaotic Wandering	79
4.5	Conclusions	89
5	Intermittent Chaos in Phase-Locked Loops	91
	T. Endo, A. Hasegawa and W. Ohno	
5.1	Introduction	92
5.2	Local Intermittency of Pomeau and Manneville Type	93
5.3	Global Intermittency Called “Heteroclinic Tangency Crisis” . .	94
5.4	Intermittency from High-Dimensional Systems	101
5.5	Conclusions	107

6	Dynamical Chaos in Phase-Locked Loops	111
	V. Shalfeev and V. Matrosov	
6.1	Introduction	112
6.2	Chaotic Regimes of PLL	114
6.3	Conclusion	128
7	A Chaotic Oscillator Based on Two-Port VCCS	131
	M. Kataoka and T. Saito	
7.1	Introduction	132
7.2	The Chaotic Oscillator	132
7.3	System Dynamics	138
7.4	The Existence of Attractors	139
7.5	The Transistorized Circuit	142
7.6	Conclusions	143
8	A Generic Class of Chaotic and Hyperchaotic Circuits with Synchronization Methods	151
	J. A. K. Suykens, M. E. Yalçın and J. Vandewalle	
8.1	Introduction	152
8.2	n -Scroll Attractors from a Generalized Chua's Circuit	153
8.3	Families of Scroll Grid Attractors	154
8.4	Hyperchaotic Attractors	157
8.5	Lur'e Representations	161
8.6	Synchronization Methods	163
8.7	Conclusions	166
9	Some New Circuit Design for Chaos Generation	171
	K. S. Tang, K. F. Man, G. Q. Zhong and G. Chen	
9.1	Introduction	172
9.2	Chua's Circuit	173
9.3	Modified Chua's Circuit	178
9.4	Chen's Attractor	185
9.5	Concluding Remarks	188
10	A Current Based VLSI Degree-Two Chaos Generator	191
	L. Wang, Y. Jiang and R. Newcomb	
10.1	Introduction	192
10.2	Degree-Two Chaos Generation System	192
10.3	Chaotic Nature of the System	196
10.4	Binary Hysteresis Design	200
10.5	VLSI Realization of Current Based Degree-Two Chaos Generator	204
10.6	Discussions on Initial Conditions	211

10.7 Simulation Results	211
10.8 Conclusions	212
11 Stochastic Analysis of Electrical Circuits	215
M. A. van Wyk and J. Ding	
11.1 Introduction	216
11.2 Frobenius-Perron Operators	216
11.3 Existence of Invariant Densities	218
11.4 Computation of Invariant Densities	219
11.5 Stochastic Behavior of Electrical Circuits	225
11.6 Conclusions	234
12 Chaotic Neuro-Computer	237
Y. Horio and K. Aihara	
12.1 Introduction	238
12.2 Chaotic Neural Network Model	239
12.3 SC Circuit Implementation of the Chaotic Neuron Model	241
12.4 A Large-Scale Chaotic Neuro-Computer	244
12.5 Conclusions	252
13 Complex Dynamical Behavior in Nearly Symmetric Standard Cellular Neural Networks	257
M. Forti and A. Tesi	
13.1 Introduction	258
13.2 Neural Network Model and Problem Formulation	259
13.3 Limit Cycles in Standard PWL CNNs	261
13.4 Limit Cycles in Sigmoidal CNNs	266
13.5 Complex Dynamics in Standard CNNs	272
13.6 Conclusions	274
14 Chaos in a Pulse-type Hardware Neuron Model	277
K. Saeki, Y. Sekine and K. Aihara	
14.1 Introduction	278
14.2 Chaos in a Pulse-type Hardware Neuron Model	279
14.3 The Transmission Characteristics of Chaotic Signals	288
14.4 Conclusions	293
15 Bifurcations in Synaptically Coupled Bonhöffer-van der Pol Neurons	297
K. Tsumoto, T. Yoshinaga and H. Kawakami	
15.1 Introduction	298
15.2 Coupled BVP Equations	298

15.3 Analytical Methods	299
15.4 Analytical Results	303
15.5 Concluding Remarks	314
16 Chaos in Power Electronics: An Overview	317
M. di Bernardo and C. K. Tse	
16.1 Introduction	318
16.2 Power Electronics Circuits: A Brief Overview	319
16.3 Conventional Treatments	322
16.4 Bifurcations and Chaos in Power Electronics	323
16.5 A Survey of Research Findings	324
16.6 Modelling Strategies	327
16.7 Analysis and Classification of Non-smooth Bifurcations	332
16.8 Current Status and Future Work	336
17 Use of Chaotic Switching for Harmonic Power Redistribution in Power Converters	341
H. S. H. Chung, S. Y. R. Hui and K. K. Tse	
17.1 Introduction	342
17.2 Chua's Circuit Revisit	343
17.3 Amplitude Distribution and the Power Spectral Density with Chaotic Signal	348
17.4 Mathematical Analysis	351
17.5 Studying of the PSD with Chaotic Switching	355
17.6 Experimental Verifications	356
17.7 Conclusions	359
18 Experimental Techniques for Investigating Chaos in Electronics	367
C. K. Tse	
18.1 Introduction	368
18.2 Overview of Simulation Study and Verification	368
18.3 Experimental Investigation	369
18.4 Displaying Time-domain Waveforms, Attractors and Spectra	370
18.5 Displaying Poincaré Sections	373
18.6 Displaying Bifurcation Diagrams	378
18.7 Conclusions	383
19 Nonlinear Dynamical Systems with Interrupted Characteristics: Bifurcation and Control	385
T. Kousaka, T. Ueta and H. Kawakami	
19.1 Introduction	386

19.2	Circuit Equation and Switching Action	387
19.3	Bifurcation Analysis	390
19.4	Controlling Chaos	392
19.5	The Alpazur Oscillator	394
19.6	Conclusions	398
20	Controller Synthesis for Periodically Forced Chaotic Systems	403
	M. Basso, R. Genesio and L. Giovanardi	
20.1	Introduction	404
20.2	Problem Formulation and Preliminary Results	405
20.3	Controller Synthesis	411
20.4	Application Examples	414
20.5	Conclusions	419
21	Mechanism for Taming Chaos by Weak Harmonic Perturbations	423
	N. Inaba	
21.1	Introduction	424
21.2	Circuit Setup	424
21.3	Analysis by the Use of a Constrained Equation	431
21.4	Derivation of Poincaré Map	432
21.5	Conclusions	440
22	Correlator-Based Chaotic Communications: Attainable Noise and Multipath Performance	443
	Géza Kolumbán and M. P. Kennedy	
22.1	Introduction	445
22.2	Chaotic Modulation and Demodulation	446
22.3	The Estimation Problem	449
22.4	Receiver Model	453
22.5	CSK with One Basis Function	454
22.6	CSK with Two Basis Functions	460
22.7	Comparison of Noise Performance and Feasibility of Chaotic Systems	469
22.8	Multipath Performance	471
22.9	Conclusions	478
23	Using Nonlinear Dynamics and Chaos to Solve Signal Processing Tasks	487
	M. Ogorzałek	
23.1	Introduction	488
23.2	Relation with Shadowing and Noise Reduction	490

23.3 Continuous-Time Approach	491
23.4 Discrete-time Approach	495
23.5 Trade-offs in Trajectory Reconstruction	497
23.6 Processing of Signals When no Model of Dynamics is Known	501
23.7 Conclusions	503
24 Chaos Synchronization in a Noisy Environment Using Kalman Filters	509
T. Schimming and O. De Feo	
24.1 Introduction	510
24.2 System Class	511
24.3 Kalman Filtering	513
24.4 Filtering Lur'e Systems	516
24.5 Application	519
24.6 Conclusions	524
25 Identification of a Parametrized Family of Chaotic Dynamics from Time Series	529
I. Tokuda and R. Tokunaga	
25.1 Introduction	530
25.2 Reconstructing a Parametrized Family of Chaotic Dynamics	532
25.3 Numerical Experiment on the Rössler Equations	538
25.4 Recognizing Chaotic Time Series	542
25.5 Discussions and Conclusions	543
26 Cipher-Quasi-Chaotic Sequence with Application to Spreading Spectrum Communication Systems	547
J. B. Yu	
26.1 Introduction	548
26.2 CSS Sequence Optimization	550
26.3 BER and FER Performance Comparison: LCSS/CDMA vs Q-CDMA	556
26.4 Cipher Quasi-Chaotic Sequences	559
26.5 A Chaotic Interleaver Used in Turbo Coding	567
26.6 Concluding Remarks	571
27 Image Processing in Tunneling Phase Logic Cellular Nonlinear Networks	577
T. Yang, R. A. Kiehl and L. O. Chua	
27.1 Introduction	578
27.2 Deterministic Model of Isolated Tunneling Phase Logic Element	579
27.3 One-Dimensional TPL-CNN	581

27.4 Two-Dimensional TPL-CNN	583
27.5 Image Processing Abilities	586
27.6 Concluding Remarks	590
28 Numerical Approaches to Bifurcation Analysis	593
T. Ueta and H. Kawakami	
28.1 Introduction	594
28.2 Poincaré Map	595
28.3 Computation of Bifurcation Parameter Values	598
28.4 Simulation Examples	603
28.5 An Application– Isocline with the argument	607
28.6 Comparison with Conventional Methods	608
28.7 Conclusions	609
29 Chaos in One-Dimensional Maps	611
M. A. van Wyk and W.-H. Steeb	
29.1 Introduction	612
29.2 One-Dimensional Maps	612
29.3 Orbits and Their Properties	613
29.4 Hyperbolicity	619
29.5 Stability	621
29.6 Topological Conjugacy	622
29.7 Chaos	624
29.8 Variational Equation and Lyapunov Exponent	627
29.9 Invariant Density and Ergodic Theorem	629
29.10Conclusions	636
Index	639

1



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.

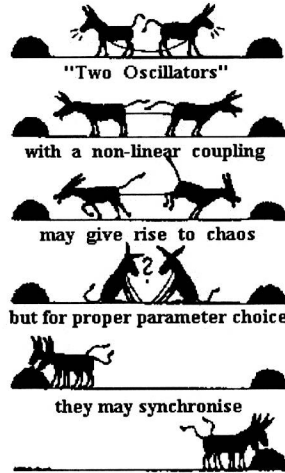


FIGURE 1.1

"COUPLING OF TWO OSCILLATORS" Dansk Standard, Kollegievej 6, DK - 2920 (Acknowledgement: 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