

## CONTENTS

1. PREFACE	v
1. INTRODUCTION	1
1.1 General	1
1.2 Nonlinearity and Chaotic Motions	1
1.3 Dissipative and Conservative Nonlinear Systems	3
1.4 Bifurcations and Chaos-Controlling and Synchronization	4
2. LINEAR AND NONLINEAR OSCILLATORS	5
2.1 Linear Oscillators and Predictability	5
2.1.1 Free Oscillations	6
2.1.2 Damped Oscillations	6
2.1.3 Damped and Forced Oscillations: Resonance	9
2.2 Damped and Driven Nonlinear Oscillators	10
2.2.1 Free Oscillations	10
2.2.2 Damped Oscillations	11
2.2.3 Forced Oscillations-Primary Resonance and Jump Phenomenon (Hysteresis)	13
2.2.4 Secondary Resonances (Subharmonic and Superharmonic)	14
2.3 Nonlinear Oscillations and Bifurcations	14
2.4 Dynamical Systems and Chaos	16
2.5 Routes to Chaos	18
3. ELECTRONIC CIRCUITS AS OSCILLATORS AND ANALOG SIMULATION OF DYNAMICAL SYSTEMS	21
3.1 Linear and Nonlinear Circuit Elements	22
3.2 Linear Circuits	25
3.3 Nonlinear Circuits: Asymptotic Behaviour	29
3.4 Simplest Circuits with a Nonlinear Resistor (Chua's Diode)	30
3.5 Analog Circuit Simulations of Nonlinear Odes	32

4. DUFFING OSCILLATOR: BIFURCATION AND CHAOS	35
4.1 Scaling Property and Three-dimensional Control Parameter Space	36
4.2 The Double-well Oscillator	37
4.2.1 Period-doubling Scenario in $f$ -space	39
4.2.2 Phase Diagram in $(f-\omega)$ Space	48
4.3 Single-well Duffing Oscillator	53
4.4 Double-hump Potential	60
4.5 Analog Simulation and Experimental Verification	62
5. DUFFING OSCILLATOR: ANALYTIC APPROACHES	67
5.1 Theoretical Analysis of Large-orbit T-periodic Solution for the Double-well Duffing Oscillator	68
5.1.1 Multiple Scale Method and Perturbative Solution for LO	69
5.1.2 Stability of LO Solution	71
5.2 SO Motion in the Double-well Duffing Oscillator and Its Theoretical Analysis	74
5.3 The Melnikov Criterion	78
5.4 Analytic Structure of the Duffing Oscillator	80
5.4.1 Movable Singularities and Nonlinear Dynamical Systems	80
5.4.2 Singularity Clustering in the Duffing Oscillator	82
6. BIFURCATION, CHAOS AND PHASE-LOCKING IN BVP AND DVP OSCILLATORS	91
6.1 The Bonhoeffer-van der Pol Oscillator	91
6.1.1 Bifurcations, Chaos and Phase-locking in the BVP Oscillator	93
6.1.2 Mode-locking and Complete Devil's Staircase Structures	101
6.2 Duffing-van der Pol Oscillator	104
6.3 Analytic Structure of the DVP Oscillator	118
6.3.1 Singularity Analysis of the DVP Equation	119
6.3.2 Infinite-Sheeted Solution(ISS) Structure	120
7. CHAOTIC OSCILLATORS WITH CHUA'S DIODE	127
7.1 Chua's Diode and Its Characteristics	127
7.2 Simple Practical Implementation of Chua's Diode	129
7.3 Autonomous Circuits with Chua's Diode	131
7.3.1 A. Chua's Autonomous Circuit	131
B. Bifurcations and Chaos: R Bifurcation Sequence	133
7.3.2 Chua's Autonomous Oscillator	135
7.4 Non-autonomous Circuits with Chua's Diode	139
7.4.1 Simplified Driven Chua's Circuit	139

7.4.2	Fourth-order Driven Chua's Circuit	142
7.5	Chaotic Dynamics of the Simplest Dissipative Non-Autonomous Circuit: Murali-Lakshmanan-Chua(MLC) Circuit	161
7.5.1	Experimental Realization	162
7.5.2	Stability Analysis	163
7.5.3	Explicit Analytical Solutions	164
7.5.4	Experimental and Numerical Studies	165
7.5.5	Chua's Diode with Single Break-point and Spiral Chua's Attractor	172
7.6	Chaotic Dynamics of the Autonomous van der Pol-Duffing (ADVP) Oscillator	175
7.6.1	Special Cases	177
7.6.2	Third-order Autonomous DVP (ADVP) Oscillator	179
8.	CONTROLLING OF CHAOS	183
8.1	Algorithm for Controlling of Chaos: Feedback and Non-feedback Methods	183
8.1.1	Feedback Controlling Algorithms	184
8.1.2	Non-feedback Methods	185
8.2	Controlling in the BVP Oscillator	187
8.2.1	Adaptive Control Algorithm (ACA) to the BVP Oscillator	188
8.2.2	Suppression of Chaos by Parametric Perturbation	193
8.2.3	Effect of Second Periodic Force	197
8.2.4	Stabilization of Unstable Periodic Orbits	199
8.2.5	Controlling of Chaos by Noise	205
8.3	Controlling in Other Oscillators	209
8.3.1	Controlling of Chaos in Chua's Circuit	209
8.3.2	Controlling of Chaos in Driven Chua's Circuit: Experimental Results	215
8.3.3	Controlling of Chaos in Duffing Oscillator and MLC Circuit	220
9.	SYNCHRONIZED CHAOTIC SYSTEMS AND SECURE COMMUNICATION	235
9.1	Pecora and Carroll Method	236
9.1.1	Drive-response Concept	237
9.1.2	Chaos Synchronization in Chua's Circuit	239
9.1.3	The Synchronized ADVP Oscillator	242
9.1.4	Asymptotic Stability and Lyapunov Function	245
9.1.5	Cascading Synchronized Systems	246

9.2 Method of One-way Coupling	248
9.3 Secure Transmission of Signals by Synchronized Chaotic Systems	256
9.4 Chaotic Signal Masking and Transmission of Analog Signals	257
9.4.1 Signal Transmission Through Cascading Synchronization	258
9.4.2 Method of One-way Coupling	265
9.5 Chaotic Switching and Digital Signal Communication	272
9.6 Recent Developments in Synchronization of Chaos	275
Appendix A: PERTURBATION AND RELATED APPROXIMATION METHODS	285
Appendix B: VAN DER POL OSCILLATOR AND CHAOS	289
Appendix C: SOME FURTHER UBIQUITOUS CHAOTIC OSCILLATORS	295
GLOSSARY	303
REFERENCES	309
INDEX	319