

Contents

1 Introduction	1
1.1 Review of Basic Linear Circuit Elements	1
1.1.1 Resistor	1
1.1.2 Capacitor	2
1.1.3 Inductor	3
1.1.4 Fractional-Order Elements	4
1.2 Memristor	7
1.3 Historical Background of the Mem-Element	8
1.4 Organization of the Book	10
References	11
2 Memristor: Models, Types, and Applications	13
2.1 The Missing Element History	13
2.2 HP Memristor	14
2.3 Basic Memristor Fingerprints	16
2.4 Memristor Models	16
2.4.1 Linear Ion Drift Model	16
2.4.2 Nonlinear Ion Drift Model	18
2.4.3 Simmons Tunnel Barrier Model	18
2.4.4 Threshold Adaptive Memristor Model	19
2.4.5 Window Functions	19
2.5 Mathematical Modeling of HP Memristor	23
2.6 Mathematical Representations of Time-Invariant Memristor	27
2.6.1 Extended Memristor	27
2.6.2 Generic Memristor	29
2.6.3 Ideal Memristor	29
2.7 Memristor Implementation Types	32
2.8 Memristor-Based Applications	34
2.8.1 Analog Circuits	34
2.8.2 Neuromorphic Circuits	40

2.8.3	Chaotic System	40
2.8.4	Digital Applications	43
References	46
3	Memristor Mathematical Models and Emulators	51
3.1	Continuous Symmetrical Model	52
3.1.1	Current-Controlled Memristor	53
3.1.2	Voltage-Controlled Memristor	53
3.1.3	Circuit Emulators	55
3.2	Continuous Nonsymmetrical Model	57
3.2.1	Experimental Results	59
3.3	Switching Model	61
3.4	Fractional-Order Model.	63
3.4.1	Fractional-Order Elements Relations.	63
3.4.2	Fractional-Order Memristor Model.	64
3.4.3	Step Input Voltage.	65
3.4.4	Sinusoidal Input.	67
3.5	Memristor Emulation Circuits for Analog Applications.	69
3.5.1	Simple COTS Realization of Floating Memristor	69
3.5.2	MOS Realization of Memristor Emulator	75
References	83
4	Memristor-Based Relaxation Oscillator Circuits.	85
4.1	Introduction.	85
4.2	Voltage Controlled Oscillators	86
4.2.1	R-M Relaxation Oscillator.	87
4.2.2	M-R Based Oscillator.	92
4.2.3	Memristor-Based VCO	96
4.2.4	Discussion and Comparison	97
4.3	Effect of Boundary on R-M Oscillator	98
4.3.1	Mathematical Analysis	98
4.3.2	Discussion and Comparison	101
4.4	Two-Series Memristors Analysis	102
4.5	Symmetric Memristive Two-Gate Oscillator	107
4.5.1	Oscillation Concept	107
4.5.2	Mathematical Analysis	108
4.5.3	Circuit Validation	111
4.6	Asymmetric Memristive Two-Gate Oscillator.	112
4.6.1	Mathematical Analysis	113
4.6.2	Discussion and Comparison	114
4.7	Power Consumption of Two Series Memristors	115
References	119

5	Memristor-Based Multilevel Digital Systems	121
5.1	Number Systems	121
5.1.1	The Conventional Number Systems	121
5.1.2	Redundant Number Systems	125
5.2	Addition and Subtraction Circuits	126
5.2.1	Ripple-Carry Adder (RCA)	126
5.2.2	Carry-Lookahead Adder (CLA)	127
5.2.3	Carry-Select Adder	127
5.2.4	Carry-Skip Adder	128
5.3	Memristor-Based Digital Circuits	129
5.3.1	Memristor Quantization	129
5.3.2	One Memristor One Transistor Circuit	131
5.3.3	Doublet Generator Circuit	131
5.4	Memristor-Based Adder/Subtraction Circuits	133
5.4.1	Memristor-Based Ternary Half Adder Circuit	133
5.4.2	Memristor-Based Redundant Half Adder Circuit	136
5.4.3	N-Bits CSD Redundant Binary Adder	141
5.5	Memristor-Based Redundant Multiplier	143
5.5.1	CMOS Architecture	143
5.5.2	Memristor-Based Digital Circuit	144
5.5.3	Redundant Multiplier	145
	References	150
6	Memcapacitor: Modeling, Analysis, and Emulators	151
6.1	Introduction	151
6.1.1	Memcapacitive Systems	151
6.1.2	Mathematical Representations of Time-Invariant Memcapacitor	155
6.1.3	Physical Realizations	157
6.1.4	First-Order Memcapacitor Model	158
6.2	Mathematical Modeling of Memcapacitor	159
6.3	Boundary Dynamics of Memcapacitor	161
6.4	Memcapacitor Response Under Voltage Excitations	164
6.4.1	Step Response	164
6.4.2	Sinusoidal Response	167
6.4.3	General Periodic Excitation Response	170
6.5	Detailed Analysis of Two Series Memcapacitors	172
6.5.1	Mathematical Analysis	172
6.5.2	Practical Cases	174
6.5.3	Circuit Simulation and Validation	175
6.6	Detailed Analysis of Two Parallel Memcapacitors	177
6.6.1	Mathematical Analysis	177
6.6.2	Circuit Simulation and Validation	178

- 6.7 General Analysis of Series and Parallel Memcapacitors. 179
 - 6.7.1 Series Memcapacitors. 179
 - 6.7.2 Parallel Memcapacitors. 180
- 6.8 Charge-Controlled Memristor-Less Memcapacitor Emulator. 182
- References 185

- 7 Memcapacitor Based Applications. 187**
 - 7.1 Introduction. 187
 - 7.2 Resistive-Less Memcapacitor-Based Oscillator. 188
 - 7.2.1 Mathematical Analysis 189
 - 7.2.2 Special Cases 191
 - 7.2.3 Simulation Verification 193
 - 7.2.4 Stored Energy 194
 - 7.3 Boundary Effect on Memcapacitor-Based Oscillator 195
 - 7.3.1 C-MC Oscillator Configuration 195
 - 7.3.2 MC-C Oscillator Configuration 196
 - 7.3.3 Results and Discussion 196
 - 7.4 Memcapacitor Bridge Synapses 198
 - 7.4.1 Mathematical Analysis of Memcapacitor Bridge. 200
 - 7.4.2 Weight Programming 202
 - 7.4.3 SPICE Validation. 203
- References 205

- 8 Meminductor: Modeling, Analysis, and Emulators. 207**
 - 8.1 Introduction. 207
 - 8.2 Mathematical Representations of Time-Invariant Meminductor. 209
 - 8.2.1 Extended Meminductor. 209
 - 8.2.2 Generic Meminductor. 210
 - 8.2.3 Ideal Meminductor. 210
 - 8.3 Mathematical Model of Meminductor. 211
 - 8.4 Meminductor Response Under Current Excitations. 212
 - 8.4.1 Step Response. 212
 - 8.4.2 Sinusoidal Response. 214
 - 8.4.3 Periodic Signals Response. 216
 - 8.5 Memristor-Based Meminductor Emulator 218
 - 8.6 Memristor-Less Meminductor Emulators 221
 - 8.6.1 Circuit Realization of Meminductor Emulator 224
 - 8.6.2 Circuit Validation 225
- References 226

- Appendix A: Memristor, Memcapacitor, and Meminductor. 229**



<http://www.springer.com/978-3-319-17490-7>

On the Mathematical Modeling of Memristor,
Memcapacitor, and Meminductor

Radwan, A.G.; Fouda, M.E.

2015, XX, 231 p. 188 illus., 29 illus. in color., Hardcover

ISBN: 978-3-319-17490-7