

Contents

Preface	xiii
Acknowledgments	xvii
1 Wireless Systems—A Circuits Perspective	1
1.1 Introduction	1
1.2 Spheres of Wireless Activity—Technical Issues	3
1.2.1 The Home and the Office	5
1.2.2 The Ground Fixed/Mobile Platform	7
1.2.3 The Space Platform	7
1.3 Wireless Standards, Systems, and Architectures	8
1.3.1 Wireless Standards	8
1.3.2 Conceptual Wireless Systems	8
1.3.3 Wireless Transceiver Architectures	10
1.4 Power- and Bandwidth-Efficient Wireless Systems—Challenges	12

1.5	MEMS-Based Wireless Appliances Enable Ubiquitous Connectivity	15
1.6	Summary	16
	References	17
2	<u>Elements of RF Circuit Design</u>	19
2.1	Introduction	19
2.2	Physical Aspects of RF Circuit Design	19
2.2.1	Skin Effect	20
2.2.2	Transmission Lines on Thin Substrates	23
2.2.3	Self-Resonance Frequency	33
2.2.4	Quality Factor	35
2.2.5	Moding (Packaging)	39
2.3	Practical Aspects of RF Circuit Design	40
2.3.1	dc Biasing	40
2.3.2	Impedance Mismatch Effects in RF MEMS	41
2.4	Problems	43
2.5	Summary	47
	References	48
3	<u>RF MEMS-Enabled Circuit Elements and Models</u>	51
3.1	Introduction	51
3.2	RF/Microwave Substrate Properties	52
3.3	Micromachined-Enhanced Elements	55
3.3.1	Capacitors	55
3.3.2	Inductors	57
3.3.3	Varactors	67
3.4	MEM Switches	75
3.4.1	Shunt MEM Switch	75
3.4.2	Low-Voltage Hinged MEM Switch Approaches	78

3.4.3	Push-Pull Series Switch	80
3.4.4	Folded-Beam-Springs Suspension Series Switch	83
3.5	Resonators	87
3.5.1	Transmission Line Planar Resonators	87
3.5.2	Cavity Resonators	87
3.5.3	Micromechanical Resonators	88
3.5.4	Film Bulk Acoustic Wave Resonators	98
3.6	MEMS Modeling	104
3.6.1	MEMS Mechanical Modeling	105
3.6.2	MEMS Electromagnetic Modeling	106
3.7	Summary	109
	References	109

4 Novel RF MEMS–Enabled Circuits 115

4.1	Introduction	115
4.2	Reconfigurable Circuit Elements	116
4.2.1	The Resonant MEMS Switch	116
4.2.2	Capacitors	118
4.2.3	Inductors	121
4.2.4	Tunable CPW Resonator	123
4.2.5	MEMS Microswitch Arrays	124
4.3	Reconfigurable Circuits	126
4.3.1	Double-Stub Tuner	127
4.3.2	<i>N</i> th-Stub Tuner	130
4.3.3	Filters	132
4.3.4	Resonator Tuning System	133
4.3.5	Massively Parallel Switchable RF Front Ends	136
4.3.6	True Time-Delay Digital Phase Shifters	137
4.4	Reconfigurable Antennas	139
4.4.1	Tunable Dipole Antennas	139
4.4.2	Tunable Microstrip Patch-Array Antennas	140

4.5	Summary	141
	References	142
5	RF MEMS-Based Circuit Design—Case Studies	145
5.1	Introduction	145
5.2	Phase Shifters	146
5.2.1	Phase Shifter Fundamentals	146
5.2.2	X-Band RF MEMS Phase Shifter for Phased Array Applications—Case Study	151
5.2.3	Ka-Band RF MEMS Phase Shifter for Phased Array Applications—Case Study	155
5.2.4	Ka-Band RF MEMS Phase Shifter for Radar Systems Applications—Case Study	159
5.3	Film Bulk Acoustic Wave Filters	163
5.3.1	FBAR Filter Fundamentals	163
5.3.2	FBAR Filter for PCS Applications—Case Study	165
5.4	RF MEMS Filters	167
5.4.1	A Ka-Band Millimeter-Wave Micromachined Tunable Filter—Case Study	167
5.4.2	A High-Q 8-MHz MEM Resonator Filter—Case Study	171
5.5	RF MEMS Oscillators	183
5.5.1	RF MEMS Oscillator Fundamentals	184
5.5.2	A 14-MHz MEM Oscillator—Case Study	187
5.5.3	A Ka-Band Micromachined Cavity Oscillator—Case Study	191
5.5.4	A 2.4-GHz MEMS-Based Voltage-Controlled Oscillator—Case Study	194
5.6	Summary	201
	References	201

Appendix A:		
GSM Radio Transmission and Reception		
Specifications		205
A.1	Output Power	206
A.1.1	Mobile Station	206
A.1.2	Base Station	211
A.2	Output RF Spectrum	213
A.2.1	Spectrum Due to Modulation and Wideband Noise	214
A.2.2	Spectrum Due to Switching Transients	221
A.3	Spurious Emissions	222
A.3.1	Principle of the Specification	223
A.3.2	Base Transceiver Station	224
A.3.3	Mobile Station	227
A.4	Radio Frequency Tolerance	229
A.5	Output Level Dynamic Operation	229
A.5.1	Base Transceiver Station	230
A.5.2	Mobile Station	230
A.6	Modulation Accuracy	231
A.6.1	GMSK Modulation	231
A.6.2	8-PSK Modulation	231
A.7	Intermodulation Attenuation	233
A.7.1	Base Transceiver Station	234
A.7.2	Intra BTS Intermodulation Attenuation	234
A.7.3	Intermodulation Between MS (DCS 1800 & PCS 1900 Only)	235
A.7.4	Mobile PBX (GSM 900 Only)	235
A.8	Receiver Characteristics	236
A.8.1	Blocking Characteristics	236
A.8.2	AM Suppression Characteristics	241

A.8.3	Intermodulation Characteristics	242
A.8.4	Spurious Emissions	243
List of Acronyms		245
About the Author		249
Index		251