

# Contents

Contributors .....	xiii
About the Editors.....	xv
Foreword by Charles F. Campbell.....	xvii
Foreword by Ramesh K. Gupta.....	xix
Preface .....	xxi

## **CHAPTER 1 Microwave Transistor Modeling ..... 1**

1.1 Introduction.....	1
1.2 Microwave Transistor Technologies.....	2
1.3 Transistor Modeling.....	7
1.4 Small-Signal Modeling.....	9
1.5 Noise Modeling .....	18
1.6 Large-Signal Modeling.....	20
Acknowledgments .....	34
References.....	34

## **CHAPTER 2 Radio Frequency and Microwave Linear and Nonlinear Characterization ..... 41**

2.1 Introduction.....	41
2.2 The Scattering Parameters.....	42
2.3 Scattering Parameter Measurements .....	44
2.4 Two-Port VNAs.....	46
2.5 Downconversion Techniques.....	47
2.6 Two-Port VNA Calibration .....	49
2.7 Load- and Source-Pull Characterization .....	51
2.7.1 Scalar Systems.....	52
2.7.2 Vectorial Systems .....	54
2.8 System-Level Characterization .....	55
2.8.1 Measurement System Synchronization .....	57
References.....	60

## **CHAPTER 3 Nonlinear Analysis and Design of Oscillator Circuits ..... 65**

3.1 Introduction.....	66
3.2 Basic Concepts in Oscillator Circuits .....	66
3.2.1 Oscillation Mechanism: Start-Up and Steady-State .....	66
3.2.2 Invariance Versus Phase Shifts .....	76

	3.2.3 Impact of the Harmonic Content.....	77
	3.2.4 Phase-Space Representation.....	79
<b>3.3</b>	Negative Resistance Through Gain and Feedback.....	81
<b>3.4</b>	General Stability Analysis of Oscillator Circuits.....	85
	3.4.1 Stability of the <i>dc</i> Solution.....	85
	3.4.2 Stability of the Periodic Oscillation.....	87
	3.4.3 Approximate Stability Analysis of the Periodic Solution.....	89
<b>3.5</b>	Initial Linear Design to Fulfill the Oscillation Start-Up Conditions.....	94
<b>3.6</b>	Oscillator Design With Harmonic-Balance Simulations.....	99
	3.6.1 Harmonic Balance.....	99
	3.6.2 Use of an Auxiliary Generator for Oscillator Analysis and Synthesis.....	101
<b>3.7</b>	Stability Analysis.....	106
	3.7.1 Local Stability Analysis.....	106
	3.7.2 Bifurcations.....	109
<b>3.8</b>	Phase Noise.....	113
	3.8.1 Frequency-Domain Techniques.....	114
	3.8.2 Phase-Noise Dynamics.....	114
	3.8.3 Conversion Matrix Approach.....	116
	3.8.4 Carrier-Modulation Approach.....	118
	3.8.5 Near Carrier Spectrum Due to Phase Noise.....	120
	3.8.6 Application Example.....	120
<b>3.9</b>	Reduced-Order Models for Oscillator Circuits.....	121
	3.9.1 Inner Level.....	122
	3.9.2 Outer Level.....	124
<b>3.10</b>	Phase-Locked Loops.....	125
	3.10.1 VCO Formulation.....	127
	3.10.2 PLL Formulation.....	128
	3.10.3 Application Example.....	129
	References.....	130
<b>CHAPTER 4</b>	<b>Microwave Power Amplifiers: Design and Technology.....</b>	<b>135</b>
<b>4.1</b>	Introduction.....	135
<b>4.2</b>	Device Characteristics and Power Match Condition.....	136
<b>4.3</b>	Power Amplifier Figure of Merits.....	143
<b>4.4</b>	Design Strategies for High-Efficiency PAs.....	151
	4.4.1 Tuned Load.....	162
	4.4.2 Ideal Class F or Inverse Class F (Class $F^{-1}$ ).....	163
	4.4.3 Ideal Class E.....	164
	4.4.4 High-Frequency HT Approaches.....	165

4.5	Technologies for PAs Realization.....	168
4.5.1	Semiconductor Technologies for PAs.....	169
4.5.2	Hybrid Microwave PAs.....	171
4.5.3	Microwave Monolithic PAs .....	174
4.6	Linearity Issues.....	177
4.6.1	Systems Classification (Memoryless vs. Memory PA).....	178
4.6.2	Influence of Bias Point.....	181
4.6.3	Influence of Harmonic Loadings .....	182
4.7	PA Solutions for Communication Systems: The Doherty Example .....	184
4.8	Analysis Issues.....	190
	References.....	193
<b>CHAPTER 5</b>	<b>Technology Design Interaction: System Driven Technology Choices .....</b>	<b>209</b>
5.1	Introduction.....	209
5.1.1	System Architecture Selection .....	210
5.1.2	Battery Voltage Considerations.....	212
5.1.3	Mid- and Low-Power Efficiency Considerations .....	215
5.1.4	Considerations for Average Power Tracking and ET.....	218
5.1.5	Multimode, Multiband PAs .....	219
5.1.6	Wireless LAN Amplifiers .....	223
5.2	Technology Selection and Characterization .....	224
5.2.1	How Do We Pick a Technology? .....	225
5.2.2	Overall Process Features .....	227
5.2.3	Passive and Active Device Concerns.....	229
5.2.4	Device Characterization for Process Selection.....	234
5.3	Figure of Merit, Yield, and Cost.....	249
5.4	Circuit Level Design .....	250
5.4.1	Getting Started and Floor Planning.....	250
5.4.2	Packaging and System Level Impacts.....	252
5.5	Large-Signal Modeling and Validation at the Circuit Level .....	253
	Acknowledgments .....	254
	References.....	254
<b>CHAPTER 6</b>	<b>Radio Frequency Power Amplifier for Wireless Communication .....</b>	<b>261</b>
6.1	Introduction.....	261
6.2	PA Specification.....	262
6.2.1	PA Output .....	262
6.2.2	Efficiency.....	263

6.2.3	Linearity.....	264
6.2.4	Video Bandwidth.....	265
<b>6.3</b>	<b>PA Topologies for Wireless Communication .....</b>	<b>265</b>
6.3.1	Doherty PA .....	266
6.3.2	ET PA .....	273
6.3.3	LINC PA.....	279
<b>6.4</b>	<b>Transistor Technology for PA Design .....</b>	<b>286</b>
6.4.1	Silicon CMOS Technologies.....	286
6.4.2	The GaAs HBT.....	287
6.4.3	The GaN High Electron-Mobility Transistor.....	288
<b>6.5</b>	<b>Broadband and Multiband PA.....</b>	<b>290</b>
6.5.1	Broadband PA Design .....	291
6.5.2	Multiband PA Design .....	294
	References.....	299
<b>CHAPTER 7</b>	<b>Nonlinear Applications at the Transmitter System Level .....</b>	<b>301</b>
7.1	Introduction.....	301
7.2	Power Dissipation Versus Linearity.....	302
7.2.1	Power Along the Characteristic Curves.....	303
7.2.2	Knee Voltage Profiles .....	305
7.2.3	Load Line Selection for Efficiency.....	307
7.2.4	Variable Power Supply Option .....	308
7.3	PA Operating Modes With a Variable Supply Voltage .....	309
7.3.1	Booth Chart Fundamentals.....	309
7.3.2	L-Mode Operation .....	310
7.3.3	C-Mode Operation.....	311
7.3.4	P-Mode Operation .....	313
7.4	Signal Linearity and Accuracy Requirements .....	314
7.5	DPS Transmitter Principles .....	315
7.5.1	ET: L-Mode Only .....	315
7.5.2	DPS Characterization .....	321
7.5.3	Polar Modulation: C-Mode and P-Mode Only .....	323
7.5.4	Transistor Types With Best Performance .....	329
	References.....	332
<b>CHAPTER 8</b>	<b>System-Level Nonideality Characterization for Compensation .....</b>	<b>333</b>
8.1	Introduction.....	333
8.2	Baseband Characterization and Modeling .....	334

<b>8.3</b>	System-Level Nonideality .....	335
	8.3.1 Nonlinearity .....	335
	8.3.2 Memory Effects .....	339
	8.3.3 IQ Imbalance .....	341
<b>8.4</b>	Characterization Approaches.....	342
	8.4.1 Memoryless Characterization .....	342
	8.4.2 Quasimemoryless Characterization .....	342
	8.4.3 Characterization With Volterra Models .....	345
	8.4.4 Characterization With Various Excitations.....	349
	8.4.5 Characterization With X-Parameters .....	350
<b>8.5</b>	Characterization With Offset Multisine Excitation .....	352
	8.5.1 Theory of Multisine Offsetting .....	353
	8.5.2 Spectrum Plots With Offset Multisine Excitation .....	356
	8.5.3 IM3 Profile.....	360
	8.5.4 Focused Application: Memory Effects Characterization .....	362
<b>8.6</b>	Characterization and Modeling of Transmitter Emission Into Receive Band .....	364
	8.6.1 Measuring the Deterministic Components of RxBN.....	366
	8.6.2 Identification of Nonlinearity Orders.....	369
	8.6.3 Modeling of Deterministic RxBN .....	372
<b>8.7</b>	From Characterization to System-Level Compensation .....	374
	References.....	376
	Index .....	381