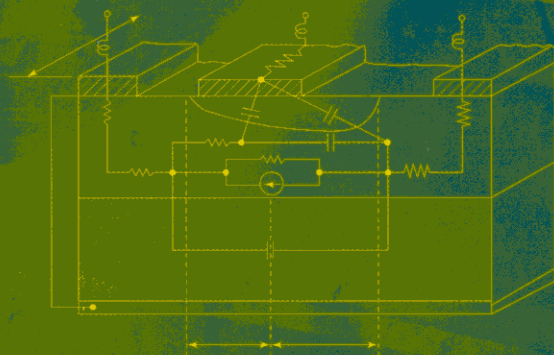


RF and Microwave Circuit and Component Design for Wireless Systems



KAI CHANG, INDER BAHL, and VIJAY NAIR

Wiley Series in Microwave and Optical Engineering • Kai Chang, Series Editor

Contents

Preface	xvii
1 Introduction	1
1.1 Objectives and Brief History	1
1.2 Frequency Spectra and Atmospheric Propagation Loss	4
1.3 Wireless Applications	5
1.4 Organization of This Book	6
References	7
2 General Wireless Systems	9
2.1 Introduction	9
2.2 Wireless System Frequency Allocations	10
2.2.1 Cellular Radio Systems	10
2.2.2 Cordless Telephony	11
2.2.3 Mobile Satellite Systems	13
2.3 Cellular Systems in the United States, Europe, and Japan	13
2.3.1 Analog Cellular Systems	13
2.3.2 Digital Cellular Systems	14
2.3.3 Code Division Multiple Access Systems	17
2.4 Cordless Telephony	19
2.4.1 Analog Cordless Phones	19
2.4.2 Digital Cordless Telephones	20
2.4.3 WACS/PACS	21
2.4.4 DCS 1800	22
2.5 Wireless LAN Systems	22

2.6 Satellite Communication Systems	23
2.6.1 Iridium System	24
2.6.2 Globalstar System	26
2.6.3 ICO-P System	27
2.7 Future Wireless Systems	29
2.7.1 Bluetooth Systems	29
2.7.2 PCN/PCS Systems	31
2.7.3 Third Generation Cellular Systems	33
2.7.4 MMDS/LMDS	33
References	35
3 Overview of Active Devices and Circuit Technologies	37
3.1 Active Device Types	37
3.2 Circuit Types and Their Fabrication	42
3.3 Active Device Operation	43
3.3.1 Si Bipolar Transistor	43
3.3.2 GaAs MESFET	49
3.3.3 Heterojunction Field-Effect Transistors	55
3.3.4 Heterojunction Bipolar Transistors	61
3.3.5 Future Trend	70
3.4 Circuit Manufacturing Technologies	70
3.4.1 Printed Circuit Board	72
3.4.2 Hybrid Integrated Circuit	73
3.4.3 Monolithic Integrated Circuit	78
3.4.4 Multichip Modules	81
3.4.5 Technology Comparison and Choices	81
References	83
4 Transmitter and Receiver System Parameters	87
4.1 Introduction	87
4.2 Receiver System Considerations	87
4.2.1 Natural Sources of Receiver Noise	89
4.2.2 Receiver Noise Figure	91
4.2.3 Equivalent Noise Temperature	93
4.2.4 Dynamic Range, 1dB Compression Point, and Minimum Detectable Signal	93
4.2.5 Third-Order Intercept Point and Intermodulation Products	95

4.3 Transmitter System Considerations	99
4.3.1 Transmitter Noise	100
4.3.2 Adjacent Channel Power Ratio	102
References	103
5 Transmission Lines and Impedance Matching Techniques	105
5.1 Introduction	105
5.2 Transmission Line Equation	106
5.3 Reflection, Transmission, and Impedance	110
5.4 Voltage Standing-Wave Ratio	112
5.5 Smith Charts	116
5.6 <i>S</i> -Parameters	122
5.7 Wires and Twin Lines	124
5.8 Coaxial Lines	125
5.9 Microstrip Lines	128
5.9.1 Analysis Formulas	130
5.9.2 Synthesis Formulas	130
5.9.3 Effects of Strip Thickness	131
5.9.4 Effects of Enclosure or Shield	132
5.9.5 Graphical Method	132
5.9.6 Effects of Dispersion	132
5.9.7 Losses	135
5.10 Other Planar Transmission Lines	136
5.10.1 Striplines	136
5.10.2 Coplanar Waveguides and Coplanar Striplines	138
5.10.3 Slotlines	139
5.11 Waveguides	141
5.11.1 TE Modes	144
5.11.2 TE_{10} Mode	145
5.11.3 TM Modes	146
5.12 Lumped Elements	146
5.12.1 Lumped Resistors	147
5.12.2 Lumped Capacitors	149
5.12.3 Lumped Inductors	151
5.13 Impedance Matching Networks	154
5.13.1 Matching Stubs	155
5.13.2 Single-Section Quarter-Wavelength Transformer	155
5.13.3 Lumped Elements	156

5.13.4 Multisection Quarter-Wavelength Transformers	159
5.13.5 Tapered Transformers	162
5.14 Discontinuities	164
References	169
6 Filters and Couplers	171
6.1 Filters	171
6.1.1 Filter Parameter Definition	171
6.1.2 Types of Filters	174
6.1.3 Requirements for Wireless Applications	174
6.2 Filter Synthesis	174
6.2.1 Traditional Filter Design Approach	175
6.2.2 Solutions to Low-Pass Prototype Design	176
6.2.3 Filter Design From Prototype Low-Pass Filter	180
6.2.4 Bandpass Filter Design Using Coupling Coefficients	184
6.3 Filter Realizations	185
6.3.1 Lumped Element Filters	186
6.3.2 Coaxial Filters	186
6.3.3 Microstrip Line Filters	190
6.3.4 SAW Filters	193
6.4 Couplers	196
6.4.1 Coupler Parameter Definition	197
6.4.2 Coupler Requirements for Wireless Applications	198
6.5 Design of Couplers	199
6.5.1 90° Hybrid	199
6.5.2 Rat-Race Hybrid	203
6.5.3 Coupled Line Directional Couplers	206
6.5.4 Other Couplers	211
References	215
7 Switches	221
7.1 Introduction	221
7.1.1 Switch Parameter Definitions	221
7.1.2 Devices for Switches	222

7.1.3 Basic Requirements of a Switch for Wireless Applications	229
7.2 Design of Switches	229
7.2.1 Device Models	229
7.2.2 Types of Switches	234
7.2.3 Switch Configurations	237
7.2.4 Basic Theory of Switches	240
7.3 Multiport Switches	243
7.3.1 Multithrow Switches	243
7.3.2 Matrix Switches	243
7.3.3 Diversity Switch	244
7.4 High Isolation Switches	245
7.5 Broadband Switches	248
7.6 High Power Switches	250
7.6.1 Impedance Transformation Technique	253
7.6.2 Stacked FETs Method	254
7.6.3 Resonant Circuit Technique	255
7.6.4 Power Handling of PIN Diode Switches	258
7.7 Low Distortion Switches	259
7.8 Switching Speed	262
7.9 Biasing of Switching Devices	263
7.9.1 Biasing of PIN Diodes	263
7.9.2 Biasing of FETs	265
7.9.3 Single Positive Power Supply Operation	265
7.9.4 Switches With Integrated Control	266
References	267
8 Low-Noise Amplifiers	271
8.1 Introduction	271
8.2 Two-Port Description of a Device	271
8.2.1 Noise Modeling	272
8.2.2 Low-Noise Behavior of BJTs and MESFETs	275
8.3 Circuit Design Considerations	279
8.4 Amplifier Power Gain	279
8.4.1 Transducer Power Gain	280
8.5 Amplifier Stability	283
8.5.1 Stability Circles	283

8.5.2 Constant Gain Circles	287
8.5.3 Constant Noise Figure Circles	290
8.6 Small Signal Amplifier Design Procedure	292
8.7 Narrow Band Amplifiers	293
8.7.1 Maximum Power Gain Design	293
8.7.2 Low-Noise Amplifier Design	294
8.8 Low-Noise Amplifiers for Wireless Applications	295
8.8.1 Silicon Low-Power LNAs	297
8.8.2 GaAs Low-Power LNAs	301
8.8.3 HBT Low-Noise Amplifiers	308
References	310
9 Mixers	313
9.1 Introduction	313
9.2 Mixer Fundamentals	313
9.3 Down Converting and Up Converting Mixers	314
9.4 System Considerations	315
9.5 Devices for Mixers	317
9.5.1 Diode Mixer Theory and Operation	317
9.5.2 FET Mixer Theory and Operation	322
9.5.3 Dual-Gate FET (DGFET) Mixer	327
9.6 Mixer Classifications	330
9.6.1 Single-Ended Mixers	330
9.6.2 Balanced Mixers	331
9.6.3 Couplers	332
9.6.4 Single Balanced Mixers (SB Mixers)	339
9.6.5 Double Balanced Mixers (DB Mixers)	341
9.6.6 Image Reject Mixers	344
9.6.7 Gilbert Cell Mixers	346
9.7 Monolithic Low-Power Mixer Examples	347
9.7.1 Introduction	347
9.7.2 Mixer Implementation in Silicon Technologies	347
9.7.3 GaAs MESFET Mixers	352
9.7.4 Mixer Implementation in HEMT	354
9.8 Monolithic Low-Power Downconverters	355
9.8.1 Downconverter Characterization	357
9.8.2 Design Examples	358
References	363

10 Oscillators and Modulation	367
10.1 Introduction	367
10.2 Oscillator Characteristics	367
10.3 General Theory	368
10.4 Oscillators Using Gunn and IMPATT Devices	370
10.5 Small-Signal Design for Transistor Oscillators	375
10.6 Large-Signal Design for Transistor Oscillators	379
10.7 Transistor Oscillator Circuits	379
10.7.1 Feedback Oscillators	379
10.7.2 Reflection-Type Oscillators	381
10.7.3 Stable Dielectric Resonator Oscillators	381
10.8 Voltage-Tunable Transistor Oscillators	384
10.9 Noise In Transistor Oscillators	387
10.10 Crystal Oscillators	390
10.11 Phase-Locked Oscillators	392
10.12 Frequency Synthesizers	393
10.13 Modulation and Demodulation Techniques	394
10.13.1 Analog Modulation and Demodulation	395
10.13.2 Digital Modulation	397
References	402
11 Power Amplifiers	405
11.1 Introduction	405
11.1.1 Amplifier Parameter Definitions	406
11.1.2 Classes of Power Amplifiers	410
11.1.3 Power Amplifier Requirements	413
11.1.4 Device/Circuit Technologies	415
11.2 Device Models — Linear and Nonlinear	415
11.2.1 Linear Model	415
11.2.2 Nonlinear Model	416
11.3 Power Amplifier Design	418
11.3.1 Device Type and Size	418
11.3.2 Device Models and Loadpull Data	419
11.3.3 Design Methodology	422
11.3.4 Matching Networks	424
11.3.5 Biasing Power Amplifiers	425
11.3.6 Fabrication Technology	426
11.3.7 Stability Analysis	427
11.3.8 Thermal Design	433

11.4 Design of Linear Power Amplifiers	434
11.4.1 Predistortion Techniques	435
11.4.2 Linear Amplifier Design Example	435
11.5 High Efficiency Amplifiers	437
11.5.1 Class B Design	437
11.5.2 Class E Design	443
11.5.3 Class F Design	448
11.5.4 Comparison Between Various Classes	452
11.6 Power Combining Techniques	454
11.7 Measurements	458
11.7.1 Loadpull Measurements	458
11.7.2 IP3/IM3	463
11.7.3 ACPR Measurement	465
References	466
12 Antennas	473
12.1 Introduction	473
12.2 Isotropic Radiator, Plane Waves, and Far-Field Region	475
12.3 Antenna Analysis	478
12.4 Antenna Characteristics and Parameters	479
12.4.1 Input VSWR and Input Impedance	479
12.4.2 Bandwidth	480
12.4.3 Power Radiation Patterns	480
12.4.4 Half-Power Beamwidth and Sidelobe Level	481
12.4.5 Directivity, Gain, and Efficiency	481
12.4.6 Polarization and Cross-Polarization Level	483
12.4.7 Effective Area	484
12.4.8 Beam Efficiency	484
12.4.9 Back Radiation	484
12.4.10 Estimation of High-Gain Antennas	484
12.5 Monopole and Dipole Antennas	484
12.5.1 Radiation Patterns and Directivity	486
12.5.2 Input Impedance	487
12.5.3 Whip, Folded, Sleeve, and Inverted Monopoles	488
12.6 Loop Antennas	490
12.7 Horn Antennas	492
12.8 Parabolic Dish Antennas	494
12.9 Microstrip Patch Antennas	496

12.9.1 Patch Antenna Design Using Transmission Line Model	497
12.9.2 Radiation Patterns and Feeding Methods	500
12.10 Other Antennas	504
12.11 Antenna Arrays and Phased Arrays	506
References	511
Index	513