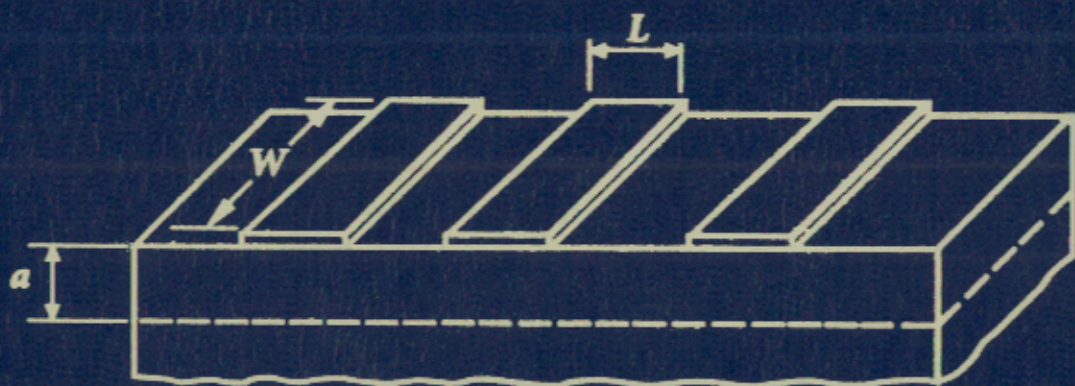


HANDBOOK
OF
RF/MICROWAVE
COMPONENTS
AND
ENGINEERING



EDITED BY
KAI CHANG

CONTENTS

Preface	xv
Contributors	xvii
1. Transmission Lines	1
<i>Inder J. Bahl</i>	
1.1 Basics of Transmission Lines	1
1.2 Characteristics of Conventional Transmission Structures	2
1.3 Characteristics of Planar Transmission Lines	19
1.4 Quasi-Planar Transmission Lines	42
1.5 Coupled Lines	54
References	61
2. Transmission-Line Discontinuities	67
<i>K. C. Gupta</i>	
2.1 Introduction	67
2.2 Coaxial-Line Discontinuities	68
2.3 Rectangular Waveguide Discontinuities	74
2.4 Stripline Discontinuities	97
2.5 Microstrip Discontinuities	103
2.6 Finline Discontinuities	116
2.7 Discontinuities in Other Planar Transmission Structures	120
References	121

3. Filters, Hybrids and Couplers, Power Combiners, and Matching Networks	127
<i>Inder J. Bahl</i>	
3.1 Filters	127
3.2 Hybrids and Couplers	157
3.3 Power Combiners	186
3.4 Impedance-Matching Networks	190
References	201
4. Cavities and Resonators	209
<i>Michael Dydyk</i>	
4.1 Introduction	209
4.2 Basic Definitions	210
4.3 Design of and Coupling to Waveguide-Cavity Resonators	214
4.4 Design of Planar Resonators	226
4.5 Microstrip Dielectric Resonators	238
4.6 Effects of Surface Finish on Quality Factors	252
References	253
Appendix A	255
5. Ferrite Control Components	259
<i>William E. Hord</i>	
5.1 Introduction	259
5.2 Isolators	270
5.3 Circulators	273
5.4 Phase Shifters	279
5.5 Subassemblies Using Ferrite Phase Shifters	289
References	292
6. Surface Acoustic Wave Devices	295
<i>David P. Morgan</i>	
6.1 Introduction	295
6.2 Basic SAW Devices	299
6.3 Propagation Effects and Materials	316
6.4 Nonreflective SAW Transducers	327
6.5 P-Matrix	336
6.6 Internal Reflectivity — Gratings and Transducers	341
6.7 Coupled-Mode Equations	349
6.8 Low-Loss Filters — Nonresonant	353
6.9 Resonators and Resonator Filters	364

6.10	Concluding Remarks	376	
	Acknowledgments	378	
	References	378	
7.	Quasi-Optical Techniques		387
	<i>Paul F. Goldsmith, Tatsuo Itoh, Karl D. Stephan, and Amir Mortazawi</i>		
7.1	Gaussian Beam Propagation	387	
7.2	Quasi-Optical Interfaces to Planar Circuits	397	
7.3	Active Quasi-Optical Devices	400	
7.4	Quasi-Optical/Spatial Power Combining	405	
7.5	Quasi-Optical/Spatial Amplifier Arrays	408	
	References	422	
8.	Components for Surveillance and Electronic Warfare Receivers		427
	<i>James B. Y. Tsui and Charles H. Krueger</i>		
8.1	Introduction	427	
8.2	Basics of EW Receivers [1, 2]	427	
8.3	Superheterodyne Receivers	428	
8.4	Instantaneous Frequency Measurement Receivers	434	
8.5	Introduction to Channelized Receivers [1, 2]	443	
8.6	Compressive Receivers [60–69]	458	
8.7	Bragg Cell Receivers [82–86]	465	
8.8	Cueing Receivers	470	
8.9	Frequency-Selective Limiters [109–112]	473	
8.10	Signal-To-Noise Enhancers	475	
8.11	Digital Electronic Warfare (EW) Receivers [113–118]	476	
8.12	Summary	481	
	References	482	
9.	Antennas I: Fundamentals and Numerical Methods		489
	<i>F. K. Schwering, A. W. Glisson, and M. A. Morgan</i>		
9.1	Fundamentals	489	
	References	507	
9.2	Numerical Techniques	508	
	References	552	
10.	Antennas II: Reflector, Lens, Horn, and Other Microwave Antennas of Conventional Configuration		561
	<i>Donald G. Bodnar, J. J. Lee, G. L. James, F. K. Schwering, and J. W. Mink</i>		
10.1	Reflector Antennas	562	
	References	589	

- 10.2 Lens Antennas 591
References 620
- 10.3 Horn Antennas 622
References 641
- 10.4 Dipole and Monopole Antennas 643
References 671
- 10.5 Other Microwave Antennas 673
References 699

11. Antennas III: Array, Millimeter Wave, and Integrated Antennas 701

Robert J. Mailloux, F. K. Schwering, and A. A. Oliner

- 11.1 Array Antennas 701
References 729 *
- 11.2 Millimeter Wave Antennas 730
References 769

12. Antennas IV: Microstrip Antennas 775

Y. T. Lo, S. M. Wright, J. A. Navarro, and M. Davidovitz

- 12.1 General Introduction 775
- 12.2 Various Theories for Microstrip Antenna Elements 780
- 12.3 Analysis of Infinite Arrays of Microstrip Antenna Elements 806
- 12.4 Applications and Designs 850
References 899

13. Antennas V: Active Integrated Antennas 905

Jonathan D. Fredrick and Tatsuo Itoh

- 13.1 Introduction and History 905
- 13.2 Integrated Antenna Oscillators 906
- 13.3 Coupled Oscillators and Phase Control 909
- 13.4 Amplifying Antennas 911
- 13.5 Signal Processing Arrays 915
References 920

14. Mixers and Detectors 923

Erik L. Kollberg

- 14.1 Introduction 923
- 14.2 Some Common Detector and Mixer Devices 923
- 14.3 Optimization of Diode Detectors 937
- 14.4 Mixers: Simple Theory and Basic Definitions 941

- 14.5 Theoretical Modeling of Schottky Barrier Mixers 949
- 14.6 Single- and Multiple-Diode Mixers 956
- 14.7 Intermodulation in Microwave Mixers 964
- 14.8 Practical Implementation of Microwave Mixers 967
- 14.9 Practical Implementation of Millimeter Wave Schottky Barrier Mixers 973
- 14.10 Submillimeter Wave Schottky Diode Mixers 979
- 14.11 Superconducting Millimeter Wave Mixers 983
- 14.12 Fet Mixers 987
- 14.13 Further Aspects on Microwave and Millimeter Wave Mixers 995
- References 999

15. Multipliers and Parametric Devices **1007**

J. W. Archer and R. A. Batchelor

- 15.1 Introduction 1007
- 15.2 Manley–Rowe Relationships 1008
- 15.3 Practical Nonlinear Reactance Devices 1009
- 15.4 Multiplier Design Using Varactor Diodes 1018
- 15.5 Multipliers Using Step-Recovery Diodes 1035
- 15.6 Parametric Amplifiers and Varactor Frequency Converters 1044
- References 1054

16. Semiconductor Control Devices: PIN Diodes **1059**

Joseph F. White

- 16.1 The PIN Diode— an Extension of the Pn Junction 1059
- 16.2 Microwave Equivalent Circuit 1067
- 16.3 High Rf Power Limits 1090
- References 1095

17. Semiconductor Control Devices: Phase Shifters and Switches **1099**

Ajay I. Sreenivas

- 17.1 Introduction 1099
- 17.2 Loaded-Line Phase Shifters 1099
- 17.3 Reflection Phase Shifter 1109
- 17.4 Switched-Line Phase Shifters 1116
- 17.5 High-Pass/Low-Pass Phase Shifter 1120
- 17.6 Analog Phase Shifters [50–56] 1125
- 17.7 Miscellaneous Considerations 1126
- References 1130

18. Transferred Electron Devices	1135
<i>Cheng Sun</i>	
18.1 Introduction	1135
18.2 Negative Differential Mobility	1136
18.3 Modes of Operation for Oscillators	1139
18.4 Modes of Operation for Amplifiers	1145
18.5 Equal-Area Rule	1146
18.6 Equivalent-Circuit Models	1149
18.7 Oscillator/Amplifier Circuits and Monolithic Device Development	1153
18.8 Power Combining	1163
18.9 Epitaxial Material Growth and Device Fabrication	1166
18.10 Conclusions and Recent Developments	1171
References	1173
19. IMPATT and Related Transit-Time Devices	1179
<i>Kai Chang and H. John Kuno</i>	
19.1 Introduction	1179
19.2 Device Physics and Modeling	1180
19.3 Device Design and Fabrication	1191
19.4 Oscillators	1207
19.5 Power Amplifiers	1220
19.6 Power Combiners	1227
19.7 IMPATT Diode for Frequency Multiplication and Conversion	1240
19.8 Noise Characteristics and Spurious Oscillations	1241
19.9 Related Transit-Time Devices (BARITT, TRAPATT, TUNNETT, and MITTAT)	1247
19.10 Other Devices	1253
19.11 Recent Development	1258
19.12 Summary and Future Trends	1261
References	1261
20. Microwave Silicon Bipolar Transistors and Monolithic Integrated Circuits	1271
<i>Craig P. Snapp</i>	
20.1 Introduction	1271
20.2 Bipolar Transistor Structure and Modeling	1275
20.3 Discrete Transistor Design and Performance	1283
20.4 Monolithic Microwave Integrated Circuits	1293
20.5 Projections	1308
References	1311

21. FETs: Power Applications	1315
<i>H. A. Hung</i>	
21.1 Introduction	1315
21.2 Status of Power FETs and Amplifiers	1316
21.3 Power FET Modeling	1319
21.4 Power FET Designs	1336
21.5 Matching Circuit Designs	1341
21.6 Fabrication Processes	1355
21.7 Measurement Techniques	1361
21.8 Thermal Considerations	1366
21.9 Packaging Design	1369
21.10 Reliability and Radiation Effects	1371
21.11 Conclusions	1372
Acknowledgment	1373
Appendix A	1373
Appendix B	1375
Appendix C	1379
References	1381
22. FETS: Low-Noise Applications	1389
<i>Thomas A. Midford</i>	
22.1 Introduction	1389
22.2 Low-Noise MESFET Device Physics	1392
22.3 Noise Performance and Models	1399
22.4 Low-Noise MESFET Design and Fabrication	1411
22.5 Low-Noise Amplifier Design	1431
22.6 Conclusions and Outlook	1443
References	1449
23. High-Electron-Mobility Transistors: Principles and Applications	1455
<i>Jacques Zimmermann and Georges Salmer</i>	
23.1 Introduction	1455
23.2 Principle and Model of the HEMT	1457
23.3 Small-Signal Equivalent Circuit	1463
23.4 Technology of the HEMT	1465
23.5 Physical Analysis of the HEMT	1468
23.6 Low-Temperature Behavior	1473
23.7 Low-Noise Amplification	1476
23.8 Power Amplification	1482
23.9 New HEMT Structures	1486
23.10 Conclusion	1493
References	1493

24. Heterojunction Bipolar Transistors and Applications	1497
<i>J. S. Yuan</i>	
24.1 RF Device Parameters	1500
24.2 Transistor Reliability	1504
24.3 HBT Models	1517
24.4 Circuit Applications	1521
References	1541
25. Oscillators and Frequency Synthesizers	1547
<i>Ulrich L. Rohde</i>	
25.1 Introduction	1547
25.2 Frequency Synthesizer Fundamentals	1548
25.3 Important Characteristics of Synthesizers	1556
25.4 Building Blocks of Synthesizers	1560
25.5 Phase Locked Loop Designs	1575
25.6 The Fractional- N Principle	1596
References	1602
26. RF Components	1609
<i>Vijay Nair</i>	
26.1 Active Devices	1609
26.2 Two-Port Description of a Three-Terminal Device	1658
26.3 Passive Components	1665
References	1669
27. Microwave Superconductors	1673
<i>Carles Sans and Guo-Chun Liang</i>	
27.1 Superconductor Technology	1673
27.2 Superconducting Devices	1685
27.3 Superconducting Systems and Applications	1694
References	1707
28. Microwave MEMS and Micromachining	1711
<i>H. J. De Los Santos, S. J. Cunningham, A. S. Morris, III, S. F. Bart, and W. S. Best</i>	
28.1 Introduction	1711
28.2 MEMS Fabrication Techniques	1712
28.3 MEMS-Based Devices	1720
28.4 MEMS-Based Circuits and Systems	1734
28.5 MEMS Packaging	1743
28.6 Summary	1752
References	1752
Index	1759