

2827-0896

Radio Engineering for Wireless Communication and Sensor Applications

Antti V. Räsänen
Arto Lehto



Artech House
Boston • London
www.artechhouse.com

Contents

	Preface	<i>xv</i>
	Acknowledgments	<i>xvii</i>
1	Introduction to Radio Waves and Radio Engineering	1
1.1	Radio Waves as a Part of the Electromagnetic Spectrum	1
1.2	What Is Radio Engineering?	4
1.3	Allocation of Radio Frequencies	4
1.4	History of Radio Engineering from Maxwell to the Present	6
	References	9
2	Fundamentals of Electromagnetic Fields	11
2.1	Maxwell's Equations	11
2.1.1	Maxwell's Equations in Case of Harmonic Time Dependence	14
2.1.2	Interpretations of Maxwell's Equations	15

2.2	Fields in Media	17
2.3	Boundary Conditions	20
2.4	Helmholtz Equation and Its Plane Wave Solution	22
2.5	Polarization of a Plane Wave	26
2.6	Reflection and Transmission at a Dielectric Interface	28
2.7	Energy and Power	31
	References	33
3	Transmission Lines and Waveguides	35
3.1	Basic Equations for Transmission Lines and Waveguides	38
3.2	Transverse Electromagnetic Wave Modes	40
3.3	Transverse Electric and Transverse Magnetic Wave Modes	42
3.4	Rectangular Waveguide	44
3.4.1	TE Wave Modes in Rectangular Waveguide	44
3.4.2	TM Wave Modes in Rectangular Waveguide	50
3.5	Circular Waveguide	52
3.6	Optical Fiber	56
3.7	Coaxial Line	58
3.8	Microstrip Line	61
3.9	Wave and Signal Velocities	65
3.10	Transmission Line Model	66
	References	68

4	<u>Impedance Matching</u>	69
4.1	Reflection from a Mismatched Load	69
4.2	Smith Chart	74
4.3	Matching Methods	78
4.3.1	Matching with Lumped Reactive Elements	79
4.3.2	Matching with Tuning Stubs (with Short Sections of Line)	86
4.3.3	Quarter-Wave Transformer	89
4.3.4	Resistive Matching	94
	References	95
5	<u>Microwave Circuit Theory</u>	97
5.1	Impedance and Admittance Matrices	97
5.2	Scattering Matrices	101
5.3	Signal Flow Graph, Transfer Function, and Gain	104
5.3.1	Mason's Rule	109
5.3.2	Gain of a Two-Port	111
	References	113
6	<u>Passive Transmission Line and Waveguide Devices</u>	115
6.1	Power Dividers and Directional Couplers	116
6.1.1	Power Dividers	117
6.1.2	Coupling and Directivity of a Directional Coupler	119
6.1.3	Scattering Matrix of a Directional Coupler	120
6.1.4	Waveguide Directional Couplers	122
6.1.5	Microstrip Directional Couplers	124
6.2	Ferrite Devices	128
6.2.1	Properties of Ferrite Materials	128

6.2.2	Faraday Rotation	131
6.2.3	Isolators	133
6.2.4	Circulators	134
6.3	Other Passive Components and Devices	134
6.3.1	Terminations	135
6.3.2	Attenuators	136
6.3.3	Phase Shifters	138
6.3.4	Connectors and Adapters	138
	References	139
7	Resonators and Filters	141
7.1	Resonators	141
7.1.1	Resonance Phenomenon	142
7.1.2	Quality Factor	142
7.1.3	Coupled Resonator	144
7.1.4	Transmission Line Section as a Resonator	147
7.1.5	Cavity Resonators	149
7.1.6	Dielectric Resonators	153
7.2	Filters	154
7.2.1	Insertion Loss Method	155
7.2.2	Design of Microwave Filters	161
7.2.3	Practical Microwave Filters	166
	References	169
8	Circuits Based on Semiconductor Devices	171
8.1	From Electron Tubes to Semiconductor Devices	171
8.2	Important Semiconductor Devices	172
8.2.1	Diodes	172
8.2.2	Transistors	177
8.3	Oscillators	180

8.4	Amplifiers	184
8.4.1	Design of Small-Signal and Low-Noise Amplifiers	184
8.4.2	Effect of Nonlinearities and Design of Power Amplifiers	191
8.4.3	Reflection Amplifiers	192
8.5	Frequency Converters (Mixers) and Frequency Multipliers	193
8.5.1	Mixers	194
8.5.2	Frequency Multipliers	197
8.6	Detectors	198
8.7	Monolithic Microwave Circuits	201
	References	202
9	Antennas	205
9.1	Fundamental Concepts of Antennas	205
9.2	Calculation of Radiation from Antennas	212
9.3	Radiating Current Element	214
9.4	Dipole and Monopole Antennas	217
9.5	Other Wire Antennas	222
9.6	Radiation from Apertures	225
9.7	Horn Antennas	232
9.8	Reflector Antennas	234
9.9	Other Antennas	236
9.10	Antenna Arrays	239
9.11	Matching of Antennas	242
9.12	Link Between Two Antennas	242
	References	245

10	<u>Propagation of Radio Waves</u>	247
10.1	Environment and Propagation Mechanisms	247
10.2	Tropospheric Attenuation	249
10.3	Bending (Refraction) of Radio Waves in Troposphere	252
10.4	LOS Path	255
10.5	Reflection from Ground	257
10.6	Multipath Propagation in Cellular Mobile Radio Systems	260
10.7	Propagation Aided by Scattering: Scatter Link	263
10.8	Propagation via Ionosphere	265
10.9	Propagation as a Ground (Surface) Wave	267
	References	270
11	<u>Radio System</u>	271
11.1	Transmitters and Receivers	271
11.2	Noise	275
11.2.1	Receiver Noise	275
11.2.2	Antenna Noise Temperature	284
11.3	Modulation and Demodulation of Signals	287
11.3.1	Analog Modulation	288
11.3.2	Digital Modulation	297
11.4	Radio Link Budget	304
	References	306

12	Applications	307
12.1	Broadcasting	307
12.1.1	Broadcasting in Finland	308
12.1.2	Broadcasting Satellites	310
12.2	Radio Link Systems	312
12.2.1	Terrestrial Radio Links	312
12.2.2	Satellite Radio Links	314
12.3	Wireless Local Area Networks	314
12.4	Mobile Communication	317
12.5	Radionavigation	320
12.5.1	Hyperbolic Radionavigation Systems	320
12.5.2	Satellite Navigation Systems	323
12.5.3	Navigation Systems in Aviation	326
12.6	Radar	328
12.6.1	Pulse Radar	328
12.6.2	Doppler Radar	332
12.6.3	Frequency-Modulated Radar	334
12.6.4	Surveillance and Tracking Radars	335
12.7	Remote Sensing	336
12.7.1	Radiometry	337
12.7.2	Total Power Radiometer and Dicke Radiometer	340
12.7.3	Remote-Sensing Radar	343
12.8	Radio Astronomy	345
12.8.1	Radio Telescopes and Receivers	346
12.8.2	Antenna Temperature of Radio Sources	349
12.8.3	Radio Sources in the Sky	350

12.9	Sensors for Industrial Applications	353
12.9.1	Transmission Sensors	354
12.9.2	Resonators	354
12.9.3	Reflection Sensors	355
12.9.4	Radar Sensors	355
12.9.5	Radiometer Sensors	356
12.9.6	Imaging Sensors	356
12.10	Power Applications	356
12.11	Medical Applications	357
12.11.1	Thermography	358
12.11.2	Diathermy	359
12.11.3	Hyperthermia	359
12.12	Electronic Warfare	359
12.12.1	ES	360
12.12.2	EA	360
12.12.3	EP	361
	References	361
13	Biological Effects and Safety Standards	363
	References	366
	Appendix A: Vector Operations	367
	Appendix B: Physical Constants and Material Parameters	371
	List of Acronyms	373
	About the Authors	379
	Index	381