

RF and Microwave Wireless Systems. Kai Chang
Copyright © 2000 John Wiley & Sons, Inc.
ISBNs: 0-471-35199-7 (Hardback); 0-471-22432-4 (Electronic)

RF and Microwave Wireless Systems

RF and Microwave Wireless Systems

KAI CHANG

Texas A&M University



A WILEY-INTERSCIENCE PUBLICATION

JOHN WILEY & SONS, INC.

NEW YORK/CHICHESTER/WEINHEIM/BRISBANE/SINGAPORE/TORONTO

Designations used by companies to distinguish their products are often claimed as trademarks. In all instances where John Wiley & Sons, Inc., is aware of a claim, the product names appear in initial capital or ALL CAPITAL LETTERS. Readers, however, should contact the appropriate companies for more complete information regarding trademarks and registration.

Copyright © 2000 by John Wiley & Sons, Inc. All rights reserved.

No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic or mechanical, including uploading, downloading, printing, decompiling, recording or otherwise, except as permitted under Sections 107 or 108 of the 1976 United States Copyright Act, without the prior written permission of the Publisher. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 605 Third Avenue, New York, NY 10158-0012, (212) 850-6011, fax (212) 850-6008, E-Mail: PERMREQ @ WILEY.COM.

This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold with the understanding that the publisher is not engaged in rendering professional services. If professional advice or other expert assistance is required, the services of a competent professional person should be sought.

ISBN 0-471-22432-4

This title is also available in print as ISBN 0-471-35199-7.

For more information about Wiley products, visit our web site at www.Wiley.com.

To my parents and my family

Contents

Preface	xi
Acronyms	xiii
1 Introduction	1
1.1 Brief History of RF and Microwave Wireless Systems	1
1.2 Frequency Spectrums	3
1.3 Wireless Applications	6
1.4 A Simple System Example	7
1.5 Organization of This Book	8
2 Review of Waves and Transmission Lines	10
2.1 Introduction	10
2.2 Wave Propagation	12
2.3 Transmission Line Equation	17
2.4 Reflection, Transmission, and Impedance for a Terminated Transmission Line	20
2.5 Voltage Standing-Wave Ratio	22
2.6 Decibels, Insertion Loss, and Return Loss	27
2.7 Smith Charts	33
2.8 S-Parameters	39
2.9 Coaxial Lines	41
2.10 Microstrip Lines	43
2.11 Waveguides	50
2.12 Lumped Elements	54
2.13 Impedance Matching Networks	55
Problems	63
References	65
	vii

3	Antenna Systems	67
3.1	Introduction	67
3.2	Isotropic Radiator and Plane Waves	69
3.3	Far-Field Region	71
3.4	Antenna Analysis	73
3.5	Antenna Characteristics and Parameters	74
3.6	Monopole and Dipole Antennas	80
3.7	Horn Antennas	86
3.8	Parabolic Dish Antennas	88
3.9	Microstrip Patch Antennas	90
3.10	Antenna Arrays and Phased Arrays	98
3.11	Antenna Measurements	104
	Problems	104
	References	109
4	Various Components and Their System Parameters	111
4.1	Introduction and History	111
4.2	Couplers, Hybrids, and Power Dividers/Combiners	114
4.3	Resonators, Filters, and Multiplexers	118
4.4	Isolators and Circulators	128
4.5	Detectors and Mixers	130
4.6	Switches, Phase Shifters, and Attenuators	134
4.7	Oscillators and Amplifiers	139
4.8	Frequency Multipliers and Dividers	143
	Problems	145
	References	148
5	Receiver System Parameters	149
5.1	Typical Receivers	149
5.2	System Considerations	150
5.3	Natural Sources of Receiver Noise	152
5.4	Receiver Noise Figure and Equivalent Noise Temperature	154
5.5	Compression Points, Minimum Detectable Signal, and Dynamic Range	158
5.6	Third-Order Intercept Point and Intermodulation	161
5.7	Spurious Responses	166
5.8	Spurious-Free Dynamic Range	166
	Problems	168
	References	171
6	Transmitter and Oscillator Systems	172
6.1	Transmitter Parameters	172
6.2	Transmitter Noise	173

6.3	Frequency Stability and Spurious Signals	176
6.4	Frequency Tuning, Output Power, and Efficiency	177
6.5	Intermodulation	180
6.6	Crystal Reference Oscillators	184
6.7	Phase-Locked Oscillators	186
6.8	Frequency Synthesizers	188
	Problems	191
	References	194
7	Radar and Sensor Systems	196
7.1	Introduction and Classifications	196
7.2	Radar Equation	198
7.3	Radar Equation Including Pulse Integration and System Losses	202
7.4	Radar Cross Section	205
7.5	Pulse Radar	209
7.6	Continuous-Wave or Doppler Radar	212
7.7	Frequency-Modulated Continuous-Wave Radar	216
7.8	Direction Finding and Tracking	222
7.9	Moving-Target Indication and Pulse Doppler Radar	228
7.10	Synthetic Aperture Radar	232
7.11	Practical Radar Examples	233
	Problems	236
	References	242
8	Wireless Communication Systems	243
8.1	Introduction	243
8.2	Friis Transmission Equation	244
8.3	Space Loss	247
8.4	Link Equation and Link Budget	248
8.5	Effective Isotropic Radiated Power and G/T Parameters	252
8.6	Radio/Microwave Links	254
8.7	Satellite Communication Systems	255
8.8	Mobile Communication Systems and Wireless Cellular Phones	258
8.9	Personal Communication Systems and Satellite Personal Communication Systems	262
	Problems	270
	References	273
9	Modulation and Demodulation	274
9.1	Introduction	274
9.2	Amplitude Modulation and Demodulation	275
9.3	Frequency Modulation	279
9.4	Digital Shift-Keying Modulation	280

9.5 Bit Error Rate and Bandwidth Efficiency	286
9.6 Sampling and Pulse Code Modulation	289
Problems	292
References	293
10 Multiple-Access Techniques	294
10.1 Introduction	294
10.2 Frequency Division Multiple Access and Frequency Division Multiplexing	294
10.3 Time Division Multiple Access and Time Division Multiplexing	295
10.4 Spread Spectrum and Code Division Multiple Access	298
References	303
11 Other Wireless Systems	304
11.1 Radio Navigation and Global Positioning Systems	304
11.2 Motor Vehicle and Highway Applications	309
11.3 Direct Broadcast Satellite Systems	313
11.4 RF Identification Systems	313
11.5 Remote Sensing Systems and Radiometers	317
11.6 Surveillance and Electronic Warfare Systems	320
Problems	328
References	330
Index	333

Preface

Wireless personal mobile and cellular communications are expected to be one of the hottest growth areas of the 2000s and beyond. They have enjoyed the fastest growth rate in the telecommunications industry—adding customers at a rate of 20–30% a year. Presently, at least six satellite systems are being developed so that wireless personal voice and data communications can be transmitted from any part of the earth to another using a simple, hand-held device. These future systems will provide data and voice communications to anywhere in the world, using a combination of wireless telephones, wireless modems, terrestrial cellular telephones and satellites. The use of wireless remote sensing, remote identification, direct broadcast, global navigation, and compact sensors has also gained popularity in the past decade. Wireless communications and sensors have become a part of a consumer's daily life. All of these wireless systems consist of a radio frequency (RF) or microwave front end.

Although many new wireless courses have been offered at universities and in industry, there is yet to be a textbook written on RF and microwave wireless systems. The purpose of this book is to introduce students and beginners to the general hardware components, system parameters, and architectures of RF and microwave wireless systems. Practical examples of components and system configurations are emphasized. Both communication and radar/sensor systems are covered. Many other systems, such as, the global positioning system (GPS), RF identification (RFID), direct broadcast system (DBS), surveillance, smart highways, and smart automobiles are introduced. It is hoped that this book will bridge the gap between RF/microwave engineers and communication system engineers.

The materials covered in this book have been taught successfully at Texas A&M University to a senior class for the past few years. Half of the students are from RF and microwave areas, and half are from communications, signal processing, solid-state, optics, or other areas. The book is intended to be taught for one semester to an undergraduate senior class or first-year graduate class with some sections assigned to

students for self-study. The end-of-chapter problems will strengthen the reader's knowledge of the subject. The reference sections list the principal references for further reading.

Although this book was written as a textbook, it can also be used as a reference book for practical engineers and technicians. Throughout the book, the emphasis is on the basic operating principles. Many practical examples and design information have been included.

I would like to thank all of my former students who used my notes in class for their useful comments and suggestions. I would also like to thank Mingyi Li, Paola Zepeda, Chris Rodenbeck, Matt Coutant and James McSpadden for critical review of the manuscript. Michelle Rubin has done an excellent job in editing and preparing the manuscript. Taehan Bae has helped to prepared some of the art work. Finally, I wish to express my deep appreciation to my wife, Suh-jan, and my children, Peter and Nancy, for their patience and support.

KAI CHANG

February 2000

Acronyms

AF	array factor
AGC	automatic gain control
AM	amplitude modulated
AMPS	advanced mobile phone service
APTS	advanced public transit systems
ASK	amplitude shift keying
ATIS	advanced traveler information system
ATMS	advanced traffic management system
AUT	antenna under test
AVCS	advanced vehicle control system
AVI	automatic vehicle identification
BER	bit error rate
BPF	bandpass filter
BPSK	biphase shift keying
BSF	bandstop filter
BW	bandwidth
CAD	computer-aided design
CDMA	code division multiple access
CEP	circular probable error
CMOS	complementary MOS
CP	circularly polarized
CPL	cross-polarization level
CRTs	cathode ray tubes
CT1/2	cordless telephone 1/2
CTO	cordless telephone O
CVO	commercial vehicle operations
CVR	crystal video receiver
CW	continuous wave

DBS	direct broadcast satellite
DC	direct current
DECT	digital european cordless telephone
DR	dynamic range
DRO	dielectric resonator oscillator
DSB	double side band
DSSS	direct-sequence spread spectrum
ECCMs	electronic counter- countermeasures
ECMs	electronic countermeasures
EIRP	effective isotropic radiated power
EM	electromagnetic
ESM	electronic support measure
EW	electronic warfare
FCC	Federal Communications Commission
FDD	frequency division duplex
FDM	frequency division multiplexing
FDMA	frequency division multiple access
FETs	field-effect transistors
FFHSS	fast frequency- hopping spread spectrum
FHSS	frequency-hopping spread spectrum
FLAR	forward-looking automotive radar
FMCW	frequency-modulated continuous wave
FM	frequency modulated
FNBW	first-null beamwidth
FSK	frequency shift keying
GEO	geosynchronous orbit
GMSK	Gaussian minimum shift keying
GPS	global positioning system
GSM	global system for mobile communication
G/T	receiver antenna gain to system noise temperature ratio
HBTs	heterojunction bipolar transistors
HEMTs	high-electron-mobility transistors
HPA	high-power amplifier
HPBW	half-power beamwidth
HPF	high-pass filter
IF	intermediate frequency
IFM	instantaneous frequency measurement
IL	insertion loss
IMD	intermodulation distortion
IM	intermodulation
IMPATT	impact ionization avalanche transit time device
IM3	third-order intermodulation
IP3	third-order intercept point
I/Q	in-phase/quadrature-phase
IVHS	intelligent vehicle and highway system

JCT	Japanese cordless telephone
J/S	jammer-to-signal
LAN	local area network
LMDS	local multipoint distribution service
LEO	low earth orbit
LNA	low-noise amplifier
LO	local oscillator
LOS	line-of-sight
LPF	low-pass filter
LP	linearly polarized
MDS	minimum detectable signal
MEO	medium-altitude orbit
MESFETs	metal–semiconductor field-effect transistors
MIC	microwave integrated circuit
MLS	microwave landing system
MMIC	monolithic microwave integrated circuits
MSK	minimum shift keying
MTI	moving target indicator
NMT	Nordic mobile telephone
OQPSK	offset-keyed quadriphase shift keying
PAMELA	pricing and monitoring electronically of automobiles
PA	power amplifier
PAE	power added efficiency
PCM	pulse code modulation
PCN	personal communication networks
PCS	personal communication systems
PDC	personal digital cellular
PHS	personal handy phone system
PLL	phase-locked loops
PLO	phase-locked oscillators
PM	phase modulation
PN	pseudonoise
PRF	pulse repetition frequency
PSK	phase shift keying
8-PSK	8-phase shift keying
16-PSK	16-phase shift keying
QAM	quadrature amplitude modulation
QPSK	quadriphase shift keying
RCS	radar cross section
RF	radio frequency
RFID	radio frequency identification
RL	return loss
SAR	synthetic aperture radar
SAW	surface acoustic wave
SEP	spherical probable error

SFDR	spurious-free dynamic range
SFHSS	slow frequency- hopping spread spectrum
SLL	sidelobe levels
SMILER	short range microwave links for european roads
SNR	signal-noise ratio
SOJ	stand-off jammer
SPDT	single pole, double throw
SPST	single pole, single throw
SP3T	single pole, triple throw
SQPSK	staggered quadriphase shift keying
SS	spread spectrum
SS-CDMA	spread spectrum code division multiple access
SSJ	self-screening jammer
SSMI	special sensor microwave imager
STC	sensitivity time control
TACS	total access communication system
TDM	time division multiplexing
TDMA	time division multiple access
TE	transverse electric
TEM	transverse electromagnetic
TM	transverse magnetic
TOI	third-order intercept point
T/R	transmit/receive
TWTs	traveling-wave tubes
UHF	ultrahigh frequencies
VCO	voltage-controlled oscillator
VHF	very high frequency
VLf	very low frequency
VSWR	voltage standing-wave ratio
WLANs	wireless local-area networks

RF and Microwave Wireless Systems

WILEY SERIES IN MICROWAVE AND OPTICAL ENGINEERING

KAI CHANG, Editor
Texas A&M University

- FIBER-OPTIC COMMUNICATION SYSTEMS, Second Edition • *Govind P. Agrawal*
- COHERENT OPTICAL COMMUNICATIONS SYSTEMS • *Silvello Betti, Giancarlo De Marchis and Eugenio Iannone*
- HIGH-FREQUENCY ELECTROMAGNETIC TECHNIQUES: RECENT ADVANCES AND APPLICATIONS • *Asoke K. Bhattacharyya*
- COMPUTATIONAL METHODS FOR ELECTROMAGNETICS AND MICROWAVES • *Richard C. Booton, Jr.*
- MICROWAVE RING CIRCUITS AND ANTENNAS • *Kai Chang*
- MICROWAVE SOLID-STATE CIRCUITS AND APPLICATIONS • *Kai Chang*
- RF AND MICROWAVE WIRELESS SYSTEMS • *Kai Chang*
- DIODE LASERS AND PHOTONIC INTEGRATED CIRCUITS • *Larry Coldren and Scott Corzine*
- MULTICONDUCTOR TRANSMISSION-LINE STRUCTURES: MODAL ANALYSIS TECHNIQUES • *J. A. Brandão Faria*
- PHASED ARRAY-BASED SYSTEMS AND APPLICATIONS • *Nick Fourikis*
- FUNDAMENTALS OF MICROWAVE TRANSMISSION LINES • *Jon C. Freeman*
- OPTICAL SEMICONDUCTOR DEVICES • *Mitsuo Fukuda*
- MICROSTRIP CIRCUITS • *Fred Gardiol*
- HIGH-SPEED VLSI INTERCONNECTIONS: MODELING, ANALYSIS, AND SIMULATION • *A. K. Goel*
- FUNDAMENTALS OF WAVELETS: THEORY, ALGORITHMS, AND APPLICATIONS • *Jaideva C. Goswami and Andrew K. Chan*
- ANALYSIS AND DESIGN OF INTEGRATED CIRCUIT ANTENNA MODULES • *K. C. Gupta and Peter S. Hall*
- PHASED ARRAY ANTENNAS • *R. C. Hansen*
- HIGH-FREQUENCY ANALOG INTEGRATED CIRCUIT DESIGN • *Ravender Goyal (ed.)*
- MICROWAVE APPROACH TO HIGHLY IRREGULAR FIBER OPTICS • *Huang Hung-Chia*
- NONLINEAR OPTICAL COMMUNICATION NETWORKS • *Eugenio Iannone, Francesco Matera, Antonio Mecozzi, and Marina Settembre*
- FINITE ELEMENT SOFTWARE FOR MICROWAVE ENGINEERING • *Tatsuo Itoh, Giuseppe Pelosi and Peter P. Silvester (eds.)*
- SUPERCONDUCTOR TECHNOLOGY: APPLICATIONS TO MICROWAVE, ELECTRO-OPTICS, ELECTRICAL MACHINES, AND PROPULSION SYSTEMS • *A. R. Jha*
- OPTICAL COMPUTING: AN INTRODUCTION • *M. A. Karim and A. S. S. Awwal*
- INTRODUCTION TO ELECTROMAGNETIC AND MICROWAVE ENGINEERING • *Paul R. Karmel, Gabriel D. Colef, and Raymond L. Camisa*
- MILLIMETER WAVE OPTICAL DIELECTRIC INTEGRATED GUIDES AND CIRCUITS • *Shiban K. Koul*
- MICROWAVE DEVICES, CIRCUITS AND THEIR INTERACTION • *Charles A. Lee and G. Conrad Dalman*
- ADVANCES IN MICROSTRIP AND PRINTED ANTENNAS • *Kai-Fong Lee and Wei Chen (eds.)*

OPTICAL FILTER DESIGN AND ANALYSIS: A SIGNAL PROCESSING APPROACH •
Christi K. Madsen and Jian H. Zhao

OPTOELECTRONIC PACKAGING • *A. R. Mickelson, N. R. Basavanahally, and Y. C. Lee (eds.)*

OPTICAL CHARACTER RECOGNITION • *Shunji Mori, Hirobumi Nishida, and Hiromitsu Yamada*

ANTENNAS FOR RADAR AND COMMUNICATIONS: A POLARIMETRIC APPROACH •
Harold Mott

INTEGRATED ACTIVE ANTENNAS AND SPATIAL POWER COMBINING • *Julio A. Navarro and Kai Chang*

FREQUENCY CONTROL OF SEMICONDUCTOR LASERS • *Motoichi Ohtsu (ed.)*

SOLAR CELLS AND THEIR APPLICATIONS • *Larry D. Partain (ed.)*

ANALYSIS OF MULTICONDUCTOR TRANSMISSION LINES • *Clayton R. Paul*

INTRODUCTION TO ELECTROMAGNETIC COMPATIBILITY • *Clayton R. Paul*

ELECTROMAGNETIC OPTIMIZATION BY GENETIC ALGORITHMS • *Yahya Rahmat-Samii and Eric Michielssen (eds.)*

INTRODUCTION TO HIGH-SPEED ELECTRONICS AND OPTOELECTRONICS •
Leonard M. Riazat

NEW FRONTIERS IN MEDICAL DEVICE TECHNOLOGY • *Arye-Rosen and Harel Rosen (eds.)*

ELECTROMAGNETIC PROPAGATION IN MULTI-MODE RANDOM MEDIA • *Harrison E. Rowe*

ELECTROMAGNETIC PROPAGATION IN ONE-DIMENSIONAL RANDOM MEDIA •
Harrison E. Rowe

NONLINEAR OPTICS • *E. G. Sauter*

FUNDAMENTALS OF GLOBAL POSITIONING SYSTEM RECEIVERS: A SOFTWARE
APPROACH • *James Bao-yen Tsui*

INP-BASED MATERIALS AND DEVICES: PHYSICS AND TECHNOLOGY • *Osamu Wada
and Hideki Hasegawa (eds.)*

DESIGN OF NONPLANAR MICROSTRIP ANTENNAS AND TRANSMISSION
LINES • *Kin-Lu Wong*

FREQUENCY SELECTIVE SURFACE AND GRID ARRAY • *T. K. Wu (ed.)*

ACTIVE AND QUASI-OPTICAL ARRAYS FOR SOLID-STATE POWER COMBINING •
Robert A. York and Zoya B. Popović (eds.)

OPTICAL SIGNAL PROCESSING, COMPUTING AND NEURAL NETWORKS • *Francis T. S. Yu
and Suganda Jutamulia*

SiGe, GaAs, AND InP HETEROJUNCTION BIPOLAR TRANSISTORS • *Jiann Yuan*

ELECTRODYNAMICS OF SOLIDS AND MICROWAVE SUPERCONDUCTIVITY • *Shu-Ang Zhou*

Index

- Aircraft, determination of position, 308–309
- Altimeter, 220–221
- Amplifiers, 139–142
 - low-noise, 7
 - with power gain, 140–141
 - system response, 159
- Amplitude modulation and demodulation, 275–279
- Amplitude shift keying, 281
- ANADIGICS downconverter, 313–314
- Analog phase detector, 186–187
- Anechoic chamber, 104–105
- Antennas, 67–104
 - analysis, 73–74
 - arrays, 98–103
 - feeding methods, 102–103
 - grating lobes, 102
 - linear, 98–101
 - pattern multiplication, 99
 - phased, 101–103
 - back radiation, 79
 - bandwidth, 75–76
 - beam efficiency, 79
 - classification, 67–69
 - directivity, gain, and efficiency, 77–78
 - effective area, 78–79
 - far-field region, 71–72
 - half-power beamwidth, 77
 - high-gain, estimation, 79–80
 - horn, 86–89
 - input voltage standing-wave ratio and impedance, 74–75
 - isotropic radiator, 69–71
 - measurements, 104–105
 - microstrip patch, *see* Microstrip patch antennas
 - monopole and dipole, 80–86
 - folded, 83–84
 - parabolic dish, 88–91
 - polarization and cross-polarization level, 78
 - power radiation patterns, 75–77
 - sidelobe level, 77
- Anticollision systems, 311
- Antitheft tags, 316
- Array factor, 99–100
 - phased array, 101–102
- ARSR-3 radar system, parameters, 233–235
- Attenuators, 139
- Automobiles, applications, 7, 309–312
- Back radiation, antennas, 79
- Back-reradiation, 196–197
- Balanced frequency discriminator, 279–280
- Bandwidth
 - antennas, 75–76
 - efficiency, 287–288
- Beam efficiency, antennas, 79
- Beam scanning, 99–100
- Bell, Alexander Graham, 27
- Biphase switch, 283
- Biphase switch keying, 282–283
 - bandwidth efficiency, 288–289
- Bit error rate, 286–287

- Bit error rate (*continued*)
 - versus carrier-to-noise ratio, 287
- Blackbody, 317
- Brightness temperature, 317, 320
- Broadcasting, applications, 7

- Carrier signal, 275
- Carrier-to-noise ratio, versus bit error rate, 287
- Cascaded amplifiers, gain and noise figure, 156–157
- Cascaded circuit
 - equivalent noise temperature, 157–158
 - noise factor, 155–156
- Cavities, 118
- Cavity model, 92
- Cellular phone services, analog and digital, 262, 264–265
- Center-driven dipole, radiation patterns, 81, 83
- Circulators, 128–130
- Coaxial lines, 41–43
 - equivalent circuit, 17–18
 - transverse electromagnetic mode, 42
- Code division multiple access, 298–303
- Colpitts crystall oscillators, 185
- Comparator, monopulse tracking, 226, 228–229
- Components, symbols, 113
- Compression points, 158–160
- Conductor, fields inside, 10–11
- Conical scan, 224
- Continuity of flux, 14
- Continuous-wave radar, *see* Doppler radar; Frequency-modulated continuous-wave radar
- Cordless phone services, analog and digital, 262, 264–265
- Cosmos 1500 SBR, parameters and performance, 234, 236
- Couplers, 114–119
 - directional, 114–115
 - hybrid, 115–116
 - Wilkinson, 116, 118–119
- Coupling factor, 114
- Cross-polarization, antennas, 78
- Crystal reference oscillators, 184–185

- Decibel
 - as absolute unit, 31–32
 - conversion to and from power ratios, 28–29
 - definition, 27
 - gain or loss representations, 29–30
 - voltage definition, 27
- Demodulation, 274–275
 - amplitude, 275–279
- Detectors, 130–134
 - current sensitivity, 132
 - flicker noise, 132
 - nonlinear I - V characteristics, 131
- Dicke radiometer, 320–321
- Dielectric constant, relative, 14
- Digital shift-keying modulation, 280–286
- Diode control devices, ferrite and p - i - n , 135
- Dipole antennas, 80–86
- Direct broadcast satellite systems, 313–314
- Directivity
 - antennas, 77–78
 - couplers, 114
- Direct-sequence spread spectrum system, 299–300
- Dominant mode, rectangular waveguide, 54
- Doppler radar, 212–216
 - block diagram, 213–214
 - frequency response characteristics, filter bank, 214
 - output power, 216
 - relative speed calculation, 212–213
 - using superheterodyne technique, 215
- Doppler shift, 212
- Downconverter, 132–133
 - conversion loss, 134
- Driven tags, 316
- Duplexer, separating transmitting and receiving ports, 211
- Duty cycle, 209
- Dynamic range, receivers, 158–160
 - spurious-free, 166–168

- Earth station terminal, 258, 260
- Effective area
 - antennas, 78–79
 - parabolic dish antennas, 88
- Effective isotropic radiated power, 252–254
- Efficiency, antennas, 77–78
- Electric potential, Laplace equation, 42
- Electromagnetic spectrum, 3–4
- Electronic counter-countermeasures, 322–323
- Electronic countermeasures, 322–323, 325–328
- Electronic support measure, 322–325
- Electronic warfare systems, 320, 322–328
 - applications, 7
- Equivalent noise temperature, 157–158

- Far-field region, antennas, 71–72
- Fast frequency hopping spread spectrum, 300–301
- Feedforward amplifier system, block diagram, 181–182
- Feed methods
 - antenna arrays, 102–103
 - microstrip patch antennas, 96–97
 - monopulse tracking, 225
- Filter bank, frequency response characteristics, Doppler radar, 214
- Filters, 123–127
 - low-pass, DC current, 131
 - microstrip bandpass, 126–127
 - microstrip structures, 126
 - prototype circuits, 125–126
 - response, 124–125
 - types, 123–124
- First resonator mode, voltage distribution, 122–123
- Flicker noise
 - detectors, 132
 - receivers, 154
- Frequency divider, 144
- Frequency division multiple access, 257, 294–296
- Frequency division multiplexing, 294–296
 - receiver block diagram, 296
 - transmitter system, frequency spectrum, 294–295
- Frequency-modulated continuous-wave radar, 216–222
 - altimeter, 220–221
 - block diagram, 216–217
 - frequency variation rate, 217–218
 - moving-target case, 218–222
 - stationary-target case, 216–218
 - waveform for moving target, 219
- Frequency modulation, 279–280
- Frequency multiplier, 143–144
- Frequency shift keying, 282
- Frequency spectrums, 3–6
 - higher
 - advantages, 3, 5
 - disadvantages, 6
- Frequency synthesizers, 144, 188–191
 - with improved resolution, 189–190
 - multiple-loop, 190–191
- Frequency tuning, 178
- Friis transmission equation, 244–247, 326
 - received power, 248
 - representations, 29–30
- Galactic noise, 152
- Gaussian minimum shift keying, 283
- Global positioning systems, 307–309
- Gold sequences, 300, 302–303
- Green's function, free-space, 74
- Ground-to-satellite communication uplink, 248–249
- G/T parameters, 252–254
- Gunn oscillator, 179
- Half-power beamwidth, antennas, 77
- Half-wave dipole, 81
- Helmholtz equation, 15
 - antennas, 69–70
 - inhomogeneous, antennas, 73–74
- Hertz, Heinrich Rudolf, 1
- Highway applications, 7, 309–312
- Hollow-pipe waveguides, 50
- Horn antennas, 86–89
- Hybrids, 115–116
- Impedance
 - input, antennas, 75
 - intrinsic, free space, 70
 - microstrip lines, 38
 - normalized, definition, 33
 - radiation, microstrip patch antennas, 94
 - transmission line
 - terminated, 21
 - Smith charts, *see* Smith charts
- Impedance matching networks, 55, 57–63
 - adding series reactance to load, 60, 62
 - adding shunt reactance to load, 60, 62
 - lumped elements, 60–63
 - matching stubs, 55, 58
 - single-section quarter-wavelength transformer, 59–60
 - two-port, 55, 58
- In-phase/quadrature-phase modulators, 284–285
- Insertion loss, 30, 32–33
 - definition, 32
 - S -parameters, 41
- Intelligent Vehicle and Highway System, 310
- Intermodulation
 - receivers, 161–165
 - transmitters, 180–183
- Intermodulation distortion
 - two-tone test
 - linearized, 183
 - nonlinearized, 181, 183
 - products, 180
- Gain
 - antennas, 77–78

- Inverted F - and L -antennas, 83, 85
 Isolation, 114
 Isolators, 128–130
 Isotropic radiator, plane waves, 69–71
- Johnson noise, 153
- K-band satellite link, 258–259
 Kirchhoff's current and voltage laws, 18
- Laplace equation, electric potential, 42
 Line-of-sight, 243
 Link budget, 251
 Link equation, 248–252
 Local-area networks, wireless, frequency bands, 270
 Loss, representations, 29–30
 Low-noise amplifier, 7
 Lumped elements, 54–57
 impedance matching networks, 60–63
- Magit-T, 115, 117
 Marconi, Guglielmo, 1
 Maxwell, James Clerk, 1
 Maxwell equation, 14
 antennas, 70
 magnetic field, coaxial line, 43
 Medical applications, 7
 Microstrip bandpass filter, 126–127
 Microstrip circuits, resonators, 122–124
 Microstrip filter structures, 126
 Microstrip lines, 43–49
 analysis formulas, 45–46
 characteristic impedance, 38
 equivalent circuit, 49
 graphical method, 47–49
 guide wavelength, 49
 quasi-static analysis, 45
 quasi-TEM mode, 45
 synthesis formulas, 46–47
 Microstrip patch antennas, 9098
 cavity model, 92
 feed methods, 96–97
 input admittance, 94
 radiation
 conductance, 92
 impedance, 94
 patterns, 97–98
 susceptance, 92–93
 rectangular, 91–92
 transmission line model, 91–94
 Microwave dielectric substrates, properties, 44
- Microwave frequency spectrum, 3
 Microwave relay systems, 254, 256
 Microwave subsystem design, user requirement impact, 233
 Microwave systems, motor vehicle and highway applications, 309–310
 Millimeter-wave band designation, 5
 Millimeter-wave spectrum, 3
 Minimum detectable signal, receivers, 158–160
 Miteq amplifier, performance, 142
 Mixers, 130–134
 intercept point, 162–163
 multiplication of input signals, 132–133
 spurious responses, 166
 system response, 159
 Mobile communication systems, 258–260, 262–265
 frequency allocations, 260
 Modulation, 274–275. *See also* specific types
 amplitude, 275–279
 degress, 276–277
 frequency, 279–280
 pulse code, 289–292
 Modulation index, 279
 Monopole antennas, 80–86
 Monopulse tracking, 224–228
 comparator, 226, 228–229
 feed arrangements, 225
 receiver, 228, 230
 sum and difference patterns, 225–226
 Motor vehicle applications, 7, 309–312
 Moving target indicator, 228, 230–231
 Multiplexer, 127–128
- Navigation, applications, 6
 Navistar global positioning system satellite, 307–308
- Noise
 frequencymodulated, 173–175
 receiver, natural sources, 152–154
 transmitters, 173–176
 Noise figure, receivers, 154–157, 201
 Noise floor, due to match resistor load, 158
 N -port network, 39–40
 Nyquist noise, 153
- Omega transmitters, 307
 Oscillating frequency, 177–178
 Oscillators, 139–142
 circuit, 139
 crystal reference, 184–185

- frequency stability, 176–177
 - output power spectrum, 175
 - phase-locked, 186–188
 - simplified circuit, 177–178
 - spurious signals, 177
 - varactor-tuned, 178
- PAMELA, 311
- Parabolic dish antennas, 88–91
- Passive tags, 316
- Pattern multiplication, 99
- Permeability, relative, 14
- Personal communication systems, 262–263, 266–270. *See also* Satellite personal communication systems
- frequency allocations, 266
 - ultimate vision, 266, 269
- Phase-locked loops, 144
- Phase-locked oscillators, 186–188
- Phase noise, measurement, 175–176
- Phase shift, *S*-parameters, 41
- Phase shifters, 136–139
- Phase shift keying, bandwidth efficiency, 288–289
- 8-Phase shift keying
- bandwidth efficiency, 288–289
 - constellation diagram, 285
- 16-Phase shift keying
- bandwidth efficiency, 288–289
 - constellation diagram, 285
- Plane waves, isotropic radiator, 69–71
- Polarization, antennas, 78
- Power added efficiency, 141
- Power amplifier, 191
- intermodulation, 180–181
 - nonlinear characteristics, 180–182
- Power density
- directive antenna, 244
 - radar, 199
 - time-averaged, antennas, 70
- Power radiation patterns, antennas, 75–77
- Power ratios, conversion to and from decibel, 28–29
- Pseudonoise code, 300
- Pulse code modulation, 289–292
- advantages, 289
 - block diagram, 290
- Pulse doppler radar, 228, 230–231
- Pulse integration, 203
- Pulse radar, 209–212
- block diagram, 210–211
- Quadrature amplitude modulator
- bandwidth efficiency, 288–289
 - block diagram, 286
 - constellation diagram, 285
- Quadrature phase shift keying, 283–284
- variations, 286
- Quality factor, resonators, 119–121
- Quantizing steps, 291–292
- Quarter-wavelength whip antenna, 81, 83
- Quasi-TEM mode, microstrip lines, 45
- Radar, 2, 196–235
- applications, 6
 - back-reradiation, 196–197
 - basic system, 198
 - classification, 197
 - cross-section, 199, 205–209
 - calculation for simple targets, 207
 - as function of frequency, 206
 - incident and reflected waves, 205–206
 - microwave frequencies, 207–209
 - sphere, 207–208
 - direction finding and tracking, 222–228
 - conical scan, 224
 - monopulse tracking, 224–228
 - sequential lobing, 223–224
 - examples, 233–236
 - power backscattered to, 199–200
 - power density, 199
 - pulse, 209–212
 - pulse doppler, 228, 230–231
 - synthetic aperture, 232
 - tracking, types, 222
- Radar equation, 198–201
- including pulse integration and system losses, 202–205
- Radiation conductance, microstrip patch antennas, 92
- Radiation curves, different temperatures, 318
- Radiation patterns
- center-driven dipole, 81, 83
 - microstrip patch antennas, 97–98
- Radiation susceptance, microstrip patch antennas, 92–93
- Radio astronomy, applications, 7
- Radio detection and ranging, *see* Radar
- Radio frequency spectrum, 3
- Radio frequency identification systems, 313–316
- applications, 7
 - comparison of systems with different frequencies, 315
 - simplified systems, 315
- Radiometers, *see* Remote sensing systems

- Radio/microwave links, 254–255
- Radio navigation, 304–309
 - active system, 304–305
 - comparison of systems, 306
 - passive system, 305
- Receivers, 141–142, 149–168
 - channelized, 324–325
 - compression points, 158–160
 - dual-conversion, 150–151
 - dynamic range, 158–160
 - equivalent noise temperature, 157–158
 - flicker noise, 154
 - intermodulation, 161–165
 - minimum detectable signal, 158–160
 - monopulse tracking, 228, 230
 - noise, natural sources, 152–154
 - noise figure, 154–157, 201
 - selectivity, 152
 - sensitivity, 150
 - SNR ratio, 201
 - spurious-free dynamic range, 166–168
 - spurious responses, 166
 - system considerations, 150–152
 - system response, 159
 - TDMA, 298
 - third-order intercept point, 161–165
 - wide-band, electronic support measures surveillance, 324
- Rectangular waveguides, 50–54
 - properties, 51–53
- Reflection coefficient, 34
 - terminated transmission line, 21
- Regenerative frequency divider, 144
- Remote sensing systems, 317–321
 - applications, 7
 - block diagram, 319
 - generating pictures, 320–322
- Resonant frequency, 119
- Resonators, 118–125
 - equivalent circuits, 119–120
 - frequency response, 121–122
 - microstrip circuits, 122–124
 - quality factor, 119–121
- Return loss, 32–33
 - definition, 32
 - S-parameters, 41
- Sampling, pulse code modulation, 289–290
- Satellite communication systems, 255–258
 - frequencies, 257–258
- Satellite earth station, 258, 261
- Satellite personal communication systems, 262–263, 266–270
 - system parameters, 268
 - under development, 267
- Satellites, 2
 - direct broadcast systems, 313–314
 - Navistar global positioning system, 307–308
 - remote sensing, 320
- Satellite transponder, block diagram, 258, 260
- Self-screening jammer, 325–326
- Sensors, applications, 7
- Sequential lobing, 223–224
- Sidelobe level, antennas, 77
- Signal-to-noise ratio
 - Friis transmission equation, 245–246
 - output, 250
- Skin depth, 10
- Sleeve antenna, 83–84
- S-matrix, 39–40
- SMILER, 311–312
- Smith charts, 33–39
 - different, 37
 - features, 34–35
 - impedance matching networks, 60, 62–63
- Smith, P. H., 33
- Space exploration, applications, 7
- Space loss, 247–248
- S-parameters, 3943
 - definition, 41
 - properties, 39–40
 - two-port network, 40–41
- Spread spectrum, 298–303
 - features, 298
 - second modulation, 298–299
- Spread spectrum-code division multiple access, 300, 303
- Spurious responses, receivers, 166
- Spurious signals, oscillators, 177
- Stability, frequency, 176–177
- Stand-off jammer, 325–326
- Stub, impedance matching, 55, 58
- Substrate materials, microwave, properties, 44
- Surveillance systems, 320, 322–328
 - applications, 7
- Switches, 134–137
 - applications, 136
 - biphase, 283
 - on and off positions, 135, 137
 - output ports, 135, 137
- Switch-line phase shifter, 136, 138
- Symbols, components, 113
- Synthesizers, frequency, 188–191
- Synthetic aperture radar, 232

- Thermal noise, 153
- Thin-wire dipole, 82
- Third-order intercept point, receivers, 161–165
- Threeway power divider, 32–33
- Time division multiple access, 257, 295, 297–298
 - receiver, 298
 - transmitting system, block diagram, 297
- Time division multiplexing, 295, 297–298
- Toll debiting systems, 311
- Transceiver, block diagram, 151
- Transistor amplifier, circuit, 141
- Transistor oscillator, 140
- Transmission line
 - characteristic impedance, 19–20
 - coaxial, 42
 - compared to waveguides, 13
 - connected to shorted load, 26
 - equivalent circuit, 17
 - impedance, Smith charts, *see* Smith charts
 - lossless, voltage, 22
 - microstrip, *see* Microstrip lines
 - quasistatic analysis, 45
 - structures, 10–12
 - terminated, 20–22
 - voltage standingwave ratio formulas, 25
- Transmission line equation, 17–20
- Transmission line model, microstrip patch antennas, 91–94
- Transmitters
 - block diagram, 172
 - DC-to-RF conversion efficiency, 179
 - intermodulation, 180–183
 - noise, 173–176
 - Omega, 307
 - parameters, 172–174
- Transoceanic communications, 2
- Transverse electromagnetic mode, coaxial lines, 42
- Tropospheric scattering, 254, 256
- Two-bit phase shifter, 138–139
- Two-port network
 - impedance matching, 55, 58
 - noise factor, 154
 - S-parameters, 40–41
- Upconverter, 132–133
- V-band communication chips, 312
- Voltage, lossless line, 22
- Voltage-controlled oscillators
 - characteristics, 174
 - frequency modulation, 279
- Voltage standing-wave ratio, 22–28
 - definition, 23
 - formulas for transmission lines, 25
 - input, antennas, 74
 - monograph, 24
- Wave equation, 14–15, 19
- Waveguides, 50–54
 - compared to transmission lines, 13
 - structures, 11
- Wave propagation, 12, 14–17
 - cylindrical coordinates, 16
 - Helmholtz equations, 15
 - Maxwell equations, 14
 - speed, 17
 - variation in time and space domains, 16–17
- Wave propagation constant, 19
- Waves, incident and reflected, 205–206
- Wilkinson coupler, 116, 118–119
- Wire, operating at different frequencies, 10–11
- Wireless cellular phones, 258–260, 262–265
- Wireless communication systems, 243–270
 - applications, 6
 - cellular phones, 258–260, 262–265
 - effective isotropic radiated power and G/T parameters, 252–254
 - Friis transmission equation, 244–247
 - link equation and link budget, 248–252
 - mobile communication systems, 258–260, 262–265
 - personal communication systems, 262–263, 266–270
 - radio/microwave links, 254–255
 - satellite communication systems, 255–258
 - space loss, 247–248
- Wireless power transmission, 7
- Wireless systems
 - applications, 6–7
 - example, 7–8
 - history, 13
- World War II, radio communications, 2
- Y -charts, *see* Smith charts
- Z -charts, *see* Smith charts