

McGraw-Hill TELECOM

E N G I N E E R I N G

SATELLITE

Communications

third edition



Dennis Roddy

Satellite Communications

ALI • *Digital Switching Systems*
ASH • *Dynamic Routing in Telecommunications Networks*
AZZAM/RANSOM • *Broadband Access Technologies*
AZZAM • *High Speed Cable Modems*
BARTLETT • *Cable Communications*
BATES • *Broadband Telecommunications Handbook*
BATES • *Optical Switching and Networking Handbook*
BAYER • *Computer Telephony Demystified*
BEDELL • *Wireless Crash Course*
CLAYTON • *McGraw-Hill Illustrated Telecom Dictionary*, Third Edition
COLLINS • *Carrier Class Voice Over IP*
DAVIS • *ATM for Public Networks*
GALLAGHER • *Mobile Telecommunications Networking with IS-41*
HARTE • *Cellular and PCS: The Big Picture*
HARTE • *CDMA IS-95*
HARTE • *GMS Superphones*
HARTE • *Delivering xDSL*
HELDMAN • *Competitive Telecommunications*
MACARIO • *Cellular Radio*, Second Edition
MULLER • *Bluetooth Demystified*
MULLER • *Desktop Encyclopedia of Telecommunications*
MULLER • *Desktop Encyclopedia of Voice and Data Networking*
MULLER • *Mobile Telecommunications Factbook*
LACHS • *Fiber Optics Communications*
LEE • *Mobile Cellular Telecommunications*, Second Edition
LEE • *Mobile Communications Engineering*, Second Edition
LEE • *Lee's Essentials of Wireless*
LOUIS • *Telecommunications Internetworking*
PATTAN • *Satellite-Based Cellular Communications*
PECAR • *Telecommunications Factbook*, Second Edition
RICHHARIA • *Satellite Communications Systems*, Second Edition
RODDY • *Satellite Communications*, Third Edition
ROHDE/WHITAKER • *Communications Receivers*, Third Edition
RUSSELL • *Signaling System #7*, Third Edition
RUSSELL • *Telecommunications Protocols*, Second Edition
RUSSELL • *Telecommunications Pocket Reference*
SHEPARD • *Telecommunications Convergence*
SHEPARD • *Optical Networking Demystified*
SIMON • *Spread Spectrum Communications Handbook*
SMITH • *Cellular System Design and Optimization*
SMITH • *Practical Cellular and PCS Design*
SMITH • *Wireless Telecom FAQs*
SMITH • *LMDS*
TURIN • *Digital Transmission Systems*
WINCH • *Telecommunications Transmission Systems*, Second Edition

Satellite Communications

Dennis Roddy

Third Edition

McGraw-Hill

New York Chicago San Francisco Lisbon London Madrid
Mexico City Milan New Delhi San Juan Seoul
Singapore Sydney Toronto

McGraw-Hill

A Division of The McGraw-Hill Companies



Copyright © 2001 by The McGraw-Hill Companies, Inc. All rights reserved. Manufactured in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written permission of the publisher.

0-07-138285-2

The material in this eBook also appears in the print version of this title: 0-07-137176-1.

All trademarks are trademarks of their respective owners. Rather than put a trademark symbol after every occurrence of a trademarked name, we use names in an editorial fashion only, and to the benefit of the trademark owner, with no intention of infringement of the trademark. Where such designations appear in this book, they have been printed with initial caps.

McGraw-Hill eBooks are available at special quantity discounts to use as premiums and sales promotions, or for use in corporate training programs. For more information, please contact George Hoare, Special Sales, at george_hoare@mcgraw-hill.com or (212) 904-4069.

TERMS OF USE

This is a copyrighted work and The McGraw-Hill Companies, Inc. ("McGraw-Hill") and its licensors reserve all rights in and to the work. Use of this work is subject to these terms. Except as permitted under the Copyright Act of 1976 and the right to store and retrieve one copy of the work, you may not decompile, disassemble, reverse engineer, reproduce, modify, create derivative works based upon, transmit, distribute, disseminate, sell, publish or sublicense the work or any part of it without McGraw-Hill's prior consent. You may use the work for your own noncommercial and personal use; any other use of the work is strictly prohibited. Your right to use the work may be terminated if you fail to comply with these terms.

THE WORK IS PROVIDED "AS IS". McGRAW-HILL AND ITS LICENSORS MAKE NO GUARANTEES OR WARRANTIES AS TO THE ACCURACY, ADEQUACY OR COMPLETENESS OF OR RESULTS TO BE OBTAINED FROM USING THE WORK, INCLUDING ANY INFORMATION THAT CAN BE ACCESSED THROUGH THE WORK VIA HYPERLINK OR OTHERWISE, AND EXPRESSLY DISCLAIM ANY WARRANTY, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. McGraw-Hill and its licensors do not warrant or guarantee that the functions contained in the work will meet your requirements or that its operation will be uninterrupted or error free. Neither McGraw-Hill nor its licensors shall be liable to you or anyone else for any inaccuracy, error or omission, regardless of cause, in the work or for any damages resulting therefrom. McGraw-Hill has no responsibility for the content of any information accessed through the work. Under no circumstances shall McGraw-Hill and/or its licensors be liable for any indirect, incidental, special, punitive, consequential or similar damages that result from the use of or inability to use the work, even if any of them has been advised of the possibility of such damages. This limitation of liability shall apply to any claim or cause whatsoever whether such claim or cause arises in contract, tort or otherwise.

DOI: 10.1036/0071382852

Contents

Preface xiii

Chapter 1. Overview of Satellite Systems	1
1.1 Introduction	1
1.2 Frequency Allocations for Satellite Services	2
1.3 Intelsat	4
1.4 U.S. Domsats	8
1.5 Polar Orbiting Satellites	11
1.6 Problems	19
Chapter 2. Orbits and Launching Methods	21
2.1 Introduction	21
2.2 Kepler's First Law	21
2.3 Kepler's Second Law	22
2.4 Kepler's Third Law	23
2.5 Definitions of Terms for Earth-Orbiting Satellites	24
2.6 Orbital Elements	27
2.7 Apogee and Perigee Heights	29
2.8 Orbital Perturbations	30
2.8.1 Effects of a Nonspherical Earth	30
2.8.2 Atmospheric Drag	35
2.9 Inclined Orbits	36
2.9.1 Calendars	37
2.9.2 Universal Time	38
2.9.3 Julian Dates	39
2.9.4 Sidereal Time	41
2.9.5 The Orbital Plane	42
2.9.6 The Geocentric-Equatorial Coordinate System	46
2.9.7 Earth Station Referred to the IJK Frame	48
2.9.8 The Topocentric-Horizon Coordinate System	53
2.9.9 The Subsatellite Point	57
2.9.10 Predicting Satellite Position	59
2.10 Sun-Synchronous Orbit	60
2.11 Problems	62

Chapter 3. The Geostationary Orbit	67
3.1 Introduction	67
3.2 Antenna Look Angles	68
3.3 The Polar Mount Antenna	75
3.4 Limits of Visibility	77
3.5 Near Geostationary Orbits	79
3.6 Earth Eclipse of Satellite	82
3.7 Sun Transit Outage	83
3.8 Launching Orbits	83
3.9 Problems	86
 Chapter 4. Radio Wave Propagation	 91
4.1 Introduction	91
4.2 Atmospheric Losses	91
4.3 Ionospheric Effects	92
4.4 Rain Attenuation	96
4.5 Other Propagation Impairments	99
4.6 Problems	99
 Chapter 5. Polarization	 101
5.1 Introduction	101
5.2 Antenna Polarization	105
5.3 Polarization of Satellite Signals	108
5.4 Cross-Polarization Discrimination	113
5.5 Ionospheric Depolarization	115
5.6 Rain Depolarization	116
5.7 Ice Depolarization	118
5.8 Problems	118
 Chapter 6. Antennas	 121
6.1 Introduction	121
6.2 Reciprocity Theorem for Antennas	122
6.3 Coordinate System	123
6.4 The Radiated Fields	124
6.5 Power Flux Density	128
6.6 The Isotropic Radiator and Antenna Gain	128
6.7 Radiation Pattern	129
6.8 Beam Solid Angle and Directivity	131
6.9 Effective Aperture	132
6.10 The Half-Wave Dipole	133
6.11 Aperture Antennas	134
6.12 Horn Antennas	139
6.13 The Parabolic Reflector	144
6.14 The Offset Feed	149
6.15 Double-Reflector Antennas	150
6.16 Shaped Reflector Systems	154
6.17 Arrays	157
6.18 Problems	161

Chapter 7. The Space Segment	167
7.1 Introduction	167
7.2 The Power Supply	167
7.3 Attitude Control	170
7.3.1 Spinning Satellite Stabilization	172
7.3.2 Momentum Wheel Stabilization	174
7.4 Station Keeping	177
7.5 Thermal Control	179
7.6 TT&C Subsystem	180
7.7 Transponders	181
7.7.1 The Wideband Receiver	183
7.7.2 The Input Demultiplexer	186
7.7.3 The Power Amplifier	186
7.8 The Antenna Subsystem	193
7.9 Morelos	196
7.10 Anik-E	199
7.11 Advanced Tiros-N Spacecraft	200
7.12 Problems	207
 Chapter 8. The Earth Segment	 209
8.1 Introduction	209
8.2 Receive-Only Home TV Systems	209
8.2.1 The Outdoor Unit	211
8.2.2 The Indoor Unit for Analog (FM) TV	212
8.3 Master Antenna TV System	212
8.4 Community Antenna TV System	213
8.5 Transmit-Receive Earth Stations	214
8.6 Problems	220
 Chapter 9. Analog Signals	 221
9.1 Introduction	221
9.2 The Telephone Channel	221
9.3 Single-Sideband Telephony	222
9.4 FDM Telephony	224
9.5 Color Television	226
9.6 Frequency Modulation	233
9.6.1 Limiters	234
9.6.2 Bandwidth	234
9.6.3 FM Detector Noise and Processing Gain	237
9.6.4 Signal-to-Noise Ratio	239
9.6.5 Preemphasis and Deemphasis	241
9.6.6 Noise Weighting	243
9.6.7 S/N and Bandwidth for FDM/FM Telephony	243
9.6.8 Signal-to-Noise Ratio for TV/FM	246
9.7 Problems	247
 Chapter 10. Digital Signals	 251
10.1 Introduction	251
10.2 Digital Baseband Signals	251

10.3	Pulse-Code Modulation	256
10.4	Time-Division Multiplexing	260
10.5	Bandwidth Requirements	261
10.6	Digital Carrier Systems	264
10.6.1	Binary Phase-Shift Keying	266
10.6.2	Quadrature Phase-Shift Keying	268
10.6.3	Transmission Rate and Bandwidth for PSK Modulation	271
10.6.4	Bit Error Rate for PSK Modulation	271
10.7	Carrier Recovery Circuits	277
10.8	Bit Timing Recovery	278
10.9	Problems	279
Chapter 11.	Error Control Coding	283
11.1	Introduction	283
11.2	Linear Block Codes	284
11.3	Cyclic Codes	285
11.3.1	Hamming codes	286
11.3.2	BCH codes	286
11.3.3	Reed-Solomon codes	286
11.4	Convolution Codes	289
11.5	Interleaving	292
11.6	Concatenated Codes	293
11.7	Link Parameters Affected by Coding	294
11.8	Coding Gain	296
11.9	Hard Decision and Soft Decision Decoding	297
11.10	Automatic Repeat Request (ARQ)	300
11.11	Problems	302
Chapter 12.	The Space Link	305
12.1	Introduction	305
12.2	Equivalent Isotropic Radiated Power	305
12.3	Transmission Losses	306
12.3.1	Free-Space Transmission	307
12.3.2	Feeder Losses	309
12.3.3	Antenna Misalignment Losses	309
12.3.4	Fixed Atmospheric and Ionospheric Losses	310
12.4	The Link Power Budget Equation	311
12.5	System Noise	311
12.5.1	Antenna Noise	313
12.5.2	Amplifier Noise Temperature	314
12.5.3	Amplifiers in Cascade	315
12.5.4	Noise Factor	317
12.5.5	Noise Temperature of Absorptive Networks	318
12.5.6	Overall System Noise Temperature	319
12.6	Carrier-to-Noise Ratio	320
12.7	The Uplink	322
12.7.1	Saturation Flux Density	322
12.7.2	Input Back Off	324
12.7.3	The Earth Station HPA	325
12.8	Downlink	326
12.8.1	Output Back Off	328
12.8.2	Satellite TWTA Output	329

12.9 Effects of Rain	330
12.9.1 Uplink rain-fade margin	331
12.9.2 Downlink rain-fade margin	332
12.10 Combined Uplink and Downlink C/N Ratio	335
12.11 Intermodulation Noise	338
12.12 Problems	340
 Chapter 13. Interference	 345
13.1 Introduction	345
13.2 Interference between Satellite Circuits (B_1 and B_2 Modes)	347
13.2.1 Downlink	349
13.2.2 Uplink	350
13.2.3 Combined [C/I] due to interference on both uplink and downlink	351
13.2.4 Antenna gain function	351
13.2.5 Passband interference	353
13.2.6 Receiver transfer characteristic	354
13.2.7 Specified interference objectives	355
13.2.8 Protection ratio	356
13.3 Energy Dispersal	357
13.4 Coordination	359
13.4.1 Interference levels	360
13.4.2 Transmission gain	361
13.4.3 Resulting noise-temperature rise	362
13.4.4 Coordination criterion	364
13.4.5 Noise power spectral density	364
13.5 Problems	365
 Chapter 14. Satellite Access	 369
14.1 Introduction	369
14.2 Single Access	370
14.3 Preassigned FDMA	370
14.4 Demand-Assigned FDMA	375
14.5 Spade System	376
14.6 Bandwidth-Limited and Power-Limited TWT Amplifier Operation	379
14.6.1 FDMA Downlink Analysis	379
14.7 TDMA	383
14.7.1 Reference Burst	387
14.7.2 Preamble and Postamble	389
14.7.3 Carrier Recovery	390
14.7.4 Network Synchronization	390
14.7.5 Unique Word Detection	395
14.7.6 Traffic Data	398
14.7.7 Frame Efficiency and Channel Capacity	398
14.7.8 Preassigned TDMA	400
14.7.9 Demand-Assigned TDMA	402
14.7.10 Speech Interpolation and Prediction	403
14.7.11 Downlink Analysis for Digital Transmission	407
14.7.12 Comparison of Uplink Power Requirements for FDMA and TDMA	408
14.8 On-Board Signal Processing for FDMA/TDM Operation	411
14.9 Satellite-Switched TDMA	414