

CONTENTS

PREFACE	xv
ACKNOWLEDGMENTS	xvii
ABOUT THE AUTHORS	xix
ABBREVIATIONS	xxi
1 INTRODUCTION	1
1.1 End-to-End Satellite Communications System	1
1.2 What the Book is About	2
1.3 Channel and Channel Sharing	3
1.4 Payload	4
1.5 Ground Transmitter and Ground Receiver	7
1.6 System Example	7
1.7 Conventions	9
1.8 Book Sources	10
1.9 Summary of Rest of Book	10
References	13

PART I PAYLOAD	15		
2 PAYLOAD'S ON-ORBIT ENVIRONMENT	17		
2.1 What Determines Environment	17		
2.2 On-Orbit Environment and Mitigation by Spacecraft Bus	25		
2.3 General Effects of Mitigated Environment on Payload	37		
References	42		
3 ANTENNA BASICS AND SINGLE-BEAM ANTENNA	46		
3.1 Introduction	46		
3.2 Examples of Single-Beam Antenna	47		
3.3 General Antenna Concepts	48		
3.4 Reflector-Antenna Basics	55		
3.5 Steerable Single-Beam Antennas	61		
3.6 Reflector Technology for Single-Beam Antennas	62		
3.7 Horn for Single-Beam Antennas	63		
3.8 Other Antenna Components	67		
3.9 Antenna Pointing Error	71		
3.10 Antenna Autotrack	73		
3.11 Reflector-Antenna Inefficiencies	76		
3.12 Testing	81		
References	84		
4 PAYLOAD-INTEGRATION ELEMENTS	90		
4.1 Introduction	90		
4.2 Coaxial Cable Versus Waveguide	90		
4.3 Coaxial Cable	91		
4.4 Waveguide	96		
4.5 Other Integration Elements	103		
4.6 Redundancy Configurations	107		
4.7 Impedance Mismatch and Scattering Parameters	111		
References	116		
5 MICROWAVE FILTER	118		
5.1 Introduction	118		
5.2 Basics of Analog Filters	119		
5.3 Basics of Specifically Microwave Filters	125		
		5.4 Technology for Bandpass Filters	130
		5.5 Filter Units	135
		5.6 Bandpass Filter Specification	141
		References	142
		6 LOW-NOISE AMPLIFIER AND FREQUENCY CONVERTER	146
		6.1 Introduction	146
		6.2 LNAs and Frequency Converters in Payload	147
		6.3 Nonlinearity of LNA and Frequency Converter	149
		6.4 Noise Figure	153
		6.5 Low-Noise Amplifier	154
		6.6 Frequency Converter	156
		6.7 Receiver	169
		6.A Appendix. Formula for Integrating Phase Noise Spectrum	170
		References	171
		7 PREAMPLIFIER AND HIGH-POWER AMPLIFIER	175
		7.1 Introduction	175
		7.2 HPA Concepts and Terms	176
		7.3 Traveling-Wave Tube Amplifier Versus Solid-State Power Amplifier	181
		7.4 Traveling-Wave Tube Subsystem	183
		7.5 Solid-State Power Amplifier	203
		References	212
		8 PAYLOAD'S ANALOG COMMUNICATIONS PARAMETERS	218
		8.1 Introduction	218
		8.2 Gain Variation with Frequency	220
		8.3 Phase Variation with Frequency	224
		8.4 Channel Bandwidth	227
		8.5 Phase Noise	227
		8.6 Frequency Stability	228
		8.7 Spurious Signals from Frequency Converter	229
		8.8 HPA Nonlinearity	230
		8.9 Near-Carrier Spurious Signals from HPA Subsystem	230
		8.10 Stability of Gain and Power-Out	232
		8.11 Equivalent Isotropically Radiated Power	233

- 8.12 Figure of Merit G/T_s 234
- 8.13 Saturation Flux Density 237
- 8.14 Self-Interference 237
- 8.15 Passive Intermodulation Products 239
- 8.A Appendices 240
- References 242

9 MORE ANALYSES FOR PAYLOAD DEVELOPMENT 243

- 9.1 Introduction 243
- 9.2 How to Deal with Noise Figure 243
- 9.3 How to Make and Maintain Payload Performance Budgets 246
- 9.4 HPA Topics 260
- 9.5 What Nonlinearity does to Modulated Signal 264
- 9.6 Simulating Payload Performance as a Function of Gaussian Random Variables 268
- References 269

10 PROCESSING PAYLOAD AND FLEXIBLE PAYLOAD 270

- 10.1 Introduction 270
- 10.2 Processing Operations 276
- 10.3 Non-Regenerative Processing Payloads 283
- 10.4 Regenerative Payloads 287
- 10.5 Communications Parameters of Digital Processing Payload 291
- References 291

11 MULTI-BEAM ANTENNA AND PHASED ARRAY 297

- 11.1 Introduction 297
- 11.2 MBA Introduction 298
- 11.3 Reflector for MBA or Contoured Beam and Configuration of Feeds 302
- 11.4 Horn and Feed Assembly for GEO 308
- 11.5 Location of Radiating Elements in Offset-Fed Reflector MBA 314
- 11.6 Single-Feed-Per-Beam MBA 317
- 11.7 Phased Array Introduction 319
- 11.8 Radiating Element of Phased Array 322
- 11.9 Beam-Forming Network 327
- 11.10 Applications of Phased Array 330

- 11.11 Beam-Hopping 333
- 11.12 Amplification of Phased Array 334
- 11.13 Phased Array Pointing Error 341
- 11.14 Mutual Coupling in Radiating-Element Cluster 342
- 11.15 Testing MBA 343
- References 344

PART II END-TO-END SATELLITE COMMUNICATIONS SYSTEM 353

12 DIGITAL COMMUNICATIONS THEORY 355

- 12.1 Introduction 355
- 12.2 Signal Representation 356
- 12.3 Filtering in General 361
- 12.4 White Gaussian Noise 363
- 12.5 End-To-End Communications System 364
- 12.6 Bit Manipulation 365
- 12.7 Modulation Introduction 369
- 12.8 Memoryless Modulation 370
- 12.9 Maximum-Likelihood Estimation 379
- 12.10 Demodulation for Memoryless Modulation 380
- 12.11 Modulation with Memory 390
- 12.12 Maximum-Likelihood Sequence Estimation 392
- 12.13 Demodulation for Modulation with Memory 393
- 12.14 Bit Recovery 394
- 12.15 Inter-Symbol Interference 395
- 12.16 SNR, E_s/N_0 , and E_b/N_0 399
- 12.A Sketch of Proof that Pulse Transform and Signal Spectrum are Related for Memoryless Modulation 402
- References 403

13 SATELLITE COMMUNICATIONS STANDARDS 405

- 13.1 Introduction 405
- 13.2 Background 406
- 13.3 Application Examples of First-Generation Standards 411
- 13.4 Second-Generation DVB Communications Standards 412
- 13.5 Satmode Communications Standard 420
- References 422

14 COMMUNICATIONS LINK	425
14.1 Introduction	425
14.2 Primary Information Sources	426
14.3 Link Availability	426
14.4 Signal Power on Link	428
14.5 Noise Level on Link	444
14.6 Interference on Link	446
14.7 End-To-End $C/(N_0 + I_0)$	456
14.8 Link Budget	458
14.9 Implementation Loss Item in Link Budget	461
References	461
15 PROBABILISTIC TREATMENT OF DOWNLINK MARGIN FOR MULTI-BEAM PAYLOAD	465
15.1 Introduction	465
15.2 Multi-Beam-Downlink Payload Specifications	466
15.3 Analysis Method	467
15.4 Analysis Assumptions	468
15.5 Repeater-Caused Variation of C and C/I_{self} and Nominal Value	469
15.6 Combining Antenna-Caused Variation and Nominal Value into Repeater-Caused Variation	476
15.7 Combining Atmosphere-Caused Variation into Payload-Caused Variation	480
15.8 Optimizing Multi-Beam-Downlink Payload Specified on Link Availability	482
15.9 Appendix. Iteration Details for Optimizing Multi-Beam Payload Specified on Link Availability	483
16 MODEL OF END-TO-END COMMUNICATIONS SYSTEM	485
16.1 Introduction	485
16.2 Considerations for Both Software Simulation and Hardware Emulation	486
16.3 Additional Considerations for Simulation	490
16.4 Additional Considerations for Emulation	501
References	504

PART III SATELLITE COMMUNICATIONS SYSTEMS	505
17 FIXED AND BROADCAST SATELLITE SERVICES	507
17.1 Introduction	507
17.2 Satellite Television	508
17.3 Regulations in General	510
17.4 Fixed Satellite Service	510
17.5 Broadcast Satellite Service	521
References	526
18 HIGH-THROUGHPUT SATELLITES	530
18.1 Introduction	530
18.2 Frequency and Bandwidth	533
18.3 Residential Internet HTS	535
18.4 VSAT Services HTS	544
References	546
19 NON-GEOSTATIONARY SATELLITE SYSTEMS	550
19.1 Introduction	550
19.2 Iridium	552
19.3 Globalstar	559
19.4 O3B	564
19.5 OneWeb	571
19.6 Starlink	577
19.7 Telesat LEO	583
References	585
20 MOBILE SATELLITE SYSTEMS IN GEO	591
20.1 Introduction	591
20.2 Thuraya	594
20.3 Inmarsat-4 and Alphasat	604
20.4 Terrestar/Echostar XXI	620
20.5 Skyterra	628
20.6 Inmarsat-5 (Global Xpress) F1-F4	637
References	647
APPENDICES	658
INDEX	672