# Contents

<table>
<thead>
<tr>
<th>List of Acronyms</th>
<th>xi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>xvii</td>
</tr>
</tbody>
</table>

## Chapter 1  Introduction to Satellite Communications  
1.1 Early History of Satellite Communications  
1.2 Some Basic Communications Satellite System Definitions  
   1.2.1 Satellite Communications Segments  
   1.2.2 Satellite Link Parameters  
   1.2.3 Satellite Orbits  
   1.2.4 Frequency Band Designations  
1.3 Regulatory Process for Satellite Communications  
1.4 Overview of Book Structure and Topics  
References  

## Chapter 2  Satellite Orbits  
2.1 Kepler’s Laws  
2.2 Orbital Parameters  
2.3 Orbits in Common Use  
   2.3.1 Geostationary Orbit  
   2.3.2 Low Earth Orbit  
   2.3.3 Medium Earth Orbit  
   2.3.4 Highly Elliptical Orbit  
   2.3.5 Polar Orbit  
2.4 Geometry of GSO Links  
   2.4.1 Range to Satellite  
   2.4.2 Elevation Angle to Satellite  
   2.4.3 Azimuth Angle to Satellite  
   2.4.4 Sample Calculation  
References  
Problems  

## Chapter 3  Satellite Subsystems  
3.1 Satellite Bus  
   3.1.1 Physical Structure  
   3.1.2 Power Subsystem  
   3.1.3 Attitude Control  
   3.1.4 Orbital Control  
   3.1.5 Thermal Control  
   3.1.6 Tracking, Telemetry, Command, and Monitoring  
References  
Problems
3.2 Satellite Payload 46
   3.2.1 Transponder 46
   3.2.2 Antennas 49
References 50

Chapter 4 The RF Link 51
4.1 Transmission Fundamentals 51
   4.1.1 Effective Isotropic Radiated Power 53
   4.1.2 Power Flux Density 53
   4.1.3 Antenna Gain 54
   4.1.4 Free-Space Path Loss 57
   4.1.5 Basic Link Equation for Received Power 59
4.2 System Noise 61
   4.2.1 Noise Figure 63
   4.2.2 Noise Temperature 65
   4.2.3 System Noise Temperature 68
   4.2.4 Figure of Merit 72
4.3 Link Performance Parameters 73
   4.3.1 Carrier-to-Noise Ratio 73
   4.3.2 Carrier-to-Noise Density 74
   4.3.3 Energy-Per-Bit to Noise Density 75
References 75
Problems 75

Chapter 5 Link System Performance 77
5.1 Link Considerations 77
   5.1.1 Fixed Antenna Size Link 78
   5.1.2 Fixed Antenna Gain Link 79
   5.1.3 Fixed Antenna Gain, Fixed Antenna Size Link 80
5.2 Uplink 81
   5.2.1 Multiple Carrier Operation 83
5.3 Downlink 84
5.4 Percent of Time Performance Specifications 84
References 86
Problems 87

Chapter 6 Transmission Impairments 89
6.1 Radiowave Frequency and Space Communications 89
6.2 Radiowave Propagation Mechanisms 91
6.3 Propagation Below About 3 GHz 93
   6.3.1 Ionospheric Scintillation 97
   6.3.2 Polarization Rotation 99
   6.3.3 Group Delay 99
   6.3.4 Dispersion 100
6.4 Propagation Above About 3 GHz 102
   6.4.1 Rain Attenuation 103
   6.4.2 Gaseous Attenuation 107
   6.4.3 Cloud and Fog Attenuation 108
# Chapter 7 Propagation Effects Modeling and Prediction

7.1 Atmospheric Gases
- 7.1.1 Leibe Complex Refractivity Model
- 7.1.2 ITU-R Gaseous Attenuation Models

7.2 Clouds and Fog
- 7.2.1 ITU-R Cloud Attenuation Model
- 7.2.2 Slobin Cloud Model

7.3 Rain Attenuation
- 7.3.1 ITU-R Rain Attenuation Model
- 7.3.2 Crane Rain Attenuation Models

7.4 Depolarization
- 7.4.1 Rain Depolarization Modeling
- 7.4.2 Ice Depolarization Modeling

7.5 Tropospheric Scintillation
- 7.5.1 Karasawa Scintillation Model
- 7.5.2 ITU-R Scintillation Model
- 7.5.3 Van De Kamp Cloud Scintillation Model

References
Problems

# Chapter 8 Rain Fade Mitigation

8.1 Power Restoral Techniques
- 8.1.1 Beam Diversity
- 8.1.2 Power Control
- 8.1.3 Site Diversity
- 8.1.4 Orbit Diversity

8.2 Signal Modification Restoral Techniques
- 8.2.1 Frequency Diversity
- 8.2.2 Bandwidth Reduction
- 8.2.3 Time-Delayed Transmission Diversity
- 8.2.4 Adaptive Coding and Modulation

8.3 Summary
References
Problems

# Chapter 9 The Composite Link

9.1 Frequency Translation (FT) Satellite
- 9.1.1 Uplink
- 9.1.2 Downlink
CONTENTS

9.1.3 Composite Carrier-to-Noise Ratio 245
9.1.4 Performance Implications 249
9.1.5 Path Losses and Link Performance 250
9.2 On-Board Processing (OBP) Satellite 255
  9.2.1 OBP Uplink and Downlink 255
  9.2.2 Composite OBP Performance 256
9.3 Comparison of FT and OBP Performance 258
9.4 Intermodulation Noise 261
9.5 Link Design Summary 263
References 264
Problems 264

Chapter 10  Satellite Multiple Access 267
10.1 Frequency Division Multiple Access 270
  10.1.1 PCM/TDM/PSK/FDMA 271
  10.1.2 PCM/SCPC/PSK/FDMA 273
10.2 Time Division Multiple Access 274
  10.2.1 PCM/TDM/PSK/TDMA 276
  10.2.2 TDMA Frame Efficiency 277
  10.2.3 TDMA Capacity 278
  10.2.4 Satellite Switched TDMA 281
10.3 Code Division Multiple Access 284
  10.3.1 Direct Sequence Spread Spectrum 287
  10.3.2 Frequency Hopping Spread Spectrum 291
  10.3.3 CDMA Processing Gain 292
  10.3.4 CDMA Capacity 294
References 296
Problems 296

Chapter 11  The Mobile Satellite Channel 299
11.1 Mobile Channel Propagation 300
  11.1.1 Reflection 301
  11.1.2 Diffraction 301
  11.1.3 Scattering 302
11.2 Narrowband Channel 304
  11.2.1 Path Loss Factor 307
  11.2.2 Shadow Fading 310
  11.2.3 Multipath Fading 317
  11.2.4 Blockage 324
  11.2.5 Mixed Propagation Conditions 329
11.3 Wideband Channel 332
11.4 Multi-Satellite Mobile Links 334
  11.4.1 Uncorrelated Fading 334
  11.4.2 Correlated Fading 336
References 338

Appendix A  Satellite Signal Processing Elements 339
A.1 Analog Systems 340
  A.1.1 Analog Baseband Formatting 340
<table>
<thead>
<tr>
<th>CONTENTS</th>
<th>ix</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1.2 Analog Source Combining</td>
<td>342</td>
</tr>
<tr>
<td>A.1.3 Analog Modulation</td>
<td>343</td>
</tr>
<tr>
<td>A.2 Digital Baseband Formatting</td>
<td>347</td>
</tr>
<tr>
<td>A.3 Digital Source Combining</td>
<td>352</td>
</tr>
<tr>
<td>A.4 Digital Carrier Modulation</td>
<td>353</td>
</tr>
<tr>
<td>A.4.1 Binary Phase Shift Keying</td>
<td>356</td>
</tr>
<tr>
<td>A.4.2 Quadrature Phase Shift Keying</td>
<td>359</td>
</tr>
<tr>
<td>A.4.3 Higher Order Phase Modulation</td>
<td>361</td>
</tr>
<tr>
<td>A.5 Summary</td>
<td>362</td>
</tr>
<tr>
<td>References</td>
<td>362</td>
</tr>
</tbody>
</table>

**Appendix B**  
Error Functions and Bit Error Rate  
363

B.1 Error Functions  
363

B.2 Approximation for BER  
365

Index  
367