Contents

Preface xv

Acknowledgments xvii

Chapter 1 Introduction 1
  1.1 A Brief History of Land-Mobile Radio Communication 1
  1.2 Outline of Chapter Contents 3

Chapter 2 Free-Space Propagation 7
  2.1 Free-Space Transmission Loss 7
  2.2 Far-Field Qualification 8
  2.3 Additional Line-of-Sight Attenuation Factors 8
  2.4 Antenna Gain Units 10
  2.5 Additional Antenna Terminology 10
  2.6 Field Strength 12
  2.7 Example Problem: Spurious Power Emission 13
  2.8 Homework Problems
    2.8.1 Problem 1 14
    2.8.2 Problem 2 14
    2.8.3 Problem 3 15

Chapter 3 Additional Transmission Loss Relations 19
  3.1 Plane Earth Propagation Model 19
  3.2 Meteor Scatter Propagation Model 21
  3.3 Power-Law Propagation 22
  3.4 Homework Problem 23

Chapter 4 Noise Considerations 25
  4.1 Additive White Gaussian Noise 25
  4.2 Noise Equivalent Bandwidth 26
  4.3 Noise Figure 26
  4.4 Y-Factor Measurement 28
  4.5 System Noise Figure and G/T 29
Chapter 5  Sample Radio Link Analyses  
5.1 Satellite TVRO Link Analysis  
5.2 Land-Mobile Radio Link Analysis  
5.2.1 Example 1  
5.2.2 Example 2  
5.3 Homework Problem  

Chapter 6  Character of Land-Mobile Radio Propagation  
6.1 Power-Law Propagation Regime  
6.2 Lognormal-Shadowing Propagation Regime  
6.3 Rayleigh-Fading Propagation Regime  
6.4 Summary  
6.5 Homework Problem  

Chapter 7  Probability Theory Refresher  
7.1 What Is Probability?  
7.1.1 Axiomatic  
7.1.2 Relative Frequency  
7.1.3 Classical  
7.1.4 Measure of Belief  
7.2 Operations with Events  
7.3 Probability Laws  
7.4 Concept of the Random Variable  
7.4.1 Definitions  
7.4.2 Distribution Function  
7.4.3 Density Function  
7.5 Mathematical Expectation  
7.5.1 Expected Value  
7.5.2 Conditional Expected Value  
7.5.3 Variance  
7.5.4 General Moments  
7.5.5 Characteristic Functions  
7.6 Sample Applications  
7.6.1 Gaussian (Normal) Density Function  
7.6.2 Gaussian Distribution Function  
7.6.3 Mean of Gaussian Random Variable  
7.6.4 Variance of Gaussian Random Variable  
7.6.5 Linear Transformation of a Gaussian Random Variable  
7.6.6 Moments of a Rayleigh Random Variable
## Contents

7.6.7 Moments of an Exponential Random Variable 69  
7.6.8 Conditional Expectation Example 69  
7.6.9 Analysis of Peak-to-Average Power Ratio for Speech 70  
7.6.10 Moments of a Rician-Distributed Random Variable 72  
7.6.11 Analysis of Battery Savings Potential Using Power Control 75  

7.7 Homework Problems 78  
7.7.1 Problem 1 78  
7.7.2 Problem 2 79  
7.7.3 Problem 3 80  

### Chapter 8 Central Limit Theorem 85

8.1 Sum of Many Independent, Identically Distributed Random Variables 85  
8.2 Rapidity of Convergence 87  
8.3 Central Limit Theorem 89  
8.4 Homework Problems 89  
8.4.1 Problem 1 89  
8.4.2 Problem 2 90  
8.4.3 Problem 3 92  

### Chapter 9 Probability Theory Refresher, Continued 93

9.1 Functions of a Single Continuous Random Variable 93  
9.2 Extension of Random Variable Concept to Two Variables 94  
9.3 Sample Applications 95  
9.3.1 Sum of Two Random Variables 95  
9.3.2 Square Root of Sum of Squares of Two Random Variables 97  
9.3.3 Maximum of Two Random Variables 97  
9.4 Estimation of Distribution Parameters 99  
9.4.1 Rayleigh-Distribution Parameter 99  
9.4.2 Lognormal Distribution Parameters 101  
9.4.3 Maximum Likelihood Estimation in General 102  
9.5 Other Aspects of Rayleigh Fading 103  
9.5.1 Level Crossing Rate 103  
9.5.2 Average Fade Duration 104  
9.5.3 Test of Distribution 106  
9.6 Homework Problems 110  
9.6.1 Problem 1 110  
9.6.2 Problem 2 111  
9.6.3 Problem 3 112  
9.6.4 Problem 4 114  

### Chapter 10 Coverage Analysis and Simulation 121
10.1 Area Coverage with Power-Law Propagation and Lognormal Shadowing 121
10.2 Impact of Rayleigh Fading on Coverage 122
10.3 Analysis of Composite Rayleigh-Lognormal Distribution 124
10.3.1 Mean and Standard Deviation of Power in Decibels for Rayleigh-Faded Signal 124
10.3.2 Mean and Standard Deviation of Power in Decibels for Rayleigh plus Lognormal-Faded Signal 125
10.3.3 Composite Distribution Function 125
10.3.4 Monte Carlo Simulation Results 128
10.3.5 Regression Analysis 130
10.4 Measurement of Trunked System Subscriber Unit Signal Characteristics 133
10.4.1 Acquiring Information about the ISW 133
10.4.2 Estimating the Subscriber Unit Transmit Frequency 133
10.4.3 Estimating the Subscriber Unit Range 134
10.4.4 Measured Results 136
10.5 Adjacent Channel Interference Considerations in the Land-Mobile Radio Service 138
10.6 Spectrum Efficiency Potential of 25-kHz Offset Channel Assignments in the 821-to 824- and 866- to 869-MHz Public Safety Bands 142
10.6.1 Geographic Separation Requirements 142
10.6.2 Channel Assignment Procedure 145
10.7 Interference Potential of Cordless Telephone Sharing with Public Safety Band Users 147
10.8 Further Sharing of UHF Television by Private Land-Mobile Radio Services 149
10.8.1 Cochannel Sharing 150
10.8.2 Noncochannel Sharing 158
10.9 800-MHz SMR Cochannel Spacing 159
10.9.1 Summary 159
10.9.2 FCC Spacing Rules and Engineering Justification 162
10.9.3 Probability of Interference Analysis 163
10.9.4 Discussion of the Shortcomings 165
10.9.5 Alternative Interference Analysis 167
10.9.6 Equivalent Short-Spacing Methodologies 168
10.10 Cellular System Operation 170
10.10.1 The Cellular Concept 170
10.10.2 Call Control and Handoff 171
10.10.3 Reuse Patterns and Performance 175
10.10.4 Cochannel Isolation Characteristics 176
10.10.5 Spectrum Efficiency Measures 179
10.10.6 Generation of Correlated Signal Strength Draws for Multiple Site Reuse System Simulations 180

10.11 Analysis of Intermodulation Interference 183
  10.11.1 Wide-Area Coverage Site Receiver Intermodulation Probability 184
  10.11.2 Small-Area Coverage Site (Cellular) Receiver Intermodulation Probability 185
  10.11.3 Transmitter IM 188

10.12 Homework Problems 189
  10.12.1 Problem 1 189
  10.12.2 Problem 2 190
  10.12.3 Problem 3 192
  10.12.4 Problem 4 192
  10.12.5 Problem 5 193
  10.12.6 Problem 6 195
  10.12.7 Problem 7 196
  10.12.8 Problem 8 197

Chapter 11 Diversity 205

  11.1 Classification of Techniques 205
    11.1.1 Space Diversity 205
    11.1.2 Polarization Diversity 207
    11.1.3 Angle Diversity 207
    11.1.4 Frequency Diversity 207
    11.1.5 Time Diversity 208
    11.1.6 Other Techniques 208
  11.2 Selection Diversity Combining 208
  11.3 Maximal-Ratio Combining 209
  11.4 Analysis of a Special Form of Selection Diversity 212
  11.5 Homework Problems 216
    11.5.1 Problem 1 216
    11.5.2 Problem 2 216

Chapter 12 Simulcast 221

  12.1 Description 221
  12.2 Two-Signal Frequency Modulation Simulcast Analysis 222
  12.3 Capture Analyses 224
    12.3.1 Independent Rayleigh Fading, Fixed Average Power, Envelope Analysis 224
    12.3.2 Independent Rayleigh Fading, Fixed Average Power, Power Analysis 225
12.3.3 Independent Rayleigh Fading, Fixed Average Power, Envelope Analysis Including Threshold 226
12.3.4 Independent Lognormal Fading, Power Analysis Including Threshold 227
12.3.5 Independent Rayleigh Fading with Independent Lognormal Fading of Average Power, Power Analysis Including Threshold 228
12.4 Computer Simulation of Analog FM Simulcast Performance 229
12.5 Rapid, Robust Method for Establishing Signal Quality 234
12.5.1 Algorithm for Estimating Amplitude and Phase of a Sinusoid 234
12.5.2 Simulated Performance 235
12.5.3 Application: Automated Measurements of Delivered Audio Quality 237
12.6 Computer Simulation of Digital Simulcast Coverage 240
12.6.1 Approximate Methods for Reducing Multisite Problems to Two-Site Problems 240
12.6.2 Multipath Spread Model 241
12.6.3 Comparisons of Model Performance 245
12.6.4 Use of the Multipath Spread Model in Coverage Predictions 246
12.7 Homework Problem 246

Chapter 13 Traffic Engineering 249
13.1 Message Length Characteristics 249
13.2 Traffic Load Estimation 253
13.2.1 Nominal System Peak Load 253
13.2.2 System-to-System Variation of Peak Load 255
13.2.3 Day-to-Day Variation of Peak Load 257
13.2.4 Interconnect and Mixed Traffic Loads 257
13.3 Grade-of-Service Evaluation 260
13.3.1 Blocked Calls Lost, Erlang-B Viewpoint 260
13.3.2 Blocked Calls Delayed, Erlang-C Viewpoint 263
13.3.3 Poisson Viewpoint 264
13.3.4 Application to Trunked Dispatch Grade of Service 265
13.4 Trunked System Control Channel Performance 267
13.4.1 Introduction 267
13.4.2 Example Control Channel Operation 267
13.4.3 Simulation Description 268
13.4.4 Simulation Results 270
13.4.5 Experiment Description 270
13.4.6 Experiment Results 272
13.5 Analysis of Trunked System Performance with Load Shedding 273
13.6 Analysis of Group Call Access Delay 275
13.6.1 Introduction 275
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.5.4 Threshold-and-Below Noise</td>
<td>327</td>
</tr>
<tr>
<td>15.5.5 Overall Fading Performance</td>
<td>328</td>
</tr>
<tr>
<td>15.5.6 Random FM Noise</td>
<td>328</td>
</tr>
<tr>
<td>15.5.7 Alternative View of Overall Fading Performance</td>
<td>330</td>
</tr>
<tr>
<td>15.6 Performance in the Presence of Noise, Interference, and Rayleigh</td>
<td></td>
</tr>
<tr>
<td>Fading</td>
<td>331</td>
</tr>
<tr>
<td>15.7 Homework Problems</td>
<td>332</td>
</tr>
<tr>
<td>15.7.1 Problem 1</td>
<td>332</td>
</tr>
<tr>
<td>15.7.2 Problem 2</td>
<td>333</td>
</tr>
<tr>
<td>Chapter 16 Building Shadowing Adjustment Model Investigation</td>
<td>341</td>
</tr>
<tr>
<td>16.1 Introduction</td>
<td>341</td>
</tr>
<tr>
<td>16.1.1 The Problem</td>
<td>341</td>
</tr>
<tr>
<td>16.1.2 Prior Art</td>
<td>342</td>
</tr>
<tr>
<td>16.1.3 Chicago Building Database</td>
<td>343</td>
</tr>
<tr>
<td>16.2 Artificial Neural Network Models</td>
<td>345</td>
</tr>
<tr>
<td>16.2.1 Brief Tutorial on Artificial Neural Networks</td>
<td>345</td>
</tr>
<tr>
<td>16.2.2 Artificial Neural Network Software</td>
<td>349</td>
</tr>
<tr>
<td>16.2.3 Artificial Neural Network Model Performance</td>
<td>351</td>
</tr>
<tr>
<td>16.3 Group Classification Models</td>
<td>354</td>
</tr>
<tr>
<td>16.4 Linear Regression Models</td>
<td>357</td>
</tr>
<tr>
<td>16.5 Conclusions</td>
<td>358</td>
</tr>
<tr>
<td>16.6 Homework Problem</td>
<td>358</td>
</tr>
<tr>
<td>Index</td>
<td>365</td>
</tr>
</tbody>
</table>