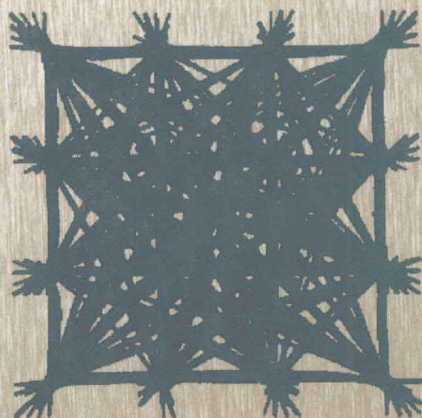
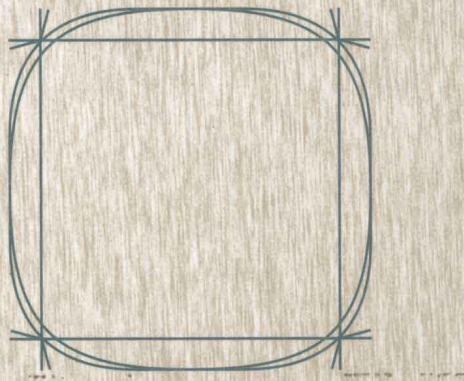
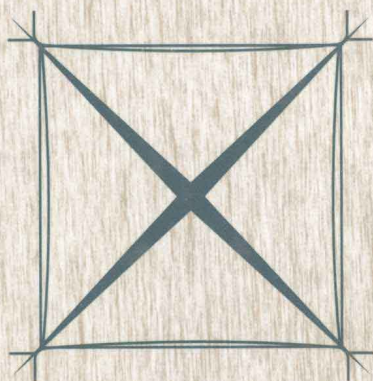


INTRODUCTION TO
DIGITAL
COMMUNICATION
SECOND EDITION



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INTRODUCTION TO DIGITAL COMMUNICATION

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Preface

The philosophy of this book remains the same as that of the first edition, in particular to provide an introduction to the essentials of digital communications based on sound mathematical underpinnings and anchored in the literature of the various topics considered. After providing a treatment of the basic theory of digital modulation and coding in the first eight chapters, the three additional specialized areas of spread spectrum, cellular, and satellite communications are given one-chapter overviews. The intent is to not only provide firm foundation in the basic theory of digital communications, but to give an introduction to three areas that have provided the basis of a number of applications in recent years and show avenues of research that are currently receiving much attention. For example, spread-spectrum communications includes the subareas of code families with good correlation properties, multiuser detection, and ultra wideband communications for resolving multipath channels. Cellular radio provides a host of research areas, such as capacity optimization of multiuser communication systems and means for accommodating mixed-rate traffic. Satellite communications has enjoyed a resurgence of interest with the proposed (with one realized) low-earth orbit mobile voice communication systems, satellite navigational systems, and small aperture antenna system applications. With this philosophy, we feel that both the needs of the practicing engineer in the communications industry and the senior/beginning graduate student are met. The former is provided with a means to review or self-study a topic of importance on the job, and the latter is provided background in basic theory with an introduction to possible topics for further research.

Virtually all electrical engineering programs include a course on linear systems in the junior year, and this book is written under that assumption. However, since the content of these linear systems courses varies from program to program, an overview of linear systems is included in Chapter 2. An additional reason for providing this information is to set notation and define special signals used throughout the book.

Another assumption of the authors is that the typical student taking a course using this book will have had a junior-level course on probability. Often such courses contain additional topics from statistics and random processes. However, since coverage of these topics varies from program to program, the necessary material on random processes for this book is included in Chapter 2. For those students that may not have had a prior course on probability, our recommendation is that one be taken before a course taught using this book is taken. However, for very diligent students who may not wish to do this, or whose

probability course was taken in the distant past, Appendix A of this book provides a brief overview of the necessary topics from probability. This material may be reviewed in conjunction with Chapter 1 and will not be needed until the latter part of Chapter 2, where random processes are covered.

After an introduction to the general features of digital communication systems, Chapter 1 includes an overview of channel characteristics and an introduction to link power calculations. The latter subject is returned to in Chapters 10 and 11 in conjunction with a consideration of cellular radio and satellite communication links, respectively. The introduction of this subject in Chapter 1 provides a link between performance requirements of communication systems in terms of signal-to-noise ratio at the receiver input and the requirements of transmitter power implied by the performance desired and the channel attenuation characteristics.

As already mentioned, Chapter 2 is a review of signal and system theory, analog modulation, and random processes. In addition to providing definitions of basic signals and setting notation, a very simple simulation of noise through a linear system (Butterworth digital filter) is illustrated by an example. This sets the context for simulation of a simple digital communication system illustrated by example in Chapter 3. The student is then encouraged to do his or her own simulations in several problems of Chapter 3.

In Chapter 3, the subject of digital data transmission is introduced. The receiver structure assumed is that of a linear filter followed by a threshold detector. Optimization of the receiver filter through maximization of peak signal-to-root-mean-square noise ratio at its output leads to the concept of the classic matched filter receiver. The data transmission schemes considered are binary. Although the channel is initially considered to be of infinite bandwidth, optimum systems for the strictly bandlimited case are eventually considered. Equalization methods for compensating for intersymbol interference introduced by bandlimiting in the channel are next considered. The chapter ends with a brief consideration of signal design for bandlimited channels and noise effect in pulse-code modulation systems.

The purpose of Chapter 4 is to provide a sound theoretical basis for the digital modulation systems introduced in Chapter 3, as well as to extend the results in several directions. The approach used is that of Bayes's detection couched in the language of signal space. The background noise is assumed to be additive and white, which allows the use of any orthogonal basis function set that spans the signal space, giving a very clear geometric picture of the digital signal reception process. As an extension of Chapter 3, Chapter 4 considers M -ary digital data transmission and the explicit treatment of modulation schemes suitable for practical channels. The concepts of equivalent bit error probability and bandwidth efficiency in terms of bits per second per hertz of bandwidth are introduced in order to provide a basis of comparison of M -ary systems. The chapter ends with several example design problems and a basic introduction to orthogonal frequency division multiplexing.

Building on the ideal systems covered in Chapter 4, Chapter 5 takes up several topics that can be considered degradation sources for those ideal systems. Synchronization methods at various levels (i.e., carrier, bit, and frame) are discussed, and the degradation imposed by imperfect carrier synchronization is characterized. Fading channel effects are

characterized and diversity transmission for combating them is discussed. The chapter ends by discussing envelope plots, eye diagrams, and phasor plots as means to characterize communication system performance and their generation by computer simulation is illustrated.

Chapters 6 through 8 take up the subject of coding, with the elements of information theory and block coding considered in Chapter 6 and the elements of convolutional coding considered in Chapter 7. Theoretical foundations are provided, but the major underlying objective of Chapters 6 and 7 is always one of system applications. All coding techniques considered in Chapters 6 and 7 are characterized in terms of their ability to lower the signal-to-noise ratio required to achieve a desired probability of bit error (power efficiency) and the bits per second that can be supported per hertz of bandwidth (bandwidth efficiency). Chapter 8 provides a brief treatment of another error control scheme called automatic repeat request (ARQ), which utilizes a feedback channel.

Chapter 9 contains an overview of spread-spectrum communications. The important concept of multiuser detection is considered where, when signals from multiple users are being received, the detection process takes into account their statistical characteristics and the improvement of detector performance over what could be obtained if the other-user signals were treated as noise.

Chapter 10 deals with cellular radio communications. The cellular concept is introduced along with the major degradations experienced in such systems including other-user interference and multipath fading. First- and second-generation cellular systems are discussed and provide an excellent example of a case where the move has been made from analog to digital transmission for several reasons.

Chapter 11 treats satellite communications as an example where digital communications concepts and applications have come into extensive use over the years. The concepts are illustrated with several design examples. Characteristics of several low-earth orbit satellite communication systems for mobile phone communications are summarized.

The first edition of this book has been used successfully to teach courses on digital communications to ambitious undergraduates and first-year graduate students for several years. Typically, after the introduction provided in Chapter 1 is covered, basic digital modulation theory and coding (Chapters 3–7) are covered after spending some time on signal, system, and random process review. The use of computer simulation is emphasized from the start, with the assignment at about mid-semester of a computer simulation project to be worked on throughout the semester. Weekly problem sets are assigned and graded. An in-class closed-book midterm examination is given to encourage students to become intimately familiar with basic random process, modulation and digital detection principles (usually, this occurs at the end of Chapter 3). Depending on the scope of the computer project and the initiative shown by the class, a final examination may or may not be given.

We wish to thank the many persons who have contributed either directly or indirectly to this book. These include our colleagues at various locations throughout the world. We specifically thank David Kisak of SAIC for his careful review and constructive criticism of Chapters 6 through 8, Nick Alexandru for his corrections of several examples in the first edition, Jerry Brand of Harris Corporation and John Haug of Motorola for their

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Any errors or shortcomings that remain are the responsibility of the authors.

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Rodger Ziemer
Roger Peterson
January 17, 2000

Contents

Preface	xvii
1 Introduction to Digital Data Transmission	1
1.1 <i>Introduction</i>	1
1.2 <i>Components of a Digital Communication System</i>	5
1.2.1 General Considerations	5
1.2.2 Subsystems in a Typical Communication System	5
1.2.3 Capacity of a Communications Link	8
1.3 <i>Communications Channel Modeling</i>	11
1.3.1 Introduction	11
1.3.2 Specific Examples of Communication Channels	11
1.3.2.1 Propagation Channels	11
1.3.2.2 Land Line	13
1.3.2.3 Compact Disc (CD) Channels	14
1.3.3 Approaches to Communication Channel Modeling	15
1.3.3.1 Discrete Channel Approach	15
1.3.3.2 Waveform Description of Communication Channels	16
1.3.4 Interference and Distortion in Communication Channels	17
1.3.5 External Channel Propagation Considerations	24
1.4 <i>Communication Link Power Calculations</i>	25
1.4.1 Decibels in Communication System Performance Calculations	25
1.4.2 Calculation of Power Levels in Communication Systems; Link Budgets	26
1.5 <i>Driving Forces in Communications</i>	31
1.6 <i>Computer Use in Communication System Analysis and Design</i>	32
1.7 <i>Preview of the Book</i>	33
References	35
Problems	36

2	Signals, Systems, Modulation, and Noise: Overview	41
2.1	<i>Review of Signal and Linear System Theory</i>	41
2.1.1	Introduction	41
2.1.2	Classification of Signals	41
2.1.3	Fundamental Properties of Systems	42
2.1.4	Complex Exponentials as Eigenfunctions for a Fixed, Linear System; Frequency Response Function	44
2.1.5	Orthogonal Function Series	45
2.1.6	Complex Exponential Fourier Series	47
2.1.7	The Fourier Transform	51
2.1.8	Signal Spectra	53
2.1.9	Energy Relationships	53
2.1.10	System Analysis	55
2.2	<i>Basic Analog Modulation Techniques</i>	56
2.2.1	Double-Sideband Modulation	56
2.2.2	The Hilbert Transform; Single-Sideband Modulation	57
2.2.3	Angle Modulation	60
2.3	<i>Complex Envelope Representation of Bandpass Signals and Systems</i>	65
2.3.1	Bandpass Signals	65
2.3.2	Bandpass Systems	67
2.4	<i>Signal Distortion and Filtering</i>	70
2.4.1	Distortionless Transmission and Ideal Filters	70
2.4.2	Group and Phase Delay	70
2.4.3	Nonlinear Systems and Nonlinear Distortion	79
2.5	<i>Practical Filter Types and Characteristics</i>	82
2.5.1	General Terminology	82
2.5.2	Butterworth Filters (Maximally Flat)	85
2.5.3	Chebyshev Filters (Equal Ripple)	86
2.5.4	Bessel (Maximally Flat Delay) Filters	88
2.6	<i>Sampling Theory</i>	88
2.6.1	The Lowpass Sampling Theorem	89
2.6.2	Nonideal Effects in Sampling	92
2.6.3	Sampling of Bandpass Signals	92
2.6.4	Oversampling and Downsampling to Ease Filter Requirements	94
2.6.5	Pulse Code Modulation	94
2.6.6	Differential Pulse Code Modulation	98
2.7	<i>Random Processes</i>	98
2.7.1	Mathematical Description of Random Processes	98
2.7.2	Input-Output Relationships for Fixed Linear Systems with Random Inputs; Power Spectral Density	105

2.7.2.1	Partial Descriptions	105
2.7.2.2	Output Statistics of Linear Systems	108
2.7.2.3	The Central and Noncentral Chi-Square Distributions	112
2.7.3	Examples of Random Processes	112
2.7.4	Narrowband Noise Representation	114
2.7.5	Distributions of Envelopes of Narrowband Gaussian Processes	117
2.8	<i>Computer Generation of Random Variables</i>	119
2.8.1	Introduction	119
2.8.2	Generation of Random Variables Having a Specific Distribution	120
2.8.3	Spectrum of a Simulated White Noise Process	122
2.8.4	Generation of Pseudo-Noise Sequences	125
2.9	<i>Summary</i>	129
	References	133
	Problems	134
3	Basic Digital Communication Systems	141
3.1	<i>Introduction</i>	141
3.2	<i>The Binary Digital Communications Problem</i>	141
3.2.1	Binary Signal Detection in AWGN	141
3.2.2	The Matched Filter	145
3.2.3	Application of the Matched Filter to Binary Data Detection	148
3.2.3.1	General Formula for P_E	148
3.2.3.2	Antipodal Baseband Signaling	150
3.2.3.3	Baseband Orthogonal Signaling	150
3.2.3.4	Baseband On-Off Signaling	151
3.2.4	Correlator Realization of Matched Filter Receivers	154
3.3	<i>Signaling Through Bandlimited Channels</i>	155
3.3.1	System Model	155
3.3.2	Designing for Zero ISI: Nyquist's Pulse-Shaping Criterion	157
3.3.3	Optimum Transmit and Receive Filters	160
3.3.4	Shaped Transmit Signal Spectra	164
3.3.5	Duobinary Signaling	166
3.4	<i>Equalization in Digital Data Transmission</i>	168
3.4.1	Introduction	168
3.4.2	Zero-Forcing Equalizers	169
3.4.3	Minimum Mean-Square Error Equalization	173
3.4.4	Adaptive Weight Adjustment	177
3.4.5	Other Equalizer Structures	182
3.4.6	Equalizer Performance	183

3.5	<i>A Digital Communication System Simulation Example</i>	184
3.6	<i>Noise Effects in Pulse Code Modulation</i>	190
3.7	<i>Summary</i>	194
	References	195
	Problems	196
4	Signal-Space Methods in Digital Data Transmission	199
4.1	<i>Introduction</i>	199
4.2	<i>Optimum Receiver Principals in Terms of Vector Spaces</i>	202
4.2.1	Maximum a Posteriori Detectors	202
4.2.2	Vector Representation of Signals	205
4.2.2.1	<i>K</i> -Dimensional Signal Space	
	Representation of the Received Waveform	206
4.2.2.2	Scalar Product	206
4.2.2.3	Gram-Schmidt Procedure	207
4.2.2.4	Schwarz's Inequality	209
4.2.2.5	Parseval's Theorem	210
4.2.3	MAP Detectors in Terms of Signal Spaces	212
4.2.4	Performance Calculations for MAP Receivers	215
4.3	<i>Performance Analysis of Coherent Digital Signaling Schemes</i>	219
4.3.1	Coherent Binary Systems	219
4.3.2	Coherent <i>M</i> -ary Orthogonal Signal Schemes	220
4.3.3	<i>M</i> -ary Phase-Shift Keying	224
4.3.4	Quadrature-Amplitude Modulation	227
4.4	<i>Signaling Schemes Not Requiring Coherent References at the Receiver</i>	232
4.4.1	Noncoherent Frequency-Shift Keying (NFSK)	232
4.4.2	Differential Phase-Shift Keying (DPSK)	235
4.5	<i>Comparison of Digital Modulation Systems</i>	241
4.5.1	Bit Error Probabilities from Symbol Error Probabilities	243
4.5.2	Bandwidth Efficiencies of <i>M</i> -ary Digital Communication Systems	244
4.6	<i>Comparison of <i>M</i>-ary Digital Modulation Schemes on Power and Bandwidth-Equivalent Bases</i>	245
4.6.1	Coherent Digital Modulation Schemes	245
4.6.2	Noncoherent Digital Modulation Schemes	247
4.7	<i>Some Commonly Used Modulation Schemes</i>	248
4.7.1	Quadrature-Multiplexed Signaling Schemes	249
4.7.1.1	Quadrature Multiplexing	249
4.7.1.2	Quadrature and Offset-Quadrature Phase-Shift Keying	251
4.7.1.3	Minimum-Shift Keying	254

4.7.1.4	Performance of Digital Quadrature Modulation Systems	254
4.7.2	Gaussian MSK	258
4.7.3	$\pi/4$ -Differential QPSK	258
4.7.4	Power Spectra for Quadrature Modulation Schemes	261
4.8	<i>Design Examples and System Tradeoffs</i>	266
4.9	<i>Multi-h Continuous Phase Modulation</i>	271
4.9.1	Description of the Multi-h CPM Signal Format	271
4.9.2	Calculation of Power Spectra for Multi-h CPM Signals	276
4.9.3	Synchronization Considerations for Multi-h CPM Signals	282
4.10	<i>Orthogonal Frequency Division Multiplexing</i>	284
4.10.1	Introduction	284
4.10.2	The Idea behind OFDM	286
4.10.3	Mathematical Description of DFT-Implemented OFDM	286
4.10.4	Effect of Fading on OFDM Detection	291
4.10.5	Parameter Choices and Implementation Issues in OFDM	293
4.10.5.1	OFDM Symbol Rate for Combating Delay Spread	293
4.10.5.2	Realizing Diversity in OFDM	294
4.10.5.3	Implementation Issues	295
4.10.6	Simulation of OFDM Waveforms	295
4.11	<i>Summary</i>	296
	References	299
	Problems	301
5	Channel Degradations In Digital Communications	307
5.1	<i>Introduction</i>	307
5.2	<i>Synchronization in Communication Systems</i>	307
5.2.1	Carrier Synchronization	308
5.2.2	Symbol Synchronization	317
5.2.3	Frame Synchronization	319
5.3	<i>The Effects of Slow Signal Fading in Communication Systems</i>	321
5.3.1	Performance of Binary Modulation Schemes in Rayleigh Fading Channels	321
5.3.1.1	Introduction	321
5.3.1.2	Bit Error Probability Performance in Slow Rayleigh Fading	322
5.3.1.3	The Use of Path Diversity to Improve Performance in Fading	324
5.3.1.4	DPSK Performance in Moderately Fast Rayleigh Fading	329

5.3.2	Performance of M -ary Modulation Schemes in Slow Fading	332
5.3.2.1	Introduction	332
5.3.2.2	M -ary PSK and DPSK Performance in Slow Rayleigh Fading	333
5.3.2.3	M -ary PSK and DPSK Performance in Slow Ricean Fading	336
5.3.2.4	M -ary QAM Performance in Slow Rayleigh Fading	338
5.3.2.5	M -ary Noncoherent FSK Performance in Slow Ricean Fading	341
5.3.3	M -ary PSK and DPSK Performance in Slow Fading with Diversity	342
5.3.3.1	Rayleigh Fading	342
5.3.3.2	Ricean Fading	344
5.4	<i>Diagnostic Tools for Communication System Design</i>	349
5.4.1	Introduction	349
5.4.2	Eye Diagrams	350
5.4.3	Envelope Functions for Digital Modulation Methods	351
5.4.4	Phasor Plots for Digital Modulation Systems	353
5.5	<i>Summary</i>	358
	References	361
	Problems	362
6	Fundamentals of Information Theory and Block Coding	366
6.1	<i>Introduction</i>	366
6.2	<i>Basic Concepts of Information Theory</i>	368
6.2.1	Source Coding	368
6.2.2	Lempel-Ziv Procedures	374
6.2.3	Channel Coding and Capacity	384
6.2.3.1	General Considerations	384
6.2.3.2	Shannon's Capacity Formula	385
6.2.3.3	Capacity of Discrete Memoryless Channels	387
6.2.3.4	Computational Cutoff Rate	391
6.3	<i>Fundamentals of Block Coding</i>	394
6.3.1	Basic Concepts	395
6.3.3.1	Definition of a Block Code	395
6.3.3.2	Hamming Distance and Hamming Weight	395
6.3.3.3	Error Vectors	397
6.3.3.4	Optimum Decoding Rule	398
6.3.3.5	Decoding Regions and Error Probability	400
6.3.3.6	Coding Gain	402
6.3.3.7	Summary	403
6.3.2	Linear Codes	404
6.3.2.1	Modulo-2 Vector Arithmetic	404

6.3.2.2	Binary Linear Vector Spaces	406
6.3.2.3	Linear Block Codes	408
6.3.2.4	Systematic Linear Block Codes	411
6.3.2.5	Distance Properties of Linear Block Codes	412
6.3.2.6	Decoding Using the Standard Array	413
6.3.2.7	Error Probabilities for Linear Codes	417
6.3.3	Cyclic Codes	422
6.3.3.1	Definition of Cyclic Codes	423
6.3.3.2	Polynomial Arithmetic	423
6.3.3.3	Properties of Cyclic Codes	426
6.3.3.4	Encoding of Cyclic Codes	427
6.3.3.5	Decoding of Cyclic Codes	427
6.3.4	Hamming Codes	429
6.3.4.1	Definition of Hamming Codes	429
6.3.4.2	Encoding of Hamming Codes	430
6.3.4.3	Decoding of Hamming Codes	432
6.3.4.4	Performance of Hamming Codes	432
6.3.5	BCH Codes	436
6.3.5.1	Definition and Encoding for BCH Codes	436
6.3.5.2	Decoding of BCH Codes	441
6.3.5.3	Performance of BCH Codes	443
6.3.6	Reed–Solomon Codes	444
6.3.6.1	Definition of Reed–Solomon Codes	444
6.3.6.2	Decoding the Reed–Solomon Codes	446
6.3.6.3	Performance of the Reed–Solomon Codes	446
6.3.7	The Golay Code	447
6.3.7.1	Definition of the Golay Code	447
6.3.7.2	Decoding the Golay Code	448
6.3.7.3	Performance of the Golay Code	449
6.4	<i>Coding Performance in Slow Fading Channels</i>	450
6.5	<i>Summary</i>	452
	References	462
	Problems	463
7	Fundamentals of Convolutional Coding	470
7.1	<i>Introduction</i>	470
7.2	<i>Basic Concepts</i>	470
7.2.1	Definition of Convolutional Codes	471
7.2.2	Decoding Convolutional Codes	478
7.2.3	Potential Coding Gains for Soft Decisions	482
7.2.4	Distance Properties of Convolutional Codes	485
7.3	<i>The Viterbi Algorithm</i>	489
7.3.1	Hard Decision Decoding	489
7.3.2	Soft Decision Decoding	500
7.3.3	Decoding Error Probability	504

7.3.4	Bit Error Probability	506
7.4	<i>Good Convolutional Codes and Their Performance</i>	507
7.5	<i>Other Topics</i>	510
7.5.1	Sequential Decoding	511
7.5.2	Theshold Decoding	511
7.5.3	Concatenated Reed–Solomon/Convolutional Coding	512
7.5.4	Punctured Convolutional Codes	514
7.5.5	Trellis-Coded Modulation	516
7.5.6	Turbo Codes	522
7.5.7	Applications	526
7.6	<i>Summary</i>	526
	References	530
	Problems	532
8	Fundamentals of Repeat Request Systems	536
8.1	<i>Introduction</i>	536
8.2	<i>General Considerations</i>	537
8.3	<i>Three ARQ Strategies</i>	538
8.3.1	Stop-and-Wait ARQ	538
8.3.1.1	General Description	538
8.3.1.2	Throughput Calculation	539
8.3.2	Go-Back- <i>N</i> ARQ	544
8.3.2.1	General Description	544
8.3.2.2	Throughput Calculation	546
8.3.3	Selective Repeat ARQ	548
8.3.3.1	General Description	548
8.3.3.2	Throughput Calculation	550
8.4	<i>Codes for Error Detection</i>	551
8.4.1	General Considerations	551
8.4.2	Hamming Codes	555
8.4.3	BCH Codes	556
8.4.4	Golay Codes	556
8.5	<i>Summary</i>	557
	References	559
	Problems	559
9	Spread-Spectrum Systems	562
9.1	<i>Introduction</i>	562
9.2	<i>Two Communication Problems</i>	563
9.2.1	Pulse-Noise Jamming	563
9.2.2	Low Probability of Detection	566
9.3	<i>Types of Spread-Spectrum Systems</i>	568
9.3.1	BPSK Direct-Sequence Spread Spectrum	569

9.3.2	QPSK Direct-Sequence Spread Spectrum	577
9.3.3	Noncoherent Slow-Frequency-Hop Spread Spectrum	583
9.3.4	Noncoherent Fast-Frequency-Hop Spread Spectrum	586
9.3.5	Hybrid Direct-Sequence/Frequency-Hop Spread Spectrum	586
9.4	<i>Complex-Envelope Representation of Spread-Spectrum Systems</i>	589
9.5	<i>Generation and Properties of Pseudorandom Sequences</i>	594
9.5.1	Definitions and Mathematical Background	594
9.5.2	m -Sequence Generator Configurations	596
9.5.3	Properties of m -Sequences	597
9.5.4	Power Spectrum of m -Sequences	599
9.5.5	Tables of Polynomials Yielding m -Sequences	601
9.5.6	Security of m -Sequences	604
9.5.7	Gold Codes	605
9.5.8	Kasami Sequences (Small Set)	607
9.5.9	Quaternary (Four-Phase) Sequences	608
9.5.10	Walsh Codes	610
9.6	<i>Synchronization of Spread-Spectrum Systems</i>	611
9.7	<i>Performance of Spread-Spectrum Systems in Jamming Environments</i>	614
9.7.1	Introduction	614
9.7.2	Types of Jammers	616
9.7.3	Combating Smart Jammers	616
9.7.4	Error Probabilities for Barrage Noise Jammers	618
9.7.5	Error Probabilities for Optimized Partial Band or Pulsed Jammers	621
9.8	<i>Performance in Multiple User Environments</i>	624
9.9	<i>Multiuser Detection</i>	628
9.10	<i>Examples of Spread-Spectrum Systems</i>	633
9.10.1	Space Shuttle Spectrum Despreaders	633
9.10.2	Global Positioning System	636
9.11	<i>Summary</i>	641
	References	642
	Problems	644
10	Introduction to Cellular Radio Communications	650
10.1	<i>Introduction</i>	650
10.2	<i>Frequency Reuse</i>	651
10.3	<i>Channel Models</i>	658
10.3.1	Path Loss and Shadow Fading Models	659
10.3.1.1	Free Space Path Loss	660

10.3.1.2	Flat Earth Path Loss	661
10.3.1.3	Okumura/Hata Path Attenuation Model	664
10.3.1.4	Log-Normal Shadow Fading	666
10.3.2	Multipath Channel Models	667
10.3.2.1	Rayleigh Fading (Unresolvable-Multipath) Models	669
10.3.2.2	Ricean (Unresolvable) Fading	687
10.3.2.3	Summary	691
10.3.2.4	Resolvable Multipath Components	692
10.3.2.5	A Mathematical Model for the WSSUS Channel	693
10.4	<i>Mitigation Techniques for the Multipath Fading Channel</i>	698
10.4.1	Introduction	698
10.4.2	Space Diversity	701
10.4.3	Frequency Diversity	701
10.4.4	Time Diversity	702
10.4.5	Multipath Diversity and RAKE Receivers	703
10.5	<i>System Design and Performance Prediction</i>	706
10.5.1	Introduction	706
10.5.2	Performance Figures of Merit	707
10.5.3	Frequency Reuse	708
10.5.4	Cells Are Never Hexagons	713
10.5.5	Interference Averaging	713
10.6	<i>Advanced Mobile Phone Service</i>	715
10.6.1	Introduction	715
10.6.2	Call Setup and Control	717
10.6.3	Modulation and Signaling Formats	718
10.7	<i>Global System for Mobile Communications</i>	720
10.7.1	Introduction	720
10.7.2	System Overview	722
10.7.3	Modulation and Signaling Formats	724
10.7.4	Summary and Additional Comments	730
10.8	<i>Code Division Multiple Access</i>	731
10.8.1	Introduction	731
10.8.2	Forward Link Description	735
10.8.3	Reverse Link Description	743
10.8.4	Capacity of CDMA	747
10.8.5	Additional Comments	752
10.9	<i>Recommended Further Reading</i>	753
10.9.1	Cellular Concepts and Systems	754
10.9.2	Channel Modeling and Propagation	754
10.9.3	Concluding Remarks	756
	References	756
	Problems	759