



国外电气信息类优秀教材改编系列
Adapted Oversea Excellent Textbooks on Electrical Engineering

PEARSON
Prentice
Hall

数字通信基础

改编版

Digital Communication Essentials

改编版

原著 Bernard Sklar

改编 毕光国



高等教育出版社
Higher Education Press

国外电气信息类优秀教材改编系列

Adapted Oversea Excellent Textbooks on Electrical Engineering

Digital Communication Essentials

数字通信基础

改编版

原著 **Bernard Sklar**

改编 毕光国

高等教育出版社

图字:01-2005-0705号

"Original edition, entitled DIGITAL COMMUNICATIONS; FUNDAMENTALS AND APPLICATIONS, 2nd Edition by SKLAR, BERNARD, published by Pearson Education, Inc., publishing as Prentice-Hall PTR, Copyright © 2001

All right reserved. No part of this book may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording or by any information storage retrieval system, without permission from Pearson Education Inc.

China Adapted edition published by Pearson Education Asia Ltd. and Higher Education Press, Copyright © 2006

This Adapted edition is manufactured in the People's Republic of China, and is authorized for sale only in People's Republic of China (excluding Taiwan and the Special Administrative Regions of Hong Kong and Macau).

本书封面贴有 **Pearson Education** (培生教育出版集团) 激光防伪标签。无标签者不得销售。

For sale and distribution in the People's Republic of China exclusively (except Taiwan, Hong Kong SAR and Macao SAR).

仅限于中华人民共和国境内(但不允许在中国香港、澳门特别行政区和中国台湾地区)销售发行。

图书在版编目(CIP)数据

数字通信基础 = Digital Communication Essentials:
改编版/[美]斯克拉(Sklar, B.)著;毕光国改编. —
北京:高等教育出版社, 2006. 3
ISBN 7-04-018357-9

I. 数... II. ①斯... ②毕... III. 数字通信—
英文 IV. TN914.3

中国版本图书馆 CIP 数据核字(2005)第 160881 号

出版发行	高等教育出版社	购书热线	010-58581118
社 址	北京市西城区德外大街 4 号	免费咨询	800-810-0598
邮政编码	100011	网 址	http://www.hep.edu.cn
总 机	010-58581000		http://www.hep.com.cn
经 销	蓝色畅想图书发行有限公司	网上订购	http://www.landaco.com
印 刷	北京外文印刷厂		http://www.landaco.com.cn
		畅想教育	http://www.widedu.com
开 本	787×960 1/16	版 次	2006 年 3 月第 1 版
印 张	46.25	印 次	2006 年 3 月第 1 次印刷
字 数	870 000	定 价	57.00 元

本书如有缺页、倒页、脱页等质量问题,请到所购图书销售部门联系调换。

版权所有 侵权必究

物料号 18357-00

Digital Communication Essentials

(改编版) 序

Bernard Sklar 所著的《Digital Communications—Fundamentals and Applications》(Second Edition)是一本很实用的数字通信教科书。它系统全面地论述了数字通信的基本理论,并对数字通信领域的许多新技术和新应用作了适当的介绍。它适于作不同类型和学制的大专院校高年级本科生和一年级研究生的教科书或参考书。这本教材编写系统完整、阐述深入浅出、取材新颖实用、数学表述精练易懂、习题丰富利于思考,已在我国的一些高等学校中采用,颇受欢迎。

Bernard Sklar 博士具有 40 多年技术设计和管理工作的经验,先后在多家著名航空、航天和工业机构任职,参与 MILSTAR 军事卫星系统的研发。他还在 UCLA 和 USC 等多所美国著名大学教授工程课程,并在世界各地对工程师进行专业培训。其丰富的阅历和先进的经验使他所著的这本教材既有理论深度,又极具实用性。

高等教育出版社考虑到我国各类相关专业的本科生的教学需要,也根据教育部为加快培养大批高质量信息技术人才而开展英语授课或双语教学的重要举措,经过对大量国外教材的遴选并与 Pearson Education, Inc. 和作者 Bernard Sklar 博士的多次反复谈判,决定出版这本《Digital Communication Essentials (改编版)》。本书是从 Bernard Sklar 所著的《Digital Communications—Fundamentals and Applications》(Second Edition)一书中精选了数字通信的最基本的部分内容改编而成,以适应我国相关专业本科高年级一学期的数字通信课程的教学需要。

原书内容供两个学期的数字通信课程的教学。本书在改编时从原书中删去了一部分超出本科一学期教学需要的内容,删去部分包括原书第 5 章(通信链路分析)、第 8 章(信道编码第 3 部分)、第 14 章(加密和解密)和第 15 章(衰落信道)的内容。把第 13 章(信源编码)中的 13.3 节(差分脉冲编码调制)和 13.4 节(自适应预测)两节内容合并到第 2 章(格式化和基带调制)中,而将其余各节删去。另外,将第 11 和 12 两章中的 11.1 节和 12.1~12.5 节内容整合在一起,组成本书第 9 章,而将其余各节删去。根据上述对原书各章节内容的重新编排,

II Digital Communication Essentials(改编版)序

对各章所附的参考文献、习题、思考题等均作了相应的重新整合与编号。

除了上述各章内容安排上所作的删改调整,以及少量必要的文字改动和个别印刷错误的订正以保持内容的连贯性、整体性和正确性外,本书原样保留原书的序言、图文和其他内容,不作改动,以保持原书的特点和风格。

本书(改编版)由高等教育出版社委托毕光国负责内容精选、整合和改编,并征得了原书作者 Bernard Sklar 博士的同意和授权。在改编过程中,研究生刘苏、许晓丹、王艳、马燕、严磊等同学参与了具体的文字校对和订正工作。由于本人水平所限和时间仓促,改编版难免有不妥之处,敬请使用本书的老师、同学和其他读者不吝指正。

毕光国

2005年6月

于东南大学移动通信国家重点实验室

Preface^①

Of *Digital Communications: Fundamentals and Applications—Second Edition*

This second edition of *Digital Communications: Fundamentals and Applications* represents an update of the original publication. The key features that have been updated are:

- The error-correction coding chapters have been expanded, particularly in the areas of Reed – Solomon codes, turbo codes, and trellis-coded modulation.
- A new chapter on fading channels and how to mitigate the degrading effects of fading has been introduced.
- Explanations and descriptions of essential digital communication concepts have been amplified.
- End-of-chapter problem sets have been expanded. Also, end-of-chapter question sets (and where to find the answers), as well as end-of-chapter CD exercises have been added.
- A compact disc (CD) containing an educational version of the design software System View by ELANIX accompanies the textbook. The CD contains a workbook with over 200 exercises, as well as a concise tutorial on digital signal processing (DSP). CD exercises in the workbook reinforce material in the textbook; concepts can be explored by viewing waveforms with a windows-based PC and by changing parameters to see the effects on the overall system. Some of the exercises provide basic training in using System View;

① 本序为原著《Digital Communications—Fundamentals and Applications》(Second Edition)的序,其内所列章节内容均与原著相对应。

II Preface

others provide additional training in DSP techniques.

The teaching of a one-semester university course proceeds in a very different manner compared with that of a short-course in the same subject. At the university, one has the luxury of time—time to develop the needed skills and mathematical tools, time to practice the ideas with homework exercises. In a short-course, the treatment is almost backwards compared with the university. Because of the time factor, a short course teacher must “jump in” early with essential concepts and applications. One of the vehicles that I found useful in structuring a short course was to start by handing out a check list. This was not merely an outline of the curriculum. It represented a collection of concepts and nomenclature that are not clearly documented, and are often misunderstood. The short-course students were thus initiated into the course by being challenged. I promised them that once they felt comfortable describing each issue, or answering each question on the list, they would be well on their way toward becoming knowledgeable in the field of digital communications. I have learned that this list of essential concepts is just as valuable for teaching full-semester courses as it is for short courses. Here then is my “check list” for digital communications.

1. What mathematical dilemma is the cause for there being several definitions of bandwidth? (See Section 1.7.2.)
2. Why is the ratio of bit energy-to-noise power spectral density, E_b/N_0 , a natural figure-to-merit for digital communication systems? (See Section 3.1.5.)
3. When representing timed events, what dilemma can easily result in confusing the most-significant bit (MSB) and the least-significant bit (LSB)? (See Section 3.2.3.1.)
4. The error performance of digital signaling suffers primarily from two degradation types. a) loss in signal-to-noise ratio, b) distortion resulting in an irreducible bit-error probability. How do they differ? (See Section 3.3.2.)
5. Often times, providing more E_b/N_0 will not mitigate the degradation due to intersymbol interference (ISI). Explain why. (See Section 3.3.2.)
6. At what location in the system is E_b/N_0 defined? (See Section 4.3.2.)
7. Digital modulation schemes fall into one of two classes with opposite behavior characteristics. a) orthogonal signaling, b) phase/amplitude signaling. Describe the behavior of each class. (See Section 4.8.2 and 9.7.)
8. Why do binary phase shift keying (BPSK) and quaternary phase shift keying (QPSK) manifest the same bit-error-probability relationship? Does the same hold true for M -ary pulse amplitude modulation (M -PAM) and M^2 -ary quadrature ampli-

tude modulation (M^2 -QAM) bit-error probability? (See Sections 4.8.4 and 9.8.3.1.)

9. In orthogonal signaling, why does error-performance improve with higher Dimensional signaling? (See Section 4.8.5.)

10. Why is *free-space loss* a function of wavelength? (See Section 5.3.3.)

11. What is the relationship between received signal to noise (S/N) ratio and carrier to noise (C/N) ratio? (See Section 5.4.)

12. Describe four types of trade-offs that can be accomplished by using an error-correcting code. (See Section 6.3.4.)

13. Why do traditional error-correcting codes yield error-performance degradation at low values of E_b/N_0 ? (See Section 6.3.4.)

14. Of what use is the *standard array* in understanding a block code, and in evaluating its capability? (See Section 6.6.5.)

15. Why is the Shannon limit of -1.6 dB not a useful goal in the design of real systems? (See Section 8.4.5.2.)

16. What are the consequences of the fact that the Viterbi decoding algorithm does not yield *a posteriori* probabilities? What is a more descriptive name for the Viterbi algorithm? (See Section 8.4.6.)

17. Why do binary and 4-ary orthogonal frequency shift keying (FSK) manifest the same bandwidth-efficiency relationship? (See Section 9.5.1.)

18. Describe the subtle energy and rate transformations of received signals: from data-bits to channel-bits to symbols to chips. (See Section 9.7.7.)

19. Define the following terms: Band, State, Communications Resource, Chip, Robust Signal. (See Sections 1.1.3 and 7.2.2, Chapter 11, and Sections 12.3.2 and 12.4.2.)

20. In a fading channel, why is signal dispersion independent of fading rapidity? (See Section 15.1.1.1.)

I hope you find it useful to be challenged in this way. Now, let us describe the purpose of the book in a more methodical way. This second edition is intended to provide a comprehensive coverage of digital communication systems for senior level undergraduates, first year graduate students, and practicing engineers. Though the emphasis is on digital communications, necessary analog fundamentals are included since analog waveforms are used for the radio transmission of digital signals. The key feature of a digital communication system is that it deals with a finite set of discrete messages, in contrast to an analog communication system in which messages are de-

IV Preface

fined on a continuum. The objective at the receiver of the digital system is not to reproduce a waveform with precision; it is instead to determine from a noise-perturbed signal, which of the finite set of waveforms had been sent by the transmitter. In fulfillment of this objective, there has arisen an impressive assortment of signal processing techniques.

The book develops these techniques in the context of a unified structure. The structure, in block diagram form, appears at the beginning of each chapter; blocks in the diagram are emphasized, when appropriate, to correspond to the subject of that chapter. Major purposes of the book are to add organization and structure to a field that has grown and continues to grow rapidly, and to insure awareness of the “big picture” even while delving into the details. Signals and key processing steps are traced from the information source through the transmitter, channel, receiver, and ultimately to the information sink. Signal transformations are organized according to nine functional classes: Formatting and source coding, Baseband signaling, Bandpass signaling, Equalization, Channel coding, Multiplexing and multiple access, Spreading, Encryption, and Synchronization. Throughout the book, emphasis is placed on system goals and the need to trade off basic system parameters such as signal-to-noise ratio, probability of error, and bandwidth expenditure.

ORGANIZATION OF THE BOOK

Chapter 1 introduces the overall digital communication system and the basic signal transformations that are highlighted in subsequent chapters. Some basic ideas of random variables and the *additive white Gaussian noise* (AWGN) model are reviewed. Also, the relationship between power spectral density and autocorrelation, and the basics of signal transmission through linear systems are established. Chapter 2 covers the signal processing step, known as *formatting*, in order to render an information signal compatible with a digital system. Chapter 3 emphasizes *baseband signaling*, the detection of signals in Gaussian noise, and receiver optimization. Chapter 4 deals with *bandpass signaling* and its associated modulation and demodulation/detection techniques. Chapter 5 deals with *link analysis*, an important subject for providing overall system insight; it considers some subtleties that are often missed. Chapters 6, 7, and 8 deal with *channel coding*—a costeffective way of providing a variety of system performance trade-offs. Chapter 6 emphasizes *linear block codes*, Chapter 7 deals with *convolutional codes*, and Chapter 8 deals with *Reed – Solomon codes* and *concatenated codes* such as *turbo codes*.

Chapter 9 considers various modulation/coding system *trade-offs* dealing with probability of bit-error performance, bandwidth efficiency, and signal-to-noise ratio. It also treats the important area of coded modulation, particularly *trellis-coded modulation*. Chapter 10 deals with *synchronization* for digital systems. It covers phase-locked loop implementation for achieving carrier synchronization. It covers bit synchronization, frame synchronization, and network synchronization, and it introduces some ways of performing synchronization using digital methods.

Chapter 11 treats *multiplexing* and *multiple access*. It explores techniques that are available for utilizing the communication resource efficiently. Chapter 12 introduces *spread spectrum* techniques and their application in such areas as multiple access, ranging, and interference rejection. This technology is important for both military and commercial applications. Chapter 13 deals with *source coding* which is a special class of data formatting. Both formatting and source coding involve digitization of data; the main difference between them is that source coding additionally involves data redundancy reduction. Rather than considering source coding immediately after formatting, it is purposely treated in a later chapter so as not to interrupt the presentation flow of the basic processing steps. Chapter 14 covers basic *encryption/decryption* ideas. It includes some classical concepts, as well as a class of systems called public key cryptosystems, and the widely used E-mail encryption software known as *Pretty Good Privacy* (PGP). Chapter 15 deals with *fading channels*. Here, we deal with applications, such as mobile radios, where characterization of the channel is much more involved than that of a nonfading one. The design of a communication system that will withstand the degradation effects of fading can be much more challenging than the design of its nonfading counterpart. In this chapter, we describe a variety of techniques that can mitigate the effects of fading, and we show some successful designs that have been implemented.

It is assumed that the reader is familiar with Fourier methods and convolution. Appendix A reviews these techniques, emphasizing those properties that are particularly useful in the study of communication theory. It is also assumed that the reader has a knowledge of basic probability and has some familiarity with random variables. Appendix B builds on these disciplines for a short treatment on statistical decision theory with emphasis on hypothesis testing—so important in the understanding of detection theory. A new section, Appendix E, has been added to serve as a short tutorial on *s-domain*, *z-domain*, and digital filtering. A concise DSP tutorial also appears on the CD that accompanies the book.

VI Preface

If the book is used for a two-term course, a simple partitioning is suggested; the first seven chapters can be taught in the first term, and the last eight chapters in the second term. If the book is used for a one-term introductory course, it is suggested that the course material be selected from the following chapters: 1, 2, 3, 4, 5, 6, 7, 9, 10, 12.

ACKNOWLEDGMENTS

It is difficult to write a technical book without contributions from others. I have received an abundance of such assistance, for which I am deeply grateful. For their generous help, I want to thank Dr. Andrew Viterbi, Dr. Chuck Wheatley, Dr. Ed Tiedeman, Dr. Joe Odenwalder, and Serge Willinegger of Qualcomm. I also want to thank Dr. Dariush Divsalar of Jet Propulsion Laboratory (JPL), Dr. Bob Bogusch of Mission Research, Dr. Tom Stanley of the Federal Communications Commission, Professor Larry Milstein of the University of California, San Diego, Professor Ray Pickholtz of George Washington University, Professor Daniel Costello of Notre Dame University, Professor Ted Rappaport of Virginia Polytechnic Institute, Phil Kossin of Lincom, Les Brown of Motorola, as well as Dr. Bob Price and Frank Amoroso.

I also want to acknowledge those people who played a big part in helping me with the first edition of the book. They are: Dr. Maurice King, Don Martin and Ned Feldman of The Aerospace Corporation, Dr. Marv Simon of JPL, Dr. Bill Lindsey of Lincom, Professor Wayne Stark of the University of Michigan, as well as Dr. Jim Omura, Dr. Adam Lender, and Dr. Todd Citron.

I want to thank Dr. Maurice King for contributing Chapter 10 on Synchronization, and Professor Fred Harris of San Diego State University for contributing Chapter 13 on Source Coding. Also, thanks to Michelle Landry for writing the sections on Pretty Good Privacy in Chapter 14, and to Andrew Guidi for contributing end-of-chapter problems in Chapter 15.

I am particularly indebted to my friends and colleagues Fred Harris, Professor Dan Bukofzer of California State University at Fresno, and Dr. Maury Schiff of Elanix, who put up with my incessant argumentative discussions anytime that I called on them. I also want to thank my very best teachers—they are my students at the University of California, Los Angeles, as well as those students all over the world who attended my short courses. Their questions motivated me and provoked me to write this second edition. I hope that I have answered all their questions with clarity.

I offer special thanks for technical clarifications that my son, Dean Sklar, sug-

gested; he took on the difficult role of being his father's chief critic and "devil's advocate." I am particularly indebted to Professor Bob Stewart of the University of Strathclyde, Glasgow, who contributed countless hours of work in writing and preparing the CD and in authoring Appendix E. I thank Rose Kernan, my editor, for watching over me and this project, and I thank Bernard Goodwin, Publisher at Prentice Hall, for indulging me and believing in me. His recommendations were invaluable. Finally, I am extremely grateful to my wife, Gwen, for her encouragement, devotion, and valuable advice. She protected me from the "slings and arrows" of everyday life, making it possible for me to complete this second edition.

BERNARD SKLAR

Tarzana, California

郑重声明

高等教育出版社依法对本书享有专有出版权。任何未经许可的复制、销售行为均违反《中华人民共和国著作权法》，其行为人将承担相应的民事责任和行政责任，构成犯罪的，将被依法追究刑事责任。为了维护市场秩序，保护读者的合法权益，避免读者误用盗版书造成不良后果，我社将配合行政执法部门和司法机关对违法犯罪的单位和个人给予严厉打击。社会各界人士如发现上述侵权行为，希望及时举报，本社将奖励举报有功人员。

反盗版举报电话：(010) 58581897/58581896/58581879

传 真：(010) 82086060

E - mail：dd@hep.com.cn

通信地址：北京市西城区德外大街4号

高等教育出版社打击盗版办公室

邮 编：100011

购书请拨打电话：(010)58581118

策划编辑 刘激扬

责任编辑 王莉莉

封面设计 刘晓翔

版式设计 王莹

责任校对 康晓燕

责任印制 陈伟光

Contents

PREFACE

Of Digital Communications ; Fundamentals and Applications

—*Second Edition* I

1

SIGNALS AND SPECTRA	1
1.1 Digital Communication Signal Processing,	2
1.1.1 <i>Why Digital?</i>	2
1.1.2 <i>Typical Block Diagram and Transformations</i> ,	4
1.1.3 <i>Basic Digital Communication Nomenclature</i> ,	11
1.1.4 <i>Digital versus Analog Performance Criteria</i> ,	14
1.2 Classification of Signals,	14
1.2.1 <i>Deterministic and Random Signals</i> ,	14
1.2.2 <i>Periodic and Nonperiodic Signals</i> ,	15
1.2.3 <i>Analog and Discrete Signals</i> ,	15
1.2.4 <i>Energy and Power Signals</i> ,	15
1.2.5 <i>The Unit Impulse Function</i> ,	17
1.3 Spectral Density,	17
1.3.1 <i>Energy Spectral Density</i> ,	18
1.3.2 <i>Power Spectral Density</i> ,	18
1.4 Autocorrelation,	20
1.4.1 <i>Autocorrelation of an Energy Signal</i> ,	20
1.4.2 <i>Autocorrelation of a Periodic (Power) Signal</i> ,	21
1.5 Random Signals,	21
1.5.1 <i>Random Variables</i> ,	21
1.5.2 <i>Random Processes</i> ,	23
1.5.3 <i>Time Averaging and Ergodicity</i> ,	26

II Contents

1.5.4	<i>Power Spectral Density and Autocorrelation of a Random Process</i> ,	27
1.5.5	<i>Noise in Communication Systems</i> ,	31
1.6	Signal Transmission through Linear Systems ,	35
1.6.1	<i>Impulse Response</i> ,	35
1.6.2	<i>Frequency Transfer Function</i> ,	37
1.6.3	<i>Distortionless Transmission</i> ,	38
1.6.4	<i>Signals, Circuits, and Spectra</i> ,	44
1.7	Bandwidth of Digital Data ,	47
1.7.1	<i>Baseband versus Bandpass</i> ,	47
1.7.2	<i>The Bandwidth Dilemma</i> ,	49
1.8	Conclusion ,	53

2

2	FORMATTING AND BASEBAND MODULATION	58
2.1	Baseband Systems ,	59
2.2	Formatting Textual Data(Character Coding) ,	62
2.3	Messages, Characters, and Symbols ,	62
2.3.1	<i>Example of Messages, Characters, and Symbols</i> ,	65
2.4	Formatting Analog Information ,	66
2.4.1	<i>The Sampling Theorem</i> ,	66
2.4.2	<i>Aliasing</i> ,	73
2.4.3	<i>Why Oversample?</i>	77
2.4.4	<i>Signal Interface for a Digital System</i> ,	79
2.5	Sources of Corruption ,	80
2.5.1	<i>Sampling and Quantizing Effects</i> ,	81
2.5.2	<i>Channel Effects</i> ,	82
2.5.3	<i>Signal-to-Noise Ratio for Quantized Pulses</i> ,	82
2.6	Pulse Code Modulation ,	84
2.7	Uniform and Nonuniform Quantization ,	86
2.7.1	<i>Statistics of Speech Amplitudes</i> ,	86
2.7.2	<i>Nonuniform Quantization</i> ,	87
2.7.3	<i>Companding Characteristics</i> ,	89
2.8	Differential Pulse-Code Modulation ,	90
2.8.1	<i>One-Tap Prediction</i> ,	93
2.8.2	<i>N-Tap Prediction</i> ,	95

2. 8. 3	<i>Delta Modulation</i> ,	97
2. 8. 4	<i>Sigma-Delta Modulation</i> ,	98
2. 8. 5	<i>Sigma-Delta A-to-D Converter(ADC)</i> ,	103
2. 8. 6	<i>Sigma-Delta D-to-A Converter(DAC)</i> ,	104
2. 9	<i>Adaptive Prediction</i> ,	107
2. 9. 1	<i>Forward Adaptation</i> ,	107
2. 9. 2	<i>Synthesis/Analysis Coding</i> ,	108
2. 10	<i>Baseband Transmission</i> ,	110
2. 10. 1	<i>Waveform Representation of Binary Digits</i> ,	110
2. 10. 2	<i>PCM Waveform Types</i> ,	111
2. 10. 3	<i>Spectral Attributes of PCM Waveforms</i> ,	115
2. 10. 4	<i>Bits per PCM Word and Bits per Symbol</i> ,	117
2. 10. 5	<i>M-ary Pulse-Modulation Waveforms</i> ,	118
2. 11	<i>Correlative Coding</i> ,	121
2. 11. 1	<i>Duobinary Signaling</i> ,	121
2. 11. 2	<i>Duobinary Decoding</i> ,	122
2. 11. 3	<i>Precoding</i> ,	123
2. 11. 4	<i>Duobinary Equivalent Transfer Function</i> ,	124
2. 11. 5	<i>Comparison of Binary with Duobinary Signaling</i> ,	125
2. 11. 6	<i>Polybinary Signaling</i> ,	127
2. 12	<i>Conclusion</i> ,	127

3

BASEBAND DEMODULATION/DETECTION	134
3. 1 <i>Signals and Noise</i> ,	135
3. 1. 1 <i>Error-Performance Degradation in Communication Systems</i> ,	135
3. 1. 2 <i>Demodulation and Detection</i> ,	136
3. 1. 3 <i>A Vectorial View of Signals and Noise</i> ,	140
3. 1. 4 <i>The Basic SNR Parameter for Digital Communication Systems</i> ,	147
3. 1. 5 <i>Why E_b/N_0 Is a Natural Figure of Merit</i> ,	148
3. 2 <i>Detection of Binary Signals in Gaussian Noise</i> ,	150
3. 2. 1 <i>Maximum Likelihood Receiver Structure</i> ,	150
3. 2. 2 <i>The Matched Filter</i> ,	153
3. 2. 3 <i>Correlation Realization of the Matched Filter</i> ,	155
3. 2. 4 <i>Optimizing Error Performance</i> ,	158

IV Contents

3.2.5	<i>Error Probability Performance of Binary Signaling,</i>	162
3.3	Intersymbol Interference,	167
3.3.1	<i>Pulse Shaping to Reduce ISI,</i>	170
3.3.2	<i>Two Types of Error-Performance Degradation,</i>	174
3.3.3	<i>Demodulation/Detection of Shaped Pulses,</i>	178
3.4	Equalization,	182
3.4.1	<i>Channel Characterization,</i>	182
3.4.2	<i>Eye Pattern,</i>	184
3.4.3	<i>Equalizer Filter Types,</i>	185
3.4.4	<i>Preset and Adaptive Equalization,</i>	192
3.4.5	<i>Filter Update Rate,</i>	194
3.5	Conclusion,	195

4

BANDPASS MODULATION AND DEMODULATION	202	
4.1	Why Modulate?	202
4.2	Digital Bandpass Modulation Techniques,	203
4.2.1	<i>Phasor Representation of a Sinusoid,</i>	206
4.2.2	<i>Phase Shift Keying,</i>	208
4.2.3	<i>Frequency Shift Keying,</i>	210
4.2.4	<i>Amplitude Shift Keying,</i>	210
4.2.5	<i>Amplitude Phase Keying,</i>	211
4.2.6	<i>Waveform Amplitude Coefficient,</i>	211
4.3	Detection of Signals in Gaussian Noise,	212
4.3.1	<i>Decision Regions,</i>	213
4.3.2	<i>Correlation Receiver,</i>	214
4.4	Coherent Detection,	219
4.4.1	<i>Coherent Detection of PSK,</i>	219
4.4.2	<i>Sampled Matched Filter,</i>	220
4.4.3	<i>Coherent Detection of Multiple Phase-Shift Keying,</i>	225
4.4.4	<i>Coherent Detection of FSK,</i>	228
4.5	Noncoherent Detection,	231
4.5.1	<i>Detection of Differential PSK,</i>	231
4.5.2	<i>Binary Differential PSK Example,</i>	233
4.5.3	<i>Noncoherent Detection of FSK,</i>	235