世界优秀教材中国版

数字通信基础 改编版

Digital Communication Essentials 改编版

原著 Bernard Sklar

改编 毕光国

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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，

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;

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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。

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-

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, Muliplexing 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 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.

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

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

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