

国外电子与通信教材系列

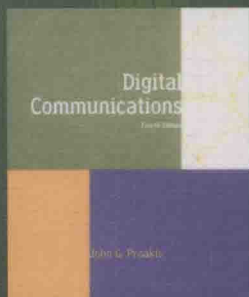
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# 数字通信

(第四版)

Digital Communications  
Fourth Edition



[美] John G. Proakis 著



电子工业出版社

Publishing House of Electronics Industry

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# 数字通信

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Digital Communications

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北京 · BEIJING

## 内 容 简 介

本书是数字通信领域的一本经典教材,通过对概率论及随机过程的复习,详细介绍了数字和模拟信源编码、数字调制信号和窄带信号与系统的特征、加性高斯白噪声中数字通信的调制和最佳调制与检测方法、基于最大似然准则的载波相位估计和定时同步的方法、不同信道模型的信道容量及随机编码、带限信道的信号设计、受到符号间干扰恶化信号的解调与检测问题、自适应信道均衡、多信道与多载波调制、扩展频谱信号和系统、衰落信道上的数字通信。本书适合通信工程相关专业的高年级本科生、研究生及工程技术人员阅读。

John G. Proakis: **Digital Communications, Fourth Edition.**

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## 序

2001年7月间,电子工业出版社的领导同志邀请各高校十几位通信领域方面的老师,商量引进国外教材问题。与会同志对出版社提出的计划十分赞同,大家认为,这对我国通信事业、特别是对高等院校通信学科的教学工作会很有好处。

教材建设是高校教学建设的主要内容之一。编写、出版一本好的教材,意味着开设了一门好的课程,甚至可能预示着一个崭新学科的诞生。20世纪40年代MIT林肯实验室出版的一套28本雷达丛书,对近代电子学科、特别是对雷达技术的推动作用,就是一个很好的例子。

我国领导部门对教材建设一直非常重视。20世纪80年代,在原教委教材编审委员会的领导下,汇集了高等院校几百位富有教学经验的专家,编写、出版了一大批教材;很多院校还根据学校的特点和需要,陆续编写了大量的讲义和参考书。这些教材对高校的教学工作发挥了极好的作用。近年来,随着教学改革不断深入和科学技术的飞速进步,有的教材内容已比较陈旧、落后,难以适应教学的要求,特别是在电子学和通信技术发展神速、可以讲是日新月异的今天,如何适应这种情况,更是一个必须认真考虑的问题。解决这个问题,除了依靠高校的老教师和专家撰写新的符合要求的教科书外,引进和出版一些国外优秀电子与通信教材,尤其是有选择地引进一批英文原版教材,是会有好处的。

一年多来,电子工业出版社为此做了很多工作。他们成立了一个“国外电子与通信教材系列”项目组,选派了富有经验的业务骨干负责有关工作,收集了230余种通信教材和参考书的详细资料,调来了100余种原版教材样书,依靠由20余位专家组成的出版委员会,从中精选了40多种,内容丰富,覆盖了电路理论与应用、信号与系统、数字信号处理、微电子、通信系统、电磁场与微波等方面,既可作为通信专业本科生和研究生的教学用书,也可作为有关专业人员的参考材料。此外,这批教材,有的翻译为中文,还有部分教材直接影印出版,以供教师用英语直接授课。希望这些教材的引进和出版对高校通信教学和教材改革能起一定作用。

在这里,我还要感谢参加工作的各位教授、专家、老师与参加翻译、编辑和出版的同志们。各位专家认真负责、严谨细致、不辞辛劳、不怕琐碎和精益求精的态度,充分体现了中国教育工作者和出版工作者的良好美德。

随着我国经济建设的发展和科学技术的不断进步,对高校教学工作会不断提出新的要求和希望。我想,无论如何,要做好引进国外教材的工作,一定要联系我国的实际。教材和学术专著不同,既要注意科学性、学术性,也要重视可读性,要深入浅出,便于读者自学;引进的教材要适应高校教学改革的需要,针对目前一些教材内容较为陈旧的问题,有目的地引进一些先进的和正在发展中的交叉学科的参考书;要与国内出版的教材相配套,安排好出版英文原版教材和翻译教材的比例。我们努力使这套教材能尽量满足上述要求,希望它们能放在学生们的课桌上,发挥一定的作用。

最后,预祝“国外电子与通信教材系列”项目取得成功,为我国电子与通信教学和通信产业的发展培土施肥。也恳切希望读者能对这些书籍的不足之处、特别是翻译中存在的问题,提出意见和建议,以便再版时更正。



中国工程院院士、清华大学教授

“国外电子与通信教材系列”出版委员会主任

## 出版说明

进入21世纪以来,我国信息产业在生产和科研方面都大大加快了发展速度,并已成为国民经济发展的支柱产业之一。但是,与世界上其他信息产业发达的国家相比,我国在技术开发、教育培训等方面都还存在着较大的差距。特别是在加入WTO后的今天,我国信息产业面临着国外竞争对等的严峻挑战。

作为我国信息产业的专业科技出版社,我们始终关注着全球电子信息技术的发展方向,始终引进国外优秀电子与通信信息技术教材和专业书籍放在我们工作的重要位置上。在2000年至2001年间,我社先后从世界著名出版公司引进出版了40余种教材,形成了一套“国外计算机科学教材系列”,在全国高校以及科研部门中受到了欢迎和好评,得到了计算机领域的广大教师与科研工作者的充分肯定。

引进和出版一些国外优秀电子与通信教材,尤其是有选择地引进一批英文原版教材,将有助于我国信息产业培养具有国际竞争能力的技术人才,也将有助于我国国内在电子与通信教学工作中掌握和跟踪国际发展水平。根据国内信息产业的现状、教育部《关于“十五”期间普通高等教育教材建设与改革的意见》的指示精神以及高等院校老师们反映的各种意见,我们决定引进“国外电子与通信教材系列”,并随后开展了大量准备工作。此次引进的国外电子与通信教材均来自国际著名出版商,其中影印教材约占一半。教材内容涉及的学科方向包括电路理论与应用、信号与系统、数字信号处理、微电子、通信系统、电磁场与微波等,其中既有本科专业课程教材,也有研究生课程教材,以适应不同院系、不同专业、不同层次的师生对教材的需求,广大师生可自由选择和自由组合使用。我们还将与国外出版商一起,陆续推出一些教材的教学支持资料,为授课教师提供帮助。

此外,“国外电子与通信教材系列”的引进和出版工作得到了教育部高等教育司的大力支持和帮助,其中的部分引进教材已通过“教育部高等学校电子信息科学与工程类专业教学指导委员会”的审核,并得到教育部高等教育司的批准,纳入了“教育部高等教育司推荐——国外优秀信息科学与技术系列教学用书”。

为做好该系列教材的翻译工作,我们聘请了清华大学、北京大学、北京邮电大学、南京邮电大学、东南大学、西安交通大学、天津大学、西安电子科技大学、电子科技大学、中山大学、哈尔滨工业大学、西南交通大学等著名高校的教授和骨干教师参与教材的翻译和审校工作。许多教授在国内电子与通信专业领域享有较高的声望,具有丰富的教学经验,他们的渊博学识从根本上保证了教材的翻译质量和专业学术方面的严格与准确。我们在此对他们的辛勤工作与贡献表示衷心的感谢。此外,对于编辑的选择,我们达到了专业对口;对于从英文原书中发现的错误,我们通过作者联络、从网上下载勘误表等方式,逐一进行了修订;同时,我们对审校、排版、印制质量进行了严格把关。

今后,我们将进一步加强同各高校教师的密切关系,努力引进更多的国外优秀教材和教学参考书,为我国电子与通信教材达到世界先进水平而努力。由于我们对国内外电子与通信教育的发展乃存在一些认识上的不足,在选题、翻译、出版等方面的工作中还有许多需要改进的地方,恳请广大师生和读者提出批评及建议。

电子工业出版社

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## A B O U T T H E A U T H O R

JOHN G. PROAKIS has been on the faculty of Northeastern University since September of 1969. During the period 1982–1997, he held the administrative positions of Chairman of the Department of Electrical and Computer Engineering, Associate Dean of Research and Graduate Studies, and as Interim Dean of the College of Engineering. He has also served on the staffs of GTE Laboratories and the MIT Lincoln Laboratory.

Dr. Proakis received the BSEE Degree from the University of Cincinnati, the MSEE Degree from MIT, and the Ph.D. in Engineering from Harvard University. His professional experience and research interests are in the general areas of digital communications and digital signal processing, about which he has written extensively.



The fourth edition of *Digital Communications* has undergone a minor revision. Several new topics have been added, including serial and parallel concatenated codes, punctured convolutional codes, turbo TCM and turbo equalization, and spatial multiplexing. Since this is an introductory-level text, the treatment of these topics is limited in scope.

The book is designed to serve as a text for a first-year graduate-level course for students in electrical engineering. It is also designed to serve as a text for self-study and as a reference book for the practicing engineer involved in the design of digital communications systems. As a background, I presume that the reader has a thorough understanding of basic calculus and elementary linear systems theory and some prior knowledge of probability and stochastic processes.

**Chapter 1** is an introduction to the subject, including a historical perspective and a description of channel characteristics and channel models.

**Chapter 2** contains a review of the basic elements of probability and stochastic processes. It deals with a number of probability distribution functions and moments that are used throughout the book. It also includes the derivation of the Chernoff bound, which is useful in obtaining bounds on the performance of digital communications systems.

**Chapter 3** treats source coding for discrete and analog sources. Emphasis is placed on scalar and vector quantization techniques, and comparisons are made with basic results from rate-distortion theory.

In **Chapter 4**, the reader is introduced to the representation of digitally modulated signals and to the characterization of narrowband signals and systems. Also treated in this chapter are the spectral characteristics of digitally modulated signals. New material has been added on a linear representation of CPM signals.

**Chapter 5** treats the design of modulation and optimum demodulation and detection methods for digital communications over an additive white Gaussian noise channel. Emphasis is placed on the evaluation of the error rate performance for the various digital signaling techniques and on the channel bandwidth requirements of the corresponding signals.

**Chapter 6** is devoted to carrier phase estimation and time synchronization methods based on the maximum-likelihood criterion. Both decision-directed and non-decision-directed methods are described.



**Chapter 7** treats the topics of channel capacity for several different channel models and random coding.

**Chapter 8** treats linear block and convolutional codes. The new topics added to the chapter include serial and parallel interleaved concatenated block and convolutional codes, punctured and rate-compatible convolutional codes, the soft-output Viterbi algorithm (SOVA), and turbo TCM.

**Chapter 9** is focused on signal design for bandlimited channels. This chapter includes the topics of partial response signals and run-length-limited codes for spectral shaping.

**Chapter 10** treats the problem of demodulation and detection of signals corrupted by intersymbol interference. The emphasis is on optimum and sub-optimum equalization methods and their performance. New topics added to the chapter include Tomlinson-Harashima precoding, reduced complexity maximum-likelihood detectors, and turbo equalization.

**Chapter 11** treats adaptive channel equalization. The LMS and recursive least-squares algorithms are described, together with their performance characteristics. This chapter also includes a treatment of blind equalization algorithms. New topics added include the tap-leakage algorithm and methods for accelerating the initial convergence of the LMS algorithm.

**Chapter 12** treats multichannel and multicarrier modulation. The latter subject is particularly appropriate in view of several important applications that have been developed over the past two decades.

**Chapter 13** is devoted to spread spectrum signals and systems. The benefits of coding in the design of spread spectrum signals is emphasized throughout this chapter.

**Chapter 14** treats communication through fading channels. Several channel fading statistical models are considered, with emphasis placed on Rayleigh fading and Nakagami fading. Trellis coding for fading channels is also included in this chapter. New material added includes a brief treatment of fading and multipath characteristics of mobile radio channels, receiver structures for fading multipath channels with intersymbol interference, and spatial multiplexing using multiple transmit and receive antennas.

**Chapter 15** treats multiuser communications. The emphasis is on code-division multiple access (CDMA), signal detection and random access methods, such as ALOHA and carrier-sense multiple access (CSMA).

With 15 chapters and a variety of topics, the instructor has the flexibility to design either a one- or two-semester course. Chapters 3 through 6 provide a basic treatment of digital modulation/demodulation and detection methods. Channel coding, treated in Chapters 7 and 8, can be included along with modulation and demodulation in a one-semester course. The topics of channel equalization, fading channels, spread spectrum, and multiuser communications can be covered in a second-semester course.

Throughout my professional career, I have had the opportunity to work with and learn from a number of people whom I should like to publicly acknowledge. These include Dr. R. Price, P.R. Drouilhet, Jr., and Dr. P.E. Green, Jr., who introduced me to various aspects of digital communications through fading

multipath channels and multichannel signal transmission during my employment at the MIT Lincoln Laboratory. I am also indebted to Professor D.W. Tufts, who supervised my Ph.D. dissertation at Harvard University and who introduced me to the problems of signal design and equalization for band-limited channels. Over the years, I have had the pleasure of working on a variety of research projects in collaboration with colleagues at GTE and Stein Associates, including Dr. S. Stein, Dr. B. Barrow, Dr. A.A. Giordano, Dr. A.H. Levesque, Dr. R. Greenspan, Dr. D. Freeman, P.H. Anderson, D. Gooding, and J. Lindholm. At Northeastern University, I have had the benefit of collaborating with Dr. M. Salehi, Dr. M. Stojanovic, and Dr. D. Brady. Dr. T. Schonhoff provided the graphs illustrating the spectral characteristics of CPFSK, and H. Gibbons provided the data for the graphs in Chapter 14 that show the performance of PSK and DPSK with diversity. The assistance of these colleagues is greatly appreciated.

McGraw-Hill and I would like to thank the following reviewers of this edition for their valuable suggestions: William E. Ryan, *University of Arizona*; Tan Wong, *University of Florida*; and Raymond Pickholtz, *George Washington University*.

Finally, I wish to express my appreciation to Gloria Doukakis, for typing the manuscript of this edition, and to Apostolos Rizos for preparing the Solutions Manual.

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