

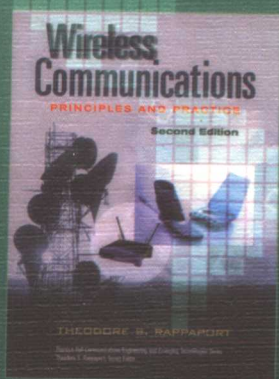
国外电子与通信教材系列

英文版

# 无线通信 原理与应用

(第二版)

Wireless Communications  
Principles and Practice, Second Edition



[美] Theodore S. Rappaport 著



电子工业出版社  
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## 内 容 简 介

本书是一本大学无线通信课程的权威教材,面向那些已经熟悉诸如概率论、通信原理和基本电磁学等技术概念的学生和工程师。全书深入浅出地讨论了无线通信技术与系统设计方面的内容,包括无线网络涉及的所有基本问题,特别是3G系统和无线局域网的问题,并对无线网络技术新发展和全球主要的无线通信标准给出了论述。全书共分11章,集中讲述了蜂窝的概念、移动无线电传播、调制技术、多址技术以及无线系统与标准,结合理论对无线通信系统的各个方面做了精辟的论述和统计分析。全书语言生动、流畅,以详细的讲解和实际的例子来阐明重要的知识点,非常适合有一定通信理论基础的工程技术人员和在校相关专业的师生阅读。

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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。

吴佑寿

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手的严峻挑战。

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,始终把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 and 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、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,我们通过与作者联络、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仍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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# Preface

**T**he second edition of this text has been written to initiate the newcomer to wireless personal communications, one of the fastest growing fields in the engineering world. Technical concepts which are at the core of design, implementation, research, and invention of wireless communication systems are presented in an order that is conducive to understanding general concepts, as well as those specific to current and evolving wireless communication systems and standards. This text is based upon my experiences as an educator, researcher, technical trainer, and consultant, and continues to be modeled from an academic course first developed for electrical engineering students in 1990, when there were fewer than five million cellular subscribers worldwide. As we begin the 21<sup>st</sup> century, more than 600 million people, about 10% of the world's population, pay a monthly subscription for wireless telephone service, and this figure will approach 50% by the end of the first decade of the 21<sup>st</sup> century.

This text continues to evolve, and has been modified and updated since its first edition, making it a useful book for practicing engineers, as well as for researchers, graduate students, and undergraduate students. The text has been prepared to provide fundamental treatment about many practical and theoretical concepts that form the basis of wireless communications, and has been designed for easy but thorough treatment of vital material that all wireless practitioners must be comfortable with. I have tried to emphasize the technical concepts with worked example problems, and numerous, carefully crafted homework problems at the end of each chapter that are based on real-world industry issues. The second edition contains dozens of new homework problems and examples, as well as up-to-the minute technical details of the many emerging wireless standards throughout the world, making this book particularly useful for industry short-courses or state-of-the-art academic classroom use.



References to journal articles are used liberally throughout this text to enable the interested reader to delve into additional reading that is always required to master any field. To support newcomers to the wireless field, and at the request of the Institute of Electrical and Electronics Engineers (IEEE), I have also prepared a low-cost two volume compendium of many of the original journal articles that first taught the fundamentals that are now used throughout the wireless industry—this compendium series is a useful, but not required, supplement to this text. Whether you intend to use this book for individual study, or for classroom use, or for use as a handbook, this text has been written as a complete, self-contained teaching and reference book. The numerous examples and problems found throughout the text have been provided to help the reader solidify the material.

This book has been designed for the student or practicing engineer who is already familiar with technical concepts such as probability, communication theory, and basic electromagnetics. However, like the wireless communications industry itself, this book combines material from many different technical disciplines, so it is unlikely that any one person will have had introductory courses for all of the topics covered. To accommodate a wide range of backgrounds, important concepts throughout the text are developed from first principles, so that readers learn the foundations of wireless communications. This approach makes it possible to use this book as a handbook or as a useful teaching tool in a classroom setting.

The material and chapter sequence in this text have been adapted from an entry-level graduate course which I first taught in 1991 at the Virginia Polytechnic Institute and State University. Chapter 1 demonstrates the historic evolution of the wireless communications industry, and the evolution of wireless systems from first generation analog to second generation (2G) digital systems. Chapter 1 also documents the rapid early growth of cellular radio throughout the world and provides a state of the industry in the mid 1990s. Chapter 2 provides an overview of the major modern wireless communication systems of the 21<sup>st</sup> century, such as third generation (3G), Wireless Local Area Networks (WLANs), Local Multipoint Distribution Services (LMDS), and Bluetooth. Chapter 2 causes the reader to see how wireless networks are beginning to penetrate our daily lives for data and multimedia applications, as well as voice service. Chapter 3 covers fundamental cellular radio concepts such as frequency reuse and handoff, which are at the core of providing wireless communication service to subscribers on the move using limited radio spectrum. Chapter 3 also demonstrates the principal of trunking efficiency, and how trunking and interference issues between mobiles and base stations combine to affect the overall capacity of cellular systems. Chapter 4 presents radio propagation path loss, link-budgets, and log-normal shadowing, and describes different ways to model and predict the large-scale effects of radio propagation in many operating environments. Chapter 5 covers small-scale propagation effects such as fading, time delay spread, and Doppler spread, and describes how to measure and model the impact that signal bandwidth and motion have on the instantaneous received signal through the multipath channel. Radio wave propagation has historically been the most difficult problem to analyze and design for, since unlike a wired communication system which has a constant, stationary transmission channel (i.e., a wired path), radio channels are random and undergo shadowing and multipath fading, particularly when one of the



terminals is in motion. New material in Chapter 5 also teaches a fundamental and new way of modeling spatial-temporal channels, which is vital for the development of *smart antennas* and position location systems.

Chapter 6 provides extensive coverage of the most common analog and digital modulation techniques used in wireless communications and demonstrates tradeoffs that must be made in selecting a modulation method. Issues such as receiver complexity, modulation and demodulation implementation, bit error rate analysis for fading channels, and spectral occupancy are presented. Channel coding, adaptive equalization, and antenna diversity concepts are presented in Chapter 7. In portable radio systems where people communicate while walking or driving, these methods may be used individually or in tandem to improve the quality (that is, reduce the bit error rate) of digital mobile radio communications in the presence of fading and noise.

Chapter 8 provides an introduction to speech coding. In the past decade, there has been remarkable progress in decreasing the needed data rate of high quality digitized speech, which enables wireless system designers to match end-user services to network architectures. Principles which have driven the development of adaptive pulse code modulation and linear predictive coding techniques are presented, and how these techniques are used to evaluate speech quality in existing and proposed cellular, cordless, and personal communication systems are discussed. Chapter 9 introduces time, frequency, and code division multiple access, as well as more recent multiple access techniques such as packet reservation and space division multiple access. Chapter 9 also describes how each access method can accommodate a large number of mobile users and demonstrates how multiple access impacts capacity and the network infrastructure of a cellular system. Chapter 10 describes networking considerations for wide area wireless communication systems, and presents practical networking approaches that are in use or have been proposed for future wireless systems. Chapter 11 unites all of the material from the first nine chapters by describing and comparing the major existing second generation (2G) cellular, cordless, and personal communication systems throughout the world. The tradeoffs made in the design and implementation of wireless personal communications systems are illuminated in this final chapter. The compilation of the major wireless standards makes Chapter 11 particularly useful as a single source of information for a wide range of wireless systems that are commercially deployed today.

Appendices which cover trunking theory, noise figure, noise calculations, and the Gaussian approximation for spread spectrum code division systems provide details for those interested in solving many practical wireless communications problems. The appendices also include hundreds of mathematical formulas and identities for general engineering work. I have attempted to place numerous useful items in the appendices, so that this text may be easily used by students or practicing engineers to solve a wide range of problems that may be outside the scope of the immediate text.

For industry use, Chapters 1–5, 9, and 11 will benefit working engineers in the cellular/PCS system design and radio frequency (RF) deployment, operations, and maintenance areas. Chapters 1, 2, 6–8, and 11 are tailored for modem designers and digital signal processing (DSP) engineers new to wireless. Chapters 1, 2, 10, and 11 should have broad appeal to network operators and managers, business and legal professionals, as well as working engineers.

To use this text at the undergraduate level, the instructor may wish to concentrate on Chapters 1–6, or Chapters 1–5, and 9, leaving the other chapters for treatment in a second semester undergraduate course or a graduate level course. Alternatively, traditional undergraduate courses on communications or network theory may find in Chapters 1, 2, 3, 4, 6, 8, 9, and 10 useful material that can be inserted easily into the standard curriculum. In using this text at the graduate level, I have been successful in covering most of the material in Chapters 1–6 and 10 during a standard half-year semester and Chapters 7–11 in a follow-on graduate course. In Chapters 2, 10, and 11, I have attempted to cover important but rarely compiled information on practical network implementations and worldwide standards.

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