国外电子与通信教材系列

现代无线通信系统电波传播

Radio Propagation for Modern Wireless Systems

英文版

[美] Henry L. Bertoni 著

PH PTR

電子工業出版社
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北京 · BEIJING

内容简介

本书是由世界无线通信专家亨利·伯托尼编写的关于无线电波传播模型的权威性教科书。它为读者打开了理解无线信道中无线电波传播的大门。本书就建筑物、地形、树丛对路径损耗的影响进行了广泛而深入的研究，形成了窄带和宽带系统的空间变化、到达角度、延时扩散等关键影响的统一观点。通过大量例子给出了对建筑物拐角衍射的清晰描述，也给出了以前从未发表过的城市中移动物体及移动物体路径损耗的研究内容，并提出了新的针对特定位置预测和基于射线理论信道统计模拟的有效模型。书中对频谱再利用的透彻介绍和对现实世界中建筑物、地形、树丛的精确模型的介绍为每一个无线系统设计人员提供了非常有价值的信息。

本书适合无线通信专业的高年级本科生和研究生学习参考，也可供致力于无线通信工程的广大工程技术人员学习参考。

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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、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

The commercial success of cellular mobile radio since its initial implementation in the early 1980s has led to an intense interest among wireless engineers in understanding and predicting radio propagation characteristics within cities, and even within buildings. In this book we discuss radio propagation with two goals in mind. The first is to provide practicing engineers having limited knowledge of propagation with an overview of the observed characteristics of the radio channel and an understanding of the process and factors that influence these characteristics. The second goal is to serve as text for a master's-level course for students intending to work in the wireless industry. Books on modern wireless applications typically survey the issues involved, devoting only one or two chapters to radio channel characteristics, or focus on how the characteristics influence system performance. Now that the wireless field has grown in scope and size, it is appropriate that books such as this one examine in greater depth the various underlying topics that govern the design and operation of wireless systems. The material for this book has grown out of tutorials given by the author to engineering professionals and a course on wireless propagation given by the author at Polytechnic University as part of a program in wireless networks. It also draws upon the 15 years of experience the author and his students have had in understanding and predicting propagation effects.

Cellular telephones gave the public an active role in the use of the radio spectrum as opposed to the previous role of passive listener. This social revolution in the use of the radio spectrum ultimately changed governmental views of its regulation. Driven by the requirement to allow many users to operate in the same band, cellular telephones also created a technical revolution through the concept of spectral reuse. Systems that do not employ spectral reuse avoid interference by operating in different frequency bands and are limited in performance primarily by noise. In these systems, lack of knowledge of the propagation conditions can be compensated for by increasing the transmitted power, up to regulatory limits. In contrast, the concept of spec-

tral reuse acknowledges that in commercially successful systems, interference from other users will be the primary factor limiting performance. In designing these systems, it is necessary to balance the desired signal for each user against interference from signals intended for other users. Finding the balance requires knowledge of the radio channel characteristics. Chapter 1 is intended to introduce the student reader to the concept of spectrum reuse and in the process to give examples of how the propagation characteristics influence the balance between desired signal and interference, and thereby influence system design. As in all chapters, examples are discussed to illustrate the concepts, and problems are included at the end of the chapter to give the students experience in applying the concepts.

In modern systems, the radio links are about 20 kilometers or less, the antennas that create the links lie near to or among the buildings or even inside the buildings, and the wavelength is small compared to the building dimensions. As a result, the channel characteristics are strongly influenced by the buildings as well as by vegetation and terrain. In this environment, signals propagate from one antenna to the other over multiple paths that involve the processes of reflection and transmission at walls and by the ground and the process of diffraction at building edges and terrain obstacles. The multipath nature of the propagation makes itself felt in a variety of ways that have challenged the inventiveness of communication engineers. Although initially a strong limitation on channel capacity, engineers have begun to find ways to harness the multipath signals so as to achieve capacities that approach the theoretical limit. However, each new concept for dealing with multipath calls for an even deeper understanding of the statistical characteristics of the radio channel. In Chapter 2 we describe many of the propagation effects that have been observed in various types of measurements, ranging from path loss for narrowband signals, to angle of arrival and delay spread for wideband transmission. As in other chapters, an extensive list of references is cited to aid the professional seeking a detailed understanding of particular topics. For the student reader, this chapter serves as an introduction to the types of measurements that are made, the methods used to process the data, and some of the statistical approaches used to represent the results. Understanding the measurements, their processing, and their representation also serves to guide the theoretical modeling described in subsequent chapters.

The level of presentation assumes that the reader has had an undergraduate course in electromagnetics with exposure to wave concepts. The presentation does not attempt to derive the propagation characteristics from Maxwell's equations rigorously; rather, the goal is to avoid vector calculus. The reader's background is relied on for acceptance of some wave properties; other properties are motivated through heuristic arguments and from basic ideas, such as conservation of power. For example, in Chapter 3 we start with the fundamental properties of plane waves and call on the reader's background in transmission lines when discussing reflection and transmission at the ground and walls. Wherever possible in this and following chapters, the theoretical results are compared to measurements. Thus plane waves are used to model observed interference effects, which are referred to as fast fading, and to model Doppler spreading. Plane wave properties and conservation of power are used in Chapter 4 to justify the properties of spherical

waves radiated by antennas and to motivate the ray description of reflection at material surfaces. By accounting for these reflections, propagation on line-of-sight paths in urban canyons is modeled. Circuit concepts are used to obtain the reciprocity of propagation between antennas, and to derive expressions for path gain or loss.

Diffraction at building edges is an important process in wireless communications. It allows signals to reach subscribers who would otherwise be shadowed by the buildings. Because the reader is not expected to be familiar with this process, Chapter 5 explores diffraction in some detail. For simplicity, the scalar form of the Huygens–Kirchhoff integral is use as a starting point. We first use it to give physical meaning to the Fresnel ellipsoid about a ray, which is widely employed in propagation studies to scale physical dimensions. The geometrical and uniform forms of the fields diffracted by an absorbing half screen are derived. In these expressions we identify a universal component that applies to diffraction by any straight building edge or corner and a diffraction coefficient whose specific form is dependent on the nature of the edge. Diffraction coefficients for several types of edges and corners are given without derivation. Using heuristic ray arguments, the results obtained for plane waves are generalized to spherical waves radiated by antennas and to multiple edges. These results are cast in terms of path gain or loss, which is convenient for wireless applications.

Chapter 6 formulates the problem of average path loss in residential environments in terms of multiple diffraction past rows of buildings. Relying on the Huygens–Kirchhoff formulation, the diffraction problem is solved for various ranges of base station and subscriber antenna height. These results show how the frequency, average building height, and row separation influence the range dependence and height gain of the signal. This approach to diffraction is used in Chapter 7 to investigate the effects of randomness in building construction on shadow fading. Chapter 7 also makes use of diffraction to examine the effects of terrain and vegetation on the average path loss.

Propagation predictions that make use of a geometrical description of individual buildings are discussed in Chapter 8. Various ray-based models that incorporated the processes of reflection and diffraction at buildings have been developed to make such site-specific predictions. Their accuracy has been evaluated primarily by comparing predictions against measurements of the small area average received signal. However, the ray models have started to be used to predict higher-order channel statistics, such as time delay and angle spread, through Monte Carlo simulations. This approach can generate values for the statistical descriptors of the radio channel that are employed in advanced communication systems and show how these values depend on the distribution of building size and shape in different cities.

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I would like to acknowledge the people who contributed to this book. First I must thank my wife Helene Ebenstein for continued encouragement during is writing, and for proof reading the final manuscript. Byung-Chul Kim of Polytechnic University prepared many of the computed curves, as well as many of the drawings. Additional computed curves and drawings were prepared by Jeho Lee, Hyun-Kyu Chung and Cheolhang Cheon of Polytechnic, and George Liang of Site Ware Technologies. The programs appearing on the web site for this book were prepared by Byung-Chul Kim, Hyun-Kyu Chung, George Liang, Jeho Lee and Leonard Piazzi. I was fortunate to have worked with a number of students whose ideas and efforts are embodied in the book. Finally, I would like to thank Mohsen Gharabaghloo for introducing me to the problems of propagation for cellular mobile radio in the early 1980's.

目录概览

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