国外电子信息精品著作(影印版)

无线网络RF工程：硬件、天线和传播

RF Engineering for Wireless Networks: Hardware, Antennas, and Propagation

Daniel M. Dobkin

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内 容 简 介

本书涉及电磁理论、天线理论和电波传播理论，在论述了基本理论、方法的同时，更注重学科发展的前沿。本书图文并茂，尤其是在图的制作上，显得非常新颖和活跃、直观而大方，图的选取和制作很严谨和细致。可作为研究生的教材，对于专家和工程技术人员也具有很大的参考价值。

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《国外电子信息精品著作》序

20世纪90年代以来，信息科学技术成为世界经济的中坚力量。随着经济全球化的进一步发展，以微电子、计算机、通信和网络技术为代表的信息技术，成为人类社会进步过程中发展最快、渗透性最强、应用面最广的关键技术。信息技术的发展带动了微电子、计算机、通信、网络、超导等产业的发展，促进了生命科学、新材料、能源、航空航天等高新技术产业的成长。信息产业的发展水平不仅是社会物质生产、文化进步的基本要素和必备条件，也是衡量一个国家的综合国力、国际竞争力和发展水平的重要标志。在中国，信息产业在国民经济发展中占有举足轻重的地位，成为国民经济重要支柱产业。然而，中国的信息科学支持技术发展的力度不够，信息技术还处于比较落后的水平，因此，快速发展信息科学技术成为我国迫在眉睫的大事。

要使我国的信息技术更好地发展起来，需要科学工作者和工程技术人员付出艰辛的努力。此外，我们要从客观上为科学工作者和工程技术人员创造更有利于发展的环境，加强对信息技术的支持与投资力度，其中也包括与信息技术相关的图书出版工作。

从出版的角度考虑，除了较好较快地出版具有自主知识产权的成果外，引进国外的优秀出版物是大有裨益的。洋为中用，将国外的优秀著作引进到国内，促进最新的科技成就迅速转化为我们自己的智力成果，无疑是值得高度重视的。科学出版社引进一批国外知名出版社的优秀著作，使我国从事信息技术的广大科学工作者和工程技术人员能以较低的价格购买，对于推动我国信息技术领域的科研与教学是十分有益的事。

此次科学出版社在广泛征求专家意见的基础上，经过反复论证、仔细遴选，共引进了接近30本外版书，大体上可以分为两类，第一类是基础理论著作，第二类是工程应用方面的著作。所有的著作都涉及信息领域的最新成果，大多数是2005年后出版的，力求“层次高、内

容新、参考性强”。在内容和形式上都体现了科学出版社一贯奉行的严谨作风。

当然，这批书只能涵盖信息科学技术的一部分，所以这项工作还应该继续下去。对于一些读者面较广、观点新颖、国内缺乏的好书还应该翻译成中文出版，这有利于知识更好更快地传播。同时，我也希望广大读者提出好的建议，以改进和完善丛书的出版工作。

总之，我对科学出版社引进外版书这一举措表示热烈的支持，并盼望这一工作取得更大的成绩。

中国科学院院士
中国工程院院士
2006 年 12 月

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Chapter 1

Introduction

1. The Beauty of Wires, the Inevitability of Wireless

The first gem of wisdom I ever acquired about consulting, obtained many years ago from a former schoolmate, was to ensure that everything is plugged in: no continuity, no data. Wires carry voltages and currents from one place to another. Their behavior is reasonably simple and predictable—at least for sufficiently low data rates and short lengths—and they can be seen, grabbed, traced, and tugged.

Wires are also an irritating and sometimes intolerable umbilical cord to the mother network. Look behind a typical personal computer or engineering workstation: you'll be hard put to find which plug goes with which cable. One person in a café with a laptop plugged into an Ethernet port on the wall is a curiosity; five, sitting at different tables with colorful category 5 cables snaking randomly along the floor between chairs and people, are an eyesore and a safety hazard. It's great to return your rental car and receive an instant printed receipt; the folks who provide the service would have a tough time dragging wires behind them down the long lines of cars, to say nothing of the angry businessmen and -women falling flat on the asphalt as they hurried to their flights. Sometimes wires won't do.

Accept that we have to cut the cords and break the old rules: no continuity, but lots of data. How is it done? What new complexities are introduced when the old metal conduit for current is removed? How are the resulting difficulties surmounted? What limits remain? It turns out that the way signals are modulated, transmitted, propagated, and received in a wireless link all change drastically from their wired counterparts. However, these changes can mostly be concealed from the data network: if things are done right, the network can't tell that the wires have been left behind.

This book is about the measures that must be taken, the obstacles that are encountered, and the limitations that result when data are to be moved wirelessly from place to place. The book is focused on local and personal area networks—*LANs* and *PANs*—although we will show how technologies developed for local communications can in some cases be deployed over long distances. We will concentrate on Institute of Electrical and Electronic Engineers (IEEE) 802.11–based wireless LANs—*Wi-Fi* networks—though we will discuss related technologies, and many of the lessons we will learn are broadly applicable.

Though we will touch on recent standards developments and provide examples of commercial practice, this book is not an attempt to provide an up-to-date snapshot or exhaustive survey of the state of the art; even in an age of rapid publication, any such summary will rapidly be rendered obsolete by the continual advancement of technology and industry. Rather, the reader should be armed upon completion of this book to understand why things work the way they do and thus distinguish between pretense and progress.

Most importantly, this book is about signals, not bits. We will touch upon the digital side of the problem of wireless networking, but we are primarily concerned with what happens between the point where bits are converted to voltages *here* and where the reverse operation occurs at a distant *there*. Some readers may be familiar with the *Open Systems Interconnect (OSI) reference model* for digital communications, a standard for imposing some hierarchical order on the various tasks required to communicate between two end-users within a network (Figure 1-1). In OSI terms, this book is about the *physical* layer of a wireless data link, with a few digressions into the *medium-access control* sublayer, but rarely higher. The reader whose interest extends also up the stack and sideways into network integration is referred to the many excellent texts that already touch upon the digital side of wireless LANs; a few examples can be found in the suggested reading at the end of this chapter.

2. What You Need to Proceed

The book is intended to be nearly self-contained: no previous acquaintance with radio technology is necessary. The reader ought to have some background in the physical sciences and an acquaintance with the basic electrical engineering concepts of voltage, current, resistance, capacitance, and inductance, along with their conventional schematic representations. Familiarity with the importance of harmonic (sinusoidal)

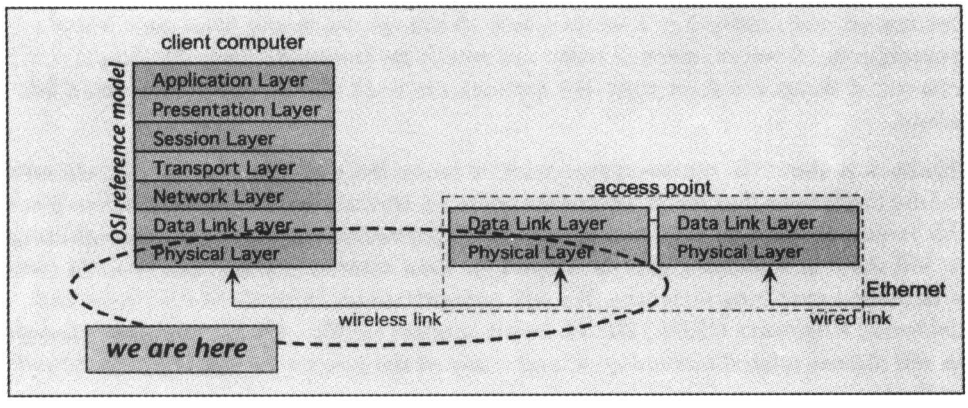

Figure 1-1: Location Relative to the OSI Reference Model

excitations is also assumed, though we provide a brief review of the use of complex exponentials to represent such signals. Though every effort is made to emphasize physical intuition before mathematical methodology, the reader ought to be comfortable with algebra and recognize the meaning of derivatives and integrals even if the mechanics of performing them is a bit rusty. Vectors and gradients will inevitably appear in the discussion of antennas and propagation. Certain aspects of Fourier transform theory, which play a vital role in wireless communications, will be briefly reviewed, though again a prior encounter with the notions of frequency and time representations of a signal is very helpful.

The more sophisticated reader may perhaps encounter a surprising dearth of certain expected vectorial complexities: I nowhere resort to Maxwell's equations, and nary a cross product is to be found. I do sink to taking a divergence of a vector field here and there, but the reader can bypass those scattered indulgences with little cost. Furthermore, though diffraction is examined in some detail, the estimable Mr. Huyghens and his principle are not in evidence, and though near-field and far-field regions are defined, the distinction is found to be mathematical rather than physical. In fact, the treatment of electromagnetism presented herein is exclusively in terms of the vector and scalar potentials, A and ϕ, acting on and created by actual currents and charges. In this attempt I have followed in part the prescriptions of Carver Mead in his book *Collective Electrodynamics*; I hope that the resulting presentation will provide a simpler and more appealing method of approaching a complex topic, though the results are equivalent to those obtained by conventional means, and readers with the requisite expertise can always fall back on more traditional approaches.

3. An Overview of What Is to Come

Figure 1-2 gives an overview of the remainder of the text.

We first cover some of the basics of wireless communications. We begin with the idea of multiplexing and then examine what happens when a high-frequency carrier is modulated to convey information, and why a trade-off between bandwidth, data rate, and noise tolerance must inevitably arise. We survey the typical modulation schemes used in digital data transmission, including a pair of somewhat exotic beasts—orthogonal frequency-division multiplexing and pulsed ultrawideband—that play an increasing role in the modern wireless world. We introduce the idea of a wireless link and the specialized terminology used in the radio world to describe voltage, power, and noise.

In the unavoidable exception to prove the rule, we digress into the digital domain to cover some basics of wireless local area networks, emphasizing the IEEE 802.11 committee's alphabet soup but not forgetting the unexpected radio legacy of King Harald "Bluetooth" Blätand of ancient Denmark, or some of the interesting activities of other task groups within the IEEE. While emphasizing the radio-related aspects of the standards, we also touch gingerly upon the domains of coding and encryption, by

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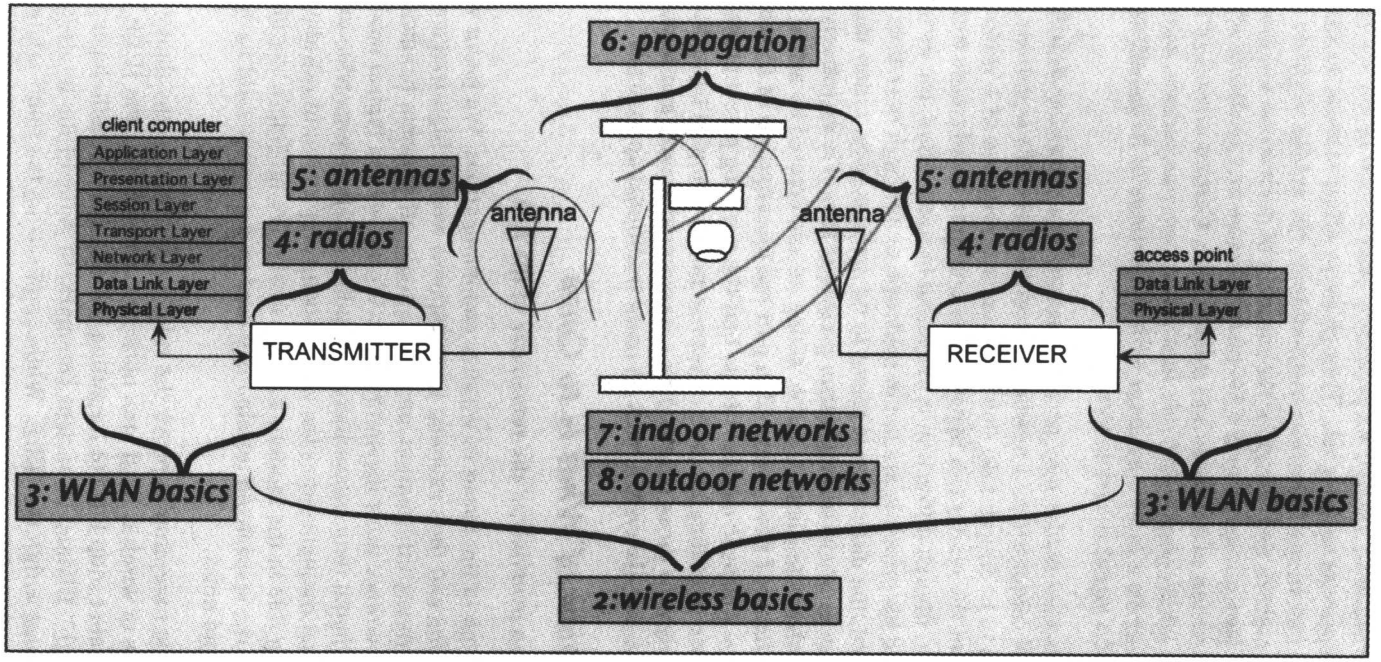

Figure 1-2: Overview of the Remainder of the Text

which the digital designers seek to compensate for the inadequacies of the uncertain wireless link.

We then plunge into the workings of digital radios: amplification, noise, and distortion; frequency conversion and spurious signals; frequency synthesis and phase noise; filters and filtering. We summarize by trying to design a radio chain to achieve a desired performance and examining how the requirements translate into the cost and complexity of the resulting chipset. The chapter ends with some examples of radio chips for wireless local area network and wireless personal area network applications and a quick look at the other pieces of the puzzle: the bit of PC board and external components that together with the integrated chips make a low-cost digital radio.

Having examined the creation of a signal, we examine its transmission and reception by means of antennas, exposing an antenna as nothing but a means to avoid cancellation of the effects of its currents. We show how antenna directivity allows us to estimate the amount of the transmitted power that arrives at the receiver given the antenna characteristics, at least for the ideal environment we know we will never encounter in this life. We briefly survey the operating principles behind a number of different types of commonly encountered antennas, with some emphasis on the tools for understanding how arrays of antennas can be used to produce interesting results not achievable from a single radiator.

We next abandon the pretense of ideality and treat propagation in some small fraction of the unmanageable complexity it deserves. Our poor transmitted wave finds itself reflected, absorbed, diffracted, and refracted by all manner of obstacles, on scales from the microscopic to the global, leading to the bugaboos of the radio world: attenuation, fading, and multipath. We examine how fading is surmounted with the aid of diversity antennas, appropriate modulations, and more sophisticated adaptive antenna arrays.

Our theoretical apparatus as complete as it is going to be, we plunge into the empirical realities of real indoor and outdoor networks. We review construction practices in sufficient detail to provide insight into existing buildings but not to obtain a general contractor's license and combine them with published information on microwave absorption and reflection to obtain some idea of where waves ought to go and where they ought not. We provide a survey of software tools to automate the tasks of getting the network to work, and some samples of their output. Our roving eye then moves into the wild outdoors, where we examine how buildings confine signals through reflection and diffraction, and how trees play a key role in limiting outdoor microwave links. We examine area coverage networks, point-to-multipoint networks for providing Internet access, and point-to-point links between fixed locations. The curvature of the earth, both real and effective, reminds us that we've gone as far as short-range radios, and this book, are going to take us. A brief review of safety precautions for outdoor work brings us to the end of the journey, save for the unusually determined reader, for whom

appendices on regulatory and measurement considerations, as well as a few derivations mercifully avoided in the text, are provided.

4. Acknowledgments

The book you're about to read has benefited from the time, thought, and experience of many helpful people. Special thanks go to Jay Kruse of Tropos Networks, who reviewed many incarnations of the materials in detail and provided helpful insight and suggestions. Jay's colleagues Cyrus Behroozi, Tom Blaze, and Malik Audeh also provided support and allowed me to tag along on surveying expeditions. The folks at WJ Communications, including Ron Buswell, Don McLean, Mike O'Neal, Rich Woodburn, Mark Bringuel, John Tobias, Kevin Li, Ray Allan, and Steve Weigand, gave me access to test equipment and facilities for many of the measurements reported here as well as encouragement and microwave wisdom. Jim Mravca and Nathan Iyer were particularly helpful in providing insight on system and integrated circuit design. Bill McFarland and David Su of Atheros and Kevin Wang at Silicon Wave helped correct the descriptions of RF chipsets. Greg des Brisay and Bob Arasmith shared their practical knowledge of outdoor network installations; Pat McCaffrey of Hidden Villa kindly provided access to the network site described in Chapter 8. Rajeev Krishnamoorthy shared his experiences in the early development of wireless LAN technology. Miki Genossar provided guidance on the ultrawideband work of the IEEE standards bodies. Markus Moisio and Jussi Kiviniemi of Ekahau and Baris Dandar of ABP Systems provided demonstration software and guidance in surveying. Skip Crilly clarified the operation of the Vivato access point. Thanks also to Mark Andrews, Martin Chaplin, Rob Martin, Ana Bakas, William Stone, Franz Chen, W.R. Vincent, Richard Adler, David Freer, Simon Perras, Luc Bouchard, and Vinko Erceg. Harry Helms, my editor at Elsevier, was always entertaining as well as encouraging. Last but not by any means least, my long-suffering spouse, Nina, not only put up with innumerable weekend absences but also provided expert linguistic support on short notice to navigate the Chinese Ministry of Information Industries website.

Further Reading

General Introductions to Networking

Understanding Data Communications (6th Edition), Gilbert Held, New Riders, 1999: *Simple and accessible, though some coverage areas are already rather dated.*

Communication Networks, Alberto Leon-Garcia and Indra Widjaja, McGraw-Hill, 2003: *An academic text with modern emphasis on Internet Protocol.*

Introductions to Wireless LANs

802.11 Networks: The Definitive Guide, Matthew Gast, O'Reilly, 2002: *It is, at least on the digital side. A thorough review of standards and tools.*

Jeff Duntemann's Drive-By Wi-Fi Guide, Paraglyph Press, 2003: *Accessible introduction and hands-on guide to setting up common equipment.*

Wireless LANs, Jim Geier, Macmillan, 1999: *The technical information here is already somewhat old, but this book has a nice discussion of how to plan and manage network installation projects.*

Chapter 2

Basics of Wireless Communications

1. Harmonic Signals and Exponentials

Before we begin to talk about wireless, we briefly remind the reader of a previous acquaintance with three concepts that are ubiquitous in radio engineering: sinusoidal signals, complex numbers, and imaginary exponentials. The reader who is familiar with such matters can skip this section without harm.

Almost everything in radio is done by making tiny changes—modulations—of a signal that is periodic in time. The archetype of a smooth periodic signal is the sinusoid (Figure 2-1), typically written as the product of the angular frequency ω and time t.

Both of these functions alternate between a maximum value of 1 and minimum value of -1; cosine starts at $+1$, and sine starts at 0, when the argument is zero. We can see that cosines and sines are identical except for an offset in the argument (the *phase*):

$$\cos(\omega t) = \sin\left(\omega t + \frac{\pi}{2}\right) \qquad [2.1]$$

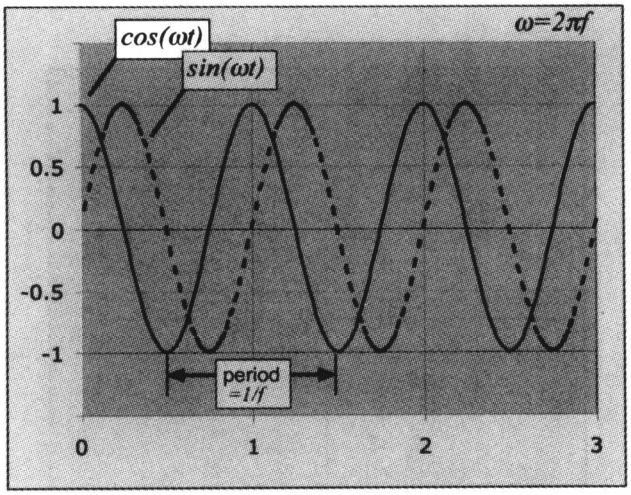

Figure 2-1: Cosine and Sine Functions

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