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

通信原理

——系统、调制与噪声

第5版 影印版

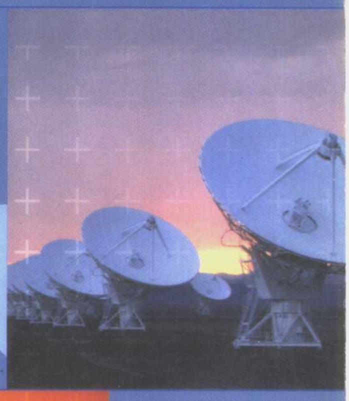
Principles of Communications

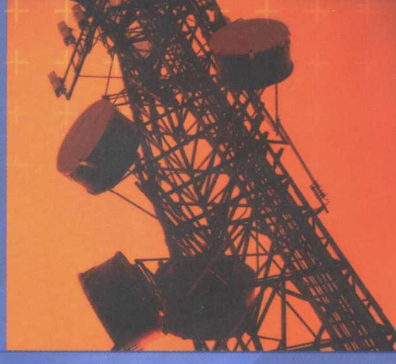
Systems, Modulation and Noise

Fifth Edition

• Rodger E. Ziemer
• William H. Tranter

WILEY





高等教育出版社
Higher Education Press

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

通信原理

——系统、调制与噪声

第5版 影印版

Principles of Communications

Systems, Modulation and Noise

Fifth Edition

• Rodger E. Ziemer
• William H. Tranter

WILEY

高等教育出版社
Higher Education Press

图字：01－2003－3476号

Principles of Communication: Systems, Modulation and Noise, 5th ed.
Rodger E. Ziemer and William H. Tranter

图书在版编目(CIP)数据

通信原理：系统、调制与噪声：第5版/(美)齐默(Ziemer, R.E.)，(美)特兰特(Tranter, W.H.)著. 影印本. —北京：高等教育出版社，2003.9
ISBN 7－04－013046－7

Ⅰ.通… Ⅱ.①齐…②特… Ⅲ.通信理论－英文
Ⅳ.TN911

中国版本图书馆CIP数据核字(2003)第067106号

出版发行	高等教育出版社	**购书热线**	010－64054588
社　址	北京市西城区德外大街4号	**免费咨询**	800－810－0598
邮政编码	100011	**网　址**	http://www.hep.edu.cn
总　机	010－82028899		http://www.hep.com.cn
经　销	新华书店北京发行所		
印　刷	北京铭成印刷有限公司		
开　本	787×1092　1/16	**版　次**	2003年9月第1版
印　张	40.75	**印　次**	2003年9月第1次印刷
字　数	500 000	**定　价**	49.50元

Rodeger Ziemer dedicates this book to:
His wife, Sandy
Their children and spouses, Mark and Susie Ziemer
and Dean and Amy Nilson
And their grandchildren, Kristie Jorgenson, Lorissa Ziemer, Chad Ziemer,
and a yet to be named grandchild

Bill Tranter dedicates this book to:
His wife, Judy
And to their two children, Elizabeth and John

前　言

20世纪末，以计算机和通信技术为代表的信息科学和技术对世界经济、科技、军事、教育和文化等产生了深刻影响。信息科学技术的迅速普及和应用，带动了世界范围信息产业的蓬勃发展，为许多国家带来了丰厚的回报。

进入21世纪，尤其随着我国加入WTO，信息产业的国际竞争将更加激烈。我国信息产业虽然在20世纪末取得了迅猛发展，但与发达国家相比，甚至与印度、爱尔兰等国家相比，还有很大差距。国家信息化的发展速度和信息产业的国际竞争能力，最终都将取决于信息科学技术人才的质量和数量。引进国外信息科学和技术优秀教材，在有条件的学校推动开展英语授课或双语教学，是教育部为加快培养大批高质量的信息技术人才采取的一项重要举措。

为此，教育部要求由高等教育出版社首先开展信息科学和技术教材的引进试点工作。同时提出了两点要求，一是要高水平，二是要低价格。在高等教育出版社和信息科学技术引进教材专家组的努力下，经过比较短的时间，第一批引进的20多种教材已经陆续出版。这套教材出版后受到了广泛的好评，其中有不少是世界信息科学技术领域著名专家、教授的经典之作和反映信息科学技术最新进展的优秀作品，代表了目前世界信息科学技术教育的一流水平，而且价格也是最优惠的，与国内同类自编教材相当。

这项教材引进工作是在教育部高等教育司和高教社的共同组织下，由国内信息科学技术领域的专家、教授广泛参与，在对大量国外教材进行多次遴选的基础上,参考了国内和国外著名大学相关专业的课程设置进行系统引进的。其中，John Wiley公司出版的贝尔实验室信息科学研究中心副总裁 Silberschatz 教授的经典著作《操作系统概念》，是我们经过反复谈判，做了很多努力才得以引进的。William Stallings先生曾编写了在美国深受欢迎的信息科学技术系列教材，其中有多种教材获得过美国教材和学术著作者协会颁发的计算机科学与工程教材奖,这批引进教材中就有他的两本著作。留美中国学者 Jiawei Han 先生的《数据挖掘》是该领域中具有里程碑意义的著作。由达特茅斯学院的 Thomas Cormen 和麻省理工学院、哥伦比亚大学几位学者共同编著的经典著作《算法导论》，在经历了 11 年的锤炼之后于 2001 年出版了第二版。目前任教于美国 Massachusetts大学的 James Kurose 教授，曾在美国三所高校先后 10 次获得杰

出教师或杰出教学奖，由他主编的《计算机网络》出版后，以其体系新颖、内容先进而倍受欢迎。在努力降低引进教材售价方面，高等教育出版社做了大量和细致的工作。这套引进的教材体现了权威性、系统性、先进性和经济性等特点。

教育部也希望国内和国外的出版商积极参与此项工作，共同促进中国信息技术教育和信息产业的发展。我们在与外商的谈判工作中，不仅要坚定不移地引进国外最优秀的教材，而且还要千方百计地将版权转让费降下来，要让引进教材的价格与国内自编教材相当，让广大教师和学生负担得起。中国的教育市场巨大，外国出版公司和国内出版社要通过扩大发行数量取得效益。

在引进教材的同时，我们还应做好消化吸收，注意学习国外先进的教学思想和教学方法，提高自编教材的水平，使我们的教学和教材在内容体系上，在理论与实践的结合上，在培养学生的动手能力上能有较大的突破和创新。

目前，教育部正在全国35所高校推动示范性软件学院的建设和实施，这也是加快培养信息科学技术人才的重要举措之一。示范性软件学院要立足于培养具有国际竞争力的实用性软件人才，与国外知名高校或著名企业合作办学，以国内外著名IT企业为实践教学基地，聘请国内外知名教授和软件专家授课，还要率先使用引进教材开展教学。

我们希望通过这些举措，能在较短的时间，为我国培养一大批高质量的信息技术人才，提高我国软件人才的国际竞争力，促进我国信息产业的快速发展，加快推动国家信息化进程，进而带动整个国民经济的跨越式发展。

教育部高等教育司

二〇〇二年三月

PREFACE

In the fifth edition of this book, we have maintained the same guiding principle as in the previous four editions. This principle is to provide, in a single volume, a thorough treatment of the principles of communications at the physical layer suitable for college seniors, beginning graduate students, and practicing engineers. This is accomplished by providing overviews of the necessary background in signal, system, probability, and random process theory required for the analog and digital communications topics covered in the book. In addition to stressing fundamental concepts, sections on currently important areas such as spread spectrum, cellular communications, and orthogonal frequency-division multiplexing are provided. The illustrative examples provided in previous editions are supplemented in this edition with computer examples, written in MATLAB, interspersed throughout the book. These examples range from programs for computing performance curves to simulation programs for certain types of communication systems and algorithms. Reactions to previous editions have shown that the book's emphasis on fundamentals, as opposed to specific technologies, serves the user well while keeping the length reasonable. This strategy appears to have worked well for advanced undergraduates, for new graduate students who may have forgotten some of the fundamentals, and for the working engineer who may use the book as a reference or who may be taking a course after-hours.

One new feature of the fifth edition of *Principles of Communications* is the inclusion of MATLAB-based computer examples within each chapter. We realize that some users of this book will view the inclusion of computer code within the main body of the book as an attribute and some will view it as a distraction. For this reason, we have chosen to include only two or three MATLAB examples in each chapter. While we feel that exposure to modern computational tools for analysis and simulation is important, we have limited the use of MATLAB so that the character of the book would not be significantly changed. While those using the book may retype the MATLAB code from the code appearing in the book, this is not necessary. The publisher maintains a web site from which all code may be downloaded. The URL is

www.wiley.com/college/ziemer

From time to time other interesting computer examples will be placed on this web site. MATLAB was chosen for these examples because of its widespread use in both academic and industrial settings. Most engineering students are familiar with MATLAB and will be able to understand the examples without difficulty. We also like it for its rich graphics library.

In addition to the in-chapter computer examples, a number of "computer exercises" are included at the end of each chapter. These exercises follow the end-of-chapter problems and are designed to make use of the computer in order to illustrate basic principles and to provide additional insights into the text material. Similar exercises were included in the fourth edition and a number of users of the book found them valuable. There are a number of motivations for the inclusion of these problems. The computer is now accepted as a valuable tool in engineering education and is now well integrated into engineering curricula. Computer usage allows students to work more complex problems. Furthermore, students will gain important insights through working these problems. While these problems can be worked by writing programs in a variety of languages we strongly recommend the use of scientific problem-solving programs such as MATLAB, MATHCAD, and MATHEMATICA.

As mentioned in the preface to the fourth edition, the past two decades have seen many new applications for communication theory concepts. Cellular radio is an ubiquitous example. In addition, new technologies for the implementation of these systems continue to be developed. While there is always a strong desire to include a variety of new applications and technologies in a new edition of a book, we strongly feel that a first course in communications serves the student best if the emphasis is placed on fundamentals. We feel that application examples and specific technologies, which often have short lifetimes, are best treated in subsequent courses after students have mastered the basic theory and analysis techniques. We have, however, been sensitive to new techniques that are fundamental in nature and have added material as appropriate.

In order to compare this edition with the previous edition, we briefly consider the changes chapter by chapter. As mentioned previously, with the exception of Chapter 1, computer examples have been included in all chapters. In Chapter 1, the tables have been updated. Chapter 2, which is essentially a review of signal and system theory, remains basically unchanged. Chapter 3, which is devoted to basic modulation methods, has been updated by deleting the material on switching modulators and the section on analog pulse modulation has been shortened. Computer examples have been added for determining the spectra of modulated signals. In addition, a complete simulation of a phase-locked loop is included in order to illustrate acquisition behavior.

Chapter 4, which deals with basic probability theory, now includes a section on Ricean random variables. A related appendix on the chi-square distribution has been added. This material is motivated by the study of fading channels and cellular communications later in the book. Chapter 5 has been shortened significantly by placing the material on the proof of the narrowband noise model and the study of the origin encirclement problem (important for an understanding of thresholding in FM systems) in the appendices. We felt that this material, while still important, is outside the scope of many introductory courses.

In Chapter 6, which treats the noise performance of various analog modulation schemes, the section on threshold extension has been expanded slightly to include material on the effect of modulation on threshold effects and to examine in more detail threshold effects in pulse code modulation. The consideration of threshold effects in pulse code modulation builds a bridge to the remainder of the book, which treats digital communication systems.

Binary digital data transmission is the subject of Chapter 7. The section dealing with fading channels has been expanded. This is an important subject in today's world because of the rapidly expanding use of mobile communication systems. Computer examples on computing performance curves for binary modulation systems, plotting optimum transmitter and receiver filter frequency response functions for binary signaling in a bandlimited channel, and plotting error probability curves for various binary modulation techniques operating in flat fading have been added. In addition, a simulation program of a delay/multiply detector for differential phase-shift keying has been added in order to compare its performance with that of the optimum detector.

Chapter 8 treats more advanced topics in data communication systems including M-ary systems, bandwidth efficiency, synchronization, spread-spectrum systems, and satellite links. New sections or expansions of previously appearing sections are included on Gaussian minimum-shift keying, the computation of power spectra for various types of line code representations of baseband data signals, the performance of direct-sequence spread-spectrum systems in a multiuser environment, cellular radio communication systems, and multicarrier modulation. In addition, computer examples on plotting bit error probability performance curves for M-ary phase-shift keying, spectra for continuous-phase frequency-shift keying, and the bit error probability for direct-sequence spread-spectrum systems operating in multiuser environments have been added.

Chapter 9, which deals with optimum receivers and signal-space concepts, is little changed from the previous edition. A computer example that determines and plots the receiver-operating characteristic has been added.

Chapter 10 provides the student with a brief introduction to the subjects of information theory and coding. A brief discussion of turbo coding has been added to this chapter. Also added is a computer example that allows the student to investigate erasure channels in detail.

We have used this text for various types of courses for a number of years but the passage of time has altered the initial philosophy on which this book was based. In particular, it was originally written for a two-semester course sequence, with the first semester covering basic background material on linear systems and noiseless modulation, and the second covering noise effects on analog and digital modulation systems. With a previous background by the students in linear systems and probability theory, we know of several instances where the book has been used for a one-semester course on analog and digital communication system analysis in noise. While probably challenging for all but the best students, this nevertheless gives an option that will get students exposed to modulation system performance in noise in one semester. In short, we feel that it is presumptuous for us to tell instructors using the book what material to cover and in what order. Suffice it to say we feel that there is more than enough material included in the book to satisfy almost any course design at the senior or beginning graduate levels.

A solutions manual is available from the publisher. This manual contains complete solutions to all odd-numbered problems and answers to all even-numbered problems. Partial solutions are given to even-numbered problems in those cases in which we felt that some guidance would be helpful. In addition, complete MATLAB solutions to all computer exercises are given in the solutions manual.

We wish to thank the many persons who have contributed to the development of this textbook and who have suggested improvements for the fifth edition. We especially thank our colleagues and students at the University of Colorado at Colorado Springs, the University of Missouri-Rolla, and Virginia Tech for their comments and suggestions. The help of Dr. William Ebel at St. Louis University is especially acknowledged. We also express our thanks to the many colleagues who have offered suggestions to us by correspondence or orally at technical conferences. The industries and agencies that have supported our research deserve special mention since, by working on these projects, we have expanded our knowledge and insight significantly. These include the National Aeronautics and Space Administration, the Office of Naval Research, the National Science Foundation, GE Aerospace, Motorola Inc., Emerson Electric Company, Battelle Memorial Institute, DARPA, Raytheon, and the LGIC Corporation. The expert support of Cyndy Graham, who worked through many of the LaTeX-related problems and who contributed significantly to the development of the solutions manual, is gratefully acknowledged.

We also thank the reviewers of this and all previous editions of this book. The reviewers for the fifth edition deserve special mention. They were:

John Kieffer—University of Minnesota
Laurence G. Hassebrook—University of Kentucky
Donley Winger—Cal Poly-San Luis Obispo
Michael Fitz—Purdue University

Costas Georghiades—Texas A&M
Nirwan Ansari—New Jersey Institute of Technology
Venkatachalam Anantharam—UC–Berkeley
Masoud Salehi—Northeastern University
John Rulnick—Worchester Polytechnic Institute
Marvin Siegel—Michigan State University
James V. Krogmeier—Purdue University

All reviewers contributed significantly to this book. They caught many errors and made many valuable suggestions. The authors accept full responsibility for any remaining errors or shortcomings.

Finally, our families deserve much more than a simple thanks for the patience and support that they have given us throughout more than twenty-five years of seemingly endless writing projects. It is to them that this book is dedicated.

Rodger E. Ziemer
William H. Tranter

郑重声明

策划编辑　李　慧

责任编辑　李　慧

封面设计　王凌波

责任印制　孔　源

CONTENTS

CHAPTER 1

INTRODUCTION

At the dawn of the twenty-first century, we live in a world in which electrical communications is so pervasive that we access the Internet to purchase products or download new software applications to our computers without a second thought. Yet the importance of such communications in today's world is so crucial that we cannot imagine modern society without it. Modern nations have for the past couple of decades been moving more and more into an era, which some people refer to as the "information age," much like the era—more than 100 years ago—when the world underwent drastic changes because of the industrial revolution. The prosperity and continued development of modern nations depends more and more on origination and dissemination of *information*, rather than on the production and distribution of manufactured goods. Examples illustrating that information is valued more than goods and services are manifold—the explosion during the last decade in the use of cellular telephones, the Internet, personal digital assistants, and two-way pagers provides only a few examples of means to access and convey information at anytime and anyplace.

This book is concerned with the theory of systems for the conveyance of information. A *system* is a combination of circuits and devices which is assembled to accomplish a desired result, such as the transmission of intelligence from one point to another. A characteristic of communication systems is the presence of uncertainty. This uncertainty is due in part to the inevitable presence in any system of unwanted signal perturbations, broadly referred to as *noise*, and in part to the unpredictable nature of information itself. Systems analysis in the presence of such uncertainty requires the use of probabilistic techniques.

Noise has been an ever-present problem since the early days of electrical communication, but it was not until the 1940s that probabilistic systems analysis procedures were used to analyze and optimize communication systems operating in its presence [Wiener 1949; Rice 1944, 1945].[1] It is also somewhat surprising that the unpredictable nature of information was not widely recognized until the publication of Claude Shannon's mathematical theory of communications [Shannon 1948] in the late 1940s. This work was the beginning of the science of information theory, a topic that will be considered in some detail later.

A better appreciation of the accelerating pace at which electrical communication is developing can perhaps be gained by the historical outline of selected communications-related events given in Table 1.1.

With this brief introduction and history, we now look in more detail at the various components that make up a typical communication system.

1.1 THE BLOCK DIAGRAM OF A COMMUNICATION SYSTEM

Figure 1.1 shows a commonly used model for a single-link communication system.[2] Although it suggests a system for communication between two remotely located points, this block diagram is also applicable to remote sensing systems, such as radar or sonar, in which the system input and output may be located at the same site. Regardless of the particular application and configuration, all information transmission systems invariably involve three major subsystems—a transmitter, the channel, and a receiver. In this book we will usually be thinking in terms of systems for transfer of information between remotely located points. It is emphasized, however, that the techniques of systems analysis developed in this book are not limited to such systems.

We will now discuss in more detail each functional element shown in Figure 1.1.

Input Transducer The wide variety of possible sources of information results in many different forms for messages. Regardless of their exact form, however, messages may be categorized as *analog* or *digital*. The former may be modeled as functions of a continuous-time variable (e.g., pressure, temperature, speech, music), whereas the latter consists of discrete symbols (e.g., written text). Almost invariably, the message produced by a source must be converted by a transducer to a form suitable for the particular type of communication system employed. For example, in electrical communications, speech waves are converted by a microphone to voltage variations. Such a converted message is referred to as the *message signal*. In this book, therefore, a *signal* can be interpreted as the variation of a quantity, often a voltage or current, with time.

Transmitter The purpose of the transmitter is to couple the message to the channel. Although it is not uncommon to find the input transducer directly coupled to the transmission medium, as for example in some intercom systems, it is often necessary to *modulate* a carrier

[1]References in brackets [ ] refer to Historical References in the Bibliography.

[2]More complex communications systems are the rule rather than the norm: a broadcast system, such as television or commercial radio, is a one-to-many type of situation which is composed of several sinks receiving the same information from a single source; a multiple-access communication system is where many users share the same channel and is typified by many satellite communications systems; a many-to-many type of communications scenario is the most complex and is illustrated by examples such as the telephone system and the Internet, both of which allow communication between any pair out of a multitude of users. For the most part, we consider only the simplest situation in this book of a single sender to a single receiver, although means for sharing a communication resource will be dealt with under the topics of multiplexing and multiple access.

TABLE 1.1 A Brief History of Communications

Interval	Year	Event
	1826	Georg Simon Ohm establishes law on voltage-current relationship in resistors
	1838	Samuel F. B. Morse demonstrates telegraph
80 years	1864	James C. Maxwell predicts electromagnetic radiation
	1876	Alexander Graham Bell patents the telephone
	1887	Heinrich Hertz verifies Maxwell's theory
	1897	Guglielmo Marconi patents a complete wireless telegraph system
	1904	Fleming invents the diode
	1905	Reginald Fessenden transmits speech signals via radio
	1906	Lee De Forest invents the triode amplifier
	1915	Bell System completes U.S. transcontinental telephone line
40 years	1918	B. H. Armstrong perfects superheterodyne radio receiver
	1920	J. R. Carson applies sampling to communications
	1931	Teletypewriter service is initialized
	1933	Edwin Armstrong invents frequency modulation
	1937	Alec Reeves conceives pulse-code modulation (PCM)
	1936	Television broadcasting begun by the BBC
	WW II	Radar and microwave systems are developed; Statistical methods are applied to signal extraction problems
	1948	Transistor is invented—Walter Brattain, John Bardeen, and William Shockley
20 years		Claude Shannon's "A Mathematical Theory of Communications" is published
	1950	Time-division multiplexing is applied to telephony Color television broadcasting introduced in the United States
	1956	First successful transoceanic telephone cable
	1960	Laser demonstrated by Maiman First communication satellite, Telstar I, launched (1962)
10 years	to	Experimental pulse code modulation systems; Experimental laser communications; Integrated circuits; Digital signal processing; live television coverage of the moon exploration (1968)
	1970	Time-shared computing
	1970	Commercial relay satellite communications (voice and digital); Gigabit signaling rates; Large-scale integration; Integrated circuit realization of communications circuits; Intercontinental computer communication nets; Low-loss light fibers;
10 years	to	Optical communication systems; Packet-switched digital data systems; Interplanetary grand tour launched (1977); Communications accomplished from Jupiter, Saturn, Uranus, and Neptune (encounter in August 1989); Microprocessor,
	1980	computed tomography; Supercomputers developed
	1980	Satellite "switchboards in the sky"; Mobile, cellular telephone systems; Multifunction digital displays; 2 gigasample/s digital
10 years	to	oscilloscopes; Desktop publishing systems; Programmable digital signal processors; Digitally tuned receivers with autoscan;

(continued)