

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

通信系统

——通信中的信号与噪声

第四版 影印版

Communication Systems

An Introduction to Signals and
Noise in Electrical Communication

Fourth Edition

■ A. Bruce Carlson
Paul B. Crilly
Janet C. Rutledge



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A. Bruce Carlson & Paul B. Crilly & Janet C. Rutledge

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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、哥伦比亚大学的

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

*To the memory of my father and mother,
Albin John Carlson and Mildred Elizabeth Carlson*
A. Bruce Carlson

*To my parents,
Lois Crilly and I. Benjamin Crilly*
Paul B. Crilly

*To my son, Carter:
May your world be filled with the excitement of discovery*
Janet C. Rutledge

Preface

This text, like its previous three editions, is an introduction to communication systems written at a level appropriate for advanced undergraduates and first-year graduate students in electrical or computer engineering. New features in this edition include the introduction of two other authors, Professors Rutledge and Crilly, to provide additional expertise for topics such as optical links and spread spectrum.

An initial study of signal transmission and the inherent limitations of physical systems establishes unifying concepts of communication. Attention is then given to analog communication systems, random signals and noise, digital systems, and information theory. However, as indicated in the table of contents, instructors may choose to skip over topics that have already been or will be covered elsewhere.

Mathematical techniques and models necessarily play an important role throughout the book, but always in the engineering context as means to an end. Numerous applications have been incorporated for their practical significance and as illustrations of concepts and design strategies. Some hardware considerations are also included to justify various communication methods, to stimulate interest, and to bring out connections with other branches of the field.

PREREQUISITE BACKGROUND

The assumed background is equivalent to the first two or three years of an electrical or computer engineering curriculum. Essential prerequisites are differential equations, steady-state and transient circuit analysis, and a first course in electronics. Students should also have some familiarity with operational amplifiers, digital logic, and matrix notation. Helpful but not required are prior exposure to linear systems analysis, Fourier transforms, and probability theory.

CONTENTS AND ORGANIZATION

A distinctive feature of this edition is the position and treatment of probability, random signals, and noise. These topics are located after the discussion of analog systems without noise. Other distinctive features are the new chapter on spread spectrum systems and the revised chapter on information and detection theory near the end of the book. The specific topics are listed in the table of contents and discussed further in Sect. 1.4.

Following an updated introductory chapter, this text has two chapters dealing with basic tools. These tools are then applied in the next four chapters to analog communication systems, including sampling and pulse modulation. Probability, random signals, and noise are introduced in the following three chapters and applied to analog systems. An appendix separately covers circuit and system noise. The remaining

six chapters are devoted to digital communication and information theory, which require some knowledge of random signals and include coded pulse modulation.

All sixteen chapters can be presented in a year-long undergraduate course with minimum prerequisites. Or a one-term undergraduate course on analog communication might consist of material in the first seven chapters. If linear systems and probability theory are covered in prerequisite courses, then most of the last eight chapters can be included in a one-term senior/graduate course devoted primarily to digital communication.

The modular chapter structure allows considerable latitude for other formats. As a guide to topic selection, the table of contents indicates the minimum prerequisites for each chapter section. Optional topics within chapters are marked by the symbol ★.

INSTRUCTIONAL AIDS

Each chapter after the first one includes a list of instructional objectives to guide student study. Subsequent chapters also contain several examples and exercises. The exercises are designed to help students master their grasp of new material presented in the text, and exercise solutions are given at the back. The examples have been chosen to illuminate concepts and techniques that students often find troublesome.

Problems at the ends of chapters are numbered by text section. They range from basic manipulations and computations to more advanced analysis and design tasks. A manual of problem solutions is available to instructors from the publisher.

Several typographical devices have been incorporated to serve as aids for students. Specifically,

- Technical terms are printed in boldface type when they first appear.
- Important concepts and theorems that do not involve equations are printed inside boxes.
- Asterisks (*) after problem numbers indicate that answers are provided at the back of the book.
- The symbol ‡ identifies the more challenging problems.

Tables at the back of the book include transform pairs, mathematical relations, and probability functions for convenient reference. An annotated bibliography is also provided at the back in the form of a supplementary reading list.

Communication system engineers use many abbreviations, so the index lists common abbreviations and their meanings. Thus, the index additionally serves as a guide to many abbreviations in communications.

ACKNOWLEDGMENTS

We are indebted to the many people who contributed to previous editions. We also want to thank Profs. John Chaisson, Mostofa Howlader, Chaouki Abdallah, and

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Special thanks for support, encouragement, and sense of humor go to our spouses and families.

A. Bruce Carlson
Paul B. Crilly
Janet C. Rutledge

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The numbers in parentheses after section titles identify previous sections that contain the minimum prerequisite material. The symbol ★ identifies optional material.

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chapter

1

Introduction

CHAPTER OUTLINE

1.1 Elements and Limitations of Communication Systems

Information, Messages, and Signals Elements of a Communication System Fundamental Limitations

1.2 Modulation and Coding

Modulation Methods Modulation Benefits and Applications Coding Methods and Benefits

1.3 Historical Perspective and Societal Impact

Historical Perspective Societal Impact

1.4 Prospectus

Attention, the Universe! By kingdoms, right wheel!" This prophetic phrase represents the first telegraph message on record. Samuel F. B. Morse sent it over a 16 km line in 1838. Thus a new era was born: the era of electrical communication.

Now, over a century and a half later, communication engineering has advanced to the point that earthbound TV viewers watch astronauts working in space. Telephone, radio, and television are integral parts of modern life. Long-distance circuits span the globe carrying text, data, voice, and images. Computers talk to computers via intercontinental networks, and control virtually every electrical appliance in our homes. Wireless personal communication devices keep us connected wherever we go. Certainly great strides have been made since the days of Morse. Equally certain, coming decades will usher in many new achievements of communication engineering.

This textbook introduces electrical communication systems, including analysis methods, design principles, and hardware considerations. We begin with a descriptive overview that establishes a perspective for the chapters that follow.

1.1 ELEMENTS AND LIMITATIONS OF COMMUNICATION SYSTEMS

A communication system conveys information from its source to a destination some distance away. There are so many different applications of communication systems that we cannot attempt to cover every type. Nor can we discuss in detail all the individual parts that make up a specific system. A typical system involves numerous components that run the gamut of electrical engineering—circuits, electronics, electromagnetics, signal processing, microprocessors, and communication networks, to name a few of the relevant fields. Moreover, a piece-by-piece treatment would obscure the essential point that a communication system is an integrated whole that really does exceed the sum of its parts.

We therefore approach the subject from a more general viewpoint. Recognizing that all communication systems have the same basic function of **information transfer**, we'll seek out and isolate the principles and problems of conveying information in electrical form. These will be examined in sufficient depth to develop analysis and design methods suited to a wide range of applications. In short, this text is concerned with communication systems as **systems**.

Information, Messages, and Signals

Clearly, the concept of **information** is central to communication. But information is a loaded word, implying semantic and philosophical notions that defy precise definition. We avoid these difficulties by dealing instead with the **message**, defined as the physical manifestation of information as produced by the source. Whatever form the message takes, the goal of a communication system is to reproduce at the destination an acceptable replica of the source message.

There are many kinds of information sources, including machines as well as people, and messages appear in various forms. Nonetheless, we can identify two distinct message categories, **analog** and **digital**. This distinction, in turn, determines the criterion for successful communication.

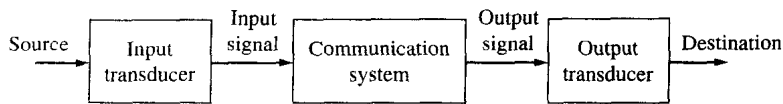


Figure 1.1-1 Communication system with input and output transducers.

An **analog** message is a physical quantity that varies with time, usually in a smooth and continuous fashion. Examples of analog messages are the acoustic pressure produced when you speak, the angular position of an aircraft gyro, or the light intensity at some point in a television image. Since the information resides in a time-varying waveform, an analog communication system should deliver this waveform with a specified degree of **fidelity**.

A **digital** message is an ordered sequence of symbols selected from a finite set of discrete elements. Examples of digital messages are the letters printed on this page, a listing of hourly temperature readings, or the keys you press on a computer keyboard. Since the information resides in discrete symbols, a digital communication system should deliver these symbols with a specified degree of **accuracy** in a specified amount of time.

Whether analog or digital, few message sources are inherently electrical. Consequently, most communication systems have input and output **transducers** as shown in Fig. 1.1-1. The input transducer converts the message to an electrical **signal**, say a voltage or current, and another transducer at the destination converts the output signal to the desired message form. For instance, the transducers in a voice communication system could be a microphone at the input and a loudspeaker at the output. We'll assume hereafter that suitable transducers exist, and we'll concentrate primarily on the task of **signal transmission**. In this context the terms **signal** and **message** will be used interchangeably since the signal, like the message, is a physical embodiment of information.

Elements of a Communication System

Figure 1.1-2 depicts the elements of a communication system, omitting transducers but including unwanted contaminations. There are three essential parts of any communication system, the transmitter, transmission channel, and receiver. Each part plays a particular role in signal transmission, as follows.

The **transmitter** processes the input signal to produce a transmitted signal suited to the characteristics of the transmission channel. Signal processing for transmission almost always involves **modulation** and may also include **coding**.

The **transmission channel** is the electrical medium that bridges the distance from source to destination. It may be a pair of wires, a coaxial cable, or a radio wave or laser beam. Every channel introduces some amount of transmission **loss** or **attenuation**, so the signal power progressively decreases with increasing distance.