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Principles of Electronic Communication Systems

Third edition

电子通信系统原理（第3版）

Louis E. Frenzel Jr. 著

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Principles of Electronic Communication Systems(3rd Ed.)

影 印 版 序

日新月异的现代信息技术中，通信技术始终位于发展的前列。据统计，通信行业的年均增长率近 10 年来始终处于两位数的百分比。迅猛发展的技术催生了对通信技术人才的迫切需求，通信工程专业的学生也面临着巨大的挑战。而目前大学的通信工程专业大多局限于传统的电信通信系统，教学大纲主要包括程控交换和短波通信等内容。随着互联网技术的发展和逐步渗透，现代通信系统，特别是第三代移动通信系统，已经逐步从传统的电路交换，发展到以分组交换和 IP 传输为核心的新的通信系统架构。

在我们多年讲授“通信系统”课程的教学实践中，很难找到能够反映以上这种技术融合的中文教材，更别提双语教学中亟需的英语原文教材。尽管过去几年国内多家出版社引进多本电子通信系统方面的教材，但无论是教材内容的技术先进性还是内容的深度，都不能满足“通信系统”课程的需要。

可喜的是，无意之中在网上发现了 Louis E Frenzel Jr 所著的这本教材，发现本教材有关通信系统部分的论述是按照微波通信、光纤通信、卫星通信、移动通信、网络通信等内容分章进行的，这一点特别符合国内大多数院校的教学方式。在清华大学出版社的共同努力下，我们对原书的内容进行了改编。原书中包含了通信原理和通信系统两大部分的内容，考虑到国内大多数院校的课程设置，同时也受到篇幅的限制，在改编中删除了原书中有关通信原理的内容（原书第 2 章至第 9 章），剩余的章节重新进行了编号。此外，考虑到国内读者的习惯，在每章的大节之后增加了小节的三级编号。在征得原书作者的同意之后，对原书中的部分文字错误也进行了修订。

本人才疏学浅、水平有限，改编中难免存在不当之处，请读者批评指正。

刘家康
于北京理工大学

Preface

This new third edition of *Principles of Electronic Communication Systems* is fully revised and updated to make it one of the most current textbooks available on wireless, networking, and other communications technologies. Because the field of electronic communications changes so fast, it is a never-ending challenge to keep a textbook up to date. While principles do not change, their emphasis and relevance do as technology evolves. Furthermore, students need not only a firm grounding in the fundamentals but also an essential understanding of the real world components, circuits, equipment, and systems in everyday use. This latest edition attempts to balance the principles with an overview of the latest techniques.

One of the major goals of this latest revision is to increase the emphasis on the *system level understanding* of wireless, networking, and other communications technologies. Because of the heavy integration of communications circuits today, the engineer and the technician now work more with printed circuit boards, modules, plug-in cards, and equipment rather than component level circuits. As a result, older obsolete circuits have been removed from this text and replaced with more integrated circuits and block diagram level analysis. Modern communications engineers and technicians work with specifications and standards and spend their time testing, measuring, installing, and troubleshooting. This edition moves in that direction. Detailed circuit analysis is still included in selected areas where it proves useful in understanding the concepts and issues in current equipment.

In the past, a course in communications was considered an option in many electronic programs. Today, communications is the largest sector of the electronics field with the most employees and the largest equipment sales annually. In addition, wireless, networking or other communications technologies are now contained in almost every electronic product. This makes a knowledge and understanding of communication a must rather than an option for every student. Without at least one course in communications, the student may graduate with an incomplete view of the products and systems so common today. This book can provide the background to meet the needs of such a general course.

As the Communications and Networking Editor for Electronic Design Magazine (Penton Media) and editor of the Wireless System Design Update online newsletter, I witness daily the continuous changes in the components, circuits, equipment, systems, and applications of modern communications. As I research the field, interview engineers and executives, and attend the many conferences for the articles and columns I write, I have come to see the growing importance of communications in all of our lives. I have tried to bring that perspective to this latest edition where the most recent techniques and technologies are explained. That perspective coupled with the feedback and insight from some of you who teach this subject has resulted in a text that best fits the 21st century student.

New to this Edition

Here is a chapter-by-chapter summary of revisions and additions to this new edition.

Chapter 1	Significant update of the applications section.
Chapter 2	Addition of code division multiple access, the Radio Data System and SCA subsystems in FM radios. Elimination of the older no-longer-used

PAM telemetry system coverage. A new section on time and frequency division duplexing.

Chapter 3 — Expanded coverage of digital modulation and spectral efficiency. Addition of an explanation of how different digital modulation schemes affect the bit error rate (BER) in communications systems. Comparisons based on BER vs. carrier to noise radio (C/N) are added. Updated sections on spread spectrum and OFDM. A new section on convolutional and turbo coding.

Chapter 4 — Previous chapter 4 Computer Networking has been revised into a new chapter called Introduction to Networking and LANs. The coverage has been expanded and updated to include things like mesh networking fundamentals, the latest Ethernet standards including Power over Ethernet (PoE), and improved explanation of LAN equipment.

Chapter 5 — Minor revisions and updates.

Chapter 6 — Improved explanation of the near and far fields. Introduction to the automatic antenna tuner.

Chapter 7 — A new chapter focusing on the Internet, chapter 9 includes the Internet material from the previous chapter 4 but with extensive new material. Detailed explanation of how information travels via the Internet. Addition of descriptions of Internet core technologies like ATM, Frame Relay, and Sonet. Considerably expanded discussion of the TCP/IP protocol. Expanded explanation of routers including line cards and switch fabrics. Introduction of a new section on storage area networks (SANs) and their transmission technologies including Fibre Channel and iSCSI. A new section on Internet security including encryption and authentication.

Chapter 8 — Extensively revised and updated. New material on microwave antennas including phased arrays, beam forming arrays, adaptive antennas, and the smaller ceramic and PC board antennas like the loop, meander line, and inverted-F. The concepts of diversity and multiple input multiple output (MIMO) are added.

Chapter 9 — Revised and updated. New materials include a section on Very Small Aperture Terminals and expanded coverage of GPS.

Chapter 10 — Elimination of the section on paging. Updated section on cordless phones. New section on voice over Internet protocol (VoIP) digital telephones.

Chapter 11 — New section on MSA optical transceiver modules, types and specifications. Expanded section on electronic dispersion compensation. New section on passive optical networks (PONs) used in fiber to the home (FTTH) broadband systems.

Chapter 12 — This is a new chapter on Cell Phone Technologies. It covers all major analog and digital cell phone standards and systems and frequency allocations. GSM, GPRS, and EDGE TDM systems are covered as well as both cdma2000 and WCDMA systems. Typical chips are reviewed. Fourth generation systems are introduced.

Chapter 13 — A new chapter on wireless technologies. Coverage includes wireless LAN (802.11a/b/g/n), Bluetooth, ZigBee, Ultra wideband (UWB), WiMAX, RFID, near field communications (NFC), ISM band short range radios, and infrared wireless. Coverage of personal area networks and mesh systems is included.

Chapter 14 — Communications Tests and Measurement chapter is revised and updated. A new section on the widely used boundary scan and JTAG test system for chips and boards has been added.

Chapter 15 — Television has been dropped from the book, but the chapter has been revised and updated, and placed on the Online Learning Center website for those who choose to assign it. It now includes new digital television information, new cable standards, and mobile (cell phone video) television standards.

In a large book such as this, it's difficult to give every one what he or she wants. Some want more depth others greater breadth. I tried to strike a balance between the two. As always, I am always eager to hear from those of you who use the book and welcome your suggestions for the next edition.

Learning Features

Principles of Electronic Communication Systems third edition has been completely redesigned to give it a more attractive and accessible page layout. To guide readers and provide an integrated learning approach, each chapter contains the following features:

- Chapter Objectives
- Key Terms
- Pioneers of Electronics articles
- Good to Know margin features
- Examples with solutions
- Chapter Summary
- Questions
- Problems
- Critical Thinking

Student Resources

Laboratory & Activities Manual

A major change with this third edition is the availability of a new laboratory manual. The Lab Manual developed for the second edition will be retained for those of you who use it. This new *Laboratory & Activities Manual* provides more actual hands-on hardware experiments with modern circuits and components. While many circuits are still explored, the attempt is to push toward more systems-level experiments. Building a practical, affordable but meaningful lab is one of the more difficult parts of creating a college course in communications. This new manual provides practice in the principles by using the latest components and methods. Affordable and readily available components and equipment have been used to make it easy for professors to put together a communications lab that validates and complements the text.

Many of the exercises in the *Laboratory & Activities Manual* involve web access and search to build the student's ability to use the vast resources of the Internet and World Wide Web. The practical engineers and technicians of today have become experts at finding relevant information and answers to their questions and solutions to their problems this way. While practicing this essential skill of any communications engineer or technician knowledge, the student will be able to expand his or her knowledge of any of the subjects in this book, either to dig deeper into the theory and practice or get the latest update information on chips and other products.

Online Learning Center ("OLC") website, www.mhhe.com/frenzel3e

This text-specific site includes a number of student-oriented resources, including:

- Chapter outlines and summaries.

- MultiSim version 9 Primer, for those who want to get up and running with this popular simulation software. The section is written to provide communications examples and applications.
- MultiSim circuit files for communications electronics.
- Web Links to industrial and educational sites of interest.
- Link to the Work-Ready Electronics; these activities, created by the MATEC research center, show the practical skills needed in various areas of interest—including communications—in the context of modern industry.

Instructor Resources

Instructor Productivity Center CD-ROM

This CD includes the following resources for adopters of the text:

- Answers and solutions to all text problems.
- Answers and information for the Lab & Activity Manual.
- Electronic test banks with a mix of questions for each text chapter.
- PowerPoint presentations for all chapters of the text.

Online Learning Center ("OLC") website, www.mhhe.com/frenzel3e

The OLC contains student resources, plus the following instructor resources:

- Answers and solutions to the text problems and lab activities, under password protection.
- PowerPoint presentations for each chapter online.
- Additional quiz questions for each chapter, which can be assigned or used for student self-study.
- Blackboard and WebCT cartridges for use with these popular classroom management systems.

Classroom Performance System (CPS) from eInstruction is available for adopters; its "clicker" system provides a vehicle for in-class quizzing and concept reinforcement, and classroom management.

Acknowledgements

While producing a new edition of a book does not involve the same effort as writing a new book, this latest revision was a major project. My special thanks to Managing Developmental Editor Jonathan Plant, and Publisher Thomas Casson for their continued support and encouragement to make this happen. It has been a pleasure to work with you both.

And my appreciation also goes out to those professors who reviewed the book and offered your feedback, criticism and suggestions. Thanks for taking the time to provide that valuable input. I have implemented virtually all of your recommendations. I especially appreciate the extensive input from Walt Curry of the United States Naval Academy, most of which I have included. The following reviewers looked over the manuscript in various stages, and provided a wealth of good suggestions for the new edition:

Heng Chan
Mohawk College (ON)

Captain Walter N. Currier Jr.
United States Naval Academy (MD)

William C. Donaldson
Wake Techical College (NC)

Robbie Edens
ECPI College of Technology (SC)

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George C. Wallace Community College (AL)

Pravin M. Raghuwanshi
DeVry University (NJ)

William Salice
ECPI College of Technology (VA)

Randy Winzer
Pittsburg Sate University (KS)

With the latest input from industry and the suggestions from those who use the book, this edition should come closer than ever to being an ideal text for teaching current day communications electronics.

Lou Frenzel
Austin, Texas
2006

Guided Tour

Learning Features

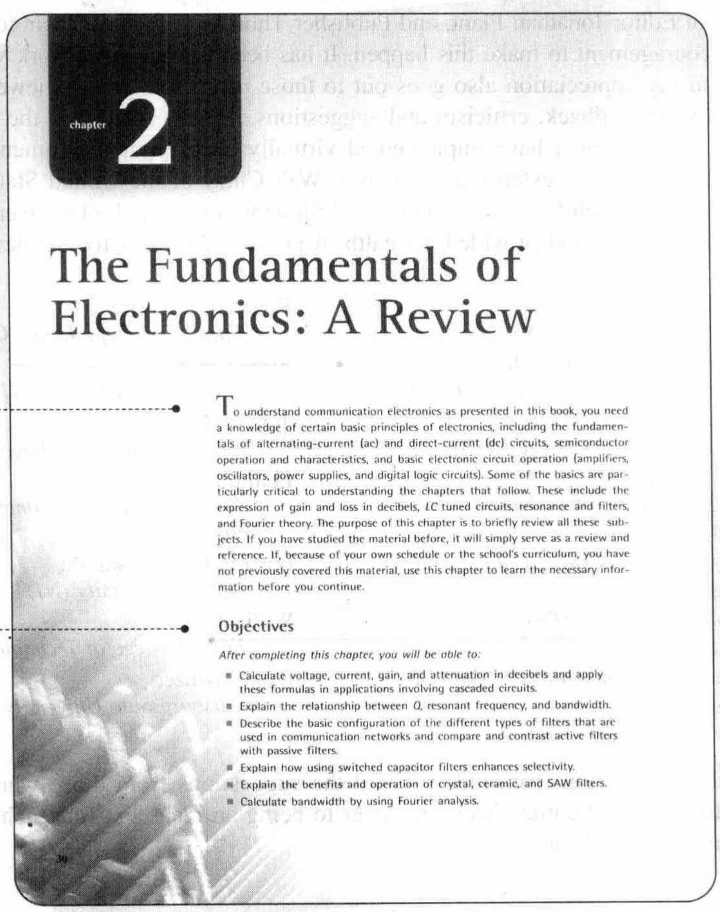
Many new learning features have been incorporated into the third edition of *Ptinciples of Electronic Communication Systems*. These learning features, found throughout the chapters, include:

Chapter Introduction

Each chapter begins with a brief introduction setting the stage for what the student is about to learn.

Chapter Objectives

Chapter Objectives provide a concise statement of expected learning outcomes.



chapter 2

The Fundamentals of Electronics: A Review

To understand communication electronics as presented in this book, you need a knowledge of certain basic principles of electronics, including the fundamentals of alternating-current (ac) and direct-current (dc) circuits, semiconductor operation and characteristics, and basic electronic circuit operation (amplifiers, oscillators, power supplies, and digital logic circuits). Some of the basics are particularly critical to understanding the chapters that follow. These include the expression of gain and loss in decibels, *LC* tuned circuits, resonance and filters, and Fourier theory. The purpose of this chapter is to briefly review all these subjects. If you have studied the material before, it will simply serve as a review and reference. If, because of your own schedule or the school's curriculum, you have not previously covered this material, use this chapter to learn the necessary information before you continue.

Objectives

After completing this chapter, you will be able to:

- Calculate voltage, current, gain, and attenuation in decibels and apply these formulas in applications involving cascaded circuits.
- Explain the relationship between *Q*, resonant frequency, and bandwidth.
- Describe the basic configuration of the different types of filters that are used in communication networks and compare and contrast active filters with passive filters.
- Explain how using switched capacitor filters enhances selectivity.
- Explain the benefits and operation of crystal, ceramic, and SAW filters.
- Calculate bandwidth by using Fourier analysis.

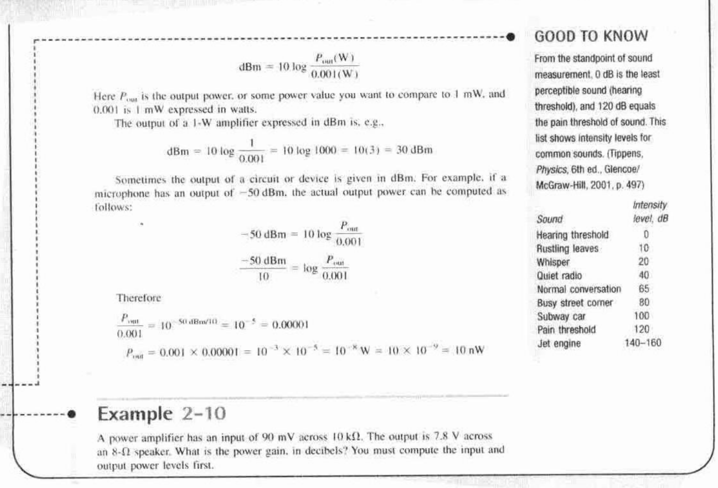
30

Examples

Each chapter contains worked-out Examples that demonstrate important concepts or circuit operations, including circuit analysis, applications, troubleshooting, and basic design.

Good To Know

Good To Know statements, found in margins, provide interesting added insights to topics being presented



$$\text{dBm} = 10 \log \frac{P_{out}(\text{W})}{0.001(\text{W})}$$

Here P_{out} is the output power, or some power value you want to compare to 1 mW, and 0.001 is 1 mW expressed in watts.

The output of a 1-W amplifier expressed in dBm is, e.g.,

$$\text{dBm} = 10 \log \frac{1}{0.001} = 10 \log 1000 = 10(3) = 30 \text{ dBm}$$

Sometimes the output of a circuit or device is given in dBm. For example, if a microphone has an output of −50 dBm, the actual output power can be computed as follows:

$$-50 \text{ dBm} = 10 \log \frac{P_{out}}{0.001}$$

$$\frac{-50 \text{ dBm}}{10} = \log \frac{P_{out}}{0.001}$$

Therefore

$$\frac{P_{out}}{0.001} = 10^{-50 \text{ dBm}/10} = 10^{-5} = 0.00001$$

$$P_{out} = 0.001 \times 0.00001 = 10^{-3} \times 10^{-5} = 10^{-8} \text{ W} = 10 \times 10^{-9} = 10 \text{ nW}$$

GOOD TO KNOW

From the standpoint of sound measurement, 0 dB is the least perceptible sound (hearing threshold), and 120 dB equals the pain threshold of sound. This list shows intensity levels for common sounds. (Tippens, *Physics*, 6th ed., Glencoe/McGraw-Hill, 2001, p. 497)

Sound	*Intensity level, dB*
Hearing threshold	0
Rustling leaves	10
Whisper	20
Quiet radio	40
Normal conversation	65
Busy street corner	80
Subway car	100
Pain threshold	120
Jet engine	140–160

Example 2-10

A power amplifier has an input of 90 mV across 10 kΩ. The output is 7.8 V across an 8-Ω speaker. What is the power gain, in decibels? You must compute the input and output power levels first.

Pioneers of Electronics

Students can use summaries when reviewing for examinations, or just to make sure they haven't missed any key concepts. are listed to help solidly learning outcomes.

Chapter Review

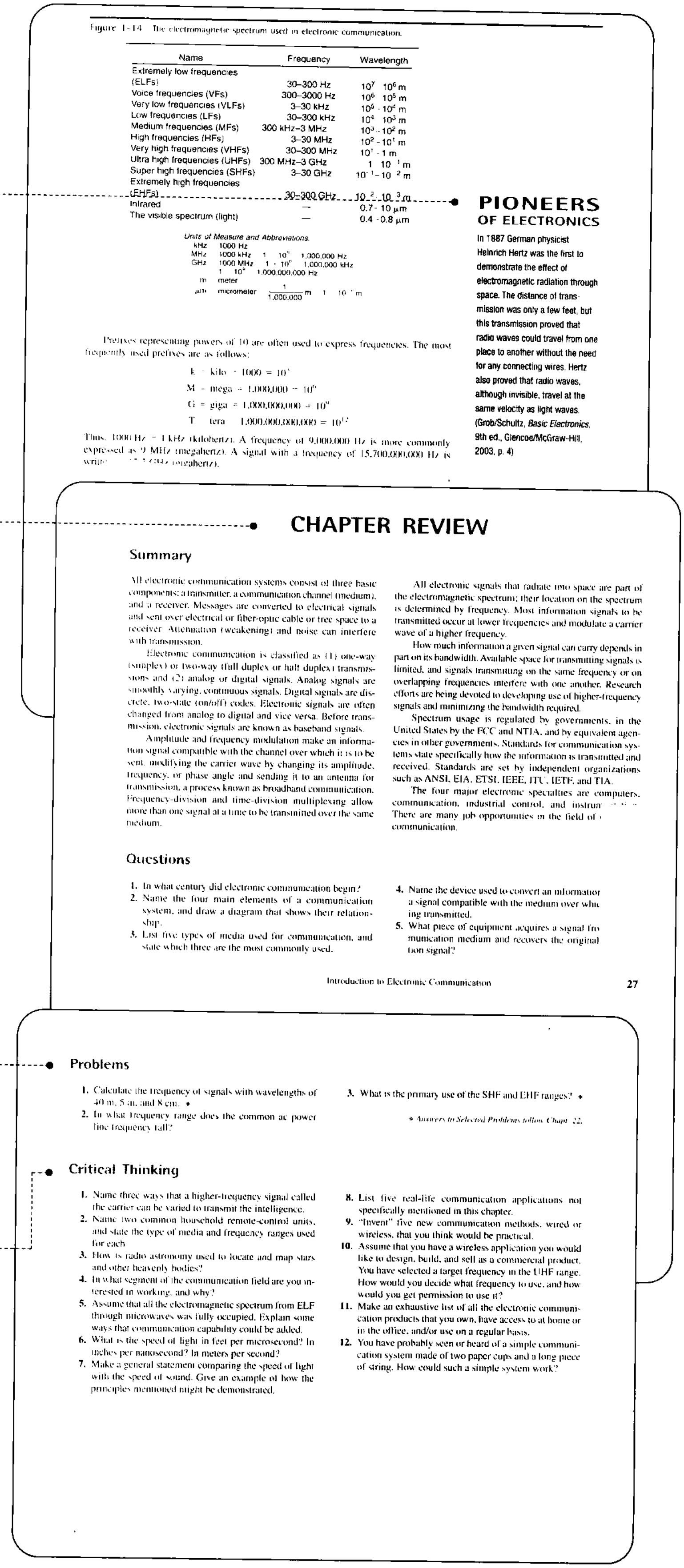
Students can use summaries when reviewing for examinations, or just to make sure they haven't missed any key concepts. Important circuit derivations and definition are listed to help solidly learning outcomes.

Problems

Students obtain back by Problems that immediately follow most Examples. Answers to these problems are found at the end of each chapter.

Critical Thinking

A wide variety of questions and problems are found at the end of each chapter; over 30% are new or revised in this edition. Those include circuit analysis, trouble shooting, critical thinking, and job interview questions.



Contents

chapter 1

Introduction to Electronic Communication

Objectives

After completing this chapter, you will be able to:

- Explain the functions of the three main parts of an electronic communication system.
- Describe the system used to classify different types of electronic communication and list examples of each type.
- Discuss the role of modulation and multiplexing in facilitating signal transmission.
- Define the electromagnetic spectrum and explain why the nature of electronic communication makes it necessary to regulate the electromagnetic spectrum.
- Explain the relationship between frequency range and bandwidth and give the frequency ranges for spectrum uses ranging from voice to ultra-high-frequency television.
- List the major branches of the field of electronic communication and describe the qualifications necessary for different jobs.

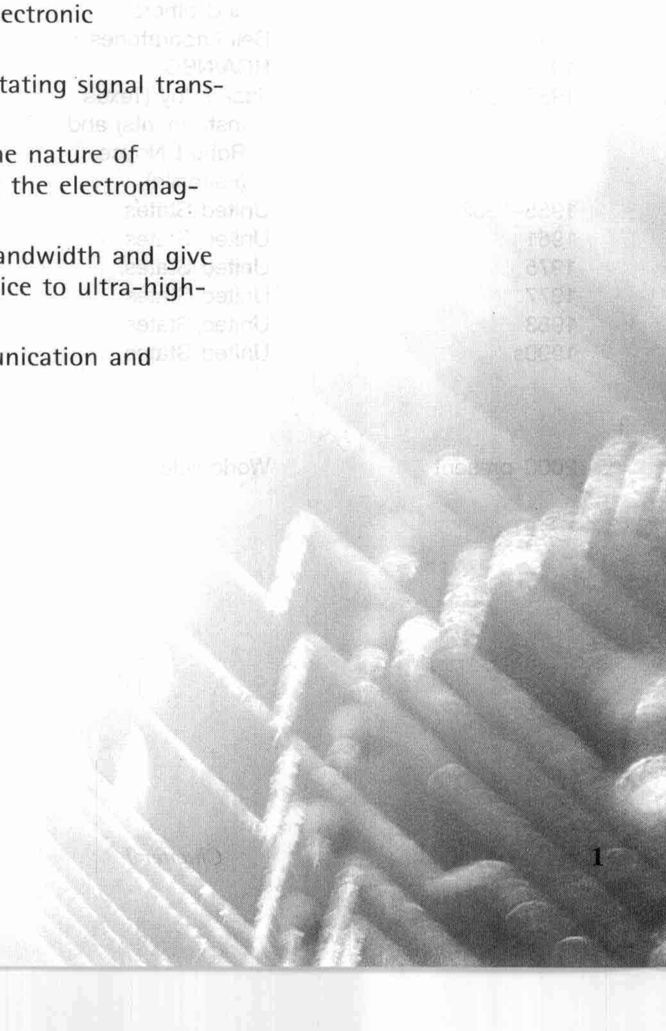


Figure 1-1 Milestones in the history of electronic communication.

When?	Where or Who?	What?
1837	Samuel Morse	Invention of the telegraph (patented in 1844).
1843	Alexander Bain	Invention of facsimile.
1866	United States and England	The first trans-Atlantic telegraph cable laid.
1876	Alexander Bell	Invention of the telephone.
1877	Thomas Edison	Invention of the phonograph.
1879	George Eastman	Invention of photography.
1887	Heinrich Hertz (German)	Discovery of radio waves.
1887	Guglielmo Marconi (Italian)	Demonstration of "wireless" communications by radio waves.
1901	Marconi (Italian)	First trans-Atlantic radio contact made.
1903	John Fleming	Invention of the two-electrode vacuum tube rectifier.
1906	Reginald Fessenden	Invention of amplitude modulation; first electronic voice communication demonstrated.
1906	Lee de Forest	Invention of the triode vacuum tube.
1914	Hiram P. Maxim	Founding of American Radio Relay League, the first amateur radio organization.
1920	KDKA Pittsburgh	First radio broadcast.
1923	Vladimir Zworykin	Invention and demonstration of television.
1933–1939	Edwin Armstrong	Invention of the superheterodyne receiver and frequency modulation.
1939	United States	First use of two-way radio (walkie-talkies).
1940–1945	Britain, United States	Invention and perfection of radar (World War II).
1948	John von Neumann and others	Creation of the first stored program electronic digital computer.
1948	Bell Laboratories	Invention of transistor.
1953	RCA/NBC	First color TV broadcast.
1958–1959	Jack Kilby (Texas Instruments) and Robert Noyce (Fairchild)	Invention of integrated circuits.
1958–1962	United States	First communication satellite tested.
1961	United States	Citizens band radio first used.
1975	United States	First personal computers.
1977	United States	First use of fiber-optic cable.
1983	United States	Cellular telephone networks.
1990s	United States	Adoption and growth of computer networking, including local-area networks (LANs). Global Positioning System (GPS) for satellite navigation. The Internet and World Wide Web.
2000–present	Worldwide	Third-generation digital cell phones, wireless local-area networks, digital broadcast radio, and 40-Gbps fiber-optic communication.

1-1 The Significance of Human Communication

Communication

Communication is the process of exchanging information. People communicate to convey their thoughts, ideas, and feelings to others. The process of communication is inherent to all human life and includes verbal, nonverbal (body language), print, and electronic processes.

Two of the main barriers to human communication are language and distance. Language barriers arise between persons of different cultures or nationalities.

Communicating over long distances is another problem. Communication between early human beings was limited to face-to-face encounters. Long-distance communication was first accomplished by sending simple signals such as drumbeats, horn blasts, and smoke signals and later by waving signal flags (semaphores). When messages were relayed from one location to another, even greater distances could be covered.

The distance over which communication could be sent was extended by the written word. For many years, long-distance communication was limited to the sending of verbal or written messages by human runner, horseback, ship, and later trains.

GOOD TO KNOW

Fax machines have been in use since the 1930s. These early machines were primarily utilized by news services to transmit photographs by using free space or radio waves rather than telephone lines.

Human communication took a dramatic leap forward in the late nineteenth century, when electricity was discovered and its many applications were explored. The telegraph was invented in 1844 and the telephone in 1876. Radio was discovered in 1887 and demonstrated in 1895. Figure 1-1 is a timetable listing important milestones in the history of electronic communication.

Well-known forms of electronic communication, such as the telephone, radio, TV, and the Internet, have increased our ability to share information. The way we do things and the success of our work and personal lives are directly related to how well we communicate. It has been said that the emphasis in our society has now shifted from that of manufacturing and mass production of goods to the accumulation, packaging, and exchange of information. Ours is an information society, and a key part of it is communication. Without electronic communication, we could not access and apply the available information in a timely way.

This book is about electronic communication, and how electrical and electronic principles, components, circuits, equipment, and systems facilitate and improve our ability to communicate. Rapid communication is critical in our very fast-paced world. It is also addictive. Once we adopt and get used to any form of electronic communication, we become hooked on its benefits. In fact, we cannot imagine conducting our lives or our businesses without it. Just imagine our world without the telephone, radio, fax, television, cell phones, or computer networking.

1-2 Communication Systems

All electronic communication systems have a transmitter, a communication channel or medium, and a receiver. These basic components are shown in Fig. 1-2. The process of communication begins when a human being generates some kind of message, data, or other intelligence that must be received by others. A message may also be generated by a computer or electronic current. In *electronic communication systems,* the message is referred to as *information,* or an intelligence signal. This message, in the form of an electronic signal, is fed to the transmitter, which then transmits the message over the communication channel. The message is picked up by the receiver and relayed to another human. Along the way, noise is added in the communication channel and in the receiver. *Noise* is the general term applied to any phenomenon that degrades or interferes with the transmitted information.

Electronic communication systems

Information

Noise