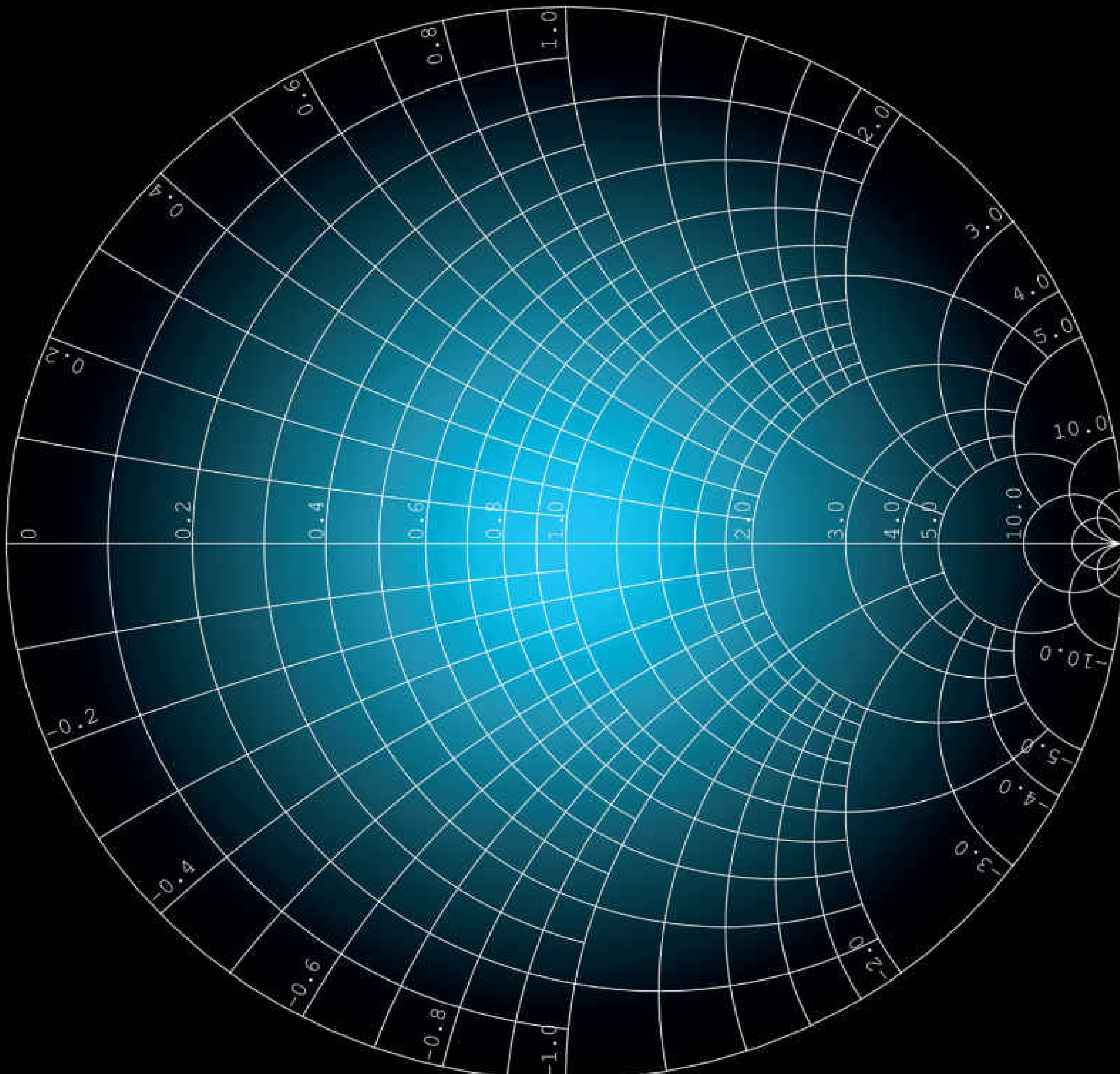
PRINCIPLES OF

FIFTH EDITION

ELECTRONIC COMMUNICATION SYSTEMS



Mc Graw Hill

LOUIS E. FRENZEL JR.

Principles of Electronic Communication Systems

Fifth Edition

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Preface

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To Instructors

This new fifth edition of the *Principles of Electronic Communication Systems* has been fully reviewed and updated. A book such as this needs revision frequently as the technology changes continually. Of course, the fundamentals of electronics communications do not change. However, the ways these principles are applied do change occasionally. During the past five years since the introduction of the previous fourth edition, some major changes and additions have taken place. Most of these changes are important to those of you teaching communications technology and for those of you who are out looking for work in this field. A high percentage of the new jobs involves the most recent developments.

As a writer and editor for a major electronics magazine, I am able to keep up on all the new products and technologies by way of continuous monitoring and interacting with the industries and companies that design, manufacture, and apply the new equipment. Keeping track of all of this is a full-time job.

This new version of the book is a balance of standard fundamentals and principles plus an introduction to the most recent and relevant products and technologies. It also incorporates the suggestions that some of you have provided, for which I am grateful. Here are the highlights of this new edition. Note most of the chapter sequences and numbers have changed and two new chapters (12 and 15) have been added.

- Chapters 1 through 7 are pretty much the same. Fundamentals do not change much, although these chapters were edited and updated.

- Chapters 8 and 9 on transmitters and receivers also remain pretty much the same except for minor updates. Also, some material from these chapters has been moved to the new Chapter 12 covering software-defined radios (SDRs).
- Chapters 10 and 11 have been reversed. It is important to cover the digital fundamentals before diving into multiplexing. Heavy edit.
- Chapter 12 is a new chapter covering software-defined radios.
- Chapter 13 on transmission lines has been updated.
- Chapter 14 on networking has been updated with enhancements to the Ethernet coverage.
- Chapter 15 is a totally new chapter that covers popular wired communication techniques and serial interfaces. Wire or cable, it’s still a major form of communications.
- Chapter 16 on antennas and propagation has been updated.
- Chapter 17 on Internet technologies has been revised to include topics such as Internet telephony, virtualization, and cloud usage.
- Chapter 18 on microwaves and millimeter waves has been enhanced with increased coverage of relevant antenna technology such as MIMO and agile beam-forming phased arrays.
- Chapter 19 on satellites has been updated with new GPS information and other new material.
- Chapter 20 on optical technology received minor updating.
- Chapter 21 on the cellular technologies is virtually all new. LTE coverage has been updated and expanded. Full coverage of the new 5G New Radio standard and systems has been added.

- Chapter 22, covering the various popular short-range wireless technologies, has been extensively updated adding new Bluetooth (LE) and Wi-Fi 6 (802.11ax) versions. The Internet of

Things (IoT) material has been increased and the full spectrum of new wireless standards and methods has been added.

- Chapter 23 on test and measurement has been updated with new instruments and methods. The addition of VNAs and S-parameters was overdue.

You will notice that I omitted mention of one chapter: previous Chapter 18 on telecommunications. This chapter covered legacy telephones and telephone systems. Wired telephones have been fading away for years, and today most people use only their cell phones. In fact, in many locations throughout the United States, local loop-wired telephone service is no longer available. Further, telephone companies are gradually sunsetting their wired service and putting most of their investments into the buildout of their wireless systems, especially the new 5G NR services. Employment opportunities in the wired telecom field have mostly disappeared. I felt it best to use the available space in this textbook on the more up-to-date technologies. Some of the more useful telecom material has been incorporated into other chapters as appropriate.

I have continued with the end-of-chapter Online Activities. It is essential that all of you who use this book know that there is more communications and wireless knowledge and information out there than you can ever absorb. A good Internet search is essential if you ever want to dig deeper or to look more broadly at any given subject. The topics I chose reflect current trends and applications.

I have tried to edit out the older discrete component circuits where appropriate and replace them with the equivalent IC devices used today. I have left in discussion of some popular discrete component circuits where they are still used. I know some of you still like to teach the older circuits. That’s fine if you do, but you may want to point out that the real world uses more ICs as well as complete systems on a chip (SoC).

A mixed bag of new appendices has also been included. These are informational pieces on subjects that do not fit conveniently into the main chapters. Hopefully you will find them useful.

Before I conclude, let me give you my view of where the industry and technology are headed. These are not only the trends and developments I see but also what the market analysists and company CEOs are saying and thinking. Hopefully this will give you clues as to how to slant your course coverage and better target what graduates really need to know to get hired today. It is easy to fall into a pattern of teaching the same things repeatedly each semester as it is easier to proceed with previously developed materials than it is to add new relevant material. Don’t be one of those who does a good job of teaching the history of communications but ignores the movements and emphasis that is needed out in the real world. The fundamentals are important and you must continue to teach them but also shift the emphasis as needed and add new material regularly. I hope this revised edition will help with that effort. Yes, I have taught this before so know there is always more material to cover than there is time to include it.

Macro Trends

1. The emphasis today is on systems more than on individual components and circuits. Engineers and technicians work with the end equipment, related modules, and subassemblies and not so much so with components. While you teach the components, put the focus on the application, including the related equipment, module, PCB or IC. A good approach is to use more block diagrams and signal flow discussions. Give the big picture or, as they say, the 10,000-ft view.

2. Most new comm and wireless equipment today operates at the microwave or millimeter-wave frequencies. Remember microwaves begin at 1 GHz. So common things like Bluetooth, ZigBee, satellite TV, and GPS are all microwave devices. Low-frequency gear is still around, of course, but virtually all new applications and equipment operate at frequencies from the 5-GHz 802.11ax Wi-Fi to the single-chip auto radars at 77 GHz. Most of the new 5G cellular gear operates in the range from 1 GHz to 6 GHz with all the new mmWave systems using the 28-, 37-, 39-GHz to 47-GHz bands. Electronics and communications at these frequencies are

different. Start shifting your teaching emphasis to those components and circuits that work at those frequencies.

3. What engineers and techs do all day is fuss with test gear. You must teach test and measurement. While the scope is still a prominent bench instrument, today the more useful RF instruments are the spectrum analyzer, vector network analyzer, and RF signal emulators and generators. I am sure you know that these instruments are extremely expensive. Few if any college labs can afford them, but do work toward acquiring them. Buy used, borrow, or rent if you can so that you can give students at least some short lab experiences with them. And lectures and demos are better than nothing.
4. Add coverage of electromagnetic compatibility (EMC) and electromagnetic interference (EMI). There is so much wireless floating around out there that interference and coexistence of technologies have become problems. A major part of a wireless engineer's or technician's work is tracking down EMI and eliminating or minimizing it. This is another topic that requires specialized test gear.
5. Finally, make students realize that virtually every phase of communications and wireless is heavily regulated. Make sure they know about the FCC and NTIA, the spectrum issues, and all of the rules and regulations in the CFR 47 Parts 0–99, especially Parts 15 and 18. And mention all of the standards bodies and industry alliances. These often hidden or ignored organizations control the whole technology and industry and are dynamite sources of information.

Thanks for continuing to use this text. Let me and/or McGraw Hill know if you find any errors or if you wish to suggest additional or revised coverage.

To Students

This book is loaded with information. As you will probably discover, the course you are taking will probably not cover all the chapters as it is too much to include in one semester. Here are some of suggestions to help you make it through the course.

This book assumes that you have had some prior course or training in electronics. Most of you will have had the prerequisites in one or more college courses or acquired this knowledge in military service or company training programs. Even self-study is a valid way to learn the fundamentals.

Then again, you may not have had any electronics background. If that is the case, you may want to get that background education before continuing here.

If you have had some basic electronics background but it has been a while since you have acquired it, you have probably forgotten much of this knowledge. One recommended solution is to keep one or more electronics fundamentals books around so you can look up what you forgot or never learned. Chapter 2 in this book covers much of what you probably learned in an AC Circuits course that should expedite your learning. My own McGraw Hill textbook, *Contemporary Electronics, Fundamentals, Devices, Circuits and Systems*, covers all that you should know.

Check out the book list in Appendix A that recommends those books I found to be helpful.

As it has turned out, the communications sector is the largest part of the U.S. electronics industry. Because of that, many jobs are available. Taking this course and finishing your education should provide you with enough credentials to get one of those communications jobs. If you get one of those jobs, you may want to keep this textbook as a reference as you may need it occasionally. Anyway, good luck with the course, your education, and job search. Here’s to your coming success.

Lou Frenzel

Acknowledgments

My special thanks to McGraw Hill portfolio manager Beth Bettcher for her continued support and encouragement to make this new edition possible. Thanks also to Beth Baugh and the other helpful McGraw Hill support staff, including Jeni McAtee and Alyson Platt. It has been a pleasure to work with all of you.

I also want to thank Nancy Friedrich of *Microwaves & RF* magazine and Bill Baumann from *Electronic Design* magazine, both of Penton Media Inc. (Now Endeavor Business Media), for permission to use sections of my articles in updating chapters 20 and 21.

My appreciation also goes out to those professors who reviewed the book and offered their feedback, criticism, and suggestions. Thanks for taking the time to provide that valuable input. I have implemented most of their recommendations. The following reviewers provided a wealth of good suggestions for the new edition:

John Bosshard
Texas A&M University

William I. Dolan
Kennebec Valley Community College

Byron Garry
South Dakota State University

Venkata Khambhammettu
ECPI University, Virginia Beach

Mervin Moats Jr.
Central Carolina Community College

Prentice Tyndall
Pitt Community College

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 textbook for teaching current day communications electronics.

Lou Frenzel

Guided Tour

Learning Features

The fifth edition of *Principles of Electronic Communication Systems* retains the popular learning elements featured in previous editions. These include:

Chapter Introduction

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

Chapter Objectives

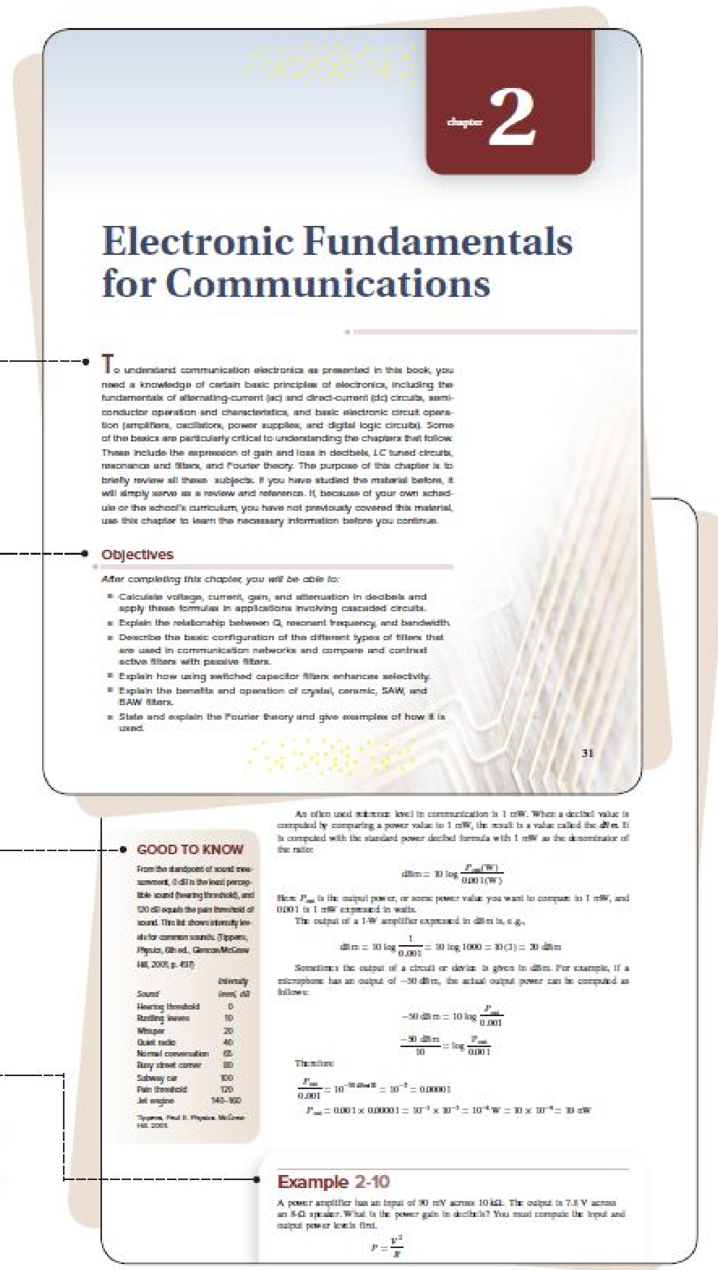
Chapter Objectives provide a concise statement of expected learning outcomes.

Good To Know

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

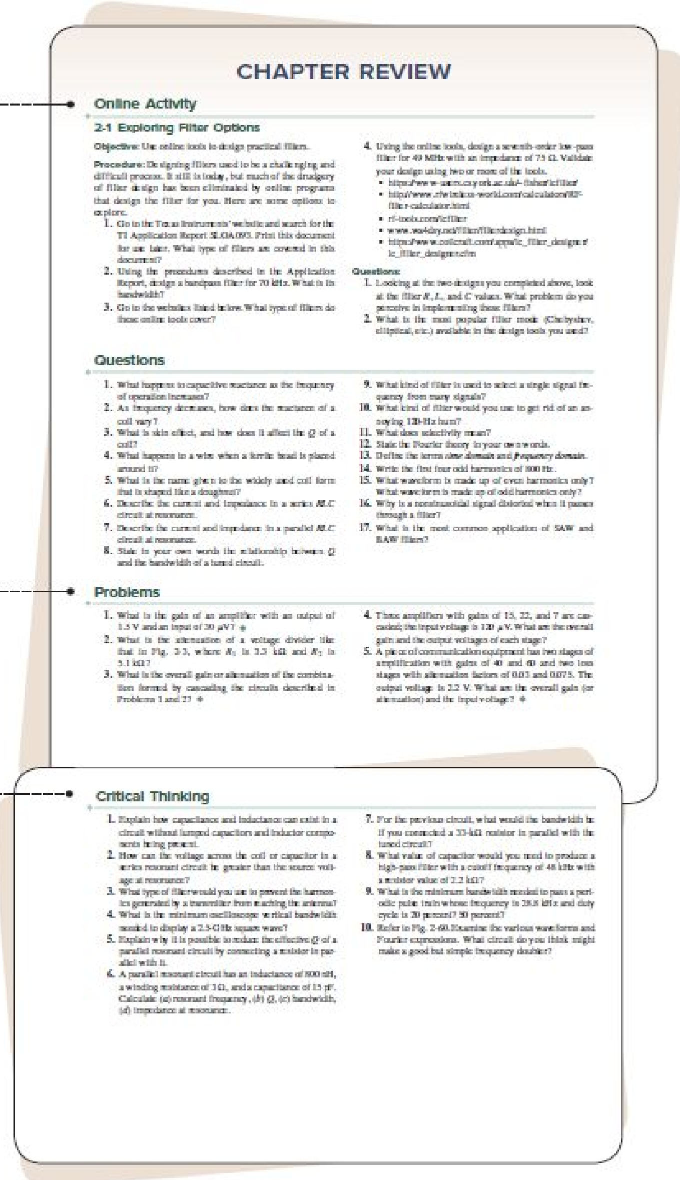
Examples

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



Online Activities

These sections give students the opportunity to further explore new communications techniques, to dig deeper into the theory, and to become more adept at using the Internet to find needed information.



Problems

Students can obtain critical feedback by performing the Practice Problems at the end of the chapter. Answers to selected problems are found at the end of the book.

Critical Thinking

A wide variety of questions and problems are found at the end of each chapter. Those include circuit analysis, troubleshooting, critical thinking, and job interview questions.

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.
- State the benefit of licensing and certification and name at least three sources.

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

page 2

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 transatlantic telegraph cable laid.
1876	Alexander Bell	Invention of the telephone.
1887	Heinrich Hertz (German)	Discovery of radio waves.
1887	Guglielmo Marconi (Italian)	Demonstration of "wireless" communications by radio waves.
1901	Marconi (Italian)	First transatlantic 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).
1947	New York City, New York	First regular network TV broadcasts.
1948	John von Neumann and others	Creation of the first stored program electronic digital computer.
1948	Bell Laboratories	Invention of transistor.
1948	James Van Damager, California	First cable TV.
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.
1963	Cape Canaveral, Florida	Initial geosynchronous satellite.
1969	MIT, Stanford University	Prototype of Internet access developed.
1973–1976	Metcalfe	Ethernet and first LANs.
1975	United States	First personal computers.
1977	United States	First use of fiber-optic cable.
1982	Carnegie Melon University	First instance of Internet of Things (IoT).
1982	United States	TCP/IP protocol adopted.
1982–1990	United States	Internet development and first use.
1983	United States	Cellular telephone networks.
1993	United States	First browser Mosaic.
1994	Carl Malmud, United States	Internet radio begins.
1995	United States	Global Positioning System deployed.
1996–2001	Worldwide	First smartphones by BlackBerry, Nokia, Palm.
1997	United States	First wireless LANs.
2000	Worldwide	Third-generation digital cell phones.
2004–2006	United States	Social media begins.
2005–2007	United States	Beginning of streaming TV.
2007	California	Apple iPhone.
2009	United States	Transition: analog to HD digital broadcast TV.
2009	Worldwide	First fourth-generation LTE cellular networks.
2009	Worldwide	First 100 Gb/s fiber optical networks.
2019	Uruguay	Beginning of 5G cellular service.

1-1 The Significance of Human 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.

Communication

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. But that problem has been solved today with modern electronic communications.

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. Fig. 1-1 is a timetable listing important milestones in the history of electronic communication.

GOOD TO KNOW

Marconi is generally credited with inventing radio, but he did not. Although he was a key developer and the first deployer of radio, the real credit goes to Heinrich Hertz, who first discovered radio waves, and Nicola Tesla, who first developed real radio applications.

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, e-mail, television, cell phones, tablets, or computer networking.

1-2 Communication Systems

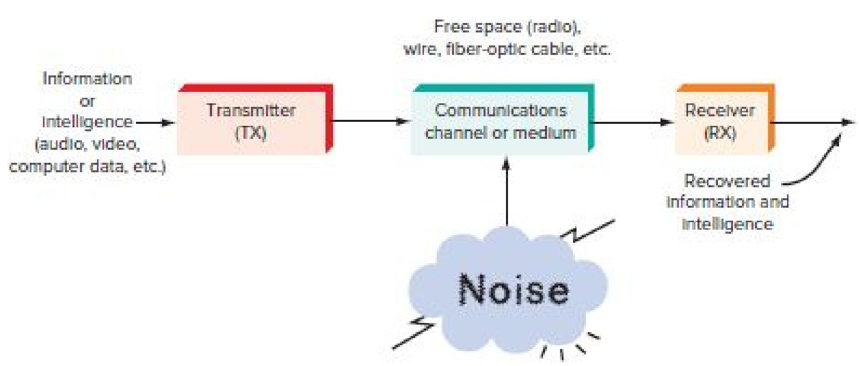
All electronic communication systems have a transmitter, a communication channel or medium, and a receiver. These basic components are shown in Fig. 1-2. The process of communication begins when a human being generates some kind of message, data, or other intelligence that must be received by others. 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 unwanted phenomenon that degrades or interferes with the transmitted information.

Electronic communication systems

Information

Noise

Figure 1-2 A general model of all communication systems.



Transmitter

The first step in sending a message is to convert it into electronic form suitable for transmission. For voice messages, a microphone is used to translate the sound into an electronic *audio* signal. For TV, a camera converts the light information in the scene to a video signal. In computer systems, the message is typed on a keyboard and converted to binary codes that can be stored in memory or transmitted serially. Transducers convert physical characteristics (temperature, pressure, light intensity, and so on) into electrical signals.

Audio

page 4

The *transmitter* itself is a collection of electronic components and circuits designed to convert the electrical signal to a signal suitable for transmission over a given communication medium. Transmitters are made up of oscillators, amplifiers, tuned circuits and filters, modulators, frequency mixers, frequency synthesizers, and other circuits. The original intelligence signal usually modulates a higher-frequency carrier sine wave generated by the transmitter, and the combination is raised in amplitude by power amplifiers, resulting in a signal that is compatible with the selected transmission medium.

Transmitter

Communication Channel

The *communication channel* is the medium by which the electronic signal is sent from one place to another. Many different types of media are used in communication systems, including wire conductors, fiber-optic cable, and free space.

Communication channel

Electrical Conductors. In its simplest form, the medium may simply be a pair of wires that carry a voice signal from a microphone to a headset. It may be a coaxial cable such as that used to carry cable TV signals. Or it may be a twisted-pair cable used in a local-area network (LAN).

Optical Media. The communication medium may also be a fiber-optic cable or “light pipe” that carries the message on a light wave. These are widely used today to carry long-distance calls and all Internet communications. The information is converted to digital form that can be