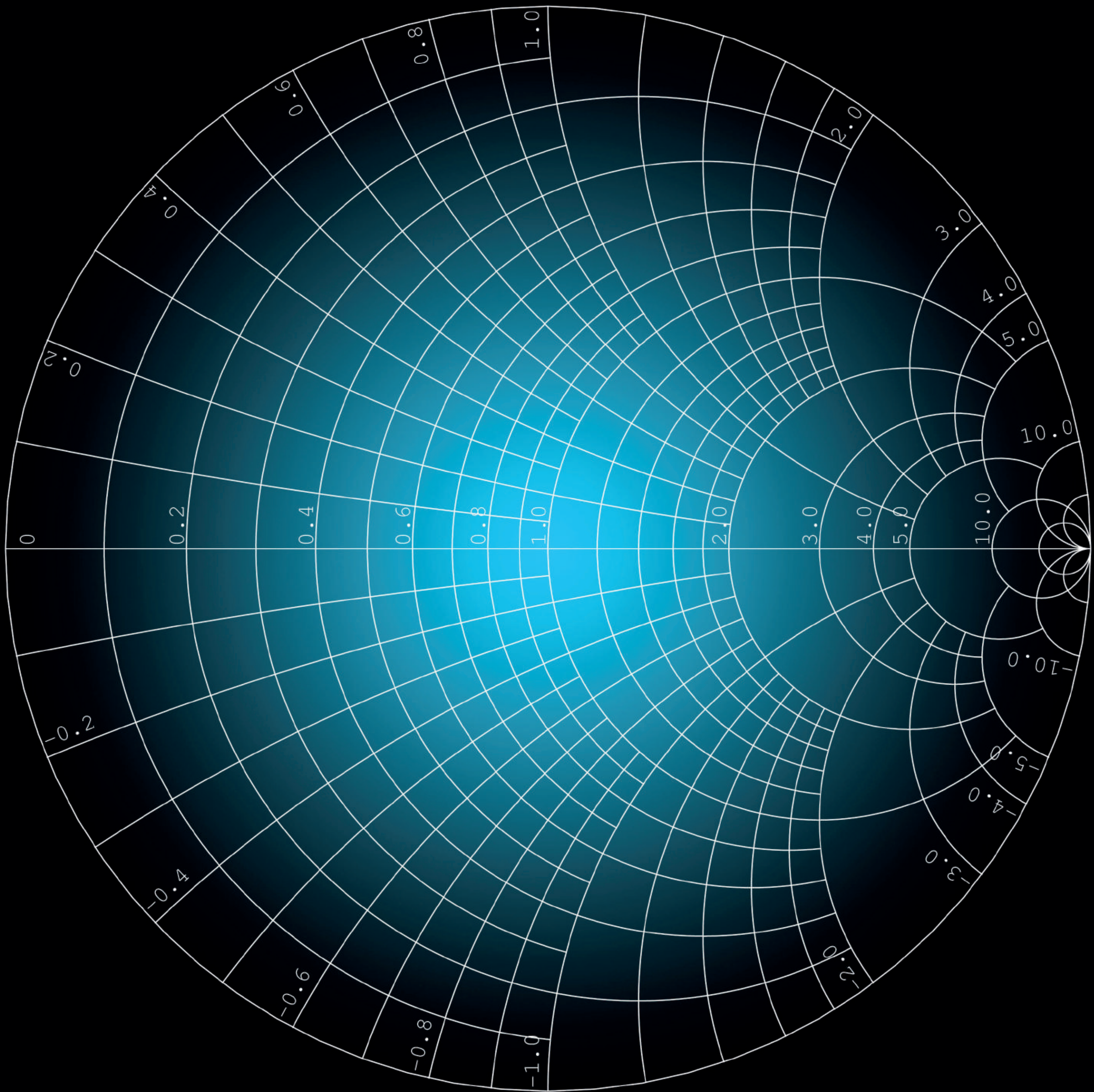
PRINCIPLES OF

ELECTRONIC COMMUNICATION SYSTEMS

FIFTH EDITION



Mc Graw Hill

LOUIS E. FRENZEL JR.

Principles of Electronic Communication Systems

Fifth Edition

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PRINCIPLES OF ELECTRONIC COMMUNICATION SYSTEMS, FIFTH EDITION

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Content Project Managers: *Jeni McAtee, Samantha Donisi*
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Preface

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

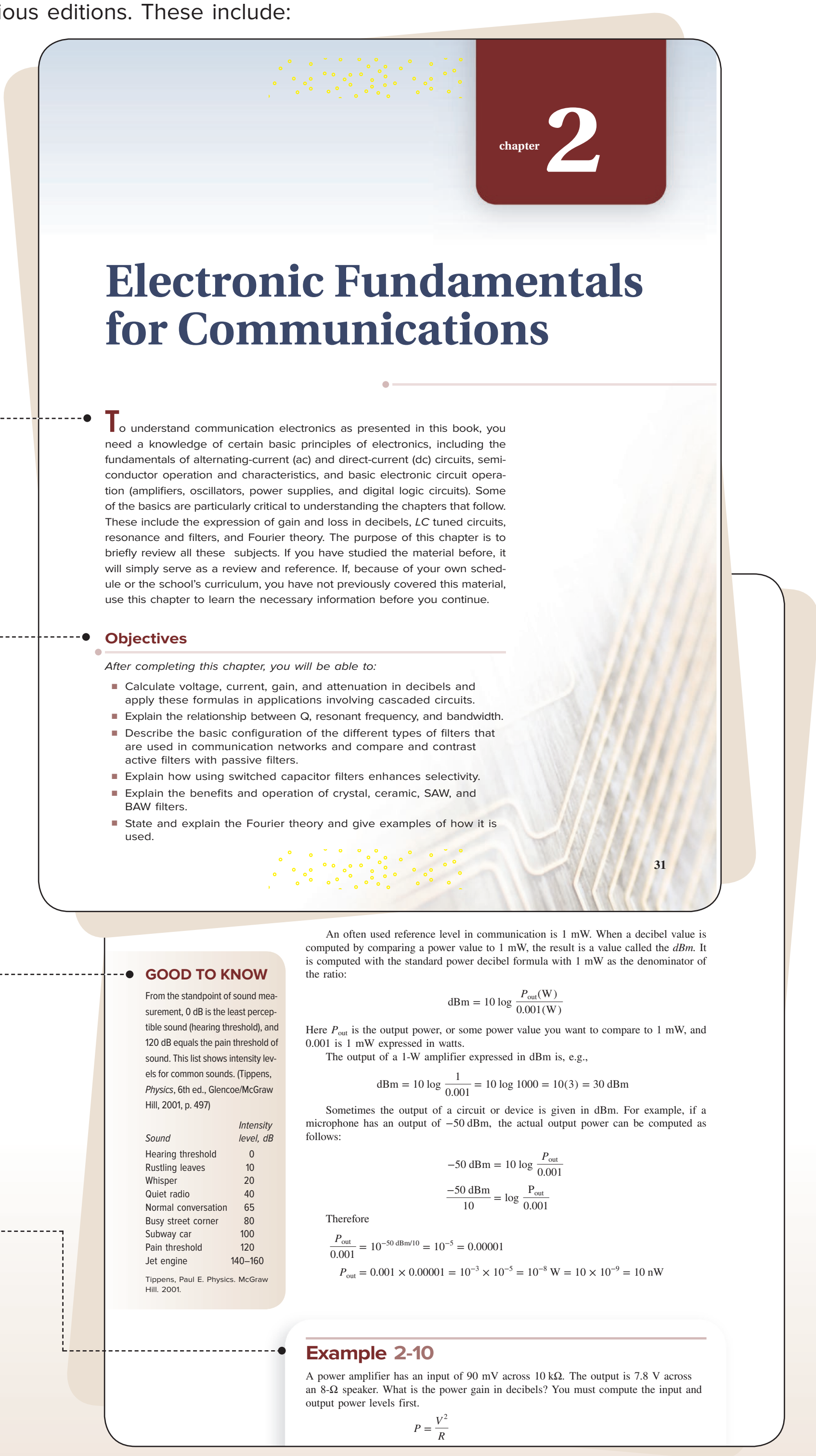
Chapter Objectives provide a concise statement of expected learning outcomes.

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.



chapter 2

Electronic Fundamentals for Communications

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, SAW, and BAW filters.
- State and explain the Fourier theory and give examples of how it is used.

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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

Tippens, Paul E. Physics. McGraw Hill. 2001.

An often used reference level in communication is 1 mW. When a decibel value is computed by comparing a power value to 1 mW, the result is a value called the *dBm*. It is computed with the standard power decibel formula with 1 mW as the denominator of the ratio:

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

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

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

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

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.

$$P = \frac{V^2}{R}$$

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 REVIEW

Online Activity

2-1 Exploring Filter Options

Objective: Use online tools to design practical filters.

Procedure: Designing filters used to be a challenging and difficult process. It still is today, but much of the drudgery of filter design has been eliminated by online programs that design the filter for you. Here are some options to explore.

1. Go to the Texas Instruments' website and search for the TI Application Report SLOA093. Print this document for use later. What type of filters are covered in this document?
2. Using the procedures described in the Application Report, design a bandpass filter for 70 kHz. What is its bandwidth?
3. Go to the websites listed below. What type of filters do these online tools cover?
4. Using the online tools, design a seventh-order low-pass filter for 49 MHz with an impedance of 75 Ω. Validate your design using two or more of the tools.
   - https://www-users.cs.york.ac.uk/~fisher/lcfilter/
   - http://www.rfwireless-world.com/calculators/RF-filter-calculator.html
   - rf-tools.com/lcfilter
   - www.wa4dsy.net/filter/filterdesign.html
   - https://www.coilcraft.com/apps/lc_filter_designer/lc_filter_designer.cfm

Questions:

1. Looking at the two designs you completed above, look at the filter R, L, and C values. What problem do you perceive in implementing these filters?
2. What is the most popular filter mode (Chebyshev, elliptical, etc.) available in the design tools you used?

Questions

1. What happens to capacitive reactance as the frequency of operation increases?
2. As frequency decreases, how does the reactance of a coil vary?
3. What is skin effect, and how does it affect the Q of a coil?
4. What happens to a wire when a ferrite bead is placed around it?
5. What is the name given to the widely used coil form that is shaped like a doughnut?
6. Describe the current and impedance in a series RLC circuit at resonance.
7. Describe the current and impedance in a parallel RLC circuit at resonance.
8. State in your own words the relationship between Q and the bandwidth of a tuned circuit.
9. What kind of filter is used to select a single signal frequency from many signals?
10. What kind of filter would you use to get rid of an annoying 120-Hz hum?
11. What does selectivity mean?
12. State the Fourier theory in your own words.
13. Define the terms *time domain* and *frequency domain*.
14. Write the first four odd harmonics of 800 Hz.
15. What waveform is made up of even harmonics only? What waveform is made up of odd harmonics only?
16. Why is a nonsinusoidal signal distorted when it passes through a filter?
17. What is the most common application of SAW and BAW filters?

Problems

1. What is the gain of an amplifier with an output of 1.5 V and an input of 30 μV? ◆
2. What is the attenuation of a voltage divider like that in Fig. 2-3, where R_1 is 3.3 kΩ and R_2 is 5.1 kΩ?
3. What is the overall gain or attenuation of the combination formed by cascading the circuits described in Problems 1 and 2? ◆
4. Three amplifiers with gains of 15, 22, and 7 are cascaded; the input voltage is 120 μV. What are the overall gain and the output voltages of each stage?
5. A piece of communication equipment has two stages of amplification with gains of 40 and 60 and two loss stages with attenuation factors of 0.03 and 0.075. The output voltage is 2.2 V. What are the overall gain (or attenuation) and the input voltage? ◆

Critical Thinking

1. Explain how capacitance and inductance can exist in a circuit without lumped capacitors and inductor components being present.
2. How can the voltage across the coil or capacitor in a series resonant circuit be greater than the source voltage at resonance?
3. What type of filter would you use to prevent the harmonics generated by a transmitter from reaching the antenna?
4. What is the minimum oscilloscope vertical bandwidth needed to display a 2.5-GHz square wave?
5. Explain why it is possible to reduce the effective Q of a parallel resonant circuit by connecting a resistor in parallel with it.
6. A parallel resonant circuit has an inductance of 800 nH, a winding resistance of 3 Ω, and a capacitance of 15 pF. Calculate (*a*) resonant frequency, (*b*) Q, (*c*) bandwidth, (*d*) impedance at resonance.
7. For the previous circuit, what would the bandwidth be if you connected a 33-kΩ resistor in parallel with the tuned circuit?
8. What value of capacitor would you need to produce a high-pass filter with a cutoff frequency of 48 kHz with a resistor value of 2.2 kΩ?
9. What is the minimum bandwidth needed to pass a periodic pulse train whose frequency is 28.8 kHz and duty cycle is 20 percent? 50 percent?
10. Refer to Fig. 2-60. Examine the various waveforms and Fourier expressions. What circuit do you think might make a good but simple frequency doubler?

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.

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.

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.

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.

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

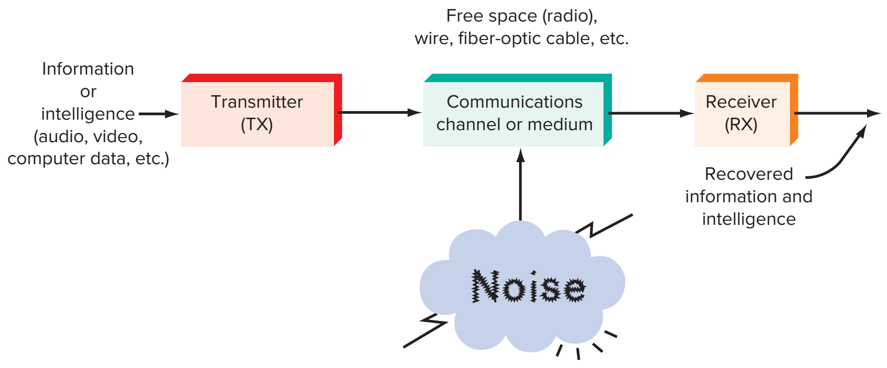
Noise

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

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



Transmitter

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.

Communication Channel

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.

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 used to turn a laser diode off and on at high speeds. Alternatively, audio or video analog signals can be used to vary the amplitude of the light.

Wireless radio

Free Space. When free space is the medium, the resulting system is known as radio. Also known as *wireless, radio* is the broad general term applied to any form of wireless communication from one point to another. Radio makes use of the electromagnetic spectrum. Intelligence signals are converted to electric and magnetic fields that propagate nearly instantaneously through space over long distances. Communication by visible or infrared light also occurs in free space.

Other Types of Media. Although the most widely used media are conducting cables and free space (radio), other types of media are used in special communication systems. For example, in sonar, water is used as the medium. Passive sonar "listens" for underwater sounds with sensitive hydrophones. Active sonar uses an echo-reflecting technique similar to that used in radar for determining how far away objects under water are and in what direction they are moving.

The earth itself can be used as a communication medium, because it conducts electricity and can also carry low-frequency sound waves.

Alternating-current (ac) power lines, the electrical conductors that carry the power to operate virtually all our electrical and electronic devices, can also be used as communication channels. The signals to be transmitted are simply superimposed on or added to the power line voltage. This is known as *carrier current transmission* or *power line communications (PLC).* It is used for some types of remote control of electrical equipment.

Carrier current transmission

Receivers

A *receiver* is a collection of electronic components and circuits that accepts the transmitted message from the channel and converts it back to a form understandable by humans. Receivers contain amplifiers, oscillators, mixers, tuned circuits and filters, and a demodulator or detector that recovers the original intelligence signal from the modulated carrier. The output is the original signal, which is then read out or displayed. It may be a voice signal sent to a speaker, a video signal that is fed to an LCD screen for display, or binary data that is received by a computer and then printed out or displayed on a video monitor.

Receiver

Transceivers

Most electronic communication is two-way, and so both parties must have both a transmitter and a receiver. As a result, most communication equipment incorporates circuits that both send and receive. These units are commonly referred to as *transceivers.* All the transmitter and receiver circuits are packaged within a single housing and usually share some common circuits such as the power supply. Telephones, handheld radios, cellular telephones, and computer modems are examples of transceivers.

Transceiver

Attenuation

Signal *attenuation,* or degradation, is inevitable no matter what the medium of transmission. Attenuation is proportional to the square of the distance between the transmitter and the receiver. Media are also frequency-selective, in that a given medium will act as a low-pass filter to a transmitted signal, distorting digital pulses in addition to greatly reducing signal amplitude over long distances. Thus considerable signal amplification, in both the transmitter and the receiver, is required for successful transmission. Any medium also slows signal propagation to a speed slower than the speed of light.

Attenuation

Noise

Noise is mentioned here because it is the bane of all electronic communications. Noise comes from many different sources including thermal agitation in components, power lines, atmospheric phenomena like lightning, other electrical and electronic equipment such as motors, relays, and power supplies. Most noise is experienced in the receiver part of any communications system. For that reason, we cover noise at that more appropriate time in Chapter 9. While some noise can be filtered out, the general way to minimize noise is to use components that contribute less noise and to lower their temperatures. The measure of noise is usually expressed in terms of the signal-to-noise (S/N) ratio (SNR), which is the signal power divided by the noise power and can be stated numerically or in terms of decibels (dB). Obviously, a very high SNR is preferred for best performance.

1-3 Types of Electronic Communication

Electronic communications are classified according to whether they are (1) one-way (simplex) or two-way (full duplex or half duplex) transmissions and (2) analog or digital signals.

Simplex

Simplex communication

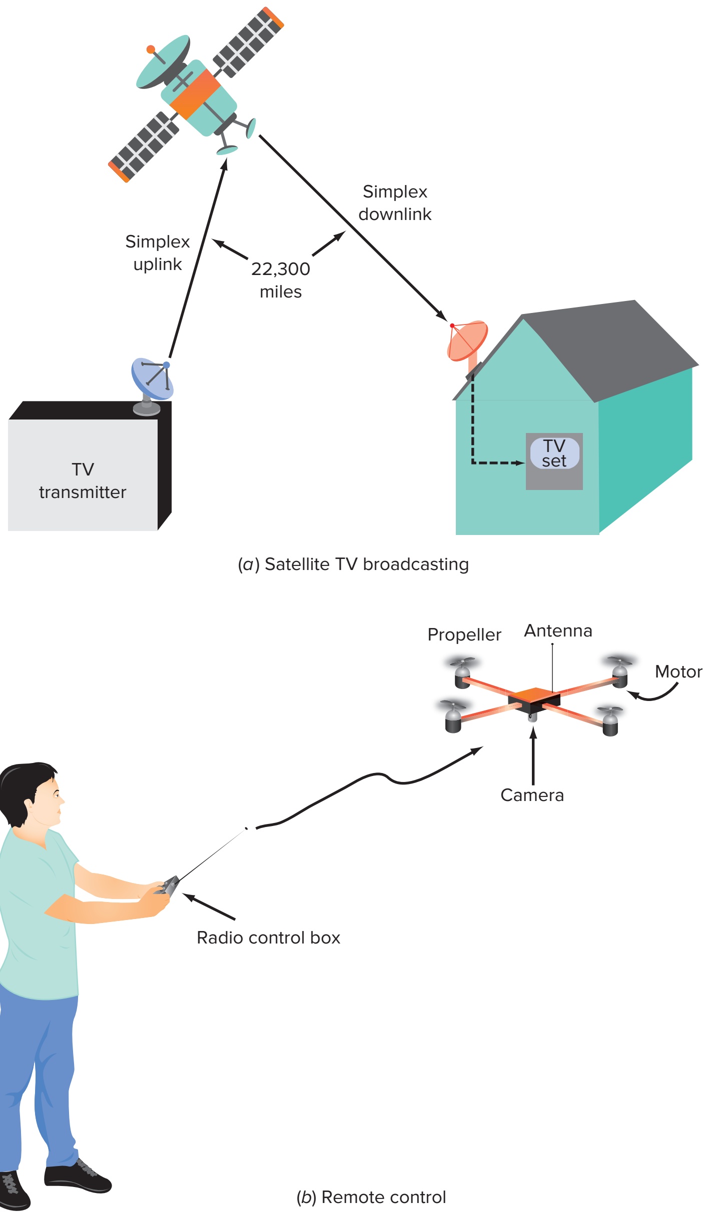
The simplest way in which electronic communication is conducted is one-way communications, normally referred to as *simplex communication.* Wireless microphones are a form of simplex communications. Other examples are shown in Fig. 1-3. The most common forms of simplex communication are radio and TV broadcasting. Satellite radio and TV are also simplex. Another example of one-way communication is transmission to a remotely controlled vehicle like a toy car or drone.

In Fig. 1-3(*a*), the satellite transmits the TV programming to the home antenna and TV set. The TV does not talk back so this is a simplex downlink.

The satellite gets its programming material from a ground-based TV station that transmits it up to the satellite by way of a simplex uplink. No two-way communication takes place. The up and down links are separate simplex connections.

Another example is shown in Fig. 1-3(*b*). The control link to the drone is simplex. However, if the drone's camera transmits video back to the operator, a form of duplex transmission is taking place.

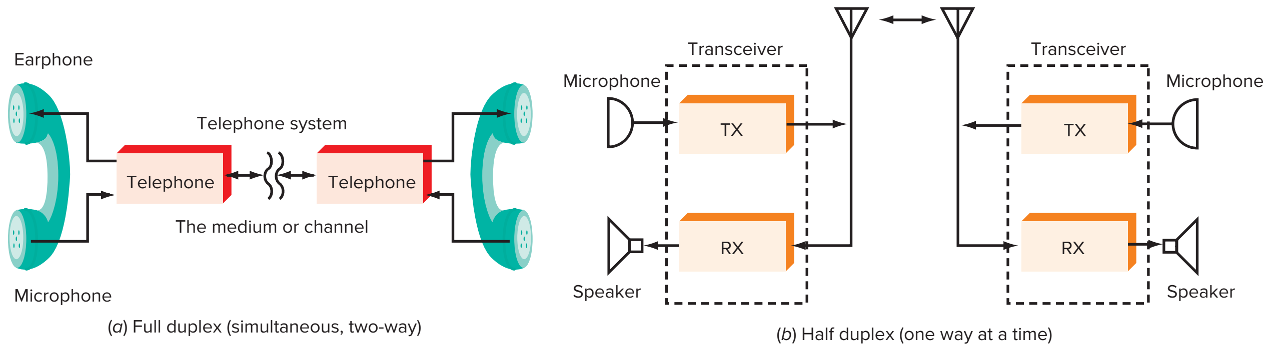
Figure 1-3 Simplex communication.



(*a*) Satellite TV broadcasting

(*b*) Remote control

Figure 1-4 Duplex communication. (*a*) Full duplex (simultaneous two-way). (*b*) Half duplex (one way at a time).



Full Duplex

The bulk of electronic communication is two-way, or *duplex communication.* Typical duplex applications are shown in Fig. 1-4. For example, people communicating with one another over the telephone can talk and listen simultaneously, as Fig. 1-4(*a*) illustrates. This is called *full duplex communication.*

Duplex communication

Full duplex communication

Full duplex also applies to wired communications. For example, a cable between two locations may have two pairs of wires. Each pair is used for one of the two directions of transmission. This permits the exchange of information simultaneously over both pairs in both directions.

Half Duplex

The form of two-way communication in which only one party transmits at a time is known as *half duplex communication* [see Fig. 1-4(*b*)]. The communication is two-way, but the direction alternates: the communicating parties take turns transmitting and receiving. Most radio transmissions, such as those used in the military, fire, police, aircraft, marine, and other services, are half duplex communication. Citizens band (CB), Family Radio, and amateur radio communication are also half duplex.

Half duplex communication

Half duplex operation is often used in some wired communications. A common arrangement is a single two-wire bus to which two or more communications nodes (transceivers) are connected. All of the nodes share the bus. This means that two or more nodes cannot transmit at the same time without interfering with one another. Nodes take turns so that only one transits at a time.

Analog Signals

An *analog signal* is a smoothly and continuously varying voltage or current. Some typical analog signals are shown in Fig. 1-5. A sine wave is a single-frequency analog signal.

Analog signal

Figure 1-5 Analog signals. (*a*) Sine wave "tone." (*b*) Voice. (*c*) Video (TV) signal.

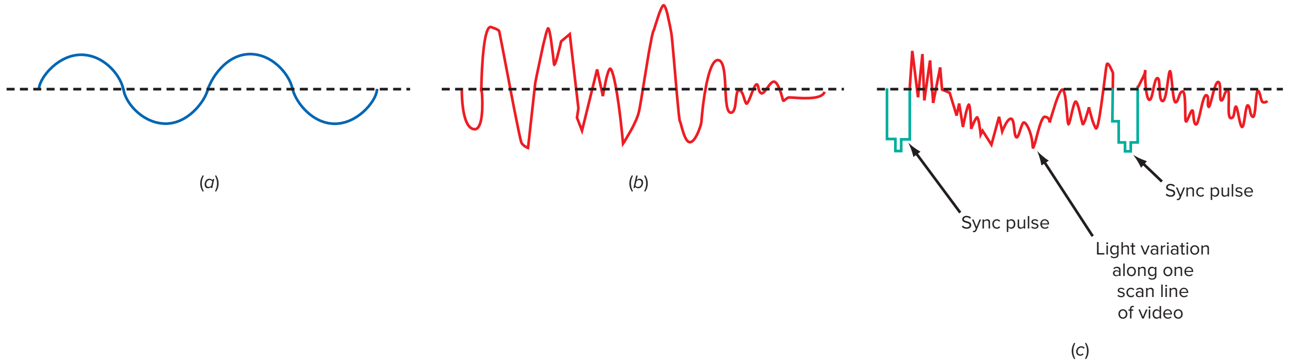
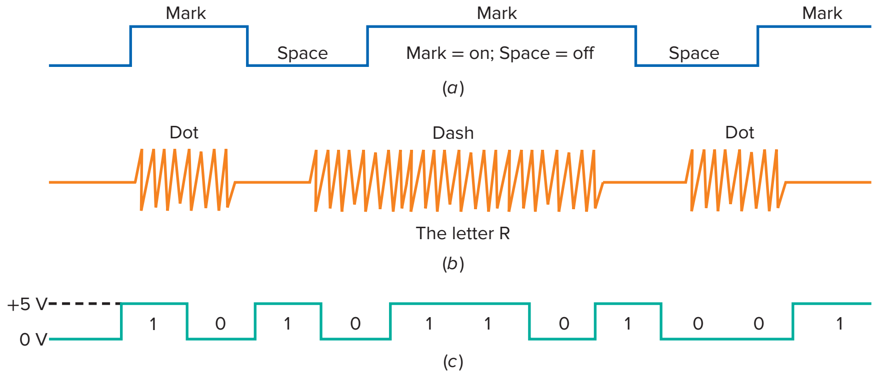


Figure 1-6 Digital signals. (*a*) Telegraph (Morse code). (*b*) Continuous-wave (CW) code. (*c*) Serial binary code.



Voice and video voltages are analog signals that vary in accordance with the sound or light variations that are analogous to the information being transmitted. Sensors measuring physical characteristics like temperature, pressure, or light level produce analog signals.

Digital Signals

Digital signal

Digital signals, in contrast to analog signals, do not vary continuously, but change in steps or in discrete increments. Most digital signals use binary or two-state codes. Some examples are shown in Fig. 1-6. The earliest forms of both wire and radio communication used a type of on/off digital code. The telegraph used Morse code, with its system of short and long signals (dots and dashes) to designate letters and numbers. See Fig. 1-6(*a*). In radio telegraphy, also known as continuous-wave (CW) transmission, a sine wave signal is turned off and on for short or long durations to represent the dots and dashes. Refer to Fig. 1-6(*b*).

ASCII

Data used in computers is also digital. Binary codes representing numbers, letters, and special symbols are transmitted serially by wire, radio, or optical medium. The most commonly used digital code in communications is the *American Standard Code for Information Interchange* (*ASCII*, pronounced "ask key"). Fig. 1-6(*c*) shows a serial binary code.

Many transmissions are of signals that originate in digital form, e.g., telegraphy messages or computer data, but that must be converted to analog form to match the transmission medium. An example is the transmission of digital data over the telephone network, which was designed to handle analog voice signals only. If the digital data is converted to analog signals, such as tones in the audio frequency range, it can be transmitted over the telephone network.

Analog signals can also be transmitted digitally. It is very common today to take voice or video analog signals and digitize them with an analog-to-digital (A/D) converter. The data can then be transmitted efficiently in digital form and processed by computers and other digital circuits.

Modulation

Multiplexing

GOOD TO KNOW

Multiplexing has been used in the music industry to create stereo sound. In stereo radio, two signals are transmitted and received—one for the right and one for the left channel of sound. (For more information on multiplexing, see Chap. 10.)

1-4 Modulation and Multiplexing

Modulation and multiplexing are electronic techniques for transmitting information efficiently from one place to another. *Modulation* makes the information signal more compatible with the medium, and *multiplexing* allows more than one signal to be transmitted concurrently over a single medium. Modulation and multiplexing techniques are basic to electronic communication. Once you have mastered the fundamentals of these techniques, you will easily understand how most modern communication systems work.

Baseband Transmission

Before it can be transmitted, the information or intelligence must be converted to an electronic signal compatible with the medium. For example, a microphone changes voice signals (sound waves) into an analog voltage of varying frequency and amplitude. This signal is then passed over wires to a speaker or headphones. This is the way the telephone system works.

A video camera generates an analog signal that represents the light variations along one scan line of the picture. This analog signal is usually transmitted over a coaxial cable. Binary data is generated by a keyboard attached to a computer. The computer stores the data and processes it in some way. The data is then transmitted on cables to peripherals such as a printer or to other computers over a LAN. Regardless of whether the original information or intelligence signals are analog or digital, they are all referred to as baseband signals.

In a communication system, baseband information signals can be sent directly and unmodified over the medium or can be used to modulate a carrier for transmission over the medium. Putting the original voice, video, or digital signals directly into the medium is referred to as *baseband transmission.* For example, in many telephone and intercom systems, it is the voice itself that is placed on the wires and transmitted over some distance to the receiver. In most computer networks, the digital signals are applied directly to coaxial or twisted-pair cables for transmission to another computer.

Baseband transmission

In many instances, baseband signals are incompatible with the medium. As a result, the baseband information signal, be it audio, video, or data, is normally used to modulate a high-frequency signal called a *carrier.* The higher-frequency carriers radiate into space more efficiently than the baseband signals themselves. Such wireless signals consist of both electric and magnetic fields. These electromagnetic signals, which are able to travel through space for long distances, are also referred to as *radio-frequency (RF) waves,* or just radio waves.

Carrier

Radio-frequency (RF) wave

Broadband Transmission

Modulation is the process of having a baseband voice, video, or digital signal modify another, higher-frequency signal, the carrier. The process is illustrated in Fig. 1-7. The information or intelligence to be sent is said to be *impressed* upon the carrier. The carrier is usually a sine wave generated by an oscillator. The carrier is fed to a circuit called a modulator along with the baseband intelligence signal. The intelligence signal changes the carrier in a unique way. The modulated carrier is amplified and sent to the antenna for transmission. This process is called *broadband transmission.*

Broadband transmission

Figure 1-7 Modulation at the transmitter.

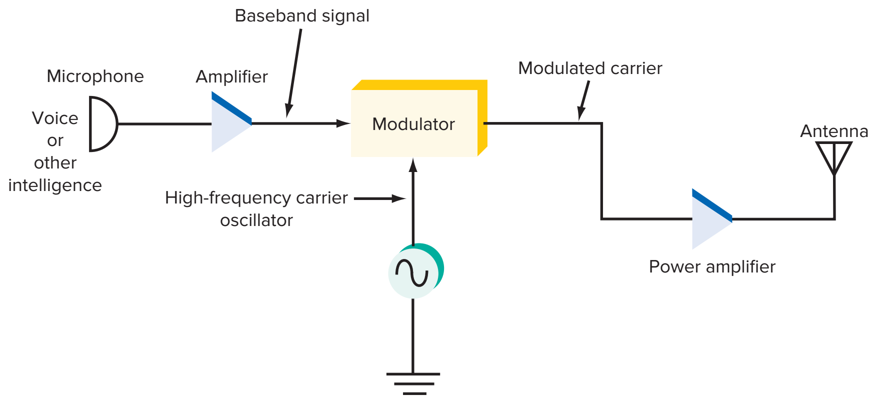
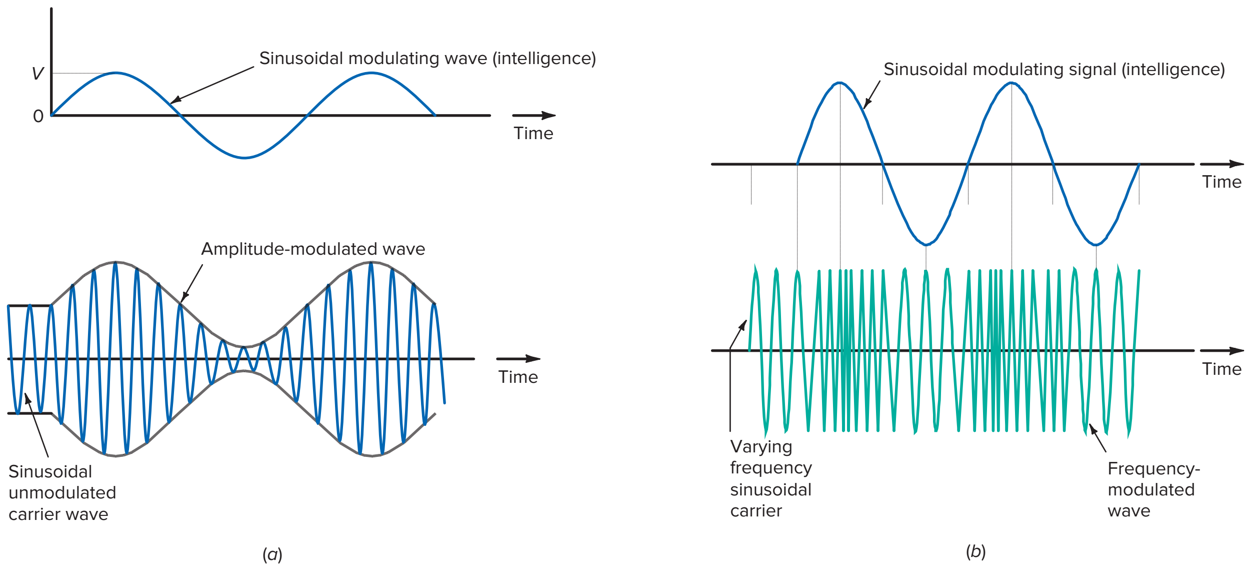


Figure 1-8 Types of modulation. (*a*) Amplitude modulation. (*b*) Frequency modulation.



Consider the common mathematical expression for a sine wave:

$$v = V_p \sin (2\pi ft + \theta) \quad \text{or} \quad v = V_p \sin (\omega t + \theta)$$

where v = instantaneous value of sine wave voltage
V_p = peak value of sine wave
f = frequency, Hz
ω = angular velocity = $2\pi f$
t = time, s
$\omega t = 2\pi ft$ = angle, rad ($360° = 2\pi$ rad)
θ = phase angle

Amplitude modulation (AM)

Frequency modulation (FM)

Phase modulation (PM)

Frequency-shift keying (FSK)

Phase-shift keying (PSK)

Modems

The three ways to make the baseband signal change the carrier sine wave are to vary its amplitude, vary its frequency, or vary its phase angle. The two most common methods of modulation are *amplitude modulation (AM)* and *frequency modulation (FM)*. In AM, the baseband information signal called the modulating signal varies the amplitude of the higher-frequency carrier signal, as shown in Fig. 1-8(*a*). It changes the V_p part of the equation. In FM, the information signal varies the frequency of the carrier, as shown in Fig. 1-8(*b*). The carrier amplitude remains constant. FM varies the value of f in the first angle term inside the parentheses. Varying the phase angle produces *phase modulation (PM)*. Here, the second term inside the parentheses (θ) is made to vary by the intelligence signal. Phase modulation produces frequency modulation; therefore, the PM signal is similar in appearance to a frequency-modulated carrier. Two common examples of transmitting digital data by modulation are given in Fig. 1-9. In Fig. 1-9(*a*), the data is converted to frequency-varying tones. This is called *frequency-shift keying (FSK)*. In Fig. 1-9(*b*), the data introduces a 180°-phase shift. This is called *phase-shift keying (PSK)*. Devices called *modems* (*mo*dulator-*dem*odulator) translate the data from digital to analog and back again. Both FM and PM are forms of angle modulation.

At the receiver, the carrier with the intelligence signal is amplified and then demodulated to extract the original baseband signal. Another name for the demodulation process is detection. (See Fig. 1-10.)

Figure 1-9 Transmitting binary data in analog form. (*a*) FSK. (*b*) PSK.

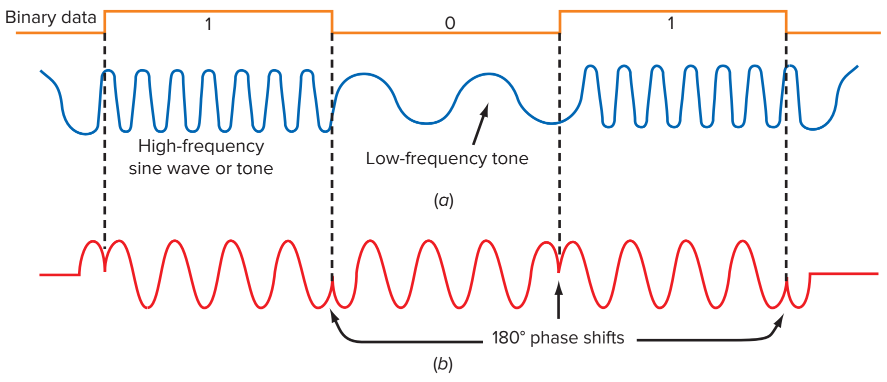
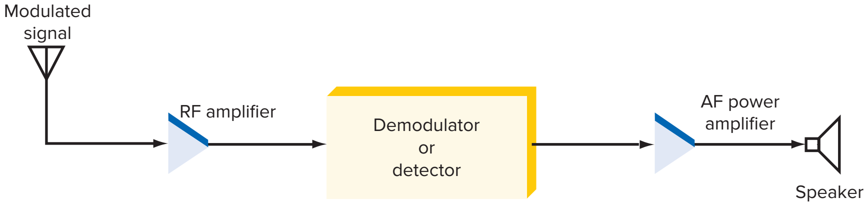


Figure 1-10 Recovering the intelligence signal at the receiver.



Multiplexing

The use of modulation also permits another technique, known as multiplexing, to be used. Multiplexing is the process of allowing two or more signals to share the same medium or channel; see Fig. 1-11. A multiplexer converts the individual baseband signals to a composite signal that is used to modulate a carrier in the transmitter. At the receiver, the composite signal is recovered at the demodulator, then sent to a demultiplexer where the individual baseband signals are regenerated (see Fig. 1-12).

There are three basic types of multiplexing: frequency division, time division, and code division. In *frequency-division multiplexing,* the intelligence signals modulate sub-carriers on different frequencies that are then added together, and the composite signal is used to modulate the carrier. In optical networking, wavelength division multiplexing (WDM) is equivalent to frequency-division multiplexing for optical signal.

Frequency-division multiplexing

In *time-division multiplexing,* the multiple intelligence signals are sequentially sampled, and a small piece of each is used to modulate the carrier. If the information signals are sampled fast enough, sufficient details are transmitted that at the receiving end the signal can be reconstructed with great accuracy.

Time-division multiplexing

Figure 1-11 Multiplexing at the transmitter.

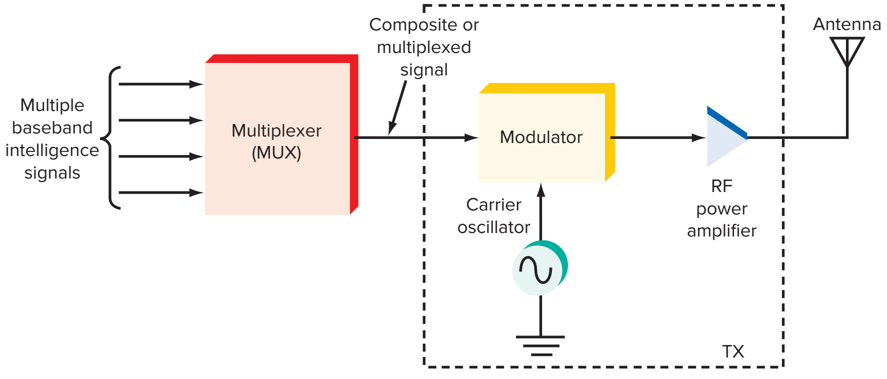
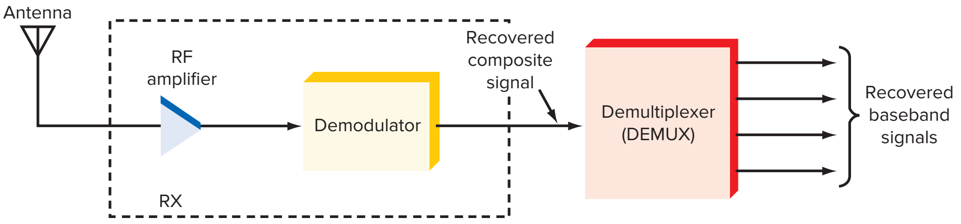


Figure 1-12 Demultiplexing at the receiver.



In code-division multiplexing, the signals to be transmitted are converted to digital data that is then uniquely coded with a faster binary code. The signals modulate a carrier on the same frequency. All use the same communications channel simultaneously. The unique coding is used at the receiver to select the desired signal.

1-5 The Electromagnetic Spectrum

Electromagnetic waves are signals that oscillate; i.e., the amplitudes of the electric and magnetic fields vary at a specific rate. The field intensities fluctuate up and down, and the polarity reverses a given number of times per second. The electromagnetic waves vary sinusoidally. Their frequency is measured in cycles per second (cps) or hertz (Hz). These oscillations may occur at a very low frequency or at an extremely high frequency. The range of electromagnetic signals encompassing all frequencies is referred to as the *electromagnetic spectrum.*

Electromagnetic spectrum

All electrical and electronic signals that radiate into free space fall into the electromagnetic spectrum. Not included are signals carried by cables. Signals carried by cable may share the same frequencies of similar signals in the spectrum, but they are not radio signals. Fig. 1-13 shows the entire electromagnetic spectrum, giving both frequency and wavelength. Within the middle ranges are located the most commonly used radio frequencies for two-way communication, TV, cell phones, wireless LANs, radar, and other applications. At the upper end of the spectrum are infrared and visible light. Fig. 1-14 is a listing of the generally recognized segments in the spectrum used for electronic communication.

Figure 1-13 The electromagnetic spectrum.

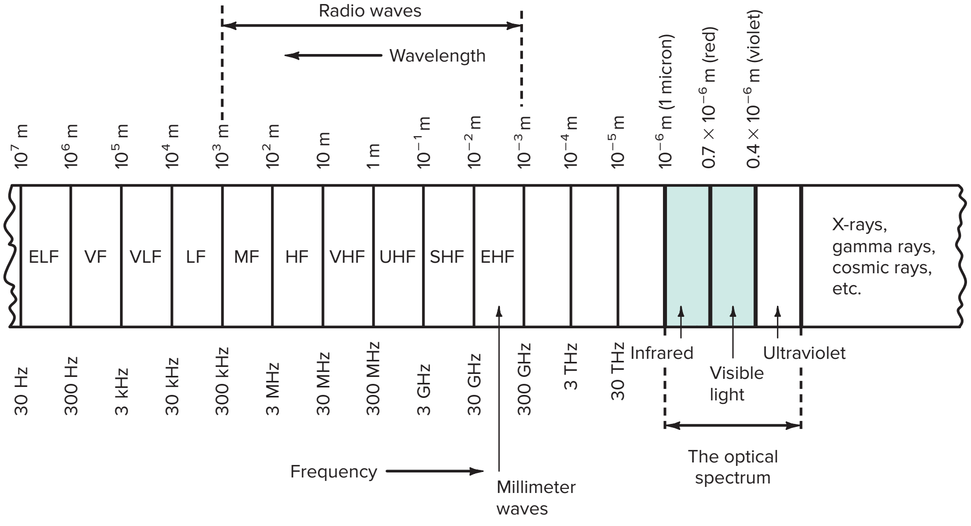


Figure 1-14 The electromagnetic spectrum used in electronic communication.

Name	Frequency	Wavelength
Extremely low frequencies (ELFs)	30–300 Hz	10^7–10^6 m
Voice frequencies (VFs)	300–3000 Hz	10^6–10^5 m
Very low frequencies (VLFs)	3–30 kHz	10^5–10^4 m
Low frequencies (LFs)	30–300 kHz	10^4–10^3 m
Medium frequencies (MFs)	300 kHz–3 MHz	10^3–10^2 m
High frequencies (HFs)	3–30 MHz	10^2–10^1 m
Very high frequencies (VHFs)	30–300 MHz	10^1–1 m
Ultra high frequencies (UHFs)	300 MHz–3 GHz	1–10^{-1} m
Super high frequencies (SHFs)	3–30 GHz	10^{-1}–10^{-2} m
Extremely high frequencies (EHFs)	30–300 GHz	10^{-2}–10^{-3} m
Infrared	—	0.7–10 μm
The visible spectrum (light)	—	0.4–0.8 μm

Units of Measure and Abbreviations:

kHz = 1000 Hz

MHz = 1000 kHz = 1×10^6 = 1,000,000 Hz

GHz = 1000 MHz = 1×10^6 = 1,000,000 kHz

= 1×10^9 = 1,000,000,000 Hz

m = meter

$\mu m = \text{micrometer} = \frac{1}{1{,}000{,}000}\ m = 1 \times 10^{-6}\ m$

Frequency and Wavelength

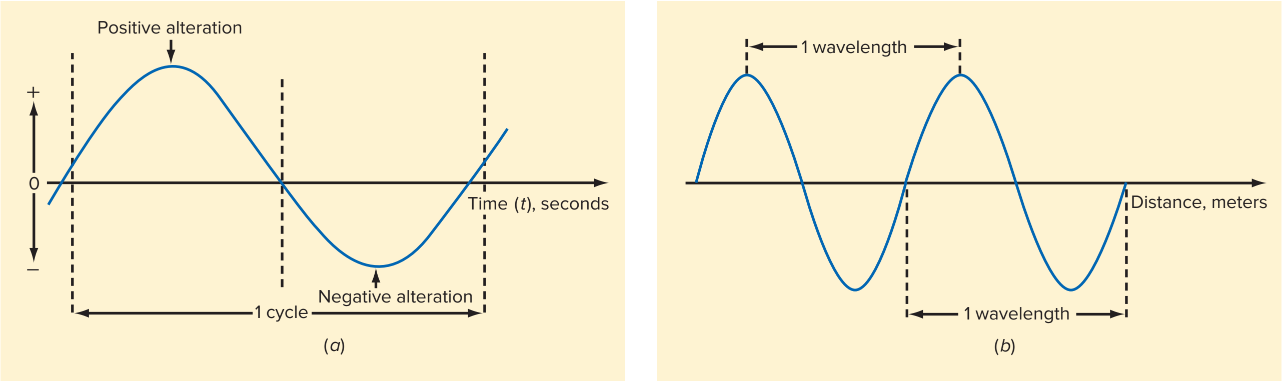
A given signal is located on the frequency spectrum according to its frequency and wavelength.

Frequency. *Frequency* is the number of times a particular phenomenon occurs in a given period of time. In electronics, frequency is the number of cycles of a repetitive wave that occurs in a given time period. A cycle consists of two voltage polarity reversals, current reversals, or electromagnetic field oscillations. The cycles repeat, forming a continuous but repetitive wave. Frequency is measured in cycles per second (cps). In electronics, the unit of frequency is the hertz, named for the German physicist Heinrich Hertz, who was a pioneer in the field of electromagnetics. One cycle per second is equal to one hertz, abbreviated (Hz). Therefore, 440 cps = 440 Hz.

Frequency

Fig. 1-15(*a*) shows a sine wave variation of voltage. One positive alternation and one negative alternation form a cycle. If 2500 cycles occur in 1 s, the frequency is 2500 Hz.

Figure 1-15 Frequency and wavelength. (*a*) One cycle. (*b*) One wavelength.



PIONEERS OF ELECTRONICS

In 1887 German physicist Heinrich Hertz was the first to demonstrate the effect of electromagnetic radiation through space. The distance of transmission was only a few feet, but this transmission proved that radio waves could travel from one place to another without the need for any connecting wires. Hertz also proved that radio waves, although invisible, travel at the same velocity as light waves. (Grob/Schultz, *Basic Electronics*, 9th ed., Glencoe/McGraw Hill, 2003, p. 4)

Prefixes representing powers of 10 are often used to express frequencies. The most frequently used prefixes are as follows:

$$k = \text{kilo} = 1000 = 10^3$$
$$M = \text{mega} = 1{,}000{,}000 = 10^6$$
$$G = \text{giga} = 1{,}000{,}000{,}000 = 10^9$$
$$T = \text{tera} = 1{,}000{,}000{,}000{,}000 = 10^{12}$$

Thus, 1000 Hz = 1 kHz (kilohertz). A frequency of 9,000,000 Hz is more commonly expressed as 9 MHz (megahertz). A signal with a frequency of 15,700,000,000 Hz is written as 15.7 GHz (gigahertz).

Wavelength

Wavelength. *Wavelength* is the distance occupied by one cycle of a wave, and it is usually expressed in meters. One meter (m) is equal to 39.37 in (just over 3 ft, or 1 yd). Wavelength is measured between identical points on succeeding cycles of a wave, as Fig. 1-15(*b*) shows. If the signal is an electromagnetic wave, one wavelength is the distance that one cycle occupies in free space. It is the distance between adjacent peaks or valleys of the electric and magnetic fields making up the wave.

Wavelength is also the distance traveled by an electromagnetic wave during the time of one cycle. Electromagnetic waves travel at the speed of light, or 299,792,800 m/s. The speed of light and radio waves in a vacuum or in air is usually rounded off to 300,000,000 m/s (3×10^8 m/s), or 186,000 mi/s. The speed of transmission in media such as a cable is less.

The wavelength of a signal, which is represented by the Greek letter λ (lambda), is computed by dividing the speed of light by the frequency f of the wave in hertz: $\lambda = 300{,}000{,}000/f$. For example, the wavelength of a 4,000,000-Hz signal is

$$\lambda = 300{,}000{,}000/4{,}000{,}000 = 75 \text{ m}$$

If the frequency is expressed in megahertz, the formula can be simplified to $\lambda(\text{m}) = 300/f(\text{MHz})$ or $\lambda(\text{ft}) = 984\, f(\text{MHz})$.

The 4,000,000-Hz signal can be expressed as 4 MHz. Therefore $\lambda = 300/4 = 75$ m.

Very high frequency signal wavelength

A wavelength of 0.697 m, as in the second equation in Example 1-1, is known as a *very high frequency signal wavelength*. Very high frequency wavelengths are sometimes expressed in centimeters (cm). Since 1 m equals 100 cm, we can express the wavelength of 0.697 m in Example 1-1 as 69.7, or about 70 cm.

Example 1-1

Find the wavelengths of (*a*) a 150-MHz, (*b*) a 430-MHz, (*c*) an 8-MHz, and (*d*) a 750-kHz signal.

a. $\lambda = \dfrac{300{,}000{,}000}{150{,}000{,}000} = \dfrac{300}{150} = 2 \text{ m}$

b. $\lambda = \dfrac{300}{430} = 0.697 \text{ m}$

c. $\lambda = \dfrac{300}{8} = 37.5 \text{ m}$

d. For Hz (750 kHz = 750,000 Hz):

$$\lambda = \frac{300{,}000{,}000}{750{,}000} = 400 \text{ m}$$

For MHz (750 kHz = 0.75 MHz):

$$\lambda = \frac{300}{0.75} = 400 \text{ m}$$

If the wavelength of a signal is known or can be measured, the frequency of the signal can be calculated by rearranging the basic formula $f = 300/\lambda$. Here, f is in megahertz and λ is in meters. As an example, a signal with a wavelength of 14.29 m has a frequency of $f = 300/14.29 = 21$ MHz.

Example 1-2

A signal with a wavelength of 1.5 m has a frequency of

$$f = \frac{300}{1.5} = 200 \text{ MHz}$$

Example 1-3

A signal travels a distance of 75 ft in the time it takes to complete 1 cycle. What is its frequency?

$$1 \text{ m} = 3.28 \text{ ft}$$

$$\frac{75 \text{ ft}}{3.28} = 22.86 \text{ m}$$

$$f = \frac{300}{22.86} = 13.12 \text{ MHz}$$

Example 1-4

The maximum peaks of an electromagnetic wave are separated by a distance of 8 in. What is the frequency in megahertz? In gigahertz?

$$1 \text{ m} = 39.37 \text{ in}$$

$$8 \text{ in} = \frac{8}{39.37} = 0.203 \text{ m}$$

$$f = \frac{300}{0.203} = 1477.8 \text{ MHz}$$

$$\frac{1477.8}{10^3} = 1.4778 \text{ GHz}$$

Frequency Ranges from 30 Hz to 300 GHz

For the purpose of classification, the electromagnetic frequency spectrum is divided into segments, as shown in Fig. 1-13. The signal characteristics and applications for each segment are discussed in the following paragraphs.

Extremely low frequency (ELF)

Extremely Low Frequencies. *Extremely low frequencies (ELFs)* are in the 30- to 300-Hz range. These include ac power line frequencies (50 and 60 Hz are common), as well as those frequencies in the low end of the human audio range.

Voice frequency (VF)

Voice Frequencies. *Voice frequencies (VFs)* are in the range of 300 to 3000 Hz. This is the normal range of human speech. Although human hearing extends from approximately 20 to 20,000 Hz, most intelligible sound occurs in the VF range.

Very low frequency (VLF)

Very Low Frequencies. *Very low frequencies (VLFs)* extend from 9 kHz to 30 kHz and include the higher end of the human hearing range up to about 15 or 20 kHz. Many musical instruments make sounds in this range as well as in the ELF and VF ranges. The VLF range is also used in some government and military communication. For example, VLF radio transmission is used by the navy to communicate with submarines.

Low frequency (LF)

Subcarrier

Low Frequencies. *Low frequencies (LFs)* are in the 30- to 300-kHz range. The primary communication services using this range are in aeronautical and marine navigation. Frequencies in this range are also used as *subcarriers,* signals that are modulated by the baseband information. Usually, two or more subcarriers are added, and the combination is used to modulate the final high-frequency carrier.

Medium frequency (MF)

Medium Frequencies. *Medium frequencies (MFs)* are in the 300- to 3000-kHz (0.3- to 3.0-MHz) range. The major application of frequencies in this range is AM radio broadcasting (535 to 1605 kHz). Other applications in this range are various marine and amateur radio communication.

High frequency (HF)

High Frequencies. *High frequencies (HFs)* are in the 3- to 30-MHz range. These are the frequencies generally known as short waves. All kinds of simplex broadcasting and half duplex two-way radio communication take place in this range. Broadcasts from many foreign countries occur in this range. Government and military services use these frequencies for two-way communication. An example is diplomatic communication between embassies. Amateur radio and CB communication also occur in this part of the spectrum.

Very high frequency (VHF)

Very High Frequencies. *Very high frequencies (VHFs)* encompass the 30- to 300-MHz range. This popular frequency range is used by many services, including land mobile radio, marine and aeronautical communication, FM radio broadcasting (88 to 108 MHz), and television channels 2 through 13. Radio amateurs also have 2- and 6-m bands in this frequency range.

White Spaces. White spaces are unused TV channels. Several years ago, most TV stations abandoned their spectrum assignments in the 2 to 13 channel range. They moved to one of the higher TV channels in the 14 to 51 range. Because of this, there are many unused channels. Therefore, these 6-MHz-wide channels can be used for other applications. These channels lie in the 54- to 698-MHz range. The specific channels abandoned vary from one geographical area to another. The 6 MHz of channel bandwidth permits them to carry high-speed data for telemetry service or some IoT application. Use of these white spaces does not require a license, but the user must register with a database that all nodes will use to check for other activity on a channel before using it. This listen-before-talk approach is part of a transmission scheme called cognitive radio (CR). CR is an automated system that lets multiple users share an unused channel when it is available. The Federal Communications Commission (FCC) restricts the transmit power level, but at these low frequencies with an appropriate modulation method for digital data and a good antenna, a range of many miles can be achieved. New standards have been developed to serve this wireless activity. To date, there have not been many adopters.

Ultrahigh Frequencies. *Ultrahigh frequencies (UHFs)* encompass the 300- to 3000-MHz range. This, too, is a widely used portion of the frequency spectrum. It includes the UHF TV channels 14 through 51, and it is used for land mobile communication and services such as cellular telephones as well as for military communication. Some radar and navigation services occupy this portion of the frequency spectrum, and radio amateurs also have bands in this range.

Ultrahigh frequency (UHF)

Microwaves and SHFs. Frequencies between the 1000-MHz (1-GHz) and 30-GHz range are called *microwaves.* Microwave ovens usually operate at 2.45 GHz. *Superhigh frequencies (SHFs)* are in the 3- to 30-GHz range. These microwave frequencies are widely used for satellite communication and radar. Wireless LANs like Wi-Fi and many cellular telephone systems also occupy this region.

Microwave

Superhigh frequency (SHF)

Extremely High Frequencies. *Extremely high frequencies (EHFs)* extend from 30 to 300 GHz. Electromagnetic signals with frequencies higher than 30 GHz are referred to as *millimeter waves*. Equipment used to generate and receive signals in this range is extremely complex and expensive, but there is growing use of this range for satellite communication telephony, computer data, fifth-generation (5G) cellular networks, and some specialized radar.

Extremely high frequency (EHF)

Millimeter wave

Frequencies Between 300 GHz and the Optical Spectrum. Sometimes referred to as the terahertz region, this portion of the spectrum is virtually uninhabited. It is a cross between RF and optical. Lack of hardware and components limits its use.

Optical spectrum

Infrared region

Visible spectrum

Light

The Optical Spectrum

Right above the millimeter wave region is what is called the *optical spectrum,* the region occupied by light waves. There are three different types of light waves: infrared, visible, and ultraviolet.

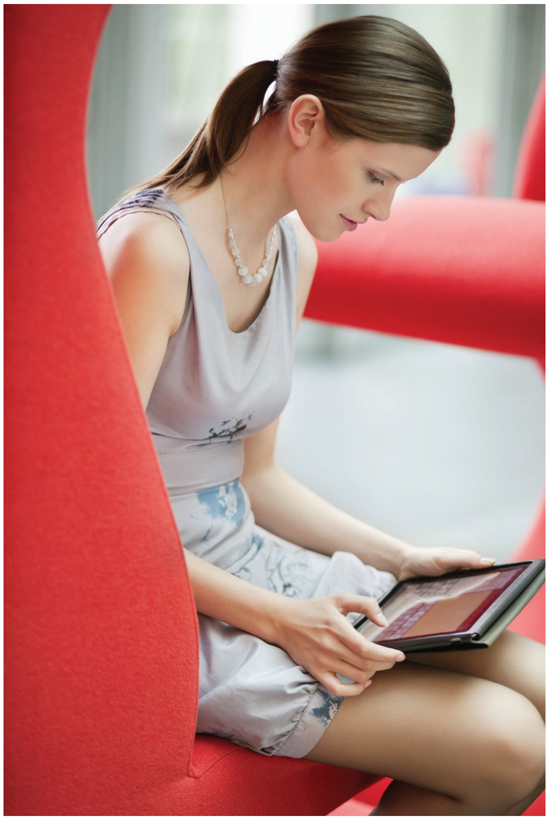
Infrared. The *infrared region* is sandwiched between the highest radio frequencies (i.e., millimeter waves) and the visible portion of the electromagnetic spectrum. Infrared occupies the range between approximately 0.1 millimeter (mm) and 700 nanometers (nm), or 100 to 0.7 micrometer (μm). One micrometer is one-millionth of a meter. Infrared wavelengths are often given in micrometers or nanometers.

Infrared radiation is generally associated with heat. Infrared is produced by light bulbs, our bodies, and any physical equipment that generates heat. Infrared signals can also be generated by special types of light-emitting diodes (LEDs) and lasers.

Infrared signals are used for various special kinds of communication. For example, infrared is used in astronomy to detect stars and other physical bodies in the universe, and for guidance in weapons systems, where the heat radiated from airplanes or missiles can be picked up by infrared detectors and used to guide missiles to targets. Infrared is also used in most new TV remote-control units where special coded signals are transmitted by an infrared LED to the TV receiver for the purpose of changing channels, setting the volume, and performing other functions. Infrared is the basis for all fiber-optic communication.

Infrared signals have many of the same properties as signals in the visible spectrum. Optical devices such as lenses and mirrors are often used to process and manipulate infrared signals, and infrared light is the signal usually propagated over fiber-optic cables.

The Visible Spectrum. Just above the infrared region is the *visible spectrum* we ordinarily refer to as *light.* Light is a special type



The tablet computer has become a popular communications device thanks to Wi-Fi and cellular links.

Fabrice Lerouge/Onoky Photography/SuperStock

GOOD TO KNOW

Although it is expensive to build a fiber-optic or wireless network, servicing each additional user is cost-effective. The more users a network has, the lower the overall cost.

of electromagnetic radiation that has a wavelength in the 0.4- to 0.8-μm range (400 to 800 nm). Light wavelengths are usually expressed in terms of angstroms (Å). An angstrom is one ten-thousandth of a micrometer; for example, 1 Å = 10^{-10} m. The visible range is approximately 8000 Å (red) to 4000 Å (violet). Red is low-frequency or long-wavelength light, whereas violet is high-frequency or short-wavelength light.

Light is used for various kinds of communication. Light waves can be modulated and transmitted through glass fibers, just as electric signals can be transmitted over wires. The great advantage of light wave signals is that their very high frequency gives them the ability to handle a tremendous amount of information. That is, the bandwidth of the baseband signals can be very wide.

Light signals can also be transmitted through free space. Various types of communication systems have been created using a laser that generates a light beam at a specific visible frequency. Lasers generate an extremely narrow beam of light, which is easily modulated with voice, video, and data information.

Ultraviolet light (UV)

Ultraviolet. *Ultraviolet light (UV)* covers the range from about 4 to 400 nm. Ultraviolet generated by the sun is what causes sunburn. Ultraviolet is also generated by mercury vapor lights and some other types of lights such as fluorescent lamps and sun lamps. Ultraviolet is not used for communication; its primary use is medical.

Beyond the visible region are the X-rays, gamma rays, and cosmic rays. These are all forms of electromagnetic radiation, but they do not figure into communication systems and are not covered here.

1-6 Bandwidth

Bandwidth (BW)

Bandwidth (BW) is that portion of the electromagnetic spectrum occupied by a signal. It is also the frequency range over which a receiver or other electronic circuit operates. More specifically, bandwidth is the difference between the upper and lower frequency limits of the signal or the equipment operation range. Fig. 1-16 shows the bandwidth of the voice frequency range from 300 to 3000 Hz. The upper frequency is f_2 and the lower frequency is f_1. The bandwidth, then, is

$$BW = f_2 - f_1$$

Example 1-5

A commonly used frequency range is 902 to 928 MHz. What is the width of this band?

$$f_1 = 902 \text{ MHz} \qquad f_2 = 928 \text{ MHz}$$

$$\text{BW} = f_2 - f_1 = 928 - 902 = 26 \text{ MHz}$$

Example 1-6

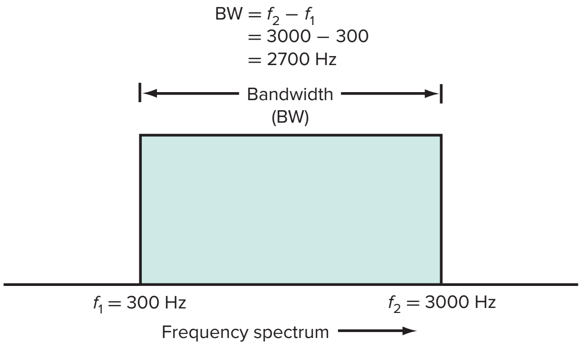
Automotive radar has been assigned a bandwidth of 5 GHz. If the low-frequency limit is 76 GHz, what is the upper-frequency limit?

$$\text{BW} = 5 \text{ GHz} \qquad f_1 = 76 \text{ GHz}$$

$$\text{BW} = f_1 - f_2$$

$$f_2 = \text{BW} + f_1 = 5 + 76 = 81 \text{ GHz}$$

Figure 1-16 Bandwidth is the frequency range over which equipment operates or that portion of the spectrum occupied by the signal. This is the voice frequency bandwidth.



Channel Bandwidth

When information is modulated onto a carrier somewhere in the electromagnetic spectrum, the resulting signal occupies a small portion of the spectrum surrounding the carrier frequency. The modulation process causes other signals, called *sidebands,* to be generated at frequencies above and below the carrier frequency by an amount equal to the modulating frequency. For example, in AM broadcasting, audio signals up to 5 kHz can be transmitted. If the carrier frequency is 1000 kHz, or 1 MHz, and the modulating frequency is 5 kHz, sidebands will be produced at $1000 - 5 = 995$ kHz and at $1000 + 5 = 1005$ kHz. In other words, the modulation process generates other signals that take up spectrum space. It is not just the carrier at 1000 kHz that is transmitted. Thus the term *bandwidth* refers to the range of frequencies that contain the information. The term *channel bandwidth* refers to the range of frequencies required to transmit the desired information.

Sideband

Channel bandwidth

The bandwidth of the aforementioned AM signal is the difference between the highest and lowest transmitting frequencies: BW = 1005 kHz − 995 kHz = 10 kHz. In this case, the channel bandwidth is 10 kHz. An AM broadcast signal, therefore, takes up a 10-kHz piece of the spectrum.

Signals transmitting on the same frequency or on overlapping frequencies do, of course, interfere with one another. Thus a limited number of signals can be transmitted in the frequency spectrum. As communication activities have grown over the years, there has been a continuous demand for more frequency channels over which communication can be transmitted. This has caused a push for the development of equipment that operates at the higher frequencies. Prior to World War II, frequencies above 1 GHz were virtually unused, since there were no electronic components suitable for generating signals at those frequencies. But technological developments over the years have given us many microwave components such as klystrons, magnetrons, and traveling-wave tubes, and today transistors, integrated circuits, and other semiconductor devices that routinely work in the microwave and millimeter wave ranges.

More Room at the Top

The benefit of using the higher frequencies for communication carriers is that a signal of a given bandwidth represents a smaller percentage of the spectrum at the higher frequencies than at the lower frequencies. For example, at 1000 kHz, the 10-kHz-wide AM signal discussed earlier represents 1 percent of the spectrum:

$$\% \text{ of spectrum} = \frac{10 \text{ kHz}}{1000 \text{ KHz}} \times 100$$
$$= 1\%$$

GOOD TO KNOW

The Federal Communications Commission (FCC) was formed in 1934 to regulate interstate and foreign communication. A primary function of the FCC is to allocate bands of frequencies and set limitations on broadcast power for different types of radio and TV operations. The FCC also monitors broadcasts to detect unlicensed operations and technical violations. In addition to TV and radio stations, the FCC licenses about 50 million transmitters operated by individuals, businesses, ships and airplanes, emergency services, and telephone systems. FCC policy is set by five commissioners who are appointed by the President for five-year terms.

But at 1 GHz, or 1,000,000 kHz, it represents only one-thousandth of 1 percent:

$$\% \text{ of spectrum} = \frac{10 \text{ kHz}}{1{,}000{,}000 \text{ kHz}} \times 100$$
$$= 0.001\%$$

In practice, this means that there are many more 10-kHz channels at the higher frequencies than at the lower frequencies. In other words, there is more spectrum space for information signals at the higher frequencies.

The higher frequencies also permit wider-bandwidth signals to be used. A TV signal, e.g., occupies a bandwidth of 6 MHz. Such a signal cannot be used to modulate a carrier in the MF or HF ranges because it would use up all the available spectrum space. Television signals are transmitted in the VHF and UHF portions of the spectrum, where sufficient space is available.

Today, virtually the entire frequency spectrum between approximately 30 kHz and 100 GHz has been spoken for. Some open areas and portions of the spectrum are not heavily used, but for the most part, the spectrum is filled with communication activities of all kinds generated from all over the world. There is tremendous competition for these frequencies, not only between companies, individuals, and government services in individual carriers but also between the different nations of the world. The electromagnetic spectrum is one of our most precious natural resources. Some even feel that there is a spectrum shortage that inherently limits new wireless developments. Because of this, communication engineering is devoted to making the best use of that finite spectrum. A considerable amount of effort goes into developing communication techniques that will minimize the bandwidth required to transmit given information and thus conserve spectrum space. This provides more room for additional communication channels and gives other services or users an opportunity to take advantage of it. Many of the techniques discussed later in this book evolved in an effort to minimize transmission bandwidth.

Spectrum Management

Governments of the United States and other countries recognized early on that the frequency spectrum was a valuable and finite natural resource and so set up agencies to control spectrum use. In the United States, Congress passed the Communications Act of 1934. This Act and its various amendments established regulations for the use of spectrum space. It also established the FCC, a regulatory body whose function is to allocate spectrum space, issue licenses, set standards, and police the airwaves. The Telecommunications Act of 1996 has also greatly influenced the use of spectrum. The FCC controls all telephone and radio communications in this country and, in general, regulates all electromagnetic emissions. The FCC even auctions off available segments of spectrum to the highest bidder. Telecommunications companies seeking new spectrum for more cell phone coverage are the main buyers. The *National Telecommunications and Information Administration (NTIA)* performs a similar function for government and military services. Other countries have similar organizations.

National Telecommunications and Information Administration (NTIA)

The *International Telecommunications Union (ITU),* an agency of the United Nations that is headquartered in Geneva, Switzerland, comprises 189 member countries that meet at regular intervals to promote cooperation and negotiate national interests. Typical of these meetings are the World Administrative Radio Conferences, held approximately every two years. Various committees of the ITU set standards for various areas within the communication field. The ITU brings together the various countries to discuss how the frequency spectrum is to be divided up and shared. Because many of the signals generated in the spectrum do not carry for long distances, countries can use these frequencies simultaneously without interference. On the other hand, some ranges of the frequency spectrum can literally carry signals around the world. As a result, countries must negotiate with one another to coordinate usage of various portions of the high-frequency spectrum to prevent mutual interference.

International Telecommunications Union (ITU)

Regulations

The rules and regulations for communications in the United States are defined by the Code of Federal Regulations (CFR) 47, Parts 0 through 100. Anyone working in the communications field should be familiar with it. You can find it online via the FCC website or order it from the Government Printing Office (GPO).

Standards

Standards are specifications and guidelines that companies and individuals follow to ensure compatibility between transmitting and receiving equipment in communication systems. Although the concepts of communication are simple, there are obviously many ways to send and receive information. A variety of methods are used to modulate, multiplex, and otherwise process the information to be transmitted. If each system used different methods created at the whim of the designing engineer, the systems would be incompatible with one another and no communication could take place. In the real world, standards are set and followed so that when equipment is designed and built, compatibility is ensured. The term used to describe the ability of equipment from one manufacturer to work compatibly with that of another is *interoperability*.

Standards

Interoperability

Standards are detailed outlines of principles of operation, blueprints for construction, and methods of measurement that define communication equipment. Some of the specifications covered are modulation methods, frequency of operation, multiplexing methods, word length and bit formats, data transmission speeds, line coding methods, and cable and connector types. These standards are set and maintained by numerous nonprofit organizations around the world. Committees made up of individuals from industry and academia meet to establish and agree upon the standards, which are then published for others to use. Other committees review, revise, and enhance the standards over time, as needs change.

In working in the communication field, you will regularly encounter many different standards. For example, there are standards for long-distance telephone transmission, digital cell phones, local-area networks, and computer modems. Listed below are organizations that maintain standards for communication systems. For more details, go to the corresponding website.

American National Standards Institute (ANSI)—www.ansi.org
Electronic Industries Alliance (EIA)—www.eia.org
European Telecommunications Standards Institute (ETSI)—www.etsi.org
Institute of Electrical and Electronics Engineers (IEEE)—www.ieee.org
International Telecommunications Union (ITU)—www.itu.org
Internet Engineering Task Force (IETF)—www.ietf.org
Optical Internetworking Forum (IF)—www.oiforum.com
Telecommunications Institute of America (TIA)—www.tiaonline.org
Third Generation Partnership Project (3GPP)—www.3gpp.org

1-7 A Survey of Communication Applications

The applications of electronic techniques to communication are so common and pervasive that you are already familiar with most of them. You use the telephone, listen to the radio, and watch TV. You also use other forms of electronic communication, such as cellular telephones, ham radios, CB and Family radios, home wireless networks for Internet access, texting, electronic mail, and remote-control garage door openers. Fig. 1-17 lists all the various major applications of electronic communication.

Figure 1-17 Applications of electronic communication.

Simplex (One-Way)

1. *AM and FM radio broadcasting.* Stations broadcast music, news, weather reports, and programs for entertainment and information. It includes shortwave.
2. *Digital radio.* There is both satellite and terrestrial. Radio programming is transmitted in digital format.
3. *TV broadcasting.* Stations broadcast entertainment, informational, and educational programs by radio.
4. *Digital television (DTV).* Radio transmission of television programming is performed by digital methods, both satellite and terrestrial, e.g., high-definition television (HDTV) and Internet Protocol Television (IPTV). IPTV is also known as streaming video or over the top (OTT) TV.
5. *Cable television.* Movies, sports events, and other programs are distributed to subscribers by fiber-optic and coaxial cable.
6. *Facsimile.* Printed visual material is transmitted over telephone lines. A facsimile, or fax, machine scans a document and converts it to electronic signals that are sent over the telephone system for reproduction in printed form by another fax machine. Faxes can also be sent from a computer.
7. *Wireless remote control.* This category includes a device that controls any remote item by radio or infrared. Examples are missiles, satellites, drones, robots, toys, and other vehicles or remote plants or stations. A remote keyless entry device, garage door opener, and the remote control on your TV set are other examples.
8. *Internet of Things (IoT).* The monitoring or control of remote devices, appliances, and other items in a home, office, or other facility is usually accomplished by a combination of wireless and Internet connectivity.
9. *Navigation and direction-finding services.* Special stations transmit signals that can be picked up by receivers for the purpose of identifying exact location (latitude and longitude) or determining direction and/or distance from a station. Such systems employ both land-based and satellite stations. The services are used primarily by boats and ships or airplanes, although systems for cars and trucks are being developed. The Global Positioning System (GPS) which uses 24 satellites is the most widely used.
10. *Telemetry.* Measurements are transmitted over a long distance. Telemetry systems use sensors to determine physical conditions (temperature, pressure, flow rate, voltages, frequency, etc.) at a remote location. The sensors modulate a carrier signal that is sent by wire or radio to a remote receiver that stores and/or displays the data for analysis. Examples are satellites, rockets, pipelines, plants, and factories.
11. *Radio astronomy.* Radio signals, including infrared, are emitted by virtually all heavenly bodies such as stars and planets. With the use of large directional antennas and sensitive high-gain receivers, these signals may be picked up and used to plot star locations and study the universe. Radio astronomy is an alternative and supplement to traditional optical astronomy.
12. *Surveillance.* Surveillance means discreet monitoring or "spying." Electronic techniques are widely used by police forces, governments, the military, business and industry, and others to gather information for the purpose of gaining some competitive advantage. Techniques include phone taps, tiny wireless "bugs," clandestine listening stations, and reconnaissance airplanes and satellites.
13. *Music services.* Continuous background music is transmitted for doctors' offices, stores, elevators, and so on by local FM radio stations on special high-frequency subcarriers that cannot be picked up by conventional FM receivers. Internet music services like Apple Music, Spotify, Pandora, Google Play, Amazon Music, and many others are also available.
14. *Internet radio and video.* Music and video are delivered on a computer via the Internet.

Duplex (Two-Way)

15. *Telephones.* One-on-one verbal communication is transmitted over the vast worldwide telephone networks employing wire, fiber optics, radio, and satellites.
    a. Cordless telephones provide short-distance wireless communication for cord-free convenience.
    b. Cell phones provide worldwide wireless communications via handsets and base stations and the wired telephone system. In addition to voice communications, cell phones facilitate e-mail, Internet access, instant message service, video, and games.

(continues on next page)

Figure 1-17 (*continued*)

c. Internet telephones, known as voice over the Internet protocol (VoIP) phones, use high-speed broadband services (cable, DSL, wireless, fiber) over the Internet to provide digital voice communications.

d. Satellite phones use low-earth-orbit satellites to give worldwide voice service from any remote location on earth.

16. *Two-way radio.* Commercial, industrial, and government communication is transmitted between vehicles, handheld units, and base stations. Examples include police, fire, taxi, forestry service, trucking companies, aircraft, marine, military, and government.

17. *Radar.* This special form of communication makes use of reflected microwave signals for the purpose of detecting ships, planes, and missiles and for determining their range, direction, and speed. Most radar is used in military applications, but civilian aircraft and marine services also use it. Police use radar in speed detection and enforcement. Advanced driver assistance systems (ADAS) in many newer vehicles use radar for speed control, automated braking, and obstacle detection.

18. *Sonar.* In underwater communication, audible baseband signals use water as the transmission medium. Submarines and ships use sonar to detect the presence of enemy submarines. Passive sonar uses audio receivers to pick up water, propeller, and other noises. Active sonar is like an underwater radar with which reflections from a transmitted ultrasonic pulse are used to determine the direction, range, and speed of an underwater target.

19. *Amateur radio.* This is a hobby for individuals interested in radio communication. Individuals may become licensed "hams" to build and operate two-way radio equipment for personal communication with other hams.

20. *Citizens radio.* Citizens band (CB) radio is a special service that any individual may use for personal communication with others. Most CB radios are used in trucks and cars for exchanging information about traffic conditions, speed traps, and emergencies.

21. *Family Radio Service.* This is a two-way personal communication with handheld units over short distances (<2 mi).

22. *The Internet.* Worldwide interconnections via fiber-optic networks, telecommunications companies, cable TV companies, Internet service providers, and others provide World Wide Web (WWW) access to millions of websites and pages and electronic mail (e-mail).

23. *Wide-Area Networks (WANs).* Worldwide fiber-optic networks provide long-distance telephone and Internet services.

24. *Metropolitan-area networks (MANs).* Networks of computers transmit over a specific geographic area such as a college campus, company facility, or city. Normally they are implemented with fiber-optic cable, but may also be coaxial cable or wireless.

25. *Local-area networks (LANs).* Wired (or wireless) interconnections of personal computers (PCs), laptops, servers, or mainframe computers within an office or building for the purpose of e-mail, Internet access, or the sharing of mass storage, peripherals, data, and software.

1-8 Jobs and Careers in the Communication Industry

The electronics industry is roughly divided into four major specializations. The largest in terms of people employed and the dollar value of equipment purchased is the communications field, closely followed by the computer field. The industrial control and instrumentation fields are considerably smaller. Hundreds of thousands of employees are in the communication field, and billions of dollars' worth of equipment is purchased each year. The growth rate varies from year to year depending upon the economy, technological developments, and other factors. But, as in most areas in electronics, the communication field has grown steadily over the years, thanks to the Internet and the exploding cellular industry, creating a relatively constant opportunity for employment. If your interests lie in communication, you will be glad to know that there are many opportunities for long-term jobs and careers. The next section outlines the types of jobs available and the major kinds of employers.

Types of Jobs

The two major types of technical positions available in the communication field are engineer and technician.

Engineer

Engineers. *Engineers* design communication equipment and systems. They have bachelor's (B.S.E.E.), master's (M.S.E.E.), or doctoral (Ph.D.) degrees in electrical engineering, giving them a strong science and mathematics background combined with specialized education in electronic circuits and equipment. Engineers work from specifications and create new integrated circuits, equipment or systems, which are then manufactured.

Many engineers have a bachelor's degree in electronics technology from a technical college or university. Some typical degree titles are bachelor of technology (B.T.), bachelor of engineering technology (B.E.T.), and bachelor of science in engineering technology (B.S.E.T.).

Bachelor of technology programs are sometimes extensions of two-year associate degree programs. In the two additional years required for a bachelor of technology degree, the student takes more complex electronics courses along with additional science, math, and humanities courses. The main difference between the B.T. graduate and the engineering graduate is that the technologist usually takes courses that are more practical and hands-on than engineering courses. Holders of B.T. degrees can generally design electronic equipment and systems but do not typically have the depth of background in analytical mathematics or science that is required for complex design jobs. However, B.T. graduates are generally employed as engineers. Although many do design work, others are employed in engineering positions in manufacturing and field service rather than design.

Some engineers specialize in design; others work in manufacturing, testing, quality control, and management, among other areas. Engineers may also serve as field service personnel, installing and maintaining complex equipment and systems. If your interest lies in the design of communication equipment, then an engineering position may be for you.

Although a degree in electrical engineering is generally the minimum entrance requirement for engineers' jobs in most organizations, people with other educational backgrounds (e.g., physics and math) do become engineers. Technicians who obtain sufficient additional education and appropriate experience may go on to become engineers.

Technician

Technicians. *Technicians* have some kind of postsecondary education in electronics, from a vocational or technical school, a community college, or a technical institute. Many technicians are educated in military training programs. Most technicians have an average of two years of formal post–high school education and an associate degree. Common degrees are associate in arts (A.A.), associate in science (A.S.) or associate of science in engineering technology or electronic engineering technology (A.S.E.T. or A.S.E.E.T.), and associate in applied science (A.A.S.). The A.A.S. degrees tend to cover more occupational and job-related subjects; the A.A. and A.S. degrees are more general and are designed to provide a foundation for transfer to a bachelor's degree program. Technicians with an associate degree from a community college can usually transfer to a bachelor of technology program and complete the bachelor's degree in another two years. However, associate degree holders are usually not able to transfer to an engineering degree program but must literally start over if the engineering career path is chosen.

Technicians are most often employed in service jobs. The work typically involves equipment installation, troubleshooting and repair, testing and measuring, maintenance and adjustment, or operation. Technicians in such positions are sometimes called *field service technicians, field service engineers,* or *customer representatives.*

Technicians can also be involved in engineering. Engineers may use one or more technicians to assist in the design of equipment. They build and troubleshoot prototypes and in many cases actually participate in equipment design. A great deal of the work involves testing and measuring. In this capacity, the technician is known as an *engineering technician, lab technician, engineering assistant,* or *associate engineer.*

Technicians are also employed in manufacturing. They may be involved in the actual building and assembling of the equipment, but more typically are concerned with final testing and measurement of the finished products. Other positions involve quality control or repair of defective units. One type of high-paid technician in short supply is the tower climber who installs, maintains, and repairs antennas, cabling, and lighting.

Other Positions. There are many jobs in the communication industry other than those of engineer or technician. For example, there are many outstanding jobs in technical sales. Selling complex electronic communication equipment often requires a strong technical education and background. The work may involve determining customer needs and related equipment specifications, writing technical proposals, making sales presentations to customers, and attending shows and exhibits where equipment is sold. The pay potential in sales is generally much higher than that in the engineering or service positions.

Another position is that of technical writer. Technical writers generate the technical documentation for communication equipment and systems, producing installation and service manuals, maintenance procedures, and customer operations manuals. This important task requires considerable depth of education and experience.

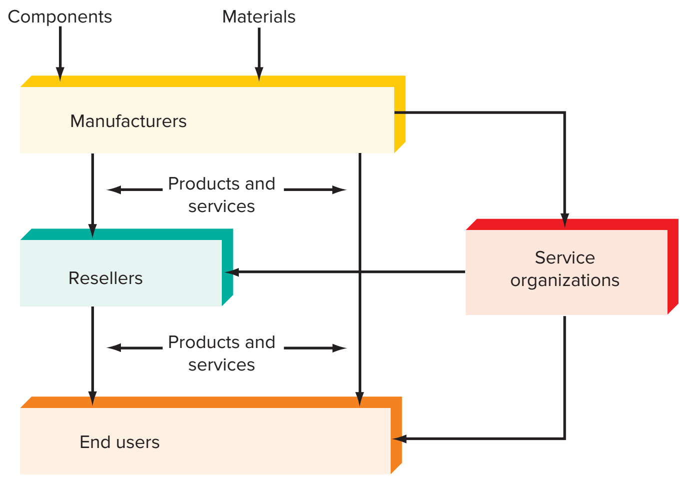
Finally, there is the position of trainer. Engineers and technicians are often used to train other engineers and technicians or customers. With the high degree of complexity that exists in communication equipment today, there is a major need for training. Many individuals find education and training positions to be very desirable and satisfying. The work typically involves developing curriculum and programs, generating the necessary training manuals and presentation materials, creating online training, and conducting classroom training sessions in-house or at a customer site.

Major Employers

The overall structure of the communication electronics industry is shown in Fig. 1-18. The four major segments of the industry are manufacturers, resellers, service organizations, and end users.

Manufacturers. It all begins, of course, with customer needs. Manufacturers translate customer needs into products, purchasing components and materials from other electronics companies to use in creating the products. Engineers design the products, and manufacturing produces them. Manufacturing also includes the companies that make the components like integrated circuits, transistors, capacitors, and other basic parts. There are jobs for engineers, technicians, salespeople, field service personnel, technical writers, and trainers.

Figure 1-18 Structure of the communication electronics industry.



Resellers. Manufacturers who do not sell products directly to end users sell the products to reselling organizations, which in turn sell them to the end user. For example, a manufacturer of marine communication equipment may not sell directly to a boat owner but instead to a regional distributor or marine electronics store or shop. This shop not only sells the equipment but also takes care of installation, service, and repairs. A cellular telephone or fax machine manufacturer also typically sells to a distributor or dealer who takes care of sales and service. Most of the jobs available in the reselling segment of the industry are in sales, service, and training.

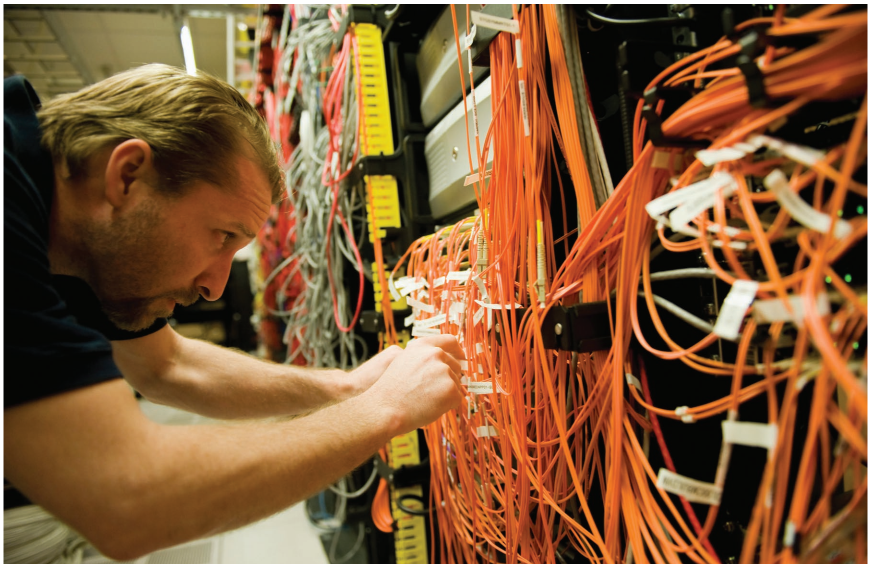
Service Organizations. These companies usually perform some kind of service, such as repair, installation, or maintenance. One example is an avionics company that does installation or service work on electronic equipment for private planes. Another is a systems integrator, a company that designs and assembles a piece of communication equipment or more often an entire system by using the products of other companies. Systems integrators put together systems to meet special needs and customize existing systems for particular jobs. Other types of service organization are the communications services providers like cellular network carriers (e.g., AT&T, Verizon), Internet providers, cable TV companies, and Internet web companies (e.g., Google, Yahoo, Amazon).

End Users. The end user is the ultimate customer—and a major employer. Today, almost every person and organization is an end user of communication equipment. The major categories of end users in the communication field are:

Telephone companies
Radio users—mobile, marine, aircraft, etc.
Radio and TV broadcast stations and cable TV companies
Business and industry users of satellites, networks, etc.
Transportation companies (airlines, shipping, railroads)
Government and military
Internet companies
Personal and hobby
Consumers

There are an enormous number of communication jobs with end users. Most are of the service type: installation, repair, maintenance, and operation of equipment.

Most communication technicians perform installation, maintenance, and troubleshooting.



Fuse/Getty Images

Licensing and Certification

A good way to validate your knowledge of communications electronics is to obtain a relevant license or certification.

For engineers, there is the professional engineering (PE) license or registration. Engineering specialties include one in Electrical and Computer: Electronics, Controls, and Communications. The license requires a bachelor's degree in engineering, several examinations, and a minimum of years of work experience in the field. Some jobs require an FCC license to ensure your competence in electronics and knowledge of the related rules and regulations. Otherwise, the main benefit of a license or certification is to prove your knowledge and skills to a prospective employer. Such a credential is an added bonus to any A.A.S., B.S.E.T., or B.S.E.E. degree you may get. For some employers, a license or certification may be acceptable in lieu of a degree.

Licensing and certification typically require taking an exam on communications topics. The FCC exam includes tests on rules and regulations as well as electronic fundamentals and communications circuits, equipment, and practices. Most certifications also have exams that cover the same electronic fundamentals and communications circuits, equipment, and practices. Some certifications require a specific amount of job experience.

Listed below are some of the licenses and certifications available for communications.

- FCC General Radiotelephone Operators License (GROL)—Two-part exam on rules and regulations and communications electronics. An optional exam on radar is available. No job experience is required.
- International Society of Certified of Electronic Technicians (ISCET)—This organization offers several basic certifications in electronic fundamentals as well as a journeyman certification in a variety of electronic specializations including communications. No job experience is required.
- Electronic Technicians Association International (ETA-I)—This organization offers a wide range of certifications on electronics with specializations in electronic fundamentals, communications, radar, fiber optics, and several others.
- The International Association for Radio, Telecommunications and Electromagnetics (iNARTE)—This organization offers multiple certifications in all phases of communications, including telecommunications, electromagnetic compatibility, and wireless devices at both the technician and engineering levels. These certifications require various education levels (degrees) and job experience as well as exams.
- Cisco—This company is a major supplier of networking and wireless equipment and offers certifications in many networking-related areas. An example is the Cisco Certified Network Associate (CCNA) Wireless. Cisco certification is widely recognized throughout industry.
- For engineers, there is the professional engineering (PE) license or registration. Engineering specialties include one in Electrical and Computer: Electronics, Controls, and Communications. The license requires a bachelor's degree in engineering, several examinations, and a minimum number of years of relevant work experience.
- The Institute of Electrical and Electronic Engineers (IEEE) offers the Wireless Communications Engineering Technology (WCET) certification. This credential is given after one passes a comprehensive and rigorous exam on wireless fundamentals with an emphasis on cellular technology.

There are other certifications for a variety of specialties that you will discover. Many of the certifying organizations, such as ETA-I, ISCET, and iNARTE, are also granted authority to give the FCC GROL exams. The GROL is probably the best overall credential to have for wireless jobs, and you may wish to complement it with a certification appropriate to the work you are seeking.

Certification and licensing is an excellent way to prove to yourself and any employer that you are knowledgeable and competent in communications. Give serious consideration to this opportunity.

CHAPTER REVIEW

Online Activity

1-1 Exploring the Regulatory Agencies

Objective: Become familiar with the FCC and NTIA.

Procedure:

1. Go to the FCC website at www.fcc.gov.
2. Explore the website.
3. Go to the NTIA website at www.nita.doc.gov.
4. Explore the website.
5. Use these websites and their search feature to answer the questions below.

Questions:

1. To whom does the FCC report within the government?
2. To whom does the NTIA report within the government?
3. What is the purpose and function of the FCC?
4. What is the purpose and function of the NTIA?
5. What is the FCC Code of Federal Regulations (CFR) Title 47?
6. On the NTIA website, locate the large colorful frequency spectrum chart. Examine it to see what services are identified and where they are located. Is the chart available as a wall chart for purchase?

1-2 Examining FCC Rules and Regulations

Objective: Investigate FCC CFR Title 47 and find answers to electronic communication rules and regulations.

Procedure:

1. Go to the FCC website www.fcc.gov.
2. Click on the rules and regulations link on the left.
3. Access FCC CFR Title 47.
4. Study the different parts.
5. Use this reference to answer the questions below.

Questions:

1. What is contained in Subpart A of Part 2 that may be useful?
2. In Part 2, what communications services can occupy the spectrum from 108 to 138 MHz?
3. What part pertains to commercial operators' licenses?
4. Describe briefly what is in Part 15.
5. Describe briefly what is in Part 18.
6. Which part covers TV broadcasting?
7. What part covers radar?
8. What parts cover Citizens' Band radio and the Family Radio Service? State the frequency bands of each.
9. Is cable TV regulated by the FCC? Which part if so?
10. List all of the modes and modulation methods allowed by amateur radio operation.
11. Which part covers RF interference and electromagnetic compatibility?
12. Which parts cover cell phones and wireless local-area networks?

1-3 Investigate Licensing and Certification

Objective: To learn more about the benefits of licensing and certification and how to obtain them.

Procedure:

1. Go to the FCC website www.fcc.gov.
2. On the FCC site, locate the information on commercial operators' licenses (GROL).
3. Go to each of the following websites and investigate these major licensing and certification sources:
   a. International Society of Certified Electronic Technicians—www.iset.org.
   b. Electronic Technician Association International—www.eta-i.org.
   c. The International Association for Radio, Telecommunications and Electromagnetics—www.narte.org.
   d. National Council of Examiners for Engineering and Surveying (NCEES).
4. Check out the certification options at Cisco and Microsoft.
5. Answer the questions below.

Questions:

1. What is the GROL and who is required to have one?
2. What is the procedure for getting a GROL?
3. List any available supplements to the GROL.
4. List the basic requirements for a communications-related certification from each of the organizations listed above. Which one appeals to you most?
5. Which certification requires education and job experience qualifications?

Questions

1. In what century did electronic communication begin?
2. Name the four main elements of a communication system, and draw a diagram that shows their relationship.
3. List five types of media used for communication, and state which three are the most commonly used.
4. Name the device used to convert an information signal to a signal compatible with the medium over which it is being transmitted.
5. What piece of equipment acquires a signal from a communication medium and recovers the original information signal?
6. What is a transceiver?
7. What are two ways in which a communication medium can affect a signal?
8. What is another name for *communication medium?*
9. What is the name given to undesirable interference that is added to a signal being transmitted?
10. Name three common sources of interference.
11. What is the name given to the original information or intelligence signals that are transmitted directly via a communication medium?
12. Name the two forms in which intelligence signals can exist.
13. What is the name given to one-way communication? Give three examples.
14. What is the name given to simultaneous two-way communication? Give three examples.
15. What is the term used to describe two-way communication in which each party takes turns transmitting? Give three examples.
16. What type of electronic signals are continuously varying voice and video signals?
17. What are on/off intelligence signals called?
18. How are voice and video signals transmitted digitally?
19. What terms are often used to refer to original voice, video, or data signals?
20. What technique must sometimes be used to make an information signal compatible with the medium over which it is being transmitted?
21. What is the process of recovering an original signal called?
22. What is a broadband signal?
23. Name the process used to transmit two or more baseband signals simultaneously over a common medium.
24. Name the technique used to extract multiple intelligence signals that have been transmitted simultaneously over a single communication channel.
25. What is the name given to signals that travel through free space for long distances?
26. What does a radio wave consist of?
27. Calculate the wavelength of signals with frequencies of 1.5 kHz, 18 MHz, and 22 GHz in miles, feet, and centimeters, respectively.
28. Why are audio signals not transmitted directly by electromagnetic waves?
29. What is the human hearing frequency range?
30. What is the approximate frequency range of the human voice?
31. Do radio transmissions occur in the VLF and LF ranges?
32. What is the frequency range of AM radio broadcast stations?
33. What is the name given to radio signals in the high-frequency range?
34. In what segment of the spectrum do TV channels 2 to 13, and FM broadcasting, appear?
35. List five major uses of the UHF band.
36. What are frequencies above 1 GHz called?
37. What are the frequencies just above the EHF range called?
38. What is a micrometer, and what is it used to measure?
39. Name the three segments of the optical frequency spectrum.
40. What is a common source of infrared signals?
41. What is the approximate spectrum range of infrared signals?
42. Define the term *angstrom* and explain how it is used.
43. What is the wavelength range of visible light?
44. Which two channels or media do light signals use for electronic communication?
45. Name two methods of transmitting visual data over a telephone network.
46. What is the name given to the signaling of individuals at remote locations by radio?
47. What term is used to describe the process of making measurements at a distance?
48. List four ways radio is used in the telephone system.
49. What principle is used in radar?
50. What is underwater radar called? Give two examples.
51. What is the name of a popular radio communication hobby?
52. What device enables computers to exchange digital data over the telephone network?
53. What do you call the systems of interconnections of PCs and other computers in offices or buildings?

54. What is a generic synonym for radio?
55. Name the three main types of technical positions available in the communication field.
56. What is the main job of an engineer?
57. What is the primary degree for an engineer?
58. What is the primary degree for a technician?
59. Name a type of technical degree in engineering other than engineer or technician.
60. Can the holder of an associate of technology degree transfer the credits to an engineering degree program?
61. What types of work does a technician ordinarily do?
62. List three other types of jobs in the field of electronic communication that do not involve engineering or technician's work.
63. What are the four main segments of the communication industry? Explain briefly the function of each.
64. Why are standards important?
65. What types of characteristics do communication standards define?

Problems

1. Calculate the frequency of signals with wavelengths of 40 m, 5 m, and 8 cm. ◆
2. In what frequency range does the common ac power line frequency fall?
3. What is the primary use of the SHF and EHF ranges? ◆

◆ *Answers to Selected Problems follow Chap. 23.*

Critical Thinking

1. Name three ways that a higher-frequency signal called the carrier can be varied to transmit the intelligence.
2. Name two common household remote-control units, and state the type of media and frequency ranges used for each.
3. How is radio astronomy used to locate and map stars and other heavenly bodies?
4. In what segment of the communication field are you interested in working, and why?
5. Assume that all the electromagnetic spectrum from ELF through microwaves was fully occupied. Explain some ways that communication capability could be added.
6. What is the speed of light in feet per microsecond? In inches per nanosecond? In meters per second?
7. Make a general statement comparing the speed of light with the speed of sound. Give an example of how the principles mentioned might be demonstrated.
8. List five real-life communication applications not specifically mentioned in this chapter.
9. "Invent" five new communication methods, wired or wireless, that you think would be practical.
10. Assume that you have a wireless application you would like to design, build, and sell as a commercial product. You have selected a target frequency in the UHF range. How would you decide what frequency to use, and how would you get permission to use it?
11. Make an exhaustive list of all the electronic communication products that you own, have access to at home or in the office, and/or use on a regular basis.
12. You have probably seen or heard of a simple communication system made of two paper cups and a long piece of string. How could such a simple system work?

chapter 2

Electronic Fundamentals for Communications

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, SAW, and BAW filters.
- State and explain the Fourier theory and give examples of how it is used.

2-1 Gain, Attenuation, and Decibels

Most electronic circuits in communication are used to process signals, i.e., to manipulate signals to produce a desired result. All signal processing circuits involve either gain or attenuation.

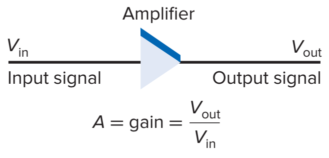
Gain

Gain

Gain means amplification. If a signal is applied to a circuit such as the amplifier shown in Fig. 2-1 and the output of the circuit has a greater amplitude than the input signal, the circuit has gain. Gain is simply the ratio of the output to the input. For input (V_{in}) and output (V_{out}) voltages, voltage gain A_V is expressed as follows:

$$A_V = \frac{\text{output}}{\text{input}} = \frac{V_{out}}{V_{in}}$$

Figure 2-1 An amplifier has gain.



The number obtained by dividing the output by the input shows how much larger the output is than the input. For example, if the input is 150 μV and the output is 75 mV, the gain is $A_V = (75 \times 10^{-3})/(150 \times 10^{-6}) = 500$.

The formula can be rearranged to obtain the input or the output, given the other two variables: $V_{out} = V_{in} \times A_V$ and $V_{in} = V_{out}/A_V$.

If the output is 0.6 V and the gain is 240, the input is $V_{in} = 0.6/240 = 2.5 \times 10^{-3} = 2.5$ mV.

Example 2-1

What is the voltage gain of an amplifier that produces an output of 750 mV for a 30-μV input?

$$A_V = \frac{V_{out}}{V_{in}} = \frac{750 \times 10^{-3}}{30 \times 10^{-6}} = 25{,}000$$

Since most amplifiers are also power amplifiers, the same procedure can be used to calculate power gain A_P:

$$A_P = \frac{P_{out}}{P_{in}}$$

where P_{in} is the power input and P_{out} is the power output.

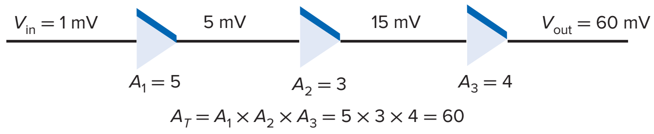
Example 2-2

The power output of an amplifier is 6 watts (W). The power gain is 80. What is the input power?

$$A_P = \frac{P_{out}}{P_{in}} \quad \text{therefore} \quad P_{in} = \frac{P_{out}}{A_P}$$

$$P_{in} = \frac{6}{80} = 0.075 \text{ W} = 75 \text{ mW}$$

Figure 2-2 Total gain of cascaded circuits is the product of individual stage gains.



When two or more stages of amplification or other forms of signal processing are cascaded, the overall gain of the combination is the product of the individual circuit gains. Fig. 2-2 shows three amplifiers connected one after the other so that the output of one is the input to the next. The voltage gains of the individual circuits are marked. To find the total gain of this circuit, simply multiply the individual circuit gains: $A_T = A_1 \times A_2 \times A_3 = 5 \times 3 \times 4 = 60$.

If an input signal of 1 mV is applied to the first amplifier, the output of the third amplifier will be 60 mV. The outputs of the individual amplifiers depend upon their individual gains. The output voltage from each amplifier is shown in Fig. 2-2.

Example 2-3

Three cascaded amplifiers have power gains of 5, 2, and 17. The input power is 40 mW. What is the output power?

$$A_P = A_1 \times A_2 \times A_3 = 5 \times 2 \times 17 = 170$$

$$A_P = \frac{P_{out}}{P_{in}} \qquad \text{therefore} \qquad P_{out} = A_P P_{in}$$

$$P_{out} = 170(40 \times 10^{-3}) = 6.8 \text{ W}$$

Example 2-4

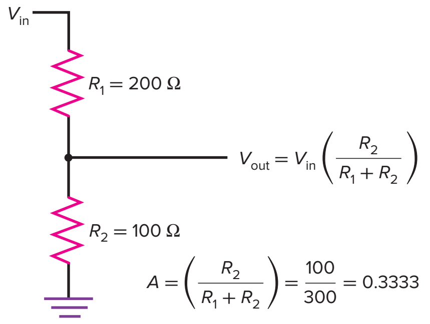
A two-stage amplifier has an input power of 25 μW and an output power of 1.5 mW. One stage has a gain of 3. What is the gain of the second stage?

$$A_P = \frac{P_{out}}{P_{in}} = \frac{1.5 \times 10^{-3}}{25 \times 10^{-6}} = 60$$

$$A_P = A_1 \times A_2$$

If $A_1 = 3$, then $60 = 3 \times A_2$ and $A_2 = 60/3 = 20$.

Figure 2-3 A voltage divider introduces attenuation.



Attenuation

Attenuation

Attenuation refers to a loss introduced by a circuit or component. Many electronic circuits, sometimes called stages, reduce the amplitude of a signal rather than increase it. If the output signal is lower in amplitude than the input, the circuit has loss, or attenuation. Like gain, attenuation is simply the ratio of the output to the input. The letter A is used to represent attenuation as well as gain:

$$\text{Attenuation } A = \frac{\text{output}}{\text{input}} = \frac{V_{out}}{V_{in}}$$

Circuits that introduce attenuation have a gain that is less than 1. In other words, the output is some fraction of the input.

An example of a simple circuit with attenuation is a voltage divider such as that shown in Fig. 2-3. The output voltage is the input voltage multiplied by a ratio based on the resistor values. With the resistor values shown, the gain or attenuation factor of the circuit is $A = R_2/(R_1 + R_2) = 100/(200 + 100) = 100/300 = 0.3333$. If a signal of 10 V is applied to the attenuator, the output is $V_{out} = V_{in}A = 10(0.3333) = 3.333$ V.

When several circuits with attenuation are cascaded, the total attenuation is, again, the product of the individual attenuations. The circuit in Fig. 2-4 is an example. The attenuation factors for each circuit are shown. The overall attenuation is

$$A_T = A_1 \times A_2 \times A_3$$

With the values shown in Fig. 2-4, the overall attenuation is

$$A_T = 0.2 \times 0.9 \times 0.06 = 0.0108$$

Given an input of 3 V, the output voltage is

$$V_{out} = A_T V_{in} = 0.0108(3) = 0.0324 = 32.4 \text{ mV}$$

Figure 2-4 Total attenuation is the product of individual attenuations of each cascaded circuit.

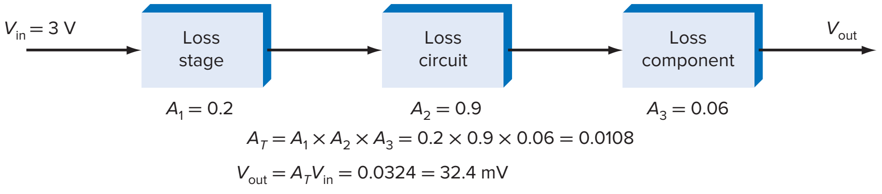
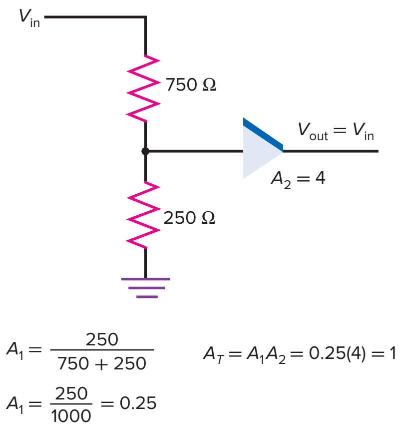


Figure 2-5 Gain exactly offsets the attenuation.



It is common in communication systems and equipment to cascade circuits and components that have gain and attenuation. For example, loss introduced by a circuit can be compensated for by adding a stage of amplification that offsets it. An example of this is shown in Fig. 2-5. Here the voltage divider introduces a 4-to-1 voltage loss, or an attenuation of 0.25. To offset this, it is followed with an amplifier whose gain is 4. The overall gain or attenuation of the circuit is simply the product of the attenuation and gain factors. In this case, the overall gain is $A_T = A_1 A_2 = 0.25(4) = 1$.

Another example is shown in Fig. 2-6, which shows two attenuation circuits and two amplifier circuits. The individual gain and attenuation factors are given. The overall circuit gain is $A_T = A_1 A_2 A_3 A_4 = (0.1)(10)(0.3)(15) = 4.5$.

For an input voltage of 1.5 V, the output voltage at each circuit is shown in Fig. 2-6.

In this example, the overall circuit has a net gain. But in some instances, the overall circuit or system may have a net loss. In any case, the overall gain or loss is obtained by multiplying the individual gain and attenuation factors.

Example 2-5

A voltage divider such as that shown in Fig. 2-5 has values of $R_1 = 10$ kΩ and $R_2 = 470$ Ω.

a. What is the attenuation?

$$A_1 = \frac{R_2}{R_1 + R_2} = \frac{470}{10{,}470} \qquad A_1 = 0.045$$

b. What amplifier gain would you need to offset the loss for an overall gain of 1?

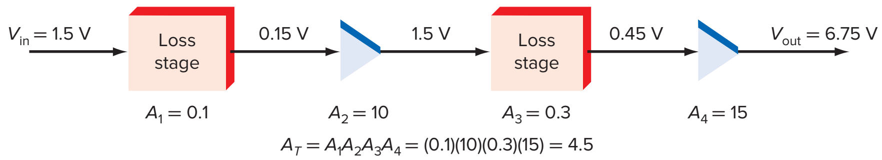
$$A_T = A_1 A_2$$

where A_1 is the attenuation and A_2 is the amplifier gain.

$$1 = 0.045 A_2 \qquad A_2 = \frac{1}{0.045} = 22.3$$

Note: To find the gain that will offset the loss for unity gain, just take the reciprocal of attenuation: $A_2 = 1/A_1$.

Figure 2-6 The total gain is the product of the individual stage gains and attenuations.



Example 2-6

An amplifier has a gain of 45,000, which is too much for the application. With an input voltage of 20 μV, what attenuation factor is needed to keep the output voltage from exceeding 100 mV? Let A_1 = amplifier gain = 45,000; A_2 = attenuation factor; A_T = total gain.

$$A_T = \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{100 \times 10^{-3}}{20 \times 10^{-6}} = 5000$$

$$A_T = A_1A_2 \qquad \text{therefore} \qquad A_2 = \frac{A_T}{A_1} = \frac{5000}{45{,}000} = 0.1111$$

Decibels

Decibel (dB)

The gain or loss of a circuit is usually expressed in *decibels (dB)*, a unit of measurement that was originally created as a way of expressing the hearing response of the human ear to various sound levels. A decibel is one-tenth of a bel.

When gain and attenuation are both converted to decibels, the overall gain or attenuation of an electronic circuit can be computed by simply adding the individual gains or attenuations, expressed in decibels.

It is common for electronic circuits and systems to have extremely high gains or attenuations, often in excess of 1 million. Converting these factors to decibels and using logarithms result in smaller gain and attenuation figures, which are easier to use.

Decibel Calculations. The formulas for computing the decibel gain or loss of a circuit are

$$\text{dB} = 20 \log \frac{V_{\text{out}}}{V_{\text{in}}} \qquad \textbf{(1)}$$

$$\text{dB} = 20 \log \frac{I_{\text{out}}}{I_{\text{in}}} \qquad \textbf{(2)}$$

$$\text{dB} = 10 \log \frac{P_{\text{out}}}{P_{\text{in}}} \qquad \textbf{(3)}$$

Formula (1) is used for expressing the voltage gain or attenuation of a circuit; formula (2), for current gain or attenuation. The ratio of the output voltage or current to the input voltage or current is determined as usual. The base-10 or common log of the input/output ratio is then obtained and multiplied by 20. The resulting number is the gain or attenuation in decibels.

Formula (3) is used to compute power gain or attenuation. The ratio of the power output to the power input is computed, and then its logarithm is multiplied by 10.

Example 2-7

a. An amplifier has an input of 3 mV and an output of 5 V. What is the gain in decibels?

$$\text{dB} = 20 \log \frac{5}{0.003} = 20 \log 1666.67 = 20(3.22) = 64.4$$

b. A filter has a power input of 50 mW and an output of 2 mW. What is the gain or attenuation?

$$\text{dB} = 10 \log \frac{2}{50} = 10 \log 0.04 = 10(-1.398) = -13.98$$

Note that when the circuit has gain, the decibel figure is positive. If the gain is less than 1, which means that there is an attenuation, the decibel figure is negative.

Now, to calculate the overall gain or attenuation of a circuit or system, you simply add the decibel gain and attenuation factors of each circuit. An example is shown in Fig. 2-7, where there are two gain stages and an attenuation block. The overall gain of this circuit is

$$A_T = A_1 + A_2 + A_3 = 15 - 20 + 35 = 30 \text{ dB}$$

Decibels are widely used in the expression of gain and attenuation in communication circuits. The table on the next page shows some common gain and attenuation factors and their corresponding decibel figures.

Ratios less than 1 give negative decibel values, indicating attenuation. Note that a 2:1 ratio represents a 3-dB power gain or a 6-dB voltage gain.

Antilogs. To calculate the input or output voltage or power, given the decibel gain or attenuation and the output or input, the *antilog* is used. The antilog is the number obtained when the base is raised to the logarithm, which is the exponent:

Antilog

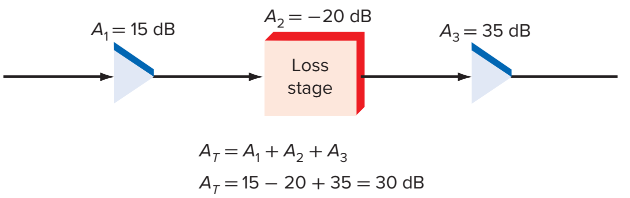
$$\text{dB} = 10 \log \frac{P_{out}}{P_{in}} \qquad \text{and} \qquad \frac{\text{dB}}{10} = \log \frac{P_{out}}{P_{in}}$$

and

$$\frac{P_{out}}{P_{in}} = \text{antilog} \frac{\text{dB}}{10} = \log^{-1} \frac{\text{dB}}{10}$$

The antilog is simply the base 10 raised to the dB/10 power.

Figure 2-7 Total gain or attenuation is the algebraic sum of the individual stage gains in decibels.



dB GAIN OR ATTENUATION		
Ratio (Power or Voltage)	**Power**	**Voltage**
0.000001	–60	–120
0.00001	–50	–100
0.0001	–40	–80
0.001	–30	–60
0.01	–20	–40
0.1	–10	–20
0.5	–3	–6
1	0	0
2	3	6
10	10	20
100	20	40
1000	30	60
10,000	40	80
100,000	50	100

Remember that the logarithm y of a number N is the power to which the base 10 must be raised to get the number.

$$N = 10^y \qquad \text{and} \qquad y = \log N$$

Since

$$\text{dB} = 10 \log \frac{P_{\text{out}}}{P_{\text{in}}}$$

$$\frac{\text{dB}}{10} = \log \frac{\text{P}_{\text{out}}}{P_{\text{in}}}$$

Therefore

$$\frac{P_{\text{out}}}{P_{\text{in}}} = 10^{\text{dB}/10} = \log^{-1} \frac{\text{dB}}{10}$$

The antilog is readily calculated on a scientific calculator. To find the antilog for a common or base-10 logarithm, you normally press the (Inv) or (2^{nd}) function key on the calculator and then the (log) key. Sometimes the log key is marked with 10^x, which is the antilog. The antilog with base e is found in a similar way, by using the (Inv) or (2^{nd}) function on the (ln) key. It is sometimes marked e^x, which is the same as the antilog.