1

Introduction

CHAPTER OUTLINE

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

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

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

1.1 ELEMENTS AND LIMITATIONS OF COMMUNICATION SYSTEMS

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

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

Information, Messages, and Signals

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

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

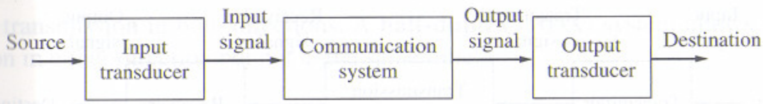

Figure 1.1–1 Communication system with input and output transducers.

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

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

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

What are the elements of a communication System?

Elements of a Communication System

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

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

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

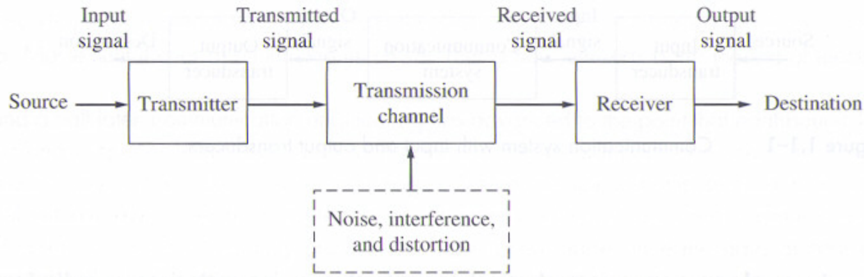

Figure 1.1–2 Elements of a communication system.

The **receiver** operates on the output signal from the channel in preparation for delivery to the transducer at the destination. Receiver operations include **amplification** to compensate for transmission loss, and **demodulation** and **decoding** to reverse the signal-processing performed at the transmitter. **Filtering** is another important function at the receiver, for reasons discussed next.

Various unwanted undesirable effects crop up in the course of signal transmission. Attenuation is undesirable since it reduces signal **strength** at the receiver. More serious, however, are distortion, interference, and noise, which appear as alterations of the signal **shape.** Although such contaminations may occur at any point, the standard convention is to blame them entirely on the channel, treating the transmitter and receiver as being ideal. Figure 1.1–2 reflects this convention.

Distortion is waveform perturbation caused by imperfect response of the system to the desired signal itself. Unlike noise and interference, distortion disappears when the signal is turned off. If the channel has a linear but distorting response, then distortion may be corrected, or at least reduced, with the help of special filters called **equalizers.**

Interference is contamination by extraneous signals from human sources—other transmitters, power lines and machinery, switching circuits, and so on. Interference occurs most often in radio systems whose receiving antennas usually intercept several signals at the same time. Radio-frequency interference (RFI) also appears in cable systems if the transmission wires or receiver circuitry pick up signals radiated from nearby sources. Appropriate filtering removes interference to the extent that the interfering signals occupy different frequency bands than the desired signal.

Noise refers to random and unpredictable electrical signals produced by natural processes both internal and external to the system. When such random variations are superimposed on an information-bearing signal, the message may be partially corrupted or totally obliterated. Filtering reduces noise contamination, but there inevitably remains some amount of noise that cannot be eliminated. This noise constitutes one of the fundamental system limitations.

Finally, it should be noted that Fig. 1.1–2 represents one-way or **simplex** (SX) transmission. Two-way communication, of course, requires a transmitter and receiver at each end. A **full-duplex** (FDX) system has a channel that allows simultaneous transmission in both directions. A **half-duplex** (HDX) system allows transmission in either direction but not at the same time.

Fundamental Limitations

An engineer faces two general kinds of constraints when designing a communication system. On the one hand are the **technological problems,** including such diverse considerations as hardware availability, economic factors, federal regulations, and so on. These are problems of feasibility that can be solved in theory, even though perfect solutions may not be practical. On the other hand are the **fundamental physical limitations,** the laws of nature as they pertain to the task in question. These limitations ultimately dictate what can or cannot be accomplished, irrespective of the technological problems. The fundamental limitations of information transmission by electrical means are **bandwidth** and **noise.**

The concept of bandwidth applies to both signals and systems as a measure of **speed.** When a signal changes rapidly with time, its frequency content, or **spectrum,** extends over a wide range and we say that the signal has a large bandwidth. Similarly, the ability of a system to follow signal variations is reflected in its usable frequency response or **transmission bandwidth.** Now all electrical systems contain energy-storage elements, and stored energy cannot be changed instantaneously. Consequently, every communication system has a finite bandwidth B that limits the rate of signal variations.

Communication under real-time conditions requires sufficient transmission bandwidth to accommodate the signal spectrum; otherwise, severe distortion will result. Thus, for example, a bandwidth of several megahertz is needed for a TV video signal, while the much slower variations of a voice signal fit into $B \approx 3$ kHz. For a digital signal with r symbols per second, the bandwidth must be $B \geq r/2$. In the case of information transmission without a real-time constraint, the available bandwidth determines the maximum signal speed. The time required to transmit a given amount of information is therefore inversely proportional to B.

Noise imposes a second limitation on information transmission. Why is noise unavoidable? Rather curiously, the answer comes from kinetic theory. At any temperature above absolute zero, thermal energy causes microscopic particles to exhibit random motion. The random motion of charged particles such as electrons generates random currents or voltages called **thermal noise.** There are also other types of noise, but thermal noise appears in every communication system.

We measure noise relative to an information signal in terms of the **signal-to-noise power ratio** S/N. Thermal noise power is ordinarily quite small, and S/N can be so large that the noise goes unnoticed. At lower values of S/N, however, noise degrades fidelity in analog communication and produces errors in digital communication. These problems become most severe on long-distance links when the transmission loss reduces the received signal power down to the noise level. Amplification at the receiver is then to no avail, because the noise will be amplified along with the signal.

Taking both limitations into account, Shannon (1948)† stated that the rate of information transmission cannot exceed the **channel capacity.**

$$C = B \log (1 + S/N)$$

This relationship, known as the **Hartley-Shannon law,** sets an upper limit on the performance of a communication system with a given bandwidth and signal-to-noise ratio.

1.2 MODULATION AND CODING

Modulation and coding are operations performed at the transmitter to achieve efficient and reliable information transmission. So important are these operations that they deserve further consideration here. Subsequently, we'll devote several chapters to modulating and coding techniques.

Modulation Methods

Modulation involves two waveforms: a **modulating signal** that represents the message, and a **carrier wave** that suits the particular application. A modulator systematically alters the carrier wave in correspondence with the variations of the modulating signal. The resulting modulated wave thereby "carries" the message information. We generally require that modulation be a *reversible* operation, so the message can be retrieved by the complementary process of **demodulation.**

Figure 1.2–1 depicts a portion of an analog modulating signal (part *a*) and the corresponding modulated waveform obtained by varying the amplitude of a **sinusoidal** carrier wave (part *b*). This is the familiar amplitude modulation (AM) used for radio broadcasting and other applications. A message may also be impressed on a sinusoidal carrier by frequency modulation (FM) or phase modulation (PM). All methods for sinusoidal carrier modulation are grouped under the heading of **continuous-wave** (CW) modulation.

Incidentally, you act as a CW modulator whenever you speak. The transmission of voice through air is accomplished by generating carrier tones in the vocal cords and modulating these tones with muscular actions of the oral cavity. Thus, what the ear hears as speech is a modulated acoustic wave similar to an AM signal.

Most long-distance transmission systems employ CW modulation with a carrier frequency much higher than the highest frequency component of the modulating signal. The spectrum of the modulated signal then consists of a band of frequency components clustered around the carrier frequency. Under these conditions, we say that CW modulation produces **frequency translation.** In AM broadcasting, for example, the message spectrum typically runs from 100 Hz to 5 kHz; if the carrier frequency is 600 kHz, then the spectrum of the modulated carrier covers 595–605 kHz.

†References are indicated in this fashion throughout the text. Complete citations are listed alphabetically by author in the References at the end of the book.

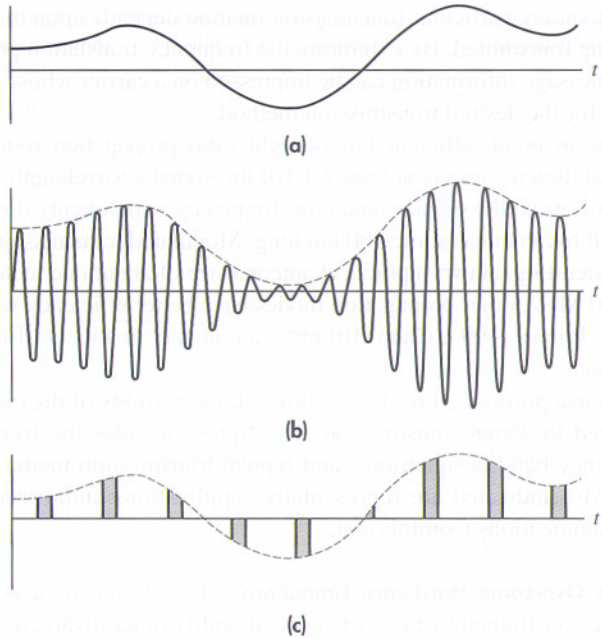

Figure 1.2–1 (*a*) Modulating signal; (*b*) sinusoidal carrier with amplitude modulation; (*c*) pulse-train carrier with amplitude modulation.

Another modulation method, called **pulse modulation,** has a periodic train of short pulses as the carrier wave. Figure 1.2–1*c* shows a waveform with pulse amplitude modulation (PAM). Notice that this PAM wave consists of short samples extracted from the analog signal at the top of the figure. **Sampling** is an important signal-processing technique and, subject to certain conditions, it's possible to **reconstruct** an entire waveform from periodic samples.

But pulse modulation by itself does not produce the frequency translation needed for efficient signal transmission. Some transmitters therefore combine pulse and CW modulation. Other modulation techniques, described shortly, combine pulse modulation with **coding.**

Modulation Benefits and Applications

The primary purpose of modulation in a communication system is to generate a modulated signal suited to the characteristics of the transmission channel. Actually, there are several practical benefits and applications of modulation briefly discussed below.

Modulation for Efficient Transmission Signal transmission over appreciable distance always involves a traveling electromagnetic wave, with or without a guiding medium.

The efficiency of any particular transmission method depends upon the frequency of the signal being transmitted. By exploiting the frequency-translation property of CW modulation, message information can be impressed on a carrier whose frequency has been selected for the desired transmission method.

As a case in point, efficient line-of-sight ratio propagation requires antennas whose physical dimensions are at least 1/10 of the signal's wavelength. Unmodulated transmission of an audio signal containing frequency components down to 100 Hz would thus call for antennas some 300 km long. Modulated transmission at 100 MHz, as in FM broadcasting, allows a practical antenna size of about one meter. At frequencies below 100 MHz, other propagation modes have better efficiency with reasonable antenna sizes. Tomasi (1994, Chap. 10) gives a compact treatment of radio propagation and antennas.

For reference purposes, Fig. 1.2–2 shows those portions of the electromagnetic spectrum suited to signal transmission. The figure includes the free-space wavelength, frequency-band designations, and typical transmission media and propagation modes. Also indicated are representative applications authorized by the U.S. Federal Communications Commission.

Modulation to Overcome Hardware Limitations The design of a communication system may be constrained by the cost and availability of hardware, hardware whose performance often depends upon the frequencies involved. Modulation permits the designer to place a signal in some frequency range that avoids hardware limitations. A particular concern along this line is the question of **fractional bandwidth**, defined as absolute bandwidth divided by the center frequency. Hardware costs and complications are minimized if the fractional bandwidth is kept within 1–10 percent. Fractional-bandwidth considerations account for the fact that modulation units are found in receivers as well as in transmitters.

It likewise follows that signals with large bandwidth should be modulated on high-frequency carriers. Since information rate is proportional to bandwidth, according to the Hartley-Shannon law, we conclude that a high information rate requires a high carrier frequency. For instance, a 5 GHz microwave system can accommodate 10,000 times as much information in a given time interval as a 500 kHz radio channel. Going even higher in the electromagnetic spectrum, one optical laser beam has a bandwidth potential equivalent to 10 million TV channels.

Modulation to Reduce Noise and Interference A brute-force method for combating noise and interference is to increase the signal power until it overwhelms the contaminations. But increasing power is costly and may damage equipment. (One of the early transatlantic cables was apparently destroyed by high-voltage rupture in an effort to obtain a usable received signal.) Fortunately, FM and certain other types of modulation have the valuable property of suppressing both noise and interference.

This property is called **wideband noise reduction** because it requires the transmission bandwidth to be much greater than the bandwidth of the modulating signal. Wideband modulation thus allows the designer to exchange increased bandwidth for

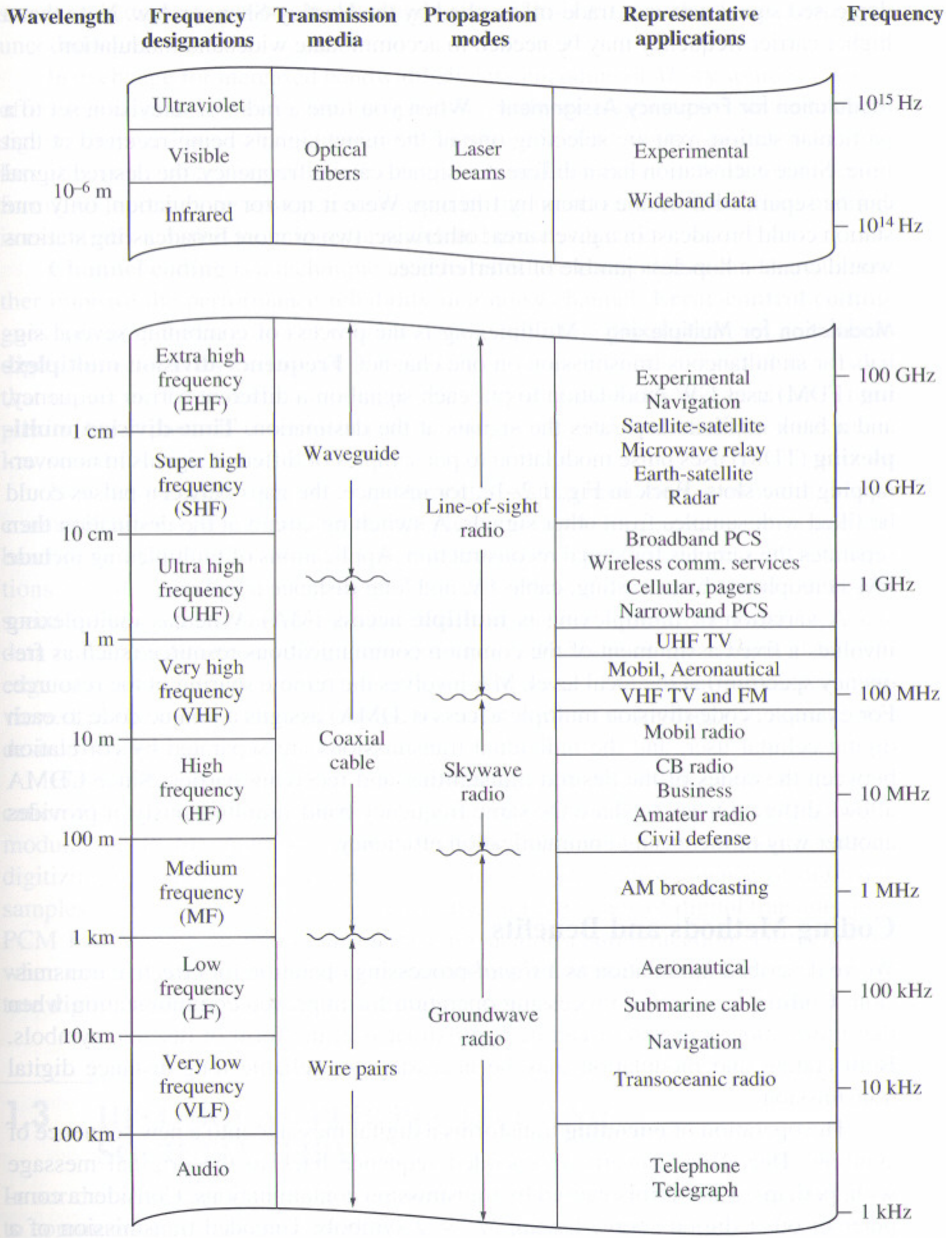

Figure 1.2–2 The electromagnetic spectrum.

decreased signal power, a trade-off implied by the Hartley-Shannon law. Note that a higher carrier frequency may be needed to accommodate wideband modulation.

Modulation for Frequency Assignment When you tune a radio or television set to a particular station, you are selecting one of the many signals being received at that time. Since each station has a different assigned carrier frequency, the desired signal can be separated from the others by filtering. Were it not for modulation, only one station could broadcast in a given area; otherwise, two or more broadcasting stations would create a hopeless jumble of interference.

Modulation for Multiplexing Multiplexing is the process of combining several signals for simultaneous transmission on one channel. **Frequency-division multiplexing** (FDM) uses CW modulation to put each signal on a different carrier frequency, and a bank of filters separates the signals at the destination. **Time-division multiplexing** (TDM) uses pulse modulation to put samples of different signals in nonoverlapping time slots. Back in Fig. 1.2–1*c*, for instance, the gaps between pulses could be filled with samples from other signals. A switching circuit at the destination then separates the samples for signal reconstruction. Applications of multiplexing include FM stereophonic broadcasting, cable TV, and long-distance telephone.

A variation of multiplexing is **multiple access** (MA). Whereas multiplexing involves a fixed assignment of the common communications resource (such as frequency spectrum) at the local level, MA involves the remote sharing of the resource. For example, code-division multiple access (CDMA) assigns a unique code to each digital cellular user, and the individual transmissions are separated by correlation between the codes of the desired transmitting and receiving parties. Since CDMA allows different users to share the same frequency band simultaneously, it provides another way of increasing communication efficiency.

Coding Methods and Benefits

We've described modulation as a *signal*-processing operation for effective transmission. **Coding** is a *symbol*-processing operation for improved communication when the information is digital or can be approximated in the form of discrete symbols. Both coding and modulation may be necessary for reliable long-distance digital transmission.

The operation of **encoding** transforms a digital message into a new sequence of symbols. **Decoding** converts an encoded sequence back to the original message with, perhaps, a few errors caused by transmission contaminations. Consider a computer or other digital source having $M \gg 2$ symbols. Uncoded transmission of a message from this source would require M different waveforms, one for each symbol. Alternatively, each symbol could be represented by a **binary codeword** consisting of K binary digits. Since there are 2^K possible codewords made up of K binary digits, we need $K \geq \log_2 M$ digits per codeword to encode M source symbols. If the source produces r symbols per second, the binary code will have Kr digits per second and the transmission bandwidth requirement is K times the bandwidth of an uncoded signal.

In exchange for increased bandwidth, binary encoding of M-ary source symbols offers two advantages. First, less complicated hardware is needed to handle a binary signal composed of just two different waveforms. Second, contaminating noise has less effect on a binary signal than it does on a signal composed of M different waveforms, so there will be fewer errors caused by the noise. Hence, this coding method is essentially a digital technique for wideband noise reduction.

Channel coding is a technique used to introduce controlled redundancy to further improve the performance reliability in a noisy channel. **Error-control coding** goes further in the direction of wideband noise reduction. By appending extra **check digits** to each binary codeword, we can detect, or even correct, most of the errors that do occur. Error-control coding increases both bandwidth and hardware complexity, but it pays off in terms of nearly error-free digital communication despite a low signal-to-noise ratio.

Now, let's examine the other fundamental system limitation: bandwidth. Many communication systems rely on the telephone network for transmission. Since the bandwidth of the transmission system is limited by decades-old design specifications, in order to increase the data rate, the signal bandwidth must be reduced. High-speed modems (data *mo*dulator/*dem*odulators) are one application requiring such data reduction. **Source-coding** techniques take advantage of the statistical knowledge of the source signal to enable efficient encoding. Thus, source coding can be viewed as the dual of channel coding in that it *reduces* redundancy to achieve the desired efficiency.

Finally, the benefits of digital coding can be incorporated in *analog* communication with the help of an analog-to-digital conversion method such as pulse-code-modulation (PCM). A PCM signal is generated by sampling the analog message, digitizing (quantizing) the sample values, and encoding the sequence of digitized samples. In view of the reliability, versatility, and efficiency of digital transmission, PCM has become an important method for analog communication. Furthermore, when coupled with high-speed microprocessors, PCM makes it possible to substitute **digital signal processing** for analog operations.

1.3 HISTORICAL PERSPECTIVE AND SOCIETAL IMPACT

In our daily lives we often take for granted the powerful technologies that allow us to communicate, nearly instantaneously, with people around the world. Many of us now have multiple phone numbers to handle our home and business telephones, facsimile machines, modems, and wireless personal communication devices. We send text, video, and music through electronic mail, and we "surf the Net" for information and entertainment. We have more television stations than we know what to do with, and "smart electronics" allow our household appliances to keep us posted on their health. It is hard to believe that most of these technologies were developed in the past 50 years.

Historical Perspective

The organization of this text is dictated by pedagogical considerations and does not necessarily reflect the evolution of communication systems. To provide at least some historical perspective, a chronological outline of electrical communication is presented in Table 1.3–1. The table lists key inventions, scientific discoveries, important papers, and the names associated with these events.

Table 1.3–1 A chronology of electrical communication

Year	Event
1800–1837	*Preliminary developments* Volta discovers the primary battery; the mathematical treatises by Fourier, Cauchy, and Laplace; experiments on electricity and magnetism by Oersted, Ampere, Faraday, and Henry; Ohm's law (1826); early telegraph systems by Gauss, Weber, and Wheatstone.
1838–1866	*Telegraphy* Morse perfects his system; Steinheil finds that the earth can be used for a current path; commercial service initiated (1844); multiplexing techniques devised; William Thomson (Lord Kelvin) calculates the pulse response of a telegraph line (1855); transatlantic cables installed by Cyrus Field and associates.
1845	Kirchhoff's circuit laws enunciated.
1864	Maxwell's equations predict electromagnetic radiation.
1876–1899	*Telephony* Acoustic transducer perfected by Alexander Graham Bell, after earlier attempts by Reis; first telephone exchange, in New Haven, with eight lines (1878); Edison's carbon-button transducer; cable circuits introduced; Strowger devises automatic step-by-step switching (1887); the theory of cable loading by Heaviside, Pupin, and Campbell.
1887–1907	*Wireless telegraphy* Heinrich Hertz verifies Maxell's theory; demonstrations by Marconi and Popov; Marconi patents a complete wireless telegraph system (1897); the theory of tuning circuits developed by Sir Oliver Lodge; commercial service begins, including ship-to-shore and transatlantic systems.
1892–1899	Oliver Heaviside's publications on operational calculus, circuits, and electromagnetics.
1904–1920	*Communication electronics* Lee De Forest invents the Audion (triode) based on Fleming's diode; basic filter types devised by G. A. Campbell and others; experiments with AM radio broadcasting; transcontinental telephone line with electronic repeaters completed by the Bell System (1915); multiplexed carrier telephony introduced; E. H. Armstrong perfects the superheterodyne radio receiver (1918); first commercial broadcasting station, KDKA, Pittsburgh.
1920–1928	*Transmission theory* Landmark papers on the theory of signal transmission and noise by J. R. Carson, H. Nyquist, J. B. Johnson, and R. V. L. Hartley.
1923–1938	*Television* Mechanical image-formation system demonstrated by Baird and Jenkins; theoretical analysis of bandwidth requirements; Farnsworth and Zworykin propose electronic systems; vacuum cathode-ray tubes perfected by DuMont and others; field tests and experimental broadcasting begin.
1927	Federal Communications Commission established.

Table 1.3–1 A chronology of electrical communication *(continued)*

Year	Event
1931	Teletypewriter service initiated.
1934	H. S. Black develops the negative-feedback amplifier.
1936	Armstrong's paper states the case for FM radio.
1937	Alec Reeves conceives pulse-code modulation.
1938–1945	*World War II* Radar and microwave systems developed; FM used extensively for military communications; improved electronics, hardware, and theory in all areas.
1944–1947	*Statistical communication theory* Rice develops a mathematical representation of noise; Weiner, Kolmogoroff, and Kotel'nikov apply statistical methods to signal detection.
1948–1950	*Information theory and coding* C. E. Shannon publishes the founding papers of information theory; Hamming and Golay devise error-correcting codes.
1948–1951	Transistor devices invented by Bardeen, Brattain, and Shockley.
1950	Time-division multiplexing applied to telephony.
1953	Color TV standards established in the United States.
1955	J. R. Pierce proposes satellite communication systems.
1956	First transoceanic telephone cable (36 voice channels).
1958	Long-distance data transmission system developed for military purposes.
1960	Maiman demonstrates the first laser.
1961	Integrated circuits go into commercial production; stereo FM broadcasts begin in the U.S.
1962	Satellite communication begins with Telstar I.
1962–1966	*High-speed digital communication* Data transmission service offered commercially; Touch-Tone telephone service introduced; wideband channels designed for digital signaling; pulse-code modulation proves feasible for voice and TV transmission; major breakthroughs in theory and implementation of digital transmission, including error-control coding methods by Viterbi and others, and the development of adaptive equalization by Lucky and coworkers.
1963	Solid-state microwave oscillators perfected by Gunn.
1964	Fully electronic telephone switching system (No. 1 ESS) goes into service.
1965	Mariner IV transmits pictures from Mars to Earth.
1966–1975	*Wideband communication systems* Cable TV systems; commercial satellite relay service becomes available; optical links using lasers and fiber optics.
1969	ARPANET created (precursor to Internet)
1971	Intel develops first single-chip microprocessor
1972	Motorola develops cellular telephone; first live TV broadcast across Atlantic ocean via satellite
1980	Compact disc developed by Philips and Sony
1981	FCC adopts rules creating commercial cellular telephone service; IBM PC is introduced (hard drives introduced two years later).
1982	AT&T agrees to divest 22 local service telephone companies; seven regional Bell system operating companies formed.

(continued)

Table 1.3–1 A chronology of electrical communication *(continued)*

Year	Event
1985	Fax machines widely available in offices.
1988–1989	Installation of trans-Pacific and trans-Atlantic optical cables for light-wave communications.
1990–2000	*Digital communication systems* Digital signal processing and communication systems in household appliances; digitally tuned receivers; direct-sequence spread spectrum systems; integrated services digital networks (ISDNs); high-definition digital television (HDTV) standards developed; digital pagers; handheld computers; digital cellular.
1994–1995	FCC raises $7.7 billion in auction of frequency spectrum for broadband personal communication devices
1998	Digital television service launched in U.S.

Several of the terms in the chronology have been mentioned already, while others will be described in later chapters when we discuss the impact and interrelationships of particular events. You may therefore find it helpful to refer back to this table from time to time.

Societal Impact

Our planet feels a little smaller in large part due to advances in communication. Multiple sources constantly provide us with the latest news of world events, and savvy leaders make great use of this to shape opinions in their own countries and abroad. Communication technologies change how we do business, and once-powerful companies, unable to adapt, are disappearing. Cable and telecommunications industries split and merge at a dizzying pace, and the boundaries between their technologies and those of computer hardware and software companies are becoming blurred. We are able (and expected) to be connected 24 hours a day, seven days a week, which means that we may continue to receive work-related E-mail, phone calls, and faxes, even while on vacation at the beach or in an area once considered remote.

These technology changes spur new public policy debates, chiefly over issues of personal privacy, information security, and copyright protection. New businesses taking advantage of the latest technologies appear at a faster rate than the laws and policies required to govern these issues. With so many computer systems connected to the Internet, malicious individuals can quickly spread computer viruses around the globe. Cellular phones are so pervasive that theaters and restaurants have created policies governing their use. For example, it was not so long ago that before a show an announcement would be made that smoking was not allowed in the auditorium. Now some theaters request that members of the audience turn off cell phones and beepers. State laws, municipal franchises, and public utility commissions must change to accommodate the telecommunications revolution. And the workforce must stay current with advances in technology via continuing education.

With new technologies developing at an exponential rate, we cannot say for certain what the world will be like in another 50 years. Nevertheless, a firm grounding in the basics of communication systems, creativity, commitment to ethical application of technology, and strong problem solving skills will equip the communications engineer with the capability to shape that future.

1.4 PROSPECTUS

This text provides a comprehensive introduction to analog and digital communications. A review of relevant background material precedes each major topic that is presented. Each chapter begins with an overview of the subjects covered and a listing of learning objectives. Throughout the text we rely heavily on mathematical models to cut to the heart of complex problems. Keep in mind, however, that such models must be combined with physical reasoning and engineering judgment.

Chapters 2 and 3 deal with deterministic signals, emphasizing time-domain and frequency-domain analysis of signal transmission, distortion, and filtering. Chapters 4 and 5 discuss the *how* and the *why* of various types of CW modulation. Particular topics include modulated waveforms, transmitters, and transmission bandwidth. Sampling and pulse modulation are introduced in Chapter 6, followed by analog modulation systems, including receivers, multiplexing systems, and television systems in Chapter 7. Before a discussion of the impact of noise on CW modulation systems in Chapter 10, Chapters 8 and 9 apply probability theory and statistics to the representation of random signals and noise.

Digital communication starts in Chapter 11 with baseband (unmodulated) transmission, so we can focus on the important concepts of digital signals and spectra, noise and errors, and synchronization. Chapter 12 then draws upon previous chapters for the study of coded pulse modulation, including PCM and digital multiplexing systems. A short survey of error-control coding is presented in Chapter 13. Chapter 14 analyzes digital transmission systems with CW modulation, culminating in a performance comparison of various methods. An expanded presentation of spread spectrum systems is presented in this edition in Chapter 15. Finally, an introduction to information theory in Chapter 16 provides a retrospective view of digital communication and returns us to the Hartley-Shannon law.

Each chapter contains several exercises designed to clarify and reinforce the concepts and analytic techniques. You should work these exercises as you come to them, checking your results with the answers provided at the back of the book. Also at the back you'll find tables containing handy summaries of important text material and mathematical relations pertinent to the exercises and to the problems at the end of each chapter.

Although we mostly describe communication systems in terms of "black boxes" with specified properties, we'll occasionally lift the lid to look at electronic circuits that carry out particular operations. Such digressions are intended to be illustrative rather than a comprehensive treatment of communication electronics.

Besides discussions of electronics, certain optional or more advanced topics are interspersed in various chapters and identified by the symbol ★. These topics may be omitted without loss of continuity. Other optional material of a supplementary nature is contained in the appendix.

Two types of references have been included. Books and papers cited within chapters provide further information about specific items. Additional references are collected in a supplementary reading list that serves as an annotated bibliography for those who wish to pursue subjects in greater depth.

Finally, as you have probably observed, communications engineers use many abbreviations and acronyms. Most abbreviations defined in this book are also listed in the index, to which you can refer if you happen to forget a definition.