DATA COMMUNICATIONS

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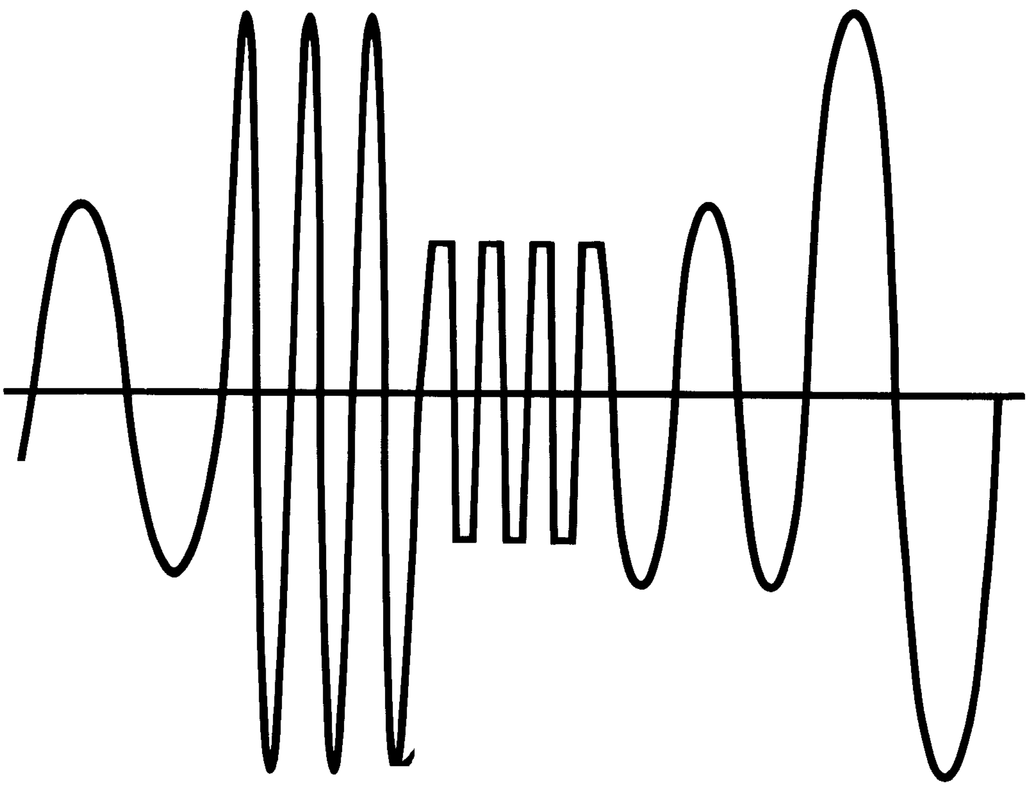

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Preface

Data Communications covers the fast-moving dynamic field of communications. This area of study involves the sending and receiving of information in digital format over distances ranging from a few inches to thousands of miles. The text is intended for courses in which equipment and systems are emphasized. These courses are generally offered as part of an overall program in electronics technology. Prerequisites are a basic understanding of analog and digital circuits, signals, and concepts together with the mathematics necessary to understand these principles. However, a brief review of these basic areas is provided as a refresher and to put these topics in the proper context and setting for data communication.

The book covers both the essential and the fundamental topics in data communications and, at the same time, many of the newer and important areas of growing technical need. These include networks, error detection and correction, data security, integrated all-digital networks, fiber optics, and the test equipment and methods that are unique to data communications.

Each chapter is divided into sections, which are followed by questions and problems designed to reinforce the ideas presented in the section. Each chapter has a summary, which brings together all the key points of the chapter, and end-of-chapter questions and problems. Answers to all odd-numbered problems are in the back of the book. Appendixes contain critical information that the student will have to use on a frequent basis in data communications work. A glossary of terms in the book is also provided.

This textbook is divided into two parts. Chapters 1 through 6 provide the concepts and theory of communications, along with the constraints and problems that any communications system must handle. The second part, Chapters 7 through 13, covers the application of this theory to real-world situations and shows how the ideas of the first part are put into actual practice in modern systems.

Chapter 1 explains what a communications system is, the many ways that a system can be used, and the different appearances of a communications system. It provides the framework for all subsequent chapters. Chapter 2 discusses the technical characteristics of a communications channel and signal, such as bandwidth, frequency, and channel capacity. These define the ultimate performance and limitations of the system.

Modulation is a key aspect of a communications system and is the subject of Chapter 3. Modulation converts the original signal into one more compatible with the channel. The overall system may use several different types of modulation, depending on desired performance, cost, and other technical considerations.

In Chapter 4, analog communications systems are studied. Electronic communication has traditionally been performed with analog systems, since the original voice or picture signal is analog in nature. Multiplexing allows several analog signals to share the same channel. The weaknesses and limitations of analog systems lead into digital communications, discussed in Chapter 5, which inherently can provide superior performance. The digital system is designed to handle only a specific set of communications signal values, and so the overall electronics of the system can be optimized for these values. Digital signals are also more directly compatible with computers and can be used easily for communication of computer data. Even analog signals can be put into digital format, to take advantage of the superior performance that a digital system can provide.

The physical path of the communications signal is the subject of Chapter 6. The choice between copper wire, coaxial cable, fiber-optic cable, and radio links is made on the basis of performance, flexibility, and cost. The technical features of each media type are studied, along with the weaknesses of each type, including susceptibility to noise and distortion.

In Chapter 7, the supporting theory of communications systems and data communications is applied to typical, practical applications. A complete, functioning system requires data encoding, protocols, data rates (baud), handshaking, and many other important elements. The various ways—both circuitry and software—of implementing these are discussed.

Chapter 8 is dedicated to a single communications interface, called *RS-232*. This is the most common interface in use. By studying RS-232 in detail, students will understand clearly many of the technical issues and considerations of other interfaces. The chapter also shows the problems and performance limitations that can occur with RS-232 and ways to overcome them in practical installations. Standard integrated circuits (ICs) for RS-232 are shown.

Other interfaces are studied in Chapter 9. Some of these extend the capabilities of RS-232, while others are used where RS-232 is not the correct technical choice. These interfaces include RS-422, RS-423, and multidrop RS-485 standards. The current loop is often used in electrically harsh environments, but has some technical peculiarities that are examined in detail.

The telephone system is the basis for many data communications systems. It is available almost everywhere and can provide effective communications under many circumstances. In Chapter 10 the basic operation of the telephone (dialing, switching, tones, and pulses) is studied, along with the role of the telephone central office and system. This role is expanded to show how and why modems are used to interface data communications circuitry to the telephone system. Specific modem models and their performance are shown.

Chapter 11 examines networks, a very important topic in modern data communications. There are many network configurations in use, each with certain performance characteristics, costs, benefits, and drawbacks. International standards are used to define network operation and the many layers of message transfer that occur. The chapter details the major network topologies, protocols, and operational sequences, along with the ICs that support these. Cellular networks that allow many portable terminals to use a limited bandwidth are studied. An all-digital type of telephone network, called *integrated digital services network (ISDN)*, is now being developed, and the overall function and ICs of ISDN are shown.

The real world of data communications must also deal with errors caused by many channel and circuit problems. Chapter 12 shows how error detection circuits are used to determine that an error has occurred and how error correction circuitry (which is more complex) can actually correct many errors. The mathematics of error detection and correction is shown, along with the protocols, ICs, and circuitry which implement the mathematics. A natural consequence of the error detection and correction methods is the ability to make digital data secure from unauthorized persons who may eavesdrop, or even try to put false data on the channel. The chapter shows how data security can be achieved by using many of the principles of random-bit sequences and digital data transmission.

Anyone involved with data communications systems must understand how they are tested, what equipment is used, and what the various tests reveal. Highly specialized equipment is usually needed, and this is shown in Chapter 13. The instruments and tests studied cover lower-level interfaces and operations, complex systems such as networks, and fiber-optic systems.

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William L. Schweber

Contents

1 An Introduction to Communications

This chapter provides a basic understanding of what a communications system is, the goal of communications, and the reasons why communications systems are vital in modern society. It begins with a brief historical background of the beginning of electrical communications and links this to modern electronic communications systems. The many different structures that a communications system may have are discussed, along with some obvious and less obvious roles of communications. The chapter also covers the changing nature of communications systems—from voice signals in analog form to digital signals, which can be either voice signals or computer data. Telecommunications, the transferring of large amounts of data in digital format from one location or computer to another, is explored.

1-1 What Is Communication?

The goal of communication is to send a message from one point to another and to ensure that the message is received properly and understood. Behind this simple concept is an extremely important and complicated subject. Communication, the ability to send and receive messages reliably and predictably, forms the nervous system of a civilization. Just as civilization has changed over the past thousands of years, the nature and practice of communications have also changed dramatically. The development of the computer and the modern information-oriented society has been both the incentive for improved communications and the result of communications capabilities.

Although communication may seem simple, it is not. In order to successfully send and receive a message, the sender and the receiver have to agree on many factors—the way the message is sent, the symbols used, the rate at which the message is transmitted, for example. Like a baby learning language, communication is a complex subject.

Ever since individuals learned to communicate with others, there has been a desire and a need to communicate faster, better, and more reliably. Data communications is the most recent development in this constant striving for improved communications. Regardless of what information the message represents—instructions, ideas, data (numbers), or reports—the concept of communication remains the same.

A society has a need to get two things from one place to another: information and physical objects, such as people or products. Before electrical and electronic communication, the only practical way to transfer information was to send it with someone. (Drums, smoke signals, and carrier pigeons have been used, too.) This, of course, limited the speed with which messages could be transported and also meant that in many cases delivery was very difficult or impossible, since travel could be dangerous and time-consuming. Electrical and electronic communications changed this; once the communications system was put in place, only the information had to be sent. This completely changed the way people did business, countries conducted foreign affairs and diplomacy, and individuals spread ideas.

Electronic communication of data began with the telegraph, perfected by Samuel Morse in 1854. This was a relatively simple communications system, which connected one end to the other in a predefined, dedicated way, with no possibility of different connections to other users. The telephone, first patented by Alexander Graham Bell in 1876, was the next major milestone. It spurred the development of communication systems because now the actual instrument of communication was located in the house or office of the user, who could choose to communicate with any other user who possessed a telephone (see Fig. 1-1). The development of the digital computer and improvements in computer performance and reduction in cost, which began in the 1950s, have increased the need for powerful communications and systems tremendously. The microprocessor integrated circuit, which puts many of the functions of a computer into a small, inexpensive box, has further increased the demand for communications since these boxes are capable of sending and receiving messages while performing other useful tasks.

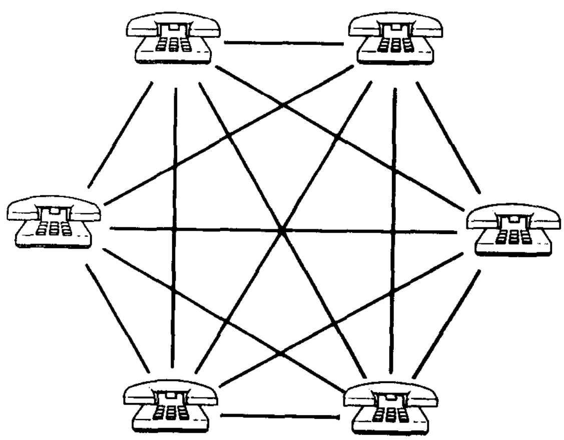

Fig. 1-1 A telephone system requires that any user be able to connect to any other user, as functionally shown above. Of course, this is not the way the phone company actually implements the connections.

Along with the increased need for communications spurred by the telephone and computer, the pathways for communications have also changed dramatically. When the telegraph and telephone were invented, the only practical method for transferring the message was copper wire, strung from one instrument to the other. The development of radio systems added another means of connecting the ends of the communications users and also gave a great deal of flexibility to the system, since the users were not tied down to the locations where the wires had been run. Worldwide communication became a reality, based on the construction of the appropriate radio transmitters and receivers. The space age has further improved on radio by using satellites in space to act as ''relay'' stations linking the various systems users, whether they be people on earth, astronauts in space, or space probes going to the other planets.

In the last decade, another method of transferring the message has grown in prominence. Fiber optics uses glass and plastic fibers as the pipe, or conduit, for the communications signals, which are sent by pulses of light through the fiber. This use of simple glass and fiber required the perfection of new technologies, such as ultrapure glass and plastic, easy-to-control sources of light, and sensitive light detectors. Now, fiber optics is used extensively for connecting the computers and phone systems of major cities and equipment centers and brings some important technical advantages that could not be achieved with copper wire, radio, or satellites.

QUESTIONS FOR SECTION 1-1

1. What are two of the many factors that have to be agreed on by the sender and receiver of a message for successful communication?
2. What is responsible for the tremendous increase in the need for better communications?
3. What are three of the many pathways available for electronic communications?
4. What is fiber optics? How is the message carried?

1-2 Uses of Communications

The use of electronic communications is much more extensive than many people realize. Besides the obvious examples of communications, such as the link between a central bank computer and an automated teller machine, there are many other types of electronic communications:

Person-to-person. The messages and information are sent by voice, usually by telephone or radio, so this is often called *voice communication*. People can also ''converse'' by typing at a terminal and seeing the other end of the conversation on a terminal screen. This can be a true two-way conversation, with give and take, or it can be a message typed in to be read at a later time by the recipient.

Computer system to peripheral device. In this system a computer system is sending messages, such as reports, to a printer, which is normally attached directly to the computer. The message is the data for the printer, and the computer needs to know whether the printer is available and ready for printing before it sends the data, or whether it becomes unavailable (someone shuts it off or it runs out of paper) during printing.

Computer to computer. An example would be a computer used in a national newspaper office. The main office computer is used to enter the articles, edit them, and prepare the layout of the pages. However, printing is done at printing facilities around the country, to ensure delivery the next morning to all readers. The main office computer transmits the contents of the newspaper to the computer in each local printing plant, which then uses this to generate an exact re-creation of the page as seen at the main office. This re-creation would be used to set up the printing press in the field plants.

Distributed systems. A *distributed system* is a system which uses individual intelligent boxes to preprocess some of the information; these boxes send only important information back to the central computer (Fig. 1-2). The intelligent boxes are called *local front ends*, or *controllers*, because they are closest to the actual source of the data. For example, a factory may use small microprocessor-based controllers to direct and monitor the operation of a large number of vats, where different batches of paint are being produced. At each vat there is a need to measure and control the flow of raw ingredients, regulate the temperature, and mix the ingredients according to the paint production process used. Associated with each vat is a local controller, which performs the actual measurement and control of the raw materials and temperature. The local controller uses a recipe that is sent to it from the central computer, which is managing the overall production plant and the use of each vat. It reports any unusual conditions to the central computer. If the controller is unable to get the temperature up to the desired value, it reports this to the main computer so that maintenance staff can be called and production temporarily stopped at that vat. The local controller in this way acts to reduce the amount of data collecting, processing, and decision making that the central computer has to perform. At

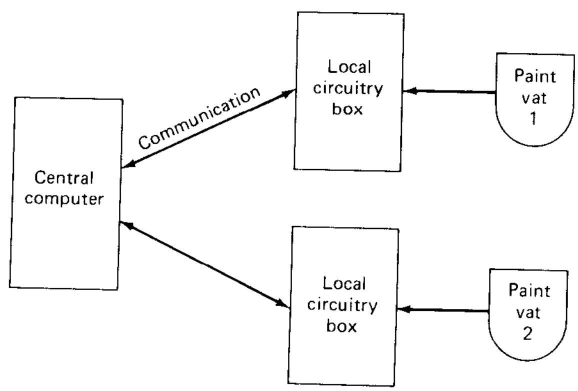

Fig. 1-2 A distributed system uses local intelligent circuitry to preprocess the data and communicate with the central computer.

the same time, the reliability of the overall system is increased, because the operation at each vat is not dependent on the central computer. Each local controller can manage the vat independently if communication to the central computer, or the central computer itself, breaks down. As the cost of microprocessor-based equipment comes down and its capabilities increase, distributed control systems will become more common.

Intracomputer communication. There is often a need to transfer data from one part of the system to another, even within a single chassis. Very often the designer of a system has divided the overall system into subparts, with circuitry (often microprocessor-based) to handle part of the total application. The various subsystems need to transfer data among themselves. For example, a computer may generate sophisticated color graphics to be used as part of a film production. One part of the computer may be performing the calculations needed to determine where the various pieces of the total image on the screen should go and what shapes to use in what places. It then passes the results of this analysis to another part of the system, which is actually responsible for drawing the picture on the screen by placing the proper shapes and colors in the right locations.

QUESTIONS FOR SECTION 1-2

1. Give two examples of computer-to-peripheral-device communications.
2. Give an example of the need for computer-to-computer communications.
3. What is a distributed system? Why does it need communications?
4. What are the advantages of a distributed system? Why is it such an important topic in modern system design?
5. Give two examples of communications within a single system.

1-3 The Structure and Types of Communications Systems

There are many ways to build a communications system that will successfully send a message from one point to another. Regardless of the system design, every communications system has the same basic functional blocks (Fig. 1-3). At one end, there is the sender of the message. This can be a person, computer, or other piece of equipment. The message then goes to a transmitter, which may be a radio transmitter, a computer designed to pass messages, or some simple circuitry within a system. The message goes over the actual communications link, which is the physical path between the sending end and the receiving end. At the receiving end, there is equipment which receives the message, extracts it from the link, and passes it on to the message user, which can also be a person, a computer, or another part of a circuit.

A properly designed and functioning communications system must integrate all the elements of the message path—from the sender through transmitter, link, and receiver equipment and to the actual user (receiver) of the message. The system can also be classified into one of three categories of ability: simplex, full-duplex, and half-duplex.

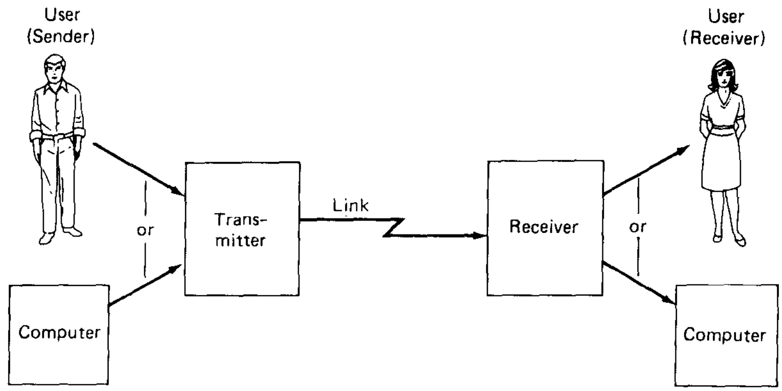

Fig. 1-3 All communications systems have the same functional blocks.

A *simplex system* is one in which the message can be sent in one direction only, from one end to the other (Fig. 1-4). There is only one transmitter and one receiver. An example of a simplex link would be a cable TV system, where the picture for the TV screen is sent from the central studio to the individual homes that are wired for cable. Another example would be a public address system, where a message can be broadcast to anyone in the listening area. (In a simplex system, it is common to have many listeners for a single transmitter.) A computer sending characters to a printer would also be a simplex system, since a printer does not send characters back.

A *full-duplex system* (or ''duplex'') is one in which the link is capable of transmitting in both directions at the same time. There is a transmitter and

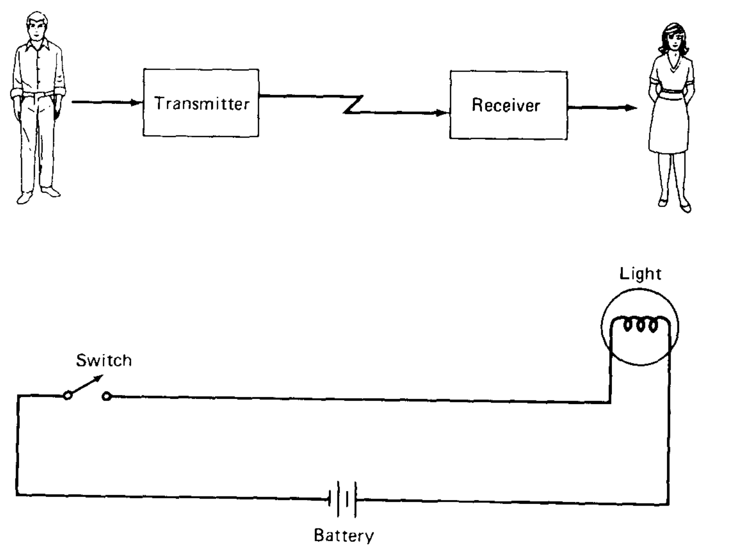

Fig. 1-4 In a simplex system, shown functionally at the top, messages can be sent in one direction only. A simple circuit for simplex communications is shown also.

receiver at each end, and they can be used simultaneously (Fig. 1-5). A telephone system is one example, since both parties on the phone can talk at the same time if they want to. (In many full-duplex systems, the capability for full-duplex operation is present but not used all the time, because it may cause confusion to have multiple talkers, just as in conversation.) Not only does a full-duplex system require more circuitry at each end and two links, but it also requires that the computer system or circuitry that is using the link be capable of both listening and talking simultaneously. Just as in conversation, this is often difficult to do in practice, even though the capability for it exists.

A third class of communications link is *half-duplex*. In a half-duplex link, each end may transmit, but only one at a time. This requires both transmitting and receiving circuitry at each end, but the actual link between the two ends may be shared (Fig. 1-6). Very often, this is the reason for a half-duplex link. For technical reasons it may be difficult to establish or build a link that can be used in two directions simultaneously, but much simpler to allow the link to be switched from one direction to the other. In other cases, the half-duplex link is used because the electronics system at each end cannot send and receive simultaneously but can only do one at a time. A microprocessor by itself can only perform one operation at a time, no matter how fast it is capable of operating. The microprocessor, therefore, would either be set to send messages or to receive them, but could not send and receive at the same instant of time. The half-duplex link is very common because it often provides the best choice for technical, performance, and cost reasons. Half-duplex is often used when one end does most of

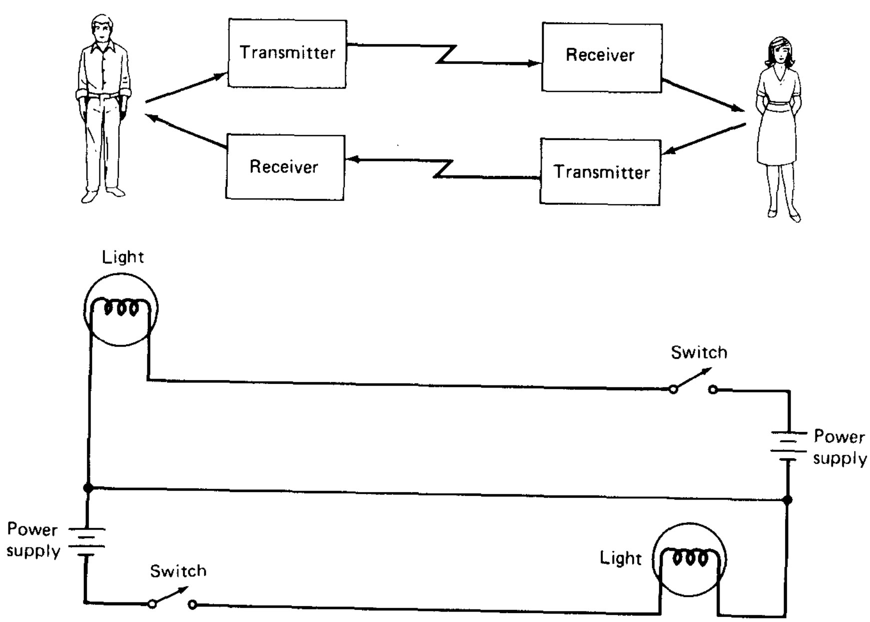

Fig. 1-5 In a full-duplex system, messages can go in both directions simultaneously as shown functionally and with a simple circuit schematic.