

F O U R T H E D I T I O N

U N D E R S T A N D I N G

# TELEPHONE ELECTRONICS

STEPHEN J. BIGELOW  
JOSEPH J. CARR  
STEVE WINDER



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# **Understanding Telephone Electronics**

**Fourth Edition**



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Stephen J. Bigelow  
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*In Memory of Joe Carr*





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# Preface

The Battle of New Orleans (1814) was the only major land battle won by the United States during the War of 1812. But it was a hollow victory because it took place two weeks after the war ended. The message announcing the end of the war did not arrive in time. Why? Communications in 1814 were very slow. Messages went by horseback courier or sailing ship. General Andrew Jackson enjoyed no better communications between Washington and New Orleans than Julius Caesar had between Rome and Gaul. Indeed, Caesar may have had better communications because of the road system built by the Romans.

The modern telecommunications revolution began less than a generation after the Battle of New Orleans when Samuel F. B. Morse invented the telegraph. By the Civil War much of the country was humming with telegraph wires, and communications between distant cities was reduced to a few minutes. Stonewall Jackson had communications that Andrew Jackson could not even comprehend. It took another generation to invent the telephone, which allowed voice communications, and still another to invent radio.

The accelerating rate of progress in communications is seen by certain historical events. The first transatlantic telegraph cable was completed between 1855 and 1857, and could transmit no faster than about 50 words per minute. It wasn't until 1955, a century later, that the first transatlantic telephone cable was laid.<sup>1</sup> Only nine years after the first transatlantic telephone cable went into service, the first global communications satellite (AT&T's *Telstar I*) was launched. In the decades since *Telstar I* so many satellites (communications and otherwise) have been launched that collisions with "space junk" have become a distinct hazard. Progress in telecommunications today proceeds at such a whirlwind pace that it is difficult to keep pace with advances.

Concurrent with, and because of, the telecommunications revolution is the development of now commonly available services such as cable TV,<sup>2</sup> the

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<sup>1</sup> *Transatlantic telephone service began in the 1930s using high-frequency short-wave radio channels. Capacity was limited, and waits of several days to get a free line were not uncommon. Ionospheric disturbances and magnetic storms, caused by solar activity, often eliminated the telephone channel for hours to days at a time.*

<sup>2</sup> *Cable TV in this context includes not just television signals but also the distribution of radio signals.*



Internet,<sup>1</sup> and wireless and cellular phone technology. Whereas Andrew Jackson and Julius Caesar had to wait weeks for messages to arrive, today we have instantaneous messaging, graphics, video, and audio available at our fingertips through the telephone companies, Internet service providers, and cable TV companies.

The baseline capability expected by the public has increased dramatically in the past two decades. Whereas in the past most users had been limited to a single-channel analog voice system (telephone), we now have the ability to conduct online sessions with participants in all states and on all continents, simultaneously.

The public switched telephone network in the United States of America is one of the true marvels of the modern world. It provides the ability to interconnect any two out of more than one hundred million telephones, usually within a few seconds of the request for connection. It is controlled by the world's largest network of interconnected and cooperating computers. Yet the telephones in this network are usable by unskilled operators without formal training (almost any child of 4 or 5 can make a telephone call).

This book is in part about that network and the technology that has made it possible. But it is more about revolutionary changes that are taking place in the way telephone conversations and data are taken into the network, switched, and transmitted. Some of the technology still in everyday use in the telephone network dates from the decade of the invention of the telephone in the 1870s. However, even this old and traditional business is being forced by economics, regulation, and competition to make massive changes in the way it does business and in the equipment and techniques used to provide the telephone service.

We begin by presenting the fundamentals of the telephone network: how it began, what the components are, and how they are connected. Next we review the basic nonelectronic telephone set. We then consider the effect of microelectronics on the construction and operation of the telephone set; for example, the effect on functions such as speech signal processing and interface with the telephone line, pulse and tone generation for dialing, and ringers. Next, we discuss how microcomputers use digital techniques and stored programs to enhance the performance and features of the telephone set. Digital transmission techniques, electronics in the central office, and network transmission concepts and fundamentals are explained. Finally, we consider new advances in cordless phone, mobile radio, and cellular phone technology. We also take a look at fiber optic technology and the Internet, as well as expand the coverage of wireless telephones—a very big market today. New information on high-definition television, modems, DSL lines, and cable modems has also been included.

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<sup>1</sup> Including both e-mail and the World Wide Web.

Like other books in the series, this book builds understanding via a step-by-step process. Try to master each chapter before going on to the next one. A quiz is provided at the end of each chapter for self-evaluation of what has been learned. Answers are given at the back of the book.

The business of providing the equipment and service for both local and long-distance telephone communication is today undergoing some of the most fundamental changes ever required to be made by any U.S. institution. Before the government breakup of AT&T in January 1984, AT&T was the largest company on earth, and its product is a service that has become a necessity for all of us. Understanding the technical side of the telephone is necessary in understanding a force in modern life that has been and will continue to be as much an agent for change as the automobile, the airplane, and the computer.





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## *First Edition:*

The authors wish to acknowledge the tutelage of Dr. John Bellamy, whose knowledge of this subject fills his students and this book. They are grateful also for the friendship and advice of John McNamara of Digital Equipment Corporation, Ken Bean of Texas Instruments, and Leo Goeller, who always has time to chat. Finally, we are grateful to the members of the International Communications Association, whose encouragement and support have changed our lives.

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1. Members of the Technical Staff, Bell Telephone Laboratories, *Engineering and Operations of the Bell System*, Bell Telephone Laboratories, Inc., 1977.
2. Members of the Technical Staff, Bell Telephone Laboratories, *A History of Engineering and Science in the Bell System, The Early Years (1875–1925)*, Bell Telephone Laboratories, Inc., 1975.
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4. Network Planning Division of AT&T, *Notes on the Network*, American Telephone and Telegraph Co., No. 500-029, 1980.

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### *Fourth Edition:*

The staff at Newnes regrets to announce that Joe Carr, revising author for this edition, passed away on November 25, 2000. As well as being the author of more than 80 books, Joe was a well-known magazine writer, lecturer, and professional engineer who brought a smile to the in-boxes of friends, family, and colleagues with his famous e-mail funnies. He will be sadly missed here at Newnes.

On Joe's behalf, we wish to thank and gratefully acknowledge Steve Winder (team leader, BT Group Engineering Services, UK) for his numerous contributions and efforts in developing this new edition. Steve lent his expertise to several chapters, providing his most extensive revisions to Chapters 3, 11, and 12. In Chapter 3, Steve introduces and details the new MC34114 device, provides coverage of DSPs and ASICs, and offers other current information pertinent to electronic speech circuits. In Chapter 11, he provides significant updates in the areas of time division multiple access (TDMA), cellular systems, and code division multiple access (CDMA). In Chapter 12, he expands coverage of modems and explores current topics such as high-definition television, DSL lines, and cable modems. These are only a few of the many essential topics Steve authored and updated throughout this book. We greatly appreciate Steve's hard work, dedication, and invaluable contributions.

We also wish to thank and acknowledge Richard Goldhor (vice president of engineering, Enounce, Inc.) and Stephen Bruder (assistant professor, New Mexico Institute of Mining and Technology), whose insightful developmental reviews were invaluable to us in planning this edition.

# 1 The Telephone System

## ABOUT THIS CHAPTER

The telephone was invented a little over a hundred years ago by Alexander Graham Bell. The telephone industry has since become one of the largest on earth.

The telephone arrived as a practical instrument over a century ago in 1876, an outgrowth of experiments on a device to send multiple telegraph signals over a single wire. Alexander Graham Bell, a native of Scotland, while conducting electrical experiments spilled acid on his trousers. His reaction, the now-famous “Mr. Watson, come here, I want you,” brought Thomas A. Watson on the run not only because of his employer’s distress, but because the words had been carried by electricity into Watson’s room and reproduced clearly on his receiving set. The simple instrument being tested on Court Street in Boston on March 10, 1876, wasn’t very practical (the acid was used in the system), but improvement followed so rapidly that putting into action Bell’s concept of a public telephone network—“this grand system . . . whereby a man in one part of the country may communicate by word of mouth with another in a distant place”—was well under way by January 1878, when the first commercial exchange was operated in New Haven. By 1907, one hotel alone (the Waldorf Astoria in New York City) had 1,120 telephones and processed 500,000 calls per year.

The American Telephone and Telegraph Company (AT&T) was incorporated in March 1885 to manage the explosive growth of the fledgling telephone network across the United States. Virtually since the beginning, AT&T worked as a legal, regulated monopoly. This means that AT&T was allowed to establish, maintain, and control a single, universal network across the country without any competition, as well as provide all telephone sets and switching equipment to the general public. The federal government regulated its policies, practices, and fees. This set the groundwork for the development of the most advanced and efficient telecommunications system in the world.

By the mid-1940s, however, the U.S. government began to question seriously the principles of the telephone monopoly in light of the general antitrust laws and alleged abuses by AT&T. An antitrust suit filed in 1949 forced AT&T to restrict its business activities to the national telephone system in 1956. During the next several decades, the Federal Communications Commission (FCC) began to allow the introduction of new products and services from competing companies. By the mid-1970s, several competitors obtained the capacity to offer long-distance telephone service.



Advances in technology and the challenges of competition caused the government once again to rethink its position on the telephone monopoly. On November 20, 1974, the Department of Justice filed a new antitrust suit against AT&T. The trial began in January 1981. One year later, AT&T agreed on terms to settle the suit. In essence, AT&T would divest all of its local operating companies. This would dissolve the monopoly held by AT&T for almost one hundred years, but it would also lift many regulatory constraints.

Official divestiture took place on January 1, 1984. The monopoly was gone. AT&T was free to compete in the nation's emerging communications market, and local operating companies were allowed to handle local service and maintain the network.

Each local telephone company is owned by a holding company for that particular region which handles the overall day-to-day business operations of the region, and leaves the local companies to concentrate on service and maintenance of the network. These holding companies are known as Regional Bell Operating Companies (RBOCs). To maintain technical consistency after divestiture, a Central Service Organization (CSO) was established to serve RBOCs across the nation by providing research and development functions. This technical organization takes the place of Bell Labs (now Lucent Technologies), which remained with AT&T after divestiture. The CSO is funded by every RBOC, so its work is utilized by all regional and local companies.

Today, telecommunications is a multibillion dollar industry employing well over one million people. This modern network handles voice and data communications efficiently and reliably in even the most remote locations. A number of new and merged telecommunications companies have arrived on the scene. For example, the Chesapeake & Potomac telephone company merged with New York and New England telephone companies to become BellAtlantic, which then became Verizon. A number of long-distance telephone providers also exist now in addition to AT&T. For example, MCI Worldcom and Sprint operate in the United States on an equal basis with AT&T. There are also a number of smaller telephone companies in the marketplace, as well as "dial-around" (10-10-xxxx) services available to the long-distance user today.

## THE TELEPHONE SET

The telephone set performs eight electrical functions to provide us with service.

An example of a telephone set like those used to originate and receive telephone calls is shown in Figure 1-1. It is simple in appearance and operation yet it performs a surprising number of functions. The most important ones are:

1. It requests the use of the telephone system when the handset is lifted.
2. It indicates that the system is ready for use by receiving a tone, called the *dial tone*.

**Figure 1-1**  
**Telephone Set**  
(Courtesy Radio  
Shack)



3. It sends the number of the telephone to be called to the system. This number is initiated by the caller when the number is pressed (or the dial is rotated in older telephones).
4. It indicates the state of a call in progress by receiving tones indicating the status (ringing, busy, etc.).
5. It indicates an incoming call to the called telephone by ringing bells or other audible tones.
6. It changes speech of a calling party to electrical signals for transmission to a distant party through the system. It changes electrical signals received from a distant party to speech for the called party.
7. It automatically adjusts for changes in the power supplied to it.
8. It signals the system that a call is finished when a caller “hangs up” the handset.

Of course, for a telephone to be of any use, it must be connected to another telephone. In the very early days of telephony, the phones were simply wired together with no switching. As the number of phones increased this became impractical, so the local exchange or central office was established to handle the switching and other functions.

## THE LOCAL LOOP

A single pair of wires connects the telephone to the central switching office. This connection is called a local loop. One connection is called the tip (T) and the other connection the ring (R).

Each subscriber telephone is connected to a central office that contains switching equipment, signaling equipment, and batteries that supply direct current to operate the telephones as shown in Figure 1-2. Each phone is connected to the central office through a local loop of two wires called a *wire pair*. One of the wires is called T (for tip) and the other is called R (for ring), which refers to the tip and ring parts of the plug used in the early manual switchboards. In some countries, including the United Kingdom, these wires are called the A-wire and the B-wire, respectively.

Switches in the central office respond to the dial pulses or tones from the telephone to connect the calling phone to the called phone. When the connection is established, the two telephones communicate over transformer coupled loops using the current supplied by the central office batteries.

## Initiating a Call

When the “receiver” handset is in the off-hook condition, the exchange sends a dial tone to the calling telephone.

When the handset of the telephone is resting in its cradle, the weight of the handset holds the switchhook buttons down and the switches are open. This is called the on-hook condition. The circuit between the telephone handset and the central office is open; however, the ringer circuit in the telephone is always connected to the central office as shown in Figure 1-2. The capacitor, C, blocks the flow of dc from the battery, but passes the ac ringing signal. (The ringer circuit presents a high impedance to speech signals so it has no effect on them.)

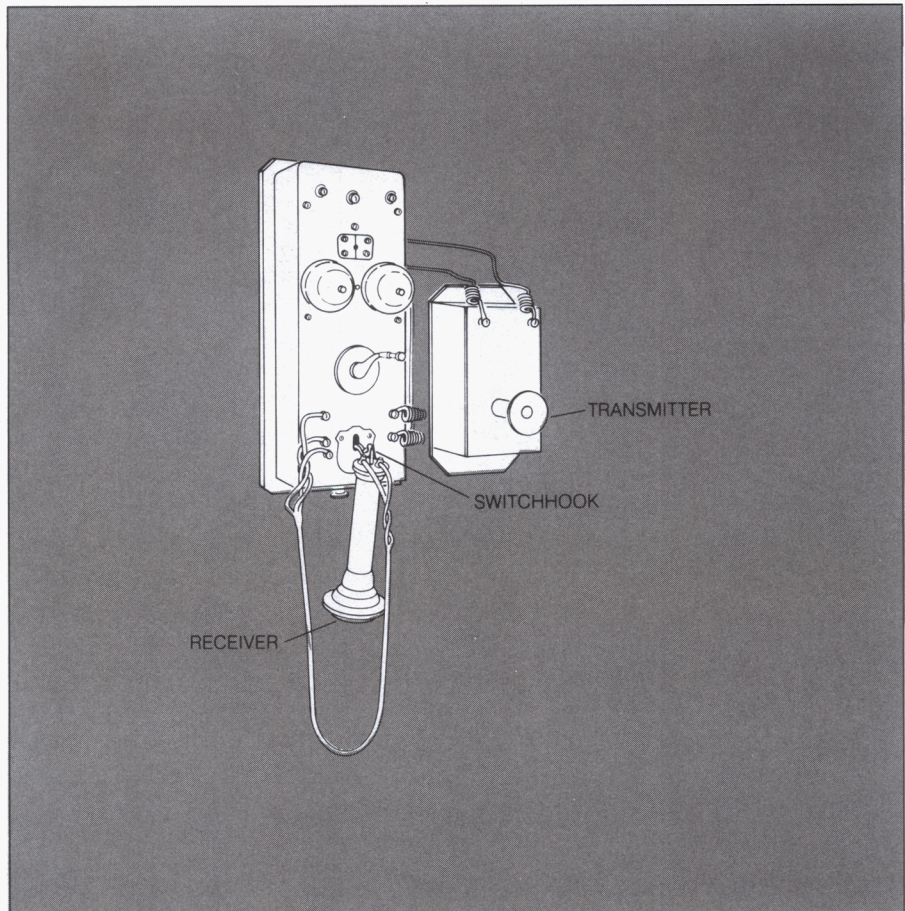
When the handset is removed from its cradle, the spring-loaded buttons come up and the switchhook closes. This completes the circuit to the exchange and current flows in the circuit. This is called the off-hook condition. (The on-hook, off-hook, and hang-up terms came from the early days of telephony, when the receiver was separate and hung on the switchhook when not in use as shown in Figure 1-3. This also explains why many people still refer to the handset of today as the receiver.)

In the telephone circuit shown in Figure 1-2 the dc path is through the switchhook, dial contacts, induction coil, and the handset transmitter and receiver. In electronic telephones the dc current supplies power to the internal integrated circuits and any excess current is returned to line through a constant current circuit. A constant current circuit has high impedance to ac signals and thus provides a dc path without shorting out the wanted audio signals. The off-hook signal tells the exchange that someone wants to make a call. The exchange returns a dial tone to the called phone to let the caller know that the exchange is ready to accept a telephone number. (The telephone number also may be referred to as an address.)





**Figure 1-3**  
**Early Telephone**  
**with Separate**  
**Receiver**  
**Hanging on**  
**Switchhook**



### **Sending a Number**

Some older telephone sets send the telephone number by dial pulses while newer telephones send it by audio *Touchtones*. These are described in historical order; note that dial pulsing is rarely used nowadays (although sometimes an option on electronic telephones).

#### **Dial Pulsing**

Numbers are sent either by a stream of pulses (pulse dialing) or by a series of audio *Touchtones* (tone dialing).

Telephone sets that use dial pulsing have a rotary dial, which opens and closes the local loop circuit at a timed rate. The number of dial pulses resulting from one operation of the dial is determined by how far the dial is rotated before releasing it. Although all network facilities are currently compatible with pulse dialing telephones, today's standard embraces the Touchtone method of dialing.