Understanding Telecommunications and Lightwave Systems
This book is dedicated to the memory of Elliott M. Gilbert (1924 – 2000)

A good friend and a brave Marine, who, in WWII, fought in the bloodiest conflict in the South Pacific, Iwo Jima.
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Introduction

There is growing recognition throughout the world that future economic and social progress will depend on effective communications. The exiting Internet has created a new interactive network economy. This new economy is now larger than the old industrial economy, which included auto manufacturing, construction and food services. The speed and force with which this new network economy is moving is not yet recognized by the general public; however, the influence it will have on how people live and work will be global and unalterable. With Internet traffic now growing tenfold yearly, there is an insatiable demand for more bandwidth.

The common goal is a global digital all-optical network that will have the capacity to carry voice circuits, Internet traffic, music and video. Lightwave communications systems have clearly emerged as the only technology that can meet the bandwidth requirements of this new network economy.

All over the world, optical fibers are replacing other transmission media in a wide variety of applications, including long-haul trunking systems, metropolitan telephone networks, undersea transmission links and the local loop to the home. Optical fiber provides the important requirements of wide bandwidth, reliability and security. It is immune to most of the technical and regulatory constraints of traditional communication systems.

The race to build a cheaper, more efficient all-optical network that will provide almost unlimited bandwidth has just begun. Optical amplifiers, optical cross-connects, dense wavelength division multiplexers and optical switches are some of the
devices that are being developed. A number of new companies are building transcontinental backbone networks of fiber optic cable linking all major cities in the world. These networks are based on Internet Protocol (IP) technology.

The third edition of *Understanding Telecommunications and Lightwave Systems* has been completely updated to reflect the advances that have been made in the telecommunications industry as a result of the explosive growth of the Internet.

This new edition includes a revised Chapter 15 on the wireless revolution and the introduction of third-generation cell phones with microbrowser capability. It also includes an expanded Chapter 11 with a section on optical switching and a revised and expanded Chapter 18 on lightwave systems. Chapter 16, *The Computer* and Chapter 17, *The Internet*, have been added. *The Computer* covers the evolution of this machine and its future potential. *The Internet* examines this multimedia structure which has created the new network economy that is changing the way people communicate at the most fundamental levels.

Although this book deals primarily with the technical and regulatory trends in North America, the basic technology is common to telephone networks throughout the world. They differ only in the political, regulatory and societal conditions existing in each country.

The book has proven to be very popular in colleges and universities as a basic text for *Man & Technology* courses. It has also been used for a series of telecommunication seminars presented to senior citizens attending Eldercollege.

This book aims to provide an overview of telecommunications as well as an introduction to the exciting technology of lightwave communications. With the range of applications continuing to expand with growing speed, this technology promises to turn the electronic age into the age of optics.
The Evolution of Telecommunications

The Telegraph

For centuries, long distance communications had been carried out by means of signal fires, lamps and flashing mirrors. However, the electric telegraph developed by Samuel Morse around 1835 actually launched long distance communications. By 1843, a telegraph line was constructed from Washington, D.C. to Baltimore. The first message sent over this line was “What hath God wrought?” which was certainly a profound question in view of the developments that followed.

By 1850, Western Union was formed in Rochester, New York. Its purpose was to carry messages in a coded form (a dot and a dash) from one person to another over a privately controlled but publicly accessible network.

The Telephone

Alexander Graham Bell demonstrated his invention, the telephone, on March 10, 1876. Bell displayed the telephone at the 1876 World's Fair in Philadelphia. The Bell Telephone Company was formed in 1877 to produce the telephone commercially. In the same year, Western Union created the American Speaking Telephone Company as a competitor to Bell. By 1880, the American Bell Telephone Company was organized to serve as the parent company. Two years later, Western Electric Company was purchased to ensure a ready supply of telephones and related equipment. In 1885, the company was incorporated and became the American Telephone and Telegraph Company (AT&T).
Wireless Communications

Guglielmo Marconi, an Italian physicist, was the inventor of wireless communications, radio telegraphy. At the turn of the century many scientists believed that the curvature of the earth would limit practical use of the wireless to a distance of 100 – 200 miles. However, in 1901, Marconi proved them wrong by transmitting a message across the Atlantic Ocean.

In 1906, Lee DeForest announced his invention, the audion tube, the forerunner to the electron tube. The electron tube was used in radio to pick up faint electromagnetic signals and boost them a thousand times stronger than the received signal. Although it was intended to improve the sensitivity of radiotelegraph receivers, telephone engineers saw its potential for boosting long-distance telephone signals as well.

AT&T Monopoly

By 1910, AT&T had gained control of Western Union. The U.S. Department of Justice threatened to institute an antitrust suit against AT&T in 1913, so it then agreed to dispose of Western Union. In 1934, the U. S. Congress created the Federal Communications Commission (FCC) and defined its powers in the Communication Act (1934). The FCC has jurisdiction over interstate and foreign commerce in communications but not telecommunications within a state. This is regulated by the state public utility commissions.

Trans-Canada System

In Canada, the Trans-Canada telephone system was turned up for service on January 25, 1932, using an all-Canadian route. The system consisted of two open-wire pairs strung on poles with voice repeaters spaced about 200 miles apart. In 1948, an additional open wire pair was strung across Canada to permit the installation of the first three-channel carrier system. This method enabled more than one telephone circuit to be carried over a pair of open wires at the same time. Ten years
later, the first microwave radio (TD-2) was turned up for service across Canada. The microwave radio provided better quality long-distance circuits and more reliability than the open wire.

**Semiconductors**

Scientists at Bell Laboratories in the United States introduced the transistor in 1947. The transistor is a solid-state device and does not require a heated cathode like the vacuum tube. Within a few years, the Bell Telephone System contained millions of transistorized elements.

By 1959, Texas Instruments and Fairchild Semiconductors successfully produced integrated circuits with transistors, capacitors and resistors placed on a square of silicon. Now, with an entire set of integrated circuits mounted together on a board, the entire board, which cost only a few dollars, could be removed and replaced in the event of a problem.

**Digital Communications**

In 1962, Bell Labs designed the first commercial pulse-code modulation (PCM) cable carrier system. The introduction of the Bell System’s T-carriers was the beginning of a trend toward digital communication in the telephone network.

Up until 1968, AT&T specified that only equipment furnished by AT&T could be attached to AT&T facilities. The Carter Electronic Corp. wanted to connect their mobile radio system to the telephone network. In the landmark 1968 Carterfone Decision, the FCC ruled that the AT&T restriction was unreasonable. This ruling gave birth to the interconnect industry, thus speeding the development of private switchboards and other devices for interconnection to the telephone network.

In 1969, a second landmark decision by the FCC permitted Microwave Communications, Inc. (MCI) to begin construction of a microwave radio system from St. Louis to Chicago. This private line system offered direct competition with Bell Tele-
phone's toll network. This decision opened the door to other specialized common carriers.

**Satellite Communications**

The world's first commercial communication satellite was launched on April 6, 1965 by the Communications Satellite Corporation (Comsat) in the United States. This satellite, named *Intelsat 1* or *Early Bird*, was placed in geostationary equatorial orbit over the Atlantic Ocean. Although the United States was a pioneer in the establishment of an international satellite network, Canada had the first domestic satellite system. The satellite, designated *Anik A1*, was launched in November 1972 and began commercial service on January 11, 1973.

**Fiber Optics**

The development of optical fiber for use in the telecommunications industry did not begin until the mid 1960s. It was initiated in 1966 by the publication of a paper by Dr. C. K. Kao (ITT England), in which he stated that pure optical fiber was theoretically capable of guiding a light signal with very little loss. By 1970, Corning Glass Works in the United States was able to produce a fiber of sufficient purity for use in telecommunications. To make the fiber, Corning used a method of synthesizing silica glass. The raw materials were vaporized and deposited inside a length of quartz glass tubing, which was then collapsed into a rod and drawn into a fiber. The technology for the other two key elements of a fiber optic system, the laser and photodiode, had been developed independently during the previous ten years.

**AT&T Break-Up**

Up until 1982, AT&T provided 85% of all local telephone service and nearly 97% of all long-distance telephone service. Then in 1982, AT&T and the U. S. Justice Department agreed to an antitrust settlement worked out by Judge Harold H. Greene.
It required the divestiture of the 22 local operating companies. The United States was divided into 160 local access and transport areas (LATAs). The Bell operating companies (BOCs) were allowed to provide only local telephone service within the LATAs. They were forbidden from providing inter-LATA service. Each of the 22 companies was incorporated into one of seven regional Bell operating companies (RBOCs), as shown in Figure 1-1.

On January 1, 1984 AT&T's monopoly of telephone communications in the United States was over. The seven RBOCs were now all independent of AT&T, but, they were restricted to providing local telephone service within their own area. However, subject to Judge Greene's approval, they began entering many new business areas.

The deregulation of the long-distance telephone industry in the United States created opportunities for other telephone carriers to establish networks of their own. AT&T's major competitors, MCI and Sprint, began building nationwide lightwave (fiber optic) networks similar to the AT&T network.

Figure 1-1 Seven Regional Bell Operating Companies
Telecommunications Act of 1996

In February, 1996, the U. S. Congress passed the Telecommunications Act of 1996, which allowed long distance carriers and cable television companies to provide long distance access, local telephone services and data transmission services to subscribers in addition to television programs. It also allowed the RBOCs to provide long-distance service to its subscribers and to build video dial tone networks so that they can become common carriers to providers of television programming.

This radical measure removes the regulatory barriers that have separated the telephone, cable and broadcast industries. In particular, it allowed long-distance operators such as AT&T, MCI and Sprint to compete in regional markets, and local operators (called the Baby Bells) to compete in the long-distance market.

In 1997, SBC (the Southwest Bell Company RBOC) purchased Pacific Telesis (another RBOC) while Nynex and Bell Atlantic (two other RBOCs) merged, putting back together some of what Judge Greene rent asunder in his Modified Final Judgment of 1984. In 1994, Pacific Telesis had spun off AirTouch, their wireless division, but in 1999, British wireless giant Vodafone bought AirTouch for $56 billion.

The fear of competition in the new liberalized markets and the explosive growth of the Internet have caused a rash of mergers and strategic alliances in the telecommunications industry. In 1999, SBC announced it would buy Ameritech Corp. for $62 billion, the largest merger in telecommunications history. In 2000, Bell Atlantic and GTE merged to form Verizon, the largest local phone company in the United States. U. S. West, which had split off its cable division, MediaOne, in 1995, sold MediaOne to AT&T for $54 million. Two weeks later, in June 2000, Qwest bought US West for $58 billion. U. S. telecommunications companies continue to race for partners as the voice and data business becomes increasingly global and the Internet blurs country borders. Table 1-1 lists the top nine mergers.
Table 1-1  Top Nine Mergers

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<td>SBC Com</td>
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<td>Qwest</td>
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<td>Airtouch</td>
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<td>MediaOne</td>
<td>AT&amp;T</td>
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<tr>
<td>Tele-com Inc.</td>
<td>AT&amp;T</td>
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<tr>
<td>GTE</td>
<td>Bell Atlantic</td>
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<td>Bell Atlantic</td>
<td>Nynex</td>
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<tr>
<td>SBC Com</td>
<td>Pacific Telesis</td>
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Not all mergers have succeeded however. For example, the proposed $129 billion merger of MCI WorldCom and Sprint, the second and third largest phone companies in the United States, did not succeed. The U. S. Justice Department blocked the merger on the grounds it would increase prices for millions of consumers. Meanwhile, AT&T, which had spun off Lucent Technologies in 1996, has split into four separate operations: consumer long distance, business services, broadband (mostly cable) and wireless. With long-distance revenues falling, AT&T and WorldCom are losing interest in this sector. But the remaining Baby Bells — Qwest, BellSouth, Verizon and SBC — have taken over a large share of this market in New York and Texas. They are currently lobbying to enter the other 48 states that bar incumbents from competing.

In Canada, B. C. Telecom in British Columbia and Telus Corp. in Alberta agreed on a $6.5 billion merger. The deal created a company that can compete nationally with Bell Canada, the nation’s largest phone company. Telus has since purchased Clearnet Communications Inc., based in Toronto, for $3.1 billion. The deal made Telus the nation’s largest wireless telephony provider with 1.8 million customers. It gave the
company a national wireless presence three years earlier than if it had to build a network from the ground up.

The Meltdown

Over the past two years, 160 million kilometers of optical fiber have been laid around the world as companies spent $35 billion to create networks based on Internet Protocol (IP) technology. Four new transcontinental carriers, Qwest, Global Crossing, Level 3 and 360networks laid most of this fiber.

As a result, there was a glut of fiber capacity just as the North American economy began to slowdown. Global Crossing's share price plunged 89%. Cash starved 360networks failed to make an interest payment of $11 million and was forced to seek bankruptcy protection.

Major telephone carriers cut their spending on telecommunication equipment. The sales slump, immediately hit the major suppliers, Nortel Networks, Lucent Technologies and Cisco Systems. All three companies had been pursuing a strategy based on aggressive expansion and acquisition. As sales of telecommunication equipment declined, these firms have reported record loses. Altogether, more than 100,000 jobs have been eliminated in the telecommunications industry over the past year. The technology companies that fuelled the booming economy of the late 1990s are now going through a period of adjustment.

Conclusion

Today, only about 10% of American homes have high-speed access to the Internet. The demand for a low cost, always on, broadband connection to small offices and homes will act as a catalyst for new entrepreneurs and investors. The new network economy is here to stay. The Internet will continue to grow and the demand for more bandwidth will continue to increase. The glut of fiber is only temporary and the technology companies will once again propel the new economy
The Internet and the new network economy is forcing the merger of telecommunications, television, computers, publishing and information services into a single interactive information industry. The existing global telecommunication network, which is partly optical and partly electrical, will be unable to keep up with the insatiable demand for bandwidth. As a result, the race is on to build an all-optical network.

On one side are the huge equipment manufactures, Nortel Networks, Lucent Technologies and Cisco Systems. On the other side are hundreds of smaller companies working on a single problem, such as how to build the first all-optical switching machine. For those companies that can develop a more efficient all-optical network, which will provide almost unlimited bandwidth, the pay off could be enormous.
When a person speaks, the vocal cords vibrate, producing sounds that are carried to the mouth. The sounds produced in speech contain frequencies that are in the 100 to 10,000 hertz (Hz) frequency band.

The notes produced by musical instruments occupy a much wider frequency band than that occupied by speech. Some instruments have a fundamental frequency of 50 Hz or less, while many other instruments can produce notes in excess of 15,000 Hz.

Sound waves when they enter the ear, cause the eardrum to vibrate, thus producing signals. These signals, in the form of electric currents, are sent to the brain where they are interpreted as sound.

The human ear can distinguish frequencies between 30 Hz and 16,500 Hz. The average human voice ranges between 200 Hz and 5,000 Hz, as shown in Figure 2-1. Telephone company circuits operate over a range of frequencies from 300 Hz to 3,400 Hz. This is sufficient to make a person's voice recognizable and understandable.

Sound moves, through the air in waves. The shorter the wavelength, the higher the frequency, or pitch, of the sound is. Most sound waves, including our voices, are made up of many different frequencies and degrees of loudness.

Electricity moves through telephone wires in much the same way as sound waves move through the air. In the case of electricity, electrons bump against other electrons, sending their energy from one end of the wire to the other. Speech is
transmitted by these electrical waves with the electricity in the wires vibrating in the same pattern as the sound waves.

Referring to Figure 2-2, when a person speaks into the mouthpiece of a telephone, the sound waves made by the vibration of the vocal cords strike a thin diaphragm, causing it to vibrate. As the sound waves compress the air against the diaphragm, tiny carbon granules through which electric current is flowing are closely packed together. This creates a good electrical path for the current.

When the sound waves become less dense, the diaphragm springs back to its original position and the granules of the carbon move farther apart. This change reduces the flow of current. The diaphragm moves back and forth many hundreds of times per second in a pattern corresponding to the sound waves striking it. Thus, the amount of electricity flowing through the carbon granules varies, generating a signal. It is this electrical signal that is sent through the wires to the receiver at the other end.

At the receiver end, the electrical signals drive an electromagnet, whose varying force causes a diaphragm in the receiver to vibrate. The vibrations passing through the air between

**Figure 2-1** The Spectrum of Human Voice

![Image of the Spectrum of Human Voice](image-url)
the receiver diaphragm and your ear are duplicates of the sound waves that struck the diaphragm of the transmitter at the other end.

The direct current (DC) for the telephone instrument is provided by a 48-volt battery at the local telephone office and fed to the telephone over a twisted pair of copper wires designated “tip” and “ring.” When the user lifts the handset from the cradle, the instrument draws the direct current from the line when the switch hook closes (see Figure 2-3). The carbon microphones in the original handset have been replaced by miniature self-polarized capacitive microphones, called electrets. The original electromagnetic receivers have been replaced by piezoelectric receivers.

In the late 1960s and early 1970s, a transducer for an electronic ringer was introduced that eventually replaced the hammer and bell ringer that was invented in 1878. The rotary dial has been largely replaced by the push-button keypad. The keypad controls the circuitry that generates either dial pulses or the tones for touch-tone dialing.
Information is produced and transmitted over the telephone network as electrical signals. These signals have two forms: analog and digital. Analog signals are continuous and can be thought of as electrical voltages that vary continuously with time. Digital signals are a series of on/off pulses and will be examined in Chapter 3.

Transmission in the telephone network was completely analog until 1962, when digital transmission was introduced. Most customer loops are still analog because of the tremendous investment that telephone companies have in this equipment. However, due to the new competition in the telephone industry and the introduction of new technologies, this situation is changing rapidly, as we will see in the following chapters.

**Review Questions for Chapter 2**

1. What is the frequency range of the human ear?
2. What is the frequency range of the average human voice?
3. What is the frequency range of a typical telephone company circuit?

4. Explain how the telephone set is provided with power from the telephone office.

5. Identify the device that replaced the original carbon microphones in the telephone set.

6. Identify two types of signaling that may be accomplished with a telephone set.