DIGITAL AND DATA COMMUNICATIONS

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PREFACE

Since 1973, technological advances in the digital area have transformed telecommunications into a highly dynamic field. Where previously telecommunication systems had only voice to accommodate, with the advent of the microprocessor chip and the accompanying low-cost computers, the need for transmission of digital information has arisen. Digital technology has also provided a means of building smaller, cheaper, and more reliable telecommunications equipment. Laser technology is providing a means of transmitting information on optic fibers. The introduction of satellites into space has expanded long-distance communications.

Along with these advances, numerous texts have been published about each new area. Because of the complexity of each area, many of these texts are highly specialized. Other texts presume either that the reader has already been in the communications field and wishes to update his or her knowledge, or that the reader is highly skilled in mathematics and can follow complex derivations that establish limits on equipment and techniques or derive the probabilities associated with error rates. These books are excellent texts for the audience intended.

However, the rapid advances in technology in this area has aroused the interest of many who have never been previously associated with this field. The unique terms and numerous acronyms used in communications, if not explained, can leave the newcomer bewildered. Also, just as the advances in digital technology have brought about the introduction to digital theory and computer programming at the high school level, the authors foresee the introduction of telecommunications systems at lower levels in our educational institutions. This is the goal of this book—to provide an understanding of existing systems to a newcomer in this area. Hopefully, this book is written so that a reader with a background in basic communications (AM and FM theory), basic digital theory, and mathematics through trigonometry can easily become acquainted with this area. Numerous examples are provided for a better understanding of the theory.

Since the existing telephone lines are still the major media of all communication systems, Chapter 1 explains how direct calls are made (Direct Distance Dialing) and describes some of the associated hardware and terminology. It also describes the private-line services that are available to the subscriber. Chapter 2 is a general chapter which provides an overview of the various aspects involved in a communications system: whether it is two-point or multipoint; if multipoint, what configuration; whether it is synchronous or asynchronous; line protocol; and error detection. Many of these aspects are covered in detail in subsequent chapters. Chapter 3 deals with the telephone lines themselves and describes the specifications they must meet in order to conduct information. It also describes the various forms of distortion that may be produced in a transmitted message. If messages are to be transmitted in digital form, Chapter 4 describes the various codes that are used and error detection and correction schemes. Chapter 5 explains the operation of a UART, a device whose main purpose is to convert parallel digital information into serial format, and vice versa. Information coming from a data terminal is in parallel form. It must be converted to a serial format in order to be sent on a single transmission line. If the data terminal is receiving information, the reverse must be accomplished. Chapter 6 deals with the RS 232C interface signals between the UART and the modem. RS 449, RS 422, and RS 423, the anticipated replacements for the RS 232C, are also described. Chapter 7 deals with the various modulation schemes used to transform digital signals to analog form suitable for transmission on a voice line. These digital signals which have been converted to analog form can now be frequency-division multiplexed with other voice channels and the resultant signal transmitted on an analog line. This is the subject of Chapter 8. Since there are lines suitable for the transmission of digital information, Chapter 9 explains pulse code modulation and delta modulation—schemes for converting analog signals to digital pulses. It also explains how these channels are time-division multiplexed together prior to being transmitted on a digital carrier. Chapters 10 through 12 deal with line protocol. Chapter 10 describes asynchronous protocol, while Chapters 11 and 12 describe the synchronous protocols. Bisynch, SDLC, and HDLC. Bisynch is a character-oriented protocol, while SDLC and HDLC are bit-oriented protocols. Chapter 13 describes how different types of computers and terminals are connected to form local area networks, and packet switching and the associated standards governing their use.

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CONTENTS

1

THE TELEPHONE NETWORK

The American Telephone and Telegraph Company (AT&T) describes the Bell System as "the world's most complicated machine." A telephone call made from any telephone in the United States to any other telephone must use this machine. The characteristic of the Bell System that makes it unique from other giant corporations is that every piece of equipment, technique, or procedure, new or old, must be capable of working with the rest of the system. This is equivalent to interfacing every IBM computer with every other IBM computer or manufacturing parts for 1983 Buicks that would also work in 1952 Chevrolets. The Bell System, prior to January 1, 1983, serviced 83% of the telephones in the United States. It was the world's largest corporation, employing over 1,000,000 people. Its assets were three times those of General Motors; its revenues 20 times those of Bank of America. What was previously the Bell System, in conjunction with nearly 2000 independent telephone companies, make up the Public Telephone Network (PTN). The PTN was designed for voice communications. When the high-volume data communications boom hit in the early 1970s, the use of the PTN was an attractive alternative to constructing separate facilities (at tremendous cost) for data circuits. Gradually, communications systems are being developed that use fiber optic links and satellite transponders which are designed for data transmission. It will be many years before these systems provide any real relief to the already overloaded PTN.

The following explanation is limited to telecommunications using the PTN. *Telco* includes all of the telephone companies that make up the PTN. Telco offers two general categories of service: *direct distance dialing* (DDD) and *private line*. DDD originally included only those switches and facilities required to complete a long-distance telephone call without the assistance of a Telco operator. The DDD now includes the entire public switched network; that is, any service associated with a telephone number. Private-line services are dedicated to a single user.

DDD NETWORK

The DDD network, commonly referred to as the *dial-up* or *switched network*, imposes several limitations that must be overcome before it can be used for data communications. A basic understanding of the electrical operation of the telephone network would be helpful. The DDD network can be divided into four main sections: instruments, dial switches, local loops, and trunk circuits. An *instrument* is the device used to originate and receive signals, such as a telephone set (telset). The instrument is often referred to as *station equipment* and the location of the instrument as the *station*. A *dial switch* is a programmed matrix that provides a temporary signal path. A *local loop* is the dedicated transmission path between an instrument and the nearest dial switch. A *trunk circuit* is a transmission path between two dial switches. The dial switches are located in Telco central offices and are categorized as local, tandem, or toll. A *local* dial switch serves a limited area. The size of the area is determined by how many telephone numbers are required or desired in a given geographical area. Telco designates these areas as branch area exchanges. A branch exchange is a dial switch. The *subscriber* is the operator or user of the instrument: if you have a home telephone, you are a subscriber. A subscriber is the customer of Telco: the person placing the call. Telco refers to this person as either the talker or the listener, depending on their role at a particular time during a conversation.

A telephone number consists of seven digits. The first three digits make up the prefix while the last four constitute the extension number. Each prefix can accommodate 10,000 telephone numbers (0000 to 9999). The capacity of a dial switch is determined by how many prefixes it serves. The local dial switch provides a two-wire cable (local loop) for each telephone number it serves (Figure 1–1). One wire is designated the *tip* and the other the *ring*. The station end of the loop is terminated in a telephone set. The dial switch applies -48 V dc on the tip and a ground on the ring of each loop. This dc voltage is used for supervisory signaling and to provide a talk battery for the telset microphone. On-hook, off-hook, and dial pulsing are examples of supervisory signaling.

When a subscriber goes off-hook (lifts the handset off the teleset cradle), a switch hook is released, completing a dc short between the tip and the ring of the loop through the telset microphone. The dial switch senses a dc current in the loop and recognizes this as an off-hook condition. This procedure is referred to as a *loop start operation*: the loop is completed to indicate an off-hook condition. The dial switch responds with an audible dial tone. On hearing the dial tone, the subscriber dials the destination telephone number. The originating and destination telephone numbers are referred to as the *calling* and the *called numbers*, respectively.

Dialing is accomplished with switch closures (dial pulses) or touch-tone signaling. Dial pulsing is the interruption of the dc loop current by a telset dialing

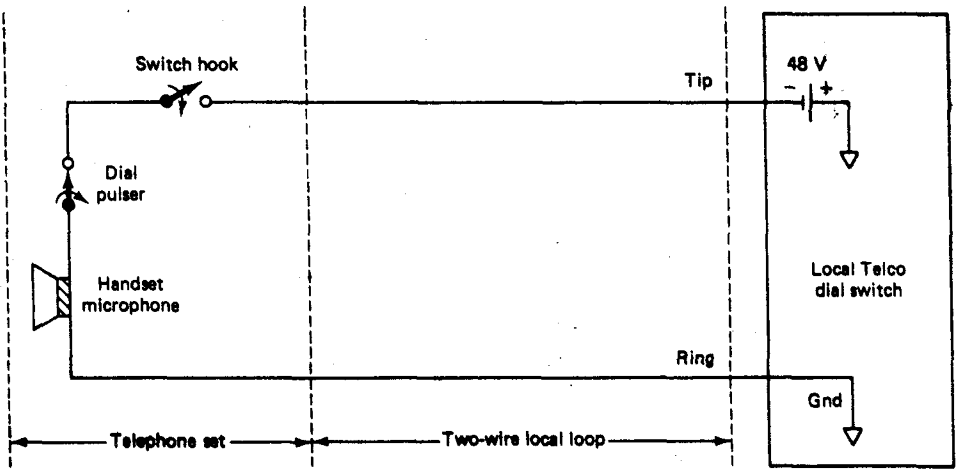

Figure 1–1 Simplified two-wire loop showing telset hookup to a local dial switch (loop start operation).

mechanism. Eight tone oscillators are contained in each telset equipped with a touch-tone pad. In touch-tone signaling, depending on the digit depressed, the telset outputs two of the eight tone frequencies.

After the entire called number has been dialed, the dial switch searches for a signal path through the switching matrix to the loop associated with the number called. Once the dial switch identifies a signal path and locates the destination loop, it tests the loop for an off-hook (busy) condition. If the destination loop is busy, the dial switch signals the calling loop with a busy signal. A station busy signal is a 60-ppm buzz. If the destination loop is on-hook (idle), the dial switch applies a 20-Hz 110-V ac ringing signal to it. A typical ringing cycle is 2 seconds on, 4 seconds off. When the destination telephone is answered (goes off-hook), the dial switch terminates the ringing signal and completes the transmission path between the two loops through the matrix. The signal path through the dial switch will be maintained as long as both loops remain closed. When either instrument goes on-hook, the signal path is interrupted.

What if the calling and the called telephone numbers are not served by the same dial switch? Generally, a community is served by only one local telephone company. The community is divided into zones; each zone is served by a different dial switch. The number of zones established in a given community is determined by the number of stations served and their density. If a subscriber in one zone wishes to call a station in another zone, a minimum of two dial switches are required. The calling station receives off-hook supervision and dial pulses are outputted as previously described. The dial switch in the calling zone recognizes that the prefix of the destination telephone number is served by a different dial switch. There are two ways that the serving dial switch can complete the call. It can locate a direct trunk (interoffice) circuit to the dial switch in the destination zone or it can route the call through a tandem switch. A *tandem switch* is a switcher's switch. It is a switching matrix used to interconnect dial switches. Trunk circuits that terminate in tandem switches are called *tandem trunks*. Normally, direct trunk circuits are provided only between adjacent zones. If a call must pass through more than one zone, a tandem switch must be used (Figure 1–2). If no direct trunks between the originating and the terminating dial switches exist and a common tandem switch is not available, the call is classified as a *toll call* and cannot be completed as dialed. Toll calls involve an additional charge and the dialed number must be preceded by a "1."

The telephone number prefix identifies which particular dial switch serves a station. With three digits, 1000 (000 to 999) prefixes can be generated for dial switches. A single metropolitan exchange alone may serve 20 to 30 prefixes. In the United States, there are over 20,000 local dial switches. It is obvious that further encoding is required to differentiate between the same prefix and extension in two different parts of the country. In the United States, an additional three-digit area code is assigned to each telephone number. The area code precedes the prefix but needs to be included only when calls are destined outside the area of the originating station. When a dialed telephone number is preceded by a "1," it is routed from the local dial switch to a toll switch by way of a *toll-connecting trunk*. Telco's present toll-switching plan

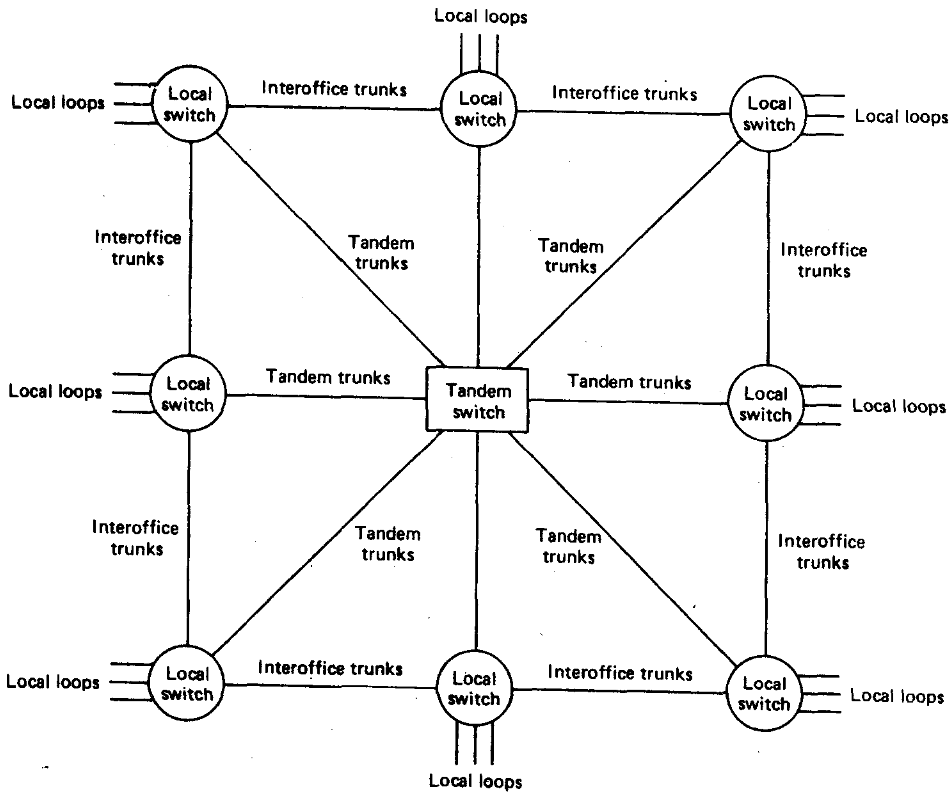

Figure 1–2 Community telephone system showing the use of a tandem switch to facilitate interzone calling.

includes five ranks or classes of switching centers. From highest to lowest classification, they are the regional center, sectional center, primary center, toll center, and end office. Local dial switches are classified as end (central) offices. All toll switches are capable of functioning as tandem switches to other toll switches.

The Telco switching plan includes a switching hierarchy that allows a certain degree of route selection when establishing a long-distance call (Figure 1–3). The choice is not offered the subscriber, but rather, the toll switches, using software translation, select the best route available at the time the call is made. The best route is not necessarily the shortest route. It is the route requiring the fewest number of dial switches. If a call cannot be completed because the necessary trunk circuits are not available, the local dial switch signals the calling station with an equipment busy signal. An equipment busy signal is similar to a station busy signal except that it repeats at a 120-ppm rate. The worst-case condition encountered when completing a long-distance call is when seven tandem toll (intertoll) trunks are required. Based on Telco statistics, the probability of this occurring is 1 in 100,000. Because software translations in the automatic switching machines permit the use of alternate routes, and each route includes many different trunk circuits, the probability of using the same facilities on identical calls is unlikely. This is an obvious disadvantage when using the PTN for data transmission because inconsistencies in the transmission parameters are introduced

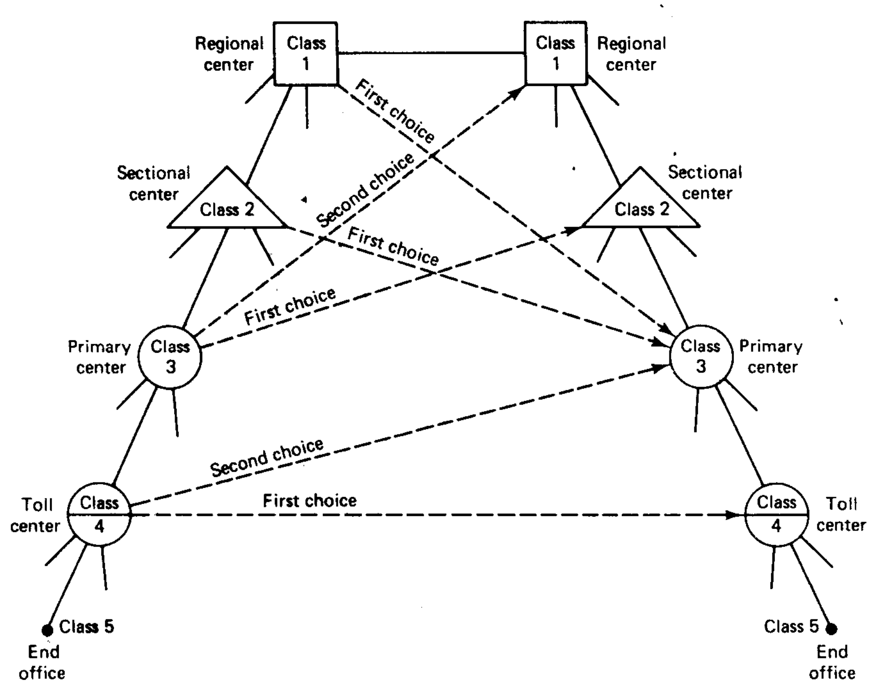

Figure 1–3 Public telephone switching hierarchy showing some possible route choices to complete a toll call between two end offices.

from call to call. Telco guarantees the transmission parameters of each local loop and trunk circuit to exceed the minimum requirements of a basic voice-grade (VG) communications channel. However, two to nine separate facilities in tandem may be required to complete a telephone call (see Figure 1–4). Since transmission impairments are additive, it is quite possible that the overall transmission parameters of a telephone connection, established through the public switched network, may be substandard. Because transmission paths vary from call to call, it is difficult to compensate for line impairments. Subscribers to the DDD network lease a dedicated loop from their station to the nearest Telco dial switch. Any additional facilities required for the subscribers to complete a call are theirs only temporarily. The subscriber uses these facilities only for the duration of the call and then they are made available for other users of the network. These temporary facilities are called *common usage trunks*—they are shared by all of the subscribers of the network.

The switching transients associated with the dial switches are another disadvantage of using the public switched network for data transmission. The older dial switches were electromechanical machines. Mechanical relay contacts were used to establish a signal path. The contact closures in the switching machines induced static interference that bled into adjacent signal paths. The static electricity caused impulse noise which produced transmission errors in the data signals. Telco is rapidly converting to *Electronic Switching Systems* (ESS). ESS machines are by no means perfectly quiet, but they are a tremendous improvement over the older electromechanical machines.

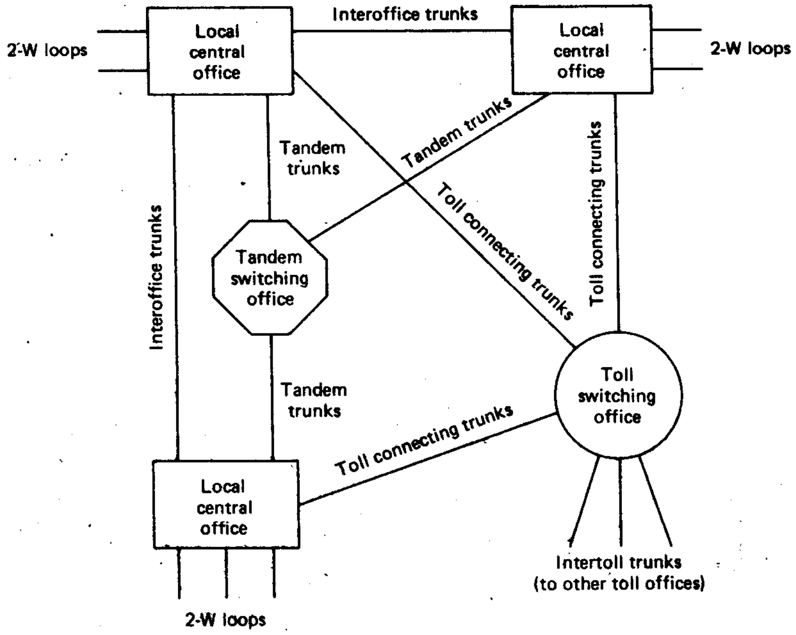

Figure 1–4 Typical switching layout showing relationship between local, tandem, and toll switches in the public telephone network.

In order for a toll call to be completed, the dialed phone number must be transferred from switch to switch. Ultimately, the switching matrix at the destination end office requires the prefix and extension numbers to establish the final connection. The transmission paths between switching machines are very often carrier systems: microwave links, coaxial cables, or digital T-carriers. Microwave links and coaxial cables use analog carriers and are ac coupled. Therefore, the traditional dc supervisory and dial pulsing techniques cannot be used. An alternate method of transferring supervisory signals using a *single-frequency (SF) tone* has been devised. An idle trunk circuit has a 2600-Hz SF tone present in both directions. An off-hook indication at either end is indicated by the removal of the SF tone. The receiving switch acknowledges the off-hook indication by removing the SF in the opposite direction. Two methods are available for dial pulsing. The SF tone can be pulsed on and off to represent the dialed number or a signaling method called *multifrequency (MF) signaling* can be used. MF is a two-of-six code similar to touch tone. However, the MF tone frequencies are higher and are transmitted at a faster rate. Touch tone and MF are not compatible. Digital T-carriers use a completely different method for transferring supervisory information. This method is explained in Chapter 9.

Hybrids and echo suppressors. Local loops (dial-up lines) consist of a two-wire pair (signal and ground). However, to achieve satisfactory long-distance performance, the telephone company found it necessary to provide four-wire circuits (see Figure 1–5). When two-wire loops are switched onto four-wire facilities as in a long-distance telephone call, an impedance-matching device called a *hybrid* or *terminating set* (Figure 1–6) is used to affect the interface.

The hybrid coil transfers the signal from the two- to the four-wire line. The balancing network compensates for impedance variations in the two-wire portion of the circuit. The amplifiers and attenuators adjust the signal voltages to required levels. Signals traveling W-E enter the terminating set from the two-wire loop and are inductively coupled into the W-E portion of the four-wire trunk. Signals received from the E-W portion of the four-wire trunk are applied to the center taps of the hybrid coils. If the impedance of the two-wire loop and the balancing network are properly matched, all currents produced by the E-W signal in the upper half of the hybrid coil will be equal and in opposite directions. Therefore, any voltages induced in the secondaries will cancel. This prevents any received signal from being returned to the sender.

If the impedance of the two-wire loop and the balancing network are not matched, the voltages induced in the secondaries of the hybrid coil do not cancel completely. This imbalance causes a portion of the received signal to be returned to the sender on the W-

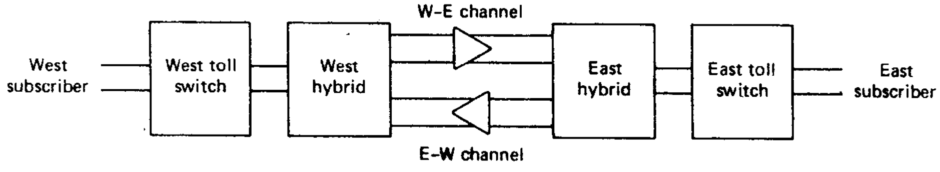

Figure 1–5 Simplified diagram of a long-distance telephone connection.

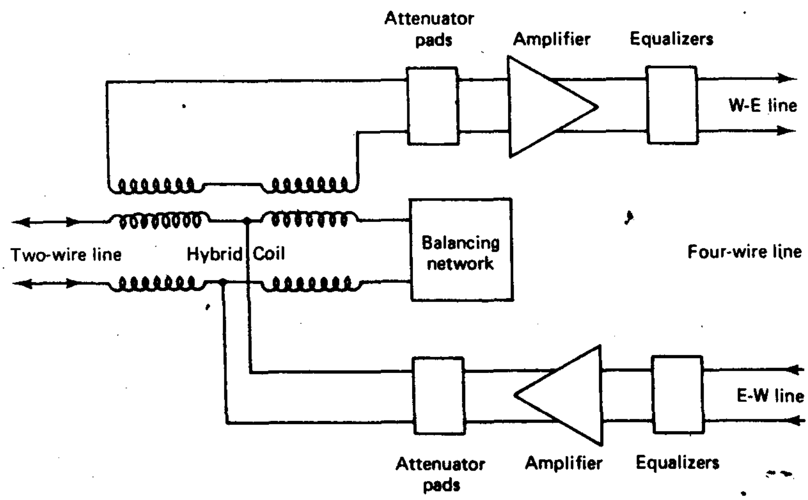

Figure 1–6 Two wire-to-four wire terminating set (hybrid).

E portion of the four-wire trunk. The returned portion of the signal is heard as an echo by the talker and, if the round-trip delay of this signal exceeds 45 ms. the echo can become quite annoying. Delays of this magnitude occur when the distance between the two telephones exceeds 1500 miles. *Echo suppressors* (Figure 1–7) are inserted at one end of a four-wire trunk circuit to eliminate this echo. The speech detector in the echo suppressor senses the presence and the direction of the signal. It then enables the appropriate amplifier and disables the amplifier for the opposite direction. With an echo suppressor in the circuit, the two parties cannot talk simultaneously. If the conversation is changing rapidly, the people talking may hear the echo suppressor turning on and off.

The telephone lines are not only used for voice but also for the transmission of digital information. When used in this manner (Chapter 9), simultaneous transmission of digital information in both directions is often desired. To accommodate this form of transmission, the telephone company has equipped the echo suppressors with a disabling mechanism. A single-frequency tone in the range 2010 to 2240 Hz, if applied for a period of 400 ms or longer, will disable the echo suppressor—both amplifiers will be enabled. The echo suppressor will remain disabled as long as signals in the 300- to 3000-Hz band are transmitted in either direction. If this signal is interrupted for 50 ms or more, the echo suppressor will automatically become active again.

PRIVATE-LINE SERVICE

In addition to subscriptions to the public switched telephone network, Telco offers a comprehensive assortment of private-line services. Private-line subscribers lease those facilities required for a complete circuit. These facilities are hard-wired together in the Telco offices and are available only to one subscriber. Private-line circuits are

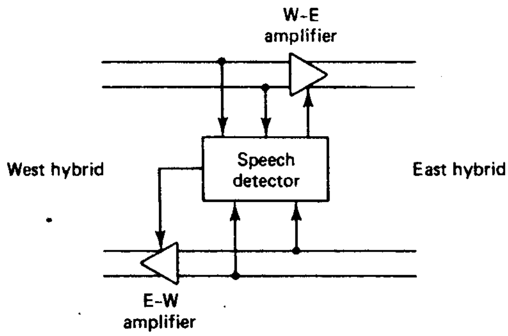

Figure 1–7 Echo suppressor.

dedicated, private, leased facilities. A dedicated circuit can be designed to meet voice-grade requirements from station to station—the end-to-end transmission parameters are fixed at the time the circuit is installed and will remain relatively constant. Circuit impairments will also remain relatively constant and can be compensated for by the subscriber. Private-line circuits afford several advantages over conventional dial-up circuits:

1. Availability
2. Improved performance
3. Greater reliability
4. Lower cost

Since private-line circuits are leased on a 24-hour basis, they are always available to the subscriber. Because the transmission parameters on a private-line circuit are guaranteed end to end, the overall performance is improved and a more reliable communications link is established. Heavy-usage private-line circuits are more economical than dial-ups. However, dial-ups are more cost-effective for a person using the lines only a small percentage of the time.

Private-line circuit arrangements differ from dial-ups only in the fact that their circuits are permanently connected and dial switches and common-usage trunks are unnecessary. The terms "local loop" and "trunk" have a slightly different meaning to private-line subscribers. On a private-line circuit, a local loop is a transmission path between an instrument and the nearest Telco office; a trunk circuit is a transmission path between two Telco offices (see Figure 1–8). The only change in the definition is the substitution of "Telco office" for "dial switch."

Examples of private-line offerings:

1. Foreign exchange (FX)
2. Full data (FD)
3. Full period (FP)
4. Digital data service (DDS)

FX circuits differ from conventional DDD subscriptions only in the fact that subscribers, instead of leasing a dedicated loop to the nearest dial switch, lease a loop to a dial switch of their choice. This facilitates toll-free interzone calling to specific zones.

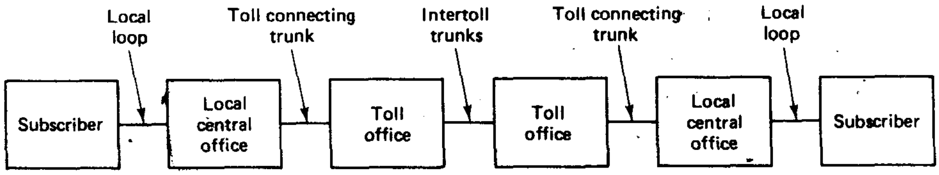

Figure 1–8 Simplified private-line circuit layout showing dedicated loops and trunks with hard-wired cross-connects in each Telco office (two-point circuit).

FD circuits are four-wire, dedicated data circuits capable of full-duplex operation at a data rate of 9600 bps (bits per second). A local bank's system of automatic teller machines is an example of an FD circuit. FP circuits are four-wire, dedicated voice circuits. The hoot-and-holler (yell-down) circuits used by auto dismantlers (previously called "junkyards") to locate used auto parts is an example of an FP circuit. DDS circuits provide two-point, full-duplex operation at synchronous data rates of 2.4, 4.8, 9.6, or 56 kbps. DDS is intended to provide a communications medium for the transfer of digital data from station to station. Conventional digital-to-analog data modems are replaced by digital-to-digital communications service units (CSUs). DDS circuits are guaranteed to average 99.5% error-free seconds at 56 kbps, and even better performance is achieved at the lower bit rates.

QUESTIONS

1. Identify the four main sections that make up the DDD network.
2. What determines the capacity of a dial switch?
3. List three examples of supervisory signals.
4. Explain loop start operation.
5. Identify two methods by which dialing may be accomplished with a telephone set.
6. What is a tandem switch called?
7. How many unique telephone numbers can a three-digit prefix accommodate?
8. Identify when the three-digit area code must be included when dialing a number.
9. How does a local dial switch identify a toll call?
10. List the five classes of Telco's present switching plan.
11. The best route between an originating and a destination station is always the shortest route. (T, F)
12. Explain the difference between an equipment busy signal and a station busy signal.
13. What is the predominant disadvantage of using the DDD network for data transmission?
14. Identify two methods of transferring supervisory signals over analog carrier systems.
15. Local loops are two-wire facilities. (T, F)
16. Identify the Telco device that performs two- wire to four-wire conversion.
17. What is the purpose of an echo suppressor?
18. When are echo suppressors required?
19. Private-line circuits are dedicated to a single user. (T, F)
20. Identify four advantages of a private-line circuit compared to a dial-up circuit.