UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Electrification Administration

BULLETIN 1751H-403

SUBJECT: **Digital Transmission Fundamentals**

TO: Telephone Borrowers
REA Telephone Staff

EXPIRATION DATE: Three years from the effective date.

EFFECTIVE DATE: Date of Approval

OFFICE OF PRIMARY INTEREST: Transmission Branch, Telecommunications Staff Division

PREVIOUS INSTRUCTIONS: None - this bulletin replaces TE&CM 950 and TE&CM 951.

FILING INSTRUCTIONS: Discard the following Telecommunications Engineering & Construction Manual (TE&CMs) Sections:

1) TE&CM 950 - Digital Transmission Systems
2) TE&CM 951 - Digital Transmission Terminology

Replace the above TE&CM Sections with this bulletin.

PURPOSE: To provide basic information on digital transmission theory, fundamentals and equipment to REA borrowers, consulting engineers and other interested parties. This bulletin assumes little or no prior knowledge of digital systems and is tutorial in nature. A glossary of terms related to digital transmission appears in Section 9, Digital Transmission Terminology.

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Acting Administrator

07/02/91
Date

DIGITAL TRANSMISSION FUNDAMENTALS

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FIGURES & TABLES

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ABBREVIATIONS & DEFINITIONS:

The acronyms and abbreviations used in this document are explained below. Definitions for these and other terms applicable to digital transmission in general are in Section 9, Digital Transmission Terminology.

A/D: Analog to Digital

AMI: Alternate Mark Inversion

APS: Automatic Protection Switch

B8ZS: Bipolar with 8 Zero Substitution

BCD: Binary Coded Decimal

BPV: Bipolar Violation

b/s: bits per second

CO: Central Office

CPE: Customer Premises Equipment

D/A: Digital to Analog

DS0: Digital Signal Level 0 (64 kb/s)

DS1: Digital Signal Level 1 (1.544 Mb/s)

DS2: Digital Signal Level 2 (6.312 Mb/s)

DS3: Digital Signal Level 3 (44.736 Mb/s)

DSX: Digital Signal Cross-connect

ESF: Extended Superframe Format

F-Bit: Framing Bit

FEXT: Far End Crosstalk

Gb: Gigabit (10^9 bits)

Gb/s: Gigabits per second

Hz: Hertz (cycles per second)

IXC: Interexchange Carrier

kb: kilobit (10^3 bits)

kb/s: kilobits per second

kHz: kilohertz

km: kilometer

LEC: Local Exchange Carrier

LSB: Least Significant Bit

MHz: Megahertz (10^6 Hz)

modem: modulator/demodulator

MSB: Most Significant Bit

mux: multiplexer

NEXT: Near End Crosstalk

PAM: Pulse Amplitude Modulation

PCM: Pulse Coded Modulation

RF: Radio Frequency

S/N: Signal to Noise Ratio

SF: Superframe

SS7: Signaling System No. 7

T1: Digital 4-wire metallic transmission at DS1

TDM: Time Division Multiplexing

μsec: microsecond (10^{-6} seconds)

VF: Voice Frequency

ZBTSI: Zero Byte Time Slot Interchange

1. INTRODUCTION & HISTORY OF DIGITAL COMMUNICATIONS

1.1 The theory of transmitting voice signals via digital transmission emerged in the late 1930s. Alec Reeves of the International Telegraph and Telephone Corporation (ITT) in Europe developed this principle in 1937 and termed it pulse code modulation, or PCM carrier. However, appropriate technology did not then exist with the capability that Reeves' theory required.

1.2 The first major technological breakthrough that paved the way for actual PCM transmission was the development of the transistor by researchers Bardeen, Brattain and Shockley of the Bell Telephone Laboratories in 1947. The transistor permitted the type of high-speed switching (without the excessive heat and the large size of vacuum tubes) that Reeves' theory required in order to convert and transmit digitized voice signals accurately. Subsequent efforts by Jack Kilby of Texas Instruments and Robert Noyce of Fairchild in the late 1950s resulted in the later development of integrated circuits which provided a more optimal packaging for the numerous transistors and other components required for digital signal processing.

1.3 In 1956 Bell Laboratories began the development of the first commercial PCM system for telecommunications purposes. It was not until 1962 that a commercial digital transmission system was deployed to carry actual telephone traffic at the Bell Telephone Company of Ohio in Akron. Additional PCM development continued into the 1960s and 1970s. PCM carrier was deployed initially for toll purposes but eventually saw use in the exchange plant as well. The same PCM principles were later used as the basis for digital central office (CO) switches.

1.4 REA borrowers significantly began using digital PCM carrier systems for interoffice trunk circuits in the late 1960s when this equipment was placed on the *REA List of Materials*. Systems designed for loop exchange use, presently known as digital loop carrier, became available in the early 1970s and are seeing increasing use as borrowers seek to improve quality, lower costs, shorten loop lengths and provision plant capable of providing modern services.

1.5 One very significant benefit arose from the use of PCM carrier transmission. This was improved audio quality. Particularly for toll connections, traditional analog voice frequency (VF) circuits produced increasing noise as the distance increased, sometimes requiring callers to shout or talk at high sound levels in order to be heard at the far end. Digital transmission quality is generally insensitive to distance in that the signals are not merely amplified along with ever increasing circuit noise, but are regenerated at regular intervals. Other benefits of digital over analog transmission include increased immunity to interference, simpler electronic circuit design and lower maintenance costs. All of these characteristic make digital transmission preferable to analog transmission.

2. ANALOG TO DIGITAL SIGNAL CONVERSION

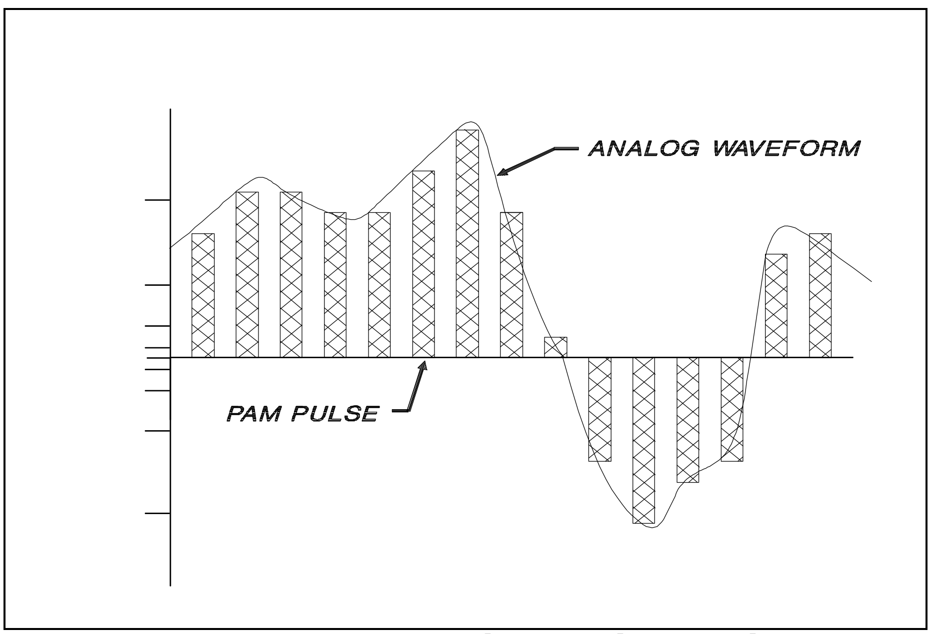
2.1 The principals of PCM carrier largely revolve around the conversion of the analog signals into digital signals, or the A/D conversion. The process also operates in the reverse direction, known as D/A, representing the conversion of the digital signals back into analog signals.

2.2 The A/D conversion for telecommunications purposes is performed by channel banks. The Western Electric Company, following the research performed by Bell Labs, built the first channel banks in the U.S. around 1960. They were designated D1. Subsequent versions using improved technology were designated D2, D3, D4 and D5. The latter two are considered current technology. (Additional detail on channel banks is located in REA Bulletin 1751H-405.)

2.3 The A/D conversion consists of two separate steps: 1) the sampling or measurement of the analog waveform level at periodic intervals and 2) the conversion of these measurements into binary numbers. In this manner the analog signal can be transmitted in digital format and then converted back into an analog signal. Earlier digital equipment performed these functions in two discrete steps; more modern equipment performs the A/D and D/A conversions in a single operation.

2.4 A graphical depiction of how the analog waveform is sampled and converted into repetitive pulses is shown in Figure 1. This stage of the A/D process is known as pulse amplitude modulation or PAM. Pulses of varying magnitudes spaced at regular intervals represent the analog signal. Both the sampling frequency and the height of the individual pulses contain the characteristics of the analog waveform.

FIGURE 1
PULSE AMPLITUDE SAMPLING OF AN ANALOG WAVEFORM



2.5 The rate or frequency at which an analog signal is sampled (or, how many PAM pulses are used) is critical to how much information is retained from the analog signal in the A/D conversion process. A theorem developed in the 1920s by H. Nyquist, a mathematician, shows that an analog signal can be faithfully reconstructed if the analog signal is sampled at a rate equal to or greater than two times the highest frequency contained in the analog signal. This is known as the Nyquist Theorem. For example, in order to represent a nominal 4 kHz bandwidth of a telecommunications voice circuit accurately, the waveform must be sampled at a rate of 8 kHz, or 8,000 times per second.

2.6 Once the analog waveform has been sampled, the magnitude or height of each pulse is determined; these are then converted from a decimal-encoded measurement to a binary-encoded number. In other words, the PAM-encoded voice signal is converted to a PCM-encoded voice signal. It is exactly at this stage in the process where the actual A/D conversion takes place, when the various pulse magnitudes are converted from a Base 10 number to a Base 2 number.

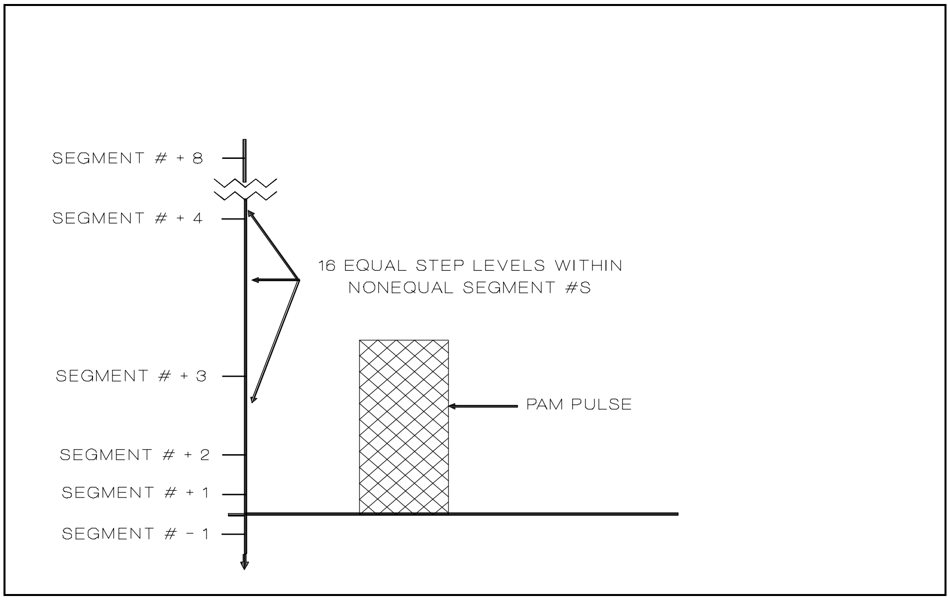
2.7 The height of each PAM pulse is electronically measured against a form of "yardstick" with an unconventional scale. The yardstick has a nonlinear scale, where the spaces between divisions varies depending upon their location along the yardstick. This is in contrast to a conventional ruler where the distance between inches is uniform, regardless of whether one is examining inch one or inch twelve. The reason for a nonlinear scale is that it affords better analog signal representation while minimizing the amount of data that has to be collected. Essentially, it results in less noise and distortion than use of a linear encoding scale at the same information rate.

2.8 The yardstick used to measure PAM pulses in North America and Japan is known as µ255, or the Mu-law. This is because it has a total of 255 gradations or divisions along its scale for representing the PAM pulses.[1] To represent the positive portion of an analog waveform, 8 *segments* extend upward from the zero line. Each segment has within it finer divisions of 16 equally spaced *steps*. Likewise, to represent the negative portions of a waveform, there are an equal number of segments and steps in the negative direction downward from the zero line. Thus, a total of 16 segments exist. The segments and steps can be viewed as somewhat comparable to the divisions of feet and inches, respectively, on a yardstick *except* that the µ255 scale is nonlinear. Figure 2 depicts the µ255 scale.

2.9 As Figure 2 shows, the µ255 scale has finer-spaced divisions at the lower signal levels where most of the analog signal, and consequently the PAM samples, reside. The coarser-spaced divisions are at the higher signal levels (both positive and negative). The nonlinear scale results in a compression of the signal which provides two advantages: 1) it requires less bandwidth, and 2) it improves the signal-to-noise ratio (S/N).

[1] With respect to international facilities, the rest of the world's telecommunication's facilities mostly use a similar, but different, segment encoding law. This is known as the A-law. International traffic from and to the U.S. must undergo a conversion from one to the other for proper decoding.

FIGURE 2
µ255 ENCODING SCALE



2.10 The magnitude of each PAM pulse measured according to the Mu-law is stored in binary form using an 8-bit digital word. As mentioned, this is where the actual conversion occurs of the analog signal into a digital format. The 8-bit word is shown in Figure 3.

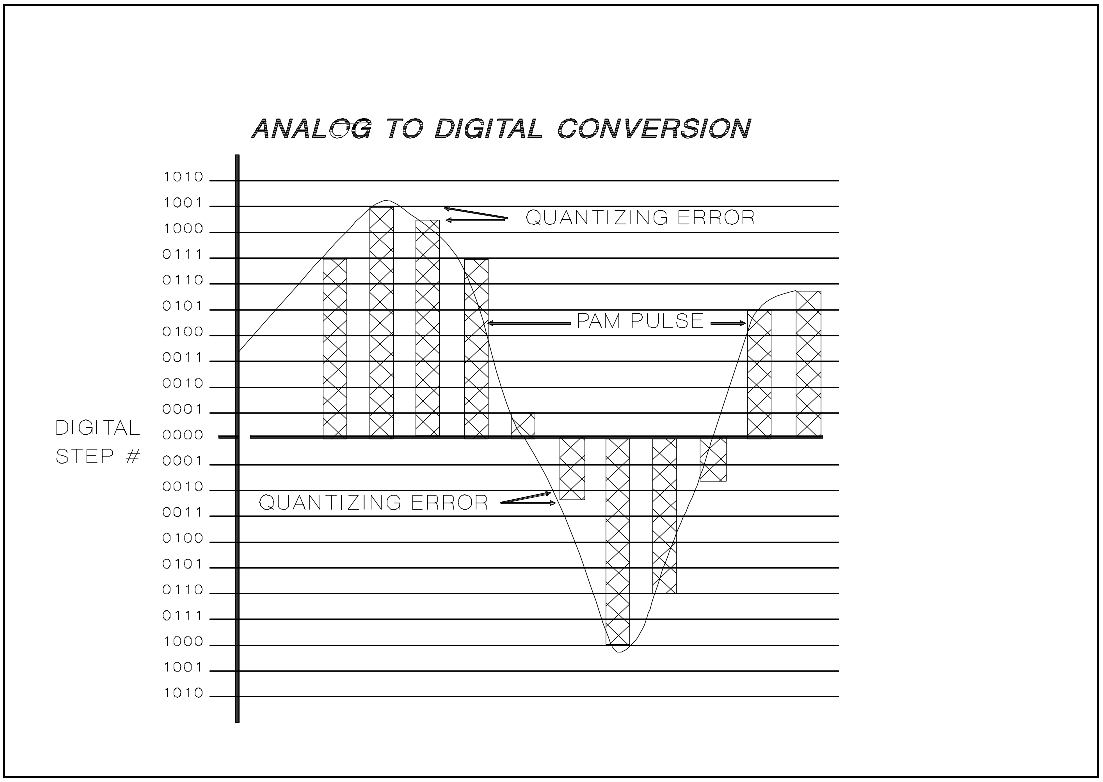
FIGURE 3
EIGHT BIT DIGITAL WORD

BIT #1	BIT #2	BIT #3	BIT #4	BIT #5	BIT #6	BIT #7	BIT #8
POSITIVE OR NEGATIVE	THREE BIT SEGMENT NUMBER			FOUR BIT STEP NUMBER			

2.11 The 8-bit word has three basic components. The first is located at bit position #1, which indicates whether the PAM pulse (as well as the analog signal) is positive or negative, represented by a 1 or 0, respectively. The second component includes bit positions #2 through #4 to indicate the segment number (out of eight possibilities) where the pulse lies. The remaining four bit positions specify the pulse magnitude in further detail; they indicate the particular step out of 16 possible steps within the noted segment.

2.12 Given that no measurement system is entirely perfect, some error is introduced into the digital representation of the analog signal. This error is referred to as quantizing error and can result in audible distortion, if excessive. In most instances the error is negligible and not noticeable to the human ear. Quantizing errors occur when the magnitude of the PAM pulse is imprecisely converted to a numeric value. For example, should the height of the pulse lie between two step positions on the µ255 scale, the signal will be read to the nearest step position. The quantizing error is the difference between the pulse's actual magnitude and its recorded magnitude. Figure 4 shows several pulses located between step levels within a single segment, and the quantizing errors that result from the difference between the actual pulse heights and their recorded values.

FIGURE 4
QUANTIZING ERROR



3. DIGITAL HIERARCHY

3.1 The Nyquist Theorem discussed in Section 2 states that a 4 kHz analog VF signal needs to be sampled at a rate of 8,000 times per second in order to be accurately represented. Given that each sample is represented in binary form by an 8-bit word, this results in a bit rate of 64,000 bits per second, or 64 kb/s, for each voice channel. A single digitized voice channel at 64 kb/s is known as Digital Signal Level 0, or DS0.

3.2 Because digital or PCM transmission equipment evolved in North America on the basis of a unit capacity of 24 voice channels or 24-DS0s, higher order digital signals were constructed from that basic building block.[2] The 24-DS0s at 64 kb/s each when combined, or multiplexed, gives a bit rate of 1,536,000 b/s, or 1.536 Mb/s. An additional 8,000 bits per second were required for organizational and timing purposes. The result is that the multiplexed transmission of 24-DS0 channels required an overall bit rate of 1,544,000 b/s, or 1.544 Mb/s. This bit rate was denoted Digital Signal Level 1, or DS1. It is also referred to as T1 when transmitted over metallic facilities. DS1s can be further combined with other DS1s to give higher bit rate digital signals. The structure of DS0, DS1 and higher order digital signals is known as the digital hierarchy. It is represented below in Table 1.

TABLE 1
DIGITAL HIERARCHY

DIGITAL SIGNAL	DIGITAL BIT RATE LEVEL CIRCUITS	EQUIVALENT # OF VF (DS0)

[2] Japan and Australia also use the 24-channel T1 format. In the remainder of the world, the 32-channel E1 format is used where the signaling and synchronization information is carried out of band in separate channels.

	DS0	64 kb/s	1
DS1	1.544 Mb/s	24	
DS2	6.312 Mb/s	96	
DS3	44.736 Mb/s	672	
DS4	274.17 Mb/s	4,032	

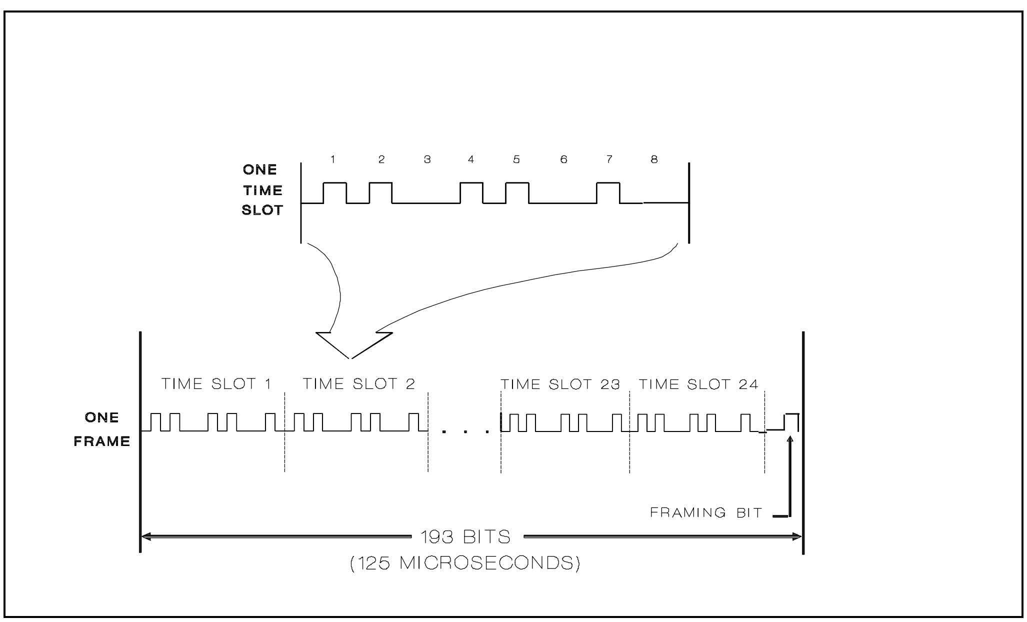
3.3 Multiplexers (sometimes called muxes) combine digital signals at a lower bit rate from the digital hierarchy into digital signals at a higher bit rate in the digital hierarchy. They are typically designated as Mxy, where the x indicates the digital signal's incoming bit rate and the y designates the digital signal's outgoing, or higher, bit rate. For example, a commonly used multiplexer is designated M13. It combines 28-DS1 signals into one DS3 bitstream. Channel banks, in addition to performing A/D and D/A conversions, also function as multiplexers, but generally only from the DS0 rate to the DS1 rate.

4. DIGITAL FRAMING

4.1 As Section 3 explains, multiple 64 kb/s voice channels are multiplexed and transmitted at DS1 or higher bit rates. To facilitate the conversion of each DS0 channel back into its analog form, the multiplexing process must be carefully structured and synchronized so that the information transmitted as channel 1 out of 24 channels will be received as channel 1 and not channel 5 or channel 18, or even portions of other channels. This organizational structure for the bitstream is known as framing.

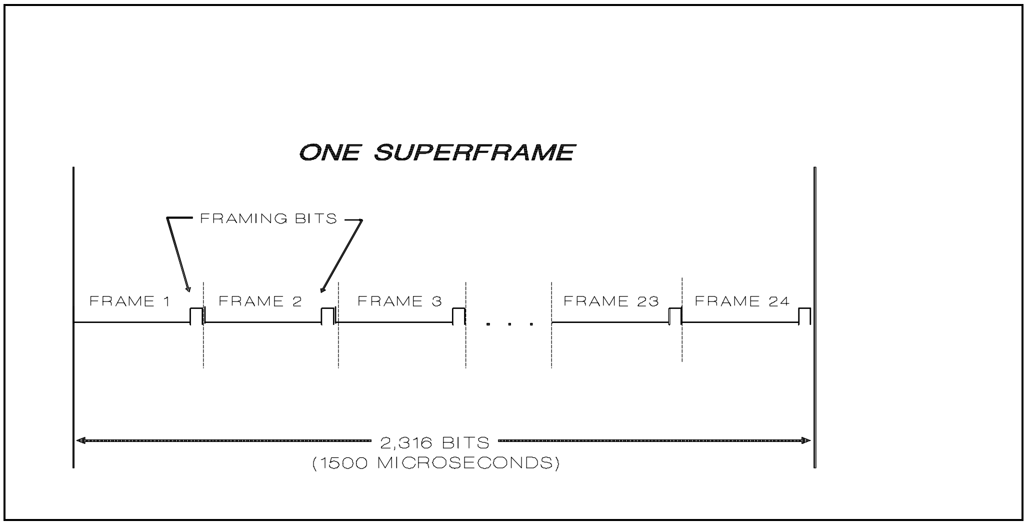
4.2 The basic form of standardized framing is known as D4 framing, after the current technology of channel banks. Each frame contains 24 time slots, or 24-64 kb/s DS0 channels of 8-bit words. In order to precisely identify the beginning of each frame, it is marked just after time slot #1 with a framing or F-bit in the 193rd bit position. Consequently, each frame consists of 193 bits (192 bits from 24 8-bit words plus the F-bit). Figure 5 illustrates this organization. Because each voice channel is sampled 8,000 times per second, the frame with 193 bits is transmitted in 1/8000 second, or 125 µsec (125 x 10^{-6} seconds).

FIGURE 5
D4 FRAMING



4.3 The basic D4 frame is further organized into what are known as D4 superframes. A single superframe contains 12 standard frames, each frame followed by its own F-bit. The superframe contains 2,316 bits which result from 12 frames of 193 bits each. A D4 superframe is shown in Figure 6.

FIGURE 6
D4 SUPERFRAME

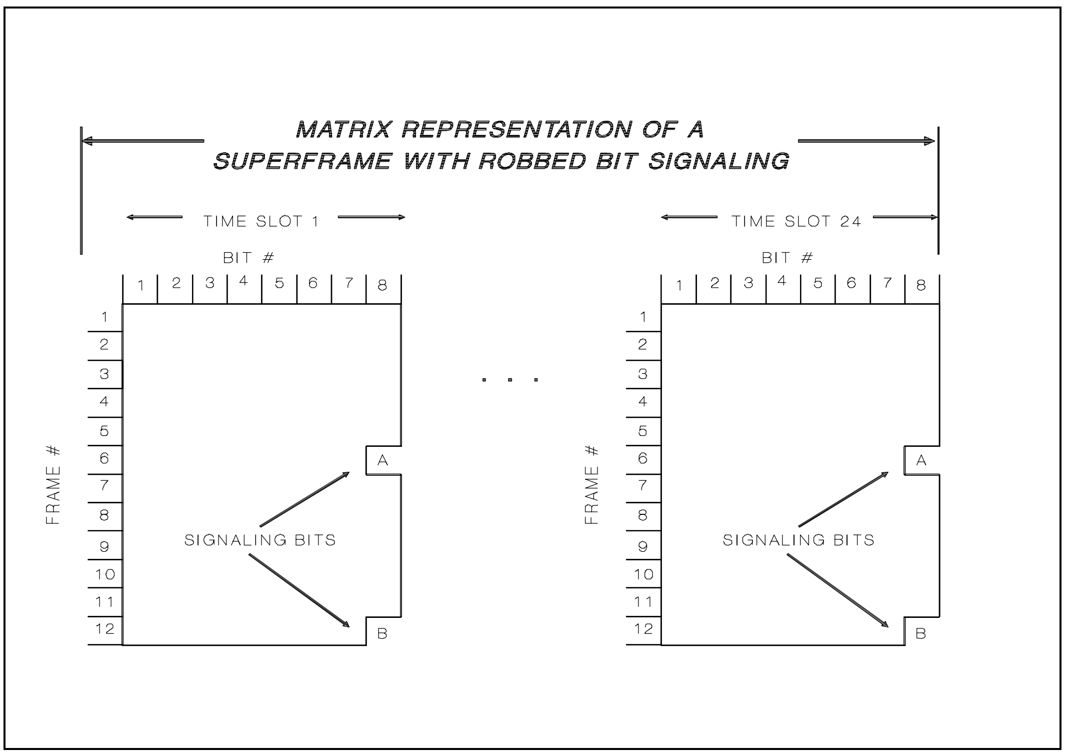


5. SIGNALING

5.1 Although a digital voice channel provides a complete communications path, it does not offer a continuous metallic path from the CO to the customer premises equipment (CPE) or telephone. Consequently, some other means to provide signaling information is required. Signaling information includes initiating ringing current for the CPE and detecting off-hook/on-hook status for both dialing and busy identification. To provide this information within each individual digital voice channel, a small number of signaling bits are employed. These bits, in effect, are "robbed" from those bits used to represent the analog voice signal in digital form. Thus, this concept is known as robbed bit signaling.

5.2 Because the robbed bits are taken from the digital representation of the analog signal in each channel, an effort was made to minimize any degradation in voice quality. To do so, the bits with the least amount of digital information are used. These bits are known as the least significant bits, or LSB. The LSB is bit position #8 of the 8-bit word shown in Figure 3. Only two bits per channel per superframe are used; one in the 6th frame and one in the 12th frame. This amounts to 48 bits per 2,316 bit superframe. The 6th frame bit is called the A-bit and the 12th frame bit is called the B-bit. These two bits (with binary numbering) permit four different signaling states to be represented. Figure 7 is a matrix illustration of the robbed bits.

FIGURE 7
ROBBED BIT SIGNALING

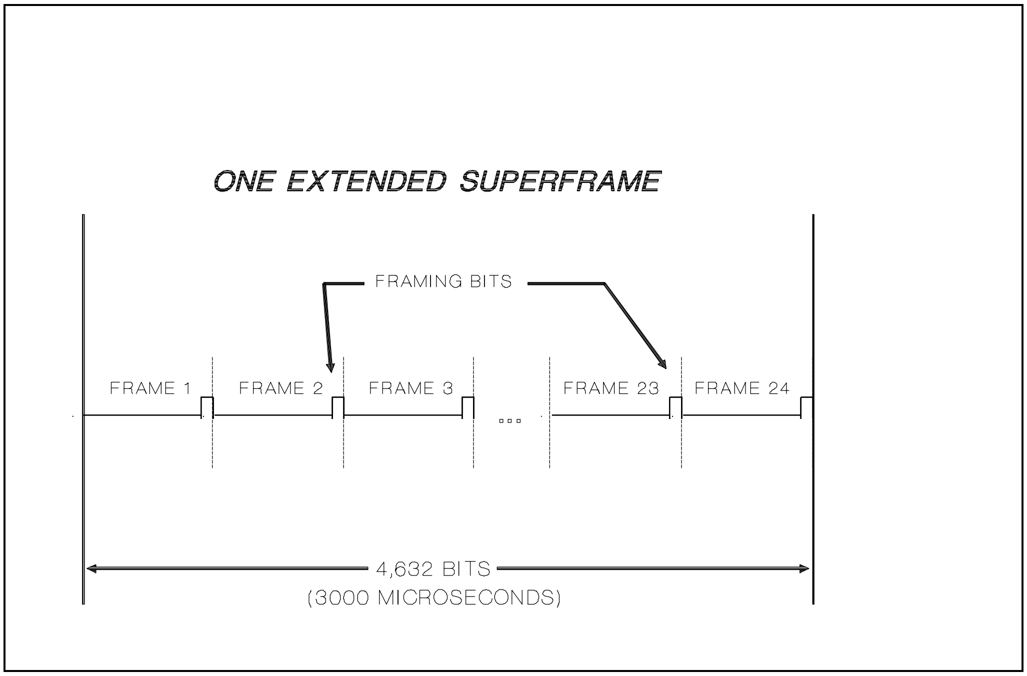


6. EXTENDED SUPERFRAME FORMAT

6.1 The superframe format (SF) that was developed for organizing a DS1 bitstream was further improved in the early 1980s by AT&T in order to provide additional bits for signaling and communication links. Because channel bank technology at that time was more mature and sophisticated, proper synchronization was possible with fewer framing bits than were required with SF framing at the time of its development. This freed up the unneeded framing bits for other purposes.

6.2 The new DS1 framing format became known as the Extended Superframe Format, or ESF. A single ESF frame contains 24 standard frames, as compared with 12 frames for SF. This improvement results in only 2,000 b/s needed for synchronization, whereas SF requires 8,000 b/s, giving a savings of 6,000 b/s for new or special features. These features include performance monitoring, control and data links transmitted outside the 24-DS0 channels. Figure 8 diagrams an ESF frame.

FIGURE 8
ESF FORMAT



6.3 Although ESF was developed by one particular vendor, its benefits have been widely recognized. Consequently, ESF framing has been adopted and incorporated in the equipment of various manufacturers of channel banks and customer T1 equipment. Many interexchange carriers (IXCs) and local exchange carriers (LECs) have also adopted this format for network interfaces. Two somewhat different versions of ESF have evolved, however. The differences pertain to how performance monitoring data is made available over the 6 kb/s communications path.[3]

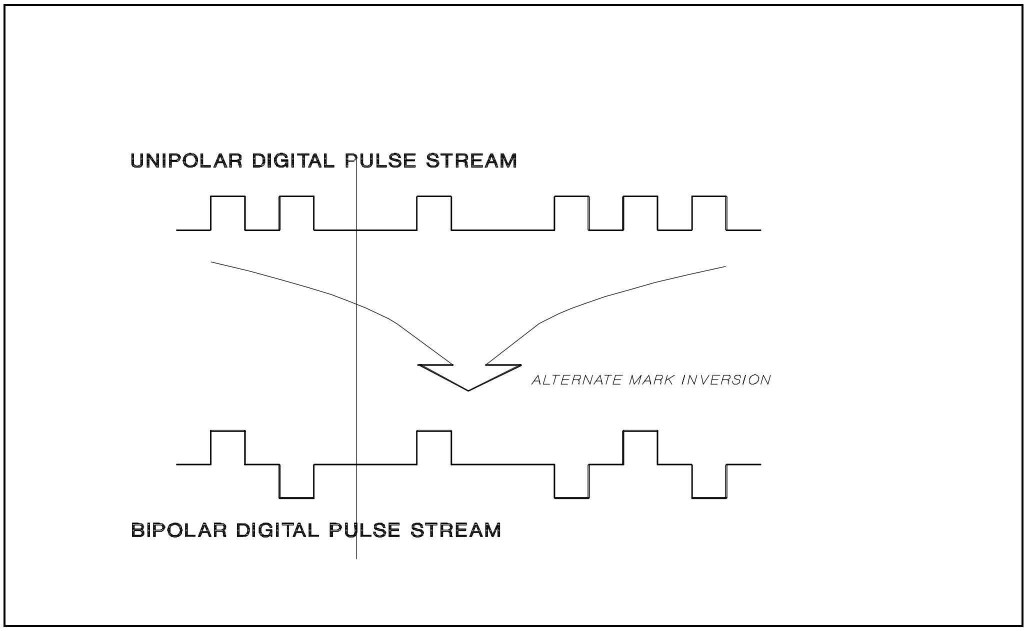
7. LINE CODING & TRANSMISSION REQUIREMENTS

7.1 Line coding is the translation of the digital information in binary format into a specific code, while retaining the PCM information content, in order to optimize its transmission over a particular medium, such as copper wire, optical fiber or radio waves. Because digital telecommunications signals were originally designed to be transported over metallic cable facilities, a line code was chosen that was appropriate to that medium. The code selected was alternate mark inversion, or AMI.

7.2 AMI is a relatively simple code. It merely requires that the ones pulses alternate in polarity from positive to negative. Zeros are unaffected. This process also can be described as the conversion of unipolar pulses to bipolar pulses. Figure 9 shows this conversion.

FIGURE 9
ALTERNATE MARK INVERSION

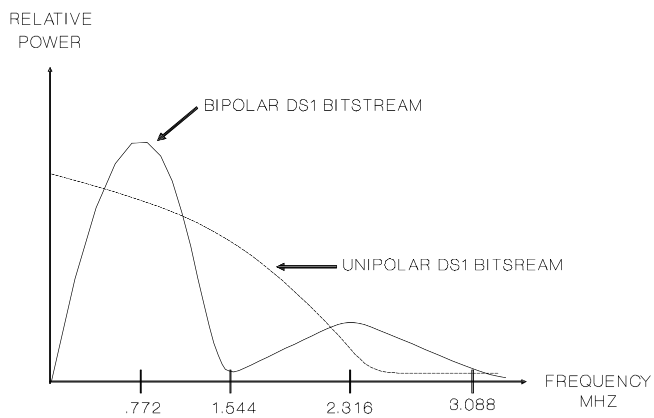
[3] The two different means for providing performance monitoring through ESF framing are addressed in: 1) AT&T Technical Publication # 54016, *Requirements for Interfacing Digital Terminal Equipment for Services Employing the Extended Superframe Format*, and 2) ANSI Telecommunications Standard T1.403-1989, *Carrier-to-Customer Installation - DS1 Metallic Interface*.



7.3 There are several reasons the AMI code is preferable to a standard unipolar signal for transmission over metallic plant. First of all, the conversion to bipolar causes the signal's spectral energy peak to be approximately halved, from 1.544 Mhz to 772 kHz. Figure 10 shows the change in frequency spectrum. The lowering of frequencies reduces the signal attentuation caused by the cable plant.

7.4 Secondly, the bipolar signal eliminates the DC voltage component in the bitstream. This facilitates the separation of the high frequency digital signal and the DC voltage which is applied to the copper pairs for powering of repeaters. Lastly, the alternating positive and negative pulses provide a convenient means for a rudimentary form of error checking. Should a timing loss occur and a ones pulse be lost or gained, equipment can recognize the error through the occurrence of two consecutive *nonalternating* pulse polarities, otherwise known as bipolar violations, or BPVs. Of course, if two consecutive pulses were lost, or any even number of consecutive pulses, the AMI format would still be preserved and no errors could be detected through observation of BPVs.

FIGURE 10
SPECTRAL ENERGY OF BIPOLAR VS. UNIPOLAR PULSE STREAM



7.5 One other requirement of a digital bitstream is necessary for a DS1 signal to be adequately transmitted on metallic plant. In order that line repeaters and terminal equipment operate in synchronization, they must receive frequent timing information from the digital signal. Timing is obtained from ones pulses; it cannot be derived from zeros. Consequently, two limitations have been placed on the number of zeros that can be continuously transmitted. They are known as the ones' density requirements and consist of the following:

Ones' Density Requirements

1) No more than 15 consecutive zeros can be transmitted.
2) A minimum of three ones must be present in every 24 bits.

7.6 The ones' density requirements pose no great problems as long as the information being transmitted is of a voice frequency nature, either pure voice or VF-encoded data from a modem. This is because voiceband signals, when encoded in digital format, inherently contain ones in sufficient quantities and frequencies to meet these requirements. The problem occurs with transmission of digital data because it legitimately can contain long strings of zeros. For example, accounting records could show months of inactivity with continuous zeros.

7.7 The problem of zeros in digital data transmission can be remedied in one of two ways by the terminal equipment. Traditionally, in order to meet the ones' density requirements, the zero in the 7th bit position has been replaced with a one when the entire 8-bit word contains all zeros. However, with the advent of common channel signaling schemes and the opportunity to use the entire 64 kb/s channel for data, it was no longer desirable to rob this bit position for ones' density purposes. To provide sufficient ones for synchronization, two different zero encoding methods were developed as an alternative that effectively hide the true zero content of the data being transmitted through encoding.

7.8 The most commonly-used encoding method is B8ZS, which stands for Binary 8 with Zero Substitution. Of lesser use is the code, ZBTSI, referring to Zero Byte Time Slot Interchange. Both codes effectively suppress continuous zeros for transmission purposes and then restore the zeros within the signal to their original content at the receiving end. Brief definitions of both B8ZS and ZBTSI are provided in Section 9.

8. OVERVIEW OF DIGITAL TRANSMISSION EQUIPMENT

8.1 Purpose

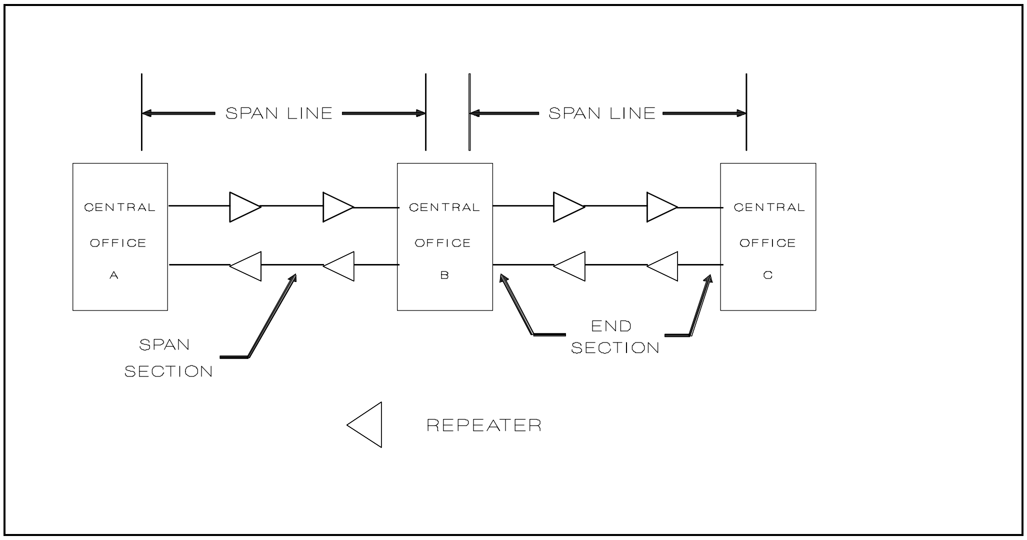
8.1.1 This section provides a brief, descriptive overview of various equipment used to transmit digital information for interexchange purposes. Although the emphasis in this section is on transmission over metallic plant (referred to as a digital span line or T-carrier) many of the principals can be applied to other technologies using digital transmission techniques.

8.1.2 This section also presents some information on newer technologies that use digital transmission. These are lightwave (or fiber optics) and digital microwave radio. They are included because of their reliance on fundamental digital transmission techniques. Other digital transmission technologies do exist in addition to T-carrier, lightwave and digital radio. These include satellite and cellular telephone, for example. However, the intent in solely presenting information on those discussed above is simply to illustrate how the fundamental digital transmission techniques may be applied. Other REA bulletins provide more specific and more detailed information on other technologies.

8.2 T-Carrier

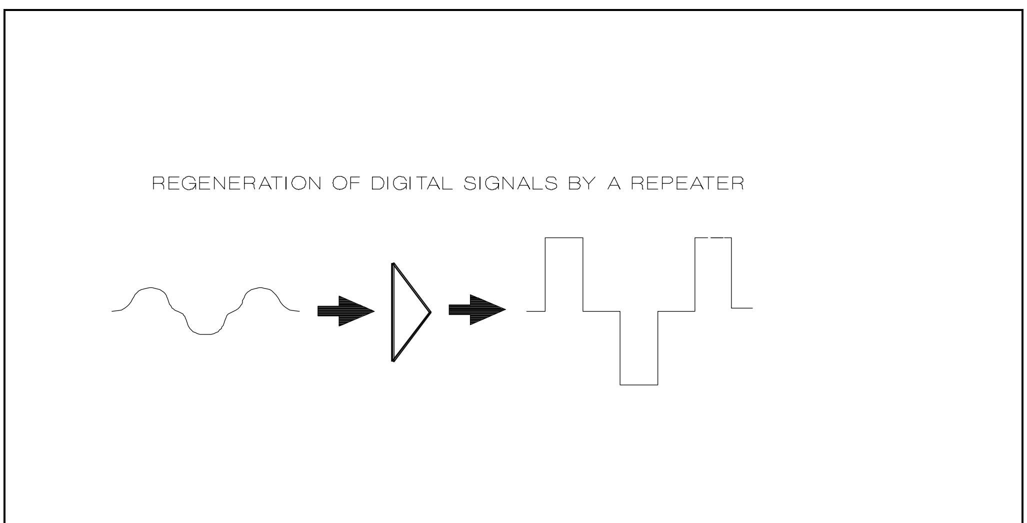
8.2.1 The overall configuration of a T1 span line system consists of the CO equipment and the span line containing the cable and the repeaters, as shown in Figure 11. Span *line* refers to the facilities connecting two terminating points, such as between two COs. It includes both the CO and line repeaters, the cable and other terminating equipment. A span *section* is the facility between two repeaters. The span section nearest to the CO is known as an end section. Digital signals on a span line are transmitted in one direction on each pair of copper wires. Thus, two pairs are required for a two-way digital connection. Frequently, a spare span is provided for backup.

FIGURE 11
OVERALL CONFIGURATION OF A T1 SPAN LINE



8.2.2 The line repeater provides an essential contribution to the operation of a span line system. Without repeaters, the DS1 digital signal can propagate a distance of only 1.5 km or so before attenuation begins to diminish the readability of the signal. As Figure 12 shows, the repeater does not merely amplify, as with analog VF system repeaters, it actually interprets the deteriorated, yet readable, incoming digital signal and regenerates an entirely new, outgoing digital signal. It is this regeneration, and not amplification, that minimizes the introduction of noise and which characterizes digital signal transmission as superior to analog.

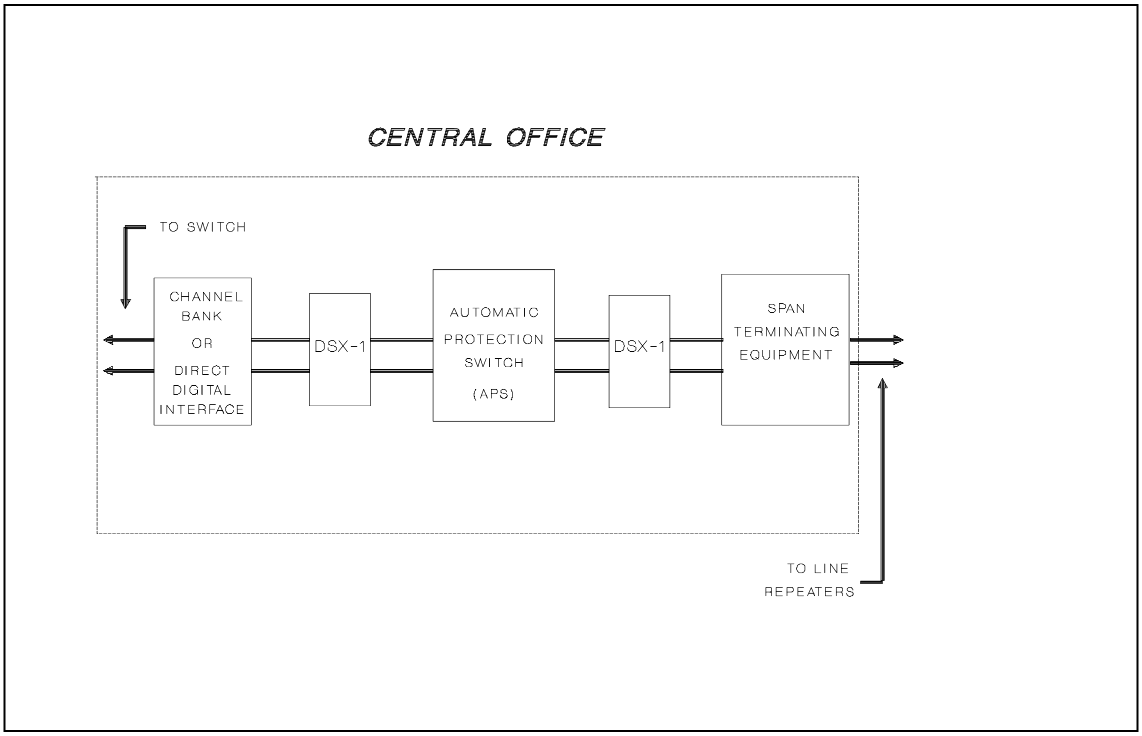
FIGURE 12
SPAN LINE REPEATER



8.2.3 The CO portion of a T1 span line contains a number of additional components integral to the reliable operation of the digital transmission system. As shown in Figure 13, the first component on the far left is the channel bank. Although not directly part of the span line system, the conversion of analog signals into digital signals by the channel bank is frequently where digital transmission begins. (For circuit-switched lines and trunks, most current digital switches directly accept a DS1 level digital signal, eliminating the need for channel banks.)

8.2.4 Connected to the channel bank is a digital signal cross-connect, or DSX. The DSX-1 refers to a cross-connect at the DS1 rate. This equipment facilitates the testing, access and mixing of certain types of traffic at the DS1 level onto various span line systems. On the far side of the channel bank is the automatic protection switch, or APS. The APS monitors the status of each span line and switches the traffic to a spare span line in the event of a failure or excessive errors. To interconnect the various span lines, a second DSX-1 appears next to the span line terminating equipment. On the far side of the second cross-connect is the span line terminating equipment, which includes repeaters and line powering components.

FIGURE 13
CENTRAL OFFICE SPAN LINE EQUIPMENT



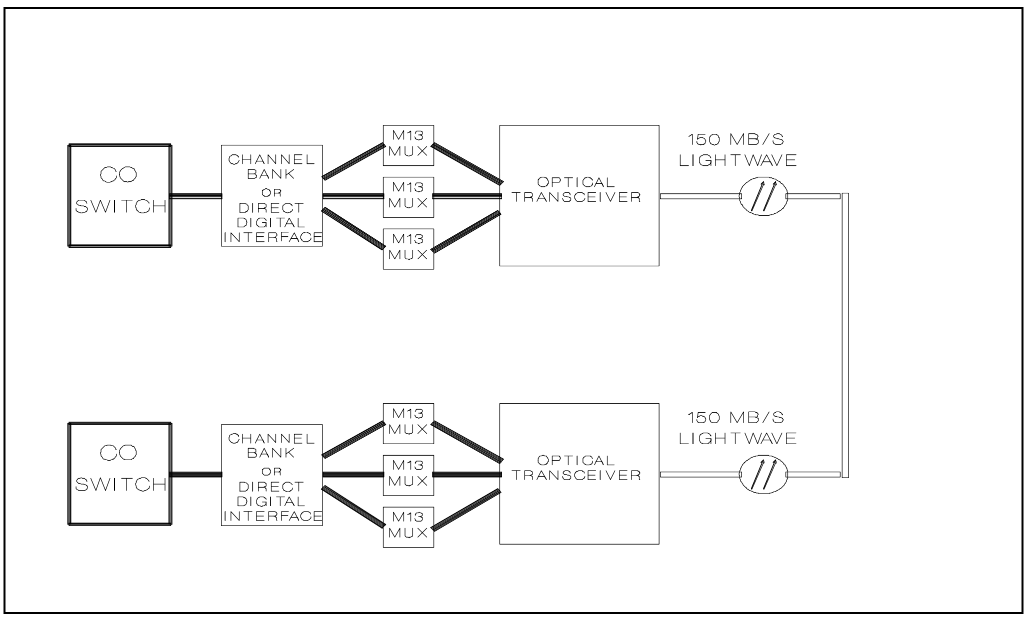
8.3 Lightwave

8.3.1 Digital transmission via lightwave systems is similar to that of span lines. One important distinction, however, is that optical digital signals do not attenuate as rapidly as electrical digital signals. Consequently, repeater use is minimized. In fact, many lightwave installations do not require any repeaters even though the distance may be on the order of 50 km to 75 km.

8.3.2 In addition, the bit rate of lightwave systems is typically many times higher than for DS1 span line transmission. Today, it is common to transmit optical digital signals at nominal bit rates ranging from 150 Mb/s to 600 Mb/s, the latter having a capacity of 12-DS3s or 8,064 DS0s. As with span lines, it is common to use one-way transmission with a separate system providing for each direction of transmission. Frequently, many systems are installed with spare fiber pairs and terminal electronics to increase reliability.

8.3.3 Because lightwave transmission systems have greater capacity and operate at a much higher digital bit rates than do metallic span lines, the role of multiplexers is much greater. A particular lightwave transmission system may use a channel bank to provide DS1 channels, but then use several additional multiplexers to construct a 150 Mb/s electrical signal. This electrical signal is then converted into an optical signal by the optical transceiver. A typical installation is shown in Figure 14. (Detailed information on lightwave systems is in REA Bulletin 1751H-601.)

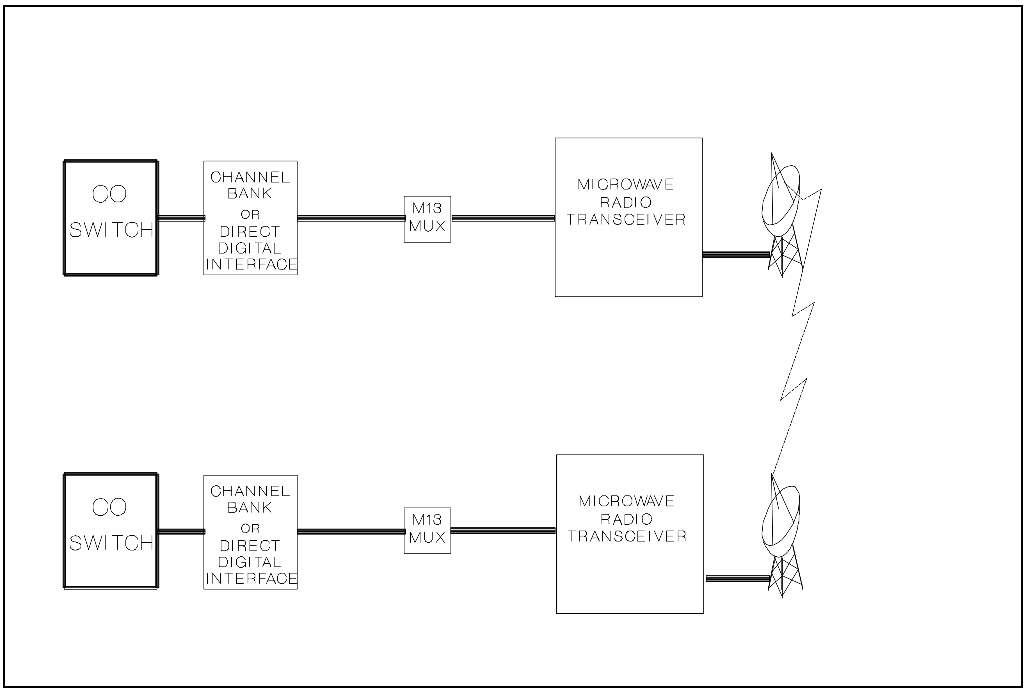
FIGURE 14
TYPICAL LIGHTWAVE SYSTEM



8.4 Microwave Radio

8.4.1 Another digital transmission system that is in common use today is digital, point-to-point microwave radio. A typical system configuration with its fundamental components is shown in Figure 15. In many respects this is similar to the lightwave system just discussed. Microwave is capable of much higher bit rates than a T1 span line system, but less than for lightwave. The capacity generally ranges from one DS1 to several DS3s per radio channel, depending upon the actual radio frequency (RF) used. As with lightwave, multiplexer use is also prevalent. Frequently, as with T1 and lightwave, backup systems are installed to increase reliability. Repeater spacings for microwave radio vary widely, ranging from roughly 5 km to 50 km. The repeater spacings are dependant upon a host of factors, including, the RF band used, expected rain intensity and environmental/terrain considerations.

FIGURE 15
TYPICAL MICROWAVE RADIO SYSTEM



9. DIGITAL TRANSMISSION TERMINOLOGY

9.1 The definitions in this section are intended for a wide range of readers, from those relatively new to digital techniques to those having considerable experience. Consequently, the definitions provided may not be as precise as those given in other more academic or scientific references. A rudimentary knowledge of general telephony is assumed.

9.2 The reader is also advised to consult REA Bulletin 1751H-601, *Lightwave Fundamentals, Systems, and Application*, for terms related primarily to lightwave systems; and REA Bulletin 1751H-501, *Fundamentals of ISDN*, for terms specific to ISDN.

9.3 Terms used within certain definitions that are separately defined in this glossary have been denoted by the use of italic print, with the exception of several, frequently used terms.

9.4 Acronyms are generally defined where the completely spelled-out term is located, except where the usage of the acronym is viewed as more common.

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2B1Q Abbreviation for 2 *Binary* 1 *Quaternary*; a digital *line code* having four information states; used in digital subscriber loop applications to obtain up to a 160 kb/s *bandwidth* for *ISDN* and other services over non-loaded, paired-wire facilities.

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A/D Abbreviation for Analog-to-Digital; a process that converts analog signals to digital signals.

add/drop multiplexer See *drop & insert*.

address Destination or storage location of a data element in a transmission or processing system.

ADPCM Abbreviation for Adaptive Differential Pulse Code Modulation; a 4-bit, digital signal encoding technique that bases its *quantizing* thresholds upon the actual levels of the input signal, thereby reducing *quantizing noise*; commonly used to encode 44 voice *channels* in place of the usual 24 *channels* in a *DS1* signal to provide *bandwidth* improvements over *differential pulse code modulation (DPCM)*.

aliasing The occurrence of distortion in a digitally-constructed analog signal that results from insufficient digital *sampling* of the original analog waveform; for voice signals, can be remedied by removal of higher frequencies with an anti-aliasing filter.

alternate mark inversion (AMI) Digital *line code* where pulses, representing a given state, alternate in polarity from positive to negative.

AMI See ***alternate mark inversion***.

ANSI Abbreviation for American National Standards Institute; a U.S. standards organization which publishes a variety of technical standards, including those for telecommunications.

analog Continuously varying signal.

APS See *automatic protection switch*.

ARQ Abbreviation for automatic request for repeat; error correcting procedure used in data transmission to retransmit data when errors are detected.

asynchronous Not *synchronous*; a process or signal that is not operating at a constant or uniform rate with respect to a second signal or process; opposite of *synchronous*.

automatic protection switch (APS) Automated transmission facility switching system used to switch traffic to alternative *channels* or facilities in the event of a failure or excessive errors.

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B3ZS Abbreviation for *Bipolar* with 3 *Zero Substitution*; a *zero substitution code* commonly used at a *DS3* transmission rate that, upon the occurrence of three consecutive zeros in a digital *bitstream*, will insert (prior to transmission) a predetermined code to cause a *bipolar violation*. At the receiving end this code will be recognized and the stream of zeros will be properly restored into the *bitstream*.

B6ZS Abbreviation for *Bipolar* with 6 *Zero Substitution*; a *zero substitution code* commonly used at a *DS2* transmission rate, that upon the occurrence of six consecutive zeros in a digital *bitstream*, will insert (prior to transmission) a predetermined code to cause a *bipolar violation*. At the receiving end this code will be recognized and the original stream of zeros will be properly restored into the *bitstream*.

B8ZS Abbreviation for *Bipolar* with 8 *Zero Substitution*; a *zero substitution code* commonly used at *DS1* and *DS1C* transmission rates that, upon the occurrence of eight consecutive zeros in a digital *bitstream*, will insert (prior to transmission) a predetermined code to cause two bipolar violations. At the receiving end this code will be recognized and the stream of zeros will be properly restored into the *bitstream*.

B-channel Designation for the 64 kb/s information-carrying *channel* in the Basic Rate Interface and the Primary Rate Interface, both of the Integrated Services Digital Network; see *ISDN*.

BISDN Abbreviation for Broadband Integrated Services Digital Network; a general designation for high *bandwidth* network capability provided at a nominal *DS3 bit rate* of 45 Mb/s or higher; see *ISDN*.

bandwidth Measure of the spectral frequency that a system is able to process or transmit; in digital systems, it is proportional to the *bit rate*.

baseband Source frequency band that contains voice, data or video information that is used in a *modulation* process.

BCD See *binary coded decimal*.

BER See *bit error rate*.

binary Numeric system of only two states, such as 0 or 1.

binary coded decimal (BCD) *Binary*-encoded form of a decimal number.

bipolar Of two polarities, positive and negative. Digital signals on T1 facilities are typically transmitted in a *bipolar format*.

bipolar violation (BPV) Occurrence of two consecutive pulses of the same polarity in a *bipolar* digital *bitstream*; not consistent with the *bipolar* standard of alternating positive and negative pulses; see *bipolar*.

bit Abbreviation for *binary* digit; the smallest unit of information in a digital system.

bit compression multiplexer Device that converts multiplexed and compressed digital signals, such as *ADPCM*, to standard *PCM* format and vice versa.

bit error rate (BER) Ratio of the number of digital bits that are in error for a given transmission or processing system to the total number of bits transmitted during a given time interval; typically expressed in units of errors per one million bits transmitted.

bit interleaving Technique for combining multiple digital *channels* on a bit-by-bit basis in the same digital *bitstream*.

bit rate Speed of a digital *bitstream*. Generally represented in units of either bits per second (b/s), kilobits per second (kb/s), megabits per second (Mb/s), or gigabits per second (Gb/s).

bit stuffing Method used for maintaining synchronization in a digitally multiplexed signal where additional pulses of ones are added; also referred to as pulse stuffing.

bitstream Series of uninterrupted, sequential bits.

block Grouping of digital bits that are transmitted or processed as a unit.

block error rate (BLER) Ratio of the number of data *blocks* in error that are transmitted or processed over a given time interval to the total number of *blocks* transmitted; typically expressed in units of errored blocks per one million *blocks* transmitted.

BPV See *bipolar violation*.

b/s Abbreviation for bits per second; also designated as bps.

buffer Temporary storage (memory) location for digital information, typically used in interfacing two devices.

bus Common pathway for the flow of digital information; also referred to as a highway.

byte Collection of *binary* digits processed or stored as a unit; for telecommunications, a byte is generally composed of 8-bits; see ***octet***.

byte interleaving Technique for combining multiple digital signals on a byte-by-byte basis in the same digital *bitstream*.

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carrier High frequency signal used to transport a second lower frequency signal by using a specific technique of incorporating the second signal; see *digital loop carrier, modulation, subscriber carrier*.

CCIS See *common channel interoffice signaling***.**

CCITT Abbreviation from the French language for the International Telegraph and Telephone Consultative Committee; an international telecommunications standards setting organization which operates under the auspices of the International Telecommunications Union, a specialized agency of the United Nations.

central office terminal (COT) Electronic central office component of a *concentrator* or *subscriber carrier* system connected to a *remote terminal* by a digital transmission facility; interfaces the digital transmission facility to the switch on an analog line basis by performing *D/A* and *A/D* signal conversions; see *remote terminal*.

channel Subdivision of a digitally-encoded and multiplexed signal representing sufficient *bandwidth* for transmission or processing of an individual voice, data or video signal.

channel bank Electronic terminal equipment that digitally encodes and time division multiplexes analog signals; also performs the reverse process by demultiplexing and decoding digital signals into analog signals; processing is generally performed on 24 *channel* groups, or multiples thereof; see ***D.***

check bit Bit used for error checking in a digital signal; a *parity bit***.**

check parity Technique for detecting digital signal errors in which an extra bit is added and then verified at the receiving end.

clear channel capability (CCC) Feature available to a digital bitstream that provides a full 64 kb/s of user available *bandwidth* (as opposed to 56 kb/s) and any combination of zeros and ones in each *DS0 channel*. To provide this capability, the signaling and supervisory information are transmitted over a separate *channel* and either the *B8ZS* or *ZBTSI zero substitution code* is used.

clear channel signal See *clear channel capability***.**

clock Device that generates periodic signals at a uniform rate for unit or system synchronization.

codec Abbreviation for coder/decoder; a device that converts analog signals into *binary*-coded digital signals, and vice versa.

common channel interoffice signaling (CCIS) Interoffice transmission signaling network that transmits signaling information in digital format on circuits separate from the message channels.

companding law Defined standard for the nonlinear (or nonuniform) compression and expansion of analog signal levels.

compandor Abbreviation for compressor/expandor; device that compresses the amplitude range of analog signals prior to signal transmission or processing and then expands the analog signal at the receiving end to restore the original amplitude range; improves the *signal-to-noise ratio*.

concentration ratio Ratio of the number of connected subscriber loops to the available transmission *channels* or paths in a line concentrator or central office switch (typically 6:1 or 4:1); used to take advantage of the diversity of telephone traffic; see *concentrator*.

concentrator Switching device, generally located at a distance from a central office, that connects a larger number of subscriber loops to a smaller number of transmission paths to the central office switch; results in increased efficiency for use of outside plant cable facilities; see *concentration ratio***.**

continuously variable slope delta modulation (CVSDM) A digital *modulation* technique that samples (generally at 32,000 times per second) the slope or the rate of change, rather than the amplitude, of an analog signal prior to digital encoding.

crash point Point in the operation of a digital transmission or processing system in which certain operating parameters are beyond their acceptable range, thus causing the failure of the system.

cross-connect Mechanical or electronic device that permits the interconnection of separate *channels* or circuits; see *digital cross-connect*.

crosstalk Form of interference due to electromagnetic coupling from one circuit or *channel* to another; can occur within a single system or between systems.

CVSDM See *continuously variable slope delta modulation*.

cyclic redundancy check (CRC) Error checking procedure used in digital transmission systems in which mathematical calculations are performed on the originating signal and the results transmitted with the outgoing *bitstream*. At the receiving end, the same calculations are performed and the results are compared to those from the transmitted end.

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D Refers to one or more of a series of *channel banks* used for digital and analog signal conversion, including D1, D1A, D1B, D1C, D1D, D2, D3, D4 and D5; the higher alphanumeric reference indicates units with increased capacity, reduced size and other improvements.

D/A Abbreviation for Digital-to-Analog; a conversion process by which digital signals are converted to analog signals.

D-channel Abbreviation for the 16 kb/s signaling *channel* of the Basic Rate Interface, and for the 64 kb/s signaling *channel* of the Primary Rate Interface, both of the Integrated Services Digital Network; see ***ISDN*****.**

data skew Distortion of a digital *bitstream* resulting from lack of proper synchronization between two terminals on a transmission system.

dB Abbreviation for decibel; a logarithmic measure of the ratio of two signals, either on a voltage or power basis.

DDS Abbreviation for Digital Data Service; a Bell System term that refers to a tariffed subscriber service for transmitting data in digital format.

decoder Device that decodes a digital signal, generally into analog form.

degraded minute (DM) One-minute interval during which the *bit error rate* exceeds one bit error per one million bits transmitted, or other predetermined thresholds.

delta modulation See *differential pulse code modulation*.

demodulation Technique of recreating or extracting an original *baseband* waveform from the information contained in a *carrier* signal that has been modulated with the *baseband* information.

demultiplex Process of extracting an individual *channel* from a single composite signal made up of two or more channels previously combined through either *time division multiplexing* or *frequency division multiplexing* techniques.

DI See *drop & insert***.**

differential pulse code modulation (DPCM) Digital *modulation* technique in which the analog signal is *sampled* and *quantized* (generally employing four bits per sample) based upon the differences in signal levels over time, rather than on absolute levels; results in a reduction in *bandwidth* over standard *pulse code modulation*; also known as delta modulation.

differential phase shift keying (DPSK) *Modulation* technique in which the digital baseband signal is represented by the changes in the phase of the carrier signal; see *phase shift keying***.**

digital Device or process that uses discrete numeric states for signal representation, as opposed to use of a continuously varying or analog signal.

digital COE Abbreviation for digital central office equipment; generally an electronic, stored-program, common controlled switching system that performs the temporary interconnection of line and trunk circuits in a time domain rather than through the physical, metallic or electrical connection of circuits.

digital cross-connect system (DCS) Software-controlled electronic device that permits direct access to and interconnection of individual *DS0* and *DS1* subrate *channels* contained in a higher-order multiplexed digital *bitstream* without having to *demultiplex* the entire higher order signal; some devices also permit the direct interconnection of *DS3* signals; used to *groom* and route circuits by similar use and/or destination.

digital hierarchy Organizational structure upon which multiplexed digital signals of various bit rates are constructed; in the U.S., one *DS3* of 44.736 Mb/s comprises either: 1) 672 *DS0*s of 64 kb/s each or, 2) seven *DS2*s of 6.312 Mb/s each, or 3) 28 *DS1*s of 1.544 Mb/s each; see *DS1*, *DS2*, *DS3*.

digital loop carrier (DLC) Device that digitally encodes and *multiplexes* subscriber loop *channels* into a *DS1* signal or higher for more efficient transmission or extended range; may or may not have *concentrator* capability; see *integrated digital loop carrier*, *universal digital loop carrier*, *pair gain*.

digital pad Device that alters a digitally-encoded *bitstream* to attenuate the resulting analog signal.

digital radio Type of radio system that transmits and receives digitally-encoded signals; used for both interexchange and subscriber loop applications.

digitizing Conversion of an analog signal into digital format; see *A/D, encoder*.

digroup Grouping of digitally-encoded and multiplexed 24 *channels* operating at a nominal rate of 1.544 Mb/s, or *DS1*.

DLC See *digital loop carrier*.

DPCM See *differential pulse code modulation*.

DPSK See *differential phase shift keying*.

drop & insert (DI) Device or process that both extracts and inserts lower level digital *channels* from and to a higher order digital *bitstream* without the need to demultiplex the entire higher order signal; also may have analog-to-digital and digital-to-analog conversion capability.

DS0 Abbreviation for Digital Signal Level 0 in the *digital hierarchy*; a digitally-encoded 64 kb/s *channel*; often has a usable capacity of only 56 kb/s due to signaling and overhead information needs; the entire 64 kb/s bandwidth is available only if *clear channel capability (CCC)* is employed.

DS1 Abbreviation for Digital Signal Level 1 in the *digital hierarchy*; a digitally-encoded signal at a nominal rate of 1.544 Mb/s; often multiplexed with 24 *DS0* channels; equivalent to one *digroup*.

DS1C Modified version of the *DS1* digital transmission rate, consisting of a digitally-encoded signal at a nominal rate of 3.152 Mb/s; often multiplexed with 48 *DS0* channels.

DS2 Abbreviation for Digital Signal Level 2 in the *digital hierarchy*; a digitally-encoded signal at a nominal rate of 6.312 Mb/s; often multiplexed with either four *DS1* or 96 *DS0* channels.

DS3 Abbreviation for Digital Signal Level 3 in the *digital hierarchy*; a digitally-encoded signal at a nominal rate of 44.736 Mb/s; often multiplexed with either seven *DS2*, 28 *DS1* or 672 *DS0 channels*.

DSX Abbreviation for digital signal *cross-connect*; often used in the form DSXm, where the m is either a 1, 2 or 3 referring to a DS1, DS2 or DS3 digital signal, respectively; see *cross-connect*.

duobinary encoding Digital *bitstream* encoding scheme of four, as opposed to two, information states in which the information rate, or *bit rate*, can be doubled.

duplex Exchange of data or voice information between two devices or systems in both directions simultaneously; sometimes referred to as full duplex; see *half-duplex*.

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EFS See *error free seconds*.

encoder Device that converts the measured values obtained from the *sampling* and *quantizing* of an analog signal to a digital code.

encoding law Specifically defined means for constructing the various nonlinear (or nonuniform) amplitude levels used for *sampling* and *quantizing* an analog signal into a digital signal; in the U.S. and Japan the *Mu-law* is standard, in Europe and much of the rest of the world, the A-law is standard.

engineering loss Worst case design cable loss used in the engineering of digital *span lines*.

error code Code used to announce the presence of an error in the transmission or processing of a digital signal.

error correction Automatic system that automatically performs a correction on transmitted or processed information upon the detection of errors.

error detection Automatic system that detects the presence of errors in transmitted or processed information; detection is generally followed by either retransmission or *error correction* of the corrupted information.

error free second (EFS) One-second interval during which zero bits are in error.

errored second (ES) One-second interval during which one or more bits are in error.

error rate See *bit error rate, block error rate, residual error rate*.

ES See *errored second*.
ESF See *extended superframe format*.

extended superframe format (ESF) Improved digital *bitstream* framing scheme for *DS1* transmission that provides 24 frames (in lieu of the 12 frames used in the *superframe* format) and additional communication paths for performance monitoring and other supervisory functions; framing scheme used in D4 and D5 *channel banks*; see *frame*, *superframe*.

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FDM See *frequency division multiplexing*.

FEXT Abbreviation for far end crosstalk; form of electromagnetic noise interference between two transmission systems operating in the same direction where the source of the interference is at the far end.

FEC See *forward error correction*.

forward error correction Error correcting procedure used in data transmission where corrections on erred data are performed at the receive end.

frame Repetitive organizational grouping of digital *words* from all available *channels* in a digital *bitstream*, containing *baseband*, signaling and timing information; e.g., for the D4 frame format, a frame consists of 24 8-bit timeslots and one framing bit, operating at 1.544 Mb/s.

framing bit (F-bit) Bit used to synchronize digital *frames* by marking the divisions between *frames*; located at the 193rd bit position in each frame.

frequency division multiplexing (FDM) Technique for modulating *carrier* signals where the *baseband* information to be transmitted is placed in separate and adjacent carrier frequencies, and then combined to constitute a much wider frequency spectrum.

frequency shift keying (FSK) Digital *modulation* technique that shifts the *carrier* signal's frequency to different finite values within a predetermined range and in accordance with the characteristics of the digital *baseband* signal to be transmitted or processed.

FSK See *frequency shift keying.*

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Gb See *gigabit*.

Gb/s Abbreviation for gigabits per second; one billion (1×10^9) bits per second; also designated Gbs.

gigabit (Gb) One billion (1×10^9) bits.

groom Arrange and group like circuits or *channels* according to their respective characteristics or destinations to use transmission or switching equipment more efficiently.

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half-duplex Exchange of data or voice information between two devices or systems in either direction, but in only one direction at a time; see **duplex.**

handshaking Exchange of signaling, synchronization or control information between two devices or systems following the establishment of an interconnection.

hubbing Centralization of network functions or traffic at a single location.

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IDLC See *integrated digital loop carrier*.

impulse noise Noise having random waveform characteristics of short duration and rapid change; disturbs the accuracy of digital information transmitted by a device or system.

integrated digital network Digital network of subscriber loop, switching and interoffice trunk facilities that are all digitally-interfaced; results in continuous and uninterrupted digital transmission paths; also can refer to the integration of switching and transmission equipment.

integrated digital loop carrier (IDLC) *Digital loop carrier* system that has a direct, digital interface to a digital central office switch; eliminates the need to perform analog-to-digital signal conversion and multiplexing of loop circuits at the switch through a *central office terminal*; see *digital loop carrier*, *universal digital loop carrier*.

integrated services digital network See *ISDN*.

interface Location or device that connects two, generally differing systems; a shared boundary.

interleaving Combination of two or more digital signals into a single digital *bitstream*.

interrogation Action, by one device or system, of requesting information from another device or system.

ISDN Abbreviation for the Integrated Services Digital Network; advanced digital subscriber loop transmission concept that provides multiple *channels* of *baseband* and signaling information for the simultaneous transmission of voice, data and other special services over a single facility. The Basic Rate Interface contains a total user *bandwidth* of 144 kb/s, consisting of two 64 *kb/s B-channels* and one 16 *kb/s D-channel* for signaling or other data. The Primary Rate Interface contains a user *bandwidth* of 1.544 Mb/s, consisting of 23-*DS0* 64 kb/s *B-channels* and one 64 kb/s *D-channel* for signaling; ISDN also exists in a less specifically defined broadband format (BISDN) at rates of *DS3* and above for high *bandwidth* services.

isochronous Relationship between two signals in which the differences between their phase angles remains constant.

IXC Abbreviation for interexchange carrier; organization that transports long distance telecommunications traffic across *LATA* boundaries, both intrastate and interstate.

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jitter Instability or variability of a **signal** at a relatively rapid rate; results in pulse fluctuations in frequency, amplitude, duration and phase.

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kb See *kilobit*.

kb/s Abbreviation for *kilobits* per second; one thousand (1 x 10^3) bits per second; also designated as kbs.

kilobit (kb) One thousand (1 x 10^3) bits.

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LATA Abbreviation for Local Access and Transport Area; specifically-defined geographic areas in the U.S. established by regulators to separate telecommunications transport markets between local exchange carriers (*LECs*) and interexchange carriers (*IXCs*); *LECs* provide service within a LATA; *IXCs* provide service between LATAs.

least significant bit (LSB) Bit that contains the least amount of information; used in *bit robbing* for the transmission of signaling information.

LEC Abbreviation for local exchange carrier; organization that transports local telecommunications traffic within a *LATA*.

line code Specific technique of encoding digital signals for optimal transmission or processing through a particular medium; see *AMI, 2B1Q, non-return-to-zero.*

linear encoding Any analog-to-digital encoding scheme that uses linearly-constructed (uniform) amplitude thresholds for *sampling* and *quantizing* analog samples.

linear predictive coding (LPC) Analog-to-digital encoding scheme where *bandwidth* savings are realized through use of an algorithm which relies upon a linear or uniform function to predict the analog signal's behavior.

loss Amount of signal attenuation resulting from the transmission or processing of a given device or system.

LPC See *linear predictive coding***.**

LSB See *least significant bit***.**

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M Abbreviation for a digital multiplexer; often used in the form Mxy, that denotes multiplexing from the *DS*x level to the *DS*y level; also used in the format M44 and M24, denoting multiplexing of 44 or 24 voice *channels* into a *DS1* signal.

Mb See megabit.

master clock Highly accurate *clock* which produces timing signals for other subtending clocks or other systems.

Mb/s Abbreviation for *megabits* per second; one million (1 x 10^6) bits per second; also designated as Mbs.

megabit (Mb) One million (1 x 10^6) bits.

modem Abbreviation for modulator/demodulator; device that converts digital data into a voice frequency analog signal, and vice versa, for transmission over standard telephone lines.

modulation Process by which a *carrier* signal is varied in one fashion or another to represent or carry another signal (*baseband*) for purposes of transmission; see *carrier*.

most significant bit (MSB) Bit that contains the most amount of information in a digital *word*; see *least significant bit.*

MSB See *most significant bit*.

Mu-law Nonlinear, 16-segment, analog-to-digital *encoding law* used in N. America.

multiplex Process of combining two or more individual signals or *channels* into a single composite signal that can be subsequently *demultiplexed* for retrieval of the original individual signals. Either time or frequency division multiplexing methods are used.

multiplexer Device that *multiplexes***.**

mux Abbreviation for *multiplexer*.

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NEXT Abbreviation for near end crosstalk; a form of electromagnetic noise interference between two transmission systems operating in opposite directions where the source of the interference is at the near end.

node Meeting point for two or more lines and/or paths in a network.

non-return-to-zero (NRZ) Digital *line code* in which the two logical states are represented by positive and negative pulses, with no zero or neutral state.

nonlinear encoding Any analog-to-digital encoding scheme that uses nonlinear or nonuniform amplitude thresholds for *sampling* and *quantizing* analog signals.

NRZ See *non-return-to-zero*.

Nyquist Interval Maximum time interval at which an analog signal can be *sampled* for conversion into a digital signal and still allow the analog signal to be fully and accurately reconstructed; equal to two times the reciprocal of the highest frequency contained in the analog signal; see *Nyquist Theorem***.**

Nyquist Theorem Mathematical theorem that demonstrates that an analog signal can be fully reconstructed from digital data if the analog signal is sampled at a rate equal to or greater than two times the highest frequency in the original signal.

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octet Group of eight *binary* digits, known as an 8-bit *word*, which is processed as a unit; equivalent to a *byte*.

OSI Abbreviation for Open Systems Interconnection; structured architecture designed for information exchange between different communication or data systems

overhead bit Any digital bit that does not have voice or data information content.

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packet Collection of digital information, including signaling data, into a discrete package of a specified format which is then individually transmitted and switched to its ultimate destination; see *packet network*.

packet assembler-disassembler (PAD) Electronic device that both assembles data and information into *packet* format to prepare it for switching and transmission on a *packet network*, and performs the disassembly of the *packets* transmitted to it into the original data format; see *packet network*.

packet network Digital network designed to accommodate the transmission of individual short information messages called *packets* where the individual *channels* are only occupied for sufficient time to complete the transmission of each *packet*; see *packet assembler-disassembler*, *packet switch*.

packet switch Digital switch designed to process and route individual short messages called *packets* onto a packet network; see *packet network, packet assembler disassembler*.

pair gain Process by which the *channels* of two or more subscriber loop pairs are *multiplexed* together by either digital or analog techniques and then transmitted on facilities of lesser capacity than otherwise would be required if the same group of signals were transmitted individually on one pair of wires per channel; permits greater efficiencies in use of outside plant cable facilities.

PAM See *pulse amplitude modulation*.

parallel transmission Process by which all of the bits of each digital *word* are transmitted simultaneously along separate paths; opposite of *serial transmission*.

parity bit Bit added in a *error detection* scheme to make the total number of logical one bits either an even or odd number; see *parity check*.

parity check Method of *error detection* used in digital systems in which an additional bit is added, where necessary, to each digital *word* in order to make the total number of logical one bits either an even or odd number. At the receive end, absence of the proper parity is an indicator of errored data.

PCM Abbreviation for Pulse Code Modulation; a *modulation* technique in which the amplitude of an analog signal is *sampled* at regular intervals and converted to numerical values, which are generally represented in digital form as an 8-bit *word*. The resulting numerical values can then be used to reconstruct the analog waveform following signal transmission or processing.

phase shift keying (PSK) *Modulation* technique for digital transmission in which the phase of the *carrier* frequency is varied within a predetermined range in accordance with the characteristics of the digital *baseband* signal to be transmitted.

plesiochronous Frequency relationship between two or more signals that are at nominally the same frequency, but are not exactly equal; within some specified limits of each other; almost *synchronous*.

port Point of access in a device to provide for the input or output of information.

protocol Predetermined set of rules for how information will be exchanged in a given system or equipment.

pseudorandom signal Signal that appears to be random but is actually repetitive when examined over a sufficiently long period of time; often used for testing of digital systems.

PSK See *phase shift keying*.

pulse Signal characterized by relatively rapid rise and decay times.

pulse amplitude modulation (PAM) *Modulation* technique for digital transmission in which the amplitude of the *carrier* pulses is varied within predetermined limits in accordance with the characteristic of the digital *baseband* signal to be transmitted.

pulse code modulation See *PCM***.**

pulse interval Amount of time between two pulses, measured from the same points on each pulse.

pulse stuffing See *bit stuffing***.**

pulse width modulation (PWM) *Modulation* technique in which the pulse width of the *carrier* signal is varied within predetermined limits in accordance with the *baseband* signal to be transmitted or processed.

PWM See *pulse width modulation*.

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QAM See *quadrature amplitude modulation***.**

QPSK See *quadrature phase shift keying***.**

QRS Abbreviation for *Quasi-Random Signal*; see *pseudorandom signal***.**

QRSS See *quasi-random signal source***.**

quadrature amplitude modulation (QAM) *Modulation* technique in which the *baseband* signal is digitally represented through four different amplitude states of the *carrier* signal; a variation of *amplitude modulation*; used in *digital radio* systems.

quadrature phase shift keying (QPSK) *Modulation* technique in which the *baseband* signal is digitally represented through four different phase states of the *carrier* signal; a variation of *phase shift keying*; used in *digital radio* systems.

quantizing noise Noise or distortion occurring as a result of an analog-to-digital signal conversion; caused by inaccuracies from *quantizing sampled* analog signal levels.

quantizing Process of converting the amplitude levels of an analog signal sampled at discrete intervals to numeric values prior to digital encoding.

quasi-random signal (QRS) See *pseudorandom signal*.

quasi-random signal source (QRSS) Test pattern of *pseudorandom* digital signals used for testing the performance of digital transmission systems.

quaternary Pertaining to four separate information states.

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random signal Digital signal having no predetermined or regular pattern over a long time period.

regenerator Device that samples a weak and/or distorted digital signal, reconstructs it and then retransmits an identical new digital signal for continued transmission or processing; also referred to as a repeater.

register Device that temporarily receives and stores digital information for later retrieval.

remote terminal (RT) Electronic remote component of a *concentrator* or *subscriber carrier* system connected via a digital transmission facility to a central office switch on a direct digital basis, or through a *central office terminal*; performs *A/D* and *D/A* signal conversion between subscriber lines and the digital transmission facility; see *central office terminal*.

repeater See *regenerator***.**

RER See *residual error rate*.

residual error rate (RER) A ratio of the number of bits, blocks, or other data units that continue to be in error after being acted upon by *error correction* or *error detection* methods to the total number of bits, blocks or other units that have been transmitted; see *bit error rate*.

return loss Measure of the difference in attenuation between a reflected signal as compared to the transmitted signal on two interconnected networks; generally expressed in *dB*; a general measure of the impedance mismatch between two networks.

robbed bit signaling Process where signaling bits are included in a digital framing format by replacement of the *least significant bit* of each *channel* in certain *frames* with a signaling bit.

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S/N See *signal-to-noise ratio***.**

sampling Measurement of an analog signal at discrete intervals to obtain its characteristics prior to digital encoding.

sampling frequency Frequency at which an analog signal is sampled or measured prior to its conversion to a digital representation; see *Nyquist Interval*.

scrambling Process of rearranging a digital *bitstream* in a predetermined form to avoid consecutive zeros or repetitive patterns. The *bitstream* can then be restored to its original form at the receive end; also known as randomizing.

screened cable Outside plant cable specially constructed with internal metallic shielding around groupings of paired wires to reduce the *crosstalk* interference among different signals simultaneously transmitted within the cable.

serial transmission Process by which the bits in a digital *bitstream* are sequentially transmitted bit-by-bit along a single path; opposite of the multiple paths used in *parallel transmission*.

SES See *severely errored seconds*.

severely errored seconds (SES) One-second interval in which the *bit error rate* exceeds one bit error per 1000 bits transmitted, or other predetermined thresholds.

SF See *superframe*.

signal Any electronic message of intelligence or control.

signal-to-noise ratio (S/N) Measure of the ratio of a desired signal to an undesired signal, such as noise or adjacent *channel* interference; generally expressed in *dB*.

Signaling System No. 7 (SS7) Digital, message-switched signaling system that operates in separate out-of-band common *channels* using a *packet network*; also referred to as CCITT No. 7 signaling.

SONET Abbreviation for Synchronous Optical Network; a new and developing standard that provides for a common optical and electrical *synchronous* interface for lightwave systems and equipment.

span Sum of all digital transmission facilities between two physical locations, such as two central offices.

span line String of *regenerators* or *repeaters* between two points on a digital transmission network.

SS7 See *Signaling System No. 7*.

start bit Additional bit used to signal the beginning of a digital *word* in *asynchronous* systems.

statistical multiplexing Form of multiplexing in which *channel* assignments and *bandwidth* requirements are not dedicated but are dynamically allocated based upon the actual transmission needs of input devices at a given point in time; the device used to perform this operation is sometimes referred to as a stat *mux*.

stop bit Additional bit used to signal the end of a digital *word* in *asynchronous* systems.

subscriber carrier Electronic device that combines one or more subscriber loop *channels* through either analog or digital *multiplexing* on a *carrier* signal for transmission to the central office; achieves *pair gain* benefits by reducing the need for outside plant cable facilities; each subscriber circuit retains an independent *channel* in that no line *concentration* is performed; see *digital loop carrier*.

superframe (SF) Repetitive organizational structure for a digital *bitstream* consisting of 12 *frames*, each containing 24 *channels* of 8-bit *words* plus one framing bit, operating at the *DS1* rate of 1.544 Mb/s; the framing scheme used in D3 and some D4 *channel banks*; see *frame, extended superframe format*.

synchronization bit Bit used in a digital *bitstream* for timing or synchronization purposes.

synchronous Process or transmission that is synchronized with a common clocking system.

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T-carrier Digitally multiplexed *carrier* system operating at the *DS1* rate of 1.544 Mb/s; see *digital loop carrier*.

T1 Digital transmission system operating at a nominal rate of 1.544 Mb/s, or *DS1*, on metallic facilities.

TDM See ***time division multiplexing*.**

ternary coding Digital encoding scheme of three separate information states generally obtained through use of positive and negative *bipolar* pulses and zeros in the *bitstream*.

time division multiplexing (TDM) Any signal *multiplexing* process in which multiple *channels* or signals share a common transmission path, each for a very short time period.

time slot interchange Process of information interchange from one time slot or *channel* to another on a time division multiplexed network or device; used in *digital cross-connect systems* and *digital COE* switches.

topology Physical organization and structure of a transmission network.

tracking Measure of how accurately an analog signal is digitally coded and decoded into its original analog state.

transparent interface Interconnection between two networks or systems that permits the free exchange of information in both directions without additional processing or modification.

UDLC See *universal digital loop carrier*.

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unipolar Of one polarity, either positive or negative.

universal digital loop carrier (UDLC) *Digital loop carrier* system capable of interfacing to any central office switch at the analog line level; see *digital loop carrier, integrated digital loop carrier*.

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VF Abbreviation for voice frequency; analog signal with a nominal 4 kHz bandwidth.

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wander Instability or variability of a *signal* at a relatively slow rate; results in pulse fluctuations in frequency, amplitude, duration and phase.

word Group of bits processed as a unit that represents a single quantity or instruction; for telecommunications, generally a collection of 8-bits; often referred to as a digital *word* or *byte*.

ZBTSI Abbreviation for Zero Byte Time Slot Interchange; a digital *zero substitution code* used to provide a 64 kb/s *clear channel* in a *DS0* by replacing selected strings of eight consecutive zeros with an address location of where the zeros are to be restored at the receiving end.

zero substitution code Coding scheme used in digital transmission to ensure accurate transmission and continuous synchronization through devices that have zeros limitations; replaces long strings of consecutive zeros with a pattern of ones having *bipolar violations* (BPVs). At the receiving end, the BPVs are recognized and the original string of consecutive zeros is restored; see *B3ZS, B6ZS, B8ZS*, *ZBTSI*.